PROJECT FINAL REPORT

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Project acronym: ARCH-CULV

Project title: Super-span soil - steel bridge (animal crossing) – backfill and long - term monitoring

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Period covered: from 1st September 2008 **to** 31st August 2011

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1. FINAL PUBLISHABLE SUMMARY REPORT

Metal flexible culverts are getting more and more popular in recent years. Corrugated steel culverts have been used in many regions, inter alia: USA, Australia, Canada and Scandinavia. These structures have been used for more than **40 years in Europe**. Smaller culverts are mostly used for sewer and drainage applications. Corrugated steel culverts with greater diameters are used for **bridges and viaducts, underpasses, wildlife crossings, rockfall and avalanche protections, road and railway tunnels.** The concept of long span buried structures has evolved primarily through field experience during which spans have gradually increased and the cover depth to span ratio has decreased. In the beginning, the flexible soil-steel structures were constructed as riveted corrugated pipes with circular cross-section and a relatively short span. The second generation of that kind of structures had a span in the range of 8 – 16 m. The limit on span after which the term "long-span" is currently used is approximately 8.0 m. The progress in computational methods based on the finite elements analysis as well as the technological development of the manufacture of the corrugated plates have contributed to significant growth of the third generation of soil-steel structures. The largest steel culverts can exceed 20 m in span, for example the Whitehorse arch structure (1997) in Canada with the 24 m span can carry a 1144 t mining vehicle.

In 2008 two twin large-span flexible structures were constructed on the A4 motorway in the vicinity of Boleslawiec city in Poland, 40 km east of the Polish-German border. The location of structure is shown in Figure 1b. The structures are low-profile, metal arches with a span of 19.5 m and a rise of 6.0 m. Twin metal arches were erected on three reinforced concrete footings. Both structures which serve as animal crossings over the A4 motorway are about 75 m long. The complete animal crossing is shown in Figure 1 a, c.

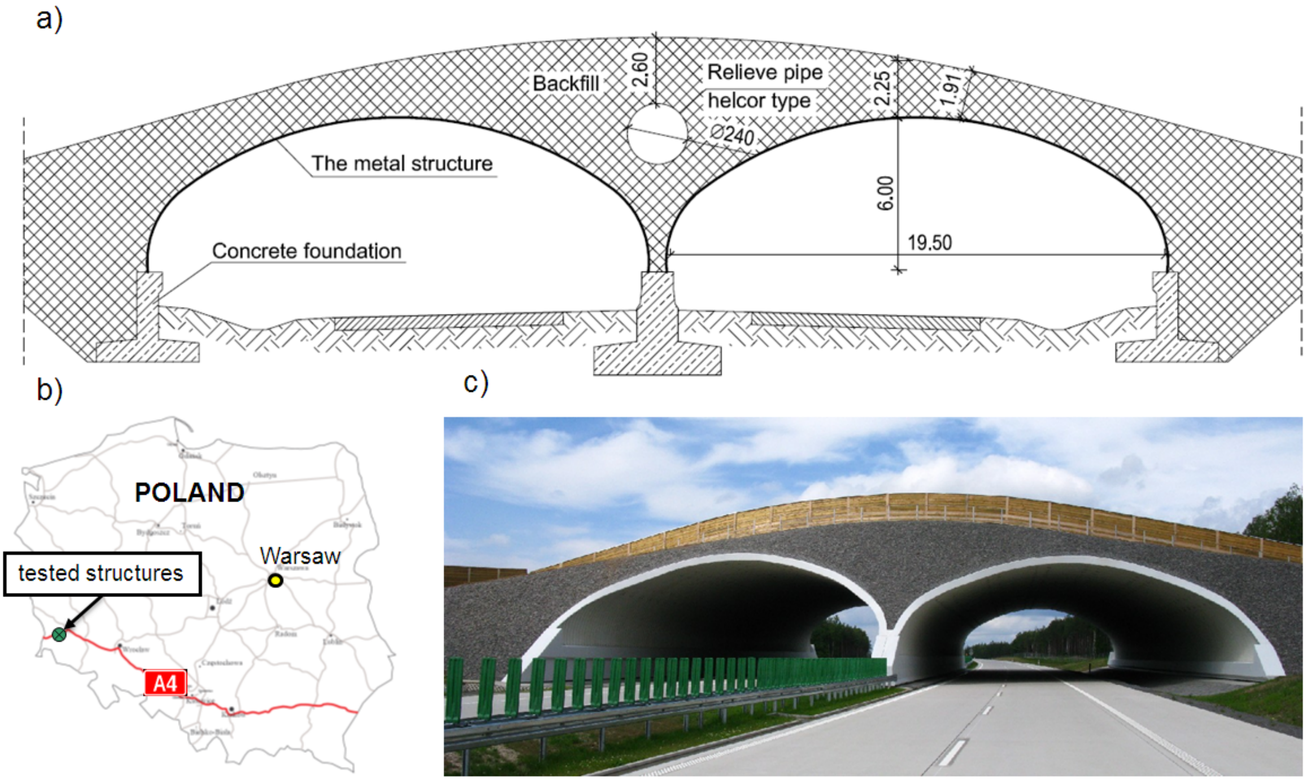


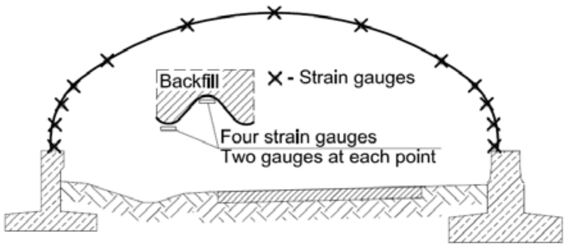
FIGURE 1. a) Geometry of the structure [m]; b) Location of tested structure; c) view of complete wildlife overpass

The project was designed to meet the following two main **research objectives**:

I. **Measurements** of the strains and the deformations in the metal structure during backfilling,
II. **The analysis** of the results, and numerical verification used to the Finite Element Method,

For the **first project objective** the methodology was based on using various gauges to measure and monitor the stress changes in the steel structure and the horizontal and vertical deformations of the structure. The strain gauges were placed at 13 points in the middle section of the structure. At each of 13 locations on the inside wall of the steel culvert, four weldable electrical resistance strain gauges were installed (circumferential and longitudinal directions). Two gauges will be fitted at the top of the corrugation and two at the bottom. Three-dimensional deflections of the structure during backfilling were measured using a geodetic laser device. Twenty eight measured points at seven sections of the west arch were placed along four lines (A, B, C, D lines in figure 2b). Lines B and C were located 1.35 m and lines A and D 7.75 m from the axis of symmetry, respectively. Deflections were registered as the changes between the fixed reference point located on the ground and the crest of corrugation for each measured point. The locations of all strain gauges and deformation points are shown in Figure 2.

a) **b)**



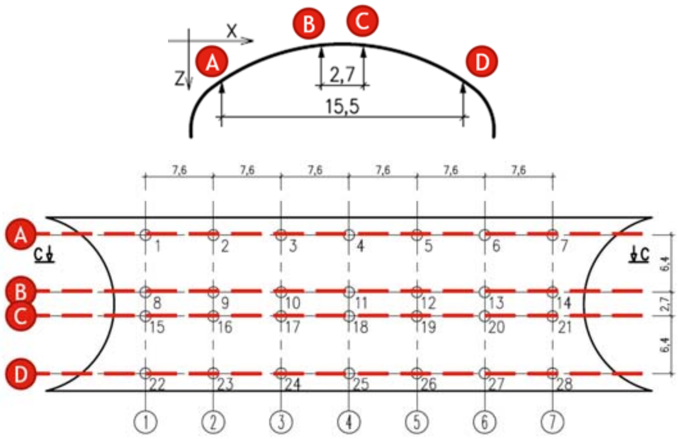
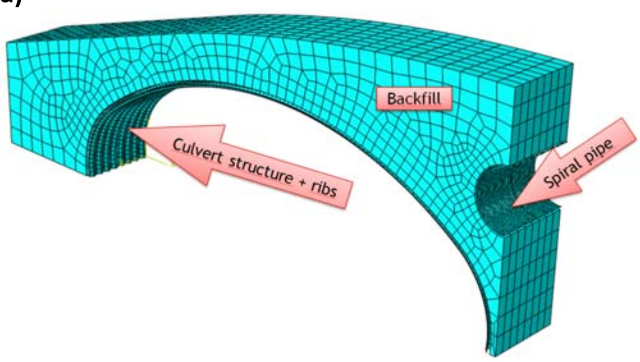


FIGURE 2. Location of the gauges on the metal arch:
a) the strain gauges;
b) deformation points [m].

For the **second project objective** the methodology was based on doing comparative and verification analyses. Various soil models will be used in numerical simulations of the soil–metal structure system using a finite element analysis. Analyses of the soil-structure system were carried out using Abaqus/CAE environment. The software is an advance, modular, finite element system for personal computers and workstations. The program includes modules to creating, submitting, monitoring, and evaluating results from linear and nonlinear static and dynamic structural problems. The numerical model is shown in Figure 3.

Detailed analysis is descripted in two reports: No. 10-1467 "Field Test of Super-Span Metal Twin Arches during Backfilling" and No. 12-1507: "Field-test of soil-steel corrugated arch with ribs and three-dimensional analysis" presented in *the Transportation Research Board (89th and 91st Annual Meeting*) in Washington, D.C. (USA) (see web address: *http://amonline.trb.org/pap@PaperNo=12-1507*).

a) **b)**



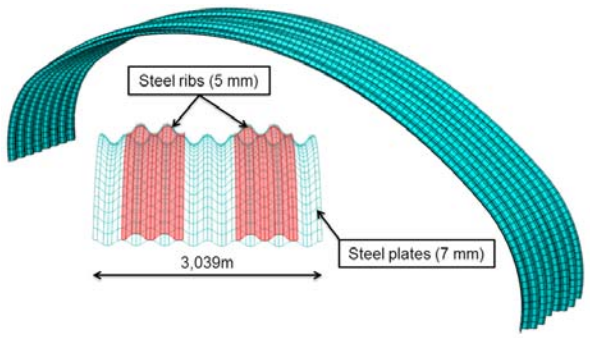
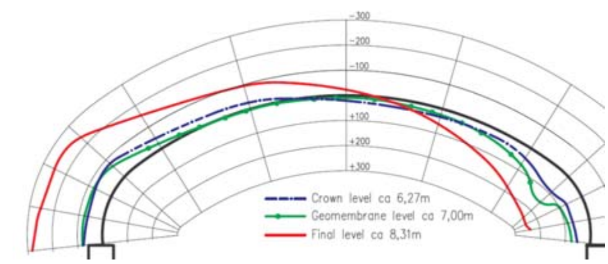


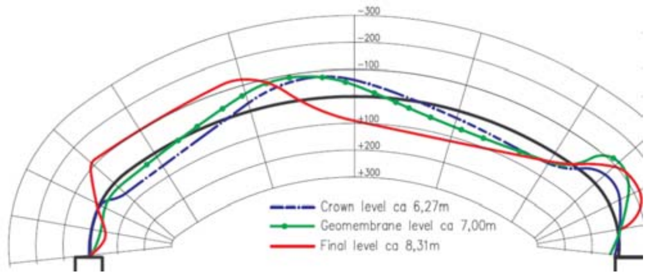
FIGURE 3. Numerical model of: a) complete structures with backfill; b) the main structure with ribs.

The main goal of ARCH-CULV project was to conduct the field measurements on a low-profile metal structure in configuration of twin arches as well as verification analyses. Three dimensional deflections in 28 points and strains (stresses) in 13 points on the steel plates were measured during backfilling process. The results obtained from the test were used to verify and compare the response, which was calculated by advanced software based on the Finite Element Method. Test results from field measurements and numerical analyses are presented in Figure 4.

a)



b)



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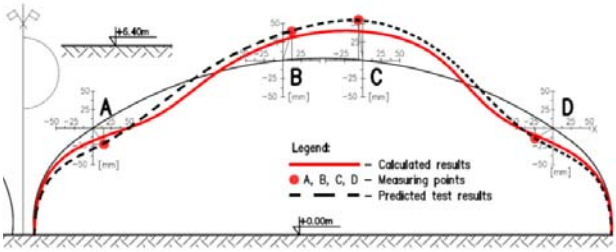

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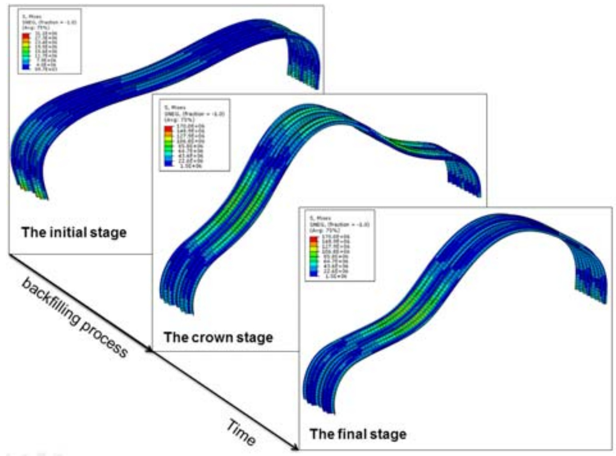

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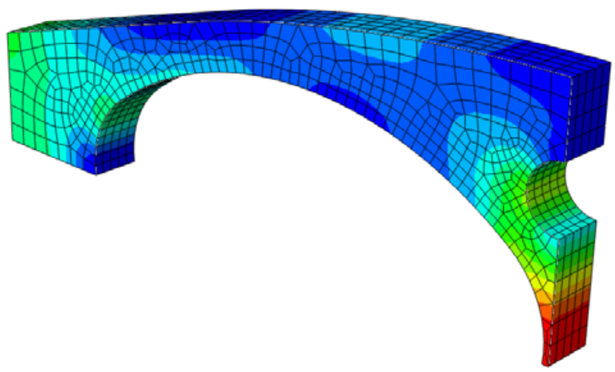

FIGURE 4. Test and calculation results:
a) distribution of bending stresses [MPa];
b) distribution of axial stresses [MPa];
c) calculated and measured displacement of the structure[mm];
d) distribution of calculated stresses and deformed shape of structure [Pa];
e) distribution of stresses in the soil.

The comparison of test and numerical results indicates that displacements and distribution of stresses in the steel structure are seen to be in good agreement. The three-dimensional numerical simulations gave deformations, which are sufficient accurate in comparison to the experimental results. Both the measurements and numerical simulation indicate that the internal forces and deformations in the arch were asymmetrical in spite of the fact that additional relieve pipe between main arches was used.

The advance features of numerical system used in ARCH-CULV project, such as:

- creating the three-dimensional detailed numerical model,
- using the load history,
- using interaction between various materials (contact surface),
- using geometrical and material nonlinearity,

contribute to obtain high degree of convergence between experimental and numerical results and better reflect of natural behaviour of flexible structures.

In addition, another structure was tested during the ARCH-CULV research project. In 2010 single large-span flexible structure was constructed in the store field of the ViaCon factory in Poland. The structure was low-profile, metal arch with a span of 17.6 m and a rise of 5.5 m. Structure were erected on two concrete footings and it was about 15 m long. Arch was constructed without addition ribs.

Three dimensional deflections in 5 points and strains (stresses) in 9 points on the steel plates were measured during backfilling process. Geometry of the structure and locations of all strain gauges are shown in Figure 5.

a) **b)**

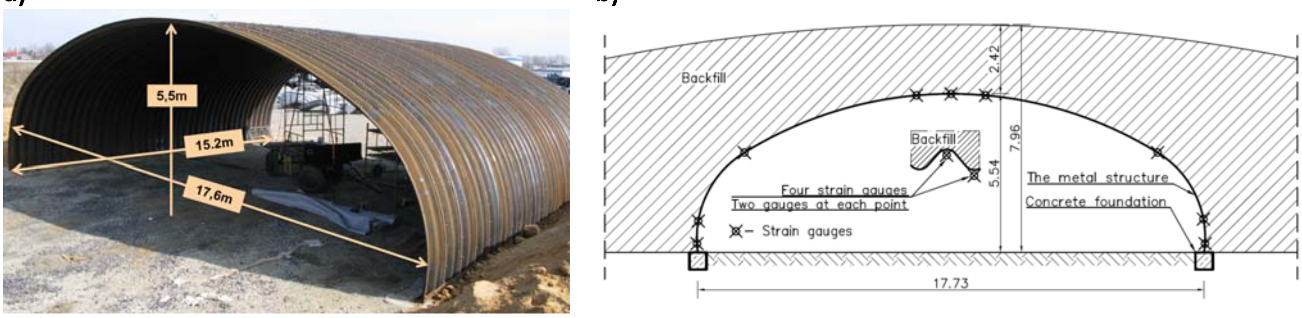

FIGURE 5. a) Geometry of the structure [m]; b) Location of the strain gauges on the metal arch [m].

Close cooperation between Wroclaw University of Technology and ViaCon Company allows conducting mentioned field, full-scale test. The benefit consists in the fact that the structure was built by culvert producer and researcher was not need addition financial resources for build on the test model.

The test results will be presented in the 2nd European Conference - Flexible Corrugated Steel Structures in Rydzyna (Poland) in April 2012.

Brief summary of the main activities carried out during ERG: ARCH-CULV research project:

- **Full-scale field test of super-span metal twin arches during backfilling.**
  Strains and deflections data were acquired on the response of the structure to the soil dead load during backfilling process on the A4 motorway.
- **Comparative and verification analyses.**
  Analyses of the soil-structure system were carried out using Finite Element Method. Proposed calculations characterized by high degree of convergence between experimental and numerical results and better reflect of natural behaviour of flexible structures. Results were presented on international conferences and published in the peer reviewed publications.
- **Academic activities.**
  The researcher was involved in academic activities. He prepared and run at the host university the course, which was organized for senior students and it concerning the testing, designing and constructing the soil-steel buried structures and geotechnical issues.
- **Cooperation between university and industry.**
  The researcher could maintain close cooperation with the flexible culvert producer (ViaCon Company) and carried on another full-scale test.
- **Addition full-scale field test of super-span single arch during backfilling.**
  Additional, complete, full-scale field test of super-span single arch during backfilling was carried out in the store field of the ViaCon factory in Poland. Installing entire structure was financed by ViaCon Company.

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