GENERAL CONCLUSIONS BASED ON THE TESTING OF VARIOUS TYPES OF CORRUGATED FLEXIBLE STRUCTURES IN LABORATORY IN NATURAL SCALE

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Abstract

Number of various tests of corrugated steel structures and pipes have been performed over 100 years of history of those. Not very many of those were full scale tests performed in fully controlled laboratory conditions under cyclic loads. This paper presents 10 years experience of full-scale in laboratory tests of corrugated steel structures and pipes with additional remarks to corrugated plastic pipe tests. All tests discussed included both static and dynamic loads with loads cycles ranging from 500 000 to 1000 000 cycles. General conclusions from these tests are presented at the last chapter.

Key words: corrugated steel structure, corrugated steel pipe, tests, laboratory, full-scale

1. INTRODUCTION

Corrugated buried flexible steel structures known as soil-steel structures are commonly used to build culverts and small bridges [4], [23], [3]. The soil-steel bridge name comes from soil-structure interaction in carrying the loads [25].

Soil-steel interaction brings huge load Bering capacity to those structure and this hale been very well documented by number of test e.g. [18], [13], [26], [27], [33], [15]. Although these types of structures were initiated in 1896 in USA and number of interesting reseach has been conducted yet still there are number of unknown factors and “sleeping reserves” in these types of structures. Therefore from 1997 a series of full scale tests on test stand in Roads and Bridges Research Institute have been started. Five tests of flexible pipes and structures have been completed so far. All of them were commissioned by Via-Con Polska. General conclusions from these test are presented in this paper.
2. DESCRIPTION OF DESTRUCTIVE TEST STAND

The Destructive Test Stand (DTS) called also Dynamic and Fatigue Test Stand (figure 1) has the form of an 80 m long and 12 m wide reinforced concrete foundation with a system of anchors, a testing bay, and a steel frame serving as a support structure for hydraulic load generating equipment. The stand is outfitted with a system of Schenck hydraulic servos with a modern control and feed system ensuring full control over the excited loads in real time, also in the case of dynamic loads.

The system comprises of:

- two servos with the maximum exciting force of 1000 kN and the maximum shift of 400 m which can excite dynamic loads of ± 800 kN, equipped with displacement and force gauges having the accuracy of 0.1% of the full range;
- one servo with the maximum exciting force of 250 kN and the shift of 500 mm which can excite dynamic loads up to ± 200 kN, equipped with gauges measuring displacements and forces with the accuracy of 0.1% of the full range, for higher frequency (1-100 Hz) dynamic tests;
- a hydraulic feeding unit of 130 l/min. capacity with an automatic air-cooling system;
- a Hydropuls S-59 electronic system which allows one to control independently two servos on the basis of the measured in real time values of piston pressure and travel. It is also possible to subordinate the excitation program to any gauge (e.g. a displacement gauge) not connected with the servos.

1 – steel frame (load up to 16 000 kN)
2 – two servos (maximum force 1 000 kN, stroke 400 mm)
3 – servo (force 250 kN, stroke 500 mm) for higher frequency (1-100 Hz) tests
4 – 130 l/min-capacity hydraulic engine with an automatic air cooling system
5 – Hydropuls S-59 electronic system enabling the independent control of the two servos on the basis of the measured, in real time, piston thrust and protrusion
6 – measuring gauges: strain gauges, displacement induction gauges (100, 50, 20 mm), temperature gauges
7 – force gauges which can measure forces up to 2 x 2 000 kN and 2 x 200 kN
8 – UPM100 measuring device enabling the measurement of 100 quantities
9 – two twelve-channel DMC 9012A digital amplifiers for dynamic tests
10 – Macintosh computer with software controlling the UPM 100 and DMC9012A devices

Figure 1. Outfit of dynamic and fatigue test stand
A data collection and acquisition system makes it possible to measure several quantities describing the course of changes in, for example, displacements, strains, stresses, forces, weights, moments and temperatures, that occur in the tested structures.

The bridge test stand together with the necessary back-up facilities form a complex for the complete testing of whole natural scale engineering structures and their particular structural components.

3. SETTING OF TESTS WITH SOME DETAILS FROM RESEARCH CONDUCTED

Following full scale tests of flexible pipes and structures have been performed so far at the Destructive Test Stand in Żmigród:
- Corrugated steel plate structure Multi Plate 150 with pipe-arch shape
- Corrugated steel plate structure Multi Plate 150 with Box Culvert shape
- Corrugated steel pipe with round shape and 80 cm diameter, type HELCOR,
- Corrugated plastic pipe diameter 80 cm, type Pecor Optima

Pending tests are comparative test of flexible half-pipe arch placed on corrugated steel and concrete foundations. The next to come is testing of flexible corrugated aluminum structures. Figure 2 presents schematic layout of performed tests.

Figure 2. Test set up – with shell – soil steel structures
Figure 3 presents pictures from conducted tests.

a) Pipe-arch Multi Plate 150, b) Box Culvert Multi-Plate 150, c) corrugated steel pipe Helcor and plastic pipe Pecor, d) preparation for comparative tests of Helcor pipes on flexible and rigid foundations

4. SOME SELECTED RESULTS FROM FULL-SCALE TESTS

Full results from tests were presented in technical reports [17], [18], [24]. Analysis of those tests have been published in several papers in Poland and abroad [11], [12], [13], [16], [19], [20], [26], [28], [36]. A short summary of the results is presented below.

4.1. Results from testing of pipe-arch MP 150

Table 1 presents earth pressure values and their distribution along circumference of tested structure’s shell under fatigue loading for 100,000 and 500,000 cycles for an overburden depth of 1.0 m.
Table 1. Values of earth pressure around pipe-arch

<table>
<thead>
<tr>
<th>MULTIPLATE; FATIGUE LOADS; OVERBURDEN = 1.0 m.</th>
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<tbody>
<tr>
<td>EARTH PRESSURE CELLS</td>
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<td>cycles</td>
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<tr>
<td>N = 5 000 cycles</td>
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<td>Max.</td>
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<td>range</td>
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<td>N = 100 000 cycles</td>
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<td>Max.</td>
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<td>range</td>
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<td>N = 500 000 cycles</td>
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MULTIPLATE; Fatigue Loads 0-500 000 cycles; Overburden 1.0 m. Average cycles, maximum and minimum.

STRAIN GAUGE T1A

Figure 4. Example of stresses in the Multi Plate pipe-arch under fatigue loading
Figure 4 shows diagram of stresses during fatigue testing of Multi Plate structures. Stresses was registered by strain gauges placed in the crown of the steel shell.

Figure 5 presents of diagrams of vertical displacement of the crown of Multi Plate steel shell (top point) under fatigue loading (for 5, 50, 100, 300, 500 thousand of cycles).

4.2. Results from testing  Box Culvert MP150

Figure 6 presents schematic layout of strain gages and induction meters around the corrugated box MP150.
General conclusions based on testing of various types of corrugated flexible structures…

Figure 7 presents vertical deformations of the crown (point 6) for three static loads with and without geogrid placed above the culvert in the cover.

![Static loads - inductive gauge No 2](image)

**Figure 7.** Vertical displacement of culvert measured by inductive gauges for three static load cases

Figure 8 are shown example of vertical displacements under destructive load for Box Culvert structures (for three inductive gauges).

![Example of vertical displacement under destructive load for Box Culvert MP 150 structure](image)

**Figure 8.** Example of vertical displacement under destructive load for Box Culvert MP 150 structure
4.3. Tests results for corrugated steel pipe Helcor and plastic pipe Pecor

Both pipes were loaded at the same time as they were placed parallel to each other in the backfill, as presented in Figure 9.

![Figure 9. Arrangement of earth pressure cells and inductive meters](image)

Figure 9 presents vertical deformation of the crown of corrugated steel for two loads cycles one after another.

![Figure 10. Displacement diagram of I5 inductive gauge for load p<sub>max</sub> = 143.1 kPa](image)
Figure 11 shows bending moments [28] from live loads at various depth of cover and load levels for corrugated steel pipe Helcor.

![Diagram showing bending moments](image1)

Figure 3. Bending moments in the wall of HELCOR pipe

Figure 12 shows diagram of vertical displacements during fatigue testing of Pecor Optima pipe. Stresses were registered by strain gauges placed in the crown of the plastic pipe.

![Diagram showing vertical displacements](image2)

Figure 12. Example of vertical displacement of Pecor Optima plastic pipe (top point) under fatigue loading
4.4. Pending comparative test of flexible corrugated arch placed on flexible and rigid foundations

Currently Roads and Bridges Research Institute performs comparative tests of behavior of corrugated steel pipe placed on corrugated flexible foundations and rigid concrete foundations. These tests are oriented to show different earth pressure distribution around the pipes and under foundations as well as compare the stress values of the steel pipe. The aim is to prepare ground for designing of flexible foundations. A separate paper is discussing the mentioned research.

4.5. Preparation Works for testing corrugated aluminum box

In coming months Roads and Bridges Research Institute will perform a load bearing capacity test on corrugated aluminum structure. The aim is to verify the load capacity under static and dynamic loads.

5. SUMMARY: GENERAL CONCLUSIONS

1. High resistance of flexible pipes and structures to dynamic loads has been noticed. It is caused by soil acting as buffer distributing the loads and muffling the dynamic action. Therefore these structures or pipes are very good to be used also under railway loads with high speeds.
2. Unit strains recorded were very small even if the loads exceed standard loads. Also earth pressure on the top of the structures is relatively low.
3. All tested structure have very high relative stiffness of soil-structure composite. Plastic pipes surrounded by soil are less stiff than steel pipes placed in soil. Soil is the main load carrying element.
4. Cycling loads show increase of recorded values with increased number of cycles and indicate fatigue of soil around the structure. Small downwards deformations of the crown occurred. It may be also attributed to horizontal displacements of supporting walls of the test bin.
5. Reserves in load bearing capacity and fatigue resistance show that with appropriate design they can be put in service under highway and railway loads for a long time.
6. During tests a decrease of increment increase of residual deformations followed by subsequent loading was observed. This is attributed to increased compaction of soil surrounding the flexible pipe or structure.
7. Presence of geogrid in overlaying layers of backfill (in the cover of the pipe or structure) decreases downwards deformation of the flexible pipe or structure. The decrease level is different for static and cyclic loads. It
indicates that there’s no need to build so called’’ transfer concrete panel’’ which are sometimes design over flexible structures.
8. A damage of flexible structure was only possible under direct load placed onto the steel shell without any cover. It reflects that soil-structure interaction is a key for performance of these type of structures or pipes.
9. Tests results can be used for many analysis of flexible structures leading to improve their performance and design.
10. Further tests are necessary to understand and describe working mechanism of soil-steel structures and subsequently fine-tune the design methods. Special challenge is for long-span structures and design of foundations. We can expect to break span limits for these kinds of structures in coming years based on performed full scale tests.

6. REFERENCES


18. WYSOKOWSKI A., KORUSIEWICZ L., KUNECKI B.: Sprawozdanie z wykonańia badań dla konstrukcji przepustów w systemie MultiPlate i z rur DV/Arot Optima i HelCor, część I: MultiPlate, część II: Rury DV/Arot Optima i HelCor, Instytut Badawczy Dróg i Mostów, Żmigród – Węglewo, czerwiec 1999.


25. POTAPOW A. S.: Doświadczenie z budowy i użytkowania metalowych rur falistych pod nasypami dróg (Изучение опыта строительства и работы металлических гофрированных труб под насыпями дорог (Заключительный отчёт)), ЗАО СИБЦНИИТ, Т-2002-03, Nowosybirsk 2002.


GENERALNE WNIOSKI Z BADAŃ LABORATORYJNYCH KONSTRUKCJI I RUR PODATNYCH ZE STALOWYCH BLACH FALISTYCH WYKONANYCH W SKALI NATURALNEJ

Streszczenie

W ciągu 100 letniej historii wykonano wiele badań rur i konstrukcji z blach falistych. Niewiele z nich wykonano w skali naturalnej i kontrowelonych warunkach w zakresie obciążeń dynamicznych. W ref. ten referat prezentuje 10 –letnie doświadczenia badań nad konstrukcjami i rurami z blach falistych w skali naturalnej z dodatkowymi uwagami na temat badań rur podatnych z rur z tworzyw sztucznych. Wszystkie badania obejmowały obciążenia cykliczne w zakresie od 500 000 do 1000 000 cykli. Generalne wnioski z badań zestawione są w ostatnim rozdziale referatu.

Słowa kluczowe: konstrukcje podatne z blach falistych, rur podatne z blach skalistych, badania w skali naturalnej, badania laboratoryjne