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NUMERICAL MODELLING OF ENGINEERING SOIL SHELL STRUCTURE

Andrzej SUROWIECKI[*], Czesław MACHELSKI[**], Piotr SASKA[***]

[*] *Faculty of National Security, the General Tadeusz Kościuszko Military Academy of Land Forces*
e-mail: a.surowiecki@wso.wroc.pl

[**] *Faculty of Civil Engineering, Wroclaw University of Technology*
e-mail: czeslaw.machelski@pwr.wroc.pl

[***] *Faculty of Management, the General Tadeusz Kościuszko Military Academy of Land Forces*
e-mail: p.saska@wso.wroc.pl

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Abstract:

The purpose of this article is to provide examples of models used in ground and shell design in engineering facilities made using corrugated sheets, such as roads and rail. Despite the small size of culverts designed for transport use, sophisticated computational models are applied to faithfully reproduce them. To calculate internal forces and displacements resulting from the utility load, spatial 3D models with a very large number of elements are used. The paper discusses simplified 2D models allowing to accurately represent an object and its operation. The focus is on discussing three ways of discretization of a shell in the form of: corrugated metal, rod mesh and orthotropic shell.

Keywords:

numerical modelling, engineering, soil, shell structure

NTRODUCTION

Soil steel structures are engineering objects used as bridge structures: flyovers, footbridges, culverts, tunnels, underpasses, access roads and passages for wild animals. Many of them are used as municipal facilities, usually they are closed ducts (pipes) or they can be used for transport, e.g. conveyor casings. They are built-in and have a form of a shell covered with specially condensed soil. They are designed in such a way that they are durable thanks to the beneficial cooperation between the main elements of a load bearing system of the classical construction, i.e. a shell based on a foundation and the soil powder covering it.

The effect of the cooperation between the shell and soil is observed as an apparent unloading of a flexible shell (in the literature [1] it is called a trumpet arch). The intensity of the impact of soil on the load bearing system depends on shell stiffness with regard to the soil powder covering it. Due to this soil steel structures are divided into two main groups: stiff and flexible ones [1]. When designing flexible soil steel structures, soil powder and a roadway are treated as important elements of a load bearing system. They play completely different roles in a stiff construction. The stiffness of a shell made of corrugated sheets is small. When soil powder is distributed on its surface, a shell is significantly deformed as it is a geometric form limiting the amount of used soil powder. As a result the construction bears the whole load of soil just like a retaining wall (which is flexible). Only when covered with soil powder the shell becomes and efficient construction element which allows to carry significant transport related loads, such as vehicles or rail vehicles, see Figure 1.

Fig. 1. Sample soil shell structure made of corrugated sheets used as a railway culvert

Source: Mellak P., Anderson A., Pettersson L., Karomi R., Dynamic behaviour of short span soil-steel composite bridge for high-speed railway-field measurements and FE-analysis, Engineering Structure

The shell in a soil shell structure performs two different technical functions. When soil powder is being distributed, it is a falsework protecting the space under a facility and when the facility is used it cooperates with the ground and surface in transferring constant and variable loads. The construction phase is essential for shell security because it is here that the biggest dislocations and internal forces operate. Hence, it attracts most of attention when the general shell geometry and parameters of corrugated sheets are determined [1].

Due to the different way a shell operates in a soil environment during construction and during its use, different computational models are applied for each of these situations. Hence, this work discusses the computational models used for such a construction separately. The model which best represents the geometry and physical features of an object is a spatial structure made of the volume elements of soil and surface as well as a shell made of corrugated sheets. Figure1 presents an example of discretization of a rail soil steel object characterised by a small span used in transport construction as a culvert. In the construction model shown in Figure 2 its construction is represented taking into account the active part of soil powder and rail surface. A 3D model was made using 61,000 elements with 275 000 degrees of freedom. Thus, the computation task was enormous [4]. The work presents possible simplifications of 3D models and opportunities for using their simplified 2D counterparts. Computations related to such models are also conducted using general MES.

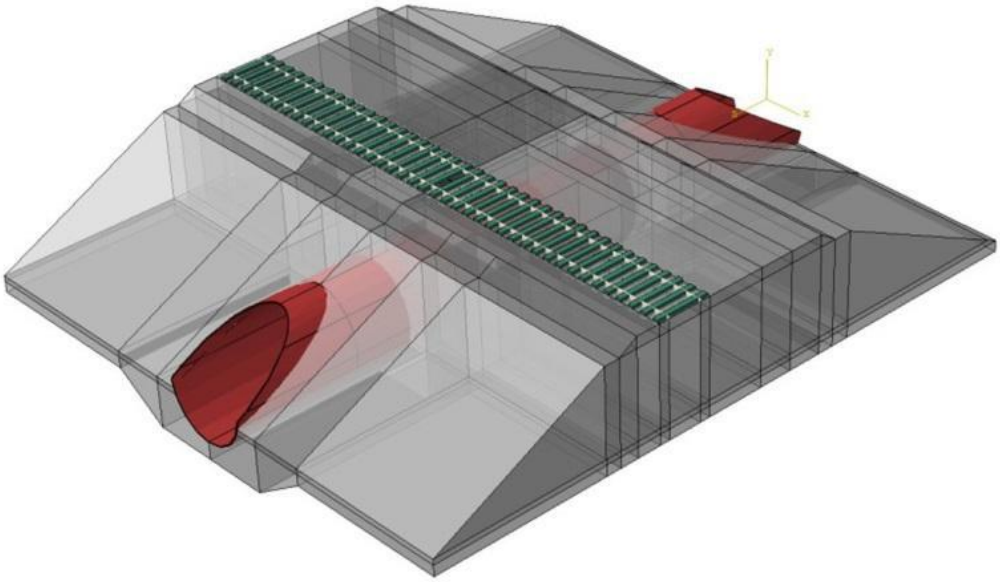

Fig. 2. Model of a railway culvert with a soil steel structure

Source: Mellak P., Anderson A., Pettersson L., Karomi R., Dynamic behaviour of short span soil-steel composite bridge for high-speed railway-field measurements and FE-analysis, Engineering Structures

1. 3D GEOMETRY MODEL

A universal (general) model of a soil steel bridge construction is spatial system of surface geometry and shells submerged in soil. In the case when a roadway is loaded with a group of concentrated forces, like in road and rail bridges, it is necessary to represent an object in a three-dimensional space (3D). To limit the size of the task, backfill soil is restricted only to the zone cooperating with a shell, as shown in Figure 2 and 3. The size of this area depends on the analysed load, i.e. a static or dynamic system.

Volume elements treated as an orthotropic continuum with the Young modulus E_z, E_x and E_y and with Poisson's ratio $\nu = 0{,}20$ are used in the discretization of soil powder. In the case of a roadway an isotropic continuum defined by E and ν appropriate for surface material is used. Ample research on objects with a static utility load shows the effectiveness of the adopted linear elastic physical properties of elements.

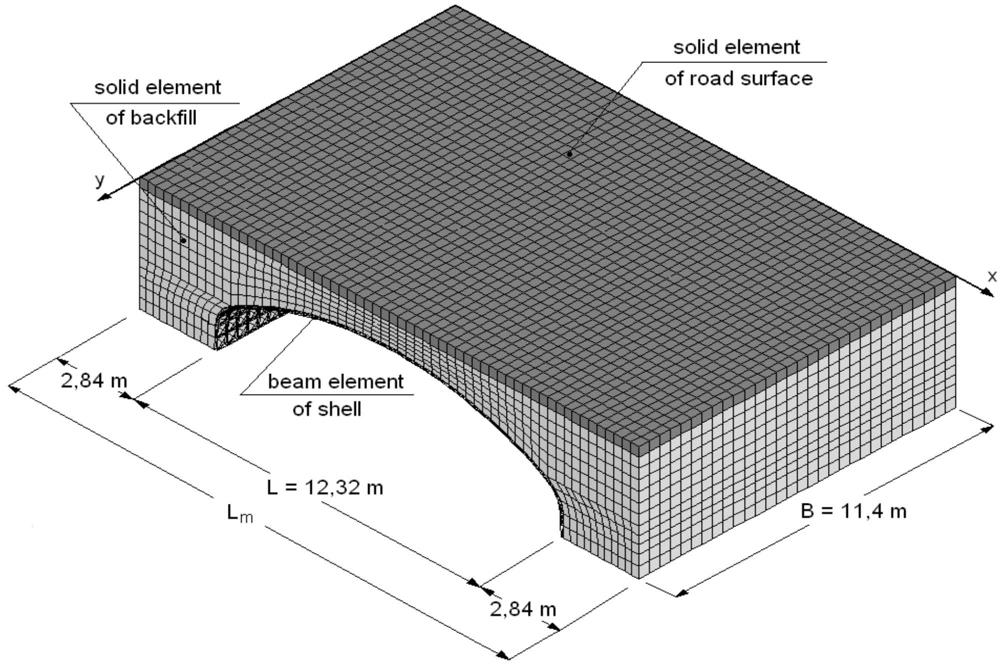

Fig. 3. Model of a soil steel road structure

Source: Machelski C., Modelowanie mostowych konstrukcji gruntowo-powłokowych, Dolnośląskie Wydawnictwo Edukacyjne, Wrocław

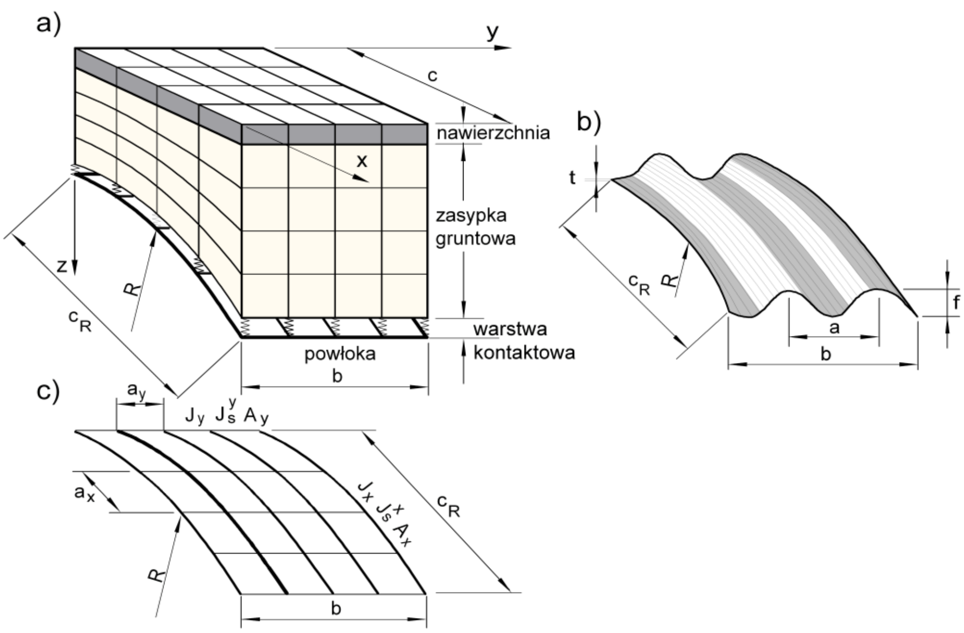

Fig. 4. Discretization of a soil steel structure model

Source: Machelski C., Modelowanie mostowych konstrukcji gruntowo-powłokowych, Dolnośląskie Wydawnictwo Edukacyjne, Wrocław, 2008

Three models of corrugates sheets are used. The most complex part of the process is the reproduction of the shape of a sheet of thickness t and isotropic physical properties, which is the case when these are steel sheets. In such a model a significant number of nodes (and elements) used to reproduce the curvatures of a corrugated sheet and the circumferential shape of a shell of radius R, as shown in Figure 4b, is important. It is easier to reproduce the geometry of corrugated sheet using rod elements, as shown in Figure 4c. Then a corrugated sheet makes a rod mesh of any mesh size a_x on a_y independent of corrugated sheet geometry. Rod meshes allow to create an influence function using kinematic input, analogically to other rod systems [1]. Such a discretization is discussed in [1].

Two-dimensional elements in the form of an orthotropic shell are equally effective in calculations [1]. A corrugated sheet with isotropic elastic properties, taken into account in the Young modulus E and Poisson's ratio ν, is reproduced in the parameters of an orthotropic shell of constant thickness h. From the bending stiffness condition in the circumferential direction (x) one obtains:

$$\frac{EI_a}{a} = \frac{E_x h^3}{12(1-\nu_x^2)} \tag{1}$$

Assuming there is a similar principle for circumferential axial forces, the following formula is obtained:

$$\frac{EA_x}{a} = E_x h \tag{2}$$

The values of the inertia moment I_a/a and the cross-sectional area A_a/a refers to the wavelength a, as shown in Figure 4b. Values presented in this way are geometric characteristics of sheet used in soil steel bridge structures [1].

The substitute thickness of an orthotropic shell is obtained from the system of equations (1) and (2):

$$h = \sqrt{12(1-\nu_x^2)\frac{I_a}{A_a}} \tag{3}$$

and the elasticity coefficient in the circumferential direction:

$$E_x = E\frac{A_a}{ah} \tag{4}$$

The bending stiffness condition in the transverse direction (y) to the circumferential direction in the following form:

$$\frac{Et^3}{12} = \frac{E_y h^3}{12} \tag{5}$$

is used to determine the second elasticity coefficient:

$$E_y = E\left(\frac{t}{h}\right)^3 \tag{6}$$

The following dependency is used to calculate Poisson's ratio of an orthotropic shell:

$$\nu_x E_y = \nu_y E_x \tag{7}$$

and the assumption that $\nu_x = \nu = 0.30$. Hence:

$$\nu_y = \nu \frac{E_y}{E_x} \tag{8}$$

Between soil powder and a shell there is a contact layer, as shown in Figure 4a. It has a special influence on the results of computations as it is used reproduce cooperation conditions between two completely different mediums – soil and steel. The models of the contact layer (interface) are differentiated, they depend on the analysed statistical issue, impact dynamics of vehicles and rail vehicles as well as long-term consequences of constant loads.

2. 2D GEOMETRY MODELS

A significant limitation of the range of the computational task is obtained by the reduction of the spatial system of surface geometry and a shell submerged in soil, as shown in Figure 3, to a flat system shown in Figure 5. In this case the main problem is the reduction of a vehicle or rail load from a road surface to a line parallel to the road axis and the circumferential section of the construction. To achieve this goal, the classical solution in the form of a force in the Boussinesq elastic half-space [1]. The efficiency of this solution is discussed in [1, 2, 3]. In the case analysed here the results of a comparison of two models, a 2D and 3D one, were used. On this basis the load division coefficients, which are frequently used in bridge structures, were determined.

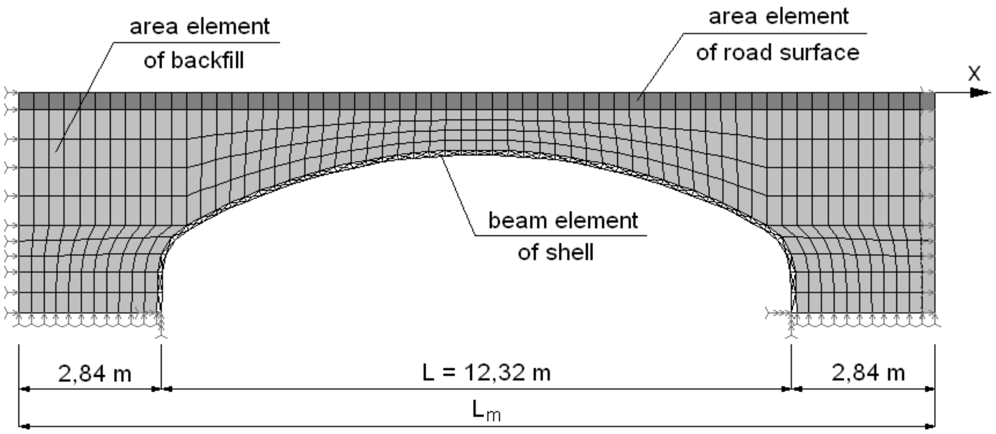

Fig. 5. Model of an object as a flat section of a soil steel structure

Source: Machelski C., Antoniszyn G., Influence of live loads on the soil-steel Bridges. Studia Geotechnica at Mechanica. Vol. XXVI, No. 3-4, 2004

3. MODELS OF CONSTANT LOADS

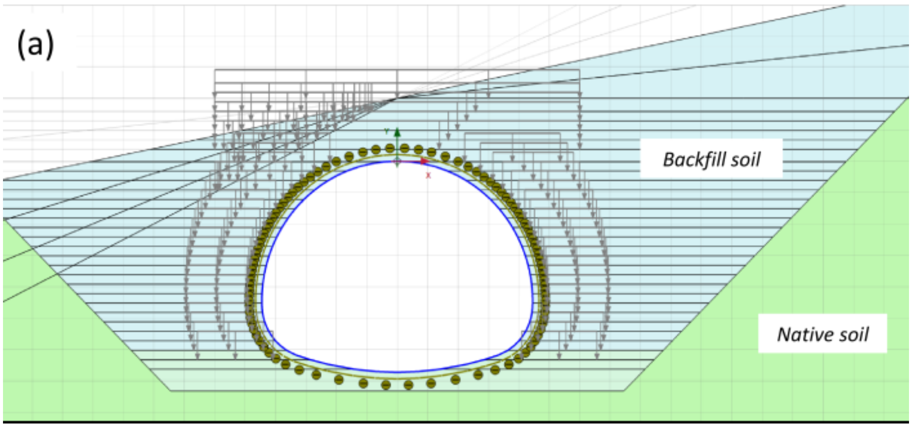

Fig. 6. Model of an object as a flat section of a soil steel structure

Source: Wadi A., Pettersson L., Karomi R., Flexible culverts in doping terrain: numerical solution of soil-steel loading effects, Engineering Structures

In statistical analyses of the cooperation between backfill soil and a shell, in the case of constant loads it is possible to use a flat 2D model. It meets the actual boundary conditions of the circumferential section of an object. Hence, one can take advantage of a significant limitation of the range of a computational task resulting from reducing a spatial system of surface geometry, as shown in Figure 3. The example given in Figure 6 meets such conditions because the object in question is a tunnel of variable surcharge slope, which was shown as alternative slope lines of the top edge of the slope.

Figure 7 presents a mesh elements used to represents a significant area of a domestic ground base. The part surrounding the shell is the slope characterised by variable thickness made of soil powder. The analysed issue is connected with the changes of internal forces in the shell during the construction of an object [5].

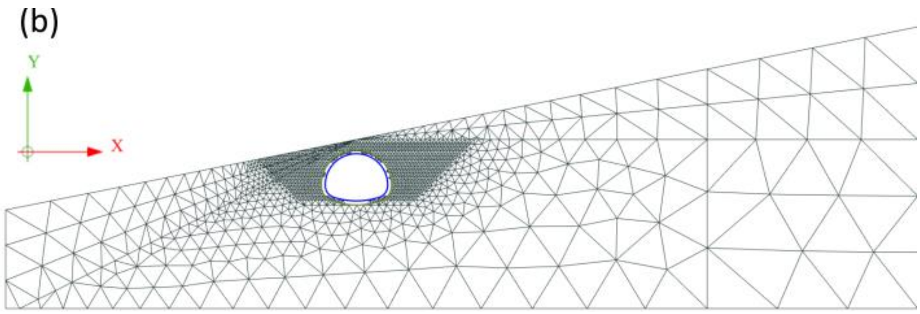

Fig. 7. Model of an object as a flat section of a soil steel structure

Source: Wadi A., Pettersson L., Karomi R., Flexible culverts in doping terrain: numerical solution of soil-steel loading effects, Engineering Structures

SUMMARY

The work is related to engineering soil shell structures which are commonly used as civil engineering structures. It focuses on the type of structures used in transport as road or rail objects. The paper discusses models of soil steel structures made using

corrugated sheets which are considered flexible. It concentrates mainly on models used to determine internal forces and displacements resulting from variable loads. In the case of such tasks, the best developed (accurate) system is a 3D system. Despite the small size of soil steel structures, their geometric range is large due to the necessity to take into account the cooperation of two completely different structure elements: ground and a shell made of corrugated sheets. The article discusses three ways of discretizing a shell in the form of: corrugated metal, rod mesh and orthotropic shell. The goal of the work was discussing simplified models allowing to accurately represents the operation of a structure using 2D models.

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BIOGRAPHICAL NOTES

Andrzej SUROWIECKI, DSc, Eng., Associate professor - the graduate of the University of Technology in Wroclaw, the Faculty of Civil Engineering. Currently, he is the professor at the Faculty of Civil Safety Engineering at the Military Academy of Land Forces. Scientific interests: mechanics of surface and subgrade, roads and railways, as well as design of communication earthen structures in terms of operational reliability.

Peter SASKA, PhD – the author of over 50 scientific publications on broadly understood military engineering. His main area of interest is the impact of an explosion on the environment, including military vehicles, and problems associated with transport infrastructure engineering, in particular the construction of roads and railways.

Czesław MACHELSKI, Professor, Eng., at Wroclaw University of Science and Technology faculty of Civil engineering. Scientific interests: shear forces in the connections of layered composite girders.

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