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STRUCTURAL CAPACITY OF EXISTING BURIED FLEXIBLE CULVERTS SWEDISH DESIGN METHODOLOGY[1]

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Knowing the structural capacity of existing bridges is essential for road administrations. This is equally true for flexible culverts as for any other type of bridge.

For older structures all necessary data for a full detailed verification of the structural capacity may not be in place. In some instances the missing data may be possible to retrieve by different measurement and testing procedures in the field and in laboratory environment. However, for most of the structures one need to rely on database information when estimating the structural capacity. In this paper the procedures for estimating the structural capacity of existing flexible culverts specific for Swedish conditions is described along with some technical aspects important for the structural capacity.

Key words: flexible culvert, existing structure, structural capacity

1. INTRODUCTION

General

The requirements for evaluating the structural capacity of bridges in Sweden are given in Ref. [1] published by the Swedish Transport Administration. This document in turn refers to Ref. [2] and [3] for evaluating the structural capacity of flexible culverts[2] (in Sweden referred to as Soil-Steel Composite Bridges; in Swedish: Rörbroar (Pipe Bridges)).

This paper

This paper aims at giving some in-sight into the procedures adopted for evaluating the structural capacity of flexible culverts in Sweden. Also some

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[2] In this paper the term ”flexible culvert” is used throughout.

technical aspects of the structural capacity are discussed. In should be noted that this paper describes procedures specific for Swedish conditions which may not be applicable elsewhere.

In Sweden the design methodology in Ref. [2] is adopted for evaluating the structural capacity of existing flexible culverts. Requirements for existing structures specific for structures in Sweden need to be observed. Inspection and maintenance are crucial for the integrity of the structure and it is important that the estimation of the structural capacity is based on information from regular inspections. If such information is not available an estimation of the structural capacity is not possible.

International knowledge

An interesting example for evaluation of the structural capacity of existing flexible culverts is the load rating procedure used in Ohio, USA, Ref. [4]. Backed up by field measurements, see Ref. [5], it is an example of how rational methods can be developed based on today's knowledge of the structural behavior of flexible culverts.

Paper out-line

The paper has the following outline. A description of various technical aspects important for the structural evaluation of an existing flexible culvert is given in Section 2. The Swedish approach for evaluating the structural capacity is presented in Section 3. The paper is ended with conclusions in Section 4.

2. TECHNICAL ASPECTS

Several important technical aspects need to be considered when performing an estimation of the structural capacity of an existing flexible culvert. It is essential that the estimation is based on information from regular inspection of the structure including such information that is important for the structural capacity and the structural integrity. Knowing the structural capacity of existing bridges is essential for road administrations. This is equally true for flexible culverts as for any other type of bridge.

For older structures all necessary data for a full detailed verification of the structural capacity may not be in place. In some instances the missing data may be possible to retrieve by different measurement and testing procedures in the field and in laboratory environment. However, since the number of structures is very big, for most of the structures one need to rely on database information when estimating the structural capacity.

Below some of these technical aspects are discussed.

Design plate thickness

Due to corrosion, typically for structures used for conveying water under roads and railways, the plate thickness might be reduced in the lower part of the conduit. Ref. [2] gives some guidelines for estimating the capacity in such cases. For corroded parts in the upper part of the conduit special investigations of the capacity must always be performed.

Observe that there must not be any local holes due to corrosion that can cause the backfill to erode and thus reducing the stabilizing forces from the soil.

Very small height of cover

For analysis of existing structures with small height of covers the Swedish approach is to increase the load using a load concentration factor. This factor takes uncertainties in load distribution, soil stiffness and strength etc. into account. It is however, at very small heights of cover, recommended that the live load influence is checked by measurements used to back-calculate the soil modulus, see Ref. [2].

The effect of live load on existing older flexible culverts was studied in a test series on three culverts in 2012. One of the culverts is shown in Figure 1. The culverts were built around 1970. The culvert span was approximately 4 m for all the culverts in the study. The height of cover varied between 0,28 m and 0,54 m. The tests are reported in Ref. [6].

Figure 1. Flexible culvert in northern Sweden built 1966. Measurements under live load were performed in 2012 recording crown deflections and steel strains.

Both crown deflection and steel strain were recorded using a three axle Scania truck with a total weight of approximately 26 tons.

Soil parameters

Typically detailed information on soil parameters is not available for existing structures. The principle of cautiousness is thus recommended and conservative soil input data is used.

An important observation in tests reported in Ref. [6] was that the largest measured steel strains were not recorded in the culvert having the smallest height of cover although all three culverts were approximately 45 years old at the time of the test. After a visual inspection this interesting result was believed to be a result of the soil quality confirming that cautiousness should be observed.

If however better information is at hand, due to i.e. performed geotechnical tests and evaluations, the methodology presented in Ref. [2], can be used for determining the characteristic soil modulus.

Design traffic load

In Sweden special traffic load patterns for verification of the structural capacity of existing bridges are defined in the bridge codes. For road bridges these are given in *TDOK 2013:0267* (Ref. [1]). In Ref. [2] these load patterns are transformed into equivalent line loads to be used in the verification of the capacity. The load patterns, 14 in a total, can be combined in two design load diagrams, giving the envelope of the maximum load effect in the design of flexible culverts. The diagrams are shown in Figure 2 and Figure 3. The live load is defined as a static load and dynamic amplification factors therefore need to be added.

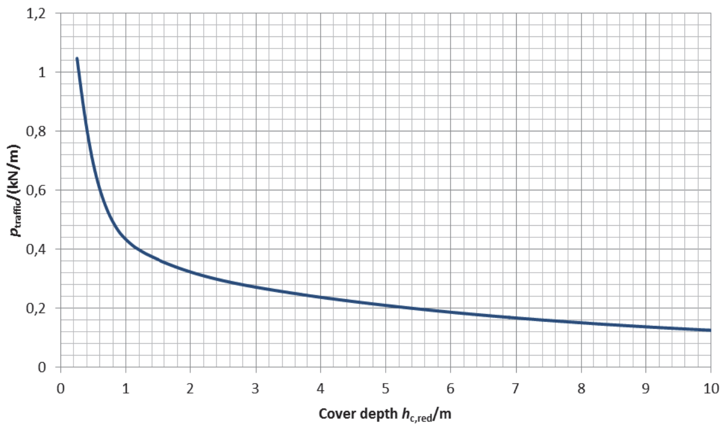

Figure 2. Envelope of the maximum equivalent line load calculated for TDOK 2013:0267, load case a

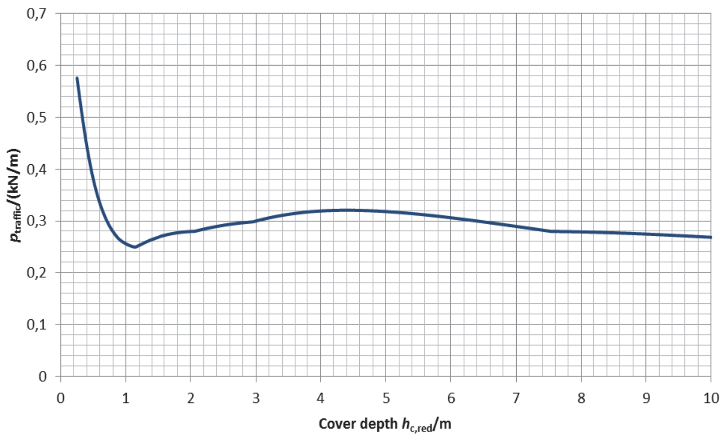

Figure 3. Envelope of the maximum equivalent line load calculated for TDOK 2013:0267, load cases b – n

Cold forming effect on steel yield strength

Based on the principles in the Eurocode an increase in the steel yield strength, as a result of the cold forming when corrugating the steel plates, may be applied. Cold forming effects, calculated using the equation below, may be used for corrugations 150×50 mm and 200×55 mm (or for corrugations with similar size) and should be taken as an average value for the full steel section.

The increased average yield strength f_{ya} may be determined using Equation (1) below, see Ref. [7], used as basis for *EN 1993-1-3* (Ref. [8]).

$$f_{ya} = f_{yb} + 5D_A (f_u - f_{yb}) / W^* \quad (1)$$

Where f_{ya}, f_{yb} and f_u are the same notations as in *EN 1993-1-3*, while D_A is equivalent to n in *EN 1993-1-3*.

W^* is the ratio of centerline length of a flange cross-section of a member in bending, or of the entire cross section of a tensile or compressive member, to the design core thickness (w/t). In the case of the corrugated section, w, can be taken as the typical length of a section consisting of two full arcs and two straight lines, compare Figure 4.

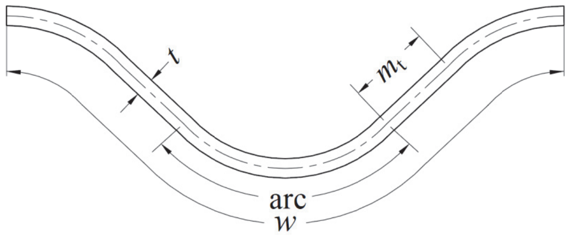

Figure 4. A typical centerline length w of a section of the corrugated culvert steel wall consisting of two full arcs and two straight lines

If the cold forming effect is used in the evaluation of the structural capacity of an existing flexible culvert (SSCB) in Sweden it should be noted that the maximum allowed yield strength used in the evaluation shall fulfil the requirement $f_{\mathrm{uk}} / f_{\mathrm{ya,k}} \geq 1,20$.

Using Equation (1), Figure 5 below show some results for 150×50 mm corrugation for some commonly used steel grades.

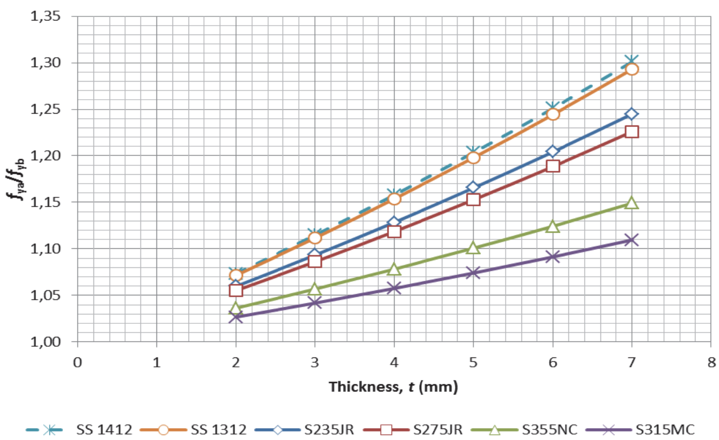

Figure 5. Average yield strength f_{ya} to basic yield strength f_{yb} for common steel types, calculated using Equation (E1) for corrugation size 150×50 mm

Capacity in the ultimate state

According to Swedish regulations verifying the capacity of existing bridge structures should be done using earlier Swedish standards (BBK94/BBK04, Ref. [9], and BSK94/BSK07, Ref. [10] etc.). For the ultimate limit state the expression for *N*/*M* interaction should therefore be taken as:

$$\left(\frac{N_{\mathrm{d,u}}}{\omega f_{\mathrm{yd}} A}\right)^{\alpha_{\mathrm{c}}} + \left(\frac{M_{\mathrm{d,u}}}{M_{\mathrm{u}}}\right) \leq 1,0 \tag{2}$$

where $\omega \cdot f_{yd} \cdot A$ is the buckling capacity of the conduit corrugated wall.

Details regarding this interaction equation N/M and its use in estimating the capacity of an existing flexible culvert can be found in Ref. [2], appendix 7.

3. SWEDISH REGULATIONS

The methodology for estimating the structural capacity of a bridge structure in Sweden include, as mentioned above, 14 live load patterns. The axle and bogie loads in these load patterns are denoted A and B respectively. The bogies have different number of axles, different distances between the axles etc. The methodology include increasing A and B until the design requirement being most critical is met. The structural capacity is described using the A and B values calculated this way.

The evaluation of the structural capacity is done with purpose made software developed by the Swedish Transport Administration, structural data and information from regular inspections in the Swedish Transport Administrations databases.

4. SUMMARY

This paper describes the Swedish Transportation Administration's approach for evaluating the structural capacity of existing flexible culverts. Using the design methodology presented in Ref. [2] as the basic design strategy, the structural capacity is, in the general case, estimated using data for a particular structure available in the Transport Administration's databases. This is done using live load specifically developed for estimating the structural capacity of road bridges, conservative assumptions regarding the backfill soil and an evaluation of the structural integrity gathered at regular inspections.

It should be noted that special cases do occur having for example non-standard designs, extremely low height of cover, severe corrosion damage and other types of structural damages where special investigations are necessary. However, since standard designs meeting specific code requirements have normally been used when designing flexible culverts in Sweden, the approach used by the Swedish Transport Administration has proven to be an effective and viable approach for most of the structures in Sweden.

Acknowledgements

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