7 BURIED STRUCTURES

7.1 SCOPE

Buried structures with span smaller than, or equal to, 3 m may also be designed to S6-00 Section 7, but the Designer shall pay due regard to empirical methods and solutions that have a proven record of success for small diameter culverts.

Commentary: *The CHBDC Commentary (C7.1 Scope, and C7.6 Soil-Metal Structures) indicates that the provisions of Section 7 apply only to buried structures with span (DH) greater than 3 m, but the CHBDC does not provide design guidance for smaller structures.*

For all types of buried structures, the Plans shall specify the following design information:

- Type of Buried Structure;
- Design Life
- Highway Design Loading;
- Unit Weight of Backfill;
- Depth of Cover, H;
- Depth of Cover, HC, at intermediate stages of construction;
- Construction Live Loading assumed in the design (corresponding to HC);
- Geometric Layout and Key Dimensions;
- Foundation and Bed Treatment;
- Foundation Allowable Bearing Capacity;
- Extent of Structural Backfill;
- Conduit End Treatment;
- Hydraulic Engineering Requirements, as appropriate;
- Roadway Clearance Envelope, as appropriate; and,
- Concrete Strength, as appropriate.
- Backfill drainage details

For Soil-Metal Structures and Metal Box Structures, the Plans shall also specify the following design information:

- Design life based on corrosion allowance calculations;
- Minimum plate thickness and coating system;
- Corrosion Loss Rates (for substrate metal and for coating system);
- Assumed Resistivity of Soil Materials;

- “pH” Range for Groundwater and/or Streamflow, as appropriate;
- Seam Strength at Critical Locations;
- Conduit Rise, D_h and Span, D_v;
- Radius at Crown, R_c;
- Radius at Spring-line, R_s; and,
- Radius at Base, R_B.

***Commentary**: Specifications for materials, fabrication and construction of buried structures shall be in accordance with SS 303 Culverts and SS 320 Corrugated Steel Pipe, where applicable. In the event of any inconsistency or conflict between the Ministry Standard Specifications and S6-00, then the Ministry Standard Specifications will take precedence and govern.*

7.3 NOTATION

Two separate notations for “A_L” appear in S6-00 Section 7, one on page 254, and one on page 255. Both descriptions for “A_L” are valid.

7.5 STRUCTURAL DESIGN

7.5.2 Load Factors

When checking buried structures for buoyancy (refer also to Clause 3.11.3), the Designer shall consider the potential effects of soil-structure interaction and soil particle behaviour.

***Commentary:** Section 7 refers generally to Section 3, Clause 3.5.1, for load factors but design of buried structures against buoyancy effects is not addressed. For buried structures, wall friction is usually dependent on actual soil-structure interface properties achieved during construction, and thereafter, so a conservative minimum value is appropriate for the buoyancy check. Also, a conservative assumption of actual soil state (minimum active or minimum at-rest) is appropriate to assure safety against buoyancy.*

7.5.5 Seismic Requirements

7.5.5.3 Seismic Design of Concrete Structures

Delete and replace with the following:

For concrete buried structures, the effects of earthquake loading shall be computed in accordance with Clauses 7.8.4.1 and 7.8.4.4 (as modified herein).

***Commentary:** Horizontal earthquake loads should be considered for large span buried structures.*

7.6 SOIL METAL STRUCTURES

7.6.1 Structural Materials

7.6.1.1 Structural Metal Plate

The use of aluminum plates and components must satisfy the minimum protective measures requirements of S6-00 Clause 2.5.2.

7.6.1.3 Soil Materials

Commentary: *Replace the expression for secant soil stiffness or modulus, E_S (on page 280 of the Commentary to S6-00), with the following;*

"$E_s = E_i [1 - (\sigma_d / (\sigma_d)_f)*R_F]$".

This expression is consistent with the result shown on page 281 of the Commentary to S6-00.

7.6.2 Design Criteria

7.6.2.1.1 General

Delete and replace with the following:

The thrust, T_f, in the conduit wall due to factored live loads and dead loads shall be calculated for ULS load combination 1 of Table 3.5.1 (a), according to the following equation:

$$T_f = \alpha_D T_D + \alpha_L T_L (1 + DLA)$$

Where the dynamic load allowance, DLA, is obtained from Clause 3.8.4.5.2. The dead and live load thrusts, T_D and T_L, respectively, shall be obtained as follows;

a) For soil-metal structures with a span of less than or equal to 10 m, T_D and T_L shall be calculated in accordance with Clauses 7.6.2.1.2 and 7.6.2.1.3, respectively;

b) For soil-metal structures with a span of more than 10 m, T_D and T_L shall be computed using a finite difference, or finite element, soil-structure interaction analysis method. The thrust expressions in Clauses 7.6.2.1.2 and 7.6.2.1.3, respectively, shall be used as an additional check to ratify the results of the finite difference, or finite element, method;

c) For deeply buried soil-metal structures, the S6-00 expressions for T_D and T_L may be too conservative. The S6-00 does not place an upper limit on the applicability of Section 7 for deeply buried soil-metal structures. Designers of deeply buried soil-metal structures may use the S6-00 methodology or, if consented to by the Ministry, may use an alternate finite difference or finite element soil-structure interaction analysis method to determine the dead and live load thrusts.

Commentary: *S6-00 does not place any limitations on the applicability of Section 7 for soil-metal structures with large spans, or for those deeply buried. Recent load rating studies indicate that the S6-00 design formulae may not be conservative for all large span soil-metal structures. Conversely, the same load rating studies show that the S6-00 design formulae for deeply buried, soil-metal structures to be overly conservative.*

7.6.2.1.2 Dead Loads

(d) "H" is measured vertically from crown of structure to finished grade, as shown in Figure 7.6.3.1.

Commentary: *The depth of cover or height of overfill, "H", is missing on Figure 7.6.2.1.2.*

7.6.2.1.3 Live Loads

Replace the second expression for "T_L" with the following:

"$T_L = 0.5\ L_T\ \sigma_L\ m_f$" (not "$T_L = 0.5\ D_T\ \sigma_L\ m_f$").

Replace Item (a) with the following:

L_T = length of dispersed live load measured at the crown level from axle loads at the road surface above the conduit.

Commentary: *The expression "$L_T = (1.45 + 2H)$" is specific to normal highway vehicle/axle loading, and may not be applicable for special vehicle/axle layouts.*

7.6.2.4 Connection Strength

Designers are advised that values of unfactored seam strength, S_s, for standard corrugation profile with bolted connections are shown in Commentary Figure C7.6.2.4.

7.6.3 Additional Design Requirements

7.6.3.1 Minimum Depth of Cover

Notwithstanding conduit wall design by any other Approved method, it is recommended that minimum cover should conform to the criteria in this Clause.

7.6.3.3 Durability

The design life for Soil-Metal Structures, based on corrosion allowance calculations, shall be 100 years.

Commentary: *The S6-00 Section 7 Commentary suggests that an expected design life of up to 100 years is achievable, and presents sample values for corrosion loss.*

The specified coating thickness for soil-metal buried structures shall be "total both sides", per ASTM A444 and CSA G401-M. The minimum galvanic coating thickness for all soil-metal buried structures shall be 610g/m^2 total both sides of plate. For culverts subject to heavy abrasion or corrosive products, additional protection shall be provided. Options including concrete liners, thicker galvanic coating and asphalt coating shall be considered. The effects of corrosive run-off or abrasive stream flows shall be accounted for in the design. Abrasive stream flows should be avoided wherever possible by appropriate hydraulic mitigation.

Commentary: *SS 320 stipulates galvanized steel sheet to ASTM A444 or CSA G401-M, both of which refer to coating thickness "total both sides", which is standard industry practice. Some culverts are more vulnerable to streambed abrasion than corrosion, per se. Some installations may be vulnerable to corrosive run-off (salts or fertilizers).*

For non-saturated soil conditions, the "AASHTO corrosion loss model", as presented in S6-00 Commentary Table C7.6.3.3(a), shall be used. The Designer shall consider whether the culvert's Structural Backfill might become saturated in high groundwater conditions.

For saturated soil conditions, a recognized corrosion loss model, which relates soil/water "pH" values to corrosion losses, shall be used (i.e. not necessarily the conservative UBC'95 model).

Portions of culverts that have both the interior and exterior faces exposed to soil and/or water (e.g. stream inside culvert) shall include corrosion loss allowances for both faces.

Commentary: *The "AASHTO" method is the industry standard for non-saturated conditions throughout North America. The S6-00 Section 7 Commentary presents two sets of values for Non-Saturated Loss Rates (i.e.*

UBC 1995 & AASHTO 1993) in Table C7.6.3.3(a), and a single set of values for Saturated Loss Rates (i.e. UBC 1995) in Table C7.6.3.3(b). Practical experience suggests that some of these corrosion loss results are too conservative in typical applications.

7.6.4 Construction Requirements

7.6.4.5 Structural Backfill

Commentary: *Refer to SS 303 Culverts, for backfill materials and compaction requirements, where applicable.*

7.6.5 Special Features

Where stiffener ribs are used to bolster structure strength, the combined plate/rib section properties shall be calculated in a cumulative (not composite) manner.

Commentary: *AASHTO Clause 12.7.2.2 allows section properties for composite SPCSP plate/rib sections to be calculated on the basis of "integral action"; this terminology is not explicit, but may imply composite action. S6-00 requires section properties for composite SPCSP plate/rib sections to be calculated in a cumulative (not composite) manner, which is conservative.*

7.7 METAL BOX STRUCTURES

The additional geometric limitations provided in AASHTO Standard Specifications for Highway Bridges (2002) Table 12.8.2A shall be applied; e.g., maximum radius at crown and minimum radius at haunch.

Unless Approved by the Ministry, soil-structure interaction shall not be considered for metal box structures larger than 8.0 m span, or 3.2 m rise.

Commentary: *The 8.0 m span limit, and the 3.2 m rise limit, for metal box structures are based on limitations in the original research. S6-00 Commentary indicates that recent (1998) test data, from as-built large- span structures, may allow the beneficial effects of soil-structure interaction to be taken into account for larger metal box structures.*

7.7.2 Design Criteria

7.7.2.2 Design Criteria for Connections

Designers are advised that values of unfactored seam strength, S_s, for standard corrugation profile with bolted connections are shown in S6-00 Commentary Figure C7.6.2.4.

Commentary: *Values of unfactored seam flexural strength are not presented in the S6-00, or in the AASHTO Standard Specifications for Highway Bridges (2002) Clauses 12.4.2 and 12.6.2.*

7.7.3 Additional Design Considerations

7.7.3.2 Durability

The design life and durability requirements for Metal Box Structures shall be the same as stipulated for Soil-Metal Structures in Supplement Clause 7.6.3.3 above.

7.7.4 Construction

7.7.4.1.2 Material for Structural Backfill

Commentary: *Refer to SS 303 Culverts, for backfill materials and compaction requirements, where applicable.*

7.8 REINFORCED CONCRETE BURIED STRUCTURES

Commentary: *It is recommended that engineering judgment be used, on a case-by case basis, to determine whether Section 7.8 or Section 8 (Concrete Structures) is more applicable for large reinforced concrete buried structures.*

The analysis and design provisions of Section 7.8 appear to focus on medium sized precast concrete pipe or box structures. These provisions may not be appropriate for large reinforced concrete buried structures (e.g. tunnels for transit systems or highway underpasses, typically over 6m in span). For example, the simplistic vertical and lateral earth pressure distributions stipulated by Clauses 7.8.5.3.1-7.8.5.3.3 may not be appropriate for large structures.

7.8.4 Loads and Load Combinations

7.8.4.4 Earthquake Loads

For concrete buried structures with span (D_h) less than or equal to 3 m, the effects of earthquake loading shall be computed in accordance with Clauses 7.8.4.1 and 7.8.4.4. The potential for, and effects of, seismic soil liquefaction shall also be investigated.

For concrete buried structures with span (D_h) greater than 3m, the effects of earthquake loading shall be computed in accordance with Section 4, Seismic Design. Seismic lateral soil pressures on each side of the buried structure shall be determined by a recognized analysis method, such as the Mononobe-Okabe expressions or Woods' procedure. Alternately, the effects of seismic soil loading may be computed using a finite difference, or finite element, soil-structure interaction analysis method. Regardless of the analysis method used, the structure shall be designed for the maximum seismic soil loading on one side, and the corresponding minimum seismic soil loading on the other side. Where appropriate, the seismic design shall include the effects from hydrodynamic mass. The potential for, and effects of, seismic soil liquefaction shall also be investigated.

Commentary: *Clause 7.8.4.4 is misleading (in title and in text) in that the text addresses only vertical, not horizontal, earthquake loads.*