7.1 Scope

Buried structures with span smaller than or equal to 3 m may also be designed to S6-14 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 (D_h) greater than 3 m, but the CHBDC provides only very minimal design guidance for smaller structures.*

For buried structures, consideration should be given to increasing the size and durability of the structure and/or providing additional measures to ensure maintainability (as per Clause 1.8.3.2) given the high cost of replacement, maintenance and renewal. Consideration should include such items as:

- *Traffic volumes,*
- *Depth of cover*
- *Detour and alternate route availability*
- *Required maintenance frequency*
- *Hydrotechnical issues*

Add the following:

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, H_c, at intermediate stages of construction;
- Construction Live Loading assumed in the design (corresponding to H_c);
- 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 and drainage details including material properties, placement and compaction

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);
- Electrochemical Properties of Soil Materials and Water in contact with the structure;
- Seam Strength at Critical Locations;
- Conduit Geometry including: Rise, $D_{v,}$ Span, $D_{h,}$ Radius at Crown, $R_{c,}$ Radius at Spring-line, R_s and Radius at Base, R_b. etc.

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.

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

7.5.5.4 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

7.6.2 Structural materials

7.6.2.1 Structural metal plate

The use of aluminum plates and components must satisfy the minimum protective measures requirements of S6-14 Clause 2.4.

7.6.3 Design criteria

7.6.3.1.1 General

Delete all 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 3.1, according to the following equation:

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

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 7.6.3.1.2 and 7.6.3.1.3, 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 7.6.3.1.2 and 7.6.3.1.3, respectively, shall be used as an additional check to clarify the results of the finite difference, or finite element, method;

c) Designers of deeply buried soil-metal structures may use the S6-14 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: *S6-14 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 S6-14 design formulae may not be conservative for all large span soil-metal structures. Conversely, the same load rating studies show that the S6-14 design formulae for deeply buried, soil-metal structures to be overly conservative. S6-14 does not place an upper limit on the applicability of Section 7 for deeply buried soil-metal structures.*

7.6.3.1.2 Dead loads

(d) "H" is measured vertically from crown of structure to finished grade, reference Figure 7.3.

Commentary: *The depth of cover or height of overfill, "H", for the various configurations of single and double corrugation soil-metal and box structures is shown on Figure 7.3.*

7.6.3.1.3 Live loads

Replace item (c)(i) with the following:

(c)(i) within the span length, position as many axles of the BCL-625 Truck or Trucks (and/or Special Truck if specified) at the road surface above the conduit as would give the maximum total load;

7.6.3.4 Connection strength

Commentary: *Designers are advised that values of unfactored seam strength for bolted steel plates, S_s, for standard corrugation profile with bolted connections are shown in Commentary Figure C7.4.*

There is currently no reference to the values of unfactored seam strength for bolted aluminum plates.

7.6.4 Additional design requirements

7.6.4.1 Minimum depth of cover

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

7.6.4.3 Durability

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

Design shall be in accordance with the Corrugated Steel Pipe Institute (CSPI) Technical Bulletins:

- Performance Guideline for Corrugated Steel Pipe Culverts (300mm to 3,600mm Diameter) – August 2013
- Performance Guideline for Buried Steel Structures - February 2012

Commentary: *The S6-14 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, polymer laminated 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" for zinc-coated steel structures, as presented in S6-14 Commentary Table C7.2, 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.

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 S6-14 Section 7 Commentary presents two sets of values for Non-Saturated Loss Rates (i.e. UBC 1995 & AASHTO 1993) in Table C7.2, and a single set of values for Saturated Loss Rates (i.e. UBC 1995) in Table C7.3. Practical experience suggests that some of these corrosion loss results are too conservative in typical applications.*

7.6.5 Construction

7.6.5.6 Structural backfill

7.6.5.6.2 Material for structural backfill

Structural backfill shall meet the requirements for Bridge End Fill accordance with SS 201.40 unless otherwise consented to by the Ministry.

7.6.6 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 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.*
S6-14 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 (2014) Tables 12.9.4.1-1 and 12.9.4.1-2 shall be applied; e.g., maximum radius at crown and minimum radius at haunch.

Unless consented to 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.

7.7.3 Design criteria

7.7.3.1.3 Live loads

Replace the definition of A_L at the end of this section with the following:

where A_L is the weight of a single axle of the BCL-625 Truck (or Special Truck if specified) for D_h< 3.6 m, or the combined weight of the two closely spaced axles of the BCL-625 Truck (or Special Truck if specified) for D_h ≥ 3.6 m, and k_4 is a factor for calculating the line load, as specified in Table 7.6

7.7.3.2 Design criteria for connections

Commentary: *Designers are advised that values of unfactored seam strength of bolted steel plates, S_s, for standard corrugation profile with bolted connections are shown in S6-06 Commentary Figure C7.4.*

Values of unfactored seam flexural strength, for steel or aluminum plates, are not presented in the S6-14, or in the AASHTO Standard Specifications for Highway Bridges (2014).

7.7.4 Additional design considerations

7.7.4.2 Durability

The design life and durability requirements for Metal box structures shall be the same as stipulated for soil-metal structures in Supplement Clause 7.6.4.3 above.

7.7.5 Construction

7.7.5.1.2 Material for structural backfill

Structural backfill shall meet the requirements for Bridge End Fill accordance with SS 201.40 unless otherwise consented to by the Ministry.

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 7.8.5.3.2 and 7.8.5.3.3 may not be appropriate for large structures.

7.8.1 Standards for structural components

For top slabs of concrete culverts which are within 600 mm of the roadway surface, shall be treated with a waterproofing membrane.

7.8.3 Installation criteria

7.8.3.1 Backfill soils

Backfill material shall meet the requirements for Bridge End Fill in accordance with SS 201.40.

7.8.4 Loads and load combinations

7.8.4.4 Earthquake loads

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: *Both horizontal and vertical earthquake loads are to be addressed.*

7.8.5.2.2 Earth Load

Commentary: *For further information refer to AASHTO Section 12.10.2.1*