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DEFORMATION OF A SOIL-STEEL STRUCTURE

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1. Introduction

The specific nature of soil-steel structures made of corrugated steel plates (CSP) depends thereon that they are consisting of two entirely different material media (soil and steel), therefore the whole load-capacity system becomes flexible [1], [2], [3], [4].

Thanks to the interaction between component units, i.e. their mutual influence, the “combined” load-carrying system is formed. So formed structural system allows to transfer external loads considerably larger than it results from treatment of the steel corrugation shell as the main carrying system in such bridges, as well as it does not cause increased stresses and displacements in them.

This paper shows the scope of the numerical study based on finite differences method (FDM) and the measurements displacements and strains obtained during backfilling and compacting of soil layers. The large load-carrying capacity of such structures (Fig. 1), showed many times during experimental tests [2], [5], [6].

2. Model of the soil-steel structure with interface elements

The computations of the soil-steel structure were conducted using the *FLAC* 2*D* program, which permits of the realization of the selected problems concerning statics and dynamics analysis of the structure. The soil is modeled as elastic-plastic model (criterion Coulomb-Mohr), with linear modulus variations with depth. Modulus variation $E(\mathrm{z}) = E_\mathrm{o} + mz$ is defined using surface modulus E_o and modulus gradient m. Two data parameters used to modeled for 95% – the first (and 98% – second) Standard Proctor are following: Poisson’s ratio $\nu_\mathrm{soil} = 0.20$ (0.0); cohesion $c_\mathrm{soil} = 0.0$ (0.0), friction angle $\phi_\mathrm{soil} = 43°$ (35°); gradient $m_\mathrm{soil} = 3.8$ MPa/m; $E_\mathrm{osoil} = 20$ MPa and unit weight of soil $\gamma_\mathrm{soil} = 20$ kN/m^3, dilation angle $\psi_\mathrm{soil} = 0.0°$ (0.0°), failure ratio $R_\mathrm{fsoil} = 0.96$ (0.85). The corrugated steel structure was modeled as bilinear elastic with material constants of: initial Young’s modulus $E_\mathrm{1s} = 207$ GPa; secondary Young’s modulus $E_\mathrm{2s} = 12$ GPa; Poisson’s ratio $\nu_\mathrm{s} = 0.30$; yield stress $\sigma_\mathrm{ys} = 300$ MPa, plate thickness $t_\mathrm{s} = 7.1\times10^{-3}$ m, moment of inertia $I_\mathrm{s} = 122638$ mm^4/mm.

The computation analysis was executed in the range of linear statics with non-linear contacts elements of interface type [2]. The loads in the form of backfill layers as evenly spreading on width of 1.00 m were applied. The analysis was conducted for 6 selected numbers of backfill what corresponded with layers (6, 9, 12, 15, 18 and 20), for which experimental field tests were also executed [2], [5].

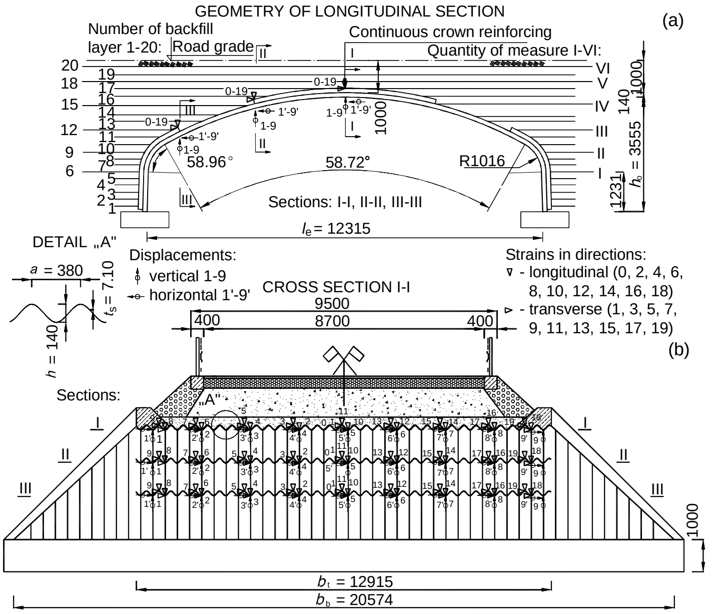

Fig. 1. The conception of the soil-steel structure
Rys. 1. Koncepcja konstrukcji gruntowo-stalowej

3. Analysis of results obtained from calculations and tests

3.1 Vertical Displacements

The highest vertical displacements in the shell structure made of corrugated steel in the section I–I (crown) were obtained from computation after final compaction of the 20th soil layer. They amounted to $f_{vc} = 3.96\times10^{-3}$ m and they were concentrated in the middle of the shell width (Fig. 2a and 3a). In the section II–II the maximum vertical displacements of the structure amounted to $f_{vc} = 2.46\times10^{-3}$ m and were situated in the middle of the span width; they also occurred during the compaction of the 20th soil layer. In the section III–III the maximum vertical displacements of the steel shell amounted to $f_{vc} = 1.31\times10^{-3}$ m and they also occurred in the middle of its width after the 15th soil layer compaction (Table 1).

3.2. Normal Stresses

The highest normal stresses in the steel shell structure obtained from the calculations, occurred in the section I–I, i.e. in crown of the shell, during the compaction of the 20th backfill layer, and their maximum value amounted to $\sigma_{yc} = 139$ MPa ($\varepsilon_{yc} = 679\times10^{-6}$). They occurred in the top of corrugations in the transversal direction of the structure (Fig. 2b and 3b). In the next section II–II, the highest normal stresses measured in transversal direction of the shell structure occurred during the compaction of the 20th backfill layer, and their value amounted to $\sigma_{yc} = 114$ MPa ($\varepsilon_{yc} = 555\times10^{-6}$) and manifested itself in the bottom of corrugations. In the last section III–III, the maximum normal stresses obtained from the calculations in the transversal direction of the shell structure were obtained in the top of

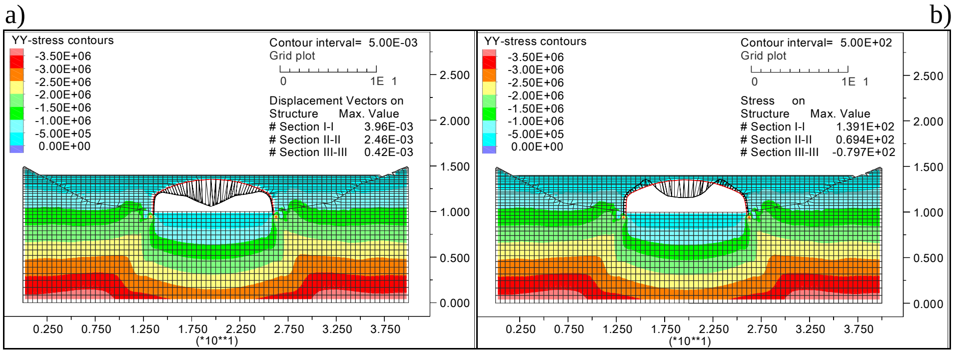

Fig. 2. Graphs of: a) vertical displacements and b) normal stresses in steel shell obtained during backfilling and compacting of soil layers

Rys. 2. Wykresy: a) przemieszczeń pionowych i b) naprężeń normalnych w stalowej powłoce otrzymane podczas zasypywania i zagęszczania warstw gruntowych

corrugations during the compaction of the 20th backfill layer their value amounted to σ_{yc} = 119 MPa ($\varepsilon_{yc} = 581\times10^{-6}$).

4. Conclusions

Based on the practical experience gained from the calculations and tests, the observations concerning the behavior of the soil-steel structure, the following general conclusions can be drawn:

1. The performance of the flexible shell made from CSP elements was beyond reproach. The average displacements and strains (normal stresses) values obtained from measurements were mostly lower than calculation values received from FDM analyzes in almost all the examined points and shell structure sections and for the same loads.

2. The relative variations between the displacements and strains obtained from the calculations by the FDM and measurements indicate small differences between these values in particular section in favor of safe behavior of the steel shell structure. They amount in range for deflections 2.85–20.00% and for strains 1.14–20.27%. Whereas the range of ratio of measured values to calculated values amounts to 0.83–1.10 for displacements and 0.85–1.23 for strains (Tables 1).

3. As the effect of executed calculations by the FDM and the experimental tests on the

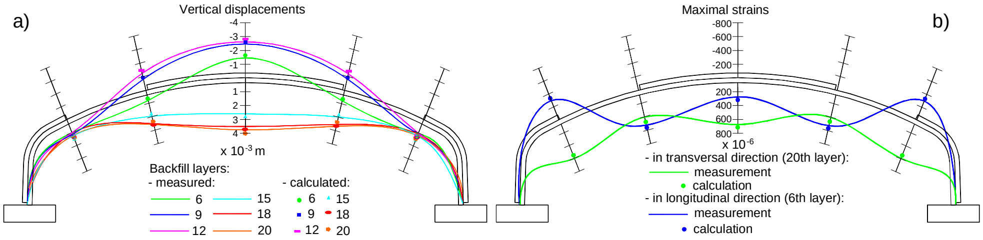

Fig. 3. The Comparison of calculated and measured values: a) deflections, b) strains

Rys. 3. Porównanie wartości obliczonych i pomierzonych: a) ugięć, b) odkształceń

Table 1. The values of maximum vertical displacements received from measurements and calculations in (10^{-3} m) in steel shell in analyzed sections during compaction of soil

Number of tested backfill	Section I–I				Section II–II				Section III–III			
	f_{vm}	f_{vc}	$(f_{vm}–f_{vc})$ / f_{vm} (%)	f_{vm} / f_{vc}	f_{vm}	f_{vc}	$(f_{vm}–f_{vc})$ / f_{vm} (%)	f_{vm} / f_{vc}	f_{vm}	f_{vc}	$(f_{vm}–f_{vc})$ / f_{vm} (%)	f_{vm} / f_{vc}
I	–1.37	–1.49	8.75	0.92	0.67	0.64	4.47	1.04	1.03	1.13	–9.71	0.91
II	–2.34	–2.56	9.41	0.91	–0.83	–0.88	6.02	0.94	1.07	1.15	–7.47	0.93
III	–2.57	–2.75	7.00	0.93	–1.20	–1.33	10.83	0.90	1.02	1.07	–4.90	0.95
IV	2.65	2.87	–8.30	0.92	1.98	1.85	6.56	1.07	**1.17**	**1.31**	–11.96	0.89
V	3.56	3.82	–7.31	0.93	**2.50**	**2.62**	–4.80	0.95	1.04	1.14	–9.61	0.91
VI	**3.72**	**3.96**	–6.45	0.94	**2.62**	**2.46**	4.58	1.04	1.15	1.22	–6.08	0.94
Notes: vertical displacements: measured f_{vm} and calculated f_{vc}.												

real object was affirmed, that for the engineering aims, the steel-soil bridge structure analysis it is possible to carry out in the plane state of strains (the two-dimensional 2*D* analysis) with the contact elements of the *interface* type between steel shell and backfill.

5. References

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DEFORMACJE KONSTRUKCJI GRUNTOWO-STALOWEJ

Streszczenie

W pracy przedstawiono wyniki obliczeń stalowej konstrukcji powłoki wykonanej z blach falistych podczas zasypywania gruntem wraz z ich analizą. Otrzymane wyniki porównano z rezultatami doświadczeń. Scharakteryzowano również założenia do obliczeń tej konstrukcji gruntowo-stalowej przy użyciu programu FLAC opartego o MRS.

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