INFLUENCE OF RESULTS OF TESTING ON MANNER OF CONSTRUCTING CULVERTS AND ANIMALS PASSAGE MADE AS BURIED FLEXIBLE STEEL STRUCTURES

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Abstract

A large number of tests of modern flexible soil-steel structures with corrugated steel plates made, among others, with the participation of the author of this paper leads to a better understanding of their behavior under static, dynamic and fatigue loads.

On this basis, methods of calculation and building of these structures are still being improved.

These aspects contribute to increasing the efficiency of flexible soil-steel structures with corrugated plates in terms of capacity, durability, and economics of these solutions. Too little attention, however, is given to taking into account the results of this type of research and testing in constructing and equipping suitable animal crossings. This is important for these objects in terms of their stiffness, dynamics - vibration, noise, etc.

These issues are discussed by the authors in this paper.

Key words: flexible steel structures, corrugated steel sheet, test results, culverts, animal passages.

1. INTRODUCTION

Different applications of corrugated steel structures to construct culverts and animal passages proved that such structures can be used to create aesthetic and environmental friendly structures. Additionally this is true because of their many advantages from both the technical and economic point of view [1], [3], [5], [6], [11], [12] and [15].

Therefore, a number of various tests of corrugated steel pipes and structures have been performed with the author as the head of a group of researchers. Most of them were done for the ViaCon Group e.g. [2], [19], [20].

Some of the conclusions from the first part of testing was summarized in the paper [16] for the first edition of this Conference (I European Conference on
Buried Flexible Steel Structures in Rydzyna 2007) and in [17]. The present paper is based on additional testing, new calculations and analysis.

2. DESCRIPTION OF THE TESTS

2.1. Test No 1 – Soil-shell structure Multi Plate type

A 14.40 m long multi-plate pipe of GL4 type whose cross-section is shown in Fig. 1 was tested. The structure was made from roll-formed corrugated plates made of Fe 360BFN steel (in accordance with European Standard EN 10025). The wall thickness was $t = 3.75$ mm.

A load configuration simulating the loading from rolling stock was chosen for the tests.

While each of the load systems was being activated, measurements of several quantities reflecting the changes taking place in the tested structure were being recorded [13], [22]:

- displacement measurements,
- strain measurements,
- earth pressure measurements,
- fatigue tests, etc.

In Fig. 2 shows an example diagram of strains (stresses) of Multi Plate steel shell under fatigue loading (from 0 to 500 thousand of cycles).

The following conclusions can be drawn from this test:

1. The unit strains (stresses), displacements and earth pressure values obtained for the tested culvert are rather low.

2. The tested structure turned out to be remarkably rigid. The main load-bearing element of such structures is the soil backfill and the steel casing provides merely protection.

3. The measurements made under fatigue load (uniformly cyclically changing loads) have shown that for all the tested parameters their values
change as the number of cycles increases and this is an upward trend. A preliminary analysis of this phenomenon shows that it is not the steel casing pipe but the soil backfill which is subject to fatigue, as a result of which the top point of tested culverts displaces vertically downwards.

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2.2. Test No 2 – Soil-shell structure Box Culvert type

Parameters of tested structure are: span 3,50 m; rise 1,40 m; thickness of steel plate 5,00mm, corrugation 150x50 mm, type of profile – Box (open shape) with concrete continuous footing. The structure was reinforced by means of ribs made of steel plates located on the top section of perimeter (in crown).

The quality of the steel material in the structure met the requirements of the European Standard EN 10025 with minimum yield stress of 235 MPa. The bolts were M20 (20 mm) with minimum tensile strength of 830 MPa.
The backfilling material was a well-graded gravel with maximum grain size 32mm. The backfilling was placed in layers with maximum thickness before compaction of 0.30 m. The required degree of compaction was 97 % Standard Proctor density. Soil cover depth over structure was 0.60 m. Instrumentation consisted of 22 electric resistance strain gauges in 11 places with a strain gauge on the top and bottom of the corrugation and 3 induction gauges used for vertical and horizontal displacement measurements.

The diagram of the tested structure with measurement points is presented in Figure 3.

![Fig. 3 Tested Box Culvert structure with places of gauge installation](image)

Research in this matter has been carried to test various aspects: e.g. fatigue test, test without and with geogrid, destroying test. Example results of displacements of the tested structure are shown in Figure 4.

Many conclusions obtained during testing of the soil-shell box structures are similar to those specified in point 2.1.

Comparing the results with and without geogrid suggest an increase of the bearing capacity of culverts with overburden retrofitted with geogrid [2].

![Fig. 4 Displacements measured with induction gauges](image)
2.3. Test No 3 – Corrugated steel pipe – HelCor type

A corrugated pipe was tested, with a diameter of 800 mm, length \( L = 8.00 \) m and steel wall thickness \( t = 2.0 \) mm.

At the same time tests were performed of a pipe made of PEHD with the same diameter.

Both pipes was located in the soil backfilling.

Steel culvert Helcor type during testing is presented in Figure 5.

![Fig. 5 Steel culverts HelCor type during testing](image)

Example result of bending moments obtained by gauges in the steel plate of the tested structure is presented in figure 6.

![Fig. 6 Example result of testing - bending moments obtained by stain gauges in the steel plate of HelCor pipe](image)

Many conclusions can be drawn from the above-mentioned tests, some of them are presented below.

Asymmetric loading and heterogeneity of the soil backfilling has an impact on the asymmetrical deformation of the culvert geometry and distribution of internal. We observed the growing increase in lasting deflection is the result of greater soil compaction after each load and fatigue load application during testing at layer \( h = 0.60 \) m (impact load history).

The manner of internal forces distribution depends on the size of external loads.
2.4. Test no 4 – Corrugated steel arch structure – founded on a corrugated flexible steel plate and rigid concrete blocks

Two arches made of HelCor pipe were used for the test. Parameters of each structure were: 2.50 m in span, 1.25 m in rise and length 4.00 m of each structure. Both were made of 2.5 mm thick steel plate with 100 x 20 mm corrugation. Steel plate was protected by hot-dip galvanization with the thickness of 42µm. One structure is placed on the rigid concrete foundation, and second on the corrugated steel plate. The backfilling material was well-graded gravel with maximum grain size of 32 mm. The backfill was placed in layers with thickness of 0.20-0.40 m. The required degree of compaction was 98% Standard Proctor density. Soil cover depth over structure was 0.60 m.

Figure 7 presents the cross section of two tested structures, and Figure 8 overview of the structure to be tested in natural scale.

Fig. 7 Tested structures: a) cross section shows construction on the rigid foundation, b) cross section of construction placed on the corrugated flexible foundation
Example of arch crown vertical displacements results are presented in figure 9 [18].
Based on the testing and analysis the following conclusions can be drawn from a scientific, cognitive, as well as practical point of view:

1. The tests of HelCor soil-structure on the rigid and flexible foundations (in this case concrete and corrugated sheets respectively), once again pointed to the large reserve of their capacity, the same was true for shells and both types of foundations.

2. Experimental results indicate full compliance of the obtained results for both models based on rigid and flexible foundations (some of the differences recorded during the study have a negligible impact on the behavior of the structure during operation).

2.5. Test no 5 – Field tests of a railway box culvert

The tested object is a soil structure with a coating made of corrugated sheets SuperCor SC-33B. It is located on the modernized railway line E-30 at km 10.330 on the Wegliniec - Legnica line near the village of Dolna Dłużyna.

The basic geometrical parameters of the object are: horizontal light - 7.41 m, vertical light - 1.68 m, the total length of the top object - 15.47 m, the total length of the bottom object - 19.12 m, average height of soil cover – 1.65 m, the angle of crossing is 90°.

The main structure of the tested object is composed of corrugated steel plates SuperCor, connected to the structure made of of high-strength bolts. The fasten-
ing structure, made of 0.55 m-thick reinforced concrete slabs, which was designed as a support for the composite coating.

General view of tested structure is presented on figure 10.

![General view of tested structure](image1.jpg)

**Fig. 10 General view of tested structure SuperCor SC-33B during testing**

Displacement measurements were performed using inductive gauges with automatic recording of results. Tests with "rolling" (rail locomotive) load were intended to check whether there is horizontal or vertical movement of the structure due to moving loads and its relevance. Furthermore, the test was carried out to demonstrate that the structure returns to its original shape when the train passes.

![View from the bottom of the structure on test equipment](image2.jpg)

**Fig. 11 View from the bottom of the structure on test equipment**
A few exemplary results of vertical and horizontal displacements from railway (under locomotive) load are presented in table 1 (J1, ….. J6 – number of measurements points).

Table 1. Runs of the locomotive from Węgliniec along the axis of the bridge – vertical and horizontal displacements

<table>
<thead>
<tr>
<th>Name</th>
<th>Time</th>
<th>J1</th>
<th>J2</th>
<th>J3</th>
<th>J4</th>
<th>J5</th>
<th>J6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>0.28</td>
<td>0.24</td>
<td>0.34</td>
<td>0.36</td>
<td>0.01</td>
<td>0.30</td>
<td>0.88</td>
</tr>
<tr>
<td>at x =</td>
<td>- -</td>
<td>0.00</td>
<td>0.00</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
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<td>0.28</td>
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<td>at x =</td>
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</table>

On the basis of this test of the structure quite a few conclusions were obtained:
1. Test results are "significant" and show the movement of the soil-shell structure during braking due to unbalanced load rolling. This may be important in the case of railway facilities where braking occurs usually in one direction (trains with locomotives).
2. However, registered displacements during tests are relatively small.

2.6. Test no 6 – Theoretical analysis of culvert structures for high-speed railways

Due to the progressive implementation of high-speed railways an appropriate analysis of the impact of these loads on corrugated steel culverts was done. A train load with speed up to 200km/h was analyzed first. The analysis of response of this type of structure to the increased load mainly from the point of view of dynamic loads was based on theoretical considerations, as well as performed on the natural scale objects.

The analyses of the actual values of deflections obtained from operational tests of several objects of this type (real measured deflections vary from 1.81 mm to 0.45 mm) indicate that actual recorded deflections are much lower than allowed by appropriate specifications.
For tested objects, these values fit in the range from $L/1800$ up to $L/20000$ [mm] which is much lower than those stipulated in norms ($L/600$) for different countries and the European Union.

This follows the fact that an essential element in the carrying of loads in these structures is soil backfill with a high suppression factor for such heavy soil-shell structures.

3. RESULTS OF TESTS OF THE CONSTRUCTION TYPE FOR CULVERTS AND ANIMALS CROSSINGS

The conclusions of these tests are presented in Section 2 of the paper and in reports from research [19], [20] and literature [2], [4], [10], [13].

Results of this study led to a change in the approach to the design, construction and maintenance of soil – steel shell structures:

1. Provided tests showed that the main load-bearing element of such structures is the soil backfill and the steel casting provides merely protection.

2. Therefore, optimal parameters of the soil backfill have been developed (backfill material and compaction parameters). During testing we observed that the unit strains (stresses), displacements and earth pressure values are rather low. The tested structure turned out to be remarkably rigid. Analysis of fatigue phenomenon shows that it is not the steel casing pipe but the soil backfill which is subject to fatigue, as a result of which the top point of tested culverts displaces vertically downwards.

Thanks to this, it was concluded that structures of this type are safe and carry large loads [14]. Thus we have shown that it is possible to further increase [8] the span of a structure (Figure 12) and increase live loads. Based on this research the use of these structures for large loads on railway lines had become more popular.

3. Performed analysis of the operational durability and anticorrosion of steel flexible structures indicated that adequate durability was ensured. Zinc anticorrosion protection is satisfactory for typical service environmental conditions. Trenchcoating is recommended for difficult environmental conditions only.

4. Experimental results indicate full compliance of results obtained for both structures on rigid and flexible foundations. Therefore the use of massive concrete foundations in such structures is not necessary and therefore uneconomic.

5. Performed tests of corrugated steel culverts in natural scale with the use of a geogrid in overlaying layers of soil backfill decreases displacement of such structures. Based on this conclusion it is possible to reduce the thickness of backfill (eg. for forest roads, paths etc.) and thickness of pavements.
6. High resistance of flexible pipes and structures to dynamic loads has been noticed. It is caused by soil acting as a buffer distributing loads and dampening dynamic action. Therefore, these structures are well-suited to be used as animal passages [21].

7. We have not noticed any effects of vibration and noise during tests. Based on this, this type of structures started to be widely applied as animal passages crossing roads and railways.

Fig. 12 Example of implementation of corrugated steel structure with long span as an animal passage over highway (A2)

5. SUMMARY

Full scale testing of structures will help us to optimize and design safer and more economic structures. It is of importance to obtain high quality test results when designing flexible structures with minimum backfilling for heavy live loads (roads and railways).

In the previous part of the paper we described how some results of performed tests influenced the manner of constructing culverts and animals passages made as buried flexible steel structures.

The results of these tests also allowed to develop appropriate recommendations for the design of this type of structures [9].

However, these recommendations were based on early results of research and do not include the latest research results and analysis. Therefore, among other, they need to be updated taking into account suggestions contained in this paper.
REFERENCES


Streszczenie

Duża liczba testów nowoczesnych podatnych konstrukcji gruntowo-stalowych z falistej blachy stalowej przeprowadzona, między innymi, z udziałem autora tej pracy, prowadzi do lepszego zrozumienia ich zachowania pod obciążeniem statycznym, dynamicznym i zmęczeniowym.

Metody przeprowadzania obliczeń i budowy tych konstrukcji są ciągle ulepszane na tej podstawie.

Te czynniki przyczyniają się do zwiększania osiągów podatnych konstrukcji gruntowo-stalowych z blach falistych pod względem wytrzymałości, trwałości i opłacalności. Zbyt mało uwagi, jednakże, poświęca się uwzględnianiu rezultatów badań i testów tego typu podczas budowania i wyposażania odpowiednich przejść dla zwierząt. Te czynniki są istotne dla takich obiektów z punktu widzenia ich sztywności, dynamiki, drgań, hałasu etc.

Te kwestie zostały omówione w tej pracy przez autorów.

Słowa kluczowe: podatne konstrukcje stalowe, stalowa blacha falista, wyniki testów, przepusty, przejścia dla zwierząt