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Mathematical model for evaluating the stress-strain state of transport structures made of prefabricated corrugated metal constructions depending on the modulus of elasticity of the foundation soil

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Abstract

Modern transport structures require effective and reliable solutions to ensure durability under various foundation conditions, which is especially relevant in the context of increasing loads and the need for adaptive infrastructure. This study aims to assess the influence of soil foundation stiffness on the stress–strain state of prefabricated corrugated metal structures of transport facilities, considering the principles of cognitive sustainability and supporting decision-making in design. To achieve this aim, a method was proposed for replacing the corrugated shell profile with a smooth orthotropic shell by recalculating the equivalent physical and mechanical parameters, and finite element modelling was performed using the Plaxis software package. The results showed that as the soil foundation's elastic modulus increases, the vertical deformations of the metal shell decrease, while axial forces and horizontal deformations increase but remain within safe limits; when the modulus exceeds 90 MPa, horizontal deformations stabilise. The results make it possible to develop adaptive engineering solutions and can be integrated into decision support systems to enhance resilience and optimise infrastructure systems at the scale of the entire transport network. The proposed numerical modelling of prefabricated corrugated metal transport structures aligns with modern principles of cognitive sustainability, which involve shifting from local assessment of individual elements to a systemic approach in infrastructure management.

Keywords

transport structure, prefabricated corrugated metal constructions, deformations, stress, modulus of elasticity of the foundation

1. Introduction

Prefabricated corrugated metal constructions are promising structures in transport infrastructure development. These constructions are used in the construction of new transport facilities on highways and railways, in the reinforcement of reinforced concrete pipes and small bridges with reduced strength characteristics, as well as in the restoration of the load-bearing capacity of damaged engineering structures (Kovalchuk et al., 2017). However, based on operational experience, it is known that such structures are prone to the development of various defects and damages, which necessitate further research into the risks associated with their construction (Mistewicz, 2019).

An analysis of previous studies (Kunecki and Korusiewicz, 2013) has shown that, during the initial period of operation, transport structures made of prefabricated corrugated metal constructions experienced deformation of their cross-sectional shape. These deformations were of a residual accumulation nature, posing the risk of the metal transitioning into a plastic state. Moreover, defects and damage to the metal elements of the structures lead to a decrease in the load-carrying and traffic capacities of roads. This calls for additional strengthening measures (Kovalchuk et al., 2016), such as double corrugation methods and additional stiffening ribs.

One of the main contributing factors is the influence of weak foundation soils on the stress-strain state of prefabricated corrugated metal structures, due to the reduction in their strength characteristics. However, this issue requires comprehensive research to identify the patterns of how the modulus of elasticity of the structure's foundation influences the stress-strain behaviour of the metal corrugated constructions.

At the same time, studies of this type have an important cognitive component, as they aim to create adaptive infrastructure capable of flexibly responding to changes in operating conditions and loads. The obtained numerical modelling results can be integrated into decision support systems, enabling system-level optimisation of the transport network and contributing to the enhancement of human-centred resilience of engineering structures throughout their entire life cycle.

Cognitive thinking in transportation is critically important because it enables systematic analysis of complex transport processes, supports optimal decision-making, and allows infrastructure to adapt to changing operating conditions. Cognitive approaches make it possible to anticipate potential risks, assess the consequences of various load scenarios, integrate data from sensors and monitoring systems, and enhance both safety and reliability of traffic operations (Fischer et al., 2025; Krizsik et al., 2025).

When designing transport structures made of prefabricated corrugated metal constructions with a cross-section greater than 6.0 meters, it is recommended to use the finite element modelling method (El-Sawy, 2003; Bayoglu Flener, 2009; Esmaeili et al., 2013; Maleska and Beben, 2019). The regulatory document VBN V.2.3-218-198 applies only to engineering calculations of such structures with diameters up to 6.0 meters. Furthermore, the research in (Wysokowski and Howis, 2011)

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established that reliable calculations of the stress-strain state of transport structures made of prefabricated corrugated metal constructions can be obtained using the finite element analysis method.

Numerical analysis of prefabricated corrugated metal structures of transport facilities involves two specific approaches. The first is modelling the corrugated metal construction, and the second is modelling the compacted soil backfill (Bayoglu Flener, 2009; Kovalchuk et al., 2018). The soil backfill is typically modelled as an elastoplastic, nonlinearly deformable medium. Each plane of the elemental volume of the soil backfill is subjected to normal stress (σ) and shear stress (τ). For this purpose, the Mohr–Coulomb model is used (Luchko, 2013). This model includes the soil's physical and mechanical parameters: unit weight, deformation modulus, Poisson's ratio, cohesion coefficient, internal friction angle, and dilatancy angle. These parameters are considered input data and significantly impact the stress-strain state of the prefabricated corrugated metal structures of the transport facility.

In studies (Korusiewicz and Kunecki, 2011; Mak et al., 2009;), based on experimental research and theoretical assessment of the stress-strain state of structures made from corrugated metal constructions, it was established that these structures can withstand overloads up to 2.5 times their design capacity, reaching only 16% of the yield strength of the steel used in the metal construction (Maleska and Beben, 2018).

In a study (Beben, 2018), during experimental investigations of corrugated metal structures under seismic loads, the maximum stress reached 92.3% of the yield strength of the construction steel. Under dynamic loads caused by moving railway rolling stock (Nabochenko et al., 2019), the maximum vertical deflection of the metal structure's diameter was recorded at 1.63 mm during the passage of a freight train, and 1.11 mm during the passage of a passenger train.

Much of the research is also devoted to studying the impact of temperature variations on the stress-strain state of transport structures made of corrugated metal constructions (Gera and Kovalchuk, 2019;   2022). Uneven temperature distribution on the surface of corrugated structures leads to the development of thermal stress states. When corrugated metal constructions are used to repair defective reinforced concrete pipes, stress concentration occurs at the material boundaries in the reinforced concrete pipe–filler–metal structure. The differences in the physical and mechanical properties of the construction materials cause this.

Studies (Beben, 2009; 2012; Elshimi, 2011; Kovalchuk et al., 2016; Machelski, 2013; Pettersson and Sundquist, 2012) have established that the load-bearing capacity of transport structures made of prefabricated corrugated metal constructions depends on the degree of compaction of the soil backfill. Insufficient compaction leads to a decrease in the load-bearing capacity of the structures. Moreover, works (Babyak and Neduzha, 2022; Yagoda et al., 2024) note that the condition of the infrastructure affects the dynamic interaction between the track and rolling stock.

From the analysis of the scientific literature, it has been determined that most studies present results evaluating the stress-strain state of corrugated metal structures subjected to variable loads from vehicles and environmental temperature effects. A significant portion of the research is also devoted to assessing the influence of the physical and mechanical properties of soil backfill on the strength characteristics of the structures. However, the issue of evaluating the stress-strain state of corrugated metal constructions with consideration of the modulus of elasticity of the foundation soil remains unresolved.

This study aims to model the stress-strain state of transport structures made of prefabricated corrugated metal constructions, considering the foundation soil's modulus of elasticity. To achieve this aim, this study investigates the distribution of stresses and deformations in the compacted soil backfill of the transport structure composed of corrugated metal constructions. Then, the patterns of deformation and stress variation in the metal structures of the transport facility, depending on the modulus of elasticity of the foundation, are established.

2. Data and methods

The theory of orthotropic shells is applied to recalculate the equivalent thickness of the corrugated metal sheet used in the structure (El-Sawy, 2003). This theory involves determining the equivalent thickness of the shell, which corresponds to the thickness of the corrugation. As a result, it allows for the determination of the actual value of the transport structure's axial stiffness EI (beam stiffness). The diagram illustrating the substitution of the corrugated isotropic shell of the transport structure with a flat orthotropic shell is shown in Fig. 1.

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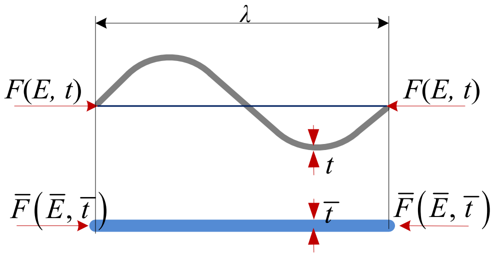

Figure 1. Diagram of replacing the corrugated metal profile of a transport structure with a smooth orthotropic shell (El-Sawy, 2003)

In Figure 1 and the formulas below, the following notations are used: E – Young's modulus; $\bar{E}$ – equivalent Young's modulus; t – thickness of the corrugated profile of the structure; $\bar{t}$ – equivalent thickness of the smooth profile; λ – length of the corrugation of the structural profile.

The formula for determining the equivalent thickness of the orthotropic shell of the transport structure is (1).

$$\bar{t} = \sqrt{12\frac{I}{A}}\ . \tag{1}$$

In this case, the equivalent Young's modulus of the steel used in the metal structure of the transport facility is calculated using (2).

$$\bar{E} = \frac{12I}{\bar{t}^3} \tag{2}$$

In formulas (1) and (2), the values I and A A represent the moment of inertia and the cross-sectional area per unit length of the corrugated shell of the transport structure, respectively.

Knowing the equivalent thickness and equivalent Young's modulus of the orthotropic shell, the axial moment of inertia of the cross-section of the smooth orthotropic shell can be determined using (3).

$$\bar{I} = \frac{\lambda\bar{t}^3}{12}\ . \tag{3}$$

In this case, the cross-sectional area of the orthotropic shell of the structural sheet is determined by (4)-

$$\bar{A} = \lambda\bar{t}\ , \tag{4}$$

Finally, the section modulus of the cross-section of the orthotropic shell of the structural sheet is determined using (5).

$$\bar{W} = \frac{\lambda\bar{t}^2}{6}\ . \tag{5}$$

These formulas calculate the equivalent geometric parameters of the orthotropic shell of corrugated metal structures in transport facilities. The presented approach can be adapted for other corrugation geometries or composite soil–structure systems with a layered foundation.

Since the methodology is based on the principle of replacing the corrugated shell with an equivalent smooth orthotropic shell by recalculating its physical and mechanical properties, changing the corrugation geometry would only require adjusting the design parameters (elastic moduli, moments of inertia, stiffness coefficients) according to the new shape.

In the case of a layered foundation, the approach can be extended by considering a multilayer soil model in the numerical simulation, where each layer is described by its own physical and mechanical parameters. This allows the stress–strain state of the structure to be assessed, accounting for the heterogeneity of the foundation and the interaction between layers, making the methodology applicable to a broader class of soil–structure systems.

The stress calculation in prefabricated corrugated metal constructions of transport structures is performed using the formula (6).

$$\sigma = \frac{N}{A} + \frac{M}{W} < f_{yd}\,, \tag{6}$$

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where: *N*, *M* – axial force and bending moment, respectively; *A*, *W* – cross-sectional area and section modulus per unit length of the metal structure; f_{yd} – yield strength.

The stress-strain state of prefabricated corrugated metal constructions is determined using the finite element analysis software Plaxis. The research can be conducted in both two-dimensional and three-dimensional problem settings. In the case of a 2D problem setup (Luchko, 2013), the stress components σ_n, τ_n on an arbitrary plane are determined based on the stresses σ_x, σ_y, τ_{xz}. The formulas are as follows:

$$\sigma_n = \sigma_x \cos^2 \alpha + \sigma_z \sin^2 \alpha + \tau_{xz} \sin 2\alpha; \quad (7)$$
$$\tau_n = (\sigma_x - \sigma_z) \sin \alpha \cos \alpha - \tau_{xz} \, s \cos 2\alpha.$$

The principal stresses, maximum σ_1 and minimum σ_2, which are related to the conditions of equilibrium, are determined using the following formulas:

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_z}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_z}{2}\right)^2 + \tau^2_{xz}} \, . \quad (8)$$

In the case of perpendicularity of the two principal planes, formula (7) can be written in the following form:

$$\sigma_n = \sigma_1 \cos^2 \alpha_1 + \sigma_2 \sin^2 \alpha_1; \quad (9)$$
$$\tau_n = (\sigma_1 - \sigma_2) \sin \alpha_1 \cos \alpha_1 .$$

The strength condition of the soil at a point, according to the Mohr-Coulomb law, is expressed by the following formula:

$$\frac{\sigma_1 - \sigma_2}{2} + \frac{\sigma_1 + \sigma_2}{2} \sin \varphi - c \cos \varphi = 0 \, . \quad (10)$$

To investigate the influence of the modulus of elasticity of the foundation soils on the stress-strain state of corrugated metal constructions, a pipe with a diameter of 7.0 meters is considered. The geometric diagram of the pipe is shown in Fig. 2.

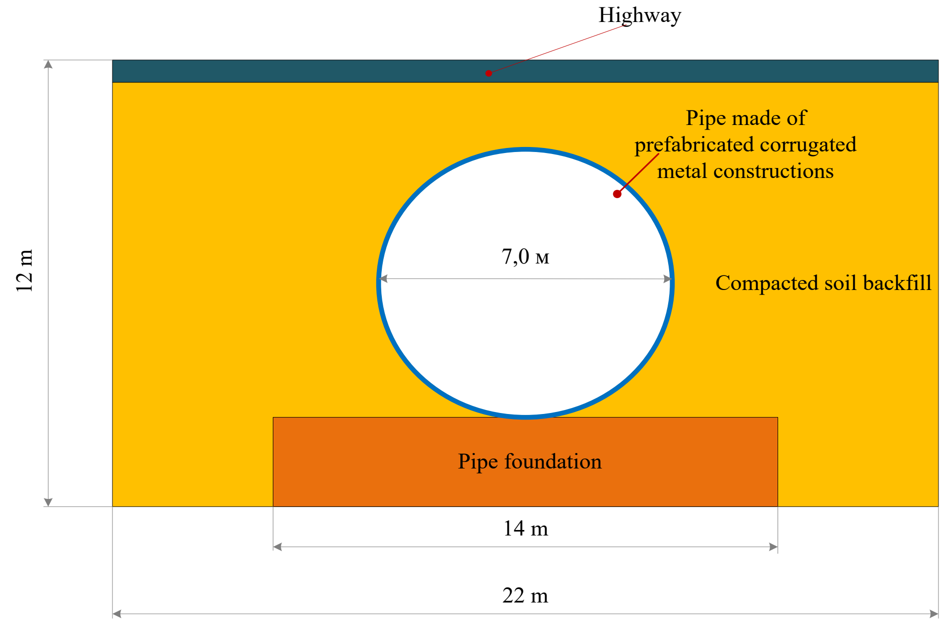

Figure 2.Geometric diagram of the pipe made of prefabricated corrugated metal constructions

A road passes above the pipe—the corrugated metal constructions of the pipe rest on a crushed stone foundation. Around the corrugated pipe, a compacted crushed stone-sand backfill is applied with the following soil properties: unit weight γ = 23.5 kN/m³; Poisson's ratio ν = 0.28; cohesion c = 10.2 kPa; internal friction angle φ = 34°; dilatancy angle ψ = 1.0°, and deformation modulus of the soil backfill E = 30 MPa.

To account for the influence of the physical and mechanical properties of the pipe's foundation soil on the stress-strain

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state of the corrugated metal constructions, the deformation modulus of the crushed stone foundation soil was varied from E = 30 MPa to E = 150 MPa, with a calculation step of 10 MPa. The soil parameters of the pipe's metal structure foundation are presented in Table 1.

Table 1. Soil Parameters of the foundation for corrugated metal pipe structures

Physical and mechanical characteristics	Crushed stone materials
Unit weight of the foundation soil of the metal structure, γ, kN/m³	12.1
Poisson's ratio of the foundation soil, ν	0.28
Cohesion of the foundation soil, c, kPa	0.03
Internal friction angle of the foundation soil, φ, °	41.9
Dilatancy angle, ψ, °	0
Variable value of the modulus of elasticity (deformation) of the pipe foundation soil, E, MPa	30–150

The load on the pipe made of prefabricated corrugated metal constructions is applied from a dump truck weighing 37 tons. In addition, the corrugated metal constructions of the pipe are subjected to additional loads from the pavement structure and their own self-weight.

The structure uses prefabricated corrugated metal constructions of the MultiPlate MP150×50 type. The corrugation wave parameters of the structure are shown in Fig. 3.

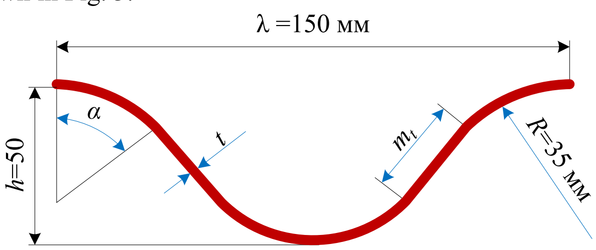

Figure 3. Geometric parameters of the corrugated profile of metal structures of the MultiPlate MP150×50 type

The main geometric parameters of the MultiPlate MP150×50 type structures, with a corrugation metal thickness of 7.0 mm, are presented in Table 2.

Table 2. Geometric parameters of the profile of MultiPlate MP150×50 type structures

t	A, mm²/mm	I, mm⁴/mm	W, mm³/mm	Z, mm³/mm
7	8,85	2801	98,3	141,9

The Young's modulus of the steel used in the corrugated metal structures of the facility is taken as $E = 2.1 \cdot 10^5$ MPa, and the Poisson's ratio is $\nu = 0.3$.

The stress-strain analysis of the pipe made of prefabricated corrugated metal constructions uses the Plaxis software. The computational model of the pipe with the applied load and boundary conditions is shown in Fig. 4.

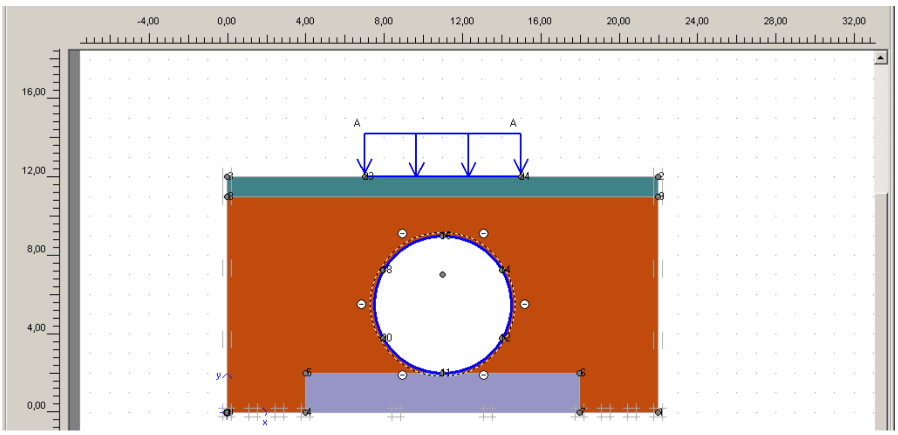

Figure 4. Computational model of the pipe

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Vertical and horizontal displacements are restricted at the bottom of the pipe's soil envelope, while vertical displacements are allowed on the lateral sides. Fifteen-node finite elements are used to build the finite element model (Santos et al., 2020). The mesh size of the finite elements in the soil backfill and foundation is larger in the areas distant from the metal structures, compared to the mesh near the pipe's metal structures. The mesh is refined in the contact zones between the metal structures and the compacted soil backfill or foundation.

The stress and deformation analysis of the compacted soil backfill and pipe foundation is carried out in a nonlinear problem setting using the Mohr–Coulomb elastoplastic model.

3. Results and discussion

3.1. Results of the stress-strain analysis of the pipe's compacted soil backfill

The results of the calculation of vertical deformations in the compacted soil backfill for a foundation modulus of 150 MPa are shown in Fig. 5, while the horizontal deformations are presented in Fig. 6.

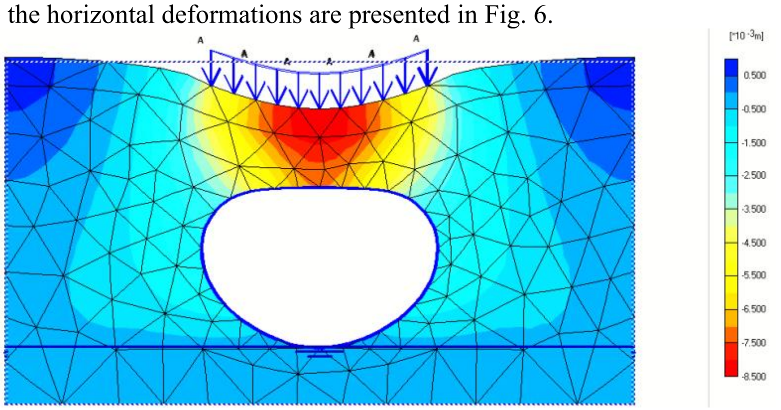

Figure 5. Vertical deformations of the compacted soil backfill of the pipe made of prefabricated corrugated metal constructions at a foundation modulus of 150 MPa

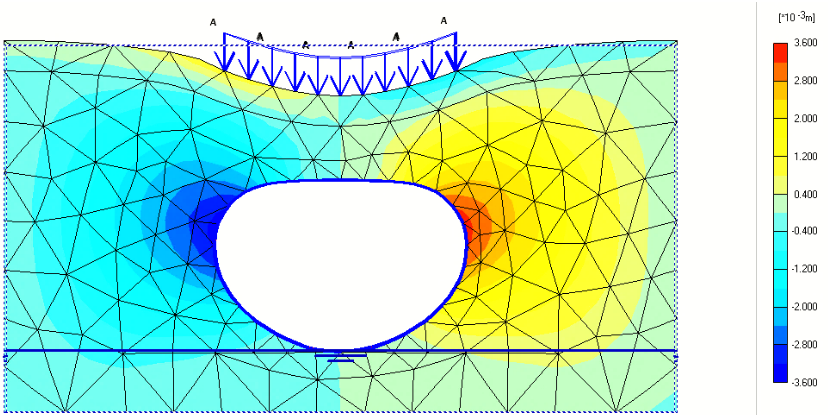

Figure 6. Horizontal deformations of the compacted soil backfill of the pipe made of prefabricated corrugated metal constructions at a foundation modulus of 150 MPa

The deformation calculation results showed that with a foundation modulus of 150 MPa for the pipe made of prefabricated corrugated metal constructions, the maximum vertical deformations reached 8.36 mm. At the same time, the horizontal deformations that occurred along the horizontal diameter of the pipe amounted to 3.41 mm.

The stress analysis results for the compacted soil backfill of the pipe made of corrugated metal constructions are shown in Fig. 7.

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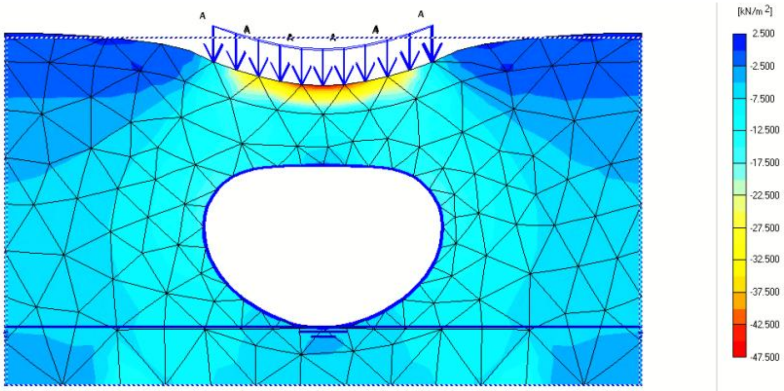

Figure 7. Stress distribution in the compacted soil backfill of the pipe made of corrugated metal constructions at a foundation soil modulus of 150 MPa

The maximum stresses occur at the crown of the pipe, with a magnitude of 46.07 kPa. At the same time, zones of plastic deformation accumulate in the pipe's arch and base areas of the soil backfill (Fig. 8).

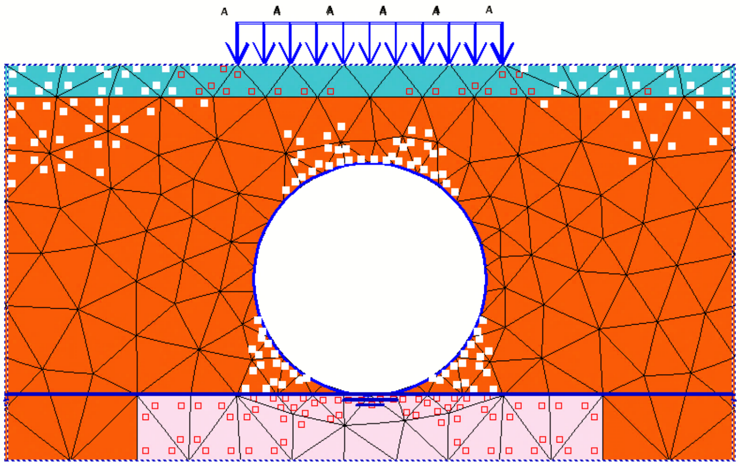

Figure 8. Distribution of plastic points in the compacted soil backfill of the pipe made of prefabricated corrugated metal constructions at a foundation soil modulus of 150 MPa

The results of multiple simulations of the stress-strain state of the pipe's compacted soil backfill, depending on the foundation soil modulus ranging from 30 MPa to 150 MPa with a calculation step of 10 MPa, are presented in Table 3.

Table 3. Stress-strain state of the compacted soil backfill depending on the modulus of elasticity of the foundation soil for the pipe made of prefabricated corrugated metal constructions

No.	Soil base modulus of elasticity, MPa	Maximum vertical deformations, mm	Maximum horizontal deformations, mm	Maximum stresses, kPa
1	30	8.87	3.35	46.62
2	40	8.72	3.37	46.45
3	50	8.63	3.38	46.41
4	60	8.57	3.38	46.31
5	70	8.52	3.39	46.32
6	80	8.48	3.39	46.29
7	90	8.46	3.39	46.27
8	100	8.43	3.4	46.12
9	110	8.41	3.4	46.12
10	120	8.39	3.4	46.08
11	130	8.38	3.4	46.13
12	140	8.37	3.4	46.09
13	150	8.36	3.4	46.07

Based on the stress-strain state analysis of the soil compaction backfill around the pipe made of prefabricated corrugated metal structures, it was determined that the maximum vertical deformations depend on the modulus of elasticity of the pipe's

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foundation soil. With a soil modulus of elasticity of E = 30 MPa, the maximum vertical deformation is 8.87 mm, while at *E* = 150 MPa it is 8.36 mm. Accordingly, the maximum horizontal deformation is 3.35 mm and 3.4 mm, respectively. At the same time, the maximum stress in the soil compaction backfill reaches 46.62 kPa at *E* = 30 MPa, and 46.07 kPa at *E* = 150 MPa.

Significant vertical deformations of the soil backfill above the crown of the corrugated metal pipe structures are observed (Fig. 5).

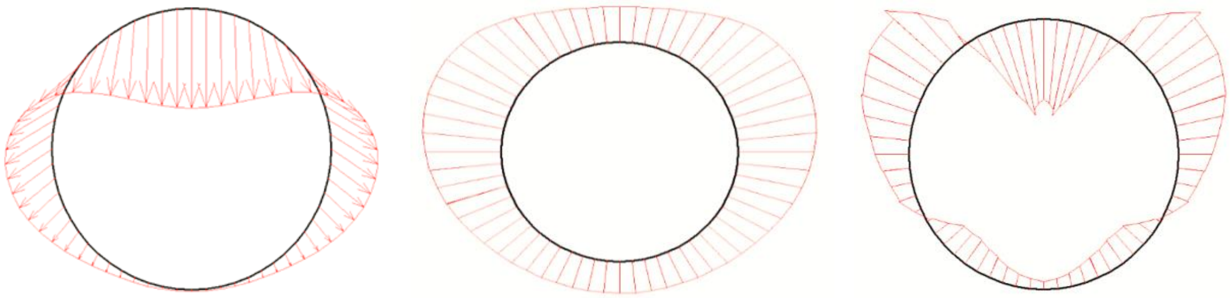
As shown in Table 3, with an increase in the modulus of elasticity of the pipe's foundation soil, the magnitude of vertical deformations in the soil compaction backfill decreases, while horizontal deformations increase. When the soil deformation modulus reaches 90 MPa or more, horizontal deformations in the soil backfill stabilise. At the same time, an increase in the modulus of elasticity of the foundation leads to a reduction in stress levels within the soil backfill.

The distribution of vertical and horizontal deformations in the soil compaction backfill of the pipe and the stresses is nonlinear. The decrease in vertical deformations becomes less significant when the foundation modulus exceeds 90 MPa, compared to the change in stresses observed in the modulus range from 30 MPa to 90 MPa.

Therefore, the modulus of elasticity of the foundation significantly affects the stress-strain state of the soil compaction backfill around pipes made of prefabricated corrugated metal structures.

3.2. Assessment of the stress-strain state of corrugated metal pipe structures depending on the modulus of elasticity of the foundation soil

To assess the stress-strain state of the corrugated metal pipe structures, it is necessary to determine the values of axial longitudinal force and bending moment. For this purpose, the Plaxis software suite obtains the total deformations, axial force, and bending moment diagrams. The distribution diagrams of deformations, axial force, and bending moment for a foundation soil modulus of elasticity of 150 MPa are shown in Fig. 9.



Total displacements | Axial force, N11 | Bending moment, M11

a ***b*** ***c***

Figure 9. Diagrams for a foundation soil modulus of elasticity of 150 MPa:
a – total deformations of the corrugated metal shell of the pipe; b – axial force in the pipe walls; c – bending moment

From the diagram of vertical deformations of the metal pipe structures (Fig. 9a), it can be seen that the maximum deformations occur at the crown of the pipe and the minimum at the base. The maximum axial force arises on the lateral sides of the metal structures, at points offset by 35 degrees from the vertical diameter (Fig. 9b). These points also exhibit the maximum positive bending moment (the metal structures are under tension). However, at the pipe crown, the bending moment is negative, indicating that the metal structures are under compression (Fig. 9c).

From the graphical dependencies of vertical and horizontal deformations of the corrugated metal pipe structures (Figs. 10–11), it is evident that the distribution is nonlinear.

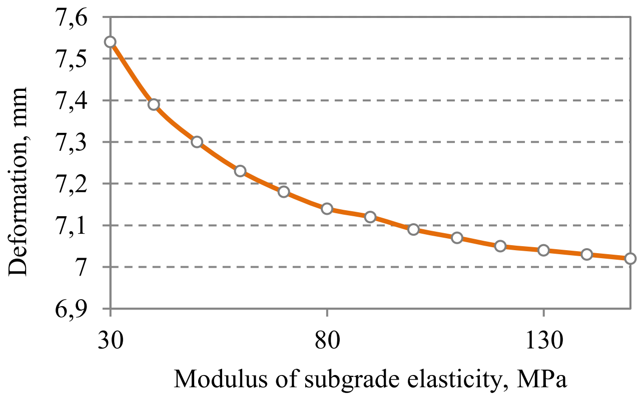


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Figure 10. Vertical deformations of corrugated metal pipe structures

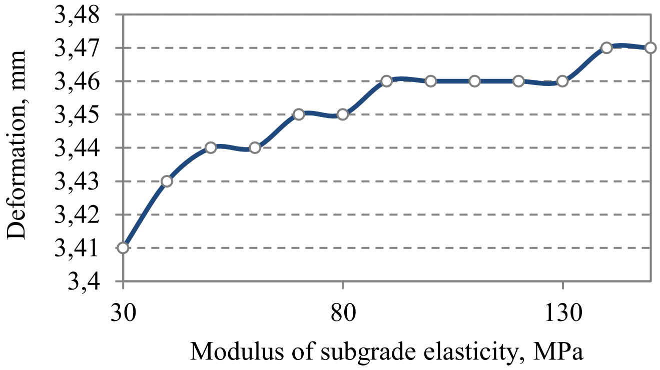

Figure 11. Horizontal deformations of corrugated metal pipe structures

The magnitude of vertical deformations of the metal pipe structures decreases with an increase in the modulus of elasticity of the pipe foundation soil, while the horizontal deformations of the metal pipe structures increase. However, the increase in horizontal deformations is marginal, and when the modulus of elasticity of the foundation soil exceeds 90 MPa, the deformations stabilise.

To determine the stresses in the prefabricated corrugated metal pipe structures, the results of the calculations of axial force and bending moment in the walls of the metal structures are presented.

The graphical dependencies of these forces are shown in Fig. 12 and Fig. 13, respectively.

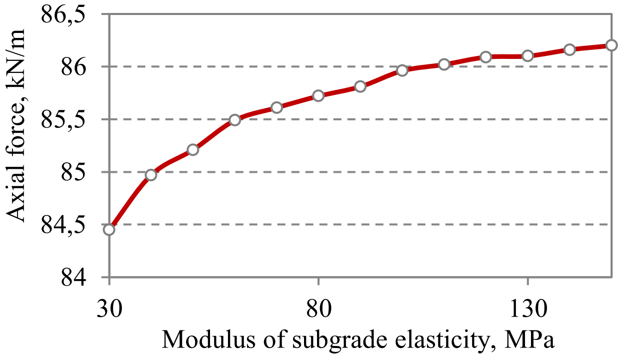

Figure 12. Dependence of axial forces in metal structures on the modulus of elasticity of the pipe foundation soil

The values of axial forces arising in the corrugated metal pipe structures increase with the growth of the modulus of elasticity of the pipe foundation soil.

The research results showed that with an increase in the modulus of elasticity of the pipe foundation soil, the vertical deformations of the metal structures decrease, while the axial forces in the metal pipe structures increase.

The maximum vertical deformation of the metal pipe structures is 7.54 mm at a foundation soil modulus of 30 MPa, and 7.02 mm at 150 MPa, while the corresponding axial force values are 84.45 kN/m and 86.20 kN/m, respectively.

A similar trend is observed in calculating bending moments in the metal pipe structures (Fig. 13).

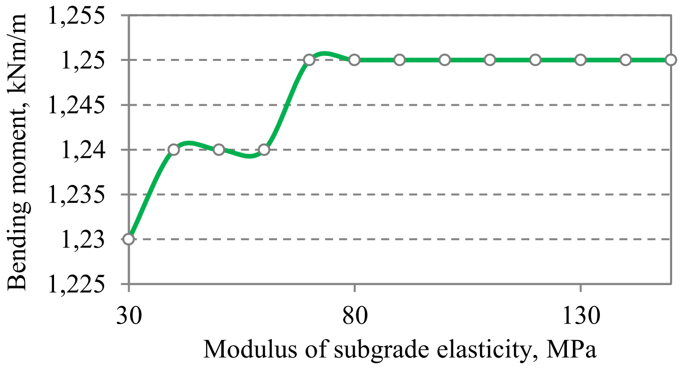

Figure 13. Dependence of bending moments in metal structures on the modulus of elasticity of the foundation soil

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It should be noted that the magnitude of the bending moments does not have a significant impact on the stress-strain state of the corrugated metal pipe structures, as the bending moment values vary only from 1.23 to 1.25 kNm/m with changes in the modulus of elasticity of the pipe foundation soil from 30 MPa to 150 MPa.

The calculation results showed that the stress values in the prefabricated corrugated metal pipe structures are 9.55 MPa at a foundation soil modulus of 30 MPa, and 9.75 MPa at a foundation soil modulus of 150 MPa.

For all values of the foundation soil modulus, the strength of the corrugated metal pipe structures is ensured, as the stresses remain within safe limits and are significantly lower than the allowable limit of 235 MPa.

Based on the results of the comprehensive study, new relationships were obtained between the modulus of elasticity of the soil foundation and the vertical deformations, axial forces, and horizontal deformations of the metal shell. These relationships make it possible to predict the behaviour of the structures at the early design stages. It was found that when the modulus of elasticity of the soil foundation exceeds 90 MPa, the horizontal deformations of the structures become stabilised, which represents a new engineering criterion for optimising foundation parameters during the design of transport facilities with prefabricated corrugated metal structures.

The continuation of further scientific research will focus on accounting for dynamic loads from moving transport units. This will make it possible to determine the deformation patterns of metal structures under dynamic loading and assess additional axial forces and stresses in the metal structures, considering the modulus of elasticity of the foundation soils.

4. Conclusion

Based on the numerical calculations of the stress-strain state of prefabricated corrugated metal structures of transport facilities, the following conclusions were obtained:

1. The finite element method can assess the stress-strain state of prefabricated corrugated metal structures of large cross-section transport facilities by conducting multivariable studies. The proposed numerical modelling of prefabricated corrugated metal structures of transport facilities aligns with modern principles of cognitive sustainability, which involve a shift from local assessment of individual elements to a system-level approach in infrastructure management.
2. The distribution of vertical and horizontal deformations in the pipe's compacted soil backfill and the stress distribution is nonlinear. For a foundation soil modulus of 30 MPa, the maximum vertical deformation of the soil backfill was 8.87 mm, and for a modulus of 150 MPa, 8.36 mm. The horizontal deformations were 3.35 mm and 3.41 mm, respectively. The maximum stresses that occur at the crown of the pipe for a foundation soil modulus of 30 MPa amounted to 46.62 kPa, and for a modulus of 150 MPa, 46.07 kPa. At the same time, the decrease in vertical deformations with an increase in the modulus of elasticity of the foundation soil from 90 MPa and higher shows a smaller difference in stress values compared to the range of moduli from 30 MPa to 90 MPa.
3. With the increase of the modulus of elasticity of the pipe foundation soil, the vertical deformations of the metal structures decrease, while the axial forces and horizontal deformations of the metal structures increase. However, the increase in horizontal deformations is marginal, and when the modulus of elasticity of the foundation soil exceeds 90 MPa, the deformations stabilise.
4. The maximum vertical deformations of the metal pipe structures at a foundation soil modulus of 30 MPa are 7.54 mm, and at a modulus of 150 MPa, 7.02 mm. At the same time, the corresponding axial forces are 84.45 kN/m and 86.20 kN/m, respectively. As a result, the stresses in the corrugated metal pipe structures are 9.55 MPa and 9.75 MPa, respectively.
5. Based on the results of the comprehensive study, new relationships were obtained between the modulus of elasticity of the soil foundation and the vertical deformations, axial forces, and horizontal deformations of the metal shell. These relationships make it possible to predict the behaviour of the structures at the early design stages. It was found that when the modulus of elasticity of the soil foundation exceeds 90 MPa, the horizontal deformations of the structures become stabilised, which represents a new engineering criterion for optimising foundation parameters during the design of transport facilities with prefabricated corrugated metal structures.

The obtained results make it possible to predict the behaviour of prefabricated corrugated metal structures under varying foundation stiffness and can be integrated into decision support systems. This will contribute to the creation of adaptive infrastructure and enhance the resilience of transport facilities in accordance with the principles of cognitive sustainability.

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