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# CHBDC BURIED STRUCTURES: CHALLENGES IN KEEPING PACE WITH PRACTICE AND INNOVATION[1]

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Soil-steel structures have been part of Canadian design codes since the 1970s. The inclusion in the Ontario design codes was necessary due to a growing use of flexible buried structures in practice. Since those early developments, the subsequent code committees have always strived to find the appropriate balance between the primary objective of providing design criteria that reflect the safety and serviceability requirements of the code and incorporating the significant practical experience of owners, engineers and industry. Each decade has seen innovations in products and applications as well as advances in research and numerical modelling. Editions of the code have acknowledged these changes, often in the non-mandatory sections, but have sometimes struggled to provide specific criteria. Instead it has provided general guidance or framework for design. Currently, many of the existing design clauses do not directly cover the applications of both flexible and rigid buried structures in regular use today.

This paper describes the key updates being proposed for the Buried Structures section of the Canadian Highway Bridge Design Code. These changes are based on input from owners, engineers and industry describing the needs for current design and practice as well as a modern framework for permitting innovation. The major changes include areas such of finite element analysis, foundation design, conduit wall buckling and the use of flexible structures in cold regions susceptible to permafrost. These major changes will be discussed conceptually as final approval is still pending before inclusion in the 2019 version. The paper will describe some of the background and rationale for the proposals. Finally, the paper will discuss the challenges faced by the sub-committee in determining what should be included in the mandatory sections of the code or in commentary.

Key words: codes, finite element modelling, buried structures, foundations, buckling, construction, cold regions

## 1. INTRODUCTION

The Canadian Highway Bridge Design Code (CHBDC; CSA S6-2014) contains Section 7 Buried Structures. Similar to other bridge codes, this single sec-

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tion often contains all design criteria related to any buried structure meeting the definition of a bridge (span greater than 3 m). The scope statement for this section indicates that the section contains analysis and design requirements for soil-metal structures, metal box structures and reinforced concrete structures. The section also specifies construction procedures, properties and dimensions of engineered soil components and requirements for construction supervision. An unstated reality for this section of the code is that most of the products used are pre-engineered components from a variety of suppliers. A section such as this requires a large and diverse sub-committee with research, design, and maintenance experience from academics, consultants, owners and suppliers.

The origins of this section of the code dates back to the 1970s (Bakht 2007) and work at the Ministry of Transportation in Ontario to develop their own bridge code standards for use in the province. Provisions prior to this were largely empirically based. The Ontario work began to introduce code approaches based on modelling supported by field performance. The Ontario code was integrated into the CHBDC in 2000.

Through successive editions of the code, this section has been tried to keep pace with innovations in the industry, particularly new and stiffer conduit wall profiles. The design approach has been to provide analytical expressions and empirical provisions where necessary. Admittedly, the code provisions have not always been able to cover all solution implemented in the field either in flexible metal structures or more rigid concrete structures.

For the 2019 CHDBC edition, the Section 7 sub-committee undertook to make significant modifications to the code to reflect new innovations, current practice and emerging needs. While this paper will focus mainly on provisions related to ‘flexible’ metal structures, the sub-committee is also making significant changes to buried concrete structures clauses proposing provision for concrete arch-type structures and open bottom concrete box-type structures. At a fundamental level, the sub-committee is also trying to develop a consistent design approach for all types of structures covered in the section as well as better linkages and consistency with other parts of the code.

Two major factors influencing the need for a major update to this section of the code are still innovations in industry, such as stiffer conduit section and connection details (Williams et al. 2012), and increasingly demanding applications in practice including heavier, non-standard live loads; large spans and lower rises; and deeper fill heights. At the same time, CHBDC seeks to be consistent with developments and criteria in other relevant design codes internationally. Finally, numerical modelling is becoming increasingly accessible as a design tool and, in the case of buried structures, increasingly necessary as a design tool.

The challenges for the sub-committee in proposing changes is to respect past practice that has been functioning successfully, accept new research, permit innovation while protecting safety and providing minimum requirements. The sub-committee must continue to address the challenge faced by all design codes which is the balance between performance criteria and prescriptive clauses. Due to industry practice being dominated by suppliers, often of proprietary products, the code must present fundamental approaches that can be applicable to all and yet still be specific enough to give design engineers guidance on limitations and minimum criteria. Finally, in a rapidly developing field what is the correct balance between mandatory criteria versus suggestions for good practice or potential solutions that may appear in the non-mandatory yet influential commentary.

This paper will describe some of the major items proposed for the 2019 editions and some of the considerations behind them. As the specific wording or criteria has many layers of approval to pass before it can be finalized, the paper will focus on the conceptual elements for each issue rather than providing the exact code text. Indeed, every item discussed in this paper is in fact only a proposal and may not make its way into the final version. None-the-less the sub-committee and the author consider these to be important items for the code to address in the next or future editions and so should be discussed. Equally, the paper will highlight generic challenges for any code developers in trying to update codes.

## 2. PROPOSED UPDATES TO CHBDC BURIED STRUCTURES

In addition to general tracking of editorials, definitions and clarifications the sub-committee undertook to address the following major items related to buried structures generally or flexible structures specifically:

- refined methods of analysis,
- prediction of wall buckling capacity,
- solutions for canada's north,
- foundation design,
- construction.

## 3. REFINED METHODS OF ANALYSIS

Numerical modelling of buried structures has been an integral part of understand behaviour, predicting response and developing design approaches since the early work of Duncan, Selig and others (Abdel-Sayed et al. 1993). It has been an integral tool in developing specifications such as those included in NCHRP 473 and NCHRP 647. There are numerical modelling packages such as CANDE created specifically for buried structures, PLAXIS developed for geotechnical and soil-structure interaction modelling that are suitable for buried structures (eg. Haji Abdulrazagh and Bayoglu Flener 2012) as well as many other custom softwares (eg. Korusiewicz 2012). However, as demonstrated by Elshimi (2011), universal finite element programs such as ABAQUS can also be used to successfully model buried structure behaviour. Hence our ability to create numerical models of soil-metal structures in varying degrees of complexity is constantly increasing.

For codes, however, the general approach has been to use the numerical modelling tools, verified by comparison with laboratory or field data, to develop analytical expression (curved fitted to parametric study results) for use in codes. These expressions have then been tested and modified by years of design implementation and field performance. This has appealed to most designers as the equations are generally quick and easy to implement. For code committees, the use of these analytical expression within the specific limits often gives the code some implicit control over safety and performance.

The challenge for CHBDC, and other codes, is that the industry is innovating in terms of new products or new applications including larger spans, shallower cover, deeper cover, challenging backfills, non-standard highway loads. In addition, the code recognizes that historically designers have sometimes used special features such as relieving slabs, stiffening ribs, or deformability techniques to allow limited movement of the arch to relieve stress. The general analytical design expressions do not cover many of these situations and are currently qualified incode text in such as way that, should the design fall outside the narrow limits of the expressions, then the design must use rigorous methods. For example, currently the CHBDC states that the analytical expressions can only be used for arch-type structures with shallow corrugations or single radius structures with deep corrugations and modest backfill heights or box-type structures for spans less than 8 m and rise less than 3.2 m. Applying those expressions beyond their stated limits is not advised.

Vallee investigated the bending moments present in single radius arch-type structures with deeper corrugations through field monitoring (Vallee et al. 2014) and modelling (Vallee 2014) and found that the code expressions can be over-conservative for certain geometries or un-conservative for others thereby illustrating the importance on not simply extending the use of these equations beyond the code limits without full study, verification and modification where necessary. Furthermore, due to both innovations and emerging practice the general sense of the code sub-committee was that an increasing percentage of new projects will require rigorous analysis as they structure will exceed the limits of the analytical expressions.

A major concern is that the current CHBDC guidance on ‘rigorous’ methods of analysis is “..rigorous methods of analysis that take into account the beneficial effects of soil-structure interaction”. For a method that is becoming increasingly necessary as a design tool, this is does not seem to be an appropriate amount of guidance for the code. Therefore, a new section is being proposed to provide more guidance to the designers. It will be called ‘refined’ methods of analysis in keeping with the use of the term for analysis of other types of bridge structures in CHBDC.

### 3.1. Proposal for Refined Methods of Analysis

Section 5 Methods of Analysis of CHBDC contains general guidance for refined methods of analysis for all other bridge types. While this was used as a model for developing a new section for buried structures, the focus on buried structures only allowed sub-committee to be more specific. The reality remains however that the code provides criteria for design and is not intended to be a design manual nor to limit the refined analysis to a single choice of software. Furthermore, this section must also be applicable to a wide variety of applications, not restrict innovation, and also be applicable to buried concrete structures. The specific wording is still being developed for approval but the elements described below are considered to be the key elements.

The code will permit the use of finite element analysis or finite difference analysis. For any numerical model, the approach must be verified by comparison with known behaviour from appropriate field data or laboratory testing. The modelling may be two dimensional or three dimensional.

All models must include soil-structure interaction.

The geometry, boundary conditions, structural characteristics and loading shall be selected to conservatively represent the behaviour of the buried structure at each of the relevant limit state conditions being considered.

The behaviour of the structure both during construction and after completion are critical in analysis and design. Modelling must consider backfilling sequence and techniques. The accumulation of force effects, the change of material properties, and deflection during construction shall be considered.

The buried structure system response can be impacted by the engineered soil envelop, the foundation system and the in-situ soil. These must be accounted for in the model.

For purposes of modelling to determine force effects or deformations, the conduit wall material may be treated as elastic-plastic. For concrete structures, the stiffness properties of materials and the extent of cracking shall be consistent with the anticipated behaviour. The specific elastic properties and characteristics of the materials shall be determined in accordance the appropriate sections of CHBDC.

Guidance on soil modelling is still being developed with the following considerations. The soil properties must be consistent with the soil type used in the field and consider strain compatibility, stress dependant nature of soil properties, and inelastic effects.

A buried structure may be analyzed using refined methods for the relevant load effects and structural responses including, but not limited to:

- axial forces in conduit wall,
- bending moments in conduit wall,
- shear forces in conduit wall,
- footing reactions,

– soil pressures surrounding the structure,
– structural stability during construction equations,
– deformations.

### 3.2. Comments

The guidance covers a large range of modelling items but is still generic enough not to limit the designer to a single software or model. It also permits the method to be used in a large number of applications. This approach is consistent with that taken by Section 5 of CHBDC for other bridge types. The refined methods clauses give general guidance and criteria allowing the engineer to choose the specifics for the application based on experience and qualifications. For engineers who may choose a customized commercial package it also highlights that there are many important considerations which they need to be aware of before proceeding. By placing these types of criteria in the mandatory text it places an obligation on the engineer to determine how and if the numerical approach they choose accounts for these issues.

The inclusion of a significant number of items and factors may deter some engineers from considering the use of buried structures if this level of knowledge of refined methods is required. The committee has weighed this against the method being the only solution for many applications and decided that providing more detailed guidance is a better solution than the current simple statement to use rigorous methods.

## 4. BUCKLING OF CONDUIT WALL IN COMPRESSION

The current code clauses for buckling strength of the conduit wall use a beam-column analogy for the conduit wall and spring modeling for the soil which is known to produce buckling loads that differ substantially from experimental evidence. The sub-committee is proposing to introduce a continuum buckling equation that is already used in a variety of buried structure codes internationally (United States, Australia and New Zealand).

The failure of a conduit wall with shallow corrugations under thrust alone must still be checked for the lessor of wall crushing, when the compressive stress reaches the yield point, or elastic buckling.

The proposed equations for buckling strength are based on the continuum model described by Moore and Selig (1990). This model is based on analytical solutions (Moore et al. 1994) modified using an adjustment factor calculated from finite element analyses (Moore, 1987; 1988) to account for the impact of shallow cover, and, if required, the impact of narrow zone of backfill support besides the culvert (Moore et al., 1994). The analytical solution provides an approximate expression for the deformation wavelength of the critical buckle that is a function of the flexural stiffness of the pipe relative to the soil. Finite element analyses (e.g. Moore, 1987; Moore et al., 1994) show that the soil adjacent to a flexible pipe is disturbed out a distance approximately equal to the buckle wavelength. Therefore, structures that have buckle wavelengths shorter than the cover depth have buckling strength that is not affected by cover depth. Structures with high flexural stiffness also have buckling strength that is independent of burial depth, because little support is being supplied by the soil.

The proposed equation will take the general form:

$$T_b = a\,(EI)^{1/3}\left(\frac{E_s}{2(1+\vartheta_s)}\right)^{2/3} R_h$$

Where $T_b$ is buckling resistance, E and I are properties of the conduit wall; $E_s$ and $\nu_s$ are properties of the soil; a is a fitting constant and $R_h$ is an adjustment factor for burial depth.

For culverts where buckling strength is influenced by shallow cover, an adjustment factor is a function of normalized burial depth (depth over span) and the flexural stiffness of the pipe relative to the surrounding soil. A lower bound solution will be provided or alternately the designer can use more detailed solution provided by Moore et al. (1994). The task group is currently working on a parametric study of deep and deeper structures consistent with those used in the field to finalize the experiences and related factors.

## 5. SOLUTIONS IN CANADA'S NORTH

Currently CHBDC contains no provisions for the design of buried structures in cold weather regions. In Canada, cold regions include the Yukon, Northwest Territories, Nunavut and the northern parts of many Canadian Provinces, stretching up to the North Pole. Those land areas can be dominated by the presence of permafrost or discontinuous permafrost. Cold weather regions give rise to several unique challenges that need to be considered in the design, construction and maintenance of buried structures. Furthermore, even the known challenges of cold weather regions are changing with warming climates. These regions have often relied on seasonal approaches to construction and road usage to take advantage of the extremes in temperature and ground conditions as appropriate. As climate change creates a shift in temperature ranges and seasonal timelines, the challenges of constructing and maintaining any structure is this dynamic environment increases.

Freeze-thaw cycles and thermal instability have potentially significant adverse impacts on the performance of buried structures in cold regions. These include permafrost degradation leading to intolerable short and long-term total and differential settlements and frost heaving due to the formation of ice lenses. In addition, thermal stresses impose large axial stresses and notable flexural stresses on buried structures. These thermally induced stresses will need to be considered in the design of buried structures in cold regions. Designers also need to consider the effects of restrictions to loading-induced wall deformations caused by rigid frozen backfill.

Moisture migration during thaw periods in the engineered backfill has been found to reduce soil stiffness. Thawing impacts on permafrost foundation soils and engineered backfill, placed frozen during construction, requires special considerations in design.

The challenge for the sub-committee in adding criteria to CHBDC is to determine what is appropriate in the mandatory text and what is more appropriate in commentary. This is a challenge faced in many aspects of code development. The mandatory section should identify the key elements a designer must consider while the commentary may address more specifics or details as they are known at the time of publishing the code. Due to the dynamic nature of the environment and the need for continual innovations in infrastructure solutions in this region, coupled with limited experience for most companies and engineers, the proposed clauses cannot be as prescriptive as other section and must highlight performance issues. Other mores specific details can be provided in the commentary.

### 5.1. Proposal for mandatory text related to structures in cold regions

Buried structures in cold regions shall consider the thermal impacts related to structure loading, structure deformation owing to thermal effects and soil stiffness variations. As a minimum, the design of buried structures in cold regions shall consider:

- thermal expansion and contraction of flexible soil- metal and rigid concrete arch structures,
- thaw and freeze cycles and their long-term impacts on the performance of the engineered backfill, with or without GRS reinforcement,
- potential degradation of permafrost and long term thaw settlements that could impact the serviceability and performance of buried structures,
- adverse impacts of winter construction (e.g., frozen materials in the engineering backfill envelope),
- large temperature changes and cyclic thermal fluctuations.

Equally important to the design considerations is the requirement that buried structure projects in cold regions utilize the expertise of professional engineers familiar with cold region engineering and buried structures.

### 5.2. Unique Emerging Solution proposed for Commentary

In addition, innovations in buried structures may provide unique solutions for these Northern regions. Numerous geosynthetic reinforced soil (GRS) composite structures have been constructed across western and other parts of Canada in the past several years. GRS composite structures are defined as buried structures whose engineered backfill is stiffened with the inclusion of closely spaced (less than 0.3 m) geosynthetic reinforcement layers. Structures that rely on geosynthetic materials for load reduction and/or soil stiffening must be analyzed using rigorous methods. Refined analysis shall consider current understanding of GRS –soil composite behaviour (FHWA-HRT-10077, 2013). The sidewalls of buried structures need to be laterally restrained by positive connection to the GRS. Open bottom GRS Arch buried structures shall have the structure base laterally supported such that the structure can be analyzed as one having full lateral restraint.

The addition of geosynthetic reinforcement to the backfill is believed to add structure resilience by encapsulating the backfill and reducing the risk of hydraulic piping and scour. It also adds resilience by enhancing the composite behaviour between the foundation/structure/engineered backfill and increasing tolerance to abnormal settlement patterns.

Since 2009 a number of structures have been successfully constructed using GRS structures in cold regions. Therefore, the description of above GRS solutions for the North is proposed to be added to the commentary using reference to specific experiential knowledge to date and the Approval of the governing jurisdiction. However, much work will still be required before design clauses can be introduced in the main body. Its inclusion in the commentary in this manner will permit the North to continue to use and develop innovations specific to its environment and needs under its own approval system.

## 6. FOUNDATION DESIGN

Buried structures must still be supported by a foundation system. In the current version of the code, very brief guidance on footing design is given. It basically says that, the footings shall be design by the provisions of Section 6 of the code, dealing with bridge foundations in general, and shall consider appropriate scour protection. Forces acting of the footing and resulting footing pressures on the soil may be determined by refined analysis.

The addition of a section on refined analysis will provide guidance on modelling however the sub-committee is proposing to add more detail on the important considerations and how to address them in design.

### 6.1. Load Effects

Text will be added to clarify the load effects, as appropriate, that a footing designer must consider including effects of thrust, shear and moments (for any fixed connection between the footing and structure base) that are transferred from the structure to the footing. Criteria for minimum vertical footing loads will be added.

### 6.2. Settlement

The impact of settlement of the structure loading is an important issue which the sub-committee is seeking to clarify. The key considerations are large total settlements plus significant differential longitudinal settlement along the footing or differential settlement transversely across the span. While the effects of the settlement are experienced by the structure, the footing designer will need to consider new limits on maximum permissible settlements unless approved by the owner and included in the refined analysis. In addition, an owner may specify more restrictive settlement limits when damage may occur in overlying pavements. In special circumstances, such as buried structures in the North, certain regions may need to permit larger movements that are seasonally influenced.

### 6.3. Accurate and Detailed Geotechnical Information

The importance of soil-structure interaction is often thought of as an issue between conduit wall and the surrounding engineered backfill. However, the geotechnical characteristics of the in-situ material surrounding the structure and interacting with the foundation is equally important. In fact, significant difference between design assumptions and in-situ realities can have major consequences for performance of the designed structured. The sub-committee is therefore proposing to add more detailed guidance to the information required during a geotechnical investigation. This would include requirements for the geotechincal report to provide site data (stratigraphy, relevant physical and engineering properties of the various strata and groundwater conditions) and recommendations for the design of structure foundations and approaches and guidance with respect to immediate and long term settlements, control of seepage and the transition treatment between engineered backfill and natural soil and/or rock. This type of requirement is difficult to detail as mandatory criteria so the commentary will be updated to contain details of specific information and its importance. A key element of a successful design is proper exchange of information between the geotechnical engineer and the structural designer. In fact, conducting these engineering activities as completely separate tasks can lead to serious problems which often have to be addressed during construction. However, the dynamic of the execution of a design cannot be controlled by the code. The strategy is to highlight the type and importance of information required as well as the party responsible for providing this information to promote better exchanges and collaborations amongst the participating engineers.

## 7. CONSTRUCTION

Proper construction of a buried structure is vitally important to its safety and successful function. The code has provided some guidance for issues to be controlled or monitored during construction. Field experience indicates that some projects are not following these procedures or there is confusion about who should be conducting the construction monitoring. Once again this presents a difficult challenge for the code committee between specifying criteria or controlling project execution.

The sub-committee is proposing to add more detailed criteria to sections dealing with construction requirements. This includes more detail of permissible deformation during construction including the ability for the designer to specify limits based on refined analysis and resilience of the structure. The need for verification of compaction of each layer of backfill as well as clarity on permissible compaction effort adjacent to the conduit wall is being proposed. The maximum differential in backfill layers from side to side is proposed to be increased to 300 mm to keep with some observed practices. Finally, the specifications on the amount of bolt torque are being made clearer. In all cases, the commentary will address the importance of the supplier's requirements in finalizing construction limits on all of the above for specific projects.

The responsibilities and qualifications of the site supervisory personnel is an execution issue. While the sub-committee does not believe it can address this directly in the code, it has provided recommendations to the regulatory agencies for their consideration.

## 8. OTHER ITEMS

The buried structures section of CHBDC has evolved quite separately from other sections. However, there is increasing focus on making approaches consistent across the code. This is being attempted with the refined analysis proposal. Another item being investigated is collaboration with Section 2 to introduce guidance on durability, sustainability and resilience of buried structures within the framework being considered for the whole of CHBDC.

With respect to other codes internationally, consistency with wall buckling provisions has already been discussed. However, a task group is examining some geometric requirements such as minimum backfill envelop, cover height and clear distance between adjacent conduits used in other codes.

The seismic design requirements of CHBDC were upgraded in 2014. This had an impact on buried structures in high seismic regions or with high stiffness. A task group is investigating the impact on final design and whether a more refined method of seismic analysis may be required for certain structures.

## 9. SUMMARY

The contents of this paper are the first discussions of potential changes for 2019 to CHDBC Section 7 Buried Structure outside the code sub-committee. Changes are not provided as exact text but are discussed more conceptually. However, the intent was to present the current challenges faced by the sub-committee in addressing modern practice and innovations in buried flexible structures. It is believed that this perspective is important for all elements of research and industry to understand. Codes have to place safety first but, where they cannot be specific, they should provide appropriate framework for engineering solutions to be developed. This is especially true for the current simple statement in CHBDC to "use rigorous methods". There is also a growing change in codes to move to more performance based approaches and be less prescriptive.

It is hoped that others who deal with code development may find some common interests and approaches in the proposals. For those not involved in code development, it is hoped that this paper will illustrate that not elements of developing a code are focussed on the purely technical aspects of refining equations and criteria.

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### LITERATURE

1. Abdel-Sayed, G; Bakht, B. and Jaeger, L.G. 1993. Soil-Steel Bridges: Design and Construction. McGraw-Hill Inc. US.
2. Bakht,B. 2007. Evolution of the design methods for soil-metal structures in Canada. Proceedings of the 1st European Conference on Buried Flexible Steel Structures. Rydzyna, Poland April 23-24.
3. CSA S6-14. 2014. Canada Highway Bridge Design Code. Canadian Standards Association. Toronto, Canada.
4. Haji Abdulrazagh, P. and Bayoglu Flener, E. 2012. Numerical analysis of box-type soil-steel Structure under static service loads. Proceedings of the II European Conference on Buried Flexible Steel Structures in Road and Railway Engineering". Rydzyna, Poland April 24 – 25.
5. Elshimi, T.M. 2011. Three-dimensional nonlinear analysis of deep-corrugated steel culverts. Ph.D. Thesis, Queen's University, Canada.

6. FHWA-HRT-10-077. 2013.Composite Behavior of Geosynthetic Reinforced Soil Mass. Technical Report. Federal Highways Administration. USA.
7. Korusiewicz, L. 2012. Computer software for calculating internal and external forces in corrugated culverts on the basis of measured strains. Proceedings of the II European Conference on Buried Flexible Steel Structures in Road and Railway Engineering". Rydzyna, Poland April 24 – 25.
8. NCHRP 647. 2010. Recommended Design Specifications for Live Load Distribution to Buried Structures. Transportation Research Board. Washington, USA.
9. NCHRP 473. 2002. Recommended Specifications for Large-Span Culverts. Transportation Research Board. Washington, USA.
10. Moore, I. D. (1988). "Elastic stability of buried elliptical tubes." Geotechnique, 38(4), 613-618.
11. Moore, I. D., "The elastic stability of shallow buried tubes." Geotechnique, Vol. 37, No. 2 (1987) pp. 151–161.
12. Moore, I.D. and Selig, E.T., 1990. Use of continuum buckling theory for evaluation of buried plastic pipe stabilityBuried Plastic Pipe Technology, ASTM STP 1093, George S. Buczala and Michael J. Cassady, Eds., American Society for Testing and Materials, Philadelphia, pp. 344-359.
13. Moore, I.D., Haggag, A. and Selig, E.T., 1994. Buckling strength of flexible cylinders with nonuniform elastic support. Intl. Journal of Solids and Structures, Vol. 31, No. 22, pp. 3041-3058.
14. Vallee, J., Newhook, J.P. and Ford, W. 2014. Construction and Monitoring of Soil-Steel Bridge with Deeper Corrugated Plates. Proceedings of 9th International Conference on Short and Medium Span Bridges Calgary, Alberta, Canada, July 15-18.
15. Vallee, J. Investigation of Increased Wall Stiffness on Load Effect Equations for Soil Metal Structures. MASc Thesis. Dalhousie University, Canada.
16. Williams, K; MacKinnon, S and Newhook, J.P. 2012. New and innovative developments for design and installation of deep corrugated buried flexible steel structures. Proceedings of the II European Conference on Buried Flexible Steel Structures in Road and Railway Engineering". Rydzyna, Poland April 24 – 25.