Structures

Master Specification

ST-RE-D2 Design of Retaining Walls

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Contents

ST-RE-D2 Retaining walls

1 General

1.1 This Part specifies the requirements for the design of the following structures:

a) Retaining walls and associated structures which support direct loading from earth pressure, hydrostatic pressure (where the retaining wall forms part of a tanked structure), and indirect lateral loading from adjacent road traffic, light railways and heavy railways near the top of the retaining wall.

b) Retaining wall types considered here include bored piles, continuous flight auger (CFA) piles and secant piles.

1.2 Refer to DPTI Design Standard: "Structural" for the design of bridge abutments. These take significant vertical loadings from bridge structures supported above (unlike typical piled retaining walls) and are subject to special AS 5100 earthquake design provisions.

1.3 The structural detailing of retaining walls must take into account the provisions of DPTI Design Standard: "Structural" where relevant.

1.4 Refer to DPTI Design Standard: "Reinforced Soil Structures" for the design of reinforced soil structures.

2 References

2.1 Unless specified otherwise, all design and / or documentation must comply with the following:

a) ST-SD-S1 "Design of Structures".

b) ST-PI-C1 "Supply and Installation of Driven Piles".

c) ST-PI-C2 "Cast in Place Concrete Piles".

d) ST-PI-C3 "Continuous Flight Auger Piles".

e) AS 2159 Piling – Design and Installation.

f) AS 4678 Earth Retaining Structures.

g) AS 5100 Bridge Design.

2.2 DPTI standards and guidelines are available from https://www.dpti.sa.gov.au/standards/major_structures_documents.

3 Design requirements for retaining walls

General

3.1 In addition to the requirements in AS 5100, soil retaining structures, including walls and piles, shall be designed with particular consideration of the expansion / contraction properties of retained clay strata. Short term, long term and progressive effects shall be considered.

3.2 Earthquake forces on retaining walls as per AS 5100.2, Section 14.5.7 must also be considered.

3.3 Where soils are above the permanent water table and unsaturated, the Contractor shall give due consideration to the following requirements in the design of retaining structures in clay soil:

a) Suction changes from the initial as-constructed condition to the equilibrium condition will occur along much of the route and the resulting volume changes will have an effect on pavements and retaining structures. These volume changes must be calculated and considered in design.

b) Deflection of pile retaining walls must consider initial deflection on excavation and further deflection due to any surcharge and suction changes during the design life. The wall cladding

must be designed to accommodate the design and construction tolerances of the retaining wall behind. The wall cladding shall be designed to be no steeper than 1H to 40V.

c) Cantilever retaining walls will move during service and the serviceability limit state deflection limit is set out in Table ST-RE-D2 3-1. The wall cladding shall be designed to be adjustable in service to accommodate this lateral movement.

d) Calculations of deflections of other forms of retaining structures must also consider movements during and after construction.

e) Notwithstanding the requirements of ST-PI-C3 "Continuous Flight Auger Piles", Clause 6 “Testing of piles” with regard to testing of piles, load testing does not apply to piled walls which act as a retention system only and have no vertical load capacity requirement.

f) Retaining walls must be detailed to visibly highlight any water ingress from behind the wall (including unplanned ingress such as from a leaking water main), thereby facilitating leak identification and repairs.

Design Life

3.4 The Contractor shall design the retaining walls and associated structures for a minimum design life of 100 years.

Design Procedure

3.5 In the Design Report the Participants shall provide calculations and details of estimated settlements and horizontal deflections including creep likely to occur during construction and the lifetime of the structure. The design shall comply with AS 4678 Earth Retaining Structures and associated amendments. Soil above groundwater level is to be considered as unsaturated and the appropriate theory to be found in the references below is to be used for estimating its strength, stiffness and volume changes.

3.6 The stiffness and volume of unsaturated clay is related inter alia, to the soil suction. In view of this the designer shall use appropriate soil suction profiles for design and provide evidence for the validity of these profiles. For example, the suction profile to be used for design of the retaining structure under surcharge or earthquake loading shall be the equilibrium suction profile for the structure and its surrounds.

3.7 The total suction of the soil in the vicinity of the retaining structure can be greatly reduced by water infiltration from nearby leaking pipes or sand layers (i.e. perched water), resulting in loss of strength and swelling of the clay soil and deformation of the wall. This is expected to be an unusual occurrence and to only affect a short section of the retaining structure. Guidance as to the suction profile in the vicinity of the wall to be used for design in this case is given in AS 4678 Figure 29, Reference e). The design of the structure shall readily allow for strengthening of the structure (e.g. by soil nails) should this occur.

Design requirements for retaining walls and associated structures

Retaining Wall Performance Standards during Design Life

3.8 For retaining walls and associated structures, the maximum horizontal movement shall be as per Table ST-RE-D2 3-1 Retaining walls performance - Horizontal movementTable ST-RE-D2 3-1.

Table ST-RE-D2 3-1 Retaining walls performance - Horizontal movement

Wall type	Maximum horizontal movement	Location to be Calculated
Reinforced soil wall	Lesser of 35 mm or proprietary system requirements	at the face of the pile cap or uppermost structural element of the wall or structure
Piled wall	Lesser of 0.5% of wall Height or 50 mm	at the face of the pile cap or uppermost structural element of the wall or structure
Soil nail wall		uppermost structural element of the wall or structure

Wall type	Maximum horizontal movement	Location to be Calculated
Other		uppermost structural element of the wall or structure

3.9 The maximum deflection applies to the serviceability limit due to soil swelling or shrinking as its suction changes from the value prior to construction to equilibrium after construction.

3.10 The pile design must also take into account the deflection which will occur during construction / excavation.

3.11 Severe wetting, earthquake or barrier design impact loading are all considered to be (separate) Ultimate Limit State loads. Additional deflections caused by this event shall be accommodated by the wall.

3.12 Miscellaneous structures, guard rail, luminaires and wall treatments (including shotcrete facing) shall be designed to ensure that they will not be damaged or be visibly out of alignment as a result of horizontal retaining wall movement. Attached items shall allow for alignment to maintain good appearance.

3.13 When flexible retaining walls are located adjacent to rigid or less flexible walls (i.e. adjacent to bridge abutments) the wall design shall be assessed to and designed to accommodate differential movement.

3.14 Where a proprietary wall system is being used, the lesser of the requirements of this Design Standard and the proprietary specified maximum horizontal deflection movement shall apply.

Retaining Wall Monitoring

3.15 Monitoring of retaining structures shall be included in the monitoring and surveillance program proposed for the embankments, pavements and bridge structures with time intervals as stipulated in RD-EW-D1 “Design of Earthworks for Roads”, Clause 6 “Earthworks performance monitoring”. Monitoring points shall be placed at the top of all walls adjacent to bridges and then spaced at intervals not exceeding 50 m along the length of the pile cap. A minimum of 2 points shall be placed on any ramps with spacing between points not to exceed 50 m. At least one point shall be placed at the highest point of the wall.

3.16 With piled walls greater than 4 metres in height, inclinometers must be installed within the piles. The proposed number and location of these shall constitute a **Hold Point**.

3.17 Given the requirements stipulated in ST-RE-D1 “Design of Reinforced Soil Structures”, Clause 3.9 (“Settlement”), the Reinforced Soil Structures (RSS) backfill shall be monitored to ensure that at least 80% of the expected settlement has occurred prior to the construction of the road pavements and / or associated structures.

Retaining Walls Adjacent to Bridges

3.18 As outward movement of the top of the retaining walls will invariably occur, they should be set back a minimum of 70 mm from the line of more rigid structures such as bridge abutments. A suitable slip joint should be incorporated at these locations to allow free movement of the retaining wall.

Retaining Wall Slopes

3.19 The visible face of retaining walls (i.e. visible facades) shall be set at a slope of 1H in 40V or flatter (to allow for serviceability limit state horizontal movement at the top of the wall).

References

3.20 The following references are provided for information:

a) Briaud J-L. 2013 Geotechnical Engineering: Unsaturated and Saturated Soils, John Wiley and Sons Inc.

b) Fredlund, D. G., and Rahardjo, H. 1993 Soil Mechanics for Unsaturated Soils, John Wiley and Sons Inc.

c) Fredlund, D. G., Rahardjo, H. and Fredlund M. D., 2012 Unsaturated Soil Mechanics in Engineering Practice, John Wiley and Sons Inc.

d) Woodburn J. A., Underpass Construction using Revetment Walls, DPTI Report GSU 1291, Sept 2009.

e) Woodburn J. A. RN6203 South Road, South Road Upgrade, Torrens Road to River Torrens, Trial Pile Wall Study DPTI Report GSU 1421, July 2014.

f) Woodburn J. A. and Herraman R. A., Revetment Walls for Stiff Unsaturated Clay, Proceedings UNSAT 2014 conf, Sydney 2014.

g) Khalili N and Khabbaz M. H. 1998, Unique Relationship for the Determination of Shear Strength of Unsaturated Soils, Geotechnique 48(5), pp681-687.

Piling

3.21 All piling shall be designed in accordance with AS 5100 and AS 2159 and the Project Durability Report.

3.22 Piling design shall take into account the safety of pile installation methods, vibration and noise, particularly where there are adjacent residential properties.

3.23 The portions of concrete piles in soil strata which have Exposure Classifications as per AS 2159 in the range of 'moderate' to 'very severe' shall be designed with sufficient durability to demonstrate the piles and pile caps achieve the specified design life using strategies including:

a) additional concrete cover (minimum 100 mm cover incorporating allowances for construction tolerances);

b) specialised concrete mix designs; and

c) appropriate construction material, equipment and methodologies.

3.24 Pile design shall include the full specifications for testing of piles and pile materials. Full consideration shall be given to the program implications of the specified testing before a pile type is selected.

3.25 Pile integrity testing shall be performed by an independent expert.

Continuous Flight Auger (CFA) Piles

Design requirements for CFA piles

3.26 The design of CFA piles must include the following design outputs:

a) details of the acceptable tolerance for installed piles (horizontal tolerance, verticality, cage depth, toe level and cut off level);

b) ensure that the piling rig is of sufficient capacity such that drilling occurs in a continuous manner without the need to withdraw the auger;

c) details of the wheels (cover spacers) to be employed and evidence that the wheels are robust enough not to be damaged during handling and installation of the pile cage and ensure that the minimum cover to steel reinforcement is maintain;

d) details of CFA pile retaining wall façade fixing provisions such that the durability of the piles is not compromised;

e) where CFA piles are visible, a finished surface specification detailing acceptance provisions for making good soil inclusions and pile bulging and the overall appearance of piles with respect to the urban design framework and durability requirements;

f) where CFA piles of the same diameter are used with differing reinforcement arrangements, clear and unambiguous methods of ensuring the correct pile cage is used in the correct orientation for each pile; and

g) details of the permissible time period from the completion of concrete batching to concrete pumping.

3.27 For piled retaining structures subject to lateral loading only dynamic testing of piles is not required to be undertaken.

Secant Pile Walls

General

3.28 Secant pile walls for DPTI projects will generally be used as a means of waterproofing (i.e. 'tanking') underpass type structures (and their approaches) that are then clad across the visible faces. It is therefore important that the secant pile wall materials and tolerances provide a watertight face that has a high degree of construction tolerance (in plan view) to facilitate cladding.

3.29 The typical maximum retained height of such an underpass wall will be in the order of 6-8 m and the variable height of the water table in Adelaide means that many of these walls will be under the permanent water table (to some degree).

3.30 As it is impossible to make such a wall completely waterproof, groundwater control and effects on the surrounding (unexcavated) environment need to be carefully considered by the designers.

3.31 In summary, the designer needs to demonstrate how a watertight structure is to be built within tolerance. This will include information on the concrete mixes (to facilitate secant pile wall construction and permeability following construction), and cladding details / fixing tolerances to accommodate wall movements. It will also show how groundwater is to be maintained in the long term.

Design requirements for secant pile walls

3.32 CFA piling shall be used for both the male and female piles; bored piles are not acceptable. In addition to the requirements for CFA piles:

a) Expanded polystyrene foam form inserts must be used for the capping beam (or other DPTI approved means). This will help ensure tolerances are met for the wall below. Pile tolerances shall meet or exceed those required by the piling code.

b) Design tolerances must also take into account requirements for any attached cladding and / or waterproofing of the lowered structure.

c) The success of CFA pile walls is also dependent upon the order and timing of the pile installation. The designer must demonstrate this planning at the design stage following consultation with a suitably qualified piling contractor. The designer must carefully consider and balance the strength of the female piles at the time of the male pile installation to ensure that the male piles do not damage any weak female piles, or run off course due to stronger female piles. This will result in a secant pile wall that is watertight, within the required structural tolerances and minimise the need for any rework.

d) Buoyancy of the tanked structure needs to be considered. Joints between the base of the Secant Pile Wall and lowered roadway will need to be waterproofed and require careful detailing. The durability of these waterproof joints and any connections between the wall and adjacent lowered roadway will need special attention by the designer.

e) Any leaks through the Secant Pile Wall for the tanked structure must be allowed to exit as near as possible to the leak location, thereby simplifying leak identification and repair. The design will typically include drainage paths (or weepholes) at the base of the facade and traffic barriers (below) in addition to and (transversely) sloping barrier top faces. Groundwater entering via the wall will then be visible over the traffic barrier face or in weepholes through the barrier base. Spoon drains at road level should then direct the water to a sump location.

3.33 Provision and acceptance of the proposed design and construction methodology / staging shall constitute a **Hold Point**.

Materials and durability

3.34 The weak mixes and short term low strengths required for the female piles have been an issue for batching plants in the past. Weak female pile mixes assist with achieving more accurate (subsequent) male CFA pile installations. Conversely the permeability of the weak female piles affects the long term performance and permeability of the wall. These opposing factors need to be

carefully considered and balanced by the designers. Issues regarding the importance of achieving appropriate weak concrete mixes consistently are considered in Reference below.

3.35 Preconstruction testing will be needed to demonstrate confidence in the female pile mix.

3.36 Provision and acceptance of proposed materials shall constitute a **Hold Point**.

References provided for information

a) N. Wharmby, B. Perry and H. Waikato "Development of Secant Pile Retaining Wall Construction Urban New Zealand". New Zealand Concrete Industry Conference, Wellington, New Zealand 2010.

Quality requirements for Secant Pile Walls

3.37 The design and quality provisions of CFA piling shall apply to the Secant Pile Wall. These quality provisions shall also apply to the weaker female concrete used in Secant Pile Wall construction (where relevant).

4 Hold points

4.1 The following is a summary of Hold Points referenced in this Part:

Ref.	Hold points	Response time
3.16	Provision and acceptance the proposed number and location of inclinometers within the piled walls greater than 4.0 m height	TBD
3.33	Provision and acceptance of the proposed design and construction methodology / staging	TBD
3.36	Provision and acceptance of proposed materials	TBD

5 Records

5.1 The following records must be prepared:

a) Geotechnical design methodology, assumptions and summary calculations.