A R C H I W U M   I N S T Y T U T U   I N Ż Y N I E R I I   L Ą D O W E J
Nr 23 ARCHIVES OF INSTITUTE OF CIVIL ENGINEERING 2017

DETERIORATED STEEL CULVERT UNDER STATIC LOADING[1]

Bartłomiej KUNECKI*, Leszek JANUSZ*, Leszek KORUSIEWICZ**
*) PhD, ViaCon Company
**) PhD, Wroclaw University of Technology

The paper describes full-scale tests of a 7,25 m long corrugated steel pipe with a diameter of 1.40 m. The corrugation pattern was 125×26 mm and the steel was 2 mm thick. The backfill height over the pipe crown was 0,5 m. The deterioration of the tested steel pipe was simulated by removing a part of its bottom. Strain gauges and optical prisms were installed on the metal surface to determine the stresses, internal forces in the metal shell and additionally its deformation. The results of the measurements are presented as graphs and tables. The main goal of the full-scale tests was to assess the performance of the deteriorated steel pipe subjected to static loads and to evaluate the changes in the distribution of the internal forces, caused by the increasing corrosion of the bottom part of the tested pipe.

Key words: Full-scale test, Corrosion, Internal forces, Deformation, HelCor

1. INTRODUCTION

Buried metal structures made of corrugated steel sheets are increasingly commonly used in different branches of industry – most commonly as culverts under traffic routes. Many of such structures carry watercourses through road or railway embankments and so the bottom part of their steel shell is highly exposed to corrosion. In order to ensure their long service life various anticorrosion protections, such as zinc coatings or additional paint or polymer coatings, are used. But corrosion is unavoidable and after an appropriately long time it can lead to the deterioration in the performance of the structure. The rate of corrosion of the coatings can substantially increase due to abrasion (the degradation of the structure's surface and edges by the rapid flow of water and the materials carried by it) or to the salinity of the water flowing off the road. Examples of research on durability of compliant structures made of corrugated steel sheets,

[1] DOI 10.21008/j.1897-4007.2017.23.14

including the relevant bibliography, can be found in El-Taher & Moore (2008) and Janusz & Madaj (2009).

The aim of this paper was to assess the effect of advancing corrosion loss processes on the behavior of compliant structures (culverts) under static load.

2. TESTED STRUCTURE

Tests were carried out on a full-scale culvert built specially for test purposes (Figure 1). A 7.25 m long steel (S250GD, minimal yield point R_e = 250 MPa) HelCor pipe 1.4 m in diameter constituted the shell. The 2 mm thick sheet's corrugation was 125 × 26 mm, as shown in Figure 2. The pipe was buried in soil the specifications of which can be found in details in Korusiewicz (2015). The backfill height above the pipe crown (the soil surcharge) amounted to 0.5 m. The backfill was laid in 25 ÷ 30 cm thick layers and compacted in accordance with the procedures proper for such structures.

Figure 1. View of tested culvert

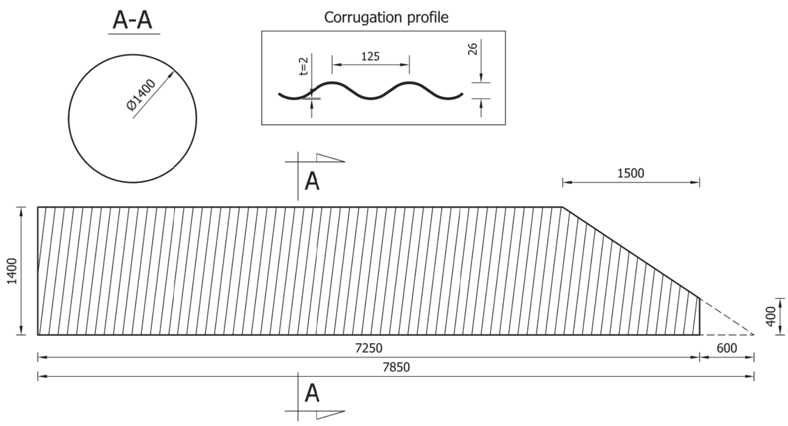

Figure 2. Geometry of the tested culvert (dimension in millimeters)

Strain gauges and optical prisms were installed in the central part of the pipe, as shown in Figure 3. The measured strains were used to determine the stresses and internal forces in the steel shell and measured displacements were used to determine the deformed shape of the pipe.

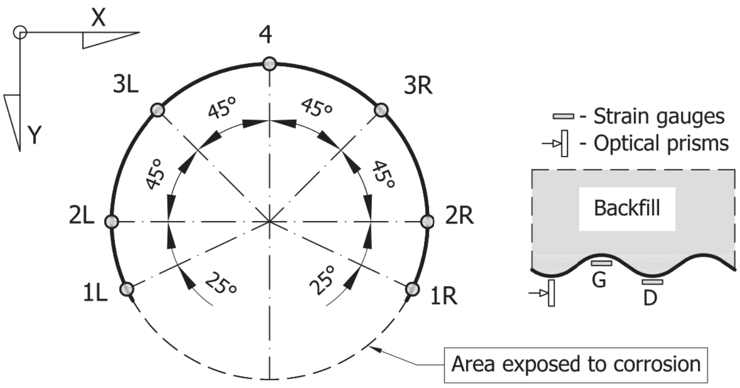

Figure 3. Schematic showing locations of strain gauges and optical prisms

The effect of corrosion was modeled as a surface loss (a puncture in the sheet) in the bottom part of the shell, by cutting out uniformly spaced holes, amounting to 24% and 48% of the assumed surface area subject to corrosion (Figure 4).

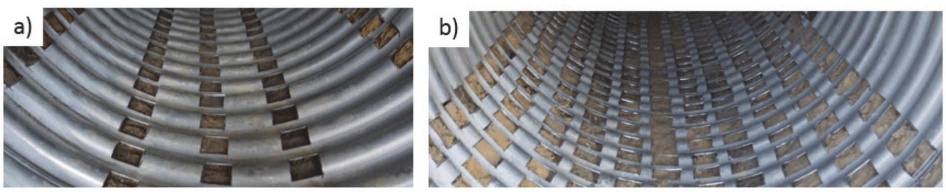

Figure 4. Simulation of material loss caused by corrosion: a) loss amounting to 24% of shell bottom surface, b) loss amounting to 48% of shell bottom surface

The test program was complex; nevertheless, the following three stages can be distinguished in it:

Stage 1 – tests of the shell at 0% corrosion of the bottom,

Stage 2 – tests of the shell at 24% corrosion of the bottom,

Stage 3 – tests of the shell at 48% corrosion of the bottom.

At each of the stages, the culvert was loaded by placing steel sheet coils on it (in its central part) − Figure 1. The load was applied symmetrically (the load axis coincided with the vertical axis of the pipe) - Figure 5. The weight of the steel coils was transferred to the top surface of the backfill via a system schematically shown in Figure 5 in order to simulate the load of one vehicle axle (P = 100 kN) exerted on the culvert. The scheme of one vehicle axle was adopted in accordance with Polish Standard PN-85/S-10030 without considering the additional uniformly distributed load as well as the dynamic factor.

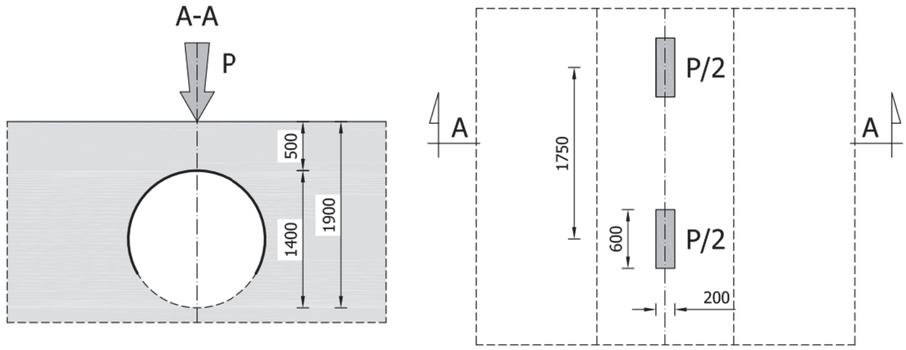

Figure 5. Culvert loading configuration (dimension in millimeters)

3. TEST RESULTS

For reasons of space, only the changes of the internal forces and displacements in the steel shell under the symmetric load P = 100 kN are presented in this paper. The results illustrate the behavior of the tested structure under the load at the different stages of testing and enable an assessment of the effect of corrosion on the considered quantities. It should be mentioned that the deformation of the culvert during backfilling process was not taken into account. Readings of measured strains and displacements were taken just after putting the static load.

The internal forces (axial forces n and bending moments m) in the specified shell cross sections were calculated from the following equations:

$$n = \left[(h-t)\sigma_D + (h+t)\sigma_G\right]\frac{A_f}{2h} \tag{3.1}$$

$$m = (\sigma_D - \sigma_G)\frac{I_f}{h} \tag{3.2}$$

where:
σ_D and σ_G – circumferential stress in the corrugation's ridge and trough, respectively;

A_f and I_f – the area and moment of inertia of the cross section (fold) per unit width;
h – corrugation height; t – sheet thickness.

Details concerning how the stresses and internal forces in the cross sections of the corrugated shells were determined on the basis of tensometric measurements can be found in Korusiewicz et al. (2012), Kunecki & Korusiewicz (2013).

The distribution of axial forces and bending moments in the tested pipe (under the applied load) for the three stages of testing is presented in Figures 6 and 7, respectively. The deformation shape of the shell for the three stages of testing is presented in Figure 8.

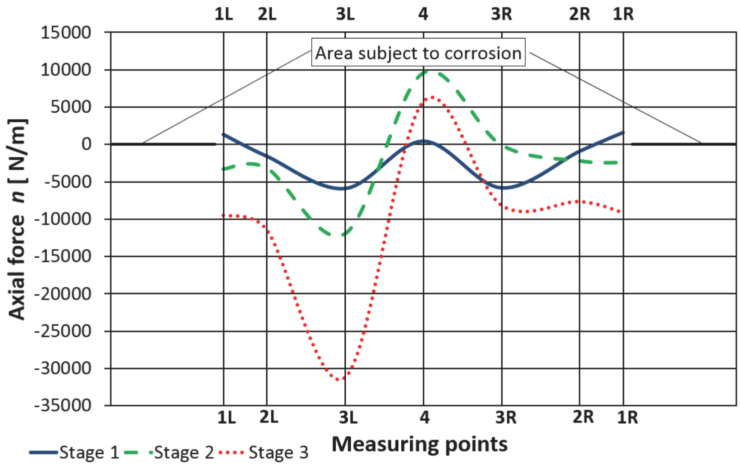

Figure 6. Axial forces in different stages of testing

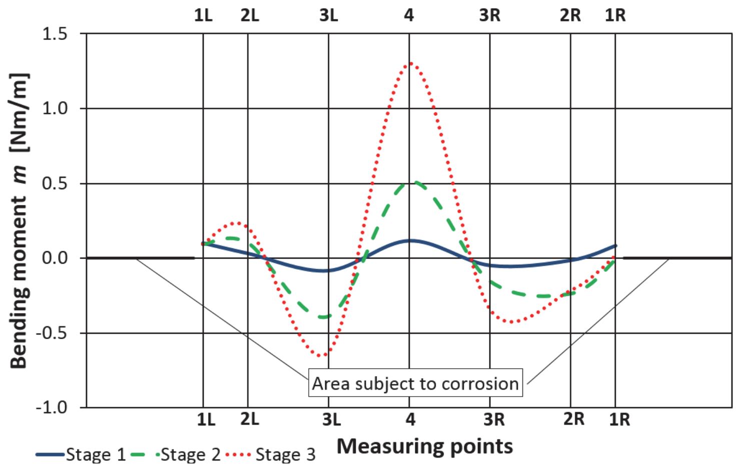

Figure 7. Bending moments in different stages of testing

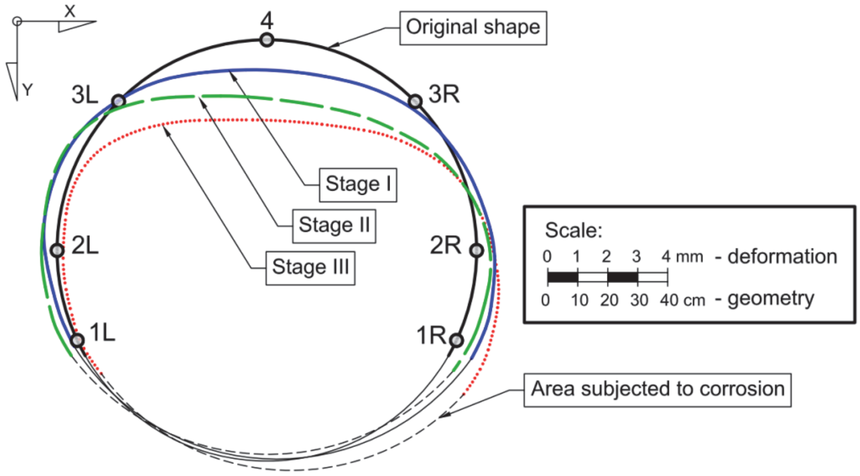

Figure 8. Deformation shape of the shell for different stages of testing (scale factor 1:100).

It should be noted that since the measuring set was calibrated before each of the stages the presented results do not include the loading history. Despite some imperfections, this procedure makes it possible to compare the response of the tested structure to the applied loads in the adopted experimental variants. The diagrams in Figure 6 and 7 show that damage to the pipe's bottom has a significant effect on the values of the internal forces and on the distribution of axial forces in the selected measuring points. The largest changes were observed in the shell crown region. A preliminary analysis of the test results for all the measuring points indicates that the highest normal stresses occur in measuring point 4. The extreme stresses (in the edge fibers of the shell cross section) σ_{ext} are an algebraic sum of the stress σ_n produced by axial force and the stress σ_m produced by bending moment. The stress values and displacements for all measuring points are presented in Table 1.

The stresses (in point 4) for the first, second and third stage of testing amount to respectively: σ_{ext} = 8.7 MPa, 41.6 MPa, 97.6 MPa; σ_n = 0.2 MPa, 4.3 MPa, 2.6 MPa; σ_m = ±8.5 MPa, ±37.3 MPa, ±95.0 MPa. The maximum deflection was recorded in point 4 and for the first, second and third stage of testing amounted to respectively: 1.0 mm, 1.9 mm, 2.7 mm.

Table 1. Stresses and displacements in the metal shell.

Point name	Stress σ_n [MPa]	Stress σ_m [MPa]	Stress σ_{ext} [MPa]	Horizontal displacement (x) [mm]	Vertical displacement (y) [mm]
Stage 1					
1L	0.6	±7.3	7.9	–0.1	0.2
2L	–0.7	±2.3	–3.0	–0.4	0.1
3L	–2.6	±6.1	–8.7	–0.5	0.3
4	0.2	±8.5	8.7	–0.7	1.0
3R	–2.6	±3.5	–6.1	0.6	0.8
2R	–0.4	±1.1	–1.5	0.6	0.2
1R	0.7	±6.0	6.7	0.5	0.6
Stage 2					
1L	–1.5	±6.9	–8.4	–0.2	0.5
2L	–1.4	±7.7	–9.1	–0.5	0.5
3L	–5.4	±28.2	–33.6	–0.9	0.7
4	4.3	±37.3	41.6	–0.6	1.9
3R	0.0	±11.1	–11.1	0.0	1.3
2R	–1.0	±17.2	–18.2	0.4	1.2
1R	–1.1	±0.5	–1.6	–0.1	1.0
Stage 3					
1L	–4.3	±6.9	–11.2	0.8	1.1
2L	–5.2	±15.0	–20.1	0.3	1.3
3L	–14.1	±45.9	–60.0	–0.3	1.4
4	2.6	±95.0	97.6	0.6	2.7
3R	–3.7	±25.1	–28.8	0.8	2.0
2R	–3.4	±15.8	–19.2	0.7	1.9
1R	–4.1	±1.3	–5.4	0.4	1.9

4. CONCLUSIONS

The following conclusions were drawn:

1) Corrosion of the culvert steel shell bottom affects the distribution and magnitude of the internal forces (stresses) and deflections in the upper uncorroded parts of the shell.
2) Bending moment has a decisive effect on the magnitude and changes of normal stress in the cross sections of the shell.
3) Even when the culvert bottom is corroded, the stresses produced by the applied loads are much lower than the yield point of the steel used (the maximum registered stress was about 2.5 times lower than the yield point).

4) It should be noted that the total stress in the given shell cross sections is a sum of the operational stresses and the stresses which arose during the backfilling process (dead load). As a rule, the latter stresses are much higher than the operational stresses (Machelski 2013) and have a decisive bearing on the satisfaction of the strength criterion for this type of structures.
5) The observed asymmetric distribution of deformations and internal forces may be caused by the loading history (the entire test program consisted of a variety of symmetrical and asymmetrical loads) as well as by the existing embankment on only one side of the tested culvert.

LITERATURE

1. El-Taher, M. & Moore I. D. 2008. Finite Element Study of Stability of Corroded Metal Culverts, *Transportation Research Record: Journal of the Transportation Research Board* 2050: 157-166. Washington D.C.: Transportation Research Board of the National Academies.
2. Janusz, L. & Madaj, A. 2009. *Engineering structures made from corrugated sheets. Design and construction*. Warsaw: WKŁ (in Polish).
3. Korusiewicz, L. 2015. Testing of a large-span soil-shell structure without stiffeners during backfilling process. *Roads and Bridges* 14(3): 203-218.
4. Korusiewicz, L., Chruścielski, G., Jasiński, R. 2012. Practical aspects of strains, stresses and internal forces estimation during field and laboratory tests of corrugated culverts. *Archives of Institute of Civil Engineering* 12: 117-131.
5. Kunecki, B. & Korusiewicz, L. 2013. Fidel tests of large-span metal arch culvert during backfilling. *Roads and Bridges* 12(3): 283-295.
6. Machelski, C. 2013. *Construction of buried corrugated metal structures*. Wroclaw: DWE (in Polish).