AS 5100 Part 3: Foundation and Soil-Supporting Structures

BTN 023
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1 Scope and Application

Bridge Technical Note (BTN) 023 – AS 5100 Part 3: Foundation and Soil-Supporting Structures states the Department of Transport and Planning's (DTP) requirements for the design and specifying the requirements for foundations (including temporary works) for structures.

Bridge Technical Notes are a Code of Practice. Compliance with Bridge Technical Notes is mandatory.

This document is to be read in conjunction with the following documents:

- AS 2159 Piling – Design and installation.
- DTP's Standard Sections

Other than as stated in this document and relevant DTP Standard Sections, the provisions of AS 5100:2017 must apply. Where this document differs from AS 5100:2017, its requirements override those of AS 5100:2017.

DTP was formerly known as Department of Transport (DoT) and VicRoads. DTP documents that must be complied with include all relevant DoT and VicRoads documents.

2 Ground Investigations

2.1 Extent of Investigations

Further to AS 5100.3 Clause 1.6.2, regardless of the foundation pile type, the minimum number of boreholes is determined as follows:

a. Bridges – one borehole at every pier and abutment, with an additional borehole for each 10 m of bridge width or part thereof.
b. Culverts (including underpasses), Shared-User-Path (SUP), major retaining walls and piled road way – one borehole at both ends and one borehole at intermediate locations at not more than 10 m intervals along the longitudinal and transverse alignment.
c. High mast lighting poles – one borehole per lighting pole.
d. Gantries – one borehole per leg of the gantry.
e. All other structures supported on piles – one borehole at both ends and one borehole at intermediate locations at not more than 30 m intervals along the longitudinal alignment of the structure.

The depths of the boreholes must be a minimum of 10 m or deeper in fill or natural soils and a minimum of 5 m below the lowest pile toe level supporting a structure so that the geotechnical information obtained is adequate for design purposes. For alignment investigation, refer to DTP Technical Notes (TN) 078 for guidance.

A geotechnical site investigation factual report containing all relevant geotechnical investigation results, including laboratory testing must be provided in accordance with AS 1726 Clause 5.6.2. The report must fully address the issues contained in AS 5100.3 Clause 1.7 and must be issued by a geotechnical consultant who is prequalified in accordance with DTP's Prequalification for Investigation (GT-INV) in Geotechnical Services category.

3 Piled Foundation

3.1 Materials

3.1.1 General

Reference must be made to AS 5100, AS 2159, DTP's Standard Sections and other relevant Australian Standards to determine the material properties to be used for the design and manufacture of steel and concrete piles.

3.1.2 Other Materials

Other materials must comply with the appropriate Australian Standard. If no standard exists, the alternative standard / specification to be adopted must be approved by the Superintendent.

3.2 Pile Design of Displacement Piles

3.2.1 Precast Concrete Piles

Concrete Strength Grade

The minimum concrete strength grade for reinforced and prestressed concrete piles must be VR400/40 in accordance with Section 610.

Concrete Cover

The minimum concrete cover must comply with the requirements in AS 5100.5 for the relevant exposure conditions, method of manufacture, compaction and concrete strength grade, including the relevant additional cover requirement when curing compounds are used.

3.2.2 Durability

The design for durability must comply with AS 2159, AS 5100.3, AS 5100.5 and AS 5100.6.

If steel, composite or jointed piles are used, the Designer must ensure that the geotechnical information used to assess durability requirements includes a report on soil reactivity and ground water movement based on testing undertaken at the subject site.

The following factors can impact the durability of steel, composite or jointed piles and must be assessed by the Designer:

a. Sites with possible electrolytic action due to stray currents, very low soil resistivity or high soil permeability.
b. If there is a proven occurrence of Sulphate Reducing Bacteria (SRB) in the soil
c. Where soils have a pH-value above 9.5 or below 4.0.

The Designers are to make themselves aware of any other site-specific conditions that may impact the durability of the foundations and make an appropriate allowance for this in the design.

Precast monolithic piles or individual segments of jointed piles must be classified as members in water for the purpose of determining the exposure classification unless it is proven by geotechnical investigation that no part of the member is below the water table.

3.2.3 Pile Toe Protection

Pile toes must be protected to ensure that piles can be driven through hard materials without damage. The pile toe must comprise either a rock shoe, cast iron shoe, cruciform driving shoe or minimum 10 mm thick welded steel plates.

3.2.4 Pile Driving Ring or Head Band

Pile driving rings must be used to prevent splitting or bursting of the top of precast concrete piles during driving. Pile driving rings or head bands must be fabricated using full penetration butt welds and backing plates.

3.2.5 Scour and Pre-boring

If piles are located in a stratum that is at risk of scour damage, the potential effects of scour must be addressed in the design of the foundations.

Unless a rigorous analysis is used, a minimum local scour allowance of 1.0 m must be used in addition to the general scour allowance.

Where pre-boring is not possible due to safety concerns or other factors, an alternative method of deducting the frictional capacity within the estimated scour depth may be permitted. Details of an alternative method for deducting the frictional capacity must be provided to the DTP Chief Engineer – Roads for review and approval.

3.2.6 Pile Chamfer

All square corners must have a 25 mm chamfer, except that chamfers on the top longitudinal corners of the precast pile as cast can be omitted provided:

- the exposure classification for the installed pile is B2 or better; and
- the geotechnical investigation results in the vicinity of the piles (less than 10 m measured in plan from the pile) confirm that the medium in which the pile is to be driven into does not include cobbles, boulders or obstructions of similar size.

3.2.7 Mechanical Joints

Mechanical joints for precast reinforced concrete piles must comply with the requirements of AS 5100.3.

Mechanical joints must not be located within 5 m of the underside of a pile-cap or in aggressive groundwater (refer to Section 3.2.2). If aggressive groundwater is present, the location of splices must allow for the potential rise in the water table due to seasonality.

The designer must specify the allowable range of depths for the mechanical joints on the drawings.

The strength of the joint, as specified by AS 5100.3, must be not less than the strength of the section of pile being joined.

3.3 Piles Testing

Pile testing must be carried out in accordance with the relevant DTP Standard Sections for the specific types of piles.

The dispensation conditions for Pile Driving Analyser (PDA) for predominantly laterally loaded piles may be applied to embedded retaining walls or other structures excluding gantry and high-mast lighting structures as defined in BTN 014, subject to compliance with the criteria listed in Table 1. Where any of the conditions cannot be fulfilled, relevant structural and geotechnical reports must be provided to the DTP Chief Engineer – Roads for review and approval.

Table 1 – PDA Dispensation Conditions for Laterally Loaded Piles excluding Gantry and High-mast Lighting Structures

PDA Dispensation Conditions		Required Documents
Geotechnical Investigation Requirement	Geotechnical investigation in compliance with this BTN.	Geotechnical Investigation Report
Structural Design Requirement	a. The ratio between the highest axial load and lowest lateral load is equal to or less than 0.25 based on the following assessments. i. Determine the highest axial load to the pile based on the load combinations in accordance with AS 5100.2. ii. Determine the lowest lateral load to the pile based on the load combinations in accordance with AS 5100.2. b. The ratio of the pile length embedded must be equal to or less than 10 times of the pile diameter. Both a and b conditions must be satisfied.	A detailed structural design report
Geotechnical Design Requirement	The lateral geotechnical capacity of the pile (Rd,g) must be designed using a maximum basic geotechnical strength reduction factor (Φ_{gb}) of 0.45 in accordance with AS 2159 Clause 4.4.7(b). a. The sum of the design ultimate geotechnical strength of the individual piles in the group or the representative soldier for a retaining wall. b. The design ultimate geotechnical strength of a block containing the soldier pile and the soil.	A detailed geotechnical design report
Lateral Deflection Limit	The total lateral deflection (including rotation and translation) of the structure supported by the pile must be demonstrated to • Comply with relevant DTP specification requirements. • Be less than 0.5% of the freestanding height of the embedded retaining wall to a limit of 20 mm.	A detailed geotechnical design report
Construction Verification Requirement	Attendance and approval of the project geotechnical consultant to confirm the materials in the bored hole are consistent with the geotechnical design assumptions.	Inspection Test Plan (ITP)
Pile Testing Requirements	Undertake pile integrity testing based on the Superintendent approved techniques. The number of piles to be tested must be in accordance with the relevant DTP's specification.	Pile Integrity Testing Report

3.4 Axial Capacity of Driven Piles and Acceptance Criteria for Pile Driving

Dynamic testing and wave-equation analysis must be used for all pile driving, except for cases where PDA dispensation conditions are applicable for laterally loaded piles as specified in Section 3.3, unless otherwise approved by the DTP Chief Engineer – Roads.

Use of the Hiley formula to prove pile capacity may be permitted by the Superintendent for the following:

- Bridges of low significance (i.e. low traffic volume and small structures).
- The risk of not achieving the required geotechnical design loads is very low.
- Dynamic testing cannot be justified economically.

If the Hiley formula is used, a geotechnical strength reduction factor of 0.4 must be adopted irrespective of the requirements specified in AS 2159.

Measurement of temporary compression (Tc) and set(s) for assessment of pile capacity must be undertaken in a safe manner and in accordance with Section 605.

3.5 Design and Proof Engineering Prequalification Requirements for Piles

The structural design of piles and the geotechnical design of a piled foundation system including temporary works (such as sheet piles), with the exception of retaining walls as specified in Section 6.1, must be conducted by an engineering consultancy that is prequalified in accordance with DTP's Prequalification for Road & Bridge Design in either the Structures – Simple (SS) or Structures – Complex (CS) category and Geotechnical Design (GT-DES), respectively. The Design must be Proof Engineered by both Structure (PE) and Geotechnical Proof Engineers (GT-PRE) prequalified in accordance with DTP's Prequalification Scheme.

4 Information Required on Drawings for Piles

In addition to the requirements of DTP's Standard Sections, the following information must be provided on the pile drawings.

4.1 Displacement and Non-displacement Piles

The following information must be shown on the drawings for concrete piles:

- Minimum characteristic concrete strength grade.
- Minimum concrete strength for lifting and handling.
- Minimum concrete strength for driving.
- Minimum cover and exposure classification.

The following information must be shown on the drawings for steel piles:

- The orientation of the piles where applicable (e.g. the positioning of major axis for H-section piles).
- Section size and mass per unit length.
- Minimum steel grade.
- The rate of corrosion.

4.2 Pile Test Loads

The Designer must determine the pile ultimate limit state design loads based on structural requirements and site conditions. Test pile or representative pile locations and the values of N and N^* must be shown on the drawings as specified in Table 2. Where the Hiley formula is used, the values from this process must be specified on the drawings.

Table 2 – Pile Ultimate State Axial Design and Test Loads

Pile Axial Loads			
Pile Location	Ultimate Limit State Design Axial Load / Pile *N*(kN)*	Pile Test Loads N (kN)	
		PDA Testing & Signal Matching	Hiley Formula**

***Include where applicable (refer to Section 3.4 of this BTN)*

Geotechnical strength reduction factor Φ_g and values for associated design assumptions must be shown on the drawings as specified in Table 3.

Table 3 – Geotechnical Strength Reduction Factor and Values for Design Assumptions

Geotechnical Strength Reduction Factor Φ_g**	
Basic Geotechnical Strength Reduction Factor Φ_{gb}**	
Intrinsic Test Factor Φ_{tf}**	
Testing Benefit Factor *K***	
Percentage of pile to be tested (in accordance with DTP Standard Sections)	

*** Refer to AS 2159 Clause 4.3.1*

4.3 Pile Joint Loads

Where mechanical pile joints are used, the Designer must specify the allowable range of reduced levels for the joint on the drawings as specified in Table 4.

Table 4 – Pile Joints

Pile Location	Joint Minimum Reduced Level (m)	Joint Maximum Reduced Level (m)	Description of Environmental Aggressiveness

4.4 Pile Toe levels

Pile toe levels must be shown on the drawings, based on the levels determined during the design phase.

4.5 Foundation Displacements

The values of serviceability limit state loads, settlements and differential settlements, used in the design must be shown on the IFC and as-built drawings.

Where applicable, serviceability limit state horizontal static and seismic displacements at the following stages must be shown on the IFC and as-built drawings.

a. Immediately after completion of construction.
b. At the end of the Defect Liability Period.
c. 25 years after completion of construction.
d. At the end of the design life.

4.6 Concrete Pile Handling Diagrams

Diagrams specifying the allowable methods for handling the piles must be included on the pile drawings.

5 Bridge Foundation Displacements

Settlement, horizontal and longitudinal displacements in piles can lead to:

- Distress in the superstructure.
- Damage to, or failure of:
    - Bearings and expansion joints.
    - Abutments, piers, and piles.
    - Barriers, kerbs, and footpaths.
- Poor riding quality, especially when horizontal displacements occur in conjunction with vertical displacements (settlements/heave).

All components of the structure must be designed for displacement-induced actions in accordance with AS 5100.3, including an appropriate allowance for displacement.

The structure and its approaches must remain serviceable over their design life.

5.1 Soil-induced Displacement

For the purpose of this BTN, soil-induced horizontal displacements are defined as displacements of structures that occur due to down-drag, settlement/heave and consolidation of backfills/in-situ soil, lateral earth pressures and ground displacements such as those due to liquefaction, slope failures or lateral spreading.

5.1.1 Vertical Settlement Limits

Permanent settlement of abutments and piers must not exceed the following limits over their design life.

- Total settlement of 20 mm.
- Differential settlement of 20 mm for Simply Supported structures.
- Differential settlement of 10 mm for Continuous structures.

5.1.2 Horizontal and Longitudinal Displacement Limits

Permanent displacements of individual abutments and piers for the same structure must not exceed the limits below over their design life.

- Total displacement of 25 mm.
- For integral piers, differential displacement (between abutment and pier or between any piers) of 10 mm.
- For other structures, differential displacement (between abutment and pier or between any piers) of 25 mm.
- Differential displacement between individual piles within the pile group of 5 mm.

Where the design requires the columns and piles to be isolated from soil movement, the gap between columns/piles and sleeves must allow for unrestrained design horizontal displacements, including seismic displacements.

5.2 Monitoring of Displacement

This section must be applied in accordance with the relevant contract specification.

The Designer must develop a horizontal displacement and settlement/heave monitoring plan and submit with the design report to the Superintendent for review. The monitoring plan must address the following issues:

- The plan must include the frequency of horizontal displacement and settlement/heave monitoring in all directions during and after construction of the works and up to the end of the Defects Liability Period.
- The location of monitoring points must be agreed to with the Superintendent and must be suitable for future use by DTP to determine any long-term displacements in design documentation.

- The monitoring points must be designed and installed as permanent markers and include permanent stable survey control points which are to be provided in as-built documentation at the time of Practical Completion or at a time agreed to by the Superintendent.
- The initial set out position for the structure survey must form the recorded base coordinate position for the survey and be supplemented by total station survey of structural components as they are completed.

In the case of integral/semi-integral structures, the Designer must propose a monitoring methodology that distinguishes between the cyclic temperature displacements and permanent displacements. The expected cyclic temperature displacement must be included in all reports, including the monitoring plan.

During and after construction and during the Defect Liability Period, horizontal displacements and settlements/heave must be recorded and reported to the Superintendent and DTP's representative. The monitoring results must be submitted together with a plot of the successive displacements on a log time scale and a prediction of the total displacement expected at each stage listed in Section 4.5.

If the monitored displacement is measured to be more than the specified displacement, the Contractor must continue to monitor displacements for a further period as agreed to with the DTP Chief Engineer – Roads and must undertake investigations to determine the cause of excessive displacements, with the following minimum requirements.

- The structures must be monitored at a minimum three monthly interval.
- The results must be provided to the Superintendent for review within five business days of the readings being taken. The Superintendent may increase the monitoring frequency if growing movements are observed or the risk within the works has increased with time.
- The report must provide an analysis of the information gathered, together with a recommendation for appropriate measures to be implemented to arrest the excessive displacements.
- The Contractor must undertake the agreed measures for arresting displacements and when the arresting works are satisfactorily completed the Contractor must continue to monitor displacements for a further period of at least 12 months. At the end of the 12 month period all the data collected is to be reviewed by the Superintendent and DTP's representative, and the required monitoring is to be re-assessed and agreed to with the DTP Chief Engineer – Roads.
- The accuracy of the instruments proposed in the monitoring system must be approved by DTP's representative prior to their deployment.

6 Retaining Walls (incl. Embedded and Gravity)

A retaining wall is a structure constructed to resist pressure from the adjoining ground or to maintain in position a mass of earth.

6.1 Design and Proof Engineering Prequalification Requirements for Retaining Walls

The design and Proof Engineering prequalification requirements for retaining walls including Reinforced Soil Structures (RSS) must comply with Table 5.

Table 5 – Design and Proof Engineering Prequalification Requirements for Retaining Walls

Height[1] (m)	Applicability	Design Prequalification Requirements		Proof Engineering Prequalification Requirements	
		Structural	Geotechnical	Structural	Geotechnical
All Retaining Walls excl. RSS					
H < 0.4	All walls	N/A	N/A	N/A	N/A
0.4 ≤ H < 0.8	All the following conditions are met: • Supporting landscaping elements (non-structural) and the maximum live load at any location within 1 meter behind the wall is ○ uniformly distributed load of 3.0 kPa; ○ point load of 2.5 kN; and ○ line load of 1.3 kN/m. • Batter slope behind the wall is 6:1 or flatter	N/A	N/A	N/A	N/A
	Supporting elements other than landscaping or any of the loading conditions listed above are exceeded	SS or CS[2]	GT-DES[3]	N/A	N/A
	Batter slope behind the wall is steeper than 6:1	SS or CS[2]	GT-DES[3]	PE[4]	GT-PRE[5]
0.8 ≤ H < 1.5	Batter slope behind the wall is 6:1 or flatter	SS or CS[2]	GT-DES[3]	N/A	N/A
	Batter slope behind the wall is steeper than 6:1	SS or CS[2]	GT-DES[3]	PE[4]	GT-PRE[5]
H ≥ 1.5	All walls	SS or CS[2]	GT-DES[3]	PE[4]	GT-PRE[5]
RSS					
All heights	All walls	SS or CS[2] for structural elements (facing panels including connections)	as per Section 6.2a and b	PE[4] for structural elements (facing panels including connections)	GT-PRE[5] as per Section 6.2c

Notes:

(1) Height: free-standing (cantilever section) wall height of the retaining structure

(2) SS or CS: Prequalified in accordance with DTP's Prequalification for Road & Bridge Design in either the Structures – Simple (SS) or Structures – Complex (CS) categories

(3) GT-DES: Prequalified in accordance with DTP's Prequalification for Design in Geotechnical Services

(4) PE: Proof Engineered by Structures Proof Engineers prequalified in accordance with DTP's Prequalification Scheme

(5) GT-PRE: Proof Engineered by Geotechnical Proof Engineers prequalified in accordance with DTP's Prequalification Scheme

6.2 Reinforced Soil Structures (RSS)

The design and construction of Reinforced Soil Structures (RSS) must comply with the requirements in Section 682.

a. The internal stability of an RSS must be designed in accordance with AS 4678 or DTP-approved methodologies, e.g. Transport for NSW (TfNSW) Specification D&C R57 – Design of Reinforced Soil Walls.

b. The global stability including overturning, tilting, sliding and bearing capacity must be designed in accordance with AS 5100.3 Section 8 by a prequalified geotechnical design engineer (GT-DES) in accordance with DTP's Prequalification Scheme. The requirements for design loads and load combinations must be in accordance with AS 5100.2.
c. The internal and global stability design of RSS must be Proof Engineered by Geotechnical Proof Engineers (GT-PRE) prequalified in accordance with DTP's Prequalification Scheme. The Proof Engineering for internal design may not necessarily be undertaken by the same Proof Engineer for global design.

RSS must not be constructed within Flood Prone Areas as per Section 682.

The minimum embedment of the base course of an RSS must be 500 mm below the finished surface. If an RSS is constructed on an elevated finished ground surface, a minimum 3 m wide bench must be provided between the RSS's face and the batter slope's pinch point. The bench must have a minimum 2% crossfall with the direction away from the traffic lane.

Facing panels must be designed in accordance with BTN 009.

6.3 Displacement Limits

The maximum displacement (rotation plus translation) at any point along the full height of the wall must not exceed 5 mm per 1 m of wall height or 20 mm whichever is less.

Total settlement (consolidation and elastic settlement) must not exceed 20 mm for gravity retaining walls.

For RSS, the Section 682 displacement requirements apply.

Document Information

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1.0	14 December 2017	Document Created
1.1	5 May 2022	Revision of Section 4.1 for concrete cover requirements for curing compounds. Section 4.6 added to cover for pile chamfer requirements.
2.0	25 July 2023	Re-arranged Section 2 to 6 to group the requirements for piles under one section with the following additional requirements: a. more specific bore hole locations for culverts and piled road way b. prequalification requirements for geotechnical investigations, as well as design and proof engineering of piles c. pile testing Added PDA dispensation conditions in Section 3. Revision of Section 4.1 and 4.5 to include requirements for steel piles and horizontal displacements. Section 5 added for bridge foundation displacements and monitoring requirements. Section 6 added for prequalification requirements for design and proof engineering of Retaining Walls.

Interpretation

In this document, except where the context otherwise requires—

- The word “must” is to be understood as denoting a requirement which is mandatory.
- The word “should” is to be understood as denoting a requirement which is not mandatory but recommended.
- The word “includes” in any form is not a word of limitation. Mentioning anything after "includes" or similar expressions (including "for example") does not limit what else may be included.
- A reference to a section, clause, schedule or appendix is a reference to a clause of or schedule or appendix of this document.

Nomenclature

Where any of the following symbols are used within this document, the textual description provided to the right is its intended meaning:

ⓘ This symbol intends the accompanying text to be read as INFORMATION. Common information accompanying this symbol includes RATIONALE and GUIDANCE for the associated requirement.

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