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EVALUATION OF SIMPLIFICATIONS OF 2D MODELS OF SOIL-STEEL SHELL BRIDGES

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Abstract

For calculations of soil-steel shell bridges a specialized software based on a 2D model is often used. Concentrated forces coming from vehicles are converted in these models model to a selected circumferential strip with application of Boussinesq theory. This theory, however, doesn't fully show the work effect (internal forces) of soil-steel structures as flexible structures cooperating with soil in carrying external loads. The effectiveness of this theory was estimated in this paper according to the 3D model formed out of MES elements which were considered as precise. For this reason a comparison algorithm based on internal forces influence function for a selected steel shell strip and special and a special newly developed software MACOR was used. The analysis showed the influence of general parameters of the object (width, span) are not fully reflected in Boussinesq theory. A major influence of general geometrical parameters of the structure (span, width) on the internal forces , which are neglected in Boussinesq theory, has been documented through this analysis. Parametrical analysis was carried based on a real structure built steel-soil bridge.

Key words: soil-steel bridges, live and dead loads, stress, strain

1. INTRODUCTION

Soil-steel structures are bridges whose main structure elements are flexible, usually steel one, shell from corrugated sheet, soil backfill surrounding and cooperating with the sheet and road surface (Figure 1). Such structures are designed and made in a way to cause advantageous cooperation of a shell with the other two elements, considered in bridge construction as non-structural [1].

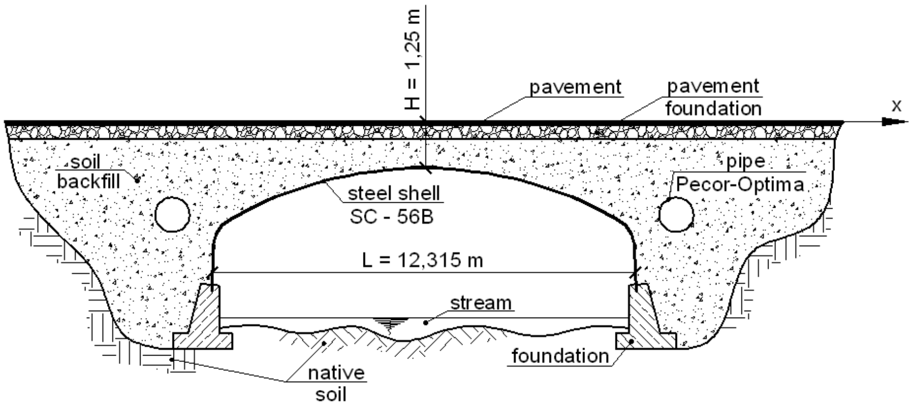


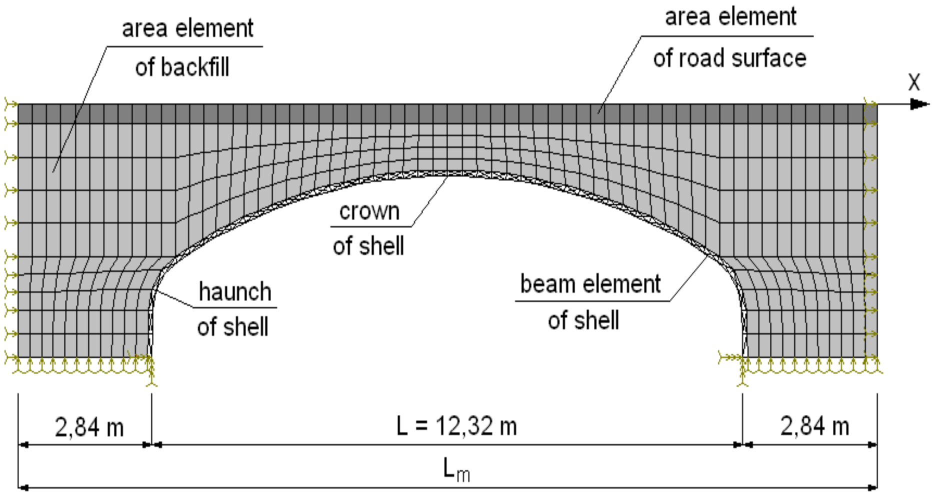
Figure 1. Longitudinal section of the soil-steel bridge in Szczytna.

For calculations of soil-steel structures a specialized software based on a 2D model developed from MES elements is often used (Figure 2a). The 2 D model is constructed from circumferential strip of a shell of width “a”. The model is represents well external force systems formed as a result of dead loads (weight of bridge). In the case of live loads (caused by vehicles), concentrated forces from the roadway surface are brought to the analyzed shell strip (model 2D), applying Boussinesq theory. This is also used in bridge designing in various methods [3]. The spatial model of a 3D structure (Figure 2b) enables more reliable representation of external forces in the shell from local loads. However, it requires a big number of elements and increased amount of work for digitalization of the object [4]. For such calculations there are usually used general MES systems. The 3D model used here has been made as a result of numerical tests of many models of the shell surrounded by soil and on the basis of result of researches with real objects [5,6]. In this paper there were considered two models [7], shown in Figure 2, where:

- the corrugated sheet was simulated as beam elements;
- the soil backfill was simulated as 2D or 3D isotropic continuum ;
- the road surface as surface or volumetric isotropic elements;
- the interface was simulated by using 1D elastic elements.

The numerical analysis was made by using the *COSMOS/M* system. The examples of numerical analysis were based on geometric parameters at Szczytna village, as shown in Figure 1 [9].

a) 2D model



b) 3D model

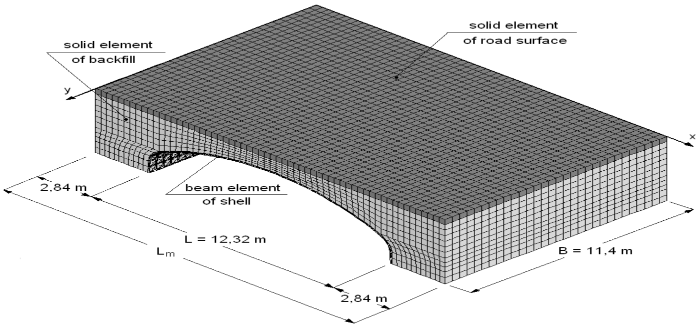


Figure 2. Numerical models of the bridge

2. LOAD INTENSITY RATE

The external force influence surface *S* in the analyzed point of the shell A(x_o, y_o), obtained when used 3D model, can be presented in a form of two profiles given in Figure 3:

- longitudinal one for the force moving along the *x* axis $(y_p = y_o)$;
- transverse one for the force moving along the *y* axis $(x_p = x_o)$;

According to the definition of the influence surface, the internal *S* force from an optionally laying concentrated *P* force can be found out by the following equation:

$$S(x_o, y_o) = \eta(x_o, x_p, y_o, y_p)\cdot P\,. \tag{1}$$

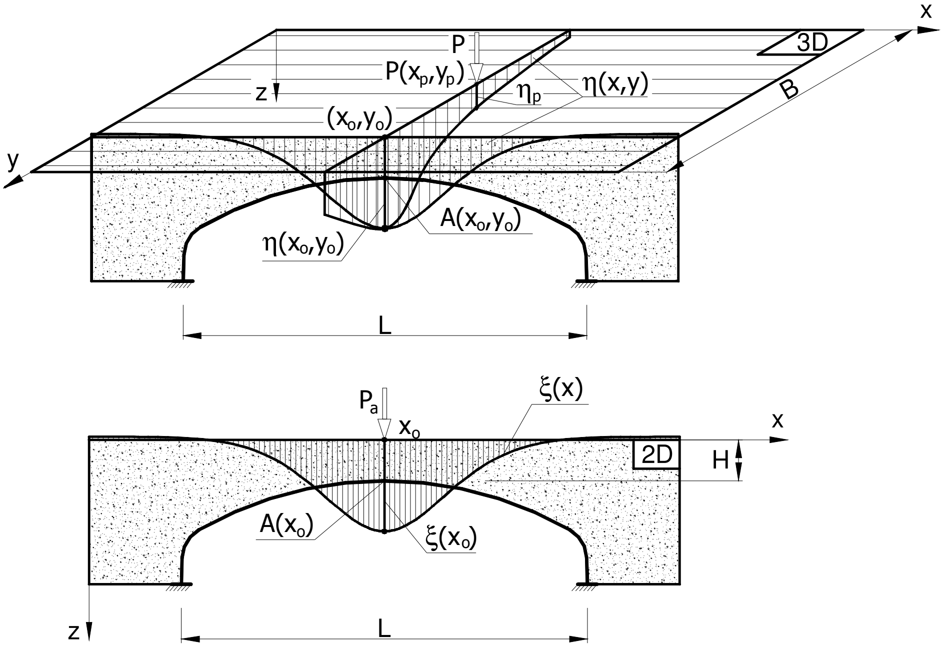


Figure 3. Sections of influence surface and influence line of internal force *S*

In a specific case when the *P* force is directly over the analyzed point $A(x_o, y_o)$, the following equation should be applied:

$$S(x_o, y_o) = \eta(x_o, y_o)\cdot P\,. \tag{2}$$

If the 2D model is used, the internal force $S(x_o, y_o)$ from a concentrated load *S* should be calculated with the following equation:

$$S(x_o) = \xi(x_o, x_p)\cdot P_a \tag{3}$$

where P_a is the load from the concentrated force $P(x_p, y_{p.})$, falling onto the structure sector of the width *a*. By comparing equations (1) and (2), we obtain:

$$C = \frac{P_a}{P} = \frac{\eta(x_o, y_o)}{\xi(x_o)}\,. \tag{4}$$

Considering the above, the load of an analyzed shell strip of a width ‘a” in 2 D model is equal:

$$P_a = C\cdot P\,. \tag{5}$$

The internal force *S* calculated with a use of both 2D and 3D models are the same when load force P is placed above $A(x_o, y_o)$.

3. COMPARITIVE ANALYSIS

Table 1 shows comparison of results obtained from model 3D and 2D, for a sample structure showed on Figure 1. As a load vehicle a three axis truck TATRA has been taken. It has following spacing of axles a_{ij} axle loads P_i : P_1= 50 kN, a_{12} = 3,55 m, P_2 = 100 kN, a_{23} = 1,35 m, P_3 = 100 kN. The load was placed in such a way that a middle axis of the truck (P_2) was located over the middle of a span of the bridge, which is x_o = 2,84 m+ L/2. In the longitudinal section wheels of the truck are aligned in accordance to coordinates y_I = 8,0 m and y_{II} =9,9 m. The analyzed strip is located under wheel line y_o= 8,0 m.

Table 1. Results of comparative analysis

Analyzed point at the shell	Model 3D				Model 2D			
	N [kN]	M [kNm]	σ [MPa]	w [mm]	N [kN]	M [kNm]	σ [MPa]	w [mm]
Middel of span	-7.45	3.69	-10.29	-1.58	-7.28	3.59	-9.97	-1.95
Middle of corner	-10.35	-2.74	-8.25	---	-9.03	-2.93	-8.55	---
where: N – axial force, M – bending moment, σ – normal stress, w – displacement								

By comparing values of internal forces specified in table 1 one can notice good accordance in the range of normal stresses and bending moments. Bigger differences of results are in the case of normal force at the haunch and deflections. It is related to that load intensity factor C (4) was calculated from normal stresses in the middle span of the bridge. Nevertheless results presented in table 1 indicate the efficiency of 2D models also in the case of concentrated live loads. In this case we have used software called MACOR which is available at ViaCon Polska. MACOR incorporates plan dimensions of the bridge (B, L) and the thickness of cover H. As for the shell structures the software uses currently available corrugated steel structures type Multi-Plate and SuperCor with gauges and dimensions commercially offered. The curvature of the crown and haunch areas are incorporated, too. Choosen results in a form of the load rate intensity obtained with the use of MACOR are presented at Figure 4. They are related to results obtained with a use of a commonly applied in the Boussinesq theory dimensionless parameter marked as μ_B. The value of μ_B incorporates location of points P and A as in the equation (5):

$$\mu_B(x,y)=\frac{3a}{4}\frac{\left[H^2+(x_o-x_p)^2\right]^2}{\left[H^2+(x_o-x_p)^2+(y_o-y_p)^2\right]^{\frac{5}{2}}} \tag{5}$$

When the force is located above analyzed point P (x_o, y_o) then the equation (5) is simplified to :

$$\mu_B = \frac{3}{4}\frac{a}{H} \tag{6}$$

The values of as μ_B can be compared with as μ_{num} included in equation (7):

$$P_a = \eta(x,y)\frac{1}{C}\cdot P = \mu_{num}(x,y)\cdot P \tag{7}$$

as these parameters have identical physical meaning. Both values μ indicate how much of the force P placed to the road surface is transferred as a load of the strip of width "a" in the 2 D model. Both values are obtained with entirely different assumptions, though.

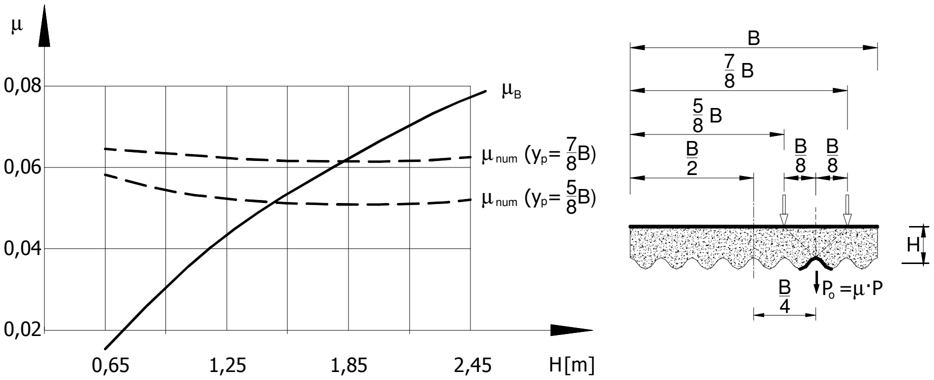


Figure 4. The values of the coefficients μ_B and μ_{num} depending on depth of the cover H

The results presented in Figure 4 indicate that an influence of the height of cover is on the distribution of load onto the soil-steel flexible structure is much bigger than what appears from the same distribution of force in the soil in accordance to Boussinesq. These differences are clearly visible especially when H is minimal. The case of low cover is however common and in favor for clearance are under the bridge [5]. Figure 5 presents changes of P_a determined by function $\mu(x, y)$ from (5) onto analyzed shell strip depending from basic geometrical parameters of the bridge B,L,H. Graphs $\mu(x_0, y_0)$ presented on Figure 5 get value as for the structure presented on Figure 1 in the central point (H=1,25 m). Results presented on Figure 5 are related also to plan dimensions of the structure B and L which are not included by formula (5) by Bussinesq. They have an important influence on μ, as well as depth of cover H.

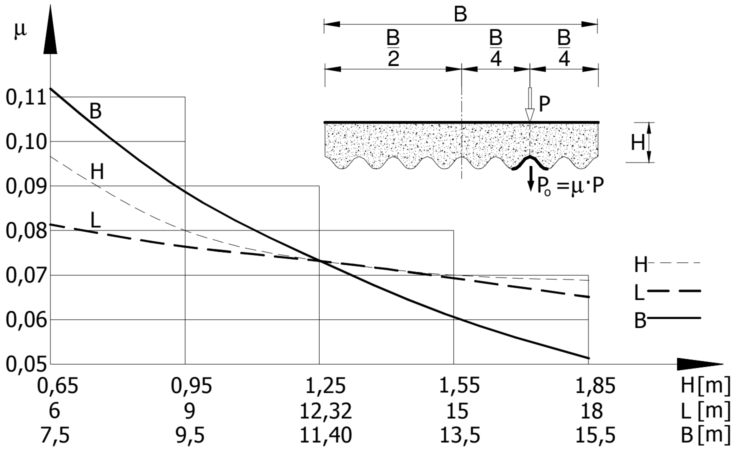


Figure 5. Function $\mu(x, y)$ depending on basic shell parameters

4. INFLUENCE LINES OF INTERNAL FORCES

Figure 6 shows examples of transverse profiles of influence planes of normal stress η(y₀,y) at the crown of the shell, i.e. for $x_o = L/2$+a. The lay-out of the analyzed strips at cross sections of the bridge is defined by the equation:

$$y_o = B\frac{15+2i}{30} \qquad \text{for } i = 0, 1, 2, \ldots, 7. \tag{8}$$

The diagrams presented in Figure 6 are laying out in such a way that extreme values of the ordinates are identical for the strips considering their position:

$$\frac{B}{5} < y_o < \frac{4B}{5} \tag{9}$$

(*B* is the width of the bridge structure). The extreme strips are normally overloaded because the $\eta(y)$ values for $y_o > 0{,}8B$ obviously increase. In bridge structures embankments are paved and used by pedestrians so those fragments of structures are not endangered to concentrated loads caused by vehicles' wheels. Considering the above we can come to conclusion that circumferential strips of a shell which are underneath a roadway are stressed in the same way.

Figure 7 presents given example of transverse and longitudinal influence plane profiles of the normal stress for the $y_o = 3B/4$ strip and point lying in the crown of shell ($x_o = L/2$). Geometrical parameters of the bridge were taken as for the already built object shown in Figure 1, where the width of the road crown is B = 11.40m. The influence of the soil backfill thickness (cover) *H* on the value of the ordinates of the stress influence plane is presented in Figure 7.

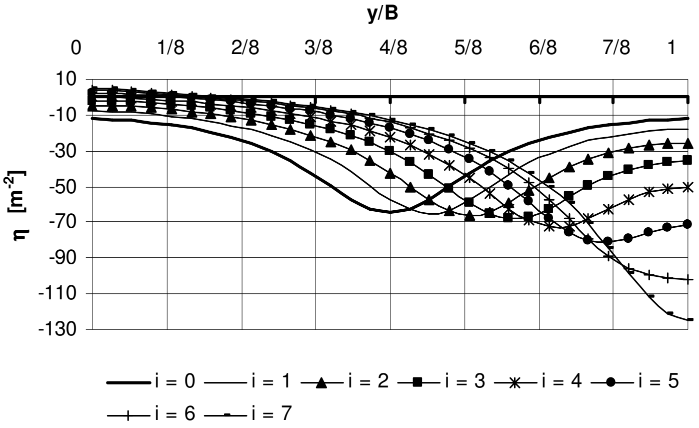


Figure 6. Transverse profiles of influence planes as a function of location of the strip in the longitudinal-section of the bridge y_0

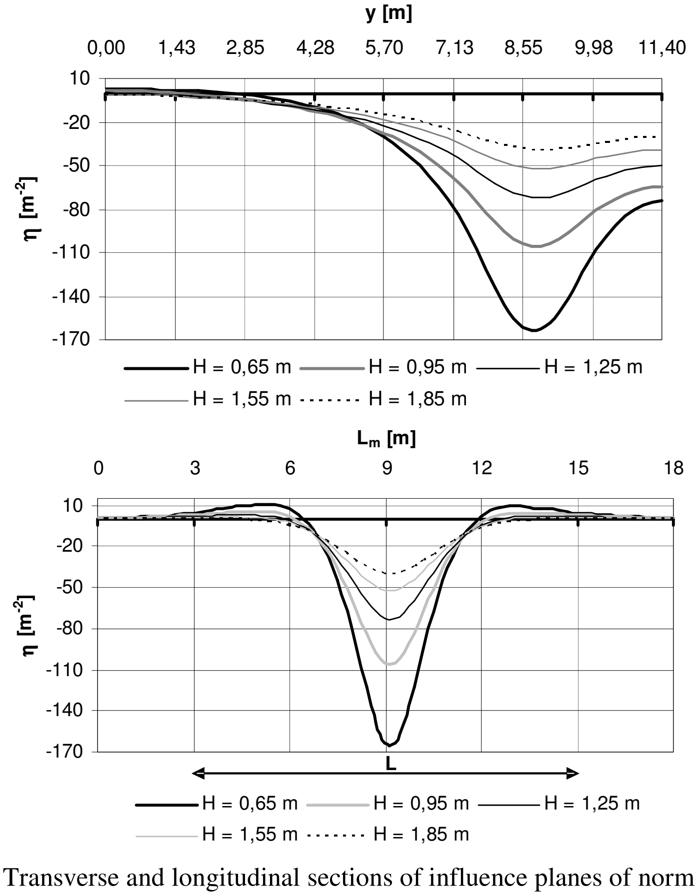


Figure 7. Transverse and longitudinal sections of influence planes of normal stresses depending on the depth of the cover

Shape of $\eta(x, y)$ function indicates that along with H increase the ordinates are decreasing. It gives evidence of the decreasing influence of local loads (concentrated) onto the shell strain. At the efficiently thick cover the concentrated loads are spread out on the entire width of the shell. Advantageous influence of the increased thickness of the cover is limited by the stresses caused by the soil backfill dead weight.

5. CONCLUSIONS

For the design calculations for soil-steel structures specialist software based on a 2D model is being used. The concentrated forces coming from vehicles which are loads for the bridge are brought to a selected section (2D model) with Boussinsq theory. In this paper the commonly applied Boussinesq theory was analyzed considering the MES 3D and 2D models. For this reason there had been worked out a comparison algorithm based on the function of internal forces influence in a selected strip of a steel shell. The parametric analysis was based on an example of a classical bridge constructed in Szczytna (Poland). The results of the analysis showed big differences between used models and especially considering the objects of minimum thickness of soil backfill (cover). An influence of geometrical parameters of the object (width, span) onto internal forces - neglected in many designing guidelines of the objects- has been shown. In the light of the given results this theory (Bussinesq) does not fully give the essence of the work of soil-steel bridge systems (internal forces) as flexible structures cooperating with the soil in carrying external loads. From the results of researches and many numerical analysis of soil-steel structures [5, 6,7,8,9,10] we can draw a conclusion that those objects cannot be treated as belonging to the same isomorphic group.

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SZACOWANIE UPROSZCZEŃ MODELI 2D MOSTÓW GRUNTOWO-POWŁOKOWYCH

Streszczenie

Do obliczeń projektowych konstrukcji gruntowo-powłokowej wykorzystuje się najczęściej specjalistyczne programy oparte na modelu 2D. Siły skupione pochodzące od pojazdów, będące obciążeniem jezdni obiektu mostowego, sprowadzane są zwykle w tym modelu do wydzielonego wycinka obwodowego z zastosowaniem teorii Boussinesq. W pracy poddano ocenie jej skuteczność w obliczeniach konstrukcji podatnych, współpracujących z gruntem w przenoszeniu obciążeń zewnętrznych. Wyniki oceny odniesiono do rezultatów uważanych z dokładne, uzyskanych z modelu 3D, utworzonego z elementów MES. W tym celu opracowano algorytm porównawczy oparty na funkcji wpływu sił wewnętrznych i własnym programie komputerowym MACOR. W wyniku przeprowadzonej analizy wykazano, że teoria ta nie ujmuje w pełni geometrii mostowych układów gruntowo-powłokowych. Wskazano na znaczny wpływ ogólnych parametrów geometrycznych obiektu (szerokość, rozpiętość) na siły wewnętrzne, pomijane w teorii Boussinesq. Analizę parametryczną wykonano na przykładzie wybudowanego, klasycznego mostu o konstrukcji gruntowo-powłokowej.

Słowa kluczowe: mosty gruntowo-powłokowe, obciążenia zmienne, uproszczenia modelu