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 1 ARCHIVES OF INSTITUTE OF CIVIL ENGINEERING 2007

COMPARATIVE FULL SCALE TESTS OF BEHAVIOUR OF CORRUGATED STEEL ARCH STRUCTURE PLACED ON CORRUGATED FLEXIBLE FOUNDATIONS AND RIGID CONCRETE FOUNDATIONS

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Abstract

Since January 2007 at the Road and Bridge Institute in Żmigród two steel arch made from the HelCor pipe are tested in natural scale. The structures have a span of 2,5 m, rise of 1,25 m and are manufactured from the 100 x 20 mm corrugated steel with plate thickness of 2,5 mm. One of the structure is placed on flexible steel foundation, the second on the rigid concrete foundation. With the use of hydraulic servos and a steel frame which is a support structure for the hydraulic load generating equipment, construction is going to be loaded by static and fatigue loads. The tests are oriented to show the differences between the flexible steel construction placed on corrugated flexible foundations and rigid concrete foundations The paper focuses on results obtained during backfilling the two constructions.

Key words: flexible structures, flexible foundations, rigid foundations, natural scale test, results comparison, FEM

1. INTRODUCTION

The authors presents the full scale tests of flexible soil-steel structure that are currently performed at the Roads and Bridges Research Institute. These tests are the part of over 10 years experience of full scale laboratory tests of corrugated steel structures and pipes executed at the Roads and Bridges Research Institute [1]. These tests are oriented to show the differences between the corrugated steel arch, placed on corrugated flexible foundations and rigid concrete foundations. According to current Polish steel bridge design standard, the constructions ought to be settled by rigid foundations, however this standard does not take into consideration the flexible steel-soil constructions specificity. For this reason the concrete foundations in flexible structures are over-designed. The results of the test will be the base to prepare a design method for flexible foundations.

2. TEST DESCRIPTION

2.1. The aim of the test

These tests are oriented to show the differences between earth pressure distribution around the steel structure and under foundations as well as to compare the stress values in the corrugated steel arch, placed on corrugated flexible foundations and rigid concrete foundations. Numerical analysis using Finite Elements Method in CandeCAD™ software was made for comparison.

2.2. The test stand

Test is executed in the Destructive Test Stand (DTS) called also Dynamic and Fatigue Test Stand or simply STEND. It has the form of an 80,0 m long and 12,0 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 STEND 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. A separate paper describes mentioned test stand [1].

2.3. Tested structure

Two arches made of HelCor pipe were used for test. Parameters of each structure are: 2,5 m in span, 1,25 m in rise and length of 4,0 m. Both were made of 2,5 mm thick steel plate and 100 x 20 mm corrugation, protected by hot-dip galvanization with thickness of 42μm. One structure is placed on the rigid concrete foundation, and second on the corrugated steel plate. The backfilling material is well-graded gravel with maximum grain size of 32 mm. The backfill was placed in layers with thickness after compaction of 20-40 cm. The required degree of compaction was 98% Standard Proctor density. Soil cover depth over structure is 0,6 m. Figure 1 presents the cross section of two structures prepared for the live load test.

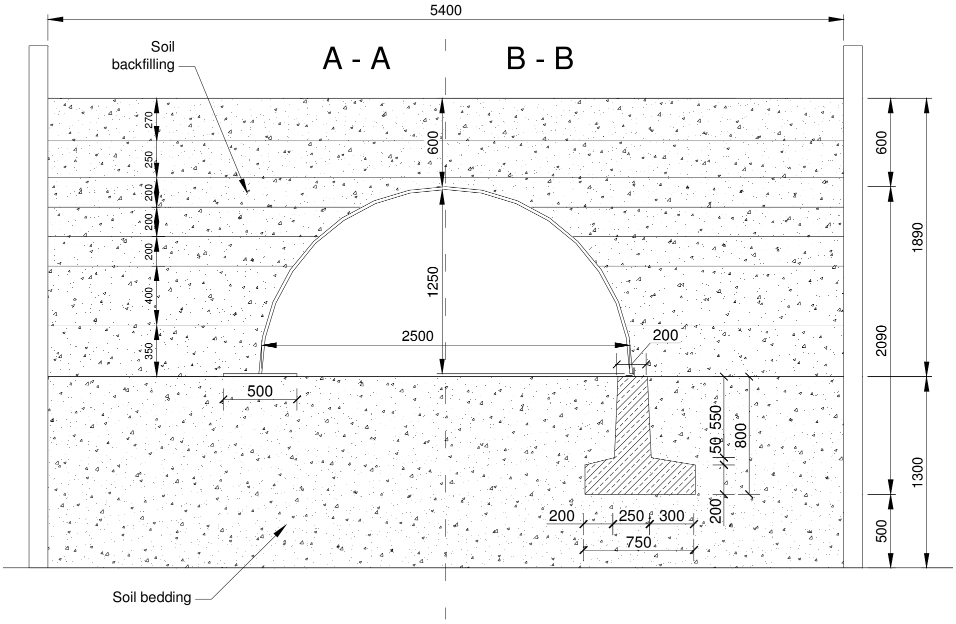

Figure 1. Tested structures on the stand. A – A cross section shows construction on the flexible foundation and the B – B cross section shows construction on the rigid foundation as shown on figure 2

2.4. Loads

Load configuration that simulates road loading was chosen. The load was modeled according to Polish Standard PN-85/S-10030. For transmitting the load from the servo to the tested model special steel structure was used. The main part of test program is static live load class A in accordance with PN-85/S-10030, where total weight of simulated truck is K=800 kN transmitted by 8 wheels, each 100 kN. In tested model 4 wheels were applied to load each of the two tested structures (figure 2). 3 cycles of live load are expected.

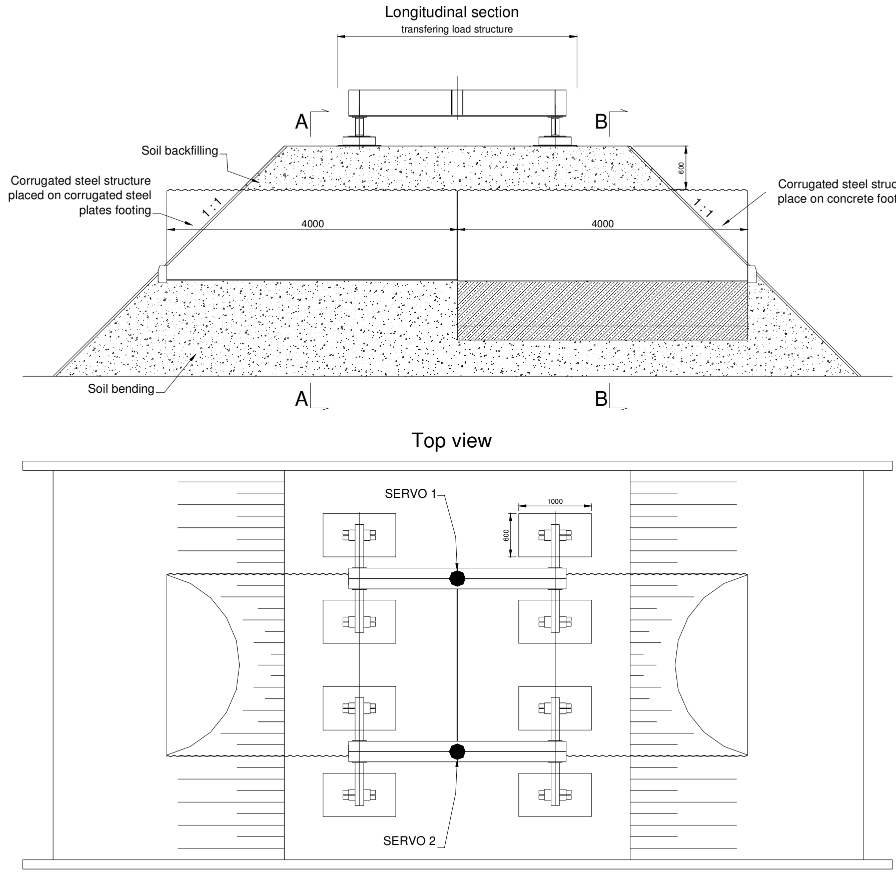

Figure 2. Transferring load construction

2.5. Instrumentation

The instrumentation consists of 6 electric resistance strain gauges located at the top and bottom of the corrugation, 3 induction gauges used for vertical and horizontal displacement measurements and 12 earth pressure cells (figure 3).

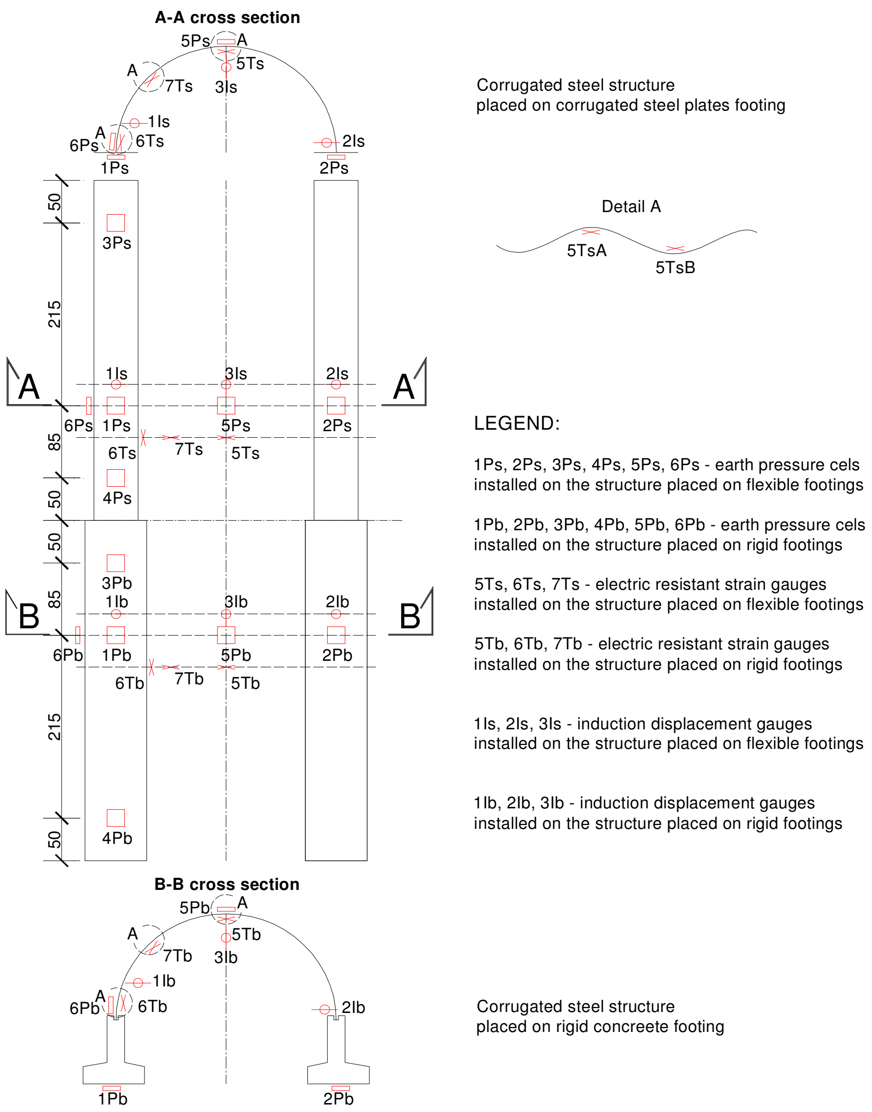

Figure 3. Location of instrumentation

2.6. Scope of test

Test scope includes:

1. The soil tests:
   - grain-size distribution;
   - friction angle;
   - humidity;

- degree of compaction;

2. The flexible and rigid foundations tests:
   - measurement of vertical and horizontal displacements during backfilling and under live load;
   - measurement of pressure under foundations during backfilling and under live load;
3. The steel construction tests:
   - measurement of deformations and vertical and horizontal displacements during backfilling and under live load;
   - measurement of soil pressure to the construction during backfilling and under live load;

2.7. Photographic documentation

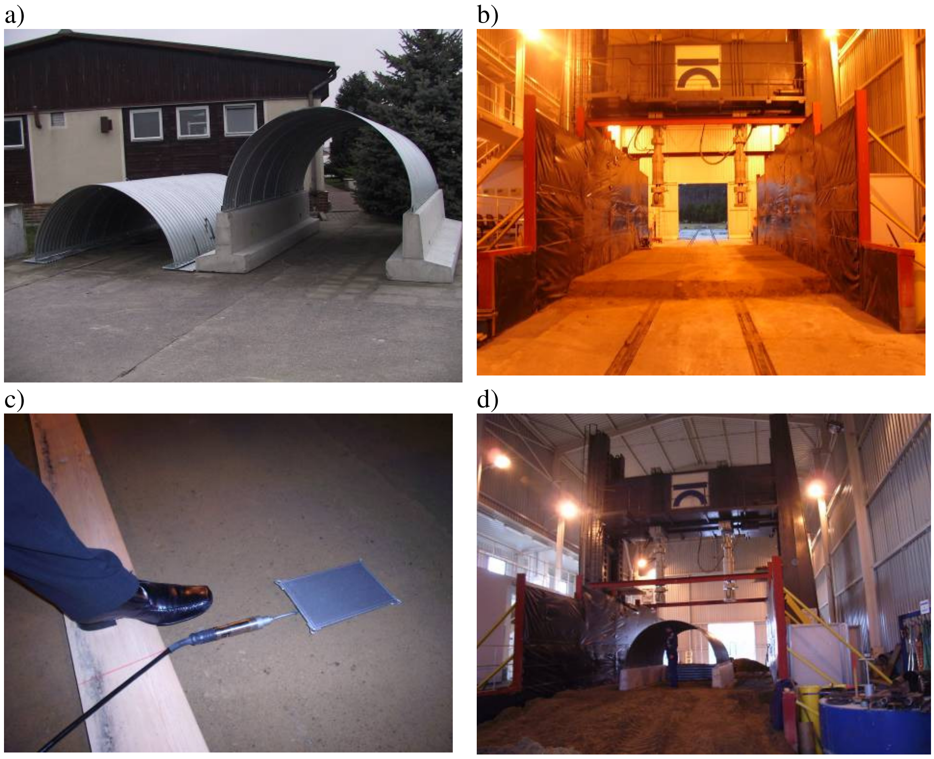

Figure 4. a) HelCor steel arches delivered to Roads and Brigdes Research Institute; b) first compacted soil layer c) earth pressure cell used for measurement of soil stress under foundation. d) corrugated flexible structure settled on rigid concrete foundations at the stand

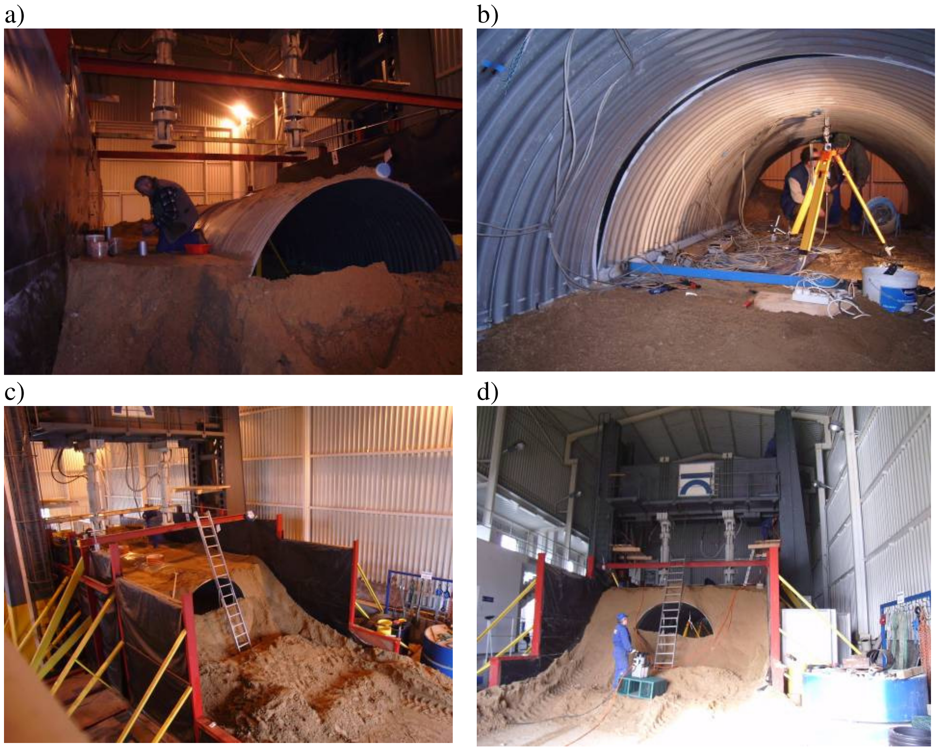

Figure 5. a) testing of degree of compaction; b) installation of measurement gauges; c) backfilling procedure; d) structure before slope pavement using cobblestones

3. TEST RESULTS

3.1. Soil tests

Current examinations at construction of the model contained all soil tests. A detailed research on all essential parameters of soil was made. Degree of compaction of soil for each individual layer with thickness of 0,20 - 0,30 m placed under foundations was checked. While layer had required degree of compaction next layer was placed.

After right installation and the assembly of the steel structure together with foundations next layers of backfill material were placed and degree of compaction and humidity were controlled. All measured parameters of soil were higher than specified in Polish recommendations [2], [3].

3.2. Steel and concrete foundations tests

During installation of the concrete foundations as well as during backfilling procedure on both constructions the measurements of displacements and pressure within foundations were done. The results of tests are showed at the tabele 1. After making the backfilling of concrete foundations to the level of the steel foundations the measurement gauges were seted to zero.

Table 1. Results of the pressure under foundations and the horizontal displacements of the foundations measured during backfilling

Soil layer		Total backfilling thickness	Construction placed on flexible foundation				
			Pressure under foundation			Horizontal displacements of foundations	
Number	Thickness		1Ps	4Ps (control)	2Ps	1Is	2Is
[-]	[m]	[m]	[kPa]	[kPa]	[kPa]	[mm]	[mm]
1	0,35	0,35	0,0	0,0	0,1	-1,41	1,21
2	0,40	0,75	0,0	2,2	2,1	-2,60	0,44
3	0,20	0,95	1,3	5,2	3,7	-2,66	0,78
4	0,20	1,15	1,5	8,3	5,5	-2,76	0,73
5	0,20	1,35	0,0	7,1	4,3	-2,78	0,80
6	0,25	1,60	4,4	18,6	17,4	-2,53	1,00
7	0,25	1,85	0,0	18,6	15,3	-2,41	1,04

Soil layer		Total backfilling thickness	Construction placed on rigid foundation				
			Pressure under foundation			Horizontal displacements of foundations	
Number	Thickness		1Pb	3Pb (control)	2Pb	1Ib	2Ib
[-]	[m]	[m]	[kPa]	[kPa]	[kPa]	[mm]	[mm]
1	0,35	0,35	0,7	0,4	0,8	-0,10	-0,03
2	0,40	0,75	2,5	1,2	3,7	-1,01	-1,32
3	0,20	0,95	4,4	2,1	5,8	-1,14	-1,38
4	0,20	1,15	4,9	3,0	8,6	-1,19	-1,44
5	0,20	1,35	5,7	3,4	12,6	-1,19	-1,47
6	0,25	1,60	9,9	6,3	21,9	-1,05	-1,40
7	0,25	1,85	9,2	6,4	21,8	-0,97	-1,35

3.3. Steel construction tests

During backfilling procedure on both constructions the measurements of individual deformations, displacements as well as soil pressure were done. The results of tests are showed at the table 2.

Table 2. Results of the arch crown displacements measured during backfilling

Soil layer		Backfilling thickness	Arch crown displacement on flexible foundation	Arch crown displacement on rigid foundation
Number	Thickness			
[-]	[m]	[m]	[mm]	[mm]
1	0,35	0,35	0,66	0,40
2	0,40	0,75	4,39	4,49
3	0,20	0,95	5,63	5,87
4	0,20	1,15	7,22	7,30
5	0,20	1,35	7,40	7,45
6	0,25	1,60	5,46	5,48
7	0,25	1,85	4,51	4,70

4. CACULATION WITH THE USE OF CANDECAD SOFTWARE - FINITE ELEMENT METHOD

For calculation of internal forces and displacements in both arches, the Cande-Cad ™ software was used. It is a two dimensional, non-linear finite element computer program works in AutoCad® environment, developed exclusively for the design, analysis and evaluation of buried pipes, structures and other soil structures. Building a numerical model one has to define steel, soil and interface elements parameters. From the author's experience the results are very sensitive for sake of choosing different soil model for the backfill material. Some definitions of soil can be found in [4]. For numerical simulation of backfill material the Duncan soil model (Selig hyperbolic) was used [4]. For this gravelly sand (SW) compacted to 98 % of Standard Proctor Density was used. The curved steel structure members were modeled as a number of straight beam-column elements connected in nodal points. Owning to the crown ribs different section (crown and the remaining part of the structure) parameters were used. Between steel and backfill the interface elements with the following parameters were used:

- Coefficient of friction 0,3;
- Tensile braking force 0,175 kN/m;

With the use of numerical analysis the individual stages of backfilling process (layers of 30 cm thickness) were taken into account. Physical parameters of structure and values of live and dead load similar to tested structure were applied. It allowed to compare results obtained in numerical analysis with test results.

The FEM model is shown in Figure 6. Some results from the numerical model adequately to the test results are showed in Figure 7 and 8.

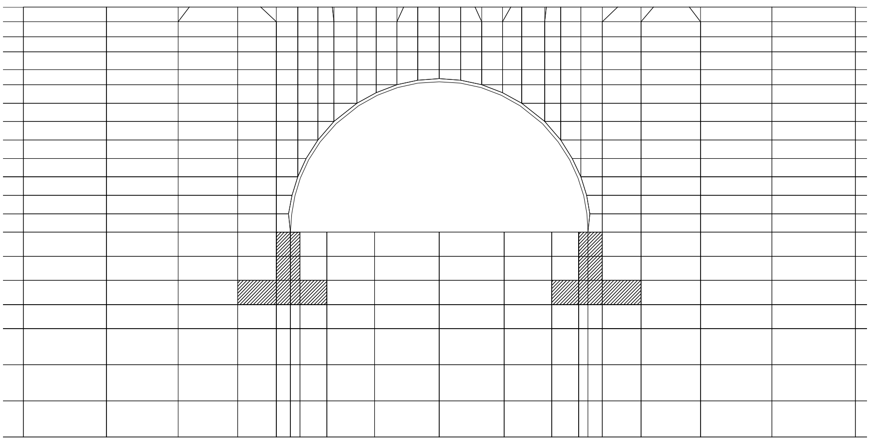

Figure 6. FEM mesh of the topic structure placed on rigid concrete foundation

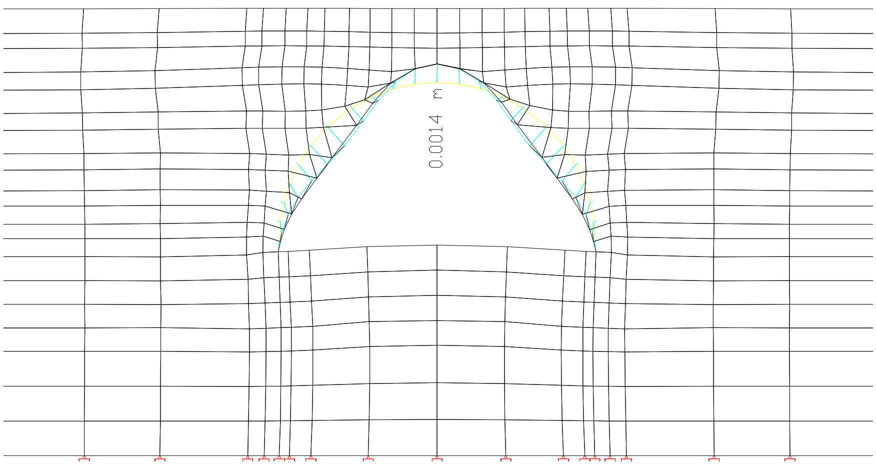

Figure 7. Displacement after complete backfilling calculated in FEM for construction placed on rigid concrete foundations

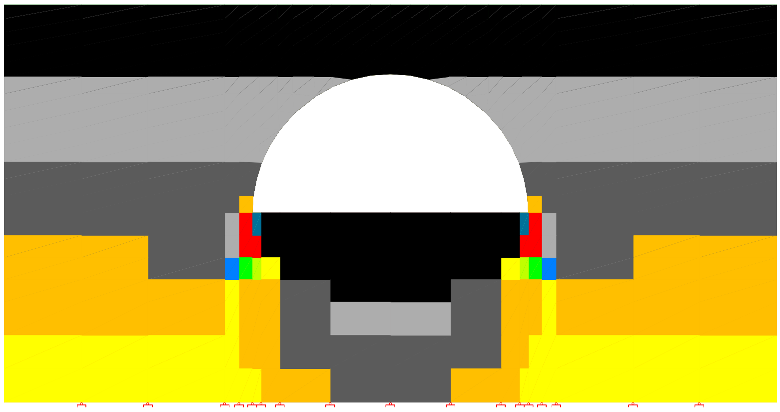

Figure 8. Soil pressure in Y-axis after complete backfilling calculated in FEM for construction placed on rigid concrete foundations

5. COMPARISON OF RESULTS AND CONCLUSIONS

At the below table 3 comparision of some results measured and calculated during backfilling are showed. Rest of the results includes the live static and fatigue loads will be presented on conference.

Table 3. Result comparision for construction on rigid concrete foundations after complete backfilling

	Dislacements [mm]	Pressure [kPa]	
	Crown – vertcial	Under foundation	
Measured	4,70	9,2	21,8
FEM in CandeCAD™	1,30	35,0	35,0

1. In spite of the differences in values, we can say that measured and calculated results are cohesive. Based on author's experience in CandeCAD™ analysis it is expected that during live loading tests the results from FEM and tests shall be similar;
2. Measured diseplacements values in the crown were similar for both structures, placed on flexible and rigid foundations, during backfilling;
3. Measured horizontal displacements at foundations during backfilling showes, that the construction placed on steel flexible foundation should be backfilled carrefuly to avoid the inadmissible displacements to one site. That displacement is permanent.

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PORÓWNAWCZE BADANIA W SKALI NATURALNEJ NAD ZACHOWANIEM KONSTRUKCJI Z BLACH FALISTYCH O KSZTAŁCIE ŁUKOWYM NA PODATNYCH FUNDAMENTACH Z BLACH FALISTYCH ORAZ NA SZTYWNYCH FUNDAMENTACH BETONOWYCH

Streszczenia

Od stycznia 2007 roku w Instytucie Dróg i Mostów w Żmigrodzie dwie stalowe konstrukcje o kształcie łukowym w skali naturalnej wykonane z rur HelCor są poddane testom. Kontrukcje mają rozpiętość 2,5 m, wysokość 1,25 i zostały wyprodukowane z blachy falistej o fali 100 na 20 mm i o grubości 2,5mm. Jedna z konstrukcji jest umieszczona na podatnych fundamentach z blach falistych, druga na fundamentach betonowych. Przy użyciu obciążników hydraulicznych i stalowych ram które wspierają przyrządy generujące obciażenie hydrauliczne, konstrukcja jest poddana obciążeniom stałymi i zmiennymi. Testy mają na celu pokazanie różnicy w zachowaniu się konstrukcji podatnych na fundamentach podatnych i fundamentach sztywnych. Praca koncentruje się na wynikach otrzymanych w trakcie zasypywania obu konstrukcji.

Słowa kluczowe: kontrukcje podatne, fundamenty podatne, fundamenty sztywne, testy w naturalnej skali, porównanie wyników, metoda elementów skończonyc (MES)