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PROGNOSIS OF DEFORMATION OF A SOIL-STEEL STRUCTURE ON STEEL, CORRUGATED, FLEXIBLE SUPPORTS

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Abstract

The paper presents the results of survey measurements of deformation of a soil-steel structure in the construction phase during backfilling. Geometrical parameters defining the deformation of the steel corrugated flexible structures are: elevation that causes deflection in the key course, and narrowing that changes the horizontal dimension of the inside diameter of the structure (the span). The parameter that links both mentioned displacements is the change of the radius of the structure key course. Maximum displacements appear when the backfill reaches the key course level. The measurements of displacements of the shell during the backfilling of lower layers, allow us to forecast maximum deformation parameters. They are used to assess the safety during structure construction phase, before the structure's maximum loading. Comparative analysis presented in the paper is the basis for verifying algorithms used in predicting of the structure's deformation during backfilling. The analyzed soil-steel bridge is characterized by a complex structural geometry and is based on steel corrugated flexible supports, which is a characteristic feature of such structures. For these reasons, predicting parameters defining the deformation of the shell during construction is difficult.

Key words: soil-steel bridges, flexible supports, backfilling, estimation of displacements

1. TECHNICAL PARAMETERS OF THE STRUCTURE

The analyzed soil-steel structure was designed and build as an overbridge on the car racing track in the town of Mikołajki in Poland. Multi Plate MP 200×55 VBH-15 structure type with a span L = 10.36 m, height h = 5.934 m and 7.0 mm plate thickness was chosen, as in Figure 1. The choice of the was caused by technical considerations and, especially, the short time of construction. For that reason also supports wers designed in the form of corrugated steel flexible foundations, not the classic concrete ones.

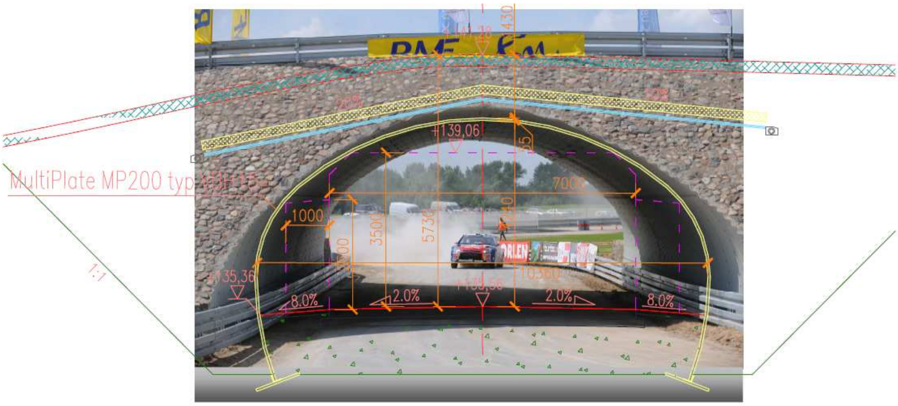

Fig. 1. Overbridge design and operation stage

The geometry of the shell shown in Figure 2 is composed of five (three types) stretches of radii of curvature *R*, *R1* and *R2*. The characteristic cross-sectional dimensions are the height h = 5.934 m and a maximum horizontal dimension (the span) L = 10.36 m. The proportion of these dimensions form a cross-sectional geometric parameters used in the calculations [2, 4]

$$\kappa = \frac{h}{L} = \frac{5.934}{10.36} = 0.573 \tag{1.1}$$

Structure top length is B_k = 13.86 m and bottom length in support line is B_p = = 24.03 m.

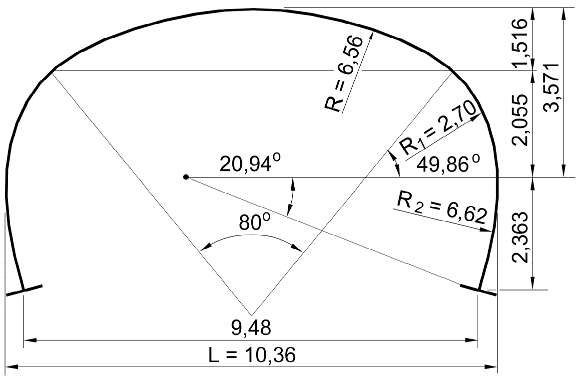

Fig. 2. Shell cross-section and geometry [m]

A characteristic feature of the analyzed object is its supportdesigned to be made of steel corrugated flexible plates with the same 200×55 mm profile. This kind of support is one of the soil-steel structure's flexible foundation. To this group belongs also the foundation of the corrugated metal sheet, but with a vertical groin [5]. There are also supports made of reinforced concrete piles and steel rolled sections (e.g. tubes, sheet piles).

The test results of the soil-steel structures built on flexible foundations indicate that in their operation they are similar to structures built on massive concrete supports [9]. Such similarity lies in the fact that the loads affectinf the supports during the backfill as well as during operation are so small that it is not necessary to build them with high rigidity, as in conventional concrete bridges. Through interaction of the shell with backfill in the transmission of operational loads flexible foundations are as effective as solid ones.

2. DEFORMATION OF THE SHELL DURING BACKFILLING

To determine the displacements of a soil-steel structure during backfilling, complex computational procedures must be applied, resulting from changes in soil physical parameters of the model along with the escalation of the backfill [8]. This paper presents a method based on the results of survey measurements [7] with the use of a precision measuring device, providing a satisfactory accuracy of 0.5mm. Steel shells, made of corrugated metal sheets with a low profile, as in the analyzed work, are characterized by high value displacements.

For the analyzed structure we carried out survey measurements of vertical displacements in the key course, and the change of the horizontal dimension of the inside diameter L. Measurements were carried out in three cross-sections spaced approximately 7.0 m (along the longitude axis of the object, marked as 1, 2, 3). Due to the fact that up to the level of z_g = 1.76 m the structure was backfilled on both sides (outside and inside the shell) measurements of deformation started from that level of backfill.

Horizontal displacements obtained from measurements shown in Figure 3, consists of two groups of lines designated as **L** and **P**, respectively from the left (**L**) and right (**P**) side of the shell. They show that during the laying of backfill there occurred abalanced inclination, of the shell (along the legth of the structure) with a value

$$\Delta u = u_L - u_P \tag{2.1}$$

The graph in Figure 3 show that the horizontal displacements of the lower parts of the structure stabilize with the backfill is located above the level z_g = = 4.80 m. This phenomenon is characteristic for soil-steel structures, and know as "hanging" of shell in the soil. Symbols 1 and 3 Shown in Figure 3 refer to inlet and outlet cross-section and symbol 2 refers to the middle, longitude symmetry axis cross-section. The distance between the two groups of lines show that the shell tilted to the left by about 20 mm.

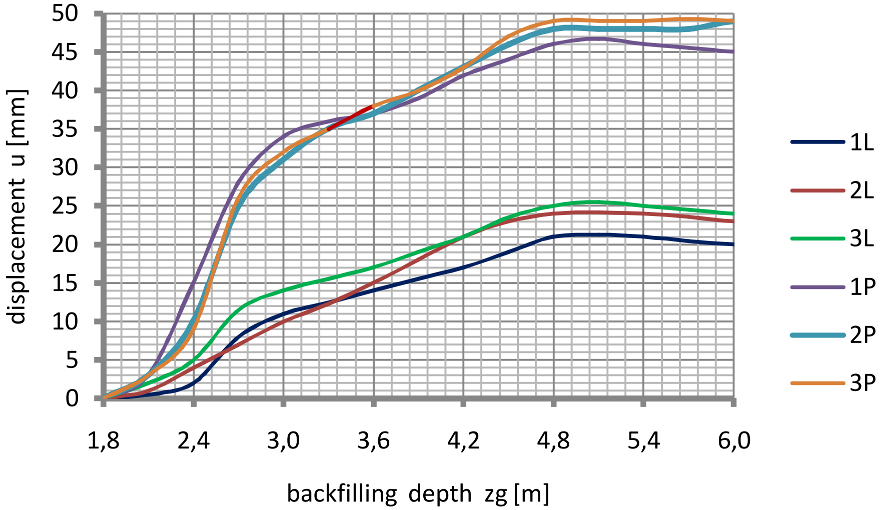

Fig. 3. Shell horizontal displacements (narrowing)

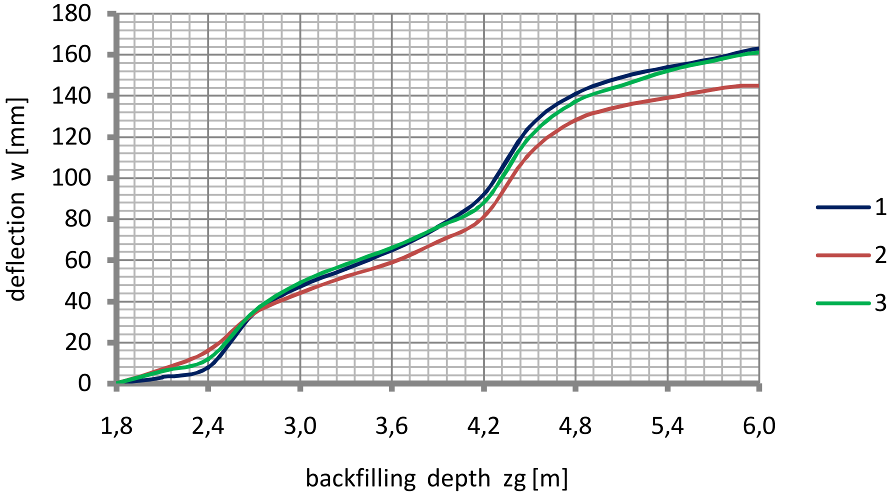

Fig. 4. Shell key course vertical displacements (uplift)

In case of the key course vertical displacements (uplift), shown in Figure 4, we observed a commonly occurring case of increased uplift at both ends (inlet/outlet – points 1 and 3) in relation to the key course (point 2). The shape of uplift lines $w(z_g)$ shows similarity in the whole range of the structure backfilling

Figure 5 shows the results for the middle section (in the longitude axis of symmetry of the structure, point 2). The deflection in the key course from Figure 4 (w) was accompanied by an aggregated horizontal displacement, causing narrowing (changing the span), as in formula

$$2u = u_L + u_P \tag{2.2}$$

The third parameter of deformation is the change of the radius of the shell curvature in the key course, denoted as dR. It is calculated on the basis of replacement shell curvature and a circle of radius R_Z described onto the isosceles triangle formed at three measuring points **L**, **K**, **P**. R_Z dependence on the dimensions of the triangle, as in Figure 6, is entered in the formula

$$R_Z = \frac{4M^2 + L^2}{8M} \tag{2.3}$$

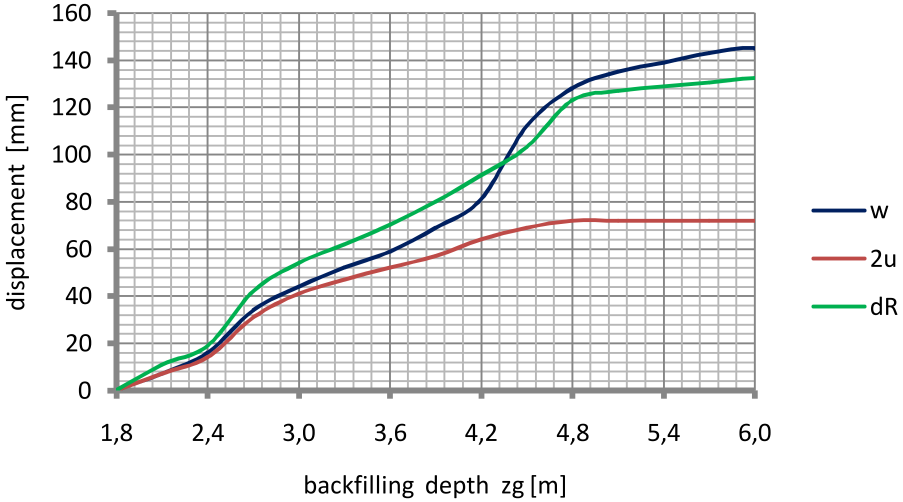

Fig. 5. Characteristic parameters of shell deformation

As a result of deformation of the shell shown in Figure 6 dimensions of the triangle are changing as well as the curvature R_Z of the shell to the value of

$$R_{uw} = \frac{4(M + w_k)^2 + (L - 2u)^2}{8(M + w_k)} \tag{2.4}$$

The difference of radiuses, which also takes into account the uplift w and narrowing $2u$ gives a global measure of shell deformation

$$dR = R_z - R_{uw} = \frac{w_k \cdot L^2 + 4Mu(L-u)}{8M(M+w_k)} - \frac{w_k}{2} \tag{2.5}$$

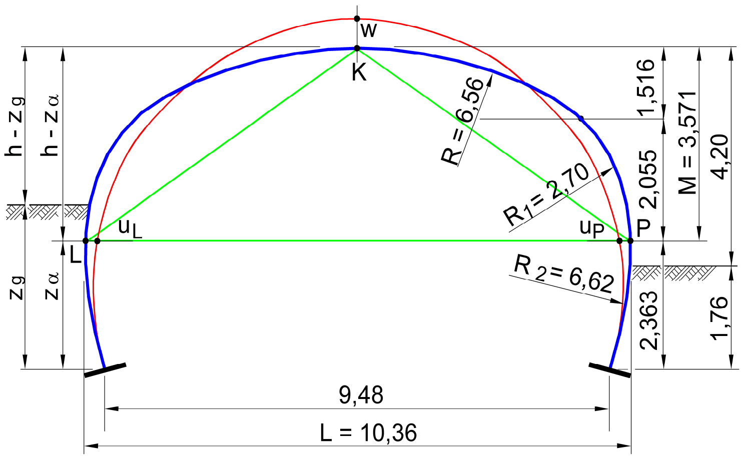

Fig. 6. Schell deformation scheme

Calculated from (2.5) *dR* value depends on the level of narrowing measuring z_α which is the distance from the key course *M*, as in formulas (2.3) - (2.5)

$$M = h - z_\alpha \tag{2.6}$$

As shown in [2] the value of $dR(z_\alpha)$ increases with the reduction of z_α. When $z_\alpha \rightarrow 0$ a local effect of changing the radius of curvature *R* [3] is considered and not a global deformation of the triangle as defined in (2.3). The graph given in Figure 5 shows that the largest value of *dR* occurs when $z_g = h$. In the present case it is

$$\frac{dR}{R} = \frac{132,28}{6560} 100\% = 2,02\% \tag{2.7}$$

3. PROGNOSIS OF SHELL DEFORMATION

Safe range of deformation of the shell during backfilling shall be specified in the technical specifications for construction of soil-steel structures as an indicator *w/L*, where *w* is the largest deflection in the key course which was created when the backfill reached the highest point of the shell ($z_g = h$). Estimation of *w/L* value is based on the test results of built facilities [1, 7, 8, 10], initiated by Duncan [4, 6]. For this purpose below formula is used [4]

$$\frac{w}{L}=\frac{\lambda L K_w}{10^5}\frac{\gamma_g}{E_g} \tag{3.1}$$

where λ is the rigidity of the structure, what means the shell in the soil medium

$$\lambda=\frac{E_g}{E}\frac{aL^3}{J} \tag{3.2}$$

The value of *w/L* depends on the soil physical parameters: the bulk density γ_g, longitudinal modulus of elasticity E_g and the shell flexural rigidity *EI/a* (*a* – corrugation wavelength, in the case *a* = 200 mm). In both models there is a shell span *L* as the largest dimension of the horizontal cross section. The function $K_w(\lambda,\kappa)$ takes into account the rigidity of the shell in the soil medium and its shape (1.1). For the analyzed structure these parameters take the value of

$$\lambda=\frac{25}{205000}\frac{10{,}36^3}{3213{,}2}10^9=42201$$

For κ calculated from (1.1) and λ from above, K_w = 2,6 was read out [4], so

$$\frac{w}{L}=\frac{42201\cdot 10{,}36\cdot 2{,}6}{10^5}\frac{22{,}5}{25000}100\%=1{,}023\%$$

what is *w* = 106 mm.

The value of K_w is not taking into account the complex shape of the shell, formed of sheet metal with multiple radii of curvature, as in Figure 2. Shell geometry is treated as a uniform system of a single radius of curvature. In the case R_z is calculated from (2.3)

$$R_Z=\frac{4h^2+L^2}{8h}=\frac{4\cdot 5{,}934^2+10{,}36^2}{8\cdot 5{,}934}=5{,}228\ m$$

In these calculation models the function $w(z_g)$ is a monotonic course parabola, with the extreme value at the point $z_g = h$. The course of the function $w(z_g)$ for the tested structure shows characteristic changes associated with the borders of the sheet metal compartments with different radiuses of curvature, as in Figure 2. There are three ranges separated by two ordinates z_g = 2.363 m and z_g = 4.418 m visible in Figure 4. The functions $w(z_g)$ clearly differ from those found in cases of shells of regular shape [1, 3, 4, 6, 7, 10]

Due to the complex shape of the shell cross section is also difficult to forecast narrowing $2u(z_g)$. In addition, it depends on the level of measurement that is z_α, as in Figure 3, referred to as

$$z_\alpha = \alpha\, R \tag{3.3}$$

In the analyzed case measurements started from the level of backfill close to the level of $z_a - z_g = 2.363 - 1.76 = 0.6$ m, as in Figure 6. Predicting the maximum value of dR, as in (2.5), during the laying of backfill, gives a more accurate estimation when the level of measurement is in the range [5]

$$0{,}05 < \frac{z_\alpha}{R} < 0{,}29 \quad . \tag{3.4}$$

In the analyzed case

$$\alpha = \frac{z_u}{R} = \frac{3{,}571}{6{,}56} = 0{,}544 \quad .$$

Hence the estimation of dR_{max} value determined by extrapolation, as in the example given [3] is burdened with considerable error. The maximum value as a local effect is much greater [3]. Figure 7 shows the results of estimating the changes of curvature in the shell with a regular shape. The result for α = 0 was determined as accurate measurements obtained from the extensometer.

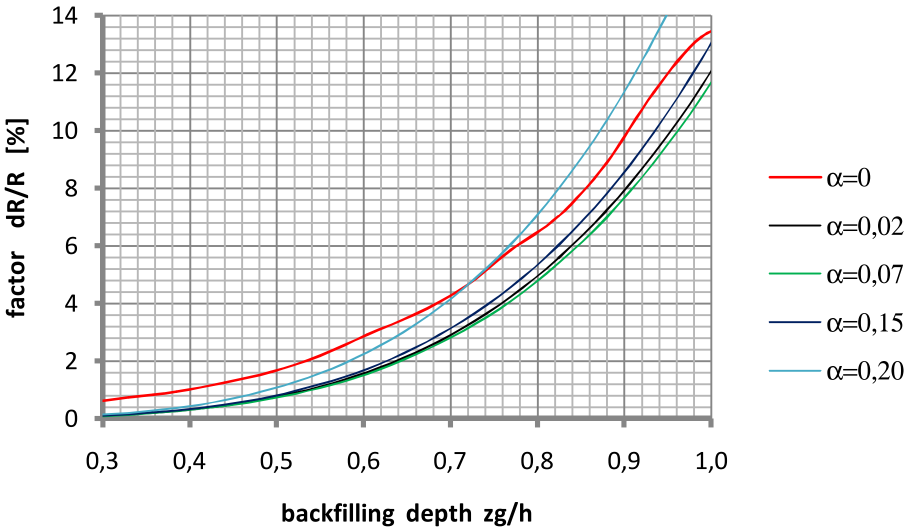

Fig. 7. Shell crown curvature changes during backfilling [5]

3. SUMMARY

Comparative analysis presented in the paper is the basis for verifying general algorithms used in predicting structure deformation during backfilling. The analyzed soil-steel bridge is characterized by a complex structural geometry and is based onsteel corrugated flexible supports, which is a characteristic feature of such structures. For these reasons, predicting the the maximum deformation parameters of the shell during construction is difficult and the calculation results may be treated as approximate.

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PROGNOZOWANIE DEFORMACJI POWLOKI OBIEKTU GRUNTOWO-POWŁOKOWEGO POSADOWIANEGO NA BLACHACH FALISTYCH

Streszczenie

W referacie przedstawiono wyniki pomiarów deformacji mostowego obiektu gruntowo-powłokowego w fazie budowy, czyli podczas układania zasypki gruntowej. Parametrami geometrycznymi określającymi deformację powłoki z blach falistych są: wypiętrzenie czyli ugięcie w kluczu oraz zwężenie czyli zmiana poziomego wymiaru światła konstrukcji. Parametrem wiążącym obydwa przemieszczenia jest zmiana promienia krzywizny części górnej powłoki, określana w kluczu. Do prognozowania maksymalnych wartości przemieszczeń, które wystąpią dopiero gdy zsypka gruntowa osiągnie poziom klucza stosuje się geodezyjne pomiary deformacji powłoki gdy zasypka układana jest na niższych poziomach. Pomiary przemieszczeń służą więc do oceny bezpieczeństwa obiektu w trakcie jego budowy, przed wystąpieniem zagrożenia przekroczenia wartości uznawanych za niebezpieczne. Analizy porównawcze podane w pracy są podstawą weryfikacji stosowanych algorytmów szacowania deformacji powłoki podczas układania zasypki gruntowej. Analizowany układ konstrukcyjny charakteryzuje się złożoną geometrią powłoki oraz. podparciem na blasze falistej, specyficznym dla tych obiektów. Z tych powodów prognozowanie parametrów określających deformacje powłoki podczas budowy jest utrudnione.

Słowa kluczowe: mosty gruntowo-powłokowe, podatne podparcie, zasypka, szacowanie przemieszczeń.