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Influence of bedding and backfill soil type on deformation of buried sewage pipeline

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Abstract: In the paper, the influence of different types of bedding and backfill soil surrounding underground sewage duct on its deformation was analysed. Impact of increased soil lateral pressure was examined by considering the construction of an embankment nearby the underground pipeline. Numerical computations of three different variants of bedding and backfill soil surrounding the pipe were carried out. Displacements and deformation of the pipe were calculated using the finite element method with adoption of elastic-perfectly plastic constitutive model of soil. Subsequent stages of the construction were taken into account. Shear strength reduction method was applied to evaluate the factor of safety of the entire system. Finally, the results and conclusions were depicted.

Keywords: Numerical analysis; buried PE pipe.

1 Introduction

Nowadays, especially in heavily urbanized areas, it is necessary to conduct construction works in the direct surroundings of the existing underground installations. This can result in exceeding the limit states of underground pipeline construction, for example, excessive deformation of the pipeline wall.

Failure analyses of sewage pipes available in the literature, for example, [1] and [2] usually concern the cases of symmetrical loads exerted on the pipe, mainly the loads resulting from the dead weight of backfill and the traffic live loads. In such cases, the lateral pressure exerted on the pipe reduces its deformation and, thus, the internal forces in the pipe. Furthermore, one can find in researches that verify the influence of dynamic loads on ducts, for example, [3]. However, designers and researchers rarely consider adverse consequences of soil lateral pressure. Common methods of designing underground sewage ducts, that is, the Scandinavian method [4] and Standard ATV-DVWK-A127 [5], consider only vertical loads acting on the pipe. None of the above mentioned documents deal with asymmetrical pipe loadings. Such a situation can occur when a new structure is built nearby and asymmetrically against the existing pipelines.

The case study presented in this paper considers the asymmetrical loading of pipes resulting from the construction of embankments in the vicinity of existing pipelines. This kind of loading was proved to be the direct cause of a failure in the form of excess pipe deformation. However, it is also presented that the excessive deformation could be avoided by the use of proper bedding and backfilling soil.

2 Case study description

In 2016 Wroclaw University of Science and Technology prepared the expert opinion on the causes of excessive deformation of underground sewage PE pipe placed a few metres under the ground surface [6]. In the real situation, the embankment was erected near the pipe after its installation in the subsoil. The construction of embankment was proved to be the direct reason of horizontal deformation. However, the aim of the analyses was to check whether the other factors had a significant influence on the existing state of deformation. Eventually, it was concluded that proper bedding and backfill soil is of crucial importance. According to the existing requirements [4] for bedding and backfill, in the case of soft soils, it is necessary to provide a layer of gravel with thickness of at least 0.2 m and a layer made of cohesionless soil with thickness of 0.15 m. The backfill has to reach 0.3 m above the pipe. The original soil can be used to fill the remaining part of excavation if the pipe is settled under green areas.

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Nevertheless, under the roads, the same material must be used for backfilling the entire excavation. Furthermore, each layer of the backfill needs to be properly compacted. In this paper, the influence of different types of bedding soil on the pipe deformation was investigated. The numerical calculations were carried out for three variants:
- 1st variant – both backfill of excavation and bedding (0.22 m depth) made of gravel,
- 2nd variant – bedding identical as in 1st variant, partial gravel backfill with height of 0.4 m above the pipe, the remaining subsoil made of original soils,
- 3rd variant – no bedding and no backfill, only original soils.

During the preparation of expert opinion, the validation of geotechnical parameters was performed based on the comparison of results from inspection carried out in real object and results from numerical simulations. The validation was carried out for the 2nd variant. In addition to that, the calculations accounting increased load were executed in order to observe the potential failure mechanism, which – in the framework of numerical analyses – is determined by the factor of safety (FOS) reaching the value of 1.0. Eventually, it allowed to evaluate pipe deformation in failure. FOS values were evaluated at every stage of construction. The shear strength reduction method [10, 11, 12] was used for this purpose. FOS was also computed for the additional 4th variant, that is, without the pipe.

3 Subsoil characteristics

In the area of the analysed object, three main geological layers were determined:
- above 2 m b.g.l. (below the ground level) – sandy-clays
- from 2 m to 8 m b.g.l. – organic soils, peats, sandy-silts and silty-clays
- below 8 m b.g.l. – sandy-clays and clay-sands

At the depth of 5.5 m b.g.l., a sewage PE DN600 pipe was installed. Before setting the pipe, an open area excavation was performed and the narrow one between two, six metre long retaining walls spaced at 3.5 m. The retaining walls were connected by struts. The excavation was filled in four stages and each layer of backfill was properly compacted. Next, the 4.6 m high embankment reinforced with geosynthetics was formed in additional six stages. The angle of embankment slope was 43°. On the embankment top surface, the parking area was designed.

4 Numerical model

Calculations were performed using the finite element commercial software ZSoil [7], especially intended for performing numerical analyses in geotechnics [8, 9]. Plain strain and elastic-perfectly plastic constitutive model of soil were assumed in the considered case. Following stages of construction and loading were distinguished:
- initial state before the excavation
- 3-stage open area excavation
- installation of retaining walls
- excavation between retaining walls
- assembly of struts
- foundation of sewage pipe
- 4-stage excavation filling with 2-stage compaction after each stage
- 6-stage embankment building with 4-stage compaction after each stage
- load applied to the top area of embankment

Elastic-perfectly plastic Coulomb-Mohr model was used for soils. Non-associated plastic flow rule was defined by the angle of dilatancy with values set down according to ZSoil manual [7]:

$$\psi = \max(0.1\varphi;\ \varphi - 25^{\circ})$$

where: ψ – angle of dilatancy, φ – internal friction angle. The interfaces between soil and pipe as well as between soil and retaining wall were modelled with the contact elements, maximum shear stress value is limited by Coulomb condition:

$$|\tau_f| \leq a + \sigma \tan\delta$$

where: adhesion a=0 , friction angle δ=0.6φ, and φ is internal friction angle of adjacent soil.

Parameters of soils, used in numerical calculations, are shown in *Table 1*.

The sewage pipe was modelled with beam elements. Long-term Young modulus E_L=200 GPa, Poisson's ratio υ=0.2 and the moment of inertia I=1.75•10^{-6} m^4/m were assumed. The circle, describing sewage pipe geometry, was discretized in 30 segments. The beam elements were also used for modelling the retaining walls. Nodes of truss elements representing struts were separated from soil continuum nodes. Reinforcement of the embankment made of geosynthetics was modelled with membrane elements, which can withstand tensile forces only. Compacting of backfill layers of the trench and forming the embankment were modelled by short-term load of

Table 1: Parameters of soils.

No	Symbol	Soil type	γ kN/m³	φ' °	c' kPa	ψ °	E_0 MPa	v -
1	Ia	Sandy-clay	20.9	14.5	18.0	1.45	21.5	0.317
2	Ib	Sandy-clay	20.9	12.5	14.0	1.25	17.0	0.322
3	Ic	Sandy-clay	20.9	10.0	11.0	1.00	12.5	0.304
4	Id	Sandy-clay	20.9	6.0	9.0	0.60	7.5	0.327
5	Ie	Gravel	18.8	38.0	1.0	14.00	127.0	0.220
6	IIa	Peats/organic soil	11.5	1.6	10.2	0.16	0.85	0.350
7	IIIa	Sandy-silt/silty-clay	18.8	6.0	12.0	0.60	4.5	0.347
8	IIIb	Fine sand/clay-sand	20.0	33.0	1.0	9.00	60.0	0.307
9	IVa	Sandy-clay/clay-sand	22.0	18.5	33.0	1.85	27.5	0.332
10	IVb	Sandy-clay/clay-sand	21.3	16.5	26.0	1.65	22.0	0.278
11	zasypka	Gravel	16.5	31.0	1.0	7.00	46.0	0.250
12	nasyp	Sand	20.0	33.0	50.0	9.00	80.0	0.25

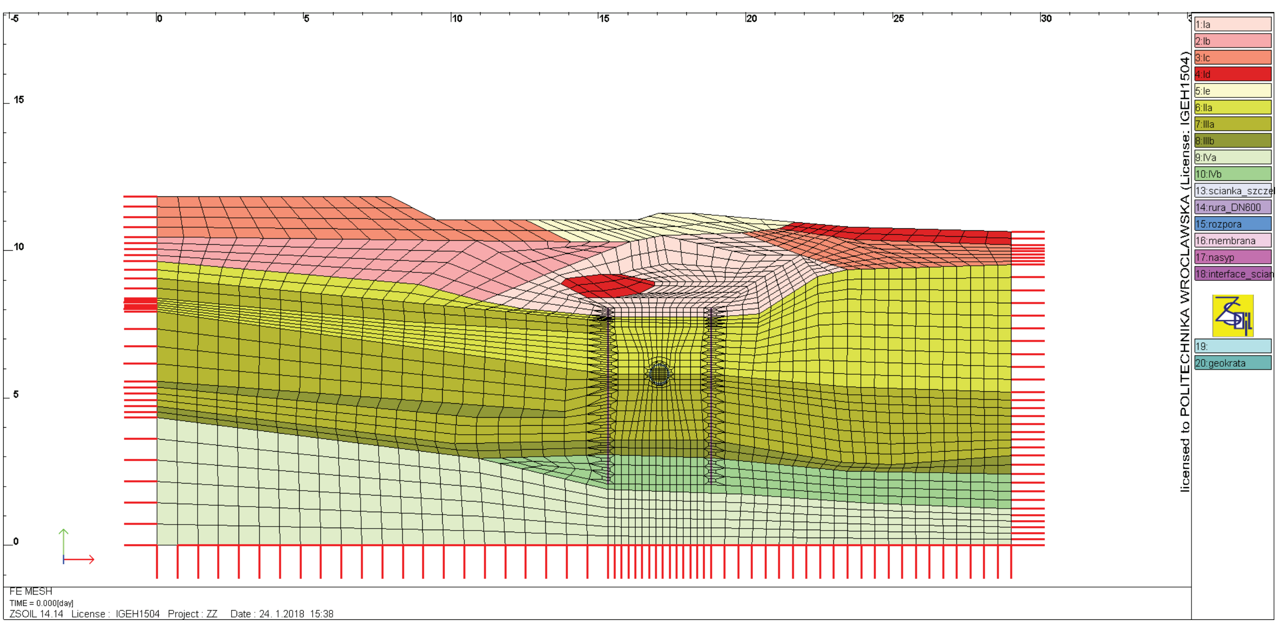

Figure 1: Numerical model for initial state.

intensity 5.0 and 30.0 kPa, respectively. The load on the crown of the embankment amounted 20.0 kPa.

In *Figures 1-3*, the numerical model at the selected stages of construction and in Figures 1–6, the different types of bedding and backfill were displayed.

Additionally, in *Figure 7*, the changes of pipe diameter are represented for different types of bedding and backfill. In *Figure 8*, the development of pipe deformations at subsequent stages is shown. Comparison of FOS values is presented.

5 Results

Summary of the results, that is, the values of displacements and changes of pipe diameter, are shown in *Table 2*.

6 Analysis of results

Analysis of results presented above leads to the following observations:

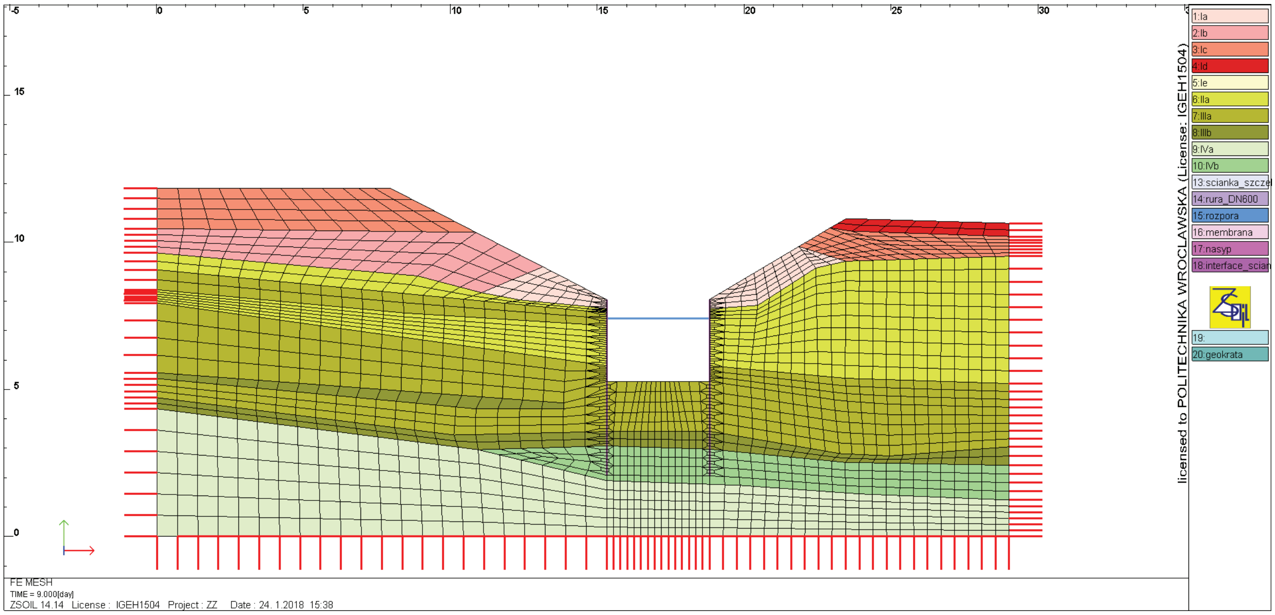

Figure 2: Numerical model after excavation.

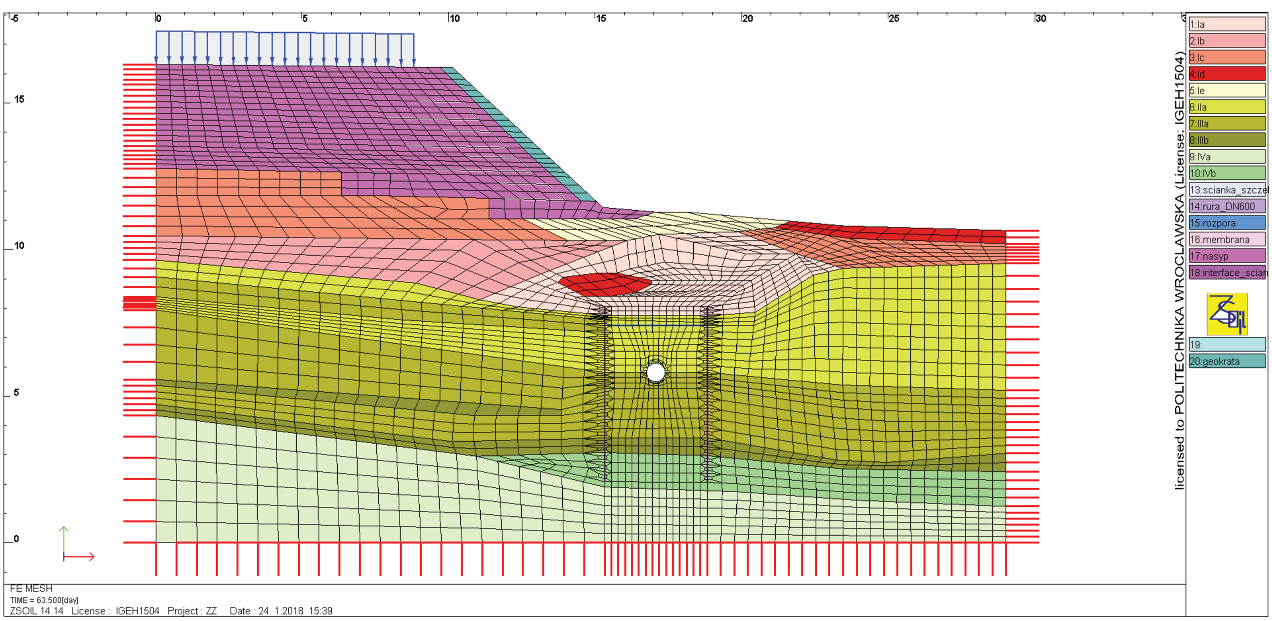

Figure 3: Numerical model for final stage.

– Type of soil around the pipe has significant influence on its deformation during backfilling the excavation if the main load is a vertical one. Changes of diameter are about 5 times greater when bedding is made of soft soil than in the case of gravel bedding.
– Deformation of pipe in both cases of gravel bedding (1st and 2nd variant) are very similar.
– Process of forming the embankment, located asymmetrically in relation to the pipe, causes mainly horizontal displacements of the pipe. They are decisively greater when there is no bedding included in numerical model.
– Factors of safety (FOS) are similar in all three variants. The greatest values occur in 1st variant with full gravel backfill. In variant with partial backfill, they are on

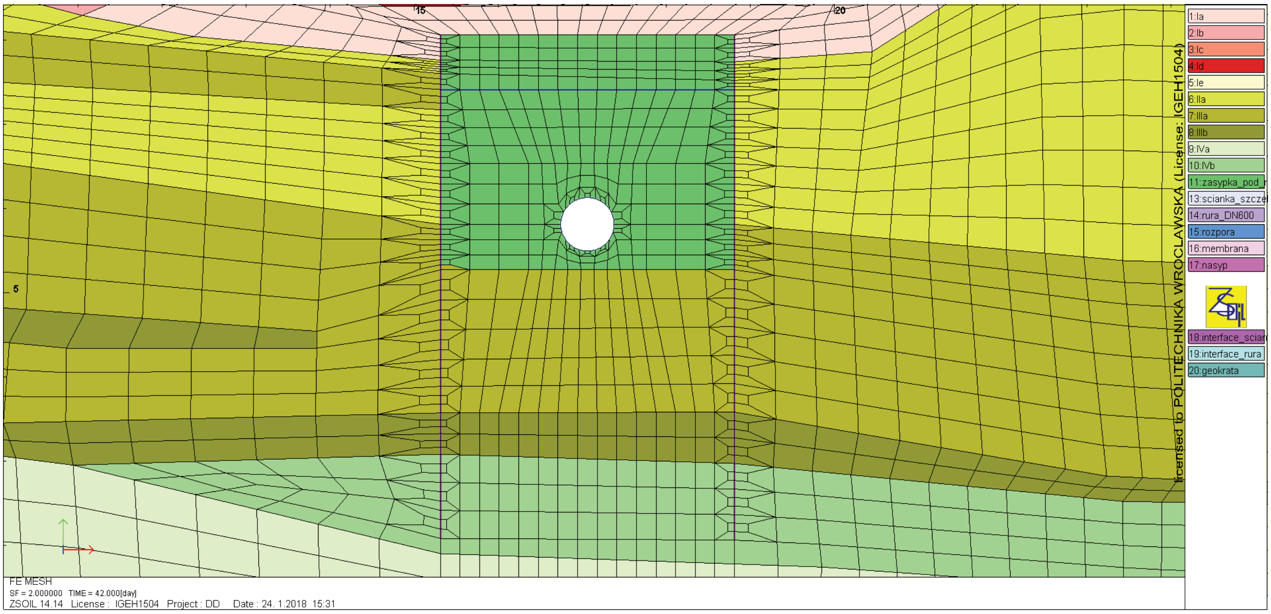

Figure 4: Numerical model – 1st variant.

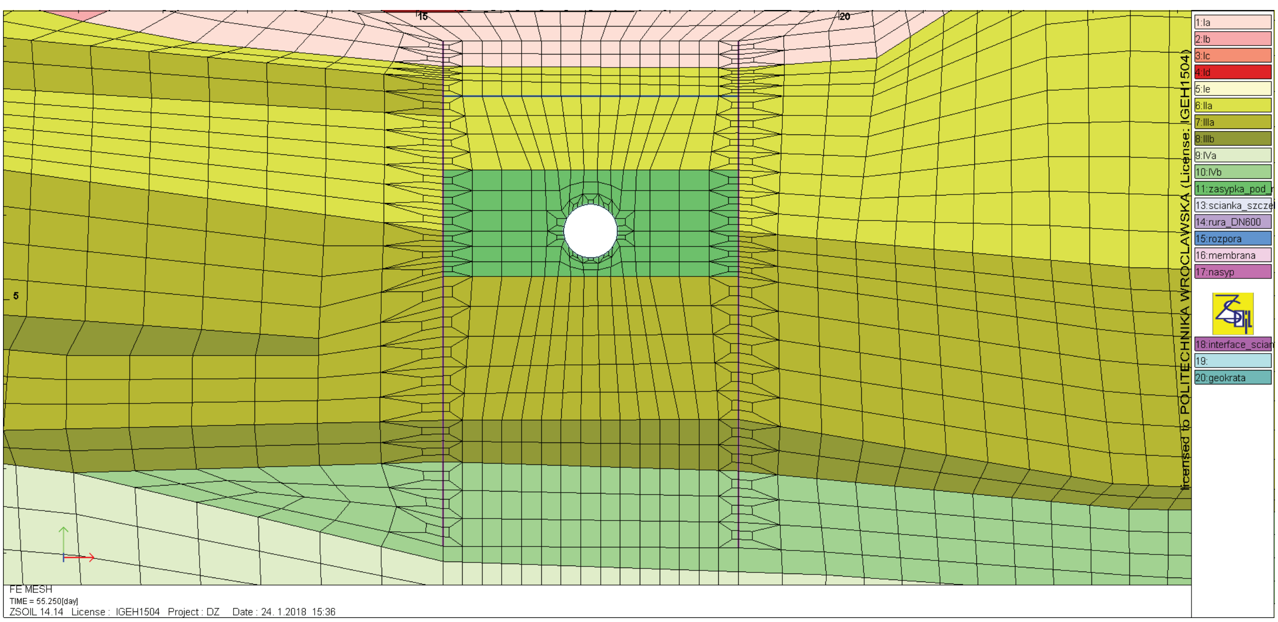

Figure 5: Numerical model – 2nd variant.

an average 3.4% lower and 6.2% lower in 3rd variant without bedding. In spite of small differences when safety coefficients are taken in consideration, only full gravel backfill allows to build entire embankment. Retaining walls and struts create a system that improves stability by lowering the sliding surface.

– Analysis was performed with assumption of plane strain. In reality, deformation along the axis of the pipe should be expected. Most likely, it would bend slightly, which would not affect the factor of stability.

7 Summary and conclusions

In this paper, the results of numerical calculations of deformation PE pipe were presented. Three different

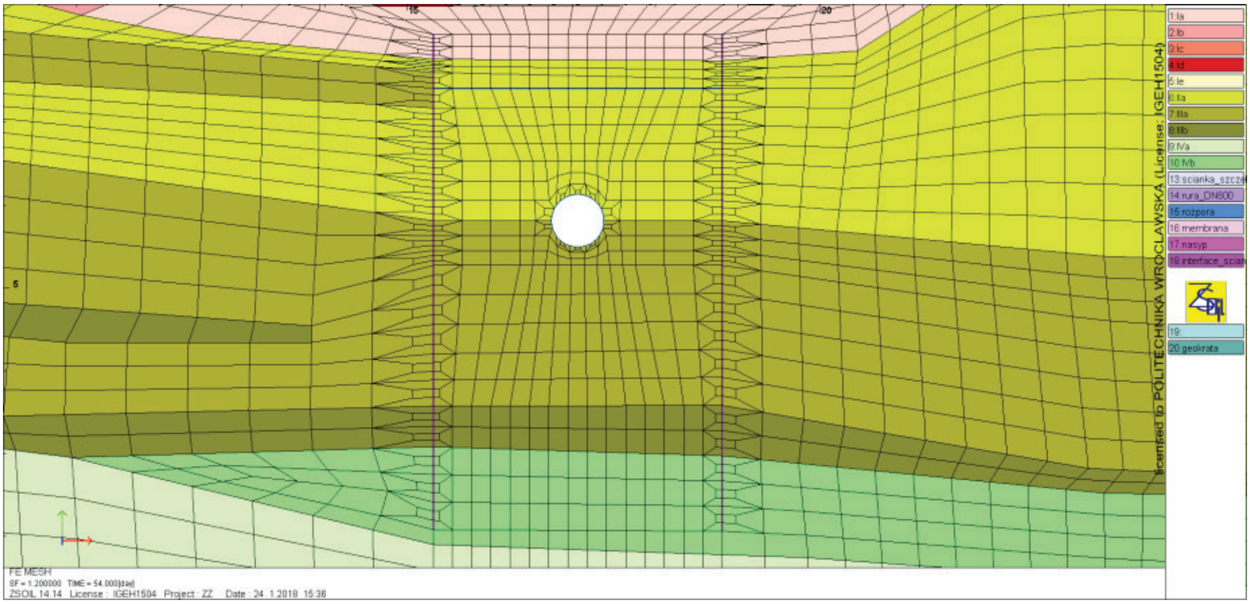

Figure 6: Numerical model – 3rd variant.

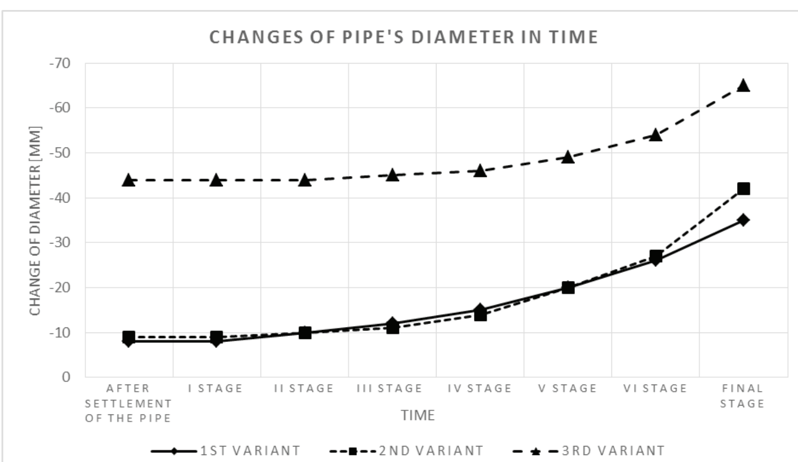

Figure 7: Changes of pipe diameter in time.

Table 2: Maximum values of horizontal (ux) and vertical (uz) displacements and changes of pipe diameter (ΔD, ΔD%).

	1st variant				2nd variant				3rd variant			
	ux	uz	ΔD	ΔD %	ux	uz	ΔD	ΔD %	ux	uz	ΔD	ΔD %
Time	mm	mm		%	mm	mm		%	mm	mm		%
After foundation of the pipe	-4	-38	-8	-1.28	-6	-38	-9	-1.38	-25	-82	-44	-6.81
I stage of embankment	6	-39	-8	-1.31	6	-39	-9	-1.40	-17	-83	-44	-6.81
II stage of embankment	19	-42	-10	-1.54	22	-41	-10	-1.55	35	-85	-44	-6.87
III stage of embankment	29	-44	-12	-1.84	33	-43	-11	-1.77	48	-85	-45	-6.99
IV stage of embankment	44	-48	-15	-2.34	48	-45	-14	-2.22	66	-85	-46	-7.15
V stage of embankment	67	-51	-20	-3.06	74	-47	-20	-3.05	94	-85	-49	-7.70
VI stage of embankment	96	-55	-26	-4.02	110	-49	-27	-4.22	138	-83	-54	-8.43
Final stage	139	-61	-35	-5.40	190	-53	-42	-6.64	290	-80	-65	-10.21

Table 3: Comparison of FOS for different types of beddings depending on the stage of construction.

Time	1st variant	2nd variant	3rd variant	4th variant
I stage of embankment	3.80	3.65 (-3.9 %)	3.60 (-5.3 %)	3.00 (-21.1 %)
II stage of embankment	2.70	2.65 (-1.9 %)	2.55 (-5.6 %)	2.05 (-24.1 %)
III stage of embankment	2.20	2.10 (-4.5 %)	2.05 (-6.8 %)	1.65 (-25.0 %)
IV stage of embankment	1.80	1.75 (-2.8 %)	1.70 (-5.6 %)	1.35 (-25.0 %)
V stage of embankment	1.50	1.45 (-3.3 %)	1.40 (-6.7 %)	<1.0
VI stage of embankment	1.35	1.30 (-3.7 %)	1.25 (-7.4 %)	<1.0
Final stage	1.00	1.00 (0 %)	1.00 (0 %)	<1.0
Average difference		-3.4 %	-6.2 %	-23.8 %

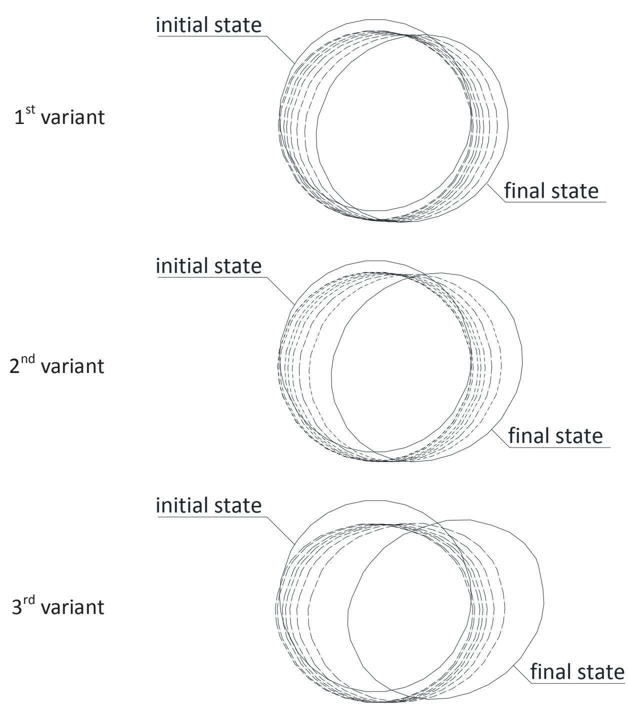

Figure 8: Deformations of pipe in time.

types of surrounding soils were considered: gravel bedding with full gravel backfill of excavation (1st variant), gravel bedding with partial gravel backfill (2nd variant) and bedding and backfill made of original soft soils (3rd variant). Appropriate soil around the pipe provides proper interaction between the pipe and the soil, which emerge in lower deformation. More specific conclusions are following:

– Existence of gravel bedding significantly reduces deformation of the pipe and is indispensable in such constructions.
– Height of the backfill does not really affect deformation of the pipe.
– Type of bedding and backfill does not impact on the value of factor of safety (FOS).
– It is very important to evaluate the influence of the new construction on the previously installed one. Underestimation of horizontal loads may lead to increased deformations or failure.

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