Evaluation of Buried Bridges/Structures – Updates to the CSA S6-25

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Abstract

With Canada's aging infrastructure, rising interest rates, and rising cost of materials, asset management is at the forefront of transportation agencies priorities across Canada. Owners of water and transportation buried structures crossings are faced with decisions to rehabilitate the structure, remove and replace or keep as-is. An integral part of the assessment of the existing crossing is load rating or evaluation of the structure. The Canadian Highway Bridge Design Code (CHBDC) CSA S6-19 excluded buried structures, commonly referred to as culverts or buried bridges, from the evaluation section that outlines the detailed design process for load rating of existing structures. In the upcoming CHBDC S6-25 version, evaluation of buried structures is addressed with additional special provisions that guides the designer/evaluator to determine the target reliability index for the ultimate limit states and determine the load rating of the structure. In this paper, the updated provisions will be discussed and a practical design example for load rating of buried structures will be presented.

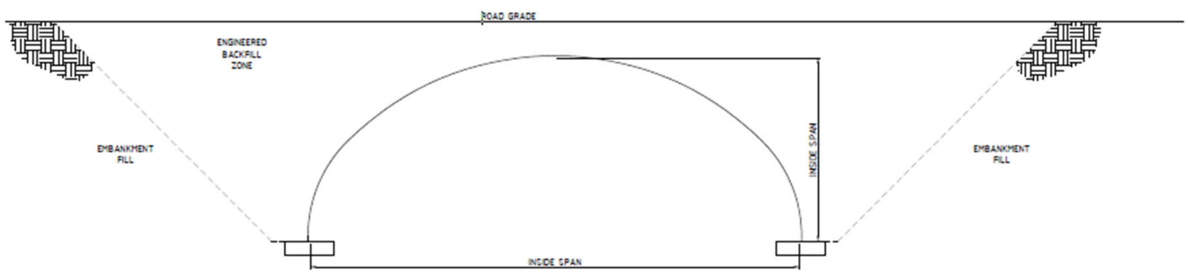
Introduction

Buried bridges (or structures) are integral components to Canadian infrastructure. This structure type is used for public and private sector such as rail, mining, and energy. Buried structures are composite systems that rely on soil-structure interaction to derive its load-carrying capacity. A buried structure system consists of a closed or open bottom structure, and engineered backfill, as shown in Figure 1. Single spans of in-service buried structures range up to 33 m. The most common structure material is concrete or steel. Soil surrounding the structure consists of engineered granular backfill with design specific criteria of drainage, strength, stiffness, and placement. The design of a buried structure of spans 3 m or greater falls under the Canadian Highway Bridge Design Code (referred to in this paper as: CHBDC, S6 or the code), and local judications requirements. Specific provisions pertaining to design for new construction are in Section 7 of the CHBDC.

Bridge inspection and load rating is a routine practice by local jurisdictions and owners. The CHBDC provides methods of load rating of existing structures to carry a particular load or a set of loads. Section 14 details evaluation procedures and methodology. Load rating is determined based on several factors, including material type, structure condition, loads considered, system redundancy, and member ductility. A major difference between design and evaluation is evaluation utilizes system behaviour and strength aspects which exist but are not accounted for during the original design. This helps owners optimize utilization of bridge assets.

Section 14 of S6-19 has several exclusions including buried structures, foundation retaining walls, loads caused by earthquakes and fire, and others. In the upcoming edition of S6-25, evaluation of buried structures is addressed with additional provisions that guide the designer/evaluator to determine the target reliability index for the ultimate limit states and determine the load rating of the structure.

Figure 1. Buried Structure (bridge) System



Updates to provisions in S6-25

Challenges in evaluating buried structures primarily arise from determining the dead load factor based on a reliability index, and defining buried structure system behaviour. To determine the reliability index, in-situ conditions require careful consideration. This section overviews how to evaluate a buried structure as per S6-25.

Updates to Section 7 of S6-25

Section 7 of S6-25 focuses on the required considerations for evaluation of buried structures, and on the analysis methods. Engineered backfill, in-situ conditions, and foundation conditions need to be evaluated as per the applicable clauses in S6-25. The applicable analysis methods are to be used to determine the straining actions for the existing structure. The updated provisions permit taking the pavement layer, if any, into consideration for the distribution of live load into the backfill and to determine the live load induced pressure at the structure crown.

Updates to Section 14 of S6-25

To determine the live load capacity factor, several load and strength parameters need to be established. The load parameters primarily depend on the target reliability index which is a function of system behavior, element behavior, inspection level, structure conditions, type of live load and category of dead load. The dead load factor is based on the load type and the target reliability index.

In the CSA S6-19, the dead load categories did not include the variation of load factors for the target reliability index. The default maximum load factor for the evaluator (although buried structures were excluded) is 1.25, which unnecessarily lowers the live load capacity factor and may affect the asset management plan for the crossing, and in expenditures by transportation agencies. For CSA S6-25, engineered backfill dead load factors and corresponding target reliability index were established using the provisions in Annex B in CSA S408-11, Guidelines for the Development of Limit States Design Standards. The backfill dead load factor for buried structures based on reliability indices ranging from 1.07 to 1.3 is introduced, as shown in Table 1. The statistical parameters used to produce the table below were, bias coefficient for unit weight = 1.0 (Fenton et al. 2015), dead load coefficient of variation = 0.07 (Fenton et al. 2015), resistance coefficient of variation = 0.1 (S6-19), resistance bias coefficient = 1.13 (S6-19).

The target reliability index for new structure is 3.75 and the corresponding dead load factor for backfill as per Section 3 of the CHBDC is 1.25, which is consistent with Table 1 below. It is noted that earth pressure dead load factors remain at 1.25 as per Section 3 of S6-25.

Factored resistances for all limit states are to be determined per the applicable clauses in the code. For soil-metal buried bridges, historical values of yield strength can be found in CSA G401 (2023) and CSPI (2007). For soil-concrete bridges, concrete strength is evaluated as per the applicable clauses in the CHBDC.

It is important to note that backfill parameters to be evaluated through sound geotechnical techniques that can produce the required characteristics for the evaluation of buried structures.

Table 1. Maximum dead load factor for target reliability index

Dead load category	**Target Reliability Index**								
	2.00	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.5**	**3.75**	**4.00**
D4 (Backfill for buried structures)	1.07	1.1	1.13	1.15	1.18	1.2	1.23	1.25	1.3

System behaviour

System behaviour takes into account the consequence of member failure on the overall system. System behaviour for buried structures depends on the structure system, structure material, transverse and longitudinal connections type and configurations, and backfill material and integrity. Determining if a buried structure is a multi-load path system can be achieved in part with the use of numerical methods as outlined in the relevant clauses of Section 7 in S6-25

Element behaviour

Ductility of the element behaviour for buried structures depends on the failure mode, material type and unique proprietary structure features. Ductility of the element can be determined based on the appropriate clause in the code, and based on published test data, if any.

Condition assessment and Material deterioration

Possible deterioration of all buried structure components should be investigated. Effects of deterioration on member strength, ductility and stability should be considered when evaluating the target reliability index for the crossing. Material deterioration for steel material include corrosion, cracking, and connection deficiencies. Material deterioration for concrete material include spalling, cracking, corrosion of reinforcement, alkali aggregate reaction. For buried structure, deterioration of backfill integrity should be considered. Signs of deterioration include structure excessive deformation relative to the footings, and road surface profile changes such as significant localized pavement cracking. Signs of scour, piping and erosion, if applicable, should be investigated. Useful information on defects and deterioration can be found in manuals by transportation agencies such as the Ontario Structure Inspection Manual (2018), and The Manual for Bridge Evaluation (2018).

Step by Step procedure for load rating of buried structures

Step by Step procedure for buried structures evaluation using ultimate state methods, using load and resistance factors, as per cl. 14.5 in S6-19.

- Condition inspection and all past and existing information to be obtained to the satisfaction of the evaluator. Any deterioration shall be considered as appropriate.
- Determine material strength, as applicable.
- Determine all limit states as per Section 7 of CHBDC.
- Establish target reliability index based on system behaviour, element behaviour and inspection level for each limit state.
- Determine dead and live load factors based on the target reliability index, load type and any other factors as stated in CHBDC. Dead load category is D4 for backfill.
- Calculate structure internal forces as per the methods stated in Section 7 of CHBDC.
- Calculate factored resistance for all limit states.
- Calculate the live load capacity factor for each limit state.

Example calculation

The following is an example calculation for the live load capacity factor for a steel buried structure. For concrete buried structures, the same procedure below can be followed as per Section 7, 8, 14 and other applicable CHBDC sections, as appropriate.

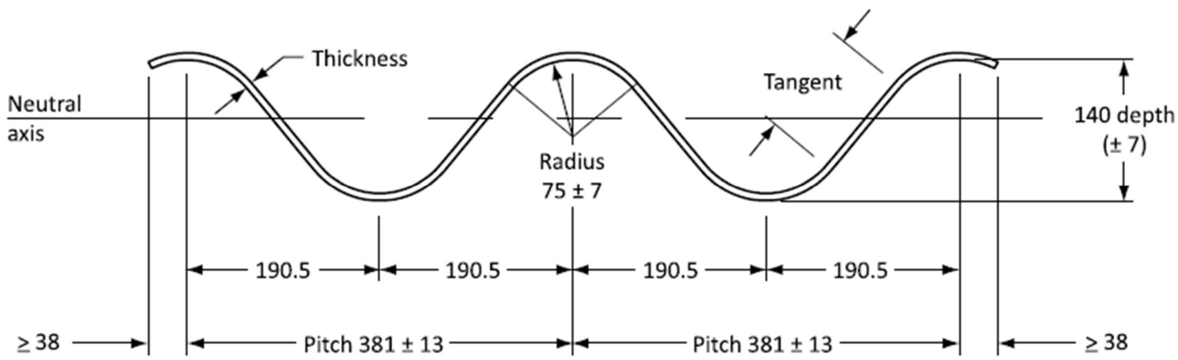
It is also considered that the structure was originally designed according to Section 7 of S6-19 and satisfies all the applicable design provisions. Live load capacity factor is calculated for the structure. For comparison, the live load capacity factor for a new structure was also calculated. The governing live load capacity factor, F, was for the plastic hinge limit state. F was calculated to be 1.42 for new structure, and 2.52 for existing structure. The results show, as expected, that there is an inherently appropriate reserve when following the provisions of Section 7 for designing soil-metal buried structures. A similar outcome is expected for concrete buried structures.

It should be noted that system behaviour and element behaviour are assessments by the author for illustration purposes only and should not be generalized for all cases or steel buried bridges. The design below was done using the equation-based method for single radius arches as detailed in Section 7 of the CHBDC. It is also assumed that the backfill and foundation conditions are in excellent condition. Further, it is assumed that the structure shows no sign of deterioration.

The example is for a steel buried structure having 9.2 m span and 4.6 m rise. The cross-section corrugated profile is 140 mm depth and 381 mm pitch, as per CSA G401, as shown in Figure 2. Steel buried structures consist of segments or “rings” that are connected bolted longitudinally at pre-defined standard spacing, i.e., the system is a multi-load path system, equivalent to multi-girder system. For compression, plastic hinge and longitudinal connection limit states, the system behaviour is considered to be S2. For the category of element behaviour, connection and compression limit states were considered as E2, and for plastic hinge limit state was considered E3.

As mentioned in the step-by-step procedure, the aforementioned categories result in, based on the tables in Section 14 of the CSA S6, target reliability indices of 3.0, 2.75, 3.0 for compression, plastic hinge, and connection limit state, respectively. The dead load factor based on the newly introduced dead load category, D4, is 1.18, 1.15 and 1.18 for the aforementioned limit states. Live load capacity factor is, then, calculated for the three failure modes considered. The lowest live load capacity factor as per cl. 14.15 in the CHBDC is calculated at 2.52 for the plastic hinge limit state. For comparison purposes, the live load capacity factor for a new construction (in design phase) was found to be 1.42.

Figure 2. Corrugation profile for the example calculation, per CSA G401 2024.



Conclusions

With rising interest rates, cost of living, and increasing material and transportation costs, asset management has become a priority for transportation agencies. Owners of buried structure crossings must decide whether to rehabilitate, replace, or maintain these structures as they are. A crucial part of this assessment is the load rating or evaluation of the existing crossing. The existing S6-19 provisions exclude buried structures from evaluation guidelines. This paper outlines the major changes in S6-25 for evaluating buried structures and details the procedure for calculating the load rating capacity factor. The analysis shows that non-deteriorated soil-metal buried structures, as expected, have a higher load capacity factor compared to newly designed structures.

References

CHBDC (Canadian Highway Bridge Design Code). 2019. Canadian Standards Association. CAN/CSA-S6-19., Mississauga, ON.: CHBDC.

CHBDC (Canadian Highway Bridge Design Code). 2025. Canadian Standards Association. CAN/CSA-S6-25., Mississauga, ON. (In-press).

CSA G401 (Corrugated steel pipe and buried structures). Canadian Standards Association. Mississauga, ON. CAN/CSA-G401-24.

Gordon A. Fenton, Farzaneh Naghibi, David Dundas, Richard J. Bathurst, and D.V. Griffiths. 2015. Reliability-based geotechnical design in 2014 Canadian Highway Bridge Design Code. Canadian Geotechnical Journal. 53(2): 236-251. https://doi.org/10.1139/cgj-2015-0158

Guidelines for the Development of Limit States Design Standards. 2011. 2011. Canadian Standard Association. Mississauga, ON.

Ontario Structure Inspection Manual (OSIM), 2018. Ontario Ministry of Transportation. Mississauga, ON.

The Manual for Bridge Evaluation. 2018. The American Highway Association of State Highway and Transportation Officials. Third Editions. MBE-3. Washington, DC.