DPTI DESIGN STANDARD: RETAINING WALLS

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1. GENERAL
This Design Standard 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, secant piles and soil nailed walls;

(d) 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;

(e) The structural detailing of retaining walls must take into account the provisions of DPTI Design Standard:“Structural” where relevant;

(f) Refer to DPTI Design Standard:“Reinforced Soil Structures” for the design of reinforced soil structures.

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

1. DPTI: Structures Group Drafting Guidelines for Consultants
2. DPTI: Design Standards: Structural
3. AS 1100: Technical Drawing
4. AS 2159: Piling
5. AS 4678: Earth Retaining Structures
6. AS 5100: Bridge Design

DPTI standards and guidelines are available from http://www.dpti.sa.gov.a/standards/major_structures_documents
3. **DESIGN REQUIREMENTS FOR RETAINING WALLS**

3.1. **General**
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 surrounding clay strata. Short term, long term and progressive effects shall be considered. Earthquake forces on retaining walls as per AS 5100.2, Section 14.5.7 must also be considered in the design.

Where excavation in clay soils are above the permanent water table the soils will be unsaturated.

Where soils are unsaturated, the Contractor shall give due consideration to the following requirements in the design of retaining structures in clay soil:

1) suction changes from the initial to the equilibrium condition are likely to 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;

2) 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 tolerances of the retaining wall behind. The wall cladding shall be designed to be no steeper than 1H to 40V.

Unpropped retaining walls will move during service and this serviceability limit state deflection limit is set out in D35 (typically 35 to 50 mm at the top of a 6 m high retained wall height). The wall cladding shall be designed to be adjustable in service to accommodate this lateral movement.

3) the computation of deflections of other forms of retaining structures must also consider movements during and after construction.

Notwithstanding the requirements of Clause 6.2 of Specification Part 417 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.

4) 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.

3.2. **Design Life**
The Contractor shall design the retaining walls and associated structures for a minimum design life of 100 years.

3.3. **Design Procedure**
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 – 2002 *Earth Retaining Structures* and associated amendments. Soil above groundwater level is to be considered as unsaturated and the appropriate theory (as detailed below) is to be used for estimating its strength, stiffness and volume.

The shear strength of an unsaturated clay shall be estimated using either the equation of Fredlund and Rahardjo (1993, p230)
viz. \( \tau_f = c' + 6 \tan \Phi' - u_n \tan \Phi^b \) \hspace{1cm} (1)

where: \( \tau_f \) = shear strength; \( c' \) = effective cohesion; \( \sigma \) = net normal stress; \( \Phi' \) = angle of internal friction; \( u_n \) = total soil suction; and \( \tan \Phi^b \) = rate of increase in shear strength with increase in total soil suction.

Or the shear strength shall be estimated using the formula given in Briaud (2013, p451), viz

\[ \tau_f = c' + (\sigma - \alpha u_n) \tan \Phi' \] \hspace{1cm} (2)

where \( \alpha \) is the ratio of water and void area. This can be estimated using the approximation based on the work of Khalili and Khabbaz (1998), namely

\[ \alpha \sim \sqrt{\left(\frac{u_{we}}{u_n}\right)} \]

where \( u_{we} \) = matric suction at air entry

Note that, for the purpose of estimating the shear strength using equations (1) and (2) above, the quantity \( u_n \) is total soil suction rather than matric suction as in References 1 and 2.

The terms \( \Phi' \), \( \Phi^b \) and \( c' \) are characteristic values. Guidance for selecting these values is given on pages 453 and 454, Briaud (2013) and Woodburn and Herraman (UNSAT 2014).

For estimating design shear strength the Material Strength & Uncertainty Factors given in Table 5.1(A) of AS 4678-2002 shall be used, the strength uncertainty factor, \( \Phi_{ub} \), to be applied to \( \tan \Phi' \) in addition to \( \tan \Phi^b \).

The stiffness and volume of unsaturated clay also depend on 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. Further guidance on suction profiles is provided in references 4, 5 and 6.

The total suction of the soil in the vicinity of the retaining structure can be greatly reduced by water 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 Figure 29, Reference 5. The design of the structure shall readily allow for strengthening of the structure (e.g. by soil nails) should this occur.

References provided for information

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

3.4 Piling

All piling shall be designed in accordance with AS 5100 and AS 2159-2009 and the Project Durability Report.

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

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:

1) additional concrete cover (minimum 100 mm cover incorporating allowances for construction tolerances);
2) specialised concrete mix designs; and
3) appropriate construction material, equipment and methodologies.

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.

Pile integrity testing shall be performed by an independent expert.

3.4 (a) Continuous Flight Auger (CFA) Piles

Design requirements for CFA piles

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

1) Details of the acceptable tolerance for installed piles (horizontal tolerance, verticality, cage depth, toe level and cut off level);
2) Ensure that the piling rig is of sufficient capacity such that drilling occurs in a continuous manner without the need to withdraw the auger;
3) 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;
4) Details of CFA pile retaining wall façade fixing provisions such that the durability of the piles is not compromised;
5) 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;
6) 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;
7) Details of the permissible time period from the completion of concrete batching to concrete pumping;
8) The test pile for dynamic testing shall be nominated on the design plans.
The quality requirements for CFA piles must include:

1) Records for CFA piling shall be submitted within 12 hours of the completion of each piling;

2) A real time monitoring system shall be deployed on to each piling rig providing the Participants and the Commissioner real time access to piling records at local computers within the site office and remotely via remote access;

3) Full-time site supervision of all piling works by the contractor by a suitably qualified person;

4) Provision of all access points of the work at all times by the Principal, Superintendent or nominated representative to inspect all piling works;

5) Details of concrete volume monitoring;

6) Details of the maximum amount of water, if any, that may be added on site prior to pumping;

7) The time duration for the construction of each pile.

3.4(b) Secant Pile Walls

General

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.

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 watertable in Adelaide means that many of these walls will be under the permanent water table (to some degree).

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.

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

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:

1) 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.

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

3) The success of CFA pile walls is also dependant 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 (weak) female piles, or run off course due to (strong) 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.

4) Bouyancy 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.

5) Any leaks via the Secant Pile Wall for the tanked structure must be made visible 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 weepholes through the barrier base. Spoondrains at road level will then direct the water to a sump location.

Provision and acceptance of the proposed design and construction methodology / staging shall constitute a HOLD POINT.

Materials and durability
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 (1) below.

Preconstruction testing will be needed to demonstrate confidence in the female pile mix. Provision and acceptance of proposed materials shall constitute a HOLD POINT.

References provided for information
1) http://www.fletcherconstruction.co.nz/Resources/Secant_Pile_Retaining_Wall_Construction_in_NZ_(Wharmby,_Concrete_Conf.2010).pdf

Quality requirements for Secant Pile Walls
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. RECORDS
The following records must be prepared:
1) Geotechnical design methodology, assumptions and summary calculations.