Land Transport Authority

# ENGINEERING GROUP

# MATERIALS & WORKMANSHIP SPECIFICATION FOR CIVIL & STRUCTURAL WORKS

## E/GD/09/104/A2

## Controlled Document

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# MATERIALS AND WORKMANSHIP SPECIFICATION for Civil &Structural Works (C&S)

## INTRODUCTION

The M&W Specifications (C&S) which follows shall be treated as one of the Contract Documents and forms a part of the Authority's Requirements.

The Contractor shall comply fully with the minimum requirements specified in this M&W Specifications (C&S) on the materials and the workmanship for the execution of the Works under the Contract. This M&W Specifications (C&S) shall be the reference and basis for the acceptance by the Engineer of any material and workmanship provided by the Contractor or on any work completed under the Contract. The Contractor's Quality Plan and the Inspection and Test Plan shall consider and include fully the minimum standards and quality for each item of material or work specified in the M&W Specifications (C&S).

This M&W Specifications (C&S) attempts to include as much as possible the various kinds of Works in the Contract. However, there may be exceptional cases when new materials or products or specialist's works are specified or proposed by the Contractor such that the manufacturer's recommendations or specification is relied on as basis for the material and workmanship standard for the completed works. For any item of material or work which is not mentioned in this M&W Specifications (C&S), the Contractor shall propose the full specification and the examinations and tests required to determine the minimum acceptable quality or standards of the material and workmanship for the Engineer's acceptance.

This M&W Specifications (C&S) shall be developed, improved and amended for the Engineer's acceptance to suit the Contractor's Design or Method Statement whenever the Contractor finds it inadequate or deficient at no extra cost to the Authority. All materials, components and methods of fabrication and construction including examination and testing shall be clearly and concisely explained in detail by the Contractor if he is proposing additional specification for the works for the Engineer's acceptance. The Engineer will not accept any changes unless the Contractor can clearly demonstrate that such change will not result in lowering the standards or quality. If the Contractor's proposal involves making changes to this M&W Specifications (C&S), the submission shall identify the marked changes for the Engineer's acceptance.

In general, the requirements of the M&W Specifications (C&S) shall be considered as minimum requirements.

The Contractor shall maintain the present format of the M&W Specifications (C&S), keeping to the present clause numbering as far as practicable. The Contractor shall add further Chapters to the M&W Specifications (C&S) as necessary.

# CHAPTER 1

# GENERAL

## 1.1 GENERAL

1.1.1 This Specification sets out the basic standard of quality of materials and workmanship required by the Land Transport Authority.

1.1.2 The Contractor shall ensure that these requirements are strictly adhered to when carrying out the Works, unless otherwise instructed.

1.1.3 The term Engineer used in this Specification refers to the Engineer appointed by the Authority for the purpose of the Contract. Where the Conditions of Contract require a Superintending Officer be appointed for the purpose of the Contract, the term Engineer in this Specification shall refer to the Superintending Officer so appointed by the Authority.

## 1.2 STANDARDS AND CODES OF PRACTICE

1.2.1 Unless otherwise specified, all materials, fittings, workmanship, construction and installations for the Works, shall comply with the appropriate standard issued by Enterprise Singapore. If such a standard does not exist, then the appropriate standard issued by the British Standards Institution shall be used. Where relevant provision does not exist, the Contractor shall submit appropriate equivalent standard to the approval of the Engineer. All standards shall include all Amendments and Addenda current at the date of Tender.

1.2.2 Where Metric and Imperial versions of the same Standard exist then the Metric version shall apply.

1.2.3 In the Specification and Drawings the abbreviation "CP" means "British Standard Code of Practice” and the abbreviation "BS" and “BS EN” means "British Standards" and “British’s adoption of Eurocode”, respectively as issued by the British Standards Institution. "SS" and “SS EN” means “Singapore Standards” and “Singapore’s adoption of Eurocode”, respectively as issued by Enterprise Singapore. “ASTM” means the “American Society for Testing of Materials” and “M&W for M&E Works” refers to Material & Workmanship Specifications for Mechanical & Electrical Works.

1.2.4 All references to Acts of Parliament are (except where the contrary is expressly stated) references to the Acts of Parliament of the Republic of Singapore.

## 1.3 TRADE NAMES

1.3.1 Wherever items bearing trade names or company names are stated in the Drawings, Specification or Bills of Quantities, the Contractor may substitute items bearing alternative trade or company names provided they are warranted equal in all respects to those specified and the Engineer’s acceptance is obtained in writing before making a substitution.

## 1.4 SAMPLES OF MATERIALS AND WORKMANSHIP

1.4.1 In addition to supplying samples of materials as specified, the Contractor shall, whenever requested by the Engineer submit samples of any material or demonstrate the level of workmanship proposed to be used in the execution of the Works for his acceptance.

1.4.2 Such samples for demonstration of Works shall be constructed or orientated so that viewing in natural light will reasonably duplicate the effect expected in the finished work. The Contractor shall maintain the samples until their removal is directed by the Engineer.

## 1.5 INSPECTION AND TESTING

1.5.1 The Engineer shall have the right to inspect the manufacture of any material at the manufacturer's works at any time. However the cost of travel and accommodation where necessary for the Authority’s representative, shall be borne by the Authority, unless stated otherwise in the Contract.

1.5.2 The Contractor shall, obtain from the manufacturer and submit to the Engineer certificates showing that tests of materials have been carried out in accordance with the requirements of this Specification.

1.5.3 The Contractor shall agree with the Engineer in writing on the date and place of test, at least one week before the date of the test. The Contractor may proceed with the test if the Engineer confirms in writing that he is unable to attend the test. However, the Contractor shall furnish to the Engineer the certified copies of the test results.

1.5.4 If as a result of such inspection, examination or test the material is found to be defective or not in accordance with the Contract, the Engineer shall notify the Contractor of his rejection in writing. The Contractor shall furnish the Engineer a method statement which defines how and when the defect is to be made good. The method statement shall be submitted within 48 hours after the Contractor receives written notification from the Engineer.

1.5.5 Upon the acceptance of the method statement by the Engineer, the tests shall be repeated under the same terms and conditions. The Contractor shall immediately make good the defects or ensure that the materials comply with the Contract. Unless otherwise accepted by the Engineer all quality assurance testing shall be performed by a SAC-SINGLAS (Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme) accredited/approved testing laboratory to be appointed by the Contractor.

## 1.6 SITE RECORDS

1.6.1 The Contractor shall keep such site records as are required by the Engineer to ensure effective quality assurance of workmanship and materials. Such records shall include, but not be limited to, the following:

(a) Daily maximum and minimum temperature

(b) Rainfall

(c) Materials testing of all aggregates, cement and concrete identifying the section of works to which they relate

(d) Casting dates for in-situ and precast concrete

(e) Formwork striking

(f) Dates of structural steelwork shot blasting and painting together with paint film thickness

(g) Dates of inspection of steelwork fabrication and records of tests carried out

(h) Tests on fire resistance of materials

(i) Detail of filling materials, their location in the Works, dates of placing and compaction test

(j) Pilings

(k) Welding

(l) Detail of prestressed members, including moulds, concrete and tensioning

(m) Inspection/certification by Professional Engineers and Safety Officers

# CHAPTER 2

# DEMOLITION, SITE CLEARANCE AND HOARDING

## 2.1 GENERAL

The Contractor shall take all necessary steps during demolition and site clearance to protect adjoining properties, fences, public roadways, footpaths, etc. and shall be responsible for making good any damage, or the replacement by an acceptable equivalent should the material be no longer obtainable in the market.

Demolition and site clearance shall be carried out in such a manner as to cause as little inconvenience as possible to adjoining properties occupier and general public and to safeguard public safety at all time. The Contractor shall be held responsible for any claims arising there from.

The Contractor shall take all necessary precautions during demolition and site clearance not to disturb existing electricity supply cables, drains, gas pipes, water supply pipes, ducts, telephone cables, radio and television relay lines, hydraulic pressure mains and other service pipes and fittings across the site. Where necessary, the above service lines and fittings shall be supported and protected.

Before work commences or during the progress of the demolition and site clearance works, should the Contractor discover any cables, pipes or fittings which are liable to be damaged during the progress of the works or may obstruct and impede the progress of the works, he shall inform the Engineer and co-ordinate with the services owners and/or utility agencies for the protection or diversion of the cables or pipes or fittings.

## 2.2 SITE HOARDING

The Contractor shall provide and erect, to the acceptance of the Engineer, all necessary protective screens, hoarding, shoring etc. that may be required, to prevent damage, nuisance or disturbance by debris, dust, noise, etc. to adjoining properties, public roadways or persons or traffic passing nearby. Unless specified otherwise, such protective hoarding shall be erected by the Contractor around the perimeter of each worksite.

The hoarding shall be erected once the Contractor takes charge of the worksite, prior to the commencement of any site work.

Unless otherwise stated in the Particular Specification the hoarding shall be constructed to the following standards.

The hoarding shall be continuous, except for the provision of gates at the entrance and exit as accepted by the Engineer.

Entrances and exits shall be suitably positioned to comply with the requirements of the relevant authorities and agencies.

Adequate warning signs accepted by the Engineer shall be posted at conspicuous locations on the hoarding to alert the public of the construction in progress. Particular attention shall be given to exits for heavy machinery and vehicles leaving the site.

Each hoarding panel shall abut/overlap the next panel. The height of the panel shall not be less than 2.4m with a gap no greater than 50 mm between the bottom of the panel and the ground.

The Contractor shall take the appropriate precautions to prevent fluid, slurry or other waste to pass under the hoarding from the worksite at any time.

The top of the hoarding shall be level and when erected on inclined ground it shall be stepped accordingly whilst not exceeding the maximum allowable gap at the base of the hoarding.

The hoarding panel shall be white in colour flat panel type with a minimum height of 2.4m. The minimum thickness of hoarding shall be 0.6mm with nominal width of 300mm. The hoarding panel shall be fixed to a structural framework spaced at appropriate distances designed by a Professional Engineer. The hoarding including its support and footings shall be designed to withstand wind loading and wind pressure due to vehicles passing by and to ensure that it shall not collapse or sway. The fixings on the hoarding shall be concealed and give a neat appearance.

The material of the hoarding shall be metallic hot-dip coated zinc/aluminium alloy-coated steel comprising 55% aluminium, 43.5% zinc and 1.5% silicon, with a minimum yield stress of 300MPa. The minimum coating mass shall be 150g/$m^2$.

The hoarding shall be removed on completion of the whole of the Works unless otherwise stated.

Removable panels shall conform to the following specifications :

(a) Removable panels, of not less than 1 metre in width and painted red, shall be provided in hoarding fronting buildings on the footpath side of the works area, at intervals of not more than 10 metres, except where not possible due to machinery or trench works.

(b) The words “Fire Service Access” in 120 millimetre characters in the four official languages shall be painted white on the works area side of the removable panels.

(c) The removable panels shall not be positioned at the main exits of buildings.

(d) In cases where a hoarding is erected to partition off a carriageway or works area, removable panels shall be erected directly opposite to those specified in (a) above. The words, as in (b) above, shall be painted on the carriageway side of the hoarding.

(e) Where removable panels are provided on hoarding on both sides of a worksite, (i.e., one on the outside of the building, and the other on the carriageway), a cross-walk/passageway shall be maintained to link up each pair of panels.

(f) Where road openings or ditches exist in the works area behind these removable panels, wooden boards or metal decking sufficient to bear a point load of 200 kilograms shall be provided.

When the hoarding is built adjacent to a public right of way the Contractor shall illuminate the outside of the hoarding using lights attached to the hoarding or shining over the top of the hoarding from within the worksite. Where work is to be carried out directly above public access area such as footpath, the Contractor is to design and provide hoarding with roof shelter.

The lights shall be located at suitable spacings to provide sufficient lighting of at least 15 lux with uniformity ratio of 0.3 to the perimeter of the hoardings where there is footpath for the public or at location where directed by the Engineer.

The lights shall be of a durable design with no sharp edges or protrusions. Emergency lighting shall be provided at suitable spacings to achieve a minimum brightness of 15 lux.

All lighting shall be of the same colour and shall not dazzle or confuse motorists.

Buildings, trees and structures shall not form part of the site boundary. All hoarding shall be erected in front of such structures, unless otherwise directed by the Engineer.

All site hoarding shall be maintained and kept in good condition at all time. Repairs to the hoardings will be required by the Contractor when considered necessary by the Engineer,

Half-height hoarding (with chain-link fence on the upper half) to be installed at the corner of road junctions or any location deemed necessary to improve sight distance of vehicles for better road and pedestrian safety, to the acceptance of the Engineer.

## 2.3 DEMOLITION

### 2.3.1 Notice of Demolition

Before commencing demolition of any part of a structure, the Contractor shall obtain the necessary approval from relevant authorities and agencies. He shall ensure all electrical, water, gas and any other services are terminated and disconnected before commencing the demolition work.

### 2.3.2 Method of Demolition

The Contractor shall submit the method statement for the demolition to the Engineer before commencement of the work. The Contractor shall comply with the procedures and recommendations as detailed in SS 557:2010.

The Contractor shall demolish the whole or part of the existing building or structure to ground level as required under the Contract. Unless otherwise specified all hard-core or stone fillings below the existing ground level shall be removed. All obsolete concrete drains, foundations including pile caps (except piles), floors, paving, etc. shall be thoroughly excavated and the voids filled with approved fill materials, well compacted in layers of 300 mm thick and levelled to required levels.

### 2.3.3 Protection of Adjacent Structures

The Contractor shall provide, erect, maintain and dismantle all necessary underpinning, shoring or other forms of support to safely protect all properties adjoining the property to be demolished. The designs for such works shall be endorsed by a Professional Engineer and a copy of the designs shall be given to the Engineer for his acceptance. The construction and adequacy of such supports shall be the entire responsibility of the Contractor. Should any subsidence or any damage result from the inadequacy of the shoring or any other support provided, the damage shall be made good by the Contractor at his own expense.
Notwithstanding the provision to ensure the stability of the adjacent structure, instrumentation and monitoring shall be carried out by the Contractor during the demolition to ensure that measures provided are sufficient. The Contractor shall furnish written monitoring reports at an interval to be agreed with the Engineer

### 2.3.4 Utilities and Services

All existing sewer mains and manholes shall be properly protected and all branch sewers from the building to be demolished shall be properly sealed off by a licensed plumber. Public Utilities Board (Water Reclamation Network) shall be notified in writing before commencing work. The voids within the abandoned sewer mains and manholes shall be filled with material accepted by the Engineer

### 2.3.5 Removal of Foundations

During removal of foundations or pile caps, the Contractor shall take all precautions to prevent soil disturbance to the surrounding foundations or damage to services in the vicinity. Should any subsidence, or any damage result, the damage shall be made good by the Contractor at his own expense.

## 2.4 MANAGEMENT OF WORKMEN MOVEMENT

The Contractor shall ensure that his workmen do not trespass into nearby properties. In the event of any trespassing, he shall indemnify the Authority against all claims for damages.

## 2.5 TREES, BUSHES, HEDGES, ETC.

The Contractor shall provide adequate protection to all trees, bushes, etc, to be preserved as requested by the National Parks Board or as directed by the Engineer.

No trees shall be felled, removed or trimmed without the prior approval of the National Parks Board and only when directed by the Engineer.

When works are carried out near to trees, the Contractor shall inform National Parks Board prior to the commencement of the work.

The stump and root of felled trees shall be grubbed up immediately and removed from the site.  All empty tree holes or cavities shall be filled with approved material to the existing ground level and compacted to the satisfaction of the Engineer.

All shrubs, roots, lalang, etc. shall be removed by cutting and/or digging and removed from site.

## 2.6 TURF AND TOPSOIL

All topsoil, turf and other vegetable matter on the site shall be excavated and removed to an approved site. The Contractor shall identify suitable locations to stack the topsoil on site subject to the acceptance of the Engineer.

## 2.7 DUMPING OF DEBRIS, ETC.

The disposal of materials and rubbish by burning on site or burying in the ground shall not be permitted under any circumstances.

The Contractor shall remove all rubbish on the site and in buildings under demolition to an approved dumping ground.

Any hazardous materials such as abandoned asbestos pipes encountered during excavation or demolition shall be handled with care. The disposal of such material shall comply with the relevant authorities' guidelines and requirements. The Contractor shall engage a licensed contractor to remove such hazardous materials to an approved dumping ground.

# CHAPTER 3

# SURVEY AND SETTING OUT

## 3.1 GENERAL

The Resident Surveyor shall be responsible for managing all aspects of surveying and setting out for the duration of the works. He shall prepare method statements for all aspects of survey work on site; each method statement shall include a risk analysis. He shall ensure that all surveys are conducted to the requisite accuracy with sufficient checks. Survey transparency, good record system and clear presentation of reliable information are expected at all times.

At the commencement of the Rail Contract, the Contractor will be supplied with a set of Primary Control Markers. The Contractor shall check the accuracy of their position and level and shall immediately notify the Engineer of any discrepancies. The Contractor shall undertake all precautions to protect these markers and to re-establish any damaged marker at his own cost.

## 3.2 SURVEY CONTROL

### 3.2.1 Survey Markers

Survey Markers shall be durable, appropriate to location and intended use. Survey Markers shall be clearly identifiable and protected from construction traffic. For installation of a Survey Marker into reinforced concrete, the Contractor shall ensure that steel reinforcement bars are to be avoided. Either removable anchors or epoxy adhesive shall be used as the method of fixing.

Benchmarks shall have a domed surface for staff placement. Primary Benchmarks shall comprise a stainless steel bolt securely placed vertically into a concrete slab, or horizontally into a column. The protrusion shall not pose a safety hazard.

Survey Markers used for horizontal control shall have an unambiguous point above (or below) which a survey instrument can be precisely centred. The point shall comprise either a punchmark or the intersection of 2 lines forming a cross. Cross-headed road nail (75mm long) complete with a coloured washer shall generally be used as a Survey Marker.

In all tunnels, station boxes and shafts, a precision demountable survey table and back plate system (see Figure 3.1) shall be installed progressively for carrying out horizontal control. The precision demountable survey tables shall be mounted on back plates that are to be attached to the tunnel lining or shaft wall until track laying is completed. Only upon written permission from the Engineer can the back plates be removed and any holes made good. The distance between adjacent intervisible back plates shall not exceed 80m. The minimum number of precision demountable survey tables required per tunnel drive is six. The back plate has been designed to accept LTA's special precision-made gyro table. Survey tables shall be installed to ensure that the top flat surface of table is level in all directions to better than 1:150. Survey tables shall allow forced centring in the horizontal plane by means of a precision threaded 5/8" instrument insert. To prevent damage to optical plummets within tribrachs, the threaded portion shall be designed not to penetrate more than 12mm into a tribrach. The Contractor shall ensure safe access to any survey table installed. A suitable working platform complete with access ladder and handrail shall be provided. In the event that the working platforms were removed, the Contractor shall reinstall the platforms whenever needed by the surveyor.

Every tunnel survey back plate and benchmark shall have a sign (see Figure 3.2) indicating that the device is required for trackworks and shall not be disturbed or removed.

### 3.2.2 Control Observation, Adjustment and Presentation

Homogeneous survey control is required prior to any setting out. Survey control shall evolve from the whole to the parts. Where practical, all survey points within a horizontal survey control network shall be occupied and observed from. Forced centring techniques shall be used throughout. A round of angular observations shall comprise the mean of observations taken on both faces of the total station. A minimum number of 4 rounds of horizontal and vertical angles shall be observed at each instrument set up. For control work, the angular spread of horizontal angles shall not exceed 3 seconds of arc. Distances shall be measured in both directions. All raw data pertaining to each set up shall be electronically recorded.

Survey control shall include redundant observations. Observation networks shall be processed using the method of least squares adjustment and the resulting residuals to the observations shall be inspected for magnitude. Any large residuals or error ellipses shall be examined and appropriate remedial action shall be taken.

Precise levelling shall be double run using equal back and fore sights at each instrument set up. Levelling sights shall never exceed 30m. On the ground surface, the Contractor shall establish stable benchmarks adjacent to the site so that the distance between adjacent benchmarks does not exceed 250m.

Height datum transfer accuracy shall be better than 2mm in a 30m deep shaft. The transfer of height datum shall be by independent means.

Azimuth transfer from surface to underground shall be better than 3 seconds of arc and point transfer shall be accurate to within 2mm. Such transfers shall be verified by independent means.

At 3 monthly intervals, the Contractor shall conduct a complete survey of all existing survey control. A bound, A4 size survey control report shall be submitted to the Engineer for acceptance within 2 weeks of completing the field work. The convention adopted shall comprise Station Name, Easting, Northing and Elevation reading from left to right. The entire control scheme shall be included in a single least squares adjustment. The report shall contain the following information: dates of survey, fixed survey control and values, specification of instrumentation used, calibration status of instrumentation used, observational acceptance criteria, list of final adjusted co-ordinates findings and conclusion. Attached to the report shall be the observations (A4 printout of electronic booking sheet or customised spreadsheet), adjustment with residuals and station error ellipses, table of differences in mm from previous co-ordinates and elevations (if applicable), a drawing clearly showing layout of scheme and measured quantities and final co-ordinates in tabular form.

## 3.3 GENERAL SETTING OUT

The Contractor shall carry out a comprehensive level survey of the Contract area before any work commences on the site that may alter original ground levels.

Pre-computation shall be carried out prior to any setting out. For rail projects, the effects of cant and throw shall be incorporated into pre-computation wherever relevant. All pre-computation shall be readily available in a spreadsheet format for use on site.

The method of setting out for each particular element of the work shall comply with the required accuracy, the method of construction, and shall be appropriate for site conditions.

In the setting out process, all elevation transfer conducted by levelling shall start on an established benchmark and finish on a different benchmark. If a significant misclosure is detected, the reason shall be determined and the necessary corrective action taken.

After the erection of the formwork and prior to concreting, a survey check shall be carried out on the formwork to ensure that the setting out has been done correctly.

A spreadsheet shall be used in all instances to tabulate the difference (or offset) in mm between the actual set out (or as-built) co-ordinates from the design co-ordinates. In cases where the design is an alignment, offsets to the alignment shall be computed for each surveyed point.

## 3.4 TUNNEL SHIELD PRE-LAUNCH SURVEY

The centre of the shield shall be driven to the design tunnel alignment. The tunnel alignment is not necessarily the same as the design track alignment. The Resident Surveyor shall obtain the track alignment and validate the tunnel alignment geometry and co-ordinates for all elements of the tunnel alignment. A list of co-ordinates (Easting, Northing & Elevation) shall be generated at 1m chainage intervals along the length of the design tunnel alignment.

Permanent reference marks or prisms are to be suitably placed inside the shield typically on bulkheads, towards the front and rear of the shield. The permanent reference marks will be used later to determine the exact orientation and position of the shield in the ground. The extrados of the shield skin shall be accurately surveyed on site to determine circularity and diameter at the front, rear and mid sections. The permanent reference marks and the guidance system targets shall also be accurately surveyed concurrently to determine their position relative to the central axis of the shield. A detail drawing together with the calculations showing the survey results is required.

The launch cradle rails, tunnel eye and seal ring shall be set out and checked prior to the shield being placed on the cradle. The contractor shall verify that the shield is correctly positioned on the cradle in accordance with the launch strategy and the design tunnel alignment. Any protrusion on the tunnel eyes shall be surveyed by the Contractor prior to the launching.

After installation of the guidance system, the Resident Surveyor shall determine that the design tunnel alignment is input correctly. It shall be clearly stated at what specific point of the shield the current co-ordinates output by the guidance system relates to (e.g. at the cutter head). The guidance system shall correctly output the current position and attitude of the shield. Independent manual surveys shall be conducted to first verify the absolute positional output of the guidance system. Regular checks shall then be conducted to ensure that the guidance system correctly indicates the position of the shield relative to the design tunnel alignment.

## 3.5 TUNNEL SURVEY DURING CONSTRUCTION

Survey control (horizontal and vertical) shall be installed progressively along the tunnel as construction permits. Underground survey control shall be configured to achieve an accuracy of 10mm in 1000m for line and 5mm for 1000m in level in the breakthrough survey. The ring number shall be included in the naming convention for survey control points. The zigzag horizontal survey control configuration shall incorporate redundant observations whilst excluding lines of sight that graze the tunnel lining. During construction, the horizontal control shall generally be situated close to the tunnel axis level. Benchmarks shall be located at 30m intervals along the entire length of the tunnel and shall be situated above the 1$^{st}$ stage concrete level, on the opposite side of the permanent walkway. Upon completion of the 1st stage concrete, benchmarks shall be transferred to a level above the proposed 2nd stage concrete.

As soon as it is practical, a base line greater than 100m in length shall be established from the shaft bottom into the tunnel. This base line shall be accurately surveyed several times from the surface by independent means to determine the co-ordinates and azimuth for the base line. Similarly a minimum of 3 benchmarks shall be installed in the proximity of the shaft bottom and vertical control accurately transferred several times from the surface by independent means. The base line and the benchmarks shall then be held fixed to progress the survey control into the tunnel.

At 3 monthly intervals, the entire tunnel survey control scheme shall be re-observed from the shaft bottom. All tunnel benchmarks shall be observed by precise levelling to determine any significant movements. The tunnel survey control shall be included in the survey control report.

When tunnel drive reaches 50% and 75% of its length, the survey control base line and the benchmarks shall be rechecked from the surface. Arrangements shall be made for the Engineer to check the underground azimuth by gyro readings.

During the early stages of each tunnel drive, intensive manual survey checks shall be made of the shield’s position and attitude by surveying the permanent reference marks inside the shield. At the same time, the automated guidance system shall be interrogated to obtain output of the shield’s position (shield’s vertical, and horizontal deviations from the design tunnel alignment at a particular chainage) and attitude (pitch, lead and roll measurements). The manual and automated shield positions shall be plotted together on the same graph with tabulation of the shield’s attitude, and forwarded daily to the Engineer. Any anomalies shall be identified, investigated and resolved. The above process shall be continued until complete confidence in the satisfactory behaviour of the automated guidance system is obtained.

Prior to any backup installation, each ring built shall be surveyed after it has emerged from the tail skin. Ring survey shall typically comprise eight 3D survey points (accuracy of a point is typically ±5mm) taken on the leading edge of the ring at approximately the crown, invert, axis, knees and shoulder positions. Absolute levels of the invert and crown shall also be taken using a level and staff. The co-ordinates of the best-fit centre of the ring shall be calculated and the vertical and horizontal offsets determined from the design tunnel alignment. A ring shall be considered out of tolerance during tunnelling when the best-fit centre deviates by more than 50mm in line or level from the design tunnel alignment. The as-built position of the rings and the output position from the guidance system shall be plotted and analysed, and any correlation anomalies investigated and resolved.

If rings are built out of tolerance, return to alignment shall be at a rate not greater than 1mm per metre.

After backup installation, the positional checking of any type of guidance system requires manual survey to be carried out originating each time from proven survey control established behind the confines of the backup. Gyro-based guidance systems shall be surveyed and updated by manual survey on a daily basis. Total station based (all non-gyro systems) guidance systems shall be thoroughly checked whenever the total station is moved forward. The Resident Surveyor shall ensure that any guidance system is correctly interpreting the true position and attitude of the shield. It shall be demonstrated by independent means that the generated guidance system offsets from the design tunnel alignment are correct.

As rings emerge from behind the backup, every alternate ring shall be comprehensively surveyed with a minimum of 8 number 3D points well distributed around the leading edge. Roll of each surveyed ring shall be determined. Ring survey shall take place progressively to ensure that no more than 200m of tunnel is required to be surveyed behind the back up at any one time. An additional 2-ring overlap of surveys is required between each survey and at each new instrument set up within a survey. The co-ordinates of the best-fit centre of the ring shall be calculated with the vertical and horizontal offsets determined from the design tunnel alignment. The as-built position of the rings and the output position from the guidance system shall be plotted and analysed. Any anomalies in correlation shall be investigated and resolved. The Resident Surveyor shall keep and maintain up-to-date graphical records showing the horizontal, vertical and radial offset of every surveyed ring relative to the design tunnel alignment. These graphs including data shall be produced and made available to the Engineer in soft copy upon request. It shall state clearly which revision of design track alignment the graphs refer to. The Contractor shall indicate on their submissions the clearances on the left shoulder, left knee and right knee in graphical records and values.

## 3.6 WRIGGLE SURVEY

Upon completion of tunnelling, when a suitable breakthrough has been effected, the survey connection shall be made and the survey misclosure determined. A survey report shall be prepared detailing the final adjusted values for all the survey control to remain in the tunnel for the purpose of track laying.

A final as-built survey to determine the 3D co-ordinates of the tunnel lining at 8 points, well spaced around the circumference of the leading edge, of each alternate ring shall be carried out. The best-fit centre of the ring and its minimum radius shall be determined. The computed horizontal, vertical and radial offset of the centre of each surveyed ring relative to the design centre shall be plotted for the entire tunnel, giving an indication of potential out of tolerance zones.

A detailed analysis to determine that there is sufficient clearance between the structure gauge and the as-built surveyed tunnel lining for system wide installations is required. This check must be carried out for every surveyed ring, cut and cover sections at 5m intervals, and station boxes. For the cut and cover tunnel, every section shall be surveyed with 3 points taken at the base, 2 at each wall, and 3 at the soffit. For station box, besides surveying the base, wall and soffit, the platform edge and columns are also required.

The Contractor shall submit to the Engineer a detailed report (in hardcopy and softcopy on CD) for each completed tunnel drive. The report shall demonstrate in tabular format that the clearances on 3 critical points (shoulder opposite walkway, walkway and drain opposite walkway) have been achieved throughout the tunnel using the proposed design track alignment. The report shall include drawings to show typical cross-sections of tunnel, structure gauge and clearances. Detailed cross-sections shall be drawn for rings where clearances are not achieved. Rings shall be referenced by ring number, chainage and best-fit centre co-ordinates. All out of tolerance areas shall be highlighted. The Contractor shall also make a clear presentation of the methodology, facts and findings to the Engineer. Each report shall be prepared and submitted to the Engineer within 6 weeks of tunnel breakthrough.

The Contractor shall carry out as-built survey of the top of 1$^{st}$ stage concrete and demonstrate that it has been placed within tolerance. The survey shall comprise 3 points (left, centre and right) in 3-D co-ordinates across the tunnel at every alternate ring. The elevations shall be compared against design elevations at each surveyed point. All out of tolerance areas shall be highlighted.

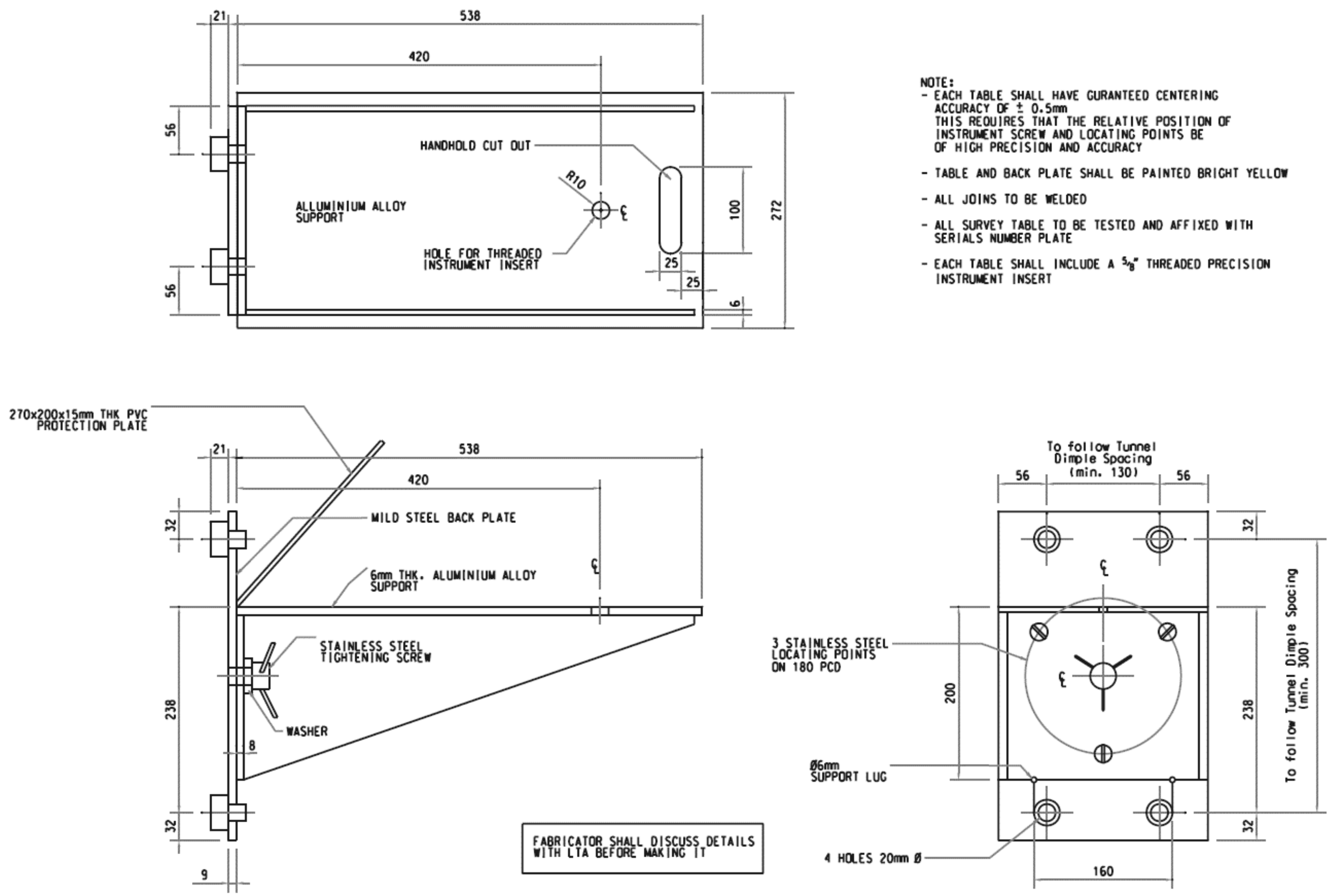
The Contractor shall carry out accurate as-built survey of all platform edges, columns and any other structures to ensure that there is no infringement of the structure gauge. These surveys shall be conducted from proven survey control that is well established, using long base lines within depot or stations. The results shall be tabulated to show the offsets in mm relative to the design alignment and also the clearance or lack of clearance from the design. All out of tolerance areas shall be highlighted.

The Contractor shall propose to the Engineer any re-alignment necessary to accommodate out of tolerance situations. If the design alignment criteria cannot be met, these out of tolerance areas shall be reconstructed at the Contractor's expense. A re-survey of these reconstructed areas is required.

## 3.7 MONITORING SURVEYS

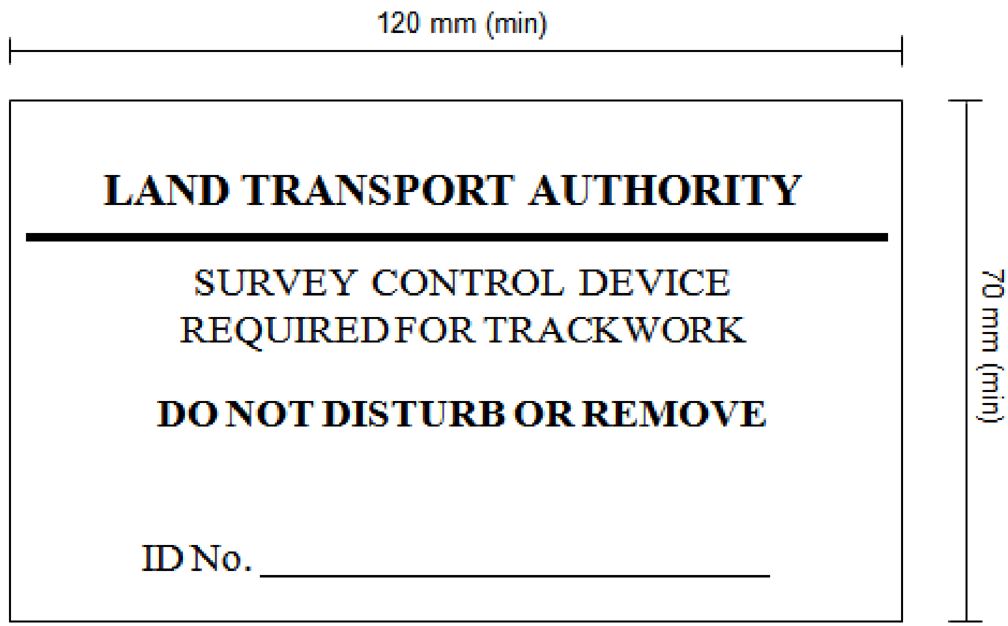
Pre-analysis techniques shall be used to demonstrate that the required accuracy of any proposed monitoring scheme can be achieved. As a minimum requirement, the design of a monitoring scheme shall take into consideration the likely range of movements to be incurred, accuracy required, accessibility to the area of interest, instrumentation to be used, the use of any special accessories, frequency of monitoring, particular site conditions, safety, data collection/processing techniques, real time or post process, maintenance of the system, stability of the points of reference and the presentation format. A detailed method statement shall be submitted to the Engineer for acceptance before any particular monitoring scheme being implemented.

All 2D and 3D monitoring schemes shall be co-ordinated on the Project grid and datum. All elevation monitoring shall be conducted on the Project datum. All monitoring points shall be clearly and unambiguously identifiable. All reference points shall be checked for stability prior to each use. A base set of readings shall be established at the start of each monitoring scheme. Base set shall comprise the average of three independent sets of readings. Monitoring reports shall be in tabular form including the base set of readings, and the relative movements in mm from the base readings for each subsequent set of observations taken. Graphical representation of movements against time shall be prepared for presentation purposes where required. If any agreed trigger levels are exceeded, the Engineer shall be notified immediately.




PRECISION DEMOUNTABLE SURVEY TABLE & BACK PLATE SYSTEM

Figure 3.1




**SURVEY CONTROL DEVICE SIGN**

NOTE:
- SIGN SHALL HAVE INFORMATION CLEARLY PRINTED ON WHITE PAPER.
- IT SHALL BE LAMINATED AND AFFIXED TO BACKPLATE OR WALL.

Figure 3.2

# CHAPTER 4

# EARTHWORKS

## 4.1 GENERAL

4.1.1 This Specification is applicable to all earthworks up to formation level. For road and railway works, formation level shall be the level on which the railway sub-ballast or road sub-base is laid.

4.1.2 Subgrade preparation for road works shall also be subject to the requirements of Chapter 10 Roadworks.

## 4.2 CLASSIFICATION OF EARTHWORK MATERIAL

4.2.1 The following definitions of earthworks shall apply to this and other clauses of the Specification in which reference is made to the definitions: -

(a) ‘Top Soil’ shall mean the top layer of soil that can support vegetation.

(b) ‘Suitable Material’ shall comprise all that is capable of being compacted in the manner specified in Clause 4.12 to form a stable fill having side slopes as indicated on the Drawings.

(c) ‘Not Suitable Material' shall mean other than Suitable Material and shall include :

(i) ‘Unsuitable Material’ – any material which is classed as “Not Suitable Material” but does not include “Contaminated Material”, “Waste Material” as defined below with clay of either liquid limit exceeding 70% or plasticity index exceeding 50%;

(ii) ‘Contaminated Material’ – any material which contains amounts of any of the contaminants that exceeds the intervention values listed in SS 593 and where the contamination was an existing condition on award of the Contract;

(iii) ‘Waste Material’ – any material that contains building debris, domestic or industrial rubbish, man-made materials, logs, stumps or any other material which the Contractor introduces into the spoil, including bentonite and bentonite slurry;

(d) ‘Rock' shall mean hard material found in ledges or masses in its original position, which would normally have to be loosened either by blasting or by pneumatic tools, or if excavated by hand, by wedges and sledge hammers. ‘Rock’ shall also include all solid boulders or detached pieces of rock exceeding 0.10 $m^3$ in size in trenches or exceeding 0.20 $m^3$ in general excavation.

(e) ‘Imported Rock Fill' shall be clean well-graded quarry waste provided by the Contractor from sources outside the Site. It shall be resistant to weathering. The maximum particle size in the material shall pass through a rigid 200mm square grid and the largest dimension of any particle shall not exceed 300 mm. The material shall not have more than 10% of its particles passing a 0.75mm BS sieve. The source and the sieve test report of the proposed material shall be submitted to the Engineer for acceptance.

(f) ‘Fill Material' shall mean Suitable Material for backfilling with the exception of Rock and Imported Rock Fill

(g) ‘Special Fill Material’ shall mean Suitable Material of which at least 95 per cent passing the 125mm BS sieve and at least 90 per cent passing the 75mm BS sieve. Up to 5 per cent of the material may be made up from isolated boulders of maximum dimensions not exceeding half the thickness of the layer of material being placed, provided that the fill can be compacted in the manner specified in Clause 4.12.

The coefficient of uniformity shall be greater than 10. The fraction passing a 75 μm BS sieve shall be less than 20% by weight and shall have the following characteristics:

(i) liquid limit not exceeding 35%; and

(ii) plasticity index not exceeding 12%

(h) ‘Selected Fill' shall be well graded granular natural sands, gravel, crushed rock, crushed concrete, well burnt shale or other materials. The material shall pass a 425 μm BS sieve, when tested in accordance with BS 1377 and shall have a plasticity index of less than 6%. The source and the sieve test report of the proposed material shall be submitted to the Engineer for acceptance.

(i) ‘Imported Fill Material' shall be Fill Material supplied by the Contractor from a source outside the Site. The source and the sieve test report of the proposed material shall be submitted to the Engineer for acceptance.

4.2.2 For the purpose of Table 4.2 of Clause 4.12, materials are grouped as follows:

(a) ‘Cohesive Soil' includes clays and marls with up to 20 percent of gravel and having a moisture content not less than the value of the plastic limit (determined in accordance with BS 1377) minus 4%.

(b) ‘Well-Graded Granular and Dry Cohesive Soils' include clays containing more than 20 per cent of gravel and/or having a moisture content less than the value of the plastic limit (determined in accordance with BS 1377) minus 4%, and well-graded sands and gravel with a uniformity coefficient exceeding 10.

(c) ‘Uniformly-Graded Material' includes sands and gravel with an uniformity coefficient of 10 or less, and all silts and pulverised fuel ashes. Any soil containing 80 per cent or more material in the particle size range 0.06mm to 0.002mm will be regarded as silt for this purpose.

4.2.3 Naturally occurring materials within the Site that are deemed as ‘Not Suitable Material’ due only to excessive moisture content may be spread and dried. The use of material treated in this way shall be subject to the acceptance of the Engineer.

## 4.3 EARTHWORK GENERAL

4.3.1 The Contractor shall carry out all earthwork in such a manner as to prevent erosion or slips and shall limit working faces to safe slopes and height. The Contractor shall ensure that all surfaces have at all times sufficient gradients to enable them to shed water without causing erosion.

4.3.2 Hauling of material from cuttings or the importation of fill material to the embankments or other areas of fill shall proceed only when sufficient compaction plant is operating at the place of deposition to ensure compliance with the requirements of Clause 4.12.

4.3.3 Construction traffic other than that required for the excavation and trimming shall not use the surface of the bottom of a cutting unless the cutting is in Rock or the Contractor maintains the level of the bottom surface at least 300 mm above formation level. Any damage to the sub-grade arising from such use of the surface shall be made good by the Contractor at his own expense with material having the same characteristics as the material which has been damaged.

4.3.4 The Contractor shall arrange for the rapid dispersal of water shed on the earthworks or on the completed formation during construction. This also includes water entering into the works from any source. Adequate means for trapping silt shall be provided and the water shall be treated in accordance with PUB’s requirement before discharged into permanent drainage system. The arrangements shall be made in respect of all earthworks including excavations whether for pipe trenches, foundations or cuttings.

4.3.5 The Contractor shall provide where necessary temporary water courses, ditches, drains, pumping or other means of maintaining the earthworks free from water. Such provision shall include carrying out the work of forming the cuttings and embankments in such a manner that their surfaces have at all times a sufficient minimum crossfall and, where practicable, a sufficient longitudinal gradient to enable them to shed water and prevent ponding.

4.3.6 Pumping shall not be regarded as meeting provisions of this Clause where a dumpling temporarily obstructs the free drainage of a cutting. In such circumstances the Contractor shall construct temporary drains to a suitable outfall or install the permanent drainage through the dumplings.

4.3.7 The Contractor shall take special care that naturally occurring materials within the site are not rendered unsuitable by his method of working. Areas of cuttings and excavation shall be so worked that rainfall is conducted rapidly away from the exposed material and at times of expected heavy rain that the cutting areas are protected by appropriate methods of working and drainage provisions. If any material that was suitable in its original position is rendered unsuitable by the Contractor's method of working an equivalent volume of imported Suitable Material shall be provided by the Contractor at his own expense.

4.3.8 If the Contractor allows exposed material, which would provide a suitable surface for placement of fill when exposed, to reach a condition where compaction of backfilling is impracticable, he shall make good at his own expense either by additional excavation and filling in the manner specified in this clause, or by waiting until the condition of the exposed material is fit to receive the approved backfill.

4.3.9 All Top Soil (including turf) shall be removed from the areas of cuttings and embankments. Top Soil shall also be removed from existing embankments required to receive paving or additional fill and from areas of new ditches and watercourses. All removed Top Soil shall, where practicable, be stockpiled for re-use to soil slopes of cuttings, embankments, berms, verges, reserves and for the provision of beds for the cultivation of trees and shrubs.

4.3.10 The Contractor shall make his own arrangements for stockpiling of Top Soil and/or Suitable Material, and for the provision of appropriate areas for the purpose.

4.3.11 All excavated Suitable Material together with the surplus from the trenches and foundation pits after backfilling shall, where possible, be incorporated in the Works and the Contractor shall programme his work to ensure that all possible material can be utilised. No excavated Suitable Material which could subsequently be utilised in the works shall be removed from the Site except on the direction or with the permission of the Engineer. Should the Contractor be permitted to remove Suitable Material from the Site to suit his operational procedure, then he shall make good at his own expense any consequent deficit of filling arising therefrom.

4.3.12 Surplus excavated materials arising from excavation and not required for filling shall become the responsibility of the Contractor who shall remove such surplus away from the site.

4.3.13 Where the excavation reveals a combination of Suitable and Not Suitable Materials the Contractor shall, unless otherwise agreed by the Engineer, carry out the excavation in such a manner that the Suitable Materials are excavated separately for use in the Works without contamination by the Not Suitable Materials.

4.3.14 The use of Top Soil shall be restricted to surface layers for planting and turfing.

## 4.4 EXCAVATION GENERAL

4.4.1 Excavation shall be carried out to the dimensions, lines, levels and slopes as indicated on the Drawings. If the Contractor excavates deeper than the depths shown on the Drawings or as instructed by the Engineer, then he shall fill in such excessive depths with Suitable Materials to the acceptance of the Engineer.

4.4.2 The bottom of all excavations shall be free from mud and water, trimmed clean, protected from the effects of weather and thoroughly compacted and consolidated by approved manners and means.

4.4.3 The Contractor shall be responsible to excavate the top 1m of soft or defective soil below the formation level and backfill with Suitable Material. Such backfill shall be well compacted in layers of accepted thickness. For road construction, additional requirements for subgrade as stated in Chapter 10 Roadworks shall be complied with.

4.4.4 Brick and concrete foundations to building structures removed during excavation may be incorporated in fill areas, subject to the acceptance of the Engineer. All such material together with any brick or concrete site clearance material permitted by the Engineer shall be regarded as Selected Fill to which the requirements of Clause 4.2.1 (h) and Clause 4.12 apply.

## 4.5 CUTTINGS AND CUT SLOPES

### 4.5.1 General

4.5.1.1 Unless otherwise specified, no portion of the earth cutting shall vary from the specified or ordered formation level by an amount exceeding 150mm. In the case of cut slopes, no portion of the completed slope shall vary by an amount exceeding 100mm (measured at right angles to the slope).

4.5.1.2 In all cuttings, whether in earth or rock, undulations in the general plane of the slope will not be permitted.

4.5.1.3 Unless otherwise specified, excavation in rock shall extend to at least 150mm below the specified formation level and backfilled with approved materials.

4.5.1.4 Any overhanging, loose or unstable material, shall be removed.

4.5.1.5 The excavation shall be so arranged that the working areas are adequately drained throughout the period of construction.

4.5.1.6 In cutting where the strata consists of earth overlaying rock which is required to be cut to a slope of 1 (H) : 2 (V) or steeper, the face of the rock shall be given its appropriate slope up to the junction of the rock and earth and the latter shall be stripped to form a bench 900mm wide and sloped to the gradient as specified.

4.5.1.7 For permanent slope in soil, which are trimmed or backfilled to 2 (H) : 1 (V) gradient and which has a total slope height greater than 4m, geocell or similar cellular confinement system for turfed slope shall be installed to prevent soil erosion.

Geocell shall meet the following requirements listed in Table 4.1.

**TABLE 4.1 Geocell Requirements**

| Property | Value | Test Method |
|---|---|---|
| Material | High density polyethylene (HDPE) | - |
| Density | Min. 0.94 g/cm$^3$ | ASTM D 1505 |
| Carbon Black Content | Min. 1.5% | ASTM D 1603 |
| Environmental Stress Crack Resistance | Min. 4000 hr | ASTM D 1693 |
| Nominal sheet thickness smooth | Min. 1.2mm | ASTM D 5199 |
| Nominal sheet thickness textured | Min. 1.5mm | ASTM D 5199 |
| Cell depth | Min. 100mm | - |
| Seam Peel Strength | Min. 1.42 kN/100mm depth cell | U.S. Army Corps of Engineers, Technical Report GL 86-19 Appendix A |
| Seam Hang Strength | A 102mm weld joint supporting a load of 72.5kg for 30 days minimum, or a 102mm weld joint supporting a load of 72.5kg for 7 days minimum while undergoing temperature change from 23$^o$C to 54$^o$C on a one hour cycle | - |

4.5.1.8 When the total slope height is greater that 6m, benches and berms shall be installed so that each berm height is less than 6m.

### 4.5.2 Shotcrete to Exposed Slopes

4.5.2.1 Shotcrete shall be applied to form a skin protection on slopes where specified on the drawing to prevent erosion and weathering.

4.5.2.2 The minimum thickness and characteristic strength of the shotcrete shall be 50 mm and 10MPa respectively. The shotcrete should be applied on an exposed slope face as soon as possible, but no later than 24 hours after cutting.

4.5.2.3 The design mix of the shotcrete shall be such that it is pumpable and the end product will adhere to the slope surface.

4.5.2.4 In order to provide for drainage of the slope surface, weepholes shall be provided through the shotcrete and 200mm into the soil or rock at 3m intervals in both horizontal and vertical directions.

## 4.6 REMOVAL OF ROCKS AND OTHER BLASTING

4.6.1 Should rock be met in the course of excavation, it shall be removed by approved means.

4.6.2 The written consent of the Engineer shall be obtained on each occasion the Contractor wishes to use explosives. If explosives are to be used, the Contractor shall obtain all necessary licences from the appropriate authorities and shall conform to all Government regulations relating to transport, storage, handling and use of the explosives and shall also conform to the rules set out by the Officer-in-Charge of Arms and Explosives.

4.6.3 The Engineer shall be fully informed by the Contractor as to the steps and precautionary measures taken to safeguard the surrounding properties. The Contractor shall be liable for any accident, damage or injury to any person property or thing, resulting from the use of explosives. When blasting is proposed to be carried out, the Contractor shall determine the danger zone likely to be created and ensure that no damage is caused to persons or property on or off site. Prior to commencing blasting operations a written report listing any existing defects in the structures in the zone which may be affected, supported by photographs where necessary, shall be submitted to the Engineer by the Contractor. The Contractor shall submit a detailed Method Statement, Risk Assessment Report, and Mitigation Measures to the Engineer for acceptance.

4.6.4 When blasting operations are being carried out, any road affected shall be closed to traffic and the appropriate signs shall be erected in accordance with the latest “Code of Practice for Traffic Control at Work Zone” published by the Land Transport Authority.

4.6.5 The Contractor shall comply with the requirements of BS PD CLC/TR 50426 in respect of the use of electrical detonators in the vicinity of static and mobile radio transmitters including normal radio and television broadcasting stations and radar units associated with aircraft movements.

## 4.7 EXCAVATION OF PITS AND TRENCHES

4.7.1 Where required by the nature of the materials to be excavated, the Contractor shall provide all necessary timber planking, strutting and shoring required to uphold the face of the excavation and any necessary stagings. The Contractor shall be responsible for the design, supply, fixing and removal of all planking and strutting required. The planking and strutting shall be of sufficient strength to resist all anticipated loadings, to ensure the safety of the workmen and to prevent damage to any adjoining property.

4.7.2 Alternatively, subject to the prior acceptance of the Engineer, the face of the excavation may be suitably battered.

4.7.3 The bottom of all excavations shall be to the correct levels as shown on the Drawings. Any over-excavation of foundation pits or trenches below the specified levels shall be filled with grade 15 concrete to the specified levels. Any pocket of soft material or loose rock in the bottoms of pits and trenches shall be removed and the resulting cavities and any large fissures filled with Grade 15 concrete or otherwise with Suitable Material. After the placing of any such concrete, no trimming of the side faces shall be carried out for within 24 hours.

4.7.4 No length of trench greater than the allowable as specified in the approved method statement for excavation shall be excavated at any one time unless accepted by the Engineer. All surplus spoil shall be removed immediately on excavation and stacked spoil for filling shall be kept tidy at all times.

4.7.5 All excavated materials from such excavations not required for backfilling shall be disposed of in accordance with the requirements of the Contract.

## 4.8 BACKFILLING OF PITS AND TRENCHES

Unless otherwise shown on the Drawings, all filling for this purpose shall consist of Suitable Material as defined in Clause 4.2, deposited and compacted by approved plant in accordance with Clause 4.12. Timber planking, strutting, shoring and other excavation supports shall be carefully removed as the filling proceeds except where they are required by the Contract to be left in position. The removal of such supports will not relieve the Contractor of his responsibilities for the stability of the Works.

## 4.9 FILLING GENERAL

4.9.1 Filling works shall include the preparation and compaction as specified under Clause 4.12.

4.9.2 All filling material, whether placed and/or compacted or awaiting placing and/or compaction which, in the opinion of the Engineer does not comply with this Specification or has been damaged by weather or in any other way, shall be removed and replaced at the Contractor's expense.

4.9.3 When the state of the weather is such that, in the opinion of the Engineer, it would adversely affect the placing of specially compacted fill, all such work shall be stopped.

4.9.4 End tipping of fill shall not be permitted except in special circumstances and then only with the acceptance of the Engineer. The end-tipped material shall be compacted to the requirements as specified in Clause 4.12.

## 4.10 FOUNDATION FOR FILLS

4.10.1 Unless otherwise specified, the natural ground over which filling is to be placed shall be cleared of all loose boulders, grass, topsoil, bushes, trees, roots and other vegetation. Material shall be removed to such depths and over such areas as are acceptable to the Engineer, and shall be disposed of in a manner depending on its nature and condition at the time. The resultant excavation shall be backfilled with Suitable Material as defined in Clause 4.2, deposited and compacted as specified in Clause 4.12.

4.10.2 Before the placing of fill commences any overhanging rock ledges or caves within the area to be filled shall be removed.

4.10.3 The construction of any section of a fill shall not commence until the formation for that section has been accepted by the Engineer.

4.10.4 Where shown on the Drawings, Imported Rock Fill shall be placed directly on naturally occurring Not Suitable Material. The Imported Rock Fill material shall be deposited and compacted so as to comply with the requirements of Clause 4.12 for the compaction of Rock.

4.10.5 In circumstances where backfill has to be deposited below standing water the Contractor shall use only Imported Rock Fill as defined in Clause 4.2. Such material may be deposited below water without the associated use of compaction plant.

## 4.11 EMBANKMENTS AND FILL SLOPES

4.11.1 Embankments and other areas of fill shall be formed of Suitable Material as defined in Clause 4.2, taken to include Imported Fill Material, Rock and Imported Rock Fill. Additionally, when permitted by the Engineer, material including imported material, which is wetter than the appropriate limit may be incorporated after drying, in accordance with Clause 4.2.

4.11.2 All earthworks material placed in or below embankments, below formation level in cuttings or elsewhere in the Works shall be deposited and compacted as soon as practicable after excavation in layers of thickness appropriate to the compaction plant used as permitted in Table 4.2. Except where staging arrangements render it impracticable, embankments shall be built up evenly over the full width and shall be maintained at all times with a sufficient camber and a surface sufficiently even to enable surface water to drain readily from them. During the construction of embankments the Contractor shall control and direct construction traffic uniformly over their full width. Damage to compacted layers by construction traffic shall be made good by the Contractor at his own expense.

4.11.3 Compaction of embankments and other areas of fill shall be undertaken to the requirements of Clause 4.12.

4.11.4 If the material deposited as fill subsequently reaches a condition such that it cannot be compacted in accordance with the requirements of the Contract, the Contractor shall as directed or accepted by the Engineer either:

(a) make good by removing the material off the embankment and replacing it with Suitable Material; or

(b) make good the material by mechanical or chemical means to improve its stability, or

(c) cease work on the material until its physical condition is again such that it can be compacted as required.

4.11.5 Rock used in rock fill embankments shall, except for any specified external cover to slopes or within 500mm of formation levels, be of such size that it can be deposited in horizontal layers each not exceeding 450mm loose depth and extending over the full available width of the embankment. Material shall be spread and levelled by a crawler tractor weighing not less than 15 tonnes and compacted in accordance with Clause 4.12. Each layer shall consist of well-graded rock and all surface voids shall be filled with fine graded materials before the next layer is placed. The top surface and side slopes of embankments so formed shall be thoroughly blinded with approved fine graded material to seal the surface. Such material may on side slopes and verges be Top Soil as defined in Clause 4.2.

4.11.6 Isolated boulders each within the range $0.02m^3$ to $0.10m^3$ in size may be incorporated in earth embankments provided that the specified compaction requirements are met and no stone exceeding $0.02m^3$ shall be placed less than 0.5m below the top of the embankment fill.

4.11.7 In constructing embankments up to and over culverts, pipe drains and bridges, the Contractor shall bring the embankments up equally on both sides. The requirements of Clause 4.13 shall also be applicable. Filling may proceed over widths less than the full width of the embankment and in steps not exceeding the depth of one layer above the adjoining area of fill.

4.11.8 If the Contractor wishes to use the surface of embankments for construction traffic before trimming to formation level, he shall bring up and maintain the area to a level not less than 150mm above formation level, whereupon construction traffic will be allowed to use the surface so formed, but any damage to the subgrade caused by the use of such surface shall be made good by the Contractor at his own expense.

4.11.9 In areas of shallow filling where after any removal of Top Soil the ground level is within 300mm of formation level, construction traffic shall not use the surface unless the Contractor brings up and maintains the surface level at least 300mm above formation level. Any damage to the subgrade arising from such use shall be made good by the Contractor at his own expense with material having the same characteristics as the subgrade material.

4.11.10 The slope faces of embankments or other fill areas shall be formed by overfilling, cutting back and trimming neatly to the determined profile.

4.11.11 The designed embankment slopes shall be reviewed by the Contractor to take account of the actual nature of the fill material, and shall be adjusted to if necessary to the acceptance of the Engineer.

4.11.12 When completed, the average planes of the slopes of embankments shall conform to those shown on the Drawings or otherwise determined. No point on the completed slope shall vary from the required slope by an amount exceeding 150mm measured at right angles to the slope. Undulations in the general plane of the slope shall not be permitted.

## 4.12 COMPACTION OF FILL

### 4.12.1 General

4.12.1.1 All materials shall be compacted in layers as soon as practicable after deposition.

4.12.1.2 Before commencing any filling, each class of material to be compacted shall be tested by a SAC-SINGLAS accredited laboratory to establish the maximum value of the dry density that can be obtained and the optimum moisture content for compaction. Testing shall be in accordance with BS 1377.

4.12.1.3 Table 4.2 may be used as a guide in establishing appropriate in-situ compaction methods. The depth of each compacted layer shall be compatible with the compaction plant used and shall not be greater than the maximum depth of compacted layer specified for each type of compaction plant**.** Earthmoving plant will not be accepted as compaction equipment. Variations from the methods given in this table, or the use of plant not included therein, will be permitted only if the Contractor demonstrates to the satisfaction of the Engineer at site trials that the required field density will be achieved.

4.12.1.4 The method of compaction being used must produce a compacted fill material having a field density of at least the following percentage of the maximum dry density previously established for that material:

(a) 95% in the case of material within 500mm of formation level

(b) 90% in the case of material more than 500mm below formation level

4.12.1.5 Notwithstanding compliance with Table 4.2, the Contractor must verify by site tests that the required field density is being achieved and make any adjustments to his compaction methods, which may be necessary

4.12.1.6 Field density shall be determined by in-situ tests in accordance with BS 1377. Each layer of fill shall be tested and accepted by the Engineer prior to the placing of the next layer. At least 3 in-situ field density tests shall be carried out for every 300$m^2$ or less of surface area of each compacted layer. In-situ field density tests shall be carried out by Sand Replacement Method or Water Displacement Method or Nuclear Method in accordance with BS 1377. Where Nuclear Method is used, it shall be calibrated to Sand Replacement Method or Water Displacement Method.

4.12.1.7 The moisture content of the in-situ material during compaction shall be maintained as close to the optimum moisture content as possible. If necessary, this shall be adjusted by wetting or drying on site to enable the required in-situ field densities of the fill material to be obtained consistently.

4.12.1.8 When materials of widely divergent characteristics are used in embankments and fill areas they shall be spread and compacted in separate clearly defined areas in such a manner as to comply with the requirements of Clause 4.12.1.

4.12.1.9 If more than one class of material is being used in such a way that is not practicable to define the areas in which each class occurs, compaction plant shall be operated as if only the material which requires the greatest compaction effort is being compacted.

4.12.1.10 The following requirements are applicable to Rock used as fill material. Each layer of Rock used as rock fill in embankments shall be spread and levelled in accordance with Clause 4.11 and systematically compacted by at least 12 passes of a towed vibratory roller with a static load per metre width of roll of at least 1800kg or a grid roller with a load per metre width of roll of at least 8000kg or other approved plant. Where, however, the rock contains sufficient soft material for satisfactory compaction to the requirements of Table 4.2 for well graded granular soil, the fill shall be compacted to the latter requirements.

4.12.1.11 In order that the Engineer may make proper provision for the supervision of compaction in the permanent work, the Contractor shall, not less than 24 hours before he proposes to carry out compaction processes during periods of overtime, apply in writing to the Engineer for permission to do so.

### 4.12.2 Compaction by Mechanical Plant

4.12.2.1 Table 4.2 gives requirements for compaction of soil by mechanical plant. This table is to be read in accordance with the following definitions:

(a) The depth of compacted layer is the height by which an embankment is raised by each successive compacted layers.

(b) The number of passes is the number of times that each point on the surface of the layer being compacted has been traversed by the compaction plant (or struck in the case of power rammers or dropping weight compactors).

The effective width of a pneumatic-tyred roller, for this purpose, is the sum of the widths of the individual wheel tracks together with the sum of the spacing between the wheel tracks provided that each spacing does not exceed 230mm. Where the spacing exceeds 230mm the effective width shall be taken as the sum of the widths of the individual wheel tracks only.

(c) The force per 100mm width of roll is the total weight on the roller divided by the total roll width. Where a smooth-wheeled roller has more than one axle the machine shall be assessed on the basis of the axle giving the highest value of force per 100mm width. Wheel load is the total weight of the roller divided by number of wheels.

(d) Tamping rollers are machines with a roll or rolls from which 'feet' project. The projected end area of each 'foot' shall exceed $0.01m^2$ and the sum of the areas of the feet shall exceed 15 per cent of the area of the cylinder swept by the ends of the feet. The requirements for tamping rollers apply to machines that have 2 rolls in tandem. If only one tamping roll traverses each point on the surface of the layer on any one pass of the machine, the minimum number of passes shall be twice the number given in Table 4.2.

(e) Vibratory rollers are self propelled or towed rollers having means of applying mechanical vibration to one or more rolls.

The requirements for vibratory rollers are based on the use of the lowest gear on a self propelled machine and a towing speed of 1800 - 2400m/hr for a towed machine. If higher gears or speeds are used, an increased number of passes shall be provided in proportion to the increase in speed of travel.

Where the mechanical vibration is applied to two rolls in tandem, the minimum number of passes shall be half the number given in Table 4.2 for the appropriate mass per metre width of one vibrating roll. If one roll differs in mass per metre width from the other the number of passes shall be calculated as for the roll with the smallest value. Alternatively the machine may be treated as having a single vibrating roll with a mass per metre width equal to that of the roll with the higher value.

Vibratory type rollers operating without vibration will be classified as smooth wheeled rollers.

Vibratory rollers shall only be operated with their vibration mechanism operating at the frequency of vibration recommended by the manufacturers. All such rollers shall be equipped with a device automatically indicating the frequency at which the mechanism is operating

(f) Vibrating-plate compactors are machines having a base plate to which is attached a source of vibration consisting of one or two eccentrically weighted shafts.

The static pressure under the plate of a vibrating-plate compactor is calculated by dividing the total weight of the machine in working order by the area in contact with compacted material.

Vibrating-plate compactors shall be operated at the frequency of vibration recommended by the manufacturer. They shall normally be operated at travelling speeds of less than 900m/hr but, if higher speeds are necessary, the number of passes shall be increased in proportion to the increase in speed of travel.

(g) Vibro-tampers are machines in which an engine-driven reciprocating mechanism acts on a spring system, through which oscillations are set up in a base plate.

(h) Power rammers are machines which are actuated by explosions in an internal combustion cylinder, each explosion being controlled manually by the operator.

In the case of power rammers and dropping weight compactors one pass will be considered as made when the compacting, shoe has made contiguous strikes on the whole of the area to be compacted.

(i) For items marked with an asterisk (*), the rollers shall be towed by track-laying tractors. Self-propelled rollers are unsuitable.

(j) Where combination of different types of categories of plant are used, the compaction requirements shall be:

The depth of layer shall be that for the type of plant requiring the least depth of layer.

The number of passes shall be that for the type of plant requiring the greatest number of passes

4.12.2.2 However, where the Contractor uses a lighter type of plant to provide some preliminary compaction only to assist the use of heavier plant, this shall be disregarded in assessing the above requirements.

## 4.13 FILL ADJACENT TO BRIDGE ABUTMENTS, CULVERTS, RETAINING WALLS AND UNDERGROUND STRUCTURES

4.13.1 Where structures against which backfill is to be placed have weepholes, a filter drain layer shall be provided. The filter drain shall consist of clean, hard and durable broken stones or hardcore conforming to the grading specified in Table 4.3. The larger stones shall be placed adjacent to the weepholes and the smaller particles behind and above the larger particles.

4.13.2 The filter drain shall extend horizontally across the whole width of the structures. Unless otherwise stated, it shall have a width of 300mm and shall vertically cover every weephole by at least 300mm.

4.13.3 Where a waterproofing membrane system is being applied progressively up an external wall of an underground structure, backfill shall not progress above a level 500mm below the top of the membrane at any stage, until the next section of the membrane above has been applied and bonded to the stage in question.

4.13.4 Within the limits defined in Table 4.4, adjacent to all structures, Special Fill Material as defined in Clause 4.2 shall be provided. Fill shall be placed in horizontal layers of thickness appropriate to the compacting plant used and shall be compacted with care to the density specified in Clause 4.12 for fill material.

## TABLE 4.2 Compaction Requirements

| Type of Compaction Plant | Category | Cohesive Soil | | Well-graded granular and dry cohesive soils | | Uniformly-graded materials | |
|---|---|---|---|---|---|---|---|
| | | Max depth of compacted layer (mm) | Min No. of passes | Max depth of compacted layer (mm) | Min No. of passes | Max depth of compacted layer (mm) | Min No. Of passes |
| Smooth-wheeled roller | Force per 100 mm width | | | | | | |
| | 2.1 – 2.6 kN | 125 | 8 | 125 | 10 | 125 | 10* |
| | 2.61 - 5.2 kN | 125 | 6 | 125 | 8 | 125 | 8* |
| | More than 5.2 kN | 150 | 4 | 150 | 8 | Unsuitable | |
| Gridroller | Force per 100 mm width | | | | | | |
| | 2.6 – 5.2 kN | 150 | 10 | Unsuitable | | 150 | 10 |
| | 5.3 – 7.8 kN | 150 | 8 | 125 | 12 | Unsuitable | |
| | More than 7.8 kN | 150 | 4 | 150 | 12 | Unsuitable | |
| Tamping roller | More than 40 kN | 225 | 4 | 150 | 12 | 250 | 4 |
| Pneumatic-tyred roller | Wheel Load | | | | | | |
| | 1– 1.5 tonnes | 125 | 6 | Unsuitable | | 150 | 10* |
| | 1.5- 2 tonnes | 150 | 5 | Unsuitable | | Unsuitable | |
| | 2– 2.5 tonnes | 175 | 6 | 125 | 12 | Unsuitable | |
| | 2.5– 4 tonnes | 225 | 5 | 125 | 10 | Unsuitable | |
| | 4 – 6 tonnes | 300 | 4 | 125 | 10 | Unsuitable | |
| | 6 - 8 tonnes | 350 | 4 | 150 | 8 | Unsuitable | |
| | 8 - 12 tonnes | 400 | 4 | 150 | 8 | Unsuitable | |
| | More than 12 tonnes | 450 | 4 | 175 | 6 | Unsuitable | |
| Vibratory roller | Force per 100 mm width | | | | | | |
| | 0.25 - 0.45 kN | Unsuitable | | 75 | 16 | 150 | 16 |
| | 0.46 - 0.70 kN | Unsuitable | | 75 | 12 | 150 | 12 |
| | 0.71–1.25 kN | 100 | 12 | 125 | 12 | 150 | 6 |
| | 1.26-1.75 kN | 125 | 8 | 150 | 8 | 200 | 10* |
| | 1.76-2.30 kN | 150 | 4 | 150 | 4 | 225 | 12* |
| | 2.31-2.80 kN | 175 | 4 | 175 | 4 | 250 | 10* |
| | 2.81-3.50 kN | 200 | 4 | 200 | 4 | 275 | 8* |
| | 3.51-4.20 kN | 225 | 4 | 225 | 4 | 300 | 8* |
| | 4.21-4.90 kN | 250 | 4 | 250 | 4 | 300 | 8* |

## TABLE 4.2 (Cont'd)

| **Type of Compaction Plant** | **Category** | **Cohesive Soil** | | **Well-graded granular and dry cohesive soils** | | **Uniformly-graded materials** | |
|---|---|---|---|---|---|---|---|
| | | **Max depth of compacted layer (mm)** | **Min No. of passes** | **Max depth of compacted layer (mm)** | **Min No. of passes** | **Max depth of compacted layer (mm)** | **Min No. Of passes** |
| Vibrating plate compacter | Static pressure under base plate | | | | | | |
| | 8.6 - 10.3 kN/m$^2$ | Unsuitable | | Unsuitable | | 75 | 6 |
| | 10.3 - 12.1 kN/m$^2$ | Unsuitable | | 75 | 10 | 100 | 6 |
| | 12.1 - 13.8 kN/m$^2$ | Unsuitable | | 75 | 10 | 150 | 6 |
| | 13.8 – 17.2 kN/m$^2$ | 100 | 6 | 125 | 6 | 150 | 4 |
| | 17.2 – 20.7 kN/m$^2$ | 150 | 6 | 150 | 5 | 200 | 4 |
| | More than 20.7 kN/m$^2$ | 200 | 6 | 200 | 5 | 250 | 4 |
| Vibro-tamper | Mass kilogramme | | | | | | |
| | 50 - 65 | 100 | 3 | 100 | 3 | 150 | 3 |
| | 65 - 75 | 125 | 3 | 125 | 3 | 200 | 3 |
| | More than 75 | 200 | 3 | 200 | 3 | 225 | 3 |
| Power rammer | Mass (kg) | | | | | | |
| | 100 | 150 | 4 | 150 | 6 | Unsuitable | |
| | More than 150 | 275 | 8 | 275 | 12 | Unsuitable | |
| Dropping weight compactor | Weight of Hammer over 5 kN | | | | | | |
| | Drop 1m to 2m | 600 | 4 | 600 | 8 | 450 | 8 |
| | Drop over 2m | 600 | 2 | 600 | 4 | Unsuitable | |

**TABLE 4.3 Filter Drain Material**

| BS Sieve Size | Percentage by weight passing |
|---|---|
| 63 mm | 100 |
| 37.5 mm | 85 - 100 |
| 20 mm | 0 - 20 |
| 10 mm | 0 - 5 |
| 3.35 mm | 0 |

**TABLE 4.4 Special Fill Adjacent to Abutments, Culvert and Retaining Walls**

| Structure | Minimum Width of Special Fill |
|---|---|
| Bridge Abutment & Wingwalls | 2 m |
| Culvert wingwalls | H/3 |
| Retaining walls | H/3 or full width of base whichever is greater |
| Barrels of box culverts | H/3 |
| Barrels of pipe culverts | 600 mm all round |

(H = height of structure)

4.13.5 For framed structures, fill at both ends of the structure shall be brought up simultaneously with the difference in levels of fills at both ends limited to 600mm.

4.13.6 No fill shall be placed against concrete structures within 28 days after placing concrete unless the Contractor has provided sufficient supports to the walls to the acceptance of the Engineer. He may also be required to submit calculations to show that no damage to the concrete structures will be caused by his backfilling earlier than 28 days.

## 4.14 PREPARATION OF RAIL TRACK FORMATION SURFACE

4.14.1 These requirements are applicable to track formation for ballasted track.

4.14.2 Preparation of the formation surface shall be carried out only after completion of any specified sub-grade drainage, piped drains, services and ducts and, unless otherwise accepted by the Engineer, immediately prior to laying sub-ballast.

4.14.3 The material for a depth of 1 metre below the formation and extending to the side slopes shall be considered to be part of the track support structure. In addition to the earthwork requirements contained elsewhere in this Specification, the following requirements shall apply:

(a) Plate bearing tests using 300mm diameter plates shall be performed at a rate of 1 test per $50m^2$ giving the following minimum values of modulus of deformation:

(i) at formation level: $60MN/m^2$

(ii) at 500mm below formation level: $45MN/m^2$

The following requirement shall be obtained for the two layers of 500mm each below formation level, expressed as a proportion of the maximum dry density as defined by standard proctor test.

(iii) Top layer: 95%

(iv) Next layer: 90%

(b) The formation shall be regulated and trimmed to comply with the following tolerances:

(i) Max. deviation from specified levels: +20mm, - 40mm

(ii) Max. deviation under 5m straight edge: 30mm

(iii) Side slope on formation: 5%

(c) The finished formation shall, after reinstatement of any soft areas, be well cleaned and free from mud and slurry.

## 4.15 PREPARATION FOR CULTIVATION WITH SPOT AND CLOSE TURFING

4.15.1 Earthwork slopes shall be trimmed and cultivated after each cutting or embankment has been completed.

4.15.2 Areas to be cultivated with grass shall be covered with topsoil accepted by the Engineer and lightly rolled to a compacted thickness of 50mm or as specified before laying turf in accordance with Chapter 18 Turfing and Planting.

## 4.16 GEOTEXTILE

Unless otherwise specified, geotextiles shall be non-woven and shall be made of polypropylene, polyethylene, polyester or a combination of the aforesaid materials. Geotextiles shall not be susceptible to bacteria and fungus attack and shall be resistant to chemical action and not affected by exposure to ultra-violet light. Where the geotextiles serve a separation or reinforcement function, class A geotextile shall be used. Where the geotextiles serve a filtration function, class B geotextiles shall be used. The requirements for class A and class B geotextiles shall be as specified in Table 4.5. The Contractor shall submit method of laying and jointing to the Engineer for acceptance prior to commencement of work

**TABLE 4.5 Physical Properties of Geotextiles**

| Physical Property | Class of Geotextile | | Specification |
|---|---|---|---|
| | Class A | Class B | |
| Minimum Unit Weight, $g/m^2$ | 125 | 50 | ASTM D5261 or ISO 9864 |
| Minimum Grab Tensile Strength, N | 530 | 270 | ASTM D4632 |
| Minimum Elongation To Break, % | 60 | 55 | ASTM D4595 or ISO 10319 |
| Minimum Trapezoidal Tear Strength, N | 180 | 80 | ASTM D4533 |
| Water Permeability, cm/sec | $2.0 \times 10^{-2}$ | $2.7 \times 10^{-2}$ | Manufacturer's test report to be submitted |

# CHAPTER 5

# PILING

## 5.1 GENERAL REQUIREMENTS FOR PILING WORK

### 5.1.1 General

The Contractor shall comply fully with the relevant recommendations of SS EN 1997-1 and the requirements of this Chapter.

### 5.1.2 Tolerances

5.1.2.1 Setting Out

The Contractor shall establish the lines, levels and positions of all piles. The pile positions shall be identified with suitable markers. When casings are used, the positions shall be checked during and after installations.

5.1.2.2 Position

The eccentricity tolerance shall not exceed 75mm in any direction at pile cut off level. A Registered Surveyor shall be engaged by the Contractor to carry out eccentricity survey of each pile. The results shall be submitted to the Engineer within 14 days after the pile has been trimmed to its cut-off level.

5.1.2.3 Verticality

For vertical piles, the maximum permitted deviation of the finished pile from the vertical is 1 in 75.

5.1.2.4 Rake

For raked piles, the piling rig shall be set and maintained to attain the required rake. The maximum permitted deviation of the finished pile from the specified rake is 1 in 25.

### 5.1.3 Forcible Correction

Installed piles shall not be subjected to any forces (direct or indirect) prior to their incorporation into the superstructure. Cracks, tilting or bending of piles are sufficient evidence that undesirable forces had been imposed on the piles. Suspected piles may be rejected at the discretion of the Engineer.

**5.1.4 Replacement of Piles**

Any piles cracked, deformed, twisted or otherwise damaged in anyway or not installed within the specified tolerance shall be rejected at the discretion of the Engineer and replaced or supplemented by substitute piles by the Contractor. The pile caps, compensating piles, and any other necessary measures, shall be designed and constructed by the Contractor.

**5.1.5 Ultimate Load Test**

The Permanent Works Piles shall not proceed until the ultimate load testing of the preliminary piles has been completed to the acceptance of the Engineer.

**5.1.6 Piling near Recently Cast Piles**

No pile or casing shall be installed within five times its diameter (measured centre to centre) from an unfilled pile excavation or from an uncased concrete pile where the concrete has been in place for less than 24 hours.

**5.1.7 Piling in Limestones**

5.1.7.1 The presence of cavity shall be considered in the construction of pile foundations in the limestones of the Jurong Formation.

5.1.7.2 At least 1 cavity probing using rock coring methods shall be conducted at the location of a pile within every pile group. Each cavity probing shall terminate after achieving a continuous core sample without cavities for a minimum depth of five times the pile diameter below its founding level. If cavity is encountered, additional cavity probing shall be conducted at the locations of all piles within the pile group. Upon completion of cavity probing, the rock coring within and below the pile location shall be properly grouted. The grout shall be of non-shrink type and be of similar compressive strength as the concrete pile.

5.1.7.3 Piles through cavities may be constructed by the provision of steel casing in the cavity zone or filling the cavity with low strength concrete or grout prior to pile casting. Any contribution of shaft friction resistance to pile capacity within the cavity zone shall be ignored.

5.1.7.4 All piles shall be founded on cavity free limestone which extends at least 5 times pile diameter below its founding level. Otherwise, any contribution to pile capacity (including the end-bearing resistance) for the section of pile affected by the cavity shall be ignored, and pile capacity shall be derived purely from its shaft friction in non-cavity zones.

5.1.7.5 The method of designing and constructing pile foundations affected by cavity shall be subject to the Engineer’s acceptance.

### 5.1.8 Records

The Contractor shall keep records as indicated by an asterisk in Table 5.1 of the installation of each pile and shall submit two copies of these records to the Engineer not later than noon of the next working day after the pile was installed. Any unusual or difficult driving or boring operation shall be noted in the record.

### 5.1.9 As-Built Details

The Contractor shall submit as-built details of the piling works including soil conditions encountered during boring on completion of all piling for a section of work. The as-built pile depths, eccentricity, cut-off-level, socket length into founding strata shall be plotted on drawings for all piles constructed and submitted to the Engineer within 4 weeks upon completing the works, including any preliminary piles that are not removed. The As-Built drawings shall be endorsed by a Registered Surveyor of the Contractor.

**Table 5.1 - Records**

| DATA | | Driven precast concrete or steel piles | Bored cast in place piles | Driven cast in place piles |
|---|---|---|---|---|
| (a) | Contract | * | * | * |
| (b) | Pile reference number (location) | * | * | * |
| (c) | Pile type | * | * | * |
| (d) | Nominal cross-sectional dimensions or diameter | * | * | * |
| (e) | Nominal diameter of underream | - | * | - |
| (f) | Length of preformed pile | * | - | - |
| (g) | Standing groundwater level | - | * | - |
| (h) | Date and time of driving, re-driving or boring | * | * | * |
| (i) | Date of concreting | - | * | * |
| (j) | Ground level at commencement of installation of pile | * | * | * |
| (k) | Working level | * | * | * |
| (l) | Depth from working level to pile toe | * | * | * |
| (m) | Toe level | * | * | * |
| (n) | Depth from working level to pile head level | - | * | * |
| (o) | Length of temporary casing | - | * | * |
| (p) | Length of permanent casing | - | * | * |

**Table 5.1 - Records (Cont'd)**

| DATA | | Driven precast concrete or steel piles | Bored cast in place piles | Driven cast in place piles |
|---|---|---|---|---|
| (q) | Type, weight, drop and mechanical condition of hammer and equivalent information for other equipment | * | - | * |
| (r) | Number and type of packing used and type and condition of dolly used during driving the pile | * | - | * |
| (s) | Set of pile in mm per 10 blows | * | - | * |
| (t) | If required, the sets taken at intervals during the last 3m of driving | * | - | * |
| (u) | If required, temporary compression of ground and pile from time of a marked increase in driving resistance until pile reaches its final level | * | - | * |
| (v) | Soil samples taken and in-situ tests carried out | - | * | * |
| (w) | Length and details of reinforcement | - | * | - |
| (x) | Concrete mix | - | * | * |
| (y) | Volume of concrete supplied to pile where this can be measured in practice | - | * | * |
| (z) | All information regarding obstructions/delays and other Interruptions to the sequence of work | * | * | * |

## 5.2 REQUIREMENTS FOR REINFORCED CONCRETE IN PILES

### 5.2.1 General

Unless otherwise specified in this Section, the requirements in Chapter 11, Concrete and Reinforcement Bars shall apply to the construction of all concrete piles. Where sulphates are found in soil or ground water, sulphate resisting cement shall be used.

### 5.2.2 Cast In-situ Concrete Piles

5.2.2.1 General

5.2.2.1.1 The method of placing and the workability of the concrete shall be such that a continuous monolithic concrete shaft of the full cross-section is formed.

5.2.2.1.2 The method of placing shall be accepted by the Engineer. If necessary, the Contractor shall incorporate an accepted set-retarding additive into the mix in order to ensure extended workability of the concrete after placement.

5.2.2.1.3 The pile shall be rejected if the interval of concreting is delayed such that initial set of previously placed batch of concrete has occurred

5.2.2.1.4 The Contractor shall take all precautions in the design of the mix and placing of the concrete to avoid arching of the concrete in a casing. No spoil, liquid or other foreign matter shall be allowed to contaminate the concrete.

5.2.2.2 Workability of Concrete

Slump measured at the time of discharge into the pile shaft or at the time of discharge into the concrete pump hopper shall be in accordance with the standards shown in Table 5.2, unless otherwise accepted.

**TABLE 5.2**

| Class of Workability | Slump | | Typical condition of use |
|---|---|---|---|
| | Minimum (mm) | Maximum (mm) | |
| A | 75 | 125 | Placed into water-free shaft |
| B | 150 | 200 | Where concrete is to be placed by tremie under drilling fluid |

5.2.2.3 Compaction

Internal vibrators shall not be used to compact concrete in the cast in-situ piles.

5.2.2.4 Placing and Cleaning of Reinforcement

The steel reinforcement shall be cleaned before being lowered accurately into position with sufficient spacer blocks to ensure the correct cover is maintained at all times. The steel reinforcement cage shall be adequately stiffened against collapse due to side-sway.

5.2.2.5 Placing Concrete in Dry Shafts

If the pile shaft is completely dry and stable, the Engineer may at his discretion, allow concrete to be discharged directly into the shaft. Before placing of concrete, all loose materials must be cleaned out.

Accepted measures shall be taken to avoid loosening of the sidewalls of the shaft, concrete segregation and bleeding and to ensure that the concrete at the bottom of the shaft is not deficient in grout.

5.2.2.6 Placing Concrete under Water or under Drilling Fluid

5.2.2.6.1 Concrete to be placed under water or drilling fluid shall be placed using a tremie pipe. Direct placement from a drop bottom bucket or hose from a concrete pump will not be accepted. At no stage shall concrete be discharged freely into the water or drilling fluid.

5.2.2.6.2 Before placing concrete, the Contractor shall ensure, by a method acceptable to the Engineer, that there is no accumulation of silt or other material at the base of the shaft.

5.2.2.6.3 The Contractor shall ensure that contaminated bentonite suspension, which could impair the free flow of concrete from the tremie pipe has not accumulated at the bottom of the shaft.

5.2.2.6.4 A sample of the bentonite suspension shall be taken from the base of the shaft using an accepted sampling device. If the specific gravity of the suspension exceeds 1.25, the placing of concrete shall not proceed. In this event, the Contractor shall modify or replace the bentonite as agreed to meet the Specification.

5.2.2.6.5 The internal diameter of the tremie pipe shall not be less than 250mm. The hopper and tremie pipe shall be clean and watertight throughout. Before any set of tremie pipe is allowed to be used, a watertightness test shall be carried out. Thereafter, the order of tremie tube connections shall not be changed until the next watertightness test. The Contractor shall carry out the watertightness test at the discretion of the Engineer whenever water is found inside the tremie tubes during concreting.

5.2.2.6.6 The pipe shall extend to the base of the shaft and a sliding plug or barrier shall be placed in the pipe to prevent direct contact between the first discharge of concrete in the tremie pipe and the water or drilling fluid. The plug or barrier shall not be retained in the mass of the concrete.

5.2.2.6.7 The tremie pipe outlet shall be kept at least 3 metre below the surface of the concrete at all stages in the pour. The Contractor shall develop a system to ensure that this requirement is met.

5.2.2.7 Trimming of Pile Head

The pile shall be cast to a minimum 600mm above the cut-off level so as to achieve sound concrete upon trimming down to the cut-off level.

5.2.2.8 Monitoring of Concrete Level during Pile Casting

For each truckload of concrete discharged, the rise in concrete level shall be counter-checked against the expected increase. If the rise in concrete level is found to be higher than it is physically possible with the amount of concrete discharged, the Contractor shall demonstrate that the integrity of the pile is to the acceptance of the Engineer.

**5.2.3 Precast Reinforced and Prestressed Concrete Piles**

5.2.3.1 General

5.2.3.1.1 Precast concrete piles must be reinforced. The minimum number of longitudinal bars provided in a precast concrete section shall be four in square piles and six in circular and hexagonal piles and their size shall not be less than 12mm in diameter. In any case, the total cross sectional area of these bars shall not be less than 1% of the cross section of the pile.

5.2.3.1.2 When the precast concrete section is square, the corners shall be chamfered.

5.2.3.1.3 Where two or more precast sections have to be joined to give the length of pile required, full details of the method of jointing shall be provided to the Engineer for acceptance. The joint shall be capable of generating the full axial and bending capacity of the pile. The Engineer may require joint testing to be carried out before acceptance.

5.2.3.2 Tolerances in Pile Dimensions

The cross-sectional dimensions of the pile shall not be less than those specified and shall not exceed them by more than 6mm. Any face of a pile shall not deviate by more than 6mm from a straight edge 3m long laid on the face, and the centroid of any cross-section of the pile shall not deviate by more than 12mm from the straight line connecting the centroids of the end faces of the piles.

5.2.3.3 Reinforcement in Piles

The main longitudinal reinforcing bars in piles not exceeding 12 m in length shall be in one continuous length unless otherwise specified. In piles exceeding 12 m long, joints will be permitted in main longitudinal bars at 12 m nominal intervals. Joints in adjacent bars shall be staggered at least 1 m apart along the length of the pile.

Joints in reinforcement shall be such that the full strength of the bar is effective across the joint.

5.2.3.4 Formwork for Piles

5.2.3.4.1 When the sides of adjacent piles are used as formwork, an accepted method shall be used to prevent adhesion between concrete surfaces.

5.2.3.4.2 The head of each pile shall be square to the longitudinal axis. The corners of the head and the corners of the pile shaft for a distance of 300mm from the head shall be chamfered 25mm x 25mm.

5.2.3.4.3 Holes for toggle bolts shall be at right angles to the faces of the pile, and shall be lined with steel tubes or other accepted material. Holes for handling and pitching shall be provided and shall be lined with steel tubes, alternatively, accepted inserts may be cast in.

5.2.3.5 Casting of Piles

The Contractor shall ensure that the Engineer is given adequate notice and every facility for inspecting the pile manufacturing process. Testing of all material used shall be in accordance with the Contract.

5.2.3.6 Cutting Off Pile Heads

5.2.3.6.1 The method of cutting the pile heads shall be accepted by the Engineer.

5.2.3.6.2 Care shall be taken to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete shall be cut away and made good with new concrete properly bonded to the old.

5.2.3.6.3 The piles shall be cut off to the required level as shown on the Drawings and to a tolerance of ±20 mm or otherwise instructed by the Engineer. For precast reinforced concrete piles, the main reinforcement shall be exposed and left reasonably straight for bonding into the pile cap. The minimum bond length of main reinforcement to be exposed shall be in accordance with SS EN 1992.

For prestressed concrete piles, the exposed prestressing wire shall extend at least 600mm into the pile cap.

5.2.3.6.4 In stripping pile heads, the concrete shall be stripped to a level such that the remaining concrete will project 75mm into the pile cap.

5.2.3.6.5 Where a pile has been formed below the required cut-off level, it shall be built-up and the reinforcement shall project for such length in accordance with SS EN 1992.

## 5.3 BORED CAST IN-SITU PILES

### 5.3.1 Boring

5.3.1.1 Temporary Casings

5.3.1.1.1 Temporary casings shall be used to maintain the stability of pile excavation which might otherwise collapse.

5.3.1.1.2 Temporary casings shall be free from distortion. They shall be of uniform cross-section throughout each continuous length. During concreting they shall be free from internal projections and encrusted concrete which might prevent the proper formation of piles.

5.3.1.2 Stability of Pile Excavation Using Drilling Fluid

5.3.1.2.1 Where the use of drilling fluid is accepted for maintaining the stability of a boring, the level of the fluid in the excavation shall be maintained so that the fluid pressure always exceeds the pressures exerted by the soils and external groundwater.

5.3.1.2.2 An adequate temporary casing shall be used in conjunction with the method to ensure stability of the strata near ground level until concrete has been placed. The fluid level shall be maintained at a level not less than 1.5 m above the level of the external groundwater.

5.3.1.2.3 In the event of a rapid loss of drilling fluid from the pile excavation, the excavation shall be backfilled without delay and the Engineer shall be informed immediately.

The Engineer’s acceptance shall be obtained before excavation at that location is resumed.

5.3.1.3 Spillage and Disposal

All reasonable steps shall be taken to prevent the spillage of drilling fluid, in particular bentonite suspension on the site in areas outside the immediate vicinity of boring. Discarded drilling fluid shall be removed from the site without delay. Disposal of bentonite shall comply with the regulations of the appropriate authority.

5.3.1.4 Pumping from Pile Excavation

Pumping from a Pile excavation shall not be permitted unless a casing has been placed into a stable stratum which prevents the flow of water from other strata in significant quantities into the boring, or unless it can be shown that pumping will not have detrimental effect on the surrounding soil or property.

5.3.1.5 Continuity of Construction

A pile constructed in a stable soil without the use of temporary casing or other form of support shall be bored and concreted without prolonged delay to ensure that the soil characteristics are not significantly impaired.

5.3.1.6 Cleanliness of Pile Bases

On completion of boring and immediately prior to casting, all loose, disturbed or remoulded soil or rock shall be removed from the base of the shaft.

5.3.1.7 Inspection

Each pile boring, where it is feasible to do so and where it is required by the Engineer, shall be inspected prior to casting. Equipment shall be provided to enable the Contractor and the Engineer to descend into the boring for the purpose of inspection. Any method of descent and the equipment used shall comply with BS 8008. Adequate lighting shall be provided.

5.3.1.8 Pile Verticality

Prior to concreting, the Contractor shall check and record the verticality of the shaft in the presence of the Engineer. If the shaft is found to be out of specified tolerance, the Contractor shall take appropriate remedial measures to correct the bore where possible to the acceptance of the Engineer.

**5.3.2 Drilling Fluid**

5.3.2.1 Bentonite supplied to the site and prior to mixing shall be in accordance with BS EN 1538.

5.3.2.2 Control tests shall be carried out on the bentonite suspension, using suitable apparatus. The density of freshly mixed bentonite suspension shall be measured daily as a check on the quality of the suspension being formed. The measuring device shall be calibrated to read to within 0.005 g/ml. Tests to determine density, viscosity, shear strength and pH value shall be applied to bentonite supplied to the pile boring. For average soil conditions, the results shall generally be within the ranges stated in Table 5.3.

5.3.2.3 The tests shall be carried out until a consistent working pattern has been established, taking account the mixing process, including:

(a) any blending of freshly mixed bentonite suspension and previously used bentonite suspension; and

(b) any process which may be used to remove impurities from previously used bentonite suspension.

**TABLE 5.3**

| Property to be measured | Range of Results at 20° C | Test Method |
|---|---|---|
| Density | Less than 1.10 g/ml | Mud density balance |
| Viscosity | 30-90 s or less than 20 cP | Marsh cone method Fann viscometer |
| Shear strength (10 minute gel strength) | 1.4 - 10.0 N/m$^2$ or 4.0 - 40.0 N/m$^2$ | Shearometer Fan Viscometer |
| pH | 9.5 - 12.0 | pH indicator paper strips or electrical pH meter |

* Where the Fann viscometer is specified, the fluid sample should be screened by a number 52 sieve (300 micron) prior to testing.

**5.3.3 Determination of Bored Pile Length**

5.3.3.1 Each pile shall be installed to its designed depth.

5.3.3.2 The length of the piles shall not be finalised before ultimate load tests of preliminary piles have been completed. Where site investigation has been specified for assessing ground conditions for piling, piles shall not be constructed prior to the completion of the site investigation.

5.3.3.3 The Contractor shall engage an experienced Geotechnical Engineer with a minimum of five years foundation experience to supervise the piling works and to verify the ground conditions and confirm the pile founding level. The pile founding level shall be acceptable to the Engineer.

**5.3.4 Concreting and Extraction of Casing**

5.3.4.1 Workability of Concrete

Temporary casings shall be extracted before the initial setting time of the concrete expires and when the concrete remains sufficiently workable to ensure that it is not lifted.

5.3.4.2 Concrete Level

5.3.4.2.1 When the casing is being extracted, a sufficient quantity of concrete shall be maintained within it to ensure that pressure from external water, drilling fluid or soil is exceeded and that the pile is neither reduced in section nor contaminated.

5.3.4.2.2 Concrete shall be placed continuously as the casing is extracted until the desired head of concrete is obtained. No concrete shall be placed in the boring once the bottom of the casing has been lifted above the top of the concrete.

5.3.4.2.3 Where two or more discontinuous lengths of casing (double casing) are used in the construction, the proposed method of working shall be submitted to the Engineer for acceptance.

5.3.4.3 Water Levels

In the event of the ground water level being higher than the required pile head casting level shown on the Drawings, the Contractor shall submit his proposals for acceptance prior to placing concrete. The pile head shall not be left below the ground water level unless acceptable precautions are taken.

### 5.3.5 Temporary Backfilling

After each pile has been cast, any empty bore remaining shall be protected and shall be carefully backfilled as soon as possible with acceptable materials.

### 5.3.6 Debonding of Bored Piles

Debonding of bored piles, where required, shall follow the details in the Code of Practice for Railway Protection.

## 5.4 DRIVEN PILES

### 5.4.1 Marking of Driven Piles

5.4.1.1 All piles, including temporary casings subsequently to be withdrawn, shall be marked at intervals of 1 metre along their length prior to pitching. In addition, the top 3 metres shall be marked at intervals of 250mm.

5.4.1.2 Steel piles shall be marked to show grade of steel, length and identification number as appropriate.

5.4.1.3 Precast concrete piles shall be marked to show their identification number, length and date of casting. Prestressed concrete piles shall be marked with the prestressing force applied.

### 5.4.2 Handling and Pitching of Driven Piles

5.4.2.1 Piles shall not be lifted other than by slinging from accepted lifting holes or points. For each section lifting points shall be clearly marked.

5.4.2.2 When handling or pitching a concrete driven pile, the compressive stress in the pile shall not exceed 0.33 of the concrete strength.

5.4.2.3 Before the commencement of driving, each pile (or the driving tube) and the leaders or guides of the pile frame shall be checked for correct rake or plumb and such rake or plumb shall be maintained during driving.

5.4.2.4 At no time during the driving operation shall the driving hammer be more than 40 mm off the centre of the pile being driven.

### 5.4.3 Strength of Piles

Piles shall not be driven until the concrete has achieved the specified characteristic strength.

### 5.4.4 Pile Shoes

5.4.4.1 The first section of each pile shall be provided with a pointed coaxial shoe made of either steel or chill hardened cast iron.

5.4.4.2 Cast iron pile shoes shall be made from chill hardened iron as used for making grey iron castings to BS EN 1561, Grade 150. The chilled iron point shall be free from major blowholes and other surface defects.

5.4.4.3 Steel pile shoes shall be manufactured from steel to BS EN 10025, Grade S275JO.

5.4.4.4 Cast steel piles shoes shall be of carbon steel to BS EN 10293, Grade A. Straps or other fastenings to cast pile shoes shall be of steel to BS EN 10025, Grade S275JO, and shall be cast into the point to form an integral part of the shoe.

### 5.4.5 Leaders and Trestles

At all stages during driving and until incorporation in the superstructure, the pile shall be adequately supported and restrained by means of leaders, trestles, temporary supports or other guide arrangements to maintain position and alignment and to prevent buckling and other damage to the pile.

### 5.4.6 Performance of Driving Equipment

The Contractor shall satisfy the Engineer regarding the suitability, efficiency and energy of the driving equipment.

**5.4.7 Length of Piles**

The pile sections used shall be of standard lengths and the number of joints shall not exceed three numbers, unless otherwise accepted by the Engineer.

**5.4.8 Driving Procedure and Redrive Checks**

5.4.8.1 The Contractor shall give adequate notice and provide all facilities to enable the Engineer to check driving resistance. A set shall be taken only in the presence of the Engineer unless otherwise accepted.

5.4.8.2 At the start of work and in a new area or section, sets shall be taken at intervals during the last 3 metres of the driving to establish the behaviour of the piles

5.4.8.3 Each pile shall be driven continuously until the specified or accepted set and/or depth has been reached.

5.4.8.4 A follower (long dolly) shall not be used unless accepted, in which case the Engineer will require the set to be revised to take into account the reduction in the effectiveness of the hammer blow.

5.4.8.5 In the event the Engineer accepts the suspension of driving, the Contractor shall ensure that the rate of penetration prior to the cessation of driving is re-established on its resumption.

5.4.8.6 Redrive checks, if required, shall be carried out to an accepted procedure.

5.4.8.7 The Contractor shall inform the Engineer without delay if an unusual change in driving characteristics is noted. A detailed record of the driving resistance over the full length of the next nearest available pile shall be taken if required

**5.4.9 Final Set**

5.4.9.1 The final set of each pile shall be recorded as the penetration in millimetres per 10 blows.

5.4.9.2 When a final set is being measured, the following requirements shall be met:-

(a) The exposed part of the pile shall be in good condition without damage or distortion.

(b) The dolly and packing, if any, shall be in sound condition.

(c) The hammer blow shall be in line with the pile axis and the impact surfaces shall be flat and at right angles to the pile and hammer axis.

(d) The hammer shall be in good condition and operating correctly.

(e) The temporary compression of the pile shall be recorded if required.

(f) When required by the Engineer, a levelling instrument shall be provided to take the final set.

**5.4.10 Driving Sequence and Risen Piles**

5.4.10.1 Piles shall be driven in an accepted sequence to minimise the detrimental effects of heave and lateral displacement of the ground. In a pile group, interior piles should be driven first to avoid hard driving conditions and to minimise heaving of adjacent installed piles.

5.4.10.2 When a pile has risen by more than 3mm as a result of adjacent piles being driven, the Contractor shall re-drive it to an accepted procedure.

5.4.10.3 Pile shall not be driven nearer than 5m from a concrete pile where concrete has been in place for less than 24 hours.

5.4.10.4 If required, preboring may be carried out to reduce the effects of uplift to an adjacent pile.

**5.4.11 Preboring**

If preboring is specified the pile shall be pitched into a hole prebored to the depth shown on the Drawings.

**5.4.12 Jetting**

Jetting shall not be used at any time during the driving of piles.

**5.5 STEEL PILES**

**5.5.1 Pile Sections and Pile Dimensions**

5.5.1.1 For standard rolled sections, the dimensional tolerances and weight shall comply with BS EN 10034 or other relevant standards as accepted by the Engineer.

5.5.1.2 For pipe piles, the dimensional tolerances and weight shall comply with BS EN 10210 or other relevant standards as accepted by the Engineer.

5.5.1.3 For proprietary sections, the dimensional tolerances shall comply with the manufacturer's standards and actual weight of sections shall not differ from the theoretical weight by more than -2.5% to +5% unless otherwise accepted by the Engineer.

### 5.5.2 Straightness of Piles

5.5.2.1 For standard rolled sections the deviation from straightness shall comply with BS EN 10034.

5.5.2.2 For pipe piles, the deviation from straightness shall comply with BS EN 10210.

5.5.2.3 For proprietary sections made up from rolled sections the deviation from straightness shall not exceed 1/600 of the length of the pile.

### 5.5.3 Fabrication of Piles

5.5.3.1 The root edges or root faces of lengths of piles that are to be butt welded shall not differ by more than 25% of the thickness of piles walls not exceeding 12mm thick or by more than 3mm for piles where the wall is thicker than 12mm. When piles of unequal thickness are to be butt welded, the thickness of the thinner material shall be the criterion.

5.5.3.2 Pile lengths shall be set up so that the differences in dimensions are matched as evenly as possible.

5.5.3.3 Adequate facilities shall be provided for supporting and aligning the lengths of pile that are fabricated on site.

### 5.5.4 Matching of Pile Lengths

When two or more pipe piles are joined, longitudinal seam welds and spiral seam welds between adjacent piles shall be evenly staggered by at least 100mm.

### 5.5.5 Inspection and Test Certificates

5.5.5.1 The Contractor shall provide the Engineer with test certificates, analyses and mill sheets. The Contractor shall ensure that adequate notice be given to the Engineer when the processes can be inspected or tests can be witnessed.

5.5.5.2 The Engineer has the right to inspect and test at any stage of the manufacturing process.

### 5.5.6 Welding

5.5.6.1 All welding to steel pile sections shall be to the requirements of Chapter 12, Structural Steelwork.

5.5.6.2 All welds shall be capable of withstanding handling, driving and design load stresses.

### 5.5.7 Strengthening of Piles

The strengthening to the toe of a pile in lieu of a shoe or the strengthening of the head of a pile shall be made using material of the same grade as the pile.

### 5.5.8 Welded Piles

5.5.8.1 Welded Pipe Piles

5.5.8.1.1 The Engineer's acceptance shall be obtained if different edge preparation from that shown on the Drawings is required for use with automatic welding machines or due to the method of rolling.

5.5.8.1.2 All welds shall be full penetration butt welds and longitudinal welds shall be made with the extension plates at the starting and finishing points of each seam.

5.5.8.2 Welded Box Piles and Proprietary Sections

Welded box piles or proprietary sections made up from two or more hot rolled sections shall be welded in accordance with the manufacturer's standards.

### 5.5.9 Spirally Welded Pipe Piles

5.5.9.1 Prior to forming a spirally welded pile the edges of the strip shall be straight. Before fabrication commences, tests as required by the Engineer in accordance with the standards for forming and welding shall be made to ensure that the welding procedure is acceptable.

### 5.5.10 Pile Coatings

Where required, pile coating shall be in accordance with Chapter 12, Structural Steelwork.

### 5.5.11 Handling and Storage of Piles

All piles within a stack shall be in groups of the same length and on accepted supports. All operations such as handling, transporting and pitching of piles shall be carried out in a manner such that damage to piles and their coatings are minimised.

### 5.5.12 Preparation of Piles Heads

If a steel superstructure is to be welded to piles, the piles shall be cut square and to within ±5mm of the levels shown on the Drawings. If piles are to be encased in concrete they shall be cut to within ±20mm of the levels shown on the Drawings, and protective coatings shall be removed from the surface of the pile heads down to a level 100mm above the soffit of the concrete.

## 5.6 BAKAU PILING (INDIGENOUS TIMBER PILES)

### 5.6.1 Pile Material

Bakau piles shall be good, sound, straight piles, with fresh uninjured bark and of reasonably uniform size.

### 5.6.2 Pile Lengths

Bakau piles supplied shall be in lengths of 3m, 5m or 6m as required. Measurement shall be from the squared-off head to the pointed end, with the under-sized end cut off.

### 5.6.3 Pile Diameter

The pile diameter shall not be less than 75mm at the larger end, measured within 150mm from its end. Such measurements shall not be over knobs and protuberances.

### 5.6.4 Examination of Piles Delivered

All bakau piles shall be inspected and accepted by the Engineer before being used. Bakau piles that have been rejected shall be removed from the site immediately.

### 5.6.5 Protection of Pile Heads

The head of the pile shall be protected with a simple steel or cast iron ring during driving. After completion of such driving, the head shall be properly squared and cut off to the required level.

### 5.6.6 Joints

All piles shall be rigidly and securely joined with steel collars 300mm long made out of 1.22mm thick (18 SWG) mild steel sheets with joints fully welded. Steel collars shall be completely coated with tar or bituminous paint.

### 5.6.7 Pile Driving Equipment

Piles shall be driven by an accepted piling frame, with a driving hammer of an accepted weight. The driving hammer used shall be of minimum 200kg in weight.

### 5.6.8 Driving

5.6.8.1 All piles shall be driven vertically in a straight line, perfectly squared from the face of the work and free from damage. The driving hammer shall be dropped from a height of 1m to 1.5m, such that the blows land squarely and centrally on the pile. The actual height of the drops shall be accepted by the Engineer.

5.6.8.2 During driving, the pile shall be effectively restrained from buckling. Inclinations of the pile exceeding 1: 75 shall be rejected.

5.6.8.3 Piles shall not be forcibly corrected to an acceptable position.

### 5.6.9 Pile Replacement

All incorrectly driven piles and piles damaged during driving shall be compensated to the acceptance of the Engineer.

## 5.7 PILE LOAD TESTING

### 5.7.1 General

This Section covers vertical and raking piles tested in compression (i.e. subjected to loads in a direction such as would cause the pile to penetrate further into the ground), vertical or raking piles tested in tension (i.e. subjected to loads in a direction such as would cause the piles to be extracted from the ground), and vertical or raking piles tested in bending (i.e. subjected to horizontal loads).

### 5.7.2 Definitions

5.7.2.1 Allowable Load: The load which may be safely applied to a pile after taking into account its ultimate bearing capacity, negative skin friction, pile spacing, overall bearing capacity of the ground below and allowable settlement.

5.7.2.2 Kentledge: The dead weight used in a loading test

5.7.2.3 Maintained Load Test: A loading test in which each increment of load is held constant either for a defined period of time or until the rate of movement (settlement or uplift) falls to a specified value.

5.7.2.4 Preliminary Pile: A pile installed before the commencement of the main piling works or specific part of the Works for the purpose of establishing the suitability of the chosen type of pile and for confirming its design, dimensions and bearing capacity.

5.7.2.5 Working Test Load: A load applied to a selected working pile to confirm that it is suitable for the load at the settlement specified. A working test load should not normally exceed 150% of the working load on a pile.

5.7.2.6 Reaction System: An arrangement of kentledge, piles, anchors or rafts that provides a resistance against which the pile is tested.

5.7.2.7 Test Pile: Any pile to which a test is, or is to be, applied.

5.7.2.8 Working Load: The service load, which the pile is designed to carry.

**5.7.3 Safety Precautions**

5.7.3.1 Personnel

All tests shall be carried out only under the direction of an experienced and competent supervisor, conversant with the test equipment and test procedure. All personnel operating the test equipment shall have been trained in its use.

5.7.3.2 Kentledge

5.7.3.2.1 Where kentledge is used, the Contractor shall comply with requirements in Appendix 5.2.

5.7.3.2.2 In addition, the distance between the outer edge of kentledge load to the edge of any road, structure or building shall not be less than the full height of kentledge load as measured from ground level.

5.7.3.2.3 Steel plates may be used instead of concrete blocks for dead weight in order to meet the minimum offset distance to the edge of any road, structure or building.

5.7.3.2.4 The weight of kentledge shall be at least 10% greater than the maximum test load and if the weight is estimated from the density and volume of the constituent materials, a factor of safety not less than 5% against error shall be allowed.

5.7.3.3 Tension Pile and Ground Anchors

Where tension piles or ground anchors are used, the Contractor shall ensure that the load is evenly transmitted to all the tie rods, cables or bolts. The extension of rods by welding shall not be permitted.

5.7.3.4 Testing Equipment

5.7.3.4.1 The Contractor shall ensure that when the hydraulic jack and load measuring device are mounted on the pile head, the whole system will be stable up to the maximum load to be applied. Means shall be provided to enable dial gauges to be read from a position clear of the kentledge stack or test frame in conditions where failure in any part of the system due to overloading, buckling, loss of hydraulic pressure etc. will not constitute a hazard to personnel.

5.7.3.4.2 The hydraulic jack, pump, hoses, pipes, couplings and other apparatus to be operated under hydraulic pressure shall be capable of withstanding a test pressure of one and a half times the maximum working pressure without leaking.

5.7.3.4.3 The maximum test load or test pressure expressed as a reading on the gauge in use shall be displayed and all operators shall be made aware of this limit.

**5.7.4 Construction of a Preliminary Pile**

5.7.4.1 Notice of Construction

The Contractor shall give the Engineer at least 48 hours' notice of the commencement of construction of any preliminary pile.

5.7.4.2 Method of Construction

5.7.4.2.1 Each preliminary pile shall be constructed in a manner similar to the working piles using similar equipment and materials unless otherwise accepted by the Engineer

5.7.4.2.2 Extra reinforcement and concrete of increased strength may be used subject to the acceptance of the Engineer.

5.7.4.2.3 Each preliminary bored pile shall be uniform in diameter along its entire shaft with overbreaks not exceeding 10% of its nominal diameter at any section. The percentage overbreak in the pile shall be computed as the percentage excess between the concrete volume discharged per truck as indicated by the concrete delivery docket and the resulting concrete displacement in the bored pile based on the nominal size of the piles. The test pile with overbreaks exceeding the specified allowable percentage shall be rejected at the discretion of the Engineer.

5.7.4.2.4 Preliminary piles shall not be incorporated into the Works.

5.7.4.3 Instrumentation for Preliminary Piles

5.7.4.3.1 The Contractor shall submit to the Engineer for acceptance, a full method statement describing the testing equipment and procedure at least 14 days prior to the commencement of construction of a preliminary pile.

5.7.4.3.2 The preliminary piles shall be instrumented with vibrating wire strain gauges and extensometer at every different geological strata. Strain gauges shall be installed at 1.5m intervals for soils layers with SPT N value greater than 50 and at intervals no greater than 3m at other layers. The strain gauges shall be installed in pairs at each level for preliminary pile with a diameter equal to or under 1m. For preliminary piles with a diameter greater than 1m, 2 pairs of strain gauges shall be installed at each level.

5.7.4.3.3 The strain gauges and extensometer casings shall be properly fixed to the reinforcement cages of the piles, and protected from damage at all stages of pile construction.

5.7.4.3.4 Where preliminary piles are required for lateral load tests, an inclinometer along the pile shaft shall also be installed.

5.7.4.4 Boring or Driving Record

5.7.4.4.1 For each preliminary pile, a detailed record of the soils encountered during boring, or of the progress during driving shall be made and submitted to the Engineer daily on the next working day.

5.7.4.4.2 Where the Engineer requires soil samples to be taken or in situ tests to be made in bored pile, the Contractor shall give the results of such tests to the Engineer without delay.

5.7.4.5 Cut-off Level

5.7.4.5.1 The preliminary pile shaft shall be cast 1m above test platform level or extended where necessary.

5.7.4.5.2 Where the preliminary pile shaft is extended above the cut-off level of a working pile in a soil which would influence the load bearing capacity of the pile, a sleeve shall be installed and kept in place during testing to eliminate friction which would not arise in the working pile.

5.7.4.6 Pile Head Construction

5.7.4.6.1 Compression Test

The pile head or cap shall be formed to give a plane surface which is normal to the axis of the preliminary pile, sufficiently large to accommodate the loading and settlement-measuring equipment and adequately reinforced or protected to prevent damage from the concentrated application of load from the loading equipment.

The pile cap shall be concentric with the preliminary pile and the joint between the cap and the pile shall have a strength equivalent to that of the pile.

Sufficient clear space shall be made under any part of the cap projecting beyond the section of the pile so that, at the maximum expected settlement, load is not transmitted to the ground except through the pile.

5.7.4.6.2 Tension Test

The test load shall be axially transmitted to the preliminary pile.

The connection between the preliminary pile and the loading equipment shall be constructed in such a manner as to provide a strength equal to the maximum load which is to be applied to the pile during the test with stress levels kept within the serviceability limit at maximum test load.

**5.7.5 Preparation of a Working Pile to be Tested**

The Contractor shall cut down or prepare the working pile similar to the requirements for preliminary piles as stated in Clause 5.7.4.5 and 5.7.4.6.

**5.7.6 Concrete Test Cubes**

5.7.6.1 Three test cubes shall be made from the concrete used in each of the preliminary piles and working piles as directed by the Engineer. If a concrete cap is cast separately from a preliminary pile or a working pile, a further three cubes shall be made from this concrete. The cubes shall be made and tested in accordance with BS 1881.

5.7.6.2 The pile test shall not commence until the sample cubes have acquired strength such that the applied direct stress is less than 0.5 times the cube strength. This requirement shall apply to both pile and pile cap.

**5.7.7 Reaction Systems**

5.7.7.1 Compression Tests

5.7.7.1.1 Compression tests shall be carried out using kentledge, tension piles or specially constructed anchorage. Kentledge shall not be used for tests on raking piles.

5.7.7.1.2 Where kentledge is to be used, it shall be supported on cribwork disposed around the pile head so that its centre of gravity is on the axis of the pile. The bearing pressure under supporting cribs shall be such as to ensure stability of the kentledge stack, and if necessary, the Contractor shall provide a pile support system to the kentledge.

5.7.7.2 Tension Tests

Tension tests shall be carried out using compression piles or rafts constructed on the ground. The inclined reaction piles, anchors, or rafts may be used subject to the acceptance of the Engineer. In all cases, the resultant force of the reaction system shall be co-axial with the test pile.

5.7.7.3 Working Piles

Working piles shall not be used as reaction piles.

5.7.7.4 Spacing

5.7.7.4.1 Where kentledge is used for loading vertical piles in compression, the distance from the edge of the test pile to the nearest part of the crib supporting the kentledge stack in contact with the ground shall not be less than 1.5 m.

5.7.7.4.2 The centre to centre spacing of vertical reaction piles, from a test pile shall not be less than 3 times the diameter of the test pile/the reaction piles or 2m, whichever is the greatest. Where a pile to be tested has an enlarged base, the same criterion shall apply with regard to the pile shafts, with the additional requirement that the surface of reaction pile shall not be closer to the base of the test pile by more than one half of the enlarged base diameter.

5.7.7.4.3 Where ground anchors are used to provide a test reaction for loading in compression, no part of the section of the anchor transferring load to the ground shall be closer to the test pile than 3 times the diameter of the test pile. Where the pile to be tested has an enlarged base, the same criterion shall apply with regard to the pile shaft, with the additional requirement that no section of the anchor transferring load to the ground shall be closer to the pile base by more than the base diameter.

5.7.7.5 Adequate Reaction

The size, length and number of the piles or anchors, or the area of the rafts, shall be adequate to transmit the maximum test load to the ground in a safe manner without excessive movement or influence on the test pile.

5.7.7.6 Care of Piles

The method employed in the installation of any reaction piles, anchors or rafts shall be such as to prevent damage to any test pile or working pile.

5.7.7.7 Loading Arrangement

The loading arrangement shall be designed to transfer the test load safely to the test pile. Full details shall be submitted to the Engineer for acceptance prior to any work related to the testing process being carried out on the site.

### 5.7.8 Equipment for Applying Load

5.7.8.1 The equipment for applying load shall consist of hydraulic rams or jacks. The hydraulic rams or jacks shall be arranged in conjunction with the reaction system to deliver an axial load to the test pile. The complete system shall be capable of transferring the maximum load required for the test.

5.7.8.2 The length of stroke of the hydraulic ram or jack shall be sufficient to cater for the deflection of the reaction system under load plus a deflection of the pile head up to 15% of the pile shaft diameter unless otherwise accepted by the Engineer.

### 5.7.9 Measurement of Load

5.7.9.1 The load shall be measured by a load measuring device and by a calibrated pressure gauge included in the hydraulic system. Readings of both the load measuring device and the pressure gauges shall be recorded. In interpreting the test data, the values given by the load measuring device shall normally be used; the pressure gauge readings are required as a check.

5.7.9.2 The load measuring device may consist of a proving ring, load measuring column, pressure cell or other appropriate system. A spherical seating shall be used in conjunction with any devices that are sensitive to eccentric loading; care must be taken to avoid any risk of buckling. Load measuring devices and jacks shall be short in axial length in order to achieve the best possible stability; the Contractor shall ensure that axial loading is maintained.

5.7.9.3 The load measuring devices shall be calibrated before each load tests, whenever adjustments are made to the device or at intervals appropriate to the type of equipment. The pressure gauge and hydraulic jack shall be calibrated together. The load measuring device, pressure gauge and hydraulic jack shall be calibrated by an accredited laboratory. Certifications of calibrations shall be submitted to the Engineer.

5.7.9.4 The Engineer’s acceptance shall be obtained before any modification of this procedure is adopted.

### 5.7.10 Adjustability of Loading Equipment

The loading equipment shall be capable of adjustment throughout the test to obtain a smooth increase of load or to maintain each load constant at the required stages of a maintained loading test.

### 5.7.11 Measuring Movement of Pile Heads

5.7.11.1 Levelling Method for Maintained Load Test Only

An optical or any other levelling method by reference to an external datum may be used.

Where a level and a staff are used, the level and scale of the staff shall be chosen to enable readings to be made to within an accuracy of 0.5mm. A scale attached to the pile or pile cap may be used instead of a levelling staff. At least two datum points shall be established on permanent objects or other well-founded structures or deep datum points shall be installed. Each datum point shall be situated so that only one setting up of the level is needed.

No datum point shall be affected by the test loading or other operations on the Site.

5.7.11.2 Independent Reference Frame

5.7.11.2.1 An independent reference frame may be set up to permit measurement of the movement of the pile. The supports for the frame shall be founded in such a manner that it will not be disturbed by any movement of ground.

5.7.11.2.2 In no case shall the supports be less than three test pile diameters or 2m, whichever is the greater, from the centre of the test pile. Check observations of any movement of the reference frame shall be made and a check shall be made of the movement of the pile head relative to an external datum during the progress of the test.

5.7.11.2.3 The measurement of pile movement shall be made by at least two dial gauges rigidly mounted on the reference frame that bear on surfaces normal to the pile axis, fixed to the pile cap or head. Alternatively, the gauges may be fixed to the pile and bear on surfaces on the reference frame. The dial gauges shall be placed in diametrically opposed positions and be equidistant from the pile axis. The dial gauges shall enable readings to be made up to within an accuracy of 0.1mm.

5.7.11.3 Other Methods

The Contractor may submit any other method for measuring the movement of pile heads for acceptance.

5.7.11.4 Calibration of Dial Gauges

The dial gauge shall be calibrated by an accredited testing company.

### 5.7.12 Protection of Testing Equipment from Weather

Throughout the test period, all equipment for measuring load and movement shall be protected from the weather.

**5.7.13 Supervision**

5.7.13.1 Notice of Test

The Contractor shall give the Engineer at least 24 hours' notice of the commencement of the test.

5.7.13.2 Records

During the progress of a test, the testing equipment and all records of the test as required in Clause 5.7.16 shall be available for inspection by the Engineer.

**5.7.14 Test Procedures**

5.7.14.1 Ultimate Load Test by Maintained Load

5.7.14.1.1 The maximum load which shall be applied in an ultimate load test is at least two and a half times the working load. The loading and unloading shall be carried out in stages as shown in Table 5.4.

5.7.14.1.2 Following each application of load, the load shall be held for not less than the period shown in Table 5.4 or until the rate of settlement is less than 0.25 mm/hr and slowing down. The rate of settlement shall be calculated from the slope of the curve obtained by plotting values of settlement versus time and drawing a smooth curve through the points.

5.7.14.1.3 Each stage of unloading shall proceed after the expiry of the period shown in Table 5.4.

5.7.14.1.4 For any period when the load is constant, time and settlement shall be recorded immediately on reaching the load and at approximately 15 min intervals for 1 hr, at 30 min intervals between 1 hr and 4 hr and at 1 hr intervals between 4 hr and 12 hr after the application of the increment of the load.

5.7.14.1.5 Testing shall continue until the maximum test load has been reached or when the settlement exceeds 10% of the pile diameter.

5.7.14.2 Working Load Test by Maintained Load

5.7.14.2.1 The maximum load which shall be applied in a working load test on a working pile is one and a half times the working load. The loading and unloading shall be carried out in stages as shown in Table 5.5.

5.7.14.2.2 Following each application of an increment of load, the load shall be held for not less than the period shown in Table 5.5 or until the rate of settlement is less than 0.25mm/hr and slowing down. The rate of settlement shall be calculated from the slope of the curve obtained by plotting values of settlement versus time and drawing a smooth curve through the points.

5.7.14.2.3 Each stage of unloading shall proceed after the expiry of the period shown in Table 5.5.

5.7.14.2.4 For any period when the load is constant, time and settlement shall be recorded immediately on reaching the load and at approximately 15 min intervals for 1 hr, at 30 min intervals between 1 hr and 4 hr and at 1 hr intervals between 4 hr and 12 hr after the application of the increment of the load.

**TABLE 5.4 Ultimate Load Test**

| Load, Percentage of Working Load | Minimum Time of Holding (minutes) | Load Cycle Number |
|---|---|---|
| 0 | - | 1 |
| 25 | 60 | |
| 50 | 60 | |
| 75 | 60 | |
| 100 | 360 (6 hr) | |
| 100 | 360 (6 hr) | |
| 75 | 10 | |
| 50 | 10 | |
| 25 | 10 | |
| 0 | 60 | |
| 0 | - | 2 |
| 25 | 10 | |
| 75 | 10 | |
| 100 | 360 (6 hr) | |
| 125 | 60 | |
| 150 | 360 (6 hr) | |
| 125 | 10 | |
| 100 | 10 | |
| 75 | 10 | |
| 25 | 10 | |
| 0 | 60 | |

**TABLE 5.4 Ultimate Load Test** (Cont'd)

| Load, Percentage of Working Load | Minimum Time of Holding (minutes) | Load Cycle Number |
|---|---|---|
| 0 | - | 3 |
| 25 | 10 | |
| 50 | 10 | |
| 75 | 10 | |
| 100 | 10 | |
| 125 | 10 | |
| 150 | 60 | |
| 175 | 60 | |
| 200 | 60 | |
| 225 | 60 | |
| 250 | 1440 (24 hrs) | |
| 200 | 10 | |
| 150 | 10 | |
| 100 | 10 | |
| 50 | 10 | |
| 0 | 30 | |

**TABLE 5.5 Working Load Test**

| Load, Percentage of Working Load | Minimum Time of Holding (minutes) | Load Cycle Number |
|---|---|---|
| 0 | - | 1 |
| 25 | 60 | |
| 50 | 60 | |
| 75 | 60 | |
| 100 | 360 (6 hr) | |
| 75 | 10 | |
| 50 | 10 | |
| 25 | 10 | |
| 0 | 60 | |
| 0 | - | 2 |
| 50 | 10 | |
| 100 | 360 (6 hr) | |
| 125 | 60 | |
| 150 | 360 (6 hr) | |
| 125 | 10 | |
| 100 | 10 | |
| 75 | 10 | |
| 50 | 10 | |
| 25 | 10 | |
| 0 | 60 | |

5.7.14.3 Requirements for Working Load Test

A pile under test shall be deemed to have failed if it does not comply with the Serviceability Limit State (SLS) criteria determined by the designer as stated in the Civil Design Criteria.

5.7.14.4 Continuity Testing

Any test that commences shall be carried to completion as specified in Clauses 5.7.14.1 and 5.7.14.2 without stoppage unless otherwise accepted by the Engineer.

**5.7.15 Testing Criteria**

5.7.15.1 Failure of Piles

5.7.15.1.1 Any working pile which fails the load test shall be replaced by one or more piles by the Contractor or as directed by the Engineer. If it is impractical or inadvisable to install substitute piles in place of a failed pile, the Contractor shall submit proposals to rectify the defect subject to the acceptance of the Engineer.

5.7.15.1.2 In addition, the Contractor shall at his expense carry out two more additional working load tests. The piles for these tests shall be selected by the Engineer.

5.7.15.2 Faulty Pile Tests

5.7.15.2.1 A load test shall be deemed to be faulty if the loading and testing requirements of the Materials and Workmanship Specification are not met, or if any test has to be discontinued due to:

(a) faulty jack or gauge,

(b) unstable support of the kentledge,

(c) cracking of or damage to the pile cap,

(d) incorrect or disturbed datum, or any other causes, then the test shall be abandoned and the results disregarded.

5.7.15.2.2 In the event of a faulty test, a further test on a new pile shall be carried out, unless otherwise accepted by the Engineer.

**5.7.16 Presentation of Results**

5.7.16.1 Results to be submitted

Results to be submitted shall include:

(a) A summary in writing to the Engineer, unless otherwise directed, within 24 hours of the completion of the test. The summary shall give the period for which the load was held, the load and the maximum settlement or uplift recorded for a working load test by maintained load for each stage of loading.

(b) The completed schedule of recorded data as in Clause 5.7.16.2 within seven days of the completion of the test.

5.7.16.2 Schedule of Recorded Data

The Contractor shall provide information about the tested pile in accordance with the following schedule where applicable.

(a) General
- Site location
- Contract identification
- Proposed structure
- Main Contractor
- Piling Contractor
- Engineer
- Client
- Date of test

(b) Pile Details

i) All types of pile

- Identification (number and location)
- Position relative to adjacent piles
- Brief description of location (e.g. in cofferdam, in cutting, over water)
- Ground level at pile position
- Head level at which test load is applied
- Type of pile (e.g. precast reinforced concrete, steel H, bored in place, driven in place, composite type)
- Vertical or raking, compression or tension
- Shape and size of cross section of pile, position of change in cross section.
- Shoe or base details
- Head details
- Length in ground
- Level of toe
- Any permanent casing or core

ii) Concrete Piles

- Concrete mix
- Aggregate type and source
- Cement type
- Slump
- Cube test results for pile and cap
- Date of casting of precast pile
- Reinforcement

iii) Steel Piles

- Steel quality
- Coating
- Filling

(c) Installation Details

i) All Piles

- Dates and times of boring, driving and concreting of test pile and adjacent piles.
- Unusual circumstances and difficulties
- Date and time of casting concrete pile cap
- Start and finish of each operation during driving or installation of a pile and subsequent testing
- Difficulties in handling, pitching and driving piles
- Delays due to sea and weather conditions

ii) Bored Piles

- Type of equipment used and method of boring
- Temporary casing, method of installation and extraction.
- Strata encountered during boring
- Water encountered during boring
- Method and details of base cleaning
- Method of placing concrete and conditions pertaining
- Volume of concrete placed vs theoretical and actual rise in concrete levels
- Concrete level before and after extraction of casing

iii) Driven Preformed Piles and Driven Cast In-Situ Piles

- Method of support of Pile and hammer (frame, hanging leaders, suspended hammer or other method)
- Driven length of pile or temporary casing at final set
- Hammer type, size and weight
- Dolly and packing, type and condition before and after driving
- Driving log (depth, blows per 250mm, interruptions or breaks in driving)
- Final set
- Redrive check, time interval and set

- At final set and at redrive set, for drop or single acting hammer, the length of the drop or stroke; for diesel hammer, the length of the stroke and the blows per minute; for double-acting hammer, the number of blows per minute
- Condition of pile head or temporary casing after driving
- Use of a follower
- Use of preboring
- Use of jetting
- Lengthening
- Details of temporary casing
- Concrete level before and after extraction of casing
- Method of placing concrete and conditions pertaining.

(d) Test Procedure

- Weight of kentledge
- Tension pile, ground anchor or compression pile details
- Plan of test arrangements showing position and distances of kentledge supports, rafts, tension or compression piles and reference frame to test pile.
- Jack capacity
- Method of load measurement
- Method(s) of penetration or uplift measurement
- Working load test by Maintained Loading
- Relevant dates and times

(e) Test Results

- In tabular form
- In graphical form: load plotted against settlement (uplift), load and settlement (uplift) plotted against time
- Ground heave

(f) Site Investigation

- Site investigation report number
- Borehole reference

5.7.16.3 Presentation of Graphical Results

The scales used for plotting load/settlement (uplift) curves shall be such that a settlement of 10 mm is equivalent to a load of 100 tonnes. The same scales shall be used for the load and settlement (uplift) against time curves.

5.7.16.4 Submission of Results to Borehole Information System (BIS)

5.7.16.4.1 The Authority has an intranet application called the Borehole Information System (BIS). The BIS is a web-based system which stores and displays borehole information and pile load test (PLT) reports obtained from all pile tests.

5.7.16.4.2 The Contractor shall submit a Summary Report for each pile load test to BIS. The Summary Report shall follow the template in Appendix 5.1. All information as listed in the template shall be submitted. The entire pile load test report shall be attached to the Summary Report. The Summary Report and other attached reports shall be in PDF format and the graphs and raw data shall be in Excel format.

5.7.16.4.3 The Summary Report and attached reports shall be submitted in softcopy in a CD with the following folder/file structure:

5.7.16.4.4 Contract No./PLT XXX/Report_01 (Maximum 5 per PLT including summary report)

5.7.16.4.5 Sub-directory naming convention shall be as follows:
PLT XXX
XXX = 001 to 999

5.7.16.4.6 Each test pile shall have its own complete reports. The Summary Report shall be named as Report_01. Other attached reports shall be named sequentially.

**5.7.17 Removal of Ground Anchors and Cutting-Off of Temporary Piles**

5.7.17.1 On completion of an ultimate load test, all temporary piles located within the road and tunnel reserve shall be cut off 2m below ground level, and the ground made good with suitable material.

5.7.17.2 All temporary piles and ground anchors located outside the road and tunnel reserve shall be removed unless otherwise instructed by the Engineer.

**5.7.18 Bi-directional Static Load Tests**

5.7.18.1 Where bi-directional static load test methods are used for ultimate load testing, the Contractor shall provide full details of the proposed test set-up, including details of previous tests carried out in similar ground conditions, with results and interpretations to substantiate the suitability of his proposal.

5.7.18.2 The Contractor shall design the placement of the embedded reaction jacks and take appropriate measures to ensure the free displacement of bentonite during concreting so that the pile quality below the jacks can be ensured.

5.7.18.3 The maximum extension of the embedded reaction jack shall be at least 10% of the pile diameter.

5.7.18.4 Interpretation of bi-directional load test and conversion into the equivalent pile-head load displacement curve shall be done by experienced personnel based on the principles described in CP4 and SS EN 1997-1.

5.7.18.5 Bi-directional load testing methods shall not be used for the testing of working piles

**5.7.19 High Strain Dynamic Testing of Piles Using Stress Wave Measurements**

The Contractor shall engage a SAC-SINGLAS accredited laboratory for high strain dynamic testing of piles, accepted by the Engineer, to carry out dynamic testing of all piles.

The dynamic testing of piles shall comply with ASTM D4945 Standard Test Method for High Strain Dynamic Testing of Deep Foundations.

The proposed system together with its method of testing, list of equipment and C.V.s of personnel involved shall be submitted to the Engineer for his prior acceptance. The test shall be conducted by a qualified engineer on site with no less than five years of dynamic pile testing experience.

The equipment employed shall be capable of measuring the pile force and velocity against time.

5.7.19.1 Testing Requirements

5.7.19.1.1 Working piles selected for dynamic testing shall be tested to the equivalent of 2.0 times the working load.

5.7.19.1.2 The Contractor shall be responsible to design and provide a suitable hammer system to test the piles to the required test load. The hammer system should, amongst others, consist of adequately heavy hammer with a controlled drop to limit the driving stresses in the pile.

5.7.19.2 Method of Testing

5.7.19.2.1 The force, velocity, displacement and the energy transferred to the pile against time shall be produced on-site in graphical form. Soil resistance shall be computed for every blow.

5.7.19.2.2 For driven piles, the energy provided on to the pile during restrike tests shall not be less than that used to initially drive the pile.

5.7.19.3 Results of the Test

5.7.19.3.1 Computer analysis of the field measurements to obtain the pile resistance distribution and vertical load against displacement relationship shall be carried out on all piles which are dynamically tested

5.7.19.3.2 The results of the dynamic load tests shall be submitted. The complete field results and graphs shall be submitted immediately and computer analysis results 3 days after the test. The detailed report, which shall include the interpretation, analysis and correlation with static load test results, shall be submitted within 7 days after testing. The format of all submissions shall be acceptable to the Engineer.

5.7.19.3.3 The piles, which are dynamically tested, shall be deemed to have failed if the measured resistance within the design load bearing layer of the pile is less than 2.0 times the designed working load or if any part of the piles is damaged. The Engineer shall review the results and his interpretation shall be final. For each pile, which has failed, substitute compensating piles shall be proposed by the Contractor for acceptance by the Engineer. If it is impractical or inadvisable to install substitute piles in place of a failed pile, the Contractor shall submit alternative proposals. In addition, the Contractor shall at his expense carry out two more additional dynamic pile load tests on other piles as selected by the Engineer.

**5.7.20 Rapid Load Tests**

5.7.20.1 A rapid load test may be considered as an alternative to replace a static load test, subject to the acceptance of the Engineer and in compliance with the prevailing regulatory requirements. The results from the rapid load test shall first be calibrated with a static load test on another pile installed in similar ground conditions.

5.7.20.2 The test methods measure the pile top deflection in response to an axial compressive force under rapid loading and shall be conducted in accordance to BS EN ISO 22477-10.

5.7.20.3 Due to the nature of the quasi-static applied loads and the need to correct the load-displacement response for damping and inertial effects, the results would only be acceptable if interpreted by qualified and experienced personnel.

**5.7.21 Lateral Load Test**

5.7.21.1 Lateral Load Test on Preliminary Piles

5.7.21.1.1 Where piles are subject to a horizontal working load exceeding 400kN or 10% of the allowable vertical pile capacity, whichever lower, then lateral load tests on preliminary piles shall be carried out. The reaction and testing system to apply a horizontal load on the preliminary pile shall be designed by the Professional Engineer of the Contractor.

5.7.21.1.2 Lateral load test shall be carried out in accordance to ASTM D3966/D3966M Standard Test Method for Deep Foundations Under Lateral Load.

5.7.21.1.3 An inclinometer shall be installed in the preliminary pile.

5.7.21.1.4 A pair of strain gauges shall be installed at 2m intervals along the length of the pile axis, commencing at the level of lateral load application up to a depth of 10m below ground level or to a depth at least 5m below the maximum bending stress due to the lateral loading, whichever deeper. Below this level, a pair of strain gauges shall be installed at 3m intervals along the remaining pile depth.

5.7.21.1.5 Strain gauges in each pair shall be installed at the same depth, symmetrically opposite each other, equidistance from and parallel to the pile axis, and in line with the applied load.

5.7.21.1.6 The inclinometer and strain gauges in the pile shall be monitored at every load step.

5.7.21.1.7 The testing procedures shall be the same as that given in Clause 5.7.21.2 except that only one load cycle is required with each load increment to be held for 1 hour until two times the horizontal working load or 300mm pile top deflection, whichever occurs first.

5.7.21.1.8 The stress levels in the pile and loading apparatus shall be kept within their respective serviceability limit at maximum test load.

5.7.21.2 Lateral Load Tests on Working Piles

5.7.21.2.1 Where piles are subject to a horizontal working load exceeding 400kN or 10% of the allowable vertical pile capacity, whichever lower, then lateral load tests on working piles shall be carried out. Lateral load tests shall be undertaken on an adjacent pair of piles. Such testing shall be undertaken by either jacking the piles apart or pulling them together.

5.7.21.2.2 The test load shall be applied at or within 0.5 metres of the pile cap soffit level. The test load shall be equal to the horizontal working load of the pile. Pile deflections shall be measured parallel to the direction of the applied load such that the movement of each pile is measured in absolute terms and not as a relative movement between piles. Dial gauges and load cells used shall be accurate to 0.1mm and 10kN for deflection and load measurements respectively.

5.7.21.2.3 Deflection shall be recorded for every 12.5% of the test load, during both loading and unloading. Where specified on the Drawings, the rotation of the pile shall be recorded at the same increments. Loading sequence shall be carried out in 2 cycles. At the first cycle, the pile shall be tested to 75% of the test load and then reduced to zero. At the second cycle the pile shall be tested to 100% of the test load and then reduced to zero.

5.7.21.2.4 For both loading cycles, the load shall only be increased if the rate of movement is less than 0.2mm in 20 minutes and subject to a minimum holding period of 20 minutes at the end of each incremental increase. The minimum holding period may be reduced to 10 minutes if the rate of movement is less than 0.1mm in 10 minutes for every load increment previously applied on the first cycle during the second loading cycle. The minimum holding period shall be 3 hours at the maximum load for both the first and second loading cycle. The minimum holding period during unloading shall be 20 minutes at the end of each incremental decrease for both load cycles. Presentation of results shall be consistent with Clause 5.7.16 modified as required for lateral load testing and as accepted by the Engineer.

5.7.21.3 Abandonment of Lateral Load Tests

5.7.21.3.1 A lateral load test shall be abandoned if any one of the following occurs:

(a) faulty jack or gauges

(b) unstable support of loading apparatus

(c) cracking of or damage to the pile

(d) incorrect or disturbed datums or any other cause.

5.7.21.3.2 If a test is abandoned a replacement test shall be carried out. The originally tested pair of piles shall not be re-tested unless in the opinion of the Engineer such re-testing will give representative results for the piles as if they had not previously been tested.

5.7.21.4 Failure of Lateral Load Tests on Working Piles

5.7.21.4.1 A pile or pile group under lateral load test shall be deemed to have failed if the lateral deflection or rotation at the pile cap soffit level exceeds the Serviceability Limit State (SLS) criteria at the test load. In this event, remedial works shall be carried out as required in Clause 5.7.21.5.

5.7.21.4.2 In addition, the Contractor shall at his expense carry out two more additional working load tests. The piles for these tests shall be selected by the Engineer.

5.7.21.5 Remedial Works for Excessive Deflections

5.7.21.5.1 In the event that a pile fails a lateral working load test, the Contractor shall carry out remedial measures.

5.7.21.5.2 Working piles, which have failed the lateral load tests and have had remedial measures applied shall then be re-tested. This re-test shall not be taken as one of the additional tests required under Clause 5.7.21.4. All piles for which the particular lateral load test was agreed to be representative, shall have similar remedial measures applied.

5.7.21.5.3 Remedial measures may consist of:

(a) Excavation of all materials for a distance of not less than 5 metres from pile face, around the entire pile to minimum 1m below the level of the pile cap soffit. The width of excavation shall be the same on all sides of the pile.

(b) Backfilling and compaction of the excavation hard against the pile in layers. The material in backfilling shall have a minimum value of modulus of deformation of 45 $MN/m^2$, as determined by a plate bearing test, following compaction to the requirements of Chapter 4, Earthworks.

5.7.21.5.4 The Contractor may propose alternative remedial measures such as compensating piles subject to the acceptance of the Engineer.

## 5.8 INTEGRITY TESTS

### 5.8.1 General

5.8.1.1 The following integrity tests shall be undertaken by the Contractor as appropriate:

(a) Proof Coring

(b) Sonic Logging

(c) Low Strain Impact Integrity Test

5.8.1.2 The testing is to be carried out by a SAC-SINGLAS accredited testing agency, to be proposed by the Contractor for acceptance by the Engineer.

5.8.1.3 All tests shall be carried out under the direction of an experienced and competent supervisor conversant with the test equipment and test procedure, and acceptable to the Engineer. All personnel operating the test equipment shall have been trained in its use. All interpretations of the test results shall be done by experienced and competent personnel.

5.8.1.4 The Contractor shall submit to the Engineer a full method statement describing the testing equipment and procedures at least two weeks before carrying out the first of any particular type of test. In the case of sonic logging the method statement shall be submitted two weeks before the concreting of the first pile to incorporate sonic logging tubes.

5.8.1.5 Test reports shall contain the following general information:

(a) contract number and name

(b) pile location plan

(c) pile reference number

(d) pile diameter

(e) working load

(f) date on which the pile was bored and concreted

(g) cube strengths of pile concrete

(h) date on which the pile was tested

(i) identification of supervisor

(j) identification of analyser

(k) the originals or clear copies of the photographic records

(l) an interpretation of each record

(m) a review of any anomalies in terms of influence of poor materials or workmanship during pile construction.

**5.8.2 Proof Coring**

5.8.2.1 The quality of concrete in bored piles shall be checked by the Contractor. This shall be achieved by vertical coring to at least 0.5 metre below the pile toe using a triple tube coring barrel at a suitable location of the pile. The core so produced shall not be affected by drilling disturbance and shall reflect the condition of concrete in the pile. It shall not be less than 50mm in diameter and shall be placed in suitable core boxes in the order of core recovery.

5.8.2.2 Coring work shall be completed before the concrete in the pile has reached an age of 28 days to allow the cores to be tested at 28 days. The Engineer shall mark the sections of the core to be tested and the Contractor shall arrange for transport to the testing laboratory. The remainder of cores shall be delivered to a core store provided by the Contractor.

5.8.2.3 The quality of cores produced shall meet the following criteria:-

(a) Concrete

i) Concrete Strength Requirements.

ii) Visually free from defects, such as contaminants and honeycombs, etc.

iii) 100% Total Core Recovery (TCR).

iv) 100% of Rock Quality Designation (RQD).

(For this purpose, concrete is considered as being rock).

(b) Soil / Rock immediately below pile toe

i) 100% Total Core Recovery

5.8.2.4 The piles, with cores not satisfying the above requirements, may be rejected at the discretion of the Engineer.

5.8.2.5 On completion of proof coring, the core cavity within and below a pile shall be grouted to the acceptance of the Engineer. The grout shall be of the same compressive strength as the pile concrete, of non-shrink type. Details of the Contractor's proposed grouting method and mixes shall be submitted to the Engineer 14 days prior to undertaking any such operation.

**5.8.3 Sonic Logging Tests**

'Sonic Logging' means the measurement of the time travel of a sound wave from an emitter to a receiver through the concrete of a pile. The emitter and the receiver shall generally be at the same level.

5.8.3.1 Sonic Logging Tubes

5.8.3.1.1 Piles selected for sonic logging tests shall be provided with sonic logging tubes cast into it.

5.8.3.1.2 The tubes shall be manufactured from steel and shall extend 0.2m to 0.5m above the pile head and 0.2 to 0.5m above the pile toe. The tube shall have an internal diameter not exceeding 50mm, except for one tube in each pile, where it shall be of internal diameter 100mm in order to allow for coring of the concrete at the base of the pile.

5.8.3.1.3 Three tubes shall be required for piles up to 800mm in diameter and four tubes shall be required for piles above 800mm in diameter.

5.8.3.2 Sonic Coring

5.8.3.2.1 At least 7 days after the pile has been cast, but before carrying out any sonic logging test, a core of concrete and soil or rock from the founding material shall be taken.

5.8.3.2.2 The core shall be taken from the base of the 100mm diameter sonic logging tube using a triple tube core barrel and shall have a minimum diameter of 50mm.

5.8.3.2.3 The acceptance of coring shall be in accordance with Clause 5.8.2.

5.8.3.2.4 The core shall be kept in a suitable box with depths clearly recorded on rigid markers, shall be photographed along with a scale and colour chart. Thereafter, these shall be delivered to a core store designated by the Engineer.

5.8.3.2.5 The scanning of the pile toe for its integrity by measuring the propagation time of transmitted waves between the vertical tubes and the pile toe/ founding strata shall also be carried out.

5.8.3.3 Sonic Logging Equipment

5.8.3.3.1 The equipment shall be properly maintained and calibrated.

5.8.3.3.2 Where necessary, means shall be provided to centralise the probes within the tubes, so that variation in the separation of the emitter and receiver resulting from clearance between the probes and the tubes does not occur.

5.8.3.4 Test Procedure

The tubes shall be filled with water. The tests shall be repeated for each pair of tubes, i.e. three runs for a pile with three tubes and six runs for a pile with four tubes.

5.8.3.5 Analysis of Test Results

Any deviation from the record to be expected from a pile constructed entirely of sound concrete and without defect shall be reported. The report shall indicate the nature, location and severity of the defect and recommendations shall be made for further testing. The implication of the existence of the defect on the performance of the pile shall be evaluated.

5.8.3.6 Submission of Results

The field records of the measured parameters shall be plotted and submitted to the Engineer immediately after the test. The detail report shall be submitted within 7 days and shall include an interpretation of the field results.

5.8.3.7 Anomalous Sonic Logging Test Results

The piles with anomalous sonic logging results shall be rejected at the Engineer discretion unless the Contractor is able to demonstrate that the pile integrity is acceptable through proof coring.

5.8.3.8 Grouting of Pile after Testing

Upon completion of sonic logging test, the access tubes and sonic coring holes, shall be grouted up in accordance with Clause 5.8.2.

**5.8.4 Low Strain Impact Integrity Test**

Low strain impact integrity test shall be carried out in accordance with ASTM D5882 Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations.

The test measures the acceleration or velocity and force (optional) induced by the impact of a hand held hammer on a pile in order to evaluate its cross-sectional area, length, continuity, as well as consistency of the pile material.

5.8.4.1 Preparation of Pile Heads

5.8.4.1.1 The Contractor shall expose sound concrete and level the surface for fixing the transducers and for hammer impact to the pile head.

5.8.4.1.2 Cast in place piles shall not be tested until the concrete has achieved its design strength.

5.8.4.2 Analysis of Test Results

5.8.4.2.1 Shafts with no significant reflections above the pile toe and with a clear pile toe reflection shall be accepted.

5.8.4.2.2 Any deviation from the record to be expected from a pile constructed entirely of sound concrete and without defect shall be reported.

5.8.4.2.3 The report shall indicate the nature, location and severity of the defect and recommendations shall be made for further testing. The implication of the existence of the defect on the performance of the pile shall be evaluate.

5.8.4.3 Submission of Results

5.8.4.3.1 The field records of the measured parameters and relevant charts shall be submitted to the Engineer immediately after the test.

5.8.4.3.2 The detail report shall be submitted within 7 days and ~~should~~ shall include an interpretation of the field results. Construction records such as concrete pour volumes against depth and soil borings logs shall be used in the interpretation of the results.

5.8.4.3.3 The report shall include the following information:

(a) Velocity of sound in concrete, appropriate to the strength of the pile.

(b) Whether the above was assumed or measured

(c) Equivalent cross-sectional area of the pile

(d) Calculated pile length

(e) Pile head stiffness

(f) Condition of the pile toe

5.8.4.4 Anomalous Test Results

The piles with anomalous test results shall be rejected at the Engineer's discretion unless the Contractor is able to demonstrate that the pile integrity is acceptable through other methods of integrity tests.

## APPENDIX 5.1

## TEMPLATE FOR PILE LOAD TEST REPORTS

1. Pile Load Test Summary

   a. Project Details
      i. Project:
      ii. Contract No:
      iii. Structure:
      iv. Pile load test no:
      v. Main Contractor:
      vi. Piling sub-contractor:
      vii. Testing sub-contractor:

   b. Pile Details
      i. Pile reference no:
      ii. Location:
      iii. Northing:
      iv. Easting:
      v. Pile type:
      vi. Pile size:
      vii. RL of pile top:
      viii. RL of pile toe:
      ix. RL of ground level:
      x. Concrete grade:
      xi. Reinforcement details:
      xii. Working load:
      xiii. Casting date:

   c. Test Details:
      i. Test date:
      ii. Test load:
      iii. Measured settlement:
      iv. Summary of test results:

2. Location Plan

## APPENDIX 5.1 (Cont'd)

3. Instrumentation Layout, Test Results and Graphs

   a. Layout
      i. Layout of settlement and load measuring devices
      ii. Location of stain gauges
      iii. Depth of extensometer

   b. Test results
      i. Records of applied loads and pile head settlements
      ii. Records of applied load and strain gauge readings
      iii. Records of applied loads and extensometer readings

   c. Graphs
      i. Load-settlement curves
      ii. Load transfer curves
      iii. Skin friction Vs applied load
      iv. End bearing Vs applied load

4. Pile Installation Records and Borehole (PDF Format)

5. Calibration Certificates

# APPENDIX 5.2

## CHECKLIST FOR STATIC PILE LOAD TEST TO BE ENDORSED BY CONTRACTOR'S PROFESSIONAL ENGINEER

**CONTRACTOR'S CHECK LIST FOR STATIC PILE LOAD TEST - DESIGN STAGE**

For Kentledge base checking there shall be a Bore Hole within 5m radius from test pile

| | | Yes | No |
|---|---|---|---|
| (A) | **Geotechnical Check List** | | |
| 1 | Bearing Capacity is checked for pile load test set-up | | |
| 1.1 | Soil Parameters used comply with GIBR | ☐ | ☐ |
| 1.2 | Factor safety is not less than 3.0 for allowable bearing capacity for foundations supporting the kentledge | ☐ | ☐ |
| 1.3 | Estimated differential settlements for Kentledge base is within 1 in 150 | ☐ | ☐ |
| 1.4 | If the answer is 'No' for Item 1.2 or 1.3, do one of the following | | |
| a | Ground improvement | ☐ | ☐ |
| b | Piling for the kentledge foundation | ☐ | ☐ |
| c | Soil replacement | ☐ | ☐ |
| d | Anchors or piles proposed as reation system with adequate design factor of safety in accordance relevant codes | ☐ | ☐ |
| (B) | **Structural Steel Design Check List** | | |
| | Steel members designed shall comply with BS EN 1993 | | |
| 1 | Beams designed for ultimate moment capacity? | ☐ | ☐ |
| 2 | Beams designed for ultimate shear capacity? | ☐ | ☐ |
| 3 | Beams checked for lateral torsional buckling? | ☐ | ☐ |
| 4 | Beam web bearing and web buckling capacity checked? | ☐ | ☐ |
| 5 | Correct assumption for the number of beams effective in web bearing and web buckling to withstand the reaction load during jacking? | ☐ | ☐ |
| 6 | Deflection of beams checked to ensure it will not compromise the overall stability of the setup? | ☐ | ☐ |
| (C) | **Others** | | |
| 1 | Spacing of beams indicated on drawings as per the calculations | ☐ | ☐ |
| 2 | Grade of steel is shown on drawings for all beams | ☐ | ☐ |
| 3 | Concrete block size and stacking details are shown on drawings | ☐ | ☐ |
| 4 | Size of steel beams shown on drawings | ☐ | ☐ |

**NOTE**

1. If any of the answer is 'No' in the above check list, a separate justification to be submitted giving the alternative solutions to the Engineer's acceptance

2. The above check list covers the issues identified for kentldge stability and this check list is not intended to be a complete check list for pile load testing

**BY PE (DESIGN):** ________________________

**ENDORSED BY QP(S):** ________________________

# CHAPTER 6

# DIAPHRAGM WALL CONSTRUCTION

## 6.1 GENERAL

6.1.1 The materials and workmanship required by other Chapters shall apply to diaphragm wall construction except where modified, amended or excluded herein.

6.1.2 The recommendations of BS EN 1538 apply except where conflict occurs, this Specification shall take precedence.

## 6.2 METHOD STATEMENT

6.2.1 The Contractor shall submit a method statement giving the full details of proposed materials, plant and operations involved in the construction of diaphragm walls. It shall include but not limited to the following:

(a) trench stability calculation;

(b) dimensions and details of diaphragm wall panels;

(c) dimensions and details of guide walls;

(d) method of verifying the assumed bearing capacity of the soil below the guide wall;

(e) maximum allowable ground water level, lowest allowable slurry level and density;

(f) the allowable surcharge, with any sketches of allowable rig/service crane positions;

(g) methods of monitoring and checking the stability of the diaphragm wall trench;

(h) the type, source, chemical and physical properties of the bentonite to be used;

(i) the mixing, transporting and placing equipment for the bentonite slurry;

(j) the cleaning and re-use of bentonite slurry;

(k) the sequence of excavation and concreting of panels;

(l) the formation of the joints and waterbars between panels;

(m) the methods of monitoring and checking the tolerances associated with the diaphragm wall panels including scanning of the verticality of the trench walls;

(n) the methods of monitoring the stability of neighbouring properties, highways, services and other underground structures;

(o) details of disposal of contaminated bentonite slurry;

p) details of lifting devices such as spreader beams used to lift the steel cages, including their maintenance schedule;

q) flowchart showing the diaphragm wall construction process;

r) site layout plan indicating the safe allowable boundary for crane sitting/movement; and

s) weight of each reinforcement cages and details of lapping between top and bottom reinforcement cage

6.2.2 Construction of diaphragm walls shall not commence until the Contractor's proposals have been accepted by the Engineer.

6.2.3 Unless otherwise accepted by the Engineer, the construction of panels shall be continuous once excavation has commenced. Excavated panels or part panels shall not be left open at night or during weekends.

## 6.3 TRENCH AND GUIDEWALL STABILITY

6.3.1 To minimise the risk of trench collapse, especially in layers of fluvial sand during or after desanding, trench stability calculations shall be prepared, taking into consideration the following:

(a) Ground water pressure. The water pressure in the ground typically increases during diaphragm walling. The water pressure used in the calculations shall be based on the highest level measured at the site plus an allowance for an increase in head and this value shall be justified before diaphragm walling begins. If the piezometers show that the water pressure is higher than the value used in the calculations, the Contractor shall not open any new trenches until the calculations have been checked for the higher value. However, panels that are already underway should be completed to avoid them standing open for any significant length of time.

(b) Slurry level. The slurry level shall always remain at least 1m above the highest piezometric level, and the slurry level used in the calculations shall be the lowest level expected in practice. A slurry level at the top of the guide wall is not acceptable as a suitable basis for calculation.

(c) Slurry density. The slurry density used in the stability calculations shall be the lowest value used in practice – which is typically after desanding. The contractor shall justify the minimum density used and back it up with field measurements.

(d) Surcharge. Surcharge shall be considered depending on the position of plant. The value shall not be less than the nominal value specified in the Design Criteria Chapter 3. If the plant is allowed to sit close to the trench, the surcharge will be much higher than the nominal value. Sketches showing the acceptable locations where the rig and service crane may be placed shall accompany the calculations.

(e) Guidewall bearing capacity. The calculations for the guidewall shall check stability against both horizontal loads and vertical loads. The vertical loads shall be checked against the bearing capacity of the soil below the guidewall. If the designer assumes a bearing capacity based on the borehole logs, he shall also propose a means by which the actual bearing capacity all along the guidewall can be verified. This could be done by inspection of the soils.

(f) Length of panel. In critical locations where a trench collapse could cause excessive settlement and potential damage to adjacent structures, the lengths of panel should be minimised.

6.3.2 The basis for the trench and guidewall stability calculations shall be carried through into the Method Statement for diaphragm walling, to ensure that the assumed design values are achieved in practice.

## 6.4 LEVELS OF WORK

6.4.1 Diaphragm walls shall be constructed to the levels shown on the Contract Drawings for the Permanent Works or to the levels proposed by the Contractor and accepted by the Engineer, which are necessary for him to complete the Temporary Works and maintain safe working operations.

## 6.5 TOLERANCES

6.5.1 Construction shall be carried out in accordance with the following tolerances:-

a) The minimum distance between guide walls shall be the diaphragm wall thickness plus 25 mm and the maximum distance shall be the diaphragm wall width plus 50mm. The guide walls shall be propped, as necessary, to maintain these tolerances during the Works. The face of the guide wall towards the trench and on the side of the trench nearest to the subsequent excavation shall be the reference line. This reference line shall not vary from a straight line or specified profile by more than ± 6mm in any 5 metres wall length and there shall be no abrupt change in the alignment of the reference line.

b) The plane of the wall face to be exposed shall be vertical to within a tolerance of 1 in 200. In addition to this tolerance 75mm shall be allowed horizontally for local protrusions beyond the wall face, resulting from irregularities in the ground excavated.

c) Where recesses and inserts are formed within the wall, they shall be positioned within a horizontal and vertical tolerance of ±70mm.

d) The longitudinal tolerances in positioning the reinforcement cage head, measured along trench shall be ±70mm, and the vertical tolerance at cage head in relation to top of guide wall shall be ±50mm.

e) Notwithstanding the requirements of this clause the horizontal tolerances may be aggregated only to the extent that they do not exceed 250mm.

6.5.2 If during the general excavation it is detected that the above stated tolerances have been exceeded, the Contractor shall submit for the acceptance of the Engineer, his proposals for remedying the defects. In addition the Engineer may call upon the Contractor to submit an amended method statement for all future diaphragm wall construction.

## 6.6 HEADROOM

6.6.1 The Contractor shall note any restricted headroom on portions of the Works and shall satisfy the Engineer that his method of excavation, spoil handling, placement of reinforcement cages, stop ends, and concreting can be accommodated within these restrictions.

## 6.7 REINFORCEMENT

6.7.1 Front and rear of cages shall be marked on site to identify them during placement. The reinforcement shall be adequately fixed to avoid damage and/or displacement during handling and lifting operations and to maintain the minimum specified cover during concreting. Lifting points shall be painted a contrasting colour for ease of identification. Lifting points and design of lifting lugs shall be acceptable to the Engineer. Spacers of an accepted type shall be incorporated in the cage construction to ensure correct cover is maintained. The spacers shall be capable of resisting deformation during cage placement within the trench and shall not entrap slurry during concreting.

## 6.8 WELDING OF REINFORCEMENT

6.8.1 Welding of cold worked high tensile reinforcement bars shall not be permitted as a method of splicing cages. Welding of hot rolled high tensile steel bars will be permitted provided that the method used will not adversely affect the properties of the bars.

## 6.9 CONCRETE

6.9.1 Structural concrete for diaphragm walls shall have a minimum cement content of 400kg/$m^3$ where the concrete is being place by tremie methods, in accordance with BS EN1997-1. Minimum slump of the concrete shall be 150 mm and the mix shall flow easily within the tremie pipe and be designed to produce a dense impervious concrete. Such structural concrete shall have a minimum strength of 30N/$mm^2$ at 28 days and the water cement ratio of the mix shall not exceed 0.55. Admixtures may be used subject to the acceptance of the Engineer.

## 6.10 BENTONITE

6.10.1 Bentonite for use in the wall support slurry shall be in accordance with BS EN1538. Samples of the bentonite to be used shall be submitted to the Engineer for acceptance.

6.10.2 Samples shall be taken so that at least one test is carried out for every ten tonnes of bentonite supplied. A certificate shall be provided with each consignment stating the properties of samples tested. Tests shall be carried out to provide the following information:

a) Apparent viscosity and gel strength of a suspension of bentonite in water.

b) Moisture content of the bentonite powder and wet screen residue on US 200 mesh sieve.

c) A statement of the conditions of test, such as any results of water analysis, mixer type, mixer speed during testing, time of stirring and time of testing after initial addition of bentonite to the water.

6.10.3 For any 100 tonnes of bentonite, moisture content shall not deviate by more than ±2%, apparent viscosity by more than ±2 cps and gel strength measured at 10 minutes by more than plus or minus 0.023 N/$m^2$.

6.10.4 Allowance shall be made for one sample of bentonite powder per panel to be tested under the same conditions as those under which testing was carried out by the supplier or manufacturer, at the date work on the panel is commenced.

6.10.5 Water used for dispersion of bentonite shall be as nearly neutral in pH as practicable and care shall be taken to exclude saline water or water contaminated by salts. Bentonite powder shall be mixed thoroughly into the water by a suitable high shearing action mixer until all lumps have been broken up and dispersed within the mix.

## 6.11 TESTING BENTONITE SLURRY

6.11.1 The testing equipment employed shall be as specified in American Petroleum Institute standards (Ref. API-RP-13B). Additional or alternative equipment may be employed with the acceptance of the Engineer.

6.11.2 Bentonite slurry shall be tested for:-

a) density using a mud balance;

b) viscosity, yield stress and gel strength using a Fann viscometer;

c) viscosity using a Marsh funnel;

d) pH with an electric pH meter; and

e) sand content.

6.11.3 A sample of bentonite slurry shall be obtained from the panel during excavation for every 5 metre depth or each change of soil type.

6.11.4 A full range of tests shall be taken when additional wall support materials are added to the slurry.

6.11.5 The pattern of relationship between gel strength, viscosity, and density shall be established on site so that:

a) The gel strength / viscosity relationship does not produce excessive combined values likely to produce slurry entrapment;

b) No flocculation of the bentonite occurs;

c) No settlement of the solids within the slurry occurs;

d) The range of values for slurry properties conform to BS EN1538 unless otherwise acceptable to the Engineer.

6.11.6 Density, viscosity and gel strength shall be measured together with sand content from a sample taken at the base of the trench immediately before concreting. The Engineer may require the slurry to be changed if the sample fails to meet the required characteristics.

## 6.12 STORAGE OF BENTONITE

6.12.1 Bentonite shall be stored in cool dry conditions. Particular care shall be taken with bulk storage to prevent balling of bentonite powder due to dampness or deterioration of properties due to dampness and heat.

## 6.13 ALTERNATIVE MATERIALS

6.13.1 The Contractor may propose additional or alternative ingredients and admixtures to the wall support slurry as specified above. Samples and full details including the supplier and manufacturer of such ingredients shall be submitted. Any such materials must not detrimentally affect the concreting or formed concrete.

6.13.2 Alternative materials shall be tested as for bentonite, where appropriate, or alternative tests shall be proposed by the Contractor to demonstrate the required properties. Storage conditions shall follow the supplier's recommendations.

## 6.14 TREMIE CONCRETE

6.14.1 Tremie pipes shall be clean, water-tight and with a minimum internal diameter of 250 mm. The outer diameter should be such that it passes freely through the reinforcement cage. The tremie pipe shall have a plug of suitable material or other means to separate concrete in the pipe from bentonite at the start of concreting. The pipe shall extend to the bottom of the trench excavation prior to concreting and care shall be taken to ensure that all bentonite slurry is expelled from the tube during the initial charging operation. The tremie pipe shall be maintained with a minimum embedment of 3.0m into the concrete to prevent the re-entry of slurry into the pipe. The Contractor shall ensure that an adequate supply of concrete to the tremie is available at all times so that placement is continuous. The number of tremie pipes per panel shall be acceptable to the Engineer. Where more than one tremie pipe is employed during concrete pouring to any one panel, the charging of concrete in the pipes shall be evenly distributed between the tubes to ensure that no differential head exists at the concrete/slurry interface over the length of the panel. This level shall be confirmed by soundings taken during the concrete pour.

## 6.15 TEST CUBES

6.15.1 Test cubes shall be made and tested in accordance with BS 1881. Test cubes shall be taken for each panel constructed and in accordance with the requirements Chapter 11 Concrete and Reinforcement Bars. Cubes shall have the same marks as the wall panel numbers and shall be sub-marked within each panel set.

## 6.16 BACKFILLING

6.16.1 Lean mix concrete with an aggregate cement ratio of 40:1 with a water cement ratio between 0.65 and 0.7 shall be employed as backfill above any cut-off level for structural concrete and be taken to the top level of the guide walls. Placing of the lean mix concrete shall take place not less than 24 hours and not more than 3 days after placing the structural concrete in each wall panel.

## 6.17 STOP ENDS

6.17.1 Stop ends, inserted before placement of concrete in the panel, shall be clean and have a smooth regular surface. Any shutter release agent shall be to the acceptance of the Engineer. Where stop ends are inserted in sections, adequate joint connections must be provided to ensure verticality of the complete tube.

6.17.2 The extraction of stop ends shall be carried out such that no damage is caused to the panels or adjacent soil and structures.

## 6.18 INSERTS

6.18.1 Box-out and adequate protection shall be done to protect any inserts. The Contractor shall submit their proposal to the acceptance of the Engineer.

## 6.19 MONITORING

6.19.1 The Contractor shall assist the Instrumentation and Monitoring Contractor in their instrumentation readings taking, necessary for the close and continuous monitoring of the movements of adjacent structures, services and underground constructions.

## 6.20 SAFETY AND EMERGENCY PROCEDURES

6.20.1 The Contractor shall take all necessary precautions to ensure stability of his excavations, guide walls and the safety of personnel in the area of operation. He shall maintain, available for immediate use, a sufficient quantity of slurry to allow for any sudden loss.

6.20.2 Should the loss continue despite the addition of slurry and the stability of the trench is at risk, the Contractor shall immediately inform the Engineer and take immediate remedial action to stabilise the trench and ensure the safety of neighbouring structures and services.

## 6.21 SITE CLEANLINESS

6.21.1 The Contractor shall ensure that the site be cleared of slurry to the acceptance of the Engineer, and that his operations be conducted in such a manner as to minimise any spillage of slurry over the site.

## 6.22 OBSTRUCTIONS

6.22.1 An obstruction is defined as material that requires chiselling, explosives, or pneumatic tools for its removal. Upon encountering an obstruction, the Contractor shall immediately inform the Engineer and agree the method to remove the obstruction.

## 6.23 DISPOSAL OF SPOIL

6.23.1 Spoil shall be separated from the slurry employed in the excavation process. It shall be disposed of as quickly as possible to an acceptable dumpsite and in such a manner that spillage and annoyance are minimised.

6.23.2 Contaminated slurry, not suitable for re-use, shall be removed from site and disposed of in accordance with Clause 6.27.

## 6.24 JOINTS

6.24.1 Where concrete is cast against previously completed wall panels, the previously formed concrete shall be cleaned so that solid substances are removed before the joint is formed. Waterbars that have been tested to BS2571 and BS2782 shall be provided and held in place by suitably designed profiled forms. The width of waterbars shall be not less than 200mm.

6.24.2 PVC (polyvinyl chloride) waterbars shall be provided and held in place by suitably designed profiled forms. The width of waterbars shall be not less than 200mm. The PVC waterstop shall be extruded from an elastomeric plastic material of which the basic resin is pure virgin polyvinyl chloride. The PVC compound shall not contain any scrapped or reclaimed material. The waterstop shall meet the performance requirements as follows:

| Property | Test Method | Required Limits |
|---|---|---|
| Water absorption | ASTM D570 | 0.15% max. |
| Tear Resistance | ASTM D624 | 35KN/m min. |
| Ultimate Elongation | ASTM D638 | 300% min. |
| Tensile Strength | ASTM D638 | 14Mpa |
| Specific Gravity | ASTM D792 | 1.45 max. |
| Hardness, Shore A | ASTM D2240 | To manufacturer's specifications |

6.24.3 When the diaphragm wall is exposed, the Contractor shall repair any joints that have jetting, spraying or leakage of water.

## 6.25 CLEANING

6.25.1 The exposed surface of the diaphragm wall shall be thoroughly cleaned to remove all traces of bentonite, soil, or other contaminating materials. This requirement shall apply irrespective of whether or not the exposed panel is to be subsequently covered by insitu concrete.

## 6.26 RECORDS

6.26.1 The following records shall be kept for each wall panel and such records shall be available for inspection by the Engineer within 24 hours of the completion of each panel.

a) Panel Number;

b) Dates and times of start and finish of panel excavation;

c) Details of any obstructions encountered and the time spent in dealing with obstructions;

d) Date and time of completion of cage placement;

e) Date and time of start and completion of panel concreting;

f) Length, width and depth of panel from top of guide wall level;

g) A log of soil type encountered from start to finish of excavation and water levels;

h) Volume of concrete used and time of any interruptions recorded in concrete supply where these exceed 15 minutes. Volumes of normal and lean mix concrete;

i) Cut-off level of concrete below top of guide wall level;

j) Date, place and time of slurry control tests and results recorded;

k) Concrete test cubes, markings, date and results obtained on testing;

l) Details of cage type for reinforcement;

m) Quantity of slurry removed from site and spoil removed from site recorded by date;

n) A graph of theoretical and placed concrete volumes with depth.

o) Trench verticality record / scanning graph;

p) Details of any trench collapse incident encountered.

## 6.27 DISPOSAL OF SLURRY

6.27.1 The Contractor is responsible for arranging his own sites for disposal of used bentonite or contaminated slurry that is not suitable for re-use. With reference to the General Specification, the Contractor shall note that used bentonite or contaminated slurry is not classified as “Unsuitable Material”.

## 6.28 CUTTING DOWN OF DIAPHRAGM WALLS

6.28.1 Concrete shall be cast to such a level that only sound concrete remains below the specified levels.

6.28.2 Diaphragm walls shall be over-cast by a minimum of 600mm where only sound concrete remains below the specified levels. It shall be cut down to sound concrete that is free of contaminants, or to such a level as is required by the design.

6.28.3 Where the cutting down extends to within two meters of any waterproofing membrane, the cutting down shall be completed before the membrane is laid.

6.28.4 Once the roof waterproofing membranes have been laid, any cutting down shall be carried out by non-percussive means.

## 6.29 TRENCH EXCAVATION VERTICALITY CHECK

6.29.1 The Contractor shall carry out the verticality check of each diaphragm wall trench excavation using a scanning device and provide the scanning graphical printout, The scanning shall be carried out for the entire depth of the excavation at the near, far faces of the excavated trench, including the both ends.

# CHAPTER 7

# SOIL IMPROVEMENT WORKS

## 7.1 GENERAL

**7.1.1** The Contractor shall appoint a Professional Engineer (Geotechnical) [PE(Geo)] who shall prepare a detailed design of the soil improvement works to the Engineer for acceptance.

**7.1.2** A detailed description of the proposed instrumentation plan and programme for the monitoring and controlling of the soil improvement works during the ground treatment shall be submitted to the Engineer for acceptance.

## 7.2 SOIL IMPROVEMENT USING PREFABRICATED DRAINS

### 7.2.1 Prefabricated Drains

7.2.1.1 The Contractor shall submit the following information of the prefabricated drains:

(a) Manufacture material;

(b) Standard weight;

(c) Dimensions and tolerances;

(d) Geometrical profile of the drain;

(e) Void ratio of the drain cross-section;

(f) Discharge capacity under overburden stress;

(g) Soaked and unsoaked tensile strength of the skeleton of the drain and corresponding maximum allowable elongation;

(h) Tensile strength of filter sleeve when wet; and

(i) Permeability coefficient of the filter sleeve

7.2.1.2 The Contractor may be requested by the Engineer to take samples of the drain material from each batch delivered to site for testing in an accredited laboratory to confirm the compliance with the properties stated.

7.2.1.3 The prefabricated drain shall be flexible and capable of being wound around without damage. It shall be strong enough so as not to break, tear or lose its drainage properties during installation.

7.2.1.4 The drain shall be capable of transmitting water along its length without significant resistance to flow and shall retain its required discharge capacity at the maximum depth.

7.2.1.5 The drain shall be sufficiently flexible to cope with the anticipated settlement of the soil while maintaining continuity and without offering any significant support to the surcharge embankment. The drain material shall be inert and maintains its properties throughout the required period of consolidation.

7.2.1.6 The transportation, site storage and handling of prefabricated drains shall be in accordance with the manufacturer's specifications. The drain shall be protected from harmful substances and environments. The drain shall be stored on site in containers or other means acceptable to the Engineer.

### 7.2.2 Method Statement

The Contractor shall submit a detailed method statement for the installation of the drains. The method statement shall include:

(a) The capacity and height of machinery to be used.

(b) The maximum depth of penetration attainable by the machinery.

(c) The speed of penetration (in m/s).

(d) The method and devices to be used for measuring the depth of penetration.

(e) The rate of installation of drains (in metres of drain per working day).

(f) Method of installation without causing damage to the adjacent prefabricated drain previously installed; and

(g) Verticality check.

### 7.2.3 Installation of Prefabricated Drains

7.2.3.1 Prior to the commencement of installation of prefabricated drains, the Contractor shall trim and level the site as necessary and lay a compacted sand mat of minimum 300mm thick on the ground surface.

7.2.3.2 All drains shall be located to 100mm tolerance of the designed layout unless otherwise specified. The Contractor shall be required to install the drains continuously to the depth in accordance with the designed requirements. The anchor shoe shall be of the minimum size capable of holding the drain in place at the required depth as the mandrel is withdrawn. The Contractor shall ensure that the drains will be installed vertically and there shall be no physical damages to the drains during the installation process.

7.2.3.3 After installation, the drains shall be cut, leaving a minimum length of 100mm above the sand mat level.

7.2.3.4 The device for measuring the penetration depth shall be calibrated, in a method acceptable to the Engineer, on a minimum of a weekly basis or at the discretion of the Engineer should there be reasons to believe that the device is not functioning.

7.2.3.5 The Contractor shall provide and install an additional drain at a distance of not more than a quarter of the drain interval from the rejected drain to compensate for the rejected drain, as directed by the Engineer.

**7.2.4 Records of Prefabricated Drain Installation Works**

7.2.4.1 The Contractor shall keep daily records of the drains installed. Copies of these shall be submitted to the Engineer within 24 hours following the drain installation.

The records shall show the following information:

(a) Date of drain installation;

(b) Type of drain used (product name);

(c) Machine No. and plant type installing the drain/ name of operator;

(d) Grid and area reference of each drain;

(e) Depth of installation for each drain below the working surface;

(f) Obstruction, aborted drain installations and delay, if any;

(g) Daily total number of drains installed;

(h) Drain roll identification numbers; and

(i) Weather conditions.

7.2.4.2 Any unusual conditions encountered shall be noted in the records.

**7.2.5 Sand Blanket**

7.2.5.1 After the completion of the installation of the vertical drains, the Contractor shall provide another layer of sand blanket of minimum 300 mm thick on top of the prefabricated drains. The sand blanket and the prefabricated drains shall be laid to extend beyond the proposed embankment surcharge areas leading to surface drains.

7.2.5.2 Sand supplied by the Contractor for building the sand blankets shall be clean and of gradation shown in Table 7.1. Samples shall be taken on site at a rate of 1 sample in every 10,000 $m^2$ plan area of sand blanket built or one sample per embankment surcharge area to verify the compliance of the material with the specification. An accredited laboratory shall be engaged to carry out permeability tests on the samples by the Constant-Head Permeability Test in accordance with BS 1377. All test reports shall be submitted to the Engineer for acceptance. Unless otherwise accepted by the Engineer, sand blanket material which fails to meet the gradation specification, in particular with more than 20% fines passing the 0.063 mm sieve opening shall be totally rejected from use in the sand blanket works.

**Table 7.1: Gradation Requirement for Sand Blanket Material**

| Sieve Opening (mm) | Acceptable range of % Passing Specified Sieve Opening |
|---|---|
| 10mm | 92 – 100 |
| 5 mm | 70 – 100 |
| 2.36 mm | 40 – 100 |
| 1.18 mm | 15 – 100 |
| 0.6 mm | 0 – 97 |
| 0.3 mm | 0 – 90 |
| 0.15 mm | 0 – 60 |
| 0.1 mm | 0 – 28 |
| 0.063 mm | 0 – 20 |
| 0.02 mm | 0 – 13 |

### 7.2.6 Surcharge Embankment Build-Up and Removal

7.2.6.1 Fill for Surcharge Embankment

The Contractor shall supply and deliver accepted fill from his own source and construct the surcharge embankments to the finished profiles and in accordance with the details as shown in the drawings. He shall propose his fill source(s) to the Engineer for acceptance prior to the commencement of the works.

7.2.6.2 Surcharge Embankment

a) The surcharge embankment shall be formed by uniform compaction to the desired profile. The Contractor shall regularly top up the embankment with additional fill to compensate for any settlements.

b) The Contractor shall ensure the stability of the embankment and its slopes at all times.

c) A gentle gradient shall be provided for the finished profile on top of the embankment for proper surface runoff. The Contractor shall submit a proposal on erosion control and maintenance to the Engineer for acceptance.

d) The method of construction of the embankment proposed by the Contractor shall be such that the heaving of the subsoil in the area adjacent to the embankment shall not be exceed the serviceability limits of the Works and all existing services and structures.

7.2.6.3 Instrumentation and Monitoring

The Contractor shall monitor the ground condition for consolidation and ground stability. The Contractor shall adhere to the sequence of operations for the placement of drains and instrumentation. The protection of the instruments shall consider the sequence of the construction.

7.2.6.4 Removal of Surcharge Embankment

a) The completed embankment shall remain and be maintained at the site with appropriate instrument monitoring for a continuous period of not less than the stipulated design period.

b) The Contractor shall show evidence to satisfy the Engineer that the design performance has been achieved before removing the surcharge.

c) Upon removal of the embankment, the fill materials shall be disposed off site to the Contractor's own dumping ground.

## 7.3 SOIL IMPROVEMENT USING JET GROUTING

Jet Grouting is a process of improving the ground by cutting it with high pressure jet(s) and mixing and replacing the resulting slurry with cement grout. The Contractor shall comply with the requirements of BS EN 12716 – Execution of Special Geotechnical Works – Jet Grouting.

### 7.3.1 Method Statement for Jet Grouting

7.3.1.1 The Contractor shall submit a detailed method statement for the grouting works. It shall include the minimum information required in BS EN12716.

7.3.1.2 The method statement shall be reviewed in the light of the results of the trial and if necessary resubmitted to the Engineer for acceptance.

### 7.3.2 Jet Grouting Trial

7.3.2.1 Before commencement of Jet Grouting works, the Contractor shall conduct a trial to demonstrate the suitability of the proposed method. This shall be carried out in accordance with the Contractor's method statement.

7.3.2.2 One minimum trial test shall be carried out at site for each soil type (based on the Civil Design Criteria) to be treated.

7.3.2.3 The trial jet grouting shall consist of a minimum of six overlapping piles formed at the depth and in similar ground conditions as the proposed jet grouting.

7.3.2.4 The effectiveness of the trial grouting shall be demonstrated with a minimum of four boreholes used to obtain cores through the full depth of the grouted block. Of the four boreholes, one shall be targeted at the centre of a pile, one at a point two third of a pile radius from the centre, and the remaining two at the overlapping areas of the piles. The cores shall be fully logged and shall be tested for strength and stiffness. A minimum of 1 sample each shall be taken from top, middle and bottom of each core for strength and stiffness testing.

7.3.2.5 The Jet Grouting trial is deemed to fail if the Total Core Recovery (TCR) fails to achieve 85% or any of the strength or stiffness tests fail the target value. Further trial(s) with more appropriate operation parameters shall be carried out.

7.3.2.6 A minimum of 3 Standard Penetration Test (SPTs) at the overlapping areas of the piles shall be carried out at each borehole. The strength and stiffness test results shall be used to correlate with the N-values. The correlation shall be agreed with the Engineer, and used only as supplementary to the more direct TCR, strength and stiffness tests for the subsequent quality control.

7.3.2.7 The Contractor shall take measures to enhance the strength/stiffness of the soils between the ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities. The boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

7.3.2.8 A grid of settlement/heave monitoring points shall be established over the trial area, at a spacing of not greater than 5m. All buildings, structures and utilities within a distance of 1.5 times the maximum depth of grouting shall also be monitored for movement. All points shall be monitored at least twice per day when drilling or grouting work is in progress.

7.3.2.9 The Contractor shall submit the results of the Jet Grouting trial to the Engineer, together with an interpretative report assessing the results of the trial and proposing any necessary changes to his method statement.

### 7.3.3 Drilling and Grouting

7.3.3.1 Before installation of the jet grout piles, the pile positions shall be marked.

7.3.3.2 The drilling and grouting plant shall be equipped with automatic, data loggers to allow the operating parameters to be checked and recorded continuously during drilling and grouting operation. All the measuring devices shall be calibrated before the start of the work, and the records of the calibration submitted to the Engineer.

7.3.3.3 Materials used as a flushing medium for drilling or as part of the grout mix shall be non-toxic and subject to the acceptance of the Engineer. The material safety data sheets for each material shall be submitted to the Engineer for acceptance.

7.3.3.4 All drilling and grouting effluent shall be collected in trenches, pits or tanks and not allowed to flow out of the site. Measures shall be taken to ensure that the effluent is not discharged into the public drainage system. All effluent shall be removed from the site and disposed of in accordance with the relevant regulations.

7.3.3.5 The empty bore above the jet grout pile shall be filled with grout during the extraction of the grouting monitor.

7.3.3.6 The requirement for settlement/heave monitoring shall be the same as for the jet grouting trial.

### 7.3.4 Records

7.3.4.1 During jet grout pile installation, the Contractor shall submit daily progress reports and record sheets on the Jet Grouting works.

7.3.4.2 The record sheets shall include:

(a) reduced levels for the ground, the top and base of the pile;

(b) inclination of the pile;

(c) quantity of materials used;

(d) operating parameters;

(e) casing size and length;

(f) drilling length;

(g) type of flushing medium

(h) duration and timing of each major activity;

(i) total materials used, and;

(j) observations on slurry return, breakdowns, interruptions during drilling or grouting and any other relevant events

7.3.4.3 The format of records shall be submitted by the Contractor to the Engineer for acceptance prior to the commencement of works.

7.3.4.4 At the completion of any continuous block or section of Jet Grouting, a summary report shall be submitted to the Engineer.

7.3.4.5 This report shall include the following information:

(a) As-built drawings showing the layout, inclination and installed depth of each jet grout pile;

(b) The results of all site investigation;

(c) Location and depth of core samples;

(d) All instrumentation monitoring readings taken before and after the Jet Grouting works; and

(e) The results of the quality control testing.

### 7.3.5 Quality Control

7.3.5.1 The following components and parameters shall be checked and recorded continuously by the automatic~~,~~ data loggers:

(a) Pressure and flow rate of fluids (air, water and grout);

(b) Pressure in hydraulic oil lines (for torque and thrust);

(c) Drilling head, including rotation speed, depth, withdrawal speed, penetration rate and mast inclination mounted on the drilling head;

(d) Borehole deviation (horizontal location and inclination); and

(e) any other relevant data.

7.3.5.2 The continuously recorded data shall be monitored by suitably qualified personnel who shall take necessary action should any data fall beyond the range of the designed working parameters.

7.3.5.3 Recorded data shall be provided to the Engineer in both hardcopy and electronic format compatible with Microsoft Excel. The format shall be agreed upon and approved by the Engineer before commencement of the works. The recorded data shall be submitted to the Engineer within 24 hours after the completion of each jet grout pile.

7.3.5.4 The grout mix shall be checked by measuring the specific gravity using a mud balance at least twice a day per rig.

7.3.5.5 The specific gravity and viscosity of the effluent return shall be checked using mud balance and Marsh cone. This shall be done at least once per pile, during grouting.

7.3.5.6 The Contractor shall confirm the quality of the jet grout by Standard Penetration Tests (SPTs) and coring.

7.3.5.7 There shall be 8 boreholes for each 1,000 cubic metres (rounded up to the nearest whole number of boreholes) of treated soil. The boreholes shall be at the overlapping area of the piles. In each borehole, the SPTs tests shall be done at the top, middle and bottom of the treated zone. SPTs may be replaced by Cone Penetration Tests (CPTs) subject to the acceptance of the Engineer. All boreholes shall be grouted with cement bentonite

7.3.5.8 There shall be 4 numbers of cores through the full depth of the piles for each 1,000 cubic metres (rounded up to the nearest whole number of cored holes) of treated soil. The cores shall be taken from the overlapping areas of the piles. The cored holes shall be grouted with cement bentonite.

7.3.5.9 The cores shall not be less than 50mm in diameter. The quality of the jet grouting shall be determined from the total core recovery (TCR) and the strength and stiffness of the recovered core. The TCR shall not be less than 85%. Where TCR is found to be less than 85%, two additional cores to the adjacent jet grout piles shall be carried out at no additional cost to the Authority. In the event that either of the additional coring fails to conform with the requirement, the Jet Grouting work is deemed to have failed.

7.3.5.10 A minimum of 1 sample shall be taken from top and middle and bottom of each core for strength and stiffness testing. The selection of coring locations shall be determined by the Engineer.

7.3.5.11 The strength and stiffness shall comply with the design requirements. If either of the strength or stiffness test fails to achieve its target value, two additional samples in the same core shall be tested for strength and stiffness at no additional cost to the Authority. In the event that either of the additional samples fails to conform with the requirement, the Jet Grouting work is deemed to have failed.

7.3.5.12 If the jet grouting work is deemed to have failed, the Contractor shall propose measures to the Engineer for acceptance. The PE(Geo) shall re-assess the design parameters of the JGP and carry out the design checks to evaluate his design to the acceptance of Engineer.

7.3.5.13 The quality, strength and stiffness of the JGP will have a major impact on the overall behaviour of the temporary works, especially in the case of sacrificial JGP layers. All data relating to the JGP quality tests shall be assessed by the PE(Geo) responsible for the design of temporary works. The PE(Geo) shall ensure that the upper bound and lower bound values of the strength and stiffness of the as built JGP have been catered for in his design.

7.3.5.14 The Contractor shall prepare a full report on the testing results, including his assessment of the results, proposals for remedial work and changes to the design of JGP and submit to the Engineer for acceptance.

7.3.5.15 The Contractor shall take measures to enhance the strength/stiffness of the soils between the ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all activities. Samples from the same boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

### 7.3.6 Movement Control of Ground, Building, Utilities and other critical structures

7.3.6.1 The Contractor shall submit a detailed method statement, including risk assessment, and types of equipments for the Jet Grouting works to ensure minimum disturbance to the ground, surrounding buildings and utilities. The Contractor shall propose the necessary control and protection measures.

7.3.6.2 The Contractor shall carry out a trial to demonstrate that the proposed method and equipment are able to ensure minimal disturbance to the ground, buildings, utilities and other critical structures within the influence zone.

7.3.6.3 The Contractor shall implement a suitable instrumentation programme for monitoring movement of ground, buildings, utilities and other critical structures.

7.3.6.4 The Contractor shall immediately cease Jet Grouting works when settlement or heave trigger levels are exceeded at any monitoring point, or there is any visible damage to buildings or utilities, during Jet Grouting works. He shall not recommence Jet Grouting works until he has proposed and demonstrated the additional measures to control the ground movements to the acceptance of Engineer.

## 7.4 DEEP SOIL MIXING (DSM)

DSM is a process of improving the ground by cutting a column of soils and mixing it mechanically, using a rotating mixing tool, with cement or lime. The DSM column can be formed either by dry mixing or wet mixing method.

### 7.4.1 Method Statement for DSM

7.4.1.1 The Contractor shall submit a detailed method statement for the DSM works.

It shall include:

(a) location and depth of each DSM column;

(b) column size, length and spacing;

(c) mixing method, binder and design mix;

(d) equipment and plant;

(e) methods used to control and measure the depth of penetration;

(f) operational parameters;

(g) target DSM column strength and stiffness;.

(h) site utilization plan;

(i) verticality check of DSM columns and control of ground movement during the installation process;

(j) quality control testing;

(k) spoil management, including collection, transportation and disposal; and

(l) trial test proposal, including the location and monitoring of the trial.

7.4.1.2 The method statement shall be reviewed in the light of the trial results and if necessary resubmitted to the Engineer for acceptance*.*

### 7.4.2 DSM Trial

7.4.2.1 Before the commencement of DSM works, the Contractor shall conduct a trial to demonstrate the suitability of the proposed method. This shall be carried out in accordance with the Contractor's method statement.

7.4.2.2 The trial shall consist of a minimum of four columns formed at the depth and in similar ground conditions as the proposed DSM. The trial shall be used to confirm the following:

(a) applicability of the operational parameters;

(b) type and quantity of binder to achieve the performance requirements;

(c) diameter of the DSM columns formed;

(d) compressive strength and stiffness of the DSM columns; and

(e) effect of the DSM on the soils above the treatment zone.

7.4.2.3 The effectiveness of the trial shall be demonstrated with a minimum of two boreholes used to obtain cores through full the depth of the DSM block. The boreholes shall be targeted within the midway between the center and outer surface of the columns. The cores shall be fully logged and shall be tested for strength and stiffness. A minimum of 1 sample each shall be taken from top, middle and bottom of each core for strength and stiffness testing.

7.4.2.4 The Contractor shall take measures to enhance the strength/stiffness of the soils between ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities. The boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

7.4.2.5 A grid of settlement/heave monitoring points shall be established over the trial area, at a spacing of not greater than 5m. All buildings, structures and utilities within a distance of 1.5 times the maximum depth of treatment shall also be monitored for movement. All points shall be monitored at least twice per day when DSM work is in progress.

7.4.2.6 The Contractor shall submit the results of the DSM trial to the Engineer, together with an interpretative report assessing the results of the trial and propose any necessary changes to his method statement.

### 7.4.3 Installation of DSM Columns

7.4.3.1 Before installation of the DSM columns, the column positions shall be marked.

7.4.3.2 The mixing materials used shall be non-toxic. The material safety data sheets for each material shall be submitted to the Engineer for acceptance.

7.4.3.3 All drilling and grouting effluent, if any shall be collected in trenches, pits or tanks and not allowed to flow out of the site. Measures shall be taken to ensure that the effluent is not discharged into the public drainage system. All effluent shall be removed from the site and disposed of in accordance with the relevant regulations.

7.4.3.4 The Contractor shall take measures to enhance the strength/stiffness of the soils between ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities. The boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

7.4.3.5 The requirement for settlement/heave monitoring shall be the same as for the DSM trial.

### 7.4.4 Records

7.4.4.1 During the DSM column installation, the Contractor shall submit daily progress reports and record sheets on the DSM works.

7.4.4.2 The record sheets shall include:

(a) material and equipment type used;

(b) reduced levels for the ground, the top and base of the column;

(c) quantity of cement or lime used per metre of DSM column;

(d) total quantity of cement and lime used in the day;

(e) operational parameters;

(f) length and diameter of DSM column installed; and

(g) duration and time of each major activity.

7.4.4.3 The format of records shall be submitted by the Contractor to the Engineer for acceptance prior to the commencement of works.

7.4.4.4 Upon completion of each continuous block or section of the DSM works, the Contractor shall submit a report to the Engineer to substantiate that the treated soil meets the specified objectives.

7.4.4.5 The report shall include the following information:

(a) as built drawings showing the layout and the length of each DSM column;

(b) results of all site investigation;

(c) location and depth of core samples;

(d) all instrumentation monitoring readings before and after the DSM works; and

(e) the results of the quality control testing carried out at site.

### 7.4.5 Quality Control

7.4.5.1 The Contractor shall confirm the quality of the DSM, by carrying out soil investigation boreholes and testing. The location of the boreholes shall be proposed to the Engineer for acceptance. There shall be 4 numbers of boreholes for each 1,000 cubic metres (rounded up to the nearest whole number of boreholes) of treated soil.

7.4.5.2 Boreholes shall be targeted within the midway between the centre and outer surface of the column to obtain samples for laboratory testing. The cores shall be inspected for continuity of the columns. The size of core shall be nominal diameter of at least 50 mm. Unconfined compression tests and triaxial compression tests with strain measurement shall be carried out to obtain the strength and compression stiffness of the columns. A minimum of 1 sample each shall be taken from top, middle and bottom of each core for strength and stiffness testing. All boreholes shall be grouted with cement bentonite.

7.4.5.3 The TCR of the cores shall not be less than 85%. A minimum of four samples shall be tested for strength and stiffness, and the results shall comply with the minimum requirements specified in the design. Where TCR is found to be less than 85%, two additional cores to the adjacent DSM columns shall be carried out at no additional cost to the Authority. In the event that either of the additional coring fails to conform with the requirement, the DSM work is deemed to have failed.

7.4.5.4 If the DSM work is deemed to have failed, the Contractor shall propose measures to the Engineer for acceptance. The PE(Geo) shall re-assess the design parameters of the DSM and carry out the design checks to evaluate his design to the acceptance of Engineer.

7.4.5.5 The quality, strength and stiffness of the DSM will have a major impact on the overall behavior of the temporary works, especially in the case of sacrificial DSM layers. All data relating to the DSM quality tests shall be assessed by the PE(Geo) responsible for the design of temporary works. The PE(Geo) shall ensure that the upper bound and lower bound values of the strength and stiffness of the as-built DSM have been catered for in his design.

7.4.5.6 The Contractor shall prepare a full report on the testing results, including his assessment of the results, proposals for remedial work and changes to the design DSM, and submit to the Engineer for acceptance.

7.4.5.7 The Contractor shall take measures to enhance the strength/stiffness of the soils between the ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities.

Samples from the same boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

### 7.4.6 Movement Control of Ground, Buildings, Utilities and other critical structures

7.4.6.1 The Contractor shall submit a detailed method statement, including risk assessment and types of equipments for the DSM works to ensure minimum disturbance to the ground, surrounding buildings and utilities. The Contractor shall propose the necessary control and protection measures.

7.4.6.2 The Contractor shall carry out a trial to demonstrate that the proposed method and equipment are able to ensure minimal disturbance to the ground, buildings, utilities and other critical structures within the influence zone.

7.4.6.3 The Contractor shall implement a suitable instrumentation programme for monitoring movement of ground, buildings, utilities and other critical structures.

7.4.6.4 The Contractor shall immediately cease DSM works when the settlement or heave trigger levels are exceeded at any monitoring point, or there is any visible damage to buildings or utilities, during DSM works. He shall not recommence DSM works until he has proposed and demonstrated the additional measures to control the ground movements to the acceptance of Engineer.

## 7.5 LIME OR CHEMICO-LIME PILES

Lime or chemico-lime piling involves the formation of piles of quicklime (unslaked lime) or chemically treated lime. The term ‘lime piles’ will be used to apply to both lime and chemico-lime piles.

### 7.5.1 Method Statement for Lime Piles

7.5.1.1 The Contractor shall submit a detailed method statement for the lime piling.

It shall include:

(a) location and depth of each lime pile;

(b) pile size, length and spacing;

(c) equipment and plant;

(d) methods of placing the lime;

(e) quantities of lime;

(f) methods used to control and measure the depth of penetration;

(g) target strength and stiffness of the ground around the piles;

(h) strength and the stiffness of the lime piles

(i) site utilization plan;

(j) verticality check of lime piles;

(k) control of ground movement during the installation process;

(l) quality control testing;

(m) soil management, including collection, transportation and disposal;

(n) safety precautions while handling and installing the lime; and

(o) trial test proposal, including the location and monitoring of the trial.

7.5.1.2 The method statement shall be reviewed in the light of the trial results and if necessary resubmitted to the Engineer for acceptance.

### 7.5.2 Lime Pile Trial

7.5.2.1 Before the commencement of lime piling works, the Contractor shall conduct a trial to demonstrate the suitability of the proposed method. This shall be carried out in accordance with the Contractor's method statement.

7.5.2.2 The trial shall consist of a minimum of 6 piles formed at the depth, at the spacing and in similar ground conditions as the proposed lime piles.

7.5.2.3 The effectiveness of the trial shall be demonstrated with a minimum of four boreholes. Of the four boreholes, two shall be targeted at the middle point of the four columns, with the remaining two targeted close to one of the lime piles. A minimum of one undisturbed sample each shall be taken from top, middle and bottom of each core for water content, undrained shear strength and stiffness testing.

7.5.2.4 Where the strength and stiffness of the piles are taken into account in the design, a minimum of two additional boreholes shall be used to obtain continuous cores through the full depth of the piles. Each borehole shall be targeted at the centre of the pile. The cores shall be fully logged and shall be tested for strength and stiffness. A minimum of 1 sample each shall be taken from top, middle and bottom of each core for strength and stiffness testing.

7.5.2.5 The Contractor shall take measures to enhance the strength/stiffness of the soils between the ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities. The boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

7.5.2.6 A grid of settlement/heave monitoring points shall be established over the trial area, at a spacing of not greater than 5m. All buildings, structures and utilities within a distance of 1.5 times the maximum depth of lime piling shall also be monitored for movement. All points shall be monitored at least twice per day when lime piling work is in progress.

7.5.2.7 The Contractor shall submit the results of the lime piling trial to the Engineer, together with an interpretative report assessing the results of the trial and proposing any necessary changes to his method statement.

**7.5.3 Installation of Lime Piles**

7.5.3.1 Before installation of the lime piles, the pile positions shall be marked.

7.5.3.2 The materials used shall be non-toxic. The material safety data sheets for the lime shall be submitted to the Engineer for acceptance.

7.5.3.3 All spoil shall be collected and removed from the site. The disposal shall be in accordance with the relevant regulations.

7.5.3.4 The requirement for settlement/heave monitoring shall be the same as for the lime pile trial.

**7.5.4 Records**

7.5.4.1 During the lime pile installation, the Contractor shall submit daily progress reports and record sheets on the lime piling works.

7.5.4.2 The record sheets shall include:

(a) material and equipment used;

(b) quantity of lime used per metre of pile;

(c) operating parameters used for pile installation;

(d) reduced levels for the ground, the top and base of the pile;

(e) inclination of the pile;

(f) length and diameter of lime pile installed;

(g) duration and timing of each major activity of the works.

7.5.4.3 The format of records shall be submitted by the Contractor to the Engineer for acceptance prior to the commencement of works.

7.5.4.4 Upon completion of each continuous block or section of the lime piling works, the Contractor shall submit a report to the Engineer to substantiate that the treated soil meets the specified objectives.

7.5.4.5 The report shall include the following information:

(a) as built drawings showing the layout and the length of each lime pile;

(b) the results of all investigation;

(c) location and depth of core samples;

(d) all instrumentation and monitoring readings before and after the lime piling works; and

(e) the results of the quality control testing.

### 7.5.5 Quality Control

7.5.5.1 The Contractor shall confirm the quality of the lime piles by carrying out soil investigation boreholes and testing. The location of the boreholes shall be proposed to the Engineer for acceptance. There shall be 4 numbers of borehole for each 1,000 cubic metres (rounded up to the nearest whole number of boreholes) of treated soil.

7.5.5.2 Of the four boreholes, two shall be targeted at the middle point of 4 adjacent piles, with the remaining two targeted close to one of the lime piles. A minimum of 1 undisturbed sample each shall be taken from top, middle and bottom of each core for water content, strength and stiffness testing.

7.5.5.3 Where the strength and stiffness of the lime piles is utilized in the design, the strength and the stiffness of the selected piles shall also be verified. At least 0.5% of the total number of lime piles (rounded up to the nearest whole number of boreholes) shall be tested. The Contractor shall carry out soil investigation boreholes to obtain continuous cores through full depth of the piles. Each borehole shall be targeted at the centre of the pile. The cores shall be fully logged and shall be tested for strength and stiffness. A minimum of 1 sample each shall be taken from top, middle and bottom of each core for strength and stiffness testing.

7.5.5.4 All boreholes shall be grouted with cement bentonite.

7.5.5.5 A minimum of one undisturbed samples from top, middle and bottom for each borehole shall be tested for water content, undrained shear strength and stiffness of the ground between the selected piles. The results shall comply with the range of values specified in the design.

7.5.5.6 If the lime piling work is deemed to have failed, the Contractor shall propose measures to the Engineer for acceptance. The PE(Geo) shall re-assess the design parameters of the lime piles and carry out the design checks to evaluate his design to the acceptance of Engineer.

7.5.5.7 The Contractor shall prepare a full report on the testing results, including his assessment of the results, proposals for remedial work and changes to the design of lime piles and submit to the Engineer for acceptance.

7.5.5.8 The Contractor shall take measures to enhance the strength/stiffness of the soils between the ground level and the top of the treated zone to ensure the strength/stiffness is sufficient and safe for all other activities. Samples from the same boreholes used to test the treated zone shall be used to measure the strength and stiffness of the soils between ground level and the top of the treated zone to demonstrate the effectiveness of the measures.

**7.5.6 Movement Control of Ground, Buildings, Utilities and other critical structures**

7.5.6.1 The Contractor shall submit a detailed method statement, including risk assessment and types of equipments for the lime piling works to ensure minimum disturbance to the ground, surrounding buildings and utilities. The Contractor shall propose the necessary control and protection measures.

7.5.6.2 The Contractor shall carry out a trial to demonstrate that the proposed method and equipment are able to ensure minimal disturbance to the ground, buildings, utilities and other critical structures within the influence zone.

7.5.6.3 The Contractor shall implement a suitable instrumentation programme for monitoring movement of ground, buildings, utilities and other critical structures.

7.5.6.4 The Contractor shall immediately cease lime piling works when the settlement or heave exceed the trigger levels at any monitoring point, or there is any visible damage to buildings or utilities, during lime piling works. He shall not recommence lime piling works until he has proposed and demonstrate the additional measures to control the ground movements to the acceptable of Engineer

# CHAPTER 8

# TEMPORARY WORKS

## 8.1 GENERAL

8.1.1 Temporary Works are defined as all construction works that are required to complete the Permanent Works.

8.1.2 The Contractor shall design, provide, maintain and remove on completion all Temporary Works as may be necessary for the execution of the Works, unless otherwise stated in the Contract.

8.1.3 All Temporary Works shall only commence once the method statement, drawings and calculations have been independently checked by an independent party to the acceptance of the Engineer. The method statement for Temporary Works shall include methods of installation and removal of the Temporary Works.

8.1.4 All Temporary Works shall be designed to the design working life of the temporary structure.

8.1.5 All materials used as load-carrying components shall be new material conforming to the relevant Singapore Standards or Singapore's adoption of Eurocode.

8.1.6 The usage of re-used materials shall be accepted by the Engineer, and the steel materials shall be assessed based on Design Guide on Use of Alternative Steel Materials to BS 5950 and Eurocode 3, (BCA:BC1).

8.1.7 Minimum headroom under temporary structures shall be 5.4m over highways, and 2.4m over footpaths.

8.1.8 Any material that represents a fire hazard or could emit noxious fumes will be rejected for use in the Temporary Works and shall be removed from site immediately.

## 8.2 DESIGN AND SUPERVISION OF TEMPORARY WORKS

8.2.1 The Contractor shall appoint a Professional Engineer (PE) with relevant experience subject to the acceptance of the Engineer. The PE and/or PE(Geo) shall check and certify the design of the Temporary Works. The PE shall also inspect and certify that the Temporary Works have been constructed to conform to the design and they are safe to load or dismantle.

8.2.2 The PE shall be responsible for the Temporary Works, including any intermediate inspections that shall be carried out if the Works are in place for more than 1 week or if there has been a change in loading conditions or after any adverse weather conditions. The Contractor shall submit a schedule of inspection for the Temporary Works by the PE.

## 8.3 FALSEWORK AND FORMWORK

8.3.1 Falsework and formwork shall be designed and erected in accordance with the Building Control Act and Regulations, Workplace Safety and Health (WSH) Act and Regulations and WSH (Construction) Regulations.

8.3.2 Falsework placed adjacent or along road carriageway shall be shielded from accidental impact (e.g. passing vehicles, errant vehicles) by suitable road safety barriers.

## 8.4 SCAFFOLDING AND STAGING

8.4.1 Timber scaffolding and wooden ladders shall not be used.

8.4.2 All scaffolding and staging shall be erected by trained and competent scaffold erectors and supervised by an appointed scaffold supervisor in compliance with the WSH (Scaffolds) Regulations.

8.4.3 Scaffold boards shall be of sound timber/ metal plank to the acceptance of the Engineer and shall be periodically inspected and all boards that are found to be damaged or showing signs of deterioration shall be replaced with suitable boards.

8.4.4 Scaffold runs and platforms shall be close-boarded with boards of a thickness such that unacceptable deflections shall not occur. All access shall be via safe close-boarded walkways.

8.4.5 Protective safety/ guard railing shall be provided on all external edges. At a minimum, the railing shall have toe boarding, a middle rail and top hand railing. The requirements of the toe board, middle rail and top hand railing shall comply with the WSH (Scaffolds) Regulations.

8.4.6 Ladders between platforms and scaffold runs at different levels shall be securely fixed in place, and rigidly constructed. The ladder rungs shall have a non-slip surface with centres not greater than 300mm.

8.4.7 Scaffolding shall undergo a weekly check by an appointed scaffold supervisor, who shall record his inspection on a site register, including the date of his inspection, his name, any findings and any PE approved modifications that he has carried out. Scaffold supervisor is to ensure that the scaffold is safe and that the “Safe to Use” tag is displayed with the period of validity. The supervisor shall also ensure that a periodic scaffold inspection is done and “Safe to Use” tag is updated to permit its use.

8.4.8 Any defect found during an inspection will be put right immediately. If this is not possible and the scaffold is not safe it will be taken out of use immediately by placing a barrier and warning sign at each access point.

8.4.9 Temporary access stairways and walkways shall comply with BS5395: Part 1, particularly with respect to clear minimum headroom and clearance, both vertically and perpendicular to the plane of the stairs.

## 8.5 TEMPORARY ROAD DECKING

For expressways and semi-expressways, the temporary decking shall be designed with a layer of minimum 75mm thick W3B asphalt premix top providing a minimum skid resistance value of 65 BPN as per BS EN 13036-4.

For temporary deck panels used on all other roads, the exposed surface of the panels shall be of a chequer-patterned surface (with protrusion height in excess of 2mm) and coated with anti-skid coating. The anti-skid coating shall provide a minimum skid resistance value of 55 BPN as per BS EN 13036-4.

For all other roads, the temporary decking shall be designed with a layer of minimum 75mm thick W3B asphalt premix top providing a minimum skid resistance value of 55 BPN as per BS EN 13036-4.

Where the temporary steel decking is used to cover localized trench/chamber within public road and construction decking within the worksite, premix top-up is not required. The steel decking shall be coated with anti-skid coating providing a minimum skid resistance value at 55 BPN as per BS EN 13036-4.

All temporary decking shall be of a chequer-patterned surface (with protrusion height in excess of 2mm).

For temporary diverted expressways and semi-expressways where road curvature exists, the top-up shall be of materials (such as concrete with reinforcement) capable of withstanding heavy vehicular traction forces. The top-up shall be a minimum of 100mm thick with 2 layers of A10 rebar welded on specially formed lugs on the deck plate.

All joints between steel decking panels shall be firmly fixed by welding or by other means.

The noise level generated by the temporary road deck shall be within the permissible noise limits specified by National Environment Agency (NEA).

### 8.5.1 Inspection and Testing of Temporary Road Deck

All testing shall be carried out using the Portable Skid Resistance Tester and according to the operating procedure defined in standard BS EN 13036-4.

All preparation, re-coating and repair to the temporary deck panels with anti-skid coating shall be carried out off-site, except where in-situ re-coating is permitted.

Before installation of new temporary deck with anti-skid coating, the following shall be carried out:

(a) Physical testing shall be carried out on two deck panels or 5% of the total number of deck panels, whichever is greater, to demonstrate that the required skid resistance value is complied with.

(b) A proposed maintenance programme/schedule and method statement shall be submitted to the Engineer for acceptance.

The contractor shall conduct a weekly visual inspection of the temporary decking in the presence of the Engineer's representative. At the end of every month, a report containing the following shall be submitted (within 1 week of the last inspection) to the Engineer for acceptance and records.

(a) Photographs and descriptive appraisal of temporary decking physical condition (e.g. report any defects/damages).

(b) Condition of the surface drainage system

(c) Surface conditions

(d) Condition of the structural integrity

(e) Remedial actions taken (if any)

Following every visual inspection, all damaged temporary deck panels with anti-skid coating, as indicated or marked by the Engineer, shall be replaced. The replacement shall be completed within a week. If the safe usage of the temporary deck panels is compromised, the temporary deck shall be ceased from usage until the damaged panels are replaced.

Physical testing of the performance of the temporary decking with anti-skid coating shall be conducted in-situ every three months unless otherwise directed by the Engineer.

Test points for the in-situ physical testing shall be spaced, not more than 5m, along the 2 wheel paths of vehicles for each traffic lane of the carriageway and shall not be within 0.2m from the edge or joint of the temporary deck panels. Prior to testing, the proposed layout of the test points shall be accepted by the Engineer.

Each test point shall be tested to obtain a minimum of three readings and the average of the readings shall be representative of the skid resistance value for that test point. Remedial work shall be carried out immediately when the skid resistance value falls below 45.

Following every physical testing, a test report containing the following information shall be submitted to the Engineer for acceptance and records within 1 week.

(a) Date and Time of Test

(b) Location of test

(c) Age of coating or Date of previous application

(d) Estimated traffic volume per day

(e) Test results (Skid Resistance Value)

(f) Remedial actions taken (if any)

The remedial work on the temporary deck panels with anti-skid coating may be either one of the following, as directed by the Engineer.

(a) In-situ reapplication of the anti-skid coating to the temporary deck panels in the area surrounding the failed test point.

(b) Replacement of the temporary deck panels surrounding the failed test point with newly coated ones.

(c) The remedial works shall cover a minimum area of a full traffic lane width by 5m longitudinally (i.e. 2.5m long from either side of the test point).

Spare temporary deck panels ready for use and in an amount not less than 10% of the total numbers of temporary deck panels used, shall be kept in stock at all times.

The Contractor shall maintain the temporary decking such that it is fit for purpose throughout the use of the deck.

### 8.5.2 Drainage and Cambering

The drainage of the temporary deck shall be such that all surface water shall be retained within the plan area of the temporary deck and be efficiently discharged through connections to the existing drainage system, to the acceptance of the Engineer.

The finished level, falls and camber of the temporary deck shall be based on the existing roadway in accordance with Civil Design Criteria (CDC) Chapter 10 unless otherwise accepted by the Engineer.

## 8.6 GROUND ANCHORS/SOIL NAIL

Where the Contractor proposes to use ground anchors/soil nail as part of his Temporary Works, he shall submit method statement details including material quality, installation and removal sequence of the ground anchor/soil nail to the acceptance of the Engineer. The ground anchors shall be de-stressed and removed to the acceptance of the Engineer.

## 8.7 SHEET PILING

8.7.1 Sheet piles shall be of interlocking and weldable type.

8.7.2 Each pile shall be in one length throughout but where required may be extended by welding on an additional length subject to the acceptance of the Engineer. All welding shall be done by a certified welder.

8.7.3 Purpose made sheet piles shall be driven to form corners and junctions. The clutches shall be of a type which shall prevent ingress of water into the excavations and shall be of a strength and rigidity such that distortion during handling, pitching and driving shall not occur.

8.7.4 The sheet piles shall be driven vertically on the lines and to the dimensions and tolerances shown on the Temporary Works Drawings and shall be pitched in panels. All temporary sheet piles shall be removed.

8.7.5 Holes in the piling for ties and attachment of waling etc., shall be drilled after driving. Burning of holes shall not be carried out without the acceptance of the Engineer.

## 8.8 STRUTS & WALINGS

The gap between the temporary walls and walers shall be infilled with concrete. All struts shall be preloaded to at least 15% of the design load. All walers shall be continuous. The loading of the compound strut and its connections shall be uniformly distributed.

## 8.9 DEWATERING

8.9.1 The Contractor shall install, operate and maintain all necessary pumping plant and drainage facilities and remove all accumulated silt and debris as required for proper execution of the works.

8.9.2 Groundwater control and drawdown shall be to the Engineer's acceptance and in line with the relevant method statement.

8.9.3 Where settlement due to consolidation is predicted to cause unacceptable damage to structures or utilities, the Contractor shall implement measures to prevent such damage.

## 8.10 REMOVAL OF TEMPORARY WORKS

8.10.1 Grouting of voids resulting from the extraction of Temporary Works shall be carried out immediately after the extraction.

8.10.2 The method of extraction or removal shall be such that there is no risk of damage to the Permanent Works and any adjacent structures or utilities.

8.10.3 The Contractor shall follow the approved construction sequence. Prior to removal of any strut, the Contractor shall demonstrate that there is sufficient support to the retained ground to avoid failure or excessive movement to the acceptance of the Engineer.

# CHAPTER 9

# INSTRUMENTATION AND MONITORING

## 9.1 OBJECTIVES

The objectives of the Instrumentation and Monitoring (IM) are to monitor the performance of the Works and the effects on existing structures, services and utilities in a form that will allow direct comparison with performance criteria and design expectations.

## 9.2 SUBMISSIONS

9.2.1 The IM Contractor shall submit detailed method statements for the installation of all instruments for the acceptance of the Engineer at least 21 days prior to commencement of installations. These method statements shall include the following information for each instrument:-

(a) Detailed drawings showing the instrument type, precise location and depth

(b) Manufacturer's specifications and recommendations for installation, maintenance and calibration

(c) Details of equipment, methods and material (including samples) used in drilling works for instrument installation

(d) Sequence of assembly and connection details

(e) Details of any backfill and grouting, where applicable

(f) Details of monitoring arrangements and verification procedures

(g) Methods of taking readings

(h) Traffic lane closure scheme, where applicable

(i) Samples of installation records including the details of each stratum encountered, where applicable

(j) Any other relevant information

9.2.2 Instrumentation readings shall be taken in accordance with the approved method statements.

9.2.3 The IM contractor shall notify the Engineer of the installation of instrument at least 48 hours in advance. All instruments related to the works shall be installed at least four weeks prior to the construction activity unless otherwise accepted by the Engineer.

9.2.4 Detailed drawings of the completed installation shall be provided together with descriptions of the principal features, mode of operation, the measuring range and the accuracy of the instruments.

9.2.5 The IM contractor shall provide detailed calculations of how raw data will be processed and a sample calculation for each instrument.

## 9.3 INSTRUMENTATION PERSONNEL AND RESOURCES

9.3.1 The IM contractor shall provide sufficient resources to ensure that the instrumentation and monitoring works are completed to the satisfaction of the Engineer. The IM contractor shall submit a detailed schedule of manpower and equipment resources to be employed for the instrumentation works one month prior to the commencement of the works or other such time agreed with the Engineer.

9.3.2 The IM contractor shall appoint at least one Senior Instrumentation Engineer (SIE) and one Instrumentation Engineer (IE), subjected to the acceptance of the Engineer. Any replacement of the SIE and IE shall have a hand-over period of at least one month. The SIE shall lead the IM contractor's monitoring team and co-ordinate all instrumentation works including the production of method statements, calibration, installation, data acquisition, data verification, data processing, data presentation and reporting. The SIE shall attend the daily monitoring meeting and monitoring review meetings with the Engineer. The frequency of such review meeting will be decided by the Engineer.

9.3.3 The IE and SIE shall possess the minimum qualification:

a) A university degree or any other professional qualification recognised by the Professional Engineers Board for registration as a professional engineer under the Professional Engineers Act (cap. 253) in Civil Engineering or Structural Engineering Discipline; or

b) A university degree in Civil Engineering or Structural Engineering from any university specified by the Commissioner of Building Control in the list, which is available at the Building and Construction Authority (BCA) website link http://www.bca.gov.sg/; or

c) A qualification as accepted by the Engineer.

In addition, the IE or SIE shall also have at least two (2) and five (5) years of relevant working experience respectively.

9.3.4 All other personnel involved in installation, testing, calibration, monitoring and maintenance of the instruments shall be qualified and experienced in the field of instrumentation, structural monitoring, geotechnical monitoring and survey, as appropriate. The IM contractor shall provide CVs of all personnel including evidence of experience and records of previous works undertaken.

## 9.4 INSTRUMENTS AND MONITORING SYSTEMS

9.4.1 Pneumatic piezometers shall not be used in the works.

9.4.2 In addition, the IM contractor shall provide track records of all instruments to demonstrate reliable performance under similar conditions and duration to the acceptance of the Engineer.

9.4.3 All instruments and measuring devices shall be manufactured by companies with proven experience in the field of construction or geotechnical instrumentation, as appropriate. The accuracy and dependability of the equipment shall not be affected by changes in temperature, humidity, stray currents or contaminants that may be encountered. Calibration certificates shall be provided by an accredited testing company.

9.4.4 Maintenance, inspection and calibration schedules for all instruments, including read out and data loggers shall be submitted prior to installation or use of the instrumentation for the acceptance of the Engineer.

## 9.5 INSTALLATION AND MAINTENANCE OF INSTRUMENTS

9.5.1 All instruments shall be installed and tested in accordance with the manufacturer's instructions or recommendations. Testing shall be undertaken as necessary to ensure satisfactory functioning of the instrument at each stage of the installation. Instruments found to be malfunctioning at any time shall be reported to the Engineer immediately and replaced at the earliest opportunity, but in any case no later than 24 hours from the time of the fault being identified.

9.5.2 All instruments shall be securely fixed and their terminations including any attendant wiring and terminal panels, shall be adequately protected against physical damage, adverse climatic conditions and ingress of water and dirt.

9.5.3 All instruments shall be tagged using aluminium rigid nameplates minimum size 2500 $mm^2$, SWG 24 or similar to the acceptance of the Engineer identifying the following:-

(a) Project title and Contract No.

(b) Instrument reference number

(c) The company name

(d) A contact telephone number

9.5.4 Drawings showing the minimum protection details for inclinometers, piezometers, extensometers and settlement points are given in Appendix 9.1. The IM contractor shall develop protection systems for other instruments. These protection systems shall provide a similar or better level of protection as those shown in Appendix 9.1. The drawings showing the proposed protection systems shall be submitted to the Engineer for acceptance. Each instrument shall be protected using the accepted protection system.

9.5.5 Periodic checks of all instruments in accordance with the approved schedule shall be carried out to confirm the validity of calibration of instrument in accordance with the manufacturer's instructions and any adjustments that are found necessary shall be made. Records of checks, errors identified and any adjustment undertaken shall be kept.

9.5.6 Copies of all certification shall be available at site office and made available for the Engineer's inspection when required.

9.5.7 All instruments or readout boxes shall be accessible for taking readings with the specified accuracy of the instrumentation maintained.

9.5.8 Measures shall be taken to ensure that electrical instrumentation is not adversely affected by other temporary or permanent electrical services and equipment (such as generator, electrical cables for site lighting, etc.), and does not affect any other services, activities or equipment within or adjacent to the Works.

## 9.6 INSTRUMENT READING AND RECORDS

9.6.1 The IM contractor shall establish a logical reference system for all the instrumentation instruments prior to installation and to the satisfaction of the Engineer so that records for any particular location can easily be recovered for interpretation or review.

9.6.2 Instrumentation readings shall be taken as soon as possible after installation and at least once per day for a period of two weeks thereafter. Where instrument readings are not stabilised, the IM contractor shall identify the cause and provide a new sets of readings after rectifying the fault. When all instruments are showing consistent results for a period of 1 week, readings shall be averaged to provide a datum reading. The works that could affect the readings of the instruments shall not proceed before a datum reading is established as agreed with the Engineer.

9.6.3 The frequency of readings shall be at least one reading per month from the establishment of datum readings or as specified on the Drawings, whichever is more frequent. The monitoring shall cease when the Completion of Whole of the Works (CWW) is achieved and the instrumentation readings are stabilised, and subject to the acceptance of the Engineer.

9.6.4 When taking instrumentation readings, the following information shall be recorded:-

(a) All site conditions that may affect the results shall be recorded, e.g., temperature and humidity readings

(b) Instrument type, location reference, datum and time of reading

(c) Personnel carrying out the monitoring

(d) Serial numbers of measuring instrument or readout unit

(e) Observations of unusual conditions that could influence the instrumentation or the structure

9.6.5 Instrument readings shall be recorded digitally for subsequent analysis by computer. Backup data shall be stored on a daily basis. Corrections shall be made for temperature difference or other factors, as appropriate but uncorrected data shall also be available. Plots of deformation, stress, raw data readings against time shall be produced together with plots of temperature and humidity when relevant.

9.6.6 The same measuring devices shall be used for the same instruments throughout the monitoring programme. If this becomes impractical, new datum readings shall be taken immediately with a replacement measuring device which shall be used for the future readings.

9.6.7 Upon completion of the monitoring, the IM contractor shall remove the instruments and reinstate to the satisfaction of the Engineer.

## 9.7 RECORDING EQUIPMENT AND ANCILLARIES

### 9.7.1 Instrumentation Cabling

9.7.1.1 All cables used in enclosed areas shall be low-smoke zero halon cables.

9.7.1.2 Cabling and tubing shall be provided with sufficient slack to accommodate potential ground movement.

9.7.1.3 Cabling for the instrumentation shall be neatly and securely fixed to appropriate cable trays, which in turn shall be securely fixed to the structure.

9.7.1.4 Cabling and connectors for instrumentation shall be of robust and water resistant construction, and shall be corrosion resistant. Any non-metallic items shall be extinguishable in the event of fire and emit no toxic fumes.

9.7.1.5 Each of the cables linked to the instruments and the loggers shall be tagged at the end of the connection. A schedule showing all cables and the connections shall be maintained.

### 9.7.2 Terminal Boxes for Remote Readout

9.7.2.1 Terminal boxes shall collect the cabling from the various remotely read instruments and from local junction boxes, so that monitoring can be conveniently carried out from a single position close to an instrumented section.

9.7.2.2 Terminal boxes shall be positioned for ease of access and shall be protected from damage.

9.7.2.3 The terminal and junction boxes shall be robust water-resistant metal boxes with lockable covers. All cable entries to the boxes shall be through watertight seals.

### 9.7.3 Remote Readout Facilities

9.7.3.1 All instruments with electrical sensors shall be capable of being read remotely using portable readout units connected via the terminal boxes. Readout units shall be supplied together with leads for plugging into the measuring device and terminal boxes.

9.7.3.2 Readout units shall have facilities for recording monitoring data onto a suitable medium for subsequent downloading to a computer for processing.

9.7.3.3 For critical instruments that require real-time monitoring, modem link and connection for direct computer link shall be made to the Engineer's site office.

### 9.7.4 Data Loggers

9.7.4.1 Data loggers shall collect the cabling from the various remotely read instruments and from junction or terminal boxes.

9.7.4.2 Data loggers shall be reliable and compatible with the instruments and have back-up power facilities. The reliability and compatibility of the logger shall be proven prior to installation, by demonstration and records of previous works.

9.7.4.3 All data loggers shall be connected to electrical mains by a flex outlet without switches. Plug sockets shall not be used.

9.7.4.4 Data loggers shall be:-

(a) Positioned for ease of access.

(b) Programmable to log data at any specified interval, including real-time.

(c) Capable of storing data for 14 days.

(d) Easily connected to a portable computer directly by cables or by modem link.

(e) Unaffected by external electromagnetic influences, and shall not affect other electrical equipment.

(f) Insulated from rain and dust.

(g) Fused against electrical power surges.

(h) Capable of automatic shut down in the event of overheating or short-circuiting.

## 9.8 SETTLEMENT POINTS

9.8.1 Detailed requirements for precise levelling systems are specified in Chapter 3, Survey and Setting Out.

9.8.2 Ground and building settlement shall be monitored by precise levelling. The installation details of settlement markers, levelling points and studs shall be submitted to the Engineer for acceptance.

## 9.9 DEEP LEVELLING DATUMS

9.9.1 Deep levelling datums, where installed to provide a reference for measurement of ground levels in areas of soft and compressible ground, shall be fixed into the hard stratum and isolated from soft and compressible overlying strata.

9.9.2 A deep levelling datum shall comprise a 25mm galvanised steel rod cast into a 250mm diameter grout filled steel casing positioned within a 300mm diameter steel casing. The annulus between the two casings shall be filled with grease. The top of the 25mm steel rod shall be carefully domed and centre punched.

9.9.3 The 300mm diameter casing shall be installed not less than 300 mm into firm ground. The 250mm diameter casing shall be driven not less than 1500mm beneath the 300mm casing.

9.9.4 The top of the deep levelling datum shall be protected by a manhole cover and a surface protection barrier.

## 9.10 ELECTROLEVEL/ MICRO-ELECTRO-MECHANICAL-SENSOR BEAMS

9.10.1 The IM contractor shall propose Electrolevel (EL)/ Micro-Electro-Mechanical-Sensor (MEMS) beams from a recognised instrumentation manufacturer and submit supporting documents of past performance to the Engineer for acceptance. The EL/ MEMS beams should be able to provide readings at appropriate time intervals from real time to daily as specified on the Drawings.

9.10.2 **System Requirements**

The EL/ MEMS beams shall meet the following requirements:-

(a) The entire system shall have a resolution of two (2) arc seconds or better with a measuring range between $\pm$ 9 degrees.

(b) The system shall not be affected by radio frequency.

(c) Temperature determination at all sensors shall be accurate to 1ºC.

(d) Minimum length of beam shall be 1m, unless agreed with the Engineer. For rail track monitoring, minimum length of beam shall be 0.5m.

(e) All EL/MEMS beams shall be uniquely calibrated against rotation and temperature by a procedure that accurately defines the working range, accuracy, sensitivity and resolution. This information shall be shown on a calibration certificate clearly identifying the sensor unit.

(f) All software used for the display, analysis and interpretation of the readings shall be acceptable to the Engineer. Methods and values used in raw output conversion and correction for temperature and tilt shall be submitted.

9.10.3 **Installation**

9.10.3.1 The installation of an EL/MEMS system shall be in accordance with the following requirements:-

(a) Fixing of the EL/MEMS beams to the structure shall be by screw or approved epoxy resin as per the manufacturer's recommendations and to the acceptance of the Engineer. Rivets shall not be used. Beam mounting points shall be firmly attached to the structure, such that the beam operates freely in the desired axis of measurement.

(b) Beams shall be protected against the effects of rapid temperature change and thermal expansion / contraction of the beam or mounting fittings shall not affect accuracy of the tilt reading.

(c) Mounted beams shall be aligned to within 1 degree of each consecutive beam and the desired axis of measurement on the structure.

(d) Impact to any structure by installation of mounting fittings or cable runs shall be minimised and only permitted with the prior acceptance of the Engineer.

(e) Beams shall be protected from disturbance from hanging wires, birds etc. Prominent warning signs shall be placed by the beams to avoid misuse.

(f) All beams sensor units shall be clearly marked with identifying codes and direction of tilt.

9.10.3.2 A calibration check and directional check shall be carried out for each beam installed. This shall involve a device able to move one end of the beam by controlled increments of 2, 4, 8, 10, and 15 millimetres. This calibration shall be performed twice for the beam to check reproducibility of results. The result of the calibration check shall be provided, clearly marked with the beam / sensor unit identifying code, for attachment to the calibration certificate.

9.10.3.3 The IM contractor shall be responsible for maintaining the beams/sensors for the required period of monitoring, and shall be responsible for the removal of the beams and making good any damage to the structures.

## 9.11 PORTABLE TILTMETER

9.11.1 Tilt plates shall be mounted on structures, using a combination of grout and anchor bolts as per the manufacturer's recommendations. Where anchor bolts are not permitted, grout shall be used as per the manufacturer's recommendations, and all the installation shall be to the acceptance of the Engineer.

9.11.2 The resolution shall be 10 arc seconds and the accuracy shall be ±0.02% Full Scale (FS).

## 9.12 INCLINOMETERS

### 9.12.1 General

9.12.1.1 Inclinometers shall take the form of an access tube with four key ways (in pairs at right angles) which shall be grouted in a borehole. The orientation of the key ways shall be such that they are parallel and perpendicular to the orientation of any tunnel, excavation or Earth Retaining and Stabilising System (ERSS) or otherwise as accepted by the Engineer.

9.12.1.2 When taking readings the inclinometer probe shall be inserted in the tube and shall travel along the whole length of the tube with its wheels engaged in each pair of the key ways in turn to obtain deformation measurements in both directions. The probe wheels shall be compatible with the key ways. Changes in inclination shall be displayed on a portable readout unit.

9.12.1.3 A suitable means of measuring the position of the probe down the borehole to an accuracy of ±10 mm from a reference point at the top of the borehole shall be provided.

9.12.1.4 Both the probe and the portable readout units shall be calibrated at intervals recommended by the manufacturer.

9.12.1.5 The inclinometer tubing shall have an outer diameter of 70 mm and shall be pre-grouted into a minimum 100 mm diameter borehole or a steel duct of at least 125mm cast into any pile or wall.

9.12.1.6 The inclinometer tubing shall be of uniform section and be free of twist in manufacture and shall not be twisted during installation. The tubing shall be provided with appropriate couplings for joining tube lengths to the required borehole length. The base of the tube shall be capped. Cap and coupling joints shall be adequately fixed and sealed so that the tube is grout and dirt tight. The grooves shall be consistent in cross section. The tubing material shall be Acrylonitrile Butadiene Styrene (ABS) plastic unless otherwise accepted by the Engineer.

9.12.1.7 The joined and sealed tubing shall be concurrently filled with clean water while being lowered into the borehole and the annulus grouted using a bentonite/cement grout tremied to the bottom of the hole. The tubing shall be held in place at the bottom until the grout sets. The tubing shall not be held down with weights attached to the top.

9.12.1.8 Immediately following installation a spiral and inclination check shall be carried out. Corrections required to data readings shall be determined and applied.

9.12.1.9 During earthworks operations the inclinometer tubes shall be extended in lengths and ahead of the fill in a manner accepted by the Engineer.

9.12.1.10 At the final ground level the inclinometer tubing shall be fitted with a removable cap protected by a protection cover and surface protection barrier.

### 9.12.2 In-Place Inclinometers (Remotely Read)

9.12.2.1 The inclinometer shall consist of a string of biaxially placed sensors located in a slotted inclinometer of ABS plastic casing.

9.12.2.2 Each in-place inclinometer shall consist of waterproof sensors remotely monitored using a computer data logging system.

9.12.2.3 The resolution of the sensors shall be 2 seconds of arc or better and the measuring range shall be at least ± 9 degrees. The operating temperature range shall be at least 0°C to +50°C.

9.12.2.4 Calibration certificates for each sensor showing calibration for both tilt and temperature shall be provided. Both calibrations shall fully characterise the sensor output response over both the specified tilt and the operating temperature range. Sample calculations to translate output to movement shall be provided.

9.12.2.5 The sensors shall be installed at spacings not greater than 3 m and shall be connected with a rigid rod or beam to give a fixed gauge length. At the end of the sensor and the gauge extension a spring loaded wheel assembly shall be fitted. Sensors mounted on sleds will not be acceptable.

9.12.2.6 Stability and gain of the reading system shall be checked at weekly intervals by means of three “dummy” electrolevels using precise resistors.

**9.12.3 Inclinometers (Manually Read)**

9.12.3.1 A mechanical pulley shall be used for taking all readings

9.12.3.2 The datum readings shall be established using at least 2 probes and shall be submitted together with the serial numbers of the probes.

9.12.3.3 All subsequent readings shall only be taken using probes with which the datum readings have already been established.

9.12.3.4 Calibration certificates for each inclinometer probe shall be provided to the Engineer.

9.12.3.5 The system accuracy shall be ± 6 mm per 25 m of casing or better.

9.12.3.6 The stability of the reading system shall be checked at weekly intervals through the use of checksum calculations.

9.12.3.7 The inclinometer and logging system shall be capable of recording movements in both directions (i.e. biaxial).

9.12.3.8 The probe used shall have the following:-

(a) A wheel base of 500mm or greater.

(b) A measurement range of ± 35 degrees or greater from vertical.

(c) A resolution of 0.02mm or better per 500mm with a repeatability of ±0.1%.

(d) A minimum radius curve for retrieval of 2.2m or less.

(e) A working temperature range of at least 0°C to +50°C.

(f) A construction (externally) of stainless steel.

9.12.3.9 Once the probe is introduced into the inclinometer and prior to the commencement of readings, the probe shall be allowed the appropriate time for its temperature to stabilise.

## 9.13 MAGNETIC EXTENSOMETERS

9.13.1 Magnetic extensometers employed in the Works shall consist of a series of magnetic rings ("spider magnets") fixed into a maximum 150mm diameter borehole with a plastic tubing allowing access to the magnetic points for the measurement of settlement.

9.13.2 The prongs on the magnetic rings shall be capable of extending beyond the circumference of the borehole into the surrounding soil.

9.13.3 The complete downhole assembly shall be grouted in place ensuring that the access tube and magnets remain undisturbed during grouting operations. The access tube shall be capped to prevent ingress of ground water.

9.13.4 The magnetic rings shall be housed in splay PVC holders suited to the ground into which they shall be installed to the acceptance of the Engineer.

9.13.5 When the tubing is anchored in stable ground, a datum magnetic ring shall be set at its base. If the bottom of the tubing is not in stable ground, the depths of the magnets shall be referenced to a level survey point at the top of the tubing which shall be surveyed by precise levelling before readings are taken.

9.13.6 The magnetic rings shall be installed at the depths accepted by the Engineer or at maximum 3m intervals.

9.13.7 The reading system shall be reliable and require minimal maintenance over the required monitoring period. Thermal or other influences shall be negligible.

9.13.8 The system shall have an accuracy of ±1.0mm.

## 9.14 ROD EXTENSOMETERS

9.14.1 Rod extensometers shall be able to measure relative movements of both elongation and reduction in the length between the anchor and the reference collar to the acceptance of the Engineer.

9.14.2 A range adjustment device fitted at the reference collar shall extend the reading range beyond that of the measurement device.

9.14.3 No more than three rods shall be installed in a single hole with each rod of a different length so that displacements at various borehole depths may be recorded.

9.14.4 Where more than three rods are required another borehole shall be prepared as close as possible to the initial hole and rods set at alternate depths in each hole.

9.14.5 Each rod shall be individually isolated by its own plastic sleeve and the complete assembly shall be grouted in place fixing the anchors to the ground but allowing free movement of each rod within its sleeve.

9.14.6 A single reference housing shall receive all of the rods from a drill hole and provide protection to the reference head.

9.14.7 A level survey point shall be fixed to the top of the reference head of the extensometer to allow precise levelling back to a datum.

9.14.8 Rods shall be fabricated from stainless steel or fibreglass.

9.14.9 Anchor points shall have extendable prongs or be rustproof paint deformed mild steel bar of 25mm diameter and 300mm long.

## 9.15 TAPE EXTENSOMETER

9.15.1 A tape extensometer shall comprise a steel tape, portable measuring instrument with metric calliper and a pair of anchor clips.

9.15.2 Anchors shall be located and fixed in a manner acceptable to the Engineer.

9.15.3 The tape extensometer shall be capable of being read to ±0.15 mm, and have a range of 20 m. A repeatability of reading to ±0.15 mm shall be demonstrated prior to use.

9.15.4 Measurements shall be taken by connecting the tape hook to the pertinent eyebolt and the tape stretched across to the next bolt. The tension of the tape shall be adjusted and the tape and calliper readings taken.

9.15.5 A minimum of two tape extensometers shall be provided at the commencement of work and these are to be calibrated against each other, so that in the event of damage to one tape, accuracy is not compromised.

## 9.16 VIBRATING WIRE PIEZOMETERS

9.16.1 The type of tip shall be chosen to suit the expected maximum groundwater pressure and the characteristics of the surrounding ground.

9.16.2 The combined accuracy of instrument and readout device shall be within ±1.0 % of the true pressure.

### 9.16.3 Installation in Boreholes Drilled from the Surface

9.16.3.1 All piezometers shall be tested before installation by submergence in still clean water to a series of depths appropriate to the anticipated pressure range of operation in order to verify the calibration and accuracy of the instrument.

9.16.3.2 The tip of each piezometer shall be air free and the porous stone of the tip shall be fully saturated by submergence in clean de-aired water for a period of at least 24 hours prior to installation. Complete de-airing of the porous stone shall be confirmed by periodic weighing.

9.16.3.3 Each piezometer shall be installed in a separate borehole of 100mm nominal diameter unless otherwise accepted by the Engineer. The complete installation shall be carried out as soon as practicable, and no later than 24 hours, after drilling to minimise the amount of deterioration or alteration of the ground at the location of the piezometer tip.

9.16.3.4 Drilling to the required depth shall be carried out without the use of air-flush in the vicinity of the tip position. Casing shall be used to stabilise the hole through unstable ground.

9.16.3.5 The hole shall be flushed until it is filled with clean water. The piezometer tip shall then be inserted under water and backfilled with clean sand to form a sand cell. The sand cell shall be of 1m height with the piezometer located in its centre.

9.16.3.6 A plug of bentonite formed of either pellets or chips shall then be tamped over the sand to form a minimum thickness of 1m. The hole shall then be backfilled with bentonite/cement grout mix to the acceptance of the Engineer. Grout backfill shall terminate at the base of the instrumentation chamber.

9.16.3.7 Where accepted by the Engineer the IM contractor may use ‘push-in’ vibrating wire piezometers utilising a mandrel of not less than 0.5m in length. In such cases there will be no requirement for a sand cell. Backfilling using bentonite and grout as specified shall be used.

9.16.3.8 Casing, if used to maintain the hole open, shall be withdrawn carefully so as not to damage the instruments or cables, and concurrently with the progress of the backfilling.

9.16.3.9 Accurate records of the depths of the piezometer, sand cell and bentonite seals shall be kept, and readings shall be recorded at each stage of the installation. For push-in piezometers the increase in pore pressure as well as dissipation shall be recorded using a data logger. The maximum pressure allowable during installation shall be 50% of the maximum for which the piezometer is rated.

## 9.17 CASAGRANDE PIEZOMETER STANDPIPE

9.17.1 The piezometer tip shall consist of a porous element or other suitable element not less than 125mm long with a diameter not less than 40mm, and shall be protected at each end by PVC fittings.

9.17.2 The porous element shall have a pore diameter of the order of 60 microns and minimum permeability 10 times greater than that of the soil being tested. If ceramic filter is used, it shall be soaked in clean water for 24 hours prior to assembly of the piezometer element. The element shall be filled with clean de-aired water before installation.

9.17.3 The PVC tubing shall have a nominal diameter of 19 to 25mm, and shall be supplied and installed in not less than 3m lengths except for one shorter length as required to suit the total standpipe dimensions. The tubes shall be joined together and to the porous element with couplings and glue as per the manufacturer's recommendations and to the acceptance of the Engineer in such a manner that the joints remain leak proof under the anticipated head of water. The tube should be of at least 12mm internal diameter to allow air bubbles to rise freely.

9.17.4 Each piezometer shall be installed in a separate borehole of 100mm nominal diameter unless otherwise accepted by the Engineer.

## 9.18 WATER STANDPIPES

9.18.1 The standpipe shall be perforated PVC tubing of nominal size 19mm to 25mm diameter with 3mm diameter holes at about 25mm centres. The perforated part shall be wrapped with two layers of nylon 2mm mesh to the satisfaction of the Engineer.

9.18.2 The PVC tubing shall be installed in not less than 3m lengths, except for one shorter length as required to suit the total standpipe dimensions. The upper end of the tube shall be set in concrete.

## 9.19 VIBRATION METER

9.19.1 The vibration recorder shall measure the Peak Particle Velocities (PPV) in 3 main directions. The longitudinal direction (L) faces the vibration source; the transverse direction (T) is perpendicular to the transverse direction and (V) is in the vertical direction.

9.19.2 For continual monitoring on critical structures, the battery shall be regularly recharged according to the manufacturer's specifications.

9.19.3 The report shall reflect the time, the peak particle velocities (PPV) and frequency of the vibration.

9.19.4 A protection using a key lock system shall be carried out to protect the sensor and the readout.

9.19.5 The working range shall be up to 30 mm/s.

9.19.6 The resolution shall be 0.254 mm/s and the accuracy shall be ±5% FS or 0.5 mm/s, whichever is larger.

## 9.20 TEMPERATURE SENSOR

The working range of the sensors shall be at least 0°C to +50°C with accuracy of ±1°C. All sensors shall be capable of being remotely monitored.

## 9.21 STRAIN GAUGE

9.21.1 Strain gauges employed in the works shall be of vibrating wire type. Sensor shall be securely attached by cable ties or other approved means. When strain gauges are used to measure the strain in reinforced concrete structures, correction factor shall be considered for concrete shrinkage and creep in converting the strain to strut load.

9.21.2 Vibrating wire strain gauges shall have the following characteristics:

(a) Strain range $2500 \times 10^{-6}$ m/m

(b) Accuracy $\pm 3.0 \times 10^{-6}$ m/m

(c) Resolution $0.5 \times 10^{-6}$ m/m

9.21.3 Signal cable shall be shielded with four 22 gauge conductors with flexible polyurethane jacket or similarly approved. The cables shall be temperature rated to a minimum range of 0°C to +50°C.

9.21.4 Adequate protective measures shall be used to protect installed strain gauges from damage during the monitoring period.

## 9.22 LOAD CELL

Load cell employed in the works shall be of vibrating wire type. The load-bearing elements are to be manufactured from high tensile, heat treated, stress relieved steel with precision ground bearing surfaces.

## 9.23 TELL-TALES

9.23.1 Tell-tales shall generally comprise two clear plastic overlapping plates one marked with a millimetre scale the other with a cross-hair marking to allow reading on two axes. The overlapping plates shall be fixed so that a gap of not greater than 1 mm separates them at the start of monitoring. The location, orientation and plate separation for each tell-tale shall be recorded on the monitoring sheets.

9.23.2 The Demountable Mechanical (DEMEC) crackmeter shall consist of a standard or a digital dial gauge attached to an Invar bar. A fixed conical point shall be mounted at one end of the bar, and a moving conical point shall be mounted on a knife edge pivot at the opposite end. The pivoting movement of this second conical point shall be measured by the dial gauge.

9.23.3 The Vibrating Wire (VW) crackmeter shall consist of a vibrating wire displacement sensor and a mounting kit with anchors. Readings shall be taken with a vibrating wire readout or a data logger. Calibration factors shall be applied to the frequency readings to convert them to a distance in mm. The initial readings shall establish a baseline. Subsequent readings shall be compared to the baseline to determine the magnitude of changes in the distance across the crack. The resolution shall be 0.025% of FS and the accuracy shall be ±0.5% of FS.

## 9.24 OPTICAL PLUMBING

The accuracy of the plumbing instrument shall be a minimum of 1:30000 and a check on its accuracy carried out prior to each day readings. The instrument shall be checked by rotating the unit through 120-degree intervals either side of the normal position and viewing the target at each interval. The centre point shall remain the same throughout the rotation.

## 9.25 AUTOMATICALLY LOGGED INSTRUMENTS

9.25.1 Data from automated monitoring systems shall be collected and stored at sufficient frequency to the acceptance of the Engineer.

9.25.2 At the commencement of instrumentation installation works, the IM contractor shall supply and maintain a computer for the Engineer's use until the completion of the instrumentation monitoring works. Details on a standard PC configuration can be found in the Particular Specifications.

9.25.3 The computer shall be able to collect all data either via modem, disc or direct from the readout units. All checking, processing, verifying and backup shall be carried out by the IM contractor. However, raw data shall be available to the Engineer.

## 9.26 FIELD DATA

9.26.1 The monitoring data required under the Contract shall be stored in a format compatible with Microsoft Excel spreadsheet program. The data from manual systems shall be supplied at daily intervals via emails or CD-ROM and supported by hard copy.

### 9.26.2 Reporting of Instrumentation Data to Database

9.26.2.1 All instruments and monitoring data files, including real-time monitoring, shall be uploaded to the Authority's database system. Details of the requirements for data format, uploading, etc. can be obtained from the Authority's database administrator. However, the Authority may update the database system and the IM contractor shall comply with the Authority's latest requirements for data format, uploading, etc.

9.26.2.2 Submissions including uploading data to LTA database system shall be made within 24 hours of the readings being taken.

## 9.27 BOREHOLE INSTALLATION

### 9.27.1 Drilling

9.27.1.1 No work shall proceed without prior acceptance of the method statement by the Engineer.

9.27.1.2 At least one full-time technician for every two drilling rigs shall be provided to supervise all drilling works and to accurately record all drilling and testing. The technicians shall possess an acceptable diploma from an approved technical institute or equivalent and shall have at least two (2) years of experience in similar works.

9.27.1.3 The drilling crew shall include a driller who has had previous experience in similar works subject to the acceptance of the Engineer.

### 9.27.2 Records and Borehole Logs

9.27.2.1 The IM contractor shall submit two copies of a daily drilling record for each borehole at the commencement of the next working day. The information in the record shall contain the following in a format acceptable to the Engineer:-

(a) Site and area.

(b) Reference number of the borehole or observation well.

(c) Brief description of the weather.

(d) Name of the person in charge of the rig.

(e) Date and hours worked on site.

(f) Details of all contacts with landowners and tenants and times of entry to and exit from all properties.

(g) Details of utilities or obstructions located.

(h) Methods of advancing the hole.

(i) Lengths of borehole for which casing was used and diameter of such casing and of uncased hole; the record should show the relation between the depth of hole and the depth of casing at all times.

(j) Water levels as with full details of any fluctuation and of the condition and return of water flush during each drilling run.

(k) Details of any water added to boreholes giving approximate quantity and time(s) when done.

(l) Description of each stratum encountered as described in the Design Criteria, Chapter 5: Geotechnical Parameters.

(m) Depth below ground surface of each change of stratum.

(n) Reference number, depths and other details of all samples obtained.

(o) Commencing and terminating depths of each drilling run, details of core barrels used, lengths of core recovered, and core orientation.

(p) The rates of penetration during coring in minutes per metre.

(q) Results of in-situ tests, together with the water levels in the boreholes during the tests.

(r) Details of any instrumentation installed.

(s) Details backfill and grouting.

(t) Details of delays or breakdowns.

(u) Total length and orientation of each borehole or observation well.

(v) Sea conditions (where applicable)

(w) State of tide (where applicable)

(x) Any other relevant information.

9.27.2.2 The IM contractor shall submit a Borehole Record to the Engineer within two days of completing the borehole to which it refers. Graphical symbols used shall be to the acceptance of the Engineer.

9.27.2.3 After the Engineer has confirmed that no further amendment is required on the log, the final log, which shall be typed, shall be submitted within seven days of receiving such confirmation.

### 9.27.3 Grouting

9.27.3.1 For all instruments installed in boreholes grouting is required for part or all of the boreholes as indicated in the manufacturer's recommended installation procedures.

9.27.3.2 The grout shall be a bentonite cement mixture with sufficient water to achieve a pumpable mix. The bentonite shall be pre-soaked 24 hours prior to usage. The proportions of the mix shall be such so as to achieve a strength similar to that of the natural ground conditions.

9.27.3.3 The IM contractor shall conduct trials on different mixes to ascertain strength characteristics at 7 days and 28 days. The materials used for the trial mixes shall be the same as those for the grouting of the boreholes. Results submitted to the Engineer shall contain details of materials, mix proportions, details of mixing procedure, and strength characteristics, etc.

9.27.3.4 No borehole shall be grouted until the trial mixes have been carried out and satisfactory results have been submitted to the Engineer.

## 9.28 RECORDS AND REPORTING

### 9.28.1 General

9.28.1.1 All data shall be checked for consistency of trends and hard copies shall be signed by the SIE.

9.28.1.2 Two copies of preliminary records of the installation of each instrument shall be duly signed by IE and submitted within 24 hours from the time of installation of each instrument. Final records for each instrument shall incorporate the Engineer's comments and be submitted within seven days of completion of installation of each instrument.

9.28.1.3 The records shall incorporate a graphical illustration of the instrument installation and shall include the following:-

(a) Instrument number and location (co-ordinates and level).

(b) Names of personnel responsible for installation.

(c) Time and date for commencement and completion of instrument.

(d) Plant and labour used.

(e) Ground conditions encountered (if applicable).

(f) Details of instrument installation (grout, fixings etc).

(g) Instrument readings during installation, calibration and immediately after installation are completed.

(h) Location of instrument terminals, housings and any leads or cabling.

(i) Details of any splices, numbers of casings or joints.

(j) Details of any breakdowns or delays.

(k) Details of any instrument protection.

### 9.28.2 As-Built Instrumentation Plan

9.28.2.1 As-built instrumentation plans shall be endorsed by the Registered Surveyor and submitted to the Engineer for acceptance.

9.28.2.2 When new instruments are installed, the plans shall be updated, endorsed and submitted to the Engineer for acceptance

### 9.28.3 Reporting

Reporting of monitoring data shall be submitted on a weekly basis unless specified otherwise. The report shall include a plan showing the location of the structure and instruments, and shall include the following information:-

(a) Plots of measured parameters vs. appropriate variables, for example, settlement vs. time, horizontal deflections vs. time, load vs. depth of excavation, settlement vs. location of tunnel / depth of excavation etc.

(b) A comparison of data with predetermined review levels.

(c) An interpretation of the data. The interpretation shall include a summary of all monitored trends against predetermined review levels. Any areas of concern or potential concern shall be highlighted within the report. The report shall be assessed and commented by the designer.

### 9.28.4 Monthly Reporting

A summary of the interpretative reports in a format acceptable to the Engineer shall be provided in the IM ontractor’s Monthly Report.

### 9.28.5 Reporting of Sprayed Concrete Lining Monitoring

9.28.5.1 The IM contractor shall process the monitoring data to provide time-deformation and time-stress diagrams immediately after taking readings, in order for the Sprayed Concrete Lining (SCL) designer to evaluate the stability of the excavation.

9.28.5.2 The diagram shall include the following information:

(a) The project details

(b) The type of measurement, such as deformation, stress, convergence

(c) The diagram page reference

(d) The location and chainage of the measuring bolts/prims

(e) A sketch of the cross section of the tunnel clearly indicating positions of the measuring bolts/prisms

(f) The detail of the excavation process such as:

i) Distance of measuring point from the tunnel face

ii) Excavation of heading, bench and invert in relation to the measurements

iii) Location of adjacent openings

(g) The duration between the excavation and initial reading taken at the measured section

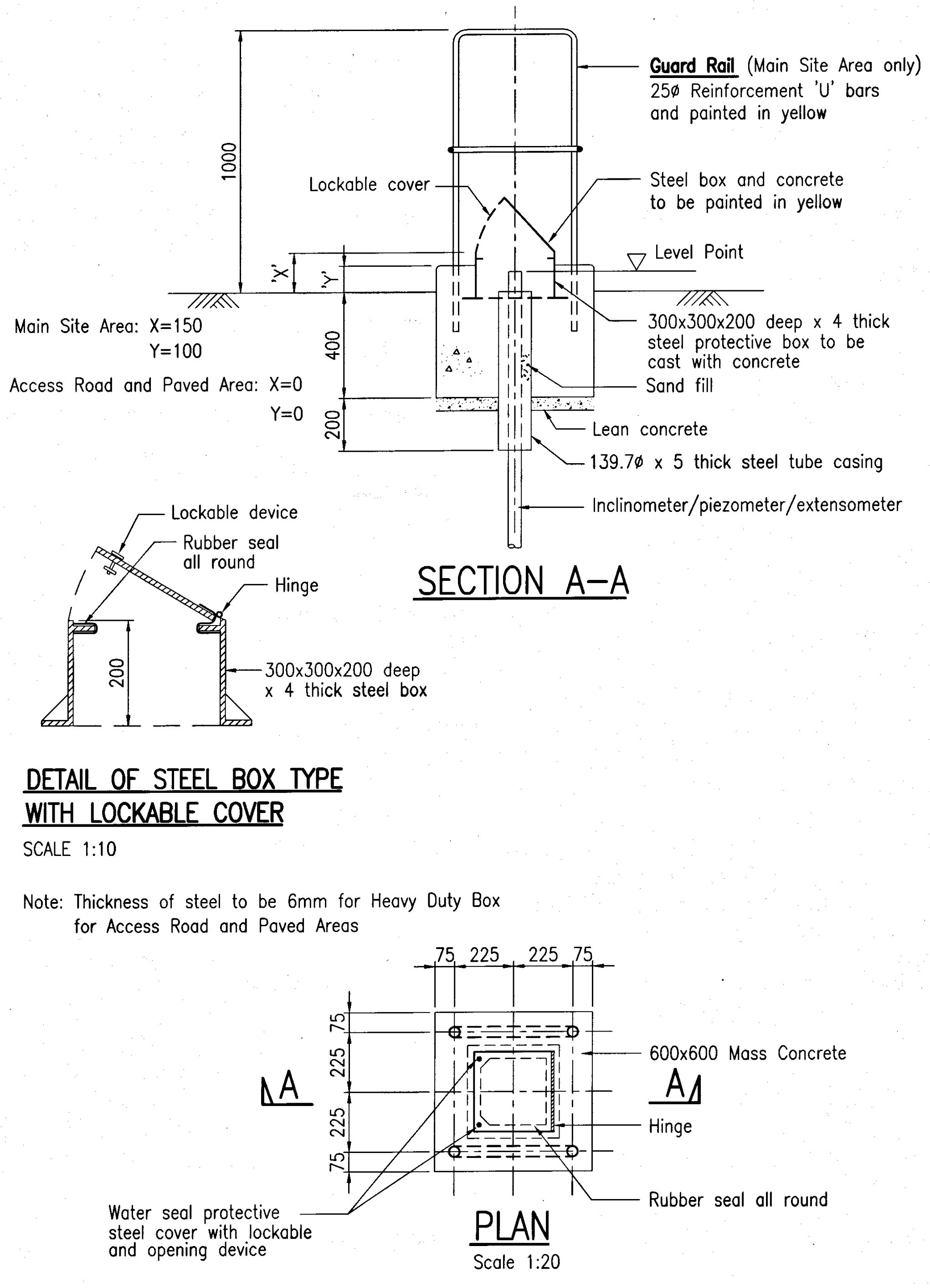
9.28.5.3 The SCL designer shall analyze the monitoring data from the deformation measurements, using an appropriate diagram to identify critical deformations likely to take place. Deformation measurements shall be supplemented by visual inspections of the surface of the tunnel walls. The development of cracks or shearing of surfaces observed shall be used for the assessment of the deformation.

9.28.5.4 The SCL designer shall process the monitoring data from extensometer measurements to provide a diagram indicating the extent of the ground displacement around the openings due to the stress redistribution processes.

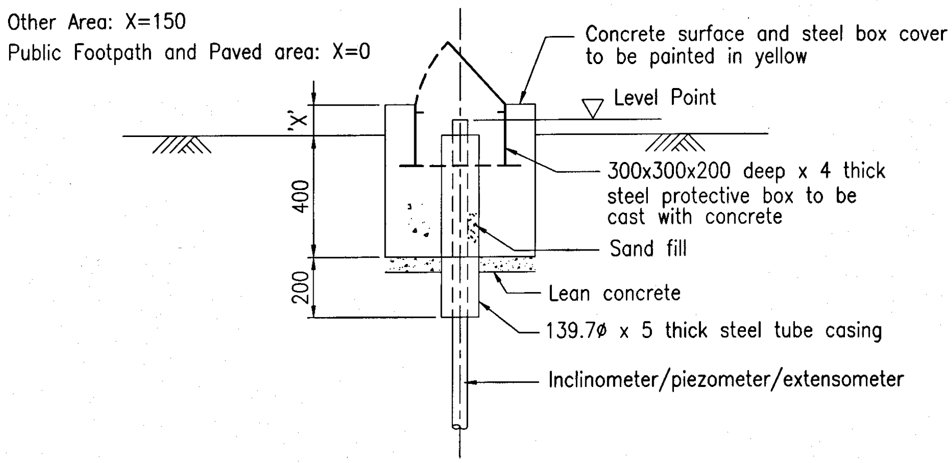
9.28.5.5 Circumferential stress shall be measured in the primary lining and the SCL designer shall process the monitoring data to provide a time-stress diagram. The development of circumferential stress over time, in particular, shall be monitored.

**APPENDIX 9.1**

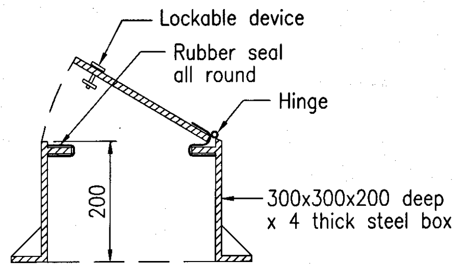
Protection Systems Type A, B, C and AA




PROTECTION SYSTEM TYPE 'A' FOR GEOTECHNICAL INSTRUMENT IN OPEN AREA WITH MOVING VEHICLES

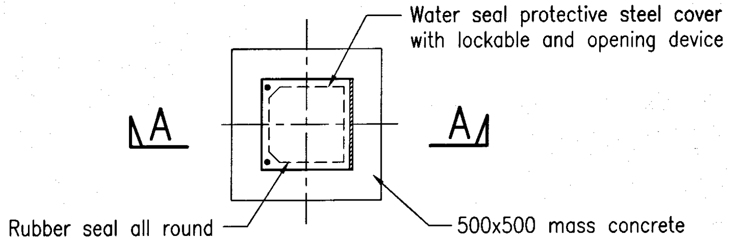



SECTION A-A




DETAIL OF STEEL BOX TYPE WITH LOCKABLE COVER

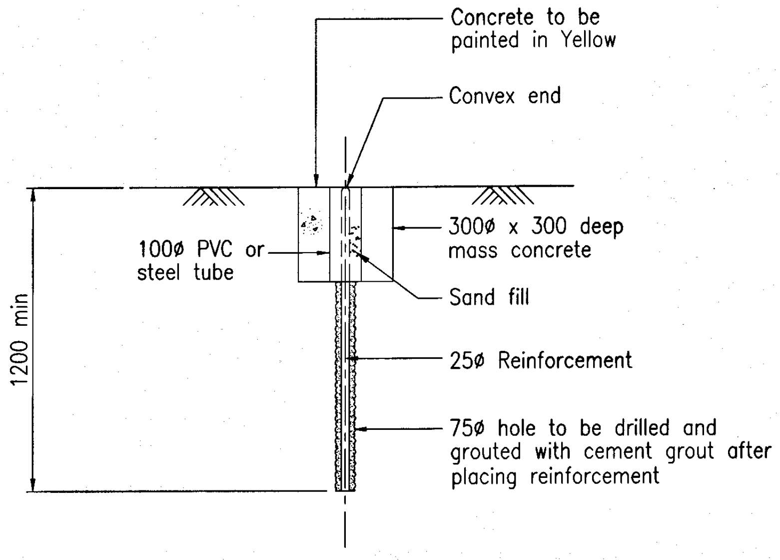
SCALE 1:10



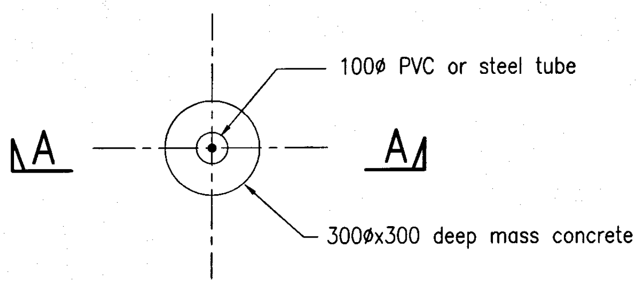

PLAN

Scale 1:20

PROTECTION SYSTEM TYPE 'B' FOR GEOTECHNICAL INSTRUMENT IN OPEN AREAS WITH NO RUN ON MOVING VEHICLES




SECTION A–A

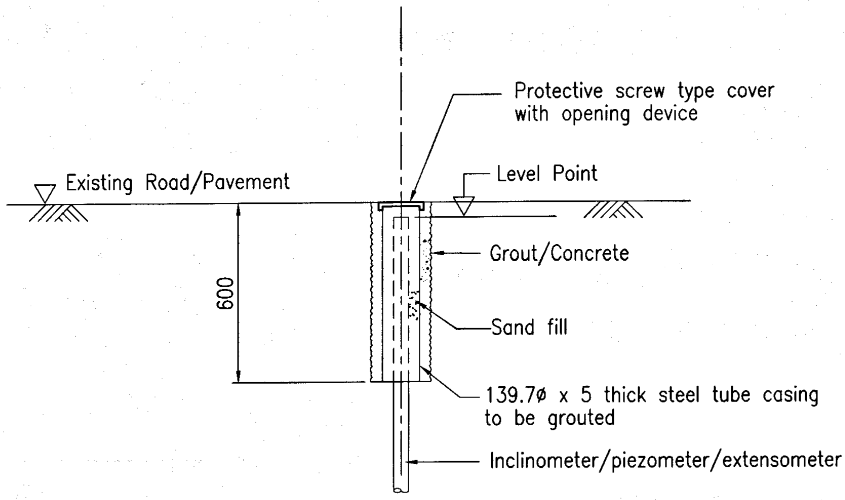



PLAN

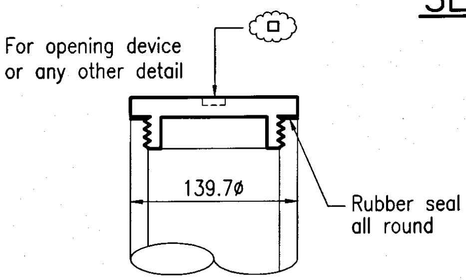
Scale 1:20

Note: For level points in public roads or pavements, steel tube and screw cover as per system type 'AA'

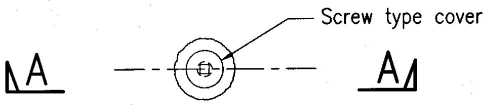
PROTECTION SYSTEM TYPE 'C' FOR GEOTECHNICAL SETTLEMENT POINTS




SECTION A–A




DETAIL OF SCREW TYPE COVER
SCALE 1:5




PLAN
Scale 1:20

PROTECTION SYSTEM TYPE 'AA' FOR GEOTECHNICAL INSTRUMENT FOR PUBLIC ROAD / PAVEMENT

# CHAPTER 10

# ROADWORKS

## 10.1 GENERAL

10.1.1 This Specification is applicable to all road works.

10.1.2 This chapter refers closely to SS EN, BS EN, BS and ASTM standards. The terms asphalt and bitumen can be used interchangeably.

10.1.3 Before work on any pavement above formation level commences all ducts, drains, and other works beneath the road must be completed and backfilled.

## 10.2 EARTHWORKS

Earthworks below formation level shall comply with the requirements of Chapter 4, Earthworks.

## 10.3 FLEXIBLE PAVEMENTS

### 10.3.1 Subgrade

10.3.1.1 Subgrade shall mean the layer defined as the 500mm of material immediately below formation level.

10.3.1.2 Materials

(a) Subgrade Soil

The soil used for the subgrade shall have a soaked CBR (California Bearing Ratio) value of not less than 6%. In addition, the following requirements shall be complied with:

(i) Subgrade in fill areas shall be formed of material defined as “Suitable Material” in Chapter 4, Earthworks.

(ii) In cut areas where the soaked CBR value of the subgrade is greater or equal to 6%, the Contractor shall compact the top 200mm of the subgrade to the density specified in Chapter 4, Earthworks.

(iii) In the event that the soaked CBR value of the subgrade is less than 6%, the Contractor shall remove and replace the soil with selected fill or stabilise the in-situ soil by approved means to a depth as required by the Engineer.

10.3.1.3 Preparation of Subgrade

On areas to be paved, the specified depths in cut areas and fill areas shall be compacted to meet the requirements for field density in Chapter 4, Earthworks. When completed the surface shall be true to the lines, grades and cross section shown on the Drawings. Any irregularities or depressions that develop under rolling shall be corrected by loosening the material at these places and adding, removing, or placing material until the surface is smooth and uniform. Any portion of the area, which is not accessible to a roller, shall be compacted to the required density by approved mechanical tampers.

All soft and yielding material and material which cannot be compacted readily when rolled or tamped shall be removed as directed by the Engineer and replaced with suitable material. After grading operations are completed, all loose stones larger than 50mm in their greatest dimension shall be removed from the surface of all proposed graded paving areas and disposed off.

10.3.1.4 Protection of the Top of Subgrade

At all times, the top of the subgrade shall be kept in such condition that it will drain readily and effectively. The Contractor shall take all necessary precautions to protect the subgrade from damage. He shall limit hauling over the finished subgrade to that which is essential for construction purposes. If ruts are formed, the subgrade shall be reshaped and rolled. Storage or stockpiling of materials on top of the subgrade shall not be permitted. Until the subgrade had been checked and approved, no sub-base, base course or pavement shall be laid thereon.

**10.3.2 Sub-Base and Base**

10.3.2.1 General

(a) Underlying Course

The underlying course shall be checked before placing and spreading of sub-base or base. Any ruts or soft area shall be corrected and rolled to the required density before the sub-base or base is placed.

To protect the underlying course and to ensure proper drainage, the spreading of the sub-base or base material shall begin along the centreline of the pavement on a crowned section or on the high side of pavements with a one-way slope.

(b) Grade Control

Grade control between the edges of the pavement shall be accomplished by means of grade stakes, steel pins or forms placed in lines parallel to the centreline of the pavement at intervals sufficiently close that string lines or check boards may be placed between the stakes, pins or forms.

10.3.2.2 Sub-base

(a) Material

Sub-base material shall be natural sand, crushed rock or crushed concrete or any other granular material accepted by the Engineer. The material shall be well graded and lie within the grading limits of Table 10.1. The particle size shall be determined in accordance with BS 1377.

**Table 10.1 Gradation of Sub-Base Material**

| BS Sieve Size | % by Weight Passing |
|---|---|
| 75 mm | 100 |
| 37.5 mm | 85 - 100 |
| 10 mm | 45 - 100 |
| 5 mm | 25 - 85 |
| 600 μm | 8 - 45 |
| 75 μm | 0 -10 |

The material passing the 425μm sieve, when tested in accordance with BS 1377, shall have a plasticity index of less than 6.

If more than 10% of the material is retained on the 20mm sieve, the whole material shall be assumed without test to have a CBR value of 30% or more. If 10% or less of the material is retained on the 20mm sieve, the fraction that passes that sieve shall satisfy the CBR requirements of 30% (soaked value) when tested in accordance with BS 1377, using the dynamic compaction method with a 4.5 kg rammer at the specified dry density and moisture content likely to be achieved in the field.

Milled waste, which is asphaltic concrete machine-milled from existing road, could be used as sub-base material subject to Engineer’s approval. Grading and CBR tests are not required for milled waste. However, 100% of the material shall pass the 63 mm sieve.

Recycled Aggregates (RA), which is a product from the processing of Construction and Demolition (C&D) wastes, could be used as sub-base material subject to Engineer’s approval. The processed RA used shall be obtained from approved C&D waste processing plant and the material shall contain at least 60% of recycled concrete aggregates, with not more than 40% of masonry/bricks and/or not more than 10% of other foreign materials such as wood, asphalt, glass, plastic and metals.

The processed RA shall lie within the grading limits of Table 10.1.

In addition, the fraction of material which passes the 20mm sieve shall satisfy the CBR requirements of 30% (soaked value) when tested in accordance with BS 1377, using the dynamic compaction method with a 4.5 kg rammer at the specified dry density and moisture content likely to be achieved in the field.

Samples of the RA shall be taken at the rate of one per 100 $m^3$ of graded RA laid and at least 3 samples shall be taken at each site in a day. These samples shall be marked with the date laid and location identification, and tested at an accredited laboratory.

(b) Laying

Sub-base material shall be placed and spread evenly by mechanical means approved by the Engineer.

(c) Compacting

The sub-base material shall be compacted in layers of not more than 200mm thick as soon as possible after laying. The depth of each compacted layer shall be compatible with the compaction plant used. Table 10.2 may be used as a reference guide for the compaction works. Each layer shall be tested and accepted by the Engineer prior to the placing of the next layer. The in-situ field density of the compacted layer expressed as a percentage of the maximum dry density shall not be less than 95%. The in-situ field density shall be determined in accordance with BS 1377 using the sand replacement method (large pouring cylinder) and the maximum dry density determined in accordance with BS 1377 using the 4.5 kg rammer method (soils with some coarse gravel-size particles). At least 3 in-situ field test shall be made for every 500$m^2$ or less of surface area of each compacted layer.

Subject to Engineer's acceptance, the in-situ field density may be determined with nuclear device in accordance with ASTM D2950 and it shall be carried out by an accredited laboratory. The maximum dry density shall be the average density of 3 laboratory compacted specimens. In the event that the measured in-situ field density is higher than the maximum dry density determined in the laboratory, the in-situ field density shall be taken as the maximum dry density. Should more than 3 nuclear in-situ field density exceed the maximum dry density, further laboratory testing shall be carried out to determine the maximum dry density.

The surface of any layer of material shall, on completion of compaction, be well closed, free from movement under compaction plant, surface irregularity, cracks or loose material. All loose/segregated or otherwise defective areas shall be made good to the full thickness of the layer and re-compacted.

**Table 10.2 Compaction Guideline for Base and Sub-Base of Road Pavement**

| **Type of Compaction Plant** | **Category** | **Number of Passes** | | |
|---|---|---|---|---|
| | | **Not greater than 100mm per layer** | **Not greater than 150mm per layer** | **Not greater than 225mm per layer** |
| Smooth-Wheeled roller | Force per 100mm width | | | |
| | 2.6 kN | 16 | Unsuitable | Unsuitable |
| | 5.2 kN | 8 | 16 | Unsuitable |
| Pneumatic-tyred roller | Wheel Load Tonnes | | | |
| | 4 - 6 | 12 | Unsuitable | Unsuitable |
| | 6 - 8 | 12 | Unsuitable | Unsuitable |
| | 8 - 12 | 10 | 16 | Unsuitable |
| | >12 | 8 | 12 | Unsuitable |
| Vibratory Roller | Static force per 100mm width of vibratory roller | | | |
| | KN | | | |
| | 0.70 – 1.25 | 16 | Unsuitable | Unsuitable |
| | 1.26 – 1.75 | 6 | 16 | Unsuitable |
| | 1.76 – 2.30 | 4 | 6 | 10 |
| | 2.31 – 2.80 | 3 | 5 | 9 |
| | 2.81 – 3.50 | 3 | 5 | 8 |
| | 3.51 – 4.20 | 2 | 4 | 7 |
| | 4.21 – 4.90 | 2 | 4 | 6 |
| Vibro-Tamper | Mass | | | |
| | Kg | | | |
| | 50 – 65 | 4 | 8 | Unsuitable |
| | 66 – 75 | 3 | 6 | 10 |
| | > 75 | 2 | 4 | 8 |

10.3.2.3 Plant-mixed Graded Granite Aggregate Base

(a) Aggregate

The base aggregate shall consist of graded crushed, clean and hard angular aggregate complying with the requirements of SS EN 12620 and conforming to the gradation shown in Table 10.3.

**Table 10.3 Gradation of Plant-mixed Graded Granite Aggregate**

| Aggregates | BS Sieve Size | % by Weight Passing |
|---|---|---|
| Coarse Aggregate | 50 mm | 100 |
| | 37.5 mm | 95 - 100 |
| | 20 mm | 60 - 80 |
| | 10 mm | 40 - 60 |
| | 5 mm | 25 - 45 |
| Fine Aggregate | 2.36 mm | 15 - 35 |
| | 425 μm | 6 - 18 |
| Filler | 75 μm | 0 - 10 |

When used in a pavement which is to carry a asphalt layer, that portion of the soil-binder material (if any) which passes a 425μm sieve shall have the following properties:

Liquid Limit - not more than 25%
Plasticity Index - not more than 6%
Linear Shrinkage - not more than 3%

The sand equivalent of the material passing the 4.8mm sieve shall not be less than 30%.

When used in a pavement which is not to carry a asphalt layer surfacing, the portion of the soil-binder material (if any) which passes a 425 μm sieve shall have the following properties:

Liquid Limit - not more than 35%
Plasticity Index - between 4 and 9%
Linear Shrinkage - between 2 and 4%

(b) Mixing

The aggregates shall be mixed at a mixing plant by continuous batch type mixing using a revolving blade, rotary pan, or rotary tilting drum mixer. The plant shall be in sound mechanical condition and shall consistently produce a uniform mixture of aggregates and water at optimum moisture content or at a moisture content as directed by the Engineer.

To achieve the desired grading, the approved sand, granite dust or filler such as laterite, shall be used.

Water used for mixing shall be clean and free from detrimental impurities.

(c) Transporting

Plant-mixed material shall be transported directly to the point where it is to be laid, and shall be covered with canvas or other approved material to prevent loss of moisture. Transport vehicles shall be equipped with discharge devices that will enable the plant-mixed material to be discharged or loaded into the hoppers of spreading machines without spillage and in such a way that segregation will be minimised.

(d) Quality Control

Samples of graded granite aggregates shall be taken at the rate of one per 100 $m^3$ of graded granite aggregate laid and at least 3 samples shall be taken at each site in a day. These samples shall be marked with the date laid and location identification, and tested at an accredited laboratory.

(e) Laying and Compacting

The material shall be deposited and spread in lanes in uniform layers of not more than 150mm thick such that the thickness of the final compacted layer shall not exceed 250mm. The base material shall be spread by an approved self-propelled mechanical spreader with an automatic tamping device.

After spreading, the base material shall be thoroughly compacted by rolling to obtain a level, even and uniformly compacted base.

Rolling shall continue until the base material is compacted to a dry density of not less than 98% of the maximum dry density as determined in accordance with BS 1377, using the vibrating hammer method. In-situ dry density tests shall be carried out in accordance with the sand replacement method (large pouring cylinder) specified in BS 1377.

Subject to Engineer's acceptance, if the nuclear device is used to determine the in-situ field density. It shall comply with the requirements specified in Clause 10.3.2.2c.

10.3.2.4 Coarse Granite Aggregate (Crusher-run) Base

(a) Aggregate

The coarse granite aggregate shall be either crushed stone or crushed gravel free from excess flat, elongated, or disintegrated pieces, dirt or other objectionable matter. The coarse aggregate shall have a percentage of wear of not more than 45 at 500 revolutions as determined by AASHTO T96 (Los Angeles Rattler Test), and shall meet the gradation requirements of Table 10.4.

**Table 10.4 Gradation of Coarse Aggregate**

| BS Sieve Size | % by Weight Passing |
|---|---|
| 90 mm | 100 |
| 63 mm | 80 - 100 |
| 37.5 mm | 20 - 65 |
| 20 mm | 0 - 15 |

The fine aggregate shall be screenings obtained from crushed stone, gravel or other similar accepted materials.

(b) Spreading

The coarse aggregate shall be deposited and spread in lanes in a uniform layer and without segregation. The maximum compacted thickness of any layer shall not exceed 250mm when vibrating roller is used for compaction, and not exceed 150mm when static roller is used. The aggregate shall be spread by machines, which can control the thickness of the layers.

(c) Compacting

After spreading, the base material shall be thoroughly compacted by rolling to obtain an even and uniformly compacted base.

(d) Applying Screenings

i) First Application of Screenings

After the layer of the coarse aggregate has been thoroughly keyed and set by rolling, screenings in an amount equal to approximately 50% of that required to fill the interstices shall be applied gradually over the surface.

ii) Second Application of Screenings

The second application of screenings, which consists of about 25% of the total required amount, shall then follow.

iii) Third Application of Screenings

The remaining 25% of the required screenings shall be applied after the completion of the second application of screenings.

The screening in each application shall be spread in thin layers with rolling and when necessary the screening shall be swept into the voids. The process of spreading, rolling and brooming of screenings shall stop until no more screening can be forced into the voids of the coarse aggregates.

(e) Sprinkling

Immediately after the voids of the coarse aggregate have been filled with screenings, the surface of the base course layer shall be sprinkled with water. This shall be followed by rolling. The sprinkling and rolling shall continue and additional screenings applied where necessary until all voids are completely filled and the coarse aggregate firmly set and bonded.

(f) Laying of Coarse Aggregate (Crusher-run) on Existing Flexible Pavement

Where existing flexible pavements are to be raised with coarse granite aggregate, the Contractor shall scarify the existing asphalt pavement surfaces with scarifying tyres fixed to rollers or with scarifying tyres of a motor graded for a depth of at least 50mm below the pavement surfaces.

All such scarified asphalt materials shall be removed before coarse aggregate is placed, rolled and applied with screenings as specified in this Specification.

10.3.2.5 Recycled Concrete Aggregate (RCA) Base

(a) RCA

RCA is crushed concrete obtained from construction and demolition (C&D) waste. RCA used shall be obtained from C&D waste processing plant accepted by the Engineer.

Processed RCA shall consist essentially of aggregate and cementitious materials such as cement paste and mortar. The processing shall include but not be limited to the following processes:

i) Crushing

ii) Removal of ferrous metals

iii) Screening and removal of foreign materials such as brick, ceramic, wood, plastic and asphaltic material

iv) Sieving of RCA into the required sizes

Besides complying with the requirements of SS EN 12620, the percentage of the impurity (by mass) and acid-soluble sulphate shall not exceed 5% and 1% respectively.

In addition, the gradation and the liquid limit, plasticity index and linear shrinkage of fine aggregates shall comply with the requirements as shown in Table 10.3 and Clause 10.3.2.3 accordingly.

If graded RCA is added with additives such as cement or other additives, the supplier shall provide the information on the type of additives used. Additives used shall be approved material which is environmentally safe. The supplier shall provide information of the bound graded RCA, method statement of construction and curing requirement to ensure the quality control and proper laying of the material.

(b) Mixing

Processed RCA shall be mixed at a mixing plant by continuous batch type mixing using a revolving blade, rotary pan, or rotary tilting drum mixer. The plant shall be in sound mechanical condition and shall consistently produce a uniform mixture of aggregates and water at optimum moisture content or at moisture content as directed by the Engineer.

Water used for mixing shall be clean and free from detrimental impurities.

(c) Transporting

Plant-mixed graded RCA shall be transported directly to the point where it is to be laid, and shall be covered with canvas or other approved material to prevent loss of moisture. Transport vehicles shall be equipped with discharge devices that will enable the plant-mixed graded RCA to be discharged or loaded into the hoppers of spreading machines without spillage and in such a way that segregation will be minimised.

(d) Quality Control

Sample of graded RCA shall be taken at the rate of one per 100 $m^3$ of graded RCA laid and at least 3 samples shall be taken at each site in a day. These samples shall be marked with the date laid and location identification, and tested at an accredited laboratory.

(e) Laying and Compacting

Plant-mixed RCA shall be deposited and spread in lanes in uniform layers of not more than 150 mm thick such that the thickness of the final compacted layer shall not exceed 250 mm. Spreading shall be carried out by an approved self-propelled mechanical spreader with an automatic tamping device.

After spreading, the graded RCA shall be thoroughly compacted to obtain a level, even and uniformly compacted base.

Rolling shall continue until the graded RCA is compacted to a dry density of not less than 98% of the maximum dry density as determined in accordance with BS 1377, using the vibrating hammer method. In-situ dry density tests shall be carried out in accordance with the sand replacement method (large pouring cylinder) specified in BS 1377.

Subject to Engineer’s acceptance, if a nuclear device is used to determine the in-situ field density, it shall comply with the requirements specified in Clause 10.3.2.2c.

10.3.2.6 Incineration Bottom Ash Sub-Base and Base

(a) Material

Incineration bottom ash (IBA) is a residual product of the combustion of municipal solid waste primarily composed of ceramics, slags, glassy material and some ferrous / non-ferrous metals. Processed IBA could be used as sub-base and base material subject to compliance with environmental requirements set by relevant agencies, and the approval of relevant agencies and the Engineer.

The gradation and CBR requirements for processed IBA shall be in accordance with Clause 10.3.2.2(a).

(b) Mixing

The processed IBA shall be mixed at a mixing plant by continuous batch type mixing using a revolving blade, rotary pan, or rotary tilting drum mixer. The processed IBA shall be blended with water and additives (if required) to produce a uniform mixture at optimum moisture content.

The optimum moisture content and maximum dry density of the final product shall be determined in the laboratory according to BS 1377, by an accredited laboratory.

Water used for mixing shall be clean and free from detrimental impurities.

(c) Storage

The processed IBA shall be stored at a storage area with proper drainage facilities (approved by NEA) to collect leachate from the stockpile. All leachate collected shall be disposed by a licensed waste collector. No storage of IBA on site shall be allowed.

(d) Transporting

Plant-mixed material shall be transported directly to the point where it is to be laid, and shall be properly sealed and covered with canvas or other approved material to prevent leakage and loss of moisture. Transport vehicles shall be equipped with discharge devices that will enable the plant-mixed material to be discharged or loaded into the hoppers of spreading machines without spillage and in such a way that segregation will be minimised.

(e) Quality Control

The requirements for quality control of plant-mixed materials at site shall be in accordance with Clause 10.3.2.3 (d).

(f) Laying and Compacting

The requirements for laying and compacting of plant-mixed materials at site shall be in accordance with Clause 10.3.2.3 (e).

10.3.2.7 Jurong Sedimentary Rock Aggregate Sub-Base and Base

Jurong Sedimentary Rock (JSR) is the excavated sedimentary rock from Jurong Island under the Jurong Rock Caverns (JRC) project by JTC Corporation. The JSR aggregate shall consist of crushed, clean and hard angular aggregate complying with the requirements of Clauses 10.3.2.1, 10.3.2.2, 10.3.2.3 and 10.3.2.4.

### 10.3.3 Asphaltic Concrete

10.3.3.1 Materials

(a) Aggregates

Aggregates shall consist of crushed granite stone, crushed gravel or crushed slag with or without sand or other inert finely divided mineral aggregate.

Based on sieve analysis, aggregates shall be classified as shown in Table 10.5.

**Table 10.5 Aggregate Classification**

| **Aggregates** | **BS Sieve Size Requirement** |
|---|---|
| Coarse Aggregate | Retained on BS 3.2mm sieve |
| Fine Aggregate | Passed BS 3.2mm sieve and retained on BS 75 μm sieve |
| Filler | Passed BS 75 μm sieve |

i) Coarse Aggregate

Coarse aggregate shall consist of sound, tough, durable particles, free from adherent coatings of clay, organic matter and other deleterious substances.

When tested in accordance with ASTM C131, it shall not show more than 40% wear. The sodium sulphate soundness loss shall not exceed 9% or shall the magnesium sulphate soundness loss exceed 12%, after five cycles, when tested in accordance with ASTM C88. Crushed coarse aggregate shall contain at least 75% by weight of pieces having at least two fractured faces. The area of each fractured face shall be equal to at least 75% of the smallest mid-sectional area of the piece. When two fractures are contiguous, the angle between the planes of fractures shall be at least 30° to be considered as two fractured faces.

Coarse aggregate shall contain not more than 8% by weight of flat or elongated pieces when tested in accordance with ASTM D4791. A flat particle is one having a width to thickness ratio of greater than 5 and an elongated particle is one having a length to width ratio of greater than 5.

The physical properties of the coarse aggregates for different type of road mixes shall conform to Table 10.6.

Steel slag used as coarse aggregate shall be air-cooled blast-furnace slag and shall have a compacted weight of not less than 1.12 tonnes/m$^3$ when tested in accordance with ASTM C29.

**Table 10.6 Properties of Coarse Aggregate**

| Property | Method of Testing | Required Standard for the different Type of Mix | | |
|---|---|---|---|---|
| | | Porous Asphalt / OGW* | WSS*/SMA* | W1/W3/W3B/ W3B(20R)*/B 1/B1(30R)* |
| Impact Value | B.S. 812 Part 112 | Not more than 25% | Not more than 25% | Not more than 30% |
| Crushing Value | B.S. 812 Part 110 | Not more than 25% | Not more than 25% | Not more than 30% |
| Water Absorption (in terms of surface dry mass) | B.S. 812 Part 2 | Not more than 1% | Not more than 1% | Not more than 1% |
| Flakiness Index | B.S. 812 Part 105.1 | Not more than 25% | Not more than 25% | Not more than 35% |
| Elongation Index | B.S. 812 Part 105.2 | Not more than 30% | Not more than 35% | Not more than 35% |
| L.A. Abrasion Value (500 revolutions) | SS 73 | Not more than 20% | Not more than 25% | Not more than 35% |
| Silt Content of Aggregate in Hot Bin (by weight) | SS 73 | Not more than 0.3% | Not more than 0.3% | Not more than 0.3% |

*OGW – Open Graded Wearing Course, WSS – Washed Steel Slag Wearing Course, SMA – Stone Mastic Asphalt, W3B(20R) & B1(30R) – Asphalt concrete using Reclaimed Asphalt Pavement.

*The use of granite filler to replace steel slag filler is subject to approval.

ii) Fine Aggregate

Fine aggregate shall consist of clean, sound durable, angular particles produced by crushing granite stone, slag or gravel and shall be free from coatings of clay, silt, clay balls or other deleterious matter.

Fine aggregate shall meet the soundness and wear requirements as specified for coarse aggregate.

The fine aggregate with any blended filler shall have a plasticity index not greater than 6%, and a liquid limit of not more than 25% when tested in accordance with ASTM D4318 and in addition shall have a silt content of not greater than 0.3% of the total weight when tested in accordance with SS EN 12620:2008.

Natural sand, when added to produce the desired gradation or to increase the workability or compatibility of the mixture shall be limited to 15% by weight.

iii) Filler

Filler shall meet the requirements of ASTM D242.

(b) Bitumen Emulsion

The bitumen emulsion shall be homogeneous after thorough mixing, for at least 30 days after delivery.

The bitumen emulsion shall be rapid setting cationic bitumen emulsion. The properties and the method of testings of the bitumen emulsion shall comply with the requirements specified in ASTM D2397: Standard Specification for Cationic Emulsified Asphalt.

(c) Bitumen

All bitumen shall be petroleum bitumen of 60/70 penetration grade. No mineral matter other than that naturally contained in such bitumen shall be present. The bitumen shall be homogeneous, free from water and shall not foam when heated to 175ºC. The bitumen shall comply to the requirements of Table 10.7.

**Table 10.7 Requirements for Bitumen**

| **Property** | **Unit** | **60/70 Penetration Grade** | | **Method of Testing** |
|---|---|---|---|---|
| | | **Min** | **Max** | |
| Penetrating at 25°C 100g, 5s | 0.1 mm | 60 | 70 | ASTM D5 |
| Flash Point, Cleveland Open Cup | °C | 232 | - | ASTM D92 |
| Ductility at 25°C, 5 cm per min | cm | 100 | - | ASTM D113 |
| Solubility in trichloroethylene | % wt | 99 | - | ASTM D2042 |
| Softening Point, Ring and Ball | °C | 47 | 56 | ASTM D36 |
| Specific Gravity at 25°C | - | 1.0 | 1.11 | ASTM D70 |
| *Thin-film oven test, 3.2 mm, 163°C, 5 hrs :* | | | | |
| a) Loss on heating | % wt | - | 0.8 | ASTM D6 |

| Property | Unit | 60/70 Penetration Grade | | Method of Testing |
|---|---|---|---|---|
| | | Min | Max | |
| b) Penetration of residue at 25°C | % of original | 54 | - | ASTM D6 |
| c) Ductility of residue at 25°C, 5 cm per min | cm | 50 | - | ASTM D113 |

(d) Admixture

The use of any admixture added to the asphaltic concrete mix shall be subject to the Engineer's approval. The Contractor shall furnish all relevant technical information, specifications, test reports and job reference of the admixture.

The Contractor shall obtain representative sample and test the samples of the admixture at an accredited laboratory and submit the test results to the Engineer.

Any admixture, which fails to comply with the requirements, shall be rejected.

(e) Water

Water used in diluting the bitumen emulsion or wetting the wheels of rollers shall be clean and free from detrimental impurities.

The water shall be obtained from a public supply where possible and may be obtained from any other source if approved by Engineer.

10.3.3.2 Mix Design

10.3.3.2.1 Dense Mix

(a) Aggregate Grading

All aggregate grading for the different types of mixes shall be in accordance with Table 10.8.

**Table 10.8 Mix Specification**

| Road Mixes | | | | | |
|---|---|---|---|---|---|
| **Mix classification** | WSS* | W1 | W3 | W3B/ W3B(20R) | B1/ B1(30R) |
| Type of Mix | Wearing Course | | | | Binder Course |
| Thickness of Course (mm) | 50 - 75 | 15 -25 | 30 - 50 | 45 - 65 | 50 - 100 |
| Max. Size of Stone | 19 mm | 10 mm | 19 mm | 19 mm | 35 mm |
| <u>% Passing of BS Sieve size:</u> | | | | | |
| 50 mm | - | - | - | - | - |
| 37.5 mm | - | - | - | - | 100 |
| 25 mm | - | - | - | - | 95 - 100 |
| 19 mm | 100 | - | 100 | 100 | 84 - 92 |
| 13.2 mm | 80 - 90 | - | 90 - 100 | 85 - 95 | 65 - 82 |
| 9.5 mm | 63 - 77 | 100 | - | - | - |
| 6.3 mm | - | 90 - 100 | 70 - 83 | 58 - 68 | 48 - 62 |
| 3.35 mm | - | 65 - 82 | 50 - 65 | 40 - 50 | 35 - 50 |
| 2.36 mm | 46 - 56 | - | - | - | - |
| 1.18 mm | - | 39 - 55 | 29 - 44 | 21 - 31 | 27 - 41 |
| 600 μm | 16 - 26 | - | - | - | - |
| 300 μm | - | 22 - 32 | 15 - 24 | 11 - 17 | 15 - 22 |
| 212 μm | 8 - 18 | - | - | - | - |
| 75 μm | 6.5 – 10.5 | 3 - 8 | 3 - 8 | 4 - 8 | 3 - 8 |
| % Soluble Bitumen (60/70 Pen Grade) (% by Wt of Total Mix) | 4.5 - 5.5 | 5.5 – 6.5 | | 4.5 – 5.5 | |
| % Void in Mix | 3.0 – 5.0 | | | 4.5 – 6.5 | 3.0 – 5.0 |

WSS* - Washed Steel slag pavement

(b) Marshall Design Criteria

All samples tested for Marshall Design Criteria shall conform to the requirements of Table 10.9.

**Table 10.9 Marshall Design Criteria**

| Criteria | Requirement | Method of testing |
|---|---|---|
| Marshall Stability (kN) (Minimum) (No. of blows = 75) | 9.0 | ASTM D1559 |
| Flow value (0.254mm units) | 8 - 16 | |
| Voids in the mix | Refer to Table 10.8 | |
| % of aggregate voids filled with bitumen binder | 75 - 82 | |
| Marshall Field Density | Above 98% of Marshall Density | - |

(c) Criteria for Acceptance

Where these samples fail to satisfy the criteria in Table 10.8 and Table 10.9, asphaltic concrete laid and represented by the unsatisfactory samples shall be rejected.

10.3.3.2.2 Porous Asphalt

(a) Aggregate and Binder

The coarse aggregate shall comply with the specifications as follow:

i) Coarse aggregates shall consist of clean, well-graded, angular, crushed granite stone of approved quality, free from dust, dirt and other deleterious materials; and free from excess of flat elongated or weathered pieces.

ii) Notwithstanding what is specified under Clause 10.3.3.1a (i), the properties of the coarse aggregate shall conform to Table 10.6.

The polymer modified bitumen shall have a performance grade not lower than PG-76 of the Performance Grade Asphalt Binder Specifications shown in Table 10.10.

The Contractor shall furnish sufficient technical data and test reports as evidence that the polymer modified bitumen is suitable for the production of porous asphaltic concrete before any work commences.

The Contractor shall provide samples of the aggregates and polymer modified bitumen and carry out tests at accredited laboratory to confirm that it meets the required performance.

## Table 10.10 Performance Graded Asphalt Binder Specification

| Performance Grade | PG 76 | | | | | PG 82 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | -10 | -16 | -22 | -28 | -34 | -10 | -16 | -22 | -28 | -34 |
| Average 7-day Maximum Pavement Design Temperature, °C [a] | <76 | | | | | <82 | | | | |
| Minimum Pavement Design Temperature, °C [a] | >-10 | >-16 | >-22 | >-28 | >-34 | >-10 | >-16 | >-22 | >-28 | >-34 |
| Original Binder | | | | | | | | | | |
| Flash Point Temp, T48: Minimum °C | 230 | | | | | | | | | |
| Viscosity, ASTM D4402: [b] Maximum 3 Pa.s (3000cP) Test Temp, °C | 135 | | | | | | | | | |
| Dynamic Shear, TP5: [c] G*/sin δ, Min. 1.00 kPa Test Temp @ 10 rad/s, °C | 76 | | | | | 82 | | | | |
| Rolling Thin Film Oven (T 240) or Thin Film Oven (T 179) Residue | | | | | | | | | | |
| Mass Loss, Maximum, % | 1.00 | | | | | | | | | |
| Dynamic Shear, TP5: G*/sin δ, Min. 2.20 kPa Test Temp @ 10 rad/s, °C | 76 | | | | | 82 | | | | |
| Pressure Aging Vessel Residue (PPI) | | | | | | | | | | |
| PAV Aging Temp, °C [d] | 100(110) | | | | | 100(110) | | | | |
| Dynamic Shear, TP5: G*/sin δ, Max. 5000 kPa Test Temp @ 10 rad/s, °C | 37 | 34 | 31 | 28 | 25 | 40 | 37 | 34 | 31 | 28 |
| Physical Hardening [e] | Report | | | | | | | | | |
| Creep Stiffness, TP1: [f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp @ 60 s, °C | 0 | -6 | -12 | -18 | -24 | 0 | -6 | -12 | -18 | -24 |
| Direct Tension, TP3: [f] Failure Strain, Minimum, 1.0% Test Temp 1.0 mm/min. °C | 0 | -6 | -12 | -18 | -24 | 0 | -6 | -12 | -18 | -24 |

Notes :

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in the Superpave™ software program or may be provided by the specifying agency, or by following the procedures as outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurement of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometer (AASHTO T 201 or T 202).

d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90ºC, 100ºC or 110ºC. The Pressure Aging Vessal (PAV) aging temperature is 100ºC for PG 76 and above, except in desert climates, where it is 110ºC.

e. Physical Hardening – TP1 is performed on a set of asphalt beams according to Section 13.1 of TP1, except the conditioning time is extended to 24hrs ±10 minutes at 10ºC above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

(b) Job Mix Design

(i) The Contractor shall propose a job mix design to the Engineer for approval. The specification shown in Table 10.11 for Porous Asphalt may be used as a guide for the job mix design.

(ii) The target binder content shall be determined by the Contractor using an approved binder drainage test and the test report shall be submitted to the Engineer with the proposed mix design. The range of the proposed binder content shall not exceed 1%.

(iii) The abrasion loss value for Marshall (50 blow) samples shall not be more than 15%. This value is the weight loss in percentage of the weight of a sample, after 300 revolutions in a Los Angeles drum, without balls and at controlled temperature. Three samples shall be tested in the laboratory trial and witnessed by the Engineer.

(iv) Laboratory and field trials shall be carried out to demonstrate to the Engineer that the proposed mix design comply with the requirements and criteria for acceptance before the Porous Asphalt can be used in the site. The compaction requirements and the number of passes shall be established in the field trial and are to be strictly followed in the construction process.

**Table 10.11 Specification for Special Road Mixes**

| **Mix Classification** | **Porous Asphalt** | **Open Graded Wearing Course (OGW)** | **Stone Mastic Asphalt (SMA)** |
|---|---|---|---|
| Thickness of Course | 25 – 45 mm | 40 – 50 mm | 40 – 60 mm |
| Max Size of Stone Aggregate Used | 13 mm | 13 mm | 13 mm |
| Total Percentage Passing Including Filler : | | | |
| Sieve Size Passing | | | |
| 50 mm | - | - | - |
| 37.5 mm | - | - | - |
| 25 mm | - | - | - |
| 19 mm | 100 | 100 | 100 |
| 13.2 mm | 79 - 89 | 90 - 100 | 90 - 100 |
| 9.5 mm | 67 - 77 | 30 - 70 | 65 - 90 |

| **Mix Classification** | **Porous Asphalt** | | **Open Graded Wearing Course (OGW)** | | **Stone Mastic Asphalt (SMA)** | |
|---|---|---|---|---|---|---|
| 6.3 mm | - | | 25 - 35 | | 40 - 60 | |
| 4.75 mm | 17 - 26 | | - | | - | |
| 3.35 mm | - | | 20 - 30 | | 25 - 37 | |
| 2.36 mm | 13 - 23 | | 18 - 26 | | 22 - 34 | |
| 1.18 mm | - | | - | | 16 - 28 | |
| 600 $\mu$m | 8 - 18 | | 12 - 20 | | 12 - 24 | |
| 300 $\mu$m | 6 - 12 | | 10 - 15 | | 7 - 19 | |
| 150 $\mu$m | 4 - 10 | | - | | - | |
| 75 $\mu$m | 4 - 8 | | 7 - 11 | | 5 - 10 | |
| Voids in the Mix (%) | 20 - 26 | | 7 - 9 | | 3 - 4 | |
| % Binder (% by Weight of Total Mix) | Min 4.5 | Max 5.5 | Min 4.5 | Max 5.5 | Min 6.0 | Max 7.0 |

(c) Field Permeability Measurement

Field permeability measurement shall be carried out using a permeameter to record the flow history of water through the porous asphalt. Hydraulic gradients are derived from the water flow velocities to calculate its coefficient of permeability (‘k’ value).

For each carriageway up to 1 lane-km length, at least three test sites are required to determine the field permeability measurement. Subsequently, one addition test site for each 300m carriageway or part thereof. In each test site, at least three permeability measurements shall be conducted.

The ‘k’ value and coefficient of variance (COV) requirements are specified below:

(i) ’k’ value requirement for a test site

The mean ‘k’ value of the three readings for a test site shall be more than 18 mm/s. However, the mean ‘k’ value for three conservative test sites shall be more than 22 mm/s.

(ii) COV requirement for a test site

At each test site, the COV for the three readings shall be less than 5%. The test shall be repeated on the same spot until a COV of less than 5% is achieved.

The coefficient of variance, COV formula is as follows:-

$$COV = \frac{\sigma}{\mu} \times 100$$

where $\sigma$ = standard deviation
$\mu$ = mean 'k' value

<u>Example to derive COV of a test site</u> :

3 no. of 'k' values obtained for a site are :
(k1 = 18.9 mm/s, k2 = 20.4 mm/s and k3 = 20.7 mm/s)

Mean 'k' value, $\mu$ = (18.9+20.4+20.7) / 3 = 20 mm/s *(pass k > 18* mm/s requirement)

Standard deviation, $\sigma = \sqrt{[(k1-\mu)^2+(k2-\mu)^2+(k3-\mu)^2]}/\sqrt{(n-1)}$
*where n = no. of tests*

$\sigma = \sqrt{[(18.9-20)^2 +(20.4-20)^2+(20.7-20)^2]} / \sqrt{(3-1)} = 0.96$

COV = $\sigma$ / $\mu$ x 100% = 0.96 / 20 x 100% = 4.8%
*(pass COV < 5% requirement)*

Therefore, 'k' value of the test site is 20 mm/s with a COV of 4.8%.

(iii) 'k' value and COV requirement for a project

The project's 'k' value and COV requirement in accordance to length of road is given in Table 10.12.

**Table 10.12 'k' value and COV Requirement for a Project**

| **Length of Road, L (lane-km)** | **'k' value** | **Coefficient of Variance, COV** |
|---|---|---|
| L ≤ 2 | k >22 mm/s | COV < 20% |
| 2 < L ≤ 4 | k >22 mm/s | COV < 35% |
| L > 4 | k >22 mm/s | COV < 40% |

<u>Example to derive 'k' value and COV for a project</u> :

'k' values obtained for 1 km road are:
(k1, k2, k3,……kn) ; *where n = no. of 'k' value*

Mean 'k' value, $\mu$ = (k1+k2+k3+,…….+kn) / 3
Standard deviation, $\sigma = \sqrt{[(k1-\mu)^2+(k2-\mu)^2+(k3-\mu)^2+\ldots.+(kn-\mu)^2]} / \sqrt{(n-1)}$

(d) Temperature before compaction

The temperature of the mix before start of compaction shall not be lower than 110°C.

(e) Criteria for Acceptance

Where these samples fail to satisfy the acceptance criteria in Table 10.13, porous asphalt laid and represented by the failed samples shall be rejected.

**Table 10.13 Criteria for Acceptance of Special Road Mixes**

| Criteria | Requirement |
|---|---|
| (a) Gradation Analysis :<br>Course Aggregate<br>Fine Aggregate<br>Filler | Refer to Table 10.11 for the requirement on the aggregate grading, bitumen/binder and voids in the mix for various mixes |
| (b) Bitumen Content | |
| (c) Voids in the mix | |
| Field Density | Above 98% of Marshall Density |
| Coefficient of permeability & Coefficient of Variance requirements for porous asphalt | k > 18mm/s & COV < 5% |

10.3.3.2.3 Open Graded Wearing Course

(a) Aggregate and Binder

The aggregate and binder of Open Graded Wearing Course (OGW) shall comply with Clause 10.3.3.2.2 (a).

(b) Job Mix Design

The Contractor shall propose a job mix design with target binder content to the Engineer for approval. The specification in Table 10.11 for OGW may be used as a guide for the job mix design.

The acceptable range in the binder content shall be ±0.5% from the target binder content by mass of total mixture.

The coarse aggregate fraction shall not be less than 75% by weight of the total aggregate content. The voids in mineral aggregate shall not be less than 17%.

The abrasion loss value for Marshall (50 blow) samples shall not be more than 5%. This value is the weight loss in percentage of the weight of a sample, after 300 revolutions in a Los Angeles drum, without balls and at controlled temperature. Three samples shall be tested in the laboratory trial and witnessed by the Engineer.

Laboratory and field trials shall be carried out to demonstrate to the Engineer that the proposed mix design complies with the requirements and criteria for acceptance before the OGW can be used at the site.
2% by mass of total aggregate of hydrated lime may be added as part of the filler content in the mix.

(c) Production, Construction and Completion

The Contractor shall comply with the following requirements for temperature control:

(i) Mixing temperature not higher than 175 °C.

(ii) Laying temperature at time of spreading not lower than 140°C.

(iii) Temperature before start of compaction not lower than 120 °C.

The Contractor may propose changes to the temperature requirements together with his proposed mix design, for the Engineer's approval.

The Contractor shall demonstrate and establish the number of passes required for compaction in the field trial. However during construction, the Contractor shall still ensure that the acceptance criteria is achieved and shall increase the number of passes as necessary.

Compaction shall be done immediately after spreading. Minimum 8 tonne steel wheel rollers shall be operated as close to the paver as possible. Pneumatic tyred rollers shall not be used. The section of the road shall only be opened to traffic when the temperature of the compacted layer is 60 °C or lower.

(d) Criteria for Acceptance

The texture depth shall be measured by the sand patch method (BS EN 13036-1:2010) and skid resistance by the pendulum test (BS EN 13036-4:2011) shall be measured within one week after completion of the new surface. One test for the texture depth and the skid resistance test shall be conducted for every 1000m$^2$ of the newly laid surface or part thereof.

Where these samples fail to satisfy the acceptance criteria in Table 10.13 and 10.14, OGW laid and represented by the unsatisfactory samples shall be rejected.

**Table 10.14 Criteria for Acceptance of Open Graded Wearing Course**

| Criteria | Requirement |
|---|---|
| Texture Depth | ≥ 1.2 mm |
| Skid Resistance | ≥ 55 BPN |

10.3.3.2.4 Stone Mastic Asphalt (SMA)

(a) Aggregate and Binder

The aggregate and binder of SMA shall comply with Clause 10.3.3.2.2(a).

(b) Job Mix Design

The Contractor shall propose a job mix design to the Engineer for approval. The specification shown in Table 10.12 for Stone Mastic Asphalt may be used as a guide for the job mix design.

The binder draindown shall be determined by Schellenberg drain-off test and shall not be more than 0.3% (after 1 hour at 170$^{o}$C).

The abrasion loss value for Marshall (50 blow) samples shall not be more than 5%. This value is the weight loss in percentage of the weight of a sample, after 300 revolutions in a Los Angeles drum, without balls and at controlled temperature. Three samples shall be tested in the laboratory trial for all the requirements including the Marshall Design Criteria of Table 10.15 and witnessed by the Engineer.

Laboratory and field trials shall be carried out to demonstrate to the Engineer that the proposed mix design comply with the requirements and criteria for acceptance before the SMA can be used in the site.

**Table 10.15 Marshall Design Criteria**

| Criteria | Requirement |
|---|---|
| Marshall Stability (kN)<br>(Minimum) (No. of blows = 50) | 9.0 |
| Flow value (0.254mm units) | 8 - 16 |

(c) Production, Construction and Completion

Unless otherwise stated below, the production, construction and completion for SMA shall follow Clause 10.3.3.2.3 (c) and Clause 10.3.3.5.

(d) Criteria For Acceptance

Where these samples fail to satisfy the acceptance criteria in Table 10.13, SMA laid and represented by the unsatisfactory samples shall be rejected.

10.3.3.2.5 Washed Steel Slag Premix (WSS)

(a) Constituent Materials

The binder shall be accepted type petroleum bitumen of 60/70 penetration grade and conform to the Table 10.7.

Aggregates shall be crushed steel slag, the nonmetallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminium, manganese, calcium and magnesium, that is developed simultaneously with steel in basic oxygen, electric, or open hearth furnaces.

The aggregates shall be processed to meet the specified requirements by crushing, screening and magnetic separation for removal of metallics.

The coarse aggregate shall comply with the specifications in Clause 10.3.3.1 and Table 10.6.

(b) Job Mix Design

The Contractor shall produce the WSS as specified in Table 10.8.

(c) Criteria for Acceptance

In addition to Clause 10.3.3.5(f)(i), all core samples for the determination of field density and thickness shall also be tested for impurity. The quantity of steel slag premix represented by the core sample with impurities (such as granite aggregates and any other materials that are not steel slag) exceeding 5% shall be rejected.

To determine the percentage of impurity, each core sample shall be cleaned, heated, broken down and the binder removed by an approved ignition method. Determine the sample weight ($W_B$) after ignition. Cool and separate the sample by sieve analysis to two portions, one that retain on the 2.36mm test sieve and the other that pass through. Remove all impurities such as granite aggregates and any other materials that are not steel slag from these two portions. Determine the total weight of all these impurities ($W_A$).

In addition, the skid resistance measured by the pendulum test (BS EN 13036-4:2011) within one week after completion of the new surface shall not be less than 55 for the BPN, failing which, asphaltic concrete laid and represented by the unsatisfactory samples shall be rejected.

<u>Example (I)</u>
Weight of steel slag core sample, ($W_B$) = 1.350 kg

Weight of granite aggregates
&/or other materials, ($W_A$) = 0.080 kg

Percentage of granite aggregates
&/ or other materials = (0.080 / 1.350 x 100)%
= 5.9% > 5%

The core sample has failed the impurity test.

<u>Example (II)</u>
Weight of steel slag core sample, ($W_B$) = 1.513 kg

Weight of granite aggregates
and/or other materials, ($W_A$) = 0.068 kg

Percentage of granite aggregates
& / or other materials = (0.068 / 1.513 x 100 )%
= 4.5% < 5%

The core sample has passed the impurity test.

10.3.3.2.6 W3B and B1 Asphaltic Concrete with JSR Aggregate

(a) Materials

The properties of JSR aggregate shall comply with the requirements in Clause 10.3.3.1.

(b) Mix Design

The mix design of W3B and B1 mixes with JSR aggregate shall meet the requirements of the Clause 10.3.3.2.1 and shall perform additional laboratory tests to meet the following additional criteria for acceptance.

(c) Additional Criteria for Acceptance

The tensile strength ratio for W3B and B1 mixes shall be determined according to BS EN 12697-12 and the results shall not be less than 80%. In addition, the indirect tensile strength tested according BS EN 12697-23 shall be at least 900kPa and 1000kPa respectively for W3B and B1 mixes.

The use of admixture/anti-stripping agent to enhance the dry and wet indirect tensile strength of the samples with JSR aggregate is subject to the acceptance of the Engineer. The contractor shall submit test report to show the improvement of the indirect tensile strength with the use of the proposed admixture/anti-stripping agent. The contractor shall furnish all relevant technical information, specification, test reports and job reference of the admixture/anti-stripping agent to the Engineer.

(d) Production, Construction and Completion

The requirements of production, construction and completion shall be in accordance with Clause 10.3.3.4 and 10.3.3.5.

10.3.3.3 Field Trial Mix by Contractor

10.3.3.3.1 The mix shall comply with the relevant mix design specified in Clause 10.3.3.2.

10.3.3.3.2 Work shall not begin until the Contractor has submitted the job mix formula and field trial mix carried out to the satisfaction of the Engineer. The job mix formula for each mixture shall not be modified unless accepted by the Engineer.

10.3.3.3.3 The job mix formula for each mixture shall indicate a single percentage of an aggregate passing each required sieve size, a single percentage of asphalt material to be added to the aggregate, and a single temperature at which the mixture is to be delivered at the point of discharge.

10.3.3.3.4 The aggregate gradation represents the limits, which shall determine suitability of aggregate for use from the source of supply. The final gradation decided or within the accepted limits designated in the tables shall be well graded from coarse to fine and shall not vary from the low limit on one sieve to the high limit on the adjacent sieves, or vice versa.

10.3.3.4 Manufacture

(a) Asphaltic Concrete Mixing Plants

The Contractor shall furnish the Engineer in advance with full details of all asphalt mixing plants to be used in accordance with the format shown in Table 10.16. Proof of approval by the relevant authority shall be submitted with the details of the Asphalt Mixing Plant

The mixing plant shall have an average output capacity of not less than 100 tonnes/hr.

Before the mixing plant can be used, the measuring, recording mechanism and temperature control gauges shall be tested by Singapore Accreditation Council accredited laboratory or other internationally recognised bodies in accordance to the manufacturer's specification. The Contractor shall submit the calibration certificates to the Engineer.

The Engineer shall have access at all times to the plant, storage yard and other facilities for processing the material. He shall be at liberty to take samples of materials, as he deems necessary.

**Table 10.16 Format for Submitting Details of Asphalt Mixing Plant**

| Asphalt Mixing Plant | |
|---|---|
| 1. Type, model and manufacturer of plant for production of premix | *Batch/continuous Feed Manufacture ________________<br>Model __________<br>Capacity Rating ________________ |
| 2. Age of Plant | ______________ years |
| 3. Average output capacity in tonnes per hour | __________Tonnes/hr |
| 4. Location of plant ** | ________________ |
| 5. If temporary site, state the period for which the plant is allowed to operate | _______Years/months |
| 6. Proof of approval for setting up plant ** | ☐ Submitted |
| 7. Submission of operations organization chart *** | ☐ Submitted |

* Delete where not applicable

** Proof of approval for setting up plant shall be attached in a separate sheet to the form.

*** To attach organization chart and relevant certificates (e.g. plant operator, technician, asphalt specialist, qualified engineer, technical manager, & etc)

(b) Heating of Bitumen Binder

The binder shall be separately heated in approved heating tanks. Thermometers shall be provided both in the storage tanks and also on the mixing platform. The temperature dials shall be readily accessible and kept clean at all times.

The bitumen of 60/70 penetration grade shall be heated to 150 -165°C.

The difference in temperature between the aggregate and the bitumen shall not exceed 15°C.

(c) Drying and Heating of Aggregates

The plant shall include at least two cold-hoppers for coarse aggregate and one for fine aggregate. When two or more fine aggregates are being incorporated in the mixture, a separate hopper shall be provided for each. The feed gates or other devices provided for controlling the output from each hopper shall be capable of accurate adjustment to ensure uniform rate of feed.

When loading the cold hoppers, care shall be taken to avoid segregation of the aggregate and they shall be kept sufficiently full to allow an even flow through the feed gates.

Aggregates shall be thoroughly dry before mixing, and the Contractor shall carry out moisture test at least once a week on a sample from each hot bin to check the effectiveness of the drying processes. If at any time the tests indicate that the drying facilities are inadequate, mixing shall cease until the Contractor has augmented his drying capability to the satisfaction of the Engineer. All drying plant shall be equipped with efficient dust extractors.

A suitable thermometer for measuring the temperature of the aggregate shall be fitted at the drier discharge and shall be maintained in good working order.

(d) Mixing Temperature

The Contractor shall ensure that the batching of the aggregates and bitumen, the dry and wet mixing time, the temperatures for the heating of the aggregates and the mix shall be accurately controlled to produce a uniformly coated and acceptable mix within the limits specified.

The aggregate shall be heated to between 150°C to 170°C. Overheating of the aggregate or binder shall be prohibited and rejected mixture shall not be used.

After heating, the hot aggregate shall be thoroughly and intimately mixed together with filler and bitumen binder in the correct proportion until every particle of aggregate is completely coated. The total mixing time may only be reduced if the Engineer is satisfied that thorough mixing can be achieved in less time.

Extracted dust shall be automatically fed back into the dry or wet admixtures. When it satisfies the specified requirements for filler, it shall be weighed into the mixture as a separate proportion. All mixing plant shall incorporate means of access to each hot bin to enable samples to be taken. The aggregate after drying and heating in a drum dryer shall be screened into at least 3 different sizes. The aggregates shall then be stored in separate hot bins for subsequent batching by weight. The use of drum mix plant, which does not incorporate this requirement, shall be prohibited.

After mixing, the asphaltic concrete shall then be discharged directly into a truck and properly covered with a canvas cover. The temperature of the mix at this stage shall be between 140ºC to 160ºC. The asphaltic concrete shall be rejected if the temperature of the hotmix measured at the truck is above 160ºC or below 140ºC.

10.3.3.5 Asphalt Laying

(a) Construction Method

(i) Asphaltic Concrete Finisher

The Contractor shall furnish the Engineer in advance with full details of the asphaltic concrete paver to be used, including date of manufacture, model, whether tracked or wheeled, previous ownership, maintenance facilities, and all other relevant particulars required by the Engineer.

The asphaltic concrete paver shall be a self-contained, power propelled unit, provided with an adjustable activated screed or strike off assembly, heated if necessary and capable of spreading and finishing courses of asphalt plant mix materials in lane widths, to the specified thickness. The asphalt paver must be able to operate at various rates of travel consistent with the rate of delivery and the type of asphalt mixture to be laid. Pavers used for shoulders and similar construction shall be capable of spreading and finishing courses of asphalt plant mix materials in the required width.

The paver shall be equipped with a receiving hopper having sufficient capacity for a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed, which shall effectively produce a surface finish without tearing, shoving or grazing the surface.

The paver shall be equipped with an automatic level control system e.g. wire sensor, sensor shoe or other approved automatic level control system to effect very precise level control on the finished level to ensure that good riding quality of the road is achieved. The electronic screed control sensors must be installed on both sides of the paver capable of sensing grade from an outside reference line, sensing the transverse slope of the screed and providing the automatic signals which operate the screed to maintain the desired grade and transverse slope. The sensor shall be so constructed that it can be operated from a reference line or ski-line arrangement.

(ii) Compaction Plant

Rollers used for compaction shall be self-propelled and of types accepted by the Engineer. Rollers shall be in good condition, capable of reversing without backlash. The use of equipment which results in excessive crushing of the aggregate shall not be permitted.

The acceptable types of rollers shall be as follows:

- Static three steel-wheeled, smooth-roll roller having a weight between 8 and 12 tonnes and a force per 100 mm width of rear wheel between 5.3kN and 7.1kN.
- Two steel-wheeled, smooth-roll tandem roller having a weight between 8 and 12 tonnes and a force per 100 mm width of rear wheel between 3.4kN and 7.1kN.
- Self-propelled vibratory tandem roller with a net weight of 10 tonnes and static force per 100 mm width in both drums of 3 kN. The roller shall be capable of transmitting vibrations at a rate between 2000 and 3000 vibrations per minute and giving amplitude of 0.4 to 0.8 mm.
- Self-propelled pneumatic rubber wheel tyre roller having a weight between 10 and 30 tonnes and with tyre pressure varying between 545 and 827 kN/m$^2$.

The Contractor shall employ at least two rollers of suitable type at the paving site for the compaction of asphalt concrete.

(iii) Concrete Cutting Saw

When asphaltic concrete cutting is required, a concrete cutting saw shall be used.

(iv) Bitumen Emulsion Sprayer

Mechanical sprayers operated by means of mechanical pumping apparatus shall be used to apply tack coat of bitumen emulsion onto the road. The emulsion shall be sprayed through a suitable nozzle to give a uniform application at the desired rate without atomisation.

(b) Transportation of Asphaltic Concrete Mix

(i) Hauling Equipment

The Contractor shall ensure that adequate transport is available to ensure continuity of supply of asphalt concrete.

Trucks used for hauling asphalt concrete shall have tight, clean, smooth, metal beds, which have been thinly coated with an approved material to prevent the mixture from adhering to the beds. After loading of the hotmix, a canvas cover shall be placed over the mixture and securely fastened to protect it from the weather regardless of the ambient temperature or haul distance.

The plant mixture shall be transported without delay from the mixing plant to the sites. If the Engineer considers that contamination of the mixture has occurred from whatever source, the whole of the load shall be rejected.

(ii) Weighing of Asphaltic Concrete

All asphaltic concrete mixes for the purpose of surfacing, regulating or rehabilitating of road surface shall be weighed at approved weighbridges as directed by the Engineer.

Asphaltic concrete quantities shall normally be computed by weight for payment purpose. If the asphaltic concrete is not weighed, the quantities shall be computed by thickness and area covered by the asphaltic concrete.

(c) Method Statement

Prior to laying of the asphaltic concrete, the Contractor shall establish the compaction effort required to compact the various asphaltic concrete mixes. He shall determine the working speed of his rollers and the number of passes required under various environmental conditions to compact the asphaltic concrete to the specified field density. The method statement shall be submitted to the Engineer for his acceptance. It shall form the basis for site supervision of the compaction work.

(d) Preparation of Site

(i) Aggregate Base Course

Prime / tack coat or asphaltic concrete shall only be applied or laid on clean and dry base course surface free of loose material.

(ii) Surface

The surface where the asphalt paving is to be laid shall be thoroughly swept, brushed, dried and cleared of all loose stones and foreign material.

Where the base is irregular and uneven, it shall be brought to uniform grade and cross section. Potholes and depressions in existing roads shall be repaired by removing all defective material to sound pavement and replaced with asphalt aggregate patching material. All premix which has been laid on the previous day/night shall be saw cut back by at least 150mm in a straight line and be treated in accordance with Clause 10.3.3.5(e)(vi) for joints prior to laying of asphaltic concrete.

All manholes, kerbs, channels and other projections against which asphalt paving is to be laid shall be cleaned and primed with a thin coat of bitumen emulsion.

Where a manhole cover is lower than the premix surface, the Contractor shall provide a wooden frame to demarcate its position so that this can be recognised and raised subsequently by the respective Utility Agency.

The Contractor shall, prior to commencement of work, inspect the site with the attending supervisor to mark and indicate by paint on the road kerb or footpath, the type of manholes and distance of it from the indicated point.

(e) Laying of Asphaltic Concrete Mix

(i) Application of Prime Coat / Tack Coat

The Contractor shall supply and apply a suitable prime coat / tack coat of cationic bitumen emulsion of rapid setting type (RS-2K) to all surfaces receiving the asphalt paving after such surfaces have been thoroughly cleaned and dried.

The emulsion shall be uniformly applied by means of a mechanical sprayer. The prime / tack coat of bitumen emulsion shall be sprayed at rates of 1.14 litre/m² and 0.54 litre/m² for aggregate base course surface and premix surface respectively.

The bitumen emulsion shall only be applied on areas where asphaltic concrete can be laid within a reasonable period of time. A period of not more than 10 minutes shall be allowed for the emulsion to break before asphalt concrete can be laid.

(ii) Laying Temperature

The temperature of the hotmix asphalt in the spreader hopper shall be 130ºC to 140ºC at the time of spreading. If the hotmix on arrival at the site is above 140ºC, it shall be allowed to cool down to the required temperature before it is being discharged into the spreader hopper. However, if the hotmix temperature falls below 130ºC on arrival at the site, the hotmix shall be rejected.

The Contractor shall supply suitable thermometer to measure the temperature of the newly laid premix and the temperature of the premix on the tippers.

(iii) Spreading and Finishing

On arrival at the site, the asphaltic concrete shall be tipped onto the hopper of the paver and shall thereupon be spread, levelled, tampered and finished to correct profile, camber or cross-fall, without causing segregation, dragging, burning or other surface defects or irregularities. The asphaltic concrete shall be fed to the paver at such a rate as to permit continuous laying, in so far as the supply and site conditions allow.

Spreading is to be discontinued until all the irregularities and other surface defects like segregation, dragging etc. have been rectified while the surface is still hot and before the final rolling is completed.

On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impracticable, the asphaltic concrete shall be spread, raked, levelled and compacted by hand tools. For such areas, the asphalt concrete shall be spread, screeded and tampered to give the required compacted thickness.

(iv) Compaction

After the asphaltic concrete has been spread, struck off, and surface irregularities adjusted, it shall be thoroughly and uniformly compacted by rolling.

Compaction of the asphaltic concrete shall commence as soon as it will bear the weight of a roller without undue movement. Initial rolling shall be carried out by a three-wheeled roller followed by intermediate rolling with a pneumatic-tyre roller. Final rolling shall be done with a tandem roller. The rolling shall not cause undue displacement, cracking or shoving.

Rolling shall be carried out in the direction of laying. Rollers shall never be allowed to stand on newly laid asphaltic concrete.

Along forms, kerbs, headers, walls and other places not accessible to the rollers, the mixture shall be thoroughly compacted with mechanical tampers. On depressed areas, a trench roller may be used.

The levels and surface accuracy of the asphalt surfacing shall be checked continuously during rolling and any displacement occurring from whatsoever cause shall be corrected immediately.

Rolling shall continue until all roller marks are eliminated, no further compression is possible and the surface is of uniform texture and true to grade and level.

The minimum density of the pavement placed each day shall be 98% of the Laboratory Marshall Density.

(v) Rolling Patterns

Rolling of a new carriageway lane shall normally start at one of the outer edges with the rolling pattern as shown in Fig. 10.1. If the surface has a transverse inclination, the rolling shall commence at the lowest side.

To counteract the outward movement on thick asphaltic concrete layers, the rolling pattern shall be as shown in Fig 10.2.

On a newly laid lane running adjacent to a previously placed and compacted lane, rolling shall commence by compacting the longitudinal joint with the rolling pattern as shown in Fig 10.3.

(vi) Joints

The asphaltic concrete at the joints (both transverse and longitudinal) shall comply with the surface requirements and present the same uniformity of texture, density, evenness etc., as other sections of the course.

In the formation of all joints, provision shall be made for proper bond with the adjacent course for the specified depth of the course. Joints shall be formed by cutting back 150 mm on the previous day's run to expose the full depth of the course; the exposed edge shall be heated to 130$^{o}$C using an infrared heater and given a light coat of bitumen emulsion. The fresh asphaltic concrete shall be raked against the joint and thoroughly tamped and rolled.

The placing of the course at transverse joint shall be as continuous as possible. The roller shall pass over the unprotected end of the freshly laid asphaltic concrete only when discontinuing the laying of the course (See Fig. 10.4).

All joints shall be constructed or saw cut. Longitudinal joint shall be saw-cut to form a wedge-shaped groove of 25mm depth and 75 mm width to enable the newly laid asphaltic concrete to flush with existing surface.

The placing of the course at longitudinal joint shall be as specified in such a manner that the joint is exposed for the shortest period possible.

The longitudinal joint in the newly placed layer shall be at least 500mm away from the joint in the layer immediately below (See Fig. 10.5). Unless otherwise approved by the Engineer, the joint in the top layer shall coincide with the lane line marking.

(vii) Weather Limitations

Plant-mix asphaltic concrete shall only be placed on a dry surface. The asphaltic concrete shall not be placed when weather conditions prevent proper handling, compaction and finishing.

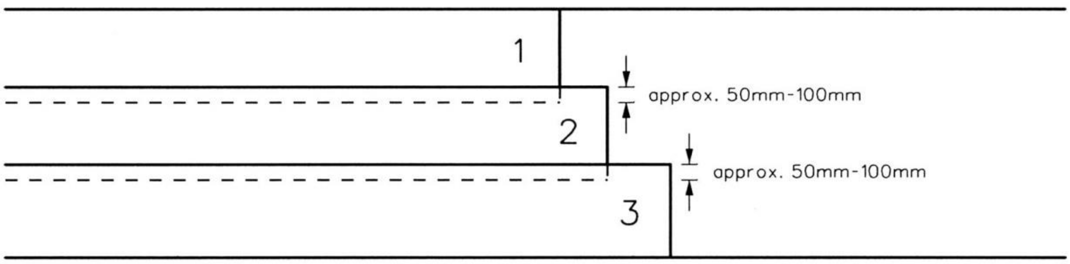



**Figure 10.1 Rolling Pattern on New Carriageway**

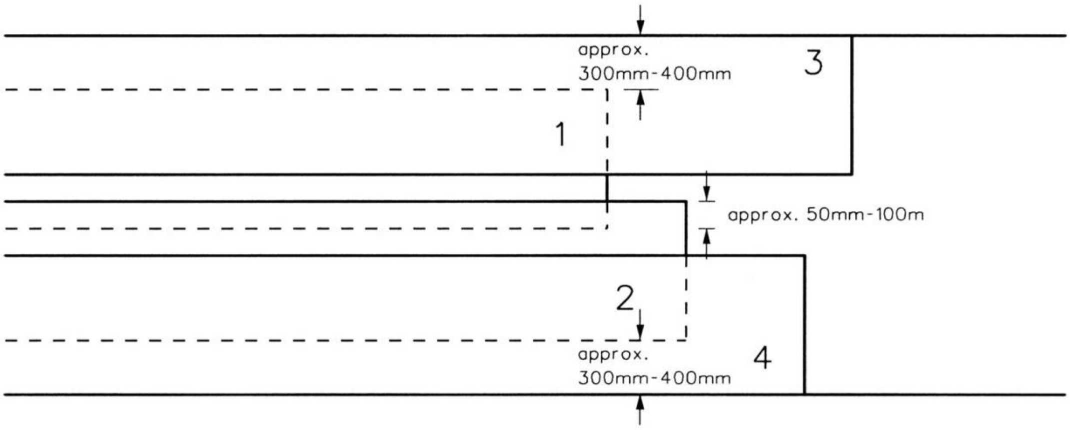



**Figure 10.2 Rolling Pattern to Minimize Lateral Outward Movement on Thick Asphaltic Concrete Layers**

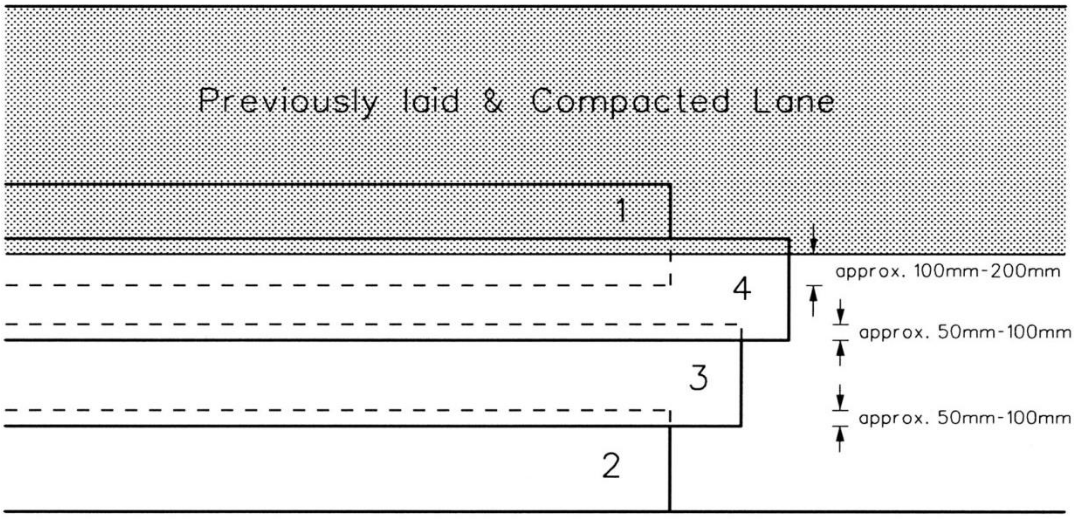



**Figure 10.3 Rolling Pattern beside a Previously Laid and Compacted Lane**

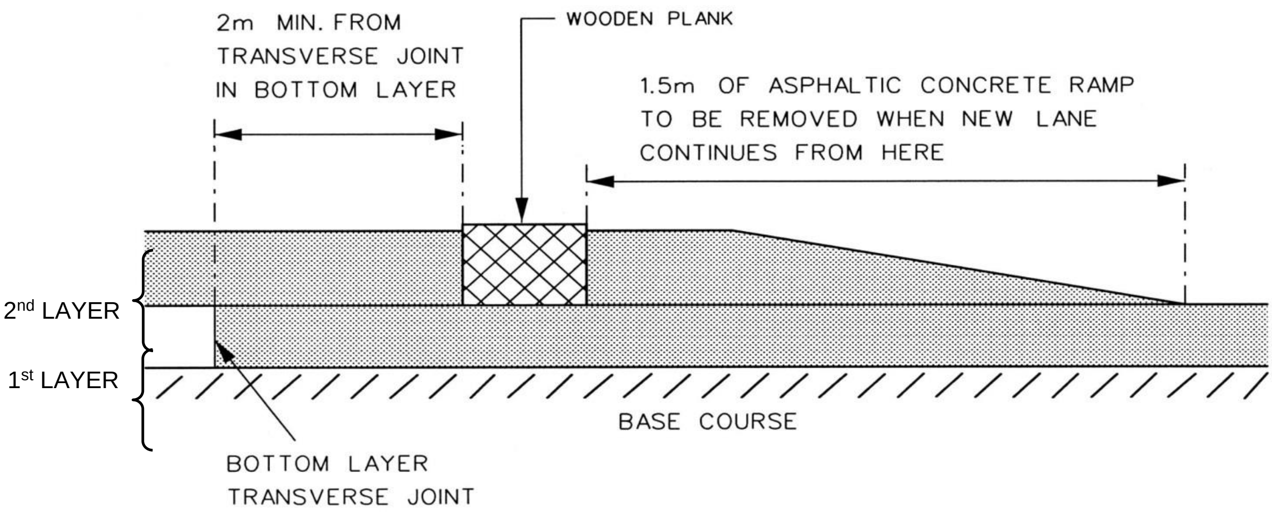



**Figure 10.4 Construction of a Transverse Joint**

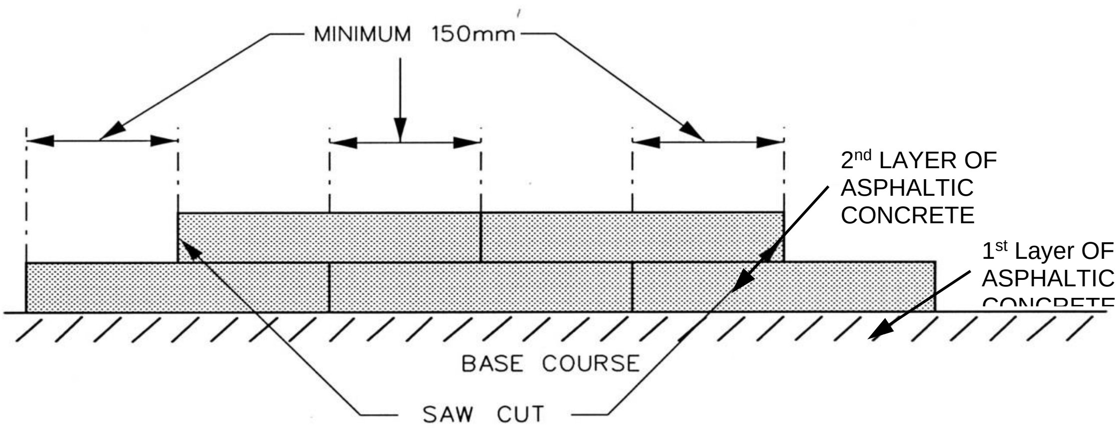



**Figure 10.5 Diagramatic View of a Longitudinal Joint**

(f) Quality Control

(i) Sampling and Testing of Asphaltic Concrete.

The contractor shall supply all necessary labour and approved equipment for the purpose of extracting core samples. Samples shall be neatly cut with a core drill or other similar equipment. No less than 1 no. of 100mm diameter core samples shall be extracted per 200m of lane or part thereof. The locations of the coring shall be determined by the Engineer on a random basis. The core samples extracted from the sites not later than 7 days after the laying of the asphaltic concrete.

The Contractor shall supply and finish new material to backfill voids left by sampling.

The Contractor shall give one day's notice to the Engineer of his intention to carry out any tests on the samples taken.

The field density of the asphaltic concrete shall be determined from the core samples extracted from the site. All core samples shall have a field density of 98% or more of the Laboratory Marshall Density. The works shall be rejected where the field densities are less than 98% of the Marshall Density.

The Marshall Density is the average of the laboratory density of all Marshall samples (75 blow on both sides of the samples) taken over the period of laying of asphaltic concrete at the corresponding site.

(ii) Site Control

At all times during the course of the paving works, the Engineer shall at his discretion, carry out tests to check that the finished surface conforms with the specified crown and grade. Any variation shall be immediately corrected by removal or addition of materials and continuous rolling.

After the completion of final rolling, the evenness of the course shall again be tested, humps or depressions exceeding the specified tolerances shall be immediately corrected by removing the defective work and replacing with new material.

(iii) Laboratory Tests

Asphaltic concrete sampled for laboratory specimens shall be chosen on a random basis.

Samples (min. 1.5kg each) shall be taken at the rate of one per 50 tonnes of asphaltic concrete laid and at least 3 samples shall be taken at each site in a day. These samples shall be marked with the mix type, date laid, location and plant identification. The Engineer shall select from all the samples taken on the particular day for each mix type per plant, a minimum of 3 and a maximum of 10 samples to be tested.

The contractor shall supply all necessary labour, equipment and approved containers with security lock to collect samples of asphaltic concrete at site and deliver the samples to the accredited laboratory for testing. The results obtained for each mix type for each day shall be deemed to be representative of all the sites for that day. When the work for a site is done over a period longer than one day, the results from all relevant days shall be used.

The samples shall be tested for bitumen content, gradation, Marshall Density, Marshall stability, stiffness ratio, percentage voids in mix and percentage of aggregates voids filled with bitumen binder.

Similarly, the Engineer shall select 3 samples per day for each mix type per plant for the determination of the Marshall Laboratory Density and other Marshall properties. The average Marshall Laboratory Density per mix type shall be used for the comparison with the field density.

**10.3.4 W3B(20R) and B1(30R) Asphaltic Concrete with Reclaimed Asphalt Pavement**

10.3.4.1 Materials

(a) Reclaimed Asphalt Pavement

Reclaimed asphalt pavement (RAP) is the term given to processed milled waste. Milled waste is generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When milled waste is properly processed, RAP shall consist of high-quality, well-graded aggregates coated by asphalt binder.

Not more than 20% and 30% RAP shall be allowed for use in asphaltic concrete for the asphaltic wearing course and base course, respectively.

(b) Processed Aggregates

Processed aggregates with residual bitumen removed from RAP shall comply with Clause 10.3.3.1(a).

(c) Aggregates

Aggregates shall consist of crushed stone or crushed gravel with or without sand or other inert finely divided mineral aggregate.

(d) Bitumen

Residual bitumen of RAP coated on processed aggregates shall be analysed for its suitability before mixing with asphaltic concrete mix. The method of analysis shall be submitted to the Engineer for approval.

(e) Admixture

No admixture (rejuvenator) shall be allowed in the asphaltic concrete with RAP.

10.3.4.2 Mix Design

The contractor shall propose the job mix design with the target binder content and aggregate grading for the Engineer's approval. The contractor shall carry out tests to determine and propose the final bitumen content. The target bitumen content for asphaltic concrete with RAP mixes shall conform to the requirements of Table 10.7.

The job mix formula shall be determined in 2 stages as follows:-

(a) Stage 1 – Marshall mix and volumetric mixture design tests; and

(b) Stage 2 – Laboratory performance related tests.

In Stage 1, volumetric analysis based on the procedures contained in Asphalt Institute MS-4 Marshall Mix Design shall be carried out. The specimen shall be prepared with 75 blows/face, using Marshall compaction method and the job mix formula shall satisfy the following volumetric properties:-

**Table 10.17 Marshall Design Criteria for Asphaltic Concrete with RAP**

| | |
|---|---|
| Marshall Stability (kN) | Min. 9.0 |
| Flow Value (0.254mm units) | 8 – 16 |
| Air voids (%) | 3 – 5 |
| Voids in Mineral Aggregate (VMA) (%) | Min. 12.0 |

In Stage 2, the properties of the mix design shall be determined. The contractor shall perform the following tests for normal mix and propose mix with 10%, 20%, 30% and 40% RAP:-

**Table 10.18 Property Tests for Mix Design**

| | |
|---|---|
| (i) | Cantabro Abrasion Loss after 300 revolutions (average of 3 samples), using Los Angeles Abrasion Machine |
| (ii) | Resilient Modulus (ASTM 4123) @ 25°C at loading frequency 0.33 Hz (average of 3 samples) |
| (iii) | Dynamic Creep Modulus (DD226: 1996) @ 45°C at 1800 cycles of loading frequency 0.5Hz (average of 3 samples) |
| (iv) | Wheel Tracking Rate (BS598: Part 110: 1998) @ 60°C (average of 6 samples) |
| (v) | Effect of Water on Bituminous Coated Aggregate using Boiling Water (ASTM D3625) and Tensile Strength Ratio (TSR) (ASTM D4867) method |

Prior to manufacture, the contractor shall submit full detail of the job mix formula for the Engineer's approval.

(a) Aggregate Grading

All aggregate grading for the different types of asphaltic concrete with RAP mixes shall be in accordance with Table 10.8.

(b) Marshall Design Criteria

All samples obtained from asphaltic concrete with RAP tested for Marshall Design Criteria shall conform to the requirements of Table 10.9.

(c) Criteria for Acceptance

Where these samples fail to satisfy the acceptance criteria in Table 10.8 and Table 10.9, asphaltic concrete with RAP mixes laid and represented by the unsatisfactory samples shall be rejected.

In addition, fresh bitumen used for the mixing of asphaltic concrete with RAP shall be tested for compliance with Table 10.7.

10.3.4.3 Manufacture

Manufacturing of asphaltic concrete with RAP shall include, but not limited to, the crushing of milled waste, screening of processed aggregates, analysis of residual bitumen coated on processed aggregates.

(a) Processing and Analysis of Milled Waste

Milled waste must be processed to the desired aggregate gradation using approved equipment consisting of crushers or granulators, screening units, conveyors, and stacker. The processed milled waste (i.e. RAP) must be analysed to determine their suitability for use and the analysis shall include, but not limited to, the characteristic of the residual bitumen and processed aggregates

(b) Stockpiling

Material contamination shall be prevented during processing and stockpiling operations. RAP shall be stored in stockpiles on smooth surfaces free of debris and organic material.

RAP stockpiles shall only consist of homogeneous RAP.

(c) Batching Plant for Asphaltic Concrete with RAP

The Contractor shall furnish the Engineer in advance with full details of all batching plants to be used for asphaltic concrete with RAP, in accordance with the format shown in Table 10.16.

The batching plant shall have an average output capacity of not less than 100 tonnes/hr.

Before the batching plant can be used, the measuring, recording mechanism and temperature control gauges shall be tested by Singapore Accreditation Council or other internationally recognized bodies in accordance to the manufacturer's specification. The Contractor shall submit the calibration certificates to the Engineer.

The Engineer shall have access at all times to the plant, storage yard and other facilities for processing the material. He shall be at liberty to take samples of materials, as he deems necessary.

(d) Heating of Bitumen Binder

The binder shall be separately heated in approved heating tanks. Thermometers shall be provided both in the storage tanks and also on the mixing platform. The temperature dials shall be readily accessible and kept clean at all times.

The bitumen of 60/70 penetration grade shall be heated to 150 - 165°C.

The difference in temperature between the aggregate and the bitumen shall not exceed 15°C.

(e) Drying and Heating of Aggregates

The plant shall include at least two cold-hoppers for coarse and fine aggregates. When two or more fine aggregates are being incorporated in the mixture, a separate hopper shall be provided for each. The feed gates or other devices provided for controlling the output from each hopper shall be capable of accurate adjustment to ensure uniform rate of feed.

When loading the cold hoppers, care shall be taken to avoid segregation of the aggregates and they shall be kept sufficiently full to allow an even flow through the feed gates.

Aggregates shall be thoroughly dry before mixing, and the contractor shall carry out moisture test at least once a week on a sample from each hot bin to check the effectiveness of the drying processes. If at any time the tests indicate that the drying facilities are inadequate, mixing shall cease until the contractor has augmented his drying capability to the satisfaction of the Engineer. All drying plant shall be equipped with efficient dust extractors.

A suitable thermometer for measuring the temperature of the aggregates shall be fitted at the drier discharge and shall be maintained in good working order.

(f) Mixing Temperature

The Contractor shall ensure that the batching of the aggregates, RAP and new bitumen, the dry and wet mixing time, the temperatures for the heating of the aggregates and the mix shall be accurately controlled to produce a uniformly coated and acceptable mix within the limits specified.

The aggregates shall be heated to between 150°C and 170°C. The aggregates used to mix and heat up cold RAP in the heating drum shall not be overheated to avoid overheating of aggregates and bitumen.

Extracted dust shall be automatically fed back into the dry or wet admixtures. When it satisfies the specified requirements for filler, it shall be weighed into the mixture as a separate proportion. All mixing plant shall incorporate means of access to each hot bin / storage bin to enable samples to be taken. Overheating of the aggregate, RAP or binder shall be prohibited and rejected mixture shall not be used.

During mixing, the hot aggregates and RAP shall be thoroughly and intimately mixed together with filler and bitumen binder in the correct proportion until every particle of aggregates is completely coated. The total mixing time may only be reduced if the Engineer is satisfied that thorough mixing can be achieved in less time.

After mixing, the asphaltic concrete with RAP shall then be discharged directly into a truck and properly covered with a canvas cover. The temperature of the mix at this stage shall be between 140ºC to 160ºC. The asphaltic concrete with RAP shall be rejected if the temperature of the hot mix measured at the truck is above 160ºC or below 140ºC.

10.3.4.4 Asphalt Laying

The requirements of asphalt laying shall be in accordance with Clause 10.3.3.5.

10.3.4.5 Quality Control and Quality Assurance

Prior to the proposed use of asphaltic concrete with RAP, the contractor shall submit the following for the Engineer's approval:-

(a) Facility plan and details of the plant that produces asphaltic concrete with RAP;

(b) Details of manufacturing process and control, and its associated Quality Management System;

(c) Quality Control and Quality Assurance (QA/QC) plan to demonstrate the elimination of sub-standard materials or poor workmanship and to ensure compliance with the specifications; and

(d) Resources and capabilities in performing in-house mix design, equipped with the necessary laboratory equipment for the QA/QC tests listed in this specification.

The QA/QC plan shall also include appropriate provisions for the Engineer to perform spot tests during the initial assessment of production control and also during routine inspection by spot samples from the running production.

The inspection and QA/QC plan must be certified by an independent accreditation body such as Singapore Accreditation Council (SAC) prior to manufacturing of asphaltic concrete with RAP and such accreditation must be carried out annually.

All relevant tests shall be carried out in independent laboratories accredited by the SAC (under SAC-SINGLAS).

The Authority may appoint an independent pavement specialist from a relevant recognised professional body or academic institution to audit the manufacturing process and control of asphaltic concrete with RAP and the QA/QC plan.

The Engineer's approval shall be valid for the duration of the project/contract or one year whichever is earlier.

## 10.4 RIGID PAVEMENT

### 10.4.1 General

The Contractor shall comply with all the requirements of Chapter 11, Concrete and Reinforcement Bars and details shown in the "Standard Details of Road Elements" unless otherwise specified in this Chapter.

### 10.4.2 Materials

(a) Tie Bars

Tie bars shall be deformed bars of high yield stress complying with the requirements of SS 560.

(b) Dowel Bars

Dowel bars shall be plain mild steel bars complying with the requirements of SS 560 and shall be free from burring or other deformation restricting slippage in the concrete. Before delivery to the construction site, a minimum of two-thirds of the length of each dowel bar shall be painted with one coat of rust preventative paint.

(c) Joint Filler

Joint filler shall be a resin-impregnated fibreboard or self-expanding cork complying with the requirements of ASTM D1752.

(d) Joint Sealers

Joint sealers shall comply with the following specifications:

| | |
|---|---|
| Hot-poured Sealant | BS EN 14188 |
| Cold-poured Sealant | BS 5212 |
| Preformed Compression Seal | ASTM D2628 |

(e) Curing Materials

Curing materials shall comply with the following specifications:

| | |
|---|---|
| Liquid membrane-forming compounds | ASTM C309, Type 2 |
| Polyethylene film | ASTM C171 |
| White burlap-polyethylene sheeting | ASTM C171 |

### 10.4.3 Construction

(a) Equipment

A paver may be used subject to the approval of the Engineer.

(b) Placing Concrete

Concrete shall be placed in a continuous operation without cold joint and thoroughly compacted by means of vibrators.

(c) Protection of Pavement

The Contractor shall have available at all time materials for the protection of the edges and surfaces of the unhardened concrete. Such protective materials shall consist of rolled polyethylene sheet at least 0.1mm thick of sufficient length and width to cover the plastic concrete slab and any edges.

(d) Joints

Longitudinal and transverse joints shall be constructed as indicated on the drawings. All joints shall be constructed true to line to an accuracy of 13mm with their faces perpendicular to the surface of the pavement. The surface across the joints shall be tested with a 3m straight edge as the joints are finished and any irregularities in excess of 4mm shall be corrected before the concrete has hardened. When required, keyways shall be accurately formed with a template of metal or wood. Transverse joints shall be at right angles to the centreline of the pavement and shall extend to the full width of the slab. The transverse joints in succeeding lanes shall be placed in line with similar joints in the first lane.

Tie bars shall be placed at right angles to concrete slab, unless otherwise specified. Tie bars shall not be painted, greased, or enclosed in sleeves.

(e) Final Leveling, Compaction and Finishing

(i) Sequence

The sequence of operations shall be the leveling and compaction, floating and removal of laitance, straightening, and final surface finish. The addition of superficial water to the surface of the concrete to assist in finishing operations shall generally not be permitted. A suitable vibrator shall be used for compaction.

(ii) Finishing at Joints

After the concrete has been placed and vibrated adjacent to the joints, the finishing machine shall be operated in a manner to avoid damage or misalignment of joints.

(iii) Leveling

The leveling of screed for the surface shall be at least 500mm longer than the maximum width of the slab to be levelled.

(iv) Straight Edge Testing and Surface Correction

After the pavement has been compacted and levelled and while the concrete is still plastic, it shall be tested for trueness with a 3 m straight edge swung from handles 1m longer than one-half the width of the slab. Straight edge testing and surface corrections shall continue until the entire surface is found to be free from observable deviation from the straight edge and until the slab conforms to the required grade and cross section. The use of long-handled wood floats shall be confined to a minimum; they may be used only in emergencies and in areas not accessible to finishing equipment.

(f) Surface Texture

The surface of the pavement shall be broom finish. It shall be applied when the water sheen has practically disappeared.

The equipment shall operate transversely across the pavement surface, providing corrugations that are uniform in appearance and approximately 2mm in depth.

(g) Alignment and Surface Tolerances

The pavement shall be constructed to the following tolerances:

(i) Lateral deviation from established alignment of the pavement edge shall not exceed ±30mm in any lane.

(ii) Vertical deviation from established grade shall not exceed ±4 mm at any point. However, the combination of permitted tolerances in different pavement levels shall not result in a reduction of the thickness of the concrete slab by more than 5 mm from that specified.

(iii) Surface smoothness deviation shall not exceed 4mm from a 3m straight-edge placed in any direction including placement along and across any pavement joint or edge.

Where any specified tolerances are exceeded, the pavement section, which is out of tolerance, shall be removed and replaced unless the Engineer directs otherwise. Any section so removed shall not be less than 3 m in length for the full width of the lane involved. When it is necessary to remove and replace a section of pavement, any remaining portion of the slab adjacent to the joints that is less than 3 m in length shall also be removed and replaced.

(h) Curing

Immediately after the finishing operations have been completed and marring of the concrete will not occur, the entire surface of the newly placed concrete shall be cured in accordance with one of the methods below. The concrete shall not be left exposed for more than half an hour during the curing period. The curing shall be maintained for 72 hours after the concrete has been placed.

(i) Impervious Membrane Method

The entire surface of the pavement shall be sprayed uniformly with an approved curing compound immediately after the finishing of the surface and before the set of the concrete has taken place. The curing compound shall not be applied during rainfall. Curing compound shall be applied by mechanical sprayers.

(ii) Polyethylene Film

The top surface and sides of the pavement shall be entirely covered with polyethylene sheeting. The units shall be lapped at least 450mm. The sheeting shall be placed and weighed to cause it to remain in contact with the surface covered. The sheeting shall have dimensions that will extend at least twice the thickness of the pavement beyond the edges of the pavement.

(iii) White Burlap-Polyethylene Sheet

The surface of the pavement shall be entirely covered with the sheeting. The sheeting used shall be such length (or width) that it will extend at least twice the thickness of the pavement beyond the edges of the slab. The sheeting shall be placed and weighed to remain in contact with the surface covered, and the covering shall be maintained fully wetted.

(i) Removing Forms

Unless otherwise specified, forms shall not be removed from freshly placed concrete until it has set for at least 12 hours, except where auxiliary forms are used temporarily in widened areas. Forms shall be removed carefully to avoid damage to the pavement. After the forms have been removed, the sides of the slab shall be cured. Honeycombed areas shall be removed and replaced. Any area or section so removed shall not be less than 3 m in length for the full width of the lane involved. When it is necessary to remove and replace a section of pavement, any remaining portion of the slab adjacent to the joints that is less than 3 m in length shall also be removed and replaced.

(j) Sealing Joints

Unless otherwise specified, the joints in the pavement shall be sealed immediately following the curing period or as soon thereafter as weather conditions permit.

## 10.5 PAVEMENT MARKINGS

### 10.5.1 Temporary Pavement Marking

Temporary pavement marking shall only be used for traffic diversion scheme of less than 3 months duration. The marking material shall comply with the requirements in SS 624:2016.

(a) Method of Application

All pavement line painting and pavement marking which include pedestrian crossing, box junctions, continuous broken lines, numerals, bus zones, arrows, lettering, etc. must be fully mechanised and drawn or spray painted by pavement line painting machine. Paint shall not be applied by brushes to pavement lines and markings.

No painting shall be done on surfaces, which are wet or damp from rain, dew or any other causes until they have been properly dried.

(b) Quality Control

(i) Wet Film Thickness

All paints for pavement marking shall be supplied ready-mixed by the manufacturer and no thinning shall be permitted.

All paints for pavement marking shall be applied to wet film thickness of 375 microns to a tolerance of 50 microns.

(ii) Maintenance Period

The Contractor shall maintain all pavement lines and markings executed by him for three months and repaint the pavement lines and markings when the degree of visibility of the painting has decreased by more than 50% during the maintenance period.

### 10.5.2 Thermoplastic Pavement Marking

#### 10.5.2.1 General

Thermoplastic road marking shall be used for permanent road marking and traffic diversion scheme of more than 3 months duration. The requirements for thermoplastic road marking material shall comply with all the requirements of SS 589: 2013 on Specification for hot-applied thermoplastic road markings materials – Materials, performance and application (including any subsequent amendments made thereto), together with details shown in the "LTA Standard Details of Road Elements".

The quality of the thermoplastic road marking materials shall meet the thermoplastic road marking material requirements as specified in Clause 4 and 5 of SS 589 and achieve field performance requirements as specified in Clause 6 of SS 589. The acceptance of the materials shall not discharge the contractor’s responsibilities from the compliance of the performance requirements stated in Clause 6 of SS 589.

#### 10.5.2.2 Equipment

Mechanisation in all aspects of painting thermoplastic road marking is compulsory and it is a pre-requisite for the Contractor to possess the thermoplastic road marking machine and road marking erasing machine. The Contractor shall also possess the measuring instruments required to conduct the field measurement as specified in Clause 6 of SS 589.

#### 10.5.2.3 Material Specification and Related Test Methods

10.5.2.3.1 Thermoplastic Road Marking Material

The tests required for the thermoplastic road marking material used shall comply with Clause 5 of SS 589 except that the material for profile thermoplastic road marking shall have the following additional characteristics:

(a) Softening point shall be greater than 100ºC.

(b) Flow resistance shall not slump by more than 2% determined by Annex B of SS 589.

(c) Luminance factor (laboratory) shall have minimum 75.

10.5.2.3.2 Test Reports for Thermoplastic Road Marking Material

The Contractor shall submit test reports for the thermoplastic road marking materials intended for use to an accredited laboratory for test as specified in Clause 4 and 5 of SS 589. The following test reports, which are valid within the last twelve (12) months are acceptable, shall be submitted:

(a) Skid resistance test and flow resistance test in accordance of Annex B & C of SS 589.

(b) Gradation of drop-on and premix glass bead.

(c) Refractive index of glass beads.

(d) Roundness of glass beads.

10.5.2.3.3 Samples to be supplied

Samples of thermoplastic road markings properly laid on 30mm x 105mm aluminium sheets shall be submitted to the Engineer for approval.

10.5.2.3.4 Information of product to be supplied by the manufacturer

The Contractor shall provide the following information from the manufacturer on the thermoplastic road marking material:

(a) The maximum safe heating temperature of the material.

(b) The temperature range of application for screed laying.

(c) The flash point of the material.

(d) The specification of the primer.

10.5.2.4 **Application of Thermoplastic road marking material to road surface**

The preparation of site for the laying of new and on existing thermoplastic road markings, preparation of material on site and adhesion to road surface shall comply with Clause 7 of SS 589.

10.5.2.5 **Field Performance Requirements and Related Test Methods**

10.5.2.5.1 Laying of Thermoplastic Road Marking and Profile Road Marking

The laying of thermoplastic road markings shall comply with the requirements as specified in LTA Standard Details of Road Elements (SDRE) and in one single pass to the specified thickness. Templates shall be used for marking arrows and letterings.

The raised segments of the profile thermoplastic road markings produced by the equipment shall have standard measurement of 50mm by 70mm, with acceptable tolerance as stated in Figure 10.6 (profile thermoplastic road markings). Any other shape or profile not conforming to the design in SDRE on profile thermoplastic road markings shall not be accepted.

10.5.2.5.2 Report of field tests

Field tests reports shall be provided (within the first 7 days and at the end of the 5th month after laying) and the results shall comply with the thermoplastic road marking performance requirements as specified in Clause 6 of SS 589. Results of field tests shall be submitted in both electronic and hard copy to the Engineer within one week after the completion of measurement. The measurement report shall contain the following information:

(a) Road name,

(b) Locations of the measurements,

(c) Measurement date and time,

(d) Type of equipment used,

(e) Name of operator carrying out the measurements,

(f) Measured data,

(g) Road surface temperature at measurements and,

(h) Photographs of the measurements.

10.5.2.5.3 Field Performance Requirements

Field tests shall be conducted and comply with the field performance requirements as specified in Clause 6 of SS589.

10.5.2.5.4 Non Compliance

Should the measured values fail to meet the field performance requirements, the existing thermoplastic road markings shall be removed and new thermoplastic road markings re-laid to meet the field performance requirements as specified in Clause 6 of SS 589. No damage to the road surface shall be caused during removal of the thermoplastic road marking.

10.5.2.5.5 Protection of New Thermoplastic Road Markings

Arrangements shall be made for the protection of new thermoplastic road markings until such time as the thermoplastic road marking material has set sufficiently to resist being damaged by traffic. The spraying of water to newly laid thermoplastic road markings to expedite the setting is not allowed. All materials laid and subsequently rendered unfit by the action of traffic or other road users shall be duly replaced.

10.5.2.5.6 Profile Thermoplastic Lane Marking

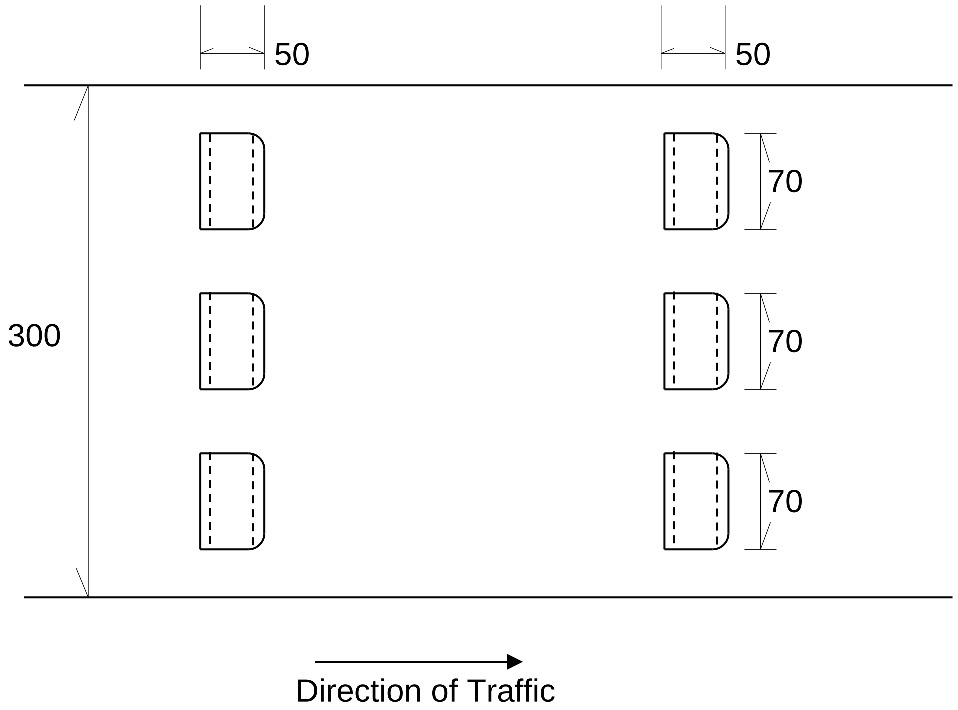
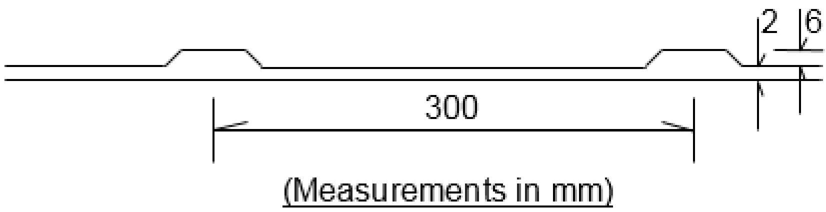



**Figure 10.6 Thermoplastic Lane Marking**




## 10.5.3 Removal of Pavement Marking

a) Removal of pavement markings on flexible pavement

Unless otherwise approved by the Engineer, mill and patch method for the affected lane(s) shall be used for removal of pavement markings

b) Removal of pavement markings on rigid pavement

Unless otherwise approved by the Engineer, removal of pavement markings shall be carried out using mechanical grinder or other equivalent methods.

## 10.6 ROAD AND RELATED FACILITIES CONSTRUCTION

### 10.6.1 Setting Out, Survey and Levelling

10.6.1.1 The Contractor shall employ a Registered Surveyor throughout the Contract Period for all survey related works inclusive of the setting out for the following:

(a) the centreline of the road reserve/pavement

(b) the limits of the road reserve

(c) the inner edge and outer edge of all slip roads

(d) the positions of culverts, bridges/underpasses all structures

(e) all drainworks

(f) kerblines of carriageway; and

(g) others works not limited to the above

10.6.1.2 All setting out works shall be demarcated on site by masonry nails or wooden pegs at 30m intervals along the straight and 5m to 30m intervals along curves in accordance with Table 10.19.

**Table 10.19 Chord Intervals for Setting Out Curves**

| Radius of Curve | Chord Intervals |
|---|---|
| R < 600 m | 5 m |
| 600 m < R < 900 m | 10 m |
| 900 m < R < 1800 m | 15 m |
| 1800 m < R | 30 m |

10.6.1.3 Tangent points of curves shall also be demarcated if they fall within the chord intervals. Reference pegs indicating the chainage and reduced levels of the corresponding stations shall be driven alongside with the demarcating pegs.

10.6.1.4 The setting out plan shall be endorsed by the Registered Surveyor and submitted to the Engineer prior to setting out on site.

10.6.1.5 The Contractor shall submit to the Engineer a set of as-built drawings after the completion of the Works. The as-built drawings shall be certified as correct by a Registered Surveyor.

### 10.6.2 Materials and Colour Codes for Demarcation

10.6.2.1 For demarcation in existing road surfaces or hard surfaces, 4mm diameter masonry nails of length not less than 100mm shall be used and driven flush with the surface. A circle in accordance with the colour codes set out in Table 10.18 shall be painted on the surface of the nail.

10.6.2.2 For demarcation on other ground, durable wooden pegs of not less than 50mm diameter and 600mm long shall be used and be driven 300mm into the ground and secured in concrete. Other means of securing the pegs in position may be used subject to the acceptance of the Engineer. All protruding stems of wooden pegs shall be painted in accordance with colour codes set out in Table 10.20.

**Table 10.20 Colour Codes for Demarcation**

| Nature of Peg | Colour |
|---|---|
| Centreline | Yellow |
| Kerbline | Yellow and White |
| Road Reserve | Orange |
| Reference Peg | White |
| Intersection Point | Red |

### 10.6.3 Construction Tolerance

10.6.3.1 Surface Levels

The levels of pavement courses shall be determined from the designed carriageway vertical profile and cross-falls as specified. The surface level of the constructed pavement courses/formation at any point shall be within the appropriate tolerances stated in Table 10.21.

However, for the flexible pavements, the negative tolerance shall not be permitted in conjunction with the positive permitted tolerance for the surface of the base course if the thickness of the wearing course is thereby reduced by more than 10 mm.

For checking compliance with Table 10.21, measurements of surface levels shall be taken at grid points of 30m centres longitudinally, 10m centres on curves and 3m centres transversely starting 1m from the edge of the pavement. In any length of pavement represented by the grid, compliance with the requirements of Table 10.21 shall be deemed to be met when not more than 1 measurement in 10 exceeds the tolerance permitted in Table 10.21.

**Table 10.21 Surface Level Tolerances at any Point**

| Formation | Sub-base | Base | Asphaltic Base Course | Wearing Course |
|---|---|---|---|---|
| ±25 mm | ±20 mm | ±15 mm | ±5 mm | ±5 mm |

10.6.3.2 Pavement Surface Roughness

10.6.3.2.1 Finished Pavement Surface

Other than satisfying the surface level tolerance specified in Clause 10.6.3.1, the Contractor shall determine the surface roughness characteristics of finished pavement from measurement of longitudinal profile of top pavement surface and comply with the acceptance limits defined in Table 10.22.

Finished pavement shall be defined as the completed and final asphalt overlay or resurfaced road with minimum thickness of 40mm.

The Contractor shall be responsible for the measurement, equipment, reporting and compliance with the requirements for finished pavement surface roughness. A quality control plan on pavement roughness measurement shall be submitted to the Engineer for approval prior to commencement of paving work. Any measurement performed not in accordance with the approved quality plan shall be rejected.

10.6.3.2.2 Measurement of Pavement Surface Roughness

The finished pavement surface to be measured shall be based on segments of 100m length in each traffic lane.

Pavement surface roughness shall be measured with either one of the following Class 1 profilers in accordance with ASTM E950/E950M over the segments of finished pavement specified:

(a) Walking Profiler: Class 1 profiler capable of measuring longitudinal road profile at intervals of 250mm or less and with accuracy in the elevation measurements of less than 0.5 mm.

(b) Inertial Laser Profiler: Class 1 profiler.

For finished pavement of length of 500m or less, walking profiler may be used for the measurement of surface roughness. High speed inertial laser profiler shall be used for measurement of finished pavement length of more than 500m.

The profiler shall measure longitudinal profile in both wheel paths over the entire finished pavement. Wheel path shall be deemed to be 750mm from the center of each lane. The location of the start and finish chainages where roughness measurement is to be undertaken shall be clearly marked out on site. The direction of roughness measurement shall be in the direction of traffic flow.

Measurement of roughness shall be conducted within 30 days of the completion of the pavement work. The Contractor shall engage an operator trained and certified by the profiler manufacturer to carry out the measurement.

Throughout the measurement operation, the profiler shall be operated in a continuous manner and the contractor shall ensure that the speed of measurement is within the manufacturer's operation range. Prior to the measurement, the contractor shall also ensure that the pavement surface shall be free from all foreign materials, water, debris, sand and particles that will affect the measured results.

10.6.3.2.3 Equipment calibration and system validation

All equipment shall be calibrated in accordance with the manufacturer's requirements.

A system validation test on distance measurement and roughness measurement shall be carried out in accordance with Austroads Test Method AG: AM/T002 or Test Method AG:AM/T003. Additionally, validation test for pavement roughness repeatability and bias checks for the equipment shall be carried out based on Austroads Test Method AG:AM/T004.

The Contractor shall submit calibration and validation certificates with validity within the last 12 months.

10.6.3.2.4 Reporting

The Contractor shall submit measurement report for Engineer's acceptance and it shall contain the following information including photographs and drawings:

(a) Project title / Road name;
(b) Location reference;
(c) Type of asphaltic concrete used;
(d) Profiler information such as type, model etc.;
(e) Equipment calibration & validation certificate;
(f) Name of certified profiler operator;
(g) Lane length (m);
(h) Start and Finish Chainage with reference to the road running distance and segment;
(i) Direction of travel and lane number;
(j) Left wheel path roughness (IRI) in every 10m;
(k) Right wheel path roughness (IRI) in every 10m;
(l) Lane IRI; (moving) average of Left and Right wheel path roughness (IRI), in every 10m;
(m) Lane IRI; average of Left and Right wheel path roughness (IRI), in every 100m;
(n) Identification of segments that represent any exclusion areas;
(o) Location and magnitude of bump/depression
(p) Type and location of non pavement fixtures detected;

(q) Weather, traffic condition and speed of profiler during test; and

(r) Date and time of measurement.

(s) Speed of test vehicle.

Lane IRI value shall be calculated based on average of Left and Right wheel path roughness(IRI) complying with ASTM E1926 quarter-car simulation model. A measurement report including values of Lane IRI calculated based on 10m and 100m segments shall be submitted in both electronic and hard copy forms to the Engineer within two weeks after the completion of measurement

10.6.3.2.5 Exclusion

The following areas are excluded from the requirements of pavement surface roughness measurement using Class 1 profilers:

(a) Intersections (Stop line to Stop line), roundabouts;

(b) Bridge joints, construction joints, non-asphalt finished approaches;

(c) Surface features like manhole covers, valve chambers, gratings on culverts/drains, raised markers, speed humps etc.

10.6.3.2.6 Acceptance Limits

The Lane IRI in every 100m segment shall meet the values specified in Table 10.22 for different type of road work:

**Table 10.22 Limit for Lane IRI (mm/m) in every 100m segment (or part thereof)**

| Type of road work | Expressway (Road Category 1) | Other Roads (Other Road Categories) |
|---|---|---|
| | Lane IRI Limit (mm/m) | |
| New road | Less than or equal to **2** | Less than or equal to **2.5** |
| Road resurfacing | Less than or equal to **2** | Less than or equal to **2.5** |
| Road widening | Less than or equal to **2.5** | Less than or equal to **3** |
| Temporary diversion# | Less than or equal to **3** | Less than or equal to **3.5** |

* Road widening that involves change of road profile across whole carriageway during asphalt laying and subjected to restricted working hours.
# For temporary diversion road (excluding metal decking type) of length exceeding 100m and to be implemented for a period of more than 9 months.

Where road work involves a combination of new construction, resurfacing and widening, the Lane IRI for relevant section of road shall meet the acceptance limits for corresponding type of work.

10.6.3.2.7 Pavement Surface Correction

Unless otherwise accepted by the Engineer, pavement surface correction shall be carried out by the contractor immediately by resurfacing when Lane IRI exceeds the acceptance limits defined in Table 10.22. The minimum correction area shall be in stretch of 15m long and across full lane width. Upon correction, the longitudinal profile of entire pavement surface shall be re-measured to verify compliance with acceptance limits.

10.6.3.3 Horizontal Alignment

The edges of the carriageways (kerb lines) shall be constructed to a tolerance of ±25 mm. The setting out of the horizontal alignment shall be within the minimum accuracy of 1 in 5000.

### 10.6.4 Rectification of Levels

Where the construction of the pavement course exceeds the tolerance, the Contractor shall determine the full extent of the area. The Contractor shall make good the surface of the pavement course to the acceptance of the Engineer before proceeding to the next layer.

(a) Formation or Subgrade Level

If the surface is too high it shall be re-trimmed and re-compacted in accordance with Chapter 4, Earthworks. If the surface is too low the deficiency shall be corrected by the addition of fresh suitable material of the same classification laid and compacted.

(b) Sub-base and Base

Where these consist of unbound material, the top layer shall be scarified and reshaped with added materials as necessary and re-compacted. Unless otherwise accepted by Engineer, the area treated shall not be less than 30m long and 3m wide.

(c) Asphaltic Base Course and Wearing Course

The full depth of the asphaltic base course or wearing course shall be removed and replaced with fresh material laid and compacted.

For rectification of the asphaltic base course or wearing course, the area treated shall be at least 5m or 15m long respectively and it shall be not less than one lane wide.

All rectification works shall conform to Clause 10.3.3.5.

### 10.6.5 Vehicular Traffic on Pavement

Restrictions on use are:

(a) Concrete Slabs

Vehicular traffic is permitted when the concrete compressive strength exceeds 25 N/mm².

(b) Asphaltic Base Course and Wearing Course

Vehicular traffic is permitted upon the asphaltic layer's temperature measured to be 60°C or lower.

The Contractor shall be responsible for rectification of all defects in the pavement arising from traffic use.

### 10.6.6 Vehicular Impact Guardrail

10.6.6.1 Materials

The beam shall be fabricated from sheet steel. The beam section shall be as shown on the Drawings. Bolts and nuts shall be manufactured from carbon steel and shall conform to the requirements of ASTM A307 Grade A and ASTM A563 Grade A respectively.

10.6.6.2 Mechanical Properties

The beam metal shall conform to the following tensile requirements:

- Minimum yield point - 345 N/mm²
- Minimum tensile strength - 483 N/mm²
- Elongation on a 50mm test gauge length of beam element shall not be less than 12%

The test specimens shall be prepared and tested as specified in ASTM A653. If galvanised test specimens are used, the correction for thickness shall be 0.15mm.

All bolts shall have a tensile strength of at least 414N/mm² tested as specified in ASTM A307.

10.6.6.3 Thickness of Metal

The base metal of beam or sheet shall be of nominal thickness of 3mm. The nominal thickness for the galvanised beam or sheet shall be 3.15mm with a tolerance for under specified thickness of 0.25mm. For fabricated beams, thickness measurements shall be made for tangent portions of the cross section.

10.6.6.4 Dimensions of Beam

The beam shall be shaped from sheets and shall have a projected width of not less than 305mm and a depth of not less than 76mm. The sheets used have a nominal width of 483mm. Tolerance from the nominal width of minus 3.2mm will be permissible.

The effective length of the beam element shall in general be 3810mm long with provision of mounting of post at 1905mm centres.

10.6.6.5 Connections and Splices

The beam element shall be spliced by lapping in the direction of traffic. The splice shall be fastened with eight bolts and shall not be less than 318mm in length. All connections or splices shall be formed with oval shoulder button-headed bolts to minimise projections on the roadside of the guardrails. All bolt heads shall be embossed with the manufacturer’s brand.

10.6.6.6 Terminal Sections

The terminal sections shall be fabricated from sheet steel manufactured from the same type of metal and having the same gauge thickness and galvanised in the same manner as the beam elements and also to the same mechanical properties.

10.6.6.7 Galvanising

The beam shall be hot-dipped galvanised after fabrication. The zinc used for the coating shall be in accordance with ASTM B6 or AASHTO M120 and shall be at least equal to the grade designated as “Prime Western”.

The total weight of zinc coating on all sides of beam shall not be less than 1220 $g/m^2$ of the sheet when tested in accordance with AASHTO T65 or ASTM A653 Triple Spot Test. No test specimen shall have a coating weight of less than 1100 $g/m^2$ for any Single Spot Test.

The sheets or beams shall be of prime finish that is free from injurious defects such as blister, flux and uncoated spots.

The coating shall be smooth, free of beading or sharp projections along the edges and shall adhere tenaciously to the surface of the metal. The adherence of the zinc coating to the surface of the base metal shall be determined by use of a stout knife applied with considerable pressure in a manner tending to remove a portion of the coating by paring or whittling, and it shall not be possible to peel any portion of the coating so as to expose the base metal.

All bolts, nuts and washers for use with guardrail shall be hot-dipped galvanised as specified in ASTM A153 or AASHTO M232 or sheradized as specified in BS 7371, Part 8.

10.6.6.8 Fabrication of Beam Elements and Terminal Sections

The beam elements and terminal sections shall be formed to proper shape and dimensions complying with AASHTO M180. They shall be punched and drilled with holes for mounting and splicing before galvanising and ready for assembly before being delivered to the site. No punching, drilling, cutting or welding shall be permitted in the field unless accepted by the Engineer for special reasons and for sampling.

The beam shall be uniform section, straight or curved as required and so designed that when installed it will not hold water. The edges shall be rolled or rounded to eliminate sharp edges. Warped, kinked or bent sections shall be rejected.

Beams to be erected on a radius of less than 45m shall be shop-curved.

10.6.6.9 Marking

Each beam element shall be identified by the brand name of manufacture. Markings shall not be placed at such a location on the beam section that they will be obscured after erection or in a manner that the brand will be conspicuous to any traffic. Marking material shall be able to resist obliteration during storage, transportation and erection.

Marking for end sections and back-up plates shall be on durable tags securely attached to each section or bundle.

10.6.6.10 Testing

The manufacturer or fabricator shall ensure that the material produced complies with all specification requirements. A copy of manufacturer’s certificate shall be supplied to the Engineer upon request.

However, the Engineer may still select one piece of guardrail, backing plate and terminal section from each lot of 200 pieces for testing to determine that specification requirements have been complied with. If the lot is less than 200 pieces, the Engineer may select one piece each of guardrail, backing plate and terminate section for testing. If one piece fails to meet the requirements, then two additional pieces shall be tested. If either one of these pieces fail to conform, the lot represented by these samples shall be rejected.

If in subsequent actual field use, there is detection of non-compliance with the requirements of this Specification as determined by random sampling by the Engineer, the material of the lot will be rejected.

10.6.6.11 Posts

All guardrail posts and spacers, unless otherwise specified shall comply to Chapter 12 Structural Steelworks.

10.6.6.12 Installation

The guardrail shall be erected after placing of the asphaltic base course or asphaltic wearing course unless otherwise accepted by the Engineer.

The guardrail shall be erected to the alignment, as shown on the Drawings. Adjacent rails shall be connected by lap joints, using suitable bolts, nuts and washers as shown on the Drawings.

## 10.7 FOOTPATH EXPANSION JOINT FILLER

Footpath expansion joint filler shall be an approved proprietary type complying with the following properties:

(a) Rot proof and resistant to bacteriological attack.

(b) Non water absorbent.

(c) Non-staining when in contact with concrete, mortar or granite slabs.

(d) Bitumen free.

(e) Non-extruding under load.

(f) Resilient, giving a compression of at least 50% under a load of $0.5N/mm^2$.

(g) Recovery under compression shall exceed 80% when subject to 50% compression for a period of 24 hours.

For joints up to and including 25 mm, the material shall be in a single piece with thickness to conform to the width of the joint. For joints over 25 mm, the material may be in one or two layers with total thickness to conform to the width of joint.

## 10.8 RETROREFLECTIVE SHEETING

The retroreflective sheeting used shall be suitable for the manufacturing of traffic signs, directional signs, street name signs and miscellaneous signs.

### 10.8.1 Material

The sheeting material to be used shall comply with ASTM D4956-09 Type I to XI.

### 10.8.2 Test of Reflective Sheeting and Test Report

The test methods for reflective sheetings shall conform with ASTM D4956-09.

The test reports shall cover all colours of sheeting called for in this contract and together with 1 square foot sample for each colour of sheetings and/or materials shall be submitted to the Engineer for approval before installation.

### 10.8.3 Warranty for the Reflective Sheetings and Vinyl Films

10.8.3.1 The Contractor shall jointly with the manufacturer issue a warranty to cover the quality and performance of the reflective sheetings and vinyl films in respect of colour fungus resistance and adhesion for the warranty period. The form of warranty shall be in accordance with the format shown in the General Specification.

10.8.3.2 The different sheeting and their period of Guarantee from completion of whole of the works are listed below:

| | | | |
|---|---|---|---|
| (a) | Type I and II | - | 3 years |
| (b) | Type III to VI | - | 7 years |
| (c) | Type VII to XI | - | 7 years |

10.8.3.3 For reflectivity sheetings, the guarantee shall also cover its retroreflective elements for the guaranteed period. The manufacturer is required to satisfy the Engineer by performing with an approved retroreflectometer that the reflective sheeting complies with the Federal Test Method 370 / ASTM E810 to check the submitted test result at the commencement of the Contract.

10.8.3.4 The minimum coefficient of retroreflective values of the reflective sheeting at end of warranted life shall comply with ASTM D4956-09.

10.8.3.5 The testing with the retroreflectometer has to be performed by the manufacturer to check every batch of reflective sheeting which is supplied to his Contractor to ensure that they comply with the minimum requirement as well as to check the performance of the reflective sheetings used on the signs at the end of the guaranteed period.

10.8.3.6 The readings recorded shall achieved in respect of retroreflective element and colour.

10.8.3.7 The sheeting manufacturer shall replace the signs that could not meet the aforesaid Clause within seven (7) days from being informed by the Engineer.

10.8.3.8 All completed signs shall have a coloured sticker at its rear/underside/post indicating the month and year of manufacture which shall constitute the start of the warranty. Stickers of various colours will be used to indicate the different year of manufacture as shown in Appendix 1.

10.8.3.9 The Engineer and the sheeting manufacturer shall have access to the Contractor's sign fabrication workshop to perform quality audit as necessary at all reasonable times.

**10.8.4 Transparent Process Inks**

10.8.4.1 These inks are to be used in conjunction with the reflective sheeting in the manufacturing of road signs.

10.8.4.2 The ink shall be transparent in nature such that light can pass and be reflected through it when painted on the surface of the reflective sheeting.

10.8.4.3 It shall have comparable reflectivity to that of the reflective sheeting and good reflection shall be cast back to the light source in similar range of angles of that sheeting.

10.8.4.4 It shall have high durability and resistance to fading under local weather conditions, heat and humidity. It shall not crack, delaminate and peel after being applied on the reflective sheeting and used on the roads. The expected life of the ink shall not be less than the life of the sheeting.

10.8.4.5 A Test Report from an accredited laboratory shall be submitted to the Engineer for acceptance before the transparent process ink is used.

10.8.4.6 The Test Report shall include at least the following information: the degree of transparency, the intensity of reflection when used in conjunction with different colours of sheeting, durability under weather, heat and moisture effects, stability of colour etc.

10.8.4.7 The contractor shall jointly with the manufacturer issue a warranty to cover the quality and performance in terms of reflectivity, colour, cracking and peeling of the transparent process inks. The period of Guarantee from completion of whole of the works for the transparent process ink are listed below:

(a) Type I and II sheeting - 3 years

(b) Type III to VI sheeting - 7 years

(c) Type VII to XI sheeting - 7 years

## 10.9 RAISED PAVEMENT MARKERS

### 10.9.1 Construction

(a) The lens shroud or the main body shall be of die-cast aluminium material. When installed they shall not project over the road surface by more than 25mm.

(b) The body shall have all rounded edges and all angles to the horizontal shall not exceed 60 degrees.

(c) The marker shall be of anchored type. The length of the stem shall be between 50mm and 80mm long.

(d) The filling compound shall be of epoxy based adhesive.

### 10.9.2 Reflectors

(a) All markers shall be reflectorised markers.

(b) The reflector or the reflective device shall be permanently attached to the body of the marker.

(c) The reflector shall be mounted in a protected recess of the marker.

(d) The reflectors shall be a series of small bi-convex glass lenses arranged in strips with minimum 30 lens per face, or with a retro-reflective area not less than 25cm$^2$ per face.

### 10.9.3 Effectiveness

The reflectors shall work by the principle of the incident light of the vehicle headlights being reflected back to the source.

### 10.9.4 Installation

(a) The installed marker shall be able to resist twisting, forward or sideward movement.

(b) If any of the markers are dislodged during the first year, the contractor shall replace them with the new ones.

(c) Traffic shall be allowed to go over the installed area within half an hour.

## 10.10 PRECAST CONCRETE KERBS AND DIVIDERS

All precast concrete kerbs and dividers shall conform to the drawings and requirements in SS 214.

## 10.11 SIGN DATING STICKER

All completed traffic signs must be dated according to the following sign dating colour coding system. The sign dating stickers will signal the start of the warranty period which is a requirement of the Traffic Sign specification.

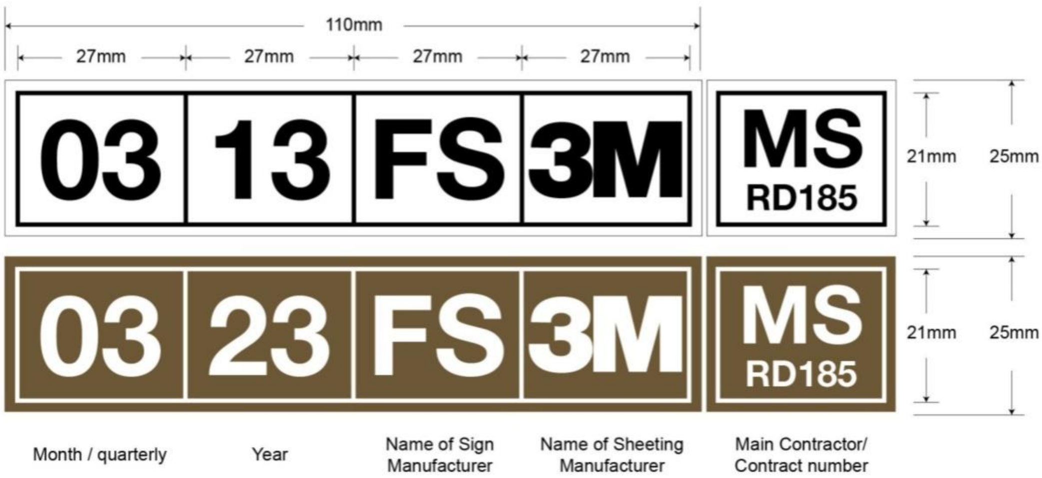
The sign dating sticker is used for sign inventory maintenance as reference to the fabrication month and year, sign manufacturer, sheeting manufacturer, main contractor and contract number.

The following constitutes a 14-year cyclical colour coding system for the signages.

| Year | Background Colour | Legend |
|---|---|---|
| 2013 | White | Black |
| 2014 | White | Red |
| 2015 | White | Blue |
| 2016 | White | Brown |
| 2017 | White | Green |
| 2018 | White | Orange |
| 2019 | White | Violet |
| 2020 | Black | White |
| 2021 | Red | White |
| 2022 | Blue | White |
| 2023 | Brown | White |
| 2024 | Green | White |
| 2025 | Orange | White |
| 2026 | Violet | White |

Example of Sign Dating Sticker

Type font : Helvetica Bold
Size : 50pt
Colour : Black




2013-2026, Colour Coding

# CHAPTER 11

# CONCRETE AND REINFORCEMENT BARS

## 11.1 CONCRETE MIX

### 11.1.1 General

The Contractor shall select the mix proportions and constituents in order to satisfy the requirements of the Contract.

Only designed mix approved by the Engineer shall be used for all Works.

All Ready-Mixed Concrete (RMC) shall be supplied by RMC producers from plants and batching plants on site which are certified under the Singapore Accreditation Council (SAC)'s Certification Scheme and in accordance with SS EN 206-1 and SS 544.

## 11.2 CONSTITUENT MATERIALS OF CONCRETE

The Contractor shall supply to the Engineer, test results to demonstrate compliance with the Standards.

### 11.2.1 Cement

The cement to be used in the Works shall be Portland cement specified in SS EN 197. Any proposal by the Contractor to partially substitute any cementitious materials, such as pulverised fly ash (PFA), ground granulated blast furnace slag (GGBS) or silica fume, for Portland cement shall be submitted for Engineer's acceptance. The Contractor shall not change the cement brand or source of any approved cementitious material until he has obtained permission in writing from the Engineer prior to the change.

PFA and GGBS mineral admixtures, where proposed to be used shall comply with the requirements in BS EN 450-1 and SS EN 15167 respectively. The silica fume shall comply with the requirements in BS EN 13263.

### 11.2.2 Aggregates

All aggregates for use in concrete shall comply with SS EN 12620. Aggregates used shall not be alkali reactive. Marine aggregates shall not be used.

Sampling and testing of all aggregates shall be carried out in accordance with the requirements of BS EN 932 Part 5 and Part 6, BS EN 933 Part 3 and Part 7, BS EN 1744 Part 1 and BS EN 1367 Part 4. Mortar Bar tests shall be conducted to determine whether or not the aggregate is alkali-reactive.

Grading tests shall be carried out before the start of any production and at weekly intervals when concrete is being produced. The Engineer reserves the right to draw samples of aggregates from any stockpile at any time for testing and the Contractor shall deliver the samples at his cost to any approved accredited laboratory. Aggregates whose grading, are found to fall outside the accepted zone shall be rejected.

#### 11.2.2.1 Washed Copper Slag (WCS) and Recycled Aggregates

The use of washed copper slag (WCS) or recycled concrete aggregates shall only be allowed for non-structural elements as listed below.

(a) Non-suspended slab excluding rigid pavement, approach slab and floor slab within a building or at apron and entrance area

(b) Road kerbs and drop inlet chambers

(c) Open channel up to type C7 size

(d) Blinding concrete

(e) Haunching to utility services

(f) Non load bearing RC walls

Quality control and testing plan shall be the same as normal concrete. All tests shall be carried out by laboratories independent from the concrete supplier.

### 11.2.3 Water

Water shall be clean and free from harmful matter. If taken from a source other than the Public Utilities Board, water shall be tested in accordance with BS EN 1008 and shall be subject to the Engineer's acceptance.

### 11.2.4 Admixtures

All admixtures for use in concrete shall comply with SS EN 934. Information to be submitted for the Engineer's acceptance before any admixture is supplied shall be in accordance with SS EN 934.

All admixtures shall be used strictly in accordance with the manufacturer’s instructions.

All concrete used to fill temporary construction holes (for example, in viaduct girders) shall be provided with an acceptable shrinkage compensating admixture.

## 11.3 REQUIREMENTS FOR APPROVED DESIGNED MIX

11.3.1 In designed mixes, the strength shall be the main criterion specified, with compliance to minimum and maximum cement content, and maximum water/cement ratio. Mix design shall be based on a target mean strength not less than the specified characteristic strength plus 8 $N/mm^2$.

11.3.2 Design of mix shall ensure no segregation and no excessive bleeding.

11.3.3 The Contractor shall submit the appropriate information as described in SS EN 206-1 for the Engineer's acceptance before any concrete is supplied.

11.3.4 Trial mixes of three separate batches of concrete shall be made using accepted materials and produced under full-scale production conditions. Sampling and testing shall be in accordance with SS EN 206-1.

11.3.5 The workability of each of the three trial batches shall be determined and six cubes made from each batch. Three from each set of six shall be tested at an age of 28 days, and three at an earlier age accepted by the Engineer. The average strength of the nine cubes tested at 28 days shall exceed the specified characteristic strength by at least 10$N/mm^2$.

11.3.6 During production the Engineer may require additional trial mixes to be made before a substantial change is made in the materials or in the proportions of the materials to be used. They need not be carried out when adjustments are made to the mix proportions in accordance with Clause 11.8.

11.3.7 The proportion of PFA and GGBS content in the concrete designed mix shall be in accordance to SS 544 Part 2 (Concrete – Complementary Standard to SS EN 206-1).

## 11.4 REQUIREMENTS FOR FRESH CONCRETE

The workability of the fresh concrete shall be such that the concrete is suitable for the conditions of handling, placing and compaction.

The temperature of concrete at the plant shall not exceed 32°C.

## 11.5 REQUIREMENTS FOR HARDENED CONCRETE

11.5.1 The grade of concrete to be used in the Works shall be as defined by the characteristic strength in $N/mm^2$ at 28 days as determined from test cubes.

11.5.2 The total chloride content of the concrete mix arising from the aggregate together with that from any admixtures and any other source shall not in any circumstances exceed the limits in SS EN 206-1 When required by the Engineer, the Contractor shall carry out tests to demonstrate that these limits are not exceeded.

11.5.3 The levels of acid-soluble sulphates (as $SO_3$) shall generally not exceed the following limits, which are indicative for the individual constituents of the mix and are subject to the overriding maxima specified for the total mix:

| | |
|---|---|
| Coarse aggregate | 0.4% by weight |
| Fine aggregate | 0.4% by weight |
| Fresh water | 500 mg/l |

11.5.4 The total estimated sulphate content as $SO_3$ of any mix, including that present in the cement shall not exceed 3.7% by weight of cement in the mix.

11.5.5 When directed by the Engineer, tests in accordance with BS 1881: Part 124 shall be made on hardened concrete to determine the total sulphate content as $SO_3$ of any mix. The concrete shall be rejected if the sulphate content exceeds 4% by weight of cement in the mix.

## 11.6 PRODUCTION OF CONCRETE

### 11.6.1 General

11.6.1.1 The production of concrete by the RMC producers shall be subject to the SAC certification scheme where the certification standards are in accordance with SS EN 206-1, SS 544: Part 1 and SS 544: Part 2.

11.6.1.2 In the event that the production of concrete is being carried out outside of Singapore, the requirements of SS EN-206-1, SS 544: Part 1 and SS 544: Part 2 shall be complied with. Proper records shall be maintained at the production plant for surveillance audit by the Engineer.

11.6.1.3 The supervision employed shall be such as to ensure the required standard of control over materials and workmanship. The Engineer shall be given all reasonable opportunity and facility to inspect the materials and manufacture of concrete and to take any samples or to make any tests, which he may require.

### 11.6.2 Ready Mixed Concrete

11.6.2.1 Ready mixed concrete shall be carried in purpose made agitators, operating continuously, or truck mixers. All concrete delivered to site shall be accompanied by a delivery docket, which can be traced to the relevant individual batching records, clearly stating the time batched, grade of concrete, specified slump, cement content and special features such as additives used.

11.6.2.2 The maximum elapsed time from the charging of the mixer with all dry materials to the discharging of the ready-mixed concrete at the site in accordance with Table 11.1. Where admixtures are used to accelerate or retard setting, the Contractor shall propose, to the Engineer for his acceptance, revised elapsed times and provide the evidence to support such figures.

**Table 11.1**

| Concrete temperature at time of placement | Maximum elapsed time from charging mixer to discharge in the forms |
|---|---|
| 5°C - 24°C | 1 hour 30 minutes |
| 24°C - 27°C | 1 hour 15 minutes |
| 28°C - 30°C | 1 hour |
| 31°C - 32° C | 45 minutes |
| 33°C - 36°C | 30 minutes |

11.6.2.3 When truck mixed concrete is used, under no circumstances shall water be added in transit.

## 11.7 CONTROL OF STRENGTH OF DESIGNED MIXES

Any adjustments of mix proportions made in order to minimize the variability of strength and to approach more closely the target mean strength shall be subjected to the approval of the Engineer. Such adjustments are regarded as part of the proper control of production but the specified limits of minimum cement content and maximum water/cement ratio shall be maintained. Such adjustments to mix proportions shall not be taken to imply any reduction in the target mean strength.

## 11.8 TESTING AND SAMPLING OF FRESH CONCRETE

### 11.8.1 General

11.8.1.1 The Contractor shall ensure that all sampling and testing of fresh and of hardened concrete are carried out by RMC producers from plants which are certified under the SAC's Certification Scheme in accordance with the relevant parts of SS EN 206-1. The RMC producer's testing laboratories including all site batching plants and testing facilities shall be fully certified and all certificates shall be submitted to the Engineer for his acceptance.

11.8.1.2 The RMC producer shall submit all test records and conduct statistical trend analysis in determining the product compliance with the relevant standards timely to the Engineer through the Contractor. All such documentation to be submitted to the Engineer shall be endorsed by the Contractor.

11.8.1.3 The Contractor shall ensure that the RMC producer(s) appointed by him will allow full access to the Engineer and Authority's appointed supervisory staff to all batching plants, testing laboratories and concrete testing facilities.

### 11.8.2 Rates of Sampling at Site

11.8.2.1 Unless directed otherwise by the Engineer, the minimum sampling rates shall be:

(i) For prestressed concrete members or for structural reinforced concrete members;

| Vol. of concrete ($m^3$) | Minimum numbers of samples |
|---|---|
| < 10 | 1 |
| 11 - 40 | 2 |
| 41 - 100 | 3 |
| 101 - 400 | 4 |
| 401 - 2500 | 2 + 1 sample per 200$m^3$ or less |
| >2500 | 15 |

(ii) For mass concrete of any grade required for each range of the concrete volume the number of samples in item (i) shall be reduced proportionally by half and rounded up to the next highest integer.

11.8.2.2 The actual rate of sampling at any time may be expected to fluctuate according to the random selection of batches to be sampled and may be increased in appropriate circumstances.

11.8.2.3 A batch shall be defined as the quantity of concrete mixed in one cycle of operations of a batch mixer or the quantity of concrete delivered to site ready mixed in a vehicle.

11.8.2.4 Where there are more than one plant supply, the sampling rate shall be proportionally distributed among the suppliers based on the volume of concrete generated from the supplier's plant.

11.8.2.5 An early assessment shall be made of the 28-day strength using a method acceptable to the Engineer. The mix shall be adjusted as necessary to achieve the specific characteristic strength.

11.8.2.6 In the event that additional test cubes are required by the Engineer to verify concrete strength prior to any struts/formwork removal, the Contractor shall make provision of taking these additional cubes including any subsequent retesting.

### 11.8.3 Testing Plan

11.8.3.1 A sample shall be taken from a randomly selected batch of concrete. The samples, whenever practicable, shall be taken at the point of discharge from the mixer or in the case of ready mix concrete at the point of discharge from the delivery vehicle. Cubes shall be prepared and cured as follows:

(a) For reinforced concrete and mass concrete, 4 cubes shall be made from each sample of concrete taken; 2 cubes for test at 7 days and 2 cubes for test at 28 days. The actual section of the structure represented by test result shall be included in the test report.

(b) For prestressed concrete, the following conditions shall apply:

(i) At least two cubes shall be tested prior to each stage of prestressing work to ensure that the minimum transfer strength for each stage has been attained.

(ii) At 28 days, at least two further cubes shall be tested to determine the characteristic strength of the sample.

11.8.3.2 The average of the cube results tested at 28 days for any given sample shall be the test result.

11.8.3.3 When the difference in strength between the two cubes divided by their mean exceeds 15%, the test result shall be deemed invalid.

### 11.8.4 Compliance Requirements

11.8.4.1 Compliance with the specified characteristic strength is attained if the average strength determined from each group of four consecutive test results and if each individual test result complies with the appropriate limits of SS EN 206-1.

11.8.4.2 Where concrete for the project is supplied by more than one source, the compliance requirement shall be determined based on the groups of results analyzed separately from each source.

11.8.4.3 Where less than four test results are available for a particular grade of concrete from a particular source, compliance shall be based on groups of two or three test results (the higher available number shall be used) in accordance with SS EN 206-1.

### 11.8.5 Quantity of Concrete Represented by Strength Test Results

(a) The quantity of concrete represented by any group of four consecutive test results shall be the quantity represented by the first to the last test samples in the group.

(b) When individual test result fails to comply with the requirements of SS EN 206-1, only the quantity of concrete represented by the particular sample shall be at risk.

(c) The quantity of concrete considered to be represented by a particular sample shall be the actual sampling rate, i.e. if for a particular pour of Q $m^3$, t samples are taken, then the quantity of concrete represented by a particular sample shall be (Q/t) $m^3$.

### 11.8.6 Action on Non-Compliance

11.8.6.1 In the event of non-compliance with the testing plan outlined in SS EN 206-1, the following actions shall be taken:

11.8.6.2 The Contractor shall before proceeding with further concreting, submit to the Engineer for acceptance, details of the action proposed to ensure that the concrete still to be placed in the Works will comply with the requirements of the Specification.

11.8.6.3 The Contractor shall propose what action is to be taken with regard to the defective concrete already placed.

11.8.6.4 In estimating the quality of the sub-standard concrete and in determining the action to be taken, the Contractor shall establish the following,

(a) The actual section of the structure represented by the test cube(s).

(b) The possible influence of any reduction in concrete quality on the strength and durability of this section of the structure

11.8.6.5 The Engineer may require tests on the hardened concrete in the structure, such as the taking of cores in addition to non-destructive tests.

### 11.8.7 Cement Content and Free Water/Cement Ratio

11.8.7.1 The maximum cement content shall be limited by the need for temperature control when early thermal and drying shrinkage are potential causes of cracking. For Ordinary Portland Cement (OPC), the maximum cement content shall not exceed 400kg/$m^3$.

11.8.7.2 The maximum free water cement ratio shall not exceed 0.45.

11.8.7.3 The above represent the maximum typical requirements. The design shall allow for more onerous exposure conditions and/or aggressive chemical and physical conditions where such conditions are likely to be present.

### 11.8.8 Percentage Air Content

The percentage air content determined from individual samples taken at the point of placing the concrete and representative of any given batch of concrete shall comply with SS EN 206-1.

### 11.8.9 Workability of Concrete

The workability of concrete shall be within the limits, specified in SS EN 206-1.

## 11.9 SURFACE FINISH OF CONCRETE

### 11.9.1 General

11.9.1.1 For all visible concrete, uniformity of colour and texture are important and all materials shall be obtained from single consistent source. The aggregates shall be durable and free of any impurities, which may cause staining. The mix proportions and the grading, particularly of the fine aggregate, shall be maintained constant. Any partial replacement of individual plywood sheets or sections of timber in large panels shall be avoided.

11.9.1.2 Where formwork ties or other embedded ferrous metal parts are built into the concrete, the whole or part of any such supports shall be capable of removal so that any part that remain embedded in the concrete shall be at less 50mm away from the surface. Holes left after the removal of such parts shall be neatly filled with well-rammed, colour matched, dry-pack mortar.

11.9.1.3 Release agents for formwork shall be carefully chosen for the particular conditions to ensure the compatibility of the release agent with the finish. Release agents shall be applied evenly and contact with reinforcement and shall be avoided. Where a concrete surface is to be permanently exposed only one release agent shall be used throughout the entire area.

11.9.1.4 For all concrete visible to the Engineer, appearance is important, and curing methods and conditions including the time of removal of formwork shall receive careful consideration. Components that are intended to have the same surface finish shall receive the same treatment and the same curing regime. Where the surface is to receive an applied finish, the Contractor shall ensure the compatibility of any sprayed on curing membrane with the finish to be applied.

### 11.9.2 Surface Finishes from Formwork or Moulds

11.9.2.1 Surface finishes from formwork or moulds shall comply with the requirements of the classes shown below:

| | |
|---|---|
| Class F1 | General surface where the finish is intended to be left as struck. |
| Class F2 | The irregularities in the finish shall be no greater than those obtained from the use of wrought board arranged in a uniform pattern. The finish is intended to be left as struck but imperfections such as fins and surface discolouration shall be made good by methods accepted by the Engineer. |
| Class F3 | The formwork shall be lined with a material accepted by the Engineer to provide a smooth finish of uniform texture and appearance. This material shall leave no stain on the concrete and shall be so joined and fixed to its backing that it imparts no blemishes. It shall be of the same type and obtained from only one source throughout any structure. The Contractor shall make good any imperfections in the finish as required by the Engineer. Internal ties and embedded metal parts will not be allowed. |
| Class F4 | The requirements for Class F4 are as for Class F3 except that internal ties and embedded metal parts will be permitted. The ties shall be positioned only in rebates or in other positions as described in the Contract or as accepted by the Engineer |
| Class F5 | The requirements for Class F5 are as for Class F3 except that the formwork has a profiled face consisting of vertical grooves approximately 25mm wide and 15mm deep, tapered section as necessary, at approximately 200mm centres. |
| Class F6 | The requirements for Class F6 are as for Class F5 except that the grooves are at approximately 750mm centres |
| Class F7 | The requirements for Class F7 are as for Class F2. Internal ties and embedded metal parts will not be allowed |

11.9.2.2 Permanently exposed concrete surfaces to all classes of finish shall be protected from rust marks and stains of all kinds.

11.9.2.3 All formwork joints for exposed surfaces of concrete to Classes F2, F3, F4, F5 and F6 finish shall form a regular pattern with horizontal and vertical lines continuous throughout each structure and all construction joints shall coincide with these horizontal or vertical lines.

### 11.9.3 Surface Finishes of Unformed Surfaces

Surface finishes of unformed surfaces shall comply with the requirements of the classes shown below:

| | |
|---|---|
| Class U1 | The concrete shall be levelled and screeded to form a uniform plain or ridged surface |
| Class U2 | After the concrete has hardened sufficiently the Class U1 finish shall be floated by hand or machine sufficiently only to produce a uniform surface free of screed marks |
| Class U3 | When the moisture film has disappeared and the concrete has hardened sufficiently to prevent laitance from being worked to the surface, a Class U1 surface shall be steel trowelled by hand or machine under firm pressure to produce a dense, smooth uniform surface free from trowel marks. |

### 11.9.4 Cementitious Spray Tile Finishes

11.9.4.1 Where cementitious spray tile finishes are required for concrete structures, the finishes shall be of a textured roughened non-slip, moisture absorbent-typed surface.

11.9.4.2 The primer, which shall be used as a bonding agent between the substrate surface and cementitious finishes, shall be of the synthetic latex resin type. The primer shall possess strong adhesive strength, excellent resistance to both water and alkali. The primer shall also have waterproofing properties.

11.9.4.3 The main ingredients for the cementitious finishes to be used shall consist of methyl-cellulose additive, Portland Cement, calcium carbonate powder, limestone (white aggregate) and perlite. Methyl-cellulose additive shall be of water-soluble type.

11.9.4.4 The cement and water shall be in accordance with Cl.11.2.1 and Cl.11.2.3 of these Specifications respectively.

11.9.4.5 The materials shall be obtained from a consistent and reliable source. All materials shall be delivered to site in their original packing.

11.9.4.6 Before the commencement of work, trial panels of size 750mm x 750mm of required quality, texture and finishes shall be prepared on site. All subsequent finishes shall be similar to the approved trial panel. The trial panel shall not be removed from site until the entire Works have been completed to the Engineer's acceptance.

11.9.4.7 The concrete surface shall be free of dirt, dust, grease, oil, mould release agents, bond breakers, laitance and any other contaminants that may interfere with adhesion. The primer shall not be applied within 14 days after the casting of concrete and the before the surface is thoroughly dried.

11.9.4.8 All cracks, blisters, fins, honeycombing and uneven joints/surface shall be made good by approved methods and materials. The surface shall be smoothened prior to the application of the coating.

11.9.4.9 No primer coats shall be applied until all the surfaces have been prepared and inspected and subsequently approved by the Engineer. Similarly, no finishing coats shall be applied until the Engineer has approved the previous coat.

11.9.4.10 The Contractor shall submit the method statements to the Engineer for acceptance, two weeks prior to the commencement of Works. Prior to commencement of coating application, the Contractor shall submit to the Engineer, the proven track record of the operators. Where required by the Engineer, the operators shall carry out trial panels to confirm their competence. The Engineer's approval shall be obtained prior to the deployment of the operators on site.

11.9.4.11 The materials shall be batched in the correct proportions in strict accordance with the manufacturer's specifications and instructions. Application methods shall be by brush, roller, spray or airless spray as recommended by the manufacturer.

11.9.4.12 The total minimum thickness of the coating shall be at least 9mm, built up in at least 3 coats of 3mm each. The final finish shall have consistent colour and texture. No coat shall be applied under adverse weather conditions such as during heavy rain. All works shall be covered up with tarpaulin sheets for protection.

## 11.9.5 Protective Coatings for Concrete Surface

### 11.9.5.1 Scope

11.9.5.1.1 Where specified in the Contract, protective coatings shall be applied to concrete surface areas as follows:

(a) Approved anti-carbonation / epoxy / silane based protective coatings on all repaired concrete surfaces (such as jacketing repairs, patch repairs and crack repairs)

(b) Approved polyurethane coatings on the bridge parapet system covering the outer face (traffic side), top sides, inner face (pedestrian side or edge of the bridge), end and wing walls.

(c) Approved anti-carbonation protective coatings for all exposed structural elements at the underside of bridges including beams, columns, soffit of deck slab, abutments, crossheads, transverse beams, diaphragm beams, wing walls, etc.

(d) Approved epoxy/silane based protective coatings for all exposed structural elements of drain culverts and at the underside of bridges spanning across waterways including beams, columns, piers, soffit of deck slab, abutments, crossheads, transverse beams, diaphragm beams, wing walls, exposed piles, etc.

11.9.5.1.2 The Contractor is required to carry out all works as specified and indicated by the Engineer. When applying the coatings, it must be able to mask the repair areas and attain a uniform appearance compared to the surrounding surface.

### 11.9.5.2 Sampling Requirements for Protective Coating

The minimum sampling of protective coating shall be in accordance to Table 11.2. If the delivery consists of different batches, then containers from every batch shall be sampled in accordance to Table 11.2. The tests shall be carried out by a Singapore Accreditation Council (SAC-SINGLAS) accredited laboratory that is accredited to carry out the tests specified in Table 11.3. If the tests show that the protective coatings do not meet the performance requirements in Table 11.3, the entire batch of the protective coating shall be rejected and the Contractor shall submit rectification proposal for the Engineer's acceptance.

**Table 11.2 Minimum Sampling Rates for Protective Coating in accordance to SS 5: Part A1: 2003**

| Total Number of Container(1) Delivered to Site (For each batch), **N** | Minimum Number of Containers to be Sampled, **n** |
|---|---|
| Up to 2 | All |
| 3 to 8 | 2 |
| 9 to 25 | 3 |
| 26 to 100 | 5 |
| 101 to 500 | 8 |
| 501 to 1000 | 13 |
| Thereafter | n = SQRT(N/2) |
| **Note:** 'Containers' shall include barrels, drums, sacks and tins. | |

### 11.9.5.3 Performance of Coating

11.9.5.3.1 Protective coatings shall be capable of improving the appearance of the concrete surface with the capability to repel dust and dirt; prevent fungus and algae growth; and bridge and seal hairline cracks.

11.9.5.3.2 The protective coatings shall be of an anti-graffiti type that is easily washable with non-stick capability that would allow for easy cleaning and removal of graffiti paint with the use of solvent.

11.9.5.3.3 The protective coatings shall be non-toxic, environmentally friendly and safe for use.

11.9.5.3.4 The minimum requirements for protective coating shall comply with Table 11.3.

**Table 11.3 Minimum Requirements for Protective Coating**

| | | |
|---|---|---|
| Algae Resistance | SS 345 | No algae growth |
| Alkali Resistance | SS 5: Part G2 | No visible change |
| Adhesion Test to Dry Concrete | BS EN ISO 4624 | 1.1N/mm$^2$ for Vertical Surface<br><br>1.5N/mm$^2$ for Horizontal surface |
| Adhesion Test to Wet Concrete | BS EN 1542 | $\geq$1.5 N/mm$^2$ at typical DFT |
| Compatibility of Coating to Wet Concrete Surface | BS EN 13578 | Surface free from blistering |
| Accelerated Weathering | BS EN 1062-11 | No blistering, cracking or flaking after 3000hrs |
| Crack Bridging Properties | BS EN 1062-7 | Up to 2mm |
| Elongation at Break | BS ISO 37 | 125% at 130microns DFT |
| Water Vapour Transmission Rate | BS EN ISO 7783 | Less than 4m equivalent air layer thickness |
| Carbon Dioxide Diffusion | BS EN 1062-6 | Diffusion equivalent air layer thickness, R >50m |

### 11.9.5.4 Proprietary Materials

The Contractor shall submit details of all proposed proprietary materials of the protective coatings system complete with proven track record and relevant test data of the proposed materials used in similar tropical weather condition to Singapore to the Engineer for acceptance.

All accepted proprietary materials shall be used in strict accordance with the manufacturers' recommendations.

### 11.9.5.5 Colour Schemes for Coating

The Contractor shall submit the colour chart of the coatings to the Engineer for selection. The Engineer may select a few colour schemes and the Contractor is required to demonstrate by preparing the concrete surface and applying the coatings to the standard as specified by the manufacturer and this Specification. The location of demonstration shall be as indicated by the Engineer. When the demonstration is successful, the demonstration panel shall be kept as the reference panel.

### 11.9.5.6 Anti Carbonation Coatings

Anti-carbonation coatings shall be applied in at least two coats to give a total dry film thickness of not less than 200 microns. The thickness of the coating shall be determined in accordance with SS 5: Part B1. Coatings shall be applied evenly and shall be free from imperfections, brush marks or pinholes.

### 11.9.5.7 Polyurethane Resin Coatings

Polyurethane resin coatings shall be 2-coat system consisting of a high build epoxy polyamide prime coat and a polyurethane enamel finish coat giving a total dry film thickness of not less than 180 microns. The thickness of the coating shall be determined in accordance with SS 5: Part B1.

### 11.9.5.8 Coatings for Marine Environment / Waterways

Epoxy/silane based protective coatings shall make up of at least 3 coats consisting of a primer, an undercoat and a finishing coat giving a total dry film thickness of not less than 240 microns. The thickness of the coating shall be determined in accordance with SS 5: Part B1. When required, an alkali resistant sealer shall be applied to the concrete surface to provide an even surface with good key to the primer.

### 11.9.5.9 Workmanship for Concrete Protective Coatings

**a) Preparation of concrete surfaces**

Areas to receive protective coatings shall be prepared as follows:

(i) Coatings shall be prepared and applied strictly to the method as recommended by the manufacturer. Surfaces to receive coatings shall be sound, free from laitance and contamination such as oils and greases and shall be at least 28 days old.

(ii) The concrete surface shall be coated as soon as possible after cleaning. There shall be no wet sheen or obvious damp appearance on the concrete surface at the start of coating.

(iii) Remove all existing decorations, surface coatings and projections. The Contractor shall be responsible to liaise and obtain the necessary approval from all relevant authorities before removing any creepers, plants, etc that affect their works.

(iv) Remove all dirt, grease, mould oils, curing compounds, organic growth and loose materials by water jet or other approved process.

The Contractor shall patch and cover blowholes, depressions and shrinkage cracks and cracks less than 0.4 mm wide with approved cementitious mortar. For cracks more than 0.4mm, the Contractor shall submit a repair methodology to the Engineer for his acceptance. After patching up the defects, the Contractor shall apply a layer of skim coat to the concrete surfaces before application of the protective coatings. The Contractor must ensure that all surfaces receiving the coatings are prepared, clean and free of defects before application of coatings.

**b) Cementitious Mortar**

Cementitious mortar to patch off or cover up unevenness or repair defective surfaces shall be applied as a thin layer not more than 10 mm in thickness to areas as directed by the Engineer.

Such patched over areas and other repaired areas shall be properly cured for at least 14 days before the application of any protective coating.

**c) Skim Coat**

Due to surface irregularities resulting from casting, finishing, repairs or surface preparation, some form of initial levelling, skim coat is necessary to ensure a smooth surface finish in the end product before the application of the protective coating. The Contractor shall identify these areas and propose a suitable product and method of application of the skim coat to the satisfaction of the Engineer.

The skim coat shall consist of 3 components or parts epoxy resin based material that finishes like concrete.

Generally, skim coat shall have the following characteristics:

(i) Excellent adhesive and cohesive strength (not less than 1.1 MPa cured at 20$^{o}$C).

(ii) Ability to seal and resist hair-line cracks.

(iii) Compatible with the overlaying coats.

(iv) Skim Coat shall be applied in a thin layer of not more than 5mm thick. It shall be used to cover up unevenness, imperfection and repaired areas and shall serve as an even base for the finishing coats to work on.

(v) The finished colour of the skim coat must match the existing concrete surface.

**d) Application of Protective Coating**

For pigmented coatings, each coat shall have different colour tints to allow for visual inspection. For those coatings that are colourless, each coat shall be inspected and accepted by the Engineer before the application of the next coat.

Coating work shall not start if weather conditions indicate that the work is likely to be interrupted by rain during the next 24 hours.

The coating material shall be mixed in clean containers before use and stirred **frequently** during use to prevent segregation. The use of thinners or dryers, if permitted, shall be strictly controlled.

**e) Recoating Requirements**

(i) The Contractor shall provide information on the methods of preparation to be used in the event that recoating of the painted surface is required.

(ii) The Contractor shall state which type of paint, other than the original product, are compatible with the finish coat for recoating purposes.

(iii) The Contractor shall provide information on the technique which can be used to repair local damage to the coating, with particular reference to colour and gloss matching of finish coats applied after a time lapse of 5 years.

(iv) The Contractor shall provide information on the most appropriate techniques for cleaning of the finish coat to remove surface soiling, with particular reference to ease of removal of graffiti or glued posters, where possible, without damage to the existing finish.

### 11.9.5.10 Warranty

The Contractor shall warrant the coatings system against peeling, blemish, growth and all defects and any malfunctioning from the Date of Completion of the whole of the Works. All defects occurring during this period are to be made good by the Contractor. The Warranty is to be provided jointly and severally by the Contractor and the manufacturer/supplier, and shall be in the format as specified.

## 11.10 CONSTRUCTION OF CONCRETE

### 11.10.1 Permissible Deviations For In-Situ And Precast Concrete Construction And Manufactured Precast Reinforced Concrete Components

11.10.1.1 The permissible deviations for in situ concrete and precast concrete construction shall comply with the values of permissible deviations given in BS 5606 and SS EN 1992 respectively. Any constructed concrete work after removal of the formwork which deviates from the intended size or position by more than the permissible values given in BS 5606 and SS EN 1992, shall either be liable for rejection or be rectified at the Contractor’s expense.

11.10.1.2 These permissible deviations shall not apply to the fabrication of the formwork.

11.10.1.3 In the case of prefabricated members, it shall be the responsibility of the Contractor to ensure appropriate fit notwithstanding the general permissible deviations given in SS EN 1992.

11.10.1.4 Notwithstanding the permissible deviations mentioned in this clause, the Contractor shall be responsible for the specified architectural finishes of the end product.

11.10.1.5 When directed by the Engineer, the Contractor shall provide the necessary manpower and tools for measuring the accuracy of the constructed in-situ and precast concrete works.

### 11.10.2 Load In Excess of Design Load

No load in excess of the design loading shall be placed on any portion of the structure.

### 11.10.3 Construction Joints

11.10.3.1 Construction joints shall be formed wherever there is a discontinuity in placing concrete in elements of concrete structures. A waterstop, which shall be either a hydrophilic expansion strip or a waterbar embedded in the structure, shall be incorporated in all construction joints in elements which form the external hull of underground structures, retaining walls and where otherwise specified in the Drawings.

11.10.3.2 Spacing of construction joints shall be in accordance with good concreting practice and adequate precautions shall be taken against shrinkage cracking. Concreting shall be carried out continuously. The joints shall be at right angles to the general direction of the member and shall take due account of shear and other stresses.

11.10.3.3 Concrete shall not be allowed to run to a feather edge and vertical joints shall be formed against a stop board. The top surface of a layer of concrete shall be level and reasonably flat unless design considerations make this undesirable. Joint lines shall be so arranged that they coincide with features of the finished work, wherever possible.

11.10.3.4 If a kicker (i.e. a starter stub) is used, it shall be at least 70mm high and carefully constructed.

11.10.3.5 Prior to re-commencement of concreting on a joint, the surface of the concrete against which new concrete will be cast shall be free from laitance and shall be roughened. Care shall be taken to ensure that the joint surface is clean and thoroughly wetted immediately before the fresh concrete is placed against it.

**11.10.4 Expansion, Contraction and Other Movement Joints**

11.10.4.1 Expansion, Contraction and Other Movement Joints shall be incorporated in the works as shown on the Drawings.

11.10.4.2 Polyethylene or similar material shall be used for expansion joint fillers and not fibre boards or bitumen impregnated material. Filler material shall be stored flat on a dry surface adequately protected from rain or moisture. Filler material that has been damaged or has started to deteriorate shall not be incorporated in the works.

11.10.4.3 The joint shall be sealed by an accepted sealer applied in strict accordance with the manufacturer's instructions to the dimensions shown on the Drawings. The surface of the concrete to which the sealer is to adhere shall be straight and cleaned of all filler material, dirt, oil, grease and other matter. The sealer shall be applied by methods recommended by the manufacturer so that the sealer is brought flush to the surface of structure and a smooth surface is achieved. Excess material and spillage shall be properly cleaned off and removed.

11.10.4.4 Dowel bars shall be installed and cast in across the movement joint where shown on the Drawings. The bars shall be straight with clean cut ends of the diameters and lengths as shown on the Drawings or in the Schedules. Cutting and cleaning of the dowel bars shall comply with the requirements of Clause 11.18 of this Specification.

11.10.4.5 The bars shall be firmly supported in the positions shown on the Drawings so that they are not displaced during the casting of the concrete in the first part of the structure. After the concrete has hardened and the formwork removed, the projecting ends shall be cleaned of all concrete spillage and painted with two coats of an accepted bituminous paint and caps shall be fitted to the free ends of the bars.

11.10.4.6 The Contractor shall protect the projecting ends of dowel bars from bending or other damage prior to concreting the succeeding bay. The bituminous paint shall be applied as soon as practicable, but end caps shall not be fitted until immediately prior to the succeeding concreting operations.

### 11.10.5 Fixing Blocks, Brackets, Cast-In Bolt Holes, Chases

11.10.5.1 All fixing blocks, brackets, cast-in bolt holes, chases, etc. shall be accurately set out and formed and carefully sealed prior to the concrete being placed. No cutting away of concrete for any of these items shall be done without the permission of the Engineer.

11.10.5.2 Bolts and other inserts to be cast into the concrete shall be securely fixed to the formwork in such a way that they are not displaced during the concreting operations, and that there is no loss of materials from the wet concrete through holes in the formwork.

## 11.11 CONCRETING OF THICK SECTIONS

11.11.1 Thick concrete section shall be defined as any structural element with its thickness exceeding 500mm. The Contractor shall take all necessary precautions and measures according to proven practices in concrete technology to prevent any form of cracking due to temperature and shrinkage effects in the casting of thick concrete sections. These shall be proposed by the Contractor and may include one or more of the following:

(a) GGBS, PFA or silica fume as a cement substitute to reduce heat of hydration and to increase durability and water tightness of concrete.

(b) Other admixtures to increase workability, improve durability and reduce heat of hydration if necessary. The admixtures to be used in concrete shall not contain chlorides.

(c) Use of flaked ice or liquid nitrogen as an additive to the concrete mix.

(d) A coolant system to contain the thermal difference and minimise thermal cracking of concrete where necessary.

(e) Controlled insulation of the concrete during curing.

(f) Delay in striking of formwork.

(g) Provision of pour strips

11.11.2 The Contractor shall ensure that casting of concrete for all thick sections is carried out in a continuous sequence. In addition, the Contractor shall submit a concrete casting plan with supporting calculations endorsed by a Professional Engineer to demonstrate that thermal and shrinkage effects are adequately addressed for the Engineer's acceptance. The Contractor may refer to CIRIA C660 or any equivalent Codes, Standards and guidelines for guidance in developing his concrete casting plan.

11.11.3 The temperature differential between the warmer interior portion and the cooler surface portion of the thick element shall be limited to 27.7°C to prevent early thermal cracking due to heat of hydration. The allowable differential shall take into consideration the boundary restraint of the structural element. The maximum temperature within the element shall not exceed 70°C. The Contractor shall propose a method of placing, curing, temperature monitoring and any other measures for acceptance by the Engineer. The Contractor shall demonstrate that his proposal shall be adequate to prevent cracking arising from heat of hydration and drying shrinkage. The design concrete mix submitted for acceptance by the Contractor shall take the above requirements into account. In the event that GGBS is being added as cement substitute at not less than 60% by mass to reduce heat of hydration, a maximum temperature within the element not exceeding 75ºC may be considered for acceptance by the Engineer. The Contractor shall carry out all necessary tests to demonstrate to the acceptance of the Engineer, that his proposed mix design together with his proposals to limit temperature differentials and to prevent early thermal cracking are satisfactory.

11.11.4 Silica fume shall form part of the cementitious content in the concrete mix for base slabs of all underground structures. The requirements for the use of silica fume shall be in compliance with Clause 11.22.

11.11.5 The Contractor shall provide and install thermocouples with electronic data recording equipment and any other necessary equipment and instruments to measure and monitor the concrete temperatures. The Contractor shall propose the location and the number of points, for thermocouples for the acceptance of the Engineer.

11.11.6 Notwithstanding the above measures and precautions the Contractor shall where practical seal, repair, and rectify any cracks on any concrete elements with epoxy resins or other accepted materials at his own expense.

## 11.12 FORMWORK

11.12.1 Formwork shall be designed to SS 580. The detailed design of the formwork shall be submitted to the Engineer for acceptance.

11.12.2 The design and construction of formwork shall take due account of the surface finish required. The formwork shall be sufficiently rigid and tight to prevent loss of grout or mortar from the concrete at all stages of placing and compacting.

11.12.3 Formwork (including supports) shall be sufficiently rigid to maintain the forms in their correct position and to correct shape and profile so that the final concrete structure is within the limits of the dimensional tolerances specified. The supports shall be designed to withstand the worst combination of self weight, formwork weight, formwork forces, reinforcement weight, wet concrete weight, construction and wind loads, together with all incidental dynamic effects caused by placing, vibrating and compacting the concrete.

11.12.4 The formwork shall be readily dismantled and removed from the cast concrete without shock, disturbance or damage.

11.12.5 The type and treatment of any lining to the forms shall be appropriate to the concrete finish required.

11.12.6 All external concrete corners required to receive waterproofing membranes and external surfaces of pre-cast elements shall be chamfered 15 x 15 mm, using hardwood fillets unless otherwise specified on the Drawings.

11.12.7 All rubbish shall be removed from the interior of the forms before the concrete is placed. The faces of the forms in contact with the concrete shall be clean and treated with a suitable release agent, where applicable. Due care shall be taken not to prejudice the future action of the hydrophilic expansion strip during cleaning / release agent operations.

11.12.8 Where holes are needed in formwork to accommodate projecting reinforcement or fixing devices, proper measures shall be taken to prevent loss of grout.

11.12.9 For sections forming the external hull of the underground structures, only cast-in formwork ties shall be used.

## 11.13 REMOVAL OF FORMWORK

11.13.1 Except for concrete being post-tensioned, no concrete shall be subjected to loading which will induce a compressive stress in it exceeding one third of its compressive strength at the time of loading, or one third of the specified characteristic strength whichever is less.

11.13.2 In the absence of other information, the recommended periods before striking formwork given in Table 5 of SS 580 may be used for concrete made with ordinary or sulphate-resisting Portland cement.

11.13.3 Any proposal to use shorter periods before striking formwork by determining the strength of the concrete in the structural element shall be to the acceptance of the Engineer. Any proposal put forward shall ensure that formwork supporting cast in situ concrete in flexure shall only be struck when the strength of the concrete in the element is 10 $N/mm^2$ or twice the stress to which it will be subjected, whichever is the greater. Any acceptance by the Engineer shall not relieve the Contractor from ensuring that striking at this time will not result in flexural cracking of the concrete or unacceptable deflection. The concrete strength in the structural element shall be assessed by test on cubes cured, as far as possible, under the same conditions as the concrete in the element.

11.13.4 When formwork to vertical surfaces such as beam sides, walls and columns is removed in less than 24 hours care shall be exercised to avoid damage to the concrete. The provision of suitable curing methods shall immediately follow the removal of the vertical formwork. The concrete shall be protected from high temperatures and suitable protection against heavy rainfall by means of suitable insulation.

11.13.5 Prior to the removal of formwork for thick section, particular care must be taken to ensure that cracking due to thermal shock does not occur. The Contractor's method statement shall consider the effect of formwork and striking times.

11.13.6 If the floor is to be used to support construction loads, props should be retained for 28 days unless the Contractor can demonstrate that the concrete has achieved the required strength from cube test.

11.13.7 The formwork shall be removed slowly, as the sudden removal of wedges is equivalent to a shock load on the partly hardened concrete.

11.13.8 Materials and plant shall not be stacked on any newly constructed floor unless sufficient support is maintained to withstand such loads without damaging the floor.

11.13.9 The Contractor shall repair all thermal cracks and shrinkage cracks to the satisfaction of the Engineer.

## 11.14 TRANSPORTING, PLACING AND COMPACTING OF CONCRETE

### 11.14.1 Method statements

Method statements for the transporting, placing and compacting of concrete shall be submitted to the Engineer for acceptance. The method statements shall demonstrate the means by which the contractor intends to ensure that the requirements of this specification are met, including for example, how the concrete will be properly compacted and cured. The statements shall highlight areas where special care is needed to ensure thorough compaction, such as around king posts (and others similar penetration), tendon ducts end blocks etc. The statement shall similarly highlight the treatment necessary to construction joints. Concrete shall not be poured when there is water, and before placing concrete, all forms shall be dry.

### 11.14.2 Transporting and Placing of Concrete

11.14.2.1 Concrete shall be transported from the mixer to the point of placing as rapidly as practicable by methods, which will prevent the segregation or loss of any of the ingredients and maintain the required workability. It shall be deposited as nearly as practicable in its final position to avoid re-handling.

11.14.2.2 All placing and compacting shall be carried out under the direct supervision of a competent member of the Contractor's staff.

11.14.2.3 Concrete used for lubricating pumplines shall not be incorporated into the concrete pour, but shall be disposed of outside the Permanent Works.

11.14.2.4 Care shall be taken to avoid the displacement of reinforcement or movement of formwork and damage to faces of the formwork.

11.14.2.5 Except where otherwise accepted by the Engineer, concrete shall be deposited in horizontal layers to a compacted depth not exceeding 300 mm where internal vibrators are used or 150 mm in all other cases.

11.14.2.6 The depth of lift to be concreted shall be the maximum that is compatible with the conditions of placing and compaction. A cohesive concrete mix, which does not segregate may be allowed to fall freely through any distance provided that special care is taken to avoid displacement of reinforcement or movement for formwork, and damage to faces of formwork. In massive sections it will be necessary to consider the effect of lift height on the temperature rise due to the heat of hydration.

### 11.14.3 Compaction

11.14.3.1 Concrete shall be thoroughly compacted by vibration. Vibration shall be applied continuously during the placing of each batch of concrete until the expulsion of air has practically ceased and in a manner which does not promote segregation of the ingredients.

11.14.3.2 Whenever vibration has to be applied externally, the design of formwork and disposition of vibrators shall receive special consideration to ensure efficient compaction and to avoid surface blemishes.

### 11.14.4 Protection Against Heavy Rainfall

When heavy rainfall is imminent, concreting shall not commence unless adequate provisions have been made to protect the formwork from flooding and non-hardened concrete from damage. Provisions such as temporary drainage openings in the formwork, suspended free draining covers and barriers to prevent flow of water into the work area from adjoining areas shall be provided.

### 11.14.5 Precautions During Hot Weather

During hot weather, additional precautions shall be taken to prevent premature setting and loss of water during the placing and compaction of concrete in the formwork. These precautions shall include:

(a) No concrete having an initial temperature exceeding the limits stated in clause 11.4 shall be deposited.

(b) Concrete shall not be placed in formwork or around reinforcement whose temperature exceeds 40°C.

(c) Newly placed concrete shall be protected by covering, shading or other means, from direct sunlight.

(d) No concrete shall be placed when the air temperature at the point of deposition exceeds 40°C.

### 11.14.6 Precautions for Thick Sections

11.14.6.1 For concrete sections thicker than 500mm, additional precautions shall be taken as defined in clause 11.11 of this Specification. The effectiveness of these precautions shall be assessed in every pour by monitoring the concrete temperature using thermocouples as follows:

(a) Three locations shall be monitored for each pour at positions to be determined by the Engineer.

(b) At each location, the following temperatures shall be monitored:

   (i) centre of the concrete section;

   (ii) 50 mm from an exposed surface;

   (i.e. walls: near face and far face: base slab: top)

(c) Monitoring shall commence from the time concrete is first discharged and may cease when the core temperature has fallen to 55°C.

11.14.6.2 Monitoring may be discontinued in subsequent pours of similar structural elements if the Contractor can demonstrate that the requirements of clause 11.11 are being met and that no thermal cracking of the concrete is occurring. Monitoring will be required again whenever in the opinion of the Engineer the nature of the concrete element being cast is changed or the precautionary measures initially adopted are modified.

### 11.14.7 Placing Concrete in Prestressed Concrete Work

11.14.7.1 Concrete in one pre-cast unit shall be placed in one continuous operation. The Contractor shall provide protective cover to avoid stoppage due to sudden rain. No unit shall be removed from the mould or erected until it has achieved its required strength.

11.14.7.2 For post-tensioned construction, temporary openings shall be provided in the formwork where necessary to enable placing and adequate compaction of concrete especially around and underneath duct and anchorages. Care shall be taken to avoid damaging the duct.

11.14.7.3 Vibrators shall not come into direct contact with the duct in the case of post-tensioned work. If the duct is damaged during concreting, the Engineer may reject the whole or a portion of the concrete cast. Duct shall be cleaned out within half an hour of completion of each concreting operation by blowing oil-free compressed air through the length of the duct.

### 11.14.8 Concreting of Anchorage Recesses

11.14.8.1 For post-tensioned work, the tendons shall be cut back to give a minimum of 30 mm cover after concreting of the recesses.

11.14.8.2 The interior surfaces of anchorage recesses shall be roughened.

11.14.8.3 Concrete conforming to the requirements of this Specification shall be cast in the recesses to the shapes designed. Prior to concreting, the surface of the anchorage recesses shall be coated with an accepted epoxy resin bonding agent.

## 11.15 CURING OF CONCRETE

### 11.15.1 Curing Methods

11.15.1.1 For concrete where elevated temperature curing is not used, curing measures shall be commenced immediately after compaction and continue for 4 days thereafter. The method of curing shall ensure that the concrete is protected against the harmful effects of weather including rain and rapid temperature changes and from drying out.

11.15.1.2 For thick sections, the curing time of 4 days shall be extended if the average temperature of the concrete during this period does not fall by more than 10°C. The extended time shall be calculated as equivalent maturity, in accordance with SS EN 1992-2.

### 11.15.2 Accelerated Curing

11.15.2.1 Elevated temperature curing may be used only with Ordinary Portland Cement. After the completion of the placing of the concrete, 4 hours shall elapse before its temperature is raised. The rise in temperature within any period of 30 minutes shall not exceed 10°C and the maximum temperature attained shall not exceed 70°C. The rate of subsequent cooling shall not exceed the rate of heating.

11.15.2.2 The maximum core temperature shall not exceed 70°C and the maximum differential between surface and core shall not result in cracking.

## 11.16 REPAIR OF CRACKS IN REINFORCED CONCRETE

### 11.16.1 General

Notwithstanding that the requirements of clause 11.9 and clauses 11.11, 11.12 and 11.14 may have been complied with, all wet cracks of any width and all dry cracks wider than 0.2 mm in the structural concrete shall be repaired. Where it is considered impractical to repair major cracking, the concrete shall be partially or completely broken out and recast at the Contractor’s cost. Cracks that are of minor importance in the opinion of the Engineer shall be patched with high strength cementitious mortar at Contractor's cost. Any cracks in walls and roof slabs (for example, due to early thermal effects) shall be repaired before the installation of waterproofing commences.

### 11.16.2 High Strength Cementitious Mortar

11.16.2.1 General

The following covers the requirements of high strength cementitious mortar for patching up cracks that are of minor importance.

11.16.2.2 Materials

High strength cementitious mortar to be used in the repair works shall have the following properties:

(a) The minimum compressive strength shall be 50 N/mm$^2$ at 7 days as determined from tests conducted in accordance with BS EN 12615 at a water powder ratio of 0.11.

(b) The minimum flexural strength shall be 9 N/mm$^2$ at 28 days.

(c) Surface absorption shall be not more than 0.005 ml/$m^2$/s for initial 10 minutes in accordance with BS 1881 initial surface absorption test.

(d) Slant/shear bond strength shall be minimum 20 N/$mm^2$ at 28 days in accordance with BS EN 12615.

Suitable admixtures with non-shrink property may be used in the high strength cementitious mortar with the prior acceptance of Engineer. The type and source of admixture, and the amount added and method of use shall be to the acceptance of the Engineer.

11.16.2.3 Submissions

The Contractor shall submit the manufacturer’s certificates verifying conformance to properties required in clause 11.16.2.2.

Application procedures shall be submitted for the Engineer's acceptance prior to commencement of the repair works.

11.16.2.4 Acceptance

The Contractor shall carry out trial mixes and cube tests and shall submit the results and obtain acceptance from the Engineer before carrying out the repair works.

11.16.2.5 Storage and Handling

All materials shall be delivered to site in sealed containers.

All materials shall be stored at temperatures recommended by the manufacturer.

11.16.2.6 Application

11.16.2.6.1 The Contractor shall ensure that all surfaces are completely free of laitance, oil, dust, grease, plaster, paint, corrosion and any other deleterious substances. Laitance shall be mechanically removed by high pressure water blasting, grit blasting or a combination of both. Oil and grease deposits shall be removed by steam cleaning, detergent scrubbing.

11.16.2.6.2 The Contractor shall cut and break out to form a groove approximately 25mm wide and minimum 5mm deep along the crack line. The groove shall be undercut to enhance grip between the high strength cementitious mortar in-fill and the existing concrete.

11.16.2.6.3 The Contractor shall ensure that high strength cementitious mortar is thoroughly mixed prior to use. For small quantities up to 10kg, hand mixing in a bucket may be adopted. For greater quantities, a forced action pan mixer shall be used.

### 11.16.3 Epoxy Grouting

11.16.3.1 General

The following covers the requirements for application of epoxy resin injection repair system for dry cracks wider than 0.2mm in structural concrete.

11.16.3.2 Submissions

Contractor shall submit chemical materials and manufacturer's certification verifying conformance to material specifications specified in Clause 11.16.3.6.

Application procedures shall be submitted for the Engineer's acceptance prior to application.

11.16.3.3 Acceptance of Injection System

11.16.3.3.1 Trial injection shall be carried out in a manner similar to that to be used for the repair prior to acceptance, and by the use of similar equipment and materials. The location shall be directed by the Engineer and any variation shall only be permitted with prior acceptance.

11.16.3.3.2 Once the epoxy injection has cured in accordance with the manufacturer's recommendation, the repaired crack shall be cored to examine the effectiveness of the repair.

11.16.3.3.3 The diameter of core shall not be less than 75 mm or as accepted by the Engineer.

11.16.3.3.4 The cored hole shall then be patched with non-shrink cementitious mortar with packer. The method of application shall be submitted to the Engineer for approval prior to application.

11.16.3.4 Packaging and Labelling

Each component shall be packaged and delivered in sealed containers.

Each container shall be clearly labelled with the manufacturer’s name, product, identification, date of manufacture, batch number, instruction for mixing, warning for handling and toxicity.

11.16.3.5 Quality Assurance: Storage and Handling

All materials shall be stored at temperatures recommended by the manufacturer.

All materials shall be handled in a safe manner and in a way to avoid breaking of container seals.

11.16.3.6 Materials: Epoxy Injection Resin

The epoxy resin used for crack injection shall comply with all of the following requirements:

(a) Two component solvent-free moisture tolerant epoxy resin.

(b) Viscosity of not more than 500 mPas at 20°C.

(c) Pot life of at least 30 minutes at 30°C.

(d) Tensile strength in excess of 20 N/mm$^2$ after full cure when tested as described in BS EN 12615.

(e) Curing time shall not be less than 4 hours.

(f) All materials shall be non-toxic and non-corrosive.

11.16.3.7 Materials: Surface Seal

The surface seal shall be epoxy patching mortar consisting of a moisture tolerant 2 component solvent-free aliphatic amine cured epoxy with fillers or materials having adequate strength and adhesion to confine the injection resin under pressure in the crack being repaired until the injected resin has cured.

11.16.3.8 Application: Preparation of Concrete Surface

Concrete surfaces to which epoxy are to be applied shall be newly exposed parent concrete free of loose and unsound materials. Prepare surfaces by mechanical abrasion unless prohibited by environmental limitations in which case acid etching may be used.

Surfaces shall be free of any deleterious materials such as laitance, curing compounds, dust, dirt and oil.

11.16.3.9 Application: Injection Points

Injection points should be installed at approximately 300mm centres. Holes of approximately 10mm diameter and 60 mm deep shall be drilled at a 45 degree angle to intercept the crack below the concrete surface at a depth accepted by the Engineer. Injection pipes shall then be inserted into each hole. The pipes and the entire length of the crack shall then be sealed using an epoxy patching mortar or other accepted materials.

11.16.3.10 Application: Injection Sequence

11.16.3.10.1 Once the epoxy patching mortar has cured in accordance with the manufacturer's instructions, or after 24 hours has elapsed whichever is greater, the epoxy resin shall be pumped into the injection point.

11.16.3.10.2 Prior to injection, the two components of the resin shall be mixed in the exact proportions recommended by the manufacturer, using a slow speed (less than 1000 rpm) electric drill with a 50mm diameter paddle. Because of the short pot life of the low viscosity solventless epoxy resins, only sufficient resin and hardener shall be mixed to enable its injection into the crack to be completed within 10 minutes.

11.16.3.10.3 The first and last injection point shall be established at or near the bottom and top respectively if the crack is vertical, or at the ends if the crack is horizontal.

11.16.3.10.4 The resin shall be pumped into the first injection point until resin is forced out of the next adjacent point. The first injection point shall then be locked off. Pumping shall then be moved to the next adjacent point. This sequence shall be repeated until all air is expelled and all the injection points have been locked off.

11.16.3.10.5 Where it is not possible to achieve flow from an adjacent injection point, the Engineer shall be informed and the Contractor's remedial measure shall be submitted for Engineer's acceptance.

11.16.3.11 Testing

To evaluate the effectiveness of the repair, the Engineer may direct the Contractor to carry out further coring in the repaired areas as specified in Clause 11.16.3.3.

11.16.3.12 Making Good

Upon completion of the injection, all injection pipes and uneven surface of the epoxy patching mortar shall be ground down to restore to the original profile.

11.16.3.13 Safety

Epoxy materials may be skin irritants or sensitive to many people. Accordingly, the Contractor shall advise applicators to avoid contact with eyes and skin, inhalation of vapours, and ingestion. The Contractor shall make protective and safety equipment available on site and heed all warnings given by the manufacturer.

### 11.16.4 Polyurethane Grouting

11.16.4.1 General

11.16.4.1.1 For wet cracks or joints with no flowing water, acrylic gel or polyurethane (PU) grout of low viscosity that forms flexible sealing shall be proposed for grouting to seal the cracks or joints. Where water is flowing through the cracks or joints, grouting shall be carried out in two stages - the first stage by using foam type of PU to stop the flowing water followed by the second stage of grouting by using acrylic gel or PU grout of low viscosity that forms flexible sealing. The grouting proposal shall be submitted to the Engineer for acceptance, and shall address pertinent issues on injection system, application, quality assurance, material specifications, testing and safety.

11.16.4.1.2 The use of PU grouts that form rigid or semi-rigid open-cell foam structures alone shall not be accepted as repair materials for cracks or joints in concrete structures.

## 11.17 PRECAST CONCRETE CONSTRUCTION

### 11.17.1 General

11.17.1.1 When the method of manufacture off the site has been accepted, no changes shall be made without the consent of the Engineer.

11.17.1.2 The Contractor shall inform the Engineer in advance of the date of commencement of manufacture and casting of each type of member. Manufacture shall be carried out with the same constituent materials as used in site cast concrete.

11.17.1.3 A copy of all cube test results relating to the work shall be sent to the Engineer for acceptance prior to the installation of the precast element.

11.17.1.4 Where tests are required on pre-cast members, the members subjected to testing shall not be delivered to site until the tests have been satisfactorily completed.

11.17.1.5 All members shall be indelibly marked to show the member type, the production line on which they were manufactured, the date on which the concrete was cast and, if they are symmetrical section, the face that will be uppermost when the member is in its correct position in the works. The markings shall be so located that they are not exposed to view when the member is in its permanent position.

### 11.17.2 Handling, Storage and Transport

11.17.2.1 The Contractor shall be responsible for designing all methods and equipment for handling, lifting and installation of the precast concrete elements. Regions in which the precast elements are to be lifted or supported shall be indicated on the Drawings and the units shall not be lifted or supported at any other points without the prior acceptance of the Engineer.

11.17.2.2 Each lifting device shall be designed for a working load of not less than 1.65 times the maximum calculated static load at that point and ultimate load of not less than 4 times the maximum static load. Suitable holes, grooves, bolts or other lifting devices shall be provided at all lifting points to ensure the accurate placing of lifting tackle.

11.17.2.3 Where lifting devices are to be cast permanently into the concrete they shall either:

(a) be detailed to provide at least 35 mm cover, between the lifting point and the finished concrete surface in the complete works in which case non-corrosion-resistant materials may be used.

or

(b) be constructed from an accepted grade of stainless steel if they are to be exposed, or provided with not less than 35 mm cover, in the completed works.

11.17.2.4 The making good of all temporary penetrations for, and/or coverings to, lifting devices shall be carried out by the Contractor in accordance with the requirements of the Engineer.

### 11.17.3 Protection

At all stages of construction, the precast concrete units and adjacent in-situ concrete if applicable, shall be properly protected to prevent damage or staining of permanently exposed concrete surface.

### 11.17.4 Assembly and Erection

11.17.4.1 The approved method of assembly and erection shall be strictly adhered to on site. Temporary supports shall be provided immediately after the pre-cast units are lifted into position. The final structural connections shall be completed as soon as is practicable.

11.17.4.2 Erection tolerances for the precast concrete viaduct parapet units shall not encroach towards the track and not more than 6 mm away from the track.

### 11.17.5 Forming Structural Connection

11.17.5.1 No structural connections shall be made until the Engineer's acceptance has been given.

11.17.5.2 The composition and water/cement ratio of the in-situ concrete or mortar used in any connection and the packing of joints shall be in accordance with the assembly instructions.

11.17.5.3 Levelling devices shall only be released or removed with the Engineer's acceptance.

### 11.17.6 Load Test of Precast Units

11.17.6.1 The loading test shall be done generally in accordance with SS EN 1992-1-1 with the exception that load test on any part of the structural element of bridges shall be increased by 15%.

11.17.6.2 Samples of the precast unit for the tests shall be provided and delivered by the Contractor at his cost to the approved Singapore Accreditation Council (SAC) accredited laboratory.

11.17.6.3 Where more than one sample from any sample batch fails to satisfy this Specification, then the entire batch of units represented by such samples shall be liable for rejection by the Engineer.

11.17.6.4 For precast concrete members which shall subsequently form parts of composite members, any of the following methods may be used at the discretion of the Engineer:

(a) The precast member may be tested along with a load system equivalent to that producing the most critical conditions in the composite members.

(b) The precast member may be made equivalent to the final composite member by casting the relevant amount of in-situ concrete, and then tested as a composite member.

11.17.6.5 If the result of any of the tests is not satisfactory, at the Engineer’s instruction, that part of the works shall be rejected and reconstructed to comply with this Specification, or other accepted measures be taken to make the works secure, all at the Contractor’s expense. No extension of time shall be entertained in this connection

## 11.18 REINFORCEMENT BARS

### 11.18.1 Materials

11.18.1.1 The steel reinforcement bars (rebar) used in the work shall be Grade 500B and 600B, unless indicated otherwise. All rebar shall comply with SS560 and SS EN 1992-1-1.

11.18.1.2 All rebar shall be sourced from steel manufacturers who have obtained the Factory Production Control (FPC) certificate in accordance with SS 560, approved by a Certification Body accredited by SAC. The steel manufacturer shall also be certified with ISO 9001.

11.18.1.3 The Contractor shall submit the following information for the Engineer's acceptance.

(a) Name of the steel manufacturer

(b) Information on the country of origin/source

(c) FPC and maintenance audit certificate

(d) Mill certificates

(e) Reports demonstrating that the product complies fully with SS 560 relating to

i) Chemical composition

ii) Mechanical properties such as tensile strength, fatigue strength and bend and re-bend performance

iii) Dimensions, mass per metre tolerances

iv) Bond strength

v) Surface geometry

### 11.18.2 Storage

The Contractor shall store the rebar to ensure traceability and in a manner that will prevent distortion, deterioration and corrosion.

### 11.18.3 Site Sampling and Testing of Rebar Prior to Fixing On Site

11.18.3.1 The Contractor shall carry out sampling and testing prior to fixing the rebar on site. Where the rebar is fabricated off site or in another county, sampling and testing shall be done off site or in another county where the rebar is located prior to fabrication.

11.18.3.2 All the taking of samples and testing shall be witnessed by the engineer or his appointed representative.

11.18.3.3 All testing shall be carried out by SAC-SINGLAS accredited laboratory.

11.18.3.4 The Contractor shall carry out sampling and testing regime in accordance with Table 11.4 below.

**Table 11.4: Sampling Regime for Rebar**

<table>
<tr><th>Nominal Diameter of Rebar (mm)</th><th>One Sampling Set</th></tr>
<tr><td>Under 20mm<br>(1 sampling set for every 100 tonnes or part thereof)</td><td rowspan="3">3 specimens for Tensile Test<br><br>1 specimen for Bend / Re-bend Test<br><br>1 specimen for Bond Test (through Surface Geometry) and Nominal Mass Test</td></tr>
<tr><td>20mm to 40mm<br>(1 sampling set for every 500 tonnes or part thereof)</td></tr>
<tr><td>Over 40mm<br>(1 sampling set for every 1000 tonnes or part thereof)</td></tr>
<tr><td>Every 3000 tonnes or part thereof)</td><td>1 cast analysis for Chemical Composition Analysis</td></tr>
</table>

11.18.3.5 The test results shall comply with the requirements in SS EN 1992-1-1 Annex C as follows:

(a) For tensile stress, the minimum values shall be 540 N/mm$^2$ and 648 N/mm$^2$ for Grade 500B and 600B rebar, respectively.

(b) For bend and re-bend tests, none of the test pieces shall have fractures or cracks visible to the naked eye.

(c) For nominal mass, the maximum deviation from nominal mass for a rebar more than 8mm diameter shall be 4.5%.

(d) For bond, the minimum relative rib area shall be 0.040 and 0.056 for bar size between 6.5mm and 12mm and more than 12mm respectively.

(e) For chemical composition, the values shall comply with Table 11.5.

**Table 11.5: Chemical Composition Limit for Rebar**

| Maximum % by Mass | | | | | |
|---|---|---|---|---|---|
| Carbon | Sulphur | Phosphorus | Nitrogen | Copper | Carbon Equivalent |
| 0.22 | 0.050 | 0.050 | 0.012 | 0.80 | 0.50 |

11.18.3.6 **Action on Non-Compliance**

When individual test result fails to comply with the requirements, in Clause 11.18.3.5, 2 numbers of retest for the whole batch of rebar with the same mill certificate shall be carried out.

In the event of failure of any retest, the whole batch of rebar with the same mill certificate shall be rejected and removed from site.

11.18.3.7 **Workmanship**

11.18.3.7.1 Rebars shall be accurately formed to the dimensions indicated on the Drawings. All rebars shall be cut and/or bent in accordance with BS 8666.

11.18.3.7.2 Rebars shall be secured against displacement outside the specified limits. Unless otherwise specified, tolerances of covers and fixings of rebars shall be in accordance to SS EN 1992.

11.18.3.7.3 Rebars shall not be surrounded by concrete unless it is free from mud, oil, paint, retarders, loose rust, loose mill scale, grease or any other substance which can be shown to affect adversely the steel or concrete chemically, or reduce the bond.

11.18.3.7.4 No splices shall be made in the rebar except where shown on the Drawings or where accepted by the Engineer. In such splices, the rebar shall be placed in contact and wired. Splices in adjacent rebars shall be staggered. Where rebar mesh has to be lapped, the amount of lap shall be either determined as for plain rebars considering the rebars of mesh which are being lapped or one whole mesh whichever is greater. Laps shall be in accordance with SS EN 1992 as appropriate.

**11.18.4 Couplers for Reinforcement Bars**

11.18.4.1 Only straight metric threaded and swaged couplers shall be used. The couplers shall be of a type which are simple to install and can be verified to be installed correctly by visual inspection.

11.18.4.2 All steel couplers shall comply with ISO 15835-1 requirements. The manufacturer of the couplers shall be certified to ISO 9001 quality assurance, or equivalent, for the manufacture of couplers. The Supplier/Installer shall be certified to ISO 9001 quality assurance, or equivalent, for rebar end processing and for coupler installation.

11.18.4.3 All couplers shall be legibly and durably marked with identification of the manufacturer, nominal bar size intended for and clear stamp of the batch or heat number. This number shall be traceable to the original cast. The relevant material mill certificates for couplers are to be submitted with each delivery. The certificates shall show the salient material properties of the couplers.

11.18.4.4 **Proving Test on Coupler System**

Prior to use of any of the accepted systems on site, the Contractor shall prepare representative gauge length assemblies and control bars for proving testing. Each sample assembly shall be subjected to Permanent Elongation/Slip Test, Static Tensile Test, Ductility Test and control bar to Static Tensile Test. The frequency for each coupler type and rebar size is summarized in Table 11.6.

**Table 11.6 Coupling Proving Test Types and Frequency**

| | Representative gauge length assemblies | | | Control bars |
|---|---|---|---|---|
| Min. sample sets per coupler type & size | 2 | | | 1 |
| Test Type | Static Tensile | Permanent/ Elongation Slip | Ductility | Static Tensile |
| Min. no. of tests per sample set | 1 | 1 | 1 | 1 |

Note: A control bar refers to a specimen length of rebar cut from the same continuous length as that of the test specimen. All specimens and control bars are to be cut from 1 continuous length. Should it necessary to use more than 1 length of rebar, then a control bar shall be taken per length and tested for comparison against corresponding specimens.

The test results shall comply with the requirements in ISO 15835 as follows:

(a) Permanent Elongation Test / Slip

When a test is made of a representative gauge length assembly (comprising rebar of the size, grade and profile to be used and a coupler of the precise type to be used), the permanent elongation/slip after loading to 60% of the characteristic yield strength and returning the load to zero should not exceed 0.1 mm.

(b) Static Tensile Test

The tensile strength of the coupled rebar in a representative gauge length assembly when tested to failure shall exceed 540 $N/mm^2$ and 648 $N/mm^2$ for grade 500B and 600B respectively. In addition, the failure of the coupled bar assembly shall occur in the bar outside the coupler and the testing machine grips.

(c) Ductility Test

The measured total elongation at maximum force in the rebar outside the length of the mechanical splice shall exceed 3.5% for both grades 500B and 600B.

The Contractor shall submit to the Engineer for acceptance a report on these proving tests, within seven working days of the tests. The report shall provide full details including:

(a) Results of all tests

(b) Details of dimensions, geometry and torquing and if applicable swaging pressures

(c) Details of test procedures

(d) Description of test rig / load cell

(e) Description of load monitoring, strain measurements

(f) Calibration certificates

From each test on the coupler and control bar specimens the following information shall be provided:

(a) Stress – Strain (or Load Displacement) curves

(b) Yield Load & Yield Strength

(c) Elongation of the mechanical connection

(d) Ultimate load & Ultimate Tensile Strength

(e) Mode of failure

(f) Gauge length used for strain measurement and statement of how gauge length was determined.

11.18.4.5 **Production Testing**

11.18.4.5.1 For Production testing, sacrificial couplers together with adequate lengths of rebar attached shall be installed next to working couplers at the same time and using the same equipment as the working couplers to form sample gauge length assemblies and control bars for production testing. The samples and the control bars shall be removed for production testing. Each sample assembly shall be subjected to a Permanent Elongation/Slip Test, Static Tensile Test and Ductility Test. A control bar shall be tested to each Static Tensile Test. The sample frequency for each bar size shall be:

(a) One gauge length assembly and one control bar for the first 10 couplers;

(b) One gauge length assembly and one control bar for the next and subsequent units of 200 couplers.

11.18.4.5.2 The Contractor shall submit to the Engineer for acceptance a monthly report of the production testing containing full details of the testing, including the same information as that for the proving tests above.

11.18.4.5.3 For threaded systems every prepared rebar end shall undergo a load test prior to leaving the supplier’s workshop. Minimum test loading shall be to 75% of the characteristic strength and maximum test loading shall be to 100% of characteristic strength. A positive indication shall be stamped on the rebar to indicate that this operation has been carried out.

11.18.4.6 **Site Quality Assurance and Checks**

11.18.4.6.1 The Contractor shall submit to the Engineer for his acceptance a method statement for mechanically connecting the rebar, and for the installation and verification inspection of couplers. This shall take into account any special requirements for horizontal, vertical and inclined couplers and shall include a rectification procedure if the connection is incorrectly made. It shall also cover the correct handling of tools and equipment for mechanical connecting on site. The following information shall also be included:

(a) For threaded couplers

i) requirements for cleanliness

ii) equipment for threading rebars

iii) equipment and method for torquing (as required), force required and method of measurement

iv) method of locking the connections on both rebars

v) method of verification of final rebar alignment and coupler integrity

(b) For swaged couplers

i) requirements for cleanliness

ii) rebar end preparation and permissible deviation

iii) equipment and method of swaging, minimum and maximum number of swages per sleeve

iv) swaging pressure/stresses, method of measurement and tolerance on pressure/stress

v) method of verification that the sleeve is swaged for the full length on both bars

vi) method of verification of final rebar alignment and coupler integrity

11.18.4.6.2 The Contractor shall arrange for a qualified Manufacturer's representative experienced in mechanically connecting rebar to be present at site before the start of work for initial training of personnel, and also to demonstrate the equipment and techniques as necessary.

11.18.4.6.3 Any special tools and equipment required for use with the couplers shall be in accordance with the recommendations of the Manufacturer for the accepted couplers. Such tools and equipment shall be serviced and calibrated at intervals recommended by the Manufacturer. The Contractor shall retain documentation in respect of servicing and calibration for inspection by the Engineer.

11.18.4.6.4 Packaging to couplers shall not be removed until they are used. All couplers shall be installed strictly in accordance with the manufacturer's recommendations
Each coupler shall be visually examined prior to use to ensure the absence of rust and of any foreign material on the inside surface. All completed couplers shall be inspected and verified in accordance with the Contractor's accepted method statement. The Contractor shall establish to the acceptance of the Engineer a procedure for documenting the inspection of the couplers and to show that every coupler installed complies with the requirements of this specification. The Contractor shall retain inspection records and shall submit copies to the Engineer within 7 days of the installation of the couplers. Couplers that do not meet the acceptance standards shall be completely removed and the bars re-connected as required.

11.18.4.6.5 All couplers shall be covered with plastic caps and where couplers are exposed to weathering and that the connection is not made within 7 days from date of casting, it shall be internally greased and plastic capped to a protection detail acceptable to the Engineer.

**11.18.5 Welding**

11.18.5.1 Welding on site of rebars shall be avoided wherever possible, but where suitable safeguards and techniques are employed and that the types of steel have the required welding properties, it may be undertaken with the acceptance of the Engineer. Before welding any rebar, the Contractor shall supply to the Engineer a welding procedure specification and an example of the weld for the type of steel, connection and weld being proposed. If such evidence is not available, the Contractor shall demonstrate satisfactory performance by means of testing to the acceptance of the Engineer.

11.18.5.2 In addition, the competence of each welder deployed on site shall also be demonstrated through the submission of independent welder qualification records before and during welding operations.

11.18.5.3 Welding may be used in fixing rebar in position, for example, by welding between crossing or lapping rebar, or between rebars and other steel members.

11.18.5.4 Structural welding shall not be carried out unless specifically shown on the Drawings.

11.18.5.5 Notwithstanding the above, the Engineer will not permit tack welding of rebars which will be subject to fluctuating stresses in the completed structure

11.18.5.6 Metal-arc welding of rebar shall be carried out in accordance with BS EN 1011 and the recommendations of the rebar manufacturer.

11.18.5.7 Other methods of welding may be used subject to the acceptance of the Engineer.

11.18.5.8 Exposed welded rebar to be built into later concrete shall be effectively protected from corrosion, to the acceptance of the Engineer.

## 11.19 TESTS ON HARDENED CONCRETE

### 11.19.1 Core Test

11.19.1.1 The Engineer reserves the right to direct that samples be cored from any portion of works for the purpose of examination and testing.

11.19.1.2 The cutting equipment and method of coring to obtain specimens shall be accepted by the Engineer.

11.19.1.3 The Contractor shall identify rebar locations using a cover meter and shall take all necessary steps to avoid damage to reinforcement during coring.

11.19.1.4 The specimens shall be produced and tested in accordance BS EN 12504. Prior to preparation for testing and after testing, the specimens shall be made available for examination by the Engineer.

11.19.1.5 The cored portion of the works shall be made good to the acceptance of the Engineer.

11.19.1.6 The equivalent cube strength of the specimen shall be submitted by the Contractor for the Engineer's acceptance.

11.19.1.7 The Contractor shall bear the costs for the core tests if:

(a) they are required because of work cube test failure, or

(b) the Engineer having doubts about the quality of concrete, calls for a core test and the core test fails

### 11.19.2 Additional Test Due to Cube Test Failure

Consequent upon work cube test failure, the Engineer may instruct that other appropriate tests be carried out in accordance with SS EN 1992 on any portion of the works for the purpose of assessing the strength. The Contractor shall bear all the cost for such test.

### 11.19.3 Load Test of Structures or Part of Structures

11.19.3.1 The Engineer may instruct the Contractor to make a load test on the works or any part thereof if in the Engineer's opinion such a test is necessary.

11.19.3.2 If the test so instructed is to be made because of cube test failure, or that the finished work, in the opinion of the Engineer is structurally defective unless proven otherwise, then the test shall be made at the Contractor's expense irrespective of the load test result.

11.19.3.3 The loading test shall be done generally in accordance with SS EN 1992 with the exception that load test on any part of the structural element of bridges shall be increased by 15%.

## 11.20 PRESTRESSING TENDONS

### 11.20.1 General

11.20.1.1 The Contractor shall submit details of proposed proprietary post-tensioning systems to the Engineer for in-principle acceptance. The system proposed by the Contractor shall be a proven system. On obtaining in-principle acceptance, the Contractor shall submit detail drawings detailing all tendon anchorage areas, reinforcement and other features to the Engineer for checking and acceptance.

11.20.1.2 The values for friction coefficient, wobble coefficient and draw-in assumed in the design shall be shown in the Drawings and test certificates shall be submitted to the Engineer for acceptance.

### 11.20.2 Materials

11.20.2.1 All prestressing steel shall carry a mill certificate from the manufacturer. The mill and test certificates shall be submitted to the Engineer prior to cutting for use of any of the steel.

(a) Cold worked high tensile alloy bar shall comply with the requirements in BS 4486.

(b) Stress relieved seven-wire strand shall comply with the requirements in BS 5896.

11.20.2.2 In addition to the testing requirements of the standards, the Contractor shall arrange for one sample of the steel from each coil intended for use in the works to be tested for proof load, breaking load, percentage elongation, relaxation and ductility at an approved independent testing laboratory.

11.20.2.3 For each coil, the full results of the tests required on material from that coil, including routine production tests, shall be made available to the Engineer prior to the cutting for use of any of the strand in the coil.

### 11.20.3 Handling and Storage

11.20.3.1 General

All prestressing steel/bars shall be protected against physical damage at all times from manufacture to grouting or encasing in concrete. Prestressing steel/bars that has sustained physical damage at any time shall be rejected. Bars shall be kept and stored straight. They shall be suitably supported to prevent excessive bending stresses and any threaded portions shall be adequately protected.

11.20.3.2 Packaging

11.20.3.2.1 Prestressing steel shall be packaged in containers or shipping forms for the protection against physical damage and corrosion during shipping and storage. A corrosion inhibitor which prevents rust or other results of corrosion shall be placed in the package or form, or shall be incorporated in a corrosion inhibitor carrier type packaging material, or when permitted by the Engineer, may be applied directly to the steel. The corrosion inhibitor shall have no deleterious effect on the steel or concrete or bond strength of steel to concrete.

11.20.3.2.2 Packaging or forms damaged from any cause shall be immediately replaced or restored to original condition. The name and any other information concerning the corrosion inhibitor shall be supplied to the Engineer on request.

11.20.3.2.3 The shipping package or form shall be clearly marked with a statement that the package contains high strength prestressing steel, the care to be used in handling, the type, kind and amount of corrosion inhibitor used (including the date when placed).

11.20.3.3 Condition of Steel

Steel which exhibits a light brown surface coating of rust, without flaking or pitting for use in the works shall be subjected to the acceptance of the Engineer.

11.20.3.4 Corrosion and Damage

Steel shall be rejected by the Engineer as unsuitable for use in the works if either of the two following conditions occur:-

(a) The steel exhibits evidence of corrosion such as may reduce its strength or ductility.

(b) There is evidence to show that the steel has been in contact with deleterious substances, or subject to splashes from the cutting operation of an oxy-acetylene torch or arc-welding processes in the vicinity which may reduce its strength or ductility or bond characteristics in the permanent works.

11.20.3.5 Protection

11.20.3.5.1 Prestressing steel for post-tensioning which is installed in members prior to placing and curing of the concrete, shall be continuously protected against rust or other corrosion, until grouted, by means of a corrosion inhibitor placed in the ducts or applied to the steel in the duct. The corrosion inhibitor shall have no deleterious effect on the steel or concrete or bond strength of steel to concrete.

11.20.3.5.2 Grouting of tendons shall be carried out as little delay as possible after installation. The duct shall be kept dry until grouting. The lower points of the ducts shall be drained. Tendons may be left in a dry duct without temporary protection up to 14 days after installation. In the case that longer period of exposure of unprotected tendons in the duct is expected due to delay during the course of construction, temporary protection measure should be proposed and submitted to the Engineer for acceptance.

11.20.3.5.3 All prestressing steel and its assembles shall be stored clear of ground, under a waterproof shelter and protected from damage and deterioration from exposure or other causes.

**11.20.4 Straightness**

11.20.4.1 Wire

Low relaxation and normal relaxation wire shall be in coils of sufficiently large diameter to ensure that the wire can be laid straight.

11.20.4.2 Strand

Prestressing strand shall be in coils of sufficiently large diameter to ensure that the strand can be laid reasonably straight.

11.20.4.3 Bars

Prestressing bars as delivered shall be straight. Bent bars shall be rejected.

**11.20.5 Cutting**

All cutting of wire, strand or bar shall be carried out using a high-speed abrasive cutting wheel, friction saw or any other mechanical method accepted by the Engineer.

**11.20.6 Duct**

11.20.6.1 All ducts used in bonded post-tensioning system shall be manufactured from galvanised steel strip. It shall be stored off the ground and protected against the weather.

11.20.6.2 Joints in the duct for the tendons shall be minimised and in any event not closer than 5 metres. The joints between sections of duct and between duct and anchorages shall be properly sealed.

11.20.6.3 In order that friction losses are kept to a minimum, the Contractor shall exercise care to prevent deformation of the duct cross section during handling and concreting and to ensure that the duct is placed accurately to the required lines and levels. Based on the tendon profile information given on the Drawings, the Contractor shall prepare shop drawings of the tendon profiles for construction purposes. These drawings shall show locating dimensions for each of the tendons at 600 mm centres or less, and shall be submitted to the Engineer for checking and acceptance. The ducts shall be firmly fixed to, or supported from, the steel reinforcement within the forms at 600 mm centres or less. The tolerance in the location of the duct shall be 3 mm from the true position.

### 11.20.7 Sheathing

11.20.7.1 All sheaths for external prestressing tendons shall be smooth, high-density polyethylene (HDPE) pipes.

11.20.7.2 The pipe material shall be in accordance with ASTM Specification D1248, “Standard specification for Polyethylene Plastics Molding and Extrusion Materials”. The HDPE pipe shall have a standard density of 941 kg/m$^3$ or greater. The requirements and test methods shall be in accordance to ASTM Specification D3035 and ASTM Specification F714.

11.20.7.3 The HDPE pipe shall be strong enough to prevent deformation when pressurised during grouting and to resist the strand punching effects at deviated positions. The PE plastic extrusion compound shall have sufficient UV stabiliser to protect the pipe from deleterious effects due to continuous outdoors exposure in accordance with the requirements in ASTM Specification D3350.

11.20.7.4 The minimum wall thickness of the pipe shall be determined from the average outside diameter of the pipe divided by 17 (DR 17) or 4mm, whichever is greater.

11.20.7.5 The sheath shall be continuous with no joining sleeves through the saddle.

11.20.7.6 The sheaths shall be protected against crushing, excessive bending, dirt contamination and corrosive elements during transport, storage and handling.

11.20.7.7 In order that friction losses are kept to a minimum, the Contractor shall exercise care to prevent deformation of the sheathing cross section during handling and concreting. The Contractor shall also ensure that the sheathing is placed accurately to the required lines and levels.

11.20.7.8 Joints in the tendon sheath shall be minimised. In no case shall the intervals between the joints be less than 5 m. All joints shall be properly sealed including the joints between the sheath and the anchorage.

11.20.7.9 Based on the tendon profile information given on the Drawings, the Contractor shall prepare shop drawings of the tendon profiles for construction purposes. These drawings shall be submitted to the Engineer for acceptance.

**11.20.8 Tensioning Apparatus**

11.20.8.1 Both force and extension measurements shall be taken during all tensioning operations. Force measurements shall be required to an accuracy of 2%, extension measurements to an accuracy of 1 mm. The force measurements shall be made by dynamometers or pressure gauges. Where the latter are used, the gauge shall be selected so as to be used at between 40% and 80% of its full capacity when the final load measurements equivalent to 75% of the ultimate strength of the tendons being stressed, are taken on any tendons.

11.20.8.2 All tensioning equipment shall be accepted by the Engineer prior to use. It is required that the strands in each multi-strand tendon be stressed simultaneously. Certified calibration by an approved laboratory shall be provided for all dynamometers or pressure gauges.

11.20.8.3 The calibration certificate shall not be more than 4 weeks old at the time the equipment is brought on site.

11.20.8.4 For the duration of the stressing operations, intermediate tests on equipment will be required every 2 weeks or when the Engineer has cause to believe that the gauge may be giving incorrect readings at stressing, whichever is sooner. This may be done on site by means of calibrated master pressure gauge that is not used in the stressing operation, or by dynamometer.

**11.20.9 Pre-tensioning**

11.20.9.1 General

Where pre-tensioning methods are used, the tension shall be fully maintained by some positive means during the period between tensioning and transfer. The transfer of stress shall take place slowly to minimise shock.

11.20.9.2 Straight Tendons

11.20.9.2.1 In the long line method of pre-tensioning, sufficient locator plates shall be distributed throughout the length of the bed to ensure that the wires or strands are maintained in their proper position during concreting. Where a number of units are made in the line, they shall be free to slide in the direction of their length and thus permit transfer of the prestressing force to the concrete along the whole line.

11.20.9.2.2 In the individual mould system, the moulds shall be sufficiently rigid to provide the reaction to the prestressing force without distortion.

11.20.9.3 Deflected Tendons

11.20.9.3.1 Where possible, the mechanisms for holding down or holding up tendons shall ensure that the part in contact with the tendon is free to move in the line of the tendon so that frictional losses are nullified. If, however, a system that develops a frictional force is used, this force shall be determined by test and due allowance made for frictional losses.

11.20.9.3.2 For single tendons, the deflector in contact with the tendon shall have a radius of not less than 5 times the tendon diameter for wire or 10 times the tendon diameter for a strand, and the total angle of deflection shall not exceed 15°.

11.20.9.3.3 The transfer of the prestressing force to the concrete shall be effected in conjunction with the release of hold-down and hold-up forces as accepted by the Engineer.

11.20.9.4 Positioning

11.20.9.4.1 Unless shown otherwise on the Drawings, tendons when stressed shall not, at any point, be further from their required positions than 5 mm.

11.20.9.4.2 Debonding sleeves shall be chemically neutral to the steel, the grease and the concrete. The material should be either High Density Polyethylene or Polypropylene. Paper and PVC Poly-vinyl chloride are not permitted. The minimum thickness shall be 0.75 mm.

**11.20.10 Post-Tensioning**

11.20.10.1 Anchorages

11.20.10.1.1 All tendon anchorages shall comply with the requirements of BS EN 13391 and the Contractor shall submit test certificates to demonstrate such compliance.

11.20.10.1.2 No damaged anchorage devices shall be used and all parts shall be protected from corrosion at all times. Threaded parts shall be protected by greased wrappings and tapped holes by suitable plugs until used.

11.20.10.1.3 Anchorages shall be positioned and maintained during concreting so that the centre line of the duct shall pass through the anchorage assembly and shall be normal to the bearing surface.

11.20.10.2 Dead End Anchorages

11.20.10.2.1 The systems used for coupling or providing dead end anchorages for the strands shall be accepted by the Engineer. The use of blind end anchorages or anchorages using bonded bulbs is not permitted. Should swaged anchorages be used, special care shall be taken during the swaging operation to ensure that the ends of the strands are not contaminated with oil or any substance likely to affect the integrity of the connection. If the swages incorporate teeth to assist in gripping the strand, it is essential that they be installed in the correct direction, as a reversal of the swage will impair the efficiency of the grip and may result in slippage of the strand under load.

11.20.10.2.2 The swaging pressure shall be carefully monitored during each swaging operation and shall not vary by more than ± 5%. Should a fall-off in swaging pressure be observed, tests shall be immediately carried out to check the gripping efficiency of the swage by means of a mono jack. The procedures to be adopted for testing the gripping efficiency shall be subject to the Engineer's prior acceptance. In addition, the diameter of each swage after installation on the strand shall be checked.

11.20.10.3 Saddles at Deviation Points for External Prestressing

11.20.10.3.1 Steel tube that is used to form the saddle shall be hot-dipped galvanised and degreased.

11.20.10.3.2 The saddle must be carefully detailed to avoid damage to the sheath or the prestressing steel during stressing. The protective sheathing must also be jointed properly.

11.20.10.3.3 Minimum radius in accordance with the relevant manufacturer’s specifications and standards must be provided for the saddle. At the Engineer’s request, tests shall be performed to verify the feasibility of a particular practical solution.

11.20.10.4 Installation of tendons

11.20.10.4.1 The procedure for installation of the strands into the duct shall be subject to the acceptance of the Engineer.

11.20.10.4.2 The Contractor shall ensure that the tendons are not kinked or otherwise damaged during installation. Likewise, care shall be taken to avoid damage to the ducts during tendon installations.

11.20.10.5 Tensioning Procedure

11.20.10.5.1 Tensioning shall be carried out only in the presence of the Engineer and by trained crews experienced in this type of work and in the use of the particular equipment involved. No member shall be stressed until the concrete in it has attained the minimum age at which control test cubes have reached the specified strength. The results of the cube tests shall be submitted to the Engineer before acceptance to proceed with tensioning is given.

11.20.10.5.2 Tendons shall be tensioned to the loads, and in the sequences, given on the Drawings.

11.20.10.5.3 The tendon force shall be raised to the specified maximum value uniformly such that the force is gradually transferred to the concrete. Extension readings shall commence after 10% of the load has been applied in order to ensure that the datum is set after slack cable has been taken up. For each tendon, the strands at the non-stressing end shall be marked with chalk or by other means so that any movement of strands relative to each other during tensioning may be observed. The draw-in at the non-stressing end shall be measured so that the appropriate allowance can be made in the measured extensions.

11.20.10.5.4 A tolerance of ± 5% of the required force will then be permitted for individual tendons, provided that the total force in the member is within 2% of the required value. Members which do not comply with these requirements may be rejected.

11.20.10.5.5 The values for the expected tendon extensions shall be determined, by the Contractor as described in Clause 11.20.1. The actual extensions measured on site shall be compared with the calculated extensions as a check, on the loss of force due to friction in the ducts. If the extension measurements indicate that friction is higher than computed using the design friction and wobble factors given on the Drawings, then the Engineer may direct that the tendons be treated with water soluble oil to reduce friction to the level given by the design factors.

11.20.10.5.6 After a tendon has been anchored, the jack pressure shall be released gradually and evenly, so as not to cause any shock to the anchorage or tendon.

11.20.10.5.7 In the event of a tendon breaking or slipping after tensioning, the tendon shall be released, replaced if necessary and prestressed.

11.20.10.5.8 Full records shall be kept of all tensioning operations, including the measured extension, pressure-gauge or load-cell readings, and the amount of draw-in at each anchorage. Copies of these records shall be supplied to the Engineer within 24 hours of each tensioning operation.

11.20.10.5.9 Following acceptance of the tensioning operation by the Engineer, the ends of the tendons shall be cut off with a disc cutter to within 6 mm of the anchorage.

**11.20.11 Safety Precautions during Tensioning**

Care shall be taken during tensioning to ensure the safety of all personnel engaged on the work and of other persons in the vicinity. Jacks shall be secured in such a manner that they will be restrained should they lose their grip on the tendons. Warning signs shall be positioned to caution that the operation is in progress. No person shall be allowed to stand behind the jacks or in close proximity behind the jacks while tensioning is in progress. The operation of the jacks and associated operations shall be carried out in such a manner and from such positions that the safety of all concerned is ensured.

**11.20.12 Stacking of Prestress/Post-Tensioned Beams**

This shall be considered in the design but shall not exceed two layers.

## 11.21 GROUTING FOR PRESTRESSING TENDONS

**11.21.1 General**

11.21.1.1 The grouting for prestressing tendons shall comply with the requirements in BS EN 445, BS EN 446 and BS EN 447.

11.21.1.2 Each prestressing tendon shall be protected against corrosion and bonded to the surrounding concrete by completely filling the void space between the tendon and its duct with cement grout. Unless directed otherwise by the Engineer, grouting of tendons shall take place within 14 days after installation of tendons. Delay in grouting of ducts shall comply with Clause 11.20.3.5.

11.21.1.3 During the course of the works and depending on the nature of the problems encountered (if any), the Engineer may amend the requirements of the following subsections of this Clause in order to ensure that proper grouting of the tendons is achieved.

**11.21.2 Properties of Grout**

11.21.2.1 General

The properties of grout shall satisfy the requirements specified in BS EN 447.

11.21.2.2 Fluidity

11.21.2.2.1 The fluidity shall be sufficiently high for ease of pumping and, if appropriate, for penetration of the grout into the strand but sufficiently low to expel the air in the duct.

11.21.2.2.2 The fluidity of the grout during the injection period shall be measured by either one of the methods given in BS EN 445 and the grout shall meet the requirements in the table below.

**Table 11.7 Fluidity Test Methods and Requirements**

| **Test methods** | **Parameters** | **Immediately after mixing** | **30 min. after mixing or at a later time specified by the grout manufacturer** |
|---|---|---|---|
| Cone method | Time, t(s) | 12s ≤ $t_o$ ≤ 25s | $1.2t_o \geq t_{30} \geq 0.8t_o$ and $t_{30} \leq 25$s |
| Grout spread method | Average spread, a (mm) | $a_o \geq 140$mm | $1.2a_o \geq a_{30} \geq 0.8a_o$ and $a_{30} \geq 140$mm |

Note:
- $t_o$ = flow time immediately after mixing
- $t_{30}$ = flow time 30 minutes after mixing
- $a_o$ = grout spread diameter immediately after mixing
- $a_{30}$ = grout spread diameter 30 minutes after mixing

11.21.2.3 Cohesion

11.21.2.3.1 Cohesion as a measure of the resistance to segregation, bleeding and settlement should preferably be improved by the use of admixtures to modify the viscosity and not increased by reducing the water/cement ratio.

11.21.2.3.2 The bleeding of the grout shall be sufficiently low to prevent excessive segregation and sedimentation of the grout materials. Bleeding shall be measured by either one of the methods given in BS EN 445 and the grout shall meet the requirements in the table below:

**Table 11.8 Bleeding Test Methods and Requirements**

| **Test methods** | **Maximum bleeding volume** |
|---|---|
| Wick-induced method | Average of 3 results ≤ 0.3% of the initial volume of the grout after 3 h kept at rest |
| Inclined tube mehod | ≤ 0.3% of the initial volume of the grout after 3 h kept at rest |

11.21.2.4 Compressive Strength

The compressive strength of grout prism assessed according to BS EN 445 shall not be less than 30 N/mm$^2$ at 28 days or 27 N/mm$^2$ at 7 days if it is proposed to estimate the likely 28 day strength at 7 days.

11.21.2.3.3 Setting time

Setting time of grout shall be measured according to BS EN 196-3 and shall comply with the following:

- Initial set of the grout; ≥ 3 hours.
- Final set of the grout; ≤ 24 hours.

## 11.21.3 Composition of Grout

11.21.3.1 General

Grout is composed of homogeneous mixture of cement and water. In addition, an accepted admixture shall be incorporated in the grout mix. Cement shall comply with BS EN 197-1 Type CEM I (Portland cement) and the mixing water for concrete shall comply with BS EN 1008.

11.21.3.2 The grout shall not contain more than

- Chloride ($Cl^-$) ≤ 0.10% by weight of cement;
- Sulfate ($SO_3^{2-}$) ≤ 4.5% by weight of cement;
- Sulfide-ions ($S^{2-}$) ≤ 0.01% by weight of cement.

The allowable limits specified above shall include chloride, sulfates, sulfites and sulfurs from all constituent materials of grout.

11.21.3.3 Admixtures

Admixtures shall be used as recommended by the manufacturer and shall be free of any chemical liable to promote corrosion of the tendon or cause damage to the grout, e.g. chlorides, nitrates and sulphates. Admixtures used shall comply with BS EN 934-1, BS EN 934-2, BS EN 934-4 and BS EN 934-6. It shall be permissible to use admixtures singly or in combination, provided it is from the same manufacturer and proven compatible.

Code compliant plasticising agents, viscosity modifying agents and gas generating admixtures may be used.

### 11.21.4 Mixing of Grout

11.21.4.1 Materials may be batched and mixed on site to produce the grout. Alternatively, the dry materials may be batched in a factory for ready-mixed grout and mixed with the liquid materials on site to produce the grout. The latter is preferred to improve the workmanship at site and to reduce error in grout mixing. All materials shall be batched by mass except the mixing water and liquid admixtures which may be batched by mass or volume. The accuracy of batching shall be:

- ± 2% for cement, dry admixtures,
- ± 1% for water and liquid admixture,

of the quantities specified.

Water contained in the liquid admixtures shall be included in the calculation of water/cement ratio.

The water/cement ratio shall not exceed 0.4. For any grout produced in accordance with BS EN 447, the following information shall be declared by the grout manufacturer:

- Mix proportions of materials;
- Water/cement ratio and its acceptable tolerance;
- Sequence of introducing the materials, type of mixer and mixing time;
- Range of temperature for which the grout complies with this BS EN 447.

11.21.4.2 Sufficient material shall be batched to ensure complete grouting of a duct and making due allowance for overflow. Mixing shall be carried out mechanically with suitable equipment to obtain a homogeneous and stable grout with the plastic properties given in Clause 6 of BS EN 447.

The mixer shall be of the high speed type such that it is capable of at least 1000 rpm with a full batch of grout. After mixing, the grout shall be kept in slow continuous agitation, until it is ready to be pumped into the duct. Water shall be added to the mixer first, followed by the cement.

11.21.4.3 The minimum time of mixing will depend upon the type of mixer and the manufacturer's recommendations shall be followed. Generally, the minimum mixing time will be between 0.5 min and 2 min. Mixing shall not normally be continued for more than 4 min. Where admixtures are used, the manufacturer's recommendations shall be followed.

### 11.21.5 Grout Tubes and Ducts

11.21.5.1 Grout tubes shall be provided adjacent to all tendon anchorages. Intermediate vent tubes shall also be provided at the high and low points of the duct, anchorages, major changes in the cross-section of the duct, such as trumpets of couplers and anchorages and in special cases, at the lowest point of a tendon having a small bending radius. In detailing the grout inlets and outlets, particular attention shall be paid to any location where a significant directional change to the tendon profile or a change in cross-section occurs. Vent tubes shall be placed at not more than 15m apart.

11.21.5.2 All grouting and venting points shall be suitably marked to enable identification of the duct to which they are connected.

11.21.5.3 All grout and vent tubes shall be at least 500 mm long, have a minimum internal diameter of 20 mm, and be provided with:-

(a) A threaded connection to the duct at the lower end.

(b) A threaded connection for the grout pump line at the upper end.

(c) A high pressure gas tap to permit quick cut-off of the grout flow.

11.21.5.4 All ducts must be large enough both to allow the threading of prestressed cable and to facilitate grouting. The cable to duct area ratio is defined as the total area of the strands based on its nominal diameter divided by the internal cross-sectional area of the duct. The following maximum cable to duct ratio shall be used:

(a) 0.4 for short cables with few directional changes and the tendons are placed by the pull through method.

(b) 0.45 for short cables with few directional changes and the tendons are pre-placed in the duct.

11.21.5.5 All ducts shall be kept free from contamination at all stages from storage to installation and shall be thoroughly clean before grouting. They shall be free of deleterious materials that would impair bonding of the grout or interfere with grouting procedures. Before grouting, each duct shall be cleaned out with oil-free compressed air and flushed out with clean water containing 0.01 kg/litre quick lime or calcium hydroxide.

### 11.21.6 Grouting Procedure

11.21.6.1 General

Prior to commencement of grouting application, the Contractor shall submit to the Engineer, the proven track record of the operators. Where required by the Engineer, the operators shall carry out trial panels to confirm their competence. The Engineer’s approval shall be obtained prior to the deployment of the operators on site.

11.21.6.2 Trials

11.21.6.2.1 Full-scale grouting trials shall be carried out using the same personnel, equipment, materials and procedures as proposed for the works. The trial shall demonstrate that the proposed grouting method, materials and equipment fills the ducts to the satisfaction of the Engineer.

11.21.6.2.2 Trials shall be undertaken as early as possible to allow proper inspection and any necessary modifications or adjustments.

11.21.6.2.3 The trials shall consist of two trials of a duct arrangement to simulate the beam geometry. The trials shall reflect the actual duct geometry and shall include typical tendon arrangements. The tendons shall be nominally stressed to ensure that the tendons assume the proper position with respect to the ducts.

11.21.6.2.4 Trial shall normally be cut at five sections for examination but more sections may be specified for complex tendon profiles as directed by the Engineer at site.

11.21.6.2.5 Grouting of the ducts shall normally be shown to leave no void which has a radial dimension greater than 5% of the maximum duct sectional dimension or which poses a risk to the integrity of the tendon. Particular attention shall be given to avoiding bleed collection or void formation at high points in the ducts or anchorages.

11.21.6.2.6 There shall be a procedure for corrective action in the event of blockage or breakdown such as backup equipment or flushing out of ducts.

11.21.6.3 Injection

11.21.6.3.1 Grouting equipment shall comply with BS EN 446.

11.21.6.3.2 The pump shall be of the positive displacement type with a safety valve to prevent the generation of excessive pressure. The connection of the pump to the duct shall be positive and the suction circuit of the pump shall be airtight. The pump shall be capable of exerting delivery pressure of at least 0.7 $N/mm^2$ and shall be fitted with pressure gauge having a full scale reading of 2 $N/mm^2$. A pressure gauge shall be provided at the duct inlet or, if this is out of sight of the pump operator, at the pump outlet to enable the flow of the grout to be checked and to give warning of incipient blockage. The baffles in the pump shall be fitted with 1.18mm sieve strainers. Piping to the pump shall have a minimum of bends, valves and changes of diameter.

11.21.6.3.3 A pump for filling horizontal ducts shall be capable of injecting grout at a continuous rate of 6m/min to 12m/min.

11.21.6.4 Injection Procedure

11.21.6.4.1 Grout shall be used within 30 min of mixing.

11.21.6.4.2 Ducts shall be grouted immediately after it has been verified that the tensioning of the prestressing steel has been successful. If there is a delay in inserting of the prestressing steel, protective soluble oils should either be applied on the prestressing steel or circulation of dry air in the ducts are to be provided to prevent corrosion on the prestressing steel.

11.21.6.4.3 The use of protective soluble oils should not have adverse effects on the prestressing steels or the properties of the grout. The bond properties of the prestressing steel with protective soluble oils should be acceptable for the design of the structure.

11.21.6.4.4 These materials shall be used in accordance with the recommendations of the manufacturer and it shall be verified that their use will not have an adverse effect upon the properties of the grout or its bond with the tendons

11.21.6.4.5 The grout injection procedure shall ensure that ducts are completely filled. Grout injection shall be continuous at an agreed rate and shall be slow enough to prevent segregation of the grout at points where flow is restricted and shall comply with BS EN 446 Clause 8. When grouting undulating ducts, the rate shall also be sufficiently fast to prevent a downward stream of grout breaking and entrapping air when this is flowing downwards. Grouting shall continue until the fluidity of density of the grout flowing from the free ends and the vent openings are the same as that of the injected grout. All vents shall be closed one after another in the direction of the flow. After closing the last vent, the pressure shall be held at 0.5 N/mm$^2$ for 5 min. The injection tubes shall then be sealed off under positive pressure of not greater than 0.1 N/mm$^2$.

11.21.6.4.6 After the completion of grouting, loss of grout from the duct shall be prevented. The tendons shall not be subjected to any vibration or shock within 24 hours after grouting.

11.21.6.4.7 Records shall be kept of the maximum and minimum ambient temperatures and the temperature of the structure adjacent to the tendons to be grouted. No grout shall be placed if the temperature of the grout or the temperature of the structure adjacent to the tendon is above 35$^o$C or the temperature for which the manufacturer has confirmed and documented the grout to satisfy the performance requirements of BS EN 447, whichever is lower.

**11.21.7 Blockages and Breakdown**

11.21.7.1 The Contractor shall provide standby flushing equipment capable of developing a pumping pressure of 2 N/mm$^2$ and of sufficient capacity to flush out any partially grouted ducts.

11.21.7.2 If blockage occurs, blocked duct shall be cleaned by, pumping water or blowing compressed air through it to remove the grout from the duct and the grouting procedure repeated.

**11.21.8 Removal of Vent Tubes**

All valves shall remain closed until the grout has set. At this stage, the vent tubes shall be removed to a minimum depth of 40 mm and the holes left in the face of the concrete rammed solid with dry pack mortar, or repaired as otherwise accepted by the Engineer.

**11.21.9 Inspection**

11.21.9.1 The Engineer may check the soundness of the grouting by visual inspection and/or by other means and the Contractor shall supply materials and assistance as required.

11.21.9.2 Where unsatisfactory grouting is discovered, the Contractor shall propose and carry out remedial measures to the acceptance of the Engineer.

11.21.9.3 Complete records shall be kept on all grouting of cable ducts and a copy of the records submitted to the Engineer.

**11.21.10 Grout Testing**

11.21.10.1 The following grout tests shall be carried out in compliance with the requirements in BS EN 447 and test methods in BS EN 445.

i) Sieve test

ii) Fluidity – cone method or grout spread method

iii) Bleeding – wick-induced test or inclined tube test

iv) Volume change – wick-induced test

v) Strength – compression test on broken halves of 40x40x160mm prism(s)

vi) Setting time measurement

vii) Density test

viii) Grout temperature ≤ 35$^{o}$C

11.21.10.2 The frequency of grout test during grouting shall be in accordance with Table 11.9 below:

**Table 11.9 Frequency of Tests during Grouting**

| **Tests** | **Frequency** |
|---|---|
| Compressive Strength | 3 tests/batch with samples taken at mixer as per BS EN 445 |
| Wick-induced bleed | 3 sets per grouting stage as per BS EN 445 |
| Volume change | 3 sets per grouting stage as per BS EN 445 |
| Fluidity | 3 tests/batch with samples taken at mixer as per BS EN 445 |
| Density | 2 tests per grouting stage (density variation in accordance with Clause 8.4 BS EN 446) |

Note: A grouting stage is the period of one continuous grouting operation. Test for bleeding and volume change are performed on the same sample.

Fluidity testing either by the Cone Method or the Grout Spread Method of BS EN 445, measured immediately after mixing only.

**11.21.11** The source of materials and procedures approved as a result of satisfactory trials shall not be departed from without the approval of the Engineer. The post-tensioning contractor shall document and implement all necessary precautions to ensure safety during grouting operations.

## 11.22 SILICA FUME CONCRETE

### 11.22.1 General

The concrete mix shall contain at least 7% of silica fume by mass of the total cementitious content in the mix. The design of the concrete mix shall be submitted for the Engineer's acceptance.

### 11.22.2 Materials

11.22.2.1 Silica fume shall be used in combination with water reducing admixture and/or superplasticiser. Silica fume shall conform to the chemical and physical requirements as given in the table below.

**Table 11.10 Chemical and Physical Requirements of Silica Fume**

| Chemical and physical requirements (BS EN 13263-1) | Characteristic value (by mass of dry silica fume) |
|---|---|
| Silicon dioxide – $SiO_2$ (%) | >85 |
| Elemental silicon - $S_i$ (%) | <0.4 |
| Free calcium oxide – CaO (%) | <1.0 |
| Sulfate – $SO_3$ (%) | <2.0 |
| Chloride content ($Cl^-$) (%) | <0.3 |
| Loss on ignition (LOI) (%) | <4.0 |
| Specific surface ($m^2$/gm) | 15-35 |
| Dry mass content in slurry (%) | <+/- 2.0 |
| Activity index (%) –Tested at a mortar age of 28 days | 100 |

11.22.2.2 The concrete mix proportions shall be determined from the results of the trial mix testing. When desired mix properties are achieved, specimens shall be prepared, cured and tested at 28 days and 56 days to determine acceptability of proposed mix proportions. All specimens shall meet the compressive strength and water penetration requirement of maximum 15mm as tested to BS EN 12390-8. In addition, the specimens when tested in accordance with ASTM C1202 shall be in the 'Very Low' permeability range as defined in that test standard.

11.22.2.3 The silica fume shall come from the same source throughout the project. If a single primary source of silica fume cannot be maintained throughout a project, the Contractor shall carry out all the necessary testing to demonstrate to the satisfaction of the Engineer that the use of silica fume shall comply with the chemical and physical requirements as specified in the above table.

### 11.22.3 Silica Fume Testing Requirement and Quality Assurance

11.22.3.1 In addition to rate of sampling in Clause 11.8.2, samples shall also be taken for every 1000$m^3$ of silica fume concrete delivered to site. The silica fume concrete shall meet the specified 28-day compressive strength and maximum water penetration at 28 days of 15mm as tested in accordance with BS EN 12390-8. In addition, the silica fume concrete shall be tested in accordance with ASTM C1202 and the results shall be within the 'Very Low' permeability range.

11.22.3.2 In the event that the tests show that the silica fume concrete do not meet the performance requirements, the entire batch of materials where the samples are taken shall be rejected and the Contractor shall submit rectification proposal for the Engineer's acceptance.

### 11.22.4 Submissions

The Contractor shall submit the following information to the Engineer for his review and acceptance:

(a) Manufacturer's product data sheets for silica fume.

(b) Laboratory test reports, name and location of primary manufacturing source of silica fume for use on the project.

(c) Silica fume concrete mix design and should include details of grading of fine and coarse aggregates, proportions of all ingredients including all admixtures, water/total cementitious materials ratio, slump (consistence) and bulk density of silica fume concrete.

(d) Proposed procedures for placing, finishing and curing silica fume concrete

(e) Proposed procedures for protecting silica fume concrete from drying and plastic shrinkage cracking during the placing and finishing process.

(f) Proposed procedures for protecting fresh silica fume concrete from rain.

### 11.22.5 Production, placing and compacting

11.22.5.1 Silica fume concrete shall be ready-mixed concrete batched, mixed and transported in accordance with ASTM C94.

The sequence and method of charging the mixer with silica fume and other ingredients shall be reviewed by the silica fume manufacturer's representative.

11.22.5.2 Silica fume concrete shall be placed and compacted by any of the currently available concreting techniques with the exception that it shall be placed at the highest practical slump typically ranging from 150mm to 225mm.

### 11.22.6 Finishing, curing and protecting

11.22.6.1 Silica fume concrete can be finished by methods similar to those used for finishing other concrete. The Contractor shall establish exact finishing methods for the project by carrying out trial placements prior to start of the actual work. These trials should be repeated until the best methods for the project and its specified mixture proportions are identified.

11.22.6.2 The Contractor shall take protective measures to ensure that the newly placed concrete does not dry out prior to and during the finishing operations.

11.22.6.3 Curing shall begin immediately after the finishing process is completed.

## 11.23 SELF COMPACTING CONCRETE

11.23.1 The constituent materials for Self-Compacting Concrete (SCC) i.e. cement, aggregates, water and admixtures shall be in accordance with Clause 11.2.

11.23.2 The SCC shall have sufficient fluidity to achieve a dense cement matrix without the need for additional compaction. The Contractor shall also ensure that the tendency for the concrete to segregate is reduced by using a viscosity modifying agent and/or reducing the amount of fines.

11.23.3 The Contractor shall submit the mix design of SCC together with proposed locations where they will be used to the Engineer for approval.

11.23.4 SCC shall be designed such that the workability of the product is maintained. During placing of SCC, free fall height shall be limited to not more than 5m and the horizontal distance from point of discharge shall be not more than 10m apart to prevent segregation.

# CHAPTER 12

# STRUCTURAL STEELWORKS

## 12.1 GENERAL

### 12.1.1 Submission Requirement

The Contractor shall submit name and license of the proposed steel fabricator, suppliers and specialist installer(s) for Engineer’s acceptance. All steel fabricator shall be accredited under the Structural Steel Fabricator Accreditation Scheme of the Singapore Structural Steel Society.

The Contractor shall produce fully detailed steelwork fabrication and shop drawings including marking drawings for all the as-built structural steelwork.

The Contractor shall coordinate and show all the required openings for services, allowances for architectural finishes and stiffener plates used for fabrication on the shop drawings for Engineer’s acceptance.

Fabrication shall not commence until the acceptance of the relevant shop drawings by the Engineer.

### 12.1.2 Materials

All structural steelwork, including structural fasteners and welding consumables etc. shall comply with the appropriate current Standards and/or Code of Practices and/or Design Guide on Use of Alternative Steel Materials to BS 5950 and Eurocode 3, (BCA:BC1).

## 12.2 DELIVERY

All deliveries of fabricated steelworks shall be accompanied with an Inspection Release Notes (IRN) certified by the Engineer’s site representative. Fabricated steelworks shall be carefully protected from damage during the course of delivery. The Engineer reserves the right to reject any damaged fabricated steelworks delivered or when installed.

## 12.3 INSPECTION AND TESTING

All certificates of tests and inspections, as well as Factory Production Control (FPC) Certificate shall be submitted to the Engineer upon delivery, for each batch of material supplied.

The Contractor shall carry out all necessary inspection to ensure that steel containing laminations or any other defects, is not incorporated in the work. Any inspection carried out by the Engineer shall not relieve the Contractor of the obligation to provide such inspection. Defective steel elements found at any stage of fabrication or subsequently discovered on Site shall be discarded and removed and replaced by sound material.

All tests on structural steel shall comply with the latest Steel Code or Regulation and it shall be carried out by a SAC/Singlas Accredited Laboratory.

All material 35 mm thick or more shall be tested by ultrasonic equipment and any which, in the opinion of the Engineer, is unsuitable due to lamination, shall be discarded and removed. Material under 35 mm thick shall be similarly tested when required by the Engineer.

The Contractor shall provide all necessary facilities, equipment and qualified personnel to carry out sampling and testing of materials, inspection of fabrication and surface treatment of the steelwork, including the handling or re-handling of materials as necessary. The Engineer shall be advised prior to sampling and testing, and shall be given the opportunity to attend.

Any work or materials which, in the opinion of the Engineer, is not in accordance with the Drawings or this Specification will be rejected. Any delay caused by such rejection shall not in any way relieve the Contractor of his obligations under the Contract.

## 12.4 FABRICATION

### 12.4.1 General

All material, before and after fabrication, shall be straight unless required to be of curvilinear form, and shall be free from twists. The fabrication tolerances shall comply with Table 12.1.

### 12.4.2 Fabrication and Storage Yards

Fabrication and storage yards shall be effectively protected against detrimental effects of weather and adverse environmental conditions.

### 12.4.3 Holing

Holes for rivets or bolts shall not be formed by gas cutting process.

Holes for close tolerance and barrel bolts shall be drilled to a diameter equal to the nominal diameter of the shank or barrel subject to a tolerance not exceeding 0.15mm.

Holes in connecting angles and plates, other than splices shall be punched full size through material not over 12 mm thick, except where required for close tolerance or barrel bolts.

Holes through more than one thickness of material for members, such as compound stanchion and girder flanges shall be drilled after the members are assembled and tightly clamped.

When holes are drilled in one operation through two or more separable parts, these parts shall be separated after drilling and the burrs removed.

#### 12.4.4 Cutting

All cut edges shall be dressed to a neat workmanlike finish and shall be smoothened and free from distortion.

#### 12.4.5 Grinding

Grinding shall include the removal of protruding or uneven surfaces of the damaged steelwork and paintwork.

### 12.5 ASSEMBLY AND ERECTION

#### 12.5.1 General

Each piece of steelwork shall be distinctly marked before delivery, in accordance with a marking diagram and shall bear such other marks as will facilitate the erection.

The component parts shall be assembled in such manner that they are neither twisted nor otherwise damaged and shall be so prepared that the specified cambers if any, are provided.

All ends of tubular members shall be sealed to prevent the access of moisture to the inside of the members.

#### 12.5.2 Erection Requirement

The erection tolerances shall comply with BS EN 1090.

A detailed method statement shall be submitted prior to commencement of work on site. The statement shall include a procedure to enable the required quality and safety of the work taking into consideration of site condition, site constraints, site restrictions and interfaces with other trades/SWCs. The statement shall also include drawings to show the layout, sections and the connection details of the temporary supports. All temporary supports shall be designed to withstand the most onerous loads during the assembly and erection, and shall maintain stability of the overall structure.

All stages of the erection procedure (including any temporary or permanent fastenings) shall be to the acceptance of the Engineer.

In particular, and without affecting the generality of this Clause, the Contractor shall ensure that the following requirements are met:

(i) The As-Built structure shall be correct to the dimensions given on the Drawings.

(ii) Permanent bolts shall not be used as service bolts during erection, where such use is liable to cause damage to the protective treatment provided to the bolt.

(iii) The Contractor shall be responsible for any loss or damage which may be caused by handling and erection of steelwork or by any of his plant. Damage to any part of the structure shall be reported to the Engineer before remedial work is started. Remedial work shall be to the acceptance of the Engineer.

### 12.5.3 Support and Foundation

Stanchion splices and butt joints of compression members dependent on contact for the transmission of compressive stresses, shall be accurately prepared so that the permitted stress in bearing is not exceeded nor eccentricity of loading created. Stanchion caps and bases shall be prepared in a similar manner to the above, and where this is obtained by machining, care shall be taken that any attached gussets, connecting angles or channels are fixed with such accuracy that they are not reduced in thickness by more than 2 mm.

Foundation bolts shall be cast to the dimensions shown on the drawings. The projecting ends of bolts shall be well greased and wrapped in sacking, which shall remain in position until the commencement of steelwork erection.

Prior to delivery of steelwork for erection, the Contractor shall check concrete bases or other seating for level, setting out, projection and full degree of adjustment of holding-down bolts or other fixings and ensure they are in accordance with the Drawings.

The Contractor shall remedy any discrepancies or inaccuracies to the acceptance of the Engineer. Modification to the steelwork or fixings, bending of holding-down bolts, or the use of an excessive number of washers to accommodate errors in position and projection of bolts or fixings shall not be carried out except with the written permission of the Engineer.

After final levelling, alignment of the steelwork, and installation of anchor bolts, the damaged existing screed shall be made good with an accepted epoxy mortar. The epoxy mortar mix and method of placing shall be submitted to the Engineer for his acceptance prior to the commencement of work.

## 12.6 WELDING

### 12.6.1 General

Welding of structural steelwork shall comply with BS EN 1011-1.

The manufacture, classification, code and size of electrodes shall be to the acceptance of the Engineer. Electrodes and fluxes shall be so chosen that the properties of the deposited metal are not inferior to those of the parent metal. Electrodes shall be used in accordance with the manufacturer's instructions. The welding plant shall be capable of maintaining at the weld the voltage and current specified by the electrode manufacturer. The Contractor shall supply instruments for the verification of such voltages and currents as may be required by the Engineer.

Welding shall be carried out under the continuous direction of an experienced and competent supervisor.

All welding works shall be protected against detrimental effects of weather.

Low Hydrogen electrodes shall be purchased in hermetically sealed containers or shall be baked by the user as recommended by the manufacturer prior to use. All welding consumables that have been removed from the original package shall be protected and stored strictly in accordance to the manufacturer’s recommendations so that the welding properties are not affected.

The Contractor shall furnish certification that the electrode or electrode-flux combination conforms to the requirements of the classification.

All welders shall possess valid test certificates in accordance with BS EN 287-1 or BS EN ISO 9606. Welder shall have at least a certificate to qualify him to do a 3G welding and only certified welder with qualification to do 4G welding shall be allowed to do overhead welding. The qualification of welder shall be submitted to the Engineer for acceptance.

### 12.6.2 Testing of Welds

Facilities, equipment and qualified personnel shall be provided to carry out any non-destructive testing and/or visual inspection of welds. The type of non-destructive testing shall include but not be limited to the following:

- magnetic particle flaw detection test (to BS EN ISO 17638)
- penetrant flaw detection test (to BS EN ISO 3452).
- ultrasonic examination (to BS EN ISO 17640)
- radiographic examination (to BS EN ISO 17636)

Unless stated in the Particular Specification or specified in the Drawings, the quality of welds shall be assessed in accordance with the acceptance levels given in BS EN ISO 5817. Any weld with defects greater than the maximum permitted shall be liable for rejection. The visual inspection of fusion welds shall be carried out in accordance with BS EN ISO 17637. Two copies of all inspection records and test results shall be forwarded to the Engineer.

The locations of the test shall be selected by the Engineer's representatives and the frequency of testing shall be as follows.

(a) Full penetration butt welds
- All weld locations shall be tested by ultrasonic or radiographic tests

(b) Partial penetration butt welds with fillet welds (leg fillet length greater than 12mm)
- min. 30% of partial penetration butt weld locations shall be tested by ultrasonic or radiographic tests and
- min. 20% of fillet welds locations shall be tested by magnetic particle flaw detection tests.

(c) Partial penetration butt welds
- min. 30% weld locations shall be tested by ultrasonic or radiographic tests.

(d) Fillet welds
- min. 30% weld locations shall be tested by magnetic particle flaw detection tests.

The Engineer may direct the Contractor to prepare test specimens in accordance with BS EN ISO 4136, BS EN ISO 9016, BS EN ISO 5178, BS EN ISO 5173, BS EN ISO 9017, BS EN ISO 17639, BS EN ISO 9015-1, BS EN ISO 9015-2, BS EN ISO 17636 and BS EN ISO 9018. When test are on butt weld the specimen shall be obtained from run-on plates of 100mm min. length. The Contractor shall make radiographic examination of weld where required by the Engineer. Welds, which in the opinion of the Engineer have any serious defects shall be cut out and renewed to the acceptance of the Engineer.

When radiographic examination is used, proper protection shall be installed to contain radiation within a confined space. Risk assessment shall be carried out and mitigation measures shall be implemented to prevent unprotected workers or members of public from the effects of radiation. The protection proposal shall be to the acceptance of the Engineer.

### 12.6.3 Welding Procedures

Details of the proposed welding procedures together with diagrams showing the build-up of all main welds shall be submitted to the Engineer for acceptance before work is started. Welding procedures shall be such that distortion is reduced to a minimum, and the sequence of welding such that all welds are made under conditions of least possible restraint. The distortion in the finished structure shall be in accordance with BS EN 1090.

Welds shall be kept free from slag or other inclusions, all adhering slag being carefully removed immediately after the completion of each run. Slag and weld spatter shall be removed from surrounding surfaces after welds have been completed.

Unless otherwise described on the Drawings, main butt welds shall be complete penetration welds. Run-on and run-off plates of the same thickness and profile as the parent metal shall be attached by means of clamps at each end of the weld. The weld shall extend at full profile for a minimum distance of 25 mm into the run-on and run-off plates. Run-on and run-off plates shall be removed by a method accepted by the Engineer. Additional metal remaining, after the removal of plates shall be removed by grinding or other accepted method. Where butt welds are ground flush there shall be no loss of parent metal.

Fillet welds shall be continuous throughout unless otherwise shown on the Drawings or where accepted by the Engineer.

For site welding, the Engineer’s acceptance shall be obtained beforehand in every case and such acceptance shall be subject to the proper conditions for welding being obtained.

## 12.7 BOLTING

Unless otherwise permitted by the Engineer, all bolts, nuts and washers shall be hot dip galvanised in accordance with BS EN 1461 or sherardized in accordance with BS 7371, Part 8 and shall be further prepared and coated to the same standard as the adjacent surfaces.

Where hot dip galvanized or sherardized bolt of grade 8.8 or higher is used, the respective nut used shall be of a class higher, e.g. Grade 8.8 bolt with Class 10 nut, Grade 10.9 bolt with Class 12 nut, to comply with BS EN ISO 4033.

The Contractor shall provide test certificates for all structural fasteners delivered to site. In addition, the Contractor shall test 2% of the structural fasteners to verify that the coating complies with the relevant code requirements.

All contact surfaces shall be thoroughly cleaned by hand wire brushing or similar means immediately prior to being brought together.

After tightening, bolt heads, nuts and washers shall be thoroughly cleaned and exposed surfaces painted with an accepted two-packed non-phenolic etch primer followed by the appropriate full system of primers and paints.

Subject to the acceptance of the Engineer, electroplated threaded components complying with BS 7371, Part 12 may be used for supporting light interior architectural finishes of less than 20 $kg/m^2$.

## 12.8 PROTECTION AGAINST CORROSION

### 12.8.1 General

Protective work shall be carried out in accordance with the relevant clauses of BS 5493.

Unless otherwise accepted by the Engineer, protective treatment shall be carried out on steelwork after fabrication. Shop treatment shall be carried out under a weather-proof, clean and dry shelter.

Steelworks shall be protected from external atmospheric conditions until completion of the treatment and the subsequent curing period.

All steelworks, including sub-frames used in architectural finishes, louver panels and etc., shall be applied with a paint coating system, except the following.

Stainless steel
- no protective system required.

Steelwork embedded in concrete
- no protective system required.

Covers and gratings
- to be galvanised only.

Bracketry and services fixings, hangers and traywork
- to be galvanised only.

Where steelwork is partially embedded in concrete, the same protective system for the exposed steel work shall be applied to the embedded steelwork over an area extending to at least 100mm beyond the exposed area.

Precaution measure shall be taken to prevent galvanic corrosion produced by contact between different metallic materials. Detail shall be submitted for the Engineer’s acceptance before assembly on Site.

12.8.2.1 Blast Cleaning

Prior to blast cleaning, any heavy layers of rust shall be removed by scraping. Visible oil, grease and dirt shall also be removed. Blast-cleaning where specified shall be carried out in accordance with BS 7079 to give a surface finish Sa 2.5 to ISO 8501-1. The abrasive shall be free from contamination, and recovered material shall be cleaned to the acceptance of the Engineer before re-use. Non-metallic (containing Silica) abrasives shall not be used. The blast-cleaned surface shall have a surface profile height between 50 and 100 microns.

Blast-cleaned steelwork shall be free from dust, mill scale and adherent particles. The first coat of primer shall be applied by an accepted airless spray process with the least possible delay and in any case, be within 2 hours of blast cleaning. The successive coats shall be applied within the time periods specified by the manufacturer. Suitable masks shall be provided at friction grip bolted connections to ensure that the friction surfaces are kept free of primer and paint.

12.8.2.2 Solvent Cleaning

The steelwork shall be solvent cleaned to remove all contamination and then washed with clean fresh water. Trapped water in crevices shall be blown out with clean dry compressed air. Solvent cleaning shall be repeated where necessary to the acceptance of the Engineer.

12.8.2.3 Hand and Mechanical Cleaning

Any heavy layers of rust shall be removed by scraping. Visible oil, grease and dirt shall also be removed. Hand and power tool cleaning shall be carried out to ISO 8501-1, St 3 grade to the acceptance of the Engineer. After hand and power tool cleaning, the steelwork surface shall be cleaned of loose dust and debris. All dust shall be removed by vacuum cleaning.

### 12.8.3 Galvanising

Galvanising for articles and products after fabrication shall be in accordance with BS EN 1461. The steelwork shall be pickled in dilute acid, then stove and dipped in a bath of smelter. Each article shall be covered evenly on all sides with zinc to achieve the specified thickness in Table 3 & 4 of BS EN 1461. Requirements for galvanized coating in a particular atmospheric exposure environment shall comply with ISO 14713-1.

Where protection coating is removed for site welding, zinc coating shall be re-applied to the surface as required under BS EN 22063 to the same thickness of the original work.

Unless otherwise accepted by the Engineer, cold formed or cold worked steel sections shall not be hot dip galvanised. Subject to the acceptance of the Engineer, light steel section used in the interior of buildings for supporting light architectural finishes may be fabricated from steel sheets or plates. The steel sheets or plates shall be hot dip galvanised in accordance to BS EN 10143.

### 12.8.4 Paints

12.8.4.1 General

All paints shall comply with SS 5, BS EN ISO 12944 where applicable unless otherwise stated. In addition, paints for steelwork shall comply with the following requirements:

a) All paints forming part of any one painting system shall be obtained from the same manufacturer. Paint shall be supplied in sealed containers of not more than 20 litres, unless otherwise accepted by the Engineer. Each container shall be clearly marked with the manufacturer's name, paint type, colour, production batch number, date of manufacture and pot life.

b) Prior to the commencement of painting of steelwork, the Contractor shall submit for the Engineer’s acceptance a full specification of the paint or paints he proposes to order, together with the name of the manufacturer whose paint he proposes to use. If instructed to do so by the Engineer, he shall supply liquid samples of the various paints concerned for examination and testing. No paint shall be used without the prior acceptance of the Engineer.

Paint that exceeds the “shelf life” specified on the container by the manufacturer, or paint that in the opinion of the Engineer has deteriorated and is not fit for use, shall be rejected.

Primers and paints shall be applied strictly in accordance with the manufacturer’s recommendations and shall be carried out by skilled painters under a competent supervisor. The Contractor shall submit the particulars of the supervisor for the Engineer’s acceptance.

12.8.4.2 Application

Paint shall not be applied when the relative humidity is in excess of 85 per cent, or when the surface temperature is less than 3°C above the dew point temperature, or when the temperature of the surface to which the coating is applied, is greater than 55°C.

Paints shall be used strictly in order of delivery from the manufacturer. Paint shall not be used after the expiration of the pot-life stipulated by the manufacturer, and paints of limited pot-life shall not be mixed with fresh paint or have thinners added to them.

Painting processes and methods shall be to the acceptance of the Engineer. All tools, solvents and plant used shall be such as to obtain the best possible results and shall be maintained in good condition throughout.

Each coat of paint shall be applied to ensure a continuous film of paint of uniform and even thickness. Successive coats shall be of a different shade so that the coverage of each coat is clearly visible. Each coat shall be thoroughly dry and cleaned of all dust and loose paint before the application of a further coat.

Sharp edges at corners, weld spatter or burr shall be removed prior to painting. Surfaces shall be cleaned by washing down with a solution of accepted liquid detergent, followed by rinsing with clean, fresh water where required by the Engineer.

Following the application of the final shop coat on any member, a curing period of not less than 36 hours shall be allowed before exposure to external atmospheric conditions.

Wherever practicable, successive coats in paint systems should differ in colour. However, manufacturer's recommendations in respect of the colours of the undercoats and first coat should be observed.

12.8.4.3 Type of Coating Systems

Systems 1, 2, 3 and 4 are for the following applications:

System 1 – Steelwork not visible to the public.

System 2 – Steelwork visible to the public (Alternative 1).

System 3 – Steelwork visible to the public (Alternative 2).

Systems 2A and 3A are normal repair procedures to Systems 2 and 3 respectively.

System 3B is a less demanding repair procedure to System 3A suitable for rafters, purlins and the like.

System 4 – Steelwork exposed to highly aggressive environmental conditions.

Unless otherwise accepted by the Engineer, for steelwork visible to the public, System 3 shall be used.

Details of the coating system shall be in accordance to Table 12.2.

12.8.4.4 Coating Specifications

The properties of the coatings shall be as follows:

A. Two-Pack Epoxy Zinc Rich Primer

- two component epoxy polyamide cured
- high flash point
- fast drying
- at least 85% zinc content in the dry film
- at least 60% volume solids

B. Two-Pack Epoxy Micaceous Iron Oxide High Build Primer

- two component epoxy polyamide cured
- high build product
- indefinite period for overcoating
- designed to be used as sealer coat over zinc epoxy primer
- micaceous iron oxide pigmentation
- at least 65% volume solids

C. Two-Pack Epoxy Fade Resistant Chemical Resistant Pigmented Paint

- High Build Paint
- two component epoxy polyamide cured high build product resistant to fumes and spillage of mild acids, alkalis, salts and solvents chemical and weather resistant pigmentation
- at least 60% volume solids

D. Two-Pack Polyurethane Fade-Resistant Chemical Resistant Pigmented Finish Paint

- two component polyurethane isocyanate cured
- very high gloss finish
- high abrasion resistance excellent chemical and solvent resistance
- chemical and weather resistant pigmentation at least 60% volume solids

E. Surface Tolerant Epoxy Primer

- two component epoxy aromatic amine cured
- designed for use over surface finish St 3 grade to ISO 8501-1
- high film thickness achievable by brush application
- aluminum paste pigmentation good chemical and solvent resistant
- long overcoating time-up to 6 months with polyurethane
- at least 80% volume solids

F. Inorganic Zinc Silicate Primer

- two component zinc silicate ethyl primer
- at least 85% zinc content in dry film
- temperature resistant up to 400 0C
- at least 60% volume solids

G. Epoxy Primer – For Galvanised /Stainless/ Carbon Steel Surfaces

- two component epoxy polyamide cured
- at least 57% solids ratio by volume

H. Two-pack Tar Free Epoxy

- two component high solids polyamine adduct cured tar free epoxy.
- at least 80% solids ratio by volume
- mixing ratio of base and hardener by volume shall be to the manufacturer’s recommendation

12.8.4.5 Coating Continuity and Thickness

The Contractor shall institute a quality control system that is acceptable to the Engineer to check the continuity and thickness of paint or metal coatings with the aid of approved electronic measuring devices which are capable of measuring the resistance of the coatings. Measurements shall comply with the recommendations of SS5.

12.8.4.6 Compatibility

The Contractor must ensure that all paints within a system have compatibility between coats and with the metal substrate. There should be adequate adhesion to substrate and between coats over the operating temperature range and there should be no under-softening to cause lifting, wrinkling or bleeding through of stains. Unless otherwise permitted by the Engineer, all components of a paint system shall be from the same manufacturer.

12.8.4.7 Toxicity

All paints and coatings shall not create a toxic hazard during application. Proper ventilation shall be provided during application to prevent buildup of toxic fumes. All paints and coatings shall not produce toxic fumes or other toxic materials when exposed to fire, so as not to cause risk to human health.

12.8.4.8 Degreasing

Degreasing shall be carried out using a water-based degreaser. The emulsified residue shall be washed off with a copious amount of fresh water. Trapped water in crevices shall be blown out with clean dry compressed air. Degreasing and washing shall be repeated where necessary to the acceptance of the Engineer.

### 12.8.5 Handling

Lifting and handling methods used during the protective treatment and in subsequent transport, storage and erection shall be such as to ensure that damage to the treatment is kept to the absolute minimum. Such damage as does occur shall be made good in accordance with Clause 12.8.4.3. The new paint shall overlap the existing paint by at least 50 mm all round the affected part.

### 12.8.6 Storage

Where it is necessary to store painted fabricated steelwork prior to erection, it shall be kept clear of the ground and stacked in such a manner as to ensure that no pools of water or dust accumulate on the surfaces. Suitable packing shall be provided between layers of stacked steelwork. Any damage found on painted work, the existing paint shall be completely removed and made good in accordance with Clause 12.8.4.3. The new paint shall overlap the existing paint by at least 50 mm all round the affected part.

**Table 12.1**

| Material & Dimension Standards | | | | | | |
|---|---|---|---|---|---|---|
| Shape | Material Quality | | | | Dimensions | Tolerances |
| | Non-alloy steels | Fine Grain Steel | Q&T Steel | Weathering steel | | |
| Universal Beams & Columns | BS EN 10025 "b" | BS EN 10113 | BS EN 10137 - 2 "c" | BS EN 10155 | BS 4 - 1 | BS EN 10034 |
| Joists | | | | | BS 4 - 1 | BS EN 10024 |
| Channels | | | | | BS 4 - 1 | BS EN 10279 |
| Rolled Asymmetric Beams | | | | | "d" | "d" |
| Angles | | | | | BS EN 10056 - 1 | BS EN 10056 - 2 |
| Rolled Tees | | | | | BS EN 10055 | BS EN 10055 |
| Split Tees | | | | | BS 4 - 1 | BS EN 10034 |
| Plates (Reversing Mill) | | | | | - | BS EN 10029 |
| Plates (Cut from Coil) | | | | | - | BS EN 10251 |
| Wide Flats | | | | | - | EU 91 |
| Hollow Sections (Hot Finished) "e" | BS EN 100210 - 1 | | - | BS7668 | BS EN 100210 - 2 | |
| Hollow Sections (Cold Finished) "e" | BS EN 10219 - 1 | | - | | BS EN 10219 - 2 "d" | |
| Product without specified maximum manganese content or are not supplier with carbon equivalent value (CEV) options. Additional requirements may therefore need to be specified, eg option 5 or 6 of BS EN 10025 | | | | | | |
| Grade S275 & S355 only. If the steel is to incorporate welded connection "Option 5 must be ordered. | | | | | | |
| Only Plate and Wide flats grade S460 | | | | | | |
| See manufacturers information for rolled asymmetric beams and S235 Cold Formed Hollow Sections | | | | | | |
| All Hollow Sections are to be Hot Finished to BS EN 10210 - 1, unless otherwise specified on drawings. | | | | | | |

## Table 12.2 Detail of Systems

| | System 1 | System 2 | System 2A | System 3 | System 3A | System 3B | System 4 |
|---|---|---|---|---|---|---|---|
| **Step 1** | Galvanise. | Blast clean | Hand and Power Tool clean. | Galvanise. | Degrease. | Degrease. | Galvanise |
| **Step 2** | Degrease. | 1 coat of shop-applied Coating A. Min D.F.T 40 microns. | 1 coat of site-applied Coating E. Min D.F.T 40 microns. | Degrease. | Grind as necessary. | Grind as necessary | Degrease. |
| **Step 3** | 1 coat of shop-applied Coating G. Min D.F.T 80 microns. | 1 coat of shop-applied Coating B. Min D.F.T 100 microns. | Solvent clean. | 1 coat of shop-applied Coating G. Min D.F.T 80 microns. | Power clean. | Power clean. | 1 coat of shop-applied Coating G. Min D.F.T 80 microns. |
| **Step 4** | 2 coats of shop-applied Coating C. Min D.F.T 80 microns per coat. | 1 coat of shop-applied Coating C. Min D.F.T 125 microns. | 2 coats of site-applied Coating C. Min D.F.T 125 microns per coat. | 2 coats of shop-applied Coating C. Min D.F.T 80 microns per coat. | 1 coat of site-applied Coating G. Min D.F.T 80 microns. | 1 coat of site-applied Coating B. Min D.F.T 80 microns. | 2 coats of shop-applied Coating H. Min D.F.T 150 microns per coat. |
| **Step 5** | | Solvent clean. | 1 coat of site-applied Coating D. Min D.F.T 50 microns. | 1 coat of shop-applied Coating D. Min D.F.T 50 microns. | 2 coats of site-applied Coating C. Min D.F.T 80 microns per coat. | 1 coat of site-applied Coating D. Min D.F.T 50 microns. | |
| **Step 6** | | 1 coat of site-applied Coating D. Min D.F.T 50 microns. | | | 1 coat of site-applied Coating D. Min D.F.T 50 microns. | | |
| **Minimum Total Dry Film Thickness (D.F.T)** | 240 microns (excluding galvanising) | 315 microns. | 340 microns. | 290 microns. (excluding galvanising) | 290 microns. | 130 microns. | 380 microns. (excluding galvanising) |

Specification of Coatings A to H are given in **Clause 12.8.4.4**

# CHAPTER 13

# ABOVE-GROUND STRUCTURES

## 13.1 GENERAL

This Chapter covers the Materials & Workmanship requirements for above-ground structures that include:

(a) all above-ground stations and trainways,

(b) vehicular bridges, and

(c) cycle and pedestrian bridges,

## 13.2 TRIAL SECTIONS

### 13.2.1 Columns

13.2.1.1 The Contractor shall construct a trial typical column with crossheads/ column heads to the Engineer's acceptance. The trial sample shall satisfy the following requirements:

(a) All features, e.g. feature grooves, recesses and test boxes, etc. shall be incorporated.

(b) It shall be constructed in parts with construction joints similar to that intended for the Permanent Works.

13.2.1.2 If the trial column is rejected, further trial columns shall be erected until a satisfactory standard is achieved. The approved trial column shall be the standard of acceptability for the columns.

13.2.1.3 The trial column can be part of the Permanent Works subject to the Engineer's acceptance.

### 13.2.2 Girders

13.2.2.1 The Contractor shall construct a trial typical section to the Engineer's acceptance. The trial sample shall satisfy the following requirements:

(a) All features, e.g. feature grooves, parapets, etc. shall be incorporated.

(b) It shall be constructed in parts with construction joints similar to that intended for the Permanent Works

13.2.2.2 If the trial section is rejected, further trials shall be erected until a satisfactory standard is achieved. The approved trial girder shall be the standard of acceptability for the Permanent Works.

13.2.2.3 The trial section can be part of the Permanent Works subject to the Engineer's acceptance.

## 13.3 WATERPROOFING/ INSULATION SYSTEMS

### 13.3.1 General

The waterproofing and/or insulation works for above-ground structures shall comply with the following clauses.

13.3.1.1 Shop Drawings and Method Statement

13.3.1.1.1 The Contractor shall submit comprehensive shop drawings and method statement showing all details and procedures for the waterproofing and/or insulation works including those at the movement joints, drainage and penetration points.

13.3.1.1.2 The Contractor shall submit a Method statement describing the details of the waterproofing and/or insulation works including protective measures at all stages. It shall be prepared in conjunction with the applicator and duly endorsed by the manufacturer of the membrane. The Method statement shall be subject to the Engineer's acceptance prior to any waterproofing and/or insulation work.

13.3.1.2 Application

The membrane shall form a continuous layer over the structure to the extent shown on the Drawings and shall be applied in accordance with the approved Method Statement.

The Contractor shall take precautions to ensure that:

(a) Once installed, the waterproofing and/or insulation membrane shall be protected from damage until the concrete screed is placed and cured.

(b) Particular attention shall be given to the avoidance of damage to the membrane when placing the reinforcement mesh and in-situ concrete screed.

(c) The time period between the installation of a section of membrane and the placing of its protective screed or tiles shall not be more than 7 working days.

(d) Construction traffic shall not be allowed to pass over the completed screed until it has attained a minimum concrete strength class of C16/20.

13.3.1.3 Flower Troughs and Planting / Turfing Areas on Bridge Decks

13.3.1.3.1 The entire length of the flower trough and entire planting/ turfing areas on bridge decks shall be waterproofed with an approved cementitious crystallisation active coating.

13.3.1.3.2 The waterproofing material, sample, specifications and application method statement shall be submitted for the Engineer's acceptance.

13.3.1.4 Water Ponding Test

13.3.2.1.1 After the completion of the waterproofing membrane installation, at least 2% of the total length or total number of spans, whichever is more onerous and subject to a minimum of 1 span of the viaduct deck shall be ponded to test for leakage and seepage.

13.3.2.1.2 The Contractor shall provide all temporary kerbs in cement mortar or by other means to provide enclosures to contain ponding water. All rainwater outlets must be plugged and the entire viaduct is flooded with 75 mm of clean water for three days, after which the viaduct shall be inspected for any sign of water penetration.

13.3.2.1.3 Should there be defective areas, the Contractor shall bear the entire cost of remedying the defects by an accepted method and re-testing to the acceptance of the Engineer.

On satisfactory completion of the ponding test, the Contractor shall carefully break up and remove any kerb or temporary barrier and plugs to outlets and remove all debris. The Contractor shall take care in doing so to prevent damage to the viaduct structure or surface. Ponding water shall be drained by accepted means and steps must be taken at all times to prevent breeding of mosquitoes and choking of rainwater down pipes.

13.3.1.5 Warranty

The performance of the viaduct decking waterproofing and/or insulation shall be warranted for a minimum period of ten (10) years from the date of Completion of the Contract. All defects occurring during this warranty period are to be made good by the Contractor. The warranty shall be given jointly and severally by the Contractor and the supplier/applicator and shall be in the format given in the General Specification.

**13.3.2 RTS Structures with Stray Currents**

13.3.2.1 Materials

13.3.2.1.1 The waterproofing/insulation membrane shall be fully bonded to the entire length of the viaduct deck. The membrane shall, at all times during construction be fully protected from any damage.

13.3.2.1.2 The Contractor shall submit for acceptance the proposed bonded waterproofing/insulation membrane system and the applicator approved by the manufacturer. The bonded waterproofing/insulation membrane shall satisfy the following requirements and other relevant requirements contained in the Specifications.

(a) Electrical resistivity shall be not less than 5000 x $10^{11}$ Ω-cm (ASTM D257)

(b) Tensile strength of the membrane shall be not less than 5000 kPa (ASTM D412)

(c) Elongation at maximum load shall be not less than 400% (ASTM D412)

(d) Puncture resistance shall be not less than 95 kgf (ASTM D5602)

(e) Adhesion of membrane to concrete shall be not less than 900 kPa (ASTM D7105)

(f) Minimum lapping at any joint shall be not less than 100mm

(g) Total thickness of the membrane shall be not less than 2.50mm (ASTM D751)

(h) Reinforcement of the membrane shall be non-woven polyester which is not less than 180 gm/$m^2$.

13.3.2.1.3 The Contractor shall submit the test reports as stated above. The Engineer may require tests to be carried out on the samples of the membrane to verify the properties.

13.3.2.1.4 The waterproofing/insulation membrane laid on horizontal surfaces shall be protected by reinforced concrete screed. On non-horizontal surfaces, the waterproofing/insulation membrane and protective reinforced concrete screed shall be laid to fall for drainage purposes.

### 13.3.3 RTS Structures without Stray Currents

13.3.3.1 The entire length of the viaduct decks without stray currents shall be applied with approved waterproofing membrane. The waterproofing membrane shall be applied by the manufacturer's approved applicators strictly in accordance with the approved Method Statement.

13.3.3.2 Joints between pre-cast segments shall be sealed with approved epoxy resin mortars before the application of the waterproofing membrane. The joint detail shall be submitted to the Engineer for acceptance.

## 13.4 DECK DRAINAGE SYSTEM

### 13.4.1 General

13.4.1.1 The capacity of the drainage system shall comply with Public Utilities Board's (PUB) Code of Practice on Surface Water Drainage. The Contractor shall submit all relevant calculations endorsed by his Professional Engineer to the Engineer's acceptance and PUB for approval.

13.4.1.2 The Contractor shall design the connections of the drainage pipe systems. All drainage pipe systems shall be:

(a) heavy-duty UPVC pipes in compliance with BS EN 13598-1 or equivalent.

(b) tested by application of air pressure upon completion. Inlet units as shown on the Drawings shall be cast in, and connected to the waterproofing in accordance with the manufacturer's instruction.

13.4.1.3 Prior to casting, all cast-in pipework shall be rigidly supported, and shall be checked for alignment and tested for water tightness.

13.4.1.4 All steel fixing shall be galvanised in accordance with the Specifications.

### 13.4.2 Road Deck Drainage

13.4.2.1 The longitudinal drainage carrier pipes shall not be smaller than 250mm diameter with cleaning eyes at intervals not more than 20 m.

13.4.2.2 The vertical drainage down pipes shall not be smaller than 250mm diameter with cleaning eyes provided at each end of the outlet pipes and wherever there are changes in direction.

### 13.4.3 RTS Deck Drainage

For RTS viaduct structures, the UPVC down pipes shall be cast in the column. Cleaning eyes shall be provided at locations wherever there are changes in direction. Where there are waterproofing/insulation membrane on the deck, the membrane shall be properly tucked into the collar inlet.

## 13.5 PARAPETS AND RAILINGS

### 13.5.1 General

13.5.1.1 For vehicular bridges, the typical railing details as shown in the Standard Details of Road Elements, shall be adopted. The bridge parapet profiles and designs shall be in accordance with Civil Design Criteria Chapter 3 and Chapter 9.

13.5.1.2 The railings shall be made of aluminium alloy.

13.5.1.3 The Contractor shall submit the detailed design, drawings and the dynamic test reports to the Engineer for acceptance before any order is placed.

### 13.5.2 Fabrication of Parapet/ Railings

13.5.2.1 Parapets shall be fabricated in accordance with the Drawings.

13.5.2.2 Bridge parapet railings shall comply with the following standards:

(a) Posts and rail end caps to BS EN 1676, BS EN 1559 and BS EN 1706

(b) Rail tubes to BS EN 12020, BS EN 755 and BS EN 573

(c) Plates to BS EN 515

(d) Stainless steel bolts to BS EN ISO 3506-1

(e) Stainless steel holding-down bolts to BS EN ISO 3506-1: Grade A4-80

### 13.5.3 Alignment of Parapets

The finished parapets shall be true to line and level throughout their length. The face of the rails shall present an even finish on the traffic face. Rails of curved panels having a horizontal curvature less than 300 metres shall be rolled to smooth curves.

Panels and members shall be free from twist and the posts shall be truly vertical.

### 13.5.4 Welding

Welding for aluminium and aluminium alloy railings shall comply with the requirements of BS EN 1011-4.

### 13.5.5 Static Loading and Material Testing

At least 2 bays of the parapet railing system including the posts and bolts supplied shall be chosen by the Engineer for static and material testing in accordance with BS 6779 at a SAC-SINGLAS accredited laboratory. All costs involved shall be borne by the Contractor.

### 13.5.6 Aluminium Parapets and Fascias for RTS Viaducts

The Contractor shall be responsible for the design and detailing of the aluminium parapets and fascias where specified in the Drawings. Detailed drawings, calculations and method statement for installation shall be submitted for acceptance by the Engineer.

## 13.6 PRECAST DECK FURNITURE FOR RTS VIADUCTS

Precast concrete units where installed shall be true to line and level throughout their lengths, along the viaduct structures The Contractor shall design and detail the panels to suit installation on the beams.

The holding down bolts/sockets shall not be in contact with any of the steel reinforcing bars in the viaduct structures.

## 13.7 LAUNCHING OF PRECAST ELEMENTS

### 13.7.1 General

The Contractor shall inform the Engineer at least one month in advance of each launching operation and submit the following to the Engineer for acceptance:

(a) Method statement including launching systems and transportation,

(b) Proposal for traffic diversion, as appropriate,

(c) Detailed programme of each launching operation.

(d) Detailed calculations of temporary supporting structures.

### 13.7.2 Transportation

The Contractor shall obtain the necessary clearances for the transportation of the pre-cast elements and movement of the lifting equipment to the launching site. Contractor's method of transportation shall demonstrate that the elements being transported would not be damaged.

A certificate of test of lifting equipment shall be submitted to the Engineer, together with particulars of the experiences of the operator.

### 13.7.3 Ground preparation

The ground of the launching area shall be prepared to ensure that it is safe to carry the load during launching operation.

### 13.7.4 Erection

13.7.4.1 Utmost precautions shall be taken to eliminate any danger to the workers and general public while launching pre-cast elements. All lifting equipment shall be designed, such that if the primary lifting mechanism fails, a secondary mechanism will ensure that the pre-cast element does not fall.

13.7.4.2 Upon erection, a fail-safe method shall be used to temporarily secure the pre-cast unit until the permanent fixing arrangements are implemented.

13.7.4.3 The securing systems, subject to the Engineer's acceptance shall include:

(a) Providing chains between beams and supports;

(b) Connecting adjacent beams by welding protruding bars of the beams; or temporary bracings between the beams;

(c) Providing wedges or brackets to the beams.

13.7.4.4 The Contractor shall:

(a) Ensure that appropriate and sufficient warning signs, lights, barricades and at least one rotating amber light are placed at each point of road closure or diversion in accordance with the LTA's Code of Practice For Temporary Traffic Control.

(b) Station at least one person in a safe position at each point of road closure, to advise and guide motorists. The person shall be equipped with a torch, reflective vest and walkie-talkie or other mean of communications within the launching site.

(c) Have one person controlling the whole launching operation with a whistle or other mean of communications with the lifting equipment operators.

(d) Ensure that there is sufficient lighting at the launching site.

(e) Ensure that no welding work on the bridge is carried out unless a protective screen is used to prevent sparks and other materials from falling onto the areas below.

(f) Install 4.5m height restriction signs of standard design immediately after launching of any pre-cast element above existing carriageway.

(g) Measure and record the actual height clearance of the bridge at every 2m along the span of the bridge above the carriageway.

(h) Measure and record the location of the smallest clear height between the carriageway and the bridge.

(i) Submit measurements showing that the height clearance of the bridge satisfies the minimum clearance to the Engineer before opening the road under the bridge to traffic.

## 13.8 PRECAST SEGMENTAL CONSTRUCTION

13.8.1 Where precast segmental match-cast method of construction is adopted, the Contractor shall ensure that the durability is not compromised between segment joints. The Contractor shall submit the detailing for a fully watertight joint between segments for the Engineer's acceptance.

13.8.2 The Contractor shall conduct mock-up tests to the acceptance of the Engineer to prove that a fully watertight joint is achieved.

# CHAPTER 14

# WATERPROOFING FOR STRUCTURES

## 14.1 GENERAL

### 14.1.1 Material Requirements

Fully bonded non-hydrophilic membranes or spray applied liquid polymer membranes shall be used for waterproofing walls and roof slabs of underground structures.

For waterproofing to base slabs of underground structures, either system as stated below shall be adopted:

i. Fully bonded membrane system with silica fume (also known as microsilica) in concrete [Figure 14.1(a)],

ii. Concrete with silica fume with the bottom 450mm of the base slab consisting of self-compacting concrete only [Figure 14.1(b)].

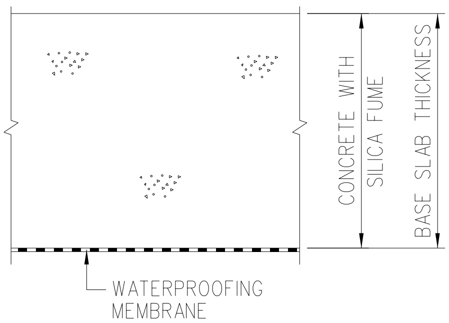



**Figure 14.1(a)**

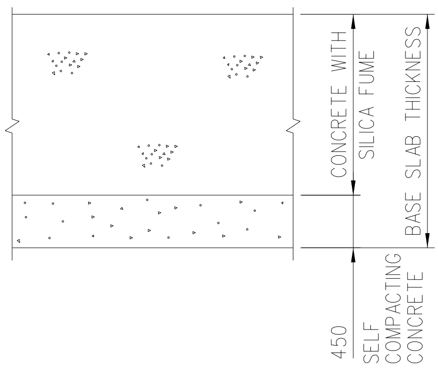



**Figure 14.1(b)**

Concrete waterproofing admixtures may be considered for waterproofing walls where site constraints prevent the use of fully bonded non-hydrophilic membranes or spray applied liquid polymer membranes, subject to the acceptance of the Engineer.

Membranes shall be weather and UV-resistant.

### 14.1.2 Performance Requirements

The watertightness standards to be applied to all underground structures, water-retaining or water-excluding structures shall be in accordance with the standards defined in Table 1.

**Table 1: Watertightness Standards**

| Structural Element | Performance Requirements |
|---|---|
| 1. External walls, permanent diaphragm walls with internal facing walls, base slabs and roof slabs of underground structures. | Free from all visible leakage, seepage and damp patches. |
| 2. Suspended slab over tracks, concourses, and public areas, areas with sensitive electrical and mechanical plant, car parks and areas where leakage would, in the opinion of the Engineer, affect the operation of the railway, roadway or other operations within the structure. | Free from all visible leakage, seepage and damp patches. |
| 3. Permanent diaphragm walls without internal facing walls. | Restricted to minor damp patches with no visible film of water. |

Note: Dampness shall be defined as moist to touch with no visible film of water.

### 14.1.3 Submission Requirements

The Contractor shall submit the following information to the Engineer for his review and acceptance.

i. Make and composition of all waterproofing materials including ancillary items such as primer, mastic sealant, and protection boards as recommended by the manufacturers.

ii. Test reports of not more than five years old shall be submitted to demonstrate that the material properties without and with 6 months thermal ageing meet the requirements and properties specified in the relevant sections of this specification. All tests shall be carried out by a Singapore Accreditation Council (SAC-SINGLAS) laboratory that is accredited to do the specified tests.

iii. Comprehensive working drawings showing, as a minimum, locations and extent of waterproofing, details and methods for waterproofing of the Works, including details of membranes, waterstops, injection tube systems, position of joints, isometric layout of waterstops and injection tubes, typical details at penetrations including king posts and piles, details at sump pits and details at contract interfaces.

iv. Manufacturer’s literature of the proposed waterproofing materials including installation recommendations and instructions.

v. Detailed method statements prepared in conjunction with, and endorsed by, the proposed applicator and manufacturer of the material, describing the waterproofing system and installation details including protective measures at all stages of the waterproofing works.

vi. Samples of the proposed waterproofing materials.

Upon acceptance of the proposed waterproofing system, the Contractor shall submit detailed shop drawings to the Engineer for his acceptance prior to commencing any waterproofing works.

### 14.1.4 Quality Assurance

The approved waterproofing materials shall be tested to verify that the material properties without thermal ageing meet the performance requirements and properties as specified in the relevant sections of the Materials & Workmanship Specification.

For waterproofing membrane installation up to 15,000m$^2$, a complete set of tests as specified in Tables 2, 3 and 4 shall be conducted on the samples taken from the waterproofing membrane delivered to site. Additional sets of test shall be conducted for every subsequent 15,000m$^2$.

For application of waterproofing admixture up to 1000m$^3$ of walls, a complete set of tests as specified in Clause 14.3.5.1 or 14.3.5.2 shall be conducted on the samples taken from the waterproof concrete delivered to site. Additional sets of test shall be conducted for every subsequent 1000m$^3$. A complete line of automated, high precision dispensing equipment with computerised control of adding waterproofing admixture as per approved trial mix shall be introduced at the batching plant for good quality control.

Samples shall be taken for every 1000m$^3$ of silica fume concrete delivered to site. A complete set of tests as specified in Clause 14.2.2 shall be conducted on the samples.

In the event that the tests show that the waterproofing materials, waterproof concrete or silica fume concrete do not meet the performance requirements, the entire batch of materials where the samples are taken shall be rejected and the Contractor shall submit rectification proposal for the Engineer’s acceptance.

The Contractor shall carry out a trial application of the waterproofing materials for the proposed waterproofing system.

Waterproofing materials shall be installed only by the manufacturer of the product or his approved applicator.

### 14.1.5 Waterproofing Application

No waterproofing works shall commence without the written consent of the Engineer.

Application of waterproofing system shall only commence upon completion of curing of the concrete. The Contractor shall ensure that surfaces to which waterproofing is to be applied shall be clean, dust free and dry and shall be prepared fully in accordance with the manufacturer’s recommendations and requirements.

All cracks on exposed surfaces of external structural members shall be effectively sealed in accordance with the relevant clauses of Chapter 11, Concrete and Reinforcement Bars before applying any waterproofing system.

Preformed bonded membrane that is used for waterproofing external walls shall be protected against damage due to backfilling, compaction and ground settlement with 100mm thick extruded polystyrene boards or equivalent material which provides the same level of protection performance [Figure 14.2(a)].

No extruded polystyrene board is required if liquefied soil stabilizer (LSS) is proposed as a backfill material between the outer face of the external wall and the earth retaining and stabilising structure (ERSS). However, if the ERSS is to be removed, a 50mm and 25 mm thick extruded polystyrene board or equivalent material which provides the same level of protection performance shall be used to protect the preformed bonded membrane and sprayed liquid polymer membrane respectively [Figure 14.2(b) and 14.2(c)].

The membrane protection boards shall only be applied after the membrane is cured.

Where preformed bonded membrane is applied to roof slabs, a 6-mil polyethylene separating sheet shall be laid before covering with a minimum 75mm thick protective Grade 20 lean concrete slab.

In the case of spray applied liquid polymer membrane that is applied to roof slabs, a 6-mil polyethylene separating sheet shall be laid before covering with a minimum 50mm thick protective Grade 20 lean concrete slab.

Damaged or non-compliant sections of the laid membrane shall be repaired in accordance with the manufacturer's recommendations and as accepted by the Engineer.

The primer shall be capable of conditioning the concrete to promote the adhesion of the membrane. In confined and poorly ventilated areas solvent-based primers shall not be used.

The membrane may be laid across changes in the plane of the concrete surface where the material is sufficiently pliable to enable the adhesive to remain in continuous contact with the primed concrete. Where this cannot be achieved, a fillet of a suitable liquid membrane or a similar fixture shall be provided and fully bonded to the concrete surface.

The two layers of membrane shall be laid with a minimum lateral overlap of 55%; i.e. a minimum of two layers shall always be present with an additional layer locally at joints. Joint transverse to the direction of laying shall be avoided wherever possible by laying each roll of membrane in a continuous length as far as practicable. Unavoidable joints shall be provided with a minimum 150mm overlap with joints in adjacent sheets staggered by at least 500mm.

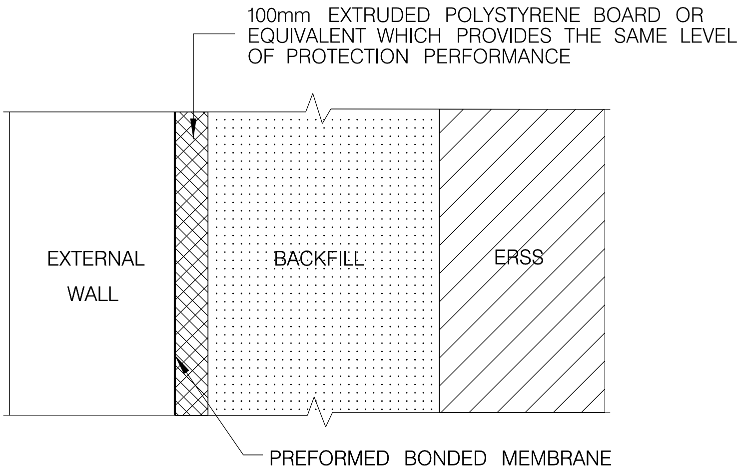



**Figure 14.2(a)**

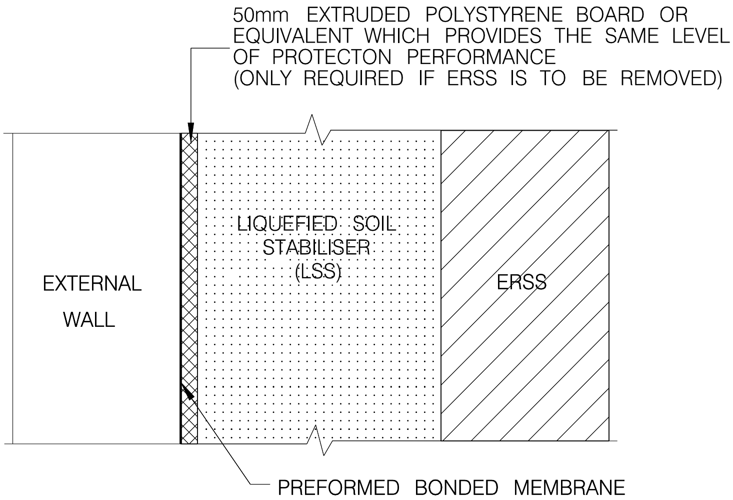



**Figure 14.2(b)**

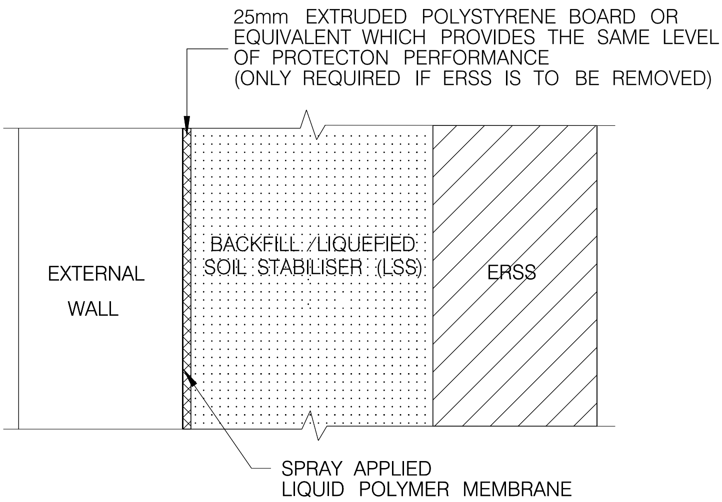



**Figure 14.2(c)**

When laying the membrane, no other works shall be carried out in the vicinity, which may cause personnel, or equipment to intentionally or accidentally come into contact with the membrane before it has been protected. Extruded polystyrene boards shall be used by the persons laying the membrane to avoid stepping directly onto the laid membrane.

### 14.1.6 Contract Interface Areas

The Contractor shall coordinate with the adjacent contractors to ensure compatibility between the Contractor's waterproofing system and that of the adjacent contracts. The first contractor to work at the interface shall extend the base slab waterproofing by at least 800mm beyond the contract limit to allow the second contractor to overlap their waterproofing. For walls and roof slab, the first contractor shall maintain with adequate protection of at least 800mm of the waterproofing within his contract to allow adequate overlapping of the waterproofing by the second contractor.

The second contractor shall be responsible for providing a watertight joint at the contract interface.

## 14.2 WATERPROOFING TO BASE SLABS OF UNDERGROUND STRUCTURES

### 14.2.1 General for Preformed Bonded Membrane

Blinding concrete shall have a minimum thickness of 75mm. Where ground conditions are such that there would be a risk of localised settlement of this blinding layer during or after subsequent construction operations, the concrete thickness shall be increased and reinforced as necessary to avoid localised settlement. A drainage layer shall be provided beneath the blinding concrete where necessary to ensure that the blinding concrete is not damaged by hydrostatic pressures prior to casting of the base slab.
Where openings must be left in the membrane for structural continuity of piles, king posts, pipes or for other items projecting below the soffit of the base slab, the membrane shall be cut away at the junction with these protrusions or penetrations and the edges sealed all round with a bituminous liquid membrane or approved sealant. The bituminous liquid membrane or sealant must be proven compatible with the membrane.

Where the base slab will be cast against diaphragm walls, piled walls, or rock faces, the membrane shall be terminated in a robust detail, and sealed with a bituminous liquid membrane or approved sealant to the acceptance of the Engineer. The bituminous liquid membrane or sealant must be proven compatible with the membrane. The wall surface shall first be levelled by the application of a steel trowelled mortar coat where there is any risk that its roughness may cause the membrane to be punctured.

### 14.2.2 General for Silica Fume Concrete

The silica fume concrete shall meet the specified 28-day compressive strength and maximum water penetration at 28 days of 15mm as tested in accordance with BS EN 12390-8. In addition, the silica fume concrete shall be tested in accordance with ASTM C1202 for rapid chloride penetration and the results shall be within the ‘Very Low’ permeability range.

Silica fume concrete shall conform to the requirements given in the relevant clauses of Chapter 11, Concrete and Reinforcement Bars.

### 14.2.3 Preformed Membrane Bonded Downwards

Surfaces to receive the waterproofing membrane shall be prepared to U3 finish prior to the application of a bituminous primer coat.

The preformed membrane shall meet the performance requirements given in Table 2.

**Table 2: Performance Requirements for Preformed Membrane Bonded Downwards**

| | |
|---|---|
| Total membrane thickness (DIN EN ISO 2286-3) | Applied on site in two separate layers of minimum 1.5 mm thick (Total thickness of 3mm) |
| Dimensional stability (SS374) | Not more than 0.5% (both longitudinal and transverse) |
| Tensile strength (SS374) | 3MPa minimum measured over the combined thickness of film and adhesive layers. |
| | 2.6MPa minimum with 6 months thermal ageing |
| Elongation at break (SS374) | 300% minimum |
| | 240% minimum with 6 months thermal ageing |
| Peel or stripping strength to concrete (ASTM D903) | 2000N/m width minimum |
| Resistance to hydrostatic head (DIN 16726) | Water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m water head. |
| Puncture resistance - (ASTM G-14 Test) | 10Nmm tear of backing film |
| Thickness, tensile strength, elongation at break, peel or stripping strength to concrete, resistance to hydrostatic head and puncture resistance after storage in aqueous solution (DIN 16726 for the storage of test specimens in aqueous solutions. The specimens shall be tested for the above properties in accordance with the respective ASTM/DIN standards ) | Properties not affected by more than 10%. |

Where external walls above the base slab are to be constructed in open cut, the membrane laid beneath the base slab shall extend 300mm beyond the limits of the base slab in order that the waterproofing to the wall may be lapped onto it. Blinding concrete beneath the membrane shall extend 500mm beyond the limits of the base slab.

As soon as possible after the membrane is laid, it shall be protected by a protective slab or screed of minimum 50mm thick.

### 14.2.4 Preformed Membrane Bonded Upwards

A preformed membrane capable of achieving full bond to the base slab may be used.

The preformed membrane shall meet the performance requirements given in Table 3.

**Table 3: Performance Requirements for Preformed Membrane Bonded Upwards**

| | |
|---|---|
| Membrane thickness (DIN EN ISO 2286-3) | Applied on site in a single layer of minimum 1.2mm thick |
| Dimensional stability (SS 374) | Not more than 0.5% (both longitudinal and transverse) |
| Tensile strength (SS 374) | Carrier Film 25MPa |
| | 22.5MPa minimum with 6 months thermal ageing |
| Elongation at break (SS 374) | 300% minimum |
| | 240% minimum with 6 months thermal ageing |
| Peel or stripping strength to concrete (ASTM D903) | 750N/mm |
| Resistance to hydrostatic head (DIN 16726) | Water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m water head |
| Puncture resistance (ASTM E154) | 1000N |
| Thickness, tensile strength, elongation at break, peel or stripping strength to concrete, resistance to hydrostatic head and puncture resistance after storage in aqueous solution (DIN 16726 for the storage of test specimens in aqueous solutions. The specimens shall be tested for the above properties in accordance with the respective ASTM/DIN standards) | Properties not affected by more than 10% |

Laps must be staggered and of minimum width 500mm. The membrane shall be laid on blinding concrete complying with the requirements of Clause 14.2.1. The adhesive side of the preformed membrane shall have its upper surface protected by a factory applied weatherable and trafficable coating of a composition that will facilitate the forming of a bond of the specified strength to the cured concrete.

The membrane shall also have sufficient strength to resist all impacts and other forces to which it may be subject to prior to placing of the structural concrete.

Membranes shall be laid such that there is a clearance of not less than 300mm beyond a construction joint and the nearest lap of the membrane. The membrane may be laid across changes in the plane of the concrete surface where the material is sufficiently pliable to enable the adhesive to remain in continuous contact with the concrete.

Where external walls above the base slab are to be constructed in open cut, the membrane laid beneath the base slab shall turn up at least 300mm from the top of the structural slab in order that waterproofing to the wall may be fully lapped on to it.

## 14.3 WATERPROOFING TO WALLS OF UNDERGROUND STRUCTURES

### 14.3.1 External Walls to Structures Built in Open Excavation (Bonded Preformed Membranes)

The preformed membrane shall meet the performance requirements given in Table 2.

The material, application and protection requirements shall be in accordance with Clause 14.1.5.

In the event that waterproofing system as shown in Figure 14.1(b) for base slab is used, the wall membrane shall be terminated as shown in Figure 14.3.

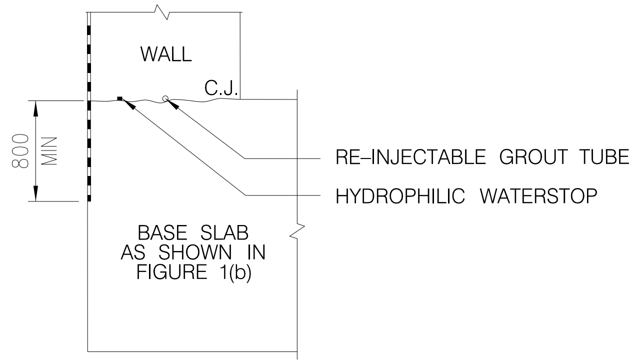



**Figure 14.3 Termination of Wall Membrane**

Membranes shall be laid such that there is a clearance of not less than 300mm beyond a construction joint and the nearest lap of the membrane.

When the membrane is being laid progressively up a wall of an underground structure, the membrane shall not extend nearer than 500mm below the nearest higher horizontal construction joint until the concrete above that joint has been placed and cured. The membrane shall be fully protected at all stages during construction.

### 14.3.2 External Walls to Structures Built in Open Excavation (Spray Applied Liquid Polymer Membrane)

The spray applied liquid polymer membrane shall be suitable for use in an ambient temperature range not greater than 40$^{o}$ C. It shall allow diffusion of water vapour to prevent any build up of pressure between the membrane and substrate. The membrane shall meet the performance requirements given in Table 4.

**Table 4: Performance Requirements for Spray Applied Liquid Polymer Membrane**

| | |
|---|---|
| Total membrane thickness | 2.5mm minimum dry film thickness and sprayed in a minimum of two coats of contrasting colours, with the second coat applied to the first coat only after the first coat has cured. Single-coat application may be considered for fast-curing membranes subject to the acceptance of the Engineer |
| Tensile strength (ASTM D412) | 4.0MPa minimum in any of the three orthogonal planes of the membrane |
| Elongation at break (ASTM D412) | 130% minimum |
| Puncture resistance (ASTM E154) | 300N minimum |
| Pull-off strength (ASTM D7234) | 2.0MPa minimum |
| Static crack bridging (ASTM C836) | 2mm minimum |
| Resistance to hydrostatic head (DIN16726) | Water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m water head |
| Thickness, tensile strength, elongation at break, pull-off strength, resistance to hydrostatic head and puncture resistance after storage in aqueous solution (DIN16726 for the storage of test specimens in aqueous solutions. The specimens shall be tested for the above properties in accordance with the respective ASTM/DIN standards) | Properties not affected by more than 10% |

The cured membrane shall be chemically resistant to the effects of seawater, hydraulic fluids, diesel fuel and diluted mineral acids etc.

The substrate shall be prepared and primed in strict accordance with the manufacturer's recommendations and requirements. The membrane shall be of a thixotropic nature and cold applied to ensure consistent thickness is achieved over all substrate irregularities.
The materials used must be based upon resin systems that do not react with moisture although the substrate should be dry during application. The liquid polymer membrane shall be terminated in a chase or by a method acceptable to the Engineer.

All components of waterproofing system shall be provided by one manufacturer. All materials must be supplied to site in unopened packaging, with batch numbers marked and corresponding manufacturer's certificates of conformity, and must be used within the product's shelf life. All components of the system exposed to rain within the curing period shall be replaced.

The membrane wet film thickness should be checked every $10m^2$ during application of each layer, using a pin or comb gauge. Destructive testing to measure dry film thickness shall be carried out on the cured membrane at every $100m^2$ or at every working shift, whichever occurs sooner, and shall be made good to the satisfaction of the Engineer.

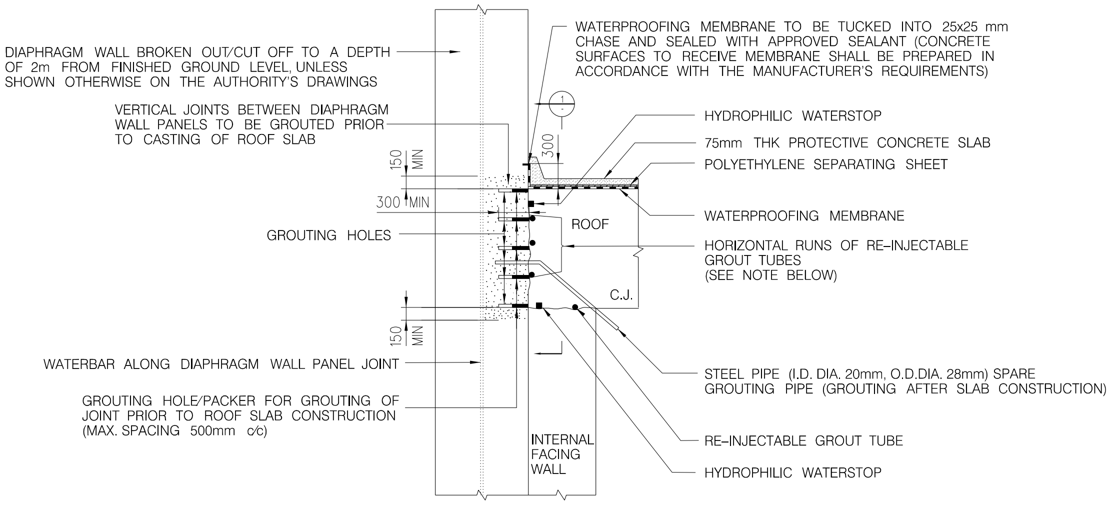
Holiday tests or similar tests to the acceptance of the Engineer shall be carried out on the cured membrane to identify any discontinuities in the membrane and to prove the integrity of the membrane.

### 14.3.3 Diaphragm Walls

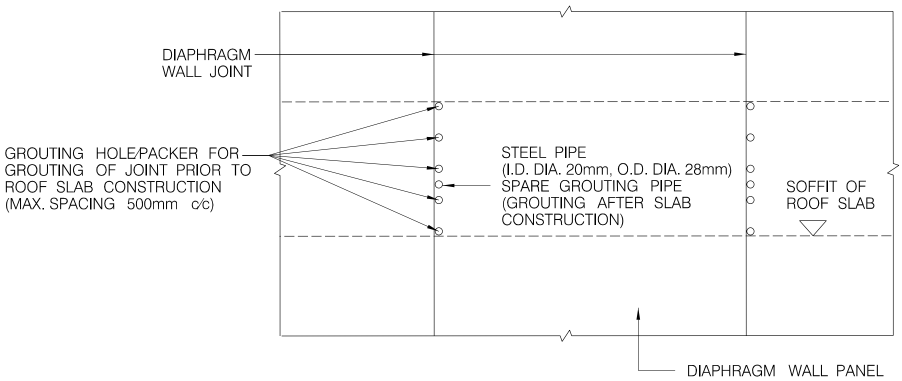
All leaks in the diaphragm walls shall be sealed. At the junctions with the base slab and roof slab, horizontal continuous runs of re-injectable grout tubes within the slab sections shall be installed on properly prepared surfaces to the satisfaction of the Engineer.

After completion of the base slab and roof slab, regardless whether there is any leak, the junction with the base slab and roof slab shall be grout injected.

Typical details showing these requirements are illustrated in Figures 14.4(a) and 14.4(b).



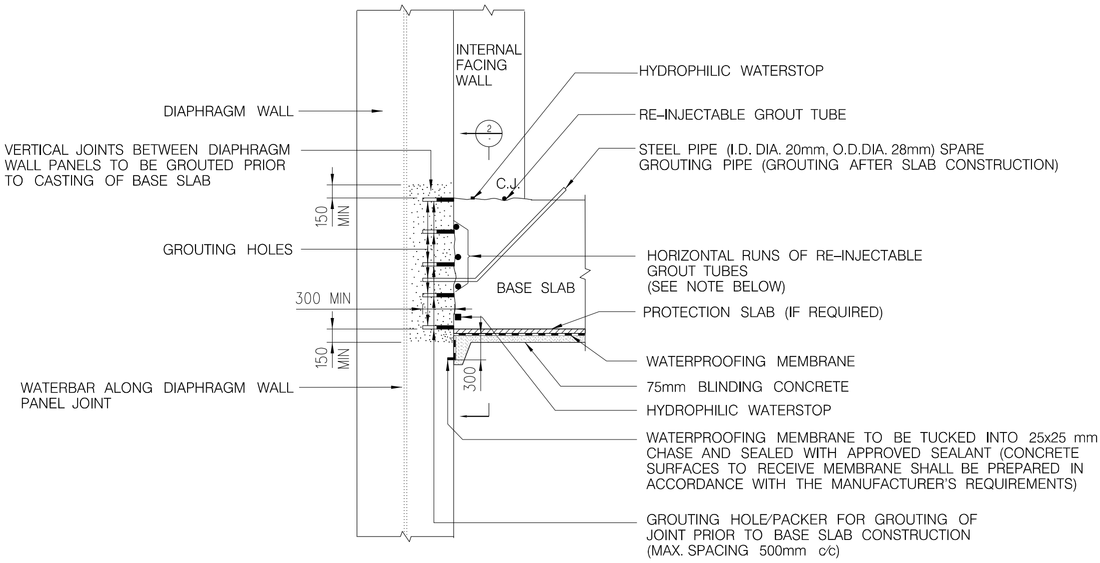

NOTE:
HORIZONTAL RUN RE-INJECTABLE GROUT TUBES TO BE INSTALLED ON PROPERLY PREPARED DIAPHRAGM WALL SURFACES AT MINIMUM CONCRETE EDGE DISTANCE OF 250MM AND MAXIMUM SPACING OF 500MM AND IN NO CASE, THE NUMBER TO BE PROVIDED BE LESS THAN 2



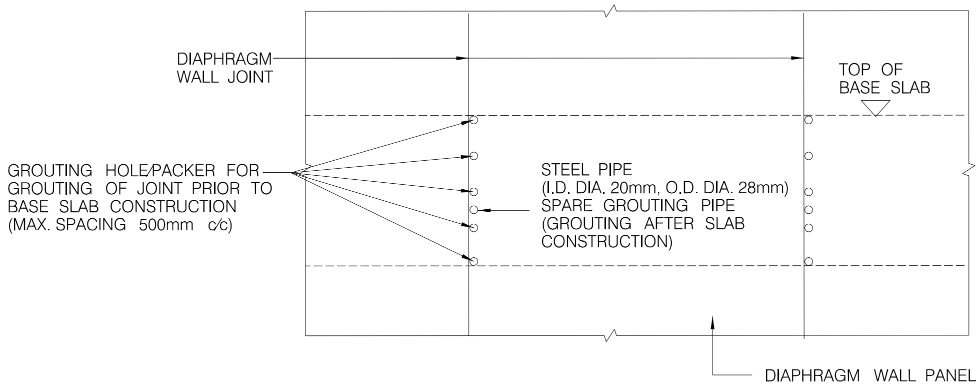

NOTE:
1. HORIZONTAL RE-INJECTABLE GROUT TUBES AND HYDROPHILIC WATERSTOP NOT SHOWN ON SECTION 1-1

1 – 1

**Figure 14.4(a) Details at Diaphragm Wall/Roof Slab Interface**




NOTE:
HORIZONTAL RUN RE-INJECTABLE GROUT TUBES TO BE INSTALLED ON PROPERLY PREPARED DIAPHRAGM WALL SURFACES AT MINIMUM CONCRETE EDGE DISTANCE OF 250MM AND MAXIMUM SPACING OF 500MM AND IN NO CASE, THE NUMBER TO BE PROVIDED BE LESS THAN 2




NOTE:
1. HORIZONTAL RE-INJECTABLE GROUT TUBES AND HYDROPHILIC WATERSTOP NOT SHOWN ON SECTION 2-2

2 – 2

**Figure 14.4(b) Details at Diaphragm Wall/Base Slab Interface**

These junctions shall be re-grouted if necessary.

Reinforced concrete internal facing wall that abuts diaphragm wall shall be waterproofed by concrete admixtures complying with requirements given in Clause 14.3.5.

### 14.3.4 External Walls Built against Pile Walls or Rock or Soil Faces

The face against which the in situ structural wall is to be cast shall be built up by infill concrete. The surface shall be smooth, free from voids, loose aggregate and sharp protrusions. Where the thickness of the infill concrete is greater than 75mm, steel mesh shall be provided.

Where membranes are applied and bonded to infill concrete surface, the primer and the waterproofing membrane shall be in accordance with the appropriate requirements of Clause 14.1.5 and Clause.14.3.1. In addition, a third layer of membrane shall be provided.

For membrane that is bonded to the external face of the in situ structural wall, the preformed membrane shall meet the performance requirements given in Table 3.

The membrane shall be continued upwards to 300mm above roof slab level. Suitable provision shall be made for continuity of the membrane with the watertightness provisions to the structure.

Typical details showing these requirements are illustrated in Figure 14.5.

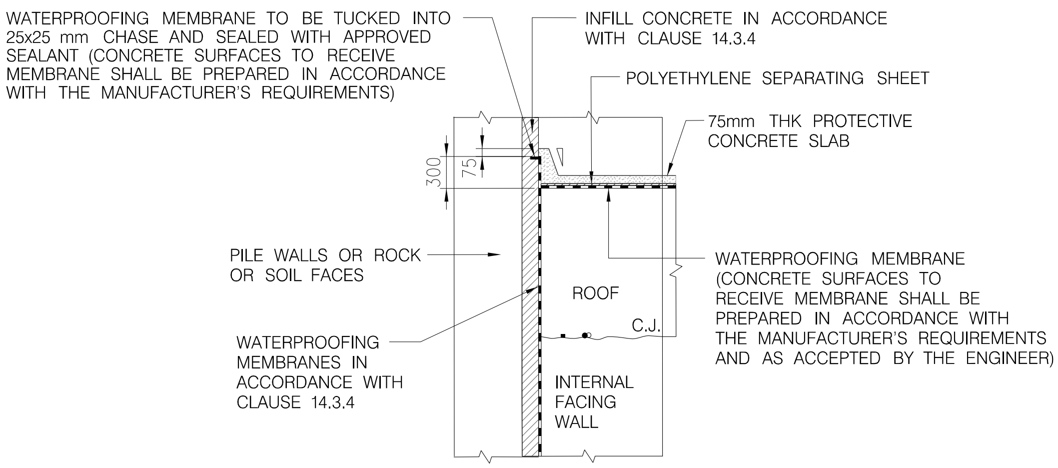



**Figure 14.5 Wall cast against pile wall rock or other soil face sealed by a waterproofing membrane**

### 14.3.5 General for Concrete Waterproofing Admixtures

Concrete waterproofing admixture shall be either of the hydrophobic and pore-blocking or crystalline growth types. The admixture shall have a proven track record of successful application in similar conditions.

Any admixtures or ingredient other than cement, aggregate or approved water-reducing admixture, used by the Contractor to comply with the absorption and permeability requirements, must be shown by an independent authority to have had no reduction in performance after field exposure for a minimum of 15 years.

If the Contractor is unable to meet the above requirements, he shall demonstrate to the satisfaction of the Engineer that the proposed materials have been successfully used in projects of similar nature and scale. In addition, the Contractor is required to provide an extended warranty in accordance with Clause 14.7.

Where concrete waterproofing admixture is used for waterproofing walls, it shall be applied to the full thickness of the walls.

14.3.5.1 Hydrophobic and Pore-Blocking Ingredient (HPI) Type

Prior to construction, trial mixes are to be conducted under the supervision of the Engineer or his Representative and with the HPI admixture manufacturer present to confirm that the proposed mix conforms to strength, w/c ratio, slump and other requirements. The trial mix concrete shall further have a corrected 30-minute water absorption of not greater than 1.0%, (one percent) as measured by BS 1881: Part 122 except that the age at test shall be 7 days. The absorption test is to be conducted on cores taken from cubes or cylinders as specified in the standard. Cast specimens, 150mm x 75mm, may also be used for testing where approved by the Engineer, in which instance a correction factor will not be applied to the measured absorption result.

The trial mix concrete shall further have an average water permeability coefficient when tested at 28 days of not greater than $5 \times 10^{-13}$ m/s as measured by the test method given in Appendix 1 under water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m (unless otherwise specified by the Engineer) and an average penetration depth not greater than 15 mm as measured by BS EN 12390-8 test under water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m (unless otherwise specified by the Engineer).

14.3.5.2 Crystalline Growth Type

A concrete admixture characterised by crystalline growth mechanism may be used subject to the acceptance of the Engineer.

Prior to construction, trial mixes are to be conducted under the supervision of the Engineer or his Representative and with the manufacturer present to confirm that the proposed mix conforms to strength, w/c ratio, slump and other requirements. The trial mix concrete shall further have an average water permeability coefficient when tested at 28 days of not greater than 5 x $10^{-13}$ m/s as measured by the test method given in Appendix 1 under water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m (unless otherwise specified by the Engineer) and an average penetration depth not greater than 15mm as measured by BS EN 12390-8 test under water head consistent with the depth at which the structure is seated and shall not in any case be less than 50m (unless otherwise specified by the Engineer).

## 14.4 WATERPROOFING TO ROOFS OF UNDERGROUND STRUCTURES

### 14.4.1 Roof Slabs with Preformed Bonded Membranes or Spray Applied Liquid Polymer Membranes

Concrete surfaces to receive the membrane shall be prepared in accordance with the membrane manufacturer's instructions and requirements.

Where the external wall to the structure has been constructed in open excavation, the bonded membrane protecting the roof slab shall be turned down and provided with a minimum 300mm lap onto the wall membrane.

Where the external wall has been cast against a pile wall or other face sealed by a waterproofing membrane, the roof membrane shall be turned up to provide a 300mm lap onto the wall membrane as shown in Figure 14.5.

Where the external wall is cast against a diaphragm wall and no wall membrane is provided, the roof membrane shall be turned up at least 300mm and tucked into a 25mm x 25mm chase cut into the diaphragm wall and sealed with an approved sealant as shown in Figure 14.4(a).

After completion of each section of membrane, and before casting the permanent protective slab, the waterproofing system shall be tested by ponding with minimum 150mm of water for a 48-hour period. The water level shall be topped up as necessary over the 48-hour period. At the end of this period, the underside of the slab shall be inspected for water leakage or dampness. Where there is any evidence of water penetration, the Contractor shall investigate and propose rectification works to the acceptance of the Engineer.

## 14.5 WATERPROOFING TO SURFACE AND PARTIALLY UNDERGROUND STRUCTURES

### 14.5.1 Ground Slabs

Waterproofing to ground slabs shall be similar to that specified for base slabs of underground structures.

### 14.5.2 External Walls Protruding Above Ground Level

Where external walls protrude above the ground level, the waterproofing membrane shall be terminated in a chase and at least 150mm above the adjacent ground level. Continuity of waterproofing between the junction with above ground structure and the external walls must also be assured.

### 14.5.3 Roof and Other Exposed Slabs

Waterproofing to roofs and other exposed slabs shall consist of a fully bonded membrane system in accordance with the requirements for roofs of underground structures. The primer and membrane shall be applied in accordance with Clause 14.1.5.

Protection to the membrane shall be provided by a dimpled or otherwise profiled polyethylene sheet, which permits drainage, 25mm thick extruded polystyrene boards, a 6-mil polyethylene separating sheet and concrete slab of minimum 75mm thickness.

At the perimeter of the roof, the termination of the waterproofing membrane, drainage layer and protective slab shall be integrated with the architectural treatment to ensure proper drainage of water.

## 14.6 STRUCTURAL CONCRETE WORKS

### 14.6.1 General

Notwithstanding the provision of the waterproofing system, the Contractor shall construct his concrete works so as to minimize the likelihood of water penetration. Special attention shall be given to the compaction and curing of concrete, particularly in areas such as at construction joints, around waterstops, king posts and other structural penetrations.

### 14.6.2 Construction Joints

Construction joints shall be watertight. All construction joints in external slabs and walls shall be provided with an effectively continuous waterstop and re-injectable grout tube.

Before placing new concrete against concrete that has already hardened, the face of the cast concrete shall be treated in accordance with the relevant clauses of Chapter 11, Concrete and Reinforcement Bars.

### 14.6.2.1 Waterstops

Waterstops shall be appropriate for the type of joint where they are used. They shall have a proven satisfactory performance when used in similar conditions.

Waterstops shall be of either barrier type flexible PVC/rubber or hydrophilic waterstops. All waterstops shall possess a hydrostatic resistance appropriate to the structure and joint in which they are installed.

Hydrophilic waterstops shall have a delayed swell action to prevent premature expansion prior to concreting and shall have a volumetric increase of not less than 120%. The hydrophilic waterstop shall exhibit good consistency in swell rate during repeated wetting and drying cycle. The water-swellable component of the hydrophilic waterstop shall not leach from the carrier matrix under any conditions.

Hydrophilic waterstops shall be installed just before concreting and shall be placed as near as possible to the face subject to hydrostatic pressure whilst conforming to the manufacturer’s requirement of minimum edge distance. They shall be firmly fixed in place so that they cannot be displaced during concreting.

### 14.6.2.2 Injection Tube System

Injection tube system shall include tough, flexible and chemically inert tubes, connecting tubes, junction boxes, grout, pumps and all other items required for their installation and use. The Contractor shall provide full details of his proposed injection tube system for the Engineer's review and acceptance.

The injection tube system shall be suitable for resinous or cementitious grout and be capable of re-injection to seal joints.

The injection tube shall be robustly fixed in place in accordance with the manufacturer's instructions and recommendations.

Different colours shall be used for horizontal and vertical runs to facilitate identification on site. Tube vent ends/packers shall be colour-coded by same colours for each end of the same tube.

Junction boxes shall be installed in locations which are readily accessible and which do not interfere with the use to which the structure will be put. Unless otherwise accepted by the Engineer, they shall be set into the concrete.

The injection hose shall be tested by injecting water through them.

Upon completion of the Works, the Contractor shall submit a manual containing detailed instructions for grouting and flushing, materials data, as-built/ record drawings showing location of all tubes, packers and corresponding junction boxes and other information pertinent to future maintenance.

### 14.6.3 Waterproofing Treatment to Pipes, King Posts and Embedded Pipes

Typical details showing the minimum requirements for waterproofing treatment around pipes, king posts and embedded pipes are illustrated in Figures 14.6(a), 14.6(b) and 14.6(c) respectively.

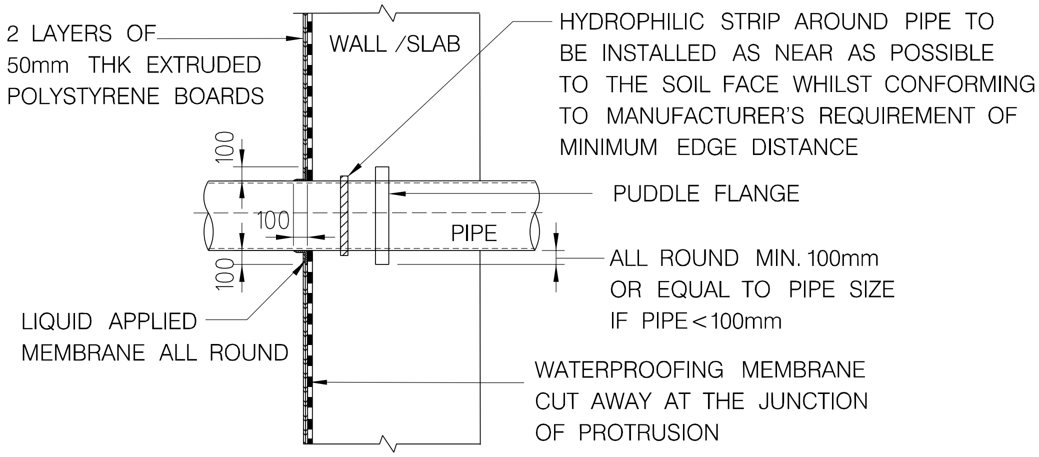



**Figure 14.6(a) Treatment at Pipe Penetration**

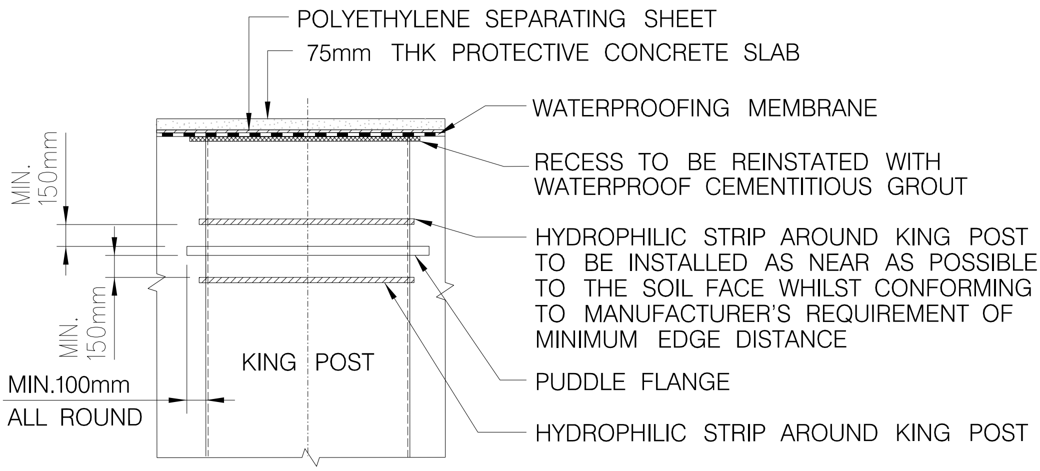



**Figure 14.6(b) Treatment at King Post (Similar treatment shall also be applied to king posts penetration at base slabs)**

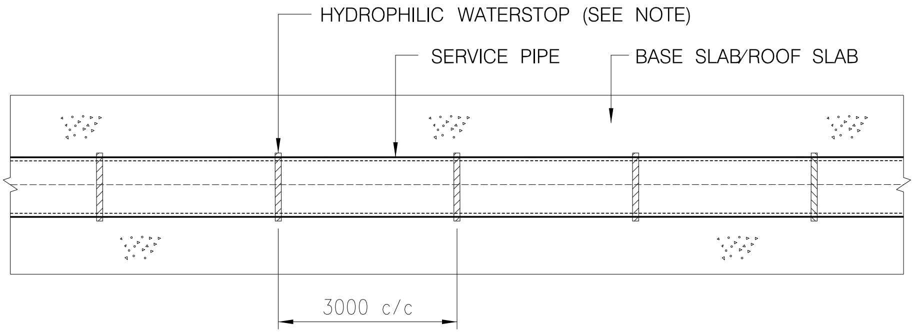



**Figure 14.6(c) Treatment of Embedded Pipe in Base and Roof Slab**

### 14.6.4 Waterproofing Treatment to Column Stumps for Future Development

Typical detail showing the minimum requirements for waterproofing treatment to column stumps on roof slab of underground structures is illustrated in Figure 14.7. The warranty of waterproofing system to the column stump or any other structure for future development shall be provided by the Contractor.

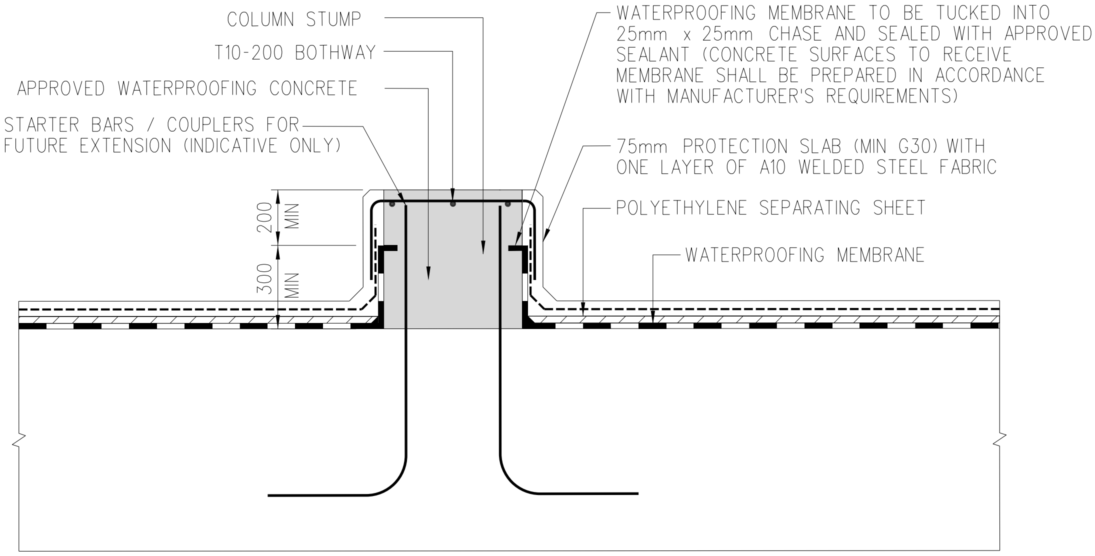



**Figure 14.7 Treatment of Column Stump for Future Development**

### 14.6.5 Piles and Pilecaps

Where the waterproofing membrane is discontinuous to permit structural connection to piles and pilecaps, the edges around the pile shall be sealed with an approved liquid membrane as shown in Figure 14.8.

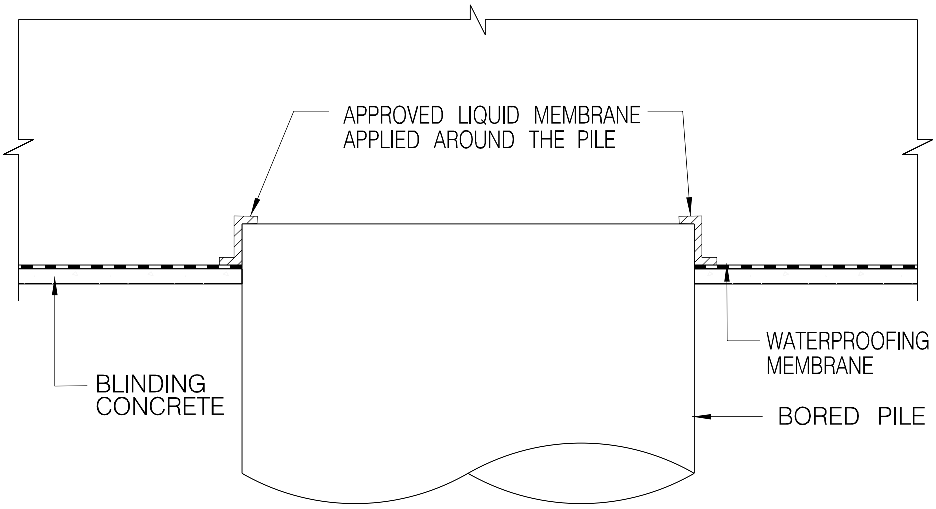
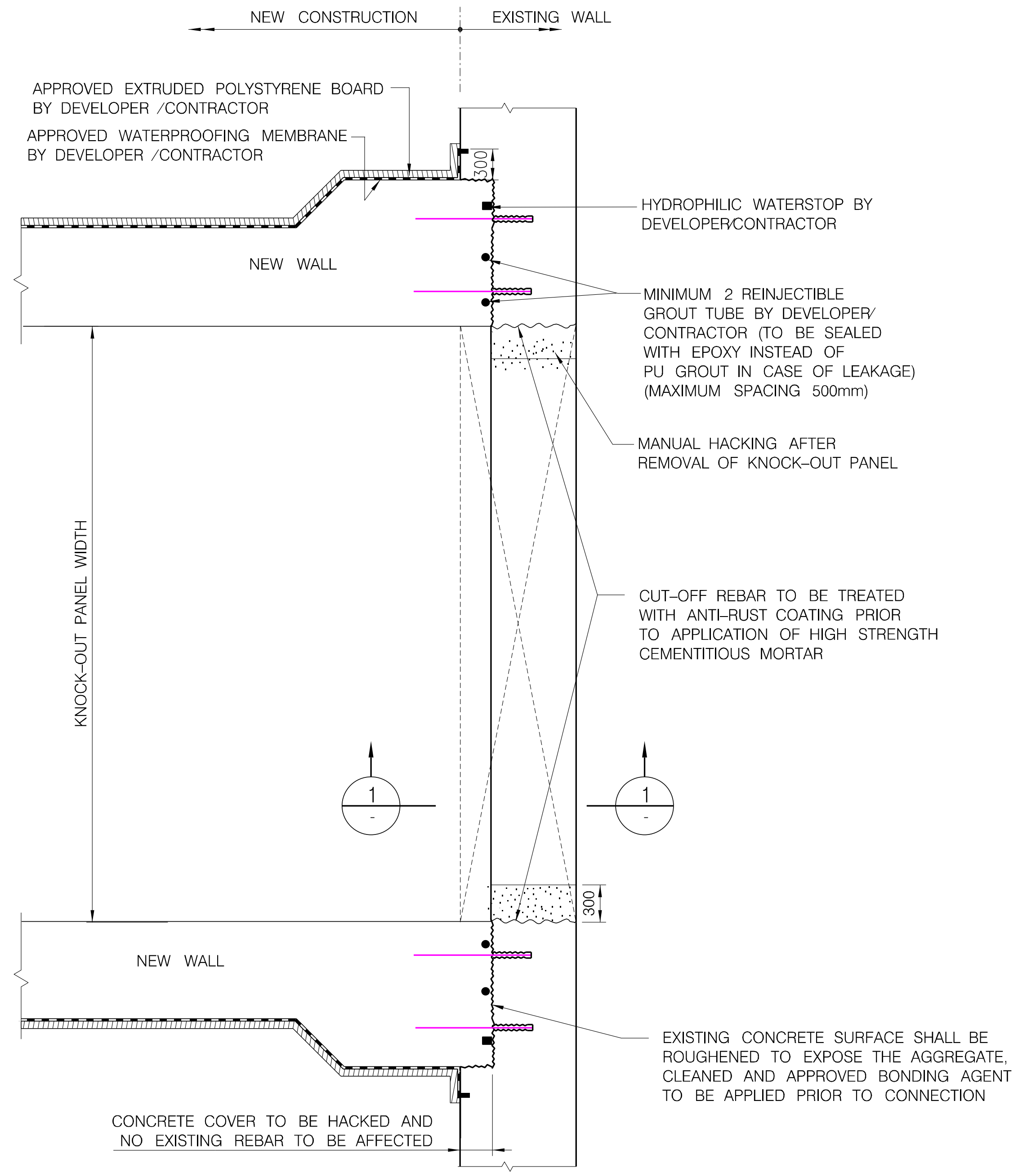



**Figure 14.8 Treatment of Piles and Pilecaps**

### 14.6.6 Waterproofing Details at Knock-out Panel

Where an underground structure connects to an existing underground structure that has knock-out panels or bulkheads, the Contractor shall, as a minimum, adhere to the waterproofing requirements as illustrated in Figure 14.9. In addition, the Contractor shall develop these details taking into consideration the proposed method and sequence of construction. The detailed design shall be carried out by the Contractor, subject to the Engineer's acceptance. The Contractor shall also ensure that the integrity of the waterproofing system of the existing structure is not compromised. In addition, the Contractor shall grout the interface between the new underground structure and existing underground structure to prevent potential leakages.




TYPICAL WATERPROOFING DETAILS AT KNOCK-OUT PANEL (PLAN VIEW)

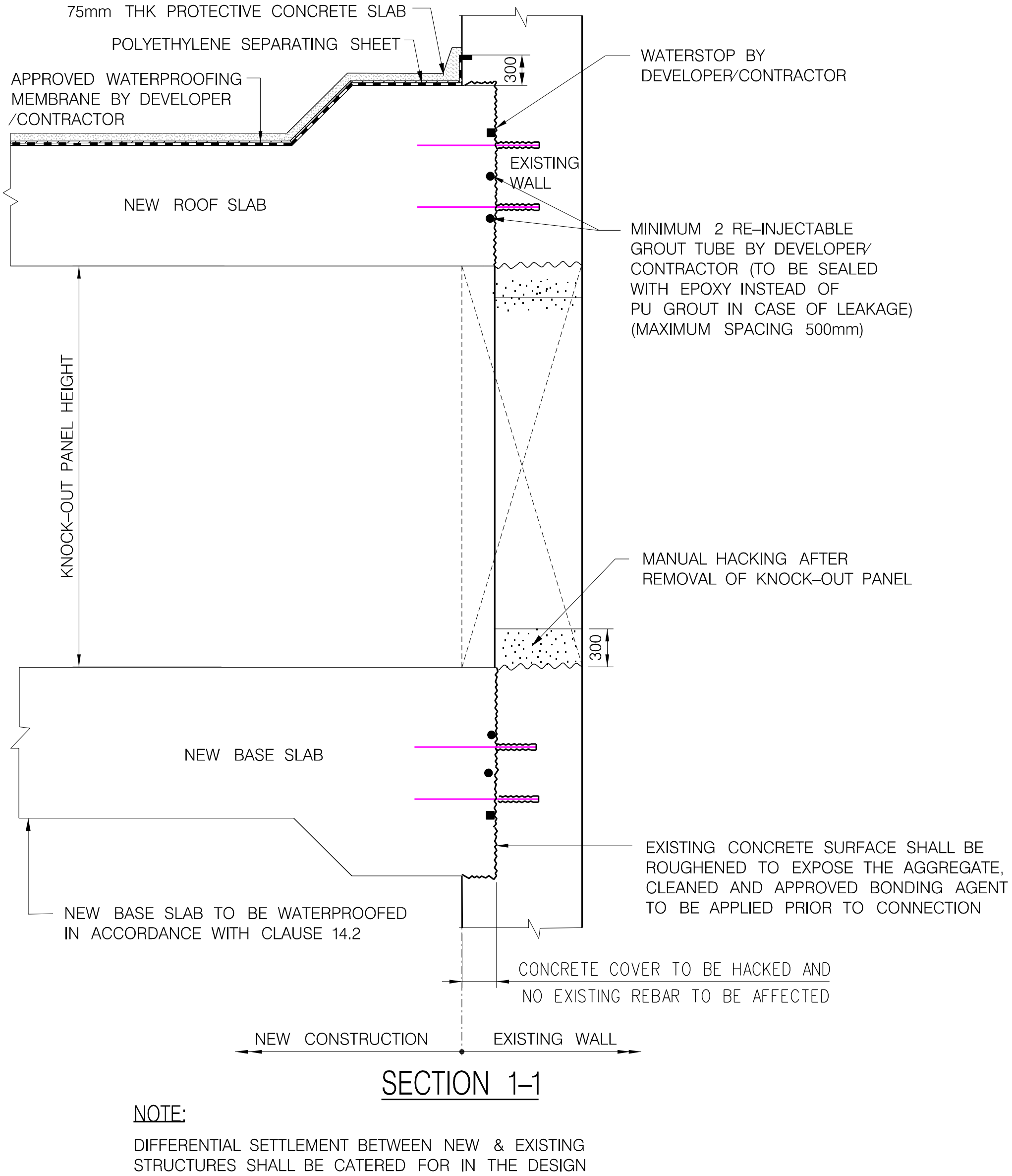



**Figure 14.9 Treatment of Knock-out Panel**

## 14.7 WARRANTY

The waterproofing warranty shall cover the watertightness of the underground structures including the waterproofing systems and shall be given jointly and severally by the Contractor and the Supplier/Applicator. The warranty shall be in accordance with the Specimen Warranty Form given in the General Specification.

If the Contractor is unable to meet the requirements given in Clause 14.3.5, the warranty shall be extended for another 5 years.

## APPENDIX 14.1

### Determination of Coefficient of Water Permeability

1. Specimens of 28-day cores of 100mm diameter by 50mm thick.

2. Specimens are placed between 2 metal plates and conditioned for 24 hours.

3. The test cell was filled up till overflowing to expel air.

4. The graduated tube was filled with water up to a height of about 2 metres.

5. The free end of the tube was connected to a test pressure consistent with the depth at which the structure is seated and shall not in any case be less than 0.50MPa (50m water head), unless otherwise specified by the Engineer.

6. The pressure was maintained throughout the test and the drop in water level in the manometer was noted and recorded.

7. A constant rate of flow was achieved, i.e. when the difference between the highest and lowest readings of the 4 consecutive readings taken at every 24 hours did not exceed 3mm.

8. The coefficient of permeability is then calculated.

# CHAPTER 15

# BEARINGS AND MOVEMENT JOINTS

## 15.1 GENERAL

This Chapter provides the technical requirements for the design, manufacture, testing, delivery, storage and installation of bearings and movement joints.

## 15.2 BEARINGS

### 15.2.1 General

15.2.1.1 All bearings shall be designed, manufactured, tested, delivered, stored and installed in accordance with the requirements of BS EN 1337 and PD 6703 as appropriate.

15.2.1.2 The Contractor shall submit design calculations and other relevant documents in accordance with BS EN 1337 for the Engineer's acceptance.

15.2.1.3 All bearings used in the Contract shall be from one supplier only, unless otherwise accepted by the Engineer.

### 15.2.2 Warranty

All bearings shall be warranted against all defects and any malfunctioning for a minimum period of ten (10) years from the date of Completion of the whole of the Works and all defects occurring during this period shall be made good by the Contractor. The Warranty is to be provided jointly and severally by the Contractor and the manufacturer, and shall be in the format shown in the General Specification.

### 15.2.3 Bearing Design

15.2.3.1 The specialist/ manufacturer shall carry out the detailed design of the bearings in accordance with BS EN 1337. The bearings shall be designed for the reactions and movements specified in the Drawings including all stages of construction. The design shall meet the technical and testing requirements of this Specification and the Drawings.

15.2.3.2 For all construction methods, the bearings and their support structure shall be detailed to prevent damage of the concrete cover.

15.2.3.3 Provisions shall be made in the design to allow the bearings including all their fixings to be inspected, repaired or replaced. All bearings shall be designed with suitable handling attachments to the bearings to facilitate the removal and replacement process. Minimum headroom clearance of 1.5m between soffit of beam and maintenance platform/area shall be provided. Proper safe access to the maintenance platform/area shall be provided.

**15.2.4 Submissions**

15.2.4.1 The Contractor shall submit the following information for the Engineer's acceptance prior to placing an order for the bearings:

(a) The name of the proposed manufacturer(s) and the location where the bearing will be manufactured.

(b) Dimensions and general details of the proposed bearings.

(c) Bearing fixing arrangements.

(d) For mild steel bearings, the protective coating shall comply with coating system as stated in Chapter 12.

(e) Evidence of satisfactory performance, under similar conditions of a similar bearing type, which the manufacturer has produced.

(f) Delivery programme (to site).

(g) Detailed method statement for bearing installation/ replacement with drawings

(h) CE marking (European Conformity) and Declaration of Performance as specified in BS EN1337. For bearings without CE marking: initial type test reports, routine test reports, production control records and material test reports and certificates.

15.2.4.2 All bearings shall be of a proven design of successful implementation in similar structures. Untried materials and designs will not be accepted. For bridge structure widening, bearing of similar type as the existing structure shall be proposed. If not available, alternative types of bearing proposal shall demonstrate its performance over the existing structure for acceptance.

15.2.4.3 The Contractor shall submit detailed drawings, calculations, material specification and method statement of bearing installation for the Engineer's acceptance. The bearings shall not be manufactured until all relevant submissions have been accepted.

15.2.4.4 A Schedule of Bearings in accordance with BS EN 1337 as shown in Appendix 15.1 shall be submitted for the Engineer's acceptance.

15.2.4.5 Movement directions shall be clearly indicated on the drawing.

**15.2.5 Inspection of Bearings**

Bearings shall be dismantled to enable visual inspection at the manufacturer's works prior to delivery.

**15.2.6 Marking, Delivery and Storage of Bearings**

All bearings shall be suitably marked to identify their types and locations.

15.2.6.1 Marking

Permanent luminous or etched in 'movement indicator' shall be marked on the side of the bearing plate. The markings shall be visible after installation to facilitate monitoring of the bearings.

15.2.6.2 Delivery

Bearings shall be delivered fully assembled. The upper and lower parts of the bearing shall be secured with transportation bolts.

15.2.6.3 Storage

Bearings shall be transported and unloaded carefully and then stored under cover in clean and dry conditions until required. An inspection shall be carried out shortly before installation, and bearings that have been damaged in store shall be rejected.

**15.2.7 Bearing Installation and Protection**

15.2.7.1 General

15.2.7.1.1 Bearings shall be installed strictly under the supervision of the specialist supplier in accordance with the approved Method Statement and the Drawings.

15.2.7.1.2 Bearing seating shall be of mortar bedding of non- shrink cementitious grout, polyester resin or epoxy resin, with concrete strength class of at least C32/40 at 7 days. The seating shall be on top of the RC stump and not exceed 25mm in height. Unless otherwise indicated in the Drawings such as the grout exceeding 25mm, bursting and spalling reinforcement shall be designed and provided based on the applied load for the seating.

15.2.7.1.3 Transfer of superstructure weight on to bearings shall not be allowed until the bedding has developed sufficient strength.

15.2.7.2 Mechanical and Laminated Elastomeric Bearings

Prior to the installation of mechanical and laminated elastomeric bearings, the position of box-outs provided, dimensions and levels of the substructures and all relevant information shall be investigated, verified and submitted to the Engineer for acceptance.

### 15.2.8 Bearing Installation Tolerances

The bearing plate shall not be recessed in to the RC structure or the bedding. Mechanical bearings and laminated elastomeric bearings shall be fixed within the tolerances as shown in Table 15.1:-

**Table 15.1 Tolerance**

| | **Description** | **Tolerances** |
|---|---|---|
| (a) | Variation from true level | Simply-supported structures ± 3 mm<br>Continuous structures:<br>0.0001 times the sum of the adjacent spans but not exceeding ± 5mm |
| (b) | Tilt of top and base plates | 1 in 500 |
| (c) | Centrelines of the bearing to their correct position | ± 3 mm |
| (d) | Orientation on plan | 1 in 1000 (to required direction) |

### 15.2.9 As-built Submission

15.2.9.1 After the bearings have been installed, the Contractor shall take all protection measures necessary to ensure that the bearings remain free from damage.

15.2.9.2 Upon completion, the Contractor shall submit as-built drawings for all the bearings installed. The as-built drawings shall include information on the Schedule of bearings. Bearing movement and rotation shall be recorded upon removal of the transportation bolts, before opening of the viaduct / bridge and at the end of Defect Liability Period. The transportation lugs and bolts shall be completely removed from the bearings. Bimetallic corrosion will occur otherwise.

15.2.9.3 Records on bearing movements shall contain data on shade temperature, date and time the movements were recorded.

### 15.2.10 Technical Requirements for Mechanical and Spherical Bearings

15.2.10.1 General

15.2.10.1.1 The sliding plates shall be of stainless steel.

15.2.10.1.2 Where bearings are provided with side guides, they shall be aligned in the direction of movement as required in the design.

15.2.10.1.3 Sliding material, such as PTFE, shall be designed in accordance with BS EN1337-2.

15.2.10.1.4 The sliding material shall be provided for the vertical sliding surfaces to each rocker plate in contact with the side guides. The side guides shall be of stainless steel.

15.2.10.2 Design and Manufacture

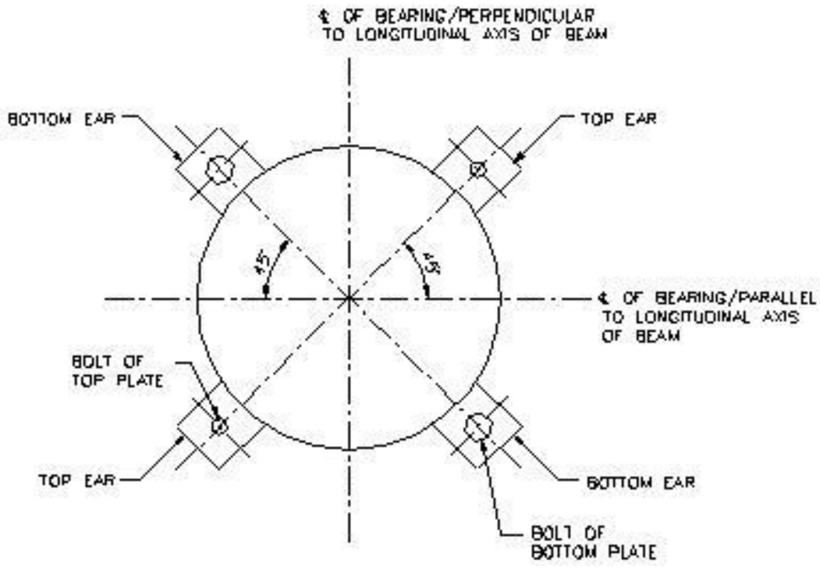
15.2.10.2.1 Bearings shall be fixed to the structures with fixing bolts or by similar means. Reliance on friction between the surfaces of the bearing and its bedding medium is not permitted.

15.2.10.2.2 Bearings shall be designed for replacement subject to a limiting vertical lift of 15 mm for RTS structures and 25mm for other structures.

15.2.10.2.3 The fixing positions shall be arranged to avoid overlapping of the top and bottom plate sockets to facilitate easy removal and replacement. An example is as shown in Figure 15.1.

15.2.10.2.4 Each bearing shall be marked with a serial number for identification.

**Figure 15.1 Notional plan view of top and bottom plates in assembled position**



15.2.10.2.5 All bearings shall be designed such that they do not sustain damage that would affect their correct functioning, or incur excessive maintenance costs during their intended life. Great care shall be exercised to ensure that lateral restraint bearings are correctly orientated.

15.2.10.3 Design for Horizontal Loads

For the bearing connections between the bearing and the concrete faces, it shall be assumed that up to 10% of the design ultimate horizontal load is caused by friction between the bearing and the concrete face. The connections for any one face shall be designed to take 0.9 times the design ultimate limit state (ULS) lateral load specified in the Schedule. The lateral load shall be shared equally between the connecting bolts.

15.2.10.4 Bearing Components including Fixings

15.2.10.4.1 All components of mechanical or spherical bearings including the mechanical fixings shall be fabricated from austenitic stainless steel of minimum grade 1.4436. Manufacturing process, delivery condition, material grades, mechanical properties, dimension tolerance, surface quality, inspection and testing of materials used shall comply to the latest European and Singapore Standards. All bolts and nuts shall be minimum grade A4-80. Materials used shall also comply with the following:

| | |
|---|---|
| Wrought stainless steel: | BS EN 10250-4 |
| Flat rolled stainless steel: | BS EN 10088 |
| Stainless steel washers: | BS EN 10088 |
| Stainless steel fasteners: | BSEN ISO 3506-1 and BS EN ISO 3506-2 |

15.2.10.4.2 Stainless steel sliding surfaces of bearings shall receive no protective treatment and care shall be taken to protect these surfaces from being damaged or coated during the application of the protective treatment to other parts of the structure.

15.2.10.5 Additional Requirements for Bearing Replacement

15.2.10.5.1 The jacking and lowering of the RTS viaduct shall only take place during the engineering hours, which is about 3 hours.

15.2.10.5.2 The Contractor shall submit a replacement strategy on how the bearings can be removed and replaced. The Contractor shall carry out full scale bearing replacement trials on the RTS structures. The replacement trials shall be carried out for each of the main bearing types at locations selected by the Engineer.

15.2.10.5.3 The cost of carrying out the replacement trials shall be included in the Contractor's contract price. Notwithstanding earlier acceptance, if the replacement requirements are not met, the Engineer shall reject all the bearings. Bearing used for the replacement test can be incorporated in the works provided it has not been damaged in any way during the replacement exercise.

15.2.10.5.4 The Contractor shall carry out bearing replacement trial after completion of all viaduct deck finishes, handrail and parapet installation, permanent way, viaduct and cable. All designs shall be able to cope with the limiting vertical lift.

15.2.10.5.5 The warranty specified for the bearing shall not be invalidated due to the replacement trial.

### 15.2.11 Testing Requirements for Mechanical and Spherical Bearings

15.2.11.1 General

Tests shall be carried out at a laboratory accepted by the Engineer. The test methods shall be subject to the Engineer’s acceptance. The equipment for testing the bearings shall comply with the requirements in BS EN 1337.

All tests shall be carried out in the presence of the Engineer. The Engineer shall be given at least 7 calendar days notice.

15.2.11.2 Acceptance Test of Assembled Bearings

15.2.11.2.1 Nominations for acceptance test for each bearing type shall be in accordance with the following: -

(a) 3 bearings out of the first batch of 10 bearings produced.

(b) 1 bearing out of each subsequent batch of 10 bearings.

15.2.11.2.2 However, if there are less than 6 bearings of one type, all bearings of that type shall be load tested. Each bearing code number given in the Drawings shall be considered as a bearing type.

15.2.11.2.3 Acceptance tests for each bearing shall include:

(a) Test for vertical load

(b) Test for coefficient of friction (where applicable)

(c) Test for lateral load

(d) Test for rotation

15.2.11.3 Additional Tests

Should any bearing fail the acceptance tests, additional tests on new bearing equivalent to the failed bearing shall be performed to demonstrate compliance with the requirements. The type and number of additional tests shall be subject to the Engineer's acceptance.

15.2.11.4 Test for Vertical Load

The bearing shall be loaded in compression to 1.2 times the maximum vertical SLS load given in the Drawings. The load shall be maintained for a minimum of three minutes.

15.2.11.5 Test for Coefficient of Friction

The coefficient of friction of the sliding surfaces of the bearing shall be determined by test. The value of the coefficient of friction shall be taken as the average result of five tests and shall be determined for both the maximum and 50% of the maximum vertical SLS load given in the Drawings. The sliding surfaces shall not be lubricated before the tests but the bearings may be given two preliminary sliding runs under load prior to taking the test readings.

15.2.11.6 Test for Lateral Load

The bearing shall be tested to 0.9 times the ULS lateral load shown on the Drawings while loaded in compression to 10% of the maximum vertical load shown on the Drawings.

15.2.11.7 Test for Rotation

The bearing shall be tested in rotation to the value for rotation given in the Drawings whilst being loaded in compression to the maximum vertical SLS load shown on the Drawings.

15.2.11.8 Failure to Meet Requirements

The bearing shall be rejected, if, following the tests for load or rotation, it exhibits any signs of failure such as:

(a) Splitting or permanent deformation of the elastomer,

(b) Tearing, cracking, debonding, or permanent deformation of the sliding material,

(c) Cracking or permanent deformation of the sealing ring or other part of the bearing,

(d) Abrasive marks indicating abnormal contact between the metal surfaces of the bearing plates or piston and the pot.

15.2.11.9 Test Certificates

The Contractor shall supply copies of the test certificates showing details of the test results of each bearing tested. The test certificates shall indicate if tolerances have been exceeded and if any faults have been observed.

**15.2.12 Technical Requirements for Laminated Elastomeric Bearings**

15.2.12.1 General

15.2.12.1.1 Laminated elastomeric bearings that contain any forms of wax are not acceptable, and inspection after delivery of bearings shall comply with BS EN 1337-11. Any foreign material found shall be removed.

15.2.12.1.2 All design of laminated elastomeric bearings shall comply with the requirement of BS EN 1337-3.

15.2.12.1.3 Steel plate reinforcement for laminated bearing shall comply with the requirements of BS EN 10025.

15.2.12.1.4 The thickness of outer and inner plates shall not be less than 3 mm and 1.5 mm respectively. No welding operation shall be carried out on an elastomeric bearing.

15.2.12.1.5 Dowel bars or shear pins shall not be used as restraints for fixed and guided sliding bearings. Alternative means of restraints (e.g. concrete restraint blocks) that can be easily inspected, maintained and replaced shall be adopted.

15.2.12.2 Design and Manufacture

For RTS structures, the bearing shall be detailed to facilitate installation and to allow subsequent replacement without having to jack up the RTS station platform by more than 3 mm.

15.2.12.3 Protective Treatment

The protective treatment for the bearings shall be appropriate to the required design life.

**15.2.13 Testing Requirements for Laminated Elastomeric Bearings**

15.2.13.1 General

15.2.13.1.1 Tests shall be carried out at laboratory accepted by the Engineer and the method of testing the bearing shall be subject to acceptance of the Engineer.

15.2.13.1.2 The equipment for testing bearings shall comply with the requirement of BS EN 1337-3.

15.2.13.1.3 All tests, shall be carried out in the presence of the Engineer.

The Engineer shall be given at least 7 calendar days notice.

15.2.13.2 Acceptance Test for Bearings

15.2.13.2.1 Nominations for acceptance test for each bearing type shall be in accordance with the following: -

(a) 3 bearings out of the first batch of 10 bearings produced.

(b) 1 bearing out of each subsequent batch of 10 bearings.

15.2.13.2.2 However, if less than 6 bearings of one type are to be produced, two bearings of that type shall be load tested. Bearing code number given in the Drawings shall be considered as a bearing type.

15.2.13.2.3 Acceptance tests for each bearing shall include:

(a) Compressive stiffness test

(b) Shear stiffness test

(c) Shear bond test at ambient temperature

15.2.13.3 Material Tests

15.2.13.3.1 Three samples of the elastomer for each bearing type shall be tested for compliance with the accepted materials specification.

15.2.13.3.2 Test methods shall conform to the latest Singapore Standard and Singapore's adoption of Eurocode and the sampling method shall be to the acceptance of the Engineer.

15.2.13.3.3 For each sample, tests for the following properties and requirements shall be performed:

(a) Ozone resistance (BS ISO 1431)

(b) Tensile strength (BS ISO 37)

(c) Tear resistance (BS ISO 34)

(d) Compression set (BS ISO 815-1)

(e) Accelerated ageing (BS ISO 188)

(f) Hardness (BS ISO 48)

(g) Ultimate tensile strain (BS ISO 37)

(h) Shear modulus (BS ISO 1827)

(i) Creep (BS ISO 8013)

15.2.13.3.4 For each bearing, the elastomer hardness shall be measured.

15.2.13.4 Dimensional Checks

Each bearing will be subjected to the following dimensional checks:

(a) Plan size and height in mm
(b) Cover of elastomer over steel plate.

15.2.13.5 Compressive Stiffness Test

15.2.13.5.1 1 bearing in 5 selected at random shall be subjected to level 2 and level 3 compressive test in accordance to BS EN 1337-3.

15.2.13.6 Shear Stiffness Test

1 bearing in 5 selected at random shall be subjected to simultaneous test loading in compression and shear in accordance BS EN 1337-3.

15.2.13.7 Shear Bond Test at Ambient Temperature

1 bearing in 5 selected at random shall be subjected to shear bond test in accordance with BS EN 1337-3.

15.2.13.8 Failure to Meet Requirements

The bearing shall be rejected, if following the load tests, it exhibits any signs of failure such as: -

(a) splitting or permanent deformation of the elastomer

(b) evidence of inadequate steel elastomer band or uneven plate placement

(c) failed to meet the specified load capacity, compressive deflection of stability requirements.

The generation of unusual load deflection curves during the tests shall also be cause for rejection by the Engineer.

15.2.13.9 Test Certificates

The Contractor shall supply copies of the test certificates showing details of the test results of each bearing tested. The test certificates shall indicate if tolerances have been exceeded and if any faults have been observed.

## 15.3 MOVEMENT JOINTS

### 15.3.1 General

15.3.1.1 The term "movement joints" in this section covers all types of permanent joints or hinge throat, which allow for longitudinal movements, transverse movements and angular rotations.

15.3.1.2 Only elastomeric in metal runners joints (modular joints), cantilever comb or tooth joints and finger plate joints are acceptable. Asphaltic plug joint may be used for small movement joint and if design allows for it.

15.3.1.3 Each type of movement joint used in a Contract shall be from one supplier, unless otherwise accepted by the Engineer.

15.3.1.4 All movement joints shall generally be installed in a straight line across the full width of the deck and the joint gap shall be of a uniform width.

### 15.3.2 Design by Specialist/ Manufacturer

The detailed design of the movement joint shall be carried out by a Specialist/ Manufacturer. The proposed joints shall comply with the following requirements:

(a) Be able to accommodate the design movements such as longitudinal, transverse and rotation, of the structure and the design loading without damage to the surfacing or the supporting structures.

(b) Not impart any undue stress to the structure unless the structure has been designed accordingly.

(c) Have good riding characteristics.

(d) Not present a skid hazard on road. The skid resistance of an expansion joint shall be at least equal to the minimum requirement of the adjacent carriageway surfacing during its working life.

(e) Not present a danger to cyclists and pedestrians on road.

(f) Have low noise emission from the joint.

(g) Give reliable operation throughout the expected movements, which include internal and external factors such as shrinkage, creep, thermal effects, imposition of live loads and settlement.

(h) Be sealed against water and foreign matter.

(i) Resist corrosion and withstand attack from grit, ultra-violet rays, ozone and petroleum derivatives.

(j) Be positively anchored to the concrete bridge deck.

(k) Facilitate easy inspection, maintenance, repair and replacement in the future, with minimum of delay or obstruction to user.

### 15.3.3 Submissions

15.3.3.1 Full details including shop drawings, calculations, material specification and method statement of installation for all proposed movement joints shall be submitted to the Engineer for acceptance prior to placing an order for the movement joints.

15.3.3.2 The submission shall also include detailed specification and computations for minimum and maximum expansion gap for the selected joints based on the movements specified in the Drawings. The movement capacity of the proposed joints shall make due allowance for the assumed temperature range at installation and be installed accordingly. Design calculations shall include fatigue and strength design for all-structural elements, connections and splices.

15.3.3.3 For RTS viaducts, all joints between the bonded waterproofing membrane and the movement joints at in-situ structures shall be fully primed before making the joint. The waterproofing membrane and movement joint shall form a continuous watertight layer. All movement joints shall be subjected to a Ponding Test in accordance with Chapter 13, not less than 2 weeks after the installation of the joint, including its seal.

15.3.3.4 The Contractor shall submit the following information for the Engineer's review and acceptance prior to placing an order for the movement joints:

(a) The name of the proposed manufacturer(s) and the location where the joints will be manufactured;

(b) Dimensions and general details of the proposed expansion joints;

(c) Joint fixing arrangements;

(d) Protective treatments applied to the elements;

(e) Records of past usage, including the names of the bridges where the joints have been installed, together with the movement capacity and installation data, etc;

(f) Delivery program (to site);

(g) Method Statement of movement joint replacement;

(h) Test reports of the movement joint and its elements to the appropriate standards.

15.3.3.5 The movement joints shall be of a proven design and the Engineer will not accept any proposal to use an untried design.

### 15.3.4 Warranty

All movement joints shall be warranted against all defects and malfunction for a minimum period of ten (10) years from the date of completion of the whole project. All defects occurring during the warranty period are to be made good by the Contractor. The warranty is to be provided jointly and severally by the Contractor and the Manufacturer.

### 15.3.5 Installation and Protection

15.3.5.1 All movement joints shall be installed by a Specialist Contractor strictly in accordance to the approved Method Statement.

15.3.5.2 The initial gap of the movement joint shall be set taking into account the ambient temperature at the time of installation. The Contractor shall account for any difference between the assumed and actual ambient temperature at time of installation. This is to ensure that the total movement specified for the joint can be achieved.

15.3.5.3 The holding-down arrangements of the movement joints shall take into account the reinforcement details of the underlying structural concrete. Rebates for movement joints shall be carefully boxed out to the correct line and level from the structural concrete.

15.3.5.4 The same joint system shall be installed across the full width of bridge deck including footway, verge, hard shoulder and central reserve. Movement joints shall also be installed for a height of at least 100mm above the adjoining paved surface up the parapet.

15.3.5.5 The movement joints shall in general be installed as late as possible to ensure that total movement is minimised. After the movement joints have been installed, the Contractor shall take all protective measures necessary to ensure that the movement joints remain free from damage.

### 15.3.6 Shipping and Handling

Field splices for the movement joint shall be avoided. Assemblies shall be designed, fabricated, and delivered to the job site as a continuous unit whenever possible. At the site, the expansion joint system shall be stored in accordance with the Manufacturer's recommendations to avoid damage and deterioration. Damaged joint system during shipping or handling shall be rejected.

### 15.3.7 Materials

15.3.7.1 The central beams, edge beams, support bars, control arms and control boxes shall be fabricated from stainless steel Grade 304. All bolts and nuts shall be A4-70 conforming to BSEN ISO 3506.

15.3.7.2 Preformed elastomeric joint seal shall be made from vulcanized compound having polymerized chloroprene as the only base polymer. The seal shall meet the property requirements as follows:

| **Property** | **Requirement** |
|---|---|
| Minimum tensile strength | 13.8 $N/mm^2$ |
| Minimum elongation at break | 250% |
| Hardness, Type A Durometer | 50-75 |
| Resistance to ozone | No crack visible by eye |

15.3.7.3 The Contractor shall carry out tests in accordance with BS EN 14188 and BS EN 14840 and submit the test reports to the Engineer's acceptance.

### 15.3.8 Water-Tightness of Movement Joints

All movement joints shall be properly sealed so that water cannot penetrate through the joint.

### 15.3.9 Replacement of Movement Joints

15.3.9.1 All movement joints shall be installed in such a manner that they can be replaced sometime in the future.

15.3.9.2 The time for removal and replacement of movement joints shall not exceed 5 hours for a road bridge.

15.3.9.3 The Contractor shall submit details that fully demonstrate how the movement joints can be removed and replaced.

### 15.3.10 Technical Requirements for Elastomeric in Metal Runners Joints (Modular Expansion Joints)

15.3.10.1 A single element joint shall consist of an elastomeric seal fitted between two metal runners, one fixed to each side of the deck joint gap.

15.3.10.2 The multi-element joint shall consist of three main components: seal, separation beams to support the seal and support bars to support the separation beams.

15.3.10.3 The seal and separation beams shall form a watertight surface. Each separation beam shall be supported by an independent support bar, which shall be welded to the separation beam. The support bars shall be suspended over the joint opening by sliding elastomeric bearings. An equidistance control system shall be incorporated which shall develop its maximum tensile force when the joint is at its maximum opening.

15.3.10.4 Provisions shall be made for access to the underside of the joints for inspection and repair/ replacement of parts liable to wear and tear.

### 15.3.11 Technical Requirements for Cantilever Comb or Tooth Joints (Sawtooth Plate Joints) or Finger Plate Joints

These types of joints shall be watertight with a waterproofing system immediately beneath the gap. Secondary drainage system in the form of a continuous trough is not acceptable.

# APPENDIX 15.1 Bearing Schedule

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | Structure Name or Reference | | | | | | | |
| 2 | Bearing Identification Mark | | | | | | | |
| 3 | Type of Bearing (Number in Accordance with BS EN 1337-1, Table 1) | | | | | | | |
| 4 | Quantity | | | | | | | |
| 5 | Seating | Material | Upper surface | | | | | |
| 6 | | | Lower surface | | | | | |
| 7 | | Characteristic Strength (N/mm$^2$) | Upper surface | | | | | |
| 8 | | | Lower surface | | | | | |
| 9 | Support Area | Upper Surface | Longitudinal (mm) | | | | | |
| 10 | | | Transverse (mm) | | | | | |
| 11 | | Lower Surface | Longitudinal (mm) | | | | | |
| 12 | | | Transverse (mm) | | | | | |
| 13 | Actions (kN) | Characteristic maxima (SLS) | Vertical $N_{Ed,ser}$ | Maximum | | | | |
| 14 | | | | Permanent | | | | |
| 15 | | | | Minimum | | | | |
| 16 | | | Transverse $Vy_{Ed,ser}$ | | | | | |
| 17 | | | Longitudinal $Vx_{Ed,ser}$ | | | | | |
| 18 | | Design maxima (ULS) | Vertical $N_{Ed}$ | | | | | |
| 19 | | | Transverse $Vy_{Ed}$ | Permanent | | | | |
| 20 | | | | Temperature | | | | |
| 21 | | | | Shrinkage | | | | |
| 22 | | | | Creep | | | | |
| 23 | | | | Variable | | | | |
| 24 | | | Longitudinal $Vx_{Ed}$ | Permanent | | | | |
| 25 | | | | Temperature | | | | |
| 26 | | | | Shrinkage | | | | |
| 27 | | | | Creep | | | | |
| 28 | | | | Variable | | | | |
| 29 | | Characteristic Combination (SLS) | Maximum $N_{Ed,ser}$ | | | | | |
| 30 | | | Maximum $V_{Ed,ser}$ | | | | | |
| 31 | | Characteristic Combination (SLS) | Minimum $N_{Ed,ser}$ | | | | | |

## APPENDIX 15.1 Bearing Schedule (Cont'd)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 32 | Actions (kN) | | Maximum $V_{Ed,ser}$ | | | | | |
| 33 | | Design Combination (ULS) | Maximum $N_{ed}$ | | | | | |
| 34 | | | Maximum $V_{ed}$ | | | | | |
| 35 | | Design Combination (ULS) | Minimum $N_{ed}$ | | | | | |
| 36 | | | Maximum $V_{ed}$ | | | | | |
| 37 | Displacement (mm) | Characteristic (SLS) | Irreversible | Transverse $V_{y,Ed,ser,i}$ | | | | |
| 38 | | | | Longitudinal $V_{x,Ed,ser,i}$ | | | | |
| 39 | | | Reversible | Transverse $V_{y,Ed,ser,r}$ | | | | |
| 40 | | | | Longitudinal $V_{x,Ed,ser,r}$ | | | | |
| 41 | | Design (ULS) | Irreversible | Transverse $V_{y,Ed,i}$ | | | | |
| 42 | | | | Longitudinal $V_{x,Ed,i}$ | | | | |
| 43 | | | Reversible | Transverse $V_{y,Ed,r}$ | | | | |
| 44 | | | | Longitudinal $V_{x,Ed,r}$ | | | | |
| 45 | Rotation (radians) | Characteristic (SLS) | Irreversible | Transverse $\alpha_{y,Ed,ser,i}$ | | | | |
| 46 | | | | Longitudinal $\alpha_{x,Ed,ser,i}$ | | | | |
| 47 | | | Reversible | Transverse $\alpha_{y,Ed,ser,r}$ | | | | |
| 48 | | | | Longitudinal $\alpha_{x,Ed,ser,r}$ | | | | |
| 49 | | Design (ULS) | Irreversible | Transverse $\alpha_{y,Ed,i}$ | | | | |
| 50 | | | | Longitudinal $\alpha_{x,Ed,i}$ | | | | |
| 51 | | | Reversible | Transverse $\alpha_{y,Ed,r}$ | | | | |
| 52 | | | | Longitudinal $\alpha_{x,Ed,r}$ | | | | |
| 53 | Bearing Dimension (mm) | Upper surface | Transverse | | | | | |
| 54 | | | Longitudinal | | | | | |
| 55 | | Lower surface | Transverse | | | | | |
| 56 | | | Longitudinal | | | | | |
| 57 | | Pot Diameter | | | | | | |
| 58 | | Height | | | | | | |

# CHAPTER 16

# BORED TUNNELS AND RELATED WORKS

## 16.1 GROUNDWATER LEAKAGE

16.1.1 A high standard of waterproofing of bored tunnel linings shall be required. Groundwater leakage rates shall not exceed a general value of 2 ml/m$^2$/h. For any 10 metre length of tunnel the leakage rate shall not exceed 5 ml/m$^2$/h.

16.1.2 The Contractor shall ensure that no loss of ground occurs through any part of the completed structure.

16.1.3 The above specified degree of watertightness shall be achieved within 100 m of the tunnel face during construction and maintained thereafter. Where the tunnel is constructed in or below soft clays of the Kallang Formation the specified degree of watertightness shall be achieved within 30 m of the tunnel face in order to minimise surface settlement due to consolidation.

16.1.4 Notwithstanding the above limits on groundwater leakage the Contractor shall ensure that there is no visible water on the inside face of the tunnel segments beyond 200m from the tunnel face during the tunnel drive and that the final 200m of tunnel are similarly water free within 1 month of breaking through.

## 16.2 PRODUCTION AND INSTALLATION OF SEGMENTAL LINING

### 16.2.1 General

16.2.1.1 The segmental pre-cast concrete lining shall consist of a number of pre-cast segments bolted together to form rings as shown on the Drawings. Each ring shall also be bolted and/or dowelled to the adjacent ring to form the tunnel lining. The bolts in this lining shall be permanent and shall be tightened to the fullest extent necessary to ensure competent building of the lining and proper contact between faces of gaskets. Radial joints in adjacent rings shall be staggered so that there are no continuous joints, except at locations acceptable to the Engineer, such as cross passages and sump locations.

16.2.1.2 The segmental lining shall be erected in the tail of the shield in such a way that the plane of the rings shall always be consistent with the attitude of the shield within the constraints of the tapered lining.

16.2.1.3 The Contractor shall retighten all of the lining bolts on a ring after erection. Retightening should be carried out as the lining passes through the tail seal brushes.

16.2.1.4 Tapered rings shall be used to negotiate horizontal and vertical curves and to correct for line and level. Packing shall not be used for this purpose. Packing to the extent allowed for in the design and testing of the gaskets is permitted to correct for out-of-plane. Packing can be used for shoving of the rams to ensure that the completed tunnel lining remains uncracked at working loads.

16.2.1.5 All segmental concrete lining shall have composite gaskets inserted into recesses or mounted on surfaces provided in all four mating surfaces of the individual segments as shown on the Drawings. The size and position of the gaskets shall be sufficient to take account of building tolerances and of manufacturing tolerances for the segments and gaskets. Where it is proposed to erect segmental lining without applying shield jacking forces to compress the gaskets, the Contractor shall demonstrate to the satisfaction of the Engineer that the required watertightness of the segment joints will still be achieved by adequately compressing the gaskets or by other acceptable means.

16.2.1.6 During tunnelling and erection of segmental lining, the jacking shoes shall be designed so that the compressive loads are properly distributed onto the concrete segmental lining without touching the gaskets, such as providing recesses into the jacking shoes to accommodate the gaskets during the segmental lining erection.

16.2.1.7 One grout hole shall be provided in each tunnel lining segment.

16.2.1.8 The Contractor shall maintain a full time inspection team independent from the casting yard staff throughout the production period. The team shall be responsible for ensuring that the agreed quality is being achieved and accepted procedures are being implemented at all stages of the segment production process. The Contractor shall demonstrate that each member of his inspection team has previous experience in concrete quality control supervision. The Contractor's inspection team shall cover all production shift work. The Contractor’s independent inspection team shall produce a weekly report on the production of the segments. The report shall include, amongst other things, the number of segments produced for the week, the number of non-conformance reports raised and any other production problems and issues. The report shall be submitted to the Engineer on a weekly basis.

16.2.1.9 Damage occurring to segments at any stage prior to erection shall be repaired in accordance with the guidelines provided in Appendix I. Repairs shall be completed sufficiently early to allow time for the cementitious mortar to cure prior to the application of the waterproof coating and for the waterproof coating to dry prior to taking the segment in to the tunnel.

16.2.1.10 Segments to which damage has occurred that cannot be repaired in accordance with the requirements in Appendix I shall be rejected, indelibly marked on the inner (concave) face and permanently removed from site.

16.2.1.11 A non-conformance report shall immediately be raised by the Contractor for any segment or ring, which is found to be damaged after erection. Should the Engineer deem that damage is sufficient to compromise the integrity of the lining or its long term durability then the Contractor shall remove it from the permanent lining and propose remedial works to the Engineer for acceptance.

16.2.1.12 Any damage occurring to the waterproof coating prior to erection shall be repaired in accordance with the coating manufacturer's recommendations.

### 16.2.2 Moulds and Surface Finishes

16.2.2.1 Moulds shall not be of materials which may warp through exposure. The dimensions of all segments shall be strictly in accordance with the Drawings and Specification and segments for each size of lining shall be freely interchangeable so that they can be properly and easily bolted together at the longitudinal and circumferential joints to provide complete rings within the specified tolerances.

16.2.2.2 The Contractor shall provide suitable steel templates to the acceptance of the Engineer for the control of the production of segments to the required tolerances during casting.

16.2.2.3 Moulds used for the production of Precast Concrete Segment Rings are to be robust and designed to conform to the accepted Segment Design Drawings and to be operational for the entire contract production requirement without the need for re-work or refurbishment. This is to be warranted by the mould manufacturer.

16.2.2.4 Only moulds that can provide a uniform surface finish in accordance with the specification requirements will be accepted. If re-conditioned moulds are proposed, only those that have been reconditioned by or under the supervision of the original manufacturer will be acceptable subject to the above provision of manufacturers' warranty for the entire segment production duration.

16.2.2.5 All formed surfaces shall have a Type C finish in accordance with SS CP 65.

16.2.2.6 All unformed surfaces shall be steel float finished with only the minimum of surface working being employed, consistent with the requirement to achieve a smooth level uniform surface, suitable for any coating that is to be applied.

16.2.2.7 The moulds shall be fully checked by an independent authority for compliance with the requirements for dimensional tolerance and the results accepted by the Engineer prior to the moulds being shipped.

### 16.2.3 Concrete Mix and Additives

16.2.3.1 Concrete shall comply with Materials and Workmanship Specification Chapter 11, Concrete and Reinforcement Bars In addition, concrete shall comply with the following requirements which shall take precedence in the event of any conflict between these requirements and those specified in Chapter 11.

16.2.3.2 The grade of concrete shall be as specified on the Drawings. The Contractor shall supply for the Engineer's acceptance details including mix design, grading and source of aggregate, admixtures and fibres together with details of tests or other data which may be relevant to the strength of concrete and fibre.

16.2.3.3 Test cubes shall be subjected to the same curing process as that proposed for the lining segments.

16.2.3.4 The type of cement used shall be High Slag Blast Furnace cement CEM IIIB or cement with fly ash (pfa) CEM IIB-V conforming to SS EN 197-1, containing not less than 74% slag or not less than 26% of pfa by mass of nucleus with ggbs conforming to SS EN 15167 and pfa conforming to BS EN 450-1.

16.2.3.5 Concrete shall satisfy the Rapid Chloride Test in accordance with ASTM C1202-97: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration. The acceptance criteria is an average 700 coulombs charge or better and not to exceed 1000 coulombs. The Contractor shall carry out a minimum of three preliminary tests prior to production to demonstrate that the proposed mix is appropriate. For at least the first five sets of production tests, 1 in 20 rings shall be tested by taking a sample from both the internal and external faces of a segment. Once it is determined which is the worst face only this face needs to be sampled. Once the test results indicate that the production concrete is of an acceptable quality and not before the first 5 sets of production tests have been completed, the Contractor may apply to the Engineer for a reduction in test frequency to 1 in 150 rings.

16.2.3.6 The nominal cement content of the concrete shall not be less than 370kg/m$^3$ and shall not be greater than 400kg/m$^3$ including silica fume.

16.2.3.7 An approved superplasticer to BS 5075 may be incorporated into the mix to ensure that the minimum possible water/cement ratio consistent with the Contractor's workability requirements is achieved.

16.2.3.8 Where polypropylene fibre is used in precast segments only 100% virgin polypropylene monofilament fibre containing no reprocessed materials shall be used. Concrete trial mixes shall incorporate the proposed production dosage of fibre.

16.2.3.9 The dosage of polypropylene fibre shall be between 0.9kg and 1.2kg of 12mm long 6 denier fibre per cubic meter of concrete unless otherwise accepted by the Engineer.

**16.2.4 Reinforcement**

All steel bar reinforcement shall be deformed high yield bars, Type 2, to BS 4449. Any mesh reinforcement used in precast segments shall be high bond wires or plain round wires to SS 32.

**16.2.5 Curing of Concrete**

All precast concrete segments shall be cured using water curing by immersion, curing at elevated temperatures (steam curing), or a combination of these systems to the acceptance of the Engineer. Moist curing, where proposed, is only allowed for curing before demoulding.

**16.2.5.1 Moist Curing**

16.2.5.1.1 Where moist curing is used all exposed concrete surfaces shall be covered with hessian or similar fabric kept thoroughly wet throughout the process. Alternatively a fog spray may be used or polythene sheet laid be in contact with the wet concrete. Other proposals may be made by the Contractor for the acceptance of the Engineer but the adopted method shall keep the surface of the concrete continuously moist until demoulding.

16.2.5.1.2 Moist curing shall be accomplished in such a way that excess water shall be available to the concrete throughout the curing process. It shall be carried out in an enclosed environment that protects the segments from the drying effect of wind and the sun and shall continue for a minimum period as required under Chapter 11, Concrete and Reinforcement Bars.

**16.2.5.2 Steam Curing**

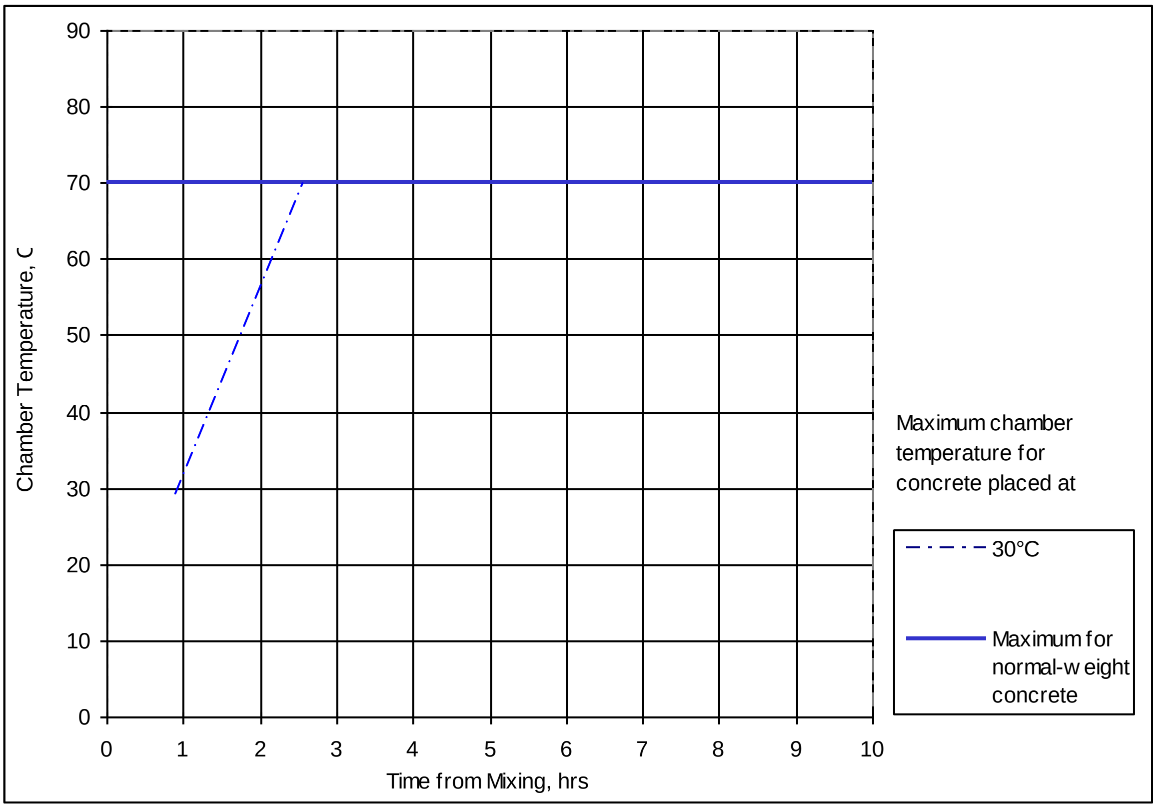
16.2.5.2.1 For low pressure steam curing sufficient steam jets or steam-entry points shall be provided to ensure that a substantially uniform temperature is maintained under the steam covers (such that the difference in temperature between any two points adjacent to the concrete mass is not more than 10°C).

16.2.5.2.2 Under no circumstances during steam curing shall steam jets be allowed to impinge upon any part of the concrete mass or of a test specimen or of their formwork or moulds nor shall any steam delivery pipe be attached directly to any formwork or moulds in such a manner as may cause localised overheating of the concrete.

16.2.5.2.3 Where steam curing is to be used the steam covers shall be placed over the concrete mass immediately following the concrete finishing operations to prevent drying out. The concrete shall remain undisturbed and shall not be exposed to steam until it has reached a minimum initial stiffness of $0.5N/mm^2$ penetration resistance when tested in accordance with SS EN 934: Specification for Admixtures for Concrete, Mortar and Grout. During this period the temperature at the surface of the concrete mass shall not exceed 35$^o$C. All concrete shall have an initial maturity of 1 hour before steam may be admitted to the steam covers except that, where necessary, a small amount of steam may be used to maintain the concrete at the temperature at which it was placed.

16.2.5.2.4 The maximum rate of temperature rise under the steam covers shall be such that the temperature at any time does not exceed the temperature which would be predicted at that time for a uniform increase in temperature at the rate of 24$^o$C/h. (This is shown diagrammatically, in Fig 16.1). In addition, the temperature rise in any one 15-minute period shall not exceed 6$^o$C.

**Figure 16.1**




16.2.5.2.5 Steaming during steam curing shall continue until the pre-determined maximum temperature under the steam covers is reached. The steam supply shall then be reduced so that this temperature is not exceeded and steaming shall be continued until the required concrete properties have been obtained. Under no circumstances shall the maximum temperature exceed 70$^o$C for normal weight concrete.

16.2.5.2.6 On completion of the steaming period which shall be at least 6 hours, and if the concrete has reached the specified strength, segments may be removed from the moulds. If there is visible evidence that any steam cured segments may be damaged by thermal shock or differential cooling, steam covers shall be left in place on completion of the steaming cycle, or replaced after removal of the element, until the temperature at the surface of the concrete mass has fallen to within 20°C of the ambient temperature.

16.2.5.2.7 If precast segments are exposed to ambient conditions immediately after steam curing the temperature change from curing to exposure to atmospheric conditions shall be regulated.

**16.2.5.3 Water Curing**

16.2.5.3.1 The segments shall be immersed fully in water in a pond immediately after demoulding for a minimum of 7 Days.

16.2.5.3.2 The temperature of the water shall not be 10°C cooler than the surface temperature of the concrete at the time the water and concrete come in contact. Water shall be potable and shall meet the requirements of Chapter 11 Concrete and Reinforcement Bars. The water shall be free of materials that have the potential to stain concrete.

16.2.5.3.3 Water lost due to evaporation or leakage shall be replaced at a rate sufficient to maintain the full immersion of the segments at all times. Alternate wetting and drying of the concrete surfaces shall not be allowed.

**16.2.6 Segments Casting Tolerances**

16.2.6.1 The Contractor may propose more stringent tolerances as may be required to suit his chosen construction methods. However, the tolerances set out in Appendix II shall not be exceeded.

16.2.6.2 At least 1 in every 100 segments produced from each mould shall be checked for compliance with specified tolerances. Each mould shall be checked for compliance with specified tolerances, after every 100 segments produced. Checks shall continue throughout the production period and shall be performed on segments selected at random by the Engineer's Representative. The Contractor shall provide suitable steel templates/measuring device to the acceptance of the Engineer for the control of the production of segments to the required tolerances.

**16.2.7 Grout Holes**

16.2.7.1 Unless they are to be used for the injection of primary grout the grout holes shall terminate short of the outer surface of the segment.

16.2.7.2 Each grout hole shall include a threaded socket cast into the segment unless otherwise accepted by the Engineer and a threaded grout plug with a hydrophilic washer. The hydrophilic washer shall only be included if the hole is used by the Contractor for grouting. The internal diameter of the socket shall be not less than 50mm. The socket shall be arranged such that the grout plug in its final position does not protrude into the tunnel beyond the inner surface of the segment. The head of the plug shall incorporate a suitable means by which it can be tightened and removed, for example a square or hexagonal socket or head, but shall be of a design that cannot trap water when inserted below axis level. The design of the socket, plug, washer and any ancillary material such as grease or other coating to the threads shall be to the acceptance of the Engineer. The assembly shall have a design life of not less than 120 years.

16.2.7.3 Grout sockets and plugs shall be capable of withstanding the ground water pressure and any additional pressure caused by grouting without leakage. In any case, they shall be able to resist a liquid pressure of not less than 7 bar above atmospheric pressure without leakage.

16.2.7.4 The clear distance between the grout socket or hole and the reinforcing bars in the segments shall be not less than the specified concrete cover to the reinforcement.

16.2.7.5 Immediately after the lining is erected each grout plug shall be fully screwed into place. When the grout plug is in place, no water or grout shall seep into the tunnel from around the outside of the socket, from between the grout plug and the socket or through the grout plug.

16.2.7.6 When a grout hole is used for secondary or tertiary grouting it shall be extended through to the exterior surface of the segment by drilling in a manner that does not cause damage to the concrete beyond the intended diameter of the hole. The diameter of the drilled hole and the means of drilling shall be to the acceptance of the Engineer.

16.2.7.7 Upon completion of the Contract the Contractor shall leave each grout hole in a condition in which the grout plug can be removed without damage to it or to any part of the socket or the tunnel lining segments, in order that the grout hole can be drilled out, grouting can be carried out and the grout plug can be replaced such that all leaks can be ~~are~~ sealed at any time.

### 16.2.8 Segment Identification

16.2.8.1 The following information shall be cast in to the internal (concave) surface of all segments or shall be incorporated on a bar code fixed permanently to the inside face of the segment:

(a) LTA - followed by the Contract Number.

(b) Date of Production

(c) Mould Number

(d) Ring Type e.g. – Left hand taper or right hand taper

(e) Segment Type e.g. - Key (S1L or S1R), S2L, S2R, S3, S4 and S5

(f) Reinforcement Type

16.2.8.2 Where used, the materials and system for bar coding shall be to the acceptance of the Engineer and shall not result in any material, which might be deleterious to the long term appearance or durability of the segment, being fixed to the face of the segment.

### 16.2.9 Surface Preparation and Repair (Casting Yard)

16.2.9.1 All blowholes, spalling of edges and gasket grooves and minor damage in the formed concrete surfaces shall be filled with a fresh specially prepared cement mix whilst the concrete is still green to produce a Type C finish to SS CP 65.

16.2.9.2 Cement mortar shall be used incorporating Styrene Butadiene Rubber (SBR) or Polyvinyl Acetate (PVA). Alternatively, polymer modified cement based mortar shall be used in accordance with the requirements of SS CP 65.

16.2.9.3 Surface preparation is not generally required but contamination such as mud, dust, mould oil, grease or other substances that may adversely affect the bond of the coating to the concrete shall be removed by hosing and/or detergent scrubbing and/or high pressure water jetting as may be required, all to the acceptance of the Engineer.

16.2.9.4 All projecting fins of hardened grout such as may occur at the joints between the sides and base of the mould shall be removed by grinding.

16.2.9.5 All segment repairs carried out at casting yard shall be recorded and reported to the Engineer. Repairs shall be carried out in accordance with the requirements in Appendix I.

16.2.9.6 Sufficient time shall be allowed for the cementitious mortar to cure prior to epoxy coating of the segment surfaces.

### 16.2.10 Rejection of Cracked or Honeycombed Segments

All segments containing honeycombing shall be rejected. Segments containing cracks shall be rejected unless otherwise accepted by the Engineer.

### 16.2.11 Trial Assembly

16.2.11.1 All units of the same type shall be interchangeable and the dimensions for each unit shown on the Drawings shall be accurately reproduced within the tolerances previously specified.

16.2.11.2 In order to check on the matching, spacing of bolt holes and interchangeability of bolted segments and before bulk manufacture is commenced the Contractor shall assemble and bolt together on a flat level base accepted by the Engineer segments to form three rings of each type of primary lining and for each mould set in the presence of and to the acceptance of the Engineer. The rings are to be built one above the other and the radial joints staggered by two thirds of a segment. No packing or gaskets are to be used in the joints between segments in these trial rings. The lowest ring shall be retained as a master ring for the duration of the Contract. The segments forming this ring may be selectively hand picked and the segments for the other two trial rings shall be picked at random.

16.2.11.3 From time to time, as the Engineer may direct, segments selected at random shall be built to form rings on the master rings to ensure that tolerances and interchangeability of segments are being maintained.

### 16.2.12 Handling

16.2.12.1 Segments shall be stacked such that the loads imposed do not cause stress and damage to the segments. Segments shall be separated by wooden timbers, wrapped in plastic sheet. Timber separators shall be vertically aligned and of sufficient strength to not deteriorate with time. Attention shall be given to timber separators at ground level which are susceptible to rotting when exposed to water. Segments which are found on inspection to be damaged or substandard on delivery to the site shall be indelibly marked and removed from the site.

16.2.12.2 Before delivery of segments to site commences the Contractor shall submit a Method Statement detailing the transport arrangements from the casting factory to site. The submission should include:

(a) Calculations to demonstrate that the load transported is within the registered capacity of the transport vehicle.

(b) Calculations to demonstrate the capacity of the vehicle load securing devices are sufficient for the load with a factor of safety of equal or greater than 2.

(c) Delivery vehicles should be fitted with designed anchor points sufficient for the capacity of the load.

(d) A final inspection and dispatch note which includes check references to control and verify the transport vehicle is correctly loaded in compliance with all relevant Road Traffic regulations. Each dispatch note shall include the contact details (name & mobile number) of site staff who can be contacted by segment delivery drivers.

(e) A list of appointed staff to ensure vehicles are correctly loaded and loads are secured as per the approved method.

(f) A route map detailing the route taken by delivery trucks from the casting factory to site. All drivers shall be familiar with the appropriate route and speed limits.

(g) An emergency procedure for the assistance and recovery of segment delivery vehicles.

### 16.2.13 Grouting of Lining

16.2.13.1 For TBM tunnels, a two component accelerated grout mix shall be used. The Contractor may propose an alternative grout mix to be used, subject to the acceptance of the Engineer. A suitable grout mix shall be proposed for each set of ground conditions to be encountered along the tunnel drive.

16.2.13.2 The grout shall be sufficiently fluid as to ensure that it flows freely under pressure into all parts of the space to be filled.

16.2.13.3 All grout mixes and injection methods shall be submitted to the Engineer for acceptance. Information given shall include:

(a) mix designs

(b) mixing and delivery systems which should be consistent with planned maximum TBM advance rate

(c) grout gel times

(d) design cube strengths at the end of one ring construction cycle

(e) design cube strengths at specified times after placement

(f) proposed operational and maximum grouting pressures with regard to the vertical tunnel alignment

(g) requirements for sampling and testing during production

(h) theoretical grout volume including considerations for use of any TBM copy cutters

16.2.13.4 Site trials for each mix and delivery system shall be carried out prior to the commencement of tunnelling to demonstrate that the proposed system works with the adopted tunnelling method and plant. The trials shall also demonstrate the properties of each grout mix and its suitability for the ground conditions.

16.2.13.5 During production strength testing of the primary grout at 1hour, 3 hours, and 6 hours after the time of placement shall be carried out at least once every five rings built or daily, whichever is more frequent. The test samples shall be taken from the TBM. The timing for testing may be extended beyond 6 hours if this reflects the actual time between injection and shoving. Other grouts shall be sampled and tested as appropriate for their use and to the acceptance of the Engineer.

16.2.13.6 All primary grouts shall achieve a minimum cube strength of 50kPa before the next 'shove' commences and a minimum of 2MPa at 28 days.

16.2.13.7 During production grout pressures shall be continuously monitored at the point of injection using in-line pressure gauges and shall be restricted to values not greater than 1.2 x total overburden.

16.2.13.8 The amount of grout used shall be recorded, and if the quantity falls short of that required to fill the void, further investigation and grouting shall be carried out.

16.2.13.9 Where accelerators are used they shall be incorporated at the point of injection of the grout and not beforehand.

16.2.13.10 In tunnels driven with a closed face machine, primary grouting of the annular void behind the segments shall take place continuously and simultaneously through at least one grout port in each quadrant as the shield progresses forward. The grout shall be injected automatically as the machine advances. In tunnels driven other than by closed face machine primary grouting may be by injection through the grout holes in the tunnel lining segments. Where this method is used the primary grout shall be injected behind each tunnel ring as the ring leaves the shield tailskin. In each case the void shall be completely filled.

16.2.13.11 Primary grouting shall be carried out to ensure that the annular void is completely filled. Grouting shall continue until at least both the minimum volume and minimum pressure criteria have been satisfied.

16.2.13.12 Grout injected through the tunnel lining shall be forced through the grout holes provided in the lining by means of adequate pressure from a grouting pan in which provision is made for keeping the grout uniformly mixed, or by a positive action pump of a type accepted by the Engineer.

16.2.13.13 The drilling shall be carried out through a grout port fitted with a shut-off valve to prevent any ground loss.

16.2.13.14 In the event that grout records indicate to the Engineer that a void or cavity is suspected the Contractor shall propose a method of investigating for such a void or cavity. Following the investigation the Contractor shall, if necessary, re-grout the tunnel lining to ensure all voids are filled. Investigation and re-grouting of the lining shall take place within 24 hours of the void being suspected, unless otherwise agreed with the Engineer. Following the discovery of one or more voids proof grouting may be required in areas directed by the Engineer to demonstrate no further voids exist.

16.2.13.15 Secondary ‘crown’ grouting shall be carried out from the machine backup at every second ring. The Contractor shall submit proposals for this work for the Engineer’s acceptance prior to the commencement of tunnelling.

16.2.13.16 The Contractor shall maintain grouting records including volumes and pressures for each stage of grouting. These shall be submitted to the Engineer at the end of each shift. The Contractor shall also calculate a rolling 10 ring average grout take which he shall submit to the Engineer on a weekly basis. All these submissions shall be made in both hard and soft copy in formats acceptable to the Engineer.

16.2.13.17 For grouts that rely on rheology, trial mixes shall be tested for the following, as a minimum:

(a) Grading curves: These should be obtained for the individual constituents and the combined mix.

(b) Cube Tests: Standard cubes, tested for compressive strength in accordance with BS EN 12390.

(c) Segregation: A sample of fresh mortar is prepared in a graduated test cylinder. The bleed water volume and mortar volume are measured at 1, 2, 3 and 8 hours.

(d) Relaxation: Cylinders of mortar are made and cured for 15 and 45 days. After curing the cylinder is stripped and the sample placed vertically, unsupported. The height of the sample is measured at regular intervals up to 24 hours. Relaxation is reported as a loss of height of the mortar sample.

(e) Wash-out test: A sample of fresh mortar is placed in a perforated container of known volume and mass. The container and sample are dropped through a 1 metre column of water five times within 15 minutes of mixing. The wash-out is calculated as the percentage loss of sample.

(f) Bleeding under pressure: The mortar is tested in a Baroid filter press for 7.5 minutes under 1 bar.

(g) Workability: Use either a standard slump cone or a Prepakt cone.

(h) Cohesion. Measured using a laboratory vane apparatus.

(i) Internal friction: A sample of mortar is prepared and fog cured at 23ºC until testing. The sample is placed in a triaxial cell and tested to determine apparent cohesion and angle of internal friction. The sample should not be consolidated or force saturated prior to testing.

16.2.13.18 The designer shall set limiting values for all of these tests. The designer shall also establish a quality control regime, including some or all of these tests, for the production grout.

16.2.13.19 In order to confirm the effectiveness of the grout used (whether dependant on rapid setting or rheology), the change in level of the invert of at least 5 of the first 20 production rings, and at least 1 ring in 50 thereafter, shall be measured. Measurement points shall be installed immediately after primary grouting for that ring, and shall be measured before and after shoving for the next 5 rings. Movement under the weight of the back-up shall also be measured. Unless accepted otherwise by the Engineer, the vertical movement of the ring at any time from completing primary grouting to the end of the back-up shall not exceed ± 5mm.

16.2.13.20 The grout shall remain effective for the design life of the tunnel. The grout shall not degrade, shrink or lose strength to an extent that the tunnel would be damaged or become unserviceable as a result.

**16.2.14 Construction Tolerances**

16.2.14.1 After grouting, the ring of segments of tunnel lining shall conform to the following tolerances:

(a) The centre of the ring of segments shall not depart from its design position by more than 42.5mm.

(b) Every internal diameter shall not be different from the design diameter by more than 25mm.

(c) The internal profile of the lining shall not depart from its design position by more than 55mm (combining i and ii above).

(d) The square and plumb (pitch and yaw) of the lining shall not differ by more than 20mm from the design value measured over the internal diameter horizontally and vertically or by more than 20mm from the attitude of the shield.

(e) The leading edge of the lining shall not be out-of-plane by more than 6mm. The Contractor shall propose a system that can check for out-of-plane.

(f) The absolute roll of the lining shall be no greater than ±40mm measured from a horizontal diameter. The roll of each ring in relation to the previous ring shall be no greater than can be accommodated within the limitations of bolt hole clearances.

(g) Lips and steps between segments at radial and circumferential joints shall not exceed 5mm.

16.2.14.2 A non-conformance report shall be raised by the Contractor for any ring which is found to be out of tolerance after erection and grouting. Any ring or part of a ring which does not satisfy these tolerances shall, if the Engineer so directs, be rebuilt by the Contractor.

16.2.14.3 At the locations of cross passages and other works where there is the possibility of additional deformation during breakout and subsequent construction the Contractor shall support the lining so that the tolerances are not infringed.

### 16.2.15 Re-Alignment of Out-of-Tolerance Lining

16.2.15.1 The Contractor shall propose immediate remedial actions to bring the tunnel ring centre into tolerance. The Contractor shall stop the TBM advance in the event the tunnel drive is out of tolerance by 5mm and no satisfactory remedial action is proposed and accepted by the Engineer.

16.2.15.2 The Contractor may propose a re-alignment to the railway to correct an out-of-tolerance tunnel drive. In exercising this proposal, it is the responsibility of the Contractor to demonstrate that:

(a) Required clearances to structure gauge are maintained

(b) The re-alignment does not deteriorate the intended operational characteristics of the line.

16.2.15.3 The location of any chainage jump due to the re-alignment shall be located at station centre.

### 16.2.16 Segment Repair in Tunnel

16.2.16.1 All segment repairs shall be carried out to the acceptance of the Engineer. Detailed records shall be kept of each repair noting the position and type of repair and the materials used. Materials shall be submitted to the Engineer for acceptance.

16.2.16.2 All segment repair materials shall be tested prior to use in the tunnels to ensure their workability and colour compatibility with the segmental lining.

### 16.2.17 Caulking Grooves and First Stage Concrete

16.2.17.1 All caulking grooves shall be thoroughly cleaned.

16.2.17.2 All caulking grooves below 1st and 2nd stage concrete level shall be maintained as open channels to prevent water under pressure from acting to lift the track slab. These channels shall connect to the drainage system leading to the sumps. This may be done by the installation of channelling in the caulking grooves or by some other means. The final method and details shall be to the acceptance of the Engineer. A testing regime shall be proposed to the acceptance of the Engineer to demonstrate that open channels have been achieved.

16.2.17.3 Crack inducers shall be proposed in the 1st stage concrete at a maximum interval of 10 rings.

### 16.2.18 Database of As-Built Lining

16.2.18.1 As part of the Project Quality Plan, the Contractor shall maintain a database of all as-built dimensions and conditions of the tunnel lining. For every ring built, the database shall include the following:

(a) diametric dimension of the lining vertically, diagonally (2 nos.) and horizontally

(b) maximum size of steps at each radial joint

(c) maximum size of steps at each circumferential joint with arc length for any step exceeding 5mm

(d) position of key

(e) maximum roll of ring compared with adjoining ring

(f) position, dimension and description of any crack

(g) position and description of any other damage.

16.2.18.2 The information shall be recorded for each ring when it is no more than 30m from the last ring built.

16.2.18.3 Information shall be recorded in a format acceptable to the Engineer. Hard and soft copies of the recorded data shall be submitted to the Engineer every week or at such other time as the Engineer may request.

16.2.18.4 The production of the database shall not relieve the Contractor from the need to produce a non-conformance report for any ring built that does not meet the requirements of this Specification.

## 16.3 FIXTURES AND COATINGS FOR SEGMENTAL LINING

### 16.3.1 General Requirements for Gaskets

16.3.1.1 All segments shall be provided with a composite gasket water sealing system consisting of a co-extruded elastomeric carrier and hydrophilic rubber as facing material. The minimum thickness of the hydrophilic rubber shall be 1mm. The system shall be designed, tested and installed to the acceptance of the Engineer and shall comply with the following requirements. The hydrophilic facing material must be compressed before annular grouting is carried out.

16.3.1.2 Unless otherwise accepted by the Engineer, the elastomeric material shall be an EPDM (Ethylene Propylene Diene Monomer) formulated to provide good retention of elasticity and low stress relaxation properties.

16.3.1.3 At least three samples of the proposed EPDM material shall be subjected to accelerated ageing tests at elevated temperatures of 60ºC, 80ºC and 100ºC. The elastic modulus of the degraded specimens shall be measured at intervals of 1, 7, 14, 28, 56 and 90 days. Based upon the results of these tests the projected elastic modulus of the EPDM material after a 120 years design life at a service temperature of 25ºC shall be calculated in accordance with Arrhenius's or the Williams–Landel–Ferry (WLF) Equation Theory. This projected value shall not differ by more than 35% from the short-term elastic modulus of the fresh material when measured at a temperature of 25ºC.

16.3.1.4 At least three further samples of the proposed EPDM material shall be subjected to accelerated stress relaxation tests at elevated temperatures of 60ºC, 80ºC and 100ºC. The residual compressive stress in the degraded specimens shall be measured at intervals of 1, 7, 14, 28, 56 and 90 days in accordance with the general procedural requirements of DIN 537 Sept 85 Method B or other procedure to the acceptance of the Engineer. Based upon the results of these tests the projected residual compressive stress in the EPDM material after a 120 years design life at a service temperature of 25ºC shall be calculated in accordance with Arrhenius's Theory. This projected residual compressive force shall not be less than 65% of the short-term compressive force of the fresh material when measured at a temperature of 25ºC.

16.3.1.5 The hydrophilic facing material shall be a vulcanised polychloroprene rubber formulated with hydrophilic polymers. The formulation of the hydrophilic material shall provide good water expansion properties with the minimum of leaching of the active materials.

16.3.1.6 The hydrophilic material shall exhibit at least a 6-times volumetric swelling when immersed for a period of 28 days in clean tap water. Further the hydrophilic material shall exhibit at least a 4-times volumetric swelling when immersed for a period of 28 days in a salt water solution containing 1% chloride ions and 0.5% sulphate ions measured as SO3.

16.3.1.7 A sample of the hydrophilic material shall also be weighed and then freely immersed in distilled water for a period of 28 days. On completion the sample shall be oven dried at 50ºC until no further weight change is recorded. The percentage weight change after the wetting and drying cycle shall not exceed 6% of the original weight.

16.3.1.8 Both the EPDM and hydrophilic material shall be resistant to acidity at least as severe as pH 5 and shall be unaffected by sustained exposure to operating temperatures of up to 40ºC.

16.3.1.9 The Contractor shall provide the Engineer with a detailed statement regarding the durability of the proposed materials demonstrating their ability to meet the specified performance criteria for the design life of the structure. The statement shall provide any further information and test data relevant to the water absorption, long term swelling capacity, relaxation, chemical resistance and ageing of the materials. In particular the materials shall be resistant to attack from all substances in the ground and groundwater at the concentrations found in the site investigation, to the alkalinity of the tunnel lining concrete and tunnel grout and shall be resistant to microbiological attack. The statement shall include a list of substances known to be deleterious to the materials, together with an analysis of the risk of contact with such substances.

16.3.1.10 The Contractor shall ensure that the grout is not permitted to penetrate to the gasket location as this would impair its function.

16.3.1.11 The selected gasket shall have a proven reputation for satisfactory performance in tunnels with similar ground water pressure.

16.3.1.12 The Contractor shall design, supply and install the gaskets and any grooves into which or the surfaces onto which they fit to the acceptance of the Engineer. They shall be in the locations shown on the Drawings or as otherwise accepted by the Engineer.

16.3.1.13 The Contractor shall carefully detail the size and depth of the gasket groove to ensure that it is of sufficient volume that when the segment faces are fully closed, the volume of rubber in the gasket can be housed within the groove. Unless otherwise accepted by the Engineer the volume of the gasket groove shall be at least 5% larger than the volume of rubber in the gasket. Where compressible joint packings are systematically incorporated between the joint surfaces the compressed thickness of the packing may be considered in the calculation of the volume of the gasket groove.

16.3.1.14 The gaskets shall form continuous loops (frames) around the segments and shall be bonded to the concrete surface with adhesives recommended by the gasket manufacturers and following the procedures recommended by the adhesive manufacturers.

16.3.1.15 The design of the gaskets shall be such as to render them inherently resistant to damage during transport and erection of the linings.

16.3.1.16 The Contractor shall provide drawings of the principal dimensions and proposed tolerances on the gaskets. The drawings shall include the dimensions and positions of the gasket grooves or mounting surfaces.

16.3.1.17 The corners of the gaskets shall be moulded to the appropriate corner angles of the segments. Detailed drawings of all segments shall be supplied by the Contractor to the gasket manufacturer. The corners of the gaskets shall be designed to ensure that the volume of rubber remains constant and that they have the same load and closure forces as the main body of the gasket. The corners of the gaskets shall be subject to full opening and closure tests to ensure the integrity of each joint.

16.3.1.18 The gasket manufacturers shall be ISO 9001 (or equivalent national or international quality standard) certified and shall have in place detailed procedures to ensure the quality control of the gaskets at each stage of their testing and manufacture.

16.3.1.19 The Contractor shall prepare detailed works procedures to cover the installation of the gaskets and the storage of segments to which these have been fitted. These procedures shall be developed from the requirements of this Specification and incorporate installation details determined from the literature of the manufacturers of the gasket and adhesive. These procedures shall be prepared for the information of the operatives engaged on the Works and as far as practical shall be in the format of cartoon drawings and diagrams illustrating the correct action at each stage of the procedure. They shall include details of the accuracy with which the gaskets have to be installed in order to obtain the performance achieved in the tests. The method statement shall include details of how the segments will be installed in the tunnel without damage to, contamination of or displacement of the gaskets. Lubricants shall be proposed and used to the acceptance of the Engineer. Any lubricants shall be as recommended by the supplier of the gaskets.

16.3.1.20 Prior to commencing manufacture of the gaskets prototype samples for each segment type shall be subject to fitting trials in order to determine the optimum tension for the gaskets. Each gasket shall be lightly tensioned to ensure that it grips the segment and fits snugly into the gasket groove. Corners of the gasket shall be square and tight fitting. These trial fittings shall be conducted by representatives of the gasket manufacturer and witnessed by the Engineer.

16.3.1.21 Installed gaskets shall be free from surface imperfections, voids, inclusions or flow marks and other defects which would impair satisfactory performance. The surfaces shall be smooth. Fabrication joints in the gasket material shall be made with such accuracy as not to impair satisfactory performance in the tunnel environment.

16.3.1.22 Prior to installation gaskets shall be stored under cover in a dry storage area in an undeformed relaxed condition at moderate temperatures and protected from direct sunlight. They shall be protected from circulating air and shall not be stored near equipment that can generate ozone (such as electric motors). The gaskets shall be kept clean, particularly avoiding contact with metals, solvents, oil and grease.

16.3.1.23 The Contractor shall specify the type of wrapping and packing he proposes for the gaskets and the conditions under which they will be stored. All deliveries shall be marked with the date of production and early deliveries shall be used first to minimise storage times.

16.3.1.24 If cleaning of gaskets is necessary only those approved for such use by the manufacturer of the gaskets shall be accepted.

16.3.1.25 Fitting of the gasket frame shall commence at the radial joint surfaces neatly pressing the gasket into the groove or on to the surface by hand. The circumferential joint surfaces shall then be fitted starting from the middle and working towards the two corners on each face. Care shall be taken to ensure that the frame is accurately located and that the corners are neither distorted nor loose. The frame may be lightly hammered into position using a rubber hammer and shall then be pressed onto the surface for a minimum period of five minutes until the adhesive has hardened.

16.3.1.26 Unless otherwise accepted by the Engineer gasket frames shall not be installed onto the segment prior to seven days before their installation into the tunnel. Each completed segment shall be inspected for correct seating of the frame and uniform adhesion prior to storage. Completed segments shall be protected from precipitation and direct sunlight. Completed segments shall be stored under covered conditions or tarpaulins prior to installation in the tunnel.

### 16.3.2 Performance Testing of Gaskets

16.3.2.1 The Contractor shall provide a test rig or rigs and carry out tests of the gaskets in Singapore to demonstrate the watertightness of the system. Tests shall be witnessed by the Engineer. The gasket-mounting surfaces of the test rig platens shall be fabricated or finished in cement mortar and shall incorporate grooves and/or mounting surfaces of the same dimensions as those on the lining segments. The gaskets shall be installed in the same manner as those on the lining segments using similar adhesives and installation procedures.

16.3.2.2 A series of tests shall be conducted for each gasket type. The tests shall be carried out using water with chemical content equivalent to the concentrations found in the ground water in the site investigation which will most impair their performance.

16.3.2.3 Each test series shall comprise the testing of a straight joint, a ‘T’ joint such as occurs at the intersection of a radial joint and a circumferential joint in the tunnel lining and a cross joint. The configuration of the test rig shall be such that it can accurately simulate the combination of gaps, steps and lips defined herein.

16.3.2.4 The gap between the faces of the test pieces, representing gaps in the joints of the tunnel lining, shall be 5mm greater than the theoretical value calculated from the shape of the joint surfaces and from the thickness of any packing which is to be used. The tests shall be performed with a lateral offset of 10mm at the groove in the following configurations.

| | | |
|---|---|---|
| Straight joint | : | one side offset |
| ‘T’ joint | : | one side of intersecting joint offset |
| Cross joint | : | one side of intersecting joint offset |

16.3.2.5 The gasket test pressure shall be defined as twice the design hydrostatic head. Unless otherwise accepted by the Engineer, the design hydrostatic head shall be considered to be the maximum distance between the invert of the tunnel and the ground surface.

16.3.2.6 The test pressure shall be applied in 1.0 bar increments by means of a variable pressure reflux valve or other stabilising device, capable of maintaining the applied pressure within 1% of the desired pressure at each pressure increment. The pressure shall be held for 15 minutes at each increment. The final pressure shall be held for 24 hours during which no visible sign of leakage shall be noticeable.

16.3.2.7 If the Contractor envisages that gaps larger than those indicated above will occur in the tunnel, due for example to the use of thicker packings, then the Contractor shall carry out tests with an appropriately larger gap. Only those gaps shall be used in the Works that are covered by a representative test.

16.3.2.8 The Contractor shall demonstrate that when the joints are closed to the fullest extent that will occur in the Works, no damage will be caused to the tunnel lining segments by the gaskets. “The fullest extent that will occur in the Works” shall be deemed to be:

(a) In the circumferential joints - Closed to the maximum extent that will be allowed by the packings in the joints.

(b) In the radial joints - Joint closed by the maximum extent that will be allowed by the gaskets.

16.3.2.9 The Contractor shall provide evidence that with smaller joint gaps and offsets than those specified above, the water pressure that can be withstood by the gaskets will not be less than the specified test pressures. This evidence can be in the form of further testing or certified results of previous tests on identical gaskets.

16.3.2.10 For hydraulic materials test results of volumetric change with time in clean fresh water shall be provided by the Contractor.

16.3.2.11 The Contractor shall prepare a prototype key/top plate test rig and demonstrate that when fully compressed into the gasket groove the gasket surfaces may slide relative to each other without causing slippage of the gasket within the groove or on the mounting surface, undue distortion of the corners of the gasket or, delamination of the hydrophilic facing material from the EPDM carrier. The same lubricant material that will be used in the tunnel during the erection of the segments shall be employed during the test. The test shall be repeated at increments of lipping between segments of 0, 5 and 10mm.

16.3.2.12 The Contractor shall prepare steel loading platens at least 100 mm in length provided with grooves or mounting surfaces of the same dimensions as those on the lining segments. The gaskets shall be installed in the same manner as those on the lining segments using similar adhesives and installation procedures. The Contractor shall determine the force required to compress the gasket during erection and prepare graphs of load and deflection. The Contractor shall ensure that the segment erector has sufficient power to compress the gasket on the radial joint surface and confirm that the tunnel lining bolts have adequate strength to provide and maintain this force.

16.3.2.13 The Contractor shall also demonstrate by appropriate testing that when fully compressed, the gasket corners do not deform to such an extent that its sealing capacity reduced to less than the minimum requirement as defined herein.

### 16.3.3 Packings

16.3.3.1 The type and thickness of packing shall be proposed by the Contractor to suit his construction tolerances and methods and to avoid damage to the rings.

16.3.3.2 Packing shall be incorporated into all circumferential joints so as to cushion the segments against excessive stresses under shield jack loading. Packing may also be used to correct the plane of the rings but not for corrections to square and plumb or for negotiating curves.

16.3.3.3 Packing shall be formed from, or coated with a fire retardant material and shall not give off toxic fumes in the event of a fire.

16.3.3.4 Packing shall generally be glued to the surface of the segments prior to erection, though insertion of packing for correction of plane will be permitted during segment erection provided that safe working practices are employed. Any glue used shall be non-flammable and suitable for use in a confined space irrespective of the ventilation provided in the tunnel.

16.3.3.5 Packing thicknesses shall be limited to those for which appropriate tests have been carried out on the composite gaskets.

16.3.3.6 The packings shall not permit rotation of the rings under the influence of torque applied by the shield of a magnitude that is detrimental to the performance of the lining.

**16.3.4 Metallic Threaded Fasteners, Washers Grout Plugs and Cast-In Fixings**

16.3.4.1 Cast-in fixings and grout plugs shall be of mild steel complying with BS 7668 and BS EN 10029, 10113, 10155 and 10210. Threaded fasteners and washers shall be of a steel grade as determined by the designer.

16.3.4.2 All threads shall be cut cleanly to comply with BS 3643 standard threads.

16.3.4.3 Non-threaded steel fixings and fittings shall be galvanised in accordance with BS 729 after manufacture. Threaded items shall be galvanised in accordance with BS 7371 Part 6 after manufacture.

16.3.4.4 As an alternative to galvanising, sherardizing to BS 7371 Part 8 Class S1 may be used for threaded items.

16.3.4.5 After coating all nuts shall be free fitting and able to be threaded on to bolts by finger pressure. Grout plugs shall be able to be threaded in to the grout sockets by hand.

16.3.4.6 As an alternative to mild steel, SG iron may be used for cast-in sockets, bolt pockets and grout plugs.

16.3.4.7 SG iron grout plugs for threaded sockets shall be malleable cast iron taper screw plugs conforming to BS 143 and 1256 and BS EN 10242 and the threads shall conform to the requirements of BS 21 Pipe Threads. The size shall be chosen by the Contractor to the Engineer's acceptance. The heads and threaded parts shall be solid. The malleable iron from which the plugs are made shall comply with BS EN 1562, Grade 300/6. The thread of the plugs shall be coated with grease after manufacture. The Contractor may propose other materials, subject to the acceptance of the Engineer.

16.3.4.8 The length of each lining bolt shall allow for two washers of a type accepted by the Engineer and for all adjustments required in the alignment of the tunnels. When fitted in position the bolt threads shall be exposed for at least 3mm clear of the nut. This applies even where the maximum build tolerances have all been used in the erection of the lining.

16.3.4.9 Lifting sockets, where used, shall be subjected to pullout tests. The test shall be performed by a SAC-SINGLAS accredited/approved testing laboratory accredited to conduct the specified test. A minimum of 2 trial tests before production and a minimum frequency of 1 test per 2000 sockets during production shall be carried out. The test shall demonstrate a factor of safety of 3 against failure at the design pullout load. The design pullout load shall be equal to the dead load of the largest segment in the ring. An additional test shall be carried out on another socket for every test that does not demonstrate this factor of safety to the satisfaction of the Engineer. Tested segments shall not be incorporated in the works.

16.3.4.10 If the Contractor proposes the use of a mixture of different metals for the fixtures and fittings he shall, as part of his proposal, demonstrate to the acceptance of the Engineer that their long-term durability is not compromised. In particular the Contractor shall demonstrate that where two different finishes or metals are to be left in contact or in close proximity with one another in the permanent works there is no risk of accelerated corrosion or other deterioration.

### 16.3.5 HIGH DENSITY POLYETHYLENE (HDPE) GROUT-LIFTING SOCKETS

As an alternative to metallic grout-lifting sockets, the Contractor may propose such sockets manufactured from HDPE, which shall comply with the following requirements.

(a) Manufacturer:

(i) The Contractor shall provide the name and location of the proposed manufacturer of the HDPE grout-lifting sockets. A track record of proven manufacturing capability shall also be provided. Only grout-lifting sockets of a proven design with a track record will be acceptable.

(ii) A non-ISO certified supplier/manufacturer will not be accepted. Other accessories, such as the screw cap shall be designed and manufactured by the same supplier.

(iii) The manufacturer's QC program to prove that the socket can be traced from the raw material supplier up to the pre-cast factory shall be provided.

(iv) The Grout-Lifting Socket shall be produced with one closed end. The socket has to be produced in a one blow molding process to ensure no joints and a watertight surface.

(v) The socket shall be produced with tight tolerances on the main dimensions:

- the outer diameter (+/- 1mm).
- the overall height (+/- 2.5mm).
- the pitch of the thread (+/-0.2mm).

(vi) The grout-lifting socket shall be equipped with the following accessories:

- Socket adaptor for the secure installation in the mould.
- Screw cap with sealing O-ring.
- Lifting pins shall be produced by the manufacturer of the socket or in accordance with his design drawings.

(b) Design:

(i) The outer shape of the grout-lifting socket shall be designed with a ribbed design or similar to enhance water-tightness and concrete adhesion.

(ii) Pin insertion lobes at the outer face to resist rotation during lifting shall also be provided.

(iii) A hydrophilic O-ring shall also be installed on the outside face of the socket to prevent leakage.

(iv) The sockets shall be equipped with a screw cap which shall not locally reduce the cap material thickness. A method for removal and tightening of the screw cap shall be taken into consideration in the design.

(v) The inside thread shall be designed with a large single pitch to allow easy installation of the lifting pin without any risk of un-screwing during the installation process due to the vibration of the erector.

(c) Material properties:

(i) The HDPE material shall comply with the following typical properties:

- Density ($g/cm^3$) 0.958
- Flexural Modulus (MPa) 965
- Tensile Strength (MPa) 29
- Ultimate Elongation (%) 1200
- Hardness (Shore) 65

(ii) The material shall be elastic to allow uniform load introduction and to avoid micro-drafts in the concrete.

(d) Testing Requirements:

(i) Pullout test:

The design pullout load shall be equal to the dead load of the largest segment in the ring. The tests shall be performed by a SAC-SINGLAS accredited/approved testing laboratory accredited to conduct the specified test. The tests shall demonstrate a factor of safety of 3 against failure at the concrete interface and 5 against failure of the inner thread at the design pullout load.

A minimum of 2 trial tests are to be carried out and results submitted to the Engineer as part of the material acceptance proposal.

During production, tests shall be conducted at a rate of 1 per every 500 segments produced from segments selected at random by a representative of the Engineer. Subject to the acceptance of the Engineer the Contractor may apply for the following relaxations after 5 tests providing all tests have passed.

Concrete Interface - 1 in 2000 from segments selected at random by a representative of the Engineer.

Inner Thread - 1 in 500 from “test panels” for sockets selected at random by a representative of the Engineer.

(e) Delivery:

(i) The sealing O-ring shall be delivered together with the screwed cap (grout plug) and shall be delivered fully assembled to the site.

(ii) Each delivery of socket shall be accompanied with production certificates to demonstrate compliance of production and material tolerances of the batch.

(iii) All grout-lifting sockets shall be transported and unloaded carefully and then stored under cover in clean and dry conditions until required.

(iv) A batch number shall be indicated on each socket, which shall refer to the production lot, the manufacturing period and the batch of raw material used. The name of the manufacturer shall also be indicated on the body of the socket, to allow an easy identification on site.

### 16.3.6 Waterproof Coatings for Segments

16.3.6.1 The outer (convex) surface of all segments together with all side faces, gasket recesses, caulking grooves and insides of bolt holes and grout holes shall be painted with a solvent free or water based emulsion epoxy coating.

16.3.6.2 All epoxy materials shall be stored, mixed and applied in strict accordance with the recommendations of the coating manufacturer.

16.3.6.3 Surfaces shall first be primed with either a penetrative primer, which may be non-pigmented, or a thinned coating of the under coat of epoxy.

16.3.6.4 The waterproof coating shall then be applied in at least two further coats. When applying one coat of epoxy coating over another the top coat shall be applied to the preceding coat within the time period for overcoating stipulated by the manufacturer and generally in a direction perpendicular to the preceding coat. The top coat shall be a contrasting colour to the preceding coat.

16.3.6.5 When tested in accordance with DIN 1048 the epoxy coated surface shall have a permeability of $<$1 x 10–17 m/s.

16.3.6.6 When tested for Moisture Vapour Transmission the epoxy coating shall have a Diffusion Coefficient of $>$3000 and an Equivalent Air Layer Thickness of $<$4.0m. The test method for water vapour permeability shall be in accordance with BS EN 1062 “Paints and Varnishes, Coating Materials and Coating Systems for Exterior Masonry and Concrete, Part 2 Permeability to Water Vapour”.

16.3.6.7 When tested in accordance with ASTM D4541 for adhesive strength to the substrate using a 50mm diameter dolly the epoxy coating shall have a minimum adhesive strength of 1.5MPa.

16.3.6.8 When tested in accordance with BS 476: Part 7 the epoxy material shall achieve a Class 1 rating for flame spread. When tested in accordance with BS 6853: Appendix B Clause B9.3 the epoxy material shall exhibit no flaming of the surface.

16.3.6.9 The Contractor shall maintain records that show the material consumption of the epoxy coating per segment. At all times these records shall be available to the Engineer.

16.3.6.10 The dry film thickness of the epoxy coating shall be checked at the discretion of the Engineer by either minor destructive or non-destructive methods. The minimum thickness shall be 200 microns.

16.3.6.11 The Contractor shall provide proof of the depth to which the primer has been absorbed into the substrate in conditions identical to those found at the site where the coating will be applied during production. This evidence shall be in the form of conventional petrographic analysis or other method to the acceptance of the Engineer.

16.3.6.12 Under the following circumstances, the applied epoxy coatings shall be deemed to fail to comply with the Specification:

(a) Rain damage.

(b) Sagging or running is evident as a result of the application of an excessive amount of epoxy coating.

(c) Maximum interval between successive coats as specified by the manufacturer has been exceeded.

(d) The coating surface has been contaminated prior to full curing.

(e) Blistering or surface delamination of the coating occurs.

16.3.6.13 Where the coating does not comply with the Specification the coated concrete shall be abraded to provide a smooth clean surface and two coats of material shall then be re-applied in a manner which is to the acceptance of the Engineer.

16.3.6.14 Where the dry film thickness is less than the minimum specified requirement a further coat shall be applied in accordance with the manufacturer’s instructions to achieve the specified thickness. The additional coat shall comply with the overcoating requirements.

16.3.6.15 The Contractor shall prepare and submit a method statement for a trial application to the acceptance of the Engineer. The Contractor shall give the Engineer 48 hours notice of his intent to commence the trial application.

16.3.6.16 A concrete panel shall be coated in accordance with the Specification and the accepted method statement. The coated surfaces shall then be inspected for compliance.

16.3.6.17 The Engineer will only accept the proposed method of application of the coating if the Contractor has demonstrated competence in using both the epoxy coating material and the application equipment. Production application shall not proceed without the acceptance of the Engineer.

16.3.6.18 If the coatings are deemed not to comply the coating operation shall be repeated using a fresh concrete panel until compliance with the Specification has been demonstrated and the method statement amended as appropriate.

16.3.6.19 The work practices adopted during the trial shall be adopted for all subsequent coating application operations.

16.3.6.20 The Contractor shall supply material safety data sheets for all components of the epoxy coating. The Contractor shall store, handle, mix and apply the coating in strict accordance with the material safety data sheets.

16.3.6.21 Particular care shall be paid to all health, safety and environmental statements contained in the material safety data sheets.

16.3.6.22 Products which are excess to requirements or which have exceeded their shelf life or which the Engineer has not accepted for whatever reason shall be disposed of in a safe and controlled manner. Empty packaging may contain harmful residues. In any case disposal shall be arranged through a licensed waste contractor in accordance with the current local waste disposal regulations.

16.3.6.23 The properties of the epoxy resin coating shall be as follows:

(a) Pot life at least 30 minutes at 30$^{o}$C

(b) Safe from exposure to rain after a minimum of 4 hours of storage at 30°C

(c) Solids content minimum 50%, maximum 55% by volume. This shall be confirmed by the Contractor with an independent test report from an accredited laboratory

(d) A contrasting colour for each coat shall be used. Colours are to be to the acceptance of the Engineer

(e) Coverage rate 200 to 250 g/m$^2$ per coat to provide a minimum total dry film thickness of 200 microns

(f) Fully compatible with the gasket adhesive

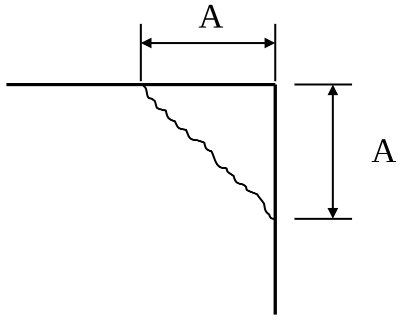
16.3.6.24 Alternative specifications may be proposed by the Contractor for the acceptance of the Engineer.

# Appendix 16.1

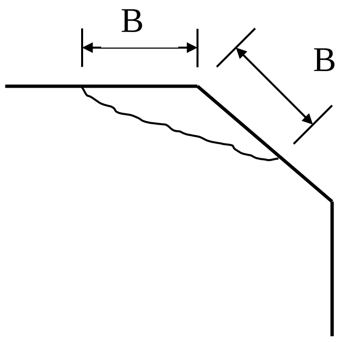
## Guidelines For Precast Segment Repair (Prior To Erection)

- **Edge Repair (Intrados)**

**a. Sharp Edge**




**b. Chamfered Edge**




**c. At Corners**

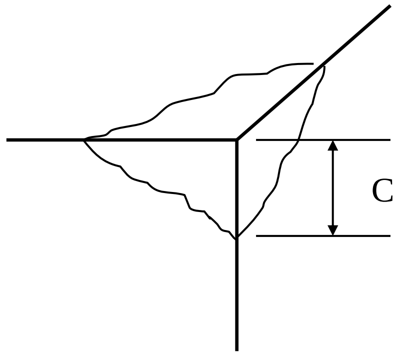



**Table 1 - Guideline for Edge Repair**

| Action | A (mm) | B (mm) | C (mm) |
|---|---|---|---|
| No repair | < 5 | < 5 | < 5 |
| Repair with Cementitious Mortar | 5 - 25 | 5 - 25 | 5 - 35 |
| Reject | > 25<br>or rebar exposed | > 25<br>or rebar exposed | > 35<br>or rebar exposed |

- **Recesses (Extrados)**

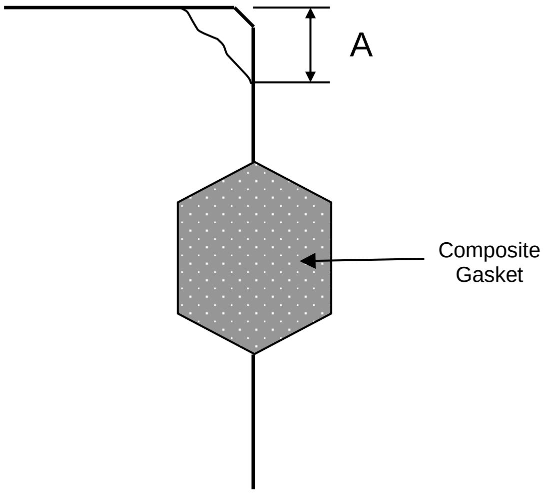



**Table 2 - Guideline for Recesses Repair**

| Action | A (mm) |
|---|---|
| Repair with Cementitious Mortar | 0 - 10 |
| Reject | > 10 |

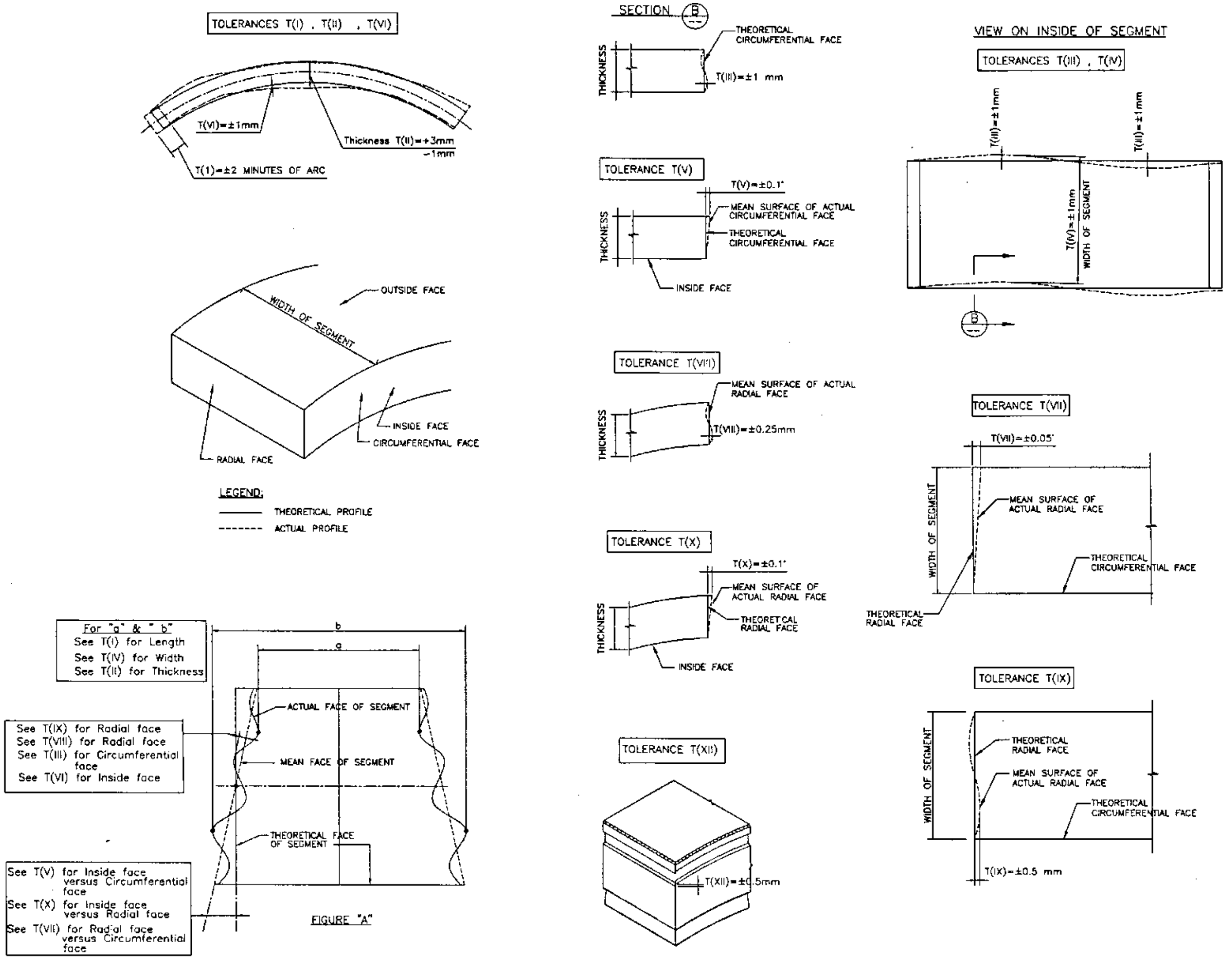
Note: All visible blowholes on glued surfaces to be filled with Cementitious Mortar

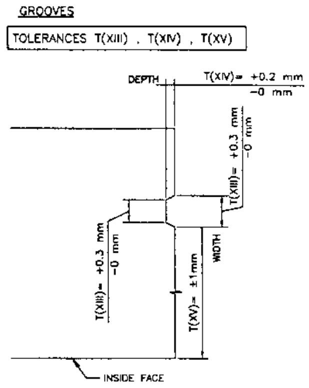
- **Blowholes**

**Table 3 - Guideline for Blowholes Repair**

| Action | Gasket Surface (mm) | Epoxy Surface (mm) | Intrados (mm) |
|---|---|---|---|
| No repair | - | - | < 2 wide |
| Repair with Cementitious Mortar | All | All | > 2 |

# Appendix 16.2




| | DESCRIPTION | CONSTRUCTION TOLERANCES |
|---|---|---|
| I | ARC LENGTHS OF CIRCUMFERENCE | +/- 2 MINUTES OF ARC |
| II | SEGMENT THICKNESS | +3 mm / -1 mm |
| III | DEVIATION OF CIRCUMFERENTIAL FACE FROM MEAN CIRCUMFERENTIAL FACE ACROSS THICKNESS AND LENGTH | +/- 1 mm |
| IV | WIDTH OF SEGMENT | +/- 1 mm |
| V | SQUARE OF MEAN SURFACE OF ACTUAL CIRCUMFERENTIAL FACE TO INSIDE FACE OF SEGMENT | +/- 0.1 DEGREE |
| VI | INSIDE FACE OF SEGMENT RELATIVE TO MEAN SURFACE OF INSIDE FACE ACROSS WIDTH & LENGTH | +/- 1 mm |
| VII | OUT-OF-SQUARE OF MEAN SURFACE OF RADIAL FACE RELATIVE TO THEORETICAL CIRCUMFERENTIAL FACE | +/- 0.05 DEGREE |
| VIII | DEVIATION OF RADIAL FACE FROM MEAN RADIAL FACE ACROSS THICKNESS | +/- 0.25 mm |
| IX | DEVIATION OF RADIAL FACE FROM MEAN RADIAL FACE ACROSS WIDTH | +/- 0.5 mm |
| X | SQUARE OF MEAN SURFACE OF ACTUAL RADIAL FACE TO INSIDE FACE OF SEGMENT | +/- 0.1 DEGREE |
| XI | DIAMETER OF BOLT HOLES | +/- 1 mm * |
| XII | EDGES OF GROOVES FOR WATERPROOFING COMPOSITE GASKETS IN RADIAL FACE TO MATCH GROOVES IN CIRCUMFERENTIAL FACE | +/- 0.5 mm |
| XIII | TOP AND BOTTOM WIDTH OF GROOVES FOR WATERPROOFING GASKETS | +0.3 mm / -0 mm |
| XIV | DEPTH OF GROOVES FOR WATERPROOFING GASKETS | +0.2mm / -0 mm |
| XV | DISTANCE FROM INNER SURFACE OF SEGMENT TO EDGE OF GASKETS GROOVE OR MOUNTING SURFACE | +/- 1 mm |

* - NOT REPRESENTED IN SKETCH.

(FOR DEFINITION OF THE TERM "THEORETICAL FACE" REFER TO FIGURE' A'.)

## BORED TUNNELS – GENERAL CONCRETE SEGMENTS CASTING TOLERANCES

# CHAPTER 17

# MINED TUNNELS AND SPRAYED CONCRETE LINING

## 17.1 GENERAL

### 17.1.1 Definitions

SCL is the abbreviation for Sprayed Concrete Lining.

This chapter covers the following:

1) Excavation and Sprayed Concrete Lining (SCL) for mined tunnels and shafts.
2) Excavation and temporary works for mined tunnels when SCL is not the primary support.
3) Any other SCL works.
4) Permanent in-situ concrete lining and waterproofing for tunnels including mined tunnels, cross passages, sumps, and where applicable bored tunnels.

### 17.1.2 Precedence and References

a) Other relevant Chapters of the Materials and Workmanship Specification should be referred together with this Chapter on Mined Tunnels and SCL. In cases of apparent conflict or ambiguity, clauses presented in this Chapter shall take precedence over the clauses stated in other Chapters of the Materials and Workmanship Specification.

b) The Contractor's attention is drawn to the following references (or guides) to ensure a safe SCL design and construction practice:

   i) ICE design and practice guide: Sprayed concrete linings (NATM) for tunnels in soft ground (1996), published by Thomas Telford Publishing.

   ii) Safety of New Austrian Tunnelling Method (NATM) Tunnels-A review of sprayed concrete lined tunnels with particular reference to London Clay (1996), published by the Health and Safety Executive.

### 17.1.3 General Requirements

a) The designer of the SCL, herein referred to as the "SCL Designer" shall preferably be the QP(D). Where the SCL Designer is not the QP(D), the design shall be endorsed by QP(D).

b) The Contractor shall propose to the Engineer for acceptance a site team comprising, but not limited to, a Site Manager, engineers, foremen and operators for the works. The Site Manager shall have at least ten years' experience in mining and SCL works of a similar type and size as envisaged under this Contract. Other key staff involved in the SCL works shall similarly have at least five years' experience. The Engineer reserves the right to reject any proposed staffs who in his opinion does not meet the requirements stated herein.

c) The Contractor shall propose and assign a suitably qualified and experienced site representative to be stationed full time on site to act on behalf of the SCL Designer. The site representative shall be fully acquainted with the approved SCL design and shall be capable of recommending design changes to allow the works to proceed on site.

The SCL Designer site representative shall:

i) verify that the works is performing in accordance to the design

ii) verify that the works is carried out in accordance to the specified quality

iii) verify that the subsurface ground conditions are similar to those assumed in the design

iv) advise on any changes to the original design if subsurface ground conditions differ from those assumed in the design

v) review and interpret instrumentation monitoring readings

vi) liaise and coordinate with the Contractor, SCL Designer and QP(S) on any proposed design change

d) At least two months before the commencement of the works, the Contractor shall present to the Engineer for his acceptance a method statement describing the construction methods related to the works. This method statement shall include, but shall not be limited, to the following:

i) Method and sequence of excavation and spoil removal

ii) List of equipment to be used, including shotcreting equipment

iii) Preparation of construction joints

iv) Installation of other ground support measures

v) Construction supervision plan

vi) Hazard analysis and risk assessment

vii) Temporary ventilation calculation

viii) Proposals for surface and subsurface monitoring, with the establishment of pre-determined, alert and work suspension levels and procedures for the evaluation of monitoring results

ix) Contingency plan and procedures for emergencies

e) Excavation works management shall be implemented by the use of an Excavation Support Sheet (ESS) or similar. The ESS shall be prepared by the SCL Site Manager, approved by the SCL Designer’s Representative, QP(S), and accepted by the Engineer.

The ESS shall include the following:

i) Location of tunnel section (chainages)

ii) Detailed excavation sequence

iii) Round/Advance length

iv) Details of all supports, including any additional pre-support or auxiliary support

v) Details of probing (location, length, etc)

The details shown in the ESS shall not deviate from the approved design drawings. Any changes to the SCL design shall be regularized with a revised ESS issued by the Contractor, endorsed by the SCL Designer's site representative, QP(S) and accepted by the Engineer.

f) The Contractor shall propose and submit to the Engineer for acceptance an appropriate format for the Change Request Excavation and Support Sheet (CRESS). If required by QP(S), a CRESS shall be raised for any minor changes to the approved design.

g) The CRESS shall be prepared and endorsed by the Contractor’s Site Manager responsible for the SCL works, the SCL designer, QP(S) and accepted by the Engineer. Unless all the four signatures are obtained, the proposals indicated on the CRESS shall not be implemented.

h) The CRESS shall address, but not be limited to, the following:

i) Location of tunnel section (chainages)

ii) The proposed change to the design

iii) Proposed changes in the method of working related to ground support including staging of application of shotcrete layers and lapping of reinforcement

iv) Pre-determined, alert and work suspension levels applicable to affected monitoring instruments

v) Changes to the monitoring to be installed in the section of tunnel

vi) Measures to be taken during stoppage of works

vii) Other instructions relevant to the tunnel section

viii) Reference to relevant design drawings

i) The Engineer may require additional supporting documents such as reports, calculations, etc, prior to the acceptance of a CRESS. Resubmission to relevant authorities may be required.

j) The Contractor's Site Manager shall hold daily site meetings with the Engineer's Site Representatives, the SCL Designer or Representative, sub-contractors' representatives, and any other relevant personnel to review the following, as a minimum:

- Daily work activities
- Instrumentation and monitoring
- ESS
- CRESS
- Health and Safety
- Quality

k) All excavated and exposed faces, except the face being excavated shall be coated with a flash coat/layer (or sealing coat/layer) of shotcrete of not less than 50 mm in thickness.

l) Only the wet method of shotcreting shall be allowed on site. Dry method of shotcreting can be allowed as contingency backup or for particularly limited shotcreting works, subject to the acceptance of the Engineer.

## 17.2 EXCAVATION

### 17.2.1 General

a) Underground excavations shall comply with the widths, lengths and depths shown on the Drawings. Proper allowance shall be made for ground deformation and construction tolerances.

b) Excavation shall be carried out in a uniform and controlled manner to create a minimum size of the opening. Methods for excavation and ground support shall be chosen such that overbreak is avoided.

c) Over-excavation shall be kept to a minimum, consistent with the need to maintain the necessary clearance according to the Drawings. No ground shall protrude inside the theoretical excavation line shown on the Drawings. The Contractor is required to perform at regular intervals a careful and systematic survey of the actual excavation profile.

d) All excavation shall not start unless shotcrete is available on site, in a quantity agreed by the Engineer but not less than sufficient for the completion of a sealing layer on the exposed excavation.

### 17.2.2 Procedure

a) Excavation procedures shall be adapted to local ground conditions. In unfavourable ground conditions, the Contractor shall propose special excavation methods and specific procedures acceptable to the Engineer which he considers can meet the requirements of the particular ground conditions so as to achieve safe excavation conditions with minimum deterioration or loosening of the ground surrounding the excavation, or to avoid overbreak and limit negative effects on already installed primary lining.

b) Where special support measures such as forepoling may lead to over-excavation, the Contractor shall ensure that the excavation profile is kept to the absolute minimum required to progress the Works.

c) Over-excavation or overbreak shall immediately be recorded prior to placing additional shotcrete layers over the initial sealing layer. In case of ground mass instability, the recording of the overbreak shall not delay application of ground support elements. The Engineer shall be informed about occurrence, location, extent and reason for the excess excavation beyond the extent proposed in the Contractor’s method statement.

d) Over-excavation shall generally be backfilled by shotcrete. If accepted by the Engineer, over-excavation may be backfilled by secondary lining concrete or other material before any mesh reinforcement is fixed in place.

e) Ground conditions may require excavation in a sequence different from that shown on the Drawings or detailed in the Contractor's Method Statement. Where necessary or instructed by the Engineer, the Contractor shall carry out such excavations in stages in order to ensure stability and safety of the Works. In this case, a CRESS shall be raised.

f) The spacing of support arches, where required, shall be in accordance with the Drawings.

g) After completion of the excavation of a particular construction stage, the Contractor shall immediately apply a sealing layer of shotcrete (minimum 50 mm thickness) to minimize or avoid deterioration of the ground due to exposure. Sealing layers for the bench / invert sections may be omitted when tunnelling in competent rock (such as GI and GII). The requirements for sealing layer shall be specified in the design. For any amendment during construction, a CRESS shall be submitted.

h) To ensure the safety of the works, tunnel excavation and primary lining application shall be continuous at all times unless otherwise accepted by the Engineer. If the state of the work permits, interruptions may be allowed on weekends and public holidays, provided that the works are secured in a safe condition. In this case, the Contractor shall submit for the Engineer’s acceptance a proposal on how the current state of the works are secured during the shut-down period including implementation and inspection procedures.

The interruption shall not be allowed until all the support elements at all necessary locations have been completed including thickening the excavation face with shotcrete. Notwithstanding the above requirements for prolonged stoppages, for any interruptions to the works longer than 72 hours, the Contractor shall identify the change on a CRESS and shall carry out any additional support measures as recommended by the SCL Designer and/or requested by the Engineer.

i) Attention is drawn to the likelihood of intercepting earlier site investigation boreholes during the excavations. The holes may or may not have been effectively sealed and could represent sources of ingress of water where they emerge into the underground opening. All steps necessary shall be taken to identify, seal and plug these voids quickly at an early stage and as far as possible away from the current excavation face.

### 17.2.3 Method

a) The excavation method shall be chosen as to minimise the settlement and disturbance of the ground mass to ensure the structural integrity of existing surface and underground structures in the vicinity of the Works.

b) The method used for the excavation shall be appropriate to the size of the underground opening and to the prevailing ground conditions. In general, excavation shall be carried out using a roadheader or other suitable mechanical equipment (e.g. backhoe). Small openings shall be excavated by hand. Any mechanical equipment for underground excavation works and transportation shall be suitable for the work specified with respect to performance and current safety regulations, as well as for compliance with the requirements of the construction schedule.

c) Excavation methods shall at all times be subject to acceptance by the Engineer.

d) Underground mechanical plant and equipment shall be powered by electricity, compressed air or diesel engine. Petrol engines are forbidden.

e) At the start of the underground excavation, the Contractor shall carry out trials to demonstrate that the excavation methods, which he proposes to use, shall achieve the required performance. During the progress of the Works the excavation methods shall be varied, as necessary, to suit the conditions and to obtain the best practicable excavation shape and surface conditions.

f) The maximum length of excavation before installation of ground support shall comply with the Drawings.

### 17.2.4 Excavation Tolerances

17.2.4.1 General

a) Based on the theoretical excavation line shown on the Drawings and on additional allowances listed below, the Contractor shall excavate a minimum excavation profile. The Contractor shall provide to the Engineer documentation to demonstrate that the excavated profile meets the required construction tolerances. Convex surfaces shall not be accepted. If convex surfaces occur, they shall be trimmed back prior to shotcreting.

b) The theoretical excavation line given on the Drawings does not include allowances for the anticipated ground deformations defined as Deformation Allowances or tolerances related to excavation accuracy defined as Additional Excavation Allowance. It is the Contractor's responsibility to determine the minimum excavation profile by adding these allowances to the theoretical excavation line in the radial direction.

17.2.4.2 Additional Allowances

a) The Contractor shall add to the theoretical excavation line the Deformation Allowances which he shall evaluate for each underground structure by means of the ground-structure interaction analysis

b) To the theoretical excavation line, enlarged by the deformation tolerances, the Contractor shall further add the Additional Excavation Allowance (over-excavation) needed to achieve the required theoretical shotcrete profile according to the Drawings. The additional excavation allowance shall depend on the Contractor's intended excavation and support measures and equipment (excavation accuracy) as well as the total thickness of the intended waterproofing system.

17.2.4.3 Survey

The excavation profile shall be carefully controlled at all times using tunnel survey profiling/scanning equipment and software, which shall be approved by the Engineer. This equipment shall be capable of providing information to the excavation teams as the excavation progress and shall not delay the excavation process." Where, in the opinion of the Engineer the excavation profile is considered small, the contractor may propose alternative method of excavation profile control.

### 17.2.5 Excavation Sequence

17.2.5.1 The Contractor shall submit to the Engineer for his acceptance his proposed excavation sequence and procedures which shall take into consideration the following key factors:

i) tunnel cross section

ii) prevailing ground condition

iii) loads

iv) overburden

v) timely excavation and installation of primary ground support

vi) timely closure of the invert

vii) ground deformation and surface settlement

viii) construction joints in the primary supports as a result of staged excavation procedure

17.2.5.2 The excavation sequence for tunnels shall be as follows:

| | |
|---|---|
| Heading: | advance length max. 1.0 m |
| Bench + Invert: | advance length max. 2.0 m |
| Invert closure: | not more than 6 m behind the face |

17.2.5.3 The Contractor and the SCL Designer's site representative shall continuously evaluate whether the current ground conditions would require deviation from the approved design sequence. This includes continuous assessment whether the excavation face needs to be further subdivided to improve stability or if additional face improvement / reinforcement measures need to be adopted. If any deviations are to be implemented, a CRESS shall be raised.

17.2.5.4 For the tunnel with diameter greater than 6m, the invert closure shall not be more than 6m behind the face. The excavation shall be with a circular or near circular tunnel and shall be done in stages (heading/bench/invert) or using a pilot tunnel. The pilot tunnel may be approximately concentric or it may share a common invert with the enlarged tunnel such that the invert of the pilot tunnel is retained and incorporated in the lining of the enlarged tunnel.

### 17.2.6 Probe Drilling

a) The Contractor shall inform the Engineer well in advance when probe drilling is scheduled to take place.

b) The Contractor shall carry out probe drilling ahead of the excavation face. The probe holes shall be overlapped such that they are at a minimum two tunnel diameters ahead of the face at any time. Actual patterns and drilling frequencies shall be accepted by the Engineer.

c) During the probe drilling operation, details of drilling parameters and other relevant observations shall be recorded for later interpretation. After the probe drilling, the Contractor shall submit to the Engineer the drilling records in a format acceptable to the Engineer.

d) Probe drilling holes may later be used as drainage holes.

### 17.2.7 Drainage

a) Inside the excavation, the Contractor shall implement appropriate drainage measures such that the excavation floor is kept dry and properly drained at all times.

b) If ground water inflow is encountered during the excavation, drainage measures shall be installed to the acceptance of the Engineer. If required, localised ground water inflow shall be treated and minimised to the acceptance of the Engineer.

c) If drainage ahead of the tunnel face is required, at least three boreholes of minimum 75mm diameter and equipped with a minimum 50mm perforated PVC pipe shall be drilled ahead of the face. All necessary measures must be undertaken to prevent the ingress of fines.

### 17.2.8 Construction Joints

17.2.8.1 Due to the staggered construction process of SCL structures, construction joints will be present in the shotcrete lining both in radial and in longitudinal direction.

17.2.8.2 The Contractor shall address the following issues in detail in the method statement:

a) Lapping of reinforcement at joints.

b) Trimming of previously sprayed concrete to achieve a full depth perpendicular joint face prior to application of a subsequent SCL.

c) Cleaning of joints and overlap reinforcement.

### 17.2.9 Break-Outs for Openings, Junctions and Similar Structures

The following shall apply:

a) The excavation for break-outs shall not commence until deformation of the structure has stabilised. The thickness shotcrete lining shall be increased around future openings. Additional support by ground dowels or any other accepted method may be required.

b) Detailed method statements shall be submitted by the Contractor at least 8 weeks prior to the commencement of the Works.

### 17.2.10 Prevention of Weathering

All necessary precautions shall be taken in order to prevent weathering or softening of excavated surfaces. All surfaces exposed by excavation shall be sealed with shotcrete as soon as possible after excavation.

### 17.2.11 Ground Support

17.2.11.1 In the case of instability of the ground, water ingress and/or sand lenses, either one or a combination of the following measures shall be used to support the face:

a) Sub-divide the excavation ground in smaller sections and sealed with shotcrete after completion of each stage;

b) Battering or doming of the ground;

c) Forepoling;

d) Increase shotcrete thickness;

e) Retaining a dumpling of ground in the centre of the face;

f) Reducing the length of the ‘advance’;

g) Ground improvement;

h) Placing a additional sealing coat of shotcrete on the face; and

i) Changing construction sequence with more comprehensive ground support measures such as ground anchors (face nailing) and pipe roof (steel pipes of a properly designed length able to result in a reduction of loading to the ground).

17.2.11.2 In all cases, any deviation from the approved method of working must be addressed by raising a CRESS.

### 17.2.12 Excavation Stoppages

The ground shall be regularly inspected for signs of deformation.

The Contractor shall carry out an assessment and inform the Engineer about his conclusions whether doming of the face or additional supports are required for the particular stoppage.

### 17.2.13 Temporary Backfill

Excavation formation levels or shotcrete inverts shall be protected against wear or deterioration caused by site traffic, by backfilling with excavated ground material or similar.

### 17.2.14 Hazard Identification and Risk Assessment

a) The contractor shall submit to the Engineer for his acceptance, a risk assessment of the Works.

b) The risk assessment shall consider, but not be limited to, the following:

   i) Design (e.g. geological information, geotechnical parameters, water ingress, overburden)

   ii) Unstable ground (e.g. failure of crown and side walls)

   iii) Failure of SCL lining (e.g. shear, compression, combined bending and thrust, punching failures)

   iv) Settlement (e.g. damage to structures and utilities)

   v) Excavation sequence (e.g. deviation from approved sequence, delayed invert and ring closure)

   vi) Site management (e.g. inexperienced team, poor workmanship, miscommunication, incorrect processes)

   vii) Instrumentation and monitoring (e.g. no readings, timely interpretation)

   viii) Material quality (e.g. shotcrete quality, defective supports, substandard materials)

   ix) Equipment failure (e.g. incorrect and defective equipment)

c) All possible hazards related to the specific work shall be identified and risks evaluated, controlled, eliminated or reduced to a level “As Low As Reasonably Practicable” (A.L.A.R.P).

d) Residual risks shall be further controlled. Response to residual risks shall be included in the contingency and emergency plans

e) The Contractor’s attention is drawn to the guide, published by the Health and Safety Executive, entitled “Safety of New Austrian Tunneling Method (NATM) Tunnels-A review of sprayed concrete lined tunnels with particular reference to London Clay (1996)” for his preparation of the risk assessment.

### 17.2.15 Quality

17.2.15.1 The SCL lining shall be constructed to an acceptable quality standard in accordance with the design intent. The following activities shall require particular attention to achieve the required quality and standard:

a) Excavation of an accurate profile

b) Maintenance of correct face profile and support measures

c) Check on lattice girder profile before installation

d) Accurate placing of reinforcement

e) Sprayed concrete application technique

f) Correct operation of shotcrete pump and accelerator dosing unit

g) Cleaning and removal of rebound

h) Sprayed concrete thickness and profile

i) Sprayed concrete strength

j) Construction and preparation of joints in lining

17.2.15.2 A pre-shotcrete checklist shall be used at each stage of the SCL installation and to record that each section to be sprayed has been prepared in accordance with the requirements i.e. joints squared back, mesh overlap provided, rebound removed, etc. The pre-shotcrete checklist shall be signed off by the Contractor and QP(S) prior to the application of each layer of shotcrete

17.2.15.3 Before commencing the SCL works, the Contractor shall submit to the Engineer for his acceptance, a Quality Assurance (QA) plan to monitor the above critical processes and ensure that the materials and workmanship adhere strictly to the proposed QA Plan.

17.2.15.4 The following is a list of quality records that shall be used to control the quality during the construction of an SCL tunnel:

i) Excavation Support Sheet (ESS)

ii) Change Request Excavation Support Sheet (CRESS)

iii) Pre-Shotcrete Checklist

iv) Lattice Girder Checklist

v) Accelerator Dosing Checklist

vi) Face Log / Probe Record Sheet

vii) Shotcrete Core Strength Record

17.2.15.5 The Contractor shall prepare a mock-up of particularly complex joints with congested reinforcements to demonstrate the constructability and effectiveness of shotcreting at these joint locations. Cores shall be obtained at the shotcreted joint locations to demonstrate the absence of voids and good shotcrete quality.

## 17.3 SHOTCRETE

### 17.3.1 Definitions

17.3.1.1 Shotcrete

Shotcrete or sprayed concrete, is a mixture of cement, aggregate, and water projected at high velocity from a nozzle into place to produce a dense, homogeneous mass. Shotcrete shall be applied directly to the ground surface in one or more layers to form the SCL structure.

17.3.1.2 Wet Method of Shotcreting

A method in which a mixture of cement and aggregate is weigh-batched and mixed with water at the shotcreting location or in mixer trucks prior to being pumped through a pipeline to a nozzle where air and admixtures, if necessary, are introduced to the mix which is projected without interruption into place.

17.3.1.3 Shotcrete Layer

A discrete thickness of shotcrete, which is allowed to set and built up from a number of passes of the nozzle.

17.3.1.4 Flash Coat/Sealing Coat

Shotcrete applied as a thin layer protecting or priming the surface of the excavated face. A flash layer (or coat) shall be at least 50mm thick.

17.3.1.5 Rebound

All material which passes through the nozzle but which does not adhere to the surface onto which shotcrete is being applied.

17.3.1.6 Admixtures

Materials which are added to the shotcrete such as accelerators, plasticisers and retarders.

### 17.3.2 Materials

17.3.2.1 Cement

a) Shotcrete mixes shall use cement of uniform chemical composition and uniform fineness. The Contractor shall provide certificates for all deliveries of cement to the Engineer. In addition, the Contractor shall make available for inspection by the Engineer, the cement analyses and the results of standard tests.

b) Cement shall comply with SS EN 197-1 as appropriate and with the requirements of Chapter 11 Concrete and Reinforcement.

c) Cement shall also comply with the following additional requirements, unless otherwise accepted by the Engineer.

i) Fineness: Not less than $340m^2/kg$

ii) Bleeding: not more than 20 ml when tested in accordance with BS EN 480-4.

iii) Compressive strength after 3 days + 1 hour on mortar prisms shall be at least $23.5N/mm^2$ to SS EN196.

17.3.2.2 Pulverised Fuel Ash

Pulverised Fuel Ash shall comply with BS EN 450-1.

17.3.2.3 Microsilica

Microsilica (condensed silica fume) shall comply with SS EN 13263-1.

17.3.2.4 Aggregates

a) Aggregates shall comply with the requirements of SS EN 12620 or SS EN 13055-1 unless otherwise specified.

b) The nominal particle size of the coarse aggregate shall be 10mm unless accepted otherwise by the Engineer.

c) Single size aggregates shall be combined in the proportions determined during the site trials.

d) Fine and coarse aggregates shall be clean. The grading shall remain within the acceptable range and wherever possible within the target range according to Table 17.1:

**Table 17.1 Target/Acceptable Aggregate Grading**

| BS Sieve Size, mm | Percentage Passing by Weight Acceptable Range, % |
|---|---|
| 10 | 95 - 100 |
| 5 | 67 - 100 |
| 2.36 | 48 - 93 |
| 1.18 | 34 - 77 |
| 0.6 | 22 - 56 |
| 0.3 | 11 - 31 |
| 0.15 | 3 - 15 |
| 0.075 | < 3 |

e) The frequency of testing of the combined aggregate grading shall be at least:

i) As part of the “Shotcrete Trial Submission”

ii) During the work, at any change in the source of the aggregates

iii) During the work, every 200 m2 of sprayed shotcrete.

iv) During the work, in case of shotcrete not reaching the design strength at any age.

17.3.2.5 Admixtures

a) Proposals for admixtures to the shotcrete mix shall be submitted to the Engineer for his acceptance. The performance of the modified mix shall be demonstrated by site trials prior to that mix being used in the Works.

b) Compatibility of all admixtures with each other and with all other shotcrete constituents shall be verified during site trials.

c) Admixtures shall be free of chlorides. In any case the percentage of chlorides shall never exceed 0.1% by weight.

17.3.2.6 Accelerators

a) Only non-alkaline liquid accelerators are permitted to be used and shall comply with SS EN 934-5 with an alkali content not exceeding 1 % by mass of the admixture.

b) Only the minimum quantity of accelerator necessary shall be permitted in normal shotcreting operations. This quantity shall follow the recommendations of the supplier and be determined by trials.

c) Testing of accelerators with regard to strength decrease of the shotcrete at 28 days shall be determined by trials and during the Works.

17.3.2.7 Plasticisers and Retarders

Plasticisers and retarders, when used to reduce the quantity of the mixing water and to improve the pumpability of the shotcrete shall comply with SS EN 934.

17.3.2.8 Metering of Admixtures

Admixtures shall be added to the shotcrete mix mechanically, which shall incorporate a metering device to accurately control the dosages. The metering device shall be built such that unauthorised alteration of the agreed dosage is prevented tamper-proof to prevent unauthorised alteration of the agreed dosage.

17.3.2.9 Fibres

The following types of fibres may be used subject to the acceptance of the Engineer:

a) Steel Fibres

Steel fibres are straight or deformed pieces of cold-drawn steel wire, straight or deformed cut sheet fibres, melt extracted fibres, shaved cold drawn wire fibres and fibres milled from steel blocks which are suitable to be homogeneously mixed into concrete or mortar, and comply with SS EN 14889-1.

b) Polymer Fibres

Polymer fibres can be straight or deformed pieces of extruded orientated and cut material which are suitable to be homogeneously mixed into concrete or mortar and which are not affected over time by the high pH of concrete, and comply with SS EN 14889-2.

**17.3.3 Shotcrete Requirements**

17.3.3.1 General

Shotcrete shall be capable of being applied in layers of up to 150mm - 200mm in thickness with good adhesion to the excavated face or previous layers of shotcrete. The applied shotcrete shall, without sagging, ensure good encasement of reinforcement, steel arches and inserts.

17.3.3.2 Strength

a) Shotcrete grade is defined by the strength of cored samples, 100mm in diameter and 100mm long. For the site trials, the samples shall be taken from cores drilled into test panels in the direction of spraying and perpendicular to the direction of spraying. For the works, tests the samples shall only be taken from cores drilled in the direction of spraying from the actual shotcrete lining placed in the Works.

b) The core strength shall be no less than:

i) Site Trials

| | Grade C25 | Grade 30 | Grade C35 |
|---|---|---|---|
| After 12 hours | 6 $N/mm^2$ | 6 $N/mm^2$ | 6 $N/mm^2$ |
| After 24 hours | 12 $N/mm^2$ | 12 $N/mm^2$ | 12 $N/mm^2$ |
| After 3 days | 18 $N/mm^2$ | 23 $N/mm^2$ | 26 $N/mm^2$ |
| After 7 days | 23 $N/mm^2$ | 28 $N/mm^2$ | 31 $N/mm^2$ |
| After 28 days | 25 $N/mm^2$ | 30 $N/mm^2$ | 35 $N/mm^2$ |

ii) Testing the works

| | Grade C25 | Grade 30 | Grade C35 |
|---|---|---|---|
| After 12 hours | 5 N/mm$^2$ | 5 N/mm$^2$ | 5 N/mm$^2$ |
| After 24 hours | 10 N/mm$^2$ | 10 N/mm$^2$ | 10 N/mm$^2$ |
| After 3 days | 15 N/mm$^2$ | 20 N/mm$^2$ | 23 N/mm$^2$ |
| After 7 days | 20 N/mm$^2$ | 25 N/mm$^2$ | 28 N/mm$^2$ |
| After 28 days | 25 N/mm$^2$ | 30 N/mm$^2$ | 35 N/mm$^2$ |

c) The grade of the concrete without addition of accelerator, expressed as 28 days characteristic cube strength, shall be, as minimum:

| | | | |
|---|---|---|---|
| For Shotcrete grade : | Grade C25 | Grade C30 | Grade C35 |
| Concrete : | Grade C35 | Grade C40 | Grade C45 |

d) The determination of the concrete grade shall also consider the reduction of strength due to the use of the accelerator, tested in accordance with Clause 17.3.2.6

e) The adequacy of the proposed concrete grade shall be verified during trial shotcrete by testing the strength of the concrete without accelerator versus the strength of the shotcrete.

f) Where early strength of the shotcrete (less than 12 hours) is being used in any part of the design of the SCL tunnel, the testing of the early strength must be carried out. The early strength of the shotcrete must achieve the specified design strength

17.3.3.3 Visual Inspection

Shotcrete shall be dense and homogeneous without segregation of aggregates or other visible imperfections.

17.3.3.4 Shotcrete Surface

Shotcrete shall be left as sprayed until it has set. The surface shall not be worked by float or any other means. If a smooth surface is required, the Contractor shall add a finishing coat of shotcrete or apply a floated off mortar layer after the shotcrete has set.

### 17.3.4 Site Trials

17.3.4.1 General

a) Site trials shall be started at least three months before the shotcreting is programmed, to ensure that the required shotcrete mix is developed and all trials and testing completed satisfactorily before shotcreting commences in the Works.

b) Before starting the trials the Contractor shall propose to the Engineer for acceptance a methodology for the development of the shotcrete mix and the tests and trials to be carried out.

c) The site trials shall employ the equipment which will be used in the Works and constituent materials shall be fully representative of those to be used in the Works.

d) Test results shall be presented in a format acceptable to the Engineer.

17.3.4.2 Development of Mix Design

The design of the shotcrete mix shall be developed in four stages.

i) Development of a suitable shotcrete mix without admixtures. Trials may be based on laboratory tests.

ii) Development of a suitable shotcrete mix with admixtures. Trials may be based on laboratory tests.

iii) Spraying test panels using the shotcrete mix (including admixtures) selected to be used in the works.

17.3.4.3 Procedure

a) Sampling and testing procedures shall be in accordance with SS EN 12504. Shotcreting equipment, including all pipelines and hoses, shall be primed with cement grout prior to mixing the first batch.

b) Testing for compressive strength shall be in accordance with SS EN 12504-1. For other laboratory tests, relevant BS or ASTM standards shall be used.

c) During the first two stages of mix development, the laboratory tests shall include as a minimum but not be limited to testing of compressive strength, bulk density and porosity.

d) For the spraying trials an experienced nozzleman shall prepare a sufficient number of test panels. The tests shall be arranged in a manner to simulate shotcrete application to both the tunnel side wall (vertical wall) and to the tunnel crown (overhead).

e) Each test panel shall be 200mm thick and at least 600mm x 600mm for manual spraying and at least 1000mm x 1000mm for robotic spraying. The panels shall be prepared by shotcreting into rigid plywood boxes, which shall be adequately braced and formed from 20mm thick plywood. The sides of the moulds shall be splayed out at least at 45° to allow egress of rebound during shotcreting. The shotcrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging. The time at which each shotcrete panel is completed shall be recorded. The panels shall be stored without disturbance, covered by polythene sheet and shall not be exposed to direct sunlight until the time of coring.

f) Cylindrical test specimens shall be cored from each test panel and tested for compressive strength as listed below. Drilling and dimensions of test specimens shall be in accordance with SS EN 12504-1. All test cores shall be drilled from areas with no rebound. Cores to be tested at different ages may come from the same panel. For each test at least one spare specimen shall be provided. The date and time at which each test is performed shall be recorded.

   i) Along spray direction:

      12-hour compressive strength : minimum 4 tests

      24-hour compressive strength : minimum 4 tests

      28-day compressive strength : minimum 4 tests

   ii) Perpendicular to spray direction

      24-hour compressive strength : minimum 4 tests

      28-day compressive strength : minimum 4 tests

g) The cores for 3 days, 7 days and 28 days compressive strength tests shall be obtained from the panels on the same day. Each cored cylinder shall be marked with a reference mark and the date and time of shotcreting and coring. The cores for 28 days strength tests shall be stored in water in accordance with SS EN 12390-2.

h) The strength of shotcrete cores from test panels shall be acceptable if both the compressive strength results for samples with their axes parallel to the direction of spraying and the compressive strength results for samples with their axes perpendicular to the direction of spraying, comply with the requirements of Clause 17.3.3.2a.

i) The site trials shall be repeated if the source or quality of any of the materials is changed or if the mix proportions are changed.

j) Target workability values shall be determined.

k) Control values for porosity and minimum density shall be established based on the core samples.

### 17.3.5 Production and Transport

17.3.5.1 Batching and Mixing

a) The individual components for the production of shotcrete shall be measured by weight with an automatic batching device, except that liquid admixtures may be measured by volume. The batching accuracy shall be within ±3% for cement, water and aggregates and within ±5% for admixtures.

b) Mixing shall be carried out in a mixer suitable for the efficient mixing and discharge of dry or wet batched materials as appropriate.

c) Regular checks shall be made to ensure that complete mixing is consistently achieved.

d) Shotcrete shall be applied within three hours of mixing. Retarders may be used, with the acceptance of the Engineer, to extend the time for placing.

17.3.5.2 Transport

Shotcrete without accelerator shall be transported by any suitable means which provides complete mixing during transportation such that segregation of the mix components is prevented. The mixture shall be effectively protected against any influence of the weather.

### 17.3.6 Equipment

17.3.6.1 General

a) All transport pipes that carry shotcrete ingredients shall be of uniform diameter laid straight or in gentle curves and protected so that the flow of ingredients through them is not restricted.

b) The shotcrete machine shall be adjusted to suit the length of the pipe that carries the shotcrete mix. Equipment shall be leak-proof. Residual deposits of materials shall be removed after each usage.

c) The air and water supply system shall be capable of supplying the delivery machine and hose at the pressures and volumes recommended by the manufacturer of the machine. No air supply system shall be used that delivers air contaminated by oil.

d) Shotcreting equipment shall be capable of feeding materials at a regular rate and ejecting shotcrete from the nozzle at velocities that will allow adherence of the materials to the surface being shotcreted with a minimum of rebound and maximum adhesion and density.

e) The placing equipment shall be so arranged that the nozzleman may use air and water in any combination to prepare raw surfaces or to clean completed work.

f) Equipment shall be provided to allow application of shotcrete to all surfaces with the nozzle at the distances from the work specified in Clause 17.3.7.1d.

g) A boom mounted or similar device shall be provided for the spray nozzle for use in conditions where manual spraying is unsafe or otherwise unsuitable or undesirable.

h) The equipment shall be set up according to the recommendations of the manufacturer.

i) Pumping shall ensure a continuous conveyance of shotcrete including any admixture except accelerator. The equipment shall incorporate a suitable metering device for liquid admixtures.

### 17.3.7 Application

17.3.7.1 General

a) Before the application of shotcrete, the excavated surfaces shall be cleaned to remove all material which may prevent proper adhesion of the shotcrete to the ground surface. The surface to receive shotcrete shall be damp and but without free water prior to application of shotcrete.

b) Action shall be taken as necessary to control ground water and prevent it adversely affecting the shotcrete lining. Water inflows which might cause deterioration of the shotcrete, or prevent adherence, shall be diverted by channels, chases, pipes or other appropriate means to the invert.

c) Where necessary, pressure relief holes shall be provided through the temporary lining to ensure that no hydrostatic pressure develops behind the lining. Water entering from the pressure relief holes shall be controlled and directed away from the excavated face.

d) Shotcrete shall only be applied by nozzlemen certified in accordance with Clause 17.3.7.3. The distance between the nozzle and the surface being shotcreted shall not exceed 1.5m. The nozzle shall, as a general rule, be held closer and perpendicular to the application surface except as necessary to permit proper encasement of reinforcement and minimise rebound.

e) No rebound material is to be covered with shotcrete. To facilitate this, and depending on ground conditions and the excavation cycle, the shotcrete shall preferably be applied from the shoulder to the crown. For vertical and near vertical surfaces application shall commence at the bottom. Layer thickness shall be governed mainly by the requirement that the material shall not sag. The rebound material shall be removed from the tunnel and shall not be used in the Works.

f) Each layer of shotcrete shall be built up by making several passes of the nozzle over the working area. The shotcrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause the nozzleman shall direct it away from the work until the flow becomes steady and uninterrupted.

g) Where a layer of shotcrete is to be covered by succeeding layers, it shall first be allowed to set and loose material and rebound shall be removed. The surface shall be finally cleaned and wetted using a blast of air and water.

h) All joints shall be carefully cleaned of all rebound and loose material using a combination of air and water. Particular attention shall be given to cleanliness and preparation of all invert joints.

i) Where two layers of reinforcement are used, the far layer shall be covered by shotcrete before the near layer is installed. The near layer shall be covered by shotcrete up to the required thickness with minimum delay.

17.3.7.2 Shotcrete Thickness and Cover

The minimum thickness of shotcrete shall be in accordance with the Drawings.

To provide a means of determining the thickness of shotcrete applied, at least one thickness marker shall be installed for every 1.5m$^2$ of area shotcreted. Steel arches, wire mesh and other reinforcement shall have at least 30mm of shotcrete cover unless otherwise accepted by the Engineer.

17.3.7.3 Proficiency of Nozzlemen

Shotcrete shall be applied only by nozzlemen, who have successfully demonstrated their competence and their ability to produce shotcrete complying in all respects with this Specification and shall hold certificates of competence issued by the Contractor and accepted by the Engineer.

### 17.3.8 Testing of the Works

17.3.8.1 General

a) During the execution of SCL works, both strength tests and stiffness tests shall be carried out on shotcrete core samples based on procedures described below.

b) Concrete cubes’ sampling & testing is required for every shotcrete strength test. Cubes shall be tested at 3 days, 7 days, 28 days and the difference in final strength between shotcrete and concrete shall be within the criteria specified in Clause 17.3.3.2.

c) Test results shall be presented in a format acceptable to the Engineer.

d) Based on the results of the stiffness and strength tests, the designer of the particular SCL structure shall assess the actual stability of the SCL structure compared to the design assumptions.

e) If the stability of the SCL tunnel is endangered because shotcrete does not meet the specified requirements considered in the SCL design, the affected shotcrete shall be repaired or replaced carefully or where practicable the deficiencies made good by application of additional shotcrete layers. Applied methods and working sequences shall be identified on a CRESS and shall be acceptable to the Engineer.

17.3.8.2 Strength Tests

a) Compressive strength tests shall be carried out on cores taken from shotcrete in the Works in accordance with SS EN 12504-1. The locations where the samples shall be taken (chainage and side wall, crown or invert) shall be agreed with the Engineer. The Contractor's attention is drawn to the fact that the Engineer will require samples taken from the crown and the invert.

b) The time of coring shall be as close as possible to 12 and 24 hours after placing. Cores required for 3, 7 and 28 day strength tests shall be obtained at the same time as those for 1 day tests and stored in the laboratory in accordance with SS EN 12390-2.

c) In the event that the required strength is achieved prior to the 28 days, the Contractor shall still conduct testing at 28 days to verify that the 28 day strengths are being achieved.

d) The frequency of coring shall be such as to obtain 3 cores each for 12, 24 hours and 3, 7 and 28 day tests for at least every 5 linear metres of tunnel. Depending on the compliance of test results with this Specification, circumstances of application and importance of construction, the frequency of work tests may be reduced or increased, subject to the agreement of the Engineer. The cores shall be drilled through the whole thickness of the shotcrete and visually inspected to verify that the shotcrete is dense and homogeneous without segregation of aggregate or other visible imperfections.

e) Tests for 12 and 24 hours strength shall be carried out at 12 hours ± 1 hour and 24 hours ±2 hours respectively.

f) Strength testing of cores taken from separately sprayed test panels instead of from the actual shotcrete lining placed in the works shall be subject to the acceptance of the SCL Designer and QP(S). Strength testing of cores taken from test panels shall only be allowed after sufficient core tests from the actual shotcrete lining have proven that the intermediate strengths are being consistently achieved. The strength requirements shall follow the ones specified in Clause 17.3.3.2 b.i). If any intermediate strength from a test panel fails to achieve the required strength, the subsequent tests shall be done from in situ cores sampled in the tunnel location where the same shotcrete delivery have been used. 28 day strength testing shall not be allowed from cores taken from test panels but shall be from cores taken from the actual shotcrete lining placed in the Works.

g) The Contractor may propose indirect testing methods such as penetration and pull out test methods to determine the early strength of shotcrete, in conjunction with coring tests. Testing methods shall be submitted to the Engineer for acceptance. Additional test panels shall be prepared underground to calibrate the indirect method to the direct method. Mechanical rebound hammers shall not be used to obtain indirect compressive strength of shotcrete.

h) Where the nominal shotcrete thickness is considered too small to achieve a core of sufficient length, the cores samples shall be taken from designated areas, where the actual shotcrete thickness has been locally increased for subsequent test coring as directed by the Engineer.

i) Test results shall comply with SS EN 14487-1.

j) If the shotcrete fails to meet the Specification, the validity of the test results shall be assessed prior to implementing remedial action acceptable to the Engineer.

17.3.8.3 Stiffness Tests

a) These tests shall be carried out to assess the stiffness behaviour of shotcrete in the Works under site conditions. The tests shall produce the modulus of elasticity of shotcrete samples and shall be carried out in accordance with the test procedure described in clauses below.

b) At least 2 sets of stiffness tests shall be carried out for every 50 linear metres of tunnel advanced, or 1000m$^2$ of sprayed surface, whichever criteria is first achieved. One set of stiffness tests consists of a series of test carried out after 1, 3, 7 and 28 days, carried out on 3 cores. The locations where the samples shall be taken from (chainage and side wall, crown or invert) shall be agreed with the Engineer. The Contractor’s attention is drawn to the fact that the Engineer may require samples also taken from the crown and the invert.

c) The tests shall be carried out on cores taken from shotcrete produced in the Works in accordance with SS EN 12504-1. The cores shall be 100 mm in diameter and 200 mm long. Where the nominal shotcrete thickness is considered too small to achieve a core of sufficient length, the cores samples may be taken from designated areas, where the actual shotcrete thickness has been locally increased for subsequent test coring as directed by the Engineer. Alternatively, the contractor may propose to take the samples from test panels produced in the Works under site conditions at the point of current shotcrete application underground. The panels shall be stored underground in the Works (with the same climatic conditions as the shotcrete placed in situ). Core samples shall be taken from the panels just before testing, and shall be tested on the same day.

d) The modulus of elasticity shall be determined in a non-destructive manner as described below on the same core sample after 1, 3, 7, 28 days on 3 cores. After the 28 days test, the samples shall be tested for its compressive strengths.

e) The test procedure shall be as follows:

   i) Axial strain shall be measured on the central part of the sample.

   ii) The modulus of elasticity at different shotcrete ages shall be determined by three loading-unloading cycles. The upper load test limit shall be ⅓ and the lower test limit shall be 1/30 of the respective compressive strength.

   iii) The modulus of elasticity is defined as the ratio of stress-difference over strain-difference relative to the upper and lower test load limit.

17.3.8.4 Workability Tests Report

a) The workability of shotcrete shall be measured by slump tests in accordance with SS EN 12350-2 after the addition of plasticiser. Samples shall be tested for every mix produced.

b) At least one test shall be taken at the arrival time of the shotcrete on site and every 30 minutes until the application of the shotcrete

c) The workability shall be within ±25mm.

d) If the Contractor intends to use a mix design with the addition of a retarder to retain the workability for a certain time, a retardation / slump retention test shall be submitted to the Engineer. The test report shall include the following:

   i) Reference to the specific mix design

   ii) Concrete grade

   iii) Target 28 days shotcrete strength

   iv) Target retardation time, including range of acceptable slump (within the criteria specified in this Chapter)

   v) Water/Cement ratio

   vi) Summary of batch weight, including additives

   vii) Time, slump & temperature at the batching plant

   viii) Time, slump & temperature at arrival on site

   ix) Time, slump & temperature at every hour for a total covering the target retardation time

   Once approved by the Engineer, the test during the work shall be in accordance with Clause 17.3.8.4b.

e) If the sump value is out of the allowable range, the shotcrete shall be rejected.

17.3.8.5 Thickness Tests

(a) The thickness of placed shotcrete shall be checked by drilling small holes to determine the ground/shotcrete interface. These tests shall be performed at least every 5 linear metres of tunnel advance or $100m^2$ of sprayed surface, whichever criteria is first achieved but not less than one test for each SCL work location. The number and positions of measurement locations shall be as agreed with the Engineer.

(b) At each measurement location 4 holes shall be drilled, one in each corner of one metre square, and the 4 holes shall show a shotcrete thickness equal to or greater than the required minimum thickness shown on the Drawings.

**17.3.9 Health and Safety**

17.3.9.1 General

The requirements of General Specification Appendix O shall apply.

17.3.9.2 Access

a) To apply shotcrete in accordance with the requirements of Clause 17.3.7, it may be necessary for the nozzleman to stand at an elevated position. For this purpose the contractor shall use a working platform, scaffolding or similar, to the acceptance of QP(S).

b) Access to the area of shotcrete application shall be restricted while equipment is operating. All personnel, other than the nozzleman, shall work at a safe distance from the spraying operations in a safe working environment.

17.3.9.3 Dust Level and Ventilation

Silica levels in dust produced by the shotcrete process shall be monitored. The Occupational Exposure Level (OEL) limit value shall be less than $5mg/m^3$, and is expressed as:

$$OEL = 10 / (S+2) \quad mg/m^3$$

Where S is the percentage of respirable crystalline silica.

Adequate ventilation shall be provided by the Contractor and shall be acceptable to the Engineer.

17.3.9.4 Care of Substances Hazardous to Health

All components of shotcrete which are potentially hazardous shall be marked, stored and used in accordance with Workplace Safety and Health Act and the Regulations.

17.3.9.5 Personal Protective Equipment

Nozzlemen shall have full protective clothing and use respirators, ear defenders and eye protection as required. Any skin likely to be exposed during the work shall be protected with a barrier cream.

17.3.9.6 Illumination

Adequate illumination shall be provided in the area where shotcrete is placed. A minimum lighting intensity shall be agreed with the Engineer.

17.3.9.7 Communications

Good communications between the nozzleman and pump operator shall be maintained at all times during the shotcrete process. The Contractor shall provide details in his Method Statement of how communications are established.

17.3.9.8 Overhead Shotcrete

Freshly applied overhead shotcrete should be considered as a safety hazard. Until the shotcrete hardens the potential of breakouts of shotcrete placed in the roof of the tunnel exists. Therefore access to the shotcreted area for unauthorised personnel shall be prevented by controlling entry to this area of the tunnel.

## 17.4 OTHER TEMPORARY SUPPORT

### 17.4.1 Rock bolts and Soil nails

17.4.1.1 Types

a) Ordinary Rock Bolt

This type of rock bolt is an untensioned rod inserted into a drilled hole and grouted along its entire length using cement grout. The rock bolt consists of a high yield steel deformed ribbed bar with cut or rolled threads at one end, a faceplate, shim plates and a nut.

b) Pre-stressed Rock Bolt

This type of rock bolt is a tensioned rod inserted into a drilled hole and grouted at the far end over a defined anchor length by quick setting resin grout or similar. The rock bolt consists of a high yield steel deformed ribbed bar with cut or rolled threads at one end, a faceplate, shim plates and a nut. After the resin grout has gained sufficient strength, the nut is tightened to achieve a defined pre-stressing force in the rod. The rod shall be grouted along its entire remaining length using cement grout before the permanent lining is placed.

c) Injected Bored Rock Bolt (IBO Rock Bolt or similar)

The IBO rock bolt is used in situations where it is difficult to keep the drill hole open sufficiently long to install a regular fully grouted rock bolt. The IBO rock bolt consists of a perforated tube, which is left in place as a sacrificial drilling rod and which is subsequently grouted.

d) Expandable Type Rock Bolt

This type of rock bolt is manufactured from a mechanically reshaped steel tube. Bushings are pressed onto the ends, which are sealed through welding. The lower bushing has a flange to hold a faceplate in place. High pressure water is injected into the steel tube through a hole in the lower bushing. This causes the steel tube to expand and to deform it against the irregularities in the drilled hole. A sleeve tube made of steel prevents the rock bolt from swelling at the borehole collar. The drillhole diameter has to be adjusted to suit the size of the rock bolt.

e) Cement grouted Fibreglass Soil Nails

This type of soil nail is an untensioned rod made from fibreglass bonded together by resin. One end of the rod is cut at 45° angle to provide a bevelled end and the other end is threaded to receive a nut. A fibreglass face plate and a fibre/resin nut of proprietary manufacture completes the assembly. The surface of the bonded fibres is left to provide a rough surface to improve bond with grout. Soil nails are usually used to strengthen excavated faces where subsequent tunnelling work is to be carried out or to provide temporary support to an excavation face during stoppages. Steel faceplates and steel nuts may be used with fibreglass soil nails but these shall be removed before excavation is resumed.

17.4.1.2 Materials

a) Cement shall be Ordinary Portland or Rapid Hardening Portland cement complying with SS EN 197-1, and the requirements of Chapter 11 Concrete and Reinforcement.

b) Cement grout shall have a water cement ratio of 0.3 to 0.35 and shall achieve a characteristic strength of at least 10N/mm$^2$ at 2 days and 30 N/mm$^2$ at 28 days when tested on mortar cubes in accordance with SS EN 196. Rock bolts grouted with cement grout shall be capable of sustaining a pullout force of 60% of the working load 12 hours after grouting. This shall be determined by site trials prior to work commencing.

c) Other admixtures including plasticisers or expanding agents shall conform to BS 5075 and shall be used only with the Engineer's agreement. The admixtures used shall have no detrimental effect on the performance of the rock bolts. Admixtures containing chlorides shall not be used.

d) Resin based grouts shall be tested in accordance with BS 6319. Full details of the resin based grout, intended to be used, shall be agreed with the Engineer.

e) Faceplates shall be of dished shape in steel to comply with BS EN 10025 with a minimum characteristic strength of 275 N/mm$^2$ and shall have hemispherical seating and a centralised slot to suit the dimensions of the different rock bolts. The dimensions of the faceplates shall be typically 150mm x 150mm x 8mm thick.

f) Bolts, nuts and seatings shall comply with the requirements of BS 4190.

g) Steel bars shall be complying with BS 4449 with a minimum characteristic strength of 500 N/mm$^2$.

h) Fibreglass soil nails shall be made from polyester resin reinforced with glass fibres in continuous strands. The glass strands shall form 65% to 75% of the weight of the soil nails. Faceplates made from fibreglass shall have a minimum diameter of 130mm.

17.4.1.3 Drilling and Installation

a) The exact locations of rock bolts shall be adapted to suit the prevailing geological conditions. When necessary to ensure the safety of the Works, rock bolts shall be installed immediately behind the face. The detailed procedures to be adopted for the installation of the rock bolts shall be in accordance with the agreed Method Statement.

b) Holes shall be drilled with an accuracy of ±10° with regard to the direction defined.

c) Drillhole diameter shall be within the range recommended by the rock bolt manufacturers to match the particular rock bolt diameter and any couplers required for extending the rock bolts.

d) Holes shall be drilled using sharp bits to produce straight holes of the required length. On completion of each drillhole and prior to the installation of each rock bolt, drillholes shall be cleaned to remove debris.

e) Installation shall be made in accordance with the rock bolt manufacturer’s recommendations and generally as follows:

    i) Some preparation of the shotcrete surface at the drillhole or rock bolt location may be necessary, involving trimming local surface irregularities or forming pads of quick setting mortar. Where mortar pads are required, they shall be larger than the faceplates and the edges shall be chamfered at 45°. Care shall be taken to ensure the mortar does not interfere with the installed rock bolt. Faceplates shall be tightly bolted against the surface using hand wrenches.

ii) The grouting material shall be injected starting from the furthest end of the drilled hole such that the rock bolt rod is completely encased in grout. The open ends of holes shall be sealed to prevent grout loss. Any grout on the exposed threads of the rock bolts shall be cleaned off.

iii) Rock bolts installed in overhead positions shall be supported where necessary until the grout has set.

17.4.1.4 Testing of Materials

a) Sets of six cubes of cement grout shall be taken for every 50 bolts installed. Sampling, preparation, curing and testing shall be in accordance with EN196.

The strength determined from any single test result shall be not less than the specified characteristic strength by more than:

1 N/mm2 for cement grout tested after 1 day

3 N/mm$^2$ for cement grout tested after 28 days

b) Tensile tests shall be carried out on proportions of steel rock bolt bars containing the threaded length from each batch of bars generally in accordance with BS 4449 and SS EN ISO 6892. At least three bars in every 1000 shall be tested to failure. Tests may be carried out at the manufacturer's works or on Site. Test certificates shall be provided.

c) At least one in every 100 fibreglass soil nails with a minimum of 3 from every batch delivered to Site shall be tested to failure. Batches of fibreglass rods, which fail at loads less than 1.5 times the working load shall be rejected.

17.4.1.5 Trials and Testing of Rock Bolts and Soil Nails

a) Prior to commencement of installation of rock bolts, 5 trial rock bolts of each type to be used in the Works shall be installed and tested. Two of the trial rock bolts shall be tested at 60% of the working load after 12 hours and the remaining tested at working load between 3 and 21 days after installation. Trial rock bolts shall be installed in similar ground conditions to those which are likely to be encountered during installation in the Works and shall be in accordance with the Specification.

b) 2% of the rock bolts installed in the Works shall be load tested to 60% of the working load, 12 hours after grouting. 5% of the installed rock bolts shall be tested to working load between 3 and 21 days after installation. Rock bolts, which fail the tests, shall be replaced.

c) The in-situ tests shall be carried out in accordance with the method for determining the strength of a rock bolt given in International Society for Rock Mechanics (ISRM) Suggested Methods for Rock Characterisation Testing and Monitoring: The specified test loads shall be applied and then released at the end of the tests.

d) The in-situ load tests shall be carried out to the working load and this load sustained for at least 10 minutes.

17.4.1.6 Records

Records shall be kept for each rock bolt installed and copies of all records shall be maintained on site after installation of the rock bolt or completion of testing, as appropriate.

### 17.4.2 Forepoling / Pipe Roof

17.4.2.1 Forepoling

a) Forepoling is a general term for the insertion of ground supports outside and ahead of the excavated tunnel face by the installation of linear type ground reinforcement at intervals around the crown.

   Treatment may include the following:

   - Ungrouted forepoling
   - Grouted forepoling inserted into a drilled hole and grouted along their entire length using cement grout.
   - Interlocking steel sheets driven to form an arch ahead of the tunnel face.

b) Forepoling shall consist of high yield steel deformed bars or steel tubes in accordance with BS 4449 or BS 4461 and of diameter not less than 25mm.

c) Where interlocking steel sheets are required for forepoling, they shall comply with BS EN 10025 with a minimum characteristic strength of 275 $N/mm^2$.

d) Grout used for grouting forepoling shall be in accordance with Clause 17.4.1.2.b and Clause 17.4.1.4.a.

e) Forepoling shall be used wherever ground conditions require roof support to allow excavation to proceed in a safe environment. Forepoling may also be installed locally in a specific portion of the tunnel crown or shoulders requiring additional ground supports during excavation.

f) Forepoling shall be used in conjunction with lattice girders or steel arches. The forepoling shall be driven above the arch or through the lattice girder closest to the excavation face and embedded into the shotcrete.

g) The length and type of forepoling shall be selected to suit the ground conditions and the expected length of advance. Typically, the length of forepoling shall be at least twice the excavation advance.

h) Typical spacing of the forepoling is between 250 and 500 mm around the crown. The actual spacing used shall be selected to suit the ground conditions, and shall be to the satisfaction of the Engineer.

i) Injected grout shall have achieved initial set before advancing the excavation.

17.4.2.2 Pipe Roofing

a) Pipe roofing refers to steel pipes forming a canopy above the tunnel's unsupported span and extending ahead of the face. Pipe roofing shall consist of steel pipes with an external diameter of at least 114 mm and a minimum wall thickness of 4.5mm. The annular gap between borehole and steel pipe shall be grouted.

b) Pipe roofing shall be used wherever ground conditions require roof support to allow excavation to proceed in a safe environment.

c) The length and type of pipe roof shall be selected to suit the ground conditions and the expected length of advance. The minimum lapping length shall be 3m or longer as specified by the SCL Designer.

d) The typical spacing of the pipe is 200mm to 400 mm on a 120 degree arc of the tunnel crown. The actual spacing used shall be selected to suit the ground conditions, and shall be to the acceptance of the Engineer.

e) In unstable ground, closer spacing together with ground treatment of the areas between the pipes shall be provided. Injected grout shall have achieved initial set before advancing the excavation.

17.4.2.3 Large Diameter Steel Pipe Pre-Support

a) This method refers to a series of contiguous large diameter steel pipes (typically over 400mm), installed by pipe jacking/micro tunnelling methods in advance of the tunnel excavation.

b) The method of installation shall allow control over the induced volume losses in order to prevent excessive settlements during the pipe jacking. Any annulus shall be supported with bentonite or similar during installation with a suitable seal provided for this purpose.

c) Grouting of the annular gap between borehole and steel pipe shall be done in order to minimize potential settlements. Grouting method and sequence shall be submitted to the Engineer for acceptance.

d) In case of loose and/or permeable ground with possibility of water seepage between contiguous pipes, one or a combination of the following measures shall be carried out:

   i) Pre-treatment of the ground

   ii) Use of interlocking pipes and provision of grouting along the longitudinal joints.

   iii) Provision of grouting valve along the pipes for treatment after pipes installation.

   Any shotcrete used as full or partial support in conjunction with this method shall comply with the requirements stated in this Chapter.

### 17.4.3 Support Arches

17.4.3.1 General

a) Support arches may be installed to maintain the designed shape of the excavation and to provide an immediate support at the working face and over the length of the previous excavation step.

Where support arches are not used the Contractor must propose other measures to ensure that the designed shape of the excavation is maintained.

b) Support arches may be formed by a rolled steel sections or by lattice girders. The size (depth) of the steel arch shall be chosen to fit to a particular shotcrete thickness and profile.

c) The profile / shape of the support arches shall be checked on a template marked out on the ground surface prior to installation.

17.4.3.2 Materials

a) Material for steel sections shall be in accordance with BS 4449 or BS 4461. All steel shall have a minimum characteristic strength of 500 $N/mm^2$ and shall be of 'weldable classification'.

b) Material for lattice girders shall comply with BS 4449, BS EN 10025 with a minimum characteristic strength of 500 $N/mm^2$.

c) Test certificates shall be obtained from the supplier confirming compliance with the appropriate Standards.

d) All steel arches prior to being encased in shotcrete shall be free from rust, oil, paint, concrete retarders, loose rust, loose mill scale, grease or any other deleterious substances.

17.4.3.3 Fabrication and Erection

Fully detailed fabrication drawings and specifications for all components of the steel arches shall be prepared. Manufacture shall be in accordance with these drawings and specifications.

17.4.3.4 Welding

All welding shall be carried out in accordance with SS EN 1011.

17.4.3.5 Connections

a) All connections shall be capable of resisting the sectional bending moments, axial forces (tension and compression) and shear forces for each stage of excavation.

b) The connections shall be designed to allow complete cover with shotcrete, so that no voids are created behind the connections.

17.4.3.6 Tolerances

a) Arches shall not deviate from the design shape by more than ±25mm.

b) The length of a complete arch shall not deviate from the design length by more than ±25mm.

c) The erected arches shall not depart from their design position by more than 50mm.

d) The arches shall be erected within ±100mm of the design centres as detailed in the agreed Method Statement.

### 17.4.4 Reinforcement

17.4.4.1 General

The reinforcement mesh shall be cleaned of any previously deposited material, which might prevent a proper bond. The standard mesh grid shall be 100mm x 100mm made up of 6 to 8mm diameter steel bars.

If not specified otherwise on the design drawings the overlap of wire mesh shall be two pitches.

17.4.4.2 Fixing

Reinforcement mesh shall be securely fixed in place and pinned as tight as possible to the previous layer of shotcrete to prevent vibration and movement during spraying. Ties, anchors and supports for the mesh shall be made of steel and suitable spacers shall be provided where necessary. Timber packings shall not be used. The method of fixing the mesh shall be such that shotcrete can be compacted soundly behind the reinforcement at all points. Laps shall be a minimum of two pitches except for the outer layer of mesh in the longitudinal direction where the overlap can be one pitch when supplemented by starter bars. Additional fixings shall be installed as necessary to fit the mesh to the excavation profile.

## 17.5 CAST IN-SITU CONCRETE LININGS

### 17.5.1 General

17.5.1.1 At least two months before the commencement of the permanent lining works, the Contractor shall submit to the Engineer for his acceptance a detailed method statement for the following:

i) Waterproofing system and installation

ii) Reinforcement details

iii) Formwork design

iv) Concreting procedure

v) Method of vibrating concrete during placement

vi) Concrete Curing

vii) Repair of Defects

17.5.1.2 Concrete and additives shall suit the special requirements for placing in a tunnel environment, but shall otherwise comply with Chapter 11 Concrete and Reinforcement.

17.5.1.3 Reinforcement shall comply in all respects with Chapter 11 Concrete and Reinforcement

### 17.5.2 Formwork

17.5.2.1 Formwork shall comply with Chapter 11 Concrete and Reinforcement.

17.5.2.2 Effective devices shall be used to hold adjacent edges or ends of formwork tightly together and in accurate alignment and in all cases to hold the formwork tightly against the concrete, which has been placed previously.

17.5.2.3 Wherever it is necessary to position grout or other pipes through the forms, the Contractor shall drill holes through the forms at the required positions shown on the Drawings. Where the holes are to be provided for embedded grout pipes to a regular pattern, the holes shall be reinforced by suitable threaded bosses with flush fitting plugs. Where the holes are provided for a single pour they shall subsequently be filled flush to the face of the form before re-use.

17.5.2.4 Formwork shall be provided with openings for concreting spaced at not more than 2.5m centres longitudinally in each side wall and in the crown. They shall be located at the spring line of the tunnel, in side walls, and alternately on each side of the tunnel centre-line in the crown. The openings shall be fitted with hinged doors, which fit flush with outer surface of the framework when closed. The dimensions of openings shall be approximately 0.6m wide x 0.4m high.

17.5.2.5 The formwork shall be maintained at all times in good condition to maintain accuracy of shape, strength, rigidity, watertightness and smoothness of surface. The Contractor shall keep all formwork clean and in good repair and shall supply and apply approved release agents to facilitate stripping.

17.5.2.6 No part of any metal tie or spacer or pipe remaining permanently embedded in the concrete shall be nearer than 50mm to the finished surface of the concrete and the face cavity shall be so formed as to permit satisfactory filling.

17.5.2.7 The Contractor shall carry out all corrective measures required by the Engineer to rectify work not constructed within tolerance. Where the tunnel is curved in plan or elevation the lining may be formed in a series of chords provided the minimum thickness of lining is maintained and tolerances on the position of the finished surface are not infringed.

**17.5.3 Preparations for placing concrete**

17.5.3.1 The surfaces of the tunnel excavation or of previously placed concrete shall be thoroughly cleaned to remove all loose and foreign materials. Rock and concrete surfaces shall be cleaned by washing with a strong stream of air and water under pressure. Concrete and grout spillage from previous pours shall be broken out and removed. Reinforcement shall be cleaned of loose rust, mill scale and concrete spillage by the use of suitable steel wire brushes.

17.5.3.2 Formwork shall be cleaned and freshly coated with a release agent immediately prior to concreting.

17.5.3.3 Concrete shall not be placed in still or running water and shall not be subjected to the action of running water until after the concrete has hardened. Where water flows from surfaces against which the concrete is to be placed, it shall be excluded from the space to be filled with concrete by caulking, diverted by pipes or other means and pumped from sumps until the concrete has hardened sufficiently to be unaffected by the action of water.

**17.5.4 Concrete placing equipment**

Concrete shall be placed by pumping equipment of suitable types with adequate placing capacity. Pumping equipment, storage hoppers, and delivery pipelines shall be lubricated at the start of each concreting operation and shall be thoroughly cleaned at the end of the operation.

**17.5.5 Placing of concrete**

17.5.5.1 Concrete shall be transported from the mixer to the formwork as rapidly as practicable by methods which will prevent the segregation or loss of any of the ingredients and maintain the workability.

17.5.5.2 Concrete shall be placed as close as possible to its final position and in continuous near level layers between construction joints located as approved or shown on the Drawings. The depth of the layers shall not exceed 500mm and each layer shall be compacted using mechanical vibrators specified below before succeeding layers are placed.

17.5.5.3 Concrete placed in the tunnel arch shall be built up over the discharge line on the crown of the formwork, the end of the discharge line being kept well buried as the concreting advances. Care shall be taken to force concrete into all irregularities in the rock surfaces, or the surface of sprayed concrete temporary support and to fill completely the tunnel arch. All voids and spaces around the posts, ribs and wall plates of temporary support shall be filled as completely as practicable. Where concrete is placed against a waterproofing membrane, particular care shall be taken to avoid penetration of the membrane during the concrete placing operations. Cavities in the arch which, due to high overbreak, are above the general level of the crown of the tunnel shall be filled by subsequent cavity grouting, and adequate grout and vent pipes shall be embedded in the concrete.

17.5.5.4 In the event of equipment breakdown or if for any other reason placing is interrupted, the Contractor shall thoroughly compact the concrete to a reasonable level or flat slope while the concrete is plastic. The concrete at the surface of such cold joints shall be cleaned with a high pressure air and water jet before the concrete hardens, to provide an irregular clean surface free from laitance. Prior to restarting concreting, the surface shall be wetted and roughened. Planned cold joints in permanent linings shall not be permitted. The work shall be so carried out that a sound dense lining is produced, admitting water only at the temporary drainage channels provided.

### 17.5.6 Compaction of concrete

17.5.6.1 Concrete shall be compacted by mechanical vibrators producing not less than 3600 vibrations per minute. Immersion type vibrators shall generally be used through special windows in the formwork, supplemented, where necessary, by approved heavy duty formwork vibrators.

17.5.6.2 Where immersion vibrators are used, one vibrator shall be provided for every 6 cubic metres per hour of concrete to be compacted. Immersion vibrators shall be, wherever practicable, operated in a near vertical position, and the vibrating head shall penetrate and revibrate concrete in the upper portion of the underlying layer. They shall be withdrawn slowly to avoid the formation of voids and shall be carefully positioned to avoid contact of the vibrating head with the formwork.

17.5.6.3 Particular care shall be taken with the compaction of concrete surrounding water bars to avoid honeycombing and to prevent the displacement of the water bar. Care shall also be taken to avoid damage to waterproof membranes and displacement of prefixed pipes, blockouts, bolts and the like.

17.5.6.4 Formwork vibrators shall be used for compacting concrete in the tunnel arch above the highest openings in the formwork. They shall be operated at intervals of not more than 1.2m behind the advancing slope of the concrete in the shoulders and crown of the arch. The location and operation of the vibrators shall be carefully co-ordinated with the withdrawal of the discharge line so as to avoid settlement and flow of the concrete from the filled crown due to improperly positioned and timed vibration.

### 17.5.7 Curing of concrete

All in-situ tunnel concrete shall be cured by either moist curing, or membrane curing. Curing shall be maintained for a period of 4 days from the time of placing.

### 17.5.8 Surface finishes

The surface finishes to arch and walls shall be Class F2 as per Chapter 11 Concrete and Reinforcement.

### 17.5.9 Concrete replacement and repair

The Contractor shall submit his detailed method statement and procedures for concrete replacement and repair to the Engineer for acceptance prior to the implementation on site.

### 17.5.10 Grouting of cast in-situ concrete linings

17.5.10.1 At least 14 days after concreting, the lining shall be grouted at the lowest pressure necessary to fill any remaining voids behind the lining.

17.5.10.2 Sufficient grouting and vent pipes shall be put into position prior to concreting.

## 17.6 WATERPROOFING SYSTEM

### 17.6.1 General

17.6.1.1 Scope

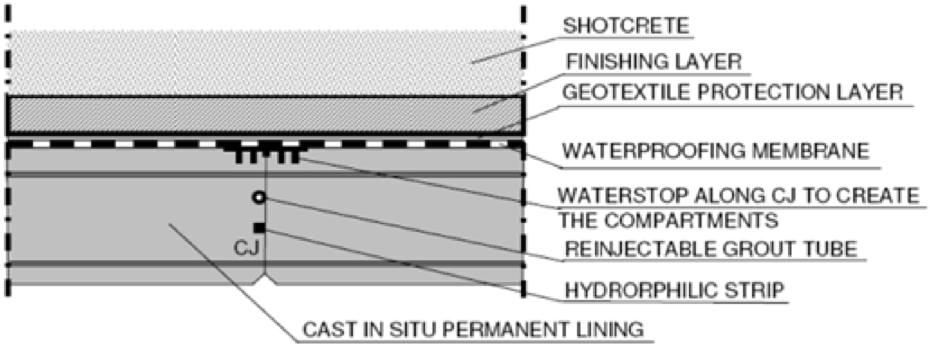
This section covers the waterproofing for all SCL structures by means of a continuous waterproofing membrane installed to the outside of the secondary concrete lining. Concrete with either waterproofing admixture or silica fume shall be used for the cast in-situ lining. The relevant requirements in Chapter 11 and Chapter 14 shall be complied with.

17.6.1.2 Description

a) The waterproofing shall be applied to the full circumference as shown on the Drawings. The waterproofing membrane shall always be located between shotcrete support and the permanent concrete lining.

b) The waterproofing system shall consist of two layers: the first layer shall be a protective geotextile fleece fastened to the shotcrete surface; the second layer shall be the actual waterproofing membrane fixed securely in accordance with the manufacturer's specifications and recommendations.

c) The membrane shall be compartmentalized in order to confine water propagation between the membrane and the cast in situ concrete. Each compartment shall be provided with injection and relief points. Compartmentalization shall be done with the installation of longitudinal and transverse waterstops along the construction joints. Waterstop shall be fully embedded in the concrete in order to assure proper watertightness among each compartment. A minimum of 2 webs on either side of the construction joint shall be provided. A typical construction joint detail is shown in the figure below.




TYPICAL CONSTRUCTION JOINT DETAIL

17.6.1.3 Submissions by the Contractor

The following information shall be furnished to the Engineer for acceptance in accordance with the Contract requirements:

a) Comprehensive and detailed Method Statement describing the installation of the waterproofing membrane including the equipment used for welding, testing of welding seams, and appropriate day-to-day procedures to ensure the quality of welding seams, and detailed repairing procedure.

b) Certificates of compliance and test results/reports attesting that the materials meet specification requirements.

c) Manufacturer's instructions for installation of fleece and water-proofing membrane, including procedures for preparation, fixing, welding and splicing, flashing etc.

d) Manufacturer's and installer's qualifications to include evidence of experience of the manufacturer and the installers, as well as resume of supervisors for the waterproofing system installation.

e) Samples as listed hereafter:

   i) Membrane: One square metre of each type of membrane.

   ii) Fleece: One square metre of each type of fleece.

   iii) Welded splice: 1 m of welded membrane splice for each type of membrane.

   iv) Fixings and fittings: 10 samples from different lots of roundels and shotnails, 2 samples of sealing flanges for each type of pipes passing through the membrane.

f) Shop Drawings showing all necessary installation details for fleece and waterproofing membrane, including installation sequence, position of joints, treatment of projections, connection to waterstops, local reinforcements etc.

17.6.1.4 Quality Assurance

a) Only suitable products shall be supplied and installed, which are designed and manufactured specifically for application in underground structures under conditions similar to those encountered on this Project and which show an acceptable performance.

b) The proposed product shall have a track record of being successfully applied on at least five recent projects of comparable nature.

c) The manufacturer's representative shall be present at least during the first 10 working days of installation and later as often as required by the Engineer.

d) The subcontractor for the erection of the waterproofing system shall be BCA registered contractor for waterproofing installation. The proposed subcontractor shall be subjected to acceptance of the Engineer.

e) All installation and testing shall be carried out under the direct supervision of an individual with recent, continuous, experience in the installation of waterproofing systems for underground structures.

f) All personnel involved in installation and testing of the waterproofing system shall be provided with adequate training prior to the beginning of the waterproofing works.

g) Installation records shall be submitted to the Engineer for acceptance with all relevant data for all seam checks etc. These records shall form part of the submission to obtain acceptance to proceed with the installation of the concrete lining.

### 17.6.2 Materials

17.6.2.1 General

The proposed proprietary materials shall be submitted to the Engineer for acceptance.

17.6.2.2 Fleece

The fleece shall be a continuous filament non-woven textile poly-propylene (geotextile) of uniform thickness and surface texture meeting the requirements listed in Table 17.2.

**Table 17.2: The Required Properties of Fleece**

| Property | Specified Value | Standard |
|---|---|---|
| Unit weight | $500g/m^2$ min | DIN 3854 |
| Thickness at 0.02 bar | 3.9 mm min | SS EN ISO 9073-2 |
| Thickness at 2.0 bar | 1.9 mm min | SS EN ISO 9073-2 |
| Tensile strength | 1000 N/5cm min | DIN EN ISO 13934 |
| Extension at break | 70 % min | DIN EN ISO 13934 |
| Extension at 30% of tensile strength | 20 % min | DIN EN ISO 13934 |
| Permeability in plane: | | |
| at 0.02 bar | $5x10^{-1}$ cm/s min | * |
| at 2.00 bar | $5x10^{-2}$ cm/s min | * |
| Resistance against acid and alkaline solutions, pH 2-13 | Loss of strength 10% max. | SN 640 550<br>DIN EN ISO 13934 |
| Resistance to Punching | 2000 N | SS EN ISO 12236 |

17.6.2.3 Waterproofing Membrane

a) The waterproofing membrane shall consist of an impermeable heat welded sheet of one of the following materials:

i) High-density polyethylene (HDPE) in accordance with SS EN ISO 1872-1 & 2.

ii) Soft polyvinyl chloride (PVC), see Table 17.3

iii) Ethylene copolymer bitumen (ECB), see Table 17.4

## Table 17.3 PVC Waterproofing Membrane (polyvinyl chloride)

| Property | Specified Value | Standard |
|---|---|---|
| Thickness | 2.0 mm min | DIN 53370 |
| Tensile strength | 15 N/mm$^2$ min | DIN 53455 / SS EN ISO 527 |
| Elongation at failure | 250% min | DIN 53455 / SS EN ISO 527 |
| Tear propagation strength | 100 N/mm min | DIN 53363 |
| Resistance under water pressure | Waterproof at 10 bar for 10 hours | DIN 16726 |
| Strength of welded seam | 13.5 N/mm$^2$ min | DIN 16726 |
| Dimensional stability after accelerating ageing | ± 2% max | DIN 16726 |
| Behaviour during perforation test | No perforation at 750mm height of fall | DIN 50014 |
| Material characteristics during and after storage at 80o C: | | DIN 16726 |
| - General appearance | No blisters | |
| - Dimensional stability, longitudinal and transverse | < - 3 % | |
| - Variation of tensile strength, longitudinal and transverse | < ± 10% | |
| - Variation of elongation at failure, longitudinal and transverse | < ± 10% | |
| - Folding at a temperature of -20 deg C | No fissures | |
| Water absorption | 1% max | DIN 53495 / DIN EN ISO 62 |
| Behaviour after storage in acid and/or alkaline solutions: | | DIN 16726 |
| - Variation of tensile strength, longitudinal and transverse | < ± 20% | |
| - Variation of elongation at failure, longitudinal and transverse | < ± 20% | |
| - Folding at a temperature of -20 deg C | No fissures | |
| Behaviour during perforation test | no perforation at 750 mm height of fall | DIN 50014 |

**Table 17.4 ECB Waterproofing Membrane (ethylene-copolymer bitumen)**

| Property | Specified Value | Standard |
|---|---|---|
| Thickness | 2.0 mm min | DIN 53370 |
| Tensile strength | 10 N/mm$^2$ min | DIN 53455 / SS EN ISO 527 |
| Elongation at failure | 500% min | DIN 53455 / SS EN ISO 527 |
| Tear propagation strength | 150 N/mm min | DIN 53363 |
| Resistance under water pressure | waterproof at 10 bar for 10 hours | DIN 16726 |
| Strength of welded seam | 7.2 N/mm$^2$ min | DIN 16726 |
| Dimensional stability after accelerating ageing | ± 2% max | DIN 16726 |
| Material characteristics during and after storage at 80$^o$ C: | | DIN 16726 |
| - General appearance | No blisters | |
| - Dimensional stability, longitudinal and transverse | < - 3 % | |
| - Variation of tensile strength, longitudinal and transverse | < ± 10% | |
| - Variation of elongation at failure, longitudinal and transverse | < ± 10% | |
| - Folding at a temperature of -20 deg C | No fissures | |
| Water absorption | 1% max | DIN 53495 / DIN EN ISO 62 |
| Behaviour after storage in acid and/or alkaline solutions: | | DIN 16726 |
| - Variation of tensile strength, longitudinal and transverse | < ± 20% | |
| - Variation of elongation at failure, longitudinal and transverse | < ± 20% | |
| - Folding at a temperature of -20 deg C | No fissures | |
| Behaviour during perforation test | no perforation at 750 mm height of fall | DIN 50014 |

b) The waterproofing membrane shall be faced with a colour contrasting laminate to allow visual check of the condition of the membrane after installation. The colour contrasting shall clearly define what is the membrane's inside and outside. The "outside" shall be in contact with the fleece.

c) The membrane shall have a smooth surface. Where reinforcement is to be placed against the waterproofing membrane a signalling layer, to give a visual indication of any mechanical damage, shall be provided on the exposed surface of the waterproofing membrane. The signalling layer shall not adversely affect the quality of the seam welds and shall be considered sacrificial and not part of the membrane for waterproofing purposes.

17.6.2.4 Temporary Drainage System

a) In case of local water inflows, temporary drains may be installed on the rock/soil and shotcrete interface as local drainage in a manner acceptable to the Engineer.

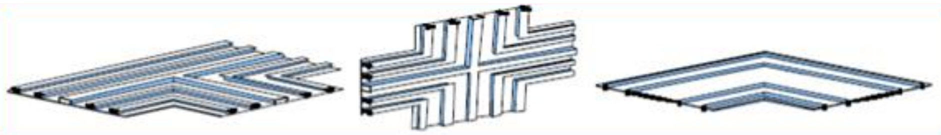
b) The Contractor shall provide a method statement for the Engineers acceptance on the installation and final curtailment of the temporary drainage system.

17.6.2.5 Accessories

a) Fixing material, flashing, reinforcement for expansion joints, sealing flanges and preparation of corners and intersections shall be as recommended by the manufacturer of the waterproofing membrane and fleece.

b) The manufacturer of the waterproofing membrane shall certify the compatibility of any accessories (including those from other manufactures) to be welded to the membrane.

c) Specially pre-fabricated junction pieces shall be used for intersection between longitudinal and transverse waterstops.



17.6.2.6 Finishing Layer

a) Prior to installation of the waterproofing system, shotcrete surfaces shall be smoothed with a finishing layer of shotcrete or a floated-off mortar layer, if required to meet the surface acceptance criteria. After application of the finishing layer or mortar layer, the final surface shall conform to the requirements of the membrane manufacturer.

b) The finishing layer shall consist of fine-graded shotcrete. The maximum aggregate size shall be less than 4mm. The strength requirements shall be as specified for shotcrete. The required bond strength to the proceding shotcrete layer shall be a minimum 0.2MPa or as specified by the Engineer and shall be demonstrated by on-site trials as agreed with the Engineer.

c) In addition, the Contractor shall demonstrate to the Engineer by site trials that the finishing layer is capable of fulfilling the requirements with regard to surface roughness and overhead application.

d) The mix design shall be submitted to the Engineer for acceptance.

e) Where the main shotcrete does not contain steel fibre, the Contractor may propose to the Engineer to smoothen the final surface of the shotcrete as an alternative to applying a finishing layer. The Contractor shall demonstrate by site trials that he is able to achieve conformance with any requirements regarding surface roughness and application thickness.

### 17.6.3 Installation

17.6.3.1 Surface Preparation

a) All surfaces to which waterproofing is to be applied shall be clean, smooth and free from deleterious materials and projections.

b) The final surface prior to the installation of the waterproofing system shall fulfill the following requirements:

    i) The ratio of the diameter to depth of surface irregularities shall be not less than 5:1.

    ii) Transitions and intersections of underground structures shall be rounded off with a minimum internal radius of 500mm.

c) Exposed steel parts such as rock bolts, if not intended to remain accessible, shall be covered with shotcrete, cement mortar, or other means acceptable to the Engineer. Protruding steel bars, wires, spacers, pipes etc. shall be cut flush with the surface unless treated with additional shotcrete. The radius of curvature of the finishing surface shall be not less than 0.2m.

d) Prior to the application of the waterproofing, the Contractor shall submit to the Engineer a wriggle survey of the final SCL tunnel profile with a clear indication of the differences with the theoretical profile. If the wriggle survey shows intrusions of the SCL profile into the theoretical design profile, the Contractor shall propose remedial measures to the Engineer for approval. Waterproofing installation and cast in situ concreting shall not proceed unless the final surface clearance is accepted by the Engineer.

17.6.3.2 Application

a) Prior to the application of the waterproofing system (fleece and membrane), all surfaces to which it will be applied, will be inspected by the Engineer. The Contractor shall not continue with the application without the Engineer's agreement.

b) All work for the application of the waterproofing system shall proceed from a safe platform. The design of the platform shall be submitted to the Engineer for acceptance.

c) The application of waterproofing elements shall follow the written instructions of the manufacturer. Generally, procedures shall be as follows:

i) Preparations: Special preparations will be required for waterproofing at intersections of underground structures and for projections passing through the membrane. They shall be carried out in accordance with the manufacturer's recommendation.

ii) Installing the fleece: The fleece shall be attached to the shotcrete surface using suitable fixings specified by the manufacturer. Two to four fixing elements shall be used per square metre. The fleece shall be laid with sufficient slack to avoid overstress during concreting. Adjacent sections of fleece shall be overlapped by 100mm minimum.

iii) Fixing of waterproofing membrane: The waterproofing membrane shall be installed to cover the fleece and shall be attached to the fleece fixings by means of thermal welding. No perforation of the membrane shall be allowed for installation purposes, except where temporary drainage is required. The waterproofing membrane's outside (defined by colour contrasting) shall be laid towards the fleece and fixed to the fixing points with sufficient slack to prevent overstressing during concreting.

iv) Connecting the waterproofing membrane: Adjacent sheets of waterproofing shall be joined by a double seam weld. Connections to water stops and temporary drainage penetration shall be carried out according to drawings to be furnished by the supplier. To produce the weld, the Contractor shall use and operate appropriate equipment, which is acceptable to the Engineer.

d) The Contractor shall take particular precautions during installation of the reinforcement to ensure that the waterproofing membrane is not punctured or otherwise damaged. During installation of reinforcement, the Contractor shall use movable protective membranes between the reinforcement and the waterproofing membrane or other methods acceptable to the Engineer. Reinforcement spacer blocks shall be suitably sized to limit bearing pressures on the waterproofing membrane and shall be seated on a protective layer of backing material.

17.6.3.3 Storage

The Contractor shall take all necessary measures to the satisfaction of the Engineer for the storage of waterproofing membranes. It is the Contractor's responsibility to ensure proper storage so that no damage occurs to the membrane.

### 17.6.4 Testing and Acceptance of Membrane

17.6.4.1 General

The Contractor shall not cast any section of the concrete lining before the waterproofing work has been inspected and accepted by the Engineer. After the waterproofing membrane is erected, and in addition to the regular tests in accordance with the Method Statement for installation of the waterproofing membrane, the Contractor shall undertake acceptance tests in the presence of the Engineer to check the adequacy of the completed work.

17.6.4.2 Tests

17.6.4.2.1 General

a) The tests shall consist of close visual inspection of the membrane, joints and fixing points shortly before concreting, together with vacuum testing of suspect punctures and pressure testing of all double seam welds.

b) The Contractor shall provide suitable access and high intensity spot lighting for these tests and shall allow adequate time for testing within the construction program.

c) Prior to the installation of waterproofing system in the Works, the Contractor shall submit to the Engineer, for acceptance, details of the intended test procedures and equipment.

d) Records of the tests shall be submitted to the Engineer. Damage identified in the tests shall be brought to the Engineer's attention and highlighted. The Contractor shall propose remedial actions to the Engineer for acceptance.

17.6.4.2.2 Seam Test with Compressed Air

a) For seams between adjacent sheets of waterproofing membrane the testing for watertightness shall be carried out by means of compressed air pumped into the channel between two welds formed by the double welded joint. The channel shall be sealed at both ends and inflated to a pressure of 200kPa.

b) The length of welding seam tested in one test shall be in accordance with the manufacturer's recommendation with respect to the minimum and maximum length.

c) The test results are acceptable when the pressure does not fall by more than 20kPa in a period of not less than 10 minutes.

17.6.4.2.3 Seam Test with Vacuum Equipment

a) Vacuum equipment shall be employed for the watertightness testing of areas of membrane of limited size such as special configurations of joints or local repairs with patches or where puncturing is suspected.

b) The testing equipment consists of a vacuum bell supplied by the membrane manufacturer, which is fitted tightly over the area to be tested and then evacuated by pumping. The test results are acceptable if a vacuum pressure of -20kPa can be achieved.

c) The test duration shall be in accordance with the recommendations of the membrane supplier/manufacturer.

17.6.4.2.4 Re-testing

Every possible care shall be taken not to damage the waterproofing membrane during or after installation. Any damages shall be repaired and re-tested before the pouring of the cast insitu concrete lining.

### 17.6.5 Warranty

The waterproofing warranty shall cover the watertightness of the underground structures including the waterproofing systems and shall be given jointly and severally by the Contractor and the Supplier/Applicator. The warranty shall be in accordance with the Specimen Warranty Form given in the General Specification

## 17.7 SPRAY APPLIED WATERPROOFING

### 17.7.1 General

a) The use of spray applied waterproofing may be allowed for Cross Passages, sumps and other minor works, as alternative to the PVC/ECB membrane system, subject to the acceptance of the Engineer.

b) At such locations, an integral waterproofing system comprising of an approved sprayed waterproofing membrane together with the secondary concrete lining with either an approved waterproofing admixture or silica fume shall be provided.

c) The sprayed waterproofing membrane shall be specifically designed for use in underground structures and shall consist of an elastic polymeric membrane, based on a cement modified polymer product, or similar product approved by the Engineer, with high bond strength to the underlying shotcrete substrate.

d) The Contractor’s attention is drawn to ITAtech Design Guidance For Spray Applied Waterproofing Membranes (ITAtech report N°2 - APRIL 2013) to ensure a safe SCL waterproofing design and construction practice.

e) The spray applied waterproof membrane shall only be installed by the manufacturer of the product or by his approved specialist applicator.

f) The total minimum thickness of the spray applied membrane shall be 3mm, which shall be applied in two coloured layers that act as a signal coat.

### 17.7.2 Submissions by the Contractor

The following information shall be submitted to the Engineer for acceptance in accordance with the Contract requirements:

a) Certificates of compliance and test results/reports confirming that the proposed materials meet the specification requirements.

b) Comprehensive and detailed Method Statements describing the installation of the waterproofing membrane including:

   i) Manufacturer

   ii) Type of system and application methods

   iii) Prior treatment of existing water ingress

   iv) Equipment to be used for installation and testing

   v) Inspection & Test Plan

   vi) Repair procedure

   vii) Risk assessment

c) Detailed instructions and recommendations from the manufacturer regarding the substrate / surface preparation and acceptance criteria, installation of drainage facilities, together with application and testing of the waterproofing membrane.

d) Details of the products and the applicator's qualifications, including the track record of the product and the evidence of the applicator's previous experience, as well as a resume for all the key personnel such as supervisors and nozzlemen for the waterproofing installation.

e) Detailed drawings shall be submitted for acceptance showing all necessary details such as drainage details, interface details, connection details, termination details, repair details etc.

### 17.7.3 Pre-Construction Trial and Testing

a) A site trial shall be conducted at least three months before the actual waterproofing application is programmed to commence on site. The trial will be witnessed by the Engineer and shall demonstrate the suitability of the material, equipment, workmanship, application methods and application personnel that will be employed to carry out the actual works on site.

b) Before commencement of the trials, the Contractor shall submit for the Engineer's acceptance, the proposed mix design of the SCL finishing layer including the acceptable combined grading envelope and a sieve analysis of the actual material sources. This material submission will also apply to any additional smoothing layer that is proposed to be used.

c) The trial shall be used to confirm the requirement for a smoothing layer to be used during the actual works. During the trial the waterproofing membrane shall be sprayed onto a substrate constructed using the identical approved shotcrete mix design that will be used for the primary SCL lining. If a smoothing layer is proposed then this will be applied to the SCL substrate before applying the waterproof membrane.

d) The trial shall determine the optimum powder : water ratio for the conditions as expected during the Works.

e) The following tests shall also be conducted for the trial panels and the results submitted to the Engineer for acceptance:

   i) Membrane hardness test

   ii) Bond Strength test

   iii) Permeability test

   iv) Thickness test

### 17.7.4 Materials

17.7.4.1 General

The proposed waterproofing membrane together with any associated materials, such as a smoothing layer, shall be submitted for the Engineer's acceptance.

17.7.4.2 Waterproofing Membrane

a) The sprayed waterproof membrane shall consist of an elastic polymeric membrane, based on a cement modified polymer product, or similar product approved by the Engineer, with high bond strength to the underlying shotcrete.

b) The waterproof membrane shall be designed to withstand the actual water pressures anticipated for the actual site conditions.

c) The first layer of the waterproof membrane shall be of a colour that will contrast with the substrate colour.

d) The waterproof membrane shall be self extinguishing and provide no risk of combustion during a fire once it is applied to the substrate.

e) The waterproof membrane shall contain no toxic components.

f) The waterproof membrane for application in mined tunnel shall comply with the performance requirements as specified in Table 17.5.

17.7.4.3 Water for mixing

Only potable water shall be used for mixing.

17.7.4.4 Storage

The Contractor shall take all necessary measures to store the material in accordance with the manufacturer's recommendations

**Table 17.5 Spray Applied Waterproofing Membrane Performance Criteria**

| **Property** | **Test Method** | **Minimum Requirement** |
|---|---|---|
| Bond to substrate | EN ISO 4624 or EN 1542 | 0.5 MPa with 28 days after membrane application |
| Watertightness | Based on EN 12390-8, with adaptation for inclusion of spray applied membrane;<br>Based on EN 14891, Part A7, for the concrete mix design | Zero penetration of water through the membrane |
| Crack Bridging | EN 1062-7 Method A: C1 Static Tensile Test – Measured at 20˚C | Class A5<br>Minimum 2.5mm |
| Flammability | EN ISO 11925-2 | Class E,<br>As defined in EN 13501-2 + A1 |
| Chemical resistance | According to EN 14414, Method A (acid solutions) and Method B (alkali solutions). Resistance against chloride (at 10% chloride concentration).<br>Testing based on EN 14414 Method A or B shall be according to the groundwater chemistry of the project as specified by the designer. | a) There shall be no visual sign of degradation;<br>b) Comparison of the tensile properties (tensile strength and elongation at break) of the tested specimen with those of a control sample. The acceptance criteria shall be a maximum change of 25% compared to the control sample tensile strength and elongation at break of the membrane. |
| Resistance to leaching | According to EN 14415, in hot water (Method A), and aqueous alkaline liquids (Method B). | a) There shall be no visual sign of degradation;<br>b) Comparison of the tensile properties (tensile strength and elongation at break) of the tested specimen with those of a control sample. The acceptance criteria shall be a maximum change of 25% compared to the control sample tensile strength and elongation at break of the membrane.<br>c) The loss in mass of the sample shall not be greater than 5% compared to the control sample. |

### 17.7.5 Installation of Membrane

17.7.5.1 Surface Cleaning

Prior to the application of the sprayed waterproof membrane the surface area shall be thoroughly cleaned using compressed air and water to remove all loose materials, dust, laitance and any other material that will impair the adhesion of the waterproof membrane.

17.7.5.2 Surface Protrusions

Exposed steel parts such as rock bolts, if not intended to remain accessible, shall be covered with shotcrete, cement mortar, or other means acceptable to the Engineer. Protruding steel bars, wires, spacers, pipes etc. shall be cut flush with the surface unless treated with additional shotcrete.

17.7.5.3 Sealing Water Leaks and Temporary Drainage System

a) Prior to the application of the sprayed waterproof membrane any areas of water ingress or damp patches evident on the initial SCL lining substrate shall be sealed to the satisfaction of the Engineer in accordance with the recommendations of the manufacturer.

b) Alternatively, water ingress may be channelled to a drainage system or diverted through bleed pipes in a manner which follows the recommendations of the waterproof membrane supplier and that is acceptable to the Engineer.

c) The strong bonding of the membrane with the underlying shotcrete substrate shall be maintained in order to confine and minimize any water ingress after the completion of the work. It is therefore not recommended to use a layer of fleece between the initial SCL substrate and the membrane as part of a drainage system, as this may result in paths being created for running water behind the membrane.

17.7.5.4 Interfaces among different waterproofing system

Details of interfaces and lapping with other waterproofing system shall be submitted to the Engineer for acceptance. Test results shall be provided to demonstrate that the spray applied membrane can meet the bonding strength requirements to the specific substrate i.e. PVC/ECB waterproofing membranes

17.7.5.5 Surface Texture

a) Prior to installation of the sprayed waterproofing membrane, shotcrete surfaces and all other substrates shall be sufficiently smooth and meet the requirements of the sprayed waterproof membrane supplier and to the acceptance of the Engineer.

b) If necessary, a smoothing layer based on the manufacturer’s recommendations shall be used.

c) The smoothing layer shall consist of either a sand/cement mix or a fine-graded shotcrete mix. The maximum aggregate size shall be less than 4mm. The required bond strength to the preceding shotcrete layer shall be a minimum 0.2MPa or as specified by the Engineer.

d) After the application of any additional smoothing layers, all surfaces shall be in accordance with the clearance requirements specified on the Drawings for the installation of the secondary permanent lining.

e) Where the main shotcrete does not contain steel fiber, the Contractor may propose to the Engineer to smoothen the final surface of the shotcrete as an alternative to applying a finishing layer. The Contractor shall demonstrate by site trials that he is able to achieve the required level of smoothness.

17.7.5.6 Application

a) The application of the waterproof membrane shall strictly follow the recommendations of the manufacturer.

b) The application shall be done only by the applicators approved during the pre-construction trial or with relevant and certified experience if accepted by the Engineer.

c) Prior to the application of the waterproofing membrane, all surfaces will be inspected by the manufacturer’s representative & approved by the Engineer. The Contractor shall not continue with the application without the Engineer’s agreement.

d) All surfaces to which waterproofing is to be applied shall be clean, smooth and free from deleterious materials and projections.

e) Prior to applying the waterproof membrane, the surface to be sprayed shall be pre dampened slightly to allow for a good bond between substrate and membrane.

f) The end of the spraying nozzle shall be maintained at an optimum distance of between 1.5m to 2.5m from the surface being sprayed.

g) Adequate ventilation shall be provided for optimal application and curing conditions.

h) Dust within the vicinity of the application area shall be avoided, and a dust suppression facility may be required.

i) An approved lapping detail shall be followed for any section of membrane being applied 6 hours later than when the previous section of membrane was applied (or as recommended by the manufacturer). The lapping shall be at least 200 to 300mm in width. Thorough cleaning of the membrane lapping section shall be done prior to spraying the new section of membrane.

17.7.5.7 Equipment

a) The equipment used for the application of the membrane shall be in accordance with the requirements of the manufacturer.

b) The equipment used shall be able to deliver the material at a regular rate and at an appropriate velocity to ensure proper adherence of the material to the substrate.

c) The air and water supply to the equipment shall be in accordance with the recommendations of the machine manufacturer.

d) The application can be either manual or by robotic equipment. If robotic equipment is used, it shall include a laser guided automated method to ensure that a uniform thickness is applied.

e) The spray equipment shall be the same as used during the pre-construction trial.

### 17.7.6 Protection of Applied Waterproof Membrane

a) The secondary lining shall not be installed over the waterproof membrane until it has cured sufficiently to achieve a Shore A hardness of at least 50 or above.

b) After the membrane has been installed, the Contractor shall take precautions to ensure that the membrane in the invert section of the tunnel is not damaged or punctured from people walking on top of the installed membrane. Suitable protection measures shall be provided in accordance with the manufactures' recommendations.

c) Particular precautions shall also be taken during the installation of the reinforcement and formwork to ensure that the waterproofing membrane is not punctured or otherwise damaged. During installation of the reinforcement, the Contractor shall use movable protective covers or similar, between the reinforcement and the waterproofing membrane or other methods acceptable to the Engineer. Reinforcement spacer blocks shall be suitably sized to limit bearing pressures on the membrane and shall be seated on a protective layer of backing material.

### 17.7.7 Repairs to Defective Waterproof Membrane

a) Areas of damaged or unsatisfactorily sprayed membrane which exhibits any defects such as punctures, cracking, water ingress, insufficient thickness or insufficient strength/toughness shall be rejected. The defective area of membrane shall be re-sprayed following the manufacturer's recommendations and providing the minimum required overlap.

b) Mixing and application of the waterproof membrane by hand to repair smaller areas of damaged membrane shall only be allowed for very minor repairs. Such repairs shall follow the recommendations of the manufacturer and shall be subject to the acceptance of the Engineer.

### 17.7.8 Inspection and Testing of the Membrane during the Work

17.7.8.1 General

The Contractor shall not cast any section of the concrete lining before the waterproofing work has been inspected and accepted by the Engineer. After the waterproofing membrane is applied, and in addition to the regular tests in accordance with the Method Statement for installation of the waterproofing membrane, the Contractor shall undertake acceptance tests in the presence of the Engineer to check the adequacy of the completed work.

17.7.8.2 Visual Cover Test

The contrasting color of the membrane with the substrate shall allow for visual inspections as part of the quality control process to ensure proper coverage of the membrane has been achieved.

17.7.8.3 Thickness Test – Wet Film Test

a) During spraying of the membrane the thickness of the applied membrane shall be continually checked using a depth gauge or needle penetrometer.

b) The equipment used to measure the thickness of the membrane shall be acceptable to the Engineer.

c) The locations of the tests shall be recorded and subsequently repaired immediately after the test has been carried out.

d) The wet film thickness tests shall be performed to a frequency agreed with the Engineer and shall be based on the length and diameter of the tunnel being lined, but at least 10 samples shall be tested for every 5m length of tunnel as a minimum. The test locations shall be as agreed with the Engineer and shall include crown, axis and invert sampling.

17.7.8.4 Thickness Test – Dry Film Test

a) To confirm that the correct thickness of membrane has been applied, the dry film direct test shall be done after curing of the membrane.

b) It shall be done by measuring the thickness of small patches cut from the membrane installed in the Work. The size of a sampled patch shall be no more than 100mm x 100 mm.

c) The equipment used to measure the thickness of the membrane patch shall be acceptable to the Engineer.

d) Thickness tests shall be performed to a frequency agreed with the Engineer and shall be based on the length and diameter of the tunnel being lined, but at least two samples shall be tested for every 5m length of tunnel as a minimum. The test locations shall be as agreed with the Engineer and shall include crown, axis and invert sampling.

e) The sections of membrane being sampled shall be clearly identified and repaired by re-spraying over the sampled area providing an overlap to the surrounding membrane of at least 200mm.

17.7.8.5 Thickness Test - Material Consumption Verification

As a counter check to the more direct testing methods, a record of actual material used shall be maintained with the purpose of verifying that a total volume of membrane, at least equal to the theoretical quantity, has been actually used to cover a predetermined work area.

17.7.8.6 Alternative Thickness Tests

Alternative test methods to verify the thickness of the applied membrane may be submitted to the Engineer for acceptance.

17.7.8.7 Bond Test

a) Testing shall be carried out by Pull-Off Adhesion strength of coating on shotcrete using portable pull-off adhesion tester in accordance with EN ISO 4624 or EN 1542. The test shall satisfy the requirement stated in Table 17.5.

b) Bond tests shall be performed to a frequency agreed with the Engineer and shall be based on the length and diameter of the tunnel being lined, but at least 1 sample shall be tested for every 5m length of tunnel as a minimum. The test locations shall be as agreed with the Engineer and shall include crown, axis and invert sampling.

17.7.8.8 Watertightness Test

a) Testing shall be carried out in accordance with SS EN 12390-8.

b) Watertightness tests shall be performed to a frequency agreed with the Engineer and shall be based on the length and diameter of the tunnel being lined, but at least 1 sample shall be tested for every 5m length of tunnel as a minimum. The test locations shall be as agreed with the Engineer and shall include crown, axis and invert sampling.

### 17.7.9 Warranty

The waterproofing warranty shall cover the watertightness of the underground structures including the waterproofing systems and shall be given jointly and severally by the Contractor and the Supplier/Applicator. The warranty shall be in accordance with the Specimen Warranty Form given in the General Specification.

# CHAPTER 18

# TURFING AND PLANTING

## 18.1 GENERAL

All turfing and planting works shall be carried out to the requirements and general satisfaction of National Parks Board (NParks) or relevant authorities (e.g. HDB, JTC). All works in connection with turfing and tree planting shall be considered accepted only upon the successful handover to the respective landowners or their agent.

## 18.2 TOPSOIL

18.2.1 Topsoil shall be fertile natural red/brown topsoil transported to the site, free from stones, clay, wood, sod, rubbish, roots, stumps or other extraneous material and obtained from naturally well drained area. Topsoil shall neither be excessively acidic or alkaline and shall be free from any toxic matter liable to be harmful to plant growth.

18.2.2 Topsoil shall generally be reasonably loose in a form containing not more than 10 - 15% of moisture content.

18.2.3 All topsoil shall be mixed with organic matter in the proportion of 3:1. This mixture shall be spread uniformly over the site, slopes and/or berms etc. where directed and shall be lightly watered if necessary, and then tamped with wooden tampers and trimmed to a consolidated thickness of 100mm for turf, 600mm for shrub areas or as specified.

18.2.4 The Contractor shall be responsible for providing and fixing the turf promptly after spreading the topsoil and tamping in order to prevent erosion. A thin layer of topsoil shall be broadcast on the turf to fill all depressions and give a level finish.

## 18.3 PLANTING

### 18.3.1 Turf

18.3.1.1 Proposed roadside verges shall be excavated to 0.6m deep, backfilled with Approved Soil Mixture (ASM) and closed turfed with 50mm thick Axonopus compressus (Cow Grass).

18.3.1.2 Disturbed roadside verges shall be reinstated with 50mm thick Axonopus compressus (cow grass) in close turfing with provision of 100mm depth planting mixture. The planting mixture shall be made up of ASM in accordance with the NParks specification.

18.3.1.3 Where a very fine lawn is specified in the Particular Specification, the following finer grasses shall be used:

(a) Serangoon Grass (Digitaria didactyla) - normally used for golf greens

(b) Bermuda Grass (Cynodon dactylon) - often used for lawn tennis courts

(c) Siglap Grass (Zoysia matrella) - found in the better house gardens

18.3.1.4 The choice of species to be used shall be decided by the Engineer.

18.3.1.5 All turf supplied by the Contractor shall be healthy and vigorous of approved type and quality. The grass or turf shall be cut square and approximately 0.3m x 0.3m (0.09 $m^2$) in size and 50mm in thickness. All turf supplied shall be free from weeds, especially Mimosa pudica, Imperata cylindrical (lallang) and Eleusine indica, and care shall be taken to include as much of the root growth as possible. The turf shall not be broken up into small pieces for planting and shall be planted as soon as possible after being cut.

18.3.1.6 Turfing shall be laid abutting unless otherwise directed, with no appreciable spaces between adjoining turf. Each sod shall be properly pegged down to prevent movement or displacement of any kind, and the turfing shall be thereafter be tampered down and rolled (except on slopes) with a suitable hand roller. On completion, the turfing shall present a uniform and regular appearance.

18.3.1.7 When carrying out turfing work, the organic matter and approved loamy soil shall be thoroughly mixed before application. This organic matter shall be laid up to 50mm below the desired turf level. The turf sods shall then be planted on top of this layer. Thereafter, gaps between sods shall be filled only with approved loamy soil, and then a thin layer of 25mm thick approved loamy soil shall be broadcast on the turf to fill all depressions to give a smooth finish, and bring the ground to the final level. No additional payment will be made for this 25mm thick layer of approved loamy soil. After planting and watering, no additional spreading of organic matter on the newly laid turfed area shall be allowed

18.3.1.8 All turfing shall be regularly watered, weeded and maintained until the growth is satisfactory. The Contractor shall include for such watering and tending such as weeding, grass-cutting, rolling, etc. at his own costs. Any badly growing or otherwise unsatisfactory turf shall be removed and replaced with approved quality turf by the Contractor at his own costs. The maintenance shall continue until all turf are properly established and handed over to NParks.

### 18.3.2 Plants

18.3.2.1 All trees, shrubs and groundcover to be used under this Contract (herein after collectively referred to as `Plants') shall be of varieties, sizes and quantities shown in contract drawings.

18.3.2.2 All plants must be positioned in accordance with the approved landscape design including allowance for safe depths and root barriers for protection of any shallow structures below the surface. Positioning of plants shall comply with the requirements given in the NParks Regulations.

18.3.2.3 All plants shall be of cultivated stock. The Contractor shall furnish all plants shown on the contract drawings. No substitutions or omissions thereof shall be permitted unless accepted by the Engineer.

18.3.2.4 All plants shall be typical of their respective species or variety and shall have normal growth and be legibly tagged with proper botanical names.

18.3.2.5 The height of a tree or single stem palm (measured from the collar of the tree to the average height of the top branches) shall be not less than the minimum size designated on the contract drawings.

18.3.2.6 The trunk of each tree shall be a single trunk growing from the single unmutilated crown of root. No parts of such trunks shall be conspicuously crooked as compared with normal trees of the same variety. Such trunks shall be free from wound, abrasions, or other damage from whatever cause.

18.3.2.7 No pruning having a diameter exceeding 250mm shall be present on any trunk of such trees. All pruning must be clean cut without damaged bark/ tearing.

18.3.2.8 Shrubs and cluster palms used in the works shall meet the requirements for spread or height specified on the contract drawings. Measurement for the height of shrubs shall be taken from the ground level to the average height of the tallest branches of the shrubs and not to the longest branch or stem. Single stemmed or thin plants shall not be accepted. The side branches shall be generous, well twigged and all shrubs, as a whole, shall be well branched to the ground.

18.3.2.9 All plants must come with pots or plastic bags in which they were originally grown and established in the nursery. The only exception being instant plants and large shrubs that have to be specially transplanted.

18.3.2.10 All plants are to be removed from their original growing receptacles prior to installation. They should be arranged in a manner such that the leaves complement each other and are within touching distance of the other and not overlapping one another unless specified to the contrary.

18.3.2.11 All planting works shall have the appearance of established growth. Plants shall be arranged with their foliage showing off their best face so that the intended design effect shall be fully realised.

18.3.2.12 Rooted cuttings of ground covers shall be laid at approximately 200 mm centres or as specified.

### 18.3.3 Planting Holes

18.3.3.1 Planting holes shall comply to the NParks Regulations. Minimum sizes shall be:

(a) 1.5m x 1.5m x 1.0m for instant tree planting

(b) 1.0m x 1.0m x 1.0m for tree and palm planting

(c) 0.6m x 0.6m x 0.6m for shrubs planting

18.3.3.2 On completion of excavation, the Contractor shall remove from site all excavated materials, debris, etc and notify the Engineer and NParks for inspection.

18.3.3.3 All planting holes shall be backfilled with topsoil of a quality as specified in the section on topsoil above.

18.3.3.4 All saplings shall be securely staked and tied as specified in the NParks Regulations.

18.3.3.5 All semi-matured trees shall be staked by guying or by ground anchors as specified and as directed by the Engineer.

18.3.3.6 Roots and root balls of all plants shall be kept damp and thoroughly protected from the sun and wind during transportation to the site at all times until planted. All plants shall be accurately set in the centre of the planting holes and at the same depth to final ground surface levels as upright in the holes before backfilling.

18.3.3.7 All backfill shall be brought to a finished level (after settlement) identical to the level of the surrounding area except directed otherwise by the Engineer. Backfill shall not be compacted by ramming.

### 18.3.4 Transplanting

Arrangements for existing trees identified for transplanting shall meet all the requirements given by NParks. The Contractor shall liaise closely with the NParks and their appointed term contractor to carry out the tree transplanting.

## 18.4 MAINTENANCE

### 18.4.1 Maintenance Period

18.4.1.1 The Contractor shall maintain all completed works and rectify all defects for a period commencing from the contract completion date up to end of the defects liability period or until the handover to the relevant authority/ landowner whichever is later.

18.4.1.2 During the period, the Contractor shall be responsible for the necessary horticultural maintenance eg. pruning, weeding, watering, forking, mowing and replacement of any defective works to the acceptance of the Engineer.

18.4.1.3 The period of maintenance shall commence only after the acceptance in writing of the completion of the entire works by the Engineer.

### 18.4.2 Watering

18.4.2.1 All turfing and planting shall be watered regularly in the absence of sufficient rainfall as required to keep the plants healthy.

18.4.2.2 It is the responsibility of the Contractor to water and spray water to remove dust to all plants regularly.

### 18.4.3 Weeding

18.4.3.1 All weeds found growing in the landscape and turfing area under maintenance must be removed by loosening the ground/soil around and under the weeds so that entire root systems are removed. Where deemed necessary, the Contractor shall apply mulch around bases of plants to prevent weeds from growing.

18.4.3.2 The weeds must be removed from the planted areas without disturbing adjacent plants.

18.4.3.3 All plant beds shall be weeded weekly.

18.4.3.4 All turfing shall be weeded at least twice a month

18.4.3.5 Grass growing in the cement joints of footpaths and along the edge of the roads adjacent to or directly fronting the side tables, centre medians, circuses etc. shall be cut or manually weeded out and cleared.

### 18.4.4 Forking

All plant beds must be forked fortnightly to loosen the soil and provide sufficient aeration for the roots. A hoe (Changkol) should not be used to loosen the soil so as not to cause damage to the roots.

### 18.4.5 Pruning

18.4.5.1 Plants must be pruned when necessary. Pruning shall be done with clean, sharp tools to produce a clean-cut face.

18.4.5.2 Dead wood and broken or badly bruised branches shall be removed. Main leaders shall not be cut.

18.4.5.3 Plants on the road reserve during the maintenance period shall be pruned back clear of the kerb line, at crossing and junctions for visibility of traffic and pedestrians, and as required by the Engineer for safety reasons.

### 18.4.6 Topdressing

Plant with exposed root planting beds and turfing with low topsoil level and those affected by rainwater splashing and erosion shall be topdressed as and when required.

### 18.4.7 Application of Pesticide

All foliage, flowering plants and trees must be treated with fungicide, mitcide and an insecticide as and when directed by the Engineer.

### 18.4.8 Application of Fertiliser

18.4.8.1 Slow release of Nitrogen, Phosphorus, Potassium (NPK) combined with fast release organic fertiliser shall be applied regularly to ensure healthy plant growth, repeating the application once every 4 - 6 weeks, or when directed by the Engineer.

18.4.8.2 All trees, foliage and flowering plants are to be given fertiliser according to the dosage, fertiliser type and frequency as shown in Table 29.1.

**Table 18.1 - Fertiliser dosage type and frequency**

| Fertiliser | Plants | Dosage | Frequency |
|---|---|---|---|
| Eg:<br>12N : 12P<br>17K : 2Mg + Te<br>15N : 15P : 15K | 1) Trees | 30 g/plant | Once/month |
| | 2) Palms | 10 g/plant | Once/month |
| | 3) Foliage and flowering shrubs | 30 g/m$^2$ | Once/month |

18.4.8.3 Turf shall be manured with a complete compound NPK fertiliser. This shall be applied at the rate of 125 kg/ha of grass after all weeds have been removed. The fertiliser shall be mixed with the topdressing and spread evenly over the field one month after planting and then again three months later.

### 18.4.9 Replacement of Plants

All dead plants/turf and plants not growing properly are to be replaced by healthy plants/turf of the same species at the Contractor's own expense.

### 18.4.10 Mowing and Rolling of Turf

18.4.10.1 After one month's growth, the grass shall be cut with a suitable rotary mower to encourage the grass to creep on the ground instead of growing upright. This operation shall be repeated at fortnightly intervals until the ground is completely covered with grass. Thereafter the grass shall be cut regularly.

18.4.10.2 Approximately two months after planting, when the grass has grown and produced a continuous cover over the whole area, the whole of the turfed areas shall be lightly rolled (roller shall not exceed 150 kg in weight) to an even surface. Rolling shall be repeated at monthly intervals until the surface is accepted by the Engineer.

18.4.10.3 Grass shall be close cut as short as possible following the general contours of the ground. The stock or blade of the grass after each cutting shall not stand higher than 20mm above the ground level. On fairly extensive and open grass areas, side tables or fields, the Contractor shall use mechanical mowers powered by small tractors.

### 18.4.11 Turf Edging

18.4.11.1 The edge of all side tables, and other grassed areas adjoining roadways, footpaths, kerbs, dividers and concrete paved areas shall be cut back to proper straight lines or curves as the case may be, and trimmed thereafter to produce a neat and tidy appearance. This work shall be carried out immediately after the grass in the area has been cut.

18.4.11.2 Where the existing ground is around established and mature tree (with girth of above 200mm measured at 1m above ground level) or around street furniture, the Contractor shall level the surrounding ground and employ a weed eater or other grass cutting machine operated by nylon string cutting "blade", to close cut the grass right up to the bases of trees or street furniture without damaging the bark or furniture.

18.4.11.3 To avoid damaging shrubs, flowering plants or young trees (with girth less than 200mm), the Contractor shall cut grass right up to the edge of the flower beds only or the weeded areas of such plants.

## 18.5 PLANTER BOXES

18.5.1 Aggregate laid in planter boxes shall be clean, smooth and free from dirt and grease.

18.5.2 Topsoil to indoor planters shall be vermiculite granules and shall contain no deleterious or foreign matter.

18.5.3 Granulated peat shall be compressed and laid in the planter box on a prepared layer of rounded aggregate.

## 18.6 INSPECTION AND ACCEPTANCE OF WORKS

18.6.1 Upon completion of the Works, the Contractor shall request the Engineer in writing to inspect and determine whether all plants are acceptable to the Engineer Should any plant be unacceptable to the Engineer, the Contractor shall replace all such plant at his own expense as and when directed by the Engineer and to the acceptance of the Engineer.

18.6.2 The Contractor must ensure that all plant beds are tidied up and free from any debris or dead plant materials immediately on completion of the planting works.

18.6.3 All areas affected by horticulture activities must be thoroughly cleaned and soil stains etc. removed to the acceptance of the Engineer.

18.6.4 Prior to handing over of the work at contract completion and at the end of the defects liability period, all plants must be groomed and neatly trimmed.

# CHAPTER 19

# DRAINAGE WORKS

## 19.1 GENERAL

### 19.1.1 General

The works covered under these specifications shall include the design, supply, installation, testing and commissioning of all Drainage works.

### 19.1.2 Design requirement

The Contractor shall perform all design functions necessary for the development, manufacture/procurement, installation and site testing of systems, sub-systems and components to provide complete and operable installations.

### 19.1.3 Workmanship

Workmanship shall be to the acceptance of the Engineer, who shall have the right to reject any material he may deem unfit for use or installed in a non-workmanlike manner.

### 19.1.4 Standards, Codes and Regulations

19.1.4.1 The design, manufacture, supply, installation, testing and commissioning of the Drainage works shall be governed by all applicable latest editions of local codes, regulations, standards and requirements issued by all the local statutory authorities and agencies which shall include the following:

(a) Public Utilities Board (PUB)

(b) Land Transport Authority (LTA)

(c) National Environment Agency (NEA)

(d) Enterprise Singapore

(e) Energy Market Authority (EMA)

19.1.4.2 The Contractor shall apply for all necessary permits required by the relevant authorities and pay all charges in connection with this work.

19.1.4.3 The whole of the installation shall be carried out by the Contractor's Licensed Plumber.

### 19.1.5 Quality Assurance

19.1.5.1 All materials such as pipes, fittings, jointing materials, components and appliances shall be of the type, size, brand, material, quality and workmanship approved by the NEA/PUB and Enterprise Singapore. Manufacturers of all these products shall have manufactured similar products for a period of at least 5 years.

19.1.5.2 All personnel engaged on welding operations shall possess a certificate of competence issued by a relevant authority.

### 19.1.6 Submissions

The Contractor shall submit the following for acceptance by the Engineer.

(a) Method statements and QA/QC procedures for site installation works, testing, commissioning and cleaning.

(b) Pipe supports and anchor details.

(c) Detailed manufacturer's drawings, material specifications, catalogues, samples and technical data.

(d) As-constructed invert levels, gradients, types and size of pipes, drains, culverts, levels at the top of sumps and horizontal distances between sumps.

## 19.2 DRAINAGE WORKS FOR BELOW GROUND STRUCTURES

### 19.2.1 General

Drainage works for below ground structures shall include works in underpasses, basements, subways, underground stations and tunnels etc.

### 19.2.2 Pipes and Fittings

19.2.2.1 Materials

Materials for pipes and fittings for Drainage Works shall be of the following:

| | | |
|---|---|---|
| (a) | Above-ground pump discharge pipes | Ductile iron pipe to BS EN 598. |
| (b) | Earth buried or cast-in pump discharge and drainage pipes (underground) | Ductile iron pipe to BS EN 598.<br><br>Earth-buried pipes shall be wrapped around with polyethylene sleeve. |
| (c) | Exposed drainage pipes (aboveground) | Hubless/socketless cast iron pipes and fittings to CISPI 301 and CISPI 310 or BS EN 877. |

19.2.2.2 Pipe Joints

Joints shall not be closer than 3000mm except where necessitated by fittings. Other types of proprietary-made joints that are approved by the relevant authorities may be adopted. Such materials shall not be used without prior consultation and acceptance by the Engineer.

19.2.2.3 Pipe Size

Minimum pipe sizes for Drainage works shall be as shown on the Drawings or otherwise as indicated below:-

(a) Floor waste to floor waste: 75mm

(b) Floor waste to floor trap: 75mm

(c) Floor trap to floor trap: 100mm

(d) Pump Discharge Pipes: 80mm

(smaller pipe size is permitted if the flow cannot meet the minimum water velocity as specified in clause 19.2.3.)

19.2.2.4 Pipe Insulation

The requirements for pipe insulation shall be as specified in Materials & Workmanship Specification (M&W) for Mechanical and Electrical (M&E) Works Chapter for Sewerage and Sanitary Plumbing.

### 19.2.3 Water Velocity

Water velocity of the pump discharge and drainage pipes shall be between 1 m/s to 2.4 m/s to maintain self-cleansing and prevent scouring.

### 19.2.4 Cleaning Eyes and Inspection Openings

The requirements for cleaning eyes and inspection openings shall be as specified in M&W for M&E Works Sewerage and Sanitary Plumbing Chapter.

### 19.2.5 Pipework Installation

The requirements for the installation works shall be as specified in M&W for M&E Works Pipework and Pumps Chapter.

### 19.2.6 Cleaning Procedure

The requirements for cleaning shall be as specified in M&W for M&E Works Water Services Chapter.

### 19.2.7 Testing and Commissioning

19.2.7.1 Drainage pipework shall be tested to BS EN 12056-2.

19.2.7.2 All pump discharge pipework shall be hydrostatically tested to at least twice the anticipated system working pressure.

### 19.2.8 Drainage Sumps and Covers

The requirements of drainage sumps & covers shall be as specified in M&W for M&E Works Sewerage and Sanitary Plumbing Chapter.

## 19.3 DRAINAGE WORKS APPLIANCES AND FITTINGS

The requirements for the supply, installation, testing and commissioning of all appliances and fittings shall be as specified in M&W for M&E Works Sewerage and Sanitary Plumbing Chapter.

## 19.4 SURFACE DRAINAGE WORKS

### 19.4.1 General

This section specifies the manufacture and installation of all surface storm water Drainage works.

### 19.4.2 Materials

19.4.2.1 The concrete and steel reinforcement shall be as specified in Chapter 11, Concrete and Reinforcement Bars. The brickwork shall be as described in the M&W for Architectural Works consisting of common bricks, set and jointed in cement and sand (1:3) gauged with mortar plasticiser.

19.4.2.2 Pipes and Fittings shall be as specified in clause 19.2.2 and M&W for M&E Works Sewerage and Sanitary Plumbing Chapter.

19.4.2.3 Conduit pipes for surface water drainage passing under building structures shall be a minimum of 300mm diameter.

19.4.2.4 Roof drainage installation, workmanship, materials and testing requirements shall be the same as those described in the Architectural Materials and Workmanship Specification.

### 19.4.3 Table Drains

Table drains shall be provided at the outer edges of any berms in cuttings or at other locations to the acceptance of the Engineer. Table drains shall be evenly graded throughout their lengths without stepping and shall be flared outwards from the formation. Table drains shall be diverted at intervals so as to discharge storm water into open drains, natural watercourses, culverts or upon the natural ground.

### 19.4.4 Precast Concrete Drains and Culverts

19.4.4.1 The roadside drains shall be constructed section by section and shall be generally completed before commencing work on the carriageway and kerbs. The precast units and sections shall be true to shape and of the correct dimensions, finish and strengthened with the required reinforcement.

19.4.4.2 All precast units shall be accepted for use by the Engineer before they are incorporated into any part of the works. Precast channels, revetment slabs, etc. shall be properly laid and bedded on a sand base at least 75mm thick, unless otherwise stated and joints pointed with cement mortar.

19.4.4.3 Side connections where required or shown on the Drawings shall be formed and secured in concrete and/or cement mortar and shall be finished to a smooth and uniform appearance.

19.4.4.4 All precast drains and culverts shall be laid to a gradient as indicated on the Drawings.

### 19.4.5 Scupper Drains

Scupper drains of 250mm diameter UPVC pipe shall be laid to the correct lines, levels and properly connected to the drop inlet chambers and roadside drains. Each pipe shall be properly bedded down and all butt joints sealed all round with cement mortar filleted up to form a collar 50mm wide by 25mm thick. Concrete sump shall be provided when the length of the scupper drain exceeds 6m.

### 19.4.6 Subsoil Drains

Unless otherwise stated, subsoil drains shall consist of 20mm size aggregate with a perforated 100mm diameter PVC pipe at its bottom, in accordance with Standard Details of Road Elements (SDRE). The whole of the subsoil drain shall be wrapped round with Geotextile Class B membrane as specified in Chapter 4, Earthworks.

### 19.4.7 Catch Drains and other Open Drains

19.4.7.1 Where the natural ground drains towards cuttings, catch drains shall be provided at each cutting during each excavation of the adjacent roadway, above each cutting unless otherwise accepted by the Engineer. The edges of catch drains shall not be less than 2.5m from the cutting. Unless otherwise directed by the Engineer, catch basins shall be at least 300mm deep and side slopes not steeper than the batter applicable to the material through which they are cut. The gradient shall be designed to ensure free flow of water and unless otherwise accepted by the Engineer, shall not be less than 1 in 100.

19.4.7.2 Catch drains shall be cut in uniform lines. Where obstructions occur in the line of a catch drain, the catch drain shall be diverted in a manner that is acceptable to the Engineer. Where graded banks are required in lieu of catch drains, the Contractor shall construct, in the same location, an embankment not less than 450mm high by 300mm wide at the top, with the side slopes not steeper than 2 horizontally to 1 vertically. Material for the embankment shall be obtained either from the excavation work or by neatly and uniformly trimming back the top edge of the batter of the adjacent cutting.

19.4.7.3 At side roads and vehicle entrances, catch drains shall be diverted to the table drains or other drainage system as accepted by the Engineer. Unless otherwise accepted by the Engineer, longitudinal median drains shall be provided between divided carriageways. Other open drains shall be provided at outlets from catch drains, table drains, subsoil drains, kerb and gutter and other points of water concentration to lead the water clear of the work to points of natural flow into culverts or into pits connected to existing drainage system. As far as practicable, the drains shall follow existing watercourses and depressions in the natural surface.

### 19.4.8 Lining of Drains

Unless otherwise accepted by the Engineer, earth drains, which have a gradient steeper than 5% shall be lined with concrete. The pitching or lining shall conform to the profile of the drains for a depth of at least 300mm and shall be carried out as specified.

### 19.4.9 Drainage Sumps And Covers

19.4.9.1 The requirements of drainage sumps and covers shall be as specified in clause 19.2.8 and the requirements herein.

19.4.9.2 The minimum internal width of all drainage sumps shall not be less than 1.5 times the width/diameter of the outgoing drain/pipe. Drains shall enter the sump at angles less than a right angle and at different levels wherever possible. The invert level of the downstream drain shall be lower than the invert level of the sump so that no stagnant water will collect in the sump.

## 19.5 CONSTRUCTION/ EXCAVATION

All excavation, backfilling, pipeline setting out, concreting works, pipe laying and clearing pipeline of obstruction shall be as specified in M&W for M&E Works Sewerage and Sanitary Plumbing Chapter and the requirements herein.

### 19.5.1 Excavation

19.5.1.1 General

The Contractor shall notify the Engineer sufficiently in advance of the beginning of any excavation. The natural ground adjacent to the structure shall not be disturbed without permission of the Engineer.

19.5.1.2 Depth

Trenches or foundation pits for structures shall be excavated to the lines and levels shown on the plans or as indicated by the Engineer. They shall be of sufficient size to permit the placing of structures at the full width and length shown.

19.5.1.3 Material Encountered

Boulders, logs and any other objectionable material encountered in excavation shall be removed.

19.5.1.4 Width of Trench

For installations in a trench, the width of the trench shall be sufficient to permit satisfactory jointing of the pipe and thorough tamping of the bedding material under and around the diameter of the pipe.

19.5.1.5 Verticality

Side walls on trenches shall be practically vertical to an elevation above the top of the pipe structure.

19.5.1.6 Completion

After the excavation is completed, the Contractor shall notify the Engineer to that effect. No bedding or pipe shall be placed until the Engineer has accepted the excavation and the character of the foundation materials.

19.5.1.7 Drainage Trenches

Excavation of drainage trenches shall be to the lines and gradients required for the pipes, channels, culverts, etc. The trench bottom shall be of sufficient width to allow adequate working space for the pipe joiners.

Unless otherwise specified, excavated material shall not be deposited within 610mm of the edges of the trench. Trenches deeper than 1.5m shall be constructed with suitable temporary ground support. The method and materials for planking and strutting shall be submitted to the Engineer for acceptance. In the event of excavations being made deeper than necessary, they shall be made up with Grade 15 concrete at the Contractor’s expense. The excavation shall be kept free from water by pumping, baling or otherwise.

19.5.1.8 Subsoil Drain Trenches

Trenches for subsoil drains having pipes up to 150mm diameter shall be excavated to a width of at least four times the nominal diameter of the pipe or as shown on the Drawings. For pipe diameter above 150mm, the width shall be the external diameter of pipe plus 450mm or as shown on the Drawings.

**19.5.2 Foundation**

19.5.2.1 Except for the sections described below, the pipe shall be placed on a firm earth foundation of uniform density for the entire length of the structure and to the line, levels and camber accepted by the Engineer.

19.5.2.2 Where rock or other unyielding material is encountered, it shall be removed to at least 300mm below the bottom of the structure. The width of the excavation shall have a minimum of 600mm greater than the pipe diameter. The excavated area shall be backfilled with selected material and shall be thoroughly compacted to provide a cushion for the structure.

19.5.2.3 When soft or yielding soil is encountered, the Contractor shall provide a uniform and adequate support for the pipe by replacing the soil with mechanically compacted granular materials or by providing piled foundation.

**19.5.3 Backfilling**

19.5.3.1 Material

Backfill material shall be selected material to the acceptance of the Engineer. Backfill material shall preferably be granular. It shall be free of vegetable matter, lumps, cinders, boulders or rocks.

19.5.3.2 Depositing of Backfill Material

The backfill material shall be deposited evenly on both sides of the pipe in layers not exceeding 150mm in depth (loose measure) and thoroughly compacted to a minimum of 90% of modified AASHTO optimum dry density.

19.5.3.3 Compaction

Compaction may be done by hand or with mechanical equipment, tamping rollers or vibrating compactors, depending upon field conditions and as accepted by the Engineer.

19.5.3.4 Minimum Depth

The Contractor shall provide a compacted earth cover of at least 600mm or one diameter, whichever is the greater, over the pipe before equipment is allowed to be driven over it.

19.5.3.5 Backfilling of Drainage Trenches

No trench shall be filled until after the drain therein has been tested and accepted. Earth filling from the bottom of trenches and to a height of 300mm above the top of the pipes shall be of selected materials, compacted, watered if necessary and well rammed on either side of the pipes. The remainder of the earth filling shall be in layers of 300mm each, watered if necessary and well rammed with mechanical rammers or other efficient means of effecting compaction.

19.5.3.6 Maintaining Shape of Structure

19.5.3.6.1 Two main movements may occur during backfilling – peaking caused by the pressure of the compacted side-fill and rolling caused by higher fill or greater compaction on one side.

19.5.3.6.2 All movements of a point on the circumference of the structure shall be limited to about 2% of the diameter of the structure.

19.5.3.6.3 Vertical plumb lines suspended from the crown of the structure on the entire line shall be used to indicate shape changes or tendency to roll during backfilling and may point to the need for strutting or some modification of the backfilling technique.

**19.5.4 Testing**

19.5.4.1 Test for Pipeline

Pipework shall be hydrostatically tested to a water head of 1500mm at the high end and not more than 2400mm at the low end. Pipelines shall be tested in sections so that the above maximum head shall not be exceeded. Unless otherwise accepted by the Engineer, the test shall commence one hour after filling the test section at which time the level of water at the vertical feed pipe shall be made up to produce the required 1500mm minimum test head. The loss of water over a thirty-minute period shall be measured by adding water at regular ten-minute intervals to maintain the original water level and recording the amounts so added. The drain will pass the test if the volume of water added does not exceed four litres per hour per 6 metres of drain per 50mm of nominal internal diameter. Drains failing to pass the test shall have the defects made good and be re-tested.

19.5.4.2 Duration

In every test, water used shall be left in the pipes until backfilling of trench filling material to a depth of at least 1 metre over the top of pipes or until permission is given by the Engineer for the water to be released. If pipes become damaged and lose water from any cause and/or admit subsoil water the Contractor shall have the pipes uncovered and the defect made good and the pipes retested as before.

19.5.4.3 Backfilling

Backfilling shall not commence until testing has been conducted to the acceptance of the Engineer.

19.5.4.4 Test for Precast Concrete Pipe Culverts

The Engineer shall have access to the casting yard where the precast concrete pipe culverts are being manufactured. A copy of the manufacturer's test certificate shall be provided to the Engineer on demand. The precast concrete pipe culvert shall be tested to SS 183.

## Product Warranties

a) This list is a guideline.

b) To be included in the Particular Specification.

| CLAUSE NUMBER | ITEM | WARRANTY PERIOD |
| --- | --- | --- |
| 10.8.3 | Reflective sheeting and vinyl films | Type I & II: 3 years<br>Type III to VI: 7 years<br>Type VII to XI: 7 years |
| 10.8.4 | Transparent Process Inks | Type I & II: 3 years<br>Type III to VI: 7 years<br>Type VII to XI: 7 years |
| 11.9.5 | Protective Coatings for Concrete Surfaces | 10 years |
| 13.3.1 | Viaduct Decking Waterproofing | 10 years |
| 14.7 | Watertightness for Structures | 10 years |
| 15.2.2 | Bearings | 10 years |
| 15.3.4 | Movement Joints | 10 years |
| 17.6.5<br>17.7.9 | Watertightness for Mined Tunnels and Sprayed Concrete Linings | 10 years |

**Checklist for references to PS, GS & Authority's Drawings in the M&W Specification**

| Chapter No. | Particular Specification<br>Clause ref. | General Specification<br>Clause ref. | Authority's Drawing(s)<br>Clause ref. |
|---|---|---|---|
| **Chapter 1** | - | - | - |
| **Chapter 2** | 2.2 | - | - |
| **Chapter 3** | - | - | - |
| **Chapter 4** | - | - | - |
| **Chapter 5** | - | - | - |
| **Chapter 6** | - | 6.27 | - |
| **Chapter 7** | - | - | - |
| **Chapter 8** | - | - | - |
| **Chapter 9** | 9.25.2 | - | - |
| **Chapter 10** | - | 10.8.3.1 | - |
| **Chapter 11** | - | - | - |
| **Chapter 12** | 12.6.2 | - | - |
| **Chapter 13** | - | 13.3.1.5 | - |
| **Chapter 14** | - | 14.7 | Fig.14.4(a) |
| **Chapter 15** | - | 15.2.2 | - |
| **Chapter 16** | - | - | - |
| **Chapter 17** | - | 17.3.9.1<br>17.6.5<br>17.7.9 | - |
| **Chapter 18** | 18.3.1.3 | - | |
| **Chapter 19** | - | - | - |

## 1.1 CLAUSES TO BE INCORPORATED INTO PARTICULAR SPECIFICATIONS AS REQUIRED

### 1.1.1 ADMINSTRATIVE CHARGE

For non-compliance with 11.8.4 of the Materials & Workmanship Specification, an administrative charge of $20/m$^3$ on the quantity of concrete at risk shall be deducted from the Contract Sum as in 11.8.5.

When successive group failures lead to the overlap of the quantity of concrete at risk, such quantities shall be considered only once.

Deduction of the administrative charge shall not relieve the Contractor of his contractual liabilities, including the works stated in 11.8.6 of the Materials & Workmanship Specification.

## 1.2 SURFACE FINISH OF CONCRETE

1.2.1 For structural element where Class F3 finish is specified, the Contractor shall provide a mock-up structure for the Engineer’s acceptance. The mock-up structure shall incorporate all expected features on the permanent structure, eg. Feature grooves and recesses etc. The Engineer will access the standard of this mock-up structure and, if not acceptable, then further mock-up structure shall be erected until a satisfactory standard is achieved. Once an acceptable mock-up structure has been constructed the Engineer will give approval for the commencement of permanent works and the mock-up shall be retained as a measure of the acceptability of these permanent works. The Contractor shall maintain the mock-up structure until the Engineer directs their removal.

For Viaduct Columns the Contractor shall provide a mock-up structure for the Engineer’s acceptance.