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FIELD TEST OF A LARGE-SPAN SOIL-STEEL ARCH WITHOUT STIFFENERS DURING BACKFILLING OPERATIONS

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Abstract

Flexible corrugated steel culverts have been used in engineering for many years, with the first application in 1931. Since that time the popularity of such structures has increased enormously. In recent years soil-steel bridges have become increasingly popular in Europe.

In 2009 a large-span flexible steel structure was built in the storage yard of the ViaCon factory in Rydzyna, Poland. The structure is a low-profile metal arch with a span of 17.7 m and a rise of 5.5 m and it has no additional steel stiffener ribs. This paper describes full-scale field tests of this structure during backfilling operations. The main aim of the field tests was to evaluate the behaviour of the structure during this process. Displacements in the middle of the structure's span and strains in the metal plates were measured. The results of the measurements are presented in the form of graphs and tables.

Key words: full-scale field test, corrugated culvert, backfilling, displacements, strains, internal forces

1. INTRODUCTION

The use of buried corrugated metal culverts as highway bridges is common because corrugated metal is lightweight, low-cost, and relatively easy to handle and install. These flexible structures are typically fabricated by bolting corrugated metal plates together to form the desired curved shape. Large-span structures as a rule are reinforced with stiffener ribs to ensure their proper strength and stiffness.

The behaviour of corrugated metal culverts has been the subject of many studies, with most of the research focusing on this behaviour during and after construction [1 – 3]. Particularly important are investigations of such structures during their setting into the ground [4 – 7] since the displacements and stresses arising then may have a major bearing on their operating safety. This particularly applies to wildlife crossing structures where service loads are negligibly small. Investigations of a wildlife crossing over the A4 motorway [7], in the form of a low-profile large-span arch reinforced with stiffener ribs raised questions about the need for the use of the latter. Therefore a similar structure without any stiffening ribs (Fig. 1) was built and tested on the premises of the ViaCon factory in Rydzyna. The aim of the tests was to determine the stresses in the steel shell and the effect of backfilling on the state of deformations.

Figure 1. View of tested structure

2. DESCRIPTION OF TESTED OBJECT

The tested object was a low-profile SuperCor structure SC-57S with a low-profile arch cross section. Its specifications were as follows:

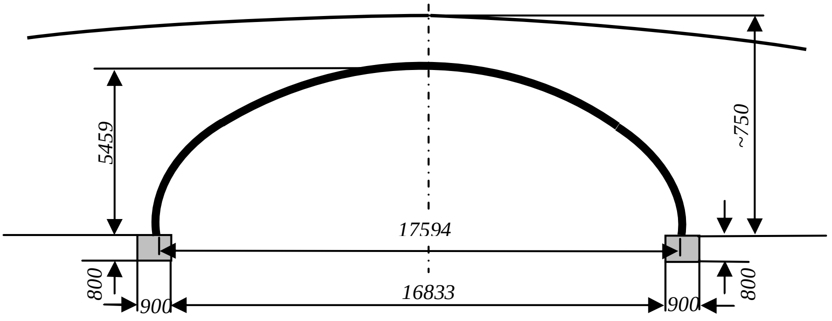
- span – 17.667 m,
- rise – 5.459 m,
- the radius of curvature of crown plates – 13.735 m,
- the radius of curvature of side plates – 3.43 m,
- length – 15.240 m.

A diagram of the structure is shown in Fig. 2.

The specifications of the corrugated plate were as follows:

- corrugation dimensions – 381×140 mm,
- plate thickness – 7.0 mm,
- steel – S315MC.

The cross section of the plate is shown schematically in Fig. 3.



Dimensions in [mm]

Figure 2. Scheme of structure

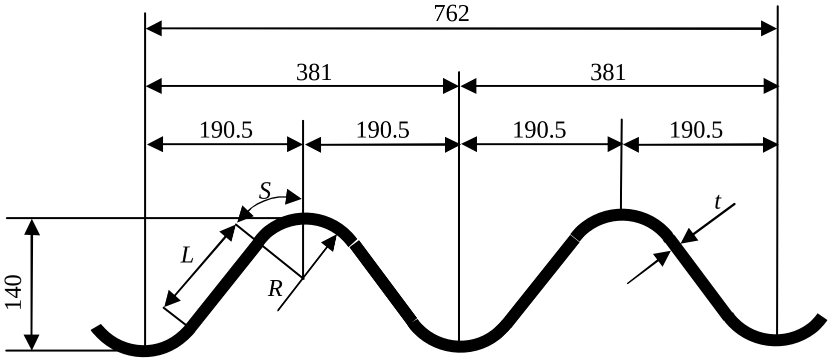


Figure 3. Scheme of corrugation

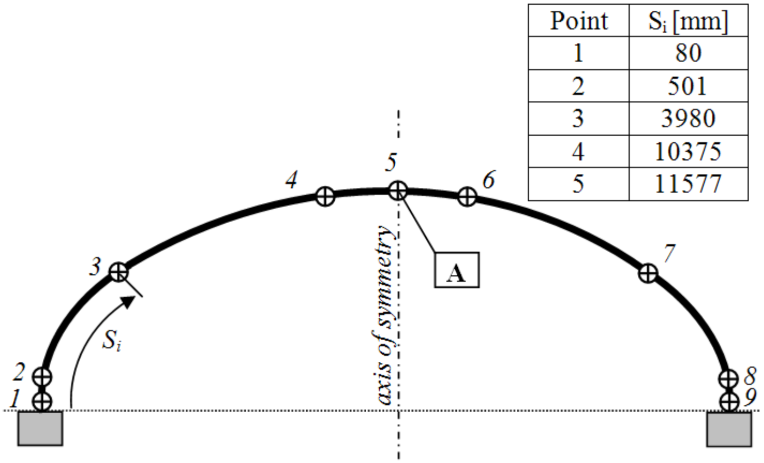
The culvert was founded on two 90 cm wide and 80 cm high concrete strip footings B15 and joined to them via channel sections fixed to previously embedded adhesive bonded anchors.

The structure was buried in sand-gravel mix compacted up to compaction index $I_{Smin} = 0.98$ (acc. to the standard Proctor test). Backfilling was carried out by laying 30 cm thick layers.

3. MEASUREMENT INSTRUMENTATION

Deformations were measured using electric resistance strain gauges (bi-directional strain gauges 1-XY91-6/120 made by HBM) and an HBM strain gauge bridge. The location of the measuring points is shown in Fig. 4. In each of the measuring points strain gauges (bi-directional rosettes) were placed on the corrugation’s ridge and in its trough. Deformations were measured in the circumferential direction and in the longitudinal direction. The details on the arrangement of the strain gauges, the measurement of deformations and the determination of stresses can be found in [6, 7].

High-precision geodesy (total station) was used to measure vertical deformations in the middle of the structure's span (point *A* in Fig. 4).



Point	S_i [mm]
1	80
2	501
3	3980
4	10375
5	11577

S_i [mm] measured from the inside of the culvert

Figure 4. Arrangement of measuring points

3. DETERMINATION OF INTERNAL FORCES

The measured strains were used to calculate the (circumferential and longitudinal) stresses in each of the measuring points. The following steel specifications were assumed for the calculations: Young modulus $E = 206000$ MPa and Poisson ratio $\nu = 0.3$.

Bending moments *m* and .normal forces *n* (perpendicular to the circumferential direction) in the longitudinal cross sections of the shell were determined on the basis of the calculated stresses. The internal forces were calculated from the relations:

$$m = \left(\sigma_{D_C} - \sigma_{G_C}\right)\frac{I_f}{h}, \tag{3.1}$$

$$n = \left[(h-t)\sigma_{D_C} + (h+t)\sigma_{G_C}\right]\frac{A_f}{2h}, \tag{3.2}$$

where: σ_{D_C} and σ_{G_C} – circumferential stresses on the corrugation's ridge and in its trough, respectively; A_f and I_f – respectively the area and moment of inertia of the cross section (fold) per unit width, h – corrugation height, t – plate thickness. The following corrugation specifications were assumed: h = 140 mm, t = 7.0 mm, A_f = 8.867 mm^2/mm, I_f = 21897.45 mm^4/mm.

The fact that all the strain gauges were stuck on the inner side of the culvert was taken into account in relations (3.1) and (3.2).

4. RESULTS

Vertical displacement of point *A* (Fig. 4) for different earth fill levels is shown in Table 1. Figure 5 shows the distribution of bending and axial stresses for several selected earth fill levels.

These test results indicate an increasing upthrust of the steel arch to the maximum value of about 8 cm up until the earth fill level reaches 5.4 m, which corresponds to approximately the arch crown height. As a result of further backfilling the upthrust gradually decreases and at the final earth fill level it becomes zero.

The maximum absolute stress during backfilling did not exceed 227 MPa, which amounts to 72% of the minimum yield stress of the culvert steel.

The extreme bending moment and axial force values were obtained when backfill layers were laid above the arch crown. They amounted to respectively: $m = -53732$ Nmm/mm for a backfill height of 5.7 m and $n = -724$ N/mm for a backfill height of 6.3 m. Further backfilling up to the final soil surcharge resulted in a reduction of the internal forces.

Table 1. Vertical displacements at culvert crown (point *A*).

Layer number	Layer thickness [cm]	Total backfill height [cm]	Vertical displacement of point A [cm]
0	0	0	0
7	30	210	1.3
8	30	240	1.9
9	30	270	2.4
10	30	300	3.0
11	30	330	3.4
12	30	360	3.9
13	30	390	4.8
14	30	420	5.6
15	30	450	6.1
16	30	480	6.8
17	30	510	7.7
18	30	540	8.0

19	30	570	7.4
20	30	600	5.8
21	30	630	4.5
22	30	660	3.0
23	30	690	2.0
24	30	720	–
25	30	750	0.0

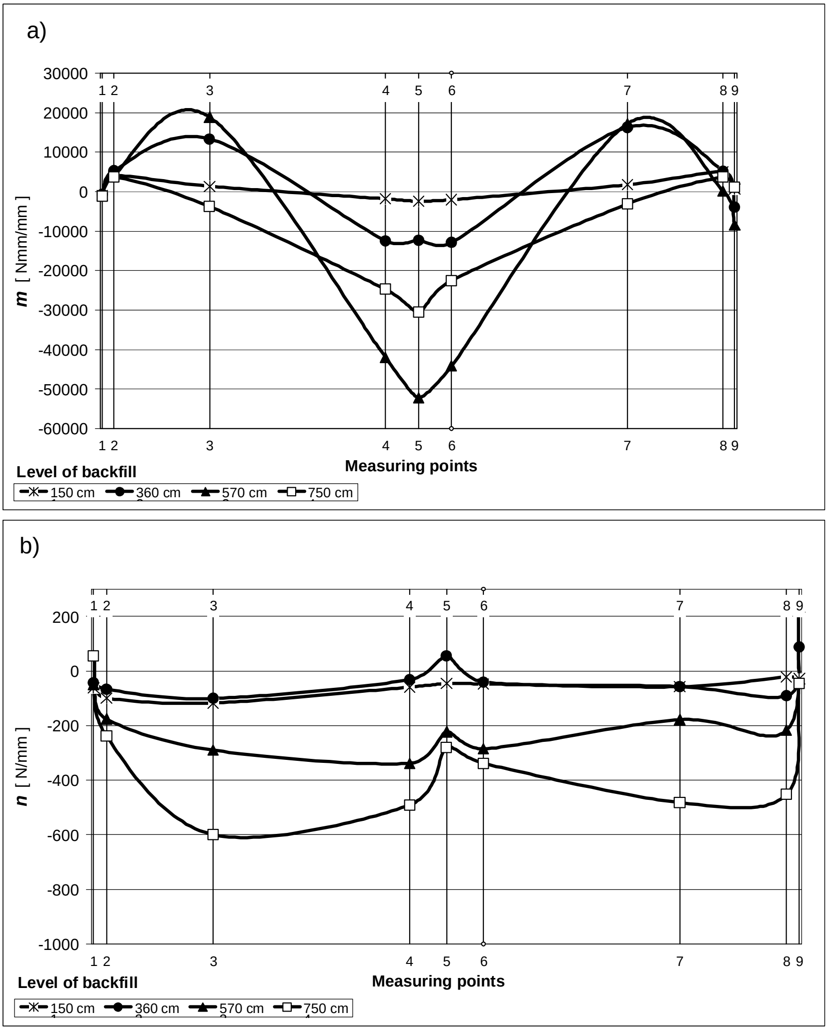


Figure5. Internal forces for different levels of backfill: a) bending moments, b) normal forces.

A comparison of the above test results with the ones reported in [7], shows that culverts of this type do not need to be reinforced with stiffener ribs in order to be used as animal crossing structures. The stability of the tested structure has been confirmed by displacement and deformation measurements carried out at different time intervals after its construction.

The authors intend to present the results of the latter measurements in another paper.

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Streszczenie

Podatne przepusty z blachy falistej są stosowane w inżynierii od wielu lat. Od 1931 r., kiedy to po raz pierwszy je zastosowano, popularność takich konstrukcji niezwykle wzrosła. W ostatnich latach mosty stalowo-ziemne zyskały również na popularności w Europie.

W roku 2009 podatna konstrukcja stalowa o dużej rozpiętości została wybudowana na placu magazynowym fabryki ViaCon w Rydzynie w Polsce. Konstrukcja to nisko-profilowy metalowy łuk o rozpiętości 17,7 m i wysokości 5,5, bez dodatkowych stalowych żeber usztywniających. Ta praca opisuje pogłębione testy terenowe tej konstrukcji podczas zasypywania. Głównym celem prób terenowych była ocena zachowania konstrukcji podczas tej operacji. Dokonano pomiaru przemieszczeń pośrodku rozpiętości konstrukcji oraz odkształceń i naprężeń metalowych blach. Rezultaty pomiarów zostały przedstawione w formie wykresów i tabel.

Słowa kluczowe: pogłębione badania terenowe, przepust z blachy falistej, zasypywanie, przemieszczenia, naprężenia, siły wewnętrzne