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COMPARISON OF TEST AND CALCULATION RESULTS OF CORRUGATED STEEL PLATE BOX STRUCTURE MP150

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Abstract

In 2003 in Road and Bridge Research Institute in Żmigród MP150 Box structure was tested in natural scale. Structure has a span of 3,5m, rise of 1,4m and is manufactured from steel with plate thickness of 5mm. With the use of hydraulic servos and a steel frame which is a support structure for the hydraulic load generating equipment, construction was loaded by static and fatigue loads. The paper focuses on results obtained under static loads.
In order to compare the test results, calculation of tested structure was performed preserving the same boundary conditions. Calculations were made with the use of Canadian standard – CHBDC. Numerical analysis using FEM was also performed in CandeCAD software. Comparative analysis of test results and results of calculation is described.

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

1. INTRODUCTION

The authors present a part of test results that in Road and Bridges Research Institute were executed. MultiPlate MP150 buried flexible corrugated steel structure was tested in natural scale for commission the ViaCon Company.

For comparison numerical analysis using Fine Elements Method in CandeCAD software and calculations with use of Canadian standard – CHBDC were made.

Parameters of tested structure are: span 3,5 *m*; rise 1,4 *m*; thickness of steel plate 5,00mm, corrugation 150x50 *mm,* type of profile – Box (open shape) with concrete continuous footing. Structure was reinforced by means of ribs made of steel plates located on the top section of perimeter (in crown).
Drawing of structure is presented in figure 1.

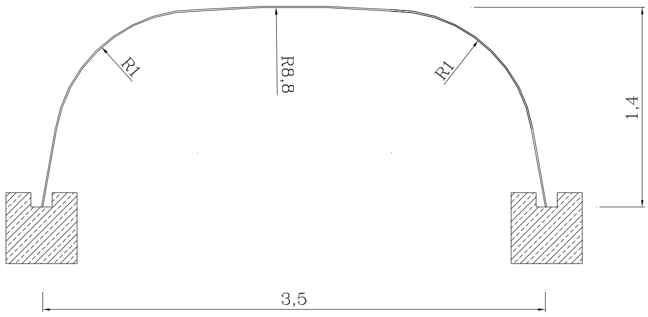

Figure 1. Tested structure: shape and main parameters

Test in a special place named The Test Stand (STEND) was executed. The STEND 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 the hydraulic load generating equipment. The STEND is outfitted with a system of hydraulic servos with a control and feeding system ensuring full control over the static and dynamic loads in real time. The system consists of two servos with the maximum force of 1000 *kN* and the maximum movement of 400 *mm*, equipped with strain and force gauges with 0,1 % full-range measuring accuracy [1]. Figure 2 presents the STEND and steel structure situated in the testing place.

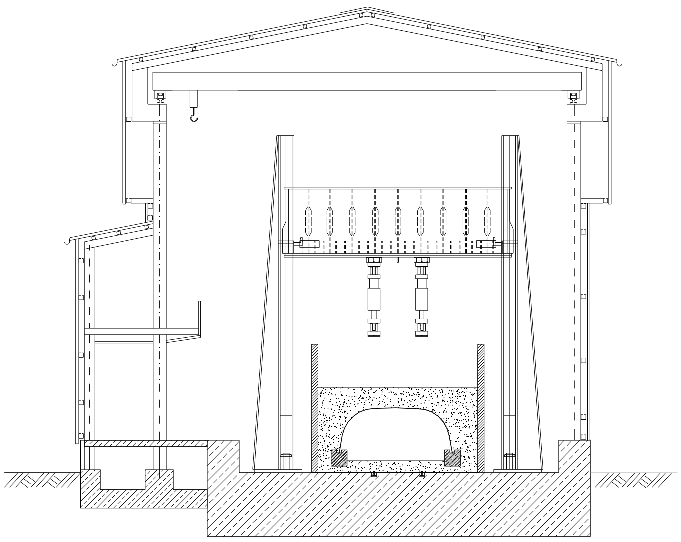

Figure 2. Testing place – STEND – General view

2. TEST DESCRIPTION

2.1. Material

The steel material of structure had quality according with European Standard EN 10025 with minimum yield stress is 235 *MPa*. The bolts were M20 (20 *mm*) with minimum tensile strength 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 0,3 *m*. The required degree of compaction was 97 % Standard Proctor density. Soil cover depth over structure was 0,6 *m* [2].

2.2. Loading program

A load configuration that simulates road loading was chosen. The load was modeled in accordance with Polish Standard PN-85/S-10030. For transmitting, the load from the servo to the tested model special steel structure was used (figure 3). A part of test program , chosen for this report, it's static live load class A in accordance with Polish Standard PN-85/S-10030, where total weight of simulated truck was K=800 *kN* with
safety factor φ =1,5 and
dynamic factor γ = 1,26 and q = 4,0 kN/m^2.
Speed of the load 40kN/s and time of the maximum load T = 600 [*s*].

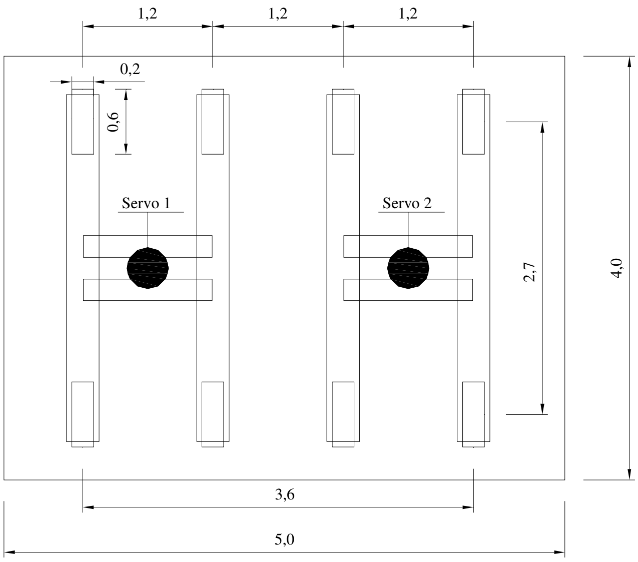

Figure 3. Transferring load by using structure with cold – formed steel beams

2.3. Data collecting equipment

The instrumentation consists of 22 electric resistance strain gauges in 11 locations with a strain gauge on the top and bottom of the corrugation (figure 4) and 3 induction gauges used for vertical and horizontal displacement measurements (figure 5) [2].

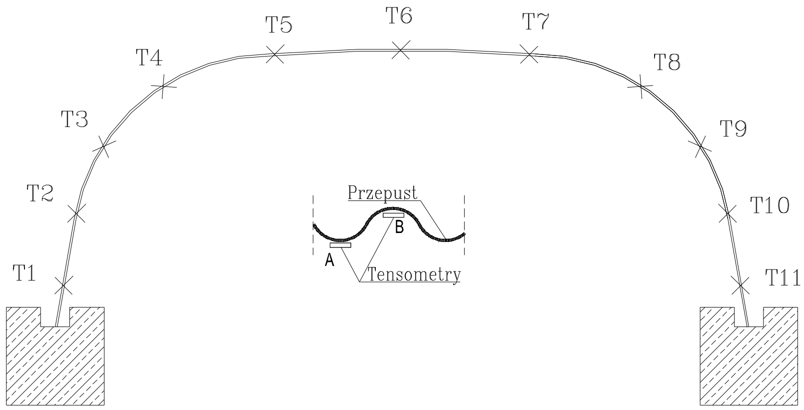

Figure 4. Electric resistance wire strain gauges

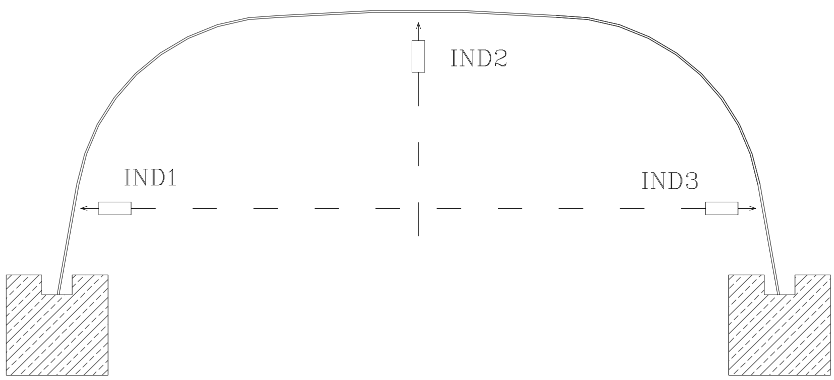

Figure 5. Induction gauges

3. TEST RESULTS

Research in this matter have been carried for many aspects (e.g. Fatigue test, destroying test, test with geogrid) and results can be found in paper [2] and [3]. Chosen results with maximum values under static live load class A and dead load were showed below:

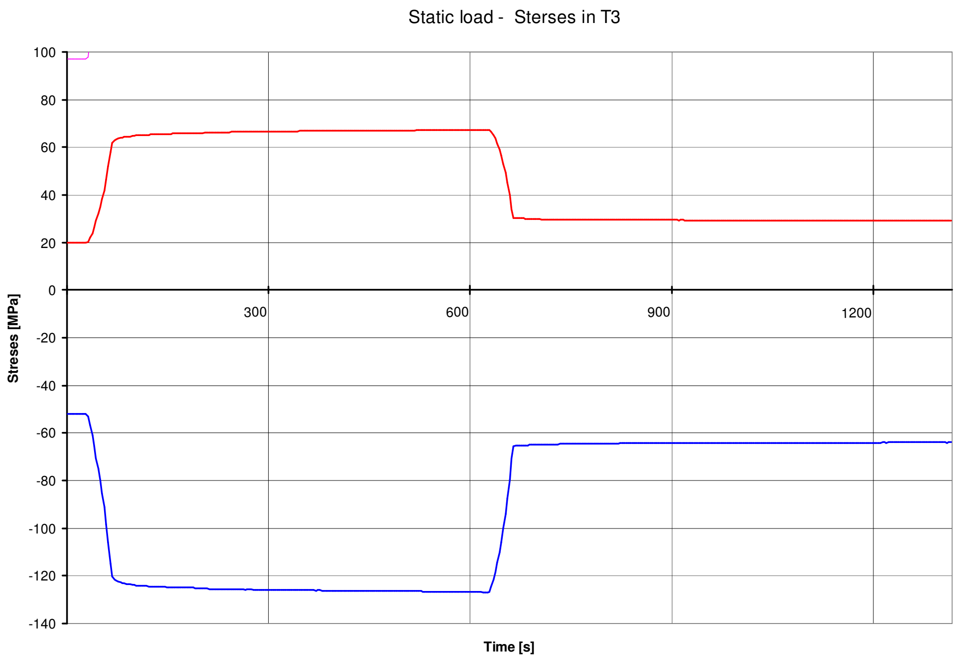

Figure 6. Stresses occurred in point T3 (see figure 4), red line – T3A, blue line – T3B

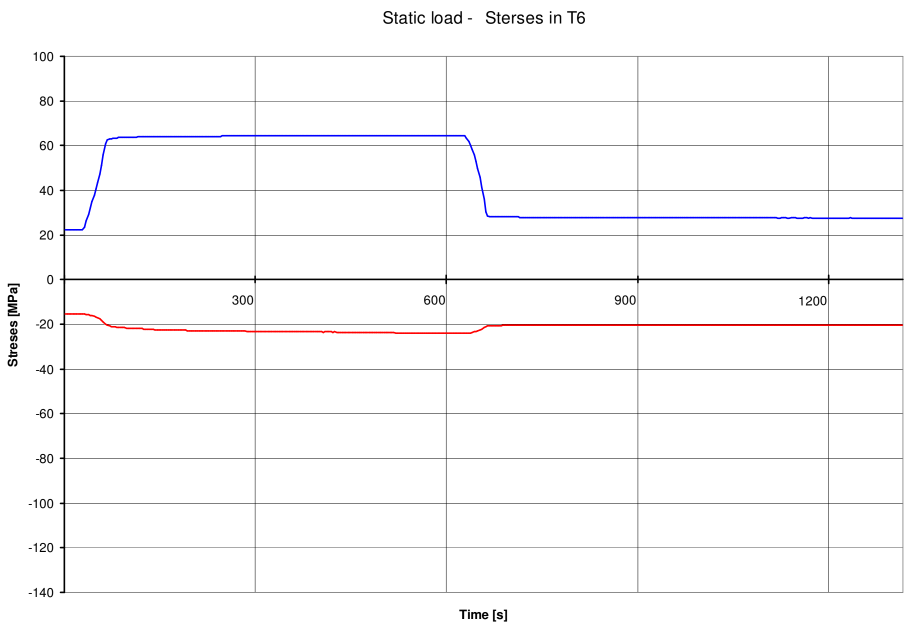

Figure 6. Stresses occurred in point T6 (crown), red line – T6A, blue line – T6B

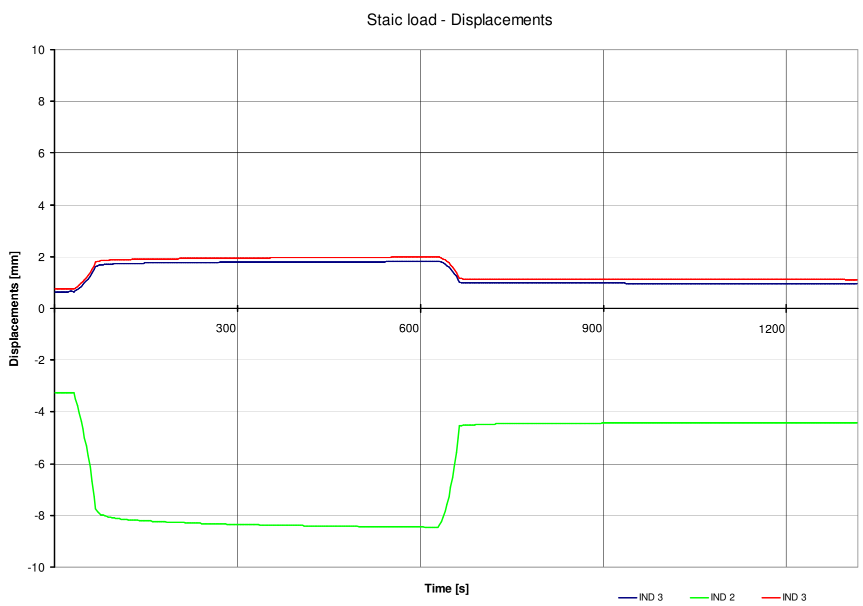

Figure 7. Displacements (vertical – green line, horizontal blue and red line) measured by induction gauges (see figure 5)

Calculated crown bending moment in T6 was:

MT6 = 3,21 *kNm/m* [2]

Calculated hunch bending moment in T3 was:

MT3 = 7,04 *kNm/m* [2]

4. CALCULATION USING CHBDC METHOD

As a one of very useful method, CHBDC is very common during design process. The main advantage of this method is fact we have results in very easy and quick way. The factored crown and hunch bending moments, caused by factored dead and live load can by calculated according to the following equations [4, 5]:

$$M_{cf} = \alpha_D M_{cD} + \alpha_L M_{cL}(1 + DLA) \tag{4.1}$$

$$M_{hf} = \alpha_D M_{hD} + \alpha_L M_{hL}(1 + DLA) \tag{4.2}$$

where:
M_{cf} – total factored crown bending moment kNm/m
M_{hf} – total factored hunch bending moment kNm/m
M_{cD} – crown bending moment due to dead load kNm/m
M_{hD} – hunch bending moment due to dead load kNm/m
M_{cL} – crown bending moment due to live load kNm/m
M_{hL} – hunch bending moment due to live load kNm/m
DLA – dynamic load as a friction of the live load
α_D – dead load factor
α_D – live load factor

and $$M_{pf} = \phi_h M_p \qquad (4.3) \qquad\qquad M_p = \frac{f_y I}{0{,}5h} \qquad (4.4)$$

where:
M_{pf} – factored plastic moment capacity *kNm/m*
$Ø_h$ – resistance factor for plastic *kNm/m*
M_p – unfactored plastic moment capacity of the section (crown and hunch) *kNm/m*
F_y – cold – formed yield strength of structure wall *MPa*
I – moment of inertia of corrugation profile (different for crown and hunch section) mm^4/mm
h – depth of cover, *m*
For calculation the same parameters of structure like tested object were used with the same values of dead and live load.

Below factors were used:
DLA – 0.21
α_D – 1,2
α_L – 1,5

and results:
M_{cD} – 4,63 *kNm/m* M_{hD} – 3,28 *kNm/m*
M_{cL} – 8,66 *kNm/m* M_{hL} – 4,51 *kNm/m*

$$M_{cf} = 21{,}28\ kNm/m \quad < \quad M_{pf} = 55{,}77\ kNm/m \qquad (4.5)$$
$$M_{hf} = 12{,}13\ kNm/m \quad < \quad M_{pf} = 18{,}75\ kNm/m \qquad (4.6)$$

5. CACULATION WITH THE USE OF CANDECAD SOFTWARE - FINITE ELEMENTS METHOD

For calculation of internal forces in Box Culvert, CandeCad ™ software was used. CandeCad™ 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 we have to define steel, soil and interface elements parameters. From the authors' 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 [6]. For numerical simulation of backfill material the Duncan soil model (Selig hyperbolic) was used [6]. 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 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* thick) 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.
Below, in figure 8, 9, 10 some drawings with results are shown:

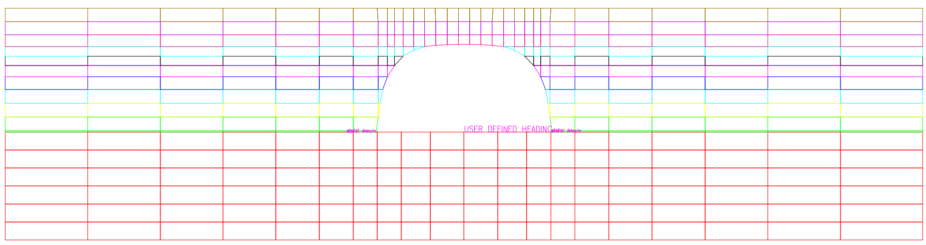

Figure 8. FEM mesh of the topic structure

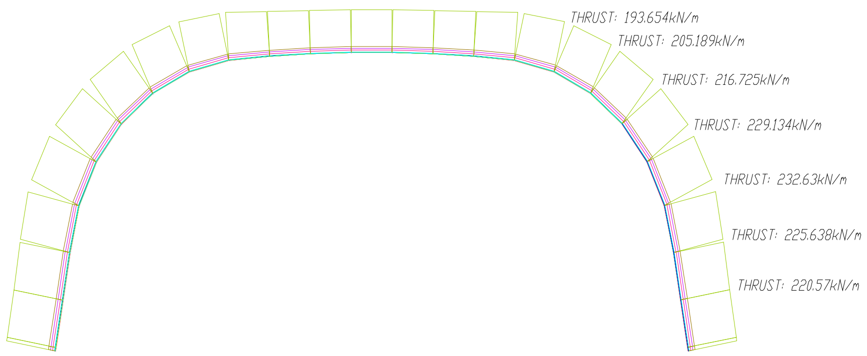

Figure 9. Thrust forces

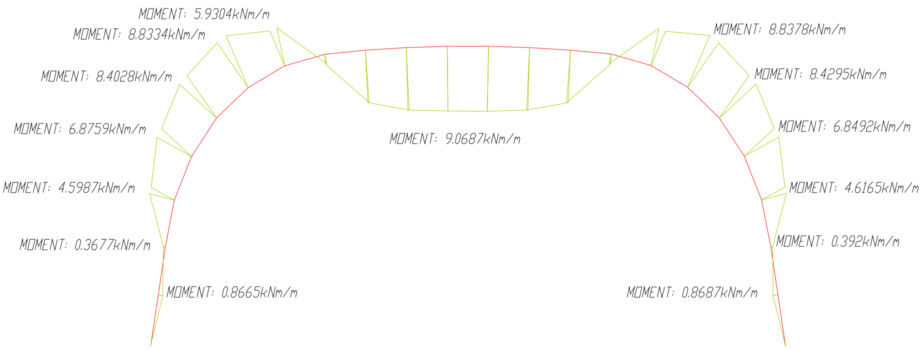

Figure 10. Bending moments

6. COMPARISON OF RESULTS AND CONCLUSIONS

At the below table 1 comparison of results is showed.
We can notice that values from research and from FEM are quite similar, and bending moments from CHBDC method are much bigger. Thrust forces which were the biggest at footing are very close from test and FEM.

Table 1. Results comparison

	Max. Displacements [*mm*]		Max. Bending Moment [*kNm/m*]		Max. Thrust forces at footing [*kN*]
	Crown - vertical	At footing - Horizontal	Crown	Hunch	
Test on the STEND	8,5	-2,0	3,21	-7.04	214,48
CHBDC	-	-	21,28	-12,13	-
FEM in CandeCAD	17,2	-3,2	9,07	-8,83	220,57

1) Presented results in every three types of analysis don't exceed permissible values,

2) In spite of the differences, we can say that results coming from three sources are rather cohesive,
3) Computational method CHBDC universally used for design seems to be safe with some of global factor because they give us higher level of inner strengths values than in tested structure and CandeCad ™ FEM analysis,
4) Based on authors' experience in CandeCad™ FEM analysis gives always results with global safety factor in comparison with results from live load tests.
5) Such comparison could look different for long span MP150 structure and requires another considering.

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PORÓWNANIE WYNIKÓW BADAŃ KONSTRUKCJI PODATNEJ Z BLACH FALISTYCH TYPU BOX MP150 Z WYNIKAMI OBLICZEŃ

Streszczenie

W roku 2003 Instytut Badawczy Dróg i Mostów w Żmigrodzie przeprowadził badania w naturalnej skali na konstrukcji MP150 Box. Konstrukcja ma rozpiętość 3,5m, wysokość 1,4m i wyprodukowana została z blachy o grubości 5mm. Konstrukcja została obciążona statycznie i dynamicznie za pomocą hydraulicznych siłowników zawieszonych na stalowej ramie. Niniejszy referat przedstawia wybrane wyniki z obciążeń statycznych.
Dla porównania wyników badań przeprowadzono obliczenia z zachowaniem jednakowych warunków drogowych. Obliczenia zostały przeprowadzone przy użyciu metody CHBDC z normy kanadyjskiej oraz metodą elementów skończonych za pomocą oprogramowania CandeCAD. W referacie opisano porównanie uzyskanych wyników.

Słowa kluczowe: podatne konstrukcje skrzynkowe, testy w naturalnej wielkości, porównanie wyników, FEM