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1 Introduction

a) The following Clauses of this document define the minimum geotechnical requirements which shall be met in the design for all projects. The requirements stipulated here are the minimum geotechnical requirements and do not preclude the Designer from using other proven methods in addition.

b) Scope briefing for all geotechnical works shall be carried out by the department’s Geotechnical Section before the commencement of any geotechnical site investigation. Geotechnical site investigation shall be carried out in accordance with AS 1726 and logging of encountered subsurface materials during geotechnical investigation works shall be in accordance with the departmental Technical Guideline on Geotechnical Borehole Logging (TGGBL). Where there is a conflict between AS 1726 and this Geotechnical Design Standard (GDS), the content of this GDS shall take precedence.

c) Prior to construction, all geotechnical design reports, including drawings, shall be submitted to the department’s Geotechnical Section in hard copy and electronic (CD) form for review. The reports shall state clearly the assumptions, the justification of parameters and the methods adopted in design and shall address all issues or concerns for the design element in question.

d) When the reports are submitted in stages (e.g., 15%, 85% and 100% design stages), each report shall be a standalone report. At the end of the full review process, a final standalone geotechnical report, including geotechnical field and laboratory data, interpretative design report/s as per Clause 1(c) shall be submitted to the department’s Geotechnical Section for their record.

e) The design calculations, duly documented as the design work progresses, shall be submitted if requested by the department’s Geotechnical Section.

f) The design, construction, maintenance and monitoring of earthworks and associated protective treatments shall ensure that permissible pavement movement or performance meets the requirements set out in the departmental Pavement Design Specifications and that post-construction in-service movements and both subsurface and surface water flows do not at any time:

i. impair or compromise pavement support, or

ii. impair or compromise support of structures, or

iii. cause pavements to fail to meet the department’s pavement performance criteria, provided regular programmed maintenance is undertaken to ensure the durability of the assets.

Under special circumstances, the Contractor/Designer may seek exemption from compliance with Clauses in this document. In order to obtain such exemption, the Contractor/Designer shall undertake a geotechnical risk assessment and demonstrate to the department why such exemption(s) are sought and under what special circumstances. Further, the Contractor/Designer shall convince the department that such non-compliance will not compromise the performance standards stipulated in this document, including safety, durability, future performance, constructability and maintenance. On submission of the geotechnical risk assessment to the department, the Contractor/Designer shall seek written
approval from the department, and obtain such approval in writing prior to dispensing with any requirement under this document.

h) All geotechnical design reports shall be certified by a Registered Professional Engineer of Queensland (RPEQ) Geotechnical Engineer.

2 Embankments

2.1 General requirements

Notwithstanding the requirements stipulated in the department’s Technical Specification MRTS04, the following also shall apply:

a) Embankment batter slopes shall not be steeper than:
   i. 1 (vertical) to 2 (horizontal) for earth-fill, and
   ii. 1 (vertical) to 1.5 (horizontal) for rockfill.

b) For embankments in earth-fill, the vertical height of any single continuous batter slope shall not exceed 10.0 m. A minimum 4.0 m wide bench shall be provided at the top of any 10 m high single continuous batter slope in an earth-fill embankment for erosion control and maintenance purposes.

c) Benches are not required for rockfill embankments.

d) Spill-through embankments at structures (e.g., bridges) shall comply with MRTS03.

e) Only ‘Class A’ material or rockfill (as defined in MRTS04) is acceptable within the structure zone as defined in Clause 2.2(h).

2.2 Performance standards

a) Embankments shall be stable at all times. The minimum Factor of Safety (FOS) during construction shall be 1.30 and in the long-term 1.50. For embankments constructed over soft foundations, regular instrumentation monitoring and the plotting of settlement and pore pressure development over time shall be carried out to aid in the demonstration of compliance with minimum FOS during construction. This data shall be provided to the department’s Geotechnical Section.

b) Post-construction in-service movements shall not impair or compromise pavement support and shall not exceed permissible pavement movement requirements as per departmental pavement design specifications.

c) The materials and construction methods used for embankments shall ensure that embankments will not be susceptible to cracking due to seasonal moisture changes, tunnelling or rill erosion.

d) Any in-service total settlement of the embankments shall not compromise the flood level requirements of the Deed.

e) Any in-service movements shall not cause the cross-section profile to deform so as to compromise efflux of surface run-off and subsurface drainage. Design and maintenance shall address treatment options to accommodate cross-section profile deformation.
f) Embankment settlements and lateral movements of the subsoils shall not adversely impact on existing and/or new structures, earthworks and services that would compromise their serviceability and/or structural integrity.

g) Batter slope erosion control measures such as revegetation and surface drainage shall be included in the design to minimise erosion and deterioration of the fill batters.

h) The ‘Structure Zone’ is defined as a length not less than 25 m within the approach to any structure (bridges, culverts, piled embankment, etc.). The maximum permissible total in-service settlements (within the first 40 years in service) within the Structure Zone and away from the Structure Zone are given in Table 2.2. Only ‘Class A’ material compacted to 98% minimum compaction density or rockfill is accepted within the structure zone. ‘Class A’ material and rockfill shall comply with and be placed in accordance to the requirement of MRTS04.

Table 2.2 – Settlement criteria

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum total in-service settlement permissible within 40 years of pavement construction (Design and handover requirement)</th>
<th>Maximum differential settlement at any time (Design and handover requirement)</th>
<th>Maximum differential settlement at any time (Intervention requirement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within Structure Zone (as per Clause 2.2(h))</td>
<td>40 mm</td>
<td>50 mm</td>
<td>Design change of grade due to differential settlement over any 5 m length of pavement shall be limited to 0.5% for sprayed seal granular asphalt over granular and full depth asphalt pavements and 0.3% for all other pavement types, in any direction of the carriageways.</td>
</tr>
<tr>
<td>Away from Structure Zone</td>
<td>150 mm</td>
<td>Sprayed seal granular, asphalt over granular, full depth asphalt and continuously reinforced concrete pavements, 200 mm. Other pavement types, 100 mm.</td>
<td></td>
</tr>
</tbody>
</table>

Note: In addition to meeting the design change of grade requirements due to differential settlement, the pavement shall meet the requirements of ‘Aquaplaning’ as per the department’s ‘Hydraulic and Drainage’.

i) If the differential settlement values given in Table 2.2 are exceeded, the Contractor shall undertake the following:

   i. For flexible and concrete pavements surfaced with asphalt, re-profile the pavement to the original design level or an alternative road surface geometry that complies with the design requirements of the Contract, prior to practical completion and/or during the Defect Liability Period (i.e. resurfacing).

   ii. For concrete pavements not surfaced with asphalt and unplanned cracking has not occurred, the Contractor shall ‘slab-jack’ the pavement with a suitable medium and
process to restore the original design level or an alternative road surface geometry that complies with the design requirements of the Contract, prior to practical completion and/or during the defects liability period. Where unplanned cracking in the concrete base has occurred, the Contractor shall, unless approved otherwise by the Principal, remove and replace the cracked slabs with new pavement in accordance with MRTS40.

j) To confirm that the performance of embankments meets the requirements stipulated in Clause 2.2(h), the Contractor shall carry out adequate instrumentation monitoring and analyses. Before handing over the asset to the department at the end of Defect Liability Period or maintenance period (whichever is longer), the Contractor shall demonstrate that the performance of embankments complies with the settlement criteria given in Table 2.2. That is, the projected settlements based on the monitoring shall be less than the permissible amounts. The extrapolation of settlement for compressible subsoil areas shall be carried out using Asaoka’s method in addition to any other method/s.

2.3 Geotechnical design for unreinforced embankments

a) The geotechnical design report shall address the following:
   i. The development of a geological model, which depicts the stratigraphy of the subsurface materials with delineation of potential drainage boundaries.
   ii. The interpretation of subsurface strata along with their geotechnical properties/parameters and the adopted design strength and compressibility parameters. The adopted design strength and compressibility parameters shall be justified.
   iii. Design pore water pressures, both the existing and the anticipated worst conditions, shall be adopted with justification provided for the values adopted.
   iv. Stability analyses in accordance with the requirements in Clause 2.3(b).
   v. Settlement analyses in accordance with the requirements in Clause 2.3(c), and
   vi. The development of a geotechnical monitoring program (as per Clause 2.7) in respect of pore water pressures and/or embankment/subsoil movements during construction and maintenance.
   vii. Anticipated construction-related issues including, but not limited to, rate of filling.

b) Stability analyses for the geotechnical design of an embankment shall comply with, and address the following:
   i. Design philosophy
      • Limit equilibrium methods based on traditional factor of safety (‘FOS’) shall be considered.
      • Soft clay foundations shall be modelled for short-term behaviour using total stress analysis (i.e., ‘Total Stress Basis’), as well as for long-term (in-service) behaviour using effective stress parameters (‘Effective Stress Basis’).
      • The embankment material shall be modelled using drained strength parameters (i.e., ‘Effective Stress Basis’).
      • The minimum FOS during construction (short-term) shall be 1.30 and in-service (long-term) shall be 1.50.
• The following potential modes of failure shall be investigated where relevant:
  1. both circular and non-circular slip surfaces
  2. sliding across the top of basal reinforcements
  3. bearing capacity failure, and
  4. settlement of the embankment, resulting from excessive elongation of the basal reinforcement.

• Any ground improvement schemes adopted shall either have proven local success (under similar geological conditions) or shall be demonstrated to be appropriate for the site conditions. The demonstration could be via:
  1. detailed analyses presented as a report, which shall be independently reviewed by the department or an appointed consultant, or
  2. conducting appropriate field trials to demonstrate that the proposed method is capable of predicting critical performance aspects as per Table 2.2.

• The influence of any disturbance due to ground improvement schemes and the loading imposed by the proposed constructions on any adjacent structures and services shall be investigated.

• The relevance of seismic stability issues shall be investigated.

• Sudden drawdown effects, if relevant, shall be checked.

ii. Loads and geometry

• Minimum of $20 \text{kPa}$ uniformly distributed live loading for long-term conditions and a minimum of $10 \text{kPa}$ uniformly distributed live loading for initial construction shall be adopted across the top of the embankment cross-section.

• The impact of existing excavations and of any known proposed excavations on embankment stability shall be assessed.

iii. Material parameters

• The minimum unit weight of embankment materials shall be $20 \text{kN/m}^3$ unless otherwise substantiated by the use of light weight material.

• Embankment shear strength parameters for earth-fill shall not exceed $c' = 5 \text{kPa}$ and $\Phi' = 30$ degrees (for ‘Class A’ and ‘Class B’ materials as per Table 14.2.2 in Technical Specification MRTS04) while for rockfill, $\Phi' = 40$ degrees.

• For embankment $>10 \text{ m}$ height, laboratory shear strength testing shall be carried out on re-compacted samples to estimate the shear strength of the embankment fill materials if other than ‘Class A’ or ‘Class B’ materials or rockfill as per MRTS04 are intended for use.

iv. Geotechnical model

Scaled cross-sections of the embankment with subsurface models depicting the design material properties, pore water pressure conditions and ground improvement elements and their associated parameters shall be established.
v. Method of analysis

Morgenstern and Price method of limit equilibrium analysis shall be the primary method of limit equilibrium analysis.

vi. Software

Industry accepted software shall be used to carry out limit equilibrium analyses required by Clause 2.3(b) (i). The submission shall include typical sections analysed and data files compatible with SLOPE/W software shall be submitted for all analysis.

vii. Presentation of stability analyses

The geotechnical design documentation shall include a report on the embankment stability analysis. The embankment stability analysis report must:

- Clearly indicate the geotechnical models and design strength parameters and pore water pressure conditions adopted, design standards complied with and shall be supported with design calculations where appropriate.
- Include cross-sections with chainages marked. These cross-sections shall show the centres of slip circles investigated and the locus and shape of the most critical circle or non-circular surface for the different critical stages of the embankment construction phase and for the design life.

c) Settlement analyses for geotechnical design of embankment/s shall comply with and address the following:

i. Design philosophy

- Settlement analysis based on Terzaghi one-dimensional consolidation theory shall be used as the primary method but does not exclude the use of other theories. Where primary consolidation under the applied embankment loads will not occur, settlement analysis may be based on elastic analysis and published correlations for time dependent settlement.
- The influence of strain rate effects, temperature and structural phenomena shall be addressed where relevant.
- Secondary consolidation (creep) issues shall be taken into account.
- The influence of continuing settlements, both vertical and horizontal, imposed by the proposed constructions on any adjacent structures and services shall be investigated and addressed.
- The performance of existing services in the light of settlements induced by the new construction should be documented as part of the design process.
- The influence of preloading, surcharging, staging and ground modification shall be investigated with respect to both primary and secondary settlements.

ii. Geotechnical model

The geotechnical model should clearly show the profiles of pre-consolidation pressure, coefficient of volume decrease \( m_v \), compression index \( C_c \), coefficient of consolidation \( c_v \), for rate of settlement analysis and any embedded sand layers. Where primary
consolidation of the foundation will not occur under the applied embankment loads, the
geotechnical model shall include elastic moduli for each unit and parameters used in the
assessment of time dependent settlement.

iii. Settlement parameters

In assessing the geotechnical parameters for settlement analyses, account shall be taken
of their dependence on stress level.

iv. Presentation of settlement calculations

The geotechnical design documentation shall include a report on the embankment
settlement analysis. The embankment settlement analysis report shall:

- clearly indicate the geotechnical models and design settlement parameters and
drainage boundary conditions adopted, design standards complied with and be
supported with design calculations where appropriate, and
- provide the settlement time history plots, along with the subject embankment location.

2.4 Additional design requirements for side-long embankments

Embankment foundations need to be excavated to competent materials as assessed by an
experienced Geotechnical Engineer/Engineering Geologist after stripping all loose colluvial slope
wash materials and/or uncontrolled fill.

Drainage design should consider both existing and future worst anticipated groundwater conditions,
magnitude of rainfall events in the region, topography and nature of anticipated maintenance over the
design life of the road.

For side-long embankments traversing natural slopes of greater than 7\(^\circ\) (> 1V:8H), the following
drainage measures shall be addressed in the design especially for embankment height > 10 m (toe to
crest):

a) toe drainage

b) basal drainage (longitudinal and transverse drains).

These are subject to ground water conditions and the catchment area of the site.

2.5 Embankment subject to permanent/semi-permanent toe inundation

At these locations, the following additional aspects shall be addressed in the design:

a) Construction

i. Shall ensure that the main body of the embankment shall be constructed with moisture
insensitive material with respect to strength, dispersion and volume reactivity below
temporary and permanent inundation levels.

ii. The skin of the embankment shall be protected with at least 300 mm minimum thickness
of rock protection within the zone likely to be subjected to temporary or permanent
inundation.

b) Stability check

i. The stability analysis of the finished embankment shall demonstrate that it is safe against
seepage forces, draw down effect and ponding/wave action.
2.6 Geotechnical design for reinforced embankments

In addition to the requirements stipulated in Clause 2.3 above, the following shall apply:

a) The primary method of design for basal reinforced embankments shall conform to British Standard 8006 (BS 8006).

b) Slope reinforcement

The design requirements for reinforced slope embankments shall conform to BS 8006. Approved reinforcements as per MRTS06 shall be used.

2.7 Ground improvement

Any ground improvement schemes adopted shall either have proven local success (under similar geological conditions) or shall be demonstrated to be appropriate for the site conditions. The demonstration could be via:

a) detailed analyses presented as a report, which shall be independently reviewed by the department or an appointed consultant, or

b) conducting appropriate field trials to demonstrate that the proposed method is capable of predicting critical performance aspects as per Table 2.2.

2.8 Geotechnical instrumentation monitoring for embankments

a) The geotechnical monitoring program for embankments, where relevant, (refer to Clause 2.3(a) (vi)) shall be documented on the drawings.

b) The geotechnical monitoring program for embankments shall:

i. address the instrumentation provisions for monitoring of pore water pressures, embankment and subsoil movements, with justification for their use, and the design objectives they are expected to clarify, and

ii. detail the nature of the instrumentation, locations (physical surveys with ‘x’, ‘y’, ‘z’ co-ordinates), positions within the ground where the instruments are to be installed (on cross-sections), frequency of instrumentation monitoring, monitoring contingency plans with other relevant details.

c) The geotechnical monitoring program for embankment shall be implemented and maintained throughout the construction of embankments.

d) All geotechnical instrumentation shall be so placed to protect them from vandalism and construction activities.

e) Instrumentation at appropriate locations shall be provided to enable the continuation of monitoring of critical elements during the Maintenance Phase of the project.

f) All monitoring data and reports shall be submitted to the department’s Geotechnical Section in hard copy and electronic form.

g) The department’s preferred method of capture and store of monitoring results is to use a web-based data acquisition system. Consideration shall be given to adopting this method.
2.9 Maintenance

a) The embankments geotechnical monitoring program shall continue to be implemented and maintained throughout the Defect Liability Period and must then shall be handed over to the department’s Geotechnical Section.

b) In addition to the geotechnical instrumentation monitoring:
   i. the Designer/Contractor shall select locations where no instruments are installed to carry out physical survey monitoring programs to establish longitudinal settlement profiles and other movements, and
   ii. visual inspections and straight edge measurements shall be undertaken to capture surface subsidence and deformations.

c) The embankment geotechnical monitoring program shall include the production of inspection reports, interpreted instrumentation monitoring reports and improvement works reports.

d) The results of the embankment geotechnical monitoring program during the Defect Liability Period shall be used:
   i. to assess the need for remedial/maintenance works, and
   ii. in the design of any necessary remedial works.

3 Cuttings

3.1 General requirements

a) Unreinforced cuts: cut batter slopes shall not be steeper than 2.0 (vertical) to 1 (horizontal). The maximum vertical height of any single continuous cut batter shall, in most cases, not exceed 10.0 m. A minimum 4.0 m wide bench shall be provided for erosion control, control of rockfall and maintenance purposes at the top of any 10.0 m high single continuous cut batter. Cuts in readily erodible or dispersive geological materials may require different strategies, e.g., flattening without benches. Such treatments must be accepted in writing by the department’s Geotechnical Section prior to commencement of construction of the cutting.

b) Reinforced cuts: reinforced (e.g., soil nail/rock dowel walls) cut batter slopes shall not be steeper than 10 (vertical) to 1 (horizontal).

3.2 Performance standards

a) The cut batters shall be stable both in the short- and long-term, with low whole-of-life maintenance addressed through recognition of the influence of local climatic and geological conditions on stability and attention to erosion issues.

b) Suitable construction techniques and interventions during construction and maintenance shall ensure minimal impact on the road user, the local residents and their dwellings, commercial property, services and the environment.

c) Slope stabilisation measures shall be carried out in a timely fashion to minimise the development of stability issues, siltation of surface and subsurface drainage and deterioration of the cut face. The slope treatments shall incorporate finishes aesthetically compatible with the surrounding streetscape and environment.
d) Where ground reinforcement techniques are used, proof testing of selected slope reinforcement elements as required by the relevant Technical Specifications shall be carried out.

### 3.3 Design requirements

#### 3.3.1 General

A geotechnical risk assessment based on preliminary analyses shall be carried out to identify whether the issues in Clauses 3.3.2 and 3.3.3 need to be addressed in order to satisfy the performance standards stipulated in Clause 3.2. This risk assessment shall be submitted to the Principal's Representative for approval. The Principal's explicit approval must be obtained by the Designer before the requirements under Clauses 3.3.2 and 3.3.3 are dispensed with. A representative ground water condition shall be considered in the design. Particular attention shall be given to long-term stability conditions as this would be generally critical for cut slopes and excavations.

#### 3.3.2 Unreinforced cuts

a) The preparation of the geotechnical design for a cutting shall include:

i. The development of a geological model, which shows the different subsurface strata with their lithologies, weathering states and structural defects, where practicable, based on factual data, geological mapping, borehole imaging and knowledge of local geology.

ii. A stability analysis in accordance with the requirements in Clause 3.3.2(b) below, and

iii. The development of a geotechnical monitoring program that considers ground water and slope stability/movements during construction and maintenance. Wherever applicable, remote continual monitoring by loggers should be implemented.

b) A stability analysis for a geotechnical design for a cutting shall comply with, and address, the following:

i. Design philosophy

   - In parts of cuttings characterised by soil and ‘soil-like’ extremely weathered rock, circular and non-circular failure mechanisms shall be considered in design, whereas in parts of cuttings characterised by MW or better rock, structurally-controlled failure mechanisms shall be investigated (including toppling, planar sliding or wedge failure modes).

   - Any parts of cuttings, the minimum FOS shall be 1.50, with a representative ground water condition. In all cases, a pore water pressure coefficient (R_u) of not less than 0.15 shall not be used even with appropriate drainage systems.

   - The potential for failure due to undermining as a result of differential weathering (typically in sub-horizontally bedded formations) shall be addressed.

   - Potential susceptibility to rapid softening and deterioration of some lithologies shall be investigated and any requirement for a stage excavation approach shall be assessed.

   - Cut batter slope designs which are based on prescriptive measures using observed performance of existing road cuttings in similar geological conditions, with consideration of long-term stability and low maintenance costs, are acceptable with the agreement of the department’s Geotechnical Section.
• The design considerations which shall be addressed include, but not be limited to, the influence of groundwater on stability, recognition of soft infill materials in discontinuities, allowance for disturbance effects due to the excavation techniques, surface water run-off issues on toe, crest and bench, and erosion in general.

ii. Fissured soil

In fissured clays, mass operational strengths which capture the relatively lower strength of fissures/slickensides surfaces shall be adopted.

iii. Method of analysis

Morgenstern and Price method of limit equilibrium analysis shall be the primary method of limit equilibrium analysis for soil-like stability problems. For structurally-controlled rock stability problems and for characterising discontinuities in rock, stereographic projection techniques shall be used.

iv. Software

As per Clause 2.3(b) (vi) of this document.

c) A geotechnical monitoring program that addresses groundwater and/or slope movements (refer Clause 3.3.2(a)(iii) above) shall specify and include:

i. the nature of geotechnical monitoring instrumentation

ii. the locations of instrumentation and their positions within the ground (i.e., ‘x’, ‘y’, ‘z’ coordinates)

iii. residual durable instrumentation which will remain at appropriate locations to enable the continuation of monitoring of critical elements during the Defect Liability Period, and

iv. monitoring contingency plans (documentation of review and alert levels and response plans) with other details.

d) Presentation of stability results

The geotechnical design documentation shall include a report on the cutting stability analysis.

The cutting stability analysis report shall include:

i. Geotechnical models, including any geotechnical domains, rockmass classification, the design strength parameters and pore water pressure conditions adopted, design standards complied with and supported with design calculations where appropriate.

ii. Analyses of kinematic and/or circular failure modes, and

iii. The design of batter and stabilisation treatments, including associated drawings.

e) Rock fall analysis

Rock fall modelling shall be carried out on all major rock cuttings with an overall height > 10 m in height, with appropriate design to ensure rock fall debris does not present a hazard to the road users.
3.3.3 Reinforced cuts

The following requirements for reinforced cuts shall apply, in addition to those stipulated in unreinforced cuts in Clause 3.3.2. Details of the design of soil nail reinforced slopes are presented in Clause 5.4.

a) The design of insitu slope stabilisation measures shall be carried out based on BS 8006 as the primary method and Technical Specification MRTS03. The use of BS 8006 will override the factors of safety stipulated in Clause 3.3.2(b). The design shall take into account the following:

i. design life
ii. overall stability and internal failure mechanisms both during construction and in the long-term
iii. impact of the proposed cuttings on existing and new structures
iv. durability and allowance for construction damage of reinforcing elements
v. influence of structural discontinuities if the cutting is in rock
vi. the behaviour of the ground under stressing loads.

b) Presentation of design calculations

i. the design of insitu stabilisation treatments shall be documented with associated drawings
ii. this documentation shall clearly indicate the geotechnical models and design strength parameters and pore water pressure conditions adopted, design standards complied with and supported with design calculations where appropriate
iii. construction sequence must be outlined and locations of reinforcing elements to be proof tested shall be identified along with their proof test loads.

3.3.4 Construction

a) The geotechnical monitoring program for ground water and/or slope movements shall be documented in the Contractor's earthworks and construction plans and drawings.

b) The geotechnical monitoring program for ground water and/or slope movements shall be implemented and maintained throughout the construction of cuttings.

The following activities shall be undertaken by the Contractor/Designer as part of the geotechnical monitoring program during construction:

i. Progressive assessment of site conditions as exposed during excavation incorporating geological mapping with subsequent updating of geological models and assessment of any need to stage excavations.
ii. Monitoring of any ground instrumentation periodically and especially during critical phases of construction, and after significant rainfall events.
iii. Implementation of contingency plans to address damage and/or malfunctioning of critical instruments.
iv. Progressive review of excavation methodology during excavation, including temporary support systems.
v. Progressive review of conditions and data that become available during construction and, if necessary, modification of cut batter design, subsurface drainage requirements and construction sequencing.

vi. Identification and assessment of local areas of potential instability. Adoption of local measures as soon as practicable to minimise the progression of such local failures. In addition, appropriate action should be taken if such local conditions be deemed to compromise the cut batter stability during its design life, have unacceptable environmental impact and/or impact on the safety of the road user or construction and maintenance workers.

vii. Execution of required proof testing operations for slope reinforcement.

4 Bridge and other structure foundations

4.1 General

Structural aspects

Reference shall be made to the department’s Design Criteria for Bridges and Other Structures for durability, structural and other requirements not covered here.

Geotechnical aspects: geotechnical investigation and reporting

Geotechnical investigation for the design of foundation shall be carried out for all bridges. The preparation of scope briefing document shall be carried out by the department’s Geotechnical Section as per Clause 1(b).

In all cases, the investigation shall adequately provide all relevant information for design and shall ensure that the site geological model can reasonably be established. Unless otherwise approved or directed by Director (Geotechnical), a minimum of two boreholes shall be drilled at every abutment and pier location. With a view to further reducing the chances of latent conditions during construction, the number of boreholes to be drilled at a particular site will depend on how well the site geology could reasonably be established. To achieve this aim, the subsurface geological model should be updated as the drilling is continuing on site. The geotechnical and structural engineers responsible for a project shall be satisfied that the obtained information from a particular site is adequate for the foundation design before the drilling contractor demobilises from the site.

Generally, the boreholes shall be drilled at a maximum spacing of 10 m or part thereof along the width of every abutment and pier of all bridges. To avoid doubt, twin bridges shall be treated as separate bridges.

For other structures, the details of Geotechnical Investigations shall be discussed and approved by the department’s Geotechnical Section.

For sites where PSC driven piles are likely to be the foundation option, all boreholes shall be extended to at least between 3 m and 5 m into substrata with consecutive Standard Penetration Test (SPT) number greater than 50 (SPT N > 50). For sites where Cast-in-Place (CIP) piles are likely to be the foundation option, all boreholes shall be extended to a minimum of 5 m into competent bedrock (Moderately and/or Slightly, Weathered).
The foundation geotechnical report shall include the following as a minimum:

- **Geological models**
  The models shall be detailed and shall be prepared for each foundation location in complex geological terrain. The models(s) shall capture as a minimum geological elements that may assist in design, such as stratigraphy of the subsurface within the depths investigated and show the various lithologies and their weathering grades with demarcation of potential zones of water ingress, structural defects, including clay seams, fault and sheared zones to enable geotechnical models to be developed.

- **Design parameters and justification.**
- **Design calculations for geotechnical axial and lateral capacities of pile(s) where relevant.**
- **Design calculations for deflection and bending moments in the pile(s) under lateral loading where relevant.**
- **Group effects when estimating settlements and the distribution of load within the piles in a group.**
- **Design of approach embankments (see Clause 2.2(h) and Table 2.2), and**
- **Construction considerations (issues that may influence construction).**

### 4.2 Design philosophy

Piles shall be designed to support the design loads with adequate geotechnical and structural capacity and with tolerable settlements in conformance to the performance requirement of the structure. The following shall be satisfied:

- **Ensure that there is an adequate margin of safety against the possibility of pile failure under working loads.**
- **Limits settlement of the foundations and the differential settlement between the foundations (abutment/piers) to values that are consistent with performance requirements of the superstructure.**
- **The overriding influence of site geology, construction methodology and quality control adopted on rock mass properties and overall design shall be recognised in the design of CIP piles.**
- **Limit the mobilisation of peak side resistance when there is uncertainty as to the ultimate capacity in end bearing in the design of CIP piles.**
- **In addition to these above, for piles socketed into rock, an iterative design methodology reviewed on the basis of socket inspections to validate the geotechnical model and the design assumptions needs to be ensured. In particular, the load transfer mechanism between the shaft and the base adopted in design needs to be justified on the basis of the socket inspections.**
- **Site inspection and verification of constructed sockets by an RPEQ qualified Geotechnical Engineer or an Engineering Geologist with over 10 years’ experience in similar civil engineering construction works is mandatory. Sign off (certification) shall be by a RPEQ Geotechnical Engineer.**
• As a means of promoting friction between the concrete used in forming the pile and the shaft/base of the socket, bentonite or polymer slurry shall not be used in excavating the pile/socket.

• As a means of promoting wall stability and socket cleanliness, permanent liners shall be installed to the top of the socket.

• Other requirements which are mandatory for a successful construction of sockets are contained in MRTS63 and MRTS63A.

4.3 Design methodology

4.3.1 Axial capacity of piles

a) Driven piles

Design of driven piles shall be carried out based on Australian Standard 5100.3 (AS 5100.3). However, the geotechnical reduction factor ($\phi_g$) shall be not higher than 0.6.

Piles at bridge abutment locations shall not be driven until the estimated post-construction settlement of the approach embankment is reduced to < 100 mm by preloading or otherwise. Any expected residual settlement of the approach embankment after a pile is driven shall be taken into account in the design. Consideration shall be given to the settlement of individual piles and pile groups resulting from negative skin friction caused by settlement of the surrounding ground.

Driven piles shall be tested to ascertain their capacity and integrity. The testing shall be carried out with Pile Driving Analyzer (PDA) and Pile Driving Monitor (PDM).

The minimum number of piles PDA tested shall be the greater of:

- 15% of piles in pier/abutment bent
- minimum one pile per pier/abutment.

All piles shall be PDM tested.

The outputs from the PDA and PDM testing shall include an estimate of mobilised axial capacity, an indication of the load-settlement characteristics and an indication of the pile integrity.

All testing shall conform to the requirement of MRTS68.

The supplier and operator of the pile driving analyser and pile driving monitor for establishing pile integrity (advanced PDM) shall be a company independent of the piling contractor.

b) Cast-in-situ piles (CIP) not socketed into rock

The design shall be carried out based on AS 5100.3, but the geotechnical reduction factor ($\phi_g$) shall be not higher than 0.6.

c) Cast-in-situ piles (CIP) socketed into rock

The design method of Pells (1999) shall be the primary design tool for the design of rock sockets with sidewall slip. Pells (1999) incorporates the work done by Rowe and Armitage (1987) and others and further addresses lateral loadings. The final design shall be checked with at least a second design method which explicitly addresses the socket/pile interface to
obtain the full load-deformation response to assist in confirming the collapse (ultimate capacity) and serviceability criteria.

4.3.2 Lateral capacity and lateral deflection of piles

a) Lateral capacity

Piles shall be designed to have adequate lateral load carrying capacity. As a minimum, the method of Broms (1965) shall be used in estimating the capacity of piles under lateral loads. The requirement of Clause 4.4.7 of AS 2159 shall also to be satisfied.

b) Lateral deflection

The lateral displacement of a pile shall not exceed the tolerable lateral displacement consistent with the performance requirement of the structure. The elastic continuum approach of Poulos (1971a/1971b) or alternative approaches based on subgrade reaction theory (Winkler Foundation), the p – y alternative or the characteristic load method (CLM) could be used.

4.4 Construction

The overriding influences of geology and construction techniques on the performance of cast-in-situ piles (CIP) are well documented. Reference should be made to MRTS63 for construction-related issues that may influence the design.

The design should be geared towards forming piles that are free of defects. Low strain or non-destructive integrity tests shall be carried out to ensure integrity of the constructed CIP piles. The supplier and operator of the pile dynamic/integrity tests shall be a company independent of the piling contractor.

4.5 Spread footings and strip footings

The design of these footings (excludes Reinforced Soil Structure Wall foundations) must satisfy the following:

- Shall be designed in accordance to the requirement of AS 5100.3.
- Limit settlement and differential settlement to values that are consistent with the performance requirements of the superstructure.
- Where the footings are founded on natural or cut slopes, the design must ensure both the short-term and long-term stability of the slopes with minimum factors of safety (FOS) of 1.5. Due consideration is to be given to such factors as reduced bearing capacity due to loss of ground resulting from batter, groundwater, geological weathering, fissuring, softening, structural defects and climate.

5 Retaining structures

5.1 General

All retaining structures shall be designed to ensure an asset that is fit for purpose and guarantees long-term performance. In addition to the requirements stipulated in this section, reference shall be made to the department’s Design Criteria for Bridges and Other Structures for durability, structural and other requirements not covered here.

The minimum design life for all walls shall be 100 years.
With the exception of embedded retaining wall, soil nailed wall, and reinforced soil wall, the loading for all other walls covered in this document shall satisfy the requirement of AS 5100.2 Clause 5.4, which refers to AS 4678 for loads and their combinations.

The minimum design vertical live load shall be 10 kPa unless noted otherwise. Vertical and lateral loads from earthworks (or other effects) on, or adjacent to, the walls shall be included in the design. Traffic impact and safety barrier loads and other superimposed structural loads (e.g., noise barriers) shall be taken into account in the design of all walls.

Compaction-induced stresses shall also be taken into consideration.

5.2 Embedded retaining walls

a) Design of embedded retaining walls, e.g., sheet pile wall, contiguous pile wall, secant pile wall, etc., shall comply with BS 8002.

b) The design report shall include the following as a minimum:
   i. geological model
   ii. geotechnical model
   iii. design parameters
   iv. ground water conditions
   v. cross-section and long-section details of the wall
   vi. bending moment and shear force diagrams for different load cases and anchor/prop loads (if any)
   vii. anchor/prop details if any
   viii. proof testing program for anchors
   ix. construction sequence
   x. short- and long-term monitoring programs.

c) Certification of construction is to be as per Clause 5.8.

5.3 Reinforced concrete cantilever retaining walls

a) The design of reinforced concrete retaining walls (RC Walls) shall satisfy the requirement of AS 5100.3.

b) The design report must include the following as a minimum:
   i. geological model
   ii. geotechnical model
   iii. design parameters
   iv. ground water conditions
   v. cross-section and long-section details of the wall.

c) Certification of construction is to be as per Clause 5.8.
d) Earth pressures shall be based on Construction Industry Research and Information Association (CIRIA) C580. Other methods are allowed if passive wall friction is ignored.

5.4 Soil nailed walls

a) The design of in-situ cut stabilisation measures shall be carried out based on BS 8006 and the department’s Technical Specification MRTS03. The design shall take into account the following:
   i. overall stability and internal failure mechanisms, both during construction and in the long-term
   ii. impact of the proposed cuttings on existing and new structures
   iii. durability and allowance for construction damage of reinforcing elements
   iv. the behaviour of the ground under stressing loads
   v. ground water conditions; the minimum pore water pressure coefficient (Ru) shall be 0.15 even with appropriate drainage systems (for example, horizontal drains).

b) The design report shall include the following as a minimum:
   i. The design of in-situ stabilisation treatments shall be documented with associated drawings. These shall include geological long sections, site-specific cross-sections pertaining to critical chainages with details given of reinforcement layouts and drainage details.
   ii. This documentation shall clearly indicate the geotechnical models and design strength parameters and pore water pressure conditions adopted, with justification, design standards complied with, and supported with design calculations where appropriate.
   iii. Construction staging and sequence shall be outlined and locations of reinforcing elements to be proof tested must be identified along with their proof test loads.
   iv. Short- and long-term monitoring programs.

c) Certification of construction is to be as per Clause 5.8.

5.5 RSS walls

a) The design of RSS walls shall conform to MRTS06. The design report shall include the following as a minimum:
   i. geotechnical model
   ii. design parameters and justification
   iii. groundwater condition
   iv. actual cross-section and long-section details of the wall (not typical sections)
   v. design calculations for internal and external stability of the wall
   vi. design calculations for global stability of the wall, certified by a RPEQ Geotechnical Engineer
   vii. all necessary tests as per MRTS06 on materials to be used as select backfill and general backfill.
b) Certification of Construction is to be as per Clause 5.8.

5.6 **Gabion retaining walls**

Gabion retaining walls shall be designed to the requirement of AS 5100.3. The maximum height of a gabion wall shall be limited to 6 m.

Gabion walls are not allowed under bridge abutments, except for the purposes of facing or for scour and erosion control purposes.

Precautionary measures against fire hazard need to be considered in the design of gabions located in high fire hazard areas.

In addition to the requirements stipulated in the contract and Clause 42 of MRTS03, the following design/construction requirements stipulated for Boulder Retaining Wall Section of MRTS03 and Clause 5.7 of this document shall be met for gabion walls:

a) foundation treatments, including concrete slurry fill
b) foundation construction requirements
c) stability
d) design report and drawings
e) tolerances and level control
f) surface runoff behind the wall
g) certification of construction shall be as per Clause 5.8.
h) drainage as per AS 4678.

5.7 **Boulder retaining walls**

5.7.1 Introduction

In the absence of specific design codes covering boulder retaining walls and the difficulties of carrying out compliance testing, the maximum effective design wall height (Figure 5.7.2) of a boulder wall is limited to 3.0 m.

5.7.2 Definition of terms

The terms used in this specification shall be as defined in Figure 5.7.2.

*Figure 5.7.2 – Typical wall section*
5.7.3 **Materials**

Refer Clause 53 of MRTS03.

5.7.4 **Design**

a) **Design**

Design shall be to AS 5100.3.

b) **Minimum wall dimensions**

i. Minimum wall dimensions shall be in accordance with Table 5.7.4-A below.

<table>
<thead>
<tr>
<th>Effective design wall height, ( H ) (m)</th>
<th>Minimum wall base dimensions, ( B ) (m)</th>
<th>Minimum width of top of wall, ( D ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1.40</td>
<td>0.500</td>
</tr>
<tr>
<td>2.0</td>
<td>1.50</td>
<td>0.500</td>
</tr>
<tr>
<td>2.5</td>
<td>( B/H = 0.7 )</td>
<td>0.750</td>
</tr>
<tr>
<td>3.0</td>
<td>( B/H = 0.7 )</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Notes:

a) For the definition of effective design wall height, ‘\( H \)’, refer the typical wall section (Figure 5.7.2).

b) A minimum foundation embedment of 0.5 m of the boulder wall into natural ground shall be provided.

c) Front batter of wall shall not be steeper than 4 vertical to 1 horizontal.

c) **Stability**

i. The stability of the wall shall be checked against the following criteria, in addition to other requirements that may be warranted depending on particular requirements. Wall friction must be ignored.

- Sliding (effective cohesion to be assumed zero, both total and effective stress calculations for sliding to be carried out). Passive resistance in front of the wall shall be ignored.
- Overturning (shall meet the requirements of the middle-third rule of structural mechanics).
- Bearing failure (total stress calculations shall be carried out).
- Global failure (both total and effective stress calculations shall be carried out).

ii. The friction angle of rockfill/backfill shall be limited to a maximum of 36º.

iii. The design resistance shall be greater than the design action effect under limit state approach. The margin of safety can be back calculated from limit state approach and shall conform to minimum factors of safety shown in Table 5.7.4-B.
Table 5.7.4-B – Minimum factor of safety

<table>
<thead>
<tr>
<th>Mode of failure</th>
<th>Required minimum FOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding</td>
<td>2.0</td>
</tr>
<tr>
<td>Overturning</td>
<td>2.0</td>
</tr>
<tr>
<td>Bearing</td>
<td>2.5</td>
</tr>
<tr>
<td>Global</td>
<td>1.5</td>
</tr>
</tbody>
</table>

d) Design report and drawings

i. A design report, certified by RPEQ Geotechnical Engineer, and all relevant drawings shall be included in the Design Documentation.

ii. The design report shall include the following as a minimum:

- source of rock fill and methodology for production control
- properties of the rock fill
- properties of the backfill material
- foundation conditions
- wall dimensions
- design calculations.

iii. The drawings shall include the following details:

- A plan showing the location of the wall along with adjoining structures.
- Wall elevation (vertical joints must be staggered).
- Wall cross sections (showing the thickness of the courses) at every change of wall height > 0.5 m and/or B/H ratio.
- Drainage details: provision of a full height 300 mm minimum thickness granular drainage blanket (see Clause 53.2.2 of MRTS03) behind the boulder wall. Continuous geosynthetic filter fabric complying with MRTS27 shall be provided at the drainage blanket/backfill interface.
- The allowable bearing pressures to be stipulated.

5.7.5 Construction

Construction requirements shall conform to Clause 53 of MRTS03. Certification of construction shall be as per Clause 5.8.

5.8 Certification of retaining structures

a) The design documentation shall include a certificate from the Designer which confirms that the design:

i. adequately allows for the site conditions, applied loadings, and relevant material properties for all components of the design, and

ii. ensures the structural integrity and serviceability of the wall for the nominated design life.
b) The Design Documentation shall include the following, in addition to the Design Certificate:
   i. design calculations
   ii. construction drawings
   iii. construction specifications, including wall construction sequence
   iv. any particular requirements for ground and/or foundation improvement
   v. arrangements for monitoring the performance of the wall over the nominated period.

c) The Design Documentation shall be submitted to department's representative prior to commencement of construction of the wall.

d) The contractor also shall submit to the department's representative, a report certified by the Contractor’s RPEQ Geotechnical Engineer (or other suitably qualified RPEQ Geotechnical Engineer) who supervised the construction of the wall. The report shall demonstrate that the wall has been duly constructed as per the relevant departmental technical specifications, Australian Standards or codes and this document and meets all the design requirements.

6 Ground anchorages

Ground anchors shall be designed to the requirement of BS 8081 and relevant departmental specifications, such as MRTS03.

7 Volumetrically active (expansive) soils

The effect of volumetrically active soils that manifest in the form of shrink-swell shall be documented for all structures, especially for bridges and culverts and light loaded structures such as pavements.

Guidance shall be sought from relevant Australian Standards and departmental Technical Notes, such as AS 2870, Technical Note 10 (TN10) and Western Queensland Best Practice Guidelines 35 and 37 (WQ35 and WQ37).

8 References


