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LARGE-SPAN SOIL-STEEL COMPOSITE BRIDGES[1]

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Soil-steel composite bridges are considered competitive structures being an economical alternative to similar span concrete bridges. They are increasingly used for road and railway bridge construction. Spans have increased and structures with spans over 20 m have been built. The continuous development of infrastructure impels designers to push the limits of these structures for bigger spans with the lowest possible height of cover.

Since the birth of the ring compression theory, different design methods have been developed to account for the various conditions and facilitate the use of bigger span structures. Yet, there is an urge to investigate whether the current design procedures are conservative or if they are reasonably accurate to predict the capacity of large-span structures.

This paper presents the on-going project involving the capacity of large-span soil-steel composite bridges. The study investigates the use of finite element modelling in predicting the performance of a case study for an ultimate limit state field test. The project also highlights the need and intention to perform an ultimate limit state test for a large-span structure. The outcome of the project is to assess the current design procedures and to reflect recommendations on the design where seen applicable.

Key words: flexible culvert, soil–steel composite bridge, Swedish design method, long-span, ultimate field test, full-scale test, loading to failure

1. INTRODUCTION

Although soil-steel composite bridges (SSCB) imply simplicity in their construction, the complex nature of the interaction between the soil and steel materials marks a challenge for practitioners. The current demand for larger structures stimulates researchers to realize the true bearing capacity of these structures. The term “large-span” might be relative, what is considered to be large 30

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years ago (i.e. 8 m span), may now considered relatively small given the current demand for larger-span structures (i.e. more than 20 m span).

At early stages, and when the structures were relatively small, flexible culverts were designed using the ring compression theory, which entails that the structures were dimensioned according to the prevailing normal force in the wall conduit. Later on, and with the drive for large-span structures, the disregard of bending moments (i.e. flexural capacity) has been reconsidered especially when large span structures are built under low height of soil cover. In 1979, the work presented by Duncan [1] provided insights for more understanding and paved the road for the design of large-span structures. In addition, the research presented in [2] for a 9.5 m span metal arch culvert field test, gave the opportunity to provide recommended specifications for large-span culverts, where the proposed modifications were adopted in the AASHTO design method [3]. The Swedish design method (SDM) was first presented in 2000 and was mainly based on the soil culvert interaction (SCI) by Duncan [1,4] and then further developed and calibrated using different full-scale field testing [5,6]. The design section of SSCB in CHBDC design method [7] has undergone many revisions as well since its first edition in 2000. It is no secret that these design methods are being developed with time to account for new market challenges and to keep track with the advances in construction techniques and the new corrugation sizes as well.

This paper briefly outlies the main research efforts initiated at KTH with the aim to investigate the rationality of current design method(s) (in particular, SDM [6]) for the design of large-span structures. The project will seek to underline design recommendations where applicable in line with SDM. The research will utilize FEM together with the intention of performing a full-scale field testing for the prediction of ultimate capacity of a large-span structure.

1.1. Overview of current span limits

Apart from metal box culvert, the SDM [6] and CHBDC [7] design methods do not explicitly state a maximum span limit for the design, the limit is normally set by the design itself, which is normally controlled by available materials, profile shapes and corrugation sizes. Other design methods such as AASHTO [3] may specify some geometric limits on long-span structures, where a maximum plate radius of 14 ft (i.e. 4,3 m) is applied.

The span limit of box culverts in AASHTO is 30 ft (i.e. 11,9 m), while the span is set at 8,0 m in CHBDC (>8 m rigorous analysis is required). SDM has no span limits on box structures.

2. LOADING TO FAILURE TESTS

Although, many culverts have been tested under live loads, yet, there are very few full-scale field tests, where metal culverts are actually loaded to failure, especially for large-span structures. Table 1 summarizes the main full-scale field loading to failure tests performed for SSCB with spans more than 3 m.

Table 1. Main loading to failure tests for metal culverts

Reference	Region	Profile type, corrugation (mm)	Span (m)	Cover (m)
Klöppel & Glock (1970) [8]	Duisburg-Hamborn Germany	Pipe arch, 152 × 51 × 4,75	6,27	1,57
Temporal et al. (1985) [9]	Newport, Wales, UK	Pipe arch, 100 × 20 × 3,0	3,83	0,36
Pettersson, L. (2007) [5] [10]	Enköping, Sweden	Pipe arch, 200 × 55 × 3,0	6,1	0,75
Flener, E (2006) [11]	Järpås, Sweden	Box culvert, 381 × 140 × 7,0	7,94	0,45
Flener, E (2007) [11]	Järpås, Sweden	Box culvert, 381 × 140 × 7,0	14,11	0,45
Lougheed, A.C. (2008) Elshimi, T. (2011) [12,13]	Ontario, Canada	Box culvert, 400 × 150 × 6,0	10,15	0,45

One may note that most of the loading to failure tests were more performed on box culverts shapes, which could be referred to the unique shape of these structures and the urge to adopt the design methods to their profiles. To authors, one of the largest loading to failure tests performed on a regular metal culvert is the Enköping case 6,1 m span (see Figure 1). Therefore, one may see the need to perform an ultimate limit state test for a large-span structure especially for open profiles (i.e. arches).

Figure 1. Enköping pipe arch, loading to failure test

3. THE USE OF FEM

The utilization of FEM has helped researchers in realizing the structural behaviour of SSCB. Several investigations have been carried out to foresee the structural behaviour by modelling SSCB in 2D and 3D simulation environments. A fair summary of those were presented in [12]. In fact, Duncan [1] has utilized 2D FEM(s) to propose a set of design equations for SSCB. One of the recent efforts to predict ultimate capacity of SSCB was presented by Elshimi [12] for the 10,11 m span box culvert listed in Table 1, where his research indicated the potential use of FEM for the prediction of ultimate capacity of SSCB.

For this project, the ultimate capacity of the Enköping pipe arch 6,1 m span (Table 1) is analysed using a detailed 3D simulation environment. The aim is to investigate and discuss the effect of different parameters (mainly soil input parameters) on its structural response, where FEM results are analysed and compared to field measurements. The simulation aims to predict the ultimate capacity for an axle load situated above the crown. A loading rig was used for the loading (see Figure 1). The dimension of one footprint (wheel) was 0.2 × 0.6 m (i.e. 0.1 × 0.6 m in symmetry). The centre distance between the two wheels axle was 2.0 m. The analysis will also highlight a detailed FEM methodology that is to be utilized for the upcoming large-span ultimate test. Figure 2 shows a snap shot of the current ongoing modelling efforts of the Enköping case.

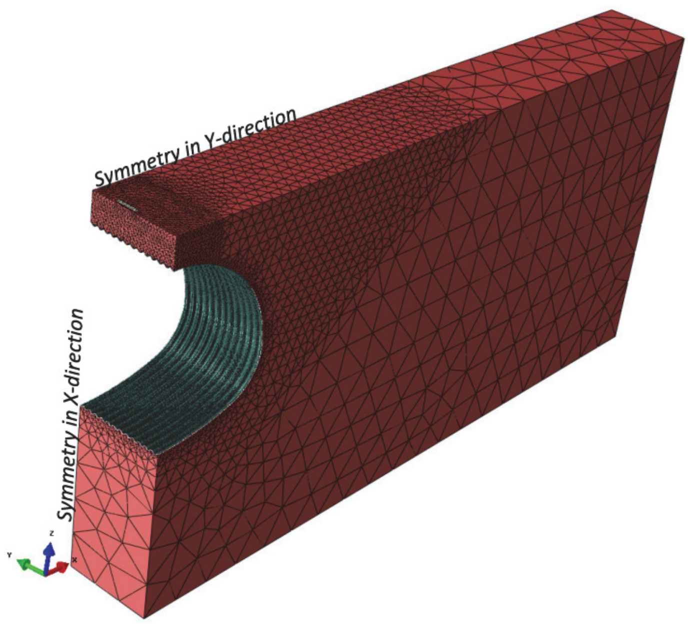

Figure 2. a 3D FEM showing the Enköping case for the prediction of ultimate capacity

4. THE FIELD TEST AND RESEARCH QUESTIONS

The overall research question is to see how close the current design method, in particular SDM, to predict the ultimate capacity of large-span structures. The intention of performing an ultimate capacity test (i.e. full-scale) will provide insights about the true capacity and how that can be linked to the design equations in SDM.

The initial plan for the test (tentatively in the summer 2017) is to have a two radius arch made of 381 × 140 × 7,0 mm (so-called SuperCor) corrugated steel. The selected span would be in the range of 15-18 m, which is chosen to correspond with the same flexibility number (λ_f) of a 25,8 m span (centre to centre) structure being currently built in Poland. The 25,8 m span structure is made of so-called UltraCor steel corrugation 500 × 237 × 9,5 mm. The depth of soil cover will be chosen to represent a low cover case for a large-span structure, which could be in the order of 10% of the tested span.

The current design approach in SDM will be investigated and further analysed to perceive possible modifications - where applicable - for the design equations. The refinements may involve load effects equations including normal forces and bending moments. The soil behaviour at low height of soil cover is studied. The mode of failure and the reserve capacity of the structure could be also studied from the test, which is considered an added knowledge to the research at hand. The design equations for buckling capacity will be also examined for possible refinements taking into consideration what other design methods have for the prediction of buckling capacity. An added investigation may involve the use of the so-called UltraCor corrugation (500 × 237 mm) and how it can be adopted in the SDM.

5. SUMMARY

The need to investigate the ultimate capacity of large-span SSCB is realized due to new market challenges in corrugation sizes and the seek for large-span structures. The current design procedure in SDM may need to be verified and tuned for the structural behaviour of large-span structures. Therefore, a project has been initiated to study large-span SSCB at the division of structural engineering and bridges, KTH Royal Institute of Technology in Sweden. The results from an intended full-scale field test, together with the help of 3D FEM will be used to incorporate possible refinements –where applicable- to SDM for a better prediction of the structural performance of large-spans SSCB.

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