Land Transport Authority

ENGINEERING GROUP

CIVIL DESIGN CRITERIA
FOR ROAD AND RAIL TRANSIT SYSTEMS

E/GD/09/106/A1

Controlled Document

Issue	Date	Prepared By	Vetted By	Approved By	Approved for Implementation	Description of Revision
A1	Feb 2010	Chua Swee Foon AgDyM	Wen Dazhi DDCDE	Neo Bian Hong D(Desg)	Paul Fok GDE	Reference renamed from PED/DD/K9/106/A7. Amendment to Cl.11.2.3.2.1 & Table 11.2.

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CHAPTER 1

GENERAL

1.1   INTRODUCTION

1.1.1   Scope

The Design Criteria give the requirements for the design and detailing of all Civil Engineering Works for the Land Transport Authority.

1.1.2   Definitions

The definitions of "Authority", "Contractor" and "Works" etc. shall be those given in the Conditions of Contract.

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

The use of the terms "rapid transit", "stations" etc, shall be taken to apply to all guided systems, whether MRT or LRT, whether steel on steel or rubber tyres on guideways, unless specifically stated otherwise or agreed otherwise with the Engineer.

1.1.3   General Obligations

1.1.3.1   Compliance with Statutory Requirements and International Standards.

All designs shall be carried out and fully endorsed by Professional Engineers holding a valid practising certificate and registered under the Professional Engineers Act, Singapore in the civil and/or structural discipline, and also by registered Accredited Checkers in accordance with the Building Control Act.

All designs shall comply with relevant regulations, Building Control Act and Fire Safety Act.

Compliance with a Singapore Standard (SS) or British Standard (BS) or a standard approved by the Authority (or accepted by the Engineer) or the requirements of these Design Criteria shall not confer immunity from legal obligations.

1.1.3.2   Adjacent Works

The design shall take into account any constraints or effects imposed by the existing and planned works and services in the surrounding areas, and works of other nearby developments.

1.2 STANDARDS

1.2.1 Use of Singapore and British Standards

The design of all Works shall comply with the appropriate current standards and/or Codes of Practice issued by the Standards, Productivity and Innovation Board (SPRING Singapore), or if such a standard and/or Code of Practice does not exist, then the appropriate current standard issued by the British Standards Institution (BSI). If an appropriate standard from SPRING Singapore and BSI does not exist and no other standard is stated in the Contract Documents, then subject to the acceptance of the Engineer and the Commissioner of Building Control of The Building and Construction Authority, an appropriate current standard from a reputable institution may be used. Three English language copies of such proposed standards shall be submitted to the Engineer.

Generally the requirements spelt out in the Particular Specification, General Specification, M&W Specification and the Design Criteria shall take precedence over any relevant Singapore or British Standards, UK Highways Agency Standards and advisory notes or other International Codes of Practices.

Where metric unit and imperial unit version of the same standard exist, the metric version shall apply.

1.2.2 Use of British Standard BS 5400

1.2.2.1 Unless noted otherwise use of BS 5400 shall be as implemented by the United Kingdom Highways Agency Standards and Advisory notes and as further amended by the Design Criteria.

1.2.2.2 References made within the Design Criteria to BS 5400 Part 2 shall be to the composite version of BS 5400 Part 2 (which forms an appendix to the United Kingdom Highways Agency Departmental Standard BD 37/01) and as further amended by the Design Criteria.

1.2.3 Use of United Kingdom Highways Agency Design Manual for Roads and Bridges

The design shall also comply with the following Standards contained in the Design Manual for Roads and Bridges, except where explicitly stated otherwise in the Design Criteria:

BD 15/92   General Principles for the Design & Construction of Bridges –
         Use of BS 5400: Pt 1: 1988
BD 16/82   Design of Composite Bridges – Use of BS 5400: Pt 5: 1979
BD 20/92   Bridge Bearings – Use of BS 5400 Pt 9: 1983
BD 24/92   Design of Concrete Highway Bridges and Structures – Use of
         BS 5400: Pt 4: 1990
BD 27/86   Materials for the Repair of Concrete Highway Structures
BD 28/87   Early Thermal Cracking of Concrete

BD 30/87   Backfilled Retaining Walls and Bridges Abutments
BD 32/88   Piled Foundations
BD 33/94   Expansion Joints for Use in Highway Bridge Decks
BD 36/92   The Evaluation of Maintenance Costs in Comparing Alternative Designs for Highway Structures
BD 37/01   Loads for Highway Bridges
BD 52/93   The Design of Highway Bridge Parapets
BD 60/94   Design of Highway Bridges for Collision Loads
BA 26/94   Expansion Joints for Use in Highway Bridge Details
BD 49/01   Design Rules for Aerodynamic Effects on Bridges
BD 31/01   The Design of Buried Concrete Box and Portal Frame Structures

1.3   DESIGN

1.3.1   Responsibility for Design

Staff with proven relevant experience shall be deployed to design and detail the Works using their skills to the best of their abilities to achieve the design objectives described in Clause 1.3.2 below.

1.3.2   Design Objectives

The design of structures and civil engineering works shall meet the following objectives: they shall be safe, robust, economical, durable, with operation and maintenance costs reduced to a practicable minimum, and shall be fit for purpose. Simplicity of structural form and layout is preferred. All structures shall be designed to be aesthetically pleasing.

The elements of all structures shall be designed and detailed to achieve the design objectives by, inter alia, the following:

(a) appropriate selection of materials
(b) consideration of the long term deterioration of materials in the service environment
(c) due care in design and detailing so as to facilitate good workmanship in construction and the achievement of design intent
(d) consideration of access and other requirements for inspection and maintenance
(e) adoption of good engineering practice
(f) use of low risk construction methods and proven techniques

The durability objective of the project shall be to achieve a service life, with appropriate maintenance, of 120 years for all permanent structures. The measure of achievement of durability shall be that all the criteria set in the design shall be maintained throughout the service life. Deterioration of materials shall be taken into account in the design and specification of the works.

Due diligence and skills shall be applied in the design and detailing to ensure that the works can be constructed economically, practically and safely.

All structural designs shall comply with all the ultimate and serviceability limit states.

1.3.3   Design of Temporary Works

All Temporary Works shall be designed and detailed to be compatible with the Permanent Works.

Temporary Works designs shall be carried out and endorsed by a Professional Engineer.

Any part of the Permanent Works that performs a temporary function during construction shall be defined as Permanent Works and shall be analysed for both conditions (permanent and temporary) and designed using Permanent Works design criteria for the more onerous condition.

1.3.4   Design For Removal of Temporary Works

1.3.4.1   All Temporary Works shall be designed for removal.

1.3.4.2   Exceptionally, the Contractor may propose to leave Temporary Works in place, where it is impracticable to remove them.

Prior to installation the Contractor shall obtain the acceptance of the Engineer for any such proposal.

1.3.4.3   Temporary Works shall be designed such that there is no risk of damage to the Permanent Works during removal.

Unless otherwise accepted by the Engineer, all voids left in the ground due to the extraction of temporary works shall be immediately filled with grout. The grout mix and method of grouting shall be submitted to the Engineer for acceptance.

1.3.4.4   Where it is agreed that Temporary Works may be left in the ground they shall be designed so that there will be no risk of ground settlement or other deleterious effects as a consequence of decay of timber or other materials.

Temporary Works that are allowed to be left behind shall be designed to be removed to a depth of 2 metres below the finished ground level unless shown otherwise on the Authority's Drawings. This shall also apply to all secant piles and diaphragm walls and the like.

Details of the construction sequence assumed, identification of the Temporary Works that are not to be removed (if any) and provisions made

in the design to satisfy the above requirements shall be detailed on the Temporary Works design drawings.

Any Temporary Works not removed shall be shown on the as-built drawings.

1.3.5 Oversite and Adjacent Developments

All structures are to be designed wholly independently of any benefit which might be obtained from oversite or adjacent development. For example, in consideration of stability against flotation or of any lateral loading, the design should allow for the development not being present if that gives a more onerous design case.

1.3.6 Structure Gauge

All moveable equipment, hinged doors, windows, etc close to the track shall be positioned so that they are not within the Structure Gauge at every position of movement. All covers to sumps, pits, etc within the track slab shall not infringe the Structure Gauge when in the open position.

1.4 CALCULATIONS

1.4.1 Method of Calculations

Unless otherwise varied by the subsequent Chapters of the Design Criteria, all calculations shall be carried out in accordance with the requirements and recommendations of appropriate current Standards.

The use of "State-of-the-Art" methods of calculations or methods that have not been extensively tried and proven within the industry will not be permitted unless prior acceptance for their use has been obtained from the Engineer. The design shall be in accordance with established good engineering practice and principles.

1.4.2 Use of Computer Programs

The use of computers is permitted, provided the computer programs to be used are accepted by the Engineer.

The programs to be used shall be those that are produced by reputable software houses, have undergone extensive testing and have been successfully used and proven in similar projects. In this respect, the relevant documents and sample calculations to demonstrate the accuracy and reliability of the programs shall be submitted. Details of computer programs, including assumptions, limitations and the like, shall be clearly explained in the design statement.

All input and output data of a computer program shall be clearly defined and the calculations shall include clear and unambiguous information of what each parameter means in the computer output forms.

When in-house spreadsheets are used, the proposed version of the spreadsheet shall be clearly indicated and submitted together with hand calculations to verify the results of the spreadsheet for all possible calculation scenarios. A print-out of the spreadsheet showing the formulae normally hidden shall also be submitted with the cell references clearly labelled along the top and left hand margins of each page.

1.4.3   SI Units

All calculations shall be carried out and presented in SI Units as specified in BS 3763. The units of stress shall be N/mm^2 or kN/m^2.

1.4.4   Language

All calculations and other documents shall be submitted in the English Language.

1.5   SURVEY & SETTING OUT

1.5.1   Levels

All levels given on the design drawings shall refer to a Project datum 100m below Singapore Land Authority Precise Levelling Datum (PLD).

1.5.2   Co-ordinates

All co-ordinates given on the design drawings shall be based on the project co-ordinate system as defined in the Particular Specification. The project co-ordinate system shall be clearly defined and indicated on the design drawings.

1.6   DURABILITY ASSURANCE

1.6.1   Design Considerations

The design shall address the durability of all elements of the structures. The design process shall incorporate an assessment of potential deterioration of materials in their exposure environments (e.g. exposure to ground water) throughout the service life, including but not limited to:

(a) durability of concrete,
(b) corrosion of metals,
(c) long term performance of sealants, waterproofing, coatings and other forms of protection,

Construction processes, which are critical to the achievement of durability, shall be identified. These include workability requirements for casting concrete around relatively congested reinforcement sections, and duration of placement in terms of delay in setting to avoid cold joints.

1.6.2   Critical Elements

Particular attention shall be given to deterioration of elements, which cannot practically be accessed for maintenance or repair during the service life. In the case of such critical elements, the design shall be premised on the element (including all its components) remaining durable throughout the service life without maintenance. Additional measures shall be incorporated in the design of such elements to address the eventuality of the primary protection failing to achieve the desired durability. Where normal methods of inspection are impossible, provision for monitoring material performance by instrumentation shall be implemented where practicable.

1.6.3   Durability Assessment

Based on the durability objectives of the project, performance criteria for materials shall be developed from an assessment of the following: -

(a) the micro-environment to which the element is exposed
(b) potential deterioration mechanisms in this micro-environment
(c) the likely material life
(d) the feasibility and cost of in situ monitoring, maintenance and/or repair
(e) the necessity and cost-effectiveness of providing additional protection
(f) the significance of deterioration.

In addition to the assessment of "the likely material life", the quality control tests to monitor the quality of concrete for durability and the acceptance criteria shall also be provided.

Any proposal to revise the Materials and Workmanship specifications shall be based on the performance criteria arising from such considerations.

1.6.4   Life Cycle Cost Analysis

Where required, life cycle cost analysis shall be undertaken as a basis for selection of materials. Such analysis will require establishment of material performance and life of all components of the element and compare the total life cycle costs of viable options, by summation of: -

(a) initial capital cost,
(b) total recurrent costs of inspection, monitoring, maintenance/repair and
(c) replacement cost

Total life cycle costs, shall be expressed in net present value by using discounted cash flow techniques based on 5% discount rate. The analysis is to be used as a decision making process, hence the life cycle costs need only be sufficiently accurate for the purpose of comparison of

options. A sensitivity analysis shall be undertaken to reflect the uncertainties related to: -

(a) predictions of material performance
(b) workmanship in construction
(c) unit rates for calculation of inspection, maintenance, repair and replacement costs.

1.6.5   The design characteristic strength, the maximum nominal aggregate size, the minimum cement content, the maximum cement content, and maximum free water: cement ratio and permitted cement types shall be shown clearly on the design drawings for reinforced, precast and prestressed concrete works together with any other restrictions on materials or properties required.

1.6.6   Drawings

The preparation of drawings shall comply with Drawing and CAD Standard (Microstation) and SS CP83.

1.7   MATERIALS AND WORKMANSHIP SPECIFICATION

Attention is drawn to the obligation to review the Materials and Workmanship Specification. The Materials and Workmanship Specification should however be regarded as a minimum standard. Any provision of the Materials and Workmanship Specification which appears incompatible with the design basis shall be highlighted, and appropriate modifications to the Materials and Workmanship Specification shall be proposed, and agreed with the Engineer.

1.8   DIMENSIONS

All dimensions given on the Authority's Drawings or within the Authority's documentation shall be taken to be minimum dimensions to be achieved on site after allowance for all construction tolerances, deflection of embedded walls, sagging of beams and floors, etc.

1.9   BLINDING

Reinforced and/or prestressed concrete shall be cast against an adequate concrete blinding and not directly against the ground. For the blinding concrete, the minimum concrete grade and thickness shall be C 15 and 50 mm respectively. The thickness and strength of blinding may need to be increased depending on the softness and irregularity of the ground and the thickness of the concrete pour. Where the ground beneath the blinding is to be removed at a later date (for example in top-down construction) a debonding membrane shall be used at the interface between the blinding and reinforced concrete. The blinding and membrane details shall be indicated on the design drawings.

1.10   LAND BOUNDARIES

1.10.1   In determining the design of the Works, the designer shall take into account the land available to the Authority and the need to optimise land use. Existing land boundaries shall be observed to avoid adverse encroachment to adjacent properties.

1.10.2   For railway projects, the Authority takes legal ownership of that portion of State land occupied by station boxes, sub-stations, depots and ancillary facilities as determined by the Singapore Land Authority. For all other railway-related facilities on State land, the Authority exercises statutory rights under the Rapid Transit Systems Act.

1.10.3   For non-State land, the Rapid Transit Systems Act allows for the permanent placement of railway related structures and facilities on the land provided that such structures and facilities shall be confined to ventilation shafts, cooling towers, emergency escapes and entrance structures which are fire-escape routes. The railway structures and railway related facilities are to be located on non-State land only as a matter of last resort and should be accessible from State land. Where in the opinion of the Authority, the design and positioning of a railway related structure or facility is such that the Authority will be required to take legal ownership of the affected non-State land, the Authority reserves the right to reject such a proposal.

1.10.4   For road design, the designer shall take into account that the roads are only built on State Land. Such State Land shall include those parcels of private land which have been identified to be acquired for the road project as well as those which had been set aside for road purposes as stipulated under a related planning condition.

1.10.5   In addition to the use of State Land, the Street Works Act allows for the permanent placement of road structures and road related facilities on non-State land. The road structures and road related facilities should be located on State land as far as possible. Road structures and road related facilities are to be located on non-State land only as a matter of last resort and should be accessible from State land.

1.10.6   The layout of the Works shall take into account proposed and existing land boundaries to make full utilisation of available land. Excision of land parcels leading to creation of remnant unusable plots shall be avoided.

1.10.7   All facilities (for example lighting posts, handrails, inspection chambers, utility service meters, etc.) that serve the Road Works shall generally be sited within the road reserves.

1.10.8   All site layout plans, including those of working sites and casting yards shall show existing cadastral information, Road Reserves Lines, Railway Protection Zones and Drainage Reserves. The designer is advised that this information available from government agencies is of lower accuracy and only locally consistent when compared to the precise survey controls

established for the construction of the project. Due allowance in the form of specific field surveys to resolve critical differences shall be made in site layout design.

1.10.9 All rooms and revenue generating elements not essential for the operation of the facility (e.g. toilets, shops, kiosks, advertising panels etc.) shall be positioned within the station box.

1.11 FLOOD PROTECTION

1.11.1 The Design Flood Level shall be in accordance with the prevailing requirements of PUB (Drainage). Traditionally PUB(Drainage) set the Design Flood Level at 1m above the highest recorded flood level at that location.

1.11.2 All entrances, vent shafts openings, tunnel portals, service entries and other openings into underground railway structures and all road thresholds and perimeters to depressed carriageways, underpasses and road tunnels shall not be lower than the Design Flood Level.

1.11.3 Where drainage or sewerage pipes discharge from the underground structure into the surface system, swan necks shall be provided at a level above the Design Flood Level. If gravity drainage provisions are made, the drainage exit points shall be above the Design Flood Level to prevent any back flow of water into the sub-surface structures during floods.

1.11.4 Platform and Crest Level

Where entrances, vent shafts, tunnel portals or other openings into underground railway structures are located on a platform, the platform level shall be set at or above the Design Flood Level. The threshold level of any opening on the platform shall be at least 150mm higher (crest level) than the platform level to prevent flooding from sudden downpours. At entrances, this requirement shall be met by sloping the surface away from the threshold and not by a step.

1.11.5 Adjoining Developments

The threshold level of any entrances and opening into any development with a connection to an underground station shall not be lower than the Design Flood Level of the station for the flood prevention of the rapid transit system. Any platforms at the entrances to adjoining developments shall also comply with the platform and crest level requirements above.

1.11.6 All arrangements for flood protection shall meet the requirements of PUB (Drainage).

CHAPTER 2

RTS ALIGNMENT

2.1   GENERAL

2.1.1   The design of the track alignment shall comply with the functional requirements stipulated in this chapter and shall take full account of all relevant factors including the design criteria, requirements of Operation, Signalling, Traction power, Rolling stock, Track maintenance, Construction constraints and cost, Existing structures and utilities, Geotechnical and tunnelling conditions, Environmental impact and Land use.

2.1.2   In third rail system, the design of the track alignment and third rail arrangements shall consider the traction power requirement of the train in used. The design shall ensure there is a continuity of traction power to prevent any possibility of a train stalling along the mainline due to loss of traction supply resulting from third rail gap.

2.1.3   The design shall be co-ordinated with all relevant designers, contractors and other authorities. The design shall comply with the specified desirable value.   The use of absolute minimum or maximum value must be demonstrated and is subject to the Authority's acceptance.

2.1.4   Rapid Transit System (RTS) is a ground based passenger transit system operated by passenger-carrying vehicles constrained to operate on a fixed guideway.

2.1.5   Mass Rapid Transit (MRT) is a rapid transit system, which provides sufficient capacity to move more than 10,000 passengers per hour per direction (pphpd). It is a steel wheel on steel rail system.

2.1.6   Light Rapid Transit (LRT) is a rapid transit system, which provides sufficient capacity to move up to 10,000 pphpd. It is a rubber tyre on concrete surface system.

SECTION A - MRT ALIGNMENT

2.2   HORIZONTAL ALIGNMENT

2.2.1   Horizontal Curves

2.2.1.1   *Track gauge* is the distance measured between the inside face of the two running rails at a point 14mm below the crown of the rails *(gauge points)*. For MRT rail systems track gauge shall be 1435mm.

2.2.1.2   *Horizontal alignment – non-tunnel* is the alignment based on a point midway between gauge points.

2.2.1.3   *Horizontal alignment – in tunnel* is the alignment based on a point on the track centre line at a height 1600mm above the rail line.

2.2.1.4   *Circular Curve* is a curve of constant radius.

2.2.1.5   *Compound Curve* is a curve formed of two or more circular curves of differing radii curving in the same direction. The circular curves may be linked by transition curves.

2.2.1.6   *Reverse Curve* is a curve formed of two or more circular curves curving in alternate directions which may be linked by transition curves. A reverse curve has no straight track between each circular curve but has abutting transition curves. For the purpose of the alignment, each part of a reverse curve shall be given a separate curve number.

2.2.1.7   The limits for radii for horizontal circular curves are shown below:

	Mainline		Depot & non - passenger Tracks
	Desirable Minimum	Absolute Minimum	Absolute Minimum
MRT system (above ground)	500m	400m	190m
MRT system (underground)	400m	300m	190m

2.2.1.8   The track shall preferably be straight throughout the length of stations. The presence of external constraints may necessitate limited encroachment of curves at station ends.

2.2.1.9   Track through platforms shall be straight. The start of a horizontal curve, transition curve or a turnout shall have a minimum distance of 20m from the platform end to avoid the vehicle throw affecting the platform nosing clearance. Where encroachment is unavoidable, this shall be limited such that the combined effects of vehicle throw and cant do not affect the

location of the nosing at platform ends by more than 20 mm when compared to straight track.

2.2.1.10 Circular curve radii shall be selected to be the maximum practicable. The radius selected for any particular curve shall not be so large as to unnecessarily impose more severe curvature of the track at either end of that curve.

2.2.1.11 The combination of circular curve and their related transition curves shall be chosen such that the length of pure circular arc between transitions is not less than the following: -

Desirable minimum   50 metres
Absolute minimum   20 metres

2.2.1.12 The length of straight track between the ends of the curves or of the transitions shall not be less than the following: -

Desirable minimum   50 metres
Absolute minimum   20 metres

2.2.1.13 Wherever possible, compound curve shall be avoided.

2.2.2 Cant and Speed

2.2.2.1 *Cant (Superelevation)* is the vertical distance by which one rail is raised above the other and measured between the crowns of the two running rails. Cant is positive when the outer rail on a curve is raised above the inner rail or negative when the inner rail is raised above the outer.

2.2.2.2 *Equilibrium Cant* is the cant required to enable a vehicle to negotiate a curve at a particular speed, known as the equilibrium speed, such that the resultant of the weight of the train and its centrifugal force is perpendicular to the plane of the rails.

2.2.2.3 *Applied Cant* is the actual cant specified for the curve.

2.2.2.4 *Cant Deficiency* is the amount by which the applied cant is less than the equilibrium cant for the speed being considered.

2.2.2.5 *Excess Cant* is the amount by which the applied cant is greater than the equilibrium cant for the speed being considered.

2.2.2.6 *Cant Gradient* expressed as a dimensionless ratio, is the gradient at which cant is increased or reduced.

2.2.2.7 *Rate of Change of Cant or of Cant Deficiency* in millimetres per second is the rate at which cant or cant deficiency is increased or reduced relative to the speed of the vehicle.

2.2.2.8   *Line Speed Limit* (in km/h) is the maximum speed permitted for any train anywhere on the line.

2.2.2.9   *Restricted Speed* is the nominal maximum permissible speed for a section of track imposed by means of a *permanent speed restriction* and is determined by the comfort condition criteria.

2.2.2.10   *Design Speed* at a particular point on the track is the speed of the train at that point calculated from the coasting run speed profiles prepared by the signalling or rolling stock designer.

2.2.2.11   *Flatout speed* at a particular point on the track is the speed of the train at that point using maximum accelerating and braking capacities on a run between two adjacent stations and is calculated from the flatout speed profiles prepared by the signalling or rolling stock designer.

2.2.2.12   The curve-speed-cant relationship shall be based on the following equations :-

$$\text{Equilibrium cant } E \ = \ \frac{11.82 \, V_e^{\,2}}{R}$$

$$\text{Maximum permissible speed} \quad V_m \ = \ 0.29 \sqrt{R \, (E_a + D)}$$

Where :
R	=	horizontal curve radius in metres
V_m	=	maximum permissible speed in kilometres per hour
V_e	=	equilibrium speed in kilometres per hour
E	=	equilibrium cant in millimetres
E_a	=	actual applied cant in millimetres
D	=	maximum allowable deficiency of cant in millimetres

Formulae are only applicable for a track gauge of 1435mm.

2.2.2.13   The maximum allowable applied cant shall be:

	Desirable Maximum	Absolute Maximum
For concrete track	125mm	150mm
For ballasted track	110mm	125mm

2.2.2.14   The amount of cant deficiency or excess cant at any point on the line shall be limited to the following :-

Plain Line	
Desirable Maximum	90mm
Absolute Maximum	110mm
Turnouts	
Maximum	90mm

2.2.2.15 Cant shall be selected to suit the design speed (typically 70% of equilibrium cant). Cant deficiency shall be checked against flatout speed to suit comfort condition criteria and cant shall be adjusted upwards as necessary. Consideration for both cant and cant deficiency shall also take into account the requirements of Clauses 2.2.3.6 and 2.2.3.7

2.2.2.16 Where constraints on the alignment design are such that the requirements of Clause 2.2.2.15 cannot be met, a permanent speed restriction shall be imposed. Such restrictions shall be minimised as far as practicable.

2.2.2.17 Suitable cant values shall be estimated during the preliminary design. The cant shall be finally selected from a consideration of the design speed and flatout speed.

2.2.2.18 Applied cant shall be specified to the nearest 5 millimetre for concrete track and ballasted track. Cant of less than 20mm need not be applied.

2.2.2.19 In cases where the design speed of the train on part or all of a curve is considerably less than the line speed limit, it may be necessary to impose a permanent speed restriction to ensure that any excess cant at the design speed is kept to a practical minimum.

2.2.2.20 Application of cant shall be introduced throughout the length of a transition curve.

2.2.2.21 At civil defence station, straight track shall be provided at civil defence blast door location where possible.

2.2.3 Transition Curves

2.2.3.1 *Transition Curve* is a curve of progressively varying radius used to link either a straight with a circular curve, or two circular curves of different radii.

2.2.3.2 *Virtual Transition* is a length over which a train car experiences a change from straight to circular curve when no transition curve occurs. Its length is the distance between outer wheelbase (equal to the bogie wheelbase plus bogie centre distance) and is theoretically placed symmetrically about the tangent point.

2.2.3.3 *Shift* is the amount by which the centre of radius of a circular curve needs to move due to the placement of transition curves.

2.2.3.4 In general for all mainline tracks, transition curves shall be provided wherever possible between a circular curve and adjoining straight track, between the different radii of compound curves and at the adjoining ends of circular curves forming reverse curves.

2.2.3.5   Transition curves shall be clothoids. The formula for clothoid is as shown in the following figure 1:

$$\theta = \frac{l}{2R}$$
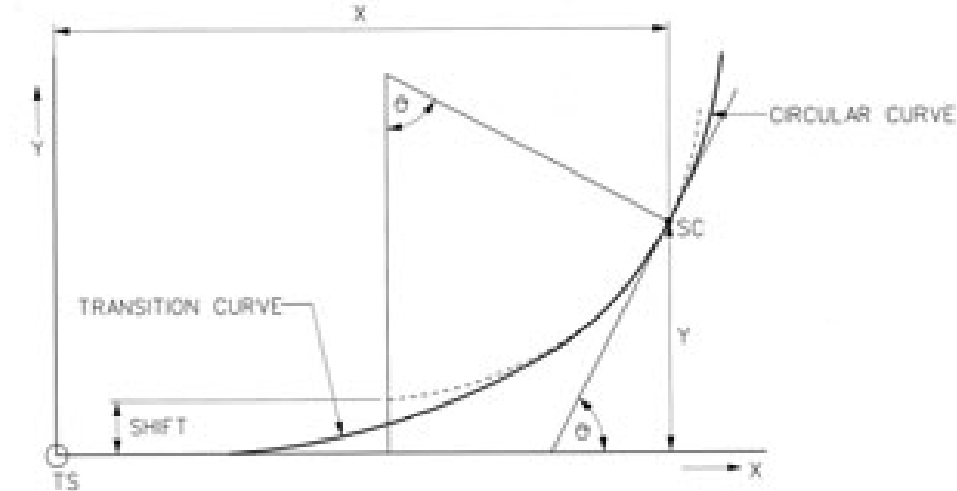
$$\theta = \left(\frac{d}{L}\right)^2 \theta$$

$$X = d\left[1 - \frac{\theta^2}{10} + \frac{\theta^4}{216} - \frac{\theta^6}{9,360} + \frac{\theta^8}{685,440}\right]$$

$$Y = d\left[\frac{\theta}{3} - \frac{\theta^3}{42} + \frac{\theta^5}{1,320} - \frac{\theta^7}{75,600} + \frac{\theta^9}{6,894,720}\right]$$

Where

R	=	horizontal curve radius
TS	=	point of change from tangent to transition curve
SC	=	point of change from transition curve to circular curve
L	=	overall transition curve length
d	=	transition curve from TS to any point on transition curve
θ	=	central angle of transition curve
X	=	tangent distance of any point on transition curve with reference to TS
Y	=	tangent offset of any point on transition curve with reference to TS

Figure 1 - Clothoid Transition Curve

2.2.3.6   The cant gradient (not cant deficiency) shall be subject to the following limits:-

Absolute maximum	= 1 : 500
Desirable	= 1 : 750
Minimum	= 1 : 1000

2.2.3.7 The rate of change of cant or cant deficiency shall be limited as follows:-

Plain Line	
Desirable maximum	35mm/s
Absolute maximum	55mm/s
Turnouts	
Absolute maximum	80mm/s

2.2.3.8 Transition curves will not normally be required between the different radii of a compound curve where the change of radius of curvature does not exceed 15% of the smaller radius. Change in cant is applied over an effective transition length centred on the point where radii change and of a length to satisfy the requirement of Clause 2.2.3.7 or car bogie centres whichever is greater.

2.2.3.9 Where a compound circular curve is employed with a change of radius greater than 15% of the smaller radius, a transition curve shall be interposed between the two parts of the curve. The length of such a transition shall be equal to the difference between the required transition lengths at each end of the curve.

2.2.3.10 When the shift of any calculated transition curve would be less than 10 mm, the actual transition curve may be omitted. In this case, the required change of cant shall be applied over a length to satisfy the requirement of Clause 2.2.3.7 or car bogie centres whichever is the greater, and in the same location as if the transition had been provided.

2.2.3.11 The length of transition curves shall wherever possible be based on the preferred cant gradient in accordance with Clause 2.2.3.6 above. In cases where it is necessary to exceed the preferred cant gradient, the rate of change of cant shall be limited in accordance with Clause 2.2.3.7 above.

2.2.3.12 Transitions between reverse curves shall wherever practicable have the same cant gradient for both transitions.

2.2.4 Chainages

2.2.4.1 The datum of chainages for new lines shall be defined and approved by the Authority.

2.2.4.2 Chainages shall be quoted in metres to three decimal places and shall be measured along the centre line of each individual track in plan with no correction for differences in elevation.

2.2.4.3 Initially a nominal 10m jump in chainage shall be provided on each track at each station centre line. Subsequent alignment revisions that results in changes to chainages shall be reflected by revising the jumps. The chainage at Contract boundaries shall not be changed. The starting

chainage at each subsequent station centre for both bounds shall be identical.

2.2.5   Co-ordinates

2.2.5.1   Calculations for the setting out of the horizontal alignment for each track shall be based on co-ordinates of horizontal intersection points of the nominal track centre line.

2.2.5.2   Co-ordinates of all salient intersection, tangent (at changes in geometry) and radius points shall be clearly tabulated in metres correct to four decimal places. Horizontal curve radii shall be quoted in metres correct to three places of decimals and shall be the actual required radii after shift has been taken into account. Deflection angles shall be quoted in degrees to the nearest one-tenth of a second.

2.3   VERTICAL ALIGNMENT

2.3.1   Vertical curves

2.3.1.1   Wherever possible vertical curves shall be positioned to avoid the coincidence with horizontal curves and, in particular with horizontal transitions.   Where such coincidence is unavoidable, the largest practicable vertical curve radius shall be employed. At station ends where a hump profile is used, a radius of 1600m may be selected.

2.3.1.2   Vertical curves shall for each location be selected on the basis of the most suitable radius of the following: -

Desirable maximum   3000 m
Desirable   2500 m
Desirable minimum   2000 m
Absolute minimum   1600 m

2.3.1.3   The length of the constant grade between consecutive vertical curves shall be as follows: -

Desirable minimum   50 m
Absolute minimum   20 m

2.3.1.4   Vertical curves shall not coincide with any part of the overall length of switches or crossings.

2.3.1.5   At station ends where vertical curves are provided in conjunction with acceleration/deceleration gradients, the tangent point of the vertical curve may be permitted only under severe constraints of the alignment to encroach within the length of the platform to a limited extent. This length of encroachment shall be such that the vertical offset of the curve from the station gradient at the platform end shall not exceed 15 mm.

2.3.1.6   Symmetrical parabolic vertical curves shall be provided whenever there is a change in grade.

2.3.2   Gradients

2.3.2.1   The absolute maximum limit for gradients shall be 3.0%. The desirable maximum gradient shall be 2.5%.

2.3.2.2   At stations, the track shall be level throughout the platform length except for the limited lengths of vertical curves as specified in Clause 2.3.1.5 above.

2.3.2.3   A drainage gradient shall be provided for all underground tracks, other than at platforms and sidings, as follows: -

Desirable minimum 0.5%
Absolute minimum 0.25%

2.3.2.4   On ballasted track, level tracks may be employed provided drainage is catered for below the ballast.

2.3.2.5   Siding tracks should either slope 0.25% towards the buffers, or be level.

2.3.2.6   Where practicable within the bored sections of tunnels, acceleration/deceleration gradients shall be provided in the form of a hump profile between stations. The desirable value of the hump shall be 6m. Where tunnels are constructed by cut-and-cover methods, hump profiles need not be employed.

2.3.3   LEVELS

2.3.3.1   Levels shall be quoted in metres to three decimal places.

2.3.3.2   Rail level on superelevated ballasted track and slab track at grade & on above ground structure refers to the level at the crown of the lower rail.

2.3.3.3   Rail level on superelevated concrete slab track in tunnel refers to the midpoint between the two running rails and is unaffected by the application of cant.

2.4   TURNOUTS AND CROSSOVERS

2.4.1   Turnouts

2.4.1.1   Turnout design shall generally be based on the following geometry:-

Operation Requirement	Turnout Type
For depot	R190-1:7.5 R190-1:9
For emergency crossover and cripple siding	R190-1:9
For reception track	R300-1:9
For turnback track / terminal station	R500-1:12 R500-1:14

The turnout type shall suit the operation speed.

The crossing angles of the turnouts are determined according to the Right Angle Measurement (RAM) as shown in Figure 2.

$$\theta = \tan^{-1}\left[\frac{1}{N}\right]$$

$$N = \frac{1}{\tan\theta}$$
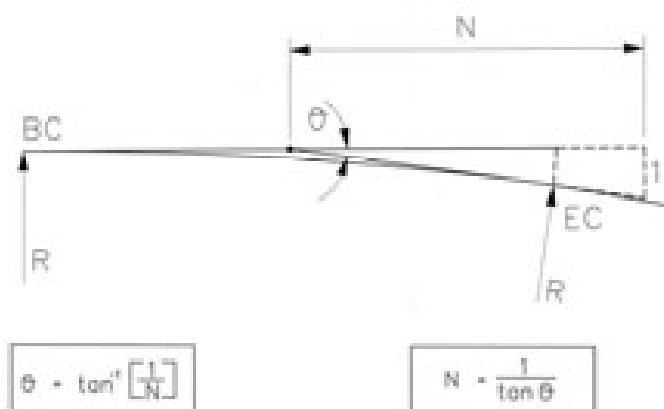
Where

θ   =   angle in degrees
BC   =   begin of curve
EC   =   end of curve
R   =   Radius of the turnout measured in the centre line of the track

Figure 2 - Right Angle Measurement (RAM)

2.4.1.2   All turnouts shall not coincide with horizontal transition and/or vertical curves, and shall be avoided in circular curves wherever possible. Turnout shall not be placed across tunnel sections with significant differential settlements

2.4.1.3   A minimum speed limit of 55 km/h for turnouts shall be allowed where regular passenger trains would normally operate.

2.4.1.4   Drawings should state co-ordinates of the intersection point (IP) of turnouts and the chainage of beginning (BC) and end of turnout.

2.4.1.5   The minimum radii of curves within turnouts shall be 190m.

2.4.1.6   As turnout is a source of noise & vibration, its location shall be selected to minimise environmental impact.

2.4.1.7   End of turnout is defined as the location where the minimum dimension (shown below) between the gauge points of the diverging crossing legs is achieved.

Turnout Type	Minimum Dimension
1:7.5 - 190m Radius	500mm
1: 9 - 190m Radius	420mm
1: 9 - 300m Radius	420mm
1:12 - 500m Radius	380mm
1:14 - 500m Radius	350mm

2.4.2   Closure Rails

Distance between adjacent turnouts shall be designed to consider factors such as third rail electrical gapping, signalling, future maintenance issues and track stability.   As a guide, the minimum length of closure rails between adjacent turnouts on the same track are as follows: -

Turnouts back to back (BC to BC)		Turnout following another turnout (End of turnout to BC of next turnout)	
Desirable minimum	Absolute minimum	Desirable minimum	Absolute minimum
21m*	4.9m	9.1m	4.9m

* Applicable only to third rail systems
Note: BC = Geometrical tangent point (Beginning of curve)

2.4.3   DIAMOND CROSSINGS

2.4.3.1   The use of diamond crossings shall be subject to the approval of the Authority.

2.5   STRUCTURE GAUGE AND CLEARANCES

2.5.1   Definitions

2.5.1.1   The *normal co-ordinated axes of a vehicle* are defined as those orthogonal axes, normal to the longitudinal centre line of the vehicle, where one axis called the *wheel line* is the line connecting the points of bearing of pairs of wheels on the rails and the second, perpendicular to the first, called the *vehicle centre line*, is central between the wheels.

2.5.1.2   The *normal co-ordinated axes of the track* are defined as those orthogonal axes, normal to the longitudinal centre line of the track, where one axis, called the *rail line* is the common tangent to the tops of the rails and the second perpendicular to the first, called the *track centre line*, is central between the rails.

2.5.1.3   The *static load gauge* is defined as the profile related to the theoretical normal co-ordinated axes of the passenger vehicle outside which no part of the vehicle shall protrude when the vehicle is stationary and unloaded and when all play in the axles and suspension are uniformly distributed either side. Building tolerances for the vehicle are included in the static load gauge.

2.5.1.4   *Horizontal throw* is the distance measured parallel to the rail line of the vehicle centre line from the track centre line when a vehicle is on a horizontal curved track, and all play in the axles and suspension are uniformly distributed either side.

Horizontal throw reaches (arithmetic) maximum midway between bogies and at the ends of the vehicle. These throws are called *centre throw* and *end throw* respectively.

2.5.1.5   *Vertical* throw is defined in a similar manner when a vehicle is on vertically curved track.

2.5.1.6   The *Kinematic Load Gauge* is defined as the vehicle profile related to the designed normal co-ordinated axes of the vehicle which covers the maximum possible distances from the vehicle centre line to any part of the vehicle taking into account the most unfavourable positions for running, including tolerances and wear.

2.5.1.7   The *Kinematic Envelope* is defined as the profile related to the designed normal co-ordinated axes of the track which covers the maximum possible distances from the track of any part of the vehicle taking into account the most unfavourable positions for running, including tolerances and wear of the track. When enlarged horizontally and vertically on curved track to allow for throw, it is referred to as the *Swept Envelope*.

2.5.1.8   The *Structure Gauge* is defined as the profile related to the designed normal co-ordinated axes of the track into which no part of any structure or fixed equipment may penetrate, taking into account all deformations and movements.

2.5.1.9   The *Service Vehicle Load Gauge* is the Kinematic Load Gauge for those rail vehicles used for construction and maintenance

2.5.1.10   The *Construction Gauge* is the structure gauge, which shall apply during construction until the time that trial running commences.

2.5.2   Train and Track Vehicles

2.5.2.1   All rail vehicles used for construction and maintenance shall conform to the service vehicle load gauge.

2.5.3   Structure Gauge

2.5.3.1   The Structure Gauge shall be based upon the Kinematic Envelope in such a way that each point on the perimeter of the Kinematic Envelope is enlarged vertically upwards by 50mm and horizontally by 100mm (two points to be constructed for each point on the Kinematic Envelope). Below the vehicle, the Kinematic Envelope is enlarged by 15mm to form the lower limit of the Structure Gauge. The Structure Gauge is the largest envelope based on the points constructed as described above. The shortest distance between the Kinematic Envelope and the Structure Gauge at any point is the *Clearance* at that point.

2.5.3.2   Special provisions shall be made to permit the intrusion of the platform nosing, the platform screen doors and platform edge columns into the Structure Gauge.

2.5.3.3   The Structure Gauge for curved track shall in all cases include an allowance for the maximum vehicle throw, both horizontal and vertical at the location being considered in accordance with Clause 2.5.4.1.

2.5.4   Throw

2.5.4.1   Horizontal throw can take the form of either centre throw or end throw. They are inversely proportional to the curve radius. When a vehicle is fully on a circular curve, throw may be calculated from the following formulae.

$$\text{Centre throw (mm)} = \frac{B^2\,10^3}{8R}$$

$$\text{End throw (mm)} = \frac{(T^2 - B^2)\,10^3}{8R}$$

Where

- B = Distance between bogie centres in metres
- R = Radius in metres
- T = Overall length of vehicle in metres

2.5.4.2   Throw on transition curves and on switch and crossing and the adjacent tracks shall be calculated where necessary.

2.5.4.3   For simplified approach, the following figures shall be applied:

Figure 3 - For End throw
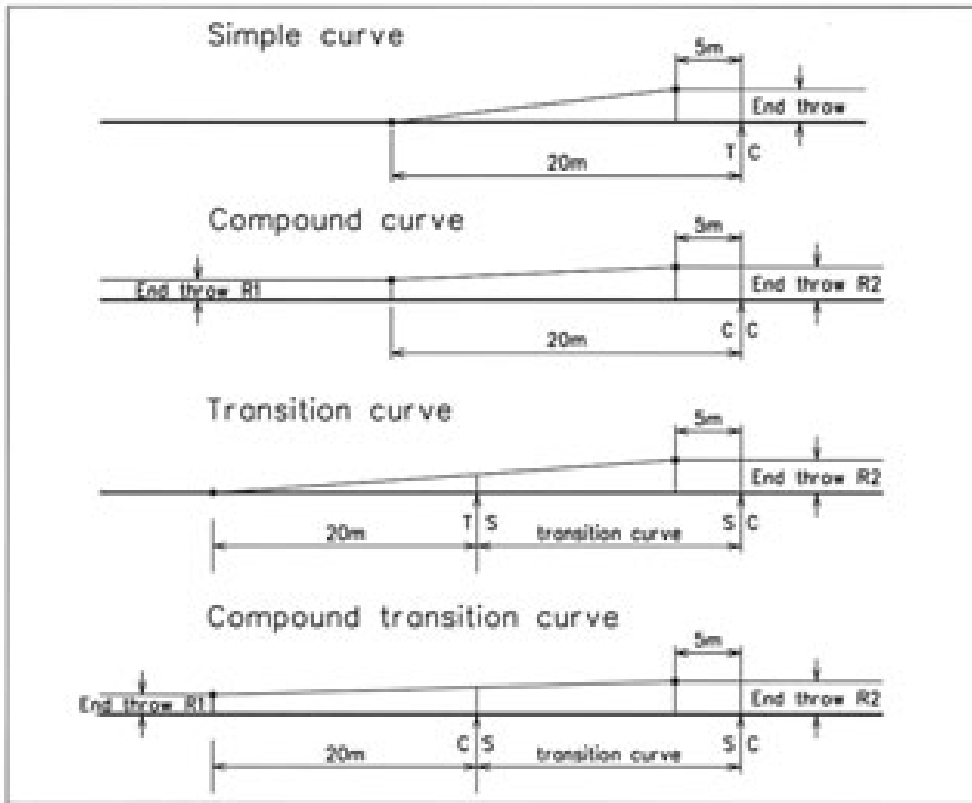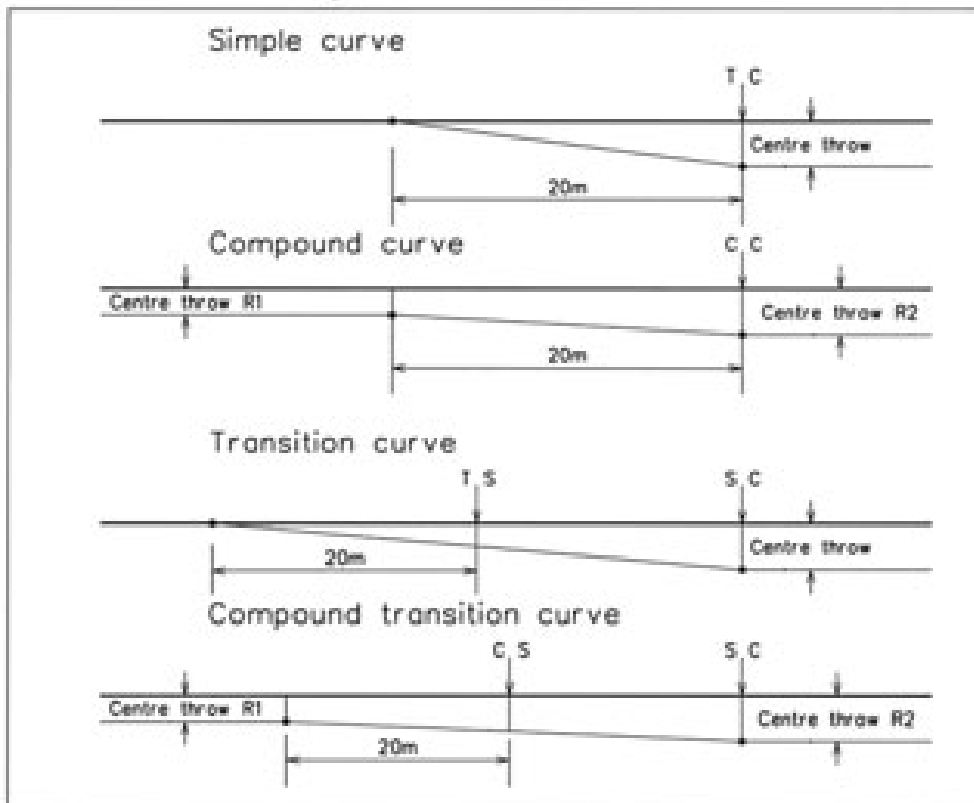
Figure 4 - For Centre throw

2.5.5 Clearance to Structure Gauge

2.5.5.1 All structure and equipment shall be designed to be clear of the Structure Gauge with adequate allowance made to take into account all tolerances of construction and fixing, and for all deflections and displacements.

2.5.5.2 All moveable equipment, hinged doors, windows, etc close to the track shall be positioned so that they are not within the Structure Gauge at every position of movement. All covers to sumps, pits, etc within the track slab shall not infringe the Structure Gauge when in the open position.

2.5.5.3 Where two tracks are side-by-side close to each other, the minimum distance between the two tracks shall be such that the structure gauge will not encroach into each other.

2.5.5.4 The fouling point for all tracks may be separated at the point of contact of the two respective structure gauges and the corresponding throws.

2.5.5.5 The fouling point for slab tracks in depot may be separated at the point of contact of the two respective Kinematic Envelopes and the corresponding throws.

2.5.6   Clearances at Platform Edge

2.5.6.1   Alongside the station platform limited intrusion into the Structure Gauge of the platform edge, platform edge columns and screen doors is permitted. Intrusions into the Structure Gauge permitted shall not extend beyond the platform length.

2.5.6.2   The limit of platform screen door edge or finished edge of platform without platform screen door shall be set at 1675mm from the track centreline (such that 75mm clearance is provided horizontally between the static load gauge and the platform edge.)

2.5.6.3   Where a curved and/or canted track is less than 20 m from the platform edge, the clear distance shall be increased to account for effect of cant and throw.   The distance shall be calculated precisely, for the worst position of the train.

2.5.6.4   Passageway, handrailings and staircases beyond the platform ends shall be designed to be clear of Structure Gauge and taking effects of throw and cant into consideration where necessary.

2.5.6.5   Alongside depot platforms, intrusions into the Structure Gauge are also permitted. The platform edge shall be set at 1715 mm (+20 - 0 mm) from the track centreline where the curved track is at least 20 m beyond the platform. Where a curved and/or canted track is less than 20 m from the platform edge, the clear distance shall be increased to account for effect of cant and throw.

2.5.6.6   In determining Kinematic Envelope and subsequently the Structure Gauge, the wear limit on the track system and the wheel shall be referred to the Code of Practice on the Maintenance of Permanent Way and Kinematic Envelope in the Rolling Stock Engineering Standard. As specified in the Code of Practice on the Maintenance of Permanent Way, top wear of the rail shall not exceed 16mm. Side wear at the rail gauge corner of the rail shall not exceed 20mm measured to the vertical at 45°.

SECTION B - LRT ALIGNMENT

2.6   GENERAL

2.6.1   This section gives guidelines to the design of alignment on which Light Rapid Transit (LRT) vehicles run on. LRT vehicle is rubber-tyre and the guideway on which it runs on is usually concrete.

2.7   HORIZONTAL ALIGNMENT

2.7.1   Horizontal Curves

2.7.1.1   Circular curve radii shall be selected to be maximum practicable. The radius selected for any particular curve shall not be so large as to unnecessarily impose more severe curvature of the guideway at either end of that curve.

2.7.1.2   The guideway shall be straight throughout the length of the stations. Transitions shall start not less than one vehicle length away from the station platform ends to avoid vehicle throw affecting platform nosing clearance.

The presence of external constraints may necessitate limited encroachment of transition curves at station ends but this shall be avoided whenever possible. Where encroachment is unavoidable, this shall be limited such that the combined effects of offsets, vehicle throw and cant do not affect the location of the platform nosing by more than 20mm when compared to straight guideway.

2.7.1.3   The limits for radii (in metres) for horizontal circular curves are:

	Main Line	Depot
Desirable minimum	100	40
Absolute minimum	50	25

2.7.1.4   In order to maintain comfort and safety of the passengers, the lateral acceleration shall not exceed the following:

Desirable maximum :   0.05g
Absolute maximum :   0.10g

where g is the acceleration due to gravity = $9.81m/s^2$.

2.7.1.5   The combination of circular curve and their related transition curves shall be chosen such that the length of pure circular arc between transitions is not less than the following:

Desirable minimum :   3 x L_{VEH}
Absolute minimum   :   1 x L_{VEH}

where L_{VEH} is the vehicle length of the vehicle

2.7.1.6   For any two consecutive circular curves with the same direction of curvature, the length of straight guideway between the ends of the curves or of the transitions where these are required shall not be less than the following:

Desirable minimum :   3 x L_{VEH}
Absolute minimum   :   1 x L_{VEH}

2.7.1.7   In an area of the main guideway where two opposing curves are connected to each other, a straight guideway without cant of at least one vehicle length shall be inserted between the curves. Where this is not achievable, the two opposing transition curves may be directly connected.

2.7.2   Cant and Speed

2.7.2.1   The final selection of suitable cant values shall take into account the design speed of the guideway section without compromising passenger comfort. The general curve-speed-cant relationship shall be based on the following equation:

$$E_q \quad = \quad \frac{G \cdot V^2}{127\,R}$$

Where

E   =   Equilibrium cant in millimetres

G   =   Wheelbase width in millimetres
V   =   Equilibrium speed in kilometres per hour
R   =   Horizontal curve radius in metres

The following figure illustrates the wheelbase width (G) and the cant (E) :
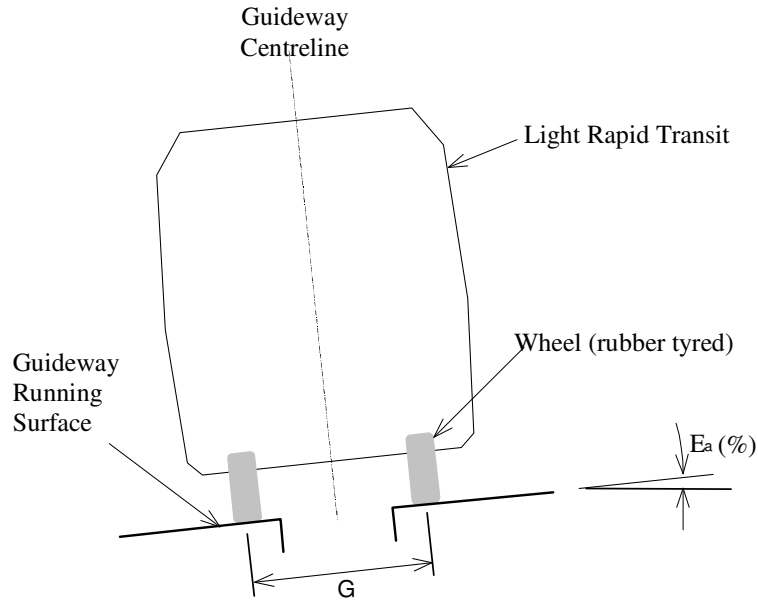
2.7.2.2 The maximum allowable applied cant and cant deficiency, both measured as a gradient to the horizontal perpendicular to the guideway centre line (as a percentage) shall be as follows:

	Applied cant, E_a (%)	Cant Deficiency, D (%)
Desirable maximum	8.5	5
Absolute maximum	10	6

2.7.3 Transition Curves

2.7.3.1 In general for mainline guideway, transition curves shall be provided:

- Between circular curve and adjoining straight
- Between the different radii of a compound curve
- At adjoining ends of circular curves forming reverse curves

2.7.3.2 Transition curves shall be clothoids as defined in clause 2.2.3.5.

2.7.3.3 The length of transition curve shall take into consideration the ride comfort arising from the temporal rate of change in centrifugal acceleration when the train negotiates the transition curve. The length of the transition curve (L_T) in metres shall be at least the value calculated from the following equations:

Desirable	Absolute
$L_T = \dfrac{V^3}{22.8R}$	$L_T = \dfrac{V^3}{45.7R}$

where :
R = Horizontal curve radius in metres

$$V \;=\; \text{Equilibrium speed of the train on the curve section in kilometres per hour}$$

Transition curves shall not be applied at the switch areas.

2.7.3.4   The application of Chainages as given in 2.2.4 applies.

2.7.3.5   The application of Co-ordinates as given in 2.2.5 applies.

2.8   VERTICAL ALIGNMENT

2.8.1   Vertical Curves

2.8.1.1   Vertical curves shall be positioned such that the coincidence with horizontal curve or horizontal transition curve is avoided. Where such coincidence is necessary, the desirable maximum vertical curve radius shall be used. At station ends where a hump profile is used, a radius of 1600m shall be used.

2.8.1.2   A vertical curve with a radius of not less than 1000m shall be used to connect guideways of different gradients.

2.8.1.3   Between consecutive vertical curves, the minimum length of constant grade to be provided shall be:

Desirable minimum : $3 \times L_{VEH}$
Absolute minimum   : $1 \times L_{VEH}$

2.8.2   Gradient

2.8.2.1   The maximum gradients are shown as follows:

Desirable maximum   :   4%
Absolute maximum   :   6%

2.8.2.2   Vertical curves shall not coincide with any part of the overall length of the switches.

2.8.2.3   At station and where vehicle is stabled or coupled/uncoupled, the guideway shall remain level throughout.

2.9   CLEARANCES TO STRUCTURE GAUGE

2.9.1   The definitions of the Kinematic Envelope and its associated Structure Gauge given in 2.5.1.7 and 2.5.1.8 apply.

2.9.2   The Structure Gauge is the enlargement of the Kinematic Envelope taking into account the throws of the vehicle in curves and the following tolerances:

- Horizontal 100mm
- Vertical 50mm upwards
- Vertical 15mm downwards below the vehicle

2.9.3   Throws shall be applied in curves of radii not greater than 1000m. The amount of throw applicable shall be obtained from formulae given in 2.5.4.1.

2.9.4   Nothing shall infringe or intrude the Structure Gauge except approved by the Authority. Only the station platform and devices such as guide rails, power rails and body grounding for safe operation may be permitted to infringe or intrude beyond the Structure Gauge.

CHAPTER 3

LOADS

3.1 SCOPE

Loads shall be determined from BD 37/01 and BS 6399 except where stated otherwise in this Chapter. In any circumstances where there is a discrepancy between the relevant standards and regulations the more critical case shall apply.

The loads given are unfactored (nominal or characteristic) loads unless specifically noted otherwise.

For load factors and loading requirements specific to the type of structure, reference shall be made to the relevant Chapters.

For structures considered susceptible to aerodynamic effects (e.g. cable-stayed and suspension bridges), design criteria for wind loads shall be specially established to the Engineer's approval, and where necessary, the requirements shall be verified by prototype or model testing.

3.2 RTS LOADS

3.2.1 General

Unless otherwise specified in the Particular Specifications, the RTS design nominal live loading shall be as follow:

RTS Types	Nominal live loading
MRT	Type RL loading in accordance with BD 37/01.
LRT	Not less than: (a) Half of Type RL loading in accordance with BD 37/01. (b) Actual system requirement. Dynamic effects shall be allowed for in accordance with BD 37/01.

All other loads (e.g. lurching, nosing, centrifugal, longitudinal, etc.) and load factors shall be in accordance with BD 37/01.

3.2.2   Derailment Loads

3.2.2.1   General

The following design requirements shall be applied to all supporting structures within the danger zone as defined below. They are not applicable to lineside railway infrastructure such as overhead line masts or signal gantries.

"Danger zone" is defined as follow:

Location		Definition
Within tunnels		Bounded by the tunnel walls.
	Platform areas	Bounded on the platform side(s) by the platform structure below platform slab level, and above platform slab level by a zone up to 2500mm from track centre-line.
	Non-platform areas	Bounded by the nearest continuous wall or 5250mm from track centre-line whichever is lesser. See Figure 3.2.2.1(a).
Within the depot and outside of any tunnels or stations		To be taken as 5250mm from the track centre-line. See Figure 3.2.2.1(b).
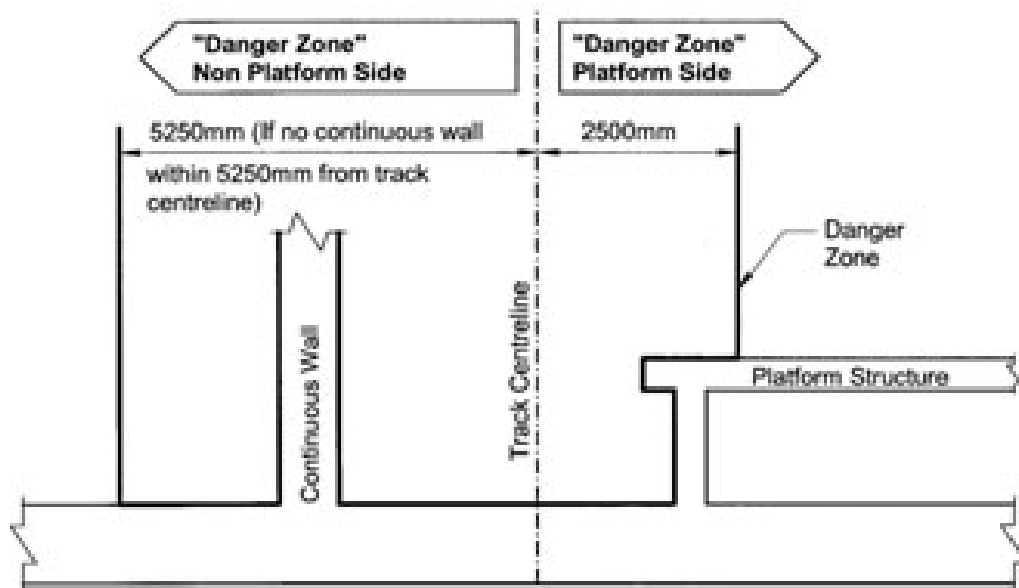
Figure 3.2.2.1 (a) - Section view of "Danger zone" within stations
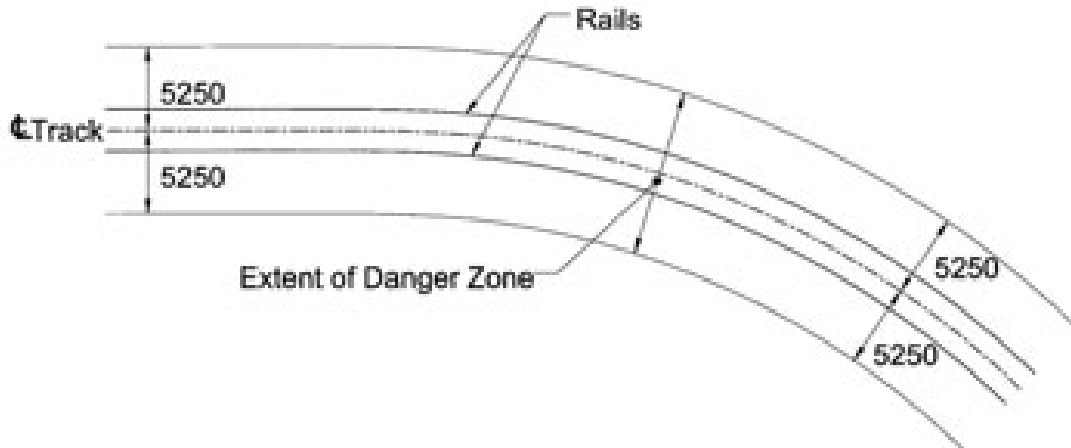
Figure 3.2.2.1(b) - Plan view of "Danger zone"
within depot and outside of tunnels

Where supports must be placed inside the danger zone, they should preferably be part of a monolithic structure (i.e. frame structural system).

Adequate protection measures shall be adopted to safeguard columns and piers located within or at the bottom of embankments, even if they are outside the danger zone because of the possibility of derailed vehicles rolling down the embankment. See Figure 3.2.2.1(c).
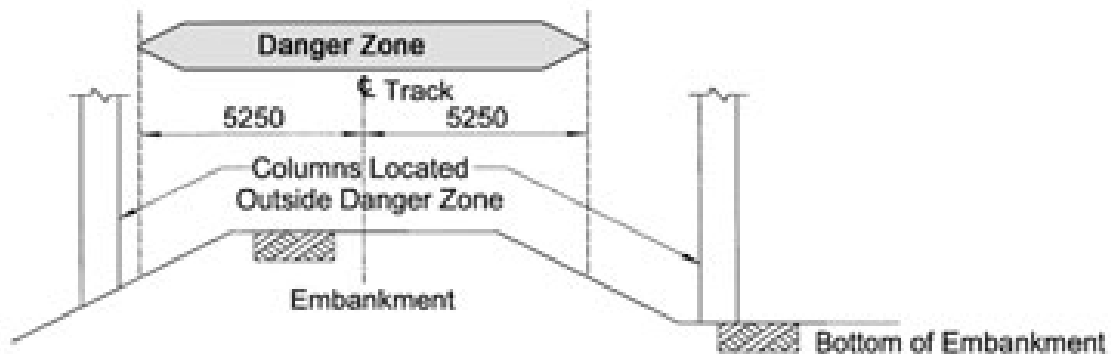
Figure 3.2.2.1 (c) – Section view of "Danger Zone" within embankment

Where individual columns are used within the danger zone a solid 'deflector' plinth shall be provided to a minimum height of the more onerous of the following:

(a)   900mm above the rail level or
(b)   1200mm above ground level.

The height of the plinth shall be constant and the ends of the plinth shall be suitably shaped in plan to deflect derailed vehicles away from the columns.

For individual columns within station areas, a solid platform construction shall be used to provide similar protection from derailed vehicles.

Where the Engineer accepted the use of ground anchors as part of the Permanent Works, and where they are situated within the danger zone, special measures shall be taken to protect the anchorages from potential damage by derailed vehicles.

3.2.2.2   Train Impact Loads

When the face of a load bearing element lies outside or does not define the boundary of the danger zone, no special provision is required.

All design shall allow for the following minimum values of loads and design parameters due to derailment. More onerous values shall be incorporated where appropriate.

All piers, columns or walls, whose nearest face defines the boundary of, or lies within, the danger zone, shall be designed for the two-point train impact loads. These two ultimate design point loads, P1 and P2 and their points of application are given in Table 3.2.2.2(i) and (ii).

Table 3.2.2.2(i) – Ultimate design loads for train impact

	Single horizontal ultimate design load P1 (kN)	Single horizontal ultimate design load P2(kN)
MRT	2000	1000
LRT	1000	500
Point of application	Up to 1100mm above track bed level	Between 1100mm and 3500mm above track bed level

The two point loads shall be applied in accordance with Table 3.2.2.2(ii) and shall not be applied simultaneously. For designs to BS 5400, γ_{f3} shall be applied in accordance with the code requirements.

Table 3.2.2.2(ii) – Application of P1 and P2

Location	Application
Within tunnels and underground stations	To act in a direction parallel to or up to 6 degrees from the direction of the adjacent track. See Figure 3.2.2.2(a).
At crossovers within tunnels	To act parallel to or up to 10 degrees from the direction of the adjacent track within 1m of the ends of dividing walls. See Figure 3.2.2.2(b).
Within the depot and outside of the tunnels	To act in any direction. The design shall cater for the most adverse direction(s).
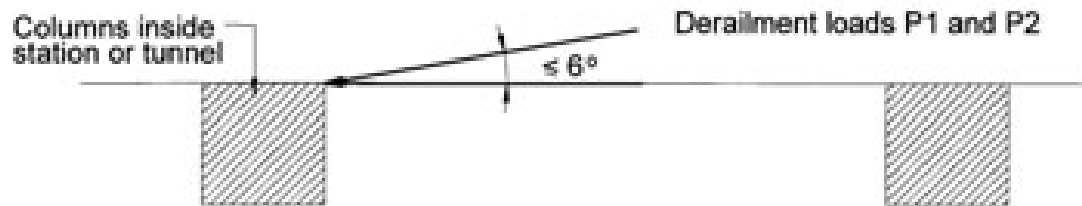
Figure 3.2.2.2(a) – Plan view showing direction of derailment loads within tunnels and underground stations
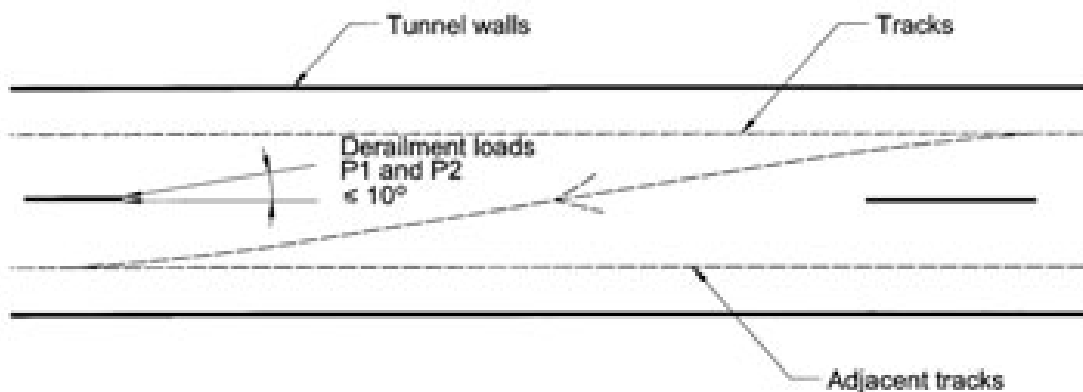
Figure 3.2.2.2(b) – Plan view showing direction of derailment loads at crossovers within tunnels

3.2.2.3   The impact loads in Clause 3.2.2.2 shall be considered in combination with permanent loads and the appropriate live loads (where inclusion is more critical) as defined below:

(a)   Structures designed to SS CP 65 or BS 5950 shall be checked in accordance with the requirements for the effects of exceptional loads or localised damage.

(b)   Structures designed to BS 5400 shall be checked in accordance with BD 60/94 using the ultimate loads given in Table 3.2.2.2. γ_{f3} shall be applied in accordance with the code requirements.

3.2.2.4   Disproportionate Collapse

All load bearing structural elements whose nearest face defines the boundary of, or lies within the danger zone, shall be detailed in accordance with SS CP 65 or BS 5950 as appropriate. Each level of a station shall be counted as a single storey.

Structures whose nearest face defines the boundary of, or lies within, the danger zone shall be designed as follows:

(a)   Where individual columns (i.e. not frame structure) are used within the danger zone, the design of the structure above them shall be such that the removal of any one column will not lead to the collapse of more than a limited portion of the structure close to the element in question under permanent loads and the appropriate live loads.

(b)   Where the load bearing element is a key element whose removal would cause the collapse of more than a limited portion of the structure close to the element in question, Table 3.2.2.4(b) (i), (ii) and (iii) shall apply.

Table 3.2.2.4(b)(i) – Design requirements

Structures		Requirement for key element
All structures		To be designed for a horizontal ultimate design load, P3 as shown in Table 3.2.2.4(b)(ii). For designs to BS 5400, γ_{f3} shall be applied in accordance with the code requirements.
Depot structure	Alongside test track	Same as above.
	Elsewhere	Not required if train speeds less than 20km/h. Otherwise, same as above.

Table 3.2.2.4(b)(ii) – Ultimate design loads P3 for disproportionate collapse

	Single horizontal ultimate design load P3 (kN)	Point of application above track bed level (mm)
MRT	4000	1100
LRT	2000	550

Table 3.2.2.4(b)(iii) – Application of P3

Location	Application
Within tunnels and underground stations	Same direction as P1 and P2. See Figure 3.2.2.2(a).
At crossovers within tunnels	Same direction as P1 and P2. See Figure 3.2.2.2(b).
Within the depot and outside of the tunnels	To act in any direction. The design shall cater for the most adverse direction(s).

The structures shall be checked for these loads in the same way as for loads P1 and P2 in clause 3.2.2.2.

3.2.3   Imposed Loads in RTS Stations

3.2.3.1   Floor Loads

Floors within a station structure shall be under the following categories as defined in BS 6399.

Floor area usage	Categories as defined in BS 6399
For railway purposes (e.g. platform and concourse levels) and areas accessible to public during emergency.	C5 (Areas susceptible to overcrowding)
For shopping and office purposes	B and D as appropriate.

The minimum unfactored floor live loads shall be in accordance with BS 6399 except where otherwise specified below.

Floor area usage	Distributed Load (kN/m^2)	Concentrated Load* (kN)
Areas susceptible to overcrowding	5	15
Traction and service substations, generator rooms	16	25
All other plant rooms	7.5	15

* Concentrated load shall be applied on a square area of 300mm side.

Where the actual extreme weights of equipment are known and verified by the relevant specialists and designers, they shall be adopted. The loads shall be taken as unfactored.

The maximum allowable equipment weight and co-existing distributed load shall be clearly indicated on the drawings. The loading arrangement which show the areas where the equipment load and co-existing distributed load are applied shall also be indicated.

Notwithstanding the requirements of BS 6399 and the above requirements, all floors shall be designed for the following loads:

(a) The total dead load of a piece of equipment at any reasonable position likely to be experienced during or after installation. Access routes and method of transportation of the equipment during installation and any subsequent removal for repair shall also be considered.

(b) The dynamic effect due to the operation of the equipment in its designed location.

3.2.3.2 Escalators

Approximate sizes and loads are given below. These sizes and loads shall be verified by the specialist contractor and the design adjusted accordingly.

Approximate size of section (mm)			Approximate Weight (kg)
Length	Width	Height	
6000	1700	2600	4500

Approximate Loads:

Escalator Rise (mm)	Reaction (kg)		
	Lower landing	Upper landing	Intermediate landing
Above 8000	0.37H + 2100	0.37H + 3200	1.14H + 5800
Up to 8000	0.37H + 2000	0.37H + 3200	1.14H + 5400
Up to 6000	0.91H + 4500	0.91H + 5100	-

Note: H is Rise in mm.

3.2.3.3 Handrailing and Balustrades

Live loads on handrailing and balustrades shall be as follows:

Floor area usage	Horizontal UDL (kN/m)	UDL applied to infill (kN/m^2)	Point Load applied to part of infill (kN)
Areas susceptible to overcrowding (public assembly areas *)	3.0	1.5	1.5
Areas accessible to maintenance staff only including those along edge of railway viaducts and railway platform end stairs	0.75	1.0	0.5

* includes areas accessible to the public during emergency.

3.2.4 Wind Loads

Approximate design loads and requirements for the design of fans and doors in underground RTS structures are given in the table below. These loads shall be verified by the relevant Specialist Contractor and the design adjusted accordingly.

Elements	Wind loads and requirements
RTS Station Structures	(a) Wind forces on the structures shall be determined in accordance with BS 6399: Part 2 using a basic wind speed of 20m/s (based on hourly mean value). Sp in BS 6399 shall be taken as not less than 1.0.
Fans and related elements in Underground RTS Structures	(a) Pressure of ± 3 kN/m^2 shall be allowed for in the design of the tunnel ventilation fans and the under-platform exhaust fans. It shall be applied to ventilation duct ways, plenums and shafts (including fitted doors and/or access hatches). (b) Pressure drop not less than ± 0.1kN/m^2 shall be allowed for across all louvre openings. (c) Except for rooms used as fan rooms or air plenums, internal differential pressure of ± 0.3kN/m^2 shall be allowed for between one room and the next and between above and below close fitting false ceilings.
Doors in Underground RTS Structures	(a) The door opening/closing mechanism for underground trainways including screen door areas shall be designed to operate under the condition of an overall differential pressure of ± 1kN/m^2. (b) Doors fitted to an air path, which leads from the atmosphere to a single running tunnel, shall be designed using a load of ± 1kN/m^2 and a cycle load of ± 0.5 kN/m^2 for six million cycles. (c) Differential pressure of ± 2 kN/m^2 and a cycle load of ± 1 kN/m^2 for six million cycles shall be assumed for cross-passage doors between adjacent running tunnels.

3.3 HIGHWAY LOADS

3.3.1 General

Highway loads shall comply with BD 37/01 except where otherwise specified below:

3.3.1.1 Carriageway

The carriageway shall be that part of the running surface which includes all traffic lanes, hard shoulders, hard strips and marker strips.

The carriageway width is the width between parapets or the width between parapets and raised kerbs of centre median, as shown in Figure 3.3.1.1. The carriageway width shall be measured in a direction at right angle to the line of parapets, lane marks or edge marking.
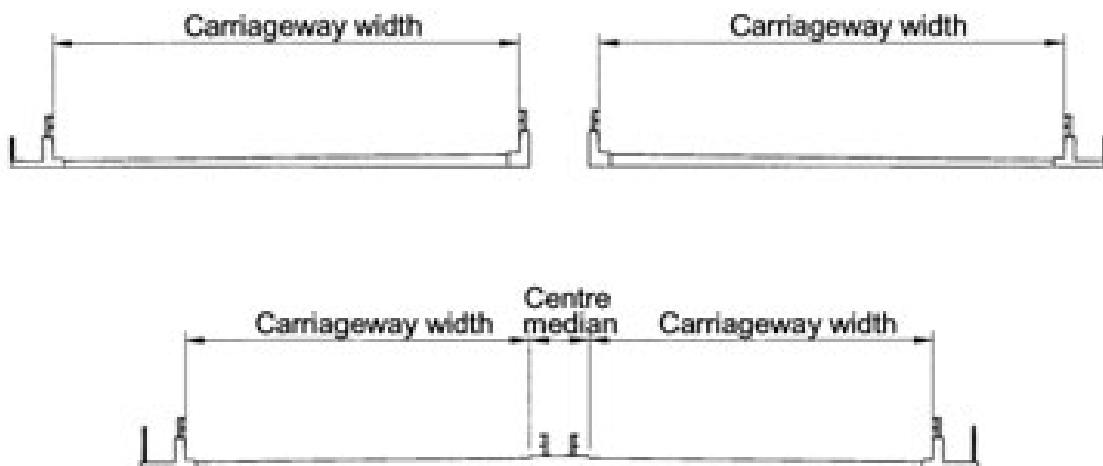
Figure 3.3.1.1 – Carriageway Width

3.3.2 Live Loads

3.3.2.1 Highway live loads shall comply with BD 37/01, except for the following:

(a) The HA Uniformly Distributed Load (HA-UDL) shall be as given below:

(i) For loaded lengths from 2m up to and including 50m

$$W = 403 \ (1/L)^{0.67}$$

(ii) For loaded lengths in excess of 50m but less than 1600m.

$$W = 43 \ (1/L)^{0.1}$$

Where L is the loaded length in metres and W is the load per metre of notional lane in kN. For loaded lengths above 1600m, the UDL shall be agreed with the Engineer.

(iii)   For application of type HA-UDL and HA Knife Edge Load (HA-KEL), at least two lanes shall have a lane factor of 1.0 and the other lanes shall have lane factors of 0.6.

(b)   HA Wheel Load

In addition to the single wheel load of 100kN specified in BD 37/01, a separate load case of 2 numbers of 120kN wheel loads placed transversely, 2m apart, shall also be considered in the design for local effects.

(c)   HA Longitudinal Traction or Braking force

The nominal HA longitudinal traction and braking force shall be 10kN/m applied to an area one notional lane wide multiplied by the loaded length plus 250kN, subject to a maximum of 850kN.

(d)   Lateral loads on piers

Piers shall also be designed for a minimum horizontal force of 5% of the nominal vertical loads that consist of the permanent vertical load and ⅓ Type HA loading on one notional lane in each direction.

This horizontal force shall be multiplied by partial load factors of 1.00 for the serviceability limit state and 1.4 for ultimate limit state. It shall be applied longitudinally and transversely at the footing/foundation level as two separate loading conditions.

(e)   HB Loading

All structures shall be designed for HB loadings as follows:

Table 3.3.2.1 - HB Loading

No. of units of HB Loading	Loading application
30 units (HB-30)	To be applied in co-existence with the relevant HA loading in accordance with BD 37/01.
45 units (HB-45)	To be restricted to the centre 5m strip of the carriageway with no traffic on all other lanes except at the following areas where HB-45 is free to travel anywhere between the parapets:

45 units (HB-45)	(i) Along slip roads or loops of the interchange or flyover with no other associated loading on the structure.
	(ii) For 80m length of the main structure prior to the approach to the slip road or loop with no other associated loading on the structure, as shown in Figure 3.3.2.1(a).
	Where two separate carriageways are supported on one structure, the loading shall be not less than:
	(i) One number of HB-45 loading at any one time; and
	(ii) Type HA loading to be also applied on the other carriageway as illustrated in Figure 3.3.2.1(b), where inclusion is more critical. At least two lanes shall have a lane factor of 1.0 and the other lanes, lane factors of 0.6.
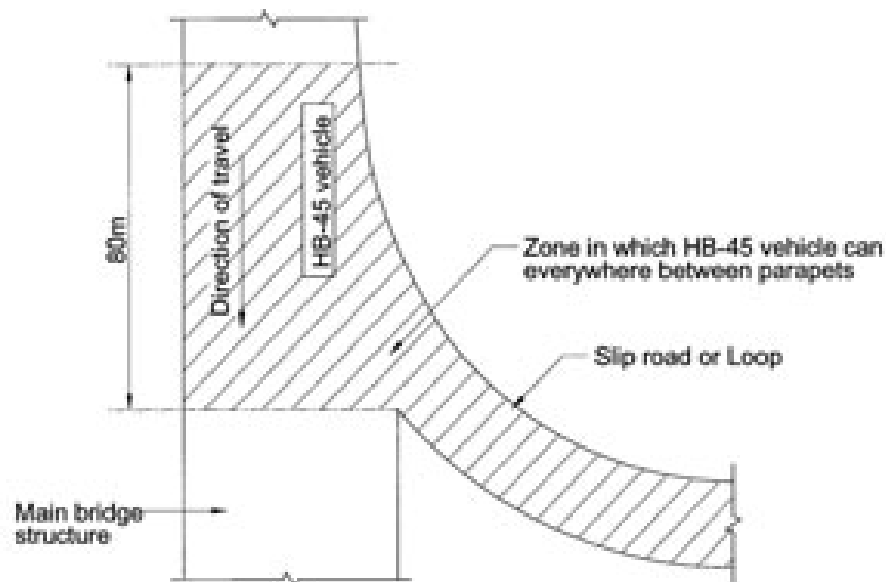
Figure 3.3.2.1 (a)
Zone in which HB-45 is free to travel before the approach to the slip road or loop
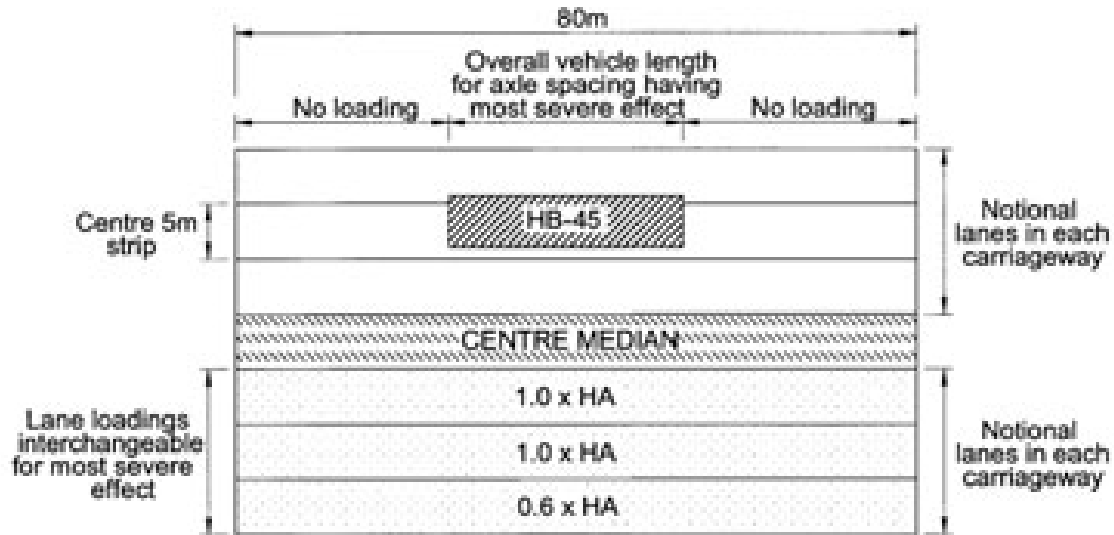
Figure 3.3.2.1 (b)
An example of HB-45 with HA loading for single structure carrying two separate carriageways.

3.3.2.2   Highway Loads on members spanning transversely

Where structural members (e.g. beams, slabs, etc.) span transversely and where it is not possible to determine the effective loaded lengths for HA-UDL, the loading given in clause 3.3.2.1 shall be applied, subject to the following modifications:

Table 3.3.2.2(a) - Highway loads on members spanning transversely

Loadcase	Loading application
HA-Loading	$20kN/m^2$ shall be applied in place of 3.3.2.1 (a). At least two lanes shall have a lane factor of 1.0 and the other lanes shall have lane factors of 0.6. HA-UDL in co-existence with HB-30 loading need not be considered.
HB-45 Loading	Where two separate carriageways are supported on one structure, the loading shall be not less than: (i) One number of HB-45 at any one time; and (ii) $20kN/m^2$ to be also applied to the other carriageway, where inclusion is more critical. At least two lanes shall have a lane factor of 1.0 and the other lanes, lane factors of 0.6.

Traction and braking force	10kN/m shall be applied to an area one notional lane wide multiplied by the length of the structure between movement joints, subject to a maximum of 850kN.

For the above load cases, γ_{fL} to be considered in load combinations is given in Table 3.3.2.2(b). γ_{f3} shall be applied in accordance with relevant code requirements.

Table 3.3.2.2(b) – Load factors γ_{fL} to be used in load combinations

Limit State	γ_{fL} to be considered in combination				
	1	2	3	4	5
ULS	1.30	1.10	1.10	-	-
SLS	1.10	1.00	1.00	-	-

3.3.2.3 Highway Loads for Underground Structures

3.3.2.3.1 Structures under roads shall be designed for the following loadings:

Table 3.3.2.3.1 - Highway Loads for Underground Structures

Depth of cover above top of structure roof slab level	Highway loads
≤ 600mm	Full vehicular live loads specified in Clause 3.3.2.1 and 3.3.2.2 as appropriate.
> 600mm	The more critical of: (i) HA wheel load and HB loading (specified in Clause 3.3.2.1 and 3.3.2.2 as appropriate). (ii) HB loading (as specified in Clause 3.3.2.1).

The structures shall be designed for the following superimposed dead loads:

(a)   The top 200mm of cover shall be considered as surfacing. γ_{fL} for superimposed dead load (premix) shall be applied in accordance with BD 37/01.

(b)   An additional uniformly distributed load of 5kN/m^2 shall be applied. γ_{fL} for superimposed dead load (others) shall be applied in accordance with BD 37/01.

3.3.2.3.2 In the case of underground structures serving road vehicles (e.g. vehicular underpass and road tunnels), highway loads inside and on top of the vehicular underpass shall be assumed to co-exist, with the exception that only HB-45 loading needs to be considered for any given load combination.

The HB-45 shall be placed anywhere over and through the structure with co-existing HA loading on that carriageway, where more onerous. HA loading shall be simultaneously applied on all the other carriageways, where more onerous.

Where it is not possible to determine the effective loaded lengths for HA loading, the highway loads, over and through the underground structure shall be in accordance with clause 3.3.2.2.

3.3.2.3.3 Dispersal of Loads

(a)   The HA-KEL may be dispersed through the surfacing and fill from the depth of 200mm below the finished road level at 1 horizontally to 2 vertically to the top of the structural slab of underground structures.

(b)   Wheel loads may be dispersed through the surfacing and fill from the finished road level at 1 horizontally to 2 vertically to the top of the structural slab of the underground structures.

3.3.3   Wind Loads

Approximate loads for the preliminary design of internal walls, claddings and false ceilings in road tunnels are given in the table below. These loads shall be verified by the relevant Specialist Contractor and the design adjusted accordingly.

Elements	Wind loads and Requirements
Elevated road related structures	The mean hourly wind speed shall be 20 m/s. Other recommendations of BD 37/01 on the computation of wind forces shall be adopted.
Internal walls, claddings and false ceilings in road tunnels	Nominal loads shall be ±1.5 kN/m^2, applied in the combinations for wind loads as defined in BD 37/01. For fatigue on metal elements of cladding, the stress cycle values shall be taken as 50 million.

3.3.4 Collision Loads

The collision loads shall be applied in accordance with Table 3.3.4.

Table 3.3.4 – Collision Loads

Description		Expressways	Other Roads
Road and railway bridge sub-structures located within Road Reserve or less than 4.5m from edge of carriageway and superstructures ≤ 5.7m clear height		BD 60/94	BD 60/94
Pedestrian Overhead Bridge sub-structures located within Road Reserve or less than 4.5m from edge of carriageway			BD 37/01
Pedestrian overhead bridge superstructures	Clear height ≤ 5.7m		* 50kN
	Clear height > 5.7m	* 50kN	* 50kN

* Nominal load to be applied in accordance to Clause 6.8.2 of BD 37/01

Collision loads shall be considered even if vehicular impact guardrails are provided or even when there is no vehicular access to column positions.

Bridge piers situated in navigational channels shall be designed for ship collision loads. The loads shall be subject to approval by the relevant authorities. Protection system against such collision loads shall be considered.

3.3.5 Loads on Parapets and Railing

Parapets and railing for road vehicle containment purposes shall be designed in accordance with the requirements in Chapter 9.

3.4 PEDESTRIAN LOADS

For structures serving pedestrians, the following loads shall be used:

Table 3.4 – Loads for structures serving pedestrians

Types of Loadings		Nominal loads (kN/m^2)
Pedestrian live load		5
Roof structures or provision for future installation of roof structures	Dead Load	0.5
	Live Load	0.5

3.5   HIGHWAY LOADS ON TEMPORARY DECK STRUCTURES

The highway loads on temporary deck structures shall be not less than the following:

(a)   HA loading as given in BD 37/01. The HA uniformly distributed load specified in Clause 3.3.1.2(a) is not applicable.

(b)   25 units of Type HB loading.

(c)   Loading from construction vehicles. Any limits on construction vehicle loading shall be clearly indicated on the Temporary Works drawings.

The load factors given in Table 1 of BD 37/01 and γ_{f3} shall be applied in accordance with code requirements. There shall be no reduction in load factors or material factors.

3.6   TEMPERATURE LOADS

Temperature loads shall be considered in accordance with the following:

(a)   Shade Air Temperature Range:
The shade air temperature range shall be taken as ±10°C from a mean temperature of 27°C. For these shade air temperatures, the extreme maximum and minimum mean temperature in concrete structures given in Table 3.6.1 shall be adopted.

(b)   Temperature in Combination with Wind Force:
Where forces due to changes in temperature are considered in combination with maximum wind forces, the temperature range for all types of structure shall be taken as 27°C ± 5°C.

(c)   Temperature Gradient:
The effects of local strains from temperature gradients within the concrete structure and parts of the structure shall be calculated from the values of maximum temperature differences given in Table 3.6.1 and Figure 3.6.1. The effects of temperature gradient need not be considered in combination with maximum wind force.

(d)   Coefficient of Thermal Expansion:
The coefficient of thermal expansion for 1.0°C shall be taken as 12×10^{-6} for steel and concrete.

(e) Temperature Range for movement joints and bearings:
Bridge bearings and movement joints shall be designed for the temperature range given in Table 3.6.1.

Table 3.6.1 – Temperatures in concrete beam or box girders

Maximum and Minimum Mean Bridge Temperature (°C)		Maximum Temperature Difference (°C) (See Figure 3.6.1)		Maximum Reversed Temperature Difference (°C) (See Figure 3.6.1)	
Surfaced and Un-surfaced		Surfaced	Un-surfaced	Surfaced	Un-surfaced
Maximum	Minimum				
35	21	13.5	15.4	8.4	13.7

Note: Surfaced means a surfacing of not less than 50mm thickness on concrete decks.

Construction type	Thermal gradient (°C)	
	Positive thermal gradient	Reverse thermal gradient
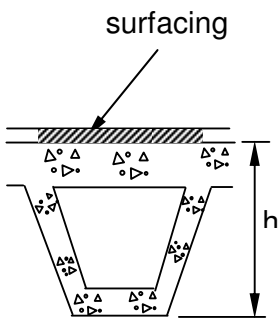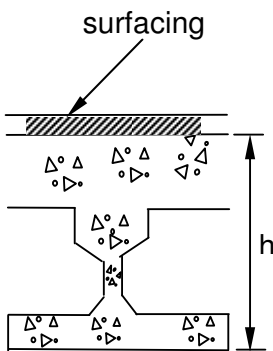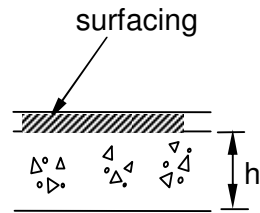
Figure 3.6.1: Temperature Gradients
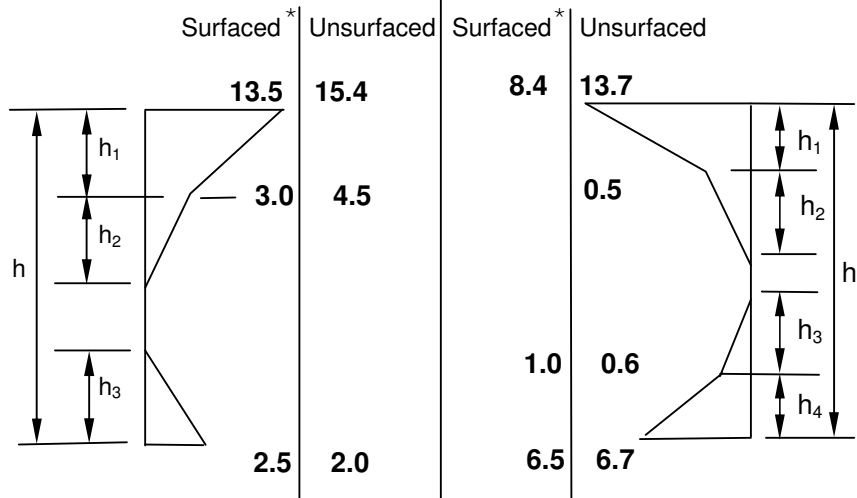
$h_1 = 0.3h \leq 0.15m$

$h_2 = 0.3h \geq 0.10m$
$\qquad \leq 0.25m$

$h_3 = 0.3h \leq (0.1m + surfacing$
$\qquad depth\ in\ metres)$

(for thin slabs, h_3 is limited by $h-h_1-h_2$)

$h_1 = h_4 = 0.2h \leq 0.25m$

$h_2 = h_3 = 0.25h \leq 0.2m$

* Surfaced means a surfacing of not less than 50mm thickness on concrete decks

3.7 SURCHARGE LIVE LOADS

3.7.1 Surcharge live loads shall be as given in Table 3.7.1. The surcharge live load shall be applied at finished ground level (existing or proposed ground level, whichever is higher).

Table 3.7.1 – Minimum surcharge live loads

	Minimum Surcharge Live Loads (kN/m^2)
Bored Tunnels	75
Temporary Works including earth retaining structures in temporary condition	20 #
Earth retaining structures in the permanent condition	25
All other structures	25

Note:
Loading from construction vehicles shall be considered if it is more onerous. Any limits on construction vehicle loading shall be clearly indicated on the Temporary Works drawings.

3.7.2 For structures influenced by loads from nearby building foundations or other structures, the following loads shall be considered:

(a) Self-weight of the existing structure with appropriate allowance for live load shall be applied as a surcharge at the foundation level of the building.

(b) The surcharge loads shall be those for which the adjacent structure had been designed. In the absence of this information, the actual weights and imposed loads determined from the most onerous occupancy class for which the building is suitable shall be used. Where the effect of this load is less than the surcharge given in Clause 3.7.1, Clause 3.7.1 requirements shall govern the design.

3.7.3 Any known future works by others which may increase the loads on the structure shall be taken into account (e.g. earth filling in flood prone areas, reclamation works etc.) as agreed with the Engineer.

3.8　GROUND AND WATER LOADS

3.8.1　Soil Unit Weights and Earth Pressure

For the bulk densities of various types of soil, refer to Chapter 5. For the design parameters, appropriate horizontal coefficients and load factors to be used, refer to Chapters 5, 6, 7 and 8.

3.8.2　Ground Loads

The following additional loading requirements due to earth pressures shall be considered:

(a)　For assessing long term ground pressures, underground structures shall be considered as rigid structures subjected to "at rest" earth pressures.

(b)　In assessing ground pressures during construction, it shall be demonstrated that the pressures are compatible with the predicted ground movements.

(c)　Where appropriate, loads due to swelling (heave) of the ground shall be considered.

3.8.3　Design Ground Water Levels

3.8.3.1　Loads due to ground water pressure shall be calculated using a density of 10.00kN/m^3 and due to seawater using a density of 10.30kN/m^3.

3.8.3.2　The most critical of the following ground water conditions shall be considered for underground and earth retaining structures:

(a)　Design Ground Water Level (DGWL) shall be at the finished ground level or at a higher level depending on site conditions and the soil investigation results. Where there is seawater, the DGWL shall be the maximum high tide level of 102.35 RL.

(b)　Water levels at exceptional condition when there is a flood. The Design Flood Level shall be derived from the highest flood levels as agreed with PUB (Drainage).

(c)　For the design of bored tunnels, the Maximum Ground Water Load shall be determined from the Design Flood Level. The Minimum Ground Water Load shall be determined from the lowest credible groundwater level unless otherwise indicated.

3.9 LOADS FOR EQUIPMENT LIFTING FACILITIES

3.9.1 Crane Gantry Girder

Loading for crane gantry girder shall be in accordance with BS 2573.

3.9.2 Overhead Runway Beams

3.9.2.1 The working load of runway beams should be determined from the maximum weight of equipment to be lifted. Design load (i.e. the nominal or characteristic load) shall be taken as 1.5 x working load, which includes an allowance for dynamic effects.

3.9.2.2 Fixings into concrete shall be designed to have an ultimate capacity of 3 x design load.

3.9.3 Eyebolts

3.9.3.1 Where eyebolts are used as fixed lifting points, they shall be designed in accordance with BS 4278 subject to the following modifications to ensure yielding before brittle failure of the base material.

3.9.3.2 Loads:

(a) The safe working load of eyebolts for lifting or hauling shall be determined from the maximum weight of equipment to be moved. Eyebolts shall be selected/ designed in accordance with BS 4278 giving consideration to the effects of non-axial load. Proof loading, taken as 2 x the safe working load, may be assumed to have included an allowance for dynamic effects.

(b) The maximum angle between the eyebolt axis and the line of application of pull shall be co-ordinated with the Specialist Contractors and clearly shown on the drawings.

3.9.3.3 Local anchorage:

(a) The anchorage capacity (e.g. pullout or cone failure) of the eyebolt fixing into the supporting member shall be designed for an ultimate load of 3 x safe working load.

(b) In the case of concrete beams or slabs, the fixing shall be effectively anchored to the top of the supporting members using reinforcement links designed for this ultimate load.

3.9.3.4   Supporting Member:

Supporting structural elements (for example slabs, walls, beams, etc) shall be designed for a service load equal to the test load and for an ultimate design load equal to the test load multiplied by a partial safety factor for load equal to at least 1.4. The test load shall be taken as not less than 1.5 x safe working load.

CHAPTER 4

TRACKWORK

4.1 GENERAL

4.1.1 This chapter provides the minimum design requirements for trackwork and its interfaces with other elements. The interfacing elements include trackway, stations, structures, traction power, communications, signalling, rolling stock and drainage.

This design criteria is applicable only to steel wheel on steel rail mass Rapid Transit System (RTS).

4.1.2 In the design of the trackwork and selection of components, considerations shall be given to the following factors, but not limited to:-

a) durability;
b) reliability, riding quality and in-car noise;
c) ease of maintenance;
d) availability and cost of track materials and components;
e) successful use of similar components in other transit railways;
f) compatibility with the rolling stock, traction and signalling systems;
g) noise and vibration propagation to adjacent properties;
h) track alignment; and
i) electrical insulation & stray current control

4.2 TRACK SYSTEM

4.2.1 General

4.2.1.1 The track shall provide a safe guide and support for trains to run on it. The design shall ensure stability, and line and level of the track under all load conditions.

The design of the track system shall take into account the provision allocated for other uses such as Civil Defence Blast Door, cable trough, services, sumps and walkway.

Only indirect fastening system shall be used in the track system.

4.2.1.2 The track system comprises of rails held in position and supported by rail fasteners at spacing of 700mm measured along the centre line of the mainline, reception track and test track.

In depot, larger spacing of no greater than 1000mm between supports/fasteners may be accepted in stabling and plain line tracks. Larger spacing between supports/fasteners in all other areas in the depot may be accepted subject to the approval of the Engineer.

4.2.2　Track Support

4.2.2.1　The track support system may be of ballast or concrete slab. The track shall be concrete slab track in tunnels. Ballasted track is preferred on elevated and at-grade tracks.

4.2.2.2　Ballasted Track

Sub-ballast and ballast shall provide stable support and drainage to the track. Cross-falls of 1:20 as shown in Figure 4.1(a) shall be provided in at-grade section. On weak or unstable ground measures shall be required to ensure stability of the sub-ballast prior to the laying of ballast and track.
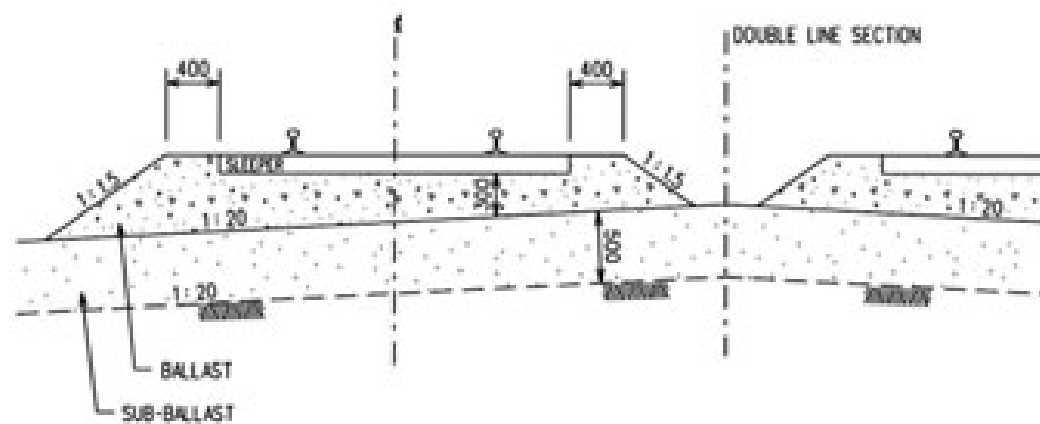
a) At grade cross section
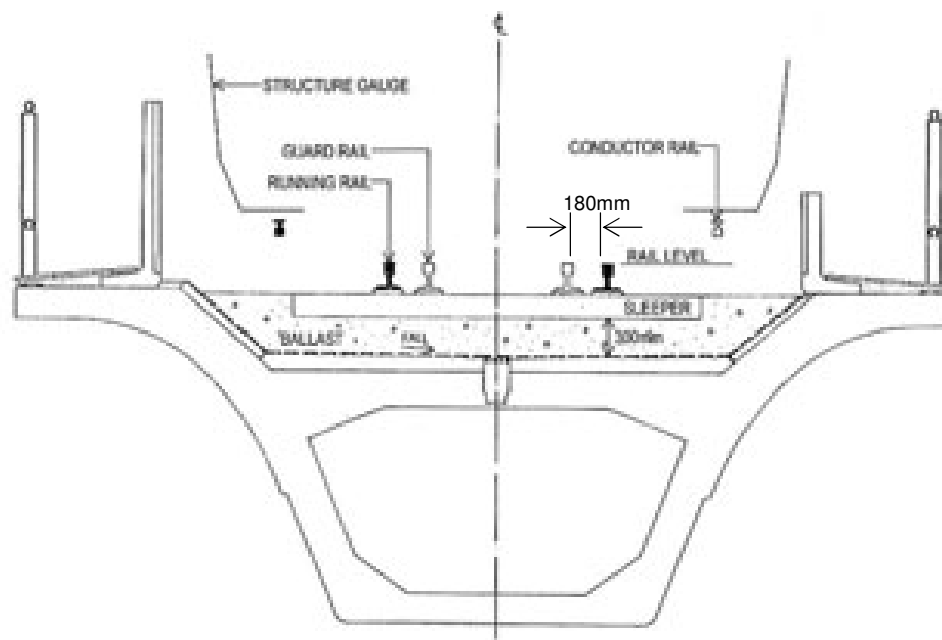
(b) Viaduct Cross Section

Figure 4.1 Ballasted Tracks

Sub-ballast layer of 500mm thick shall be provided at track sections at grade, on embankments and in cuttings for mainline as shown in Figure 4.1(a). The ballast thickness shall be at least 300mm thick measured between the bottom surface of the sleeper and the sub-ballast surface at the location of the lower rail, as shown in Figure 4.1(a) and (b).

4.2.2.3   Concrete Slab Track

2nd stage concrete refers to the second pour of concrete of at least Grade 30 (f_{cu} = 30N/mm^2), to form the trackbed over the base concrete. The construction of the track shall be of a top-down method.

Where concrete slab track is provided, the interface between the trackbed concrete and the civil works shall be at different levels according to its location, as follows: -

• For mainline, reception track and test track, the interface shall be 630mm below rail level (see Figure 4.2);

• For turnouts and crossover tracks in the mainline where conduits for services pass under the track within the trackbed concrete, the interface shall be 850mm below rail level within the extent of the conduits;

• For tracks within the depot, the interface shall be 530mm below rail level.
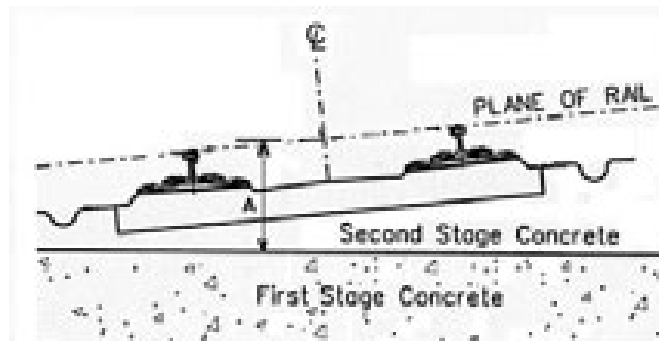
Location of Track	A (mm)
Mainline, Reception Track, Test Track	630
Crossover tracks including turnouts in mainline	850
Depot Tracks	530

Figure 4.2 Typical 2nd Stage Concrete

The above dimensions may vary by ±15mm at the civil-trackwork interface.

Within the track slab a stray current collector shall be installed as part of the reinforcement.

4.2.3   Track Components

4.2.3.1   All components in the track system shall conform to internationally recognised standards and have a proven successful use for a period of at least five years in other transit railways.

4.2.3.2   Rails

Rail shall be UIC 60 of Grade 900A according to UIC860. They shall be inclined at 1:40 to the vertical towards the track centre line except at switch and crossing areas where the rail shall be vertical. All rails shall be continuously welded.

Unless otherwise stated, standard rail of hardness of not less than 260HBW shall be used in all straight tracks and all mainline horizontal curves of radii not less than 700m. Premium rail is standard rail but head-hardened to a hardness of not less than 340HBW and not more than 390HBW. Premium rail shall be used in all horizontal curves with radii less than 700m, including the transition spirals at each end. These requirements shall also apply to siding tracks and crossover tracks in the mainline.

Standard rail shall be used in all depot tracks.

4.2.3.3   Track Fastening System

The track fastening system shall be capable of holding the rails in place when subjected to dynamic impact loads from the running trains and providing insulation to resist leakage of electrical current from the system.

In addition, the track fastening system in a concrete slab track shall have a vertical static stiffness not greater than 30kN/mm/m and the vertical dynamic stiffness not greater than 45kN/mm/m. The deflection under dynamic conditions shall not exceed 2mm.

Where required to meet noise and vibration requirement in a sensitive area, the track stiffness shall necessitate further review to determine the appropriate track fastening system or track structure to be agreed with the Engineer.

The track fastening system shall also be capable to provide an incremental vertical height adjustment to a total of 10mm at each rail support.

4.2.3.4   Sleeper

Sleepers shall provide good anchoring of the track fastening system, support to the rail and maintain a consistent gauge.

Pre-stressed monoblock concrete sleeper shall be used in all concrete slab tracks and ballasted tracks. Reinforced twin block concrete sleeper shall only be used in restricted areas subject to the approval of the Engineer.

Timber sleepers shall be used in ballasted tracks at close proximity to existing high-rise properties. The use of pre-stressed concrete sleepers in ballasted tracks in other non-noise sensitive areas is preferred; timber

sleepers can be proposed in ballasted tracks as an alternative. The source and type of wood proposed for the timber sleeper shall be subjected to the approval of the Engineer. The timber shall be seasoned and treated with suitable preservative for use in the local environment and condition.

4.2.3.5   Turnouts

Turnouts shall be designed to match the wheel profile of the train, and switch machines controlled by the signalling system. All turnouts shall have the following characteristics: -

a. the gauge shall be 1435mm in all types of turnouts and crossings, measured 14mm below the running surface;

b. crossings shall be of cast manganese type with weldable legs or of high-tensile treated carbon steel with welded extensions from premium rails;

c. rails in turnouts shall be vertical (no inclination) or shall have the same inclination as the adjacent track sections;

d. switch rails shall be the asymmetrical Zu 1-60 section;

e. opening of the switch toe shall be 130mm;

f. minimum flangeway gap between the back edge of the open switch rail and the running edge of the stock rail shall be 55mm;

g. throw force to move the switch points with all operating and switch rods connected shall not exceed 1500N;

h. check rails shall be the asymmetrical UIC 33 profile; and

i. switch rails and closure rails shall be made of premium rails in compliance with the requirements in clause 4.2.3.2.

Track stiffness of adjoining track shall be adjusted gradually to match the stiffness of the turnout.

Special drainage provisions shall be made to prevent standing water in flangeways, switch points and in the switch-throwing mechanisms.

4.2.3.6   Guard Rails

Guard rails are rails mounted on the gauge side and parallel to both running rails used to prevent a derailed vehicle from striking fixed obstructions and viaduct parapets by keeping derailed wheels adjacent to the running rails. Guard rails shall be:-

a. of UIC60 grade 900A rails and not seated inclined;

b. provided in tracks adjacent to key structural elements;

c. provided in all mainline tracks on elevated structures which do not contain derailment containment provisions;

d. fixed to double baseplate on alternate sleepers and curve inwards at the end of the line;

e. terminated with entry and exit flares at turnouts and buffer stops;

f. electrically separated at 18m intervals by a gap of 50mm wide (unless otherwise required by signalling system) to avoid interference with the signalling system;

g. electrically insulated from the adjacent running rails; and

h. the clear horizontal distance between the running rail and the adjacent guard rail shall be 180mm.

4.2.3.7   Level Crossing

The rail fastening system used for level crossings shall be of an insulated type in accordance with clause 4.3.9. The gap between the concrete and the rail shall be sealed with pre-formed elastomeric flangeway sealing section.

Alternatively, the rail can be supported on a site-installed elastomeric compound, which provides resilience under the rail, lateral support and electrical insulation between the rail and the concrete channel.

All materials used shall be chemically resistant and electrically non-conductive, capable of taking vehicular load and suitable for use in the local environment.

Placing of switch/point machine within the level crossing is not allowed.

4.3   MISCELLANEOUS

4.3.1   Walkway

In tunnels, the space between the running rails is designated as the primary route for emergency evacuation. The track slab surface shall be non-slip and free from obstruction. Any unavoidable obstruction shall be suitably bridged with a non-slip material and ramped approaches.

In addition, a side walkway along the same side of the station platform shall be provided to permit evacuation through the side doors of trains. The side walkway shall take into account the floor height and stepping distance from the train in the tunnel.

The side walkway shall be 380mm above the rail line and free of obstruction, at least 800mm wide and 2100mm headroom above the centreline of the walkway and have an even, non-slip surface. Ramps not steeper than a 1:12 gradient shall be provided in any change in level. Steps or ramp shall be provided to connect walkway to stations.

On the approach to a cross passage, ramp shall be provided to connect the trackside walkway and the cross passage with a level 210mm above the rail line. Removable steel step unit, weighing not more than 50kg shall be provided between the walkway and rail. A nominal gap of 50mm shall be allowed between the plinth and the running rail. A typical arrangement of the walkway at a cross passage is shown in Figure 4.3.

4.3.2   Buffer Stops

Sliding buffer stop located at the end of track shall be used to stop the train on impact. For trains with passengers, the deceleration rate shall be limited to 0.15g on impact. The deceleration rate on impact shall not exceed 0.22g for trains without passengers.

The Track Occupancy Distance measured from the buffer head to end of sliding as shown in Figure 4.4, shall not be larger than 12m. Provisions for the sliding buffer stop shall be optimised to obtain the shortest possible Track Occupancy Distance.
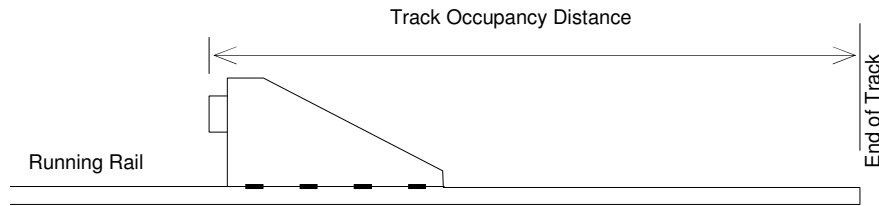
Figure 4.4 Track Occupancy Distance

4.3.3   Cable Troughs

Cables shall be placed in cable brackets installed on walls of tunnels or viaducts, or routed through conduits embedded in trackbed.

Where cable trough is to be used, it shall be placed in between sleepers perpendicular to the track with its top surface flushed with the top surface of the adjacent sleepers.

For ballasted tracks sections on grade, cable troughs are to be installed parallel to the track with the cover in the same level as the lower edge of the sloped ballast surface.

Cable troughs used on ballasted tracks shall be designed to withstand weathering and shifting due to track maintenance and adjacent activities.

4.3.4 Reference Points and Distance Indicators

Reference Points shall be placed at fixed points alongside the track and generally at 10m interval in plain line. They shall contain the following data:-

> Distance (chainage value)
> Level
> Alignment point (BC, EC, etc)
> Offset (Distance to nearest gauge face of running rail)
> Cant Value

Distance Indicators are required at every 50m in tunnels and at 100m outside tunnels. These are to be manufactured from aluminium sheets faced with high-intensity reflective film. The chainage values in black are to be superimposed on the yellow reflective film. The plates shall be mounted on the tunnel walls and viaduct parapets.

4.3.5 Cross Bonding and Jumper Cables

For bridging insulated sections of the running rail in order to ensure the flow of the negative return current, cross-bonding cables and jumper cables are required. In general, jumper cables shall be installed at all turnouts in mainlines connecting the interrupted rails on either side of the insulated sections.

The installation locations shall be co-ordinated and determined in collaboration with the Signal and Power designers. The method of cable connection to the running rail shall be subject to the approval of the Engineer.

4.3.6 Bonded Insulated Rail Joint

All bonded insulated rail joints (IRJ) shall be pre-fabricated under shelter condition and welded onto the rail. In-situ IRJ is only permitted where pre-fabricated joints cannot be welded in from geometrical reasons.

The IRJ is to separate electrically two adjacent running rail sections and shall have minimum electric resistance of 1000 ohm for a thoroughly moistened joint. The location shall be determined by the Signal and Power designers.

The joint shall be of the glued synthetic-resin type with steel fishplates and high tensile bolts and successfully installed for UIC 60 rail with a major railway system for a minimum of 5 years.

4.3.7 Welding

Rail for all mainline tracks outside the limits of turnouts shall be welded into continuous strings using the electric flash-butt welding process by means of an on-track machine.

Rail within turnout limits may be welded using an accepted thermit welding process.

Excessive weld material shall be removed and ground to match the rail head on either sides of the weld.

4.3.8 Trap Points

Where sidings/reception tracks converge on the mainlines, trap points shall be provided to guide unauthorised or runaway vehicles away from the mainlines, structures and any other hazards. Buffer stops shall be provided at the end of the trap point tracks to arrest the unauthorised or runaway vehicles. In the permanent way sidings and non-signalised areas within the depot, trap points shall be provided to prevent unauthorised vehicles movement.

4.3.9 Track Insulation

In general, adequate isolation is required to minimise traction return current leakage to the track supporting structure and for proper functioning of the signalling system. Under damp conditions and without any other trackside equipment or cable installation connected, the track system shall meet the following requirements:-

i) a minimum of 10 ohm-km resistance between the track and sub-station water earth, with both running rails of the track electrically connected; and

ii) a minimum running rail to running rail resistance of 2 ohm-km.

4.4 THIRD RAIL SYSTEM

4.4.1 General

The third rail system shall be of the bottom contact type in which vehicle-mounted current collector shoes press upwards onto the underside of the conductor rail. All provisions of the third rail system shall take into account the effect of dynamic impact of the running train. Position of components, particularly the stainless steel contact surface shall be co-ordinated with the design of collector shoes.

The complete third rail system, including the protective cover, shall be capable of withstanding a downward vertical load of 1.5kN and a shock load of 50kg steel ball free-falling 300mm, at any point without causing any permanent deflection when the load is removed.

All fastenings shall be of stainless steel minimum grade A4-80. Forging of stainless steel components shall be prohibited.

4.4.2 Conductor Rail

The conductor rail shall be manufactured from a high-conductivity aluminium alloy with a stainless steel wearing face for the train collector shoes. The stainless steel shall be joined to the aluminium either by a molecular or welding process and not only by mechanical means. The rail shall be supplied to site straight and in standard lengths.

4.4.3 Joints in Conductor Rail

Individual lengths of conductor rail shall be rigidly connected to each other, both mechanically and electrically, using splice plates made from the same aluminium alloy as the rail. The splice bars shall be fixed to the Conductor Rails by huckbolts.

4.4.4 Ramps

Entry and exit ramps shall be provided at turnouts and at other locations where a gap in the conductor rail is necessary. They shall also be provided at all electrical disconnecting points and changes of the third rail installation from one side of the track to the other. The ramp design shall take into account the differing speed requirements of a running train.

4.4.5 Cable Terminals

Cable terminals have to be installed at locations determined by power supply. Each cable terminals shall accommodate a maximum of 2 power supply cables. If more than two cables are required for the supply of traction power to the conductor rail, the cable terminals shall be installed at intervals of 1m. The materials of the cable terminals shall be selected to avoid electrical corrosion. Cable terminals shall be fixed to the conductor rails by huckbolts.

4.4.6 Conductor Rail Supports

The conductor rail support shall be designed to carry all static and dynamic loads in the system. Conductor rails shall be supported at intervals to ensure that the installed conductor rail deflection will not exceed 6mm from the design level.

4.4.7 Expansion Joints

Expansion and contraction of the conductor rail shall be accommodated by movement joints. Electrical continuity across the joint shall be maintained. Precautions shall be taken to ensure that the movement joint does not suffer from electro-chemical corrosion. The gaps of the expansion joint shall be bridged by an electrical shunt. A mid-point anchor shall be installed between two consecutive expansion joints.

4.4.8 Protective Cover

The third rail shall be provided with a continuous insulating cover to protect persons from accidental contact with the third rail and protect the third rail from foreign objects falling or being thrown onto it.

Outside tunnels, the covers shall be resistant to degradation from ultraviolet radiation from the exposure to sunlight. The materials used for the protective cover shall be unplasticized polyvinyl chloride (UPVC) and glass fibre reinforced plastic (GF-RP) inside tunnels.

4.4.9 Insulator

The insulator shall be of cast cycloaliphatic epoxy resin, resistant to fatigue cracking and suitable for a tropical climate with exposure to ultraviolet rays. The surface finish shall have high surface tracking resistance.

4.5 OTHER INTERFACING SYSTEMS

4.5.1   All information concerning the rolling stock to be used in the system shall be provided by the Authority and/or the rolling stock designer.

4.5.2   The running rails shall serve as the return path to the traction power supply.

4.5.3   The signalling system, depending on the type of system to be supplied, may employ audio frequency track circuits that is connected to the running rails for train detection purpose.

4.5.4   Stray Current Control System (see Chapter 14)
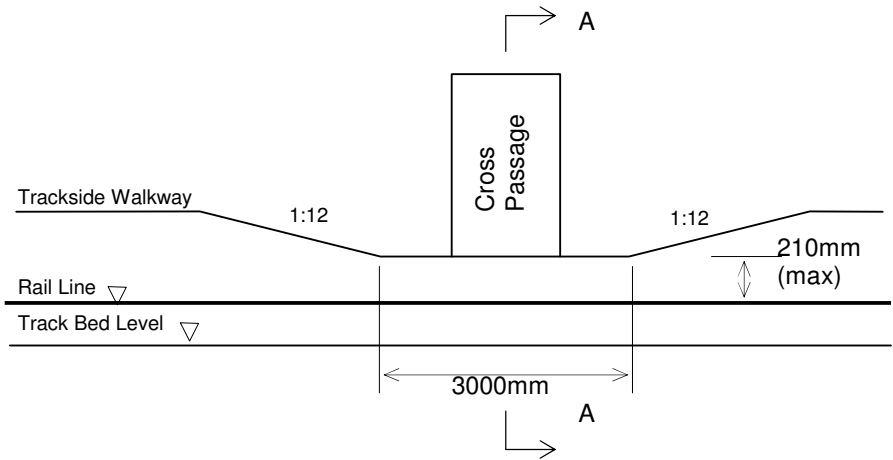
ELEVATION AT CROSS PASSAGE

A

Cross Passage

Trackside Walkway

1:12   1:12

210mm (max)

Rail Line ▽

Track Bed Level ▽

3000mm

A
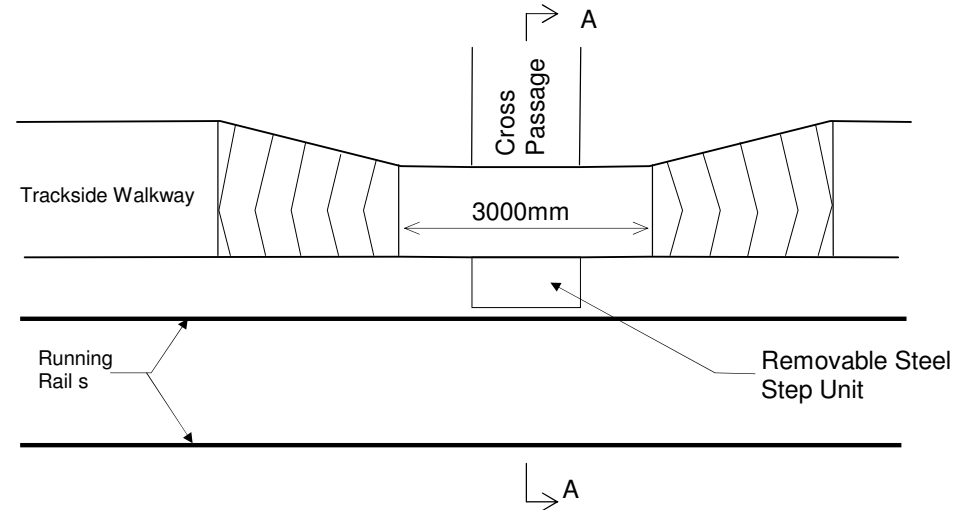
PLAN VIEW AT CROSS PASSAGE

A

Cross Passage

Trackside Walkway

3000mm

Running Rail s

Removable Steel Step Unit

A

SECTION A-A

Tunnel Wall

Trackside Walkway

Cross Passage

Walkway at Cross Passage

210mm (max)

50mm

Conductor Rail

Rail Line

Trackbed Level

Removable Steel Step Unit
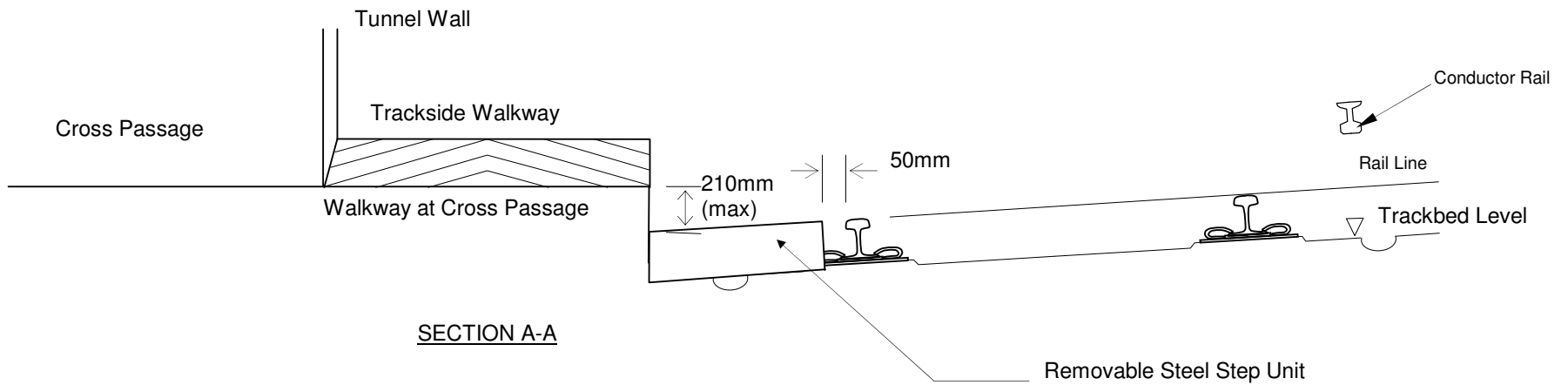
FIGURE 4.3 :   TYPICAL WALKWAY AT CROSS PASSAGE

CHAPTER 5

GEOTECHNICAL PARAMETERS

5.1   GENERAL

The Geotechnical design parameters and other requirements/ information given in this chapter have been derived from various LTA projects.

5.2   HYDROGEOLOGY

5.2.1   Rainfall

Mean monthly rainfall values based on the data from the Meteorological Service of Singapore are given in Table 5.1 below:

Table 5.1: Average Rainfall Data for Period: 1869 - 2003 (135 Years)

Month	Jan	Feb	Mar	Apr	May	Jun
Rainfall (mm)	239	165	184	180	171	163
Month	July	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	159	176	171	195	255	286

5.2.2   Design Ground Water Levels

Refer to Chapter 3.

5.3   SOIL AND ROCK CLASSIFICATION

The common soils and rocks of Singapore have been classified into a number of "Soil and Rock Types" relating to their geological origins as shown in Table 5.2.

5.4   DESIGN PARAMETERS

Minimum values for common design parameters for the soils and weathered rocks of Singapore are given in Table 5.4. The design shall be carried out using these parameters, or such higher parameters as the designer can demonstrate as being appropriate, to the acceptance of the Engineer, based on the results of the soil investigation for the Project.

The subgrade modulus for a given soil or rock depends on the length, width and the depth of the loaded area. These factors should be considered in establishing the design subgrade modulus for each type of foundation or

retaining structure. Typically, the design modulus should be derived from the elastic modulus of the loaded soil/rock by establishing the relationship between the contact pressure and the resulting settlement or deflection, using an acceptable analytical method or numerical modelling. The modulus can also be obtained from plate load tests, with appropriate modifications to the scale of the test and depth effects.

The selection of other Design Parameters which are not given in Table 5.4 shall be derived from the site investigation carried out for the Project and from other relevant geotechnical exploration, sampling and testing. Design Parameters must be justified and submitted to the Engineer for acceptance.

The parameters given in Table 5.4 are for the design of permanent and temporary structures where the minimum strength is critical to the design. They are not intended for the selection of construction equipment where the maximum strength has to be considered.

Table 5.2: Classification of Soil and Rock Types

REFERENCE	SOIL & ROCK TYPE	GENERAL DESCRIPTION	GEOLOGICAL FORMATION (PWD, 1976)
B	BEACH (Littoral)	Sandy, sometimes silty, with gravels, coral and shells.	KALLANG Littoral, possibly also part of all other members & TEKONG
E	ESTUARINE (Transitional)	Peats, peaty and organic clays, organic sands.	KALLANG Transitional, possibly part of Alluvial and Marine.
F	FLUVIAL (Alluvial)	Sands, silty or clayey sands, silts and clays.	KALLANG Alluvial, possibly part of all other members and TEKONG.
F1		Predominantly granular soils including sands, silty sands, clayey sands.	Bed of Alluvial Member of KALLANG
F2		Cohesive soils including silts, clays, sandy silts and sandy clays.	Bed of Alluvial Member of KALLANG
M	MARINE	Very soft to soft blue or grey clay.	KALLANG Marine Member.
O	OLD ALLUVIUM	Pebbles, coarse sand with fine pebbles, medium to coarse sand and clay and silt, variably cemented. See Table 5.3 for weathering classification.	OLD ALLUVIUM
FCBB	FORT CANNING BOULDER BED (also known as S3, Bouldery Clay or Boulder Bed)	A colluvial deposit of boulders in a soil matrix. The matrix is typically a hard silt or clay, but can be granular. The material is largely derived from the rocks and	Not shown in PWD (1976)

		weathered rocks of the Jurong Formation.	
S	SEDIMENTARIES (Rocks & associated soils)	Sandstones, siltstones mudstones, conglomerate and limestone. The rock has been subjected to a varying degree of metamorphism. See Table 5.3 for weathering classification.	JURONG Tengah, Rimau, Ayer Chawan and Queenstown Facies. (plus the Pandan Limestone, which was not identified in PWD (1976))
G	GRANITE (Rock and associated Residual soils)	Granitic rocks, including granodiorite, adamellite and granite. See Table 5.3 for weathering classification.	BUKIT TIMAH GRANITE

Table 5.3: Rock Weathering Classification

GEOLOGICAL CLASSIFICATION			
MRTC (1983)	**LTA Guidance Note (2001)**	**GRADE/CLASS**	**DESIGNATION**
S1 & G1	GI & SI	I	Fresh
	SII & GII	II	Slightly Weathered
S2 & G2	SIII & GIII	III	Moderately Weathered
	SIV & GIV	IV	Highly Weathered
S4 & G4	SV & GV	V	Completely Weathered
	SVI & GVI	VI	Residual Soil
O	OA	A	Unweathered
	OB	B	Partially weathered
	OC	C	Distinctly weathered
	OD	D	Destructured
	OE	E	Residual Soil

Note 1: MRTC (1983) - a weathering classification system developed in 1983 for the first phase of the MRT. This system was based on the proposals made by the Geological Society Engineering Group Working Party in 1970 (Anon 1970), but simplified for use in Singapore. The use of this system shall be discontinued and replaced by LTA Guidance Note (2001).

Note 2: LTA Guidance Note (2001) - weathering classifications based on BS 5930 (1999). See Appendix 5.1.

Note 3: Between 1983 and the issue of the guidance note, various systems for the classification of the weathering of the Old Alluvium were in use. Reference should be made to the corresponding reports for the basis of those classification systems.

Note 4: No weathering classification required for FCBB material.

Table 5.4 - Design Parameters

MRTC (1983) Classification	B	E	F1	F2	M	O					S3	Fill
Classification based on BS 5930 (1999) & LTA's Guidance Note	B	E	F1	F2	M	O Class A	O Class B	O Class C	O Class D	O Class E	FCBB	Fill
Design Parameters — Bulk Density (kN/m^3)	19	15	20	19	16	20	20	20	20	20	22	19
Coefficient of Earth Pressure at Rest (K_0)	0.5	1.0	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5
Undrained Cohesion, C_U (kPa)	0	Figure 5.1 & Note 1	0	Figure 5.2 & Note 1	Figure 5.3 & Note 1	Note 2	Note 2	Note 2	Note 2	Note 2	Note 2	0
Effective Cohesion, C' (kPa)	0	0	0	0	0	Note 3	Note 3	Note 3	Note 3	Note 3	10	0
Effective Angle of Friction (degrees)	30	5	30	22	22	Note 3	Note 3	Note 3	Note 3	Note 3	28	30

Table 5.4 - Design Parameters (cont')

MRTC (1983) Classification	S1		S2		S4		G1		G2		G4	
Classification based on BS 5930 (1999) & LTA's Guidance Note	SI	SII	SIII	SIV	SV	SVI	GI	GII	GIII	GIV	GV	GVI
Design Parameters / Bulk Density (kN/m^3)	24	24	22	22	21	21	24	24	23	23	20	20
Coefficient of Earth Pressure at Rest (K$_0$)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Undrained Cohesion, C$_U$ (kPa)	N/A	N/A	N/A	N/A	Note 2	Note 2	N/A	N/A	N/A	N/A	Note 2	Note 2
Effective Cohesion, C' (kPa)	Note 4	Note 4	Note 4	Note 4	0	0	Note 4	Note 4	Note 4	Note 4	0	0
Effective Angle of Friction (degrees)	Note 4	Note 4	Note 4	Note 4	30	30	Note 4	Note 4	Note 4	Note 4	30	30

N/A: Not Applicable.

Note 1: Figures 5.1, 5.2 & 5.3 gives the undrained cohesion of the normally or slightly over-consolidated consolidated estuarine, fluvial and marine clay. For the areas under reclaimed land, the undrained cohesion of the these clays shall be derived from in-situ tests, such as cone penetration tests or in-situ vane tests.

Note 2: Undrained conditions do not usually apply for deep excavations in these materials, but may be applicable during tunnelling. The methods outlined in Clough and Schmidt (1981) may be used to assess if undrained parameters are applicable. The design should be carried out for both drained and undrained parameters, and the more conservative of these designs should be adopted. For undrained analysis, a value of 5 x N (SPT value in blows/300mm) kPa, up to N = 50, may be adopted for the undrained cohesion in these materials, where applicable.

Note 3: Effective Stress parameters for the Old Alluvium shall be established for each site based on p'- q plots.

Note 4. Effective Stress parameters for these materials should be derived from site-specific data. The Geological Strength Index method (Hoek and Brown, 1997) is considered appropriate for this.

Undrained Cohesion, C_u (kPa)

Figure 5.1
Estuarine (E)
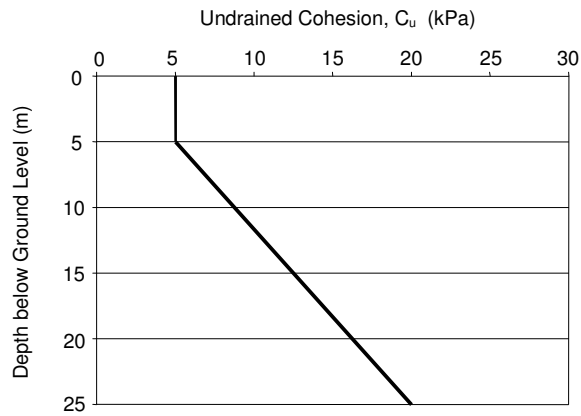
Undrained Cohesion, C_u (kPa)
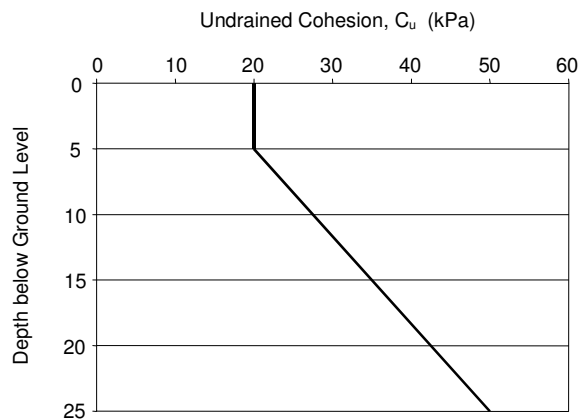
Figure 5.2
Fluvial Clay (F2)

Undrained Cohesion, C_u (kPa)
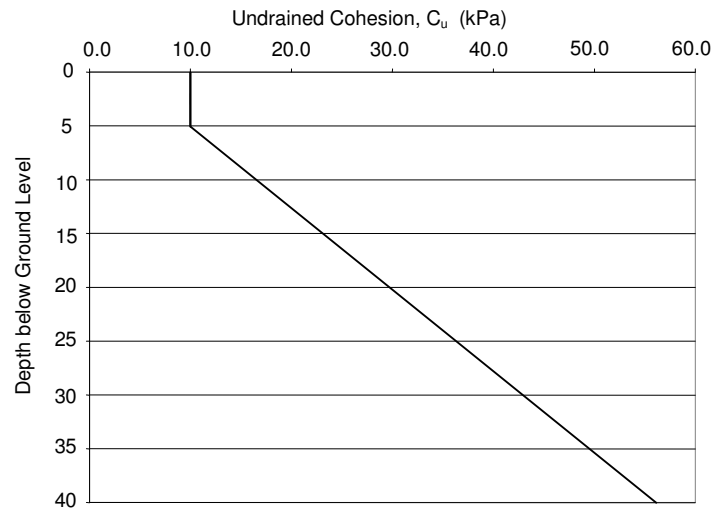
Figure 5.3
Marine Clay (M)

Note 1: Figures 5.1, 5.2 & 5.3 gives the undrained cohesion of the normally or slightly over-consolidated consolidated estuarine, fluvial and marine clay. For the areas under reclaimed land, the undrained cohesion of the these clays shall be derived from in-situ tests, such as cone penetration tests or in-situ vane tests.

5.5 SOIL AND GROUNDWATER CHEMISTRY

Chemical tests shall be carried out during the site investigation for the Project to enable appropriate design considerations for durability. The results obtained shall be classified according to the corrosion properties of soil and groundwater given in SS 289. Classifications for corrosion properties of chlorides in groundwater shall be according to Table 5.5. Any protective measures adopted shall comply with the recommendations of SS 289.

Table 5.5 - Classification of Chlorides in Groundwater

CLASS*	GROUNDWATER
	CHLORIDES ppm
1	Cl<100
2	100<Cl<500
3	500<Cl<2,000
4A/4B	2,000<Cl<20,000
5A/5B	Cl>20,000

*Class according to SS 289, Table 7a.

5.6 SITE INVESTIGATION

Additional site investigation may be conducted to justify any changes to the parameters given in Table 5.4 of this chapter as well as to obtain reliable information for an economic and safe design and to meet the tender and construction requirements.

The data collected shall be of sufficient quantity and quality to enable the following analysis to be carried out where appropriate:

(a) All forms of constructions

- settlement estimates for effects of de-watering;

- evaluation of ground settlement due to expected permeability conditions;

- Structural deformation estimates due to effects of de-watering, increase or decrease in stresses around existing underground structures;

- evaluation of methods of building protection;

- evaluation of methods of ground treatment;

- stability and deformation analyses during and after construction works;

- identification of areas with potential problems;

(b) Shallow and deep foundations

- ultimate and allowable bearing capacities for shallow foundations;

- ultimate and allowable vertical bearing capacities for deep foundations including the evaluation of negative skin friction;

- ultimate and allowable lateral bearing capacities for deep foundations;

- settlement estimates for shallow and deep foundations;

(c) Underground structures

- stability and deformation analyses for temporary and permanent retaining structures;

- evaluation of bracing or anchoring system for temporary and permanent retaining structures;

- settlement estimates for bored tunnelling, including NATM;

- evaluation of tunnelling shield requirements;

- evaluation of tunnel face stability and protection;

- evaluation of uplift, buoyancy and floatation effects;

(d) Earthworks and Soil Improvement Works

- effects of earthworks on ground water condition including, but not limiting to, water level, piezometric level and pore pressure changes;

- settlement and time estimates for improvement works.

(e) Evaluation of the chemical corrosiveness of groundwater and soils and its effect on underground structures.

References

1. Anon (1970) The logging of rock cores for Engineering purposes, Engineering Group Working Party report, *Quarterly Journal of Engineering Geology* 3, 1-24

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3. Anon (1995) The description and classification of weathered rocks for engineering purposes. *Quarterly Journal of Engineering Geology*, 28, 207 - 242.

4. Clough, G.W. and Schmidt, B. (1981). "Design and performance of excavations and tunnels in soft clay". *Soft Clay Engineering*, ed E.W. Brand and R.P.Brenner. publ. Elsevier, Amsterdam. Pp 569 to 636.

5. Hoek E. and Brown, E.T. (1997) "Practical estimates of rock mass strength. *International Journal of Rock Mechanics and Mining Science*, 34(8), 1165-1186.

APPENDIX 5.1

LTA GUIDANCE NOTE (2001)
Weathering Classifications based on BS 5930 (1999)

1. The British Standard for Site Investigation, BS 5930, was revised in 1999. A major area of revision was in the classification of weathered rocks. This note provides advice on how the various ways of classifying weathered rocks outlined in BS 5930 are to be applied in investigations for the Land Transport Authority.

2. Traditionally, the classification system used for MRT projects is a local, simplified system that follows neither the original version of BS 5930 nor the revised version. The simplified system, using terms such as G1 to 4 and S1 to 4, mixes mass and material classifications, and mixes materials with quite different engineering behaviour. Some site investigation contractors provide borehole logs, which include only the simplified classification system symbols, and do not include a detailed description of the material recovered from the borehole.

3. All site investigation work shall comply with the current version of BS5930. This means that the use of S or G 1,2,3 and 4 as weathering classifications is to be discontinued, as should the use of S4a and S4b.

4. All samples of weathered rock must be fully described as outlined in BS5930, Section 6. It is essential that Approach 1 (a factual description of the material, including comments on weathering) of Figure 19 of BS5930 (1999) is followed in all cases. This step is MANDATORY under the Standard.

5. Weathering grade classifications, at a material scale, should also be shown on the borehole log. These classifications should be based on Approach 2 (Bukit Timah Granite, Gombak Norite and Jurong Formation) and Approach 4 (Old Alluvium), also shown in Figure 19 of BS 5930. A discussion of the application of these classification systems in these rocks is given in the Attachment.

6. There should be no attempt to assess heterogeneous mass classifications (Approach 3) on the borehole records.

7. The soil and rock descriptions appearing on the final borehole log produced by the site investigation contractor shall be prepared by a geologist or engineering geologist, and should be based on inspection of the samples retrieved, driller's logs, site engineer's logs, in situ tests, laboratory tests and laboratory descriptions.

8. Both the Jurong Formation and the Old Alluvium are derived from what were originally sedimentary materials. The engineering properties of these materials are affected by factors such as lithology, stress history, degree of cementation/lithifaction and (for the Jurong Formation) degree of metamorphism or silicification. The degree of weathering is

therefore only one factor in assessing the engineering properties of the ground. It is essential that the description of the material cover all observable features, as required in the Standard, and not just weathering.

9. The material underlying much of the CBD has variously been termed 'Singapore Boulder Bed', 'Bouldery Clay' and 'S3'. It has traditionally been included as part of the Jurong Formation, hence the use of the 'S3' classification. It is now generally agreed that this deposit is of colluvial origin and is therefore not insitu Jurong Formation rock. Samples from this deposit should be described, as appropriate, using the methods outlined for soils and rocks in BS 5930 (1999). Samples obtained from the boulders should include a description of the weathering of the rock. The use of the term 'S3' should be discontinued, as should the use of alternating S2 and S4 (currently used by some contractors). The material is important enough to be given a separate Formation name, and it has been decided that 'Fort Canning Boulder Bed' is an appropriate term. The Formation name (FORT CANNING BOULDER BED) should be inserted in brackets and in capital letters under the descriptions, where the Formation can be identified with confidence (see BS 5930, Clause 41.5).

10. S4a and b were terms originally introduced to classify materials which were similar to the residual soil of the Jurong Formation, but which were encountered above the Fort Canning Boulder Bed. In some locations the material so described may be part of the Boulder Bed, but without the characteristic quartzite boulders. In other locations, it may be part of the Old Alluvium. Where hard or dense materials are encountered above what is clearly identifiable as Fort Canning Boulder Bed material, then the samples should be examined carefully to determine whether the material is colluvial or alluvial. If the material is clearly colluvial, it can be classified as 'Fort Canning Boulder Bed'. If it is alluvial, it can be classified as Old Alluvium. If no clear classification can be made, the material should be described following Approach 1, but let without classification.

11. The Jurong Formation commonly exhibits evidence of metamorphism, although the degree of metamorphism varies significantly. Where observed, such evidence of metamorphism must be described on the borehole record. In some cases, it is appropriate to use a term indicating a metamorphic rock, rather than a sedimentary rock, in the Jurong Formation i.e. Quartzite rather than Sandstone.

12. This note must be read in conjunction with BS 5930 (1999). The note is intended to ensure consistent application of the Standard, but not to change any requirement of the Standard. Reference should also be made to 'The description and classification of weathered rocks for engineering purposes'. Quarterly Journal of Engineering Geology, 28, 207 – 242 (1995), for further details of the working party report that was used in the preparation of BS 5930 (1999).

Attachment

Basis for assessing material scale weathering classifications for rocks in Singapore

BS 5930 provides three different approaches for classifying material scale weathering in rocks. These are Approach 2 (for rocks that are moderately strong or stronger in a fresh state), Approach 4 (rocks that are moderately weak or weaker in a fresh state) or Approach 5 (special cases, such as karst).

Bukit Timah Granite and Gombak Norite

Approach 2 follows the system originally devised by Moye in 1955 for granite in Australia, and which has been used for many years in Hong Kong for the granite there. The igneous rocks of the Bukit Timah Granite and Gombak Norite should be described using Approach 2 for classification.

The Geotechnical Engineering Office (GEO) in Hong Kong has produced a list of simple indicators for the assessment of weathering grades in Hong Kong. A slightly amended version is given in Table 1. These indicators can also be used in the igneous rocks of Singapore, which have a similar strength when fresh.

It is particularly important to distinguish between grades III, IV, V and VI, (where present) as there is a significant difference in the engineering behaviour of each of these grades. Typically, the weathered granite in Singapore has a thick mantle of residual soil, with only limited underlying Grade V and/or Grade IV materials. In order to identify these during site investigation, careful and frequent sampling has to be carried out once the SPT value reaches 30 blows/300mm. The 'Classifiers' are not included in Table 1, as they are provided in BS 5930.

Table 1 – Bukit Timah Granite and Gombak Norite.

Weathering classification for Bukit Timah Granite and Gombak Norite	
Grade	**Basis for assessment**
I	Intact strength, unaffected by weathering. Not broken easily by hammer – rings when struck. No visible discolouration.
II	Not broken easily by hammer – rings when struck. Fresh rock colours generally retained but stained near joint surfaces.
III	Cannot be broken by hand. Easily broken by hammer. Makes a dull or slight ringing sound when struck with hammer. Stained throughout.
IV	Core can be broken by hand. Does not slake in water. Completely discoloured.
V	Original rock texture preserved, can be crumbled by hand. Slakes in water. Completely discoloured.
VI	Original rock structure completely degraded to a soil, with none of the original fabric remains. Can be crumbled by hand.

Jurong Formation

The Jurong Formation includes a variety of sedimentary rocks that have been subjected to a variable degree of metamorphism. The Formation also includes the Pandan Limestone. The rocks of the Jurong Formation exhibit a wide range of strength in the Fresh State, and have weathered in different ways. The generally weak mudrock has weathered in a way that is best described by Approach 4, while the stronger sandstones and conglomerates have weathered in a way more like Approach 2. Where the rock is thinly bedded, which is the case in much of the Formation, it is considered impractical to apply different approaches. It is proposed to use Approach 2 for the Classification of the Jurong Formation wherever it is thinly bedded, and in all cases to Sandstone, Quartzite, Siltstone, Shale and Conglomerate. Where mudstone or Pandan Limestone are predominant in an area, then Approach 4 may be used for the mudstone and Approach 5 for the Limestone. The methods for assessing the weathering grade under Approach 2 are given in Table 2.

Table 2 - Jurong Formation

Weathering classification for Jurong Formation	
Grade	**Basis for assessment**
I	Intact strength, unaffected by weathering
II	Slightly weakened, slight discolouration, particularly along joints.
III	Considerably weakened & discoloured, but larger pieces cannot be broken by hand. (RQD is generally >0, but RQD should not be used as the major criterion for assessment).
IV	Core can be broken by hand or consists of gravel size pieces. Generally highly to very highly fractured, but majority of sample consists of lithorelics. (RQD generally = 0, but RQD should not be used as the major guide for assessment). For siltstone, shale, sandstone, quartzite and conglomerate, the slake test can be used to differentiate between Grade V (slakes) and Grade IV (does not slake).
V	Rock weathered down to soil-like material, but bedding intact. Material slakes in water.
VI	Rock degraded to a soil in which none of the original bedding remains.

For Approaches 4 and 5, reference can be made to BS 5930.

Old Alluvium

The Old Alluvium is an alluvial deposit that has been variably cemented, often to the extent that it has the strength of a very weak or weak rock. The upper zone of the Old Alluvium has typically been affected by weathering, and it is important that this weathering is described and classified. The use of Approach 4 of BS 5930 is recommended. However, although weathering of feldspars and mottling may be observed in borehole samples, it is generally difficult to assess the weathering grade from the visual inspection of samples obtained from boreholes. It is common practice in Singapore to use the blow count from SPT testing as an indicator of weathering classification. It must be understood that the SPT result is influenced by factors other than weathering. These other factors would include depositional environment, degree of cementation and the equipment and method used for the testing. Table 3 gives guidance on the typical SPT values for different weathering grades, although the final classification should be based on an assessment of both SPT and careful inspection of samples recovered. Where possible, correlation with the SPT values should be verified by comparing with any nearby large scale exposures of the Old Alluvium. Care must be taken in the SPT testing to ensure a representative test result, and classification should not be based on SPT alone.

It should be noted that at times, layers of hardpan can be found in the weathered Old Alluvium, and very high SPT values or refusal of penetration in the CPT may be due to hardpan rather than a change in weathering grade. Conversely, there may be a sudden drop in SPT N-value if a layer of uniform sand is encountered in a borehole which is not completely filled of stabilising fluid. Unlike the Bukit Timah Granite or the Jurong formation, there is little evidence of joints in the Old Alluvium. As a result, the weathering has typically penetrated as a discernible front from the surface. It is therefore unlikely that there will be more weathered beds under less weathered beds. Other factors, such as those given above, are likely to be the cause of a sudden drop in SPT resistance as the borehole is advanced.

Table 3 – Old Alluvium

Weathering Classification for Old Alluvium			
Class	Classifier	Characteristics	Indicative SPT, Blows/300mm*
A	Unweathered	Original strength	>50 (cannot usually be penetrated by CPTs with 20t load capacity)
B	Partially Weathered	Slightly reduced strength	
C	Distinctly weathered	Further weakened	30 to 50
D	Destructured	Greatly weakened, often mottled, bedding disturbed	10 to 30
E	Residual	No bedding remains	<10

* The SPT result should not be used in isolation to assess weathering, see text above

The tables given above for classifying weathered rocks provide the basis for establishing weathering descriptions under BS 5930 (1999). However, it is not necessarily the case that all of the weathering grades will be present at a particular location.

CHAPTER 6

FOUNDATIONS, PERMANENT RETAINING STRUCTURES
AND EARTHWORKS

6.1   GENERAL

6.1.1   Scope

This Chapter covers the requirements for the design of foundations, permanent retaining structures and earthworks. The foundations, retaining structures and earthworks shall be designed for both short term and long term conditions.

6.1.2   Standards and Codes of Practice

All design shall comply with SS CP 4, BS 8002, SS CP 18, BS 8006, and SS CP 65 or BS 5400 as appropriate unless otherwise modified by subsequent sections of this Chapter or unless otherwise accepted by the Engineer. In designing timber piles the requirements of SS CP 7 shall be followed.

No over-stressing of structural elements in retaining structures are allowed.

The minimum grade of concrete for all foundations shall be grade 40.

6.1.3   Ground Movements

Design of foundations, retaining structures and earthworks shall take into consideration all possible ground movements, ground conditions and groundwater levels. The design shall ensure that movements are within limits that can be tolerated by the Works without impairing the function, durability and aesthetic value of the Works.

It shall be demonstrated that the chosen foundation system or form of construction shall not result in excessive settlement of adjoining properties, structures or utilities as specified in Chapter 20.

6.1.4   Deleterious Substances in Soils

Substances in soils and ground water, which are potentially deleterious to materials used in structures in contact with the ground, shall be considered in the design and specification of all such structures and any protection system. These structures shall include but not necessarily be limited to foundations and that face of a retaining structure which is in contact with the ground.

6.1.5   Combining Various Foundation Types in a Single Structure

A combination of different foundation types or systems within a single structure shall not be permitted without the prior acceptance of the Engineer.

6.2   FOUNDATIONS

6.2.1   Shallow Foundations

6.2.1.1   General

Shallow foundations such as footings may be used where there is a suitable bearing stratum at founding level. Where compressible or loose soil layers occur below the founding stratum, deep raft foundations or Deep Foundation Elements (DFEs) shall be used.

6.2.1.2   Settlement

The maximum allowable settlement of shallow foundations shall be in accordance with Table 6.1.

6.2.1.3   Allowable Bearing Capacity

When determining the allowable bearing capacity, a factor of safety of 3 against ultimate shear failure shall be applied to dead loads alone. This may be reduced to 2.5 when applied to dead plus live loads. The more onerous condition shall be adopted.

6.2.1.4   Groundwater Level

The groundwater level shall be considered to be at finished ground level for assessing the allowable bearing capacity of a shallow foundation.

6.2.1.5   Influence of Adjacent Foundations

Where the pressure beneath a foundation is influenced by adjacent foundations, the allowable bearing pressure shall be adjusted to ensure that the maximum allowable soil bearing capacity and differential settlements are not exceeded.

6.2.1.6   Foundations on Slopes

For shallow foundations on or near slopes the following additional analyses are required:

a) Stability of the slope.
b) Allowable bearing capacity of the foundation on the slope.

6.2.2 Deep Raft Foundations

6.2.2.1 General

Deep raft foundations shall include but not necessarily be limited to the base slabs of cut and cover tunnels and stations where the base slab is not wholly supported by DFEs. Deep raft foundations may be used where there is a suitable bearing stratum at founding level with no compressible or loose soil layers.

6.2.2.2 Settlement

The maximum allowable settlement of the raft shall be in accordance with Table 6.1.

6.2.2.3 Allowable Bearing Capacity

When determining the allowable bearing capacity a factor of safety of 3 against ultimate shear failure shall be applied to dead loads alone in the permanent condition. This may be reduced to 2.5 when applied to dead plus live loads. The more onerous condition shall be adopted.

6.2.2.4 Methods of Analysis

Settlement analyses shall be carried out by using either Finite Element (FE) or Finite Difference (FD) methods. Suitable alternative methods may be used to the acceptance of the Engineer.

Where values for the subgrade modulus are used in the calculations, the values shall be confirmed by FE or FD analyses for an appropriate range of foundation geometries.

In addition to elastic settlements, consideration shall be given to the potential for non-elastic settlements such as those due to creep and consolidation.

6.2.2.5 Negative Skin Friction

Negative skin friction on the structure above the founding level shall be considered for marine soils, alluvial soils, estuarine soils, made ground and any other material that is prone to consolidation or is to be consolidated.

Computation of negative skin friction shall be by effective stress analysis.

6.2.3 Deep Foundation Elements (DFEs)

6.2.3.1 General

The term Deep Foundation Element (DFE) shall include all foundation elements designed to transfer loads by shaft friction and/or end bearing. These elements shall include but not limited to piles, pile groups, diaphragm walls, barrettes, secant and contiguous bored pile walls. In the event of any uncertainty as to whether or not a particular foundation type or element is covered by this definition written clarification shall be sought from the Engineer.

When choosing the type of foundation consideration shall be given to the impact of noise and vibration during DFE installation and current legislation on the use of piling and other construction equipment.

The minimum cover to all reinforcement (including links) shall be 75mm.

In the design of driven piles, stresses arising from impact and shock from piling hammers shall be considered.

6.2.3.2   Settlement

The maximum allowable foundation settlement shall be in accordance with Table 6.1.

6.2.3.3   Negative Skin Friction

Negative skin friction shall be considered in the design in marine soils, alluvial soils, estuarine soils, made ground and any other material that is prone to consolidation or is to be consolidated.

Computation of negative skin friction shall be by effective stress analysis.

Raking DFEs shall not be used in areas where negative skin friction is anticipated.

6.2.3.4   Working Loads

The working loads of the DFE shall be the greater of:

(a) Applied dead load + Negative skin friction and non-transient live load (eg. Fixed plant and equipment in stations).
(b) Applied dead load + total live load.

6.2.3.5   Lateral Loads

Laterally loaded DFEs shall satisfy the requirements given in Table 6.1. The analysis shall use "p-y" curve, finite element or finite difference.

6.2.3.6   Ultimate Bearing Capacity

The size of the DFE shall be demonstrated to be sufficient to provide the required bearing capacity and meet the settlement criteria. Total stress analysis and effective stress analysis shall be carried out.

The factor of safety on working loads shall comply with the following requirements:

(a)   The overall factor of safety shall be not less than 2.5
(b)   The factor of safety shall be not less than 1.5 in shaft friction alone, except in the following cases:

Case a.   When the DFE has been installed by driving
Case b.   Where there is safe man access to the base of the DFE, any loose or remoulded material is removed from the base, and the base inspected and confirmed dry before casting the concrete
Case c.   If the DFE is base grouted, using a proven method of base grouting to the acceptance of the Engineer.
Case d.   Where the end bearing is provided by S1 (SI or SII) or G1 (GI or GII) rock, and toe coring is carried out to confirm the pile/rock contact for every DFE.

If the design is based on any of these four cases, the appropriate requirements for driving, access and inspection, base grouting or toe coring must be included on the loading plan drawings. The designer may specify which of the cases is to be used, or may allow the contractor the option of selecting from two or more of these cases.

The DFE design shall be verified by Preliminary Load Testing.

For the load combination where the water table is taken at the underside of the lowest base slab as defined in Chapter 8, the geotechnical factors of safety above for DFEs may be reduced by 20%, provided that the structure is designed for the associated settlement and differential settlement.

6.2.3.7   DFE Interaction

The group effect of DFEs shall be checked in settlement and lateral deflection and in bearing capacity. The interaction between DFEs shall be assessed and considered in the calculation of the capacity and settlement based on Poulos and Davis (1980) or any other methods accepted by the Engineer.

6.2.3.8   DFEs Acting in Tension

For driven piles the ultimate skin friction under tension shall be taken as no more than 75% of the ultimate friction measured in compression. No reduction factor is required for bored piles.

The factor of safety against failure shall be demonstrated to be not less than 3.5 if the skin friction is derived from preliminary DFE tests carried out in compression.

Where the skin friction is derived from preliminary DFE tests with the DFE loaded in tension, then a factor of safety of 2.5 shall be used.

DFE groups under tension loading shall be checked for:

a) The sum of the uplift resistance of the individual DFEs, allowing for interaction effects.
b) The sum of the shear resistance along the perimeter of the group and the effective weight of the soil and DFEs within the perimeter.

All structural connections shall be designed for the design tensile force with appropriate factors of safety.

6.2.3.9   DFE Design Requirements

The structural design of DFEs shall meet the following requirements:

a) Compressive Axial Load

Concrete DFEs subject to axial load shall be designed such that the average compressive stresses across the whole section of the DFE at serviceability limit state shall not exceed the lesser of 0.25 times the characteristic cube strength of concrete at any point along the DFE or the value in accordance with SS CP 4. Where permanent casing is provided the allowable compressive stress may be increased, subject to the acceptance of the Engineer.

b) Axial Load with Coexistent Lateral Load

Concrete DFEs shall be designed as short columns according to SS CP 65 and checked at both the ultimate and serviceability limit states. The DFEs shall be designed such that the maximum crack width under working load is 0.25mm. For bridges, viaducts and abutments, the design crack width shall follow BS 5400 Part 4 Table 1 or 0.25mm whichever is more onerous.

c) Pure Tensile Axial Load

The safe tensile axial working load of the DFE shall be determined by multiplying the cross-sectional area of steel reinforcement with the permissible tensile stress. The permissible tensile stress under working load shall not exceed $0.58f_y$ N/mm^2. In addition, the DFEs shall be designed such that the maximum crack width under working load is 0.25mm. For bridges, viaducts and abutments, the design crack width shall follow BS 5400 Part 4 Table 1 or 0.25mm whichever is more onerous. The crack width calculation shall be according to SS CP 73 Annex B. The stiffening effect of concrete shall not be considered in

the calculation. The DFE shall be reinforced to the depth necessary to mobilise the required ultimate skin friction capacity in tension. Laps shall be avoided wherever possible. Where laps are necessary they shall be full strength laps assuming the reinforcement is working at the ultimate limit state at full design strength (i.e. characteristic strength of reinforcement divided by the partial safety factor for reinforcement).

Where the durability assessment, as required in Design Criteria Chapter 1, demonstrates that durability of the DFE is of concern, then suitable measures shall be taken to improve the durability. Measures to be considered shall include one or more of: sacrificial concrete, sacrificial outer casing, protection to the reinforcement, cathodic protection, or other suitable measures.

6.3   SETTLEMENT/HEAVE

The limits given for settlement and differential settlement shall also be complied with in terms of heave and differential heave.

The maximum allowable foundation settlement shall be in accordance with Table 6.1, unless otherwise accepted by the Engineer.

Table 6.1: Maximum Allowable Settlements and Horizontal Deflection

Foundation Type	Maximum Allowable Settlement		
	Total		Differential
	Short Term	Long Term	Short & Long Term
Shallow	20mm*	20mm*	1:1000*
Deep Raft	20mm*	20mm*	1:1000*
Deep Foundation Element	15mm	25mm	1:1000
Foundation Type	Maximum Allowable Horizontal Deflection		
	Total		Differential
	Short Term	Long Term	Short & Long Term
Laterally Loaded DFEs	15mm	25mm	1:1000

Short-term settlement shall consist of immediate non-recoverable settlement, elastic settlement and consolidation settlement which occurs between the date of casting and the date of Substantial Completion of that part of the works.

Long-term settlement shall consist of immediate non-recoverable settlement, elastic settlement and consolidation settlement from the date of casting to the end of the design life and creep settlement from the date of casting to the end of the design life.

For lateral loading, maximum allowable deflections shall be calculated at pile cut-off level.

Settlement shall be the settlement occurring from the time at which the base slab / pile cap is cast and shall be measured at the structural surface of the base slab / pile cap.

Where the limits in Table 6.1 are marked with an asterisk (*), these limits may be exceeded if it is demonstrated that the structure is designed for the movements to which it will be subjected without compromising the serviceability of the system and, where appropriate, the limits on track or road movements given below.

Where the foundations provide support to structures carrying railway track, the maximum anticipated settlement and differential settlement of the railway track shall be calculated. The settlement calculation shall include the effects of all anticipated loads and effects occurring after the track has been laid. These shall include but not be limited to live loads, any dead loads not applied prior to track laying, groundwater recovery, negative skin friction, known future development loads (including dewatering during such developments), creep of the material forming the foundation, and creep and/or consolidation of the founding strata. The design shall ensure that the settlement of the track under these loads and effects does not exceed 15mm and that differential settlement of the track or its plinth does not exceed 1:1000 in any plane.

Settlement is measured at any location along the track as the change of the level of the track (where the track level is taken as the mean level of the two rails). Differential settlement is measured in two directions, as follows:

(a) Perpendicular to the track - 1:1000 between the rail heads measured as the difference in the change of levels between the two rails (mm) at that location divided by a nominal gauge of 1435 mm.
(b) Parallel to the track - 1:1000 between any two points 3 metres apart, measured as the difference in the change of levels between the two points (mm) divided by 3000 mm.

The assumptions with respect to backfill and recovery of the water table level before the track is laid shall be justified and shall be stated on the drawings.

Where the foundations provide support to a road, or structures carrying a road, the maximum anticipated settlement and differential settlement of the road shall be calculated. The design shall ensure that the settlement and differential settlement do not adversely affect the function of and maintenance requirements for the road. Consideration shall be given to all aspects of the road, including, but not limited to the road pavement, drains, sumps, ancillary structures, mechanical and electrical plant, cabling and services.

6.4 DEBONDING OF DFEs

For contracts where DFEs are constructed for adjacent developments, the permanent works shall be designed for the loads imposed by those DFEs unless the DFEs are debonded such that there is no load transfer.

If it is chosen to design the permanent works for the imposed load from the DFEs, then it is required that the assumptions for load transfer along the length and at the base of the DFEs are verified by means of instrumented load tests. The number of instrumented load tests must be sufficient to provide information for all of the types of DFEs and in all of the ground conditions present.

Any imposed loads from the DFEs shall be additional to the loads and surcharges defined in Chapter 3 and in the Particular Specification.

6.5 LOAD TESTING

6.5.1 General

The number and type of load tests shall be specified in accordance with the requirements given in Table 6.2. The number and type of tests shall be indicated on the Drawings.

The Ultimate Limit State (ULS) criterion for a preliminary load test is when the settlement of the pile head has exceeded 10% of the pile diameter.

The Serviceability Limit State (SLS) criteria shall be established at 1.0 and 1.5 times the working load. An allowable residual settlement upon final release of test load shall be determined. These criteria shall be calculated to be consistent with the whole foundation system meeting the settlement requirements under Table 6.1 and shall be used as the criteria for assessing load tests. These criteria shall be stated on the Drawings.

Similar SLS criteria shall also be established for tension DFEs. SLS criteria at 1.0 times the working load shall be established for laterally loaded DFEs.

For guidance, some typical failure criteria are given below. The maximum settlement figures may be increased by 2.2% for every metre length of DFE beyond 30 metres.

SLS Failure Criteria for Bored Piles

(a) The maximum settlement at working load (second cycle) exceeds 7 mm, and
(b) The maximum settlement at 150% working load exceeds 14 mm.

SLS Failure Criteria for Driven Piles

(a) The maximum settlement at working load (second cycle) exceeds 9 mm, and
(b) The maximum settlement at 150% working load exceeds 20 mm.

Failure Criteria for all DFEs

(a) Failure of the DFE materials (due to defects in the DFEs).
(b) Failure of concrete to reach the design compressive strength.
(c) The residual settlement upon the final release of the load exceeds 5 mm.

6.5.2 Preliminary Load Tests

6.5.2.1 Test Loads

The target for the preliminary load testing is to achieve the ULS criterion.

6.5.2.2 Dimensions for Preliminary Load Tests of DFEs

Preliminary load tests on piles can be considered representative for working piles up to twice the diameter of the preliminary test piles, provided that they are installed in similar ground conditions.

For the load testing of barrettes and diaphragm wall, the contractor may propose the testing of piles in place of the barrettes or diaphragm wall. However, the contractor must ensure that the diameter of the pile is at least equal to the minimum dimension of the diaphragm wall or barrette and that the method of construction for the pile be similar to that used for construction of the diaphragm wall or barrettes.

6.5.2.3 Ground Conditions

Preliminary test DFEs shall be installed in ground similar to that where the working DFEs are to be installed.

6.5.3 Working Load Tests

6.5.3.1 Test Loads

The test loads in a Working Load Test shall be 150% of the working load of the DFEs. Where the working load of the DFE is governed by Load Combination 1 in Chapter 8, the working load test shall be 120% of the working load.

6.5.3.2 Failure of Working Load Test

A DFE is considered to have failed a loading test if it does not comply with either of the SLS criteria. Where a pile fails the test the Contractor shall install suitable compensation piles. If, in the opinion of the Engineer, it is impracticable or inadvisable to install compensation piles in place of a failed pile, the Contractor shall submit proposals to rectify the defect. The proposal is subject to the acceptance of the Engineer.

Where a DFE fails the working load test, the Contractor shall carry out two additional working load tests. The Engineer shall select the piles for these tests.

Working load tests shall be in the direction of the design load, i.e., Piles where the major load is in tension shall be tested in tension.

6.5.4 Quantity of Testing

The values in Table 6.2 represent the Authority's minimum requirement for DFE testing.

Table 6.2: Minimum Requirements for Testing of Deep Foundation Elements

Type of Test	Type of Deep Foundation Element				
	Bored Piles	**Barrettes**	**Load Bearing Secant Piled Walls**	**Load Bearing Diaphragm Walls**	**Driven Piles**
Preliminary Load (Vertical, Horizontal and Tension respectively)	2 numbers	2 numbers	2 numbers	1 in every 400m	2 numbers
Working Load (Vertical, Horizontal and Tension respectively)	2 numbers or 1.0% whichever is greater	_	_	_	2 numbers or 1.0% whichever is greater
DPT	3 numbers or 3.0% whichever is greater	5 numbers or 5.0% whichever is greater	_	_	_
PDA & CAPWAP	_	_	_	_	3 numbers or 3.0% whichever is greater
Sonic Coring	2 numbers or 0.5% whichever is greater	2 numbers or 0.5% whichever is greater	2 numbers or 0.5% whichever is greater	1 in every 30 panels	_
Sonic Logging	2 numbers or 1.0% whichever is greater	2 numbers or 0.5% whichever is greater	2 numbers or 0.5% whichever is greater	_	_
Low Strain	2 numbers or 2.0% whichever is greater	_	_	_	3 numbers or 3.0% whichever is greater

Note: When the Factor of Safety under the design load (including NSF) is greater than 5, no load testing is required. DPT = Dynamic Pile Testing. PDA = Pile Dynamic Analysis.

For the purpose of establishing the number of tests required the percentages given in Table 6.2 relate to the total number of working DFEs in a contract. Calculations of the number of tests as a percentage of the total number of DFEs shall be made to one decimal place. If the result is not a whole number then the value shall be rounded up to the nearest whole number: e.g., if 237 working piles were installed the requirement would be for 3 working load tests.

Where more than 400 piles are installed in similar ground conditions, using similar methods, on a single contract by the same piling contractor then the number of tests can be reduced on the following basis:

For the first 400 piles, the percentage shall be as shown in the Table 6.2. For piles in excess of the first 400, the percentage tested may be reduced to half of that shown in the Table 6.2 for the relevant tests.

6.5.5 Selection of DFEs for testing

DFEs to be tested shall be proposed for the acceptance of the Engineer. Piles for testing shall be selected after they have been constructed unless the method of testing requires the piles to be pre-selected.

6.6 PERMANENT GRAVITY AND CANTILEVER RETAINING WALLS

6.6.1 Lateral Earth Pressures

In computing the lateral pressure of the retained earth, the appropriate coefficient of earth pressure shall be used. For cohesive soils, the total design pressure shall not be less than that of an equivalent height of water pressure.

6.6.2 Water Pressure

Water pressure must be considered in the design notwithstanding that weep holes are provided. Design water level shall be taken at finished ground level. Tables 6.3a & 6.3b indicate the factors of safety for checking stability of retaining walls.

6.6.3 Factors of Safety for Stability

Contribution of passive resistance of the top 1500 mm of the ground in front of wall shall be ignored for permanent retaining walls.

The overall stability of the retaining wall shall comply with the factors of safety from Table 6.3a and 6.3b, whichever is more onerous.

**Table 6.3a: Factors of Safety for Retaining Wall Design
(Without Mobilisation Factors)**

Factor of Safety against:	Gravity or L-shaped	Embedded Wall
Sliding	1.5	-
Overturning	2	1.5
Overall failure	1.5	1.5

**Table 6.3b: Factors of Safety for Retaining Wall Design
(With Mobilisation Factors in accordance with BS8002)**

Factor of Safety against:	Gravity or L-shaped	Embedded Wall
Sliding	1.0	-
Overturning	1.0	1.0
Overall failure	1.0	1.0

For abutments higher than the surrounding ground, the design water level shall be taken at ⅓ the height of the abutment measured from the surrounding ground. Additional checks shall also be carried out for the design water level to be considered at the top of the abutment, but the factor of safety in Table 6.3a may be reduced by 25%.

6.6.4 Use of DFEs for Retaining Structure Foundations

If the base pressure exceeds the allowable soil bearing capacity or if the base pressure is such as to produce excessive differential settlement then walls shall be founded on DFEs.

Where DFEs are used, the interface friction angle between the base of the wall and the underlying soil shall be taken as zero.

6.6.5   Settlement and Deflections

The design shall include an assessment of the deflections and settlement of the retaining structure. The design shall demonstrate that the anticipated settlement and deflection will not cause damage to the retaining wall or to adjacent structures or utilities.

The design shall allow for the lateral loads imposed on the structure due to the action of compaction plant.

6.6.6   Seepage

Where appropriate, seepage around or under the structure shall be considered when calculating the earth pressures generated on both sides of the retaining structure.

6.7   EARTHWORKS

6.7.1   General

For the design of slopes, the effects of ground deterioration due to local climatic conditions shall be considered in the analysis. The steepest unreinforced permanent slope allowed shall be 2.0 horizontal to 1.0 vertical, unless otherwise accepted by the Engineer.

For drainage, an open concrete-lined channel should be used whenever possible. The design shall demonstrate that the short term and long term behaviour of the soils will not in any way affect the functional and aesthetic value of all earthworks. The design shall allow for all planned excavations at the toes of the slopes including the construction of drains in addition to the allowance for unplanned excavation as required in BS 8002.

For embankments on existing slopes (Figure 6.1) which exceed 1 vertical to 4 horizontal, a horizontal bench shall be cut to support the toe. The minimum width of the bench shall be equal to ⅓ of the vertical height of the fill (measured from the toe) but the bench width shall be no more than 3.5m and no less than 0.6m. The existing slopes shall be designed to have horizontal terraces cut over the full area to be covered by new fill. Each horizontal terrace shall be at least 600mm in width and shall be stepped in slopes no greater than 1 vertical to 2 horizontal. The design drawings shall indicate the construction sequence such that horizontal terraces are cut progressively as each embankment layer is placed.
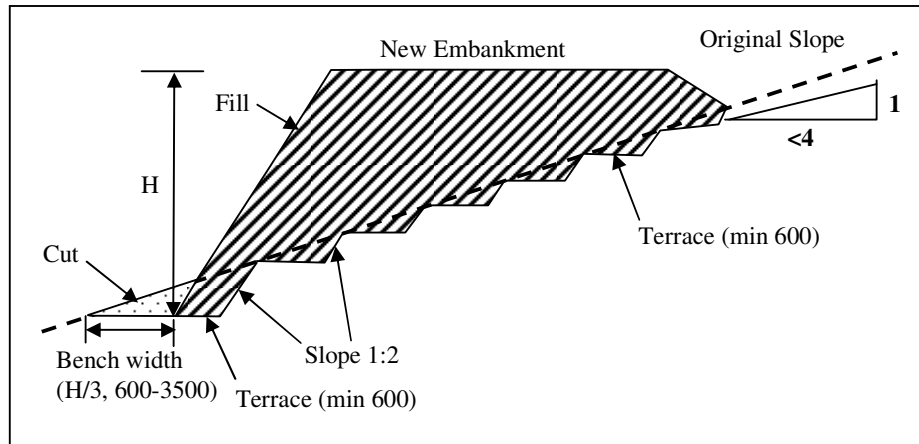
Figure 6.1 Embankments on Hillsides

Utilities shall not be allowed to be laid in parallel to railway tracks within an embankment or cutting. For utilities laid perpendicular to rail tracks, acceptance shall be obtained from the Engineer. The designer shall carry out a risk assessment and minimise the risk to the rail structure to an acceptable level.

6.7.2 Factor of Safety

The minimum factor of safety for the stability of all earthwork and cut slopes shall be 1.5.

For temporary slopes where the analysis is carried out using effective stresses with full consideration of seepage, and a failure would not affect the safety of any person, structure or utility, a factor of safety of 1.2 may be used.

6.7.3 Embankment

The design shall include benching, toe keys, ditches and drainage as required and provision for clearing vegetation, digging and breaking up of topsoil, and prevention of slope erosion.

Where embankments are required for rail tracks, the design shall ensure that differential settlement is kept minimal. Differential settlements after track installation shall be less than 1:1000 per year.

6.7.4 Soil Improvement

Soil Improvement methods may be included either singly or as a combination of methods in the design. Pilot areas of soil improvement as agreed with the Engineer shall be carried out to verify the design prior to the commencement of the main soil improvement work.

6.7.5   Drainage

Provision shall be made in the design for an adequate drainage system that incorporates sufficient capacity for the design rainfall run-off. The anticipated volume of run-off shall be determined.

Pumps shall be designed with adequate capacity to keep the works free of water. Consideration shall be given to ensure the long-term performance of the drainage system.

6.7.6   Non-Suspended Apron Structures and Services

Settlement of non-suspended apron structures and services shall be designed to be within the limits which shall not in any way affect the function, durability, and aesthetic value of such structures and services.

Special attention is required where the apron structures and services are over compressible materials eg, Marine Clays, Estuarine Clays and are adjacent to structures on DFEs or deep rafts.

6.7.7   Reinforced Earth Slopes and Walls

The design of reinforced earth slopes and walls shall satisfy both long term and short term conditions. The partial factors of safety in BS 8006 shall be complied with.

The reinforced earth slopes or walls shall be checked for both internal and external stability in accordance with BS 8006. Loading shall be in accordance with Chapter 3.

The minimum grade for concrete surfacing panels for reinforced earth walls shall be grade 40 with a minimum concrete cover of 40 mm. The panels shall be designed for vehicular impact load in accordance with BD60/94 or shall be designed such that they can be replaced. As part of the design, a method statement shall be prepared for replacement of the panels.

Allowance shall be made in the design for corrosion of metal strips used as reinforcement as follows:

$$d_c = d_{design} + r_c * (\text{life span of structure})$$

Where

d_c = actual thickness or diameter of reinforcing material to be used in construction (mm);
d_{design} = thickness or diameter of reinforcing material determined from design calculation (mm);
r_c = rate of corrosion (mm/yr).

6.8   TRANSITION SLABS

6.8.1   General

To provide a smooth transition from at-grade sections to elevated sections, at-grade separation structures, tunnels or U-Sections of tunnel approaches, a transition slab shall be provided. The transition slab shall meet the following requirements for road and rail structures.

6.8.2   Transition Slab for Highway Bridges

The transition slab shall be of a length such that in the period between its completion (as determined by the Engineer) and the end of the Maintenance Period, the change in gradient between the transition slab and road / bridge shall be less than 0.25% but in any event its length shall not be less than 6m. If necessary, ground improvement works shall be specified in conjunction with the approach slab to meet this requirement.

6.8.3   Transition Slab for Railways

Design calculations shall be carried out to estimate the anticipated settlements and rotations of transition slabs and it shall be shown that these movements shall not in anyway affect the performance of the railway line.

The length of transition slab shall be calculated and in no case be less than 6 m nor less than that given by the following:

$$L = 1.5\ H \tan (45° - \tfrac{1}{2}\,\phi)$$

Where

L = minimum length of transition slab from centre of slab support.
H = vertical distance from bottom of transition slab to bottom of abutment.
ϕ = Angle of internal friction of backfill beneath slab, in degrees.

The transition slab shall be designed assuming that it receives no support from the backfill for a distance not less than 4 m nor less than H tan (45° - ½ ϕ) from the back of the abutment.

6.9 USE OF FINITE ELEMENT OR FINITE DIFFERENCE MODELLING TECHNIQUES

The requirements on the use of finite element (FE) or finite difference (FD) modelling techniques as specified in Chapter 16 shall be followed for permanent works design.

Where structural elements have been used in a FE or FD model, justifications must be provided on their material properties and connection details. For permanent structural elements, the full stiffness of elements shall be used in the model.

References

1.   Poulos, H.G and Davies, E.H. (1980). "Pile Foundation Analysis and Design." John Wiley, New York, New York.

2.   CIRIA Report 104. (1984). "Design of retaining walls embedded in stiff clay." (Table 5).

3.   CIRIA Report C580. (2003). "Embedded retaining walls – guidance for economic design."

4.   IStructE guidelines. (2002). "Guidelines for the use of computers for engineering calculations."

CHAPTER 7

BORED TUNNELS AND RELATED WORKS

7.1   SCOPE

This chapter covers the design requirements for the following structures:

(a) Segmental linings (permanent & temporary);
(b) Cast in-situ linings (permanent & temporary);
(c) Sprayed concrete linings (SCL);
(d) Steel ribs and lagging;
(e) Cross passageways and
(f) Escape shaft.

7.2   STANDARDS AND CODES OF PRACTICE

The design of bored tunnels and related works shall comply with SS CP65, BS 5950, other relevant codes and the additional requirement herein.

7.3   DEFINITIONS OF SOFT GROUND AND ROCK

7.3.1   Soft ground shall include all grounds except GI, GII, SI & SII (see Chapter 5, Geotechnical Parameters).

7.3.2   Rock shall include grounds GI, GII, SI & SII (see Chapter 5, Geotechnical Parameters).

7.4   LOADS

7.4.1   Partial Safety Factors

The partial safety factors used for ultimate limit state and serviceability state limit state designs shall be in accordance with SS CP 65.

7.4.2   Load Combinations

7.4.2.1   The envelopes of the stress resultants at both ultimate and serviceability limit states shall be determined from the critical load combinations listed in Table 7.1.

Table 7.1 Critical load combinations for design of bored tunnels

Load Combination	Description
Load Combination 1	Full ground overburden pressure using Ground Water Level (GWL) at lowest credible level together with (where more onerous) live load surcharge
Load Combination 2	Full ground overburden pressure using GWL at finished Ground Level (GL) together with (where more onerous) live load surcharge
Load Combination 3	Full ground overburden pressure using Design Flood Level
Load Combination 4	Full ground overburden pressure using GWL at lowest credible level together with (where more onerous) live load surcharge, and additional distortion of +/-15mm on diameter to allow for future development
Any other more onerous load combinations	

7.4.3 Distortional Loading Coefficient

7.4.3.1 Distortional loading due to out-of-balance vertical and horizontal earth pressures shall be used in the analysis of tunnel in soft ground. The design shall satisfy the distortional loading coefficient, K, which is the ratio of horizontal soil pressure to vertical pressure prior to lining deformation as shown in Table 7.2.

Table 7.2 Distortional loading coefficient (K) for design of bored tunnels

Soil Type	K
E, M, F2	0.75
B, O, , GV, GVI, F1	0.5
SV, SVI	0.4
SIII, SIV, FCBB, GIII, GIV	0.3

FCBB : Fort Canning Boulder Bed

7.4.3.2 The out-of-balance parameters for the distortional loading on the linings shall take account of the relative speed of reloading of horizontal and vertical ground pressures.

7.5 DESIGN CONSIDERATIONS AND REQUIREMENTS

7.5.1 General

7.5.1.1 Whilst this section outlines the design requirements for permanent and temporary linings, which include cast in-situ concrete linings and precast segmental linings, additional requirements for precast segmental linings, SCL and ribs & lagging are described in sections 7.6, 7.7 & 7.8 respectively.

7.5.1.2 The design of tunnel linings and related works shall take into consideration the method of construction.

7.5.1.3 The design of the tunnel linings shall take into account the required life span, the proposed use, the ground conditions, proximity of one tunnel to the other, the sequence and timing of construction and the proximity of adjacent structures.

7.5.2 Tunnel Size

7.5.2.1 The tunnel shall be of sufficient size to accommodate all operational envelope requirements and provision for services, fittings and furniture as required. These may include but are not limited to the following:

(a) Structure gauge in rail tunnels with full allowance for the maximum cant;

(b) Vertical and lateral clearance envelope in road tunnels, with full allowance for the super-elevation and curve widening to take into account stopping sight distance;

(c) Track support system in rail tunnels;

(d) Drainage channels and pipes.

(e) Traction supplies.

(f) Walkway and walkway envelope.

(g) Plant and all associated furniture, bracket, cabling & etc;

(h) Dry riser fire-main with hydrants;

(i) Lighting;

(j) Pumping main;

(k) Signage and

(l) Ventilation equipment and ducting

7.5.2.2 The theoretical internal tunnel diameter is defined in the Particular Specification. This size will provide an adequate blockage ratio to satisfactorily minimise the piston effect of the trains or road vehicles as

appropriate. In addition, a minimum space of 100 mm all around shall be provided in the design to accommodate: -

(a) Construction tolerances given in the Materials & Workmanship Specification;

(b) The deformations of the tunnel section under design load and

(c) Future movements (e.g. due to future development).

Thus, the minimum constructed internal tunnel diameter shall be the theoretical size plus 200mm.

7.5.2.3   If a horseshoe-shaped tunnel is selected, it shall provide the same blockage ratio as a circular tunnel with a diameter as specified in the Particular Specification. In addition, the Contractor shall allow a minimum space of 100 mm all around as in Clause 7.5.2.2 above.

7.5.3   Design Methods

7.5.3.1   The analyses or design methods for bored tunnel linings in soft ground shall take into account interaction between lining and ground, deflection of lining and re-distribution of loading dependent upon the relative flexibility of lining and compressibility of ground.

7.5.3.2   Acceptable methods for homogeneous soil formations include:

(a) Continuum model by AM Muir Wood[1] combined with discussion by DJ Curtis[2]
(b) Bedded beam model as Duddeck and Erdmann[3]
(c) Finite element

Where stratified conditions occur, finite element modelling may be necessary.

7.5.3.3   Due account shall be taken of the degree of flexibility of the linings to be used in the soft marine clays and fluvial deposits. The flexibility may have to be reduced in order to maintain acceptable values for the deflection of the lining.

7.5.3.4   The design methods and analyses of the tunnel linings in rock shall take into account the various types of material to be encountered.

7.5.3.5   The design of tunnel linings in rock shall take into consideration the methods of construction appropriate to the rock types. The shape, length, depth and width of excavations shall be limited in the construction method to suit the material encountered.

7.5.3.6   In the evaluation of the design rock loads for both the temporary and permanent tunnel linings, due account shall be taken of the proposed method of construction.

7.5.4 Flotation and Heave

7.5.4.1 Where tunnels are relatively shallow, they shall be checked for the possibility of flotation due to differential water pressure by the following method (Figure 7.1):

$$\text{Uplift } U = \gamma_w \frac{\pi D^2}{4} - W$$

where γ_w = specific weight of water
 W = self weight of tunnel
 (See Clause 7.5.4.9 below)
 D = outside diameter of tunnel

$$\text{Restraining Force } R = \gamma' D \left(h_w + \frac{D}{2} - \frac{\pi D}{8} \right)$$
$$+ \gamma_b D (H - h_w) + 2S \left(H + \frac{D}{2} \right)$$

where γ' = submerged weight of soil
 γ_b = bulk weight of soil
 S = average shear resistance along a-a'
 = c_u for cohesive soils
 = ½ Ko γ'(H + D/2) tan ϕ for cohesionless soils
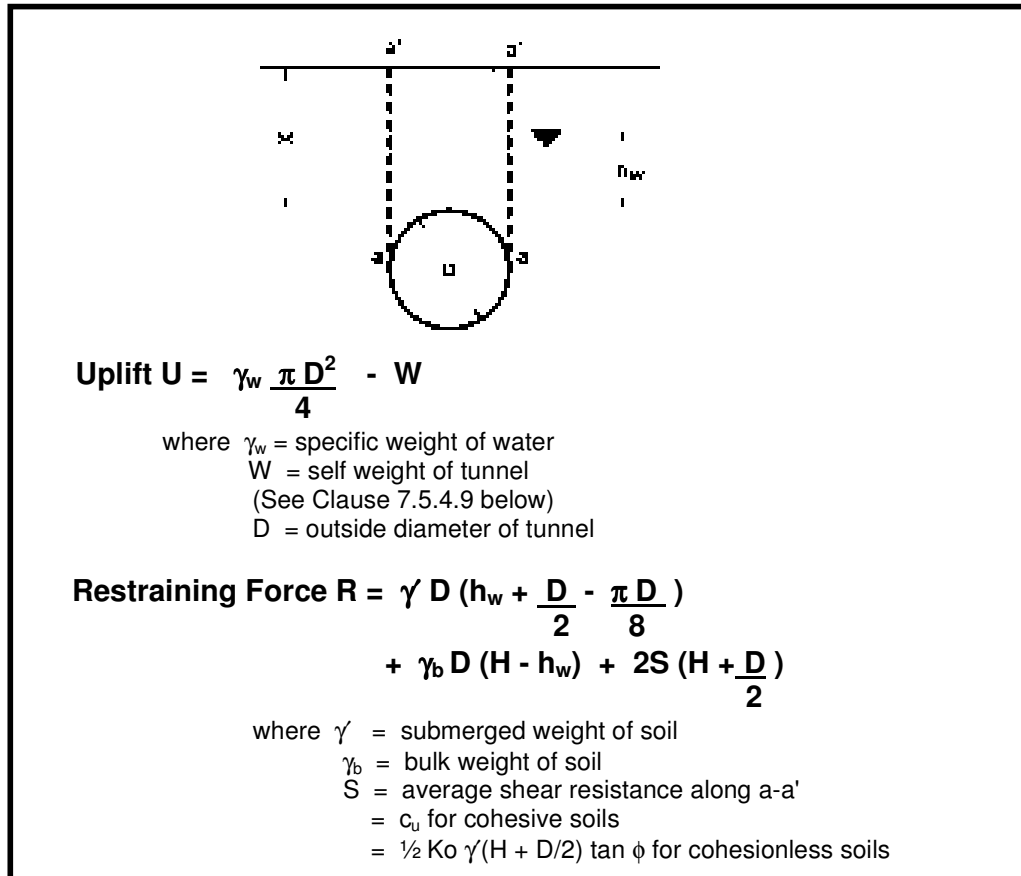
Figure 7.1 Method for checking flotation due to differential water pressure

7.5.4.2 For the equations of uplift and restraining force in Figure 7.1, the following partial safety factors shall be applied:

(a) Partial safety factor of 2.0 shall be applied to the average shear resistance of the ground along the planes of failure;

(b) Partial safety factor of 1.15 shall be applied to the average weight of ground above the tunnel, with the exception of soil type E (Estuarine) to which a partial safety factor of 1.35 shall be applied.

7.5.4.3 The resultant overall factor of safety of R/U in Figure 7.1 shall be at least 1.2.

7.5.4.4 For relatively shallow bored tunnels in clay, they shall also be checked for the possibility of heave due to shear failure of the ground at tunnel invert

level by the following method derived from the base heave analysis after Bjerrum and Eide[4] (Figure 7.2).

7.5.4.5   For the equations in Figure 7.2, the following partial safety factors shall be applied:

(a) Partial safety factor of 2.0 shall be applied to the shear strength of the soil;

(b) Partial safety factor of 1.15 shall be applied to the bulk density of the soil, with the exception of soil type E to which a partial safety factor of 1.35 shall be applied.

7.5.4.6   The bearing capacity factor in the equation outlined in Figure 7.2 shall be based on Figure 7.3.

7.5.4.7   The overall factor of safety, F in Figure 7.2 shall be

(a) At least 1.0 when surcharge, q is considered or
(b) At least 1.2 when surcharge, q is not considered.

In checking for flotation and heave the self weight of the tunnel shall include only the weight of the lining and of the first stage track concrete and shall have a partial factor of safety of 1.05 applied to it.

7.5.4.8   For tunnels in very soft clays, they shall be checked for possible heave. This check shall be in addition to the checks required under Clause 7.5.4.1 and 7.5.4.4 above and shall be carried out according to the following method (Figure 7.4). Partial safety factors shall be applied in accordance with Clause 7.5.4.2 above. The overall factor of safety R/U shall be not less than 1.0.

For the general case:
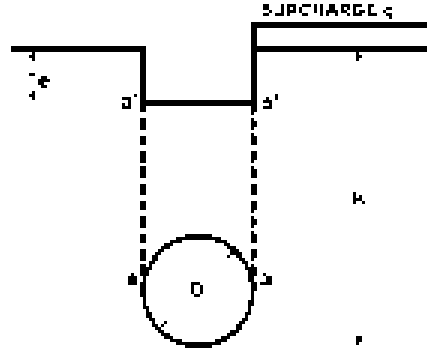
$$F \; = \; \frac{N_c \, C_u + 2\,S(H - D/2 - h_e)/D}{0.25\,(\gamma_{b1}\,\pi D) - W/D + q + \gamma_{b2}\,h_e}$$

where F = overall factor of safety
N_c = bearing capacity factor
C_u = average shear strength of soil in the zone of the tunnel invert.
γ_{b1} = average bulk density of soil in zone of tunnel.
γ_{b2} = average bulk density of soil over depth h_e.
H = depth to tunnel invert from normal ground surface.
h_e = depth of excavation above tunnel (if any)
q = surcharge at ground level beside tunnel as defined in Chapter 3
W = self weight of tunnel
D = external diameter of tunnel.
S = average C_u along a - a'

Figure 7.2 Method for checking the possibility of heave due to shear failure of the ground at tunnel invert level

Note: N_c rectangular = (0.84 + 0.16 D/L) N_c square
where L = length of structure being considered
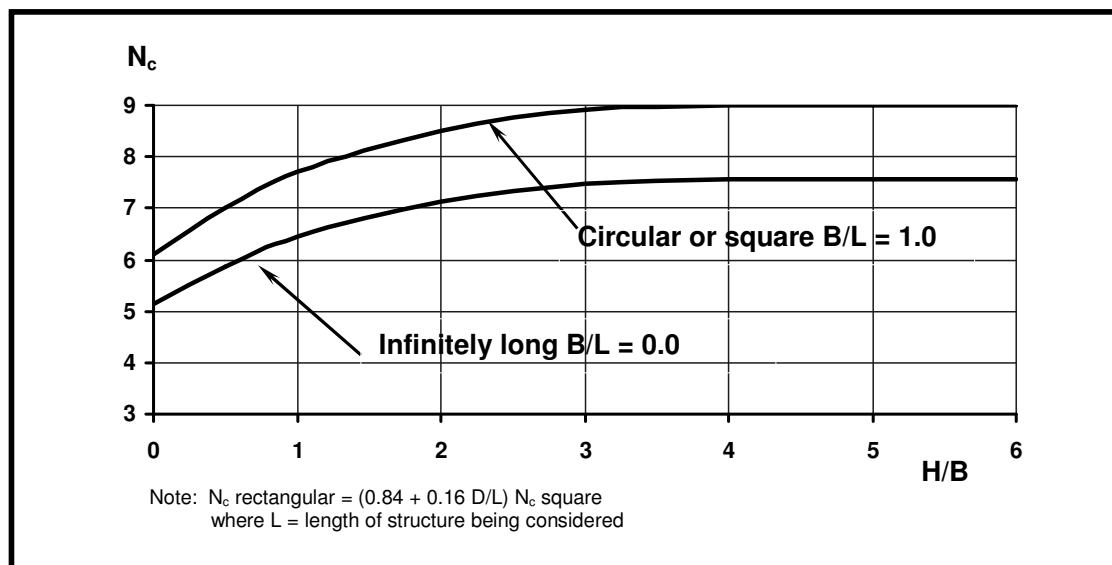
Figure 7.3 Bearing capacity factor

Uplift U = $\gamma_b \dfrac{\pi D^2}{4}$ - W

Restraining Force R = D. N_c . C_u

where, by analogy with foundations:
N_c = 8.25 (after Meyerhoff[5])

γ_b shall be determined as the average value obtained from the site investigation occurring at the tunnel horizon, i.e. over the range of depth from tunnel crown to invert.

C_u shall be the design value corresponding to the depth of the tunnel axis.
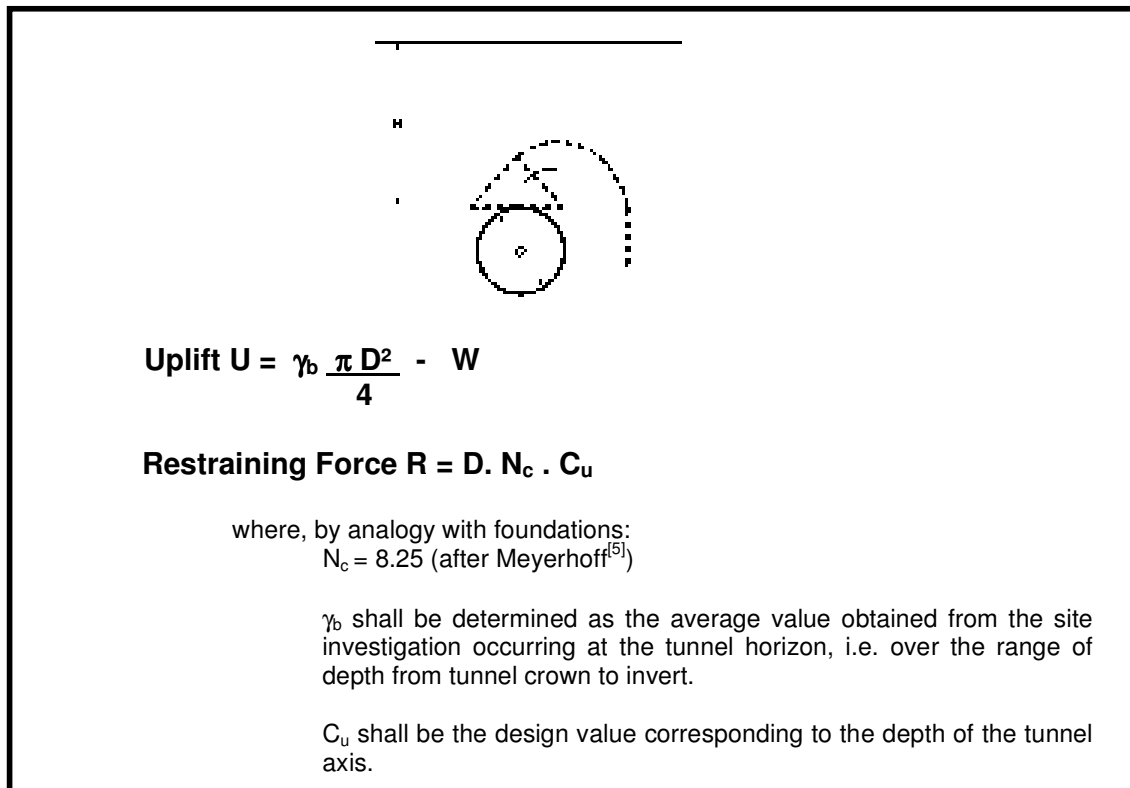
Figure 7.4 Additional check for possible heave

7.5.5   Longitudinal Stiffness

7.5.5.1   The design shall take into consideration that the modulus of subgrade reaction of soft clays that may be encountered in the invert of the tunnel may be so low that excessive deflections of the lining will occur under train or road vehicle loadings (as appropriate). The lining shall be designed to have adequate longitudinal stiffness to distribute the concentrated axle loading.

7.5.5.2   Detailed analysis of this problem shall be used to demonstrate and ensure that the following slope and deflection criteria in the longitudinal direction are not exceeded under train loading:

(a) Maximum slope of 1(V) to 2000 (H) and

(b) Maximum total deflection of 3 mm.

Similar criteria shall be established for the design of road tunnels and submitted to the Engineer for acceptance.

7.5.5.3   The above analysis shall account for the cyclic nature of the loading. The stress levels shall be established to ensure that the fatigue life of the structure exceeds the specified design life.

7.5.5.4   The design of tunnels shall take into consideration of possible long-term movements due to all future construction in close proximity to the tunnels shown on the Authority's Drawings.

7.5.5.5   An analysis of long term movements of the tunnel shall be carried out to ensure that the tolerances and adjustment limits of the track are not exceeded:

(a) Maximum allowable change in gradient: (Refer to the Particular Specifications and liaise with the trackwork designer to establish); and

(b) Maximum adjustment to track: (Refer to the Particular Specifications and liaise with the trackwork designer to establish the limit of movement incorporated in the trackwork design, and shall ensure that this limit is not exceeded).

Similar criteria shall be established for the design of road tunnels and submitted to the Engineer for acceptance.

7.5.5.6   Special attention shall be paid to the junction between tunnel and station or portal structure and at abrupt changes of ground conditions.

7.5.6   Deflections

The maximum deflection under any load combination shall not exceed 25 mm on radius. The degree of flexibility of the lining shall be designed to ensure that this limit is not exceeded.

7.5.7   Additional Distortion

7.5.7.1   In addition to the deflections caused by the ground load, loading due to known developments identified in the documents and surcharge as appropriate, the lining shall be designed to accommodate an additional distortion of +/- 15mm on diameter to allow for future development.

7.5.7.2   This shall be analysed by reducing the horizontal / vertical ground load to produce an additional +/- 15mm distortion on diameter. Alternative ways of analysing the effects of additional distortion may be proposed for the acceptance of the Engineer.

7.5.7.3   The long-term concrete creep may be considered in the selection of the concrete Young's modulus. The moment of inertia of the segments may be reduced based on the recommendation of Muir Wood[1]. The number of segments (n) in a ring shall exclude any key less than half a standard segment in length.

7.5.7.4   The requirement of Clause 7.6.1.6 shall apply in analysing the additional distortion.

7.5.7.5   The limiting crack width for design cases, which include this additional distortion, shall be 0.3mm.

7.5.8   Cast In-situ & Segmental Permanent Tunnel Linings

7.5.8.1   The analysis of the stresses induced in the final lining shall take account of the following:

(a) Short and long term horizontal and vertical ground loads in various critical load combinations;
(b) Sequence of construction;
(c) Proximity of other tunnels and structures;
(d) Distortion of the cavity; and
(e) Ground water loading.

It shall also include a 'wished in place' load case and a load case where only water pressure on the lining is considered.

7.5.8.2   In the case of shallow tunnels, the ability of the ground above the tunnel to generate sufficient passive resistance to maintain stability of the lining shall be considered.

7.5.8.3   The design of the final lining shall ignore any possible contribution to support of the imposed loads by the primary support system.

7.5.8.4   Reinforced concrete linings shall be designed as short columns in accordance with SS CP 65. The following requirements shall be met:

(a) At the Serviceability Limit State, the calculated maximum crack-width shall not exceed 0.3 mm;

(b) In respect of containment of compression reinforcement, the requirements of SS CP 65 Clauses 3.12.7.1 and 3.12.7.2 for columns shall apply.

7.5.9   Cast In-situ & Segmental Temporary Tunnel Linings

7.5.9.1   Temporary segmental linings may be used in soft ground. In other ground conditions a system of temporary support may be adopted consisting of some combination of shotcrete, rock bolts, steel arch ribs and lagging or such other system as the Contractor may propose to the acceptance of the Engineer.

7.5.9.2   A temporary concrete segmental lining may be used where it is proposed to cast the permanent tunnel lining within the temporary lining.

7.5.9.3   The temporary lining shall be designed such that it will remain functional until the permanent lining has achieved full design strength.

7.5.9.4 The temporary lining shall be designed such that there is no loss of ground into the tunnel, whether by squeezing, erosion, loss of fines or any other cause.

7.5.9.5 The lining shall be designed to ensure that there is no damage to buildings, structures or utilities due to loss of ground, excessive deflection or consolidation settlements.

7.5.9.6 In soft ground the design of the lining shall satisfy the load combinations specified in section 7.4.2. and distortional loads given in section 7.4.3. However no allowance need be made for additional distortion due to future developments unless there are specific requirements in the Particular Specification for any developments which will affect the tunnel prior to casting of the permanent lining. For other ground conditions the design loads shall be determined based on the likely speed of loading depending on the nature of the ground and method of construction and known developments that could affect the tunnel.

7.5.9.7 The temporary tunnel lining shall be of adequate internal diameter to ensure that it does not infringe on the space required for the permanent lining taking account of all construction, casting and build tolerances and of the lining deflection under load.

7.5.9.8 Cracking of the temporary lining under construction loads is acceptable provided that there is no risk of loss of ground into the tunnel or of seepage causing consolidation settlements which could adversely affect buildings, structures or utilities.

7.6 ADDITIONAL REQUIREMENTS FOR SEGMENTAL LININGS

7.6.1 General

7.6.1.1 Permanent segmental bored tunnel linings shall be in precast concrete with concrete grade at least 60 N/mm² with silica fume.

7.6.1.2 The design shall take into account, inter alia, the following:

a) The width of segment shall suit the method of construction and shall not be so large that part-shoving of the shield becomes a necessity;

b) The width of segment shall be consistent with the capacity of the circumferential bolting arrangements to withstand any shear forces induced in linings built with staggered joints;

c) The stiffness of the lining shall be compatible with the deflection limitations in accordance with Clause 7.5.6;

d) The length of segment shall be chosen with regard to bending stresses during handling and erection and the long-term stresses due to deflection and thrust;

e) Stresses induced by manufacturing and building tolerances including birdsmouthing of longitudinal joints;

f) Stresses induced by handling, erection and jacking forward of the tunnelling shield;

g) Stresses induced by grouting;

h) All metal fixings/reinforcement/inserts shall be detailed such that no electrical continuity will exist across the circumferential joints;

i) A minimum nominal cover of 40 mm to all reinforcing bars shall be provided, except only at bolt holes where reduced cover of 25mm is acceptable provided a plastic sheath is cast in;

j) The segments shall allow for all temporary loads during handling and erection.

7.6.1.3   An arrangement of staggered longitudinal joints shall be adopted. This may induce shear across the circumferential flanges. The effect of this, in particular the shear on the circumferential joint connections shall be considered in design.

7.6.1.4   The requirement of Clause 7.6.1.6 shall apply in analysing the additional distortion.

7.6.1.5   With regard to Clause 7.6.1.2(e) above, the inter-relationship between the tolerances on plane of the lining, steps between the edges of segments and the ability of the segmental lining to carry shield-jacking loads without cracking shall be taken into consideration in design. The loading in the segments arising from the shield jacks shall be considered in the analysis and suitable tolerances on these parameters to ensure that the segments remain uncracked shall be established.

7.6.1.6   The design shall allow for eccentricities of thrust between adjacent segments arising from the following factors: -

(a) Building errors such as:
  - lack of circularity;
  - steps between segments and
  - out of plane of circumferential joint.
    (Refer to M & W Specification for allowable tolerances)

(b) Casting inaccuracies
    (Refer to M & W specification for allowable tolerances)

(c) Rotation under load:
    The rotation produced at each joint between segments as the lining deflects under load shall be calculated. The resultant eccentricity in the

point of contact between segments from all these factors shall be calculated from the joint geometry.

7.6.1.7   For staggered longitudinal joints, no increase in lining flexibility will be permitted in the design. However, when analysing for additional distortion the moment of inertia of the segments may be reduced based on the recommendation by Muir Wood[1]. The number of segments (n) in a ring shall exclude any key less than half a standard segment in length.

7.6.2   Bursting Stresses

7.6.2.1   For longitudinal joints bursting stresses shall be designed to be carried in full by reinforcement. For circumferential joints under jacking loads bursting stresses shall be designed to be either resisted in full by the tensile strength of the concrete, or to be carried in full by reinforcement.

7.6.2.2   Where the stresses are carried by the concrete tensile strength, the design must calculate to the satisfaction of the Engineer the peak tensile bursting stress. The allowable tensile strength shall be taken as not greater than $0.36\sqrt{f_{cu}}$.

7.6.2.3   When the bursting stresses are resisted by reinforcement, the bursting forces shall be calculated in accordance with Clause 4.11 of SS CP65 Part 1.

7.6.2.4   Where high yield type 2 reinforcement is used to resist bursting the maximum allowable stress shall be 200 N/mm^2. For this purpose the "tendon jacking force" shall be the maximum hoop load in the lining.

7.6.3   Bearing Stresses

The permissible concrete bearing stress at the Ultimate Limit State shall be taken as 2.0 f_{cu} or 105 N/mm^2, whichever is lower.

7.7   DETAILING

7.7.1   Fixings

7.7.1.1   Every available location on each tunnel segment shall be marked to indicate where drilling is permitted for the fixing of cable brackets and other attachments.

7.7.1.2   The marking shall take the form of indented areas, dimples or the like on the surface of the segment. The indentations shall not exceed 6mm in depth.

7.7.1.3   For the purpose of defining the location of the demarcated areas, it shall be assumed that holes to suit diameter 16mm expanding bolts or sockets will be used for the fixings. The clear distance between the sides of the

hole and any reinforcement shall not be less than 40mm after making full allowance for inaccuracies in the position of the reinforcement.

7.7.2 Taper Rings

The Contractor shall design suitable taper ring linings in order to negotiate the alignment curvature and to correct for line and level during construction with the minimum use of circumferential joint packers consistent with attaining the required degree of watertightness of the tunnels.

7.7.3 Bolt Pockets

Bolt pockets in which water may possibly accumulate shall be filled with grade 30 concrete.

7.7.4 Grout Holes

Grout holes shall be provided in each segments and shall terminate short of the outer surface of the segment.

7.8 ADDITIONAL REQUIREMENTS FOR SPRAYED CONCRETE LININGS (SCL)

7.8.1 SCL should not be carried out where the stand-up time for the excavation is inadequate. As a guide stand-up time should be more than 90 minutes for a face advance of 1 metre.

Face stability assessments shall be conducted for representative sections along the length of the tunnel.

7.8.2 The design and construction methodology shall address the following :

a) length of advance;
b) whether advance should be partial face or full face;
c) inclination of face;
d) speed of ring closure;
e) face support; and
f) adjacent activities, such as excavations and ground treatment.

7.8.3 The design shall take account of the following:

a) the ground conditions including:
  - soil stratigraphy;
  - groundwater regime;
  - soil strength, stiffness and small-strain characteristics;
  - swelling and creep characteristics; and
  - Poisson's ratio.
  - the bearing capacity of the ground at the foot of an unclosed arch and the possible need for enhancement such as 'elephant's feet'

b) material properties including:
  - development of strength;
  - stiffness (modulus) appropriate to the age of the concrete and the excavation stage; and
  - creep and shrinkage especially in first two weeks after placing.

c) interaction between the ground and lining including non-linear and time dependent behaviour.

d) speed of loading, both horizontally and vertically including:
  - impact of any adjacent construction or ground treatment; and
  - water pressure relief (or lack of relief).

7.8.4   In soft ground full circle ribs shall be used at spacing equal to the length of advance.

7.8.5   The design shall be reviewed and modified during and after construction as a result of comprehensive monitoring of the following :

- the behaviour of the ground at the tunnel face in comparison with the design assumptions.
- surface settlements.
- lining deformations.
- measurements of ground loadings and displacements.

7.8.6   Appropriate contingency plans shall be prepared and implemented to modify the design and construction should the behaviour of the ground or the lining be shown by the monitoring to be outside the prediction limits.

7.9   RIBS AND LAGGING

7.9.1   The design of a temporary support system using ribs and lagging in rock shall be in accordance with a recognised method such as that described by Terzaghi[6] and a graphical analysis of the steel arch rib after Proctor and White[7].

7.9.2   The design of the temporary support system shall take into account, inter alia, the following:

(a) axial and bending stresses in the steel arch ribs induced by the rock loads;
(b) lateral stability and bracing of the steel arch ribs;
(c) the method of forming the steel arch ribs and the resultant properties of the steel;
(d) amount of preload to be applied to steel arch ribs and method of supplying this load;
(e) method of blocking and spacing of blocking points;
(f) bearing capacity of the rock at blocking points and, in the case of horseshoe-shaped cross section, under the footplates;
(g) the stand up time of the unsupported part of the excavation;

(h) the method of lagging between ribs to prevent ravelling and/or softening of the ground and

(i) the ground water regime and permeability of the ground.

7.9.3 The steel arch ribs design shall be in accordance with BS 5950.

7.10 WATERPROOFING

7.10.1 General

7.10.1.1 Notwithstanding the limits on ground water seepage rates given in M&W Chap 16, the Contractor shall ensure that no loss of ground occurs through any part of the completed structure.

7.10.1.2 In order to minimise surface settlements due to consolidation in soft ground, the specified degree of water tightness shall be achieved within 30m of the tunnel face. In all other ground conditions, the specified degree of watertightness shall be achieved by the Tunnel Basic Structure Completion Date.

7.10.1.3 For railway tunnels the design shall make provision to prevent the build up of water pressure beneath the first stage concrete or beneath the track slab concrete. To achieve this, leakage paths shall be created at each joint in the tunnel lining and any seepage directed to the drainage channel.

7.10.2 Waterproofing for Segmental Linings

7.10.2.1 The waterproofing method throughout the segmental tunnel linings shall include the use of the following:

a) A co-extruded single composite gasket consisting of an elastomeric carrier and hydrophilic facing material;

b) The elastomeric carrier shall be an EPDM (Ethylene Propylene Diene Monomer) formulated to provide good retention of elasticity and low stress relaxation properties;

c) The outer (convex) surface of all segments that contain steel bar reinforcement, 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;

d) The composite gasket shall not be in front of the bolt hole; and

e) Provision for caulking around all edges of segments.

7.10.2.1 A full specification for the above is given in the M & W Specifications. The selection of the materials to be used shall be based on life cycle cost assessment of feasible options in accordance with Clause 1.6.4.

7.10.3   Waterproofing for Cast In-situ Linings

7.10.3.1   A waterproofing membrane system is to be provided between the temporary lining and permanent in-situ concrete lining except at cross passageways. The membrane is to be compartmentalised and fully welded to cover the full tunnel extrados.

7.10.3.2   The watertightness of the membrane system, grade of concrete, thickness of lining, method of placement, treatment of construction joints and arrangements for back-grouting shall be chosen such that the specified watertightness can be achieved.

7.10.3.3   At cross passageways and sumps, an integral waterproofing system comprising approved waterproofing admixture and provisions for back-grouting shall be used for waterproofing the permanent insitu concrete lining. The type of admixture, grade of concrete, thickness of lining, method of placement, treatment of construction joints and arrangements for re-injectable back-grouting shall be chosen such that adequate waterproofing can be achieved.

7.10.3.4   Drilled-in blind holes shall be positioned and detailed where required for the fixing of brackets, equipment and other fixtures.

7.11   CROSS PASSAGEWAYS BETWEEN RUNNING TUNNELS

7.11.1   Location

7.11.1.1   For railways, cross passageways between bored running tunnels shall be located in accordance with the requirements of the Standard for Fire Safety in Rapid Transit Systems issued by the Singapore Civil Defence Force & Land Transport Authority.   For roads, cross passageways between tunnels shall be located in accordance with NFPA 502 and BD78/99.

7.11.1.2   Track cross-overs in railway tunnels and accesses for emergency vehicles in road tunnels shall not be considered as cross-passages.

7.11.1.3   When locating cross passageways consideration shall be given to the need to minimise any adverse effect on adjacent structures.

7.11.2   Dimensions and Layout

7.11.2.1   Throughout the length of the cross passageway both the minimum clear headroom and the minimum clear width shall comply with the requirements of the Building Control Regulations. At the door the requirements of the Standard for Fire Safety in Rapid Transit Systems issued by the Singapore Civil Defence Force & Land Transport Authority, shall also be complied with.

7.11.2.2 For railways the level on the cross passageway floor shall be determined, on a case by case basis, in relation to the cant of the track. Generally the cross passageway level shall be three steps above the adjoining trackbed level as determined by the trackwork designer. For roads, the level shall be proposed by the designer for the acceptance of the Engineer.

7.11.2.3 The cross passageway floor shall drain into the running tunnel drainage system, unless the cross passageway occurs at the low point of the alignment in which case a drainage sump may be located within the cross passageway.

7.11.2.4 Openings in cross passageways shall be protected with a fire door assembly having a fire resistance of not less than 2 hours with a self closing device in accordance with the Standard for Fire Safety in Rapid Transit Systems issued by the Singapore Civil Defence Force & Land Transport Authority.

7.11.3 Design Requirements

7.11.3.1 The cross passageway tunnel lining shall be designed generally in accordance with the requirements of Clause 7.5 above as appropriate with the following exceptions:

a) The maximum allowable deflection on radius shall be 15 mm and
b) Taper rings will not be required.

7.11.3.2 The junctions with the running tunnels shall be steel framed and encased with in-situ concrete or framed with reinforced concrete. The junctions shall be designed to fully support the running tunnel linings at the openings together with the ground and ground water loads on the junction itself.

7.11.3.3 Where openings are to be formed in running tunnels having segmental concrete linings the Contractor shall provide temporary internal supports to the running tunnel lining. These supports shall adequately restrain the lining such that on completion of the cross passageway and removal of the temporary supports the total deflection of the lining does not exceed the requirements of Clause 7.5.6.

7.12 SUMPS IN RUNNING TUNNELS

Refer to Chapter 11 for design requirements for pump sumps in running tunnels.

7.13 EMERGENCY ESCAPE SHAFTS

7.13.1 Location

For railways, locations of emergency escape shafts shall be in accordance with the Standard for Fire Safety in Rapid Transit Systems issued by the

Singapore Civil Defence Force & Land Transport Authority. For roads, the locations of emergency escape shafts shall be in accordance with NFPA 502.

7.13.2 Dimensions and Layout

7.13.2.1 The floor of the shaft shall be level with the walkway level in the tunnel.

7.13.2.2 For railways the layout of the shaft shall conform to the Standard for Fire Safety in Rapid Transit Systems issued by the Singapore Civil Defence Force & Land Transport Authority.

7.13.3 Design Requirements

7.13.3.1 Shaft linings shall be designed generally in accordance with Clause 7.5 with the exception that:

a) Where ground conditions are uniform there is no need to consider distortional loading.

b) The thrust in the lining shall be based on full hydrostatic pressure and at-rest (i.e. K_o) earth pressure.

7.13.3.2 The junctions with the running tunnels shall be designed to fully support the running tunnel linings and shaft linings at the openings together with the ground and ground water loads on the junction itself.

7.13.3.3 While the openings into the running tunnel and the shaft are being formed, temporary internal supports to the running tunnel lining and shaft lining shall be provided. These supports shall adequately restrain the linings such that on completion of the junction and removal of the temporary supports the total deflections of the linings do not exceed the requirements of Clause 7.5.6.

7.14 TUNNEL WALKWAY

7.14.1 Arrangement

The location and width of the tunnel walkway are shown on Authority's drawings.

7.14.2 Details of Walkway

7.14.2.1 The walkway shall fall 15 mm towards the track or road.

7.14.2.2 The handrail shall project no less than 75 mm from the tunnel wall and be clear of any tunnel service to enable easy use. The handrail shall not project into the walkway envelope.

7.14.2.3 The walkway shall be ramped down to cross-passage floor level at each cross passageway and in railway tunnels shall be ramped down to rail level at switch and crossing areas. In road tunnels the walkway shall be ramped down to road level at vehicle crossover areas.

7.15 FIRST STAGE CONCRETE IN RAILWAY TUNNELS

7.15.1 The first stage concrete is defined as the concrete between the tunnel lining and the track concrete placed by the trackwork contractor. The first stage concrete, or concrete on which the second stage is cast, should have an exposed aggregate finish.

7.15.2 The minimum concrete grade shall be grade C30 having a characteristic cube strength at 28 days of 30 N/mm^2.

References

1. Muir Wood AM. The circular tunnel in elastic ground. Geotechnique 25 No.1, 1975.

2. Curtis DJ. Discussion on 3 above. Geotechnique 26 No.1, 1976.

3. Duddeck H and Erdmann J. Structural design models for tunnels. Tunnelling 1982, pp 83-91

4. Bjerrum L. and Eide O. Stability of strutted excavations in clay. Geotechnique 6, 1956.

5. Meyerhoff GG. The ultimate bearing capacity of foundations. Geotechnique Vol.2 No.41, 1951.

6. Peck RB. Deep excavation and tunnelling in soft ground. State of the Art Report. 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City 1969.

7. Terzaghi K. Rock tunnelling with steel supports, Section 1. Commercial Shearing and Stamping Co. 1946.

8. Proctor and White. Rock tunnelling with steel supports. Commercial Shearing and Stamping Co. 1946.

CHAPTER 8

UNDERGROUND STRUCTURES

8.1   SCOPE

8.1.1   Design requirements for depressed or underground structures constructed by cut and cover methods with the exception of drainage culverts and canals are covered in this Chapter. Drainage culverts and canals shall be designed in accordance to BD31/01 or the relevant authority's requirements.

8.2   STANDARDS AND CODES OF PRACTICE

8.2.1   The design of underground structures shall comply with SS CP 65, SS CP 73, SS CP 4, BS8002, other relevant codes and the additional requirements herein.

8.3   LOADS

8.3.1   Partial Safety Factors for Earth and Water Pressure

8.3.1.1   The partial safety factors for earth and water pressure for the structures shall be according to the partial safety factors tables as shown in Figures 8.3.3-1 to 8.3.3-3.

8.3.1.2   Refer to Chapter 3 (Loads) for the definition of Design Ground Water Level at permanent condition and ground water level at exceptional condition.

8.3.1.3   For the groundwater pressure, the partial safety factors in Table 8.3.1 shall be used for the ultimate limit state design of underground structures.

Table 8.3.1   Partial Safety Factors for Groundwater Pressure in Structural Design

Groundwater Condition		Partial Safety Factor
(a)	Permanent condition	1.4
(b)	Exceptional condition	1.05

8.3.2   Ground Loads

8.3.2.1   Refer to Chapter 3 (Loads) for additional requirement due to earth pressures that shall be considered in design. The design parameters for earth pressures are given in Chapter 5 (Geotechnical Parameters).

8.3.3   Load Combinations

8.3.3.1   General

The various possible combinations of live load surcharge and/or known future development shall be considered in deriving the most onerous load combinations for underground structures. The envelopes of the stress resultants at both ultimate and serviceability limit states shall be determined from the critical load combinations listed in Table 8.3.3.

Table 8.3.3   Critical Load Combinations for Design of Underground Structures

Load Combination	Description
Load Combination 1	Maximum vertical, maximum horizontal, including end of construction stage (Figure 8.3.3 -1)
Load Combination 2	Maximum vertical, minimum horizontal (Figure 8.3.3 -2)
Load Combination 3	Minimum vertical, maximum horizontal (Figure 8.3.3 -3)
Load Combination 4	Unbalanced load (Figure 8.3.3-4)
Any other load combination that shall be determined to be more onerous.	

8.3.3.2   Underground structures shall be designed for unbalanced loads and differential settlements due to the future development(s) identified in the Particular Specification.

8.3.3.3   In applying the loads in Load Combination 4, the base of the structure shall be assumed to be rigidly restrained horizontally and to be restrained vertically to correspond to the actual foundation conditions. It may be assumed that the unbalanced loading is also restrained by a reactive pressure generated by the mobilisation of the soil stiffness on the reacting side. For closed box structures or open "U" structures with cantilever walls, if under serviceability limit state, the differential settlement across the width of the structure exceeds 1:1000, the differential loading shall be reduced by increasing the lower earth pressure until the differential settlement is less than or equal 1:1000. In addition, the horizontal movement of the top of the closed box shall not exceed 15mm. In either case, the out-of-balance loading shall be combined with other vertical conditions that may co-exist. For the serviceability limit state of cracking under this load combination, the calculated maximum crack width due to

flexure on both external and internal faces of those members forming the hull of the underground structures shall not exceed 0.3mm.

8.3.3.4   Separate load combinations shall be developed for the design of internal elements. Internal elements shall be designed for displacement compatibility with the hull elements under the load combinations used. (For example, where internal columns are supported on base slabs which deflect relative to the side walls due to external soil or hydrostatic pressure, this should be allowed for in the design of the internal elements).

8.3.3.5   For designing of structures with diaphragm walls as part of permanent structures, the design forces on the walls should be obtained from the superposition (addition) of Case 1 and 2, and then envelope with Case 3, where:

(a) Case 1
Forces on the walls from geotechnical finite element analysis at the final stage of construction, taking into consideration the full construction sequence.

(b) Case 2
Forces on the walls from structural finite element analysis of a wished-in-place model, which consider long term loading for the permanent stage of the structures. Only Load Combinations 1 and 3 need to be considered for the "wished-in-place" model (ie, one which does not model the construction sequence). The lateral earth pressure adopted shall be the difference between at rest (K_o) earth pressure and the earth pressure at the last stage of construction from Case 1.

(c) Case 3
Forces on the walls from structural finite element analysis of a wished-in-place model for all load combinations using the appropriate lateral earth pressure as required in each of the load combinations.

GWL at Design Flood Level

Permanent GWL

Line of Symmetry

Surcharge

Earth Pressure

Water Pressure

h

Z

Water Pressure

Earth Pressure

Surcharge

Hull Dead Load

Internal Dead Load, Superimposed Dead & Live Load

GWL at soffit of base slab
(End of construction)

Base Uplift Pressure
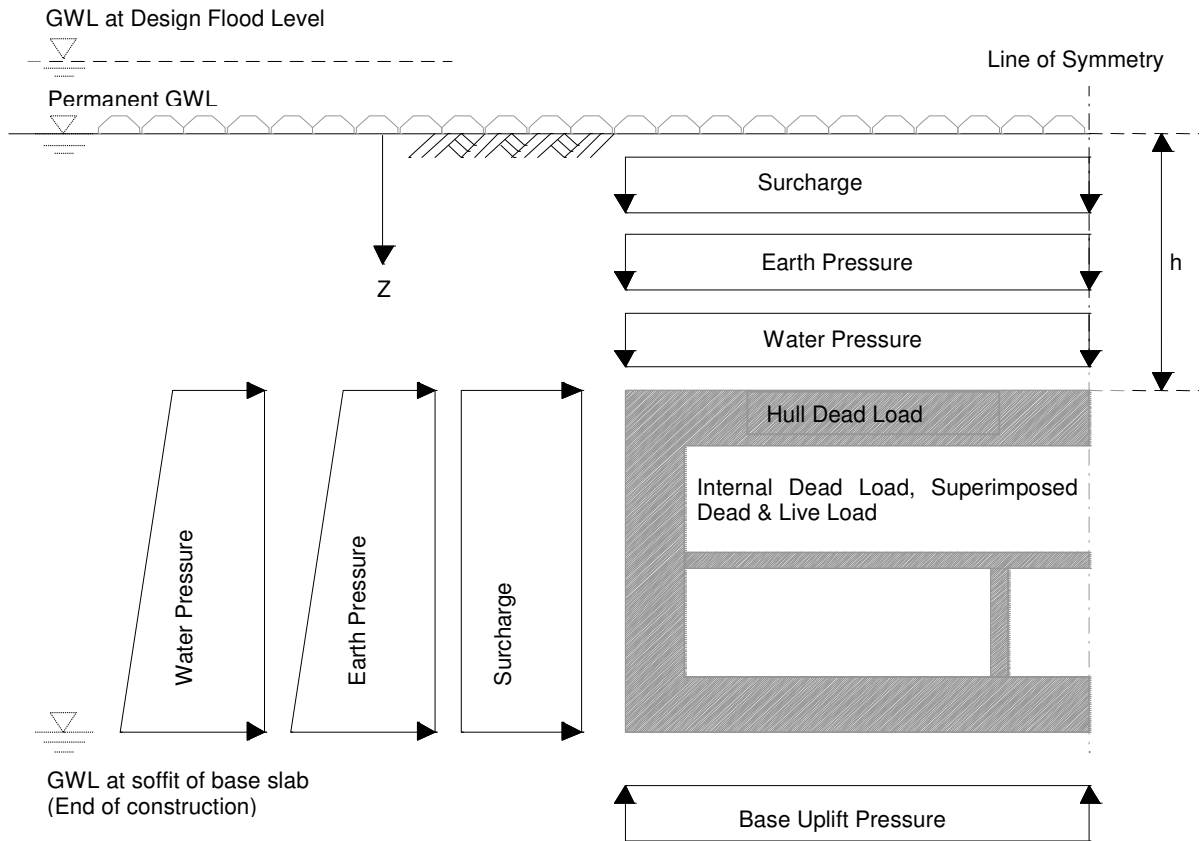
Notes:

(1)   Water pressure shall vary according to ground water levels (GWL). This load combination shall consider the most onerous of all 3 specified GWL with different load factors:
       a)   GWL at GL in permanent condition
       b)   GWL at design flood level (FL) in exceptional condition
       c)   GWL at soffit of base slab level in end of construction case (not applicable for top down construction)

(2)   When GWL is at FL, surcharge need not be considered.

Partial Safety Factor Table

Load		Vertical surcharge	Vertical Earth Pressure	Vertical water pressure		Horizontal surcharge	Horizontal earth pressure (K_o)	Horizontal water Pressure		Base uplift pressure		Hull dead load	Internal dead load	Internal live load
				Permanent GWL	Exceptional GWL (at FL)			Permanent GWL	Exceptional GWL (at FL)	Permanent GWL	Exceptional GWL (at FL)			
Partial Safety Factor	ULS	1.6	1.4	1.4	1.05	1.6	1.4	1.4	1.05	1.4	1.05	1.4	1.4	1.6
	SLS	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 8.3.3-1   Load Combination 1 (Maximum Vertical & Maximum Horizontal Load)

GL

5m below GL
or the lowest
measured
GWL whichever
Is lowest

Z

Line of Symmetry

Surcharge

Earth Pressure

h

GWL

Water Pressure

Earth Pressure

Hull Dead Load

Internal Dead Load,
Superimposed Dead & Live Load
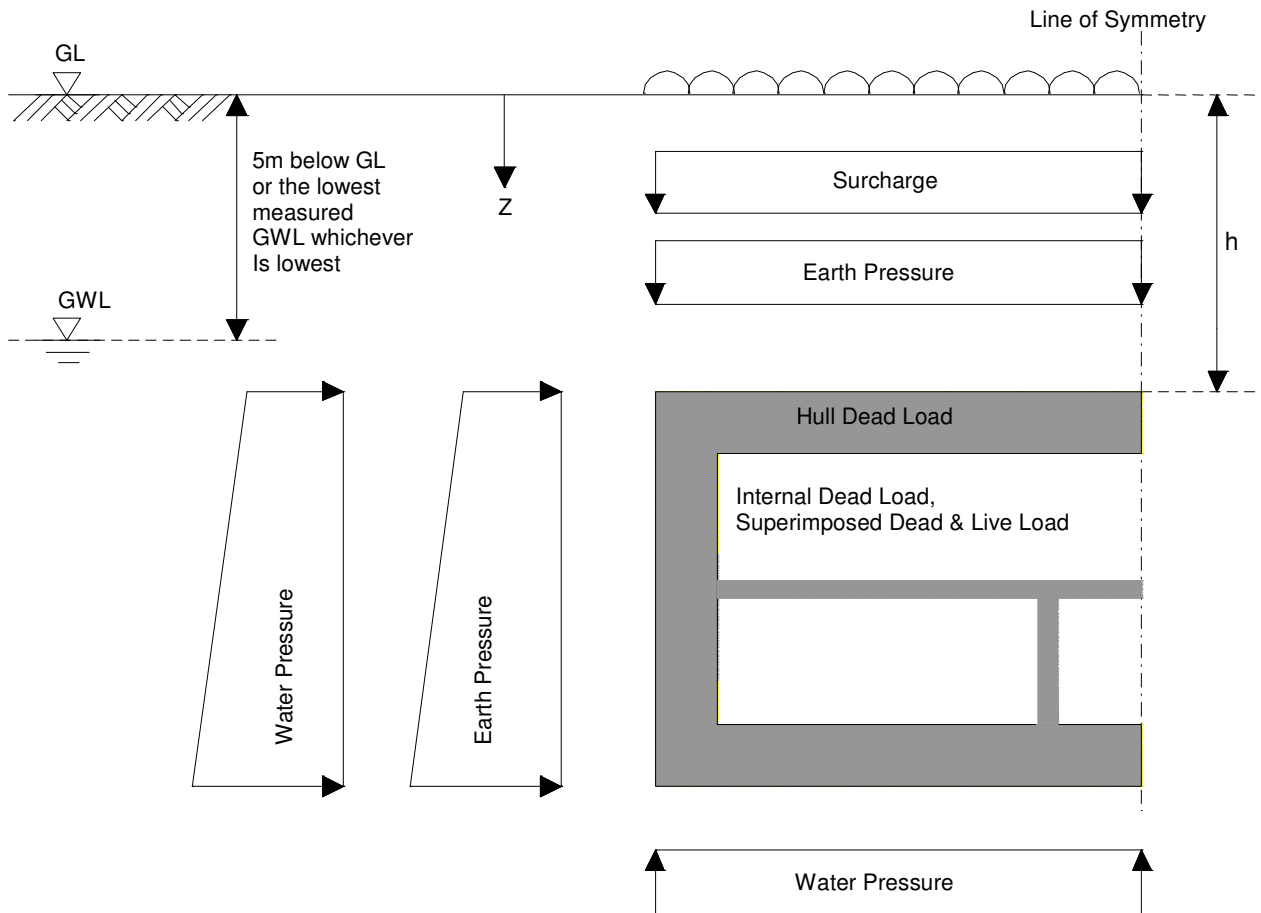
Water Pressure

Notes:
(1) The active earth pressure (K_o) is used for minimum horizontal load.

Partial Safety Factor Table

Load		Vertical surcharge	Vertical Earth Pressure	Vertical water pressure	Horizontal earth pressure (K_a)	Horizontal water Pressure	Base uplift pressure	Hull dead load	Internal dead load	Internal live load
Partial Safety Factor	ULS	1.6	1.4	1.2	1.0	1.0	1.2	1.4	1.4	1.6
	SLS	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 8.3.3-2   Load Combination 2 (Maximum Vertical & Minimum Horizontal Load)
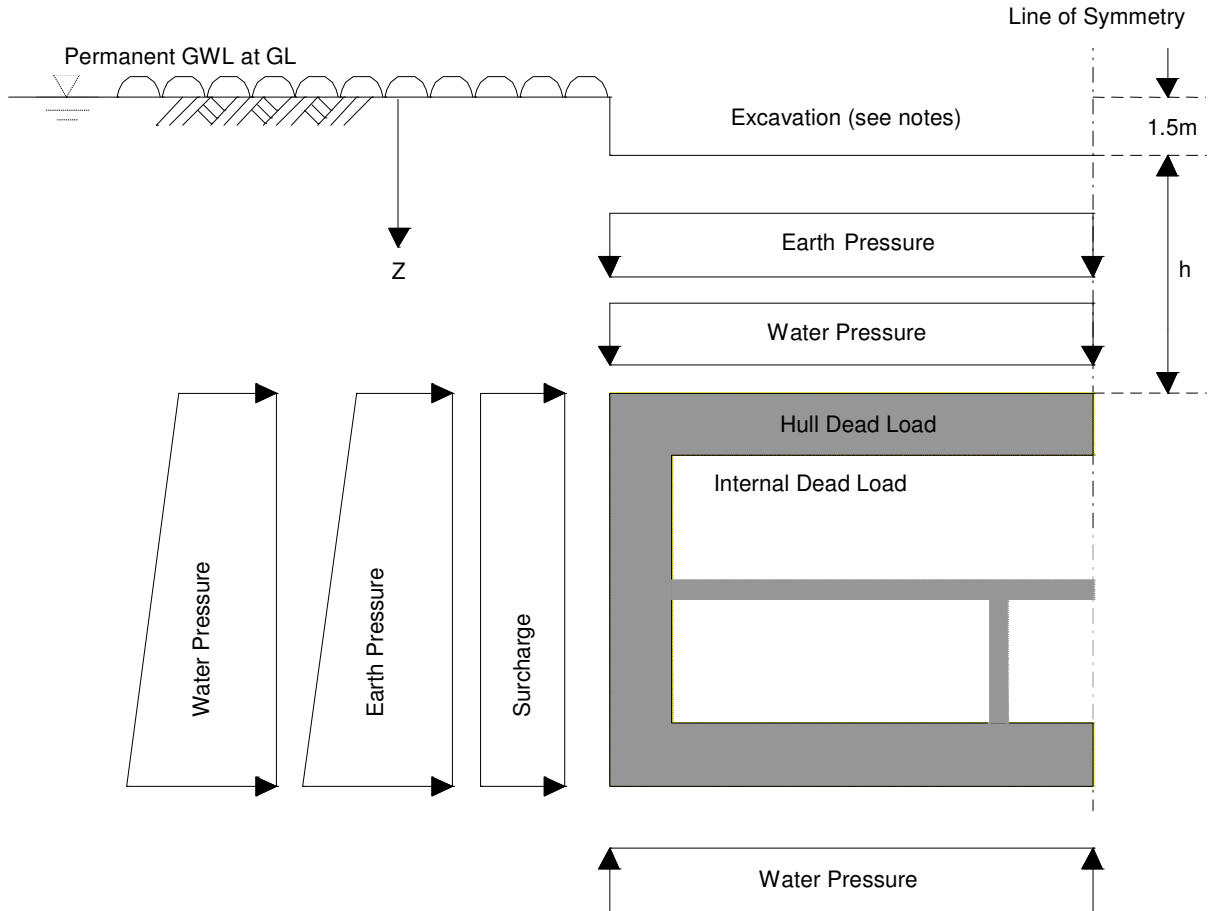
Notes:
(1) *Excavation on top of roof slab of 1.5m is allowed. This thickness of overburden shall be ignored in consideration for minimum vertical loading on the structure.*

Partial Safety Factor Table

Load		Vertical Earth Pressure	Vertical Water Pressure	Horizontal Surcharge	Horizontal Earth Pressure (K_a)	Horizontal Water Pressure	Base Uplift Pressure	Hull Dead Load	Internal Dead Load
Partial Safety Factor	**ULS**	1.0	1.0	1.6	1.4	1.4	1.0	1.4	1.4
	SLS	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 8.3.3-3 Load Combination 3 (Minimum Vertical & Maximum Horizontal Load)

Surcharge above structure if more
onerous
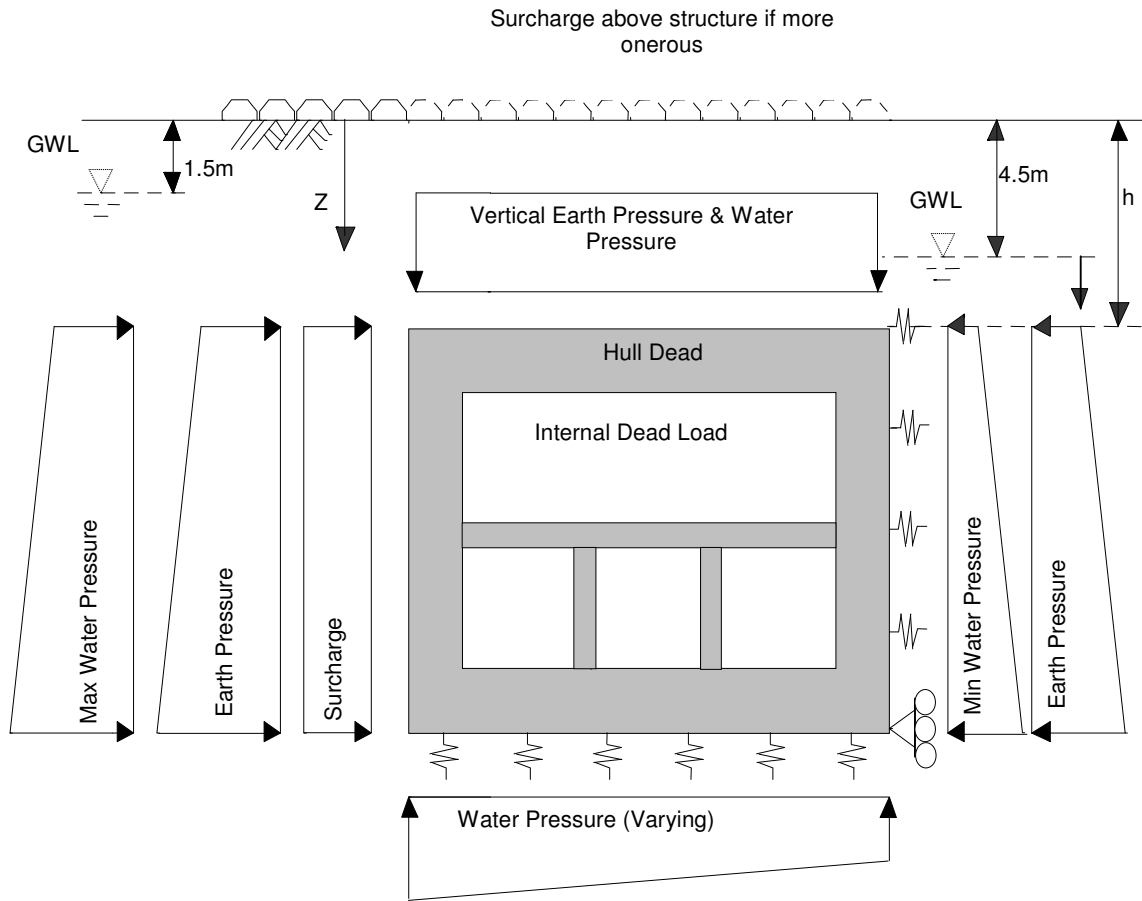
Notes:

(1) The earth pressure shall be in accordance to ground level or the lowest excavation level as stated in the Particular Specification.

Partial Safety Factor Table

Load		Vertical Surcharge	Vertical Earth Pressure	Vertical Water pressure	Horizontal Surcharge	Horizontal Earth Pressure	Horizontal Water Pressure	Base Uplift Pressure	Hull Dead Load	Internal Dead Load
Partial Safety Factor	ULS	1.6	1.4	1.2	1.6	1.4	1.2	1.2	1.4	1.4
	SLS	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 8.3.3-4 Load Combination 4 (Unbalanced Load)

8.4   DESIGN REQUIREMENTS

8.4.1   General

8.4.1.1   Reinforced concrete is preferred for the permanent works. Prestressed concrete structure may be considered, subject to the Engineer's acceptance.

8.4.1.2   The primary design objective of underground structures is that they shall be made watertight by the provision of impermeable dense durable concrete. The structure shall be capable of withstanding aggressive soil and water conditions that may be present.

8.4.1.3   The design and selection of construction method of cut and cover structure shall at least take into account of the following:

(i)   The geology;

(ii)   The hydrogeology and strata permeabilities in the vicinity of the excavation;

(iii)   The degree of lateral movement and settlement which would be expected. In this context the location of the works in relation to existing structures shall be considered;

(iv)   The depth of construction;

(v)   Any particular difficulties that special plant might face with respect to access, clearances and working space;

(vi)   The noise levels and environmental pollution produced;

(vii)   Control over heave and instability of the base of the excavation, and long term settlement and heave;

(viii)   The methods by which the completed structure shall be secured against flotation and

(ix)   The method for waterproofing the roof slab of the completed structure.

8.4.1.4   The underground structures shall be designed to be structurally continuous, no movement joint is allowed. The ground pressure distribution, long term ground / structure interaction, total and differential settlement shall be considered accordingly.

8.4.1.5   Capping beams shall be provided for contiguous bored pile and secant pile walls.

8.4.1.6   The method and sequence of construction, from installation to removal of the temporary works, shall be considered in the design and be clearly defined in the drawings. Possible imperfections in fabrication and erection shall be considered in the design. The structurally acceptable margins of tolerance shall be clearly specified for critical members and operations. Any constraints that the design may place on the construction sequence shall be identified and clearly specified in the drawings. The design of structures in which the permanent walls and slabs are also used to carry temporary construction loads must take into consideration of the loads arising from the stages of construction.

8.4.1.7   The design of temporary/permanent wall shall have sufficient cut-off to minimise the reduction in piezometric pressure in the adjacent soils. Dewatering shall avoid lowering of the water tables outside the Works.

8.4.1.8   All underground structures shall have a ground cover of 2 metres minimum, measured from top of waterproofing to the lowest point on the finished ground level unless otherwise stated by the Engineer.

8.4.1.9   A flood protection structure to achieve a Design Flood Level as specified in Chapter 3 (Loads) shall be provided at each underground structure entry and exit.

8.4.2   Robustness

Refer to Chapter 3 (Loads) for the effects of impact loads and the provision of ties.

8.4.3   Settlement

Refer to Chapter 6 (Foundation, Earthworks and Permanent Retaining Structures).

8.4.4   Crack Width

Those members exposed to earth and/or ground water and forming the hull of underground structures shall be designed such that the calculated maximum crack width due to early thermal cracking or flexure and/or tension arising from applied external service loads shall be limited to:

(a) 0.25mm for external face when subject to permanent load effects

(b) 0.3mm for external face when subject to temporary load effects which are not "locked-in" during construction

(c) 0.3mm for internal face

The crack width caused by applied external service loads shall be calculated on a plane at a distance of 40mm from the outermost reinforcement. This crack width need not be added to those caused by early-age thermal cracking and shrinkage.

8.4.5   Flotation

8.4.5.1   Underground structures shall be checked for the possibility of flotation at all stages of the construction and throughout the service life of the structure. In the permanent condition, ground water level shall be assumed to be at Design Flood Level as defined in Chapter 3 (Loads). Any loads from developments or from any other structure that would be beneficial to stability against flotation shall not be considered in the flotation assessment. Flotation check is not required for drainage culverts with weep holes.

8.4.5.2   The assessment of the general case shall be as shown in Figure 8.4.5.2.

8.4.5.3   Shear Resistance of Soil
In evaluating the design frictional resistance to uplift between elements of the structure and the surrounding ground or backfill, a partial safety factor of 2.0 on the design shear strength shall be used.   For cohesive soils, an adhesion factor shall be determined from suitable published data (e.g. Tomlinson), and for cohesionless soils earth pressure coefficients taking into account the effects of the following as appropriate:

(a) The shear strength of the backfill;

(b) The method of placing of backfill material;

(c) The temporary support system, either left in place or extracted;

(d) Grouting;

(e) The use of bentonite;

(f) The depth below ground surface and

(g) The waterproofing system for the structure.

With respect to item (g) above, where the critical shear interface is along the waterproofing membrane no frictional resistance shall be used. No shear resistance shall be allowed within 2 metres of the ground surface.
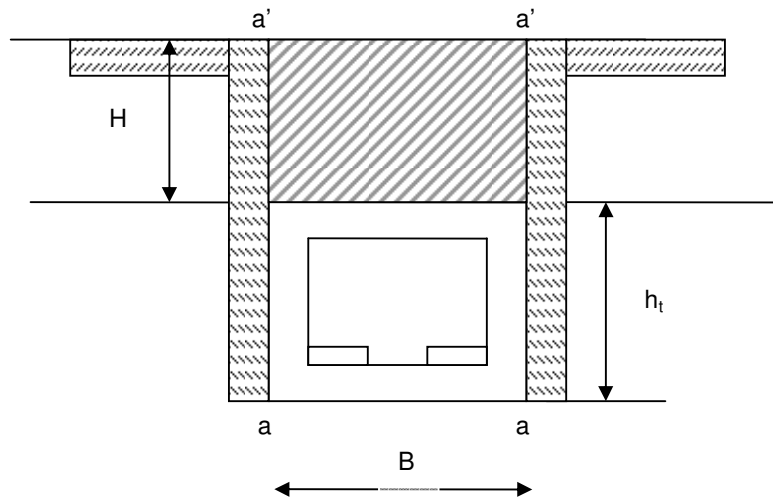
Considering 1m run of the structure,

Uplift force, $U = \gamma_w \, h_t \, B$

where γ_w = unit weight of water

h_t = height of structure

B = width of structure

Restraining force

$$R = \gamma'B(H-1.5)/\gamma_{f1} + (h_t + H - 2)2S/\gamma_{m1} + W/\gamma_{f2}$$

where γ' = submerged weight of backfill material

S = average shear resistance along a - a'

W = self weight of structure

H = depth of backfill

B = width of Structure

γ_{f1} = partial safety factor for weight of soil = 1.3*[Note 1]

γ_{f2} = partial safety factor for weight of structure = 1.1*[Note 2]

γ_{m1} = partial safety factor for shear resistance = 2.0*[Note 3]

R / U must be at least 1.1

Note 1: Since the design water table is above the finished ground level, the effective weight of the backfill shall be based on the submerged density of the material. In the calculations, backfill within the top 1.5m of the ground surface shall be ignored.

Note 2: For railways, first stage concrete (if any) may be considered as self-weight of the structure. Weight of partition walls, floor finishes, road surfacing, false ceiling, equipment and other superimposed dead load, etc shall not be considered.

Note 3: See Clause 8.4.5.3.

Figure 8.4.5.2   Flotation Assessment

8.4.5.4   Measures to Counteract Flotation

Unless otherwise accepted by the Engineer, the vertical alignment of the tunnels should not be modified to counteract the flotation forces. The use of ground anchors as a permanent measure to counteract flotation forces shall not be permitted. Suitable measures to counteract flotation forces shall be incorporated in the design. The measure(s) chosen shall suit the particular conditions and method of construction and may include:

(a) Toeing in of the base slab into the surrounding ground or fill. Where the base slab is toed into the surrounding ground or fill, the shear resistance may be obtained from the shear resistance of the ground or fill as appropriate. The shear resistance of the ground or fill above the toe shall be divided by a partial safety factor 2.0 and the adhesion factor shall not apply. The value of the weight of ground above the toe shall be calculated as for the backfill material, unless mass concrete is used. Where toes are provided, the minimum toe projection shall be 0.5m.

(b) The value of the weight of any additional thickness of concrete shall take into account the increased volume of water displaced. Increasing the dead weight of the structure by:

(i) Thickening of structural members.

(ii) Providing an extra thickness of concrete beneath the base slab tied into the structural base slab.

(iii) Deepening diaphragm walls.

(c) The provision of tension piles. The tension load in DFEs shall be calculated taking into consideration the stiffness of the DFEs and their associated structural frames.

8.4.6   **Stability of Excavation**

The stability of the completed structure against failure due to base heave under the structure shall be checked in accordance to Figure 8.4.6. In the equation based on the analysis by Bjerrum and Eide [3], a partial factor of safety of 1.15 shall be applied to the disturbing pressure due to the weight of ground beside the structure, with the exception of soil type E (Estuarine) to which a partial safety factor of 1.35 shall be applied, and a partial safety factor of 2.0 shall be applied to the shear strength of the soil.

$$F = N_c \times \frac{C_U}{(\gamma H + q - p)}$$

where F = overall factor of safety
N_c = bearing capacity factor
C_u = shear strength of clay in zone of base of structure
γ = average bulk density of soil above level of base of structure
H = depth to base of structure from ground level
q = surcharge at ground level beside structure (Refer Chapter 3)
p = resistance of completed structure to uplift expressed as a pressure at base level.

The overall factor of safety shall not be less than 1.2
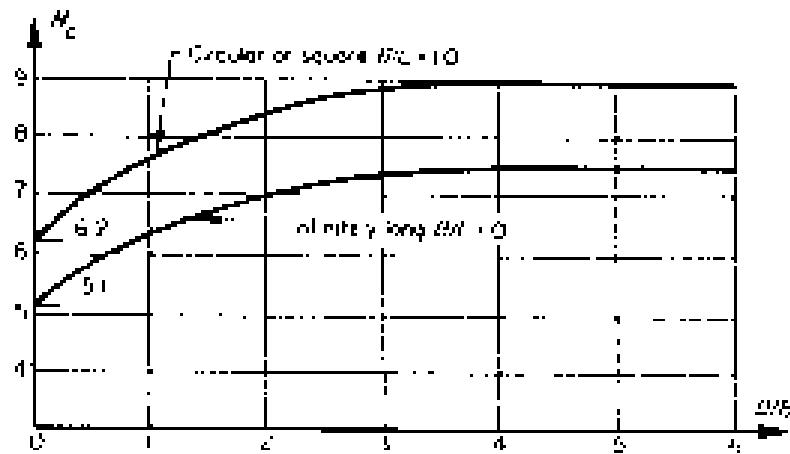
Bearing Capacity Factor

Note : N_c rectangular = (0.84 + 0.16 B/L) N_c square
where B = width of excavation
and L = length of excavation

Figure 8.4.6   Stability Check of the Structure

8.4.7   Redistribution of Moments

Modification to Clause 3.2.2 of SS CP 65 : Part 1.
Redistribution of moments is applicable only for structures designed to SS CP 65 at the ultimate limit state. Clause 3.2.2 of Part 1 of SS CP 65 applies except that redistribution is limited to 10% and the value given in condition 3 shall read 90%.
Redistribution of stress resultants will not be permitted in allowing for locked-in stress resultants.

8.4.8 Design Moments

In analysis of continuous and rigid frame members, distances to the geometric centres of members shall be used for the determination of moments. Where members are integral with (i.e. monolithic with) their supports, the design support moment may be taken at the face of the support. Where members are not designed integrally with their supports, the moments at supports shall be taken as the centre-line peak moments but may be duly reduced to allow for the effects of the support widths. However this reduction shall not exceed 10% of the centre-line peak moment.

8.4.9 Internal Facing of Diaphragm and Secant Pile Walls

8.4.9.1 An internal facing wall of in-situ reinforced concrete is mandatory for secant pile and similar walls that are incorporated into the permanent works. For diaphragm walls, an internal facing wall is not mandatory unless specified elsewhere. Irrespective of whether or not composite action is assumed, the internal facing wall shall be designed for full hydrostatic pressures.

8.4.9.2 When composite action is assumed, reinforcement ties anchored into the remote faces of the two walls shall be provided to prevent interface separation and slippage under full hydrostatic pressures. The amount of reinforcement ties shall be the higher of that required to prevent separation or for hydrostatic pressure provided they have been adequately detailed.

8.4.9.3 It shall be noted that both in-situ facing and cavity wall construction may be necessary in some circumstances stipulated in Chapter 11 (Station and Tunnel Services for Rail Projects).

8.4.10 Connections between Bored Tunnels / Cut-and-Cover Tunnels

8.4.10.1 Where bored tunnels are connected to cut and cover structures, the connection shall be designed so that completion of the joint is carried out by the contractor for the cut and cover structure.

8.4.10.2 Design of the joint shall consider the possibility of differential movement, during backfilling or subsequently. Unless it can be shown that differential movement of the bored tunnel and cut and cover structures would be sufficiently small and would not cause any overstress with a rigid joint, the joint shall be designed to permit an appropriate degree of articulation.

8.4.10.3 Particular attention shall be paid to the waterproofing detail, to ensure that the watertightness of the joint is not in any way inferior to that of the standard joint between precast tunnel segments.

8.5 DURABILITY

The elements of underground structures which form the Permanent Works in contact with earth and / or groundwater shall be considered critical elements with respect to durability. Durability provisions in the following clauses are minimum requirements.

8.5.1 Minimum Concrete Cover

8.5.1.1 The following **minimum** conditions of exposure per SS CP 65: Part 1 Table 3.2 for underground structures shall be allowed for in the designs, except where more corrosive environments are encountered:

(a) The external surface of concrete forming the hull of underground structures (i.e. roof, walls, base slabs): **severe**;

(b) Where an in-situ inner wall is cast against an embedded wall (diaphragm wall, secant pile wall or contiguous bored pile wall), both the inner face of the embedded wall and the outer face of inner wall: **severe**;

(c) The internal surface of concrete forming the hull of underground structures, and the face of all members exposed to trainways (in both cut and cover tunnels and in stations) or roadways: **severe** and

(d) Internal members of underground structures other than above: **moderate**

8.5.1.2 Notwithstanding the cover derived from the exposure conditions given in Clause 8.5.1.1 above, the nominal cover to the outermost reinforcement shall be not less than 40mm for the following locations:

(a) external and internal faces of members forming the external hull of underground structures

(b) both faces of in-situ inner walls cast against the walls of external hull members

(c) the faces of members exposed to trainways or roadways

8.5.2 Shrinkage and Thermal Cracking

8.5.2.1 Adequate consideration shall be given to the risk of early-age thermal cracking and shrinkage effects. Any requirements considered appropriate such as cement chemistry and curing methods shall be properly addressed during the review of the Materials and Workmanship Specification.

8.5.2.2 Crack widths due to early-age thermal cracking and shrinkage shall be calculated using SS CP 73. In the case of early-age thermal cracking, reference shall be made to CIRIA Report 91 for structures designed to SS CP 65. However the beneficial effects of using cement replacement materials and other techniques such as internal cooling to control the heat of hydration may be taken into account provided that suitable evidence is presented to justify the magnitude of these effects.

8.6 FIRE RESISTANCE

8.6.1 With the exception of non-load bearing separation walls, all other elements of underground structures shall be designed and detailed for a 4 hour fire resistance, unless specified otherwise for railways in the Standard for Fire Safety in Rapid Transit Systems.

8.6.2 Modification to Clause 4.1.7 of SS CP 65: Part 2

Where possible spalling shall be prevented using means other than mesh as supplementary reinforcement unless otherwise accepted by the Engineer. When it is necessary to use mesh, the minimum size shall be A252 to BS4483.

8.6.3 In the case of non-load bearing separation walls, their fire resistance shall be determined by other requirements, such as fire compartmentation etc.

8.7 ANALYSIS

8.7.1 The structure shall be analysed for the loads and effects specified herein to obtain the most severe combinations and envelopes of stress resultants on every component member.

8.7.2 The movements, both global and differential, of the structures shall be quantified from geotechnical analyses and considered in the design at all stages of construction and throughout the service life of the structure. In assessing the movements of the structures, due consideration shall be given to the movement of the ground, including settlement or heave as appropriate.

8.7.3 Analytically complex parts of structures shall be clearly identified in the Design Statement and analysed with grid analysis, finite element plate analysis, or similar, taking into account of three-dimensional behaviour. Such parts may be areas where :

(a) Irregular boundary conditions exist;

(b) The action is not predominantly one-way and

(c) The out-of-plane action cannot be accurately modelled using plane frames, or any combination of these.

8.7.4   Other parts of structures with regular shapes (e.g. box) which are away from zones of three-dimensional effects may be analysed as plane frames.

8.8   DETAILING

8.8.1   Slabs and Walls

8.8.1.1   For the reinforcement layers nearest the concrete faces, the spacing of reinforcement bars shall not be greater than 200mm and the clear spacing between bars shall not be less than 100mm, except at laps where it shall not be less than 75mm.

8.8.1.2   Particular attention shall be paid to the practicalities of the design and detailing of the slab to wall connections and the means by which the integrity of the construction joints at these connections will be assured. For external hull members, the connections between slabs and embedded walls such as diaphragm wall etc shall be designed and detailed to be monolithic.

8.8.2   Columns

Modifications to Clause 3.12.7 of SS CP65: Part 1.
The spacing of links and legs of links shall not exceed 300mm or 0.75 times the effective depth of the section whichever is lesser. The links shall be of grade 460 steel and the minimum bar diameter shall be 10mm, for column dimensions exceeding 500mm x 500mm or 600mm diameter.

8.8.3   Corner Details

Corner joints of large structural members shall be carefully detailed, particularly in the case where moments tend to "open" them. Specialist literature and the reinforcement details at corners in BD31/01 shall be consulted.

8.8.4   Construction Joints

The design and detailing shall be such that the number of construction joints will be as few as practicable. The suggested location of construction joints shall be indicated on the drawings.

8.8.5   Detailing of Shear Links

Where shear links are provided they shall enclose all tension reinforcement.

8.9 ADDITIONAL REQUIREMENTS FOR TRAINWAYS IN CUT-AND-COVER TUNNELS AND STATIONS

8.9.1 Size of Tunnels

With the exception of cells containing sidings per Clause 8.9.5, the size of each cell of a cut-and-cover tunnel shall accommodate the various items listed in Clause 7.5.2. Items (g) to (l) can be accommodated in spaces 300mm wide on the walkway side of the tunnel and 350mm wide on the opposite side of the tunnel as shown on the Authority's Drawings.

8.9.2 Cross Passageways

Cross passageways between two independent single-bound cut-and-cover tunnels shall conform to the requirements of Chapter 7 (Bored Tunnels and Related Works).

8.9.3 Drainage Sumps

The requirements of Chapter 11 (Station and Tunnel Services for Rail Projects) shall apply for sumps within the lengths of cut-and-cover tunnel.

8.9.4 Ventilation

Tunnel ventilation regime shall be maintained by the use of jet fans mounted in the roof of the cut-and-cover tunnel. Vertical enlargements in the structure shall be provided for these fans. The size and extent of the structural enlargement and clearance requirements to any overhead conductor envelope shall be determined in co-ordination with the relevant System-wide Contractors.

8.9.5 Cells Containing Sidings

The minimum internal width of cells for sidings shall accommodate:

(a) The Static Load Gauge, increased as necessary for Vehicle Throw;

(b) 600 mm minimum clearance between the Static Load Gauge (increased for Vehicle Throw) and service zones, to accommodate access at track level to a stationary train and

(c) 350 mm wide service zones on each side.

8.9.6 First Stage Concrete

The first stage concrete is defined as the concrete needed to fill the gap, if any, between the top of the structural slab/tunnel lining and the underside of the track concrete placed by the trackwork contractor. It would therefore not be necessary to provide a separate layer of first stage concrete if the top of structural slab matches the level of the underside of

the second stage (track slab) concrete. Where first stage concrete is required, the minimum thickness of the first stage concrete shall be 100mm. The minimum concrete grade for the first stage concrete shall be grade C30.

8.9.7 Concrete Finish at Interfaces between Trainway Structure, First Stage and Second Stage Concrete

The concrete finish in all trainways at the interface between the trainway structure and the first stage concrete or the second stage concrete (if no first stage is used) and between the first and second stage concrete (where both are used) shall be an exposed aggregate finish. This requirement shall be shown on the design drawings.

8.10 ADDITIONAL REQUIREMENTS FOR VEHICULAR UNDERPASSES AND DEPRESSED CARRIAGEWAYS

8.10.1 A minimum headroom clearance of 5.4 metres above all roadways shall be maintained across the full width of each carriageway. This applies to both permanent and temporary structures.

8.10.2 The underpass shall be designed to allow for positioning and housing of electrical lighting fixtures, mechanical ventilation system, if any, and openings for cabling works.

8.11 CIVIL DEFENCE DESIGN

Where Civil Defence design is required, the detailing of reinforcement shall comply with the "Civil Defence Design Criteria".

8.12 PROVISION FOR FUTURE DEVELOPMENT

8.12.1 General

The items in the following Clauses shall be addressed in the design and shall be shown clearly on drawings. There shall be supporting narrative in the Development Interface Report.

8.12.2 Knock-out Panels for Access to Future Developments

Where access is required to future developments, appropriate provisions for the future openings (generally described as "knock-out panels") shall be made in the structure. In particular the analysis, design and detailing of the structure shall allow for the opening being provided in the future. In addition appropriate trimming reinforcement shall be provided. When such knock-out panels are provided, they shall be designed to facilitate future removal without compromising the structural integrity or watertightness of the structure.

8.12.3 Fire Separation for Railway Structures

A four-hour fire separation shall be provided between railway and development areas unless specified otherwise in the Standard for Fire Safety in Rapid Transit Systems. The minimum thickness of reinforced concrete walls or slabs separating railway and development areas shall be 200mm provided that the area of steel relative to that of concrete exceeds 1%.

8.12.4 Future Known Development Loads, Structural Capacity and Settlement / Deflection

8.12.4.1 Unless indicated otherwise in the Particular Specification, cut off level of all piles and column stumps shall be 2.5m below finished ground level. Pile/column stump reinforcement shall protrude from the cut off level for a lap length and be protected by grade C20 capping concrete. Alternatively where soil cover is not available, suitably protected reinforcement couplers may be used, in which case the cut off level shall not be less than 1m below finished ground level.

8.12.4.2 The structural capacity and predicted settlement/deflection of piles and column stumps at the cut off level corresponding to the appropriate limit state shall be calculated and shown on pile/column stump capacity plans. The design shall demonstrate that the settlement limits specified in Chapter 6 (Foundations, Earthworks and Permanent Retaining Structures) will not be exceeded. Structural capacity shall be specified in terms of maximum horizontal force, vertical force and moment that can be applied at the cut off level of the pile or column stump.

8.12.5 Design Assumptions and Construction Constraints

8.12.5.1 The design shall take into consideration all requirements in the Development Interface Report as specified in General Specification and Particular Specification.

8.13 WATERPROOFING

8.13.1 The ground water seepage rates for any completed portion of an underground structure shall not exceed a general value of 0.12 litres per day per square metre ($l/d/m^2$). For any 10 square metres of external structure the seepage rate shall not exceed 0.24 litres per day per square metre ($l/d/m^2$).

CHAPTER 9

ABOVE-GROUND STRUCTURES

9.1 SCOPE

This chapter covers the design requirements for above-ground structures that include:

(a) above-ground stations and trainways,
(b) vehicular bridges,
(c) cycle and pedestrian bridges
(d) bus shelters and
(e) covered linkways

9.2 STANDARDS AND CODES OF PRACTICE

Elevated structures, including abutments, embedded retaining walls and approach structures that support RTS and vehicular loading shall be designed to BS 5400 and United Kingdom Highways Agency Departmental Standards (refer to Chapter 1).

Other aboveground structures shall be designed in accordance with SS CP 65 and BS 5950 as appropriate.

9.3 LOADS

All design loads shall be in accordance with Chapter 3.

The structure shall be analysed for the specified loads and effects to obtain the most severe combination of forces on every component member. The method and sequence of construction shall be clearly specified and taken into account in the design.

The structurally acceptable margins of tolerance as specified in the Material and Workmanship Specifications shall be clearly specified for critical members and operations.

9.4 DESIGN REQUIREMENTS

9.4.1 General

The following design requirements shall be adopted:

(a) A minimum headroom clearance of 5.4m shall be maintained across all roads for all structures.

Where the structure is more than 1000m in length above at-grade carriageways, the minimum headroom clearance of 10m shall be maintained.

The headroom clearance across Malayan Railway Land and Drainage Reserves, etc. shall comply with the requirements of the respective authorities.

(b) A minimum clear horizontal separation between structures of adjacent bridge decks shall comply with National Parks Board's requirements.

(c) Columns/Piers

The design of columns and piers and the assumed construction sequence shall be such that the sway in any direction at the top of the column-head and/or crosshead during erection will not, in any way affect construction (e.g. successful launching of pre-cast beams).

The longitudinal sway at the top of column-head and/or crosshead under the applied transient longitudinal loads (e.g. braking loads) shall not exceed an extent that will in any way affect the performance of bearings and movement joints.

(d) Inspection access

Access holes from the soffits to the voids in girders shall be provided in each span to facilitate future inspection and maintenance. These access holes:

(i) shall not be less than 600mm diameter,
(ii) shall preferably be located away from carriageways,
(iii) shall be covered with an easily removable access cover to the void. The cover shall be detailed such that it will stay in place.

Through access shall also be provided in each cell of a continuous box girder at diaphragm locations.

9.4.2 Prestressed Concrete

9.4.2.1 General

The maximum and minimum grades of concrete shall be grade C55 and C40 respectively.

All assumptions made in the determination of the design prestress loads, e.g. vertical and horizontal curvature, friction and wobble, shrinkage and creep of concrete, elastic shortening, properties of concrete and prestressing steel, etc. shall be clearly stated in the calculations and on the Drawings.

Prestressing anchorages shall be detailed such that they are easily accessible for inspection and maintenance. The detailing shall prevent the accumulation of water and dirt around the anchorage.

Where external unbonded prestressing tendons are used, the structure shall be designed in accordance with BD 58/94.

9.4.2.2   Serviceability Limit State

    (i)   Prestressed concrete used as station structures shall be designed as Class 2 in accordance with SS CP 65.

    (ii)   Modification to clauses 4.2.2(a) and (b) of BS 5400: Pt.4 -

            Prestressed concrete elements of bridge structures shall be designed as Class 2 under all load combinations, except under dead load and superimposed dead load, where they shall be designed as Class 1.

    (iii)   Modification to clause 6.3.2 of BS 5400: Pt.4 -

            For members that are both pre- and post-tensioned (i.e. hybrid system), the tensile stresses shall not exceed the design flexural tensile strength of the concrete, which shall be taken as $0.36\sqrt{f_{cu}}$ and $0.36\sqrt{f_{ci}}$ at service and transfer respectively.

    (iv)   Modification to Clause 6.7.1 of BS 5400: Pt.4 -Maximum Initial Prestress:

            Immediately after anchoring, the force in the prestressing tendon shall not exceed 70% of the characteristic strength for both pre- and post-tensioning. The jacking force shall not exceed 75% of the characteristic strength during stressing operations unless written acceptance of the Engineer has been obtained.

9.4.3 Design Surface Crack Width

For reinforced concrete bridge structures, the minimum surface crack width shall be in accordance with BS 5400: Part 4.

For reinforced concrete above-ground station structures, the minimum conditions of exposure as per SS CP 65: Part 1 Table 3.4 shall be taken as severe for external elements of station structures, and as moderate for internal elements of station structures which are completely sheltered from rain.

9.4.4 Vibrations

The design of bridge structures shall satisfy appropriate vibration serviceability requirements as specified in the relevant clauses of BD 37/01 and BD 49/01.

In the selection of the structural framework for railway stations, careful consideration shall be given to the isolation or reduction of vibration transmitted from bridge structures to the station structures. Complete isolation shall be adhered to if practical.

9.4.5 Bridge Aesthetics

9.4.5.1 General

Due attention shall be given at the concept design stage to ensure that the completed structure is aesthetically pleasing. The guidelines in BA 41/98 shall be used.

It shall be demonstrated at concept design stage, and to the acceptance of the Engineer, that the design meets the requirements outlined below. The submission shall include the deck drainage layout, showing the locations of drainage pipes and how they are concealed from public view.

At least two photo-montages (view from different angles) to illustrate the final appearance of the bridge in relation to its surroundings shall be submitted to the Engineer for acceptance, as part of the concept design submission.

9.4.5.2 Member sizes and shapes

In sizing the structural members, the following conditions shall be satisfied:

(a)   Any change in sectional depth shall be gradual.

(b)   No change in the shape of sections, other than that due to varying depth.

(c)   Column sizing shall give an appearance of a slender structure proportional to the superstructure. "Wall" like columns shall be avoided.

9.4.5.3   Treatment of furniture

Due attention shall be given to the placement or treatment of furniture such as, down pipes, street lighting, electrical cables and irrigation pipes. The deck drainage layouts shall be such that drainage pipes, electrical cables and irrigation pipes could be strategically located and hidden from public view.

9.4.5.4   Long-term appearance and detailing for effective water management

Sensitive detailing to all structural elements to reduce the chances of staining, concrete chipping off, etc. shall be exercised. Some examples of good detailing include a sloped surface, flashing and drip grooves to direct water away from vulnerable faces (e.g. parapet faces) to prevent staining and chamfers to prevent concrete chipping. Drainage pipes should also be protruded from vulnerable faces to direct water away.

9.4.6   Precast Concrete Segments

The following requirements shall be applied to the design of pre-cast concrete segments:

(a)   With dry joints, a minimum of 2.0 N/mm^2 compressive stress across the whole section of the precast segment under all load combinations shall be achieved.

(b)   With epoxy glued joints, a minimum of 1.0 N/mm^2 compressive stress across the whole section of the precast segment under all load combinations shall be achieved. In addition, there shall be a minimum of 1.5 N/mm^2 compressive stress across in-situ stitches of the precast concrete segments under all load combinations.

For pre-cast segmental bridge design, where requirements are not covered in the British Standards, the guidelines in the "AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges" shall be adopted.

9.4.7 Foundation

The effects of foundation settlements on the structures, including movement joints and bearings shall be allowed for in the design. The settlements shall be within the allowable limits specified in Chapter 6.

Where piles are subjected to bending moment, the design comprising a single row of piles is not acceptable. However, piles that directly support the superstructure and designed to act as frame system with the superstructure (i.e. column-piles) may be considered subject to the Engineer's approval.

The top of the footings/pilecaps shall be at least 1.0m below the finished ground level.

9.4.8 Bridge Abutments and Retaining Walls

9.4.8.1 Bridge Abutments

Reinforced-earth retaining structures shall not be used as bridge abutments that directly support the superstructures.

Abutments shall be designed against sliding and overturning on the footing base with a factor of safety of not less than 1.5 and 2.0 respectively. When checking against sliding and overturning, the effects of filling material in front of the abutment shall be neglected.

The characteristic earth pressure used for the design of the abutment walls shall be the "at rest" earth pressures.

Ground, surcharge and water loads shall be as specified in Chapter 3.

9.4.8.2 Retaining walls

Base slabs of retaining walls including reinforced-earth retaining structures supporting vehicle and vehicular parapets shall be designed for vehicular collision effects on the supported parapets in accordance with Annex B of BD 70/03, except for the highway live loading which shall be in accordance with Chapter 3.

9.4.9 Approach (Transition) Slab

An approach (transition) slab behind each bridge abutment or approach structure shall be provided to give a smooth transition from a rigid structure to a flexible structure as specified in Chapter 6 of the Design Criteria.

9.4.10 Integral Bridges

Bridges with integral abutments shall be designed in accordance with BA 42/96, except for the highway live loading and temperature loads which shall be in accordance with Chapter 3.

9.5 BEARINGS

9.5.1 General

Bridge bearings shall always be in compression under all load combinations.

The manufacture, installation and performance of the bearings shall strictly comply with Chapter 15 of the M & W Specification.

Structures shall be designed such that the number of bearings is minimised. Consideration shall be given for the easy maintenance and replacement of bearings.

Bearings for railway bridges shall be designed to accommodate the derailment loads specified in Clause 8.5 of BD 37/01. The corresponding viaduct rotation under derailment loads shall be controlled to minimise damage to viaduct elements.

9.5.2 Bearing Replacement

The decks and beams shall be designed so that they can be jacked off without the need for temporary works to accommodate bearing replacement. The structure shall be designed with sufficient space for the placement of jacks. The structures shall be designed to accommodate the expected jacking loads.

Drawings showing the jacking point for the replacement of bearings shall be produced as part of the design drawings.

9.6 MOVEMENT JOINTS

9.6.1 General

For vehicular bridges, only elastomeric in metal runners joints (modular joints), cantilever comb or tooth joints and finger plate joints are acceptable. Such joints shall be heavy-duty surface mounted mechanical system with bolts and reinforcement embedded in the bridge deck. They shall be provided along the full width of the bridge deck including the parapets, maintenance accesses and footpaths, strictly in accordance with the manufacturer's recommendations.

Structures shall be designed such that:

(a) The number of movement joints is minimised.

(b) Movement joints with total longitudinal movement capacity exceeding 100mm shall not be used.

The movement joints shall be designed in accordance with BD 33/94 and BA 26/94.

Movement joints in railway stations shall be located so as to avoid damage to the architectural finishes. They shall accommodate shrinkage, creep and thermal effects. They shall be designed to be easily maintained and replaceable.

The Contractor shall submit to the Engineer, for acceptance, details of the joints he proposes to use. The details of movement joints, the size, length and spacing of the holding-down bolts shall be included. This shall be substantiated by calculations that include:

(a) Design movement ranges of the proposed joints.

(b) Derivations of the resulting loads generated by the joints in accommodating these movements.

Detailed shop drawings, clearly indicating all dimensions, sections, longitudinal and transverse gradients of the joints in relation to the structure shall be submitted to the Engineer for acceptance.

9.6.2   Requirements

Movement joints shall satisfy the following requirements:

(a) They shall be either completely sealed to prevent ingress of water and granular material, or alternatively, designed to drain away water and granular material and prevent them from accumulating at the joint.

(b) They shall be designed to enable easy maintenance and parts liable to wear shall be easily replaceable.

(c) They shall be designed to accommodate shrinkage, creep, thermal effects, live loads and settlement.

(d) They shall be designed so that the passage of pedestrians and cyclists is not impeded. The size of any open gap on the riding surface of the joint shall not exceed 65mm. Where pedestrians have access, a non-slip cover plate shall be provided.

(e) They shall not unduly impair the riding quality of the surrounding surface for vehicular traffic, nor shall the passage of vehicular traffic cause undue noise or vibration.

9.7 ADDITIONAL REQUIREMENTS FOR PEDESTRIAN OVERHEAD BRIDGES

9.7.1 Stability Check

The pedestrian overhead bridge deck shall be checked for overturning under an impact load of 50kN applied in any direction between the horizontal and vertical on any part of the concrete surface of the bridge. This check shall be considered for the construction and permanent stage, and even if the clearance height of the bridge is more than 5.7m.

9.7.2 Provision of Dowel Bars Joining Precast Bridge Deck and Pier

Where dowel bars are provided at support locations to connect the pre-cast bridge deck and pier, slot holes provided on the pre-cast beam shall be dimensioned taking into account short-term shrinkage, creep and elastic shortening of the pre-cast beam. Construction tolerances to facilitate launching operations shall also be taken into consideration.

9.8 WATERPROOFING AND IRRIGATION SYSTEM FOR FLOWER TROUGH AND PLANTING/ TURFING AREAS

A waterproofing agent shall be applied to the inner surfaces of flower troughs and planting/turfing areas on structures as specified in Chapter 13 of the M & W Specification.

The design, supply and installation of the mechanical irrigation system for flower troughs shall comply with the requirements of the National Parks Board and other relevant authorities as appropriate. The hydraulic calculations shall be submitted to the relevant authorities for approval.

9.9   PARAPET SYSTEM FOR VEHICULAR AND PEDESTRIAN OVERHEAD BRIDGES

9.9.1   General

The design of parapet systems for bridges shall satisfy the requirements of BS 6779, BD 52/93 and the details shown in the Authority's Drawings, where applicable. Dimensions shown in the Authority's Drawings shall take precedence.

The design of bridge parapet systems shall conform to the BS 6779 and BD 52/93 with the following exceptions:

(a)   Of the groups of bridge parapets outlined in BD 52/93, only Groups P1, P4 and P6 shall be used as follows:

Group P1 -   Except for bridges over high-risk locations such as RTS and railway lines, Group P1 vehicle parapets shall be used for all vehicular bridges. The typical profile of Group P1 parapet shall be as shown in Figure 2 of BD52/93 with the following modifications:

(i)   The traffic face of the concrete plinth vertical shall be up to maximum 3°.

(ii)   75mm splayed raised kerb is not required except where integrated with continuous deck drainage system.

(iii)   Non-shrink grout with slopes at the edges shall be used for levelling the base plates of the P1 railing posts. The grout shall not cover the base plates.

Group P4 -   Pedestrian parapets in vehicular bridges and pedestrian overhead bridges.

Group P6 -   High containment parapets for vehicular bridges over high-risk locations such as RTS and railway lines.

(b)   Only 2-rail aluminium alloy railings mounted on a concrete parapet for Group P1 vehicle parapet and a full height concrete parapet for Group P6 high containment parapet shall be used.

(c)   Parapet railings including posts shall be of aluminium alloy for Group P1. Parapet railings including posts shall be of aluminium alloy or stainless steel for Group P4.

(d) Group P1 vehicle parapets and Group P6 high containment parapets shall have a minimum total height of 1.5m above the adjacent finished carriageway level.

(e) To calculate the vehicular impact loading as specified in Clause 7.1 of the BS 6779: Part 3, the effective longitudinal member for the concrete panel alone shall be taken as 1 irrespective of the height of the panel for Group P1 parapets.

9.9.2 Additional Requirements for Vehicular Bridge Parapets

To prevent vehicles from striking the ends of vehicular bridge parapets, safety fences shall be provided in accordance with the Authority's Drawings.

The supports for gantries, directional and information signs, etc. shall be integrated with the bridge parapet. The shape of supports must blend in with the profile of the bridge and shall be subject to the approval of the Engineer.

Unless otherwise specified, no parapet wall shall be erected on structures along the centre median of non-expressways with dual carriageways. The centre median shall be formed with kerbs of Type K2 profile as shown in the Standard Details of Road Element.

9.10 THERMAL RAIL FORCES IN RAILWAY TRACKS

Provision shall be made for horizontal transverse and longitudinal forces due to temperature variation in the rail on railway bridges. The forces shall be applied in a horizontal plane at the top of the low rail as follows:

(a) Transverse Force: The transverse force (T) per linear metre of structure per rail shall be determined by the following formula:

$$T = 535/R \text{ (KN)}$$

Where R is the radius of rail curvature in metre.

(b) Longitudinal Force: A longitudinal force of 180 kN per rail shall be applied to the first 3 columns or piers adjoining any abutment or cross-over structure.

9.11 RAILWAY DECK FURNITURE, DRAINAGE AND WATERPROOFING

The railway deck furniture, drainage and waterproofing systems shall be designed for all effects and requirements of the railway including 25mm vertical lift for bearing replacement as specified in M & W Specification Chapter 15. The extra 10mm vertical lift is in addition to the 15mm limiting vertical lift for RTS bridge beams as specified in M & W Specification Chapter 15 and is the tolerance required for bearing replacement.

9.12 ELECTRICAL AND MECHANICAL REQUIREMENTS

Electrical and Mechanical (E&M) requirements must be considered in the development of all structural designs. Such consideration shall include the following:

(a) The incorporation of stray current corrosion control systems by providing a continuous conductor for stray currents to return to the substations so as to reduce the impact of stray direct currents on structures.

(b) The incorporation of an adequate water drainage system for all structures.

(c) Reinforcement in the plinth and deck designed to avoid interference with attenuation of the signalling circuits on structures.

(d) Special care shall be taken over the location of gullies at points and crossing areas of structures.

CHAPTER 10

ROAD

10.1   GENERAL

This chapter covers the geometric design of all road and the requirements of all road related facilities.

The road design shall comply with the requirements stipulated in this Chapter. The design shall comply with the specified desirable value. The need to use the absolute minimum or maximum value must be demonstrated and is subject to the Engineer's acceptance.

No part of any road related facility e.g. bus shelter, earth retaining structures, pier foundation etc. which are to be maintained by the Authority shall be constructed outside the road reserve.

Where the relevant design requirements cannot be achieved, due to site constraints or other reasons, the potential safety hazards shall be identified, evaluated and the appropriate measures proposed to mitigate the risk associated with the hazard to achieve an acceptable level.

The details of road related facilities shown in the Authority's Standard Details of Road Elements shall be followed.

10. 2   DEFINITIONS

10.2.1   **Acceleration Lane** is an auxillary lane used to allow vehicles to increase speed without interfering with the main traffic stream.

10.2.2   **Bridge** is a vehicular structure that over crosses an existing river, lake, sea or valley.

10.2.3   **Carriageway** is a portion of a road devoted particularly to the use of vehicles, inclusive of the shoulders and auxillary lanes.

10.2.4   **Crest Curve** is a convex vertical curve in the longitudinal profile of a road.

10.2.5   **Critical Length of Grade** is the maximum length of a specific up-grade on which a heavily laden truck is able to operate without an unreasonable reduction in speed.

10.2.6   **Crossfall** is the slope, measured at the right angles to the alignment of the carriageway.

10.2.7   **Deceleration Lane** is an auxillary lane provided to allow vehicles to decrease speed.

10.2.8   **Design Speed** is a nominal speed fixed to determine the geometric properties of a road.

10.2.9   **Flyove***r* is a vehicular structure that over crosses an existing road, rail or traffic junction.

10.2.10   **Gore** is the area immediately beyond the divergence of the main carriageway and the exit ramp of an interchange.

10.2.11   **Grade** is the vertical profile of the carriageway.

10.2.12   **Grade Separation** is the separation of road, rail or other traffic so that crossing movements, which would otherwise conflict, are at different elevations.

10.2.13   **Horizontal Curve** is a curve in the plan or horizontal alignment of a carriageway.

10.2.14   **Interchange** is a grade separation of two or more roads with one or more interconnecting carriageways.

10.2.15   **Intersection** is a place at which two or more roads intersect at-grade.

10.2.16   **Intersection Sight Distance** is the sight distance required for vehicles approaching an intersection on major and side roads to be mutually visible so they can both stop prior to entering the intersection.

10.2.17   **Loop** is a circular connecting road to allow vehicles to enter or exit an interchange from one level to another level.

10.2.18   **Overtaking Sight Distance** is the sight distance required for a driver to initiate and safely complete an overtaking manoeuvre.

10.2.19   **Ramp** is connecting road between two arms of an interchange.

10.2.20   **Rate of Rotation** is the rate of change of crossfall required to achieve a suitable distance to uniformly rotate the crossfall from normal to full superelevation.

10.2.21   **Sag Curve** is a concave vertical curve in the longitudinal profile of a road.

10.2.22   **Sight Distance** is the continuous length of road ahead that is visible to the driver.

10.2.23   **Slip Road** is the connecting road to allow vehicles to enter or exit the interconnecting carriageway and to bypass the intersection at-grade.

10.2.24   **Stopping Sight Distance** is the sight distance required by a driver, travelling at a given speed, to react and stop.

10.2.25   **Superelevation** is a slope provided on a horizontal curve so as to enhance forces assisting a vehicle to maintain a circular path.

10.2.26 **Superelevation Development** is the area in which the transverse slopes on a carriageway are gradually changed from normal crossfall to superelevation.

10.2.27 **Swept Path** is the area bounded by lines traced by the extremities of the bodywork of a vehicle while turning.

10.2.28 **Transition Curve** is a curve of varying radius used to model the path of a vehicle as it enters or leaves a curve of a constant radius used for the purpose of easing the change in direction.

10.2.29 **Tunnel** is a vehicular structure that is below ground or underwater and the structure box is more than 90 metres in length.

10.2.30 **Underpass** is a vehicular structure that is below ground and the structure box is less than 90 metres in length.

10.2.31 **Undivided 2-way road** is a single lane two directional road without a physical separator as central divider.

10.2.32 **Viaduct** is a vehicular structure located above a road following the same longitudinal alignment and it is more than one kilometre in length.

10.3 CLASSIFICATION OF ROAD

The road category in relation to the class of road shall be as in Table 10.1:

Table 10.1

Class of Road	Road Category
Expressway	1
Semi-Expressway	1A
Major Arterial	2
Minor Arterial	3
Primary Access	4
Local Access	5

10.4 ROAD GEOMETRY

The geometric design requirement of road shall be as follows:-

10.4.1 Horizontal Alignment

10.4.1.1 Main Carriageway

Table 10.2

Class of Road / Parameters	Express way	Semi-Express way	Arterial Road		Other Road	
			Major	Minor	Primary / Local Access	Special Needs Access
Category	**1**	**1A**	**2**	**3**	**4 / 5**	**-**
(a) Desirable Design Speed (km/h)	90	80	70	60	50	40
(b) Desirable Minimum Radius (m)	355	270	195	145	95	65
(c) Absolute Minimum Radius (m)	340	255	185	135	90	60
(d) Desirable Maximum Superelevation (%)	5	5	5	5	5	5
(e) Absolute Maximum Superelevation (%)	6	6	6	6	6	6

10.4.1.2   Interchange Ramp & Loop, Slip Road

Table 10.3

	Expressway to Expressway, Semi-Expressway to Expressway	Expressway to Semi-Expressway, Others
(a) Desirable :		
• Design Speed (km/h)	70	60
• Minimum Radius (m)	185	135
(b) Absolute Minimum :		
• Design Speed (km/h)	60	50
• Minimum Radius (m)	135	90
(c) Absolute Maximum Superelevation (%)	6	6

10.4.1.3   Sight Distance
The following three types of sight distances are to be considered in the design :

Table 10.4

Minimum Sight Distances			
Design Speed (km/h)	Stopping Sight Distance [1], Ds (m)	Intermediate Sight Distance [2], 2Ds (m)	Overtaking Sight Distance [3] (m)
40	40	80	150
50	55	110	200
60	75	150	300
70	95	-	-
80	120	-	-
90	145	-	-
Height of eye (m)	1.15	1.15	1.15
Height of object (m)	0.20	1.15	1.15

Notes:
[1]   Sight Distance is for a level road or where the road gradient is less than 2 percent.
[2]   Intermediate Sight Distance is only applicable to undivided 2-way road (single lane each way).
[3]   Overtaking Sight Distance is only applicable to undivided 2-way road (single lane each way).

10.4.1.3.1   Sight distance for an undivided 2-way road shall be the "Intermediate Sight Distance" if the "Overtaking Sight Distance" cannot be achieved.

10.4.1.3.2   Where Intermediate Sight Distance is unachievable because of site constraints, the Stopping Sight Distance shall be used and the appropriate control measures to prohibit overtaking shall be introduced.

10.4.1.3.3   Minimum Stopping Sight Distance for road with gradient
The minimum stopping sight distance for road with gradient greater than 2 percent shall be as in Table 10.5:

Table 10.5

Design Speed (km/h)	Stopping Sight Distance (m)							
	Downgrades				Upgrades			
	-2%	-4%	-6%	-8%	+2%	+4%	+6%	+8%
40	40	40	45	45	40	40	40	40
50	55	60	60	60	55	55	55	55
60	75	75	80	80	70	70	70	70
70	95	100	100	-	90	90	90	-
80	120	125	125	-	115	110	110	-
90	145	150	155	-	140	135	135	-

10.4.1.4   Sight Distance on Horizontal Curves
On a horizontal curve where the obstruction on the inside of the curve cannot be removed, the radius of curve in the Table 10.6 shall be selected to permit adequate sight distance to be provided. These values shall be read in conjunction with Figure 10.1.

Table 10.6

V	S	Minimum Radius of centreline of inner lane (m)													
		60	70	80	90	100	120	140	160	180	200	250	300	350	400
40	40	3.3	2.8	2.5	2.2	2.0	1.7	1.4	1.3	1.1	1.0	0.8	0.7	0.6	0.5
50	55	-	-	-	4.2	3.8	3.2	2.7	2.4	2.1	1.9	1.5	1.3	1.1	1.0
60	75	-	-	-	-	-	5.9	5.0	4.4	3.9	3.5	2.8	2.3	2.0	1.8
70	95	-	-	-	-	-	-	-	-	6.2	5.6	4.5	3.8	3.2	2.8
80	120	-	-	-	-	-	-	-	-	-	-	7.2	6.0	5.1	4.5
90	145	-	-	-	-	-	-	-	-	-	-	-	8.8	7.5	6.6
		Offset Distance from centreline of the inner lane to obstruction (m)													

<u>Notes</u> :
1) The above table is to be used for level road or where road gradient is less than 2%
2) For road gradient more than 2% (up-grade or down-grade), refer to formula for computation

Where V = Design Speed, km/h
S = Stopping Sight Distance, m

10.4.1.4.1 The desirable sight distance and offset distance to the obstruction can be derived from the following :-

$$S = \frac{R}{28.65}\left[\cos^{-1}\left(\frac{R-O}{R}\right)\right] \qquad O = R\left[\left(1 - \cos\frac{28.65\ S}{R}\right)\right]$$

where R = Radius (m)
S = Stopping Sight Distance (m)
O = Offset (m)

10.4.1.5 Intersection Sight Distance

10.4.1.5.1 The desirable intersection sight distance at unsignalised junction required shall be as given in Table 10.7. The table below shall be read in conjunction with Figure 10.2.

Table 10.7

Major Road Design Speed (km/h)	Desirable Intersection Sight Distance (m)
40	75
50	100
60	125
70	155

<u>Notes</u> :
1) The above table is to be used for level road or where road gradient is less than 2%

2) For road gradient more than 2% (up-grade or down-grade), refer to formula for computation

10.4.1.5.2 The desirable intersection sight distance can be derived from the following:-

$$ISD = \frac{R_T V}{3.6} + S$$

where ISD = Intersection Sight Distance (m)
S = Stopping Sight Distance (m)
R_T = Reaction Time (s), 3 sec
V = Speed (km/h)

10.4.2 Vertical Alignment

10.4.2.1 Grades

10.4.2.1.1 Main Carriageway

Table 10.8

	Expressway	Semi-Expressway	Arterial Road		Other Road	
			Major	Minor	Primary Access	Local Access
Minimum Grade (%)	0.4 [1]	0.4 [1]	0.4 [2]	0.4 [2]	0.4 [2]	0.4 [2]
Desirable Maximum Grade (%)	4	5	5	6	6	6
Absolute Maximum Grade (%)	5	6	6	8	8	8

Notes:
[1] A road gradient of less than 0.4 % may be used for widening of expressway.
[2] For built up area, a road gradient of less than 0.4 % may be used to tie in with existing access.

10.4.2.1.2 Interchange Ramp & Loop, Slip Road

Table 10.9

Minimum Grade (%)	0.4
Desirable Maximum Grade (%)	6
Absolute Maximum Grade (%)	8

10.4.2.2   Critical Length of Grade
The length of grade shall be less than the critical values shown in Table 10.10.

Table 10.10

Grade (%)	Critical Length of Grade (m)
≤ 4	Unlimited
≤ 5	540
≤ 6	300
≤ 7	235
≤ 8	170

The Figure 10.3 illustrates the measurement of critical length of grade of a vertical curve.

10.4.2.3   Vertical Curves
A vertical curve shall be provided when there is a change in road gradient by using symmetrical simple parabolic curves.

10.4.2.3.1 Crest Curve
The minimum length of crest curve in metre shall be the greater of :
a) 0.6 times of the design speed (in km/h); or
b) curve length needed to provide the minimum stopping sight distance (refer to Figure 10.4).

10.4.2.3.2 Sag Curve
The minimum length of sag curve in metre shall be the greater of :
a) 0.6 times of the design speed (in km/h); or
b) curve length needed to provide for riding comfort (refer to Figure 10.5); or
c) curve length needed to provide headlight sight distance (refer to Figure 10.6).

10.4.2.3.3 The desirable curve length can be derived from the following equation :-
a) Crest Vertical Curves for Stopping Sight Distance

$$L = \frac{AS^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \qquad ; \quad \text{when } L > S$$

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A} \qquad ; \quad \text{when } L < S$$

where
    L   = Length of vertical curve (m)
    S   = Stopping Sight Distance (m)
    A   = Algebraic difference in road gradient (%)
    h_1 = Height of eye above roadway surface (m), 1.15m

h_2 = Height of object above roadway surface (m), 0.2m

b) Sag Vertical Curves for Headlight Sight Distance

$$L = \frac{AS^2}{200 \left(h + S(\tan q)\right)} \qquad ; \quad \text{when } L > S$$

$$L = 2S - \frac{200 \left(h + S(\tan q)\right)}{A} \qquad ; \quad \text{when } L < S$$

where
L = Length of vertical curve (m)
S = Light beam distance (m) = Stopping Sight Distance (m)
A = Algebraic difference in road gradient (%)
h = Mounting height of headlight (m), 0.6m
q = Elevation angle of beam (upwards), 1 degree

10.4.3   Type of Curves
The various types of horizontal curves used are as shown in Figure 10.7.

10.4.3.1 Simple Curve
This is an arc of constant radius which achieves the desirable deflection without using a transition curve. This type of curve shall be used whenever possible.

10.4.3.2 Compound Curve
A compound curve consists of two or more curves with deflections in the same direction immediately adjacent to each other. In general, the use of compound curve is not favoured. Where it is necessary, the following guidelines apply to compound curve:
   a) curves shall have radii greater than 1000m;
   b) where radii less than 1000m have to be used, the design speeds for each curve shall desirably be within 10km/h of each other;
   c) on main road, the ratio of the radius of the flatter curve to the sharper curve shall not exceed 1.5 : 1; and
   d) at junction intersection and ramps, the ratio of the radius of the flatter curve to the sharper curve can be up to 2 : 1.

10.4.3.3 Reverse Curve
A reverse curve consists of two curves of deflections in the opposite directions which are joined by a relatively short tangent distance. Reverse curves shall not be used unless there is sufficient distance between the curves to introduce full superelevation of the two curves. In general, the use of reverse curve is not favoured. Where it is necessary, the following guidelines apply to reverse curve:
   a) the tangent distance in metre between the reverse curves shall not be less than 0.6 times the design speed in km/h;
   b) up to 50% of the transition may be placed in the curves; and
   c) where it is not possible to provide the minimum tangent distance in (a), the radius of each curve shall not be less than minimum radius

of V^2 / 127 f, where V is the design speed in km/h and f is the side friction factor.

10.4.3.4   Broken-Back Curve

Broken-back curve consists of two curves with the deflection in the same direction that is joined by a short tangent distance. In general, the use of broken-back curve is not favoured. Where it is necessary, the length of tangent in metre shall not be less than 3 times the design speed in km/h. Where such a minimum length of tangent cannot be obtained, the alignment shall be changed, either to increase the straight section, or eliminate it entirely by the use of a compound curve, or transition curve between the two curves.

10.4.3.5   Transition Curve

Transition curve is normally used to join a straight line to a circular curve, although it may be omitted when large radii curves are used. The most frequently used form of transition is the clothoid whose curvature changes at a uniform rate along the curve. The design requirement of transition curve is given in Clause 10.4.5.

10.4.4   Corner Radius

The corner radii at an intersection affect the operation and safety of the intersection. The minimum radius shall not be less than the values specified in Table 10.11.

Table 10.11

Location	Minimum Radius
Driveway leading to Residential house (Landed Housing)	3 m
Residential Estates (Landed Housing)	6 m
Road junction	12 m
Industrial Estates	15 m

10.4.5   Transition Curve

10.4.5.1   Sections of road where the design speed is less than 60km/h do not require transition curves. Where the design speed is more than 60km/h, transition curves are not required if the associated shift in circular arc is less than 0.20m.

10.4.5.2   Transition curves are not required if the radius is equal or more than the values shown in Table 10.12.

Table 10.12

Design Speed (km/h)	Absolute Minimum Radius (m)	Desirable Radius (m)
60	235	370
70	320	505
80	415	655
90	525	830

10.4.5.3 The length of the transition curve and shift can be derived from the following:-

$$L = \frac{V^3}{3.6^3 CR} \qquad p = \frac{L^2}{24R}$$

where p = Shift (m)
L = Length of Transition (m)
V = Design Speed (km/h)
R = Radius of circular curve (m)
C = Rate of change of radial acceleration (m/s^3)
for absolute minimum radius used 0.6m/s^3
for desirable radius used 0.30m/s^3

10.4.6   Crossfall of Carriageway

The crossfall of traffic lanes and shoulders of straight sections is provided to facilitate surface water drainage to the side drains and the design requirement shall be as in Table 10.13.

Table 10.13

	At-grade road and road on other structures	Tunnel
Desirable Crossfall	1 in 30	1 in 40
Absolute Minimum Crossfall	1 in 36	1 in 50

10.4.7   Superelevation

10.4.7.1 The desirable superelevation can be derived from the following equation:

$$e + f = \frac{V^2}{127R}$$

where e = Superelevation (m/m)
V = Design Speed (km/h)

f = Side friction factor

R = Radius of Curve (m)

Table 10.14

Design Speed, V (km/h)	40	50	60	70	80	90
Side Friction Factor, f	0.16	0.16	0.15	0.15	0.14	0.13

10.4.7.2 The various percentages of superelevation and their corresponding design speeds and radii are as shown in the Figure 10.8.

10.4.7.3 In cases where the negative or positive superelevation derived is lower than the desirable crossfall, the desirable superelevation shall be pegged at the crossfall as specified in Table 10.13 to slope towards the inner radius of the carriageway.

10.4.7.4 For rotation of pavement to attain superelevation, the length required to develop the superelevation shall satisfy the larger value obtained from the following two formulae:

$$\text{(a)} \qquad L_e = \frac{|e_1 - e_2|V}{R} \qquad \text{and} \qquad \text{(b)} \qquad L_e = |e_1 - e_2|W \times 100$$

where L_e = Superelevation Development Length (m) (see Figure 10.9)

e_1 = Crossfall of carriageway (m/m) (see Table 10.13)

e_2 = Superelevation at ends of the development length (m/m)

V = Design Speed (km/h)

W = Maximum width from axis of rotation to edge of running lane (m)

R = Rate of rotation;

use 0.126 for design speed less than 80km/h

use 0.09 for design speed for 80km/h & above

10.4.7.5 Where transition curves are provided, superelevation shall be effected along the length of the curve. For simple circular curve, about ⅔ of the superelevation development length shall be introduced on the tangent approach and the remainder on the curve.

10.4.8   General Controls for Horizontal and Vertical Alignment

10.4.8.1 Horizontal Alignment

There are several general controls that shall be considered when designing the horizontal alignment:

a) where it becomes necessary to introduce curves of lower standard than the design requirement, the respective design speeds between the successive geometric elements shall not differ by more than 10 km/h;

b) where the radius of a curve is below the design requirement, additional lane width shall be provided to accommodate heavy vehicle off-tracking within the curve;

c) for small deflection angles, curves shall be sufficiently long to avoid the appearance of a kink. Curves shall be at least 150m long for a central angle of 5 degrees, and the minimum length shall be increased to 30m for each 1-degree decrease in the central angle;

d) opening at centre median along horizontal curves shall not be provided if the intersection sight distance is not achievable; and

e) on a horizontal curve, there shall be no obstruction i.e. longitudinal barrier, tree, shrub, embankment, other structure or building to restrict the driver's sight distance. If the required sight distance cannot be achieved then lane widening shall be provided.

10.4.8.2   Vertical Alignment
There are several general controls that shall be considered when designing the vertical alignment:

a) a smooth grade line with gradual changes shall be used instead of a line with numerous breaks and short lengths of grades;

b) grades through intersections shall not exceed 2 to 3% to avoid adverse effect to turning movements and ensure effective surface drainage;

c) a sag vertical curve or a flat section is desirable in advance of any channelisation at an intersection and ramp take-off at an interchange, in order to provide sufficient sight distance; and

d) broken-back grade line shall be avoided particularly in sag vertical curves, one long vertical curve is more desirable.

10.4.8.3   Combination of Horizontal and Vertical Alignment
To avoid undesirable effect of poor combination of vertical and horizontal curves, the following principles shall be observed:

a) the tangent points for both vertical and horizontal curves shall coincide;

b) when condition (a) cannot be met, the vertical curve shall be completely within the horizontal curve and have common mid-points. If the mid-points are unable to coincide, the distance between the mid-points of both curves shall be less than 0.25 times the length of the horizontal curve;

c) sharp horizontal curvature shall not be introduced near the top of crest vertical curve, or near the bottom of sag vertical curve;

d) the zero crossfall points within superelevation development length shall not coincide with bottom of sag vertical curve; and

e) both horizontal and vertical curves shall be kept as long as possible and where both are present, they shall not be considered separately.

10.5   LANE WIDTH

10.5.1   Main Carriageway
The normal lane width for a major road is 3.4m, an addition lane widening of 0.3m to the kerb lanes is required for the side friction. At road intersection, additional lane may be required for turning movement. If there are constraints, the absolute minimum lane width shall be 3m.

Recommended minimum lane widths shall be as in Table 10.15.

Table 10.15

Road Type	Lane abuts kerb	Other Lane
Expressway	3.7m	3.7m
Other Roads (two or more lanes)	3.7m	3.4m
Divided dual single-lane road; One way single-lane road	5.5m	-
Undivided dual single-lane road	5.0m (For Industrial Area) 3.7m (For Other Area)	-
Local Access	3m to 3.7m depending road reserve width and location [1]	-

Note :
[1] Actual lane width to be determined in consultation with Development & Building Control Division of Land Transport Authority.

10.5.2   Ramp or Loop

The minimum lane width for ramp or loop is 3.7m per lane, however consideration shall be given to widen the lane width for the swept path of a heavy vehicle if there are many heavy vehicles using the ramp or loop. The total width of the ramp or loop shall include the paved shoulder width in Clause 10.7.

10.5.3   Turning Lane

The turning lane at the intersection is to provide storage space for turning vehicles so as not impede the main traffic flow. Refer to Figure 10.10, the width of storage lane for turning traffic shall be 3.2m for desirable minimum and 3m for absolute minimum. The storage lane shall be 70m long or sufficiently long to store the likely number of vehicles at any interval waiting to complete the turn, whichever is the greater. A minimum of 30m taper is required for the transition.

To accommodate the traffic lights, the width of the centre divider at a junction separating the right turning lane from the opposing traffic flow shall be 1.3m for desirable minimum and 1.0m for absolute minimum.

10.5.4   Slip Road

10.5.4.1 Slip road is provided to permit left-turning vehicles to bypass the intersection. The absolute minimum merging angles for left turn slip roads shall be 50 degrees. If there are no constraints (physical and operational requirements), the angle should be increased to no more than 70 degrees.

10.5.4.2 The minimum width of a single-lane slip road shall be 5.5m with a minimum turning radius of 30m to allow for the passing of a properly parked stalled vehicle. The minimum width for a two-lane slip road shall be 7.4m with a minimum turning radius of 25m. If the minimum turning radius cannot be achieved or/and if there are many heavy vehicles using the slip road, then the slip road width shall be increased to cater for the swept path of a long vehicle. The design requirements for various radii of slip road are shown in Table 10.16:

Table 10.16

Radius on Inner Edge of slip road (m)	Width of one lane slip road (m)		Width of two lane slip road (m)	
		Where frequently used by many heavy vehicles		Where frequently used by many heavy vehicles
15	6.0	7.8	7.8	9.4
25	5.6	6.9	7.4	8.6
30	5.5	6.7	7.4	8.4
50	5.5	6.3	7.4	7.9

10.6 TRAFFIC ISLAND

10.6.1 The desirable minimum dimensions and the approach nose of the traffic island shall be as shown in the Figure 10.11.

10.6.2 Where there is a high concentration of pedestrians at the road intersection, the dimensions of the traffic island shall be increased.

10.7 ROAD CROSS-SECTION ELEMENT

10.7.1 The details of the road cross-section elements such as lane widths, centre median width, paved shoulder, sides, footpath, drains and landscaping, etc. shall be in accordance with the Authority's Drawings and the Standard Details of Road Elements.

10.7.2   The width of the paved shoulder shall be as shown in Table 10.17:

Table 10.17

Road Type	Next to slow lane / Left-hand side of carriageway	Next to fast lane / Right-hand side of carriageway
Expressway (at-grade)	2.75 m	0.9 m
Expressway's main carriageway on structure (viaduct, flyover, tunnel, underpass and associated depressed road)	2.75 m	0.9 m
Other Road's main carriageway on structure (viaduct, tunnel and associated depressed road)	2.0 m	0.6 m
Ramp & Loop	2.0m	0.6m

10.7.3   Sidetable for services, drains and landscaping shall be provided outside the shoulder of the expressway or the carriageway of other categories of roads. The sidetable shall be turfed and sloped as shown in the Standard Details of Road Elements. For roads other than expressway or ramp and loop, unless otherwise specified, drains shall be slabbed over to be used as footpath. Where raised kerbs are provided along the edge of carriageway, UPVC pipe with drop inlet chambers at 6m interval shall be provided to drain the surface water to the roadside drain. However, at the low point of a sag curve and at road junction, the spacing of the drop inlet chamber shall be at 3m interval for a distance of 30m measured between the points 15m from either side of the lowest point.

10.7.4   No split levels and open drains shall be allowed at the centre median.

10.7.5   For footpath, it shall be clear of any obstructions.

10.8   ROAD PAVEMENT

10.8.1   The types of flexible pavements for the various class of road as stipulated in Clause 10.2 are defined in the Standard Details of Road Elements and the Table 10.18:

Table 10.18
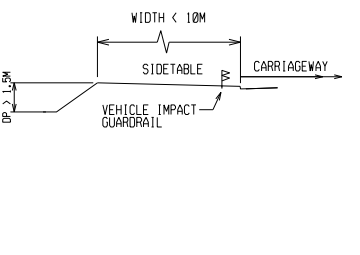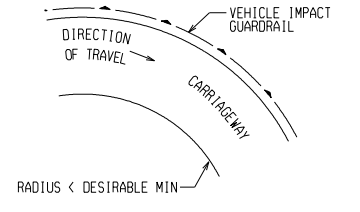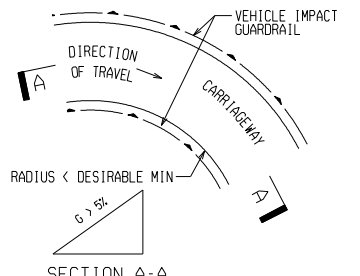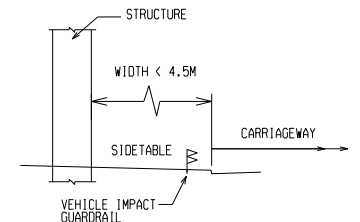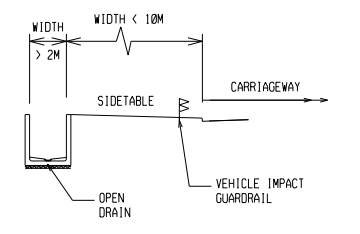
Type of Flexible Pavement	Road System
Type I	• Expressway • Semi-Expressway • Arterial Roads • Roads in Industrial Area
Type II	• Primary Access
Type III	• Local Access

10.9   VEHICULAR IMPACT GUARDRAIL

10.9.1   Vehicular impact guardrail shall be provided along expressways as shown in the Standard Details of Road Elements.

10.9.2   For other roads (at-grade), vehicular impact guardrail shall be provided at the following locations as shown in Table 10.19.

Table 10.19

Location	Requirement	Illustration
(a) Slopes	Where the difference in level between the top (carriageway level) and the toe of the slope is more than 1.5 m; and the top edge of the slope is less than 10 m from outer edge of the carriageway.	
(b) Horizontal Curves	On the outer curve of carriageway where the radius is less than desirable minimum.	
(c) Grades	On both sides of the horizontal curves where the downhill road gradient is greater than 5%.	
(d) Bridge Approaches and Other hazards	i) At approaches to bridges and parapet walls with reference Standard Details of Road Elements; ii) At other hazards such as bridge piers / columns and gantry sign supports which are located less than 4.5m from the edge of carriageway.	ii)
(e) Open drain	Internal width of drain exceeding 2 m and located less than 10 m from edge of carriageway.	

10.9.3   The arrangement of the vehicular impact guardrail shall be in accordance with the Standard Details of Road Elements. However at specific locations due to site constraints, the vehicular impact guardrail shall take into consideration the need to provide adequate visibility ahead for the driver of a vehicle and the necessary safety measures.

10.9.4   In addition to the above requirements, the design shall also take into consideration the need to provide adequate protection where the safety of pedestrians and other facilities are endangered.

10.10   CLEARANCE TO STRUCTURE

No structure shall be erected above the carriageway or too near to the carriageway that they become hazard to the road users. The minimum allowable lateral and vertical clearance shall satisfy the following clauses.

10.10.1   Lateral Clearance

10.10.1.1 Minimum lateral clearance from edge of road pavement to any structure adjacent to the road is specified as shown in Table 10.20.

Table 10.20

Type of structure	Expressway	Other Roads
a) Column, staircase, landing of Pedestrian Overhead Bridge and support to overhead gantry	2.0 m	1.2m
b) Abutment Walls of Flyovers	3.0 m	3.0m
c) Overground boxes, lamp posts, controller boxes, traffic signs posts	1.8 m	0.6 m[1] 1.2 m[2]

Notes :
[1].   If no Vehicular Impact Guardrail is installed.
[2].   Where Vehicular Impact Guardrail is installed.

10.10.1.2 For an elevated road, the minimum lateral clearance between edge of the road structure and any other structure shall be 3 m.

10.10.1.3 For vehicular tunnel/underpass/depressed road, the minimum lateral clearance between the edge of the carriageway and the inner face of the wall shall be as shown in Figure 10.12.

10.10.2   Vertical Clearance

10.10.2.1 The minimum vertical clearance from road surface to soffit of structures shall be as specified in Table 10.21 :

Table 10.21

Type of structure	All Roads
a) Pedestrian Overhead Bridge, Flyover, Rail Viaduct	5.4 m
b) Overhead Gantry Signs	5.7m
c) Soffit of deck of road viaduct running parallel to and above the road	10m

10.10.2.2 For vehicular tunnel, a minimum structure clearance of 5.9m is required as shown in Figure 10.12 with a clear envelope of 5.1m. The clear envelope could be reduced to 4.8m under 2-line lit directional signs and Variable Message Signs (VMS). Height Restriction Gantry shall be installed at the entry to vehicular tunnel.

10.10.2.3 For vehicular underpass, a minimum structural clearance of 5.6 m is required as shown in Figure 10.12 with a clear envelope of 5.1 m.

10.10.2.4 For Height Restriction Gantry where it functions as a protection to the overhead structure or any object above the carriageway, a minimum vertical clearance of 0.3m shall be allowed for between the lowest point of the gantry frame and the overhead structure or any object above the carriageway.

10.11   CROSS PASSAGE OPENINGS AND ESCAPE STAIRCASES

10.11.1   For road tunnel, the general guideline for maximum interval for cross passages and escape emergency staircases is given in Table 10.22.

Table 10.22

Provision	Maximum interval (m) [1]		
	Single-cell tunnel	Twin-cell tunnel	Slip Road or Ramp [3]
Cross-passage for Vehicle	-	1,500 [2]	-
Cross-passage for motorist/passenger [4]	-	200 [2]	-
Motorist/passenger escape emergency staircase	300 [2]	300 [2]	200

Notes:
  [1] The exact intervals needs to comply with the Singapore Civil Defence Force's latest requirements, NFPA 502 and other relevant codes
  [2] For main tunnel
  [3] For slip road or ramp longer than 100m
  [4] No steps are to be provided at cross passage between the difference bound of carriageway

10.11.2 In addition to the above requirements, the design shall also take into consideration the sight distance requirements and other factors that may affect the safe functioning of the provision.

10.12 EMERGENCY GATES

10.12.1 The emergency gates shall be provided for expressway (at-grade or viaduct) on the consideration of each direction of traffic flow with the following requirements:
   a) an emergency gate shall not exceed 3 km from an exit point; and
   b) the interval between the successive emergency gates shall not exceed 3km.

10.12.2 The emergency gates shall be designed for crash-rated requirement complying with NCHRP350 and BSEN1317:Road Restraint System.

10.12.3 In addition to the above requirements, the design shall also take into consideration the sight distance requirements and other factors that may affect the safe functioning of the provision.

10.13 MOTORCYCLIST RAINSHELTER

A separate space for rainshelter shall be provided for motorcyclists away from the traffic lanes. A provision of minimum bay size of 60m^2 (3m width, 10m straight length and 10m tapers length) shall be provided at the locations as shown in Table 10.23:

Table 10.23

Provision	Expressway	
	At-Grade	**Tunnel**
Motorcyclist Rainshelter	Along the expressway directly underneath flyover or viaduct which overcrosses the expressway	Along the expressway at the exit of the tunnel box

10.14 BUS BAY & SHELTER

10.14.1 Bus bay and shelter shall generally be provided at location close to where commuters can cross the road conveniently. The design of the bus bay and bus shelter shall refer to the Standard Details of Road Elements.

10.14.2 The following shall be taken into account during the provision of the bus bay and shelter :
   a) the interval between bus bays varies from 350 m to 400 m for major arterial road; and 300 m to 350 m in heavily built-up areas and new towns;

b) bus bay shall not be located along a curve unless sufficient sight distance can be provided;

c) the siting of a pair of bus bays and shelters shall be provided as shown in Figure 10.13;

d) bus bay shall not be located right before signalised pedestrian crossing unless overhead cantilever traffic signal pole can be provided;

e) bus bay shall not be located right before non-signalised road junction unless sufficient intersection sight distance can be achieved;

f) near signalised road junction, bus bay and shelter shall be sited as close to the junction as possible to provide convenience for the commuters who might be transferring to a bus on the opposite carriageway. Figure 10.14 and Figure 10.14.1-10.14.4 refer to the minimum distance required between the signalised junction and the bus bay;

g) outside train station, bus bay and shelter shall be sited close to the entrance of the station; and

h) bus bay and shelter along slip road shall be provided not less than 100 m from the physical nosing.

10.15   ENTRANCE AND EXIT RAMPS OF AN INTERCHANGE

10.15.1   Entrance and exit ramps of an interchange shall be designed for safe and efficient operation. They shall be located on tangent sections in order to provide maximum sight distance.

10.15.2   At the ramp entrance or exit point, adequate length of acceleration or deceleration lane shall be provided. For expressway, the design of these acceleration / deceleration lane shall conform to the Standard Details of Road Elements.

10.15.3   For at-grade major arterial road and semi-expressway, the design of the acceleration or deceleration lane shall conform to the requirement shown in Figure 10.15 under the conditions given in Figure 10.16.

10.15.4   To ensure visibility at the exits of an interchange, the minimum length of taper and deceleration lane shall be as shown in Figure 10.17.

10.15.5   The distance between successive entrance or exit ramps shall be designed in accordance with the latest edition of Highway Capacity Manual by National Research Council (U.S.), to achieve a level of service D. However, the spacing shall not be less than the specified requirement shown in Figure 10.18.

10.15.6   The above requirements shall also be applicable to other roads where the entrance and exit ramps are on bridge structure, viaduct, depressed road and road tunnel/underpass.

10.16 GORE

10.16.1 The gore is an interchange or intersection is illustrated in Figure 10.19.

10.16.2 The gore nose (i.e. start of the gore) is typically 6m wide measured between the travelled way of the two roads (including the paved shoulder) and is about 20m downstream from the start of physical nosing. The width of the gore nose may be increased if the ramp curves away from the main carriageway.

10.16.3 Where the provision of 20 x 6m clear zone cannot be achieved, an appropriate crash-rated system complying with NCHRF350 and BSEN1317: Road Restraint System shall be provided with respect to the design speed of the road.

10.16.4 The following shall be considered when designing the gore of an exit ramp:
   a) the neutral area shall be graded as nearly level with the roads and shall also be free of trees, lamp posts, signs, other physical obstacles etc. except split arrows and object marker sign. The drain at the neutral area shall also be covered with grating;
   b) the gore shall be graded as flat as practicable;
   c) where the placement of a major obstruction such as a bridge pier in a gore is unavoidable, an appropriate treatment shall be installed in front to reduce the severity of fixed object collision. The appropriate treatment shall be located on a level area free from kerbs and other physical obstacles;
   d) there shall be proper advance signs for the exit and clear road marking at the gore area;
   e) the maximum algebraic difference between the crossfalls of the through lane of the main carriageway and the exit ramp when they are adjacent to each other shall not exceed 4%; and
   f) the first lamp pole will be installed about 500mm after the neutral area.

10.17 ROAD SIGNAGE

10.17.1 The design of the road signs shall comply to the Standard Details of Road Elements and M&W Specification.

10.17.2 Road signs shall be suitably located to enable drivers to have sufficient time to react safely.

10.17.3 In general, road sign are classified as follows:
   a) Regulatory Sign: This imposes legal restrictions
   b) Warning Sign: This calls attention to hazardous conditions
   c) Information/Directional Sign

10.17.4   Directional Signs comprise the following:
   a) Advance and Intermediate Directional Sign is to inform road users of the routes ahead before they reach an interchange or road intersection.
   b) Confirmatory Directional Sign is to give the route information at an interchange or road intersection.

10.17.5   All Directional Signs shall generally be sited on the side next to the slow lane and clearly visible to the driver. It shall be noted that in some cases (e.g. for a major right turning movement, or for very wide roads) it may be appropriate to site signs on the median if it is wide enough. The minimum lateral clearance distance from the edge of the road kerb to the edge of the sign board shall be 600 mm and 750 mm where raised kerbs and flush kerbs with hard shoulders are used respectively.

10.17.6   The siting of the Directional Signs shall be in Table 10.24 for expressways and other roads.

Table 10.24

Type of Signs	Expressway	Other Roads
Advance Directional Sign	600m on the side from end of chevron marking of traffic island of an interchange	150m on the side from end of chevron marking of traffic island of an interchange or intersection
Intermediate Directional Sign	300m on the side from end of chevron marking of traffic island of an interchange	Not Applicable
Confirmatory Directional Sign	The Confirmatory Sign (which also has the exit number) is to be placed at the start of the chevron marking, however it shall be placed at least 200m from the intermediate directional sign. If the visibility is obstructed then it shall be mounted onto a cantilever support.	The Confirmatory Sign is to be placed either on the left side of the slip road/road intersection or on the traffic island.

10.17.7   The standard directional signs specified in the Standard Details of Road Elements shall be used for at-grade road and grade-separated interchanges (i.e. underpass, flyover, tunnel, viaduct) provided the visibility and the geometric design requirements meet the design standards in the Design Criteria.

10.17.8 For grade-separated interchanges on other road category where the visibility and geometric design requirements cannot be complied with the Design Criteria due to site constraints, then enhanced guidance (traffic sign showing both destination and lane use) shall be provided either by using an overhead gantry sign, cantilever sign or lane indication sign (as shown in Figure 10.21). The option to select any of these signs shall depend on the site conditions and is subject to the Authority's approval.

10.17.9 Road Signs shall be sited at 95° away from the line of a straight carriageway to avoid direct reflection from headlamp beams. For left hand bends, the 95° angle shall be measured from a line joining the sign to a point at the edge of the carriageway and 180m before the sign as shown in Figure 10.20.

10.17.10 All signs shall not be blocked by trees. On expressway within 75m in front of Advance Directional Sign, no trees shall be planted. On other roads, the corresponding distance is 45m.
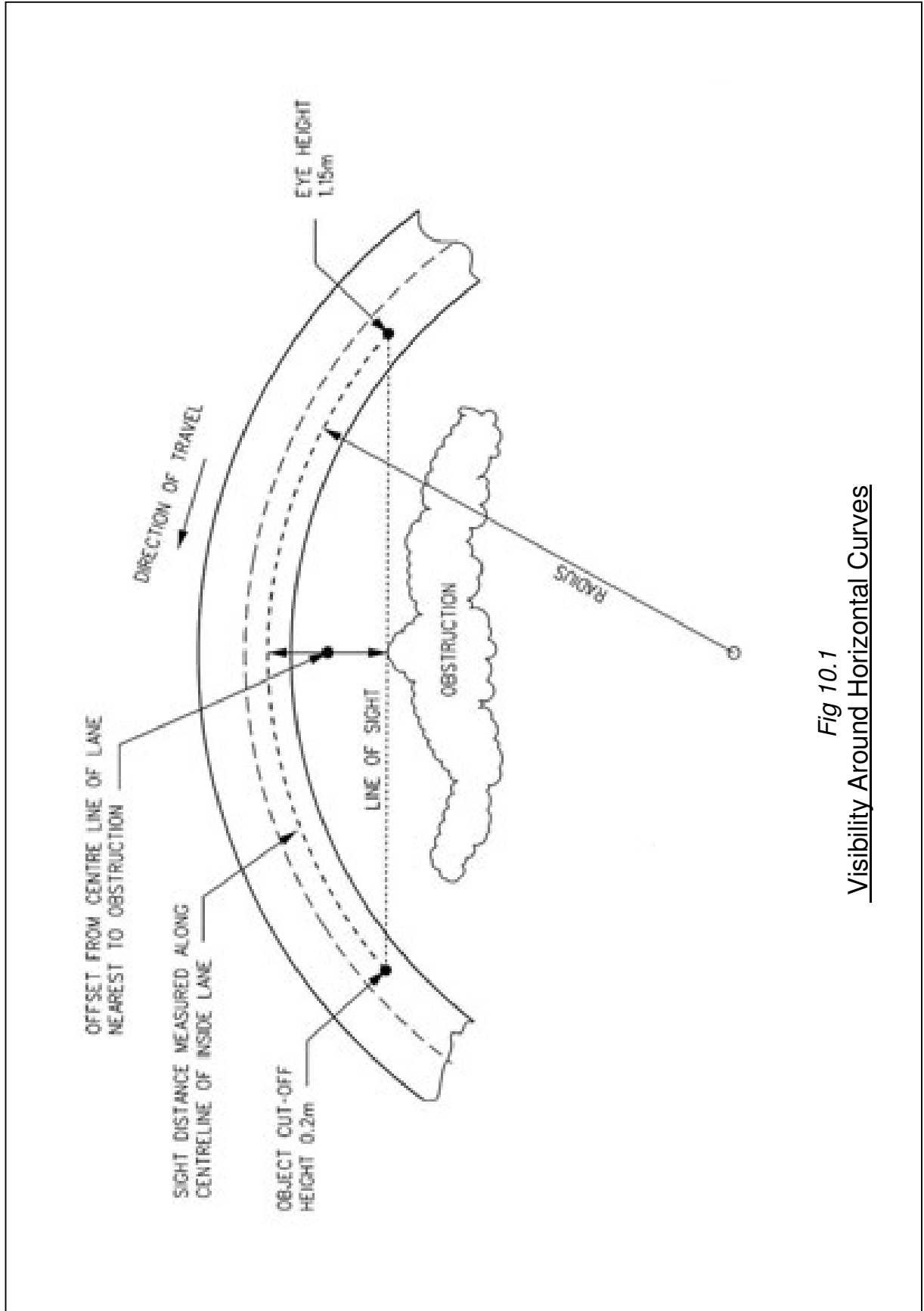
Fig 10.1
Visibility Around Horizontal Curves

Fig 10.2
<u>Sight Triangle</u>

DISD - DESIRABLE INTERSECTION SIGHT DISTANCE
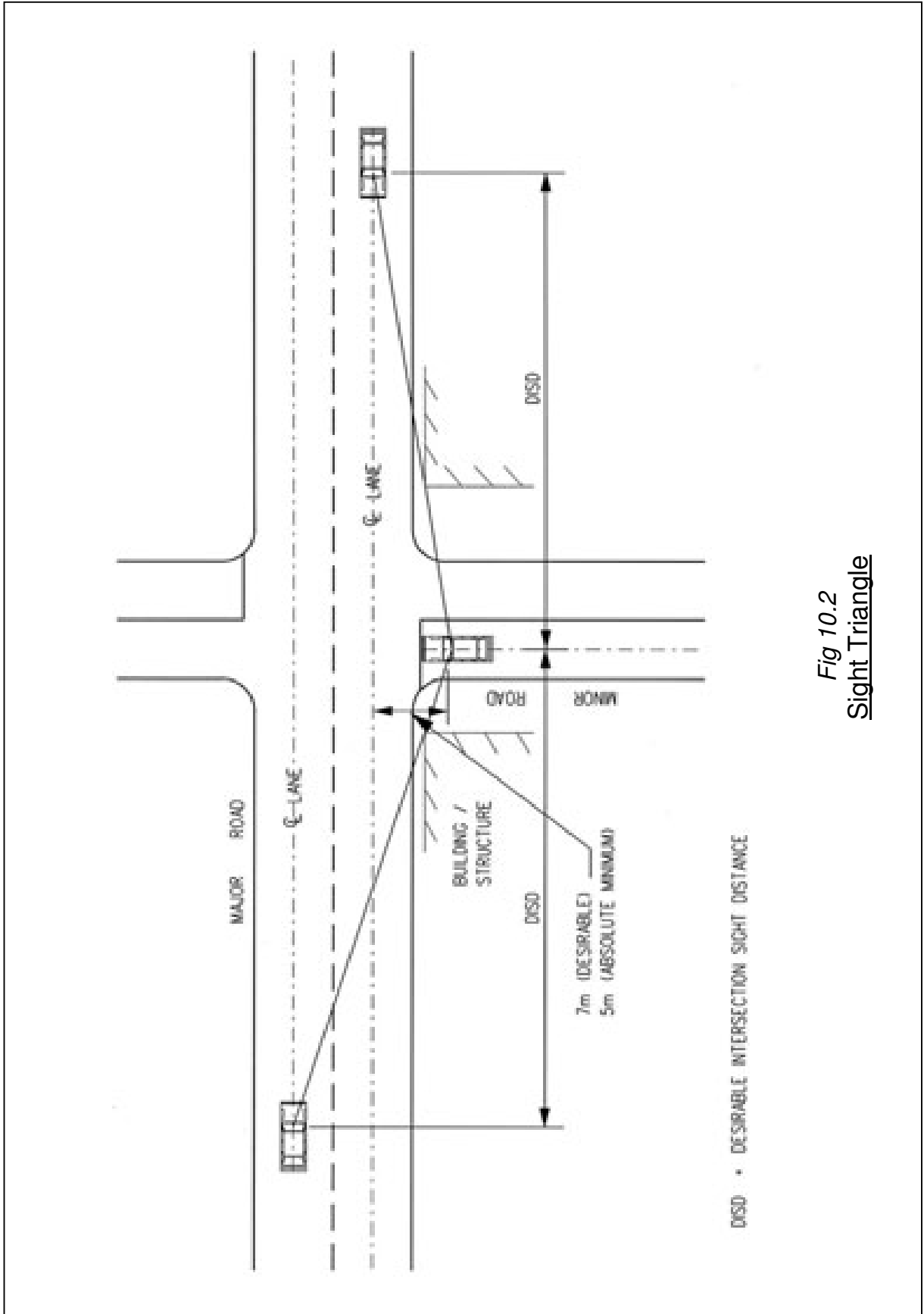
CREST VERTICAL CURVE
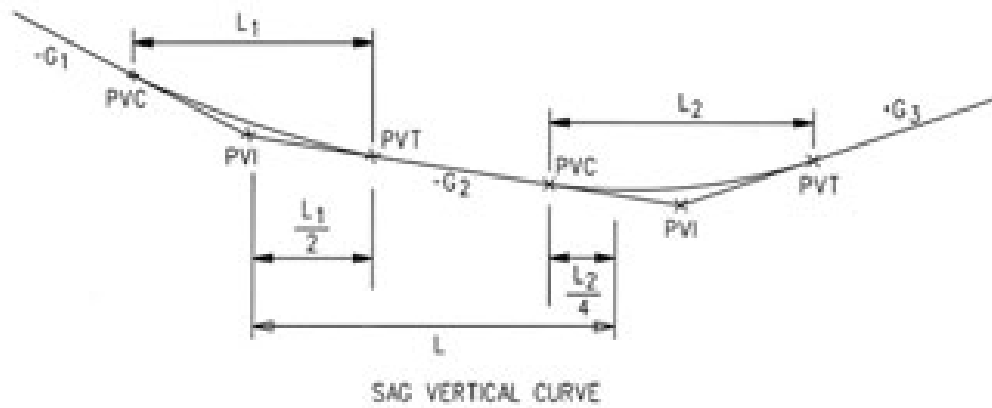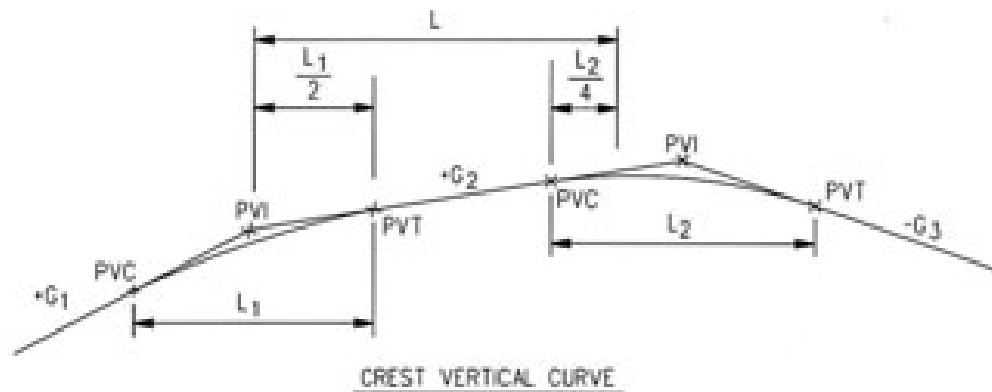
SAG VERTICAL CURVE

LEGEND

L : CRITICAL LENGTH OF GRADE
$L_1 L_2$: VERTICAL CURVE LENGTH
PVC : POINT OF VERTICAL CURVE
PVI : POINT OF VERTICAL INTERSECTION
PVT : POINT OF VERTICAL TANGENT
G : GRADIENT

NOTES :

1. FOR VERTICAL CURVES WHERE THE TWO TANGENT GRADES ARE IN THE SAME DIRECTION (BOTH UPGRADES OR BOTH DOWNGRADES), 50% OF THE CURVE LENGTH WILL BE PART OF THE LENGTH OF GRADES.

2. FOR VERTICAL CURVES WHERE THE TWO TANGENT GRADES ARE IN THE OPPOSITE DIRECTIONS (ONE GRADE UP AND ONE GRADE DOWN), 25% OF THE CURVE LENGTH WILL BE PART OF THE LENGTH OF GRADES.

3. THE ABOVE DIAGRAM IS INCLUDED FOR ILLUSTRATIVE PURPOSE ONLY. BROKEN BACK CURVES ARE TO BE AVOIDED WHENEVER PRACTICAL.

Fig 10.3
Measurement for Critical Length of Grade

Fig 10.4

Crest Vertical Curve Length for Stopping Sight Distance

SCALE 1 : 200 (Vertical)
SCALE 1 : 5000(Horizontal)

L : VERTICAL CURVE LENGTH (m)
V : DESIGN SPEED (km/h)
S : STOPPING SIGHT DISTANCE (m)
K : L/A
A : ALGEBRAIC GRADE DIFFERENCE (%)

Notes :

1) The following table is to be used for level road or where road gradient is less than 2%.
2) For road gradient more than 2% (up-grade or down-grade),
the information can be derived from the formula.

Fig 10.5
Sag Vertical Curve Length for Riding Comfort

SCALE 1 : 150 (Vertical)
SCALE 1 : 1500 (Horizontal)

L : VERTICAL CURVE LENGTH (m)
V : DESIGN SPEED (km/h)
A : ALGEBRAIC GRADE DIFFERENCE (%)

Fig 10.6

Sag Vertical Curve Length for Headlight Sight Distance

SCALE 1 : 150 (Vertical)
SCALE 1 : 3750 (Horizontal)

L : VERTICAL CURVE LENGTH (m)
V : DESIGN SPEED (km/h)
S : STOPPING SIGHT DISTANCE (m)
K : L/A
A : ALGEBRAIC GRADE DIFFERENCE (%)

Notes :

1) The following table is to be used for level road or where road gradient less than 2%.

2) For road gradient more than 2% (upgrade or down-grade),
the information can be derived from the formula.

Fig 10.7
Type of Curves

Fig 10.8
Superelevation and Radius of Horizontal Curve
SCALE 1 : 200 (Vertical)
SCALE 1 : 2500 (Horizontal)

PLAN VIEW

LONGITUDINAL SECTION

PI	POINT OF INTERSECTION OF THE MAIN TANGENTS
TS	TANGENT TO SPIRAL - COMMON POINT OF TANGENT AND SPIRAL
SLe	START OF SUPERELEVATION DEVELOPMENT
SC	SPIRAL TO CURVE - COMMON POINT OF SPIRAL AND CIRCULAR CURVE
Lp	LENGTH OF SPIRAL, TS TO SC (m)
Le	LENGTH OF SUPERELEVATION DEVELOPMENT (m)
n	NORMAL PAVEMENT CROSSFALL (%)
e	PAVEMENT SUPERELEVATION (%)

Fig 10.9
Development of Superelevation

Fig 10.10
Turning Lane Layout

MINIMUM TAPER LENGTH = 30m

MINIMUM STORAGE LENGTH = 70m

3.2m (DESIRABLE)
3.0m (ABSOLUTE MINIMUM)

1.3m (DESIRABLE)
1.0m (ABSOLUTE MINIMUM)
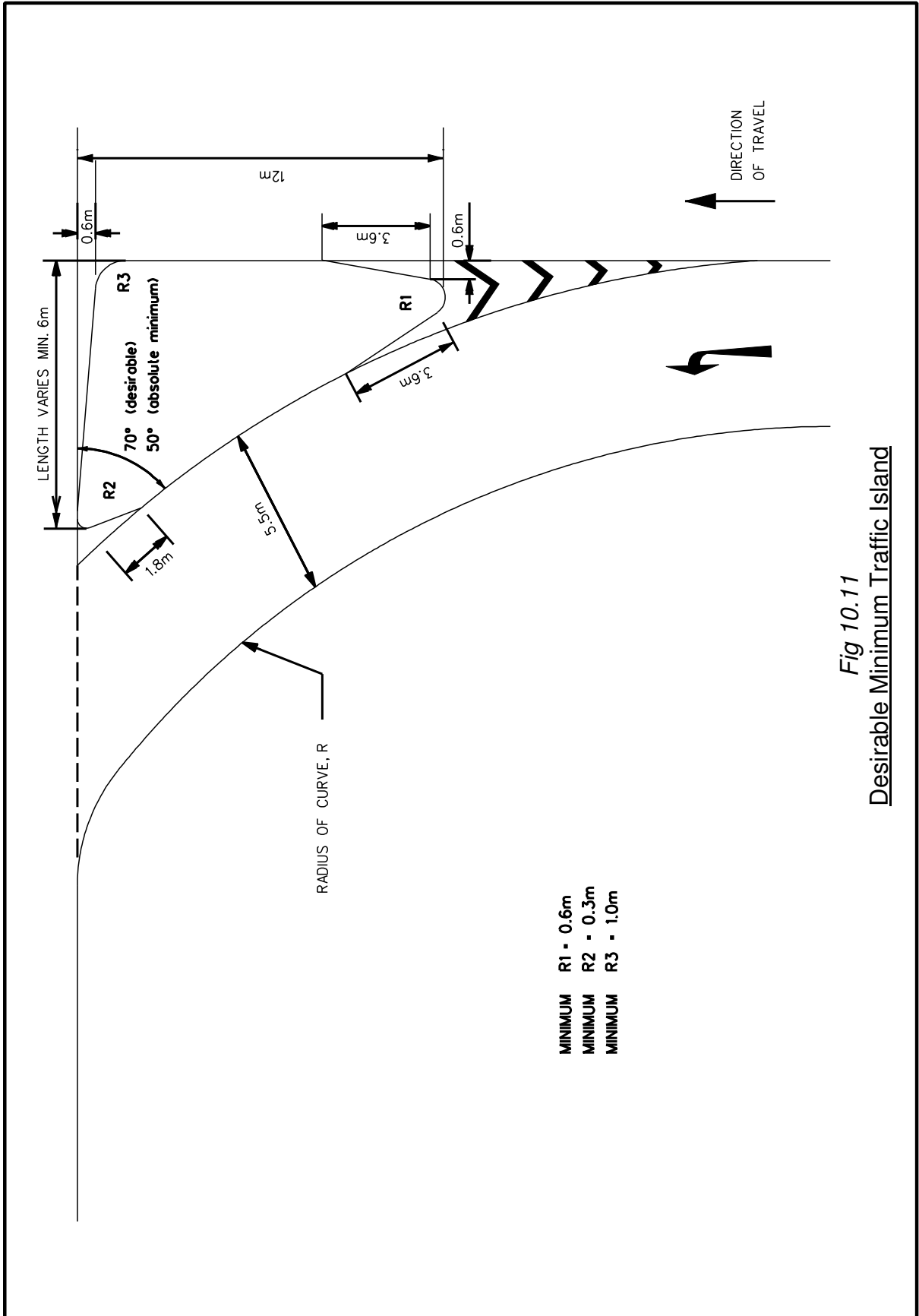
Fig 10.11
Desirable Minimum Traffic Island

DIRECTION OF TRAVEL

LENGTH VARIES MIN. 6m

70° (desirable)
50° (absolute minimum)

RADIUS OF CURVE, R

R1
R2
R3

0.6m
12m
3.6m
0.6m
3.6m
5.5m
1.8m

MINIMUM   R1 = 0.6m
MINIMUM   R2 = 0.3m
MINIMUM   R3 = 1.0m
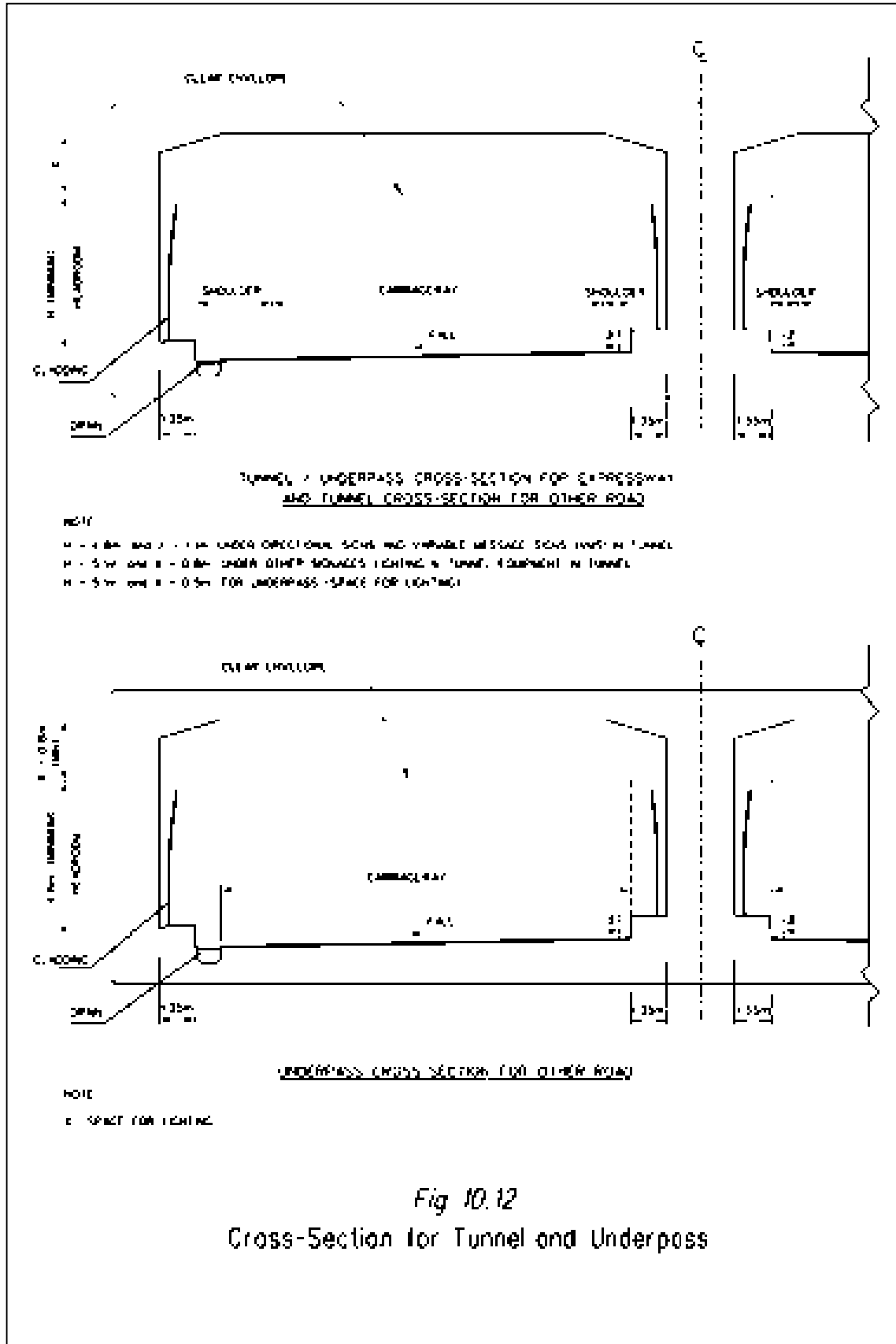
Fig 10.12
Cross-Section for Tunnel and Underpass

(a) AT PEDESTRIAN OVERHEAD BRIDGES

(b) AT ZEBRA PEDESTRIAN CROSSING OR SIGNALISED PEDESTRIAN CROSSING

(c) ALONG TWO WAY UNDIVIDED ROAD
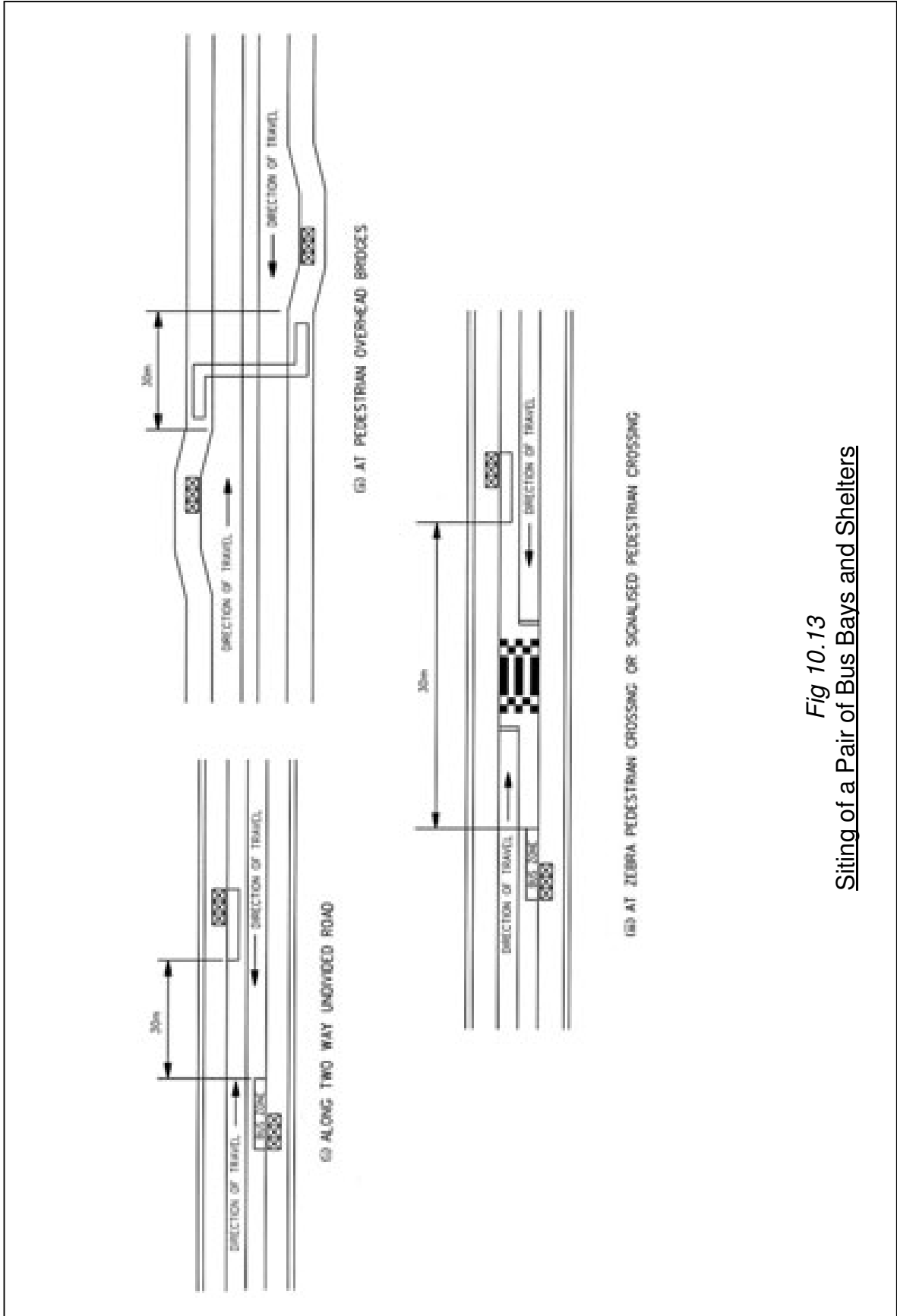
Fig 10.13
Siting of a Pair of Bus Bays and Shelters
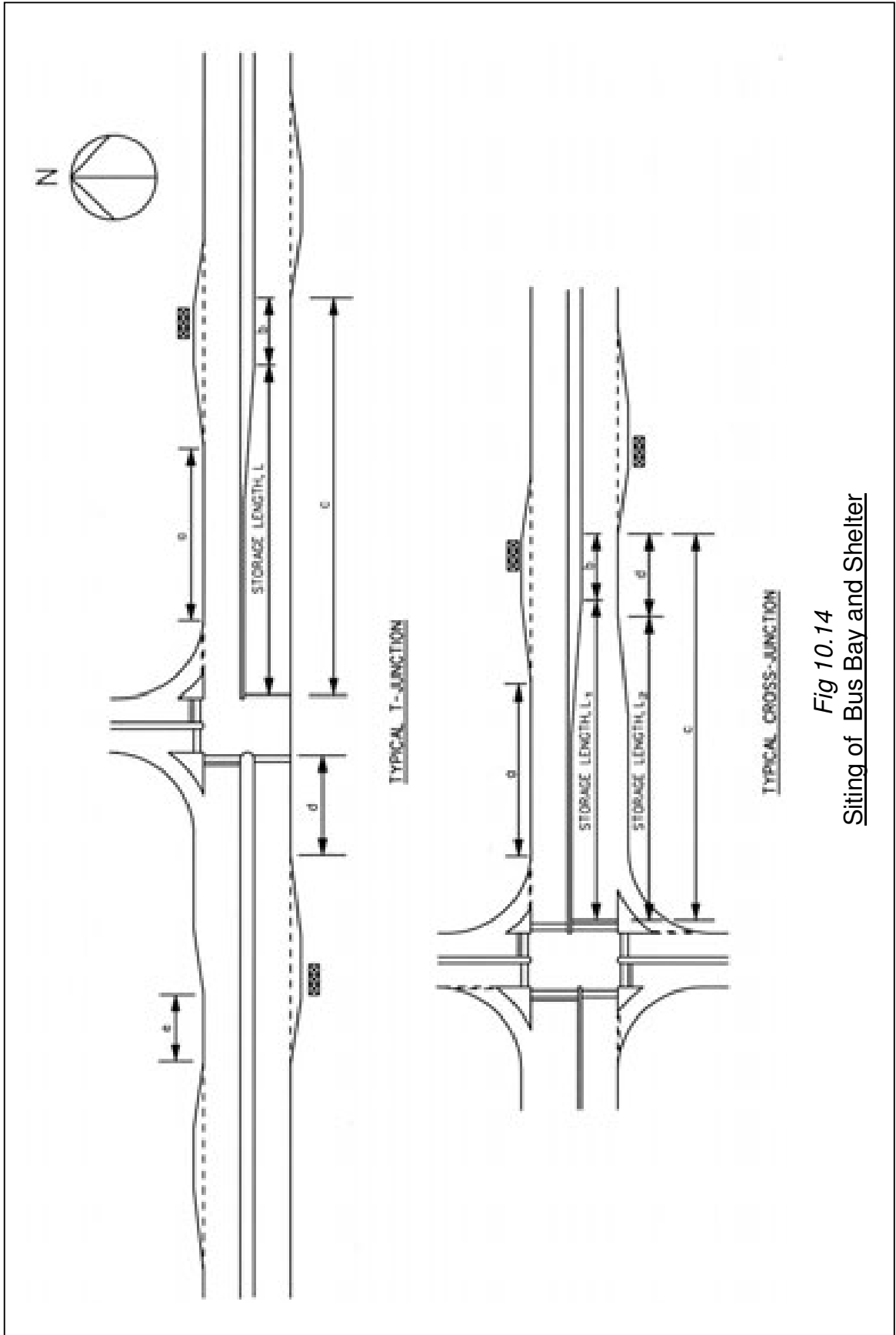
Fig 10.14
Siting of Bus Bay and Shelter

Fig 10.14.1

GUIDELINE FOR SITING OF BUS BAY ADJACENT TO T-JUNCTION

A typical T-junction layout and the dimension indicated in the table below is shown in the Figure 10.14.

Assumptions made for this guideline:
1. The road is a divided carriageway.
2. No site constraint.

Scenario	Minimum Dimension in metre					Remarks
	a^1	b	c^2	d^1	e	
Case 1 : Bus Routes in all directions :						
1) Bus bay provided :						
a) weave thru 2 lanes	30	25	80	30	20	Yellow box across the carriageway to be provided. See Note 3.
b) weave thru 3 lanes	30	25	120	30	20	Yellow box across min. 1-lane of the carriageway to be provided. See Note 3.
c) weave thru 4 lanes	30	25	160	30	20	Yellow box across min. 2-lanes of the carriageway to be provided. See Note 3.
2) Without bus bay :						
a) weave thru 2 lanes	50	25	40	50	20	See Note 3.
b) weave thru 3 lanes	50	25	80	50	20	See Note 3.
c) weave thru 4 lanes	50	25	120	50	20	See Note 3.

Note:

1 If the bus volume at the bus bay is high (exceed 120 buses/hr), double tier or higher capacity bus bay is required. LTA's Bus & Taxi Regulation Dept and Traffic Management will need to be consulted for dimension of a & d.

2 For dimension of c, c refers to the minimum weaving distance for right turning buses.

3 In the Westbound (WB) direction, the location of bus bay before the junction should be c or (L+b) whichever is greater.

GUIDELINE FOR SITING OF BUS BAY ADJACENT TO T-JUNCTION

A typical T-junction layout and the dimension indicated in the table below is shown in the Figure 10.14.

Assumptions made for this guideline :

1. The road is a divided carriageway.
2. No site constraint.

Case 3 : Bus Routes with no right turning at junction :

Scenario	Minimum Dimension in metre					Remarks
	a'	b	c	d'	e	
1) Bus bay provided :						
a) weave thru 2 lanes	30	0	30	30	20	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
b) weave thru 3 lanes	30	0	30	30	20	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
c) weave thru 4 lanes	30	0	30	30	20	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
2) Without bus bay :						
a) weave thru 2 lanes	50	0	40	50	20	See Note 2.
b) weave thru 3 lanes	50	0	40	50	20	See Note 2.
c) weave thru 4 lanes	50	0	40	50	20	See Note 2.

Notes:

1. If the bus volume at the bus bay is high (exceed 125 buses/hr), double tier or higher capacity bus bay is required. LTA's Bus & Taxi Regulation Dept and Traffic Management will need to be consulted for dimension of a & d.

2. LTA's Bus & Taxi Regulation Dept will need to be consulted and the Authority must agreed that there is no future bus route turning right in the Westbound direction.

Fig 10.14.2

Fig 10.14.3

GUIDELINE FOR SITING OF BUS BAY ADJACENT TO CROSS-JUNCTION

A typical Cross-junction layout and the direction indicated in the table below is shown in the Figure 10.14.

Assumptions made for this guideline:
1. The road is a divided carriageway.
2. No side constraint.

Scenario	Minimum Dimension in metre				Remarks
	a^{1}	b	c^{2}	d	
Case 1 : Bus Routes in all directions :					
1) Bus bay provided :					
a) weave thru 2 lanes	20	25	80	20	Yellow box across the carriageway to be provided. See Note 3.
b) weave thru 3 lanes	30	25	120	20	Yellow box across min. 1-lane of the carriageway to be provided. See Note 3.
c) weave thru 4 lanes	30	25	160	20	Yellow box across min. 2-lanes of the carriageway to be provided. See Note 3.
2) Without bus bay :					
a) weave thru 2 lanes	50	25	40	20	See Note 3.
b) weave thru 3 lanes	50	25	80	20	See Note 3.
c) weave thru 4 lanes	50	25	120	20	See Note 3.

Note:

1. If the bus volume at the bus bay is high (exceed 120 buses/hr), double tier or higher capacity bus bay is required. LTA's Bus & Taxi Regulation Dept and Traffic Management will need to be consulted for dimension of a & d.
2. For dimension of c, it refers to the minimum weaving distance for right turning buses.
3. In the Westbound (WB) direction, the location of bus-stop before the junction should be c or (L_a+b) or (L_b+d) whichever is greater.
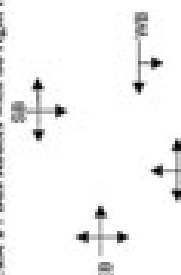
Fig 10.14.4

GUIDELINE FOR SITING OF BUS BAY ADJACENT TO CROSS-JUNCTION

A typical Cross-junction layout and the dimension indicated in the table below is shown in the Figure 10.14.

Assumptions made for this guideline:

1. The road is a divided carriageway.
2. No site constraint.

Case 2 : Bus Routes with no right turning at junction :

Scenario	Minimum Dimension in metre				Remarks
	a'	b	c	d	
1) Bus bay provided :					
a) reserve thru 2 lanes	50	0	$L_0 + d$	30	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
b) reserve thru 3 lanes	50	0	$L_0 + d$	30	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
c) reserve thru 4 lanes	50	0	$L_0 + d$	30	Yellow box across 1-lane of the carriageway to be provided. See Note 2.
2) Without bus bay :					
a) reserve thru 2 lanes	50	0	$L_0 + d$	30	See Note 2.
b) reserve thru 3 lanes	50	0	$L_0 + d$	30	See Note 2.
c) reserve thru 4 lanes	50	0	$L_0 + d$	30	See Note 2.

Note:

1. If the bus volume of the bus bay is high (exceed 120 buses/hr), double tier or higher capacity bus bay is required. LTA's Bus & Taxi Regulation Dept and Traffic Management will need to be consulted for dimension of a & d.

2. LTA's Bus & Taxi Regulation Dept will need to be consulted and the Authority must approved that there is no future bus route turning right in the Westbound direction.

DESIGN SPEED OF ROAD ON THE MAIN CARRIAGEWAY (km/h)	MINIMUM LENGTH OF ACCELERATION LANE, L									
	DESIGN SPEED OF ENTRANCE RAMP (km/h)									
	50	60	50	60	50	60	50	60	50	60
			UPGRADE				DOWNGRADE			
	G ≤ 2%		3% to 4%		5% to 6%		3% to 4%		5% to 6%	
70	65	-	95	-	104	-	45	-	40	-
80	115	90	175	100	200	125	90	90	90	90
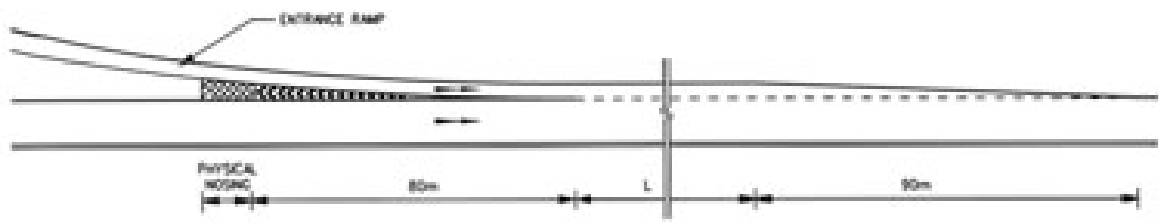
TYPICAL ACCELERATION LANE

DESIGN SPEED OF ROAD ON THE MAIN CARRIAGEWAY (km/h)	MINIMUM LENGTH OF DECELERATION LANE, L									
	DESIGN SPEED OF EXIT RAMP (km/h)									
	50	60	50	60	50	60	50	60	50	60
			UPGRADE				DOWNGRADE			
	G ≤ 2%		3% to 4%		5% to 6%		3% to 4%		5% to 6%	
70	70	55	65	50	60	45	85	70	95	75
80	90	80	85	75	75	65	110	100	125	110
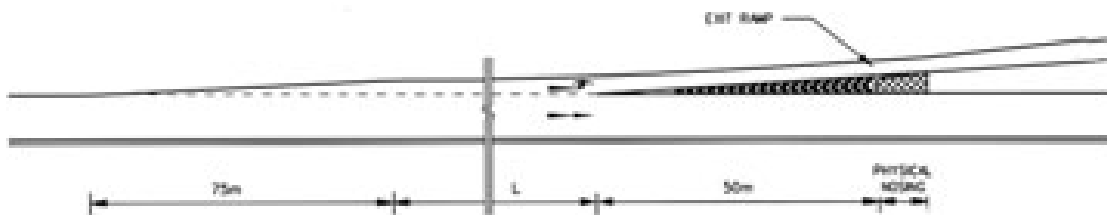
TYPICAL DECELERATION LANE

Fig 10.15
Acceleration and Deceleration Lane for Major Arterial Road
and Semi-Expressway
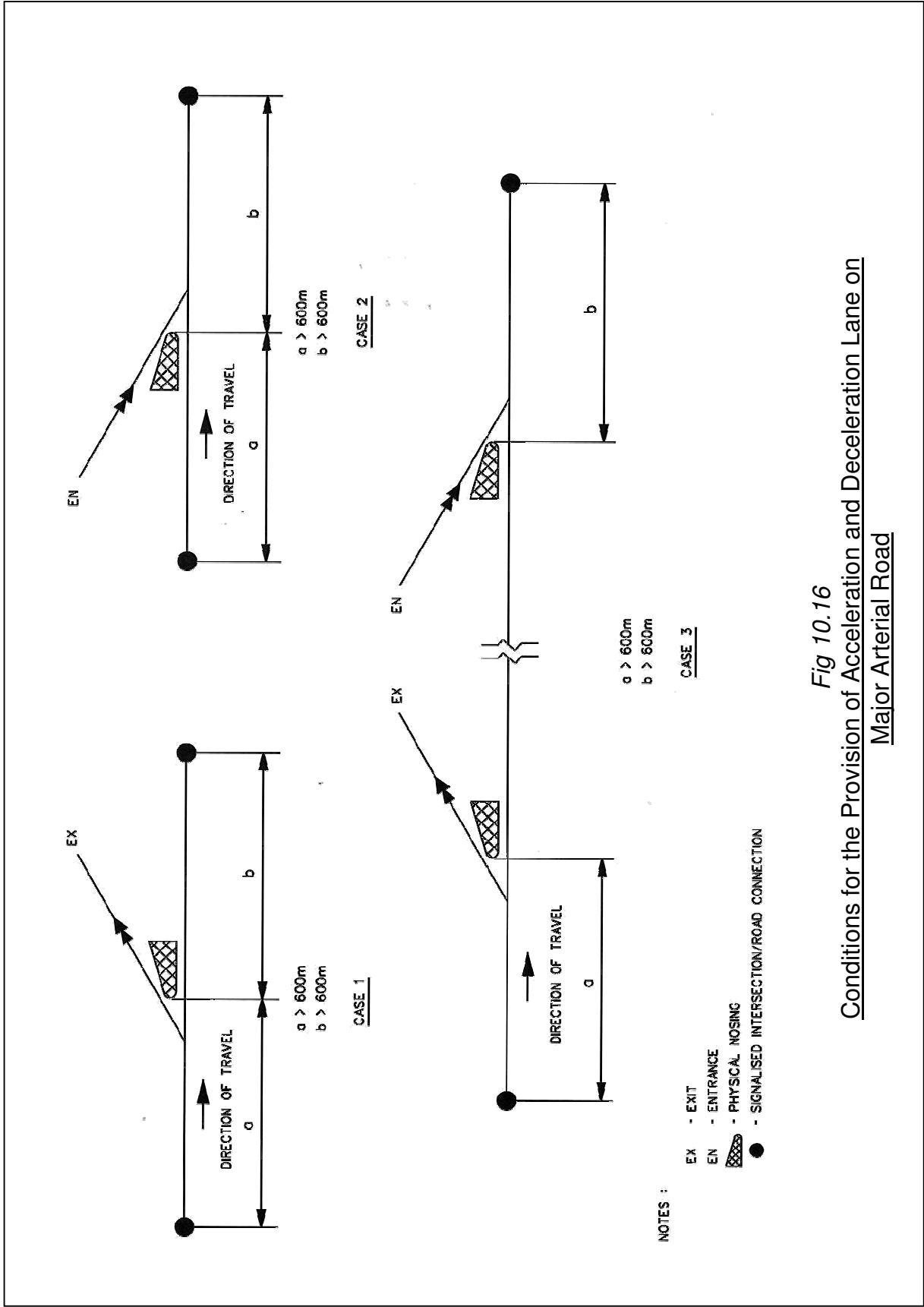
Fig 10.16
Conditions for the Provision of Acceleration and Deceleration Lane on Major Arterial Road

Min. Length of taper & Deceleration Lane for Visibility, L	EXPRESSWAY	OTHER ROADS
	400m	150m

NOTES :

Shoulder Provision for Expressway only
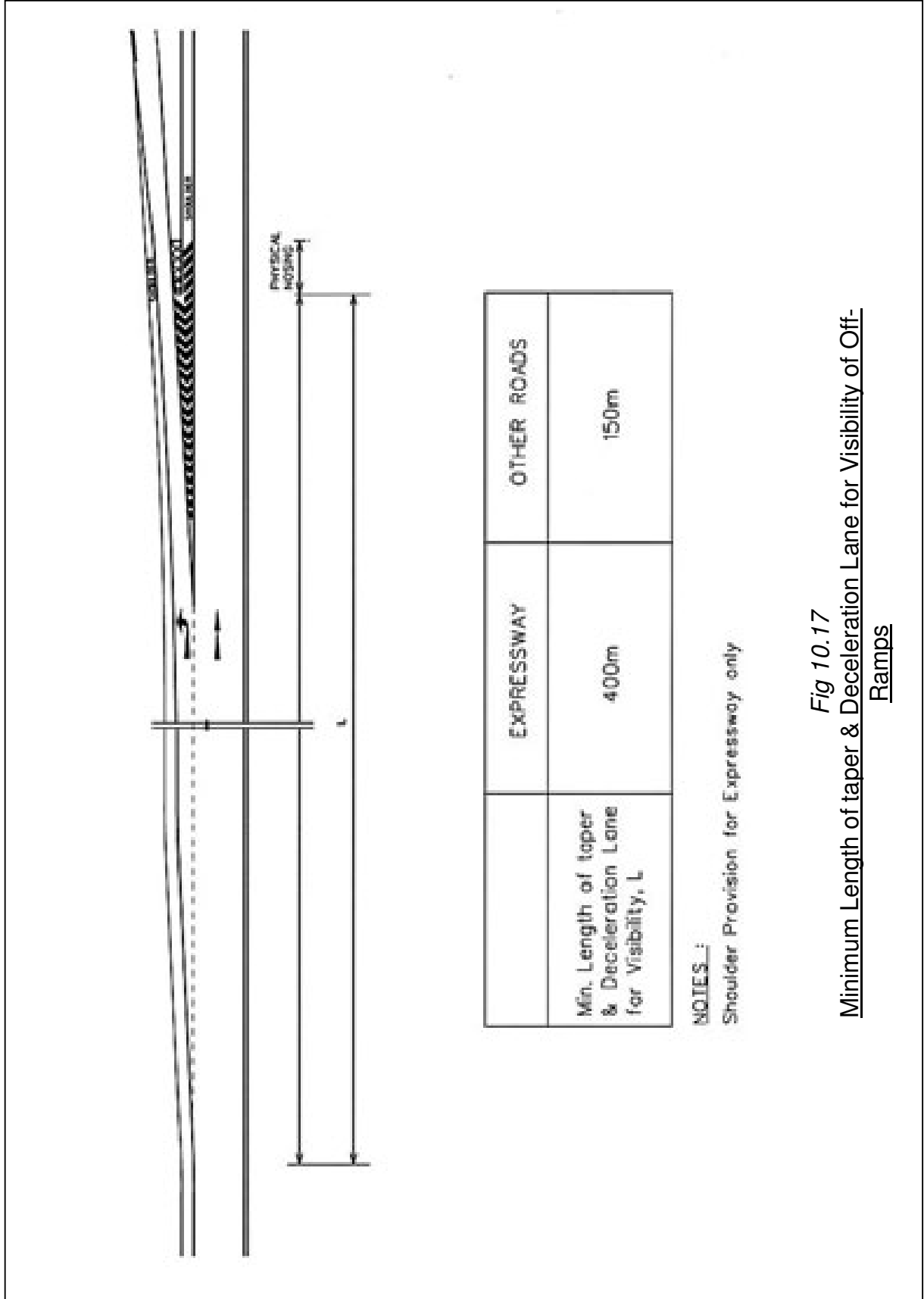
Fig 10.17
Minimum Length of taper & Deceleration Lane for Visibility of Off-Ramps

MINIMUM DESIRABLE LENGTH BETWEEN SUCCESSIVE RAMPS
MEASURED FROM END OF PHYSICAL NOSES (L)

550m	410m	550m	50m

NOTES :

EN - ENTRANCE
EX - EXIT
▨ - PHYSICAL NOSING
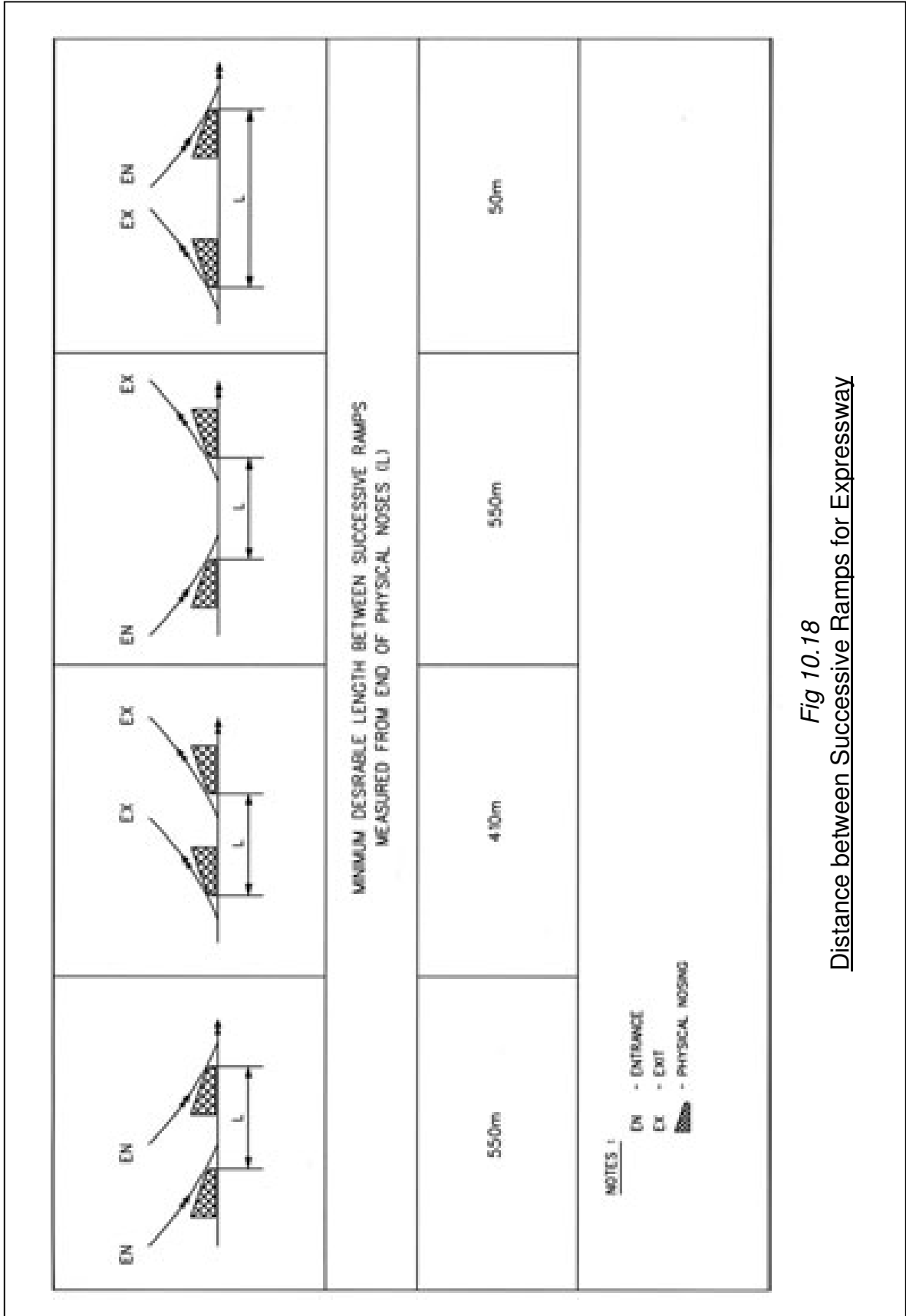
Fig 10.18
Distance between Successive Ramps for Expressway
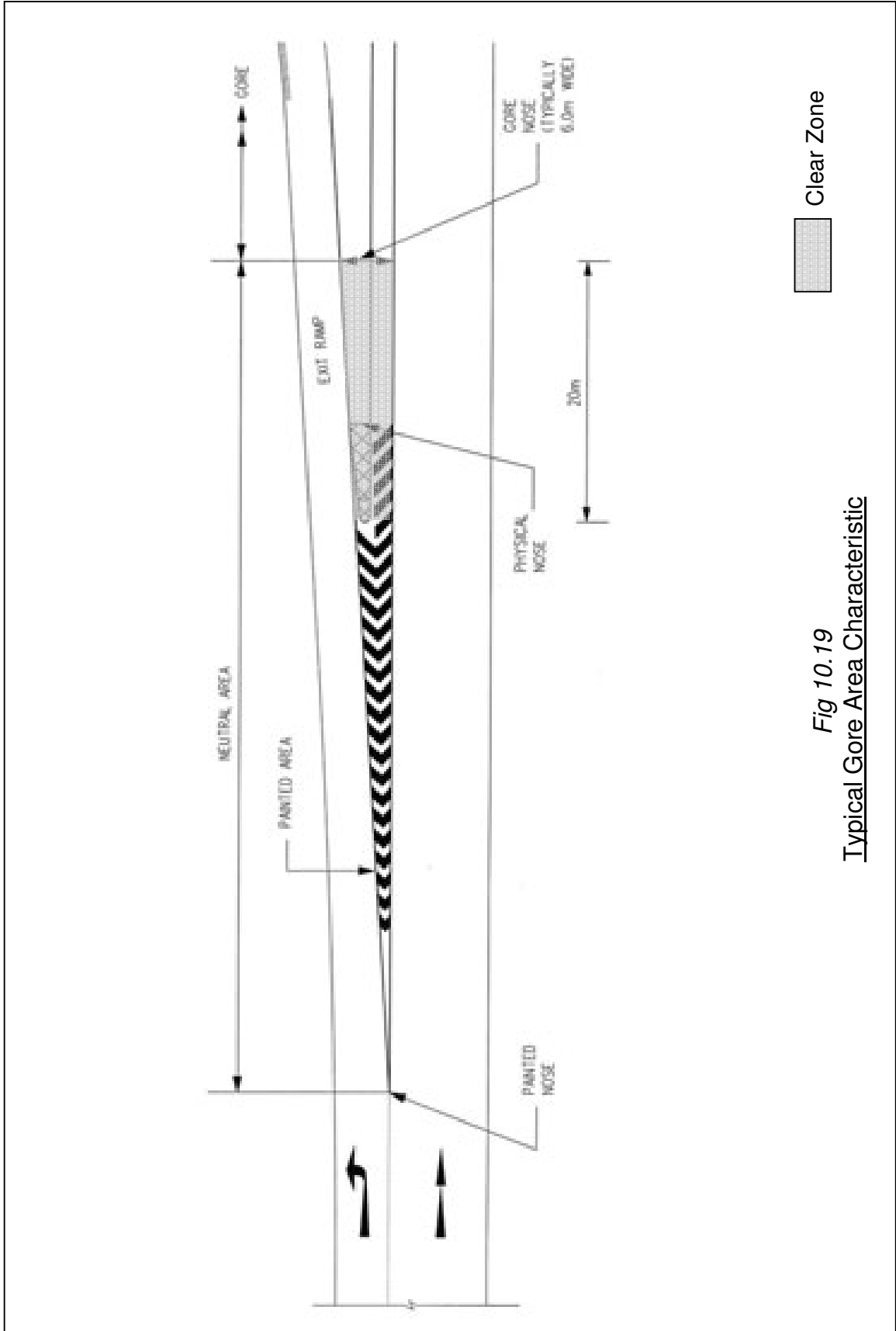
Fig 10.19
Typical Gore Area Characteristic

Clear Zone
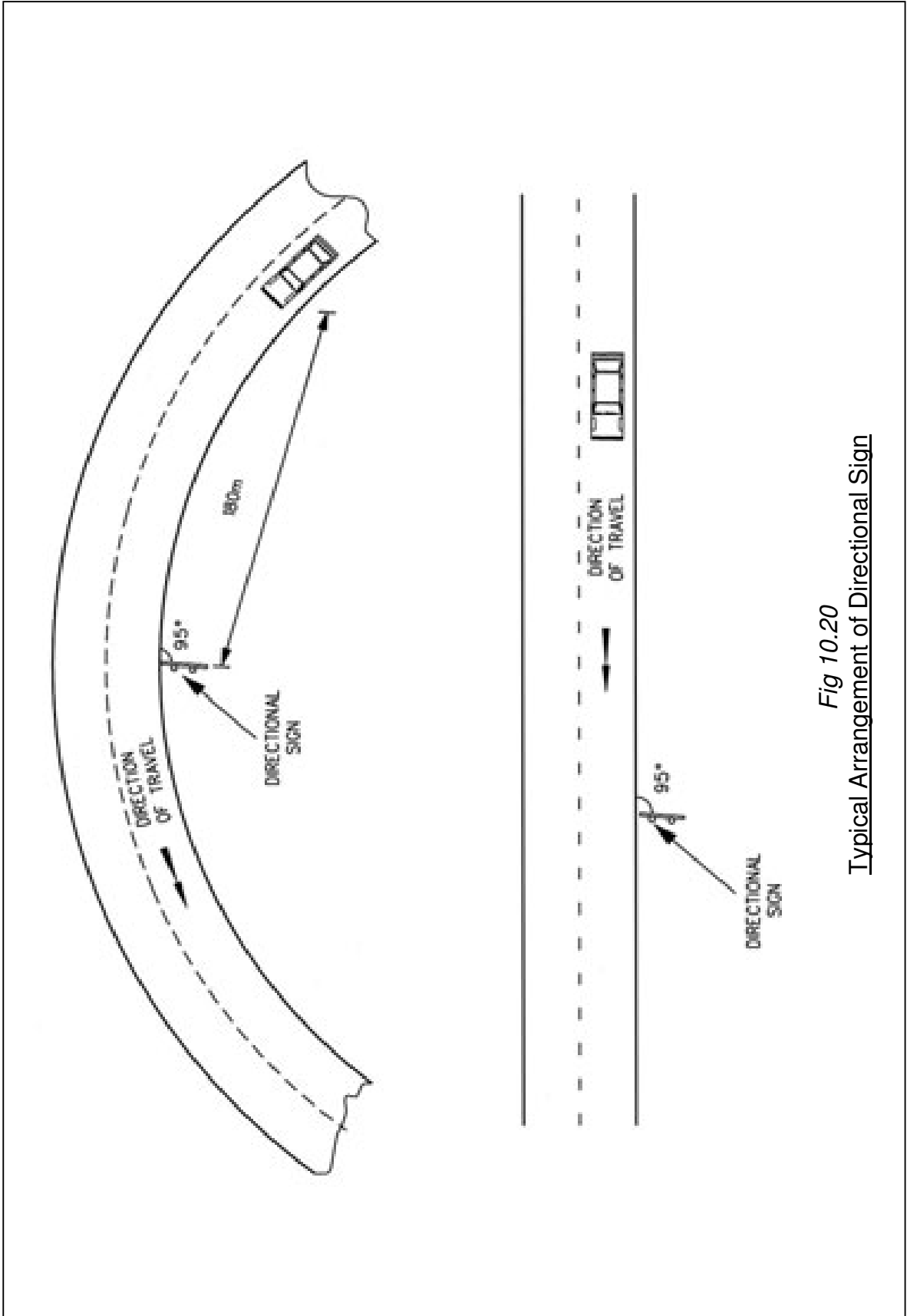
Fig 10.20
Typical Arrangement of Directional Sign

Blue background
White

CTE (SLE)
AYE (ECP)   **Normanton Park**
                  AYE (Tuas)

Blue background
White

CTE (SLE)
AYE (ECP)   **Normanton Park**
                  AYE (Tuas)
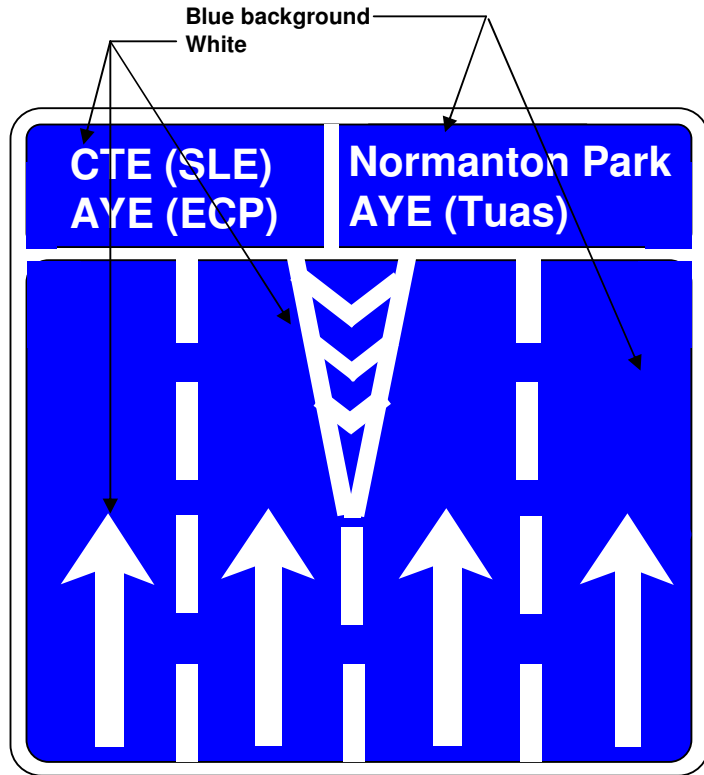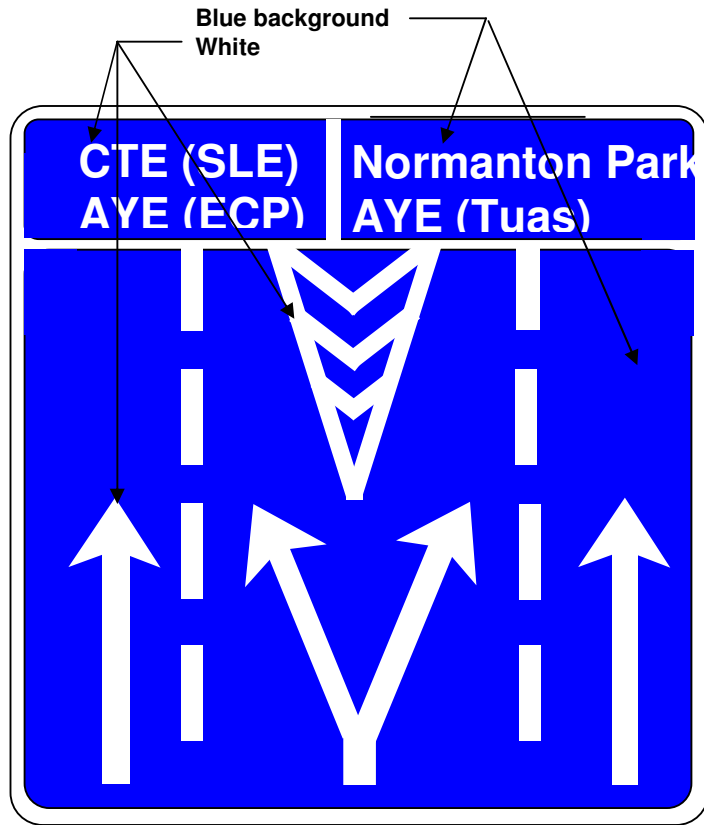
Fig 10.21
Lane Indication Signs

CHAPTER 11

STATION AND TUNNEL SERVICES FOR RAIL PROJECTS

11.1 GENERAL REQUIREMENTS

11.1.1 Standards, Codes and Regulations

The design of Station and Tunnel Services for Rail Projects shall be governed by all latest applicable local codes, regulations, standards and requirements issued by all the applicable local authorities and statutory boards including: -

(1) Public Utilities Board (PUB)

(2) Fire Safety and Shelter Department (FSSD)

(3) Productivity and Standards Board (PSB)

(4) Land Transport Authority (LTA)

(5) Building Control Authority (BCA)

11.1.2 Routing of Pipework and Services

Pipework shall comply with the requirements for water and electrical equipment in CDC Chapter 13, E&M Interface. Pipework, services and fittings shall be routed so as to accommodate future maintenance. As far as practicable, they shall not be located above escalators, tracks or voids.

11.2 DRAINAGE

11.2.1 General

11.2.1.1 All internal surfaces of structures shall be positively drained via channels, drains etc., either by gravity to existing storm water drainage or to wet sumps from where water shall be pumped to the storm water drainage to the approval of the appropriate local authorities and statutory boards and to the acceptance of the Engineer.

11.2.1.2 Separate drainage systems shall be provided for each of the following: -

(1) Tunnel Drainage

This system shall deal with water originating from:

- ground water seepage
- tunnel washing
- testing and emptying of the fire mains

- condensate from train air-conditioning
- rain water blown into the tunnel or brought into tunnel by rolling stock.

(2) Station Drainage

This system shall deal with water originating from:

- ground water seepage
- tunnel washing
- testing and emptying of the fire mains
- condensate from train air-conditioning
- condensate from ECS associated plants
- water tank overflow and drainage
- all clean water in the station
- all clean water brought into station

(3) Storm Water Drainage

This system shall deal with all rainwater falling on the station roofs and external areas to be directed into the existing storm water drainage system.

11.2.2 Tunnel Drainage

11.2.2.1 Seepage

Drainage design shall be based on permitted seepage values given in CDC Chapter 7, Bored Tunnels & Related Works. All water shall be directed so that the rails and rail fixings remain dry.

11.2.2.2 Tunnel Washing

The maximum discharge rate of 10,800 litres/hr of the tunnel washing wagon shall be allowed for in the design of the tunnel sump and pump.

11.2.2.3 Fire Main

The volume of water discharged during testing and emptying of the fire main shall be determined in co-ordination with the System-wide Contractor and allowed for in the design of the tunnel pump sump.

11.2.2.4 Condensate from Train Air-Conditioning

Condensate from moving trains may be assumed to be evaporated.

11.2.2.5   Tunnel Pump Sump

11.2.2.5.1   Location

A pump sump shall be located at every low point within each running tunnel. If the pump sump location coincides with a cross passage, then only one pump sump shall be provided and it shall be located in the cross passage.

11.2.2.5.2 Details

Provisions and layout of the pump sump shall follow that for the station as described in Clause 11.2.4.

The discharge pipes from the tunnel sump pumps shall be routed directly to the surface drains via the nearest station, vent shaft, escape shaft or service shaft/duct. The water shall not be discharged to another drainage pumping system within the Works. Swan necks shall be provided at the appropriate locations. Flap valves shall be provided at the discharge ends. Discharge pipe shall have a minimum diameter of 80mm. Velocity of water in discharge pipes shall be between 1m/s and 2.4m/s to ensure self cleansing and prevent scouring.

Tunnel drainage sumps shall be monitored at the nearest station.

11.2.2.5.3 Design and Construction

The design of the tunnel sumps and the pumps shall be in accordance with Clause 11.2.5.

The structural design of sumps shall comply to requirements in CDC Chapter 7, Bored Tunnels & Related Works and CDC Chapter 8, Underground Structures with the sumps regarded as an underground structure.

11.2.3   Station Drainage

General requirements are summarised in Table 11.1. All outlets shall be discharged to the drainage system unless stated otherwise in the specifications. The Drainage System shall incorporate these requirements and shall be designed in accordance with Clause 11.2.5. Design of Station Drainage systems shall comply with all requirements that may be imposed by the PUB.

TABLE 11.1

DRAINAGE SYSTEM PROVISION IN STATIONS

Room/Area	Requirement	Remarks
1. Seepage channel	Floor wastes at 10m max. interval	See Clause 11.2.3.1.
2. Escalator pit	Floor waste	See Clause 11.2.3.3
3. Vent Shaft/Duct	Floor waste	See Clause 11.2.3.4
4. Underplatform Areas	Channels, floor wastes	See Clause 11.2.3.7
5. All ECS associated Plant Rooms	Floor wastes	Adjacent to AHU for condensation water. See Clause 11.2.3.8
6. Lift pit	Sump	See Clause 11.2.3.9
7. Entrance stair	Floor waste per entrance	See Clause 11.2.3.10
8. Cable Trench, Valve Chamber & Maintenance Pits*	Floor waste	See Clause 11.2.3.11
9. All water tank/pump room	One sump with floor waste	For draining of tank water and overflow. See Clause 11.2.3.5
10. Adjacent to hosereel	One floor waste	For accidental spillage of water or fire fighting water. Drainage via seepage channel outlets is not allowed.
11. All enclosed staircases (at lowest landing)	One floor waste	For accidental spillage of water or fire fighting water.
12. Elevated and exposed platforms (elevated station)	Two parallel channels run along the track direction for each platform, with appropriate connection to the drainage system.	For rain water blown onto the platform plus washing water.
13. Planter in station	(a) Floor waste	Hydroponic planting discharge via a silt trap.
	(b) Surface drain	For ordinary planter.

* These are civil defence facilities in CD stations.

11.2.3.1   Seepage

11.2.3.1.1   Seepage drainage channels shall be provided at the floor level along the internal sides of all earth-backed external walls. A drainage channel of 100 mm diameter shall be formed and laid to fall to not less than 1 in 200. Discharge outlets (floor waste) of not less than 100 mm diameter shall be situated at not more than 10m centres.

11.2.3.1.2   Seepage drainage channels shall be lined with a suitable waterproofing membrane. Drainage channels, weepholes and outlets shall not pass through fire rated compartment wall.

11.2.3.1.3   Seepage drainage channels in floor finishes shall be at least 35 mm deep. A cavity of limited height shall be constructed to contain the drainage at the bottom of the wall if sufficient depth is not available in any floor finishes.

11.2.3.2   Cavity Walls

11.2.3.2.1   For the purpose of establishing cavity wall requirements are categorised as described below, and as listed in Table 11.2. For any rooms not listed therein, proposals shall be submitted and agreed with the Engineer. Where required in any given rooms/areas, cavity walls need to be provided only along the external walls.

(1) Category I

Generally, these are rooms/areas containing sensitive E&M equipment requiring extra protection from damp and moisture. Full height cavity walls shall be provided.

In addition, in rooms/areas that are accessible to the public, full height cavity walls shall also be provided to protect the architectural finishes from seepage water.

(2) Category II

Category II electrical rooms that contain moisture sensitive equipment abutting the diaphragm wall shall require full height cavity walls. The non-electrical Category II rooms will not require immediate need for cavity walls but which requires provision for installation of such walls in the future. Ample space shall be provided in these rooms/areas for future cavity wall construction and the sizing of the rooms shall take this into account. All services/equipment mounted onto the earth backed wall in such rooms/areas shall be designed such that it can be easily removed and mounted onto a cavity wall should the need arise. Ceiling services shall also be such that it will not obstruct the future construction of the cavity wall.

(3) Category III

Cavity wall is not required.

11.2.3.2.2   For full height cavity walls, it shall be constructed as an inner lining with a seepage drainage channel confined to inside the cavity. Access panels of minimum 600mm x 600mm size placed at intervals not exceeding 10 metres shall be provided on the cavity walls to permit inspection and maintenance of the drainage system. The actual position shall be coordinated and located near a floor waste.

TABLE 11.2
GUIDELINE FOR CAVITY WALL ROOM CATEGORISATION

CATEGORY I
1.   Local Sequential Control (LSC) Room
2.   Main Distribution Frame (MDF) Room
3.   Communication Equipment / Integrated Supervisory Control System (CE/ISCS) Room
4.   Coaxial Distribution Room (CDR)
5.   Signal Equipment (SE) Room
6.   Passenger Services Centre (PSC) / Maintenance Sub-Centre
7.   Telecommunications Equipment Room (TER)
8.   Store, Office and Staff Toilet
9.   All Public Areas (including toilets)
10. RC Drinking Water Tanks

CATEGORY II	
Rooms required cavity walls if abut against diaphragm wall	Rooms provided with scupper drain for future cavity wall installation
1. DB Room / AFC-DB	1. Lift Motor Room (LMR)
2. Fare Equipment Room (FER)	2. AHU Room
3. Emergency Switch Room	3. Underplatform Exhaust Fan (UPE)
4. Uninterruptible Power Supply (UPS) Room / Emergency Power Supply (EPS) Room	4. Fire Pump Room
5. Traction Power Sub-Station (TPSS)	5. Fuel Pump Room
6. LV Switch Room	6. Fuel Tank
7. 22kV Switch Room / 22kV Switch Room (intake)	7. Clean Gas Room

TABLE 11.2 (Cont'd)	
GUIDELINE FOR CAVITY WALL ROOM CATEGORISATION	
Rooms required cavity walls if abut against diaphragm wall	Rooms provided with scupper drain for future cavity wall installation
8. Tie Breaker Room	8. CD Cooling Tower Room
9. ECS Control Room	9. CD Equipment Store
10. Generator Room	10. CD First Aid Room
	11. CD Pantry
	12. CD General Store
	13. Permanent Way Store
	14. Air Intake Plenum
	15. Intake Air Lock
	16. ECS Plant Room
	17. Water Distribution Control Room
	18. Fan Room
	19. Permanent Way Store
	20. PUB Intake Monitoring Kiosk
	21. Smoke Extract Fan (SEF) Room
	22. Tunnel Ventilation Fan (TVF) Rooms
	23. Fireman's and Escape Stair
	24. Traction Transformer (Traction TX Room)
	25. Service Transformer (Service TX Room)
CATEGORY III	

1.   Ventilation Shafts

2.   CD Sliding Door Chamber

3.   Lift Shafts

4.   Trackside Wall

5. Ventilation Passageways

11.2.3.3   Escalator Pits

11.2.3.3.1   The escalators serving the entrances shall have the lower escalator landing pits graded to a minimum fall of 1:200 towards the floor trap/waste connecting to the sewerage/drainage system. The rest of the escalators shall have a dry sump at the down stream of the lower escalator landing adjacent to the escalator pit which shall be accessible outside the escalator truss.

11.2.3.3.2   For stations not located within a water catchment area, water in the escalator pits shall be discharged to the drainage system. If the station is located within a water catchment area, then it shall be discharged into the sewerage/sanitary plumbing system.

11.2.3.4   Vent Shafts/Ducts

Vent Shafts shall be detailed such that rainwater is neither drained nor blown into them. Provision shall be made at the ventilation shaft terminals to drain all rainwater into the drainage system. The base of the vent shafts/ducts shall not be allowed to accumulate any water and shall be graded to fall towards the floor waste at a gradient of 1:200 minimum.

11.2.3.5   Water Storage Tanks

11.2.3.5.1   The storage capacity of a water tank is the volume of water that can be drawn by the water booster/transfer pumps. Water tanks shall be designed to minimise dead water volume.

11.2.3.5.2   The inlet and outlet pipes of the tank shall be located to avoid stagnation of water in the tank.

11.2.3.5.3   The base of the water tank shall have a minimum fall of 1:200 towards a 200mm minimum diameter drain-off pipe with puddle flange. This shall be installed at the base of the water storage tank to drain the water storage tank completely.

11.2.3.5.4   Overflow and drain-off water from storage water tanks shall not be discharged into the seepage channels directly. They shall be discharged directly to either a drainage sump or a pump sump.

11.2.3.6   R.C. Drinking Water Tanks

RC water tanks for drinking water shall not be in direct contact with soil. Where this is not possible, a cavity of minimum 100 mm with seepage channels shall be provided between the water tank and the earth-backed wall/slab to prevent contamination from any source. Floor waste for the seepage channel shall not exceed 10m intervals. Sufficient provisions for future maintenance of the seepage channel and floor waste shall also be provided.

11.2.3.7   Underplatform Areas

Drainage channels of minimum width 100mm shall be provided in the underplatform areas with a minimum gradient of 1:200. Discharge outlets (floor waste) of not less than 100 mm diameter shall be situated at not more than 10m centres. The floor finishes of the underplatform areas shall be made to fall towards these channels.

11.2.3.8   Condensate Drainage

11.2.3.8.1   Drainage is required for condensate water from all ECS associated systems (e.g., AHU Plant Room, ECS Plant Room etc.) including air conditioning from trains, ancillary and commercial areas. All condensate water shall discharge to the drainage system unless stated otherwise in Clause 11.3.

11.2.3.8.2   The location of the condensate points and volume of discharge shall be determined through co-ordination with the system-wide contractor. Floor trap being provided shall not be used for discharging water used for the cleaning of ECS equipment.

11.2.3.8.3   Any exposed condensate drain/pipe (including floor trap) beneath the suspended floor slab shall be insulated to prevent condensation.

11.2.3.9   Lift Pit

The base of lift pit shall be graded to have a minimum fall of 1:200 towards the sump of 450mm by 450mm by 450mm as per the requirements under CP 2: The Installation, Operation and Maintenance of Electric Passenger and Goods Lifts.

11.2.3.10   Entrances

A cut off drain shall be provided across each entrance, at the top of the stairway and escalator. The collected water shall be discharged to the nearest surface drain. The structural recess for the cut off drain shall be 240mm wide with a minimum depth of 200mm deep, covered with a stainless steel grating. A catch pit shall be provided at the drain outlet, or as close thereto as can be arranged, to prevent debris from entering the drainage run. Where pipes pass through the joints between the station structure and the entrance, they shall be detailed to accommodate all movements.

The minimum platform level and crest protection level for all entrances, exits, linkages etc. shall be in accordance with PUB's latest requirements.

11.2.3.11   Cable Trenches, Valve Chambers and Maintenance Pits

The top of the cable trenches, valve chambers and maintenance pits shall be made to fall away to prevent water from flowing inside. The

floors of cable trenches, valve chambers and maintenance pits shall be graded to have a minimum gradient of 1:200 towards the floor waste.

11.2.3.12   Movement Joints

Structural movement joints are highly susceptible to water leakage and adequate provisions for the collection and discharge of all water leakage shall be provided.

11.2.3.13   Dry Sump

A dry sump is a drainage sump without any outlet. Dry sumps shall not be provided unless accepted by the Engineer.

11.2.3.14   Drainage Sump

Where the direction of a horizontal pipe changes or where two horizontal pipes merge, a drainage sump shall be provided unless the pipes are accessible from below. Pipes that are buried or cast in concrete, or located above the track are considered inaccessible from below. The design and provision of drainage sumps shall comply with sewerage and sanitary plumbing requirements.

Water in a drainage sump shall not be channelled such that its direction of flow turns through an angle of more than 90°.

11.2.4   Station Pump Sumps

11.2.4.1   Location

11.2.4.1.1   Station pump sumps shall be located to suit the individual requirements of each station and to be located at strategic locations such that the total number of pump sumps is minimised. The utilisation of every drainage pump sump shall be maximised to collect water from as many sources as possible.

11.2.4.1.2   Sumps shall be accessible for inspection and maintenance at all times. Pump sumps shall as far as possible not be located at the passageway or corridor. Each pump sump shall be located in a dedicated sump room.

11.2.4.2   Details

11.2.4.2.1   Provisions shall be made in the design of the sumps for the discharge mains, power supply and monitoring cables to the pumps.

11.2.4.2.2   Check valve of single flap type and a gate valve shall be provided on the discharge main of every pump. They shall be located above the sump such that they are accessible without the need to enter the sump and after removal of the access cover.

11.2.4.2.3   The layout shall be such as to facilitate easy removal and replacement of pumps without entering the sump. Lifting facilities (e.g., overhead runway beam, eye bolt etc.) and equipment shall be provided to enable easy lifting of the pumps. Adequate removable chain blocks shall be provided.

11.2.4.2.4   Access openings shall be provided directly above the pumps for easy installation and removal of the sump pumps. Access openings shall be fitted with aluminium chequered covers and provided with aluminium access ladders with extensible handhold up to 1150mm above access cover level. Ladder requirements are described in Clause 11.5.

11.2.4.2.5   For each sump pump, a control panel shall be placed at a convenient, easily accessible location and shall be constructed with a waterproof type enclosure.

11.2.4.2.6   A stainless steel screen shall be provided in the pump sump of every drainage sump immediately upstream of the pump sump. The location of the screen shall be such that a maintenance worker standing at the access cover level can easily clear all debris trapped.

11.2.4.2.7   The discharge pipes from the sump pumps shall be routed directly to the surface drains via the nearest and shortest route (e.g., vent shaft, service shaft/duct, entrance etc.). The water shall not be discharged to another drainage pumping system within the Works. Swan necks shall be provided at the appropriate locations. Flap valves shall be provided at the discharge ends. Discharge pipe shall have a minimum diameter of 80mm.

11.2.4.2.8   The pump sumps shall be waterproofed using an accepted waterproofing admixture or alternatively, using an accepted liquid membrane applied on the interior surfaces of the sump walls.

11.2.5   Sump and Pump Design Directives

11.2.5.1   Pump Design

11.2.5.1.1   For each pump sump, a minimum of two pumps with similar capacities shall be provided, one of which shall be the standby pump. The duty pump(s) shall be capable of handling the full discharge requirements. The stand-by pump shall be automatically activated when the duty pump fails.

11.2.5.1.2   The design of the system shall be such that the number of starts/stops for each pump shall be limited to not more than 10 per hour. However, the motor starter shall be sized to 15 starts/stops per hour.

11.2.5.1.3   Controls shall be provided such that there is an automatic change over of duty and standby pumps during each cycle of operation. This is to enable even distribution of wear and tear of the pumps.

11.2.5.2   Design Pump Capacity

11.2.5.2.1   The design pump capacity, Q_p for each sump shall be calculated using the following:

Q_p = [(seepage + condensate)] x 2 + max[tunnel washing, fire main, tank overflow]

However, the design pump capacity shall also ensure that the velocity, *V* of water in the discharge pipes is between 1.0*m/s* and 2.4*m/s* (except for the *common* water tank discharge pipe where *V* may exceed 2.4*m/s* when both pumps are operating).

11.2.5.2.2   Water seepage shall be obtained based on the contribution area of tunnel lining or earth backed external walls using the seepage rates given in M&W Chap 16 and CDC Chap 8.

11.2.5.3   Pump Selection

In order to select the proper pump, the following parameters shall be considered during the selection of the pumps: -

(1) Design Pump Capacity
(2) Operating Head
(3) Efficiency
(4) Power Rating
(5) Discharge Pipe Diameter (Max. & Min. water velocity)

Having due regard to these criteria, pumps from at least two different manufacturers available in the market shall be identified and submitted together with the calculations. The sump shall then be sized to accommodate the largest pumps.

11.2.5.4   Sump Sizing

11.2.5.4.1   The size of each sump is determined based on the following parameters:

(1) Dead water volume;

(2) Duty pump operation capacity;

(3) Reserve capacity;

11.2.5.4.2   The typical operating water levels of a pump sump shall be as shown in Figure 11.1 below.

Top of Sump

Lowest Inlet Pipe Level

Reserve Capacity, V_R

$D_R \geq 100mm$

Overflow Water Level Alarm

100mm

Duty Pump Start Level
(Standby pump shall be automatically
activated when duty pump fails)

Duty Pump operation
storage capacity, V_D

$D_D \geq 100mm$

All Pump Stop Level

50mm

Low water Level Alarm

Dead Water Volume

Varies according to
pump size
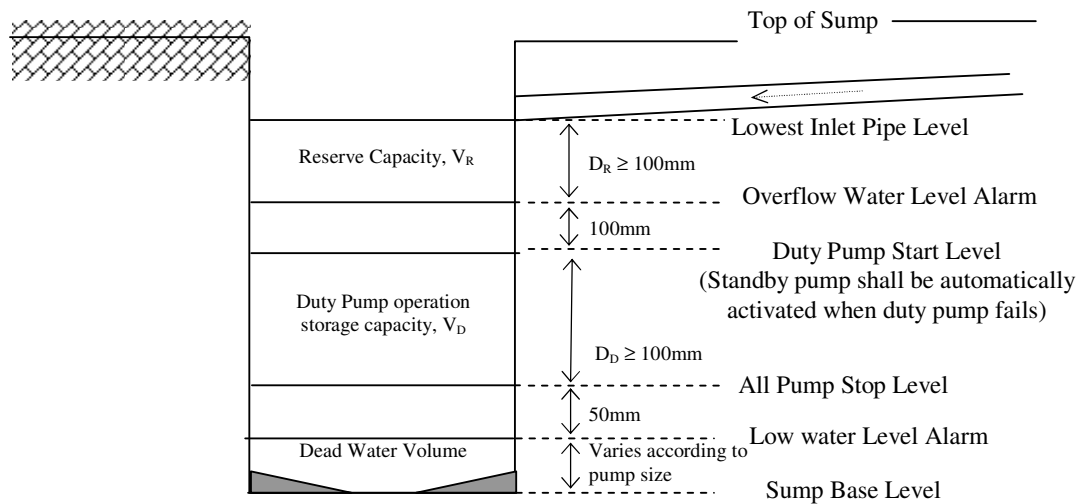
Sump Base Level

Fig. 11.1 Pump Operating Levels for Sump Sizing

11.2.5.5   Dead Water Volume

Dead water volume is measured from the Sump Base Level to the Low Water Level Alarm and shall be minimised by haunching the base of the sump.

11.2.5.6   Duty Pump Operation Storage Capacity

The Duty Pump Operation Storage Capacity is measured from the All Pump Stop Level to the Duty Pump Start Level. The volume shall be computed from:

$$V_D = \frac{Q_{select} \, xT}{4}$$

where Q_{select} is the higher flow capacity of the selected pumps (see above).

T is the time between 2 sequential starts (i.e., one complete start-stop cycle) and is computed from:

$$T = \frac{3600}{\left(No.\ of\ Start/Stops\ per\ Hour\right)} \text{ seconds}$$

Total No. of Starts/Stops per Hour shall not exceed 10 and the level between the All Pump Stop Level to the Duty Pump Start Level shall not be less than 100mm.

11.2.5.7   Duty Pump Start Level to Overflow Water Level Alarm

The level between the Duty Pump Start Level and Overflow Water Level Alarm shall be set at 100mm.

11.2.5.8   Reserve Capacity

11.2.5.8.1   The Reserve Capacity shall be measured from the Alarm Level to the Lowest Inlet Pipe Level. It shall be computed from:-

$$V_R = \lfloor (Seepage\ x2) + Condensate\ (from\ stationary\ trains) \rfloor\ x$$
$$(response\ time\ of\ 6hrs\ or\ 24hrs\ depending\ on\ accessibility)$$

The level between the Overflow Water Level Alarm and Lowest Inlet Pipe Level shall not be less than 100mm.

11.2.5.8.2   For Tunnel pump sumps, the response time shall be 24 hours.

For Station pump sumps, the response time will be taken as 24 hours if the sump is not accessible during train operation, and 6 hours otherwise.

11.2.5.2.6.3   Condensate water from stationary trains and station air conditioning plant, ancillary and commercial areas shall be determined through co-ordination with the system-wide contractor.

11.2.5.2.6.4   Accident/emergency inflow such as water tank overflow and occasionally large but manageable inflows such as track washing and fire main draining need not be considered in the computation of reserve capacity. Condensate from moving trains may be assumed to be evaporated.

11.2.6   Storm Water Drainage

Design of storm water drainage run off shall be in accordance with the Code of Practice for Surface Water Drainage, and the latest Surface Water Drainage Regulations issued by the PUB (Drainage) and any other requirements that may be imposed by PUB.

11.2.6.1   Run Off

The Rational Formula shall be used for determining surface water run off. The coefficient of run off for cutting slopes and track area shall be taken as 1.0.

Run-off from neighbouring lot or adjacent land if affected shall be diverted by new drains constructed to the approval of PUB(Drainage).

11.2.6.2   Roof Drainage

11.2.6.2.1   Roof drainage shall be designed and constructed to dissipate water from the roof by the most effective and direct route possible to the surface drains. Design of roof drainage shall be in accordance with all the latest PUB regulations and with the latest edition of SS CP26 Code of Practice for Drainage of Roofs. Rainwater outside the station shall not be drained into the Station/Tunnel pumped drainage system.

11.2.6.2.2   Rainwater pipes and outlets provided to any flat roof shall ensure that the build up of water during a flash storm does not exceed 30 mm.

11.2.6.2.3   Rainwater pipes shall be of sufficient bore, and in long lengths with easy bends to ensure that a back up of water does not occur. The outlets to flat roofs shall be filled with dome grating or equivalent to prevent dirt, leaves or any foreign substance from blocking the down pipe.

11.2.6.2.4   Notwithstanding the above, flat roofs shall be provided with overflow facilities.

11.2.6.2.5   Wherever pitched roofs form part of the structure, adequate overhang of the roof shall be provided to prevent rainwater water falling onto people who are liable to stand or walk beside the building and the rainwater must be drained to the surface drainage system. Sufficient surface water drains shall be provided on the ground level to collect all water from the roof and prevent water ponding. Roof gutters shall be avoided as far as possible. Where it cannot be avoided, the gutters of sufficient capacity to collect rainwater from the roof without spillage shall be provided across the edge of the roof. Roof gutters shall be coated with an approved waterproofing membrane with minimum ten years warranty and roof outlets shall be properly dressed and sealed with a suitable membrane at the junction with the roof. Overflow pipes shall be provided at the ends of the gutters.

11.2.6.2.6   Rainwater downpipes shall be positioned at suitable distances to collect and discharge water to the stormwater drainage system. All gutters, outlets and downpipes shall be positioned outside buildings as far as possible so that if any leak occurs, no damage to sensitive equipment, or other inconvenience, can arise. Rainwater downpipes shall be fitted with screw-on rodding eyes at the base of the stack.

11.2.6.3   Paved Areas

All paved areas around the station shall be sloped to provide effective surface run-off. The slope shall be directed away from station entrances. Adequate cut off drains shall be provided and directed into the existing storm water drainage system.

Where perimeter drains and a surface structure are provided the drain shall be integral with the main structure to avoid differential settlement problems.

11.3   SEWERAGE & SANITARY PLUMBING

11.3.1   General

General requirements are summarised in Table 11.3. The sewerage and sanitary system shall incorporate these requirements and shall be designed in accordance with Clause 11.3.3. Design of sewerage and sanitary system shall also comply with all requirements that may be imposed by the PUB.

11.3.2   Design Code

The design of sewerage drainage system shall be in accordance with the latest PUB Sewerage Department Code of Practice on Sanitary Plumbing and Drainage System, Sanitary Plumbing and Drainage System Regulations, Sewerage Procedures and Requirements Handbook by PUB, the Code of Practice on Sanitary Facilities and Fittings for Public Toilets and the Code of practice on Pollution Control.

TABLE 11.3

SEWERAGE SYSTEM PROVISION IN STATIONS

	Room/Area	Requirement	Remarks
1	Escalator pit	One floor trap	See Clause 11.2.3.3
2	All ECS associated Plant Rooms	Actual number of floor traps depend on equipment layout and room size.	Floor trap with 1 x 1 m kerbed floor basin to be located below water tap.
3	Cooling towers / exhaust plenum	One floor trap plus service channel if necessary	Floor trap with 1 x 1 m kerbed floor basin to be located below water tap, bleed off and overflow. For outdoor cooling tower area, a cover to be provided for the floor trap to prevent rain water ingress.
4	Sprinkler water tank/pump room	One floor trap	Floor trap with 1 x 1 m kerbed floor basin to be located below water tap. For washing water during cleaning of equipment
5	Water Distribution Control Room	One floor trap	Floor trap with 1 x 1 m kerbed floor basin to be located below water tap. For washing water during cleaning of equipment
6	Ancillary rooms, station control room	Floor traps where necessary	Preferred location for floor traps would be the corridor areas for condensate water.
7	Cleaner room	One floor trap	For washing water.
8	Refuse store	One floor trap	For washing water.

TABLE 11.3 (Cont'd)

SEWERAGE SYSTEM PROVISION IN STATIONS

Room/Area		Requirement	Remarks
9	Staff room	Floor trap	For wash basin.
10	Staff and public toilet	Floor waste/trap	For washing water.
11	Within WC cubical	Floor waste/trap	For washing water.
12	Commercial Areas (shops, kiosks etc.)	One floor trap per shop or kiosk.	Floor traps near taps.
13	*CD pantry	Floor trap	As per BCA guidelines.
14	*CD first aid room	Floor trap	As per BCA guidelines.
15	*CD decontamination room	Floor traps	As per BCA guidelines.
16	*CD Dry toilet	Sealed floor traps.	For waste from wash basin. The floor traps shall be covered with floor access plates during peace time. Location and spacing shall be as per BCA guidelines.

* These are civil defence facilities in CD stations. These facilities will only be used during CD operations.

11.3.3   Design Directives

11.3.3.1   Sewerage and Sanitary Plumbing System shall be constructed using approved materials, laid to fall in accordance with PUB's requirements.

11.3.3.2   Wherever possible sewage shall be gravity fed into the main sewerage network.

11.3.3.3   The pipe work where fixed to walls or under slabs shall be secured with brackets and hangers capable of supporting the fully loaded pipes.

11.3.3.4   On vertical stacks and on all branch connections rodding eyes shall be fitted to bends not exceeding 135° or at connections between pipes of different material.

11.3.3.5   All pipes shall be properly caulked and sealed at the joints and shall be to PUB's approval.

11.3.3.6   The PUB approved type of autosensing/electronic sensor flush valves shall be provided for water closets and urinals at public toilets and staff toilets. Where water pressure is inadequate for the operation of these flush valves, water tanks with booster pumps shall be provided.

Sufficient and adequate power supply shall be available to operate these flush valves.

11.3.3.7   Penetrations through beams, slabs or any structural members for waste pipes shall be avoided as far as possible.

11.3.3.8   Floor traps/wastes shall be placed with consideration to water areas/points for which the provision is made. Floor traps shall not be obstructed or covered in any manner to hinder access to maintenance personnel.

11.3.3.9   The floor of all ECS associated plant rooms (e.g. ECS Plant Room, AHU Plant Room etc.) shall be waterproofed using an accepted liquid applied membrane.

11.3.4   Sewage Pump Sumps

The design of sewage pump sumps shall be similar to that of the drainage pump sumps except that they collect and dispose waste water.

11.3.5   Sewage Ejector

11.3.5.1   Sewage ejectors shall be provided at the base level of underground stations for the collection and disposal of sewage from staff toilets, crew toilets, public toilets and waste water from plant rooms/areas. All sewage and waste water from ground level or above shall be directly discharged into the main sewerage network by gravity as far as possible.

11.3.5.2   Sewage pump sumps shall be located to suit the individual requirements of each station and to be located at strategic locations such that the total number of pump sumps is minimised. The utilisation of every sewage pump sump shall be maximised to collect water from as many sources as possible.

11.3.5.3   For CD Stations, no ejector/sewage pumping system shall be designed to serve only CD facilities. Facilities that operate only during CD Mode (e.g., dry toilet) will result in low usage of the ejector/sewage pumps and increase maintenance burden in the future. Hence, any ejector/sewage pumping system shall be designed for either peace time facilities or for both CD and peacetime facilities.

11.3.5.4   Ejector pumping system shall be located in rooms specifically designated for this purpose and with direct access facilities for maintenance. A minimum of two pumps (duty & standby pump) and an ejector tank shall be provided for each ejector system. The rooms shall be minimum 3m x 3m to comply with PUB's requirement.

11.3.5.5   Access openings shall be provided directly above the ejector tanks and pumps for easy removal/replacement. Access openings shall be fitted

with aluminium chequered covers and provided with aluminium alloy access ladders with extensible handhold up to 1150mm above access cover level. Ladder requirements are described in Clause 11.5.

11.3.5.6   Lifting facilities (e.g., overhead runway beam, eye bolt etc.) and equipment shall be provided to enable easy lifting of the ejector tanks/pumps. Adequate removable chain blocks shall be provided. Sufficient clearance all around the sewage ejector shall be provided for ease of maintenance.

11.3.5.7   Containment of over spillage of sewage from ejector tank shall be considered. A sewage sump pump shall be provided in every ejector room and connected to the ejector pumping main.

11.3.5.8   For both ejector and sewage pumps, the minimum and maximum flow velocities allowed in the discharge pipe shall be 1.0m/s and 2.4m/s respectively. This is to ensure self cleansing velocity and to prevent scouring of pipes. For each ejector/sewage pumping system, the pumps shall be designed for the peak sewage/waste water inflow generated.

11.3.5.9   Discharge pipework of minimum 100mm diameter shall consist of check valve of single flap type and a gate valve. They shall be located above the ejector tanks such that they are accessible without the need to enter the ejector sump and after removal of the access cover.

11.4   WATER SERVICES

11.4.1   General

11.4.1.1   The design of water supply to stations shall comply with the latest Singapore Standard CP 48 for Water Services and Public Utilities (water supply) Regulations.

11.4.1.2   Underground piping shall be laid at such a depth that it is unlikely to be damaged by traffic loads and vibration. Where piping has to be laid in any ground liable to subsidence then special consideration shall be given to the type of piping to be used and the type of joint to be adopted in order to minimise risk of damage due to settlement. Where piping has to be laid across recently disturbed ground, continuous longitudinal support shall be provided.

11.4.1.3   Provision shall be made at every bend, branch and dead end in a main to resist the hydraulic thrust.

11.4.1.4   The PUB's water meters chamber shall be provided above ground level. Wherever possible, a separate chamber to house the double check valve assembly for the fire fighting line shall be provided and located below ground level if it is technically feasible with a drainage facility to prevent flooding of the underground chamber. Location of the

water meter chamber shall be easily accessible for meter reading and unobstructed, and shall be approximately 1m from the site boundary.

11.4.1.5   Common water distribution pipes shall not be routed in commercial/retail areas.

11.4.1.6   All valves and taps must be accessible for service and maintenance. Where valves or taps are installed above the ceiling or behind walls (seepage walls etc.) appropriate access panels must be provided in the ceilings or walls for maintenance and repair of the valves and taps. Control valves shall be provided at strategic and easy access location. Adequate brackets supports must be provided to the supply pipe in the vicinity of the bends.

11.4.1.7   Water supply to the stations falls into the following categories:

(a) a potable water system

(b) a water system for fire fighting

(c) a Civil Defence (CD) water supply where applicable

(d) a cooling water make-up system for ECS

(e) a water supply system for plant and equipment operation

(f) a water supply system for trains/plant/machinery/ equipment washing

(g) a water system for irrigation

11.4.2   Water Supply System

11.4.2.1   Drinking water tank/pump room shall not be located next to an ejector room or toilet or any potentially polluted area.

The areas/rooms in stations that require water supply provisions are given in Table 11.4.

TABLE 11.4

WATER SUPPLY PROVISION IN STATION

Room/Area	Requirements	Remarks
1. Sprinkler Water tank/Pump room	One tap	
2. Cleaner Room	One tap with sink	
3. Refuse Store	One tap	

Room/Area	Requirements	Remarks
4. Bin Point/Bin Centre	One tap	
5. Staff Room	One tap with sink	
6. Toilets	Taps as necessary	Taps in WC cubicles with squatting pans to meet PUB requirements.
7. Planter in Stations	Taps as necessary	Liaise with PUB/Nparks to meet their specific requirements, if any.
8. *CD Pantry	As per BCA guidelines.	
9. *CD First Aid Room	As per BCA guidelines.	
10. *CD Decontamination Room	As per BCA guidelines.	
11. *CD Dry toilet	As per BCA guidelines.	
12. All ECS associated Plant Rooms	Taps as necessary	- Near condensing unit. - Near AHU. - Near filter.
13. Ejector Room	One tap	
14. Drainage Pump Room	One tap	
15. Water Distribution Control Room	One tap	
16. Cooling Tower Room/Area	One tap	
17. Commercial Areas (shops, kiosks etc.)	One tap off point	

* These are civil defence facilities in CD stations. These facilities will only be used during CD operations.

11.4.2.2   Water Storage Capacity shall be provided at all Stations to ensure that, the air conditioning system can remain operational at normal load for one operational day (approximately 18 hours) in the event of a loss of direct water supply.

11.4.2.3   Water Storage Capacity shall be provided at all Depots to ensure that, in the event of a loss of water supply for up to 24 hrs;

- The air conditioning systems to all rooms containing equipment essential to the operation of the railway system and to the operational control room can remain operational at normal load;

- Water related facilities (e.g., toilets) for the key operational personnel and their managers in the Control Centre and relevant Offices can remain operational;

- Any other facilities essential to the operation of the depot can remain operational.

The water supply to these facilities shall be a separate supply through a dedicated storage tank, so that "ramping down" of other non essential facilities will not be taken from this supply.

11.4.2.4   Water booster system shall be provided with secondary power supply.

11.4.3   Water System for Fire Fighting

If a fire engine access road is provided, every part of the fire engine access road shall be within an unobstructed distance of 50m from a hydrant. Where a public hydrant is not available, private hydrant(s) fed after the water meter shall be provided in accordance with SS CP29 and PUB Regulations.

In all cases, a 100mm x 150mm branch line tee-off after the water meter shall be laid to supply water directly to the sprinkler water tank.

Fire hydrants shall be supplied and installed by the Contractor.

11.5   ACCESS LADDERS

11.5.1   General

Access ladders shall be provided in the following instances:-

(a) Access to equipment where regular maintenance works is required.

(b) Escape or emergency exit purposes.

(c) Any other situations where it is essential to provide one. (e.g., underplatform voids in stations, air shafts etc.)

11.5.2 Design

The design shall conform to Parts 1 to 3 of BS EN ISO 14122. All fixings to the structure shall be designed in accordance with CDC Chapter 8, Underground Structures. The minimum bolt diameter shall be M12.

Extendable type handrails shall be provided where it is not practical to extend side strings above the landing level to form handrails (for example sump pits in cross passages where pedestrian access is required over the sump pit). They shall be provided at each string and shall be capable of being temporarily extended to provide temporary handrails.

11.5.3 Material

The material shall be stainless steel or aluminium.

CHAPTER 12

EXTERNAL WORKS

12.1 PAVED AREAS

12.1.1 Paved areas around structures shall be designed to withstand the loads likely to be experienced during delivery and removal of equipment. Where fire engine access is required, the area shall comply with the requirements given in the Standard for Fire Safety in Rapid Transit Systems.

12.1.2 Movement joints shall be provided to prevent cracking of finishes. These joints shall be provided in accordance with the Architectural Material and Workmanship Specification.

Movement joints shall be provided at the interface of non-suspended and suspended areas. Differential settlements at these joints shall not be a hazard to persons using the areas and in no case shall exceed 6mm.

12.1.3 Maximum long-term allowable settlement in the pavement structure around the station shall not exceed 20mm. The differential settlement between any two adjacent points within a panel shall not exceed 1: 1000 subject to a maximum of 15mm. The differential settlement between any two adjacent panels shall not exceed 6mm. All external paving shall be designed to drain off surface water efficiently to prevent ponding of water.

12.2 IRRIGATION SYSTEMS AND LANDSCAPING

12.2.1 Irrigation systems, landscaping and irrigation of land through viaduct discharge shall comply with the requirements of the National Parks Board (NParks), and all other relevant government bodies. Each irrigation system shall be proven to be workable by means of a trial of adequate time period.

12.2.2 Landscaping or turfing shall be provided on both non State Land, and state land occupied by the Authority for the purpose of constructing the Works, in accordance with any landscaping agreement reached between the Authority and the landowner. In the absence of an agreement only turfing is permissible.

12.2.3 For State Land within the road reserve, both landscaping and turfing are permissible. In the case of State Land outside of the road reserve, landscaping is permissible if NParks agrees to take over and maintain the completed landscaping.

12.2.4   Where a fully automated irrigation system is specified it shall be provided with a central control system, rain sensor and water level monitoring system. Details of such automated irrigation system are to be submitted to NParks for approval.

12.3   HANDRAILS AND RAILINGS

12.3.1   Handrails shall be designed for loadings in accordance to the requirements of Chapter 3 of this Specification.

12.3.2   Standard safety railing shall be provided for all open drains more than 1m deep. The railings shall be in accordance with the standard specified in the Code of Practice on Surface Water Drainage.

12.3.3   Where railings are required in areas other than the station premises for public safety, they shall be provided in accordance with the latest LTA Standard Railings Details found in the Standard Details of Road Elements.

12.4   FENCING AND PROTECTION AGAINST UNAUTHORISED ACCESS

12.4.1   Depots, substations, relay stations, on-line substations and at-grade sections of railway shall be fenced in accordance the Architectural Material and Workmanship Specification.

12.4.2   For railway approach structures, appropriate measures shall be incorporated in the design to make it impossible for the public to access the railway tracks.

CHAPTER 13

E&M INTERFACE

13.1 GENERAL

This chapter covers particular E&M requirements that are to be incorporated into the C&S design.

13.2 ELECTRICAL SUBSTATION

Electrical substations are required within the stations and as independent structures within the depot.

13.2.1 Cable Chamber

13.2.1.1 A cable chamber shall be provided beneath the full area of the electrical equipment rooms. The chamber shall be a through void as far as practicable and treated as one fire compartment. The cable chamber shall have a height of at least 1700 mm.

13.2.1.2 The cable chamber should be dry and free of water. Cable entry into the cable chamber through external ducts shall be sealed by means of a multiple cable transit (MCT). The cable chamber shall be waterproofed.

13.2.1.3 The cable chamber floor shall slope towards one end and floor wastes shall be provided for draining of any water present in the cable chamber and connected to the surface water drainage system.

13.2.1.4 Where it is not possible to construct main access door(s) to the cable chamber at least two manholes of 750mm x 750mm size shall be provided. These manholes shall be complete with a galvanised steel ladder. The manhole cover shall be light enough for one man to handle and designed to withstand 5kN/m^2 live load. These manholes shall be located at the two ends of the equipment room, flush to the floor, free from any obstruction and away from the escape route.

13.2.2 Others

13.2.2.1 Fixed pulling points (eyebolts) of appropriate tonnage shall be provided in the transformer rooms for installation and withdrawal of the transformers. The eyebolts must be recessed to the wall, soffit or floor. Those in the floor shall be provided with a cover and fitted flush to the floor surface. Each eyebolt shall be tested to 1.5 times safe working load and certified by Approved Person.

13.3   PLATFORM TOUCH VOLTAGE PROTECTION

13.3.1   General

13.3.1.1   The Contractor shall design and detail an effective platform insulation system to prevent passengers on the platform from possible electric shocks caused by touch voltage when boarding/alighting or touching the train or when touching the Platform Screen Doors (PSDs).

13.3.1.2   A "protection zone" (as defined below) by the platform edge areas adjacent to the tracks shall be electrically isolated (for example, from the station structure/electrical earth, or from traction earth, etc.) All appurtenances and the finishes to all structures (including floors, walls and columns) that fall within the protection zone shall be electrically isolated from earth, or provided with a suitable insulated coating, to avoid harmful touch potentials.

13.3.1.3   The extent of the protection zone shall be :

- Vertically, between the top of platform structural slab level and a minimum 2.5 metres above platform finished floor level.
- Transversely, from the platform edge to a minimum distance of 1.8 metres into the platform from any part of the inner face of the platform screen doors (PSDs) assembly, and from any metallic clad platform edge column,
- Longitudinally, for the full length of the PSD assembly to encompass anywhere that is within 1.8 metres of the PSD assembly. In situation where the end return door, in the swing open position is within the PSD protection zone, the protection zone shall be extended a further 1.8m beyond the end return door. See Figure 13.1 and 13.2.

13.3.1.4   The finishes to the platform between the platform edge and the remote side of the protection zone shall be fully electrically insulated from the structural slab below, and from all adjacent finishes and/or structures at the boundaries of the protection zone.

13.3.1.5   All cladding, including vitreous enamel, on walls or columns shall use electrically insulated fixings. Skirtings around walls or columns that fall within the protection zone shall also be isolated.

13.3.1.6   Insulated breaks in the finishes shall be provided at the boundaries of the protection zone to ensure that the isolated areas are not earthed to the non-isolated areas.

13.3.1.7   Metallic handrails that run along the platform edge in the buffer areas and which fall within the protection zone shall have an insulated finish.

13.3.2   Minimum Insulation Level

13.3.2.1   Notwithstanding 13.3.1 above, the minimum insulation levels shall be:-

a) A minimum platform floor to earth resistance of 10,000 and 35,000 ohm over a 300 x 300 mm area at 250V DC under damp and dry conditions respectively.

b) A metallic finishes (e.g. handrails, metallic cladding, etc.) to earth resistance of 50,000 ohm at 500V DC under damp condition.

c) A minimum resistance of 0.25M-ohm between PSD and Earth.

13.3.3 Insulation Details

No embedded conduit, trunking or service pipe shall be allowed to run in or through the insulated areas.

No metal dividing strip shall be allowed on the platform finishes within insulated areas.

Expansion joints on platform shall be kept to a minimum. Expansion joints shall not allow passage of water or moisture.

13.4 WATER AND ELECTRICAL EQUIPMENT

13.4.1 General Protection

13.4.1.1 No water pipe, whether gravity fed or under mains pressure, shall be located within electrical rooms (substations, switch rooms, signal rooms, battery rooms, CER, etc) or associated cable chambers. Such prohibited pipes include but are not limited to : -

   i)   Rain water down pipes;
   ii) Sewerage & sanitary plumbing pipes including local penetrations through ceiling slab;
   iii) PUB water mains supply;
   iv) Internal water services plumbing reticulation;
   v)   Sprinkler and dry riser mains;
   vi) Drainage pipework.
   vii) Pumped discharge pipework for drainage and sewerage & sanitary plumbing.

13.4.1.2 No floor trap is to be cast into the slab directly above an electrical room.

13.4.1.3 No "wet" (ECS plant room, sprinkler tank room, toilets, cleaners room etc) rooms shall be located above electrical plant rooms.

13.4.2 External Cable Manholes and Cable Ducts

13.4.2.1 External cable manholes shall be positively drained, and shall comply with Section 11.2.3.9.

13.4.2.2 Where cable ducts enter an electrical room or cable chamber, the duct shall slope away to minimise seepage into the room or chamber.

13.5 E&M EQUIPMENT DELIVERY ROUTES

13.5.1 The design shall provide adequate routes for E&M equipment to be brought into the stations and the depot and for subsequent replacement. These routes shall be clearly marked on a separate set of drawings, which shall also show the information to be agreed as below

13.5.2 The routes shall be subject to co-ordination between the Civil Contractor and the Systemwide Contractors who shall agree for the following:-

- the mode and location of supply of equipment to the site;

- the method of unloading;

- the route of the equipment from point of unloading to final position;

- the lifting requirements throughout the route and method of transport;

- the weight of the equipment and its effect on the design loads for the structure, capacity of lifting hooks, lifting beams etc, either temporary or permanent;

- requirements for temporary decking, and staging;

- protection required for equipment and structure/finishes.

13.5.3 It is envisaged that some equipment will be lowered from ground level to concourse level and platform level via the draught relief shafts. For such cases, the design of vent shafts shall take into consideration the provision of demountable louvres, panels, etc. For Civil Defence stations, staging may be necessary in the bomb pits to facilitate the movement of equipment. Such staging shall be designed to support a static load of 20 tonnes, or such higher load as may be required by the Systemwide Contractors. For delivery from tunnels, floor access hatches above the trainway with lifting beams shall be provided. The lifting beam capacity shall be the subject of co-ordination between Civil Contractor and Systemwide Contractor.

13.5.4 Fixed lifting points (eyebolts) shall be provided for installation and replacement of major pieces of equipment. The minimum requirements are:-

- For Traction Substation Transformers

  3 Nos. 5 tonne safe working load capacity lifting point in soffit of the structure(s) above the transformer, located in front of the intended location of the transformer.

- For Service Substation Transformers

  1 no. 5 tonne safe working load capacity lifting point in soffit of the structure(s) above the transformer, located in front of the intended location of the transformer.

- For Escalators

  8 nos. 5 tonne safe working load capacity lifting points for each escalator in the soffit of the structure(s) above the escalator. The safe working load capacity shall include the lateral loading at an inclination of 60 degree from vertical. Additional lifting points shall be provided when the escalator's rise exceeds 8m.

- For Lifts

  2 nos. 3 tonne safe working load capacity lifting points or 1 no. 3 tonne safe working load capacity lifting beam for each lift at each lift shaft and each lift motor room

- For Generator

  1 no. 6 tonne safe working load capacity lifting point for each generator.

  In all cases, location and safe working load shall be co-ordinated with the Systemwide Contractor.

13.6   ELECTRICITY SUPPLY TO CIVIL EQUIPMENT

13.6.1   Various pieces of equipment supplied by the Civil Contractor will require an electrical supply to operate. The design shall be co-ordinated with the E&M Contractor regarding the location, power requirements, cable routing, termination and connection for power supply to all such equipment.

13.6.2   The equipment supplied by the Civil Contractor requiring power supply includes (but may not be limited to): -

- Drainage Pumps
- Sewerage Ejectors
- Motors for Sliding Doors
- U.V Filters
- Hand Dryers
- Toilet Sensors
- Motorised Roller Shutters
- Automatic Station Entrance Doors

13.6.3 The design shall allow for a 400/230V supply with a ±10% voltage and ±2% frequency variance at the normal and emergency main low voltage distribution boards. The design shall be co-ordinated with the Electrical Services (including UPS) Contractor(s) with respect to the voltage drop between the main LV boards and the input terminals of their equipment, to ensure that the equipment will operate over the full range of supply conditions identified above. The design shall incorporate reduced voltage starting where necessary to ensure the tolerances as "seen" by the equipment are not exceeded.

13.7 EARTHING SYSTEM

13.7.1 General

a) The basic design for the earthing system is indicated on the Authority's Earthing System Interface Drawing.

b) The Civil Contractor shall carry out individual soil resistivity test at each end of the station prior to construction of the station base slab.

The soil resistivity test shall use the Wenner 4-pin method and the results submitted by the Civil Contractor shall be endorsed by a Registered Electrical Professional Engineer (PE). The Civil Contractor shall select a minimum of 2 test locations for each station subject to the approval of the Engineer. Five sets of tests shall be conducted at each location; each set at pin spacing of 2m, 4m, 6m, 8m and 10m respectively.

c) The design, installation and testing of the earthing system shall be in accordance with SS CP16. The passing criteria for earthing resistance shall be less than 1Ω. For Rapid Transit Systems, the earth mat shall be designed in accordance with ANSI IEEE 80.

d) The Civil Contractor shall prepare the necessary detailed design calculations, working drawings and test procedures and submit to the Engineer for approval.

13.7.2 Earthing Mat Design Requirements

a) The earthing mat shall be designed to limit the coupling between the lightning protection and the power system earth mat to 110V when a discharge of 100KA from a lightning strike occurs. The coupling device connecting the lightning protection and power system earthing mats shall be under the scope of the Civil Contractor. The Civil Contractor shall co-ordinate with the Electrical Services Contractor to ensure that the design meets the above design criteria.

13.7.3   Installation and Execution

a) The ringed earthing mat shall comprise earth rods inclusive of 95mm^2 bare stranded copper wire laid 300mm below basement slab/ground level. The selection of electrode material shall be resistant to corrosion in the type of soil in which it will be used. Earth rods shall be coupled together with silicon aluminium bronze coupling and the copper wire joints shall be by exothermic weld. All exothermic welds shall be inspected by the Engineer before backfilling.

b) Earth riser cables 185mm^2 cross linked polyethylene (XLPE) shall be brought from the earth mat up through the basement floor or wall to each of the equipment rooms and two nos 95mm insulated earth cables from the earthing mat to the two test locations located aboveground at station air shafts, as shown on Authority's Drawing.

c) At each riser cable entry through the basement floor or wall, a heavy-duty pipe sleeve complete with water stop seal shall be provided to prevent the ingress of water. Details shall be submitted for the Engineer's approval.

d) The Civil Contractor shall co-ordinate with the Power Supply Equipment and Cabling Contractor for termination of the earth riser cables onto the main earth bars in accordance with the Authority's Earth System Interface Drawing.

e) The copper electrodes at the earth inspection chamber at ground level shall have a label "Electrical Earth - Do Not Remove".

13.7.4   Testing

a) The Civil Contractor shall carry out the following test:
i)   Soil resistivity measurement
ii) Earth mat resistance measurement. Measurement to be endorsed by Civil Contractor's Electrical Professional Engineer.

All test equipment shall be calibrated by SPRING Singapore or an accredited laboratory.

b) The Civil Contractor shall also carry out interface co-ordination with the relevant Interface or Systemwide Contractors for joint witnessing of all earthing tests.

c) The Civil Contractor shall carry out the following earthing mat tests:

i)   Individual earthing mat test at each end of station
ii) Combined earthing mat test
iii) Continuity test after earth risers are terminated on earth bars, and
iv) Final earthing mat test as indicated below in 13.7.4e.

d) The Contractors shall submit plots of each resistance curve together with all test results to the Engineer for approval.

e) Four weeks prior to 22 kV power-on of MRT station power supplies, the Civil Contractor's Electrical PE shall carry out a final earth test. It is essential that all inspection chambers be properly completed before the final earth test.

f) The Civil Contractor's Electrical PE must submit 6 original copies of endorsed earthing certificate (Declaration of the Earthing System), test report/results, earthing mat design calculations and as-built drawings to the Engineer prior to the commissioning of station power supplies.

13.8   CABLE AND PIPE DUCTS

13.8.1   The position and requirements of all ducts shall be agreed in co-ordination with the Systemwide Contractors.

13.8.2   The ends of cable ducts shall be provided with bell-mouths to avoid possible damage to the cable.

13.8.3   UPVC shall not be used within the stations or tunnels and the Contractor shall specify an alternative material (example, ABS, FRE or approved equivalent) for cable ducts, sleeves, etc.

13.8.4   Spare ducts shall be provided for future use. The numbers (minimum 20% rounded up to the nearest whole number) and locations shall be agreed in co-ordination with the Systemwide Contractors.

13.8.5   Cable and pipe ducts shall be designed to allow maintenance of the services installed inside.

13.9   EQUIPOTENTIAL BONDING

13.9.1   The Civil Contractor and all Systemwide Contractors shall provide the necessary Equipotential Bonding (EPB) to meet all requirements of the Singapore Standard, CP5.

13.9.2   Items requiring EPB and their sizing requirements are detailed in Table 1 and 2 respectively.

13.9.3   Where EPB provisions are identified to be required in Table 1, the Civil Contractor shall provide the supplementary bonding to the nearest EPB conductor.

13.10 CABLE BRACKETS AND OTHER E&M FIXINGS IN TUNNELS

13.10.1 The position of all cable brackets and other attachments to the tunnel wall, provided or designed by another party, shall be agreed in co-ordination with that party.

13.10.2 Cable brackets and the like shall be aligned at right angles to the gradient of the tunnel.

13.10.3 In segmental concrete lined tunnels, the requirements of Clause 7.5.5 shall apply. Each cable bracket or other attachment shall be provided with sufficient adjustment (slotted holes or similar) or be provided with secondary fitments to ensure that the requirements of Clause 7.5.5 are upheld.

TABLE 1: SUMMARY OF EPB REQUIREMENTS

	Metallic Part	Comments
1	All incoming and outgoing service pipes such as water, fuel, dry riser, pumping main	Requires EPB. To be connected by a main EPB conductor to the earthing terminal as stipulated in CP5:1998, Cl. 413.2. See Figure 1. Pipe joints to be checked for electrical continuity otherwise bonding required. Pipes along the trainway to be insulated from its steel brackets to prevent leakage paths for stray currents.
2	Metal tanks	Requires EPB. May be connected electrically to incoming pipe. See Figure 2.
3	All metallic cat-walks, platforms, hand-rails, staircases, ladders within 1.8m reach of pipes, tanks, cable trays cable ladders, trunking etc which have EPB.	Requires EPB with supplementary EPB conductor connected to pipes, tanks etc. See Figure 2.
4	Any metallic catwalks, platforms, handrails, staircases, ladders etc with attached electrical cabling or fittings.	Require EPB with supplementary EPB conductor connected to exposed conductive part of fitting.
5	Any metallic catwalk, platform, handrail, staircase, ladder etc, without electrical cabling or fittings and greater than 1.8m from pipes, tanks etc.	No EPB required.
6	Metallic door frames/doors controlled by electromechanical locking mechanism	EPB required with supplementary EPB conductor connected to exposed conductive part of fitting only where voltage rating of lockset exceeds 50V.
7	Metallic supports to electrically operated equipment without direct electrical contact with the equipment	EPB required with supplementary EPB conductor connected to exposed conductive part (related electrical equipment). See Figure 3.
8	Electrically operated roller shutters	EPB required with supplementary EPB conductor connected to exposed conductive part (casing of roller shutter motor).
9	Metallic wall cladding (excluding VE)	EPB limited to panels and framework components containing, or immediately adjacent to, electrical socket outlet or other sources of electricity. Supplementary EPB conductor

		connected to exposed conductive part of fitting. See Figure 4. No EPB required for VE panelling. Details of wall cladding to be examined to ensure electrical continuity throughout.
10	Common trunking provided by Civil Contractor	EPB required with supplementary EPB conductor connected to nearest main EPB conductor.
11	Raised floor system	EPB required with supplementary EPB conductor connected to nearest earthed part (e.g., cable tray). Details of floor system to be examined to ensure electrical continuity between panels and between panels and supports.
12	Electrical facilities in toilets and shower rooms (e.g. hand-dryer, water heater, extract fan etc)	No EPB required.
13	Ceiling system	No EPB required.
14	Blast doors	No EPB required.
15	Exposed metallic parts of building structure, including roof trusses.	EPB required (as Cl 413,2 of CP5). To be connected to earthing terminal. However for roof trusses, may be connected to lightning conductor earth and no further EPB is required. Electrical continuity of structure to be checked.
16	Steel support beam to PSD	No EPB required.
17	Lifting beams and hooks	No EPB required
18	Framework of PSC and fixed metallic furniture within.	EPB required. To be connected to nearest earthed part (eg cable tray).

TABLE 2: SIZING REQUIREMENTS AS PER CP5: 1998, SECTION 547

Type	Size	Max	Min
Main EPB	½ Earthing Conductor	25 mm^2	6 mm^2
Supplementary EPB	½ Circuit Protective Conductor (cpc)	-	2.5 mm^2

Figure 13.1 - Distance between End Return and PSD > 1.8m

PSD end returns in swing open position

Platform public area

Insulation membrane to be extended 1.8m beyond the PSD assembly

Buffer area

Distance between the PSD door and end return (when swing open) > than 1.8m

Fixed panel shall be of non-metallic and non-conductive material

Physical gap between the PSD door and the fixed panels is essential and to be sealed off with insulation material

PSD Assembly

1) When end return door in open position and the distance between the end return and the PSD is more than 1.8m, the following are acceptable
   a) No coating to PSD end turn is required
   b) End return not necessary to be 'electrically floated'
   c) Insulation membrane needs to be extended 1.8m beyond the PSD assembly

Figure 13.2 - Distance between End Return and PSD < 1.8m

Detail A

PSD return door frame

See Detail A

Platform public area

PSD end return

All metallic components of the PSD end return need to be coated inclusive of door frame and handle

PSD end returns when swing open

Insulation membrane needs to be extended 1.8m beyond the PSD end return door

Distance between the PSD assembly and end return (when swing opened) < than 1.8m

Insulation coating

Fixed panel shall be of non-metallic and non-conductive material

Physical gap between the PSD assembly and the fixed panels is essential and to be sealed off with insulation material

2) When end return door in open position and the distance between the end return and the PSD is less than 1.8m, the following are required
   a) Coating to PSD end turn is required. (All metallic components of the PSD end return need to be coated with insulation material. Refer to Detail A above)
   b) End return need to be 'electrically floated'
   c) Insulation membrane needs to be extended 1.8m beyond the PSD end return door.

CHAPTER 14

STRAY CURRENT CORROSION CONTROL FOR RAILWAYS

14.1   INTRODUCTION

14.1.1   General

14.1.1.1   The Stray Current Corrosion Control (SCCC) system for steel wheel on steel rail Rapid Transit Systems (RTS) with d.c. traction supply shall have the following design objectives:

(a) Provide a SCCC system that will ensure a 120-year design life for railway structures.

(b) Provide facilities to monitor and mitigate the stray current effects on the RTS facilities and structures.

14.1.1.2   The criteria given below shall be used as a guide only. Each contractor shall evaluate the requirements for SCCC within his design, coordinate all relevant interface details with all necessary parties, and shall produce detailed design and drawings accordingly

14.1.1.3   The trackwork contractor shall take the lead in coordinating and producing an interface SCCC diagram for the entire line for coordination with all parties.

14.1.2   General Requirement

14.1.2.1   The SCCC system shall generally include the following:

(a) Isolation and/or control of all possible stray current leakage paths to minimise stray current effect on RTS and adjacent structures, public utilities and RTS services.

(b) Detection and monitoring of stray currents which do occur.

(c) Stray current drainage (collection) system which, when put into use, provides a return path for the stray current back to the traction substation negative busbar via drainage diodes.

14.1.2.2   The amount of stray current that will leak out from the track and power system shall be assessed by the Electrical Services contractor. Based on this amount of leakage current, the Civil Contractor shall prepare a quantitative analysis of the corrosion effects on the transit structure and appropriate provisions made in the design to ensure that the objectives given in Clause 14.1.1.1 are achieved.

14.2 SYSTEM REQUIREMENTS

14.2.1 Trackwork

14.2.1.1 The size of the running rails shall be adequately sized to reduce voltage drop in the running rails, which in turn will reduce leakage of stray current

14.2.1.2 The minimum track to structure earth resistance under dry and damp conditions shall be 10 ohm-km before any equipment/cables are connected. Where the measurement is carried out in smaller section, the measured resistance shall be normalised accordingly. E.g. for 500m length of track, the measured resistance shall be greater than 20 ohm (ie. 10 ohm-km/0.5 km). The minimum track to structure earth resistance can be achieved by the following methods as appropriate:

(a) Insulating pad beneath rails

(b) Insulation of rail fastenings

(c) Insulating pad beneath base plate

(d) At level crossings and similar locations, rail shall be sealed by a non-conducting filler section (Fig. 14.11)

14.2.1.3 The bottom face of running rails shall be at least 50 mm above the in-situ track concrete or ballast.

14.2.1.4 Guard rails on viaduct tracks shall be fixed on insulated fastenings. Guard rails shall be insulated from the running rails and include 20mm air gaps at every 18 metres approximately.

14.2.1.5 Permanent IRJs (complete with jumper cables) shall be provided at locations close to traction substations to segregate sections of track into electrically independent lengths to facilitate future track to earth resistance measurement. Cables shall be adequately sized based on the worst case scenario for the traction return current.

14.2.2 Elevated MRT Stations and Viaducts (Fig. 14.5 & Fig. 14.8)

14.2.2.1 The control of leakage at source shall be by insulation of the running rails as described in Clause 14.2.1 above.

14.2.2.2 Protection of viaducts against stray current corrosion shall also be provided by a high electrical resistant waterproof membrane above the structural concrete and below the ballast. The membrane shall be protected by concrete screed.

14.2.2.3 A stray current collection mesh typically formed of welded steel mesh shall be embedded in the concrete screed protecting the waterproof membrane for every track. Each panel of mesh shall be spot welded to the next to give good electrical continuity. The mesh shall be electrically continuous

over each viaduct span and over each cross-head (if applicable), but electrically separated from each other. The maximum electrical resistance of the mesh shall be less than 0.5 ohm per km.

14.2.2.4 A monitoring cable shall be welded to one end of each discrete mesh and connected to a drainage terminal box for stray current monitoring and drainage purposes.

14.2.2.5 A stray current drainage cable shall be installed along each trackway inter-connecting every drainage terminal box and terminating at the traction substation negative busbars via drainage panel.

14.2.2.6 Lightning earth electrodes shall not be used as reference electrodes for stray current monitoring. Instead a portable half-cell electrode shall be used.

14.2.3 Underground Structures (Fig. 14.6, Fig. 14.7 & Fig. 14.8)

14.2.3.1 The control of leakage at source shall be by insulation of running rails as described in Section 14.2.1 above.

14.2.3.2 In the second stage concrete under the track, a stray current collection mesh, typically formed of panels of welded steel mesh shall be installed. Each panel of mesh shall be spot welded to the next to give good electrical continuity over discrete lengths of 100m. At every 100m there shall be an electrical discontinuity created by leaving a gap of 100mm between successive lengths of mesh. The maximum electrical resistance of the mesh shall be less than 0.5 ohm per km.

14.2.3.3 A monitoring cable shall be welded to one end of each discrete mesh and connected to a drainage terminal box for stray current monitoring and drainage purposes.

14.2.3.4 A stray current drainage cable shall be installed along each trackway inter-connecting every drainage terminal box and terminating at the traction substation negative busbars via drainage panel.

14.2.4 At-Grade and Transition Sections (Fig.14.9)

14.2.4.1 The control of leakage at source shall be by insulation of running rails as described in Clause 14.2.1 above.

14.2.4.2 In ballasted track on transition structures between tunnel and viaduct, the stray current collection and monitoring system shall be of the form specified for viaducts in Clause 14.2.2 but with the welded steel mesh in lengths as specified for slab track.

14.2.4.3 For concreted track on transition structures between tunnel and viaduct, the stray current collection and monitoring system shall be of the form specified for underground structures in Clause 14.2.3.

14.2.4.4　No stray current drainage or monitoring provisions beyond that described in Clause 14.2.1 is required for ballasted at-grade sections of railway.

14.2.4.5　No utility pipe or service shall be located under the at-grade sections of railway.

14.2.5　Depots

14.2.5.1　The control of leakage at source shall be by insulation of running rails as described in Section 14.2.1 above as far as practicable.

14.2.5.2　The depot area should be electrically isolated from the main line by using permanent Insulated Rail Joints (IRJs) at appropriate locations. Remote control facilities should be provided to enable each IRJ to be bypassed to allow transfer of traction power to or from the depot in the event of substation power failure.

14.2.5.3　No monitoring or drainage system is required in the depot track area beyond that specified above.

14.3　SYSTEM COMPONENTS

14.3.1　Cabling

14.3.1.1　For underground stations and tunnels, low smoke, halogen free, fire retardant type cables with armouring shall be provided.

14.3.1.2　For above ground station and viaducts, fire retardant type cables with armouring shall be provided.

14.3.1.3　All cables shall have an insulation level of 1.8/3kV and be single core, multi-stranded copper conductor and XLPE insulated.

14.3.1.4　Cable sizes shall be as follows:

(a) Monitoring cable (from mesh to terminal box) – $35mm^2$ copper

(b) Drainage cable (inter-connecting terminal boxes) – $185mm^2$ copper

14.3.1.5　The location of the drainage cable shall be co-ordinated with the Electrical Services contractor.

14.3.2　Drainage Panels

14.3.2.1　A drainage panel shall be provided in each traction sub-station. It is used to provide a connection path between the drainage terminal box and the negative return box.

14.3.3 Drainage Terminal Boxes

14.3.3.1 Each drainage terminal box shall be provided with connection terminals for the monitoring cable and the drainage cable. Connections between terminals shall be provided within the box by tinned copper busbars or approved equivalent. The drainage terminal box shall be of stainless steel material and of IP65 construction with removable box cover.

14.3.3.2 Further details of the terminal box are shown on Figure 14.10.

14.3.4 Reference Electrodes

14.3.4.1 Zinc reference electrodes, two for each bound shall be installed in underground stations in the outer wall. Each zinc electrode shall be installed at each end of the station at convenient locations for connections to be made.

14.3.4.2 The zinc electrode interface terminal box (ITB), supplied by the Civil Contractor shall be of stainless steel material and of IP65 construction. The ITB shall be provided with removable box cover.

14.4 STRAY CURRENT LEAKAGE PATH CONTROL

14.4.1 General

14.4.1.1 No stray current leakage paths shall be formed between structural units, or between the structure and piped services, handrails and other metallic components located along the trainway. Dielectric insulation shall generally be provided to prevent stray current leakage.

14.4.1.2 No fixings or cabling for the trackwork shall affect the track insulation system or reduce substantially the track to earth/structure resistance.

14.4.2 Installations

14.4.2.1 Electrical insulation from the transit or depot structure is required for the following installations located along the trainway.

(a) Signalling equipment and/or their supports

(b) Platform Screen Doors

(c) Blue light station support frames and siding telephone support frames

(d) Metal pipes

(e) Lightning protection system to viaducts

(f) Earthing cables

(g) Sectionalising switches, high-speed circuit breakers and their supports

(h) Control boxes, test boxes, junction boxes etc and/or their supports.

14.4.3 Elevated Stations and Viaducts

14.4.3.1 The waterproofing and insulation membrane between ballast and structure concrete on the viaducts shall be a bonded system with minimum electrical resistivity of 5000 x 10^{11} Ω-cm and thickness not less than 2.5 mm.

14.4.3.2 Anchor bolts for viaduct bearings shall be isolated from the steel reinforcement in viaducts beams and cross-heads.

14.4.3.3 Any metallic handrail, fascia units, walkway and the like along the viaduct shall be electrically insulated from the steel reinforcement in viaduct beams and cross-heads.

14.4.3.4 Steel reinforcement and anchor bolts in concrete precast units used as fascia or similar shall not be in contact with the steel reinforcement of the viaduct beams.

14.4.3.5 The material of rainwater downpipes in columns shall be non-conductive.

14.4.3.6 Lightning down conductor (by others) shall be fixed with insulators to avoid electrical contact with steel reinforcement in cross-heads and columns.

14.4.3.7 An effective water drainage system shall be designed to prevent ponding of rainwater.

14.4.4 Underground Structures and Tunnels

14.4.4.1 Proper detailing shall be provided to prevent ponding of seepage water around track fastenings.

14.4.4.2 Handrails, walkways and other continuous metallic elements along the trainway shall be electrically insulated from the structure.

14.4.4.3 Tunnel segments shall be electrically separated from each other across all circumferential joints.

14.4.4.4 All non-railway metallic service pipes passing through or embedded within the RTS structure shall be insulated from the structure by a plastic sleeve.

14.4.4.5 Where zinc reference electrode is located, the structure rebar shall be extended as shown in figure 14.12. This is to allow the measurement of rebar potential with respect to zinc reference electrode be carried out to provide a basis for comparison of potentials in future. The probe shall be enclosed in a IP65 stainless steel box with removable cover and to be supplied by the Civil Contractor.

14.5 SYSTEM TESTING AND MONITORING
(refer to Fig. 14.1 to Fig. 14.4 and Appendix 2)

14.5.1 Track to Structure Earth and Water Earth Resistance

14.5.1.1 The track resistance against current leakage shall be measured with respect to:

(a) structure earth by means of the terminals from the stray current collection mesh (steel mesh).

(b) water earth by means of the earth connection in the substation.

14.5.1.2 The track to structural earth resistance measurements shall be taken at the following two stages:

(a) For newly laid track before any power and signalling trackside equipment and cabling are connected.

(b) For integrated track system when power and signalling trackside equipment and cabling are connected.

14.5.1.3 As far as possible, different track support system shall be separated electrically for testing and monitoring:

(a) Main line shall be separated from the depot tracks.

(b) Tracks on viaducts shall be separated from those on at-grade sections, transition sections or inside tunnels.

14.5.2 Stray Voltage Level Monitoring

14.5.2.1 The stray voltage level monitoring shall involve measuring the steel mesh potential with respect to a portable half-cell electrode.

14.5.3 Substation Drainage Current Measurements

14.5.3.1 Provision shall be made to facilitate the following measurements:

(a) Traction current at output of rectifier dc traction feeders for each bound

(b) Negative busbar to earth voltage

(c) Drainage current distribution and total drainage current.

14.5.3.2 These measurements will be taken at traction substations to check the system balance and to provide a basis for comparison of potentials.

14.5.4   Other Tests

14.5.4.1   In addition to the above, the following tests shall be performed:

(a) Track to stray current collection mesh resistance measurements

(b) Electrical continuity test of steel mesh

(c) Commissioning tests for reference electrodes

(d) Insulation test for insulated installations.

14.5 5   Test Procedures

14.5.5.1   The types, methods and procedures of all tests and measurements including the format for recording the test results shall be submitted to the Engineer for acceptance.

14.5.5.2   Effective fault finding methods shall be incorporated and the technical specifications of instruments and equipment used to locate stray current leakage paths shall be specified.

14.5.5.3   All rail potential measurements as well as all traction and drainage current measurements shall be taken over a 24-hour period during trial running to enable both the traction peaks and non-traction natural potential to be observed and recorded.

14.5.5.4   All test instruments and measurement charts are to be provided by the commissioning party.

14.5.5.5   Upon completion of a commissioning test, a Test Inspection Certificate shall be endorsed and submitted by the Registered Professional Engineer of the relevant contractor to the Engineer for acceptance.

14.5.5.6   All test programmes shall, unless otherwise specified, be submitted to the Engineer at least four weeks before the tests start.

Appendix 1: Stray Current Corrosion Control Requirements - Installation

Serial no.	Items	Underground tunnel and station	Viaduct/ At Grade	Depot	Design, supply, installation and commissioning to be carried out by * (see footnotes at Appendix 2)
1	Welded steel mesh to be installed under the track. External connecting terminals to be provided.	✔	✔	NA	TW (underground) C (viaduct/ at grade)
2	Monitoring cable from steel mesh reinforcement to the drainage terminal boxes to be provided. (see Fig. 14.1 to Fig.14.10)	✔	✔	NA	TW (underground) C (viaduct/ at grade)
3	Drainage terminal boxes and drainage cables interconnecting drainage terminal boxes to be installed along tunnel wall or viaducts. (see Fig. 14.1 to Fig 14.10)	✔	✔	NA	ES (Drainage Cable) TW (Monitoring Cable and Drainage Box)
4	Drainage cable from appropriate drainage terminals inside drainage terminal boxes to the drainage panel in the traction substation (see Fig. 14.1 to Fig 14.4)	✔	✔	NA	ES
5	Installation of stray current drainage units and all associated accessories at traction substations.	✔	✔	NA	ES
6	Installation of drainage cable supports	✔	✔	NA	TW (underground) C (viaduct/ at grade)
7	Zinc reference electrodes	✔ (at stations only)	NA	NA	C
8	Provision of insulating sleeves for all non-railway metallic service pipes entering or penetrating the railway structure	✔	✔	✔	C
9	Running rails to be insulated by the following methods as appropriate: a) Insulating pad beneath rails b) Insulation of rail fastenings c) Insulation beneath base plate d) At level crossings and similar locations, rail shall be sealed by a non-conducting filler section.	✔	✔	✔	TW

Serial no.	Items	Underground tunnel and station	Viaduct/ At Grade	Depot	Design, supply, installation and commissioning to be carried out by * (see footnotes at Appendix 2)
10	Bottom face of running rail shall be at least 50mm above the in-situ track concrete or ballast.	✔	✔	✔	TW
11	Depot electrically isolated from the main line system by using: a) permanent IRJs (Insulated rail joints) at appropriate locations on reception tracks b) third rail sectionalising by unbridgable gap adjacent to IRJs for segregation c) third rail and running rail sectionalising switches and associated works with remote control facilities.	NA	NA	✔	a) TW b) TW c) ES
12	Lightning down conductor strip to be fixed with appropriate insulator.	NA	✔	NA	ES
13	The following installation shall be insulated from the transit structure or depot structure: a) Signalling equipment and/or their supports b) Platform screen doors c) Blue light station and siding telephone supports d) Dry riser pipe e) Pumping mains, drainage pipes, and other piped services provided by the civil contractor f) Earthing cables g) Sectionalising switches, circuit breakers, control/ test/ junction boxes, etc	✔ ✔ ✔ ✔ ✔ ✔	✔ NA ✔ ✔ ✔ ✔	✔ NA ✔ ✔ ✔ ✔	SE SE CS, ES MS C ES, C, TW, SE, ES

Appendix 2: Stray Current Corrosion Control Requirements – Testing and Commissioning

Serial no.	Commissioning Tests	Commissioning Test to be carried out by * (see footnotes)	Remarks
1	Commissioning test for zinc reference electrodes	C	At stations only.
2	Electrical continuity test of welded reinforcement mesh (Electrical resistance shall not be more than 0.5 Ω-km)	TW (underground) C (viaduct/ at grade)	Measurements to be taken before concreting.
3	Track to structure earth resistance measurements in accordance with EN 50122-2 shall be carried out before E&M installation. (Eg. Signalling, point machines, etc.) (Pass Criterion shall not be less than 10 Ω-km)	TW	Measurements to be taken when the tracks are newly laid and before the installation of trackside equipment and cabling. (Refer to Table - Integrated System Electrical Test Requirements at trackwork interface in the General Specification)
4	Track to structure earth resistance measurements in accordance with EN 50122-2 shall be carried out after E&M installation is completed. (Pass Criterion shall not be less than 7.5 Ω-km)	TW ES, SE	Measurements to be taken after the installation of trackside equipment and cabling. TW shall be responsible for carrying out measurement only. (Refer to Table - Integrated System Electrical Test Requirements at trackwork interface of the General Specification) ES, SE shall assist TW to conduct measurements. ES, SE shall be responsible for all site preparation including cleaning, disconnection and reconnection of crossbonding cables for TW to carry out the measurement.
5	Test on all insulation for stray current corrosion control purposes under Appendix 1, Item 13 (Pass Criterion: Electrical insulation resistance shall not be less than 10 kΩ at test voltage of 250V d.c. For minimum insulation level of PSD, please refer to DC chapter 13.)	C, SE, ES	Individual contractors are required to carry out and furnish test records to confirm that the respective installations have adequate electrical insulation resistance values.

Serial no.	Commissioning Tests	Commissioning Test to be carried out by *	Remarks
6	Stray current measurement in traction substation: a) traction current at dc traction feeder for each bound b) negative busbar to earth voltage (rail potential) c) drainage current	ES	24-hr measurement to be carried out during trial running. See Clause 14.5.5.3
7	Stray voltage level measurement with respect to reference electrodes/half cell electrodes for steel mesh for stray current collection mesh (via monitoring cable)	ES	24-hr measurement shall be carried out during trial running, see Clause 14.5.5.3. Measurement results are for record purposes only. Extent of testing to be determined by the Engineer.

*Footnotes

* Legend to Appendix 1 and 2:

NA   = Not Applicable
C   = Civil contractor
TW   = Trackwork contractor
SE   = Signalling Equipment and Platform Screen Door contractor
ES   = Electrical Services contractor (inclusive of Power Supply)
MS   = Mechanical Services contractor
CS   = Communication System contractor
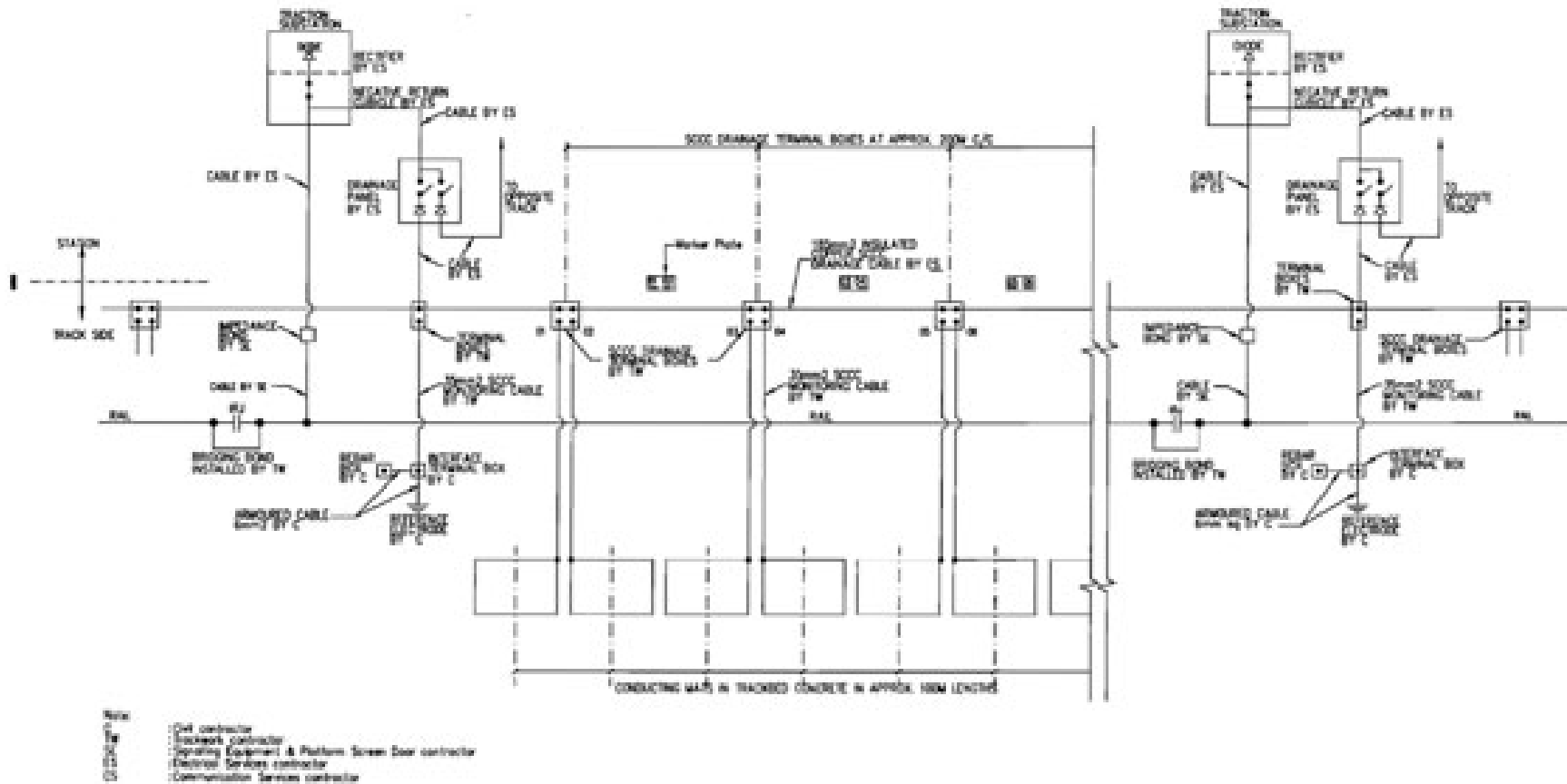
FIG. 14.1 – CIRCUIT DIAGRAM (NORMAL OPERATION)
STRAY CURRENT CORROSION CONTROL SYSTEM CONCEPT
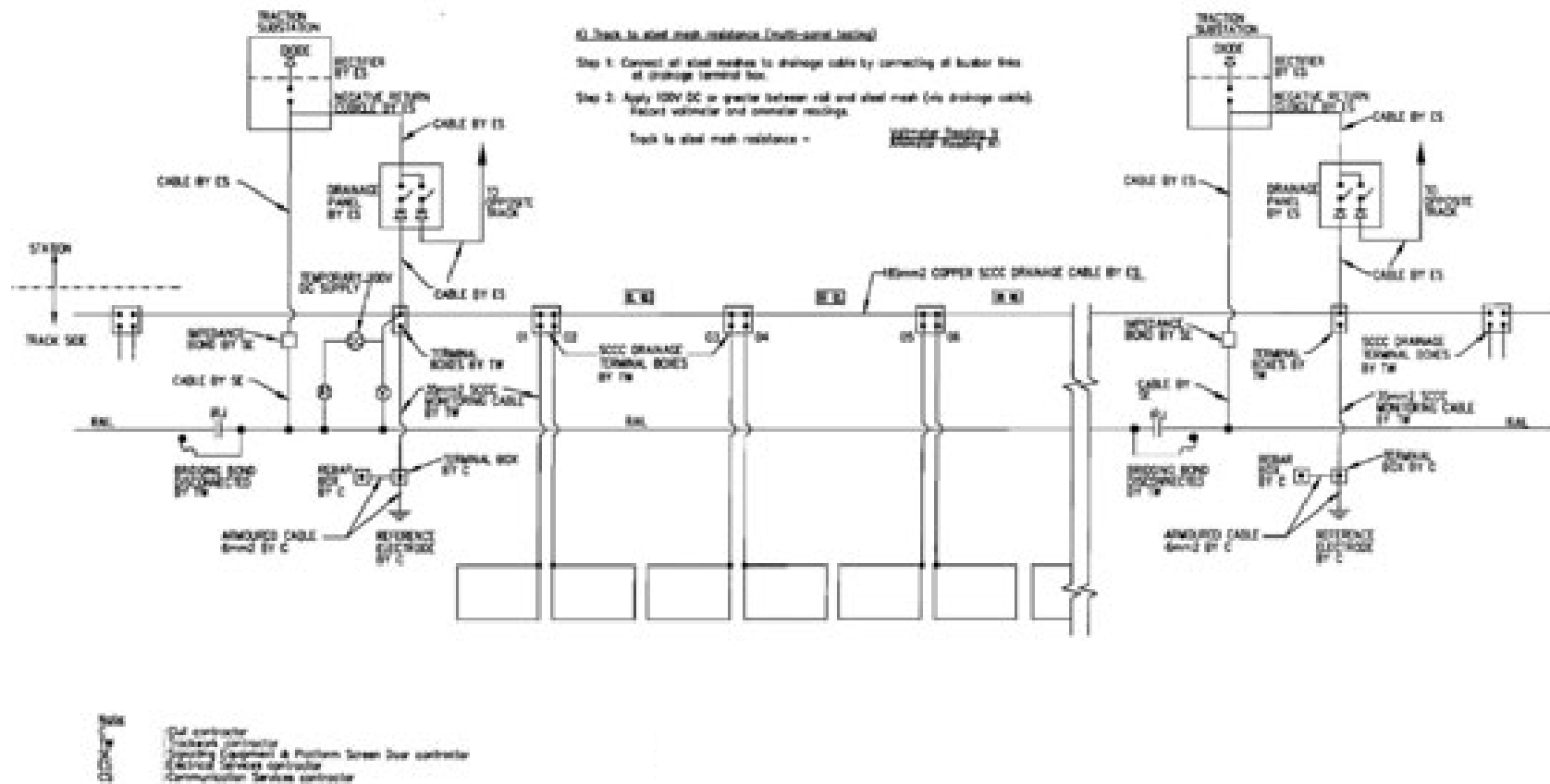
FIG. 14.2 – TESTING MODE (1) (MULTI-PANEL TESTING)
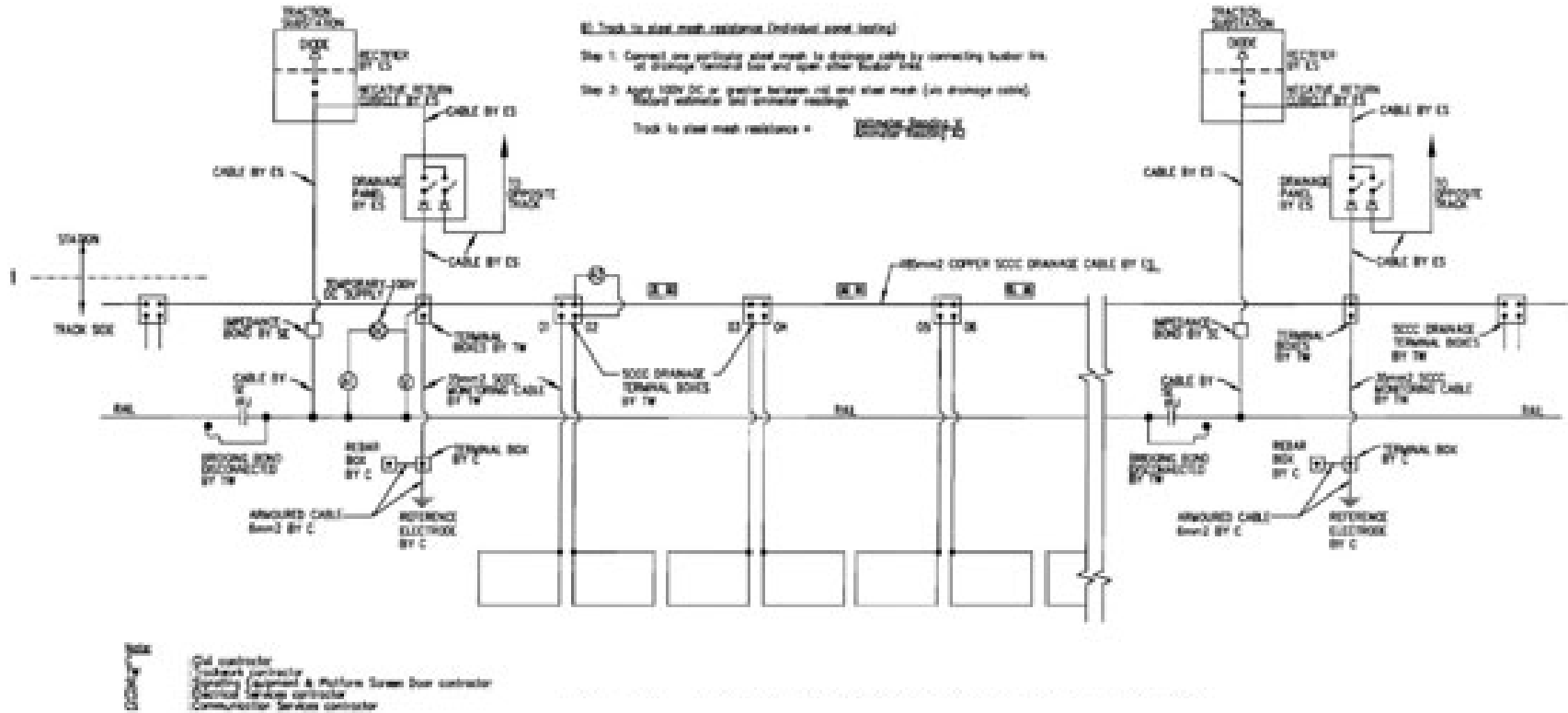
FIG. 14.3 – TESTING MODE (2) (INDIVIDUAL PANEL TESTING)

FIG. 14.4 – DRAINAGE MODE

SCCC Drainage Cable (185mm2 copper conductor)

SCCC Monitoring Cable run in pipe duct (35mm2 copper conductor by civil contractor)

SCCC Drainage Terminal Box

₵ Track

₵ Beam

Sleeper

Ballast

Cable support

Waterproof membrane

Exothermic welded or braced connection

Stray Current Collection Mesh (steel mesh by Civil contractor)
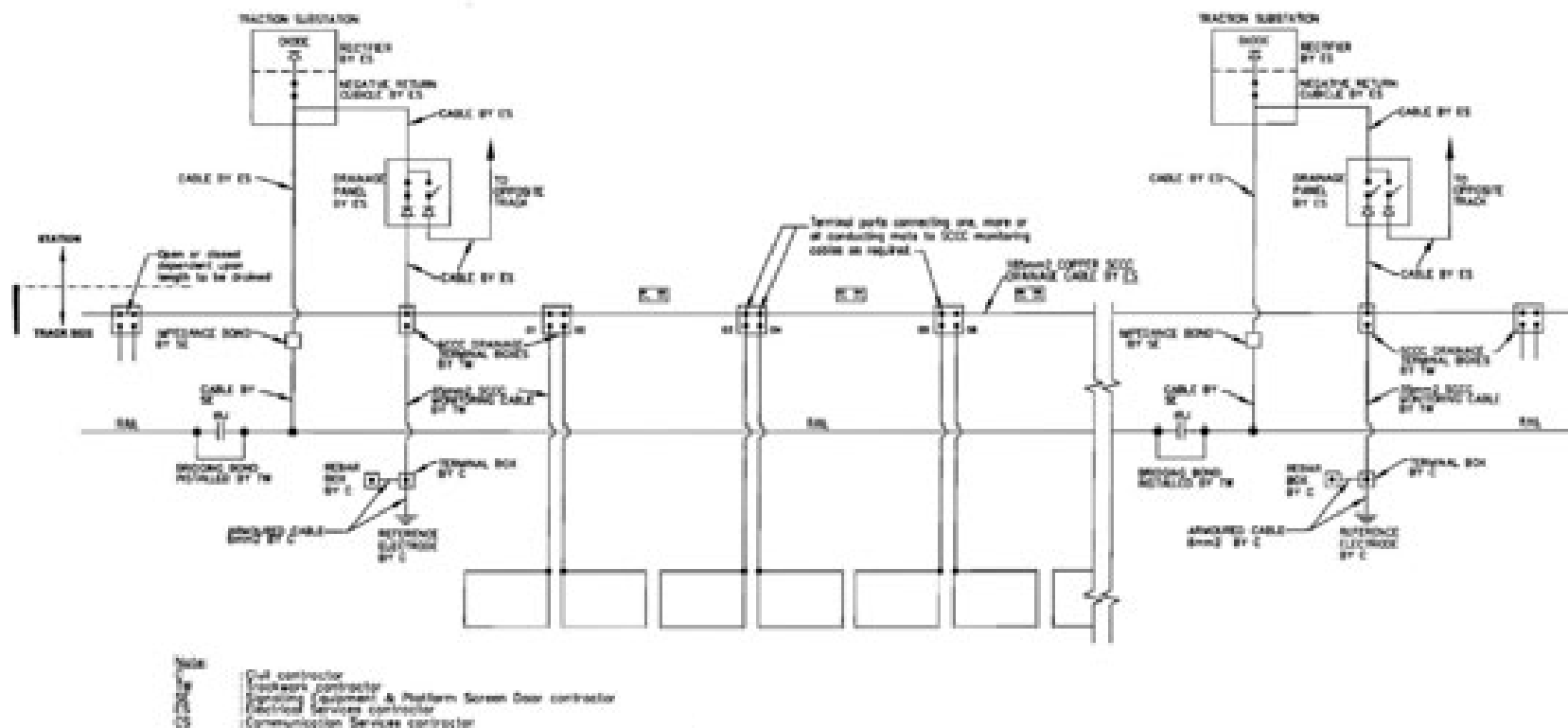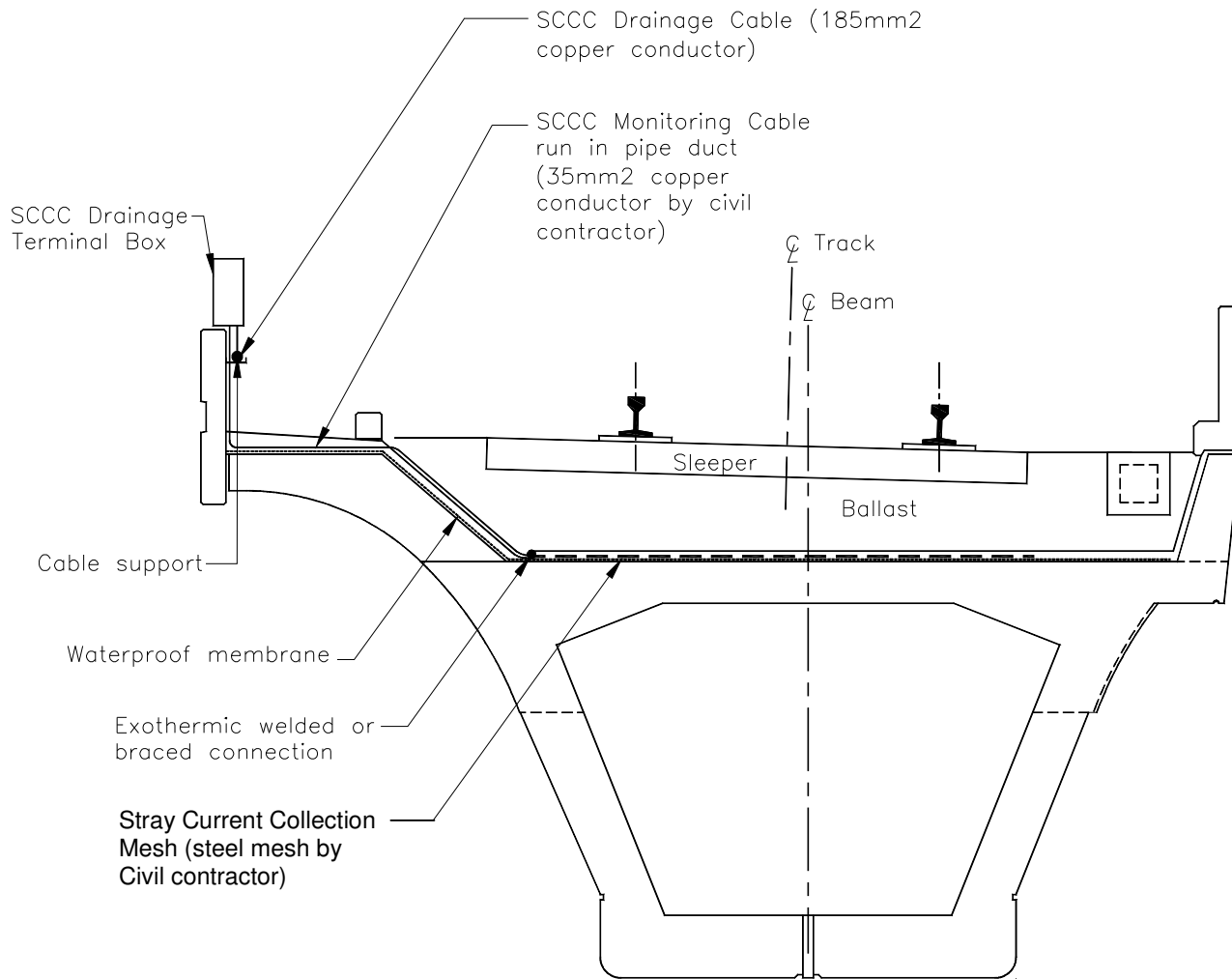
FIG. 14.5 – SECTION THROUGH VIADUCT

C Track

SCCC Drainage Cable
(185mm2 copper conductor)

Cable support

SCCC drainage terminal box

SCCC Monitoring Cable
(35mm2 copper conductor)

Exothermic welded or brazed connection

Stray Current collection mesh (steel mesh)
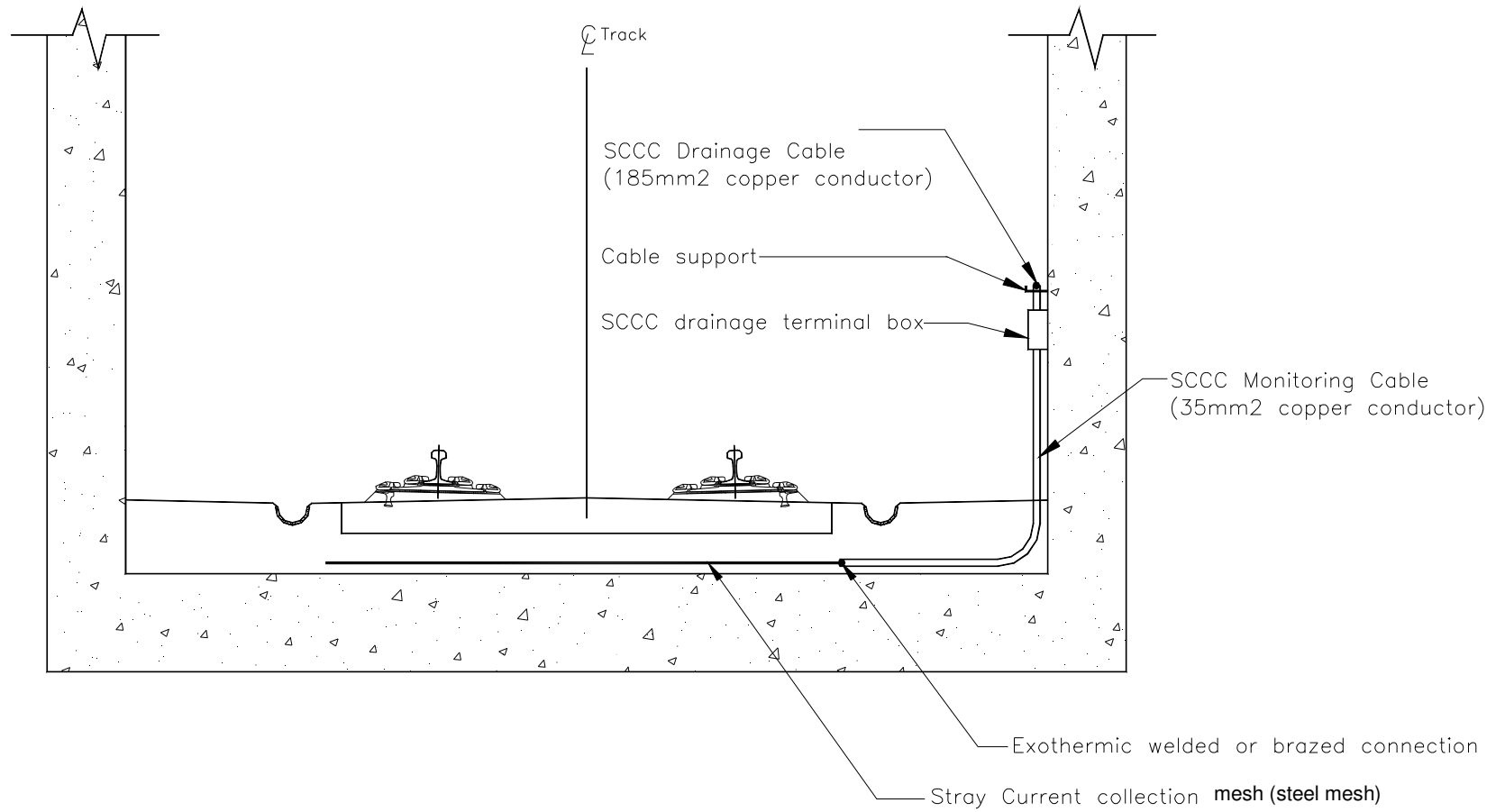
FIG. 14.6 – SECTION IN CUT AND COVER TUNNEL

C Track

SCCC Drainage Cable
(185mm2 copper conductor)

Cable tray

SCCC drainage terminal box

SCCC Monitoring Cable
(35mm2 copper conductor)

Concrete

First stage concrete

Exothermic welded or brazed connection

Stray Current Collection mesh
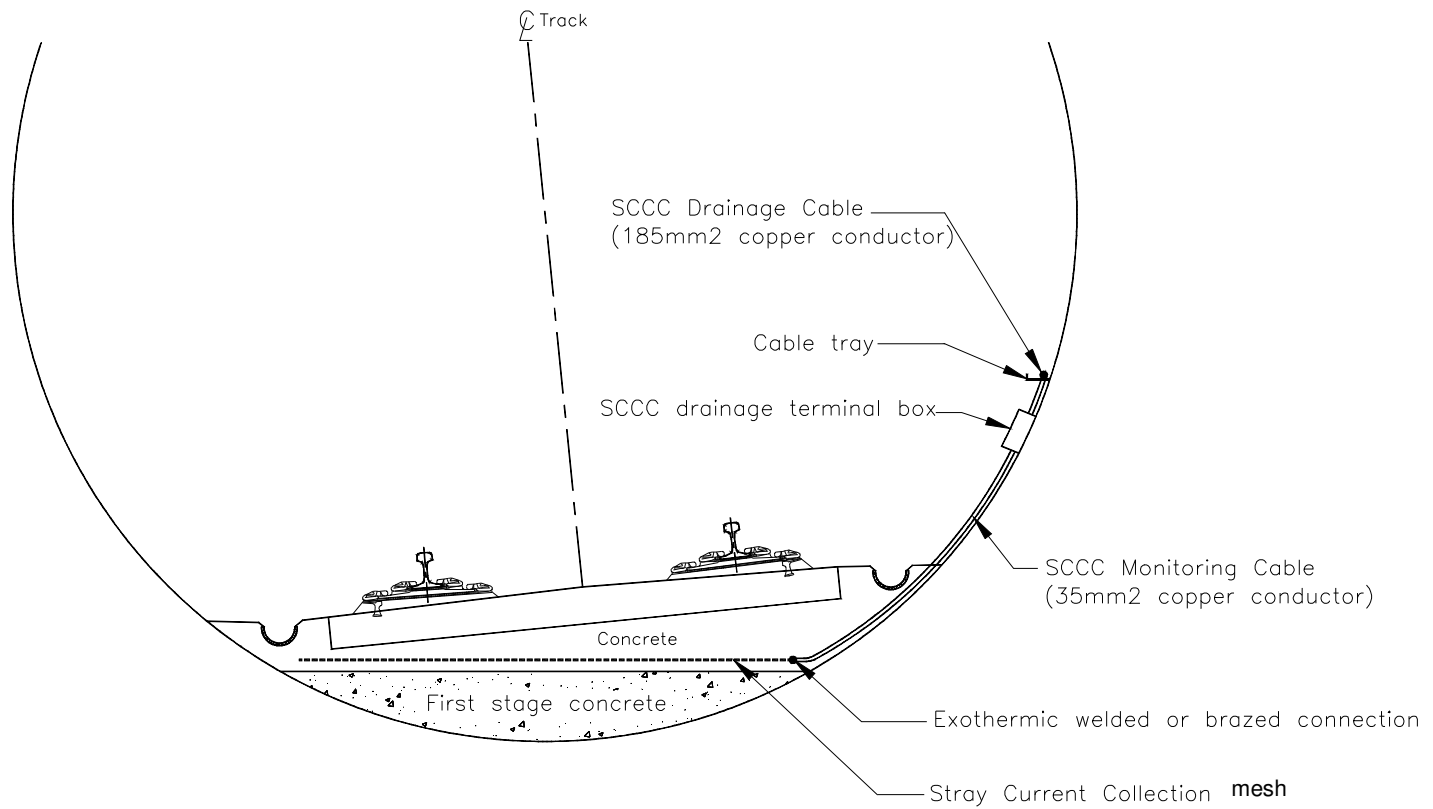
FIG. 14.7 – SECTION IN BORED TUNNEL

Pair of 35mm2 stray current monitoring cables to be Exothermic welded to plate.

Mesh to be welded throughout the overlapped length.

30x3000x6mm thk steel plate (Mesh to be welded to steel plate)

Track

10mm dia. 200 c/c Square Mesh

100mm gap at specified intervals (typically at 100m for track in tunnels and at the ends of 4 viaduct spans for track on viaducts)

300mm mesh overlapping length

FIG. 14.8 – STRAY CURRENT COLLECTION MAT (PLAN VIEW)

SCCC Drainage Cable
(185mm2 copper conductor)

SCCC drainage terminal box

SCCC Monitoring Cable
(35mm2 copper conductor by
civil contractor)

₵ Track

Sleeper

Ballast

Exothermic welded or brazed connection

Stray Current collection mesh (steel mesh)
by civil contractor)
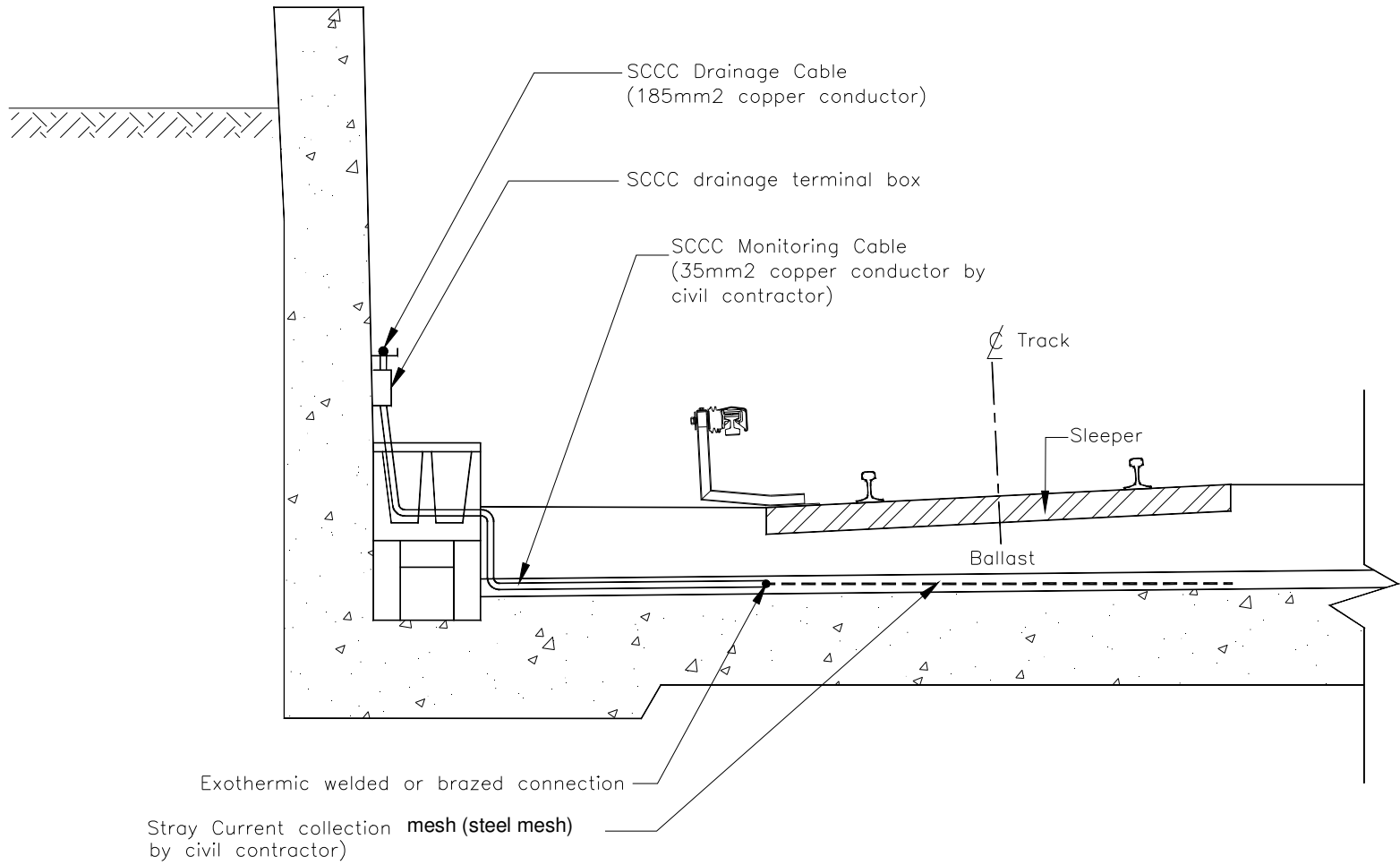
FIG. 14.9 – SECTION IN TRANSITION STRUCTURE

CABLE LUGS

REMOVABLE LINKS
TINNED COPPER BUSBAR

TERMINAL RAIL
(FOR CONNECTION OF
MONITORING EQUIPMENT
WHEN REQUIRED)

MONITORING CABLES

DRAINAGE CABLE

TYPICAL DRAINAGE TERMINAL BOX

GASKET

FRONT VIEW

SIDE VIEW
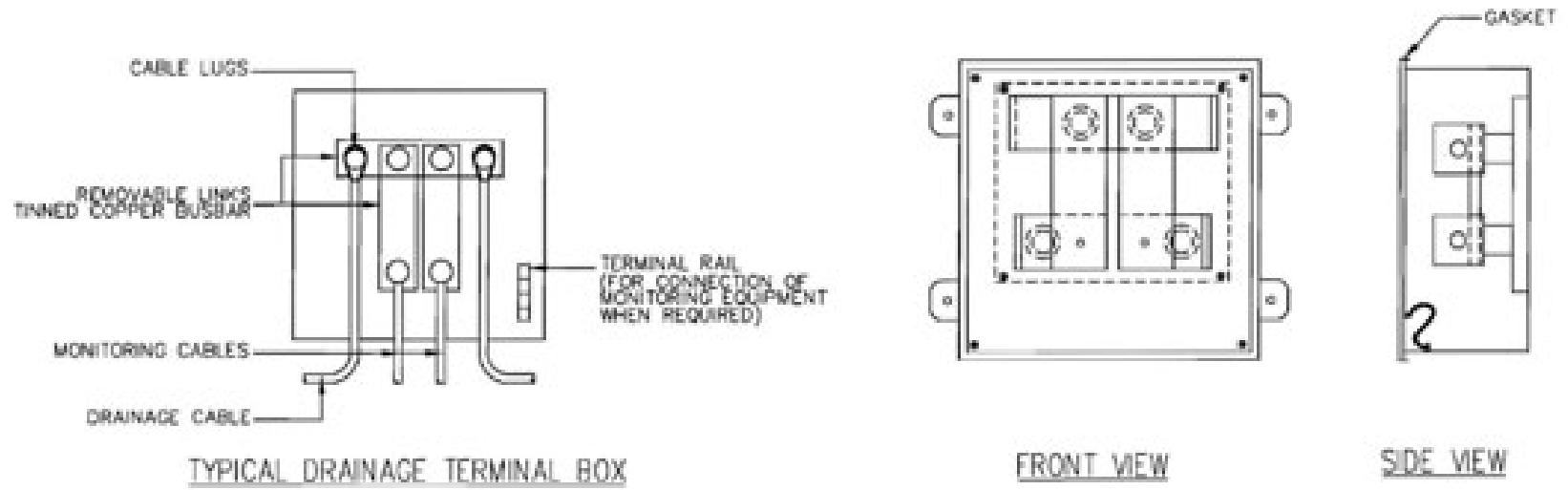
FIG. 14.10 – TYPICAL DRAINAGE TERMINAL BOX

NON CONDUCTING FILLER

RAIL FIXINGS

BASEPLATE FIXINGS
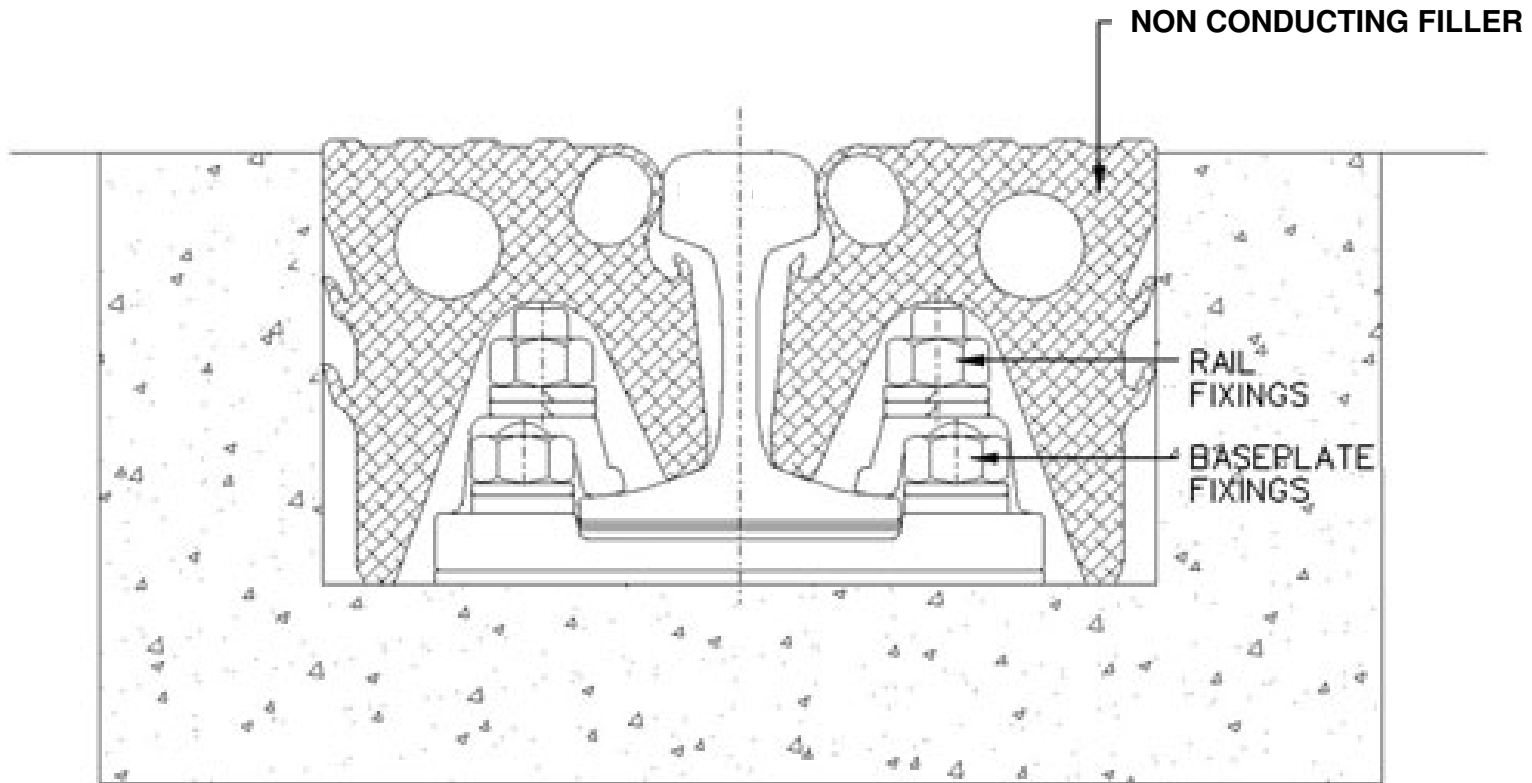
FIG. 14.11 CROSS SECTIONAL VIEW AT LEVEL CROSSING
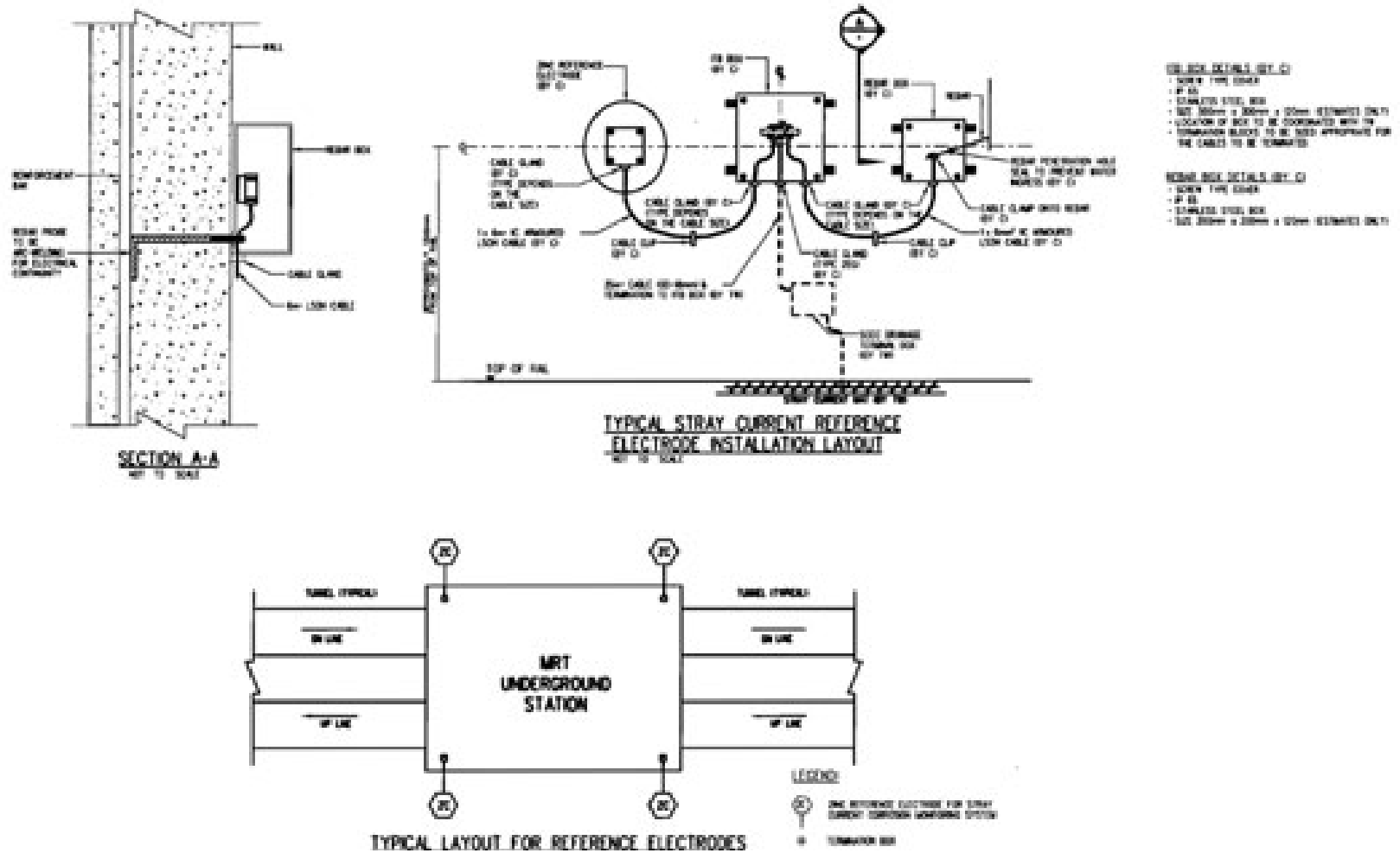
FIG. 14.12 – REBAR PROBE PROVISION DETAIL

CHAPTER 16

TEMPORARY EARTH RETAINING STRUCTURES

16.1   SCOPE

This Chapter covers the design requirements for Temporary Earth Retaining Structures (TERS) and its support system.

16.2   STANDARDS AND CODES OF PRACTICE

The design of TERS shall comply with the Building and Construction Authority's latest requirements.

The design of the temporary works shall also comply with BS8002, BS8081, SS CP4. Additionally, guidance from CIRIA Special Publication 95, CIRIA Reports C517 and C580 shall also be referred to in the design.

Reinforced concrete retaining walls including diaphragm walls, secant pile walls and contiguous bored piled walls shall be designed to SS CP 65. Structural steel works including sheetpile walls, soldier pile walls and steel strutting system shall be designed to BS5950.

16.3   LOADS

Surcharge load as defined in Chapter 3 (Loads) shall be used in the design of TERS.

16.4   DESIGN REQUIREMENTS

TERS shall be designed with the appropriate factors of safety that is not less than that of permanent works in accordance with the relevant codes of practice.

The groundwater level shall be considered at ground level for each stage of construction unless otherwise accepted by the Engineer.

The support system of the TERS shall be robust to ensure lateral stability of the excavation and control ground and wall deformation.

Continuous walers shall be provided to the TERS.

Capping beams shall be provided for contiguous bored pile walls and secant pile walls. Capping beams shall be provided for diaphragm walls where the reinforcement is not carried up to the top of the excavated

portion of the wall and where the first strutting level is placed at a level more than 2m below the top of the wall.

The design shall demonstrate that the toe-in depths of the TERS provide adequate passive reaction. The wall shall neither be overstressed, nor deflect excessively. Adequate protection shall be provided against the ingress of ground water into the excavation.

The design shall include, where appropriate, adequate precautions against base heave in soft clays during construction. Failures such as base heave, inward yielding, piping or blow-out, etc. shall also be considered.

The design shall include seepage analysis and assessments of settlements due to changes in piezometric pressures. The use of recharge wells shall also be considered in the design so as to limit any damage to adjacent buildings, structures and utilities.

The excavation support system shall be designed for appropriate stresses obtained from analysis which consider the full construction sequence through to final removal of the temporary works. The analysis shall consider appropriate boundary conditions and progressive changes in pore water pressures.

If the design of TERS are analysed by finite element or finite difference methods, relevant empirical evidence from similar excavations shall be referred to in support of the conclusions of the analyses.

The TERS shall be designed to accommodate the possible failure of an individual strut, tie rod or ground anchor at each and every stage of the construction works, in accordance with BS8002.

Unplanned excavation in accordance with BS8002 shall be allowed for in the design.

The design of TERS shall take into consideration construction tolerance and deviations due to site constraints. The design assumptions, allowable tolerances and deviations shall be clearly stated in the design documents and working drawings.

16.5   GEOTECHNICAL MODEL

The geotechnical model of the site shall be developed to provide a basis for the design of the works. The geotechnical model shall provide a coherent, three-dimensional (3-D) concept of how the major stratigraphic units and the groundwater relate to the structure being designed. The 3-D representation of the stratigraphy can be presented in contour plots or by other means acceptable to the Engineer. In hilly areas, the ground water level shall also be plotted using contours.

The geotechnical model shall be based on, inter alia:

- Information from a desk study;
- Information obtained from site walkover studies;
- Published information on the geology of Singapore and any available information on excavations or tunnels at or near the site
- Foundation records of nearby buildings;
- Site investigation carried out at the site and nearby, including boreholes, CPTs, insitu tests, geophysical surveys, trial pits and laboratory tests.

The appropriate sections to be used for the detailed design of the works shall be determined from the geotechnical model. Such sections shall not be taken directly from the geotechnical model or based on individual borehole logs. The design sections shall be derived from the geotechnical model, but with allowance for the variability and uncertainty involved in developing the model. The design shall include both 'moderately conservative' and 'worst credible' scenarios for the stratigraphy at each design section.

The geotechnical model shall be updated during construction as and when additional information is available. Information that shall be considered shall include, inter alia:

- Additional site investigation results;
- The logs from the installation of the wall, kingposts, piles, dewatering/pressure relief wells, monitoring instruments and any grouting or other geotechnical processes;
- Mapping of exposed ground during excavation.

If there is a variance between the model on which the design is based and the revised model, then the significance of the change in the model to the design shall be assessed. Where necessary, the design shall be amended to comply with the relevant codes and requirements, and to ensure that the construction can be carried out safely.

16.6   **GEOTECHNICAL PARAMETERS**

The geotechnical design parameters for each member or formation in each design section shall be based on:

- The results of laboratory testing;
- The results of in-situ testing;
- Inspection of the samples and cores;
- Back-analyses of excavations of a similar scale in similar ground as appropriate and available.

The design soil parameters used shall be clearly stated. Where the parameters have not been measured directly from field-testing, i.e., bulk

and shear modulus, a clear explanation must be given to justify the values used.

The development of the parameters shall also consider published information on that particular member or formation. Site specific data shall take precedence over general published information. However, general published information can be used as a reference to assess the reliability of the site specific data, provide a framework for interpretation and to supplement the site specific data.

Any finite element program used for the analysis of the TERS shall have the capability to demonstrate that the undrained shear strengths generated by the program are consistent with the strengths actually measured in the soil investigation (i.e. vane shear strengths and those derived from CPTs).

For the strength and stiffness of each unit in an area, the following must be determined:

- Moderately conservative values – A cautious estimate of the value relevant to the occurrence of the serviceability limit state. This value is considered to be equivalent to representative values as defined in BS8002.
- Worst credible values – Worst values that the designer reasonably believes might occur, i.e. values that are very unlikely.

Where the strength and/or stiffness vary with depth, its profiles with depth for both cases must be determined. Any lateral variations (e.g. edge of reclamations) should also be assessed and considered.

The soil parameters listed in Design Criteria Chapter 5 (Geotechnical Parameters) shall be considered as moderately conservative values.

16.7 STABILITY CHECKS

16.7.1 General

Stability checks of the proposed retaining system shall be carried out prior to any computer analyses of TERS.

16.7.2 Toe-in Depth

Toe-in stability check shall be carried out to determine the toe-in depth or embedment of the retaining walls to ensure that adequate passive resistance can be mobilised.

The check shall be carried out based on the method shown in Figure 16.7.2, unless otherwise accepted by the Engineer.

The minimum factor of safety as defined in Equation (1) shall be 1.0.

P_A = TOTAL RESULTANT ACTIVE PRESSURE

P_A1 = RESULTANT ACTIVE PRESSURE BELOW POINT (A)

$$\text{Factor of safety} = \frac{P_P * l_2}{P_{A1} * l_1 - M_S} \quad \text{Equation (1)}$$

where P_p is the total force on the passive side and P_{A1} is the total active force below the lowest strut at the active side and l_1 and l_2 are the lever arms for the total active force and passive force, respectively. M_s is the working moment capacity of the wall at the lowest strutted level. Moderately conservative values of the soil shear strength, c' and $\tan\phi$' or c_u shall be divided by 1.2 and 1.5, respectively, in deriving P_P and P_{A1}.

Figure 16.7.2 Check for adequacy of toe-in depth

16.7.3   Base Stability

The design of TERS for deep excavation shall include adequate precautions against base heave.

Base stability check shall be carried out to ensure that there is an adequate factor of safety against base failure in soft clay. This check shall be carried out based on the method in Figure 16.7.3(a): for narrow excavations, Figure 16.7.3(b): for wide excavations with flexible walls and Figure 16.7.3(c): for wide excavations with stiff walls in clay.

Checking of base stability shall be carried out not only for the final stage of excavation, but also for intermediate stages where layers of soft clay exist between ground level and the final formation level.

Where a stiff retaining wall is embedded into soil below the excavation depth, the Modified Terzaghi method shown in Figures 16.7.3(c) shall be used to calculate the factor of safety.

Factor Of Safety $= \dfrac{N_c * C_u}{\gamma * D + q}$ Equation (2)

where D is the depth of excavation, q is the surcharge, c_u is the moderately conservative value of undrained shear strength of the clay at the base, divided by a factor of 1.5, γ is the unit weight of the clay. N_c is the bearing capacity factor.

Bearing Capacity Factor for T>0.7B

Bearing Capacity Factor for T<or = 0.7B
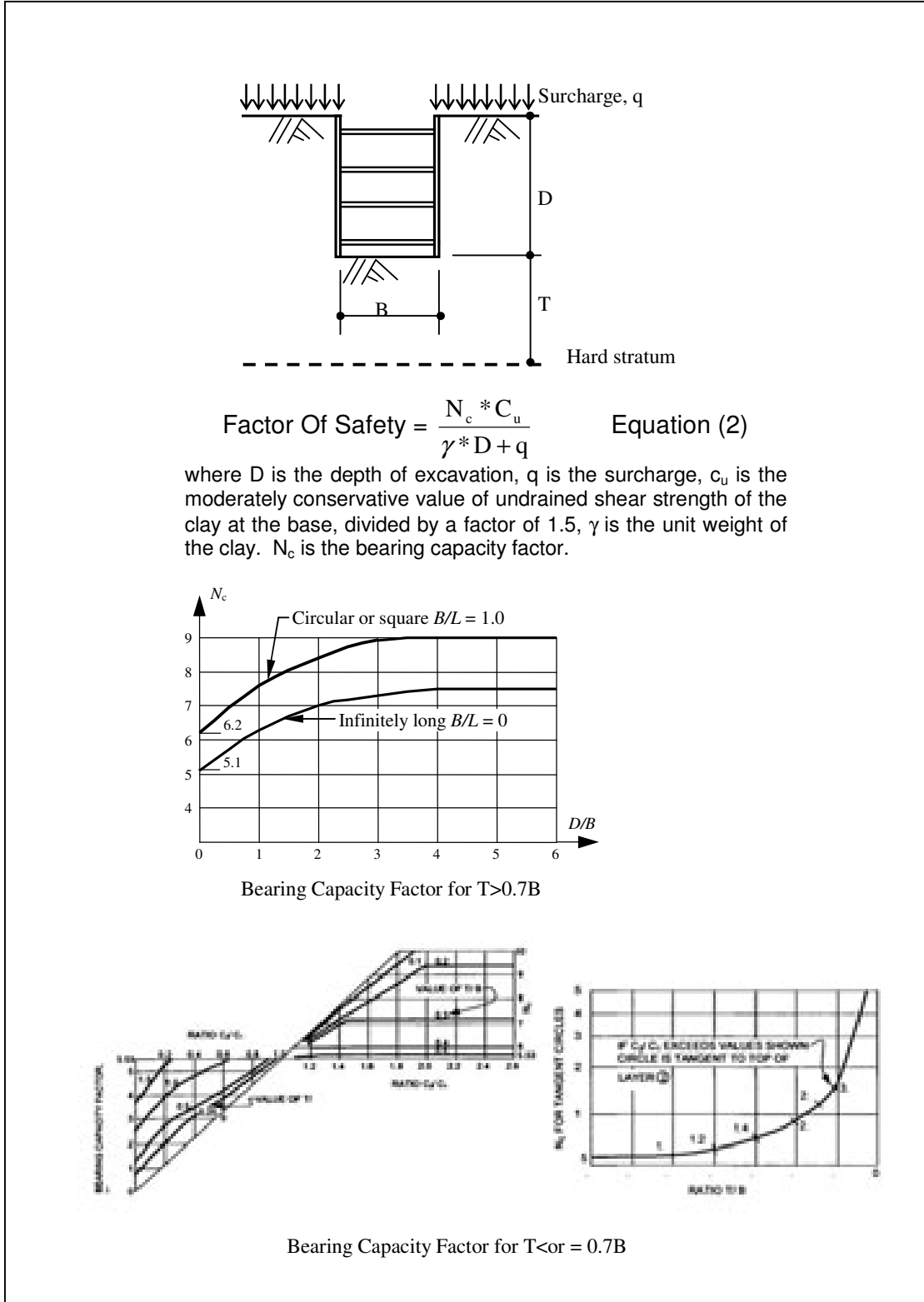
Figure 16.7.3(a)   Base heave checking for narrow excavations

$$FS = (5.7 \, c_{ub} \, B_1 + c_{uh} \, H) \, / \, (\gamma HB_1 + qB_1) \qquad \text{Equation (3)}$$

where C_{ub} is the average shear strength (based on moderately conservative value divided by 1.5) within the failure zone below the formation level, C_{uh} is the average shear strength (based on moderately conservative value divided by 1.5) above the formation level, B_1 is equal to 0.7B or depth to hard stratum, whichever is smaller, H is the maximum excavation depth and γ is the average bulk unit weight above formation level.

Figure 16.7.3(b)   Modified Terzaghi method for wide excavation with flexible walls, B> or = H

$$FS = \frac{5.7 \, c_{ub} \, B_1 + c_{uh} \, H + (1 + \alpha) c_{ud} D}{\gamma HB_1 + q \, B_s} \qquad \text{Equation (4)}$$

where α is the adhesion factor, $\alpha=1$; $B_1=0.7B$ or (T-D) whichever is smaller; T is clay thickness below formation level; and B_s is the width of surcharge loading where $B_s < B_1$, C_{uh}, C_{ud} and C_{ub} are the average shear strength (based on moderately conservative value divided by 1.5) within the zones, respectively, as shown above.

Figure 16.7.3(c)   Modified Terzaghi method for wide excavation with stiff walls in clay

The minimum factor of safety as defined in Equations 2 to 4 shall be 1.0.

16.7.4   Hydraulic Uplift

Hydraulic uplift check shall be carried out to ensure that the base of the excavation would not "blow out". This check shall be carried out in accordance with Figure 16.7.4. The minimum factor of safety as defined in Equation (5) shall be 1.2.

Standpipe

k_1

k_2

γD

D

U

$$\text{Factor of Safety} = \frac{\gamma D}{U} \qquad \text{Equation (5)}$$

where γ is the saturated unit weight of the soil, D is the depth of soil cover from the formation level to the bottom of marine clay.
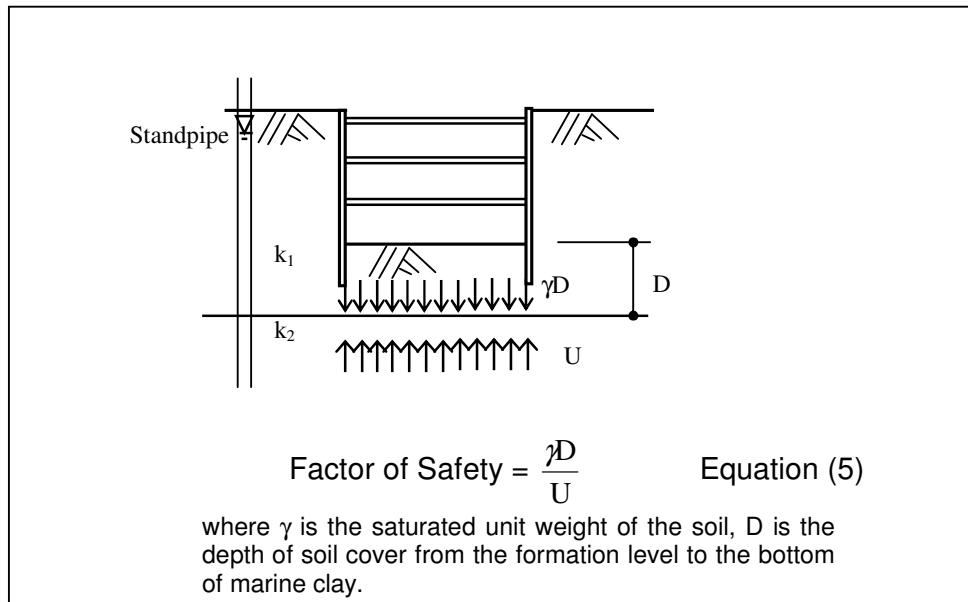
Figure 16.7.4   Factor of safety against hydraulic uplift.

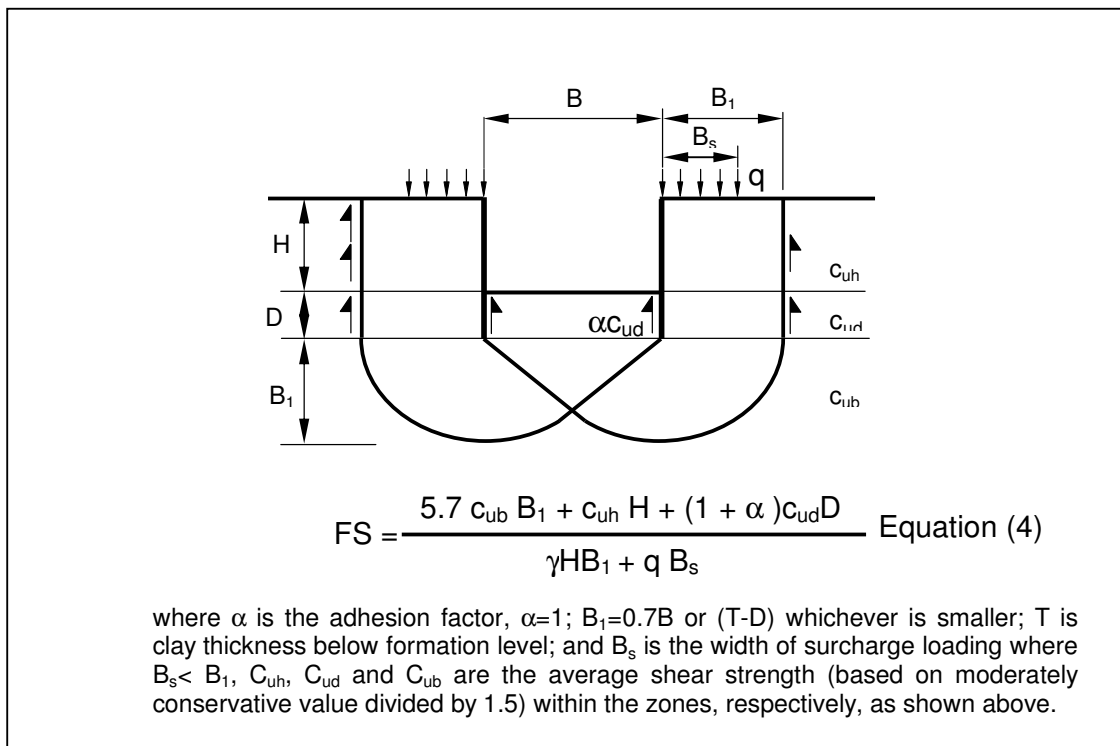Where necessary and appropriate, hydraulic uplift must be checked for intermediate levels to ensure that there is adequate factor of safety. Any development of pore pressures as the excavation progresses shall also be continuously monitored.

Where necessary and appropriate, relief wells shall be used inside the excavation.

The design shall also check for piping, where appropriate. This check shall be based on seepage analysis of the section such that the seepage force is less than the effective unit weight of the soil. The seepage force is equal to the hydraulic gradient times the unit weight of the soil.

—

16.7.5 Longitudinal Slope Stability

For long excavations, it is common to excavate along longitudinal directions with slopes. Struts and king-posts are installed progressively in bays. Analyses shall be carried out to ensure that the internal slopes in the longitudinal direction have factors of safety of not less than 1.2 and that the excavation support system will not be adversely affected by slope failures.

16.7.6 Bearing Capacity under Vertical Load

The vertical bearing capacity of the walls shall also be checked to ensure that the factor of safety against bearing capacity meets the requirement in Chapter 6 (Foundations, Permanent Retaining Structures And Earthworks). All vertical loads, including, inter alia, the weight of wall, capping beams, struts, slabs, walers and decking, the vertical component of force from angled struts or anchors and other temporary or permanent works that may be applied to the wall during the stages of excavation and construction are considered in the design, together with any surcharges that may be applicable.

16.8 USE OF FINITE ELEMENT OR FINITE DIFFERENCE MODELLING TECHNIQUES

For each type of FE or FD model used, the analysis shall be checked using close-form solutions to verify the design approach and to validate the results.

All assumptions made in the FE or FD model shall be clearly stated. The limitations of the FE or FD programs shall also be highlighted.

The selection of an appropriate constitutive model and the failure criteria of the soil model used must be clearly identified, together with a justification for their use. The influence of the model type on the design shall be assessed.

It shall be demonstrated that the boundary conditions have no significant influence on the results of the program.

Evidence shall be provided to demonstrate a step-by-step approach to the modelling. The initial equilibrium conditions for a model shall be demonstrated. The rate of convergence and the final out-of-balance forces at each stage of the construction sequence shall also be provided.

Where structural elements have been used within a FE or FD model, their material properties, connection details and a justification for their use shall be provided.

16.9   GEOTECHNICAL DESIGN

For marine and fluvial clays that have a permeability of 1×10^{-8} m/s or less undrained analysis using undrained shear strength shall be carried out. However, some degree of swelling within the excavation and consolidation outside the excavation will take place. These shall be assessed and its effects considered in the design.

For fluvial sands, drained analysis using effective stress parameters shall be carried out.

For other soil types, both drained and undrained analyses shall be carried out. The design shall be based on the more onerous case.

Wherever possible, relevant empirical evidence from similar excavations based on local Singapore experience must be referenced to, wherever possible, in support of the conclusions of the analyses.

16.9.1   'Best Estimate' and 'Worst Credible' Predictions

The design of the TERS shall be based on both 'best estimate' and 'worst credible' predictions, where

- *'Best estimate' prediction* – best estimate of what will actually be observed at various stages of the excavation, using moderately conservative values of the design parameters.

- *'Worst credible' prediction* – prediction using the worst credible values of the design parameters and soil profiles.

16.9.2   Sensitivity Analysis

The design and any associated FE or FD modelling shall not rely merely on a "one-off" analysis, in which a single set of geotechnical parameters is used.

Sensitivity analyses shall be performed and submitted as part of the design to demonstrate that the design and the model are not unduly sensitive to variations in any of the input parameters. As a minimum, the following parameters shall be evaluated:

(a) Shear strength
(b) Soil stiffness
(c) Pre-loading forces
(d) Over-excavation (NOT Unplanned-excavation)
(e) Consolidation parameters
(f) Ground treatment strength and stiffness (where applicable)

It shall also be demonstrated that the model is not unduly sensitive to any other variable for which assumptions are made within the FE or FD model.

Should the results be sensitive to any parameters, the selection of these parameters should be carefully evaluated, and the selected values for the parameters shall be conservative and be able to cover the likely scenarios occurring on site.

16.9.3   Back-Analysis

Back-analysis shall be done comprehensively with careful reviews of all design assumptions and the actual monitored behaviour of the structures.

The review of design assumptions shall include appropriateness of the models used in the original design, soil parameters, soil profiles encountered, construction sequences, drainage conditions on site and the wall stiffness. Any changes or revisions in the back-analysis shall not be arbitrary. There shall be clear rationale and substantiation, for example field or laboratory tests or additional evidence from construction records, for any changes in the model parameters.

16.9.4   Submission of Results

The submission shall include, *inter alia*, a clearly annotated printout of all legends used for the FE or FD model, soft copies of input files and plots showing the rate of convergence and final out of balance forces for each model.

The results of the analyses shall be presented in a clear, concise format. An outline format shall be submitted to the Engineer for acceptance before any design submissions are made. If necessary the format shall be revised during the design phase to ensure that the results of the analyses can be presented in a fashion which is clear and easily reviewed.

16.10   STRUCTURAL DESIGN

The retaining wall shall be designed to resist the best estimate bending moment and shear force with a factor of 1.4. A check must also be made that the wall is capable of resisting the bending moment and shear force corresponding to the 'worst credible' predictions with a factor of 1.2.

The support system shall be designed to resist the best estimate reaction with a factor of 1.4. A check must also be made that the support system is capable of resisting the reaction corresponding to the 'worst credible' predictions with a factor of 1.2.

The design of the support system shall allow for:

a)   Accidental load not less than 50kN applied normal to the strut at any point in any direction, unless otherwise demonstrated by risk assessment;

b)   One-strut failure;

c)   Temperature loads of a minimum temperature difference of ±10°C.

The design of struts, walers and strut/waler connections shall take into account of eccentricity in transfer of load from the waler to the strut. For walers made from a single section UC or UB, the eccentricity shall be taken as not less than 10% of the overall dimension of the strut in the vertical plane. Where the walers are constructed from twin beams the eccentricity in the vertical plane shall be half the distance between the webs of the two beams.

All restraints to struts shall be designed to resist 2.5% of the axial force of the strut, in addition to any loads carried by the restraints. Any bracing system that provide restraint to more than one member shall be designed to resist the sum of the restraint forces from each member that they restrain, reduced by the factor K_r obtained from:

$$K_r = (0.2+1/N_r)^{0.5}$$

where N_r is the number of parallel members restrained.

Kingposts shall be designed as an unbraced column if no triangulated bracings are provided. The effective length of embedded kingpost shall be determined from analysis to derive the position of fixity below the ground.

Buckling and bearing checks shall be carried out for all strut/waler connections. Adequate stiffeners shall be provided to prevent web buckling. Where the flange through which the load is applied is not effectively restrained against lateral movement relative to the other flange, the effective length of the web shall be taken as greater than or equal to 1.5d, where d is the depth of web.

16.11   TEMPORARY GROUND ANCHORAGES

The term 'ground anchorage' shall be as defined in BS 8081.

Any anchorage which has had an external load applied to it as part of the installation process shall be designed and constructed to be destressed before it is buried or covered by any part of the permanent works.

All anchorages, which are installed either wholly or in part outside the Railway Area or Road Reserve shall be made of non-metallic material or shall be designed to be removable as far as practicable to the acceptance of the Engineer.

The testing of ground anchorages as specified in the M&W Specifications shall be clearly indicated in the drawings.

16.12   GROUND TREATMENT

Where ground treatment is used, the design of the TERS will be highly dependent on the strength and stiffness of the treated ground. Depending on the geometry of the excavation and the ground treatment, the highest moments or shear forces can result from the highest likely values of strength and stiffness for the treated ground. It is necessary to consider the full range of strength and stiffness values for treated ground in the design.

The impact due to the scatter of strength and stiffness of treated ground shall be considered in the design. Sensitivity analysis shall be carried out taking into consideration the upper bound and lower bound strength and stiffness of the treated ground. The design shall base on the bending moment and force envelopes using the upper bound and lower bound parameters of treated ground.

There shall be no tension in the treated ground at all stages of construction.

The strain in treated ground shall be less than the strain at failure, unless the 'post-peak' behaviour is justified by testing and considered in the analysis.

The minimum requirements for the treated ground, such as strength and stiffness parameters, shall be clearly specified on the relevant drawings.

16.13   DESIGN FOR REMOVAL OF TEMPORARY EARTH RETAINING STRUCTURES

All TERS shall be designed for removal. Where TERS are to be removed, suitable methods shall be employed to minimise the ground settlement resulting from extraction.

All TERS that are not removed shall be designed to be broken out/cut off to a depth of 2 metres below the finished ground level unless shown otherwise on the Authority's Drawings. This shall also apply to all secant and diaphragm walls including guide walls.

Details of the construction sequence assumed, identification of the TERS that are not removed (if any) and provisions made in the design to satisfy the above requirements shall be detailed on the TERS drawings. The TERS not being removed shall also be shown on the as-built drawings. Any TERS that are not removed shall be agreed by the land owner.

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2. CIRIA (1993) Special Publication 95. The Design and Construction of Sheet-piled Cofferdams. Construction Industry Research and Information Association, London, UK.

3. CIRIA (1999) C517. Temporary Propping of Deep Excavations – Guidance on Design. Construction Industry Research and Information Association, London, UK.

4. CIRIA (2003) C580. Embedded Retaining Walls – Guidance for Economic Design. Construction Industry Research and Information Association, London, UK.

5. NAVFAC DM 7.2 (1982). Foundations and Earth Structures. Design Manual 7.2, Department of the Navy, Naval Facilities Engineering Command, Alexandria, VA 22332, USA.

6. Wong, K.S. & Goh, A.T.C. (2002). Basal heave stability for wide excavations. 3rd International Symposium on Geotechnical Aspects of Underground Construction in Soft Ground, Toulouse, France.

CHAPTER 18

IRRIGATION SYSTEMS

18.1 REGULATIONS, CODES AND STANDARDS

The design, manufacture, supply, installation, testing and commissioning of Irrigation Systems shall be governed by all applicable local codes of practice, regulations, standards and requirements issued by all local government and statutory authorities, agencies and service providers which shall include the following:-

(a)   National Parks Board   Nparks
(b)   Productivity and Standards Board   PSB

18.2 DESIGN CRITERIA

18.2.1   Manual irrigation system shall be designed to provide irrigation to the planting troughs, planting strips and landscape areas. The system shall comprise of coupling inlet, distribution pipe network and emitter systems e.g. sprinkler pipes, sprinkler heads and stream bubblers.

18.2.2   The mobile water tanker shall pump the water through the coupling inlet to deliver the water into the manual irrigation system. The pumping capability of the mobile water tanker shall govern the water flow rate and pressure head delivered into the system. Suitable pipe sizes and ball valve controls to distribute water to different respective irrigation zone at different time interval shall be incorporated in the system design.

18.2.3   Coupling inlet shall preferably be mounted to the column of the bridge and flyover, etc. Alternatively, it can be housed in a pit flushed to ground level with a hinged metal cover subject to the authority's acceptance. Location of the coupling point has to be within a radius of 8m from the mid-point of the lay-by and shall be easily and safely accessible by mobile water tanker.

18.2.4   Water filter shall be incorporated when sprinkler heads and bubblers are used. The filter shall be corrosion resistant with filter housing made of stainless steel grade 316. The filter shall be installed after the coupling inlet, easily accessed, removed and cleaned by flushing with water.

18.2.5   Pedestrian Overhead Bridge (POB)

The emitter systems shall be provided as follows:-

a) POB less than 25m long, 25mm stainless steel sprinkler pipe (5mm diameter holes provided at 200mm centre to centre along the bottom of the pipe) fixed to the inner wall of the trough that abuts the platform and above the soil level.

b) POB between 25m to 50m long, 25mm stainless steel sprinkler pipe (3mm diameter holes provided at 400mm centre to centre along the bottom of the pipe) fixed to the inner wall of the trough that abuts the platform and above the soil level.

c) POB exceeding 50m long, multiple pipe system of 25mm stainless steel sprinkler pipe (3mm diameter holes provided at 400mm centre to centre along the bottom of the pipe) with ball valves to channel water to different pipes. The pipes shall be fixed to the inner wall of the trough that abuts the platform and above the soil level.

d) One coupling point for each POB shall be provided unless otherwise accepted by the relevant authority.

18.2.6 Road Bridge, Vehicular Viaducts, Underpasses and Flyovers

The emitter systems shall be provided as follows:

a) Planting troughs: Stream bubblers shall be used to irrigate the plantings. The bubblers are fed via distribution pipes buried within the soil and spaced evenly along the planting trough. The bubblers shall protrude out 50mm approximately above the final planting soil level.

b) Planting strips and landscape areas: Sprinkler heads shall be used to irrigate the plantings. The sprinkler heads are fed via distribution pipes buried within the soil and located according to the planting arrangements.

c) The irrigation coverage, operating capacity and installation location of the emitters shall meet the watering intensities and duration required for the plants subject to authority's acceptance.

18.3 SPRINKLER HEADS AND STREAM BUBBLERS

a) The operation of the sprinklers and the stream bubblers shall be vibration free and shall not produce any back splash.

b) The sprinkler head and stream bubbler shall be constructed of UV-resistant plastic and stainless steel grade 304 or 316 parts.

c) The sprinkler head shall produce a fine spray of water of even distribution over the entire area of coverage. Low precipitation irrigation sprinklers are preferred. Each pop-up body shall have a filter screen and a wiper seal.

d) The bubblers shall provide consistent and precise flow rate compensating for pressure variation caused by terrain elevation or friction loss.

18.4   PIPES AND FITTINGS

18.4.1   Materials

a) The main and lateral underground pipes shall be heavy duty UPVC conforming to SS 141, Class E.

b) Stainless steel pipes and fittings conforming to BS4127: Part 2, Grade 304 shall be used for the exposed piping.

c) Heavy duty UPVC conforming to SS 141, Class E pipe sleeves shall be provided where pipes pass through walls or run under road (concrete encasement of 100mm thickness shall be provided). There shall be a minimum of 20mm clearance between pipe outside diameter and sleeve inside diameter. The space caulked with a soft non-setting waterproof mastic compound to give airtight seal.

18.4.2   Pipe Supports

a) All steel hangers, supports, anchors, bolts, nuts, washers shall be hot dip galvanised.

b) Supports shall be provided at spacings not exceeding the values specified in the table below unless otherwise indicated:-

MATERIAL OF PIPE	DIAMETER OF PIPE IN MM	MAX. SPACING OF SUPPORTS (Hori. run in m or vert. run in m)
Stainless Steel Pipe	20 - 25	2.5
	32 - 50	3.5

18.5   PIPE INSTALLATION

a) All pipes shall be rigidly anchored and supported with hangers and supports. Each length of pipe and each fitting shall be thoroughly cleaned out before installation.

b) Pipework shall be provided with sufficient flexible coupling for all forces and movements and detachable couplings for easy dismantling and assembly during maintenance.

c) Any open ended pipe or pipe connection left overnight or for any considerable period shall be protected from the entry of dirt, sand, etc. by the fixing of approved plastic or galvanised iron sheet cap securely held.

d) All exposed pipework shall have clearance of approximately 75mm from walls, ceilings or slabs. Pipe joints or fittings shall not be permitted within the thickness of walls and slabs.

e) Pipework shall be installed with correct falls gradient to ensure adequate draining.

f) A gasket, conforming to ANSI B16.21 and ASTM D2000, shall be installed between clamp and pipe or dissimilar materials.

g) All pipe works shall be equipotential bonded to the earthing system as per requirement under the CP 5, Electrical Installations.

h) Puddle flanges cast in wall shall be used when water-tightness is required.

i) Exposed pipes shall be routed and installed to blend into the structures aesthetically. Pipes shall not be cast into any structural elements/ members.

CHAPTER 19

INSTRUMENTATION

19.1 INTRODUCTION

This Chapter covers the Authority's requirements for the design and selection of instrumentation works.

The Building and Construction Authority (BCA) and other regulatory bodies also require the installation and monitoring of instruments for excavations, tunnelling, piling and other construction work. Compliance with this Chapter may not be sufficient to fully satisfy these regulatory bodies. Both the instrumentation required under this section and any additional instrumentation required to satisfy the regulatory bodies shall be designed for and shown on the drawings.

19.2 INSTRUMENTATION REQUIREMENTS

The instrumentation shall be designed and selected to:

(a) Verify the assumptions made in the design.
(b) Provide confirmation of the predicted behaviour of the support system during excavation or tunnelling.
(c) Enable the assessment of the effects of the work on buildings, utilities and other structures.
(d) Provide a record of performance.
(e) Enable construction to be carried out safely and soundly at every stage.
(f) Where required, enable appropriate contingency measures to be implemented in time.

In order to meet these requirements the instrumentation design shall include the minimum monitoring specified herein and any such additional instrumentation as is necessary.

19.3 INSTRUMENTATION PLANS AND RELATED DOCUMENTS

19.3.1 Instrumentation Plans

Instrumentation plans shall be prepared at a scale not greater than 1:500 clearly indicating the location and installation height/depth of all instrumentation. Sectional drawings shall show the extent and depth of permanent and temporary works and the strata where the instruments are to be installed. All instruments shall be clearly identified in a unique alpha-numeric sequence using the instrumentation nomenclature as defined in the LTA's Geotechnical Data Base (GDB). Each drawing shall show all of the instrumentation to be installed within the area covered in the drawing. At contract boundaries, the instruments to be installed by the adjacent contractor shall be shown.

Where multi-sensor instruments are used, they shall be clearly identified with the reduced level and/or direction of each individual sensor, such information is to be provided either on the drawings or in separate tables.

Where buildings, structures or utilities subject to special protection works are encountered, a detailed drawing shall be prepared for each individual building, structure or utility indicating the exact location of all monitoring points, including the reduced level of the proposed instrument. Sections shall also be prepared identifying clearly the extent of any existing features, cracks etc, requiring monitoring. Where possible the structural layout of the building shall also be indicated on these drawings.

All drawings for buildings, structures or utilities subject to special protection works shall be prepared at a scale not greater that 1:50 except where prior approval has been granted by the Engineer.

19.3.2   Instrumentation Tables

Instrumentation tables shall include, but not be limited to, the following information for each instrument:

(a) Instrument type
(b) Unique instrument number
(c) Sensor number
(d) Proposed Easting
(e) Proposed Northing
(f) Proposed Reduced Level of all sensors
(g) Proposed reading frequency during key stages of the works
(h) Review levels for all sensors (see Clause 19.7)

19.4   MINIMUM MONITORING

Minimum monitoring arrays shall extend along the full length of the work, including an additional length of at least 50m beyond contract boundaries.

19.4.1   Minimum Monitoring for Excavations

All excavations of depth 4.0 m or deeper from commencing level shall be monitored by Type A, B and C monitoring arrays, as shown in Figures 19.1 and 19.2, on the following basis:

(a) One Type A, B or C array for every 25m of perimeter wall or slope.
(b) An average of one Type B or C array for every 100m of perimeter wall or slope.
(c) An average of one Type C array for every 500m of perimeter wall or slope.

The distances used to assess the number of monitoring arrays shall be taken as the plan distance around the perimeter of the excavation measured at the top of the slope or retaining wall. The number of arrays

required shall be rounded up to the nearest whole number. If an excavation is being carried out in a number of adjacent sections or cells, then the perimeter shall be taken as the distance around all of the adjacent sections or cells, ignoring intermediate cross walls.

Type B and C arrays shall be located in areas of particular concern, taking into account the nature and sequence of construction, the presence of adjacent buildings and the assessed ground conditions. The Types B and C arrays are not required to be evenly spaced.

Where any portion of the excavation is continuous over 150m in length and there are no structures or utilities within the monitoring zones defined by Figure 19.3(1) and Figure 19.4(1) respectively, then the requirement for Type B and C monitoring arrays over that portion of excavation can be reduced by one half, and for unsupported excavations only, Type A arrays can be omitted.

19.4.2   Minimum Monitoring for Tunnels

All tunnelling (including pipe jacking) shall be monitored by Type D, E and F monitoring arrays, as shown in Figures 19.5 and 19.6, on the following basis:

(a) One of Type D, E or F every 25m of single tunnel.
(b) One of Type E or F for every 200m of single tunnel, on average.
(c) One of Type F for every 1000m of single tunnel, where the tunnels have an excavated diameter in excess of 3m.

The distance shall be measured along the centre line of the tunnels and shall be based on the total length of tunnelling required under the contract. The number of arrays required shall be rounded up to the nearest whole number.

Type F arrays need not be provided where the tunnels have an excavated diameter equal to or less than 3m.

For twin or multiple tunnels where the monitoring arrays overlap, the requirements for monitoring over the overlapping arrays can be reduced to provide the same level of monitoring for each of the tunnels as for the single tunnel.

Type E and F arrays shall be located in areas of particular concern, taking into account the nature and sequence of construction, the presence of adjacent buildings and the assessed ground conditions. Type E and F arrays should be particularly located in areas where it is expected that the tunnel will encounter soils of the Kallang Formation. The Types E and F arrays are not required to be evenly spaced.

Where any portion of the works is continuous over 150m in length and there are no structures or utilities within the monitoring zones defined by Figure 19.3(2) and Figure 19.4(2) respectively, then the requirement for

monitoring arrays over that portion of the works can be reduced by one half of that defined above.

19.4.3 Minimum Monitoring for Areas of Ground Treatment

A grid of settlement points to monitor heave or settlement shall be established over any area of ground treatment. The spacing between points in both directions shall not be more than 5m. This grid shall extend at least 10m beyond the edges of the ground treatment zone.

19.4.4 Minimum Monitoring for Vibration

Vibration monitoring shall be carried out on all structures where the construction activity is likely to result in vibrations, for example, piling, blasting. The vibration limit shall comply with current BCA requirements.

19.4.5 Minimum Monitoring of Struts and Ground Anchors

At least 15% of all struts and ground anchors shall be monitored for load using strain gauges and/or load cells. At least 25% of the struts and anchors monitored using strain gauges shall also be monitored using load cells. Where strain gauges are used, a minimum of 2 strain gauges coupled with temperature monitoring shall be installed at each monitoring location for struts, as shown in Figure 19.7.

As far as possible, the strut and anchor monitoring locations shall be selected so that:

(a) every strut/anchor level at the selected locations is monitored; and
(b) the strut/anchor monitoring location coincides with a Type B or C monitoring array.

Where additional struts are added to strengthen the excavation, these struts shall be monitored using load cells.

19.4.6 Minimum Monitoring of Permanent Works

All structures founded on raft foundations shall be monitored for settlement after casting of the raft foundation until the completion of the Works.

19.4.7 Minimum Monitoring of Buildings and Structures

The corners of buildings and structures, where any part of the building or structure fall within the minimum monitoring zones defined in Figure 19.3, shall be monitored by precise levelling.

Tensile strains shall be monitored by extensometers or by optical survey for all buildings with predicted tensile strain greater than 0.1% and for any building subjected to protection works.

Crack monitoring shall be carried out for existing cracks and new cracks occurring during the works, and on movement joints.

For buildings on mixed foundations, settlement points shall be placed on both sides of the junction between different foundation types.

19.4.8 Minimum Monitoring of Utilities

All utilities within the minimum monitoring zone defined in Figure 19.4 shall be monitored with settlement points placed on or just above the utility, at intervals of not more than 25m. Utilities that are less than 4m below ground level should be monitored with points on the utility, while utilities more than 4m below ground can be monitored with points placed 2m above the utility. Joints in electrical cables with voltage higher than 22kV and in fibre optic cables shall be monitored for movement across the joint.

19.4.9 Minimum Monitoring for Tunnelling Under Buildings or Structures which are in Use

Where any part of the tunnel is directly below any part of a building or structure that is in use, the following shall be implemented as a minimum: -

(a) A comprehensively monitored zone shall be set up within the area 50m before the tunnel reaches the building. The monitoring is required to confirm that the tunnelling is being carried out in such a way that the settlements are less than or equal to that expected from the design. The zone shall include at least two type E arrays, at 25m and 50m respectively from the building.
(b) The building shall be monitored in accordance with Cl. 19.4.10.
(c) The instruments in the zone and on the building shall be read when they are within 25m (in plan) of the location of the face of the tunnel. The monitoring data shall be assessed at least once per ring of advance or once per three hours, whichever is more frequent.
(d) There shall be a direct communication channel from the tunnel to the engineer assessing the results of the monitoring.

19.4.10 Minimum Monitoring in Real Time

Monitoring in real time shall be provided for the following:-

(a) Structures on mixed foundations which may be affected by the works and where a part of the structure is on foundations underlain by soft or loose soils. Real time monitoring is required for the junction between areas of different foundation systems.
(b) Structures subject to underpinning unless the structure is not occupied or in use.
(c) Structures subject to compensation grouting.
(d) Structures subject to protection works.
(e) Buildings and structures which are in use and are located directly over a bored tunnel drive in plan.
(f) All struts and ground anchors monitored for load.

(g) Joints in utility cables with voltage higher than 22kV and joints in fibre optic cables.
(h) Vibration monitoring where any construction activity is carried out near to sensitive buildings, structures, utilities or equipment.
(i) Any other structure where real time monitoring is considered necessary by the Engineer or the Qualified Person (Structural Works).

Real time monitoring system for buildings or structures shall include one or more of the following systems:

(a) Electrolevels beams with a back up system of precise levelling pins at both end of each beam
(b) Automated total station(s) reading the movement of survey prisms

Depending on the nature of the structure and the critical activity, Linear Variable Differential Transformers (LVDTs), tiltmeters, automatic inclinometers, piezometers, extensometers and / or other types of instruments may be used to provide additional real time information.

Instruments monitored in real time shall be connected to data logging equipment and the data shall be continuously accessible on computers in the Engineer's site office.

The monitoring data from the real time monitoring shall be processed and displayed automatically, such that the displayed data represents the most recently taken readings.

19.5   READING FREQUENCY FOR MONITORING INSTRUMENTS

The design shall include tables giving reading frequencies for all instruments. The frequency of reading the instruments may be varied, depending on the type of instrument and the relationship between the instrument and areas of current activity. Criteria for increasing or decreasing the frequency of reading and for ceasing monitoring shall also be given, subjected to the acceptance of the Engineer.

For real time monitoring, the designer shall assess the appropriate interval between successive readings, which shall comply with the following:

(a) For the monitoring to be considered 'real time', the time between successive reading of the same sensor or point must be less than 4 hours.
(b) During active tunnelling under buildings or critical structures, the interval between successive readings on critical sensors or points must be less than 5 minutes.

19.6   ACCURACY AND RANGE OF MONITORING INSTRUMENTS

The accuracy and reading range of all of the monitoring instruments shall be specified as part of the design.

For instruments monitored in real time using automated total station monitoring, provisions shall be made for regular manual monitoring to confirm the continued accuracy of the system.

The depth of inclinometers shall extend beyond the influence zone of the tunnels and excavations being monitored. As a minimum, inclinometers shall be taken down to at least:

(a) 2m into hard stratum; or
(b) 3m below the toe level of the retaining wall (for excavations) or 3m below invert level (for tunnels) whichever is deeper.

Where Vibrating Wire Piezometers are specified in Figures 19.1, 19.2, 19.5 and 19.6, Casagrande Piezometers may be used as an alternative where they can be demonstrated to be sufficiently responsive to changes in piezometric pressure in the surrounding ground to provide representative readings.

Ground settlement points shall be installed so that the movement of the ground can be measured. Where settlement points have to be installed through road slabs, pavements or other surface structures, they shall be anchored into the ground with sleeves provided so that the measured settlement is not affected by the presence of the structure.

The design shall include protection for all instruments, to ensure that they are suitably protected against accidental damage, vandalism, and adverse climatic conditions.

19.7   REVIEW LEVELS

Prior to the start of construction, review levels shall be assigned to every instrument installed or to be installed. The values for review levels shall form part of the design.

There shall be two review levels: Alert Level and Work Suspension Level.

The Alert level is a reading at a predetermined level prior to the Work Suspension level or required for compliance with the Contract. (for example, 70% of the expected maximum strut load, settlement or lateral deflection).

The Work Suspension level is defined as any highest or lowest (as appropriate) reading anticipated based on the design at serviceability limit state.

In addition, levels predicted in the design shall also be set for each stage of construction. If any predicted level is exceeded, the design shall be reviewed with new analyses to be undertaken to estimate the final performance, and to re-assess and evaluate the design adequacy for all remaining stages.

Where appropriate, review levels shall be set for both positive and negative readings, eg., for ground movement points, two review levels shall be set for settlement and two for heave.

If the Alert level is reached, the related instrumentation data and the temporary works design shall be reviewed. If the review concludes that the retaining wall performs as per design, work can proceed. If the review shows that the Work Suspension level is likely to be exceeded, the design shall be re-assessed and additional measures shall be implemented to ensure that the Work Suspension level will not be exceeded.

If any reading exceeds the Work Suspension level, the related part of the Works shall be made safe and then that part of the Works shall be ceased until a full re-assessment of the original design is completed and remedial measures are implemented to ensure the safety of the works.

The full re-assessment shall be carried out comprehensively with careful reviews of ALL design assumptions and the actual monitored behaviour of the structures. Where back-analysis is carried out during the full re-assessment, it shall not be limited to curve fitting of wall deflections alone. Other monitored parameters shall also be checked in the back analysis. There shall be clear evidence of improvement between computed and measured behaviour to date, i.e. from the beginning up to the stage where back analysis is carried out.
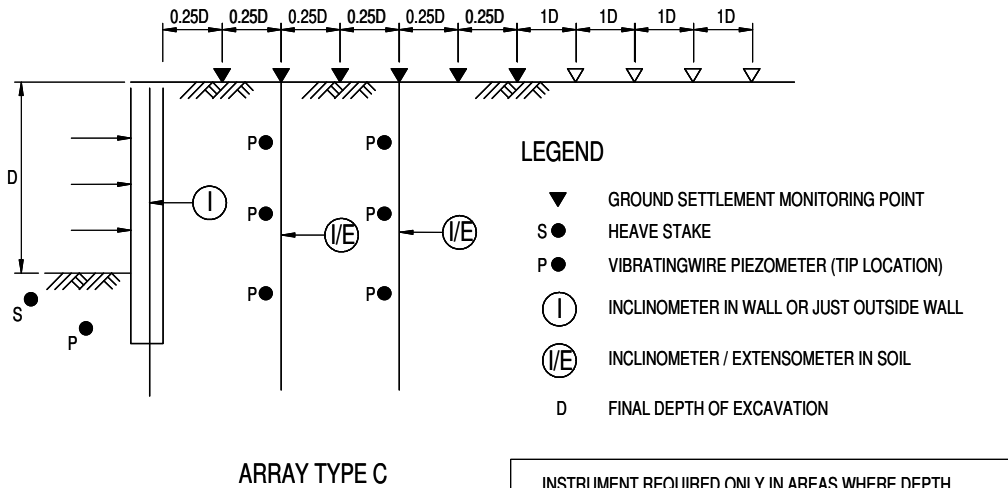
The review of design assumptions during back analyses shall include appropriateness of the models used in the original design, soil parameters, soil profiles encountered, construction sequences, drainage conditions on site and the wall stiffness. Any changes or revisions in the back analysis shall not be arbitrary. There shall be a clear rationale and substantiation, for example field or laboratory tests or additional evidence from construction records, for all changes in the model parameters.

Changes may be proposed to the values selected as review levels after a full re-assessment. Changes to review levels shall be justified on the basis of observed performance and the full re-assessment, and shall be submitted for the acceptance of the Engineer.

List of Figures:

MONITORING ARRAYS FOR SUPPORTED EXCAVATIONS

0.25D

D

ARRAY TYPE A

0.25D 0.25D 0.25D 0.25D 0.25D 0.25D 1D 1D

D

I

P ○

ARRAY TYPE B

0.25D 0.25D 0.25D 0.25D 0.25D 0.25D 1D 1D 1D 1D

D

I

P ●   P ●

P ●   P ●   I/E   I/E

S ●

P

P ●   P ●

LEGEND

▼   GROUND SETTLEMENT MONITORING POINT

S ●   HEAVE STAKE

P ●   VIBRATINGWIRE PIEZOMETER (TIP LOCATION)

Ⓘ   INCLINOMETER IN WALL OR JUST OUTSIDE WALL

Ⓘ/E   INCLINOMETER / EXTENSOMETER IN SOIL

D   FINAL DEPTH OF EXCAVATION

ARRAY TYPE C
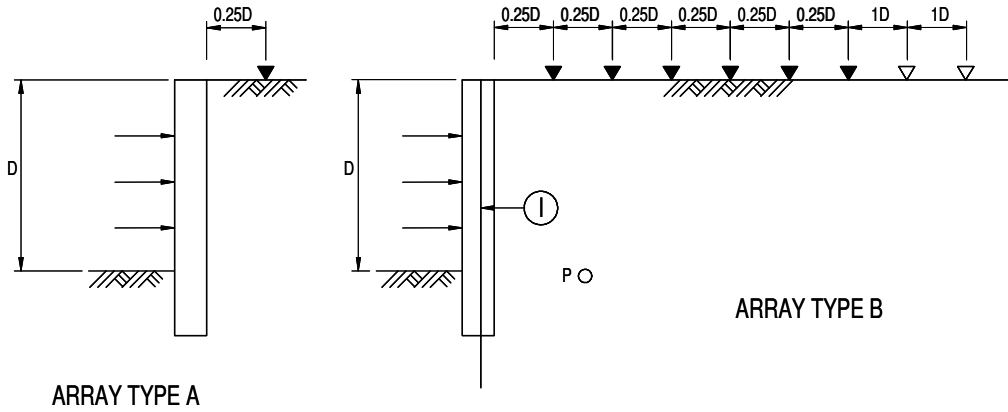
INSTRUMENT REQUIRED ONLY IN AREAS WHERE DEPTH
FROM INITIAL GROUND LEVEL TO BASE OF KALLANG
FORMATION SOIL IN THE EXCAVATION >= 10m :

▽   GROUND SETTLEMENT MONITORING POINT

P ○   PIEZOMETER

FIG 19.1

MONITORING ARRAYS FOR UNSUPPORTED (OPEN) EXCAVATIONS
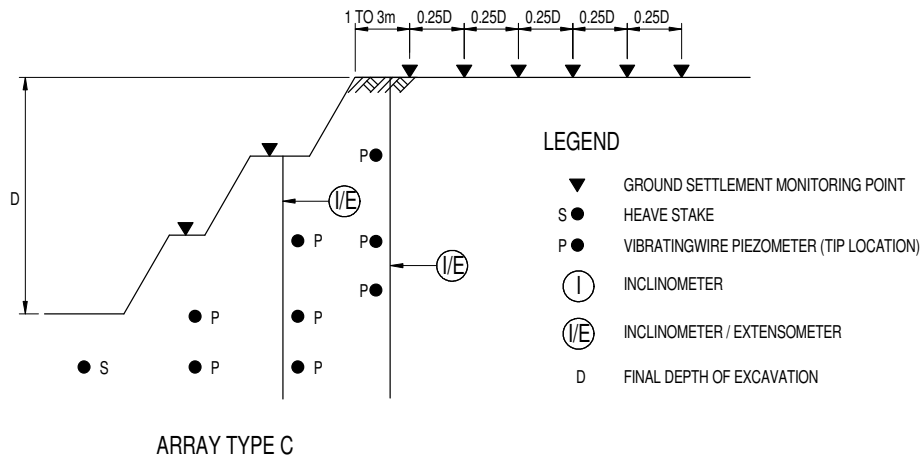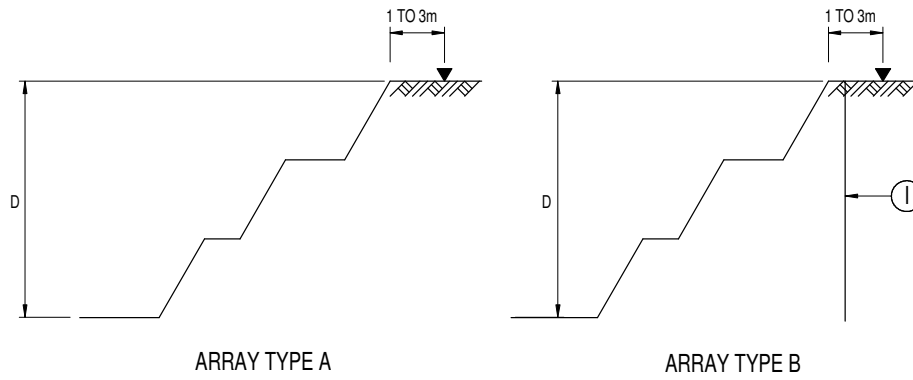
ARRAY TYPE A

ARRAY TYPE B

ARRAY TYPE C

LEGEND

▼	GROUND SETTLEMENT MONITORING POINT
S ●	HEAVE STAKE
P ●	VIBRATINGWIRE PIEZOMETER (TIP LOCATION)
Ⓘ	INCLINOMETER
(I/E)	INCLINOMETER / EXTENSOMETER
D	FINAL DEPTH OF EXCAVATION

NOTE:

BENCHES ARE ONLY SCHEMATIC. MINIMUM INSTRUMENTATION
NUMBERS ARE INDEPENDENT OF NUMBER OF BENCHES EXCEPT
THAT ONE SETTLEMENT POINT IS TO BE PLACED ON EACH
BENCH FOR TYPE C ARRAYS.

FIG 19.2

MONITORING ZONES FOR BUILDINGS AND STRUCTURES

1. EXCAVATIONS
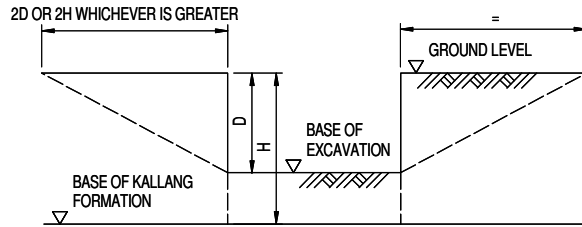
2a. TUNNEL WHERE BASE OF KALLANG FORMATION
IS ABOVE TUNNEL CROWN
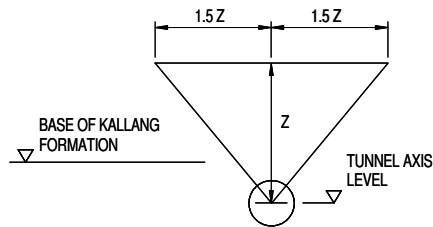
2b. TUNNEL WHERE PART OR ALL OF THE FACE
IS IN SOILS OF THE KALLANG FORMATION
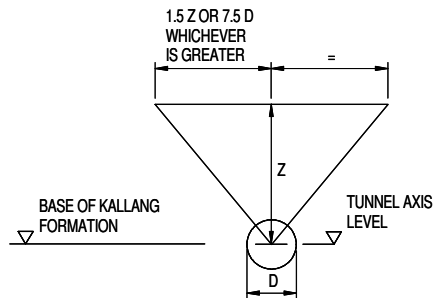
FIG 19.3

MONITORING ZONES FOR UTILITIES

1. EXCAVATIONS

1D

GROUND LEVEL

D

BASE OF
EXCAVATION

2. TUNNELS

1.5 Z   1.5 Z

Z

TUNNEL AXIS
LEVEL
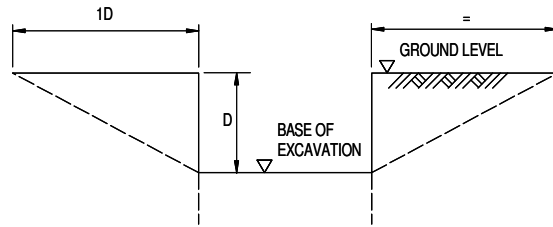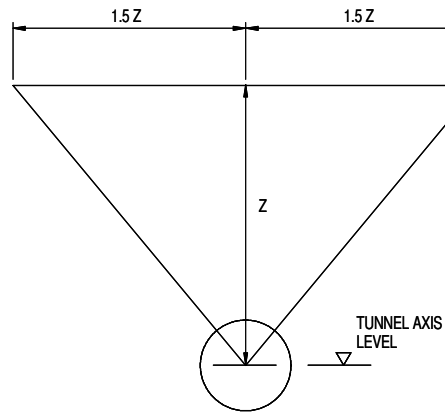
FIG 19.4

MONITORING ARRAYS FOR TUNNELS NOT IN KALLANG OR TEKONG FORMATION SOIL
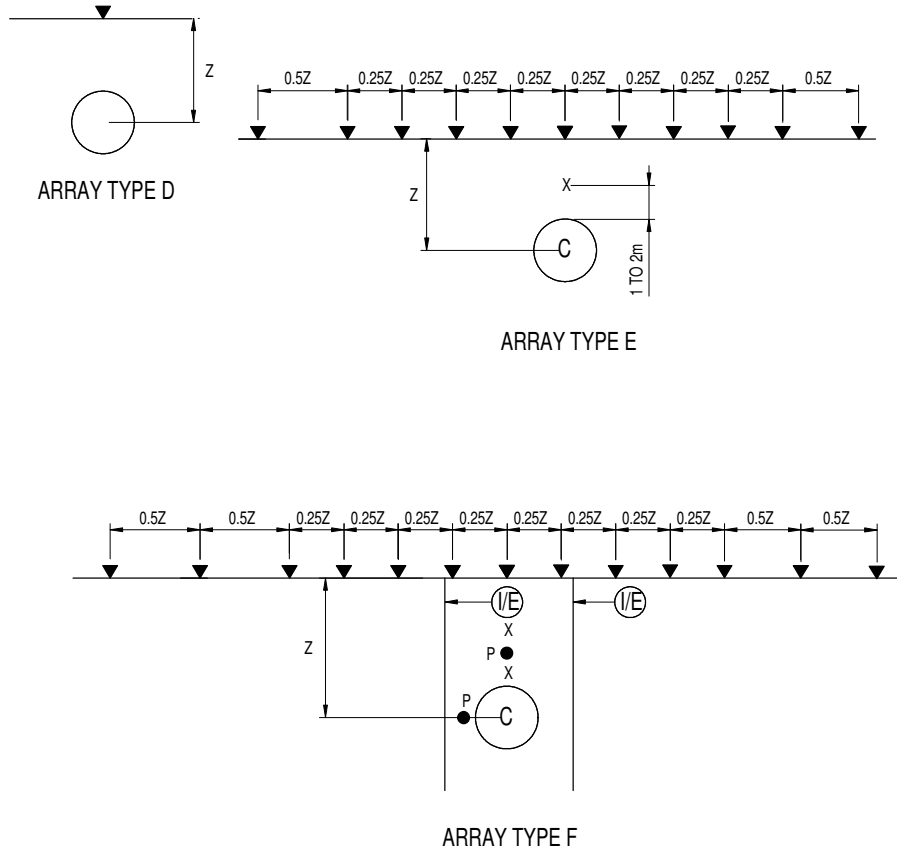
ARRAY TYPE D

ARRAY TYPE E

ARRAY TYPE F

LEGEND

▼	GROUND SETTLEMENT MONITORING POINT
X	ROD EXTENSOMETER (TIP LOCATION)
P ●	VIBRATINGWIRE PIEZOMETER (TIP LOCATION)
C	CONVERGENCE MEASUREMENTS
(I/E)	INCLINOMETER / EXTENSOMETER
Z	DEPTH TO TUNNEL CENTRE AXIS

FIG 19.5

MONITORING ARRAYS FOR TUNNELS WHERE ANY PART OF THE FACE IS IN KALLANG OR TEKONG FORMATION SOIL

ARRAY TYPE D

0.5Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.5Z

Z

X

C

1 TO 2m

ARRAY TYPE E

0.5Z | 0.5Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.25Z | 0.5Z | 0.5Z

I/E   I/E

X

Z

P P P P
P X P P
P X P P

P   P   P   C P   P   P

ARRAY TYPE F

LEGEND

▼   GROUND SETTLEMENT MONITORING POINT

X   ROD EXTENSOMETER (TIP LOCATION)

P ● VIBRATINGWIRE PIEZOMETER (TIP LOCATION)

C   CONVERGENCE MEASUREMENTS

I/E INCLINOMETER / EXTENSOMETER

Z   DEPTH TO TUNNEL CENTRE AXIS

FIG 19.6

ARRANGEMENT OF STRAIN GAUGES FOR
STRUTS, GROUND ANCHORS AND NAILS
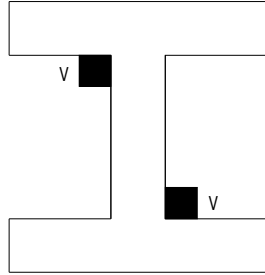
H-SECTION STRUTS
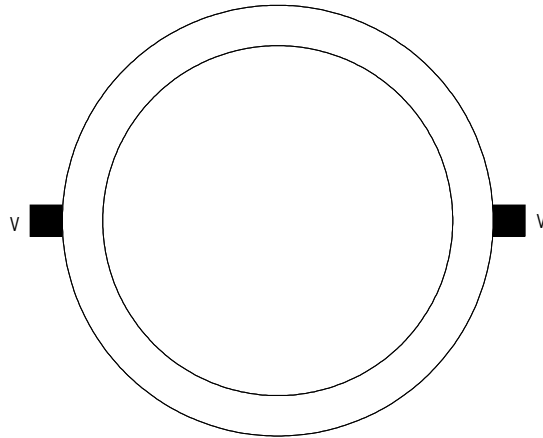
TUBULAR STRUTS
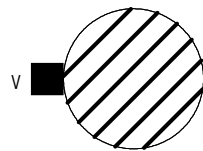
GROUND ANCHOR OR NAILS

LEGEND

V ■ VIBRATING WIRE STRAIN
     GAUGE

FIG 19.7

CHAPTER 20

ASSESSMENT OF DAMAGE TO BUILDINGS AND UTILITIES

20.1   GENERAL

Both temporary and permanent works shall be designed to ensure that ground movements are kept to an absolute minimum. In addition, it shall be noted that the use of proven construction techniques and good workmanship are essential in restricting ground loss and water table drawdown.

20.2   PREDICTION OF SETTLEMENTS

20.2.1   Ground Movements Due To Bored Tunnelling

Bored tunnelling work will generally produce a settlement trough which is related to a Gaussian distribution curve. The settlement trough for bored tunnelling works obtained by Peck (1969) and O'Reilly and New (1992) shall be used where there is no major loss of ground at the face and where there is little or no consolidation settlement.
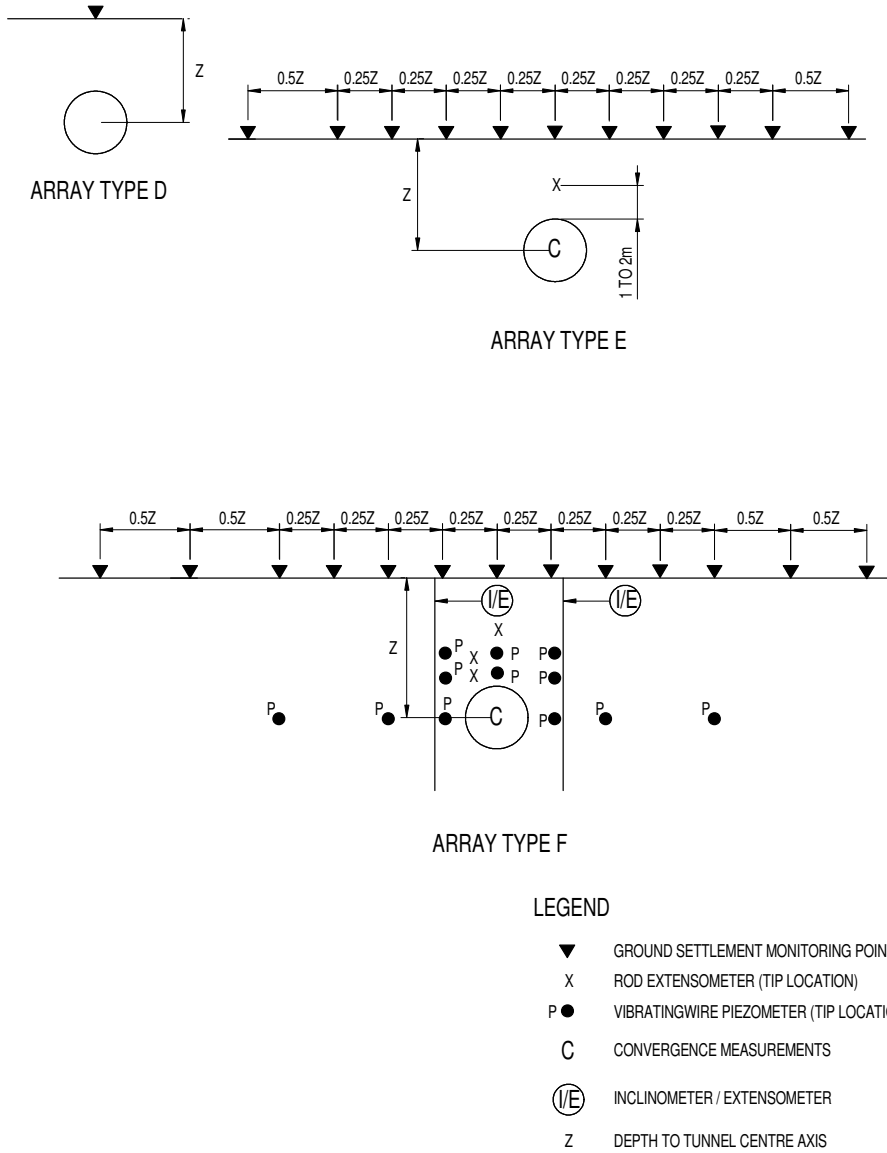
For a single tunnel, immediate surface settlement, S_v, shall be determined from the relationships:

$$S_V = S_{max} \exp\left[-\frac{y^2}{2i^2}\right]$$

Where, S_{max} is the maximum settlement above the tunnel
                  y is the horizontal distance to the tunnel
                  i is the horizontal distance from the tunnel centre line to the point of inflexion on the settlement trough

$$i = K z_o$$

Where, K is a parameter, which varies between 0.5 (for clay) and 0.25 (for sand)
                  z_o is the depth to the centre of the tunnel

$$S_{max} = \frac{0.0031.VD^2}{i}$$

Where, D is the excavated diameter of the tunnel

V   is the volume loss expressed as a percentage of the excavated tunnel face area

The suitability of the selected volume loss values shall be demonstrated in relation to the values of volume loss that occurred during tunnelling for previous phases of subway construction in Singapore. Typical values for tunnels up to 6.6m excavated diameter are shown in Table 20.1.

Table 20.1: Typical Values for K and V

Ground Type	Tunnelling Method	K (assumed)	V
S(V)/S(VI)	Greathead shield	0.45	7
S(V)/S(VI)	Greathead shield and compressed air	0.45	2
S(II)/S(III)	EPB shield	0.45	1
S(II)/S(III)	NATM	0.45	0.5
FCBB	NATM	0.45 - 0.5	1.5
FCBB	Greathead shield	0.5	5
G(V)/G(VI)	Greathead shield	0.45	2
G(V)/G(VI)	Greathead shield and compressed air	0.45	1.5
G(V)/G(VI)	TBM with compressed air	0.45	4.5
G(V)/G(VI)	NATM with compressed air	0.45	3.5
G(V)/G(VI)	EPB shield	0.45	1
OA	EPB shield	0.45	1
M	Semi-blind / semi- mechanical shield	0.5	3.5
M	Greathead shield with ground treatment and compressed air	0.5	2
M	TBM with compressed air	0.5	15
M	EPB shield	0.5	3

Values for EPB tunnelling are for tunnels where sufficient pressure was maintained in the head to minimise movement at the face, and where simultaneous tail void grouting was carried out. The values in the table exclude settlements recorded while tunnelling through the interface between rock and soil, or between rock and rock weathered to a soil-like material.

Consolidation settlements shall be assessed and superimposed on the settlements calculated as described above. Settlement contour plans along the full route of the tunnels shall be prepared. The horizontal movements and strains associated with the tunnelling shall also be predicted.

20.2.2 Ground Movements Due To Excavations

The prediction of the ground movements due to excavations shall allow for: -

(a) The installation and (where appropriate) removal of the support system.
(b) Movements during excavation.
(c) Consolidation settlements.
(d) The effects of grouting, piling, soil improvement, or any other measure required for the Works, which could cause ground movement.

The prediction for movements during excavation shall be properly related to the predicted movement of the retaining system.

Finite Element or Finite Difference methods can give misleading results for the development of ground movements outside the excavation unless the change of ground stiffness with strain is properly taken into account. All analytical predictions shall be checked against empirical methods based on previous experience of excavations in similar ground in Singapore.

Seepage analyses shall be carried out for all excavations, and the potential consolidation settlements shall be assessed.

Settlement contour plans shall be prepared for the area around excavations. Horizontal movements and strains associated with excavations shall also be predicted.

No gaps are allowed in support systems for excavations. Where gaps in the retaining system are unavoidable, the ground shall be grouted using at least two rows of injection points to avoid exposing untreated ground during excavation.

20.2.3 Combined Effects

Assessment shall be carried out of the total ground movement that could affect the structures, buildings and utilities within the minimum monitoring zones (refer to Chapter 19). The ground movements calculated shall be the sum of those due to:

(a) Tunnelling and associated work, such as shaft construction, ground treatment.
(b) Excavations and associated work.
(c) The ground movements due to the work of the adjacent contractor(s), in so far as these could affect buildings within the assessment zones.
(d) Any other construction work within the assessment zone that is likely to be concurrent with the Works.

20.3 ASSESSMENT OF DAMAGE TO BUILDINGS AND STRUCTURES

All buildings and structures within the assessment zones shall be assessed for damage. The methodology for assessment of potential damage to buildings or structures is outlined in Appendix 20.1.

Generally, the staged assessment approach outlined in Mair, Taylor and Burland (1996) shall be used.

The assessment shall be preliminary (Stage 1) based on allowable settlement and rotations or Stage 2 assessment based on Burland's Chart (as given in Clauses 20.3.1) or Stage 3 assessment by detailed structural analysis considering soil-structure interaction or combination of the above three stages of assessments as detailed in Appendix 20.1.

The assessment for every building and structure within the assessment zone shall be summarised, using the format shown in Figure 20.1.

However, it is quite common for buildings or structures in Singapore to be constructed or renovated such that they have mixed foundations. These buildings or structures can be particularly sensitive to settlement. For any building or structure that is identified as being on mixed foundations, a detailed evaluation shall be carried out, taking into account the nature of the building or structure and the foundations.

Where a building or structure is founded on piles, assessment on the adequacy of the pile capacity shall be carried out. A detailed building assessment shall also be carried out where a building is founded on piles, and where the tip of any of the piles falls within Zone A, B or C as defined in Figure 20.2. The potential for settlement at the head of such piles exceeding those calculated for 'greenfield' conditions shall be evaluated, and considered in the building assessment. If a building or structure is founded on piles with tips partially located within more than one zone or where the pile tips are partially within the zones and partially outside the zones, the effect on the building or structure due to differential movement between the piles shall also be evaluated.

20.3.1 Requirement For Assessment Of Damage To Masonry Buildings

The classification of potential damage to masonry buildings based on the work of Boscardin and Cording (1989) and Mair, Taylor and Burland (1996) in accordance with Table 20.2 could be adopted for 2nd stage assessment.

Table 20.2: Damage Category for Masonry Buildings

Category of damage	Normal degree of severity	Limiting tensile strain (ϵ_{lim}) (%)
0	Negligible	0 - 0.05
1	Very Slight	0.05 - 0.075
2	Slight	0.075 - 0.15
3	Moderate	0.15 - 0.3
4 to 5	Severe to Very Severe	> 0.3

The description of the damage associated by degrees of severity by Burland, Broms and De Mello (1977) is given in Appendix 20.2.

It should be highlighted that the classification in Appendix 20.2 and Table 20.2 was developed for brickwork or blockwork and stone masonry. It could be adapted for other forms of cladding.

Due account shall be taken of any stiffness in the buildings to resist ground deformations.

20.3.2 Additional Requirement For Assessment Of Damage To Reinforced/Prestressed Concrete Structures

For reinforced/prestressed concrete structures, such as underpasses, underground structures, bridges and structural members in a building, the procedure outline in Clause 20.3.1 shall be adopted. In addition, a serviceability performance review shall be carried out. The factors that could be taken into account in the serviceability performance review shall include the following but not be limited to;

• Basement configuration and waterproofing systems
• Cladding system
• Construction sequence
• Foundation system
• Orientation to alignment
• Previous movements
• Soil-structure interaction
• Structural continuity

20.4 ASSESSMENT OF DAMAGE TO UTILITIES

A damage assessment for every utility within the monitoring zones for utilities (refer to Chapter 19) shall be carried out. The allowable values for settlement, deformation, joint rotation, joint slip, or such other criteria as agreed with the utility agency shall be established. The allowable values shall ensure that the utility can be kept fully functional during and after the

Works. Where necessary, trial pits shall be carried out to confirm the nature of the utility and joint spacing.

Particular attention shall be given to the junction of pipes and spurs of the pipe, as outlined by Attewell, Yeates and Selby (1996). For cast iron pipes the methodology of Bracegirdle et al (1996) shall be followed.

The assessment for every utility within the assessment zone shall be tabulated. The summary shall include details of the type of utility, nature, joint type and spacing, and the allowable and predicted values for settlement, deformation, joint rotation, joint slip, or such other criteria as are agreed with the utility agency.

20.5   PROTECTIVE WORKS

For all masonry structures where the predicted degree of severity of settlement damage is "moderate" or above, protective works shall be designed and installed with the aim to restrict damage to the "slight" category or below. Where a building has historical or other significance, as stated in the Particular Specification, protective works shall be designed and installed if the predicted damage is in the "slight" category or above, with the aim of restricting damage to the "very slight" category.

For reinforced/prestressed concrete structures where the predicted serviceability limit state is exceeded, protective works shall be designed and installed with the aim satisfy the serviceability limit state criteria.

Protective works shall be in the form of underpinning, ground improvements, compaction or compensation grouting, jacking or building strengthening or some combination of these or such other means to the acceptance of the Engineer. Care shall be taken to ensure that the selected method of protection does not do more harm to the building than the original settlements.

Where any of the predicted values for a utility exceeds the allowable value, protective works shall be designed and implemented. Protective works shall be in the form of supporting, underpinning, ground improvements, compaction or compensation grouting, jacking or such other means to the acceptance of the Engineer.

If a building, structure or utility is likely to be affected by ground movements due to the work of two or more contractors, and unacceptable damage is predicted, appropriate protective measures shall be co-ordinated amongst various designers.

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Appendix 20.1
Methodology for Assessment of Potential Damage to Buildings or Structures

Estimate relevant vertical and horizontal ground movements		Carry out visual inspections of all structures within the affected zones

Shallow Foundation

Is the building a sensitive building? — YES

NO

Conduct preliminary assessment (1st Stage)

YES — Is max θ< 1:500 and δ < 10mm?

NO

Conduct 2nd stage assessment (Burland's Charts)

YES — Is damage category slight or less?

NO

Mixed Foundation

Deep Foundation

NOT OK — Determine the adequacy of pile capacity

OK

Conduct preliminary assessment (1st Stage)

Is tilt or rotation acceptable, whichever is the more onerous for serviceability? — YES

NO

Greenfield Assessment

Conduct detailed assessment (3rd Stage)

Soil Structure Interaction

Conduct detailed assessment (3rd Stage)

Is damage condition acceptable? — NO

YES

Is structure reinforced concrete? — YES

NO

Identify mitigation measures for structural protection

NOT OK

Serviceability Performance Review

OK

No mitigation measure **is required**

Is damage condition acceptable? — NO

YES

Is structure reinforced concrete? — YES

NO

Appendix 20.2

Classification of Visible Damage to Walls with Particular Reference to Ease of Repair of Plaster and Brickwork or Masonry.

Category of damage	Normal degree of severity	Description of typical damage (Ease of repair is underlined) **Note:** Crack width is only one factor in assessing category of damage and should not be used on its own as a direct measure of it.
0	Negligible	Hairline cracks less than about 0.1mm.
1	Very Slight	<u>Fine cracks which are easily treated during normal decoration</u>. Damage generally restricted to internal wall finishes. Close inspection may reveal some cracks in external brickwork or masonry. Typical crack widths up to 1mm.
2	Slight	<u>Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings.</u> Cracks may be visible externally and some repointing may be required to ensure weathertightness. Doors and windows may stick slightly. Typical crack widths up to 5mm.
3	Moderate	<u>The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced</u>. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired. Typical crack widths are 5 to 15mm or several greater than 3mm.
4	Severe	<u>Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows</u>. Windows and door frames distorted, floor sloping noticeably[1]. Walls or building leaning[1] noticeably, some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 to 25mm but also depends on the number of cracks.
5	Very Severe	<u>This requires a major repair job involving partial or complete rebuilding</u>. Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm but depends on the number of cracks.

[1]<u>Note:</u> Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.

BUILDING DAMAGE ASSESSEMENT SUMMARY SHEET

Project:

Contract Number:

Name of Building:
Address:

PHOTO

Description of Structure:

Drawings available   YES/NO

Description of Foundations

Drawings available   YES/NO
Result of Preliminary Assessment
  Maximum settlement:
  Maximum slope:
  Second stage assessment required   YES/NO

Result of Second Stage Assessment
  Maximum settlement:
  Maximum ground slope:
  Maximum tensile strain:

Detailed evaluation required   YES/NO

Attach results of detailed evaluation when required
Protection measures needed   YES/NO
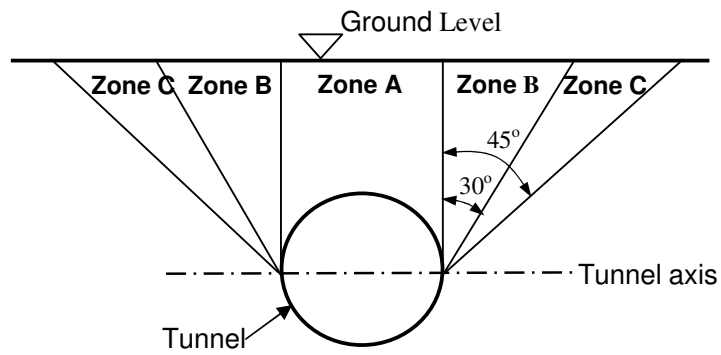Protection measures proposed:

Fig 20.1

Fig 20.2 : Definition of Zone "A", "B" and "C" after Jacobsz et al (2001), Kaalberg et al (2005) and Selematas, Standing and Mair (2005).

CHAPTER 21

LIGHTING SYSTEM

21.1 PUBLIC STREET LIGHTING

21.1.1 General

The design of lighting shall be based on the latest edition of the following publications:

(a) BS 5489 (British Standard)

(b) CIE 115 (Technical Report of Commission Internationale de L'Eclairage)

Road surface shall be taken as Class R3 road (Asphalt CIE R3). The design shall also comply with the applicable Codes, Regulations, Standards and relevant Authorities.

For new major roads and expressways, IP66 high performance lantern mounted on 10 meter pole height with 250 watts High Pressure Sodium Vapour (HPSV) lamp (of min 33,000 lumens) shall be used. The distance between each lamp pole required shall be minimum 45m, to be determined in accordance to the lighting level requirement. The lantern shall be provided with multiple adjustments to have variable light distribution to suit the road conditions. The total light output ratio shall equal or exceed 75%.

21.1.2 Lighting Level Requirements

The designed lighting levels (average illuminance at floor level) for expressway and major road is 20 lux. Minor and residential road is 10 lux.

The overall uniformity of the light distribution on the road shall be 0.30 for all categories of road. The uniformity is defined as the ratio of minimum illuminance to the designed average illuminance.

The luminaries shall meet the following requirements:
a) Luminaires shall be high performance types with tampered glass bowls.

b) Each luminaire shall be adjustable for at least full cut-off and semi cut-off light distribution as per CIE (International Commission on Illumination) definitions.

c) Luminaires shall be completed with integral control gears and shall be suitable for use on a supply voltage of 230 volts ±6%, 50 Hz.

d) Luminaires shall be suitable for use with 70W (minimum 6,600 lumens), 150W (minimum 17,500 lumens), 250W (minimum 33,000 lumens) or 400W (minimum 56,000 lumens) tubular clear high pressure sodium vapour lamps.

e) The mounting heights of the luminaries shall be between 6 m (minimum) to 10m depending on the actual requirements.

f) The mounting arrangement and wind resistant area of a luminaire shall be such as to withstand a wind-speed of 100 km per hour with a factor of safety of 5.

21.1.3 Works in Conjunction with Lighting

The following works shall be carried out:

a) Mounting details including all data, calculations, imposed loads and forces and dimensional drawings for the foundations required (piling if necessary) for the poles shall be endorsed by a registered Professional Engineer.

b) The soil bearing capacity at the site shall be ascertained so that the foundations can be correctly designed.

c) Base plates, holding-down bolts etc. shall be provided for the installation of street lighting. Heavy-duty UPVC pipes comply to SS141 Class B with pull-wire shall be provided for the underground cables.

d) All outgoing underground cables from street lighting control box shall be supplied and laid by LTA.

e) The developer shall carry out co-ordination and interfacing of incoming supply cabling work to street lighting control box with SP PowerGrid Ltd.

21.2 VEHICULAR UNDERPASS LIGHTING

21.2.1 General

Road surface shall be taken as Class R3 road (Asphalt CIE R3). Uniformity in the underpass shall not be less than 0.8.

The design of lighting shall be based on the latest edition of the following publications:

a) BS 5489 (British Standard)

b) CIE 88 (Technical Report of Commission Internationale de L'Eclairage)

The design shall also comply with the applicable Codes, Regulations, Standards and relevant Authorities.

The underpass lighting shall be provided with electronic ballasts for dimming to night time lighting level. The night time lighting level shall be in accordance with CIE88.

Dimming of the fluorescent luminaries shall be continuous.

The lighting system shall be controlled via programmable timers with RS232 interface. The timers shall be supplied inclusive of a bypass switch.

21.2.2 Emergency Lighting

In the event of power failure, the lighting level shall be in accordance with CIE88 and shall be maintained for a minimum 1 hour of operations.

21.2.3 Luminaires Requirements

The luminaries shall meet the following requirements:
a) All luminaires complete with all accessories shall be of a type specially designed for use in vehicular underpass.

b) Luminaires shall comply with BS 4533 and IEC Degrees of Protection IP 65 including requirements in jet proofing, thermal testing and dust proofing.

All underpass lighting sub-circuits shall consist of fire resistant, low smoke, halogen free armoured cables.

Design calculations to justify on the adequacy of the support system with details of all equipment and cables total weight in worst case shall be endorsed by a Professional Engineer.

21.3 TUNNEL LIGHTING

21.3.1 General

The design of lighting shall be based on the latest edition of the following publications:

(a) Road lighting Part 7 Code of Practice for the lighting of tunnels and underpasses – BS 5489 : Part 7 (British Standard)

(b) Guide for the lighting of road tunnels and underpasses – CIE 88 (Technical Report of Commission Internationale de L'Eclairage)

(c) Permanent International Associations of Roads Congresses – Report to 18th, 19th and 20th Congresses on Road Tunnels – 1987, 1991 and 1995

21.3.2   Design Parameters

In general, the recommendations of the latest edition of CIE88/BS 5489 shall be used for detail design work. The following parameters are to be considered in the design:

a) Design speed : The design speed used in the lighting calculations shall be subject to the approval of the Authority.

b) Stopping sight distance : The stopping sight distance shall be based on the recommendations of CIE 88/BS5489.

c) The access zone luminance (L_{20}) : The access zone luminance shall be based on recommendations in CIE88/BS5489 and subject to site investigations.

d) Switching control : Luminance meters shall be provided at entrance portals to adjust the entrance zone lighting level in accordance with the actual access zone luminance

e) Lamplife and maintenance : The design shall consider the optimisation of lamplife and maintenance.

21.3.3   Glare Control

Glare control as Threshold Increment (TI) set out within CIE88/BS 5489 shall be considered within the design and selection of luminaire and type of light source. The TI within the tunnel shall not exceed 15 %.

21.3.4   Emergency Lighting

In the event of power failure, backup provisions shall be provided for the tunnel lighting system by means of both Uninterruptible Power Supply (UPS) and standby generator systems.

The UPS shall be provided to ensure that there is no interruption of the tunnel lighting when transferring to standby generator supply in the event of power failure. A minimum full load backup capacity of half-hour shall be provided.

Emergency electrical power by diesel generators shall be provided for road tunnel lighting. A day tank of 700 litres shall be provided and a manual and/ or automatic fuel transfer system to give at least 6 hours of full load emergency back-up shall be provided. Additional fuel storage capacity to meet operation response time shall be considered in planning the capacity of the fuel system. The storage tank shall be housed above ground level unless there are site constraints. In general, the system shall comply with SS CP 31 and SS CP 40.

APPENDIX A

DESIGN CHECK LIST

The Contractor shall ensure that his design as shown on all Drawings and Contract documents is complete.

The check list as shown on the following pages is compiled from obvious omissions in previous MRT phases. The list is not meant to be exhaustive and it is the Contractor's duty to ensure that he has a complete design for construction.

A   STATIONS - GENERAL

1.   Access catladder - Provide approved standardised catladders to underplatform voids, vent shafts, hatches, cable towers, E&M equipment, etc.

2.   Platform endstairs - Provide safe platform endstairs for use during emergency situation, i.e adequate width, preferably 900 mm, but not less than 600 mm, and bottom riser not more than 170 mm.

3.   Floor hatch cover - All floor hatch cover should be flush with the floor and protected against damage by heavy E & M equipment movement.

4.   Maintenance Platform - Provide adequate platform with railings/catladders for maintenance access to E&M equipment, louvres, valves, water tanks, switches, etc at high level.

5.   Platform end walkways - E&M equipment mounted on the walls should not cause the platform end walkways to have inadequate width for emergency egress.

6.   Escalators - The railing balustrade design should tie in with the escalator to prevent children from falling.

      Slope surface between two escalators need some means to deter people from sliding down.

      Provide deterrent triangles at beams/slabs that are near the escalators edge.

      The gap between the escalator handrail and adjacent handrail should be at least 80 mm apart.

      Provide safety switch at roller shutter gate entrance so that the escalators will only move when the shutter gate is fully opened.

7.   Channel Gratings - provide gratings over channels/drains where access is needed.

8.   Taps and Drain Pipes - All discharge points to water taps and aircon drain pipes shall be directly over or near floor traps.

      No water tap is allowed to be installed inside the distribution board room or in other rooms where there are electrical accessories. It should be located at least 2 m away.

9.   PUB valve chambers - All PUB incoming valve chambers are to be designed with drainage provision and meter reading facility.

10.   Movement Joints - Ensure that there are no movement joints above plant rooms to eliminate risk of leakage of water into these rooms.

11.   Cover for incoming PUB meter and control valve - Ensure that cover is light enough for regular inspection and emergency usage and at the same time, secure enough to prevent the cover from pilferage.

B   UNDERGROUND STATIONS

1.   Buffer Area Railings - Provide handrailings on buffer area outside the traction substation to 5 m from the station screen door end return.

2.   Halon Cylinder Storage - Provide proper fire-rated enclosure for halon cylinder storage.

3.   Doors with direct access to track - Provide safety bar and warning sign for doors that provide direct access to trackside from station rooms.

4.   CD airfilters - CD station airfilters in rooms should not obstruct the opening of the door access.

5.   Cooling tower rooms - Design for adequate drainage facilities to prevent flooding of rooms due to backflow of water from cooling tower.

C   ELEVATED STATIONS

1.   Utility Duct - All the utility duct wall enclosures are to be sealed for proper fire rating.

2.   Ancillary Roof Access to utility ducts - The design should incorporate proper and safe access from ancillary roof area 1 to roof area 2.

3.   Platform edge for substation - Handrailings are to be provided along the platform edge for Rectifier, and L.V. switch rooms in front of the entrance for on line substation.

4.   Emergency escape doors - All Emergency escape doors leading to outside the station should not have a great drop in level.

5.   Intermediate roof slab - Warning sign required along handrail of catwalk to deter people from steeping onto ceiling panel of concourse level.

6.   Flat roof at platform level - Proper access is required for maintenance of aircon fan coils.

7.   Collection trough - The track side collection trough for rainwater downpipe should be covered with a grating where appropriate.

8.   Compressor rooms for air condition - Ensure that such rooms have sufficient ventilation to prevent breakdown of operation.

D   DEPOT

1.   Manhole access cover - The manhole access cover shall be of reasonable weight for easy handling in all buildings.

2.   Ventilation Fans - provide permanent access to all high level ventilation fans in depot building.

3.   Gantry Platform - Provide kick boards for gantry platform.

4.   Rail Infringement - Drain grating at open position shall not infringe the rail at tracks entering the depot building.

5.   Windows swing - Sliding windows should be adopted to buildings with walkways adjacent to it.

6.   Volatile Store - Roller shutter without perforation shall not be used as it does not provide free air ventilation to the room.

7.   Fuel Station - Concrete pavement instead of bitumen surface around the fuel station shall be adopted.

8.   Upstand Kerb - All upstand kerb of cable manhole should be highlighted with black yellow strip marking.

E   TUNNELS

1.   Sump Pump Control Panel - Provide proper access to tunnel sump pump control panels.

2.   Blast Door roller housing - Provide ramps to blast door roller housing which is above the track level.

3.   Tunnel Booster Fans - provide collapse frame and maintenance access platform to the tunnel booster fan units.

4.   Floating Slab Track - gap between floating slab track and tunnel wall to be backfilled.

5.   Trackside Drain - trackside drain near platform steps to be covered with gratings.

F   VIADUCTS

1.   Low viaduct parapet on non-walkway side - Provide additional railings on the low parapet wall where there is no third rail to act as deterrent for staff safety.

2.   Viaduct near station end stairs - 3 m of handrailing to be provided on parapet leading to emergency access from track to end stairs.

3.   Bearings - Are they all accessible for future maintenance and replacement?

        Check at non-standard location such as cross over beams, at station etc.

4.   Drainage system for viaduct - Is the system designed for movements of viaduct beams?

5.   Walkways - Should have no dead ends.

6.   Railings - To be provided near station at places where detrained passenger is likely to make use of for escape.

7.   Vandals - Are there adequate barriers at at-grade section to prevent vandals from getting onto viaducts?

G TRACKWORKS

1. Steel grating shall be lightweight covers for tunnel sump instead of heavy concrete covers.

2. Buffer rubber (or wood) shall be fixed on buffer stops in depot.

3. Buffer stops at end of viaducts to be designed to stop train travelling at maximum speed in restricted mode of 18 km/h.

4. Difference in levels of rubber joint packer between Floating Slab units and tunnel would cause tripping hazard. Proposed maximum difference in level of 10 mm and maximum gap of 5 mm.

5. Fill up cable recess of traction jumper cables between running rails on slab track in tunnel.

6. Ballast infill between tracks and near sectionalising switches. Propose the following :-

   i)   Sect. switches - 150 mm below plinth level

   ii)   Track spacing 4.7 to 6 m - 200 mm thick layer of ballast

   iii) Track spacing > 6 m - blockwork kerb 150 mm high to retain ballast