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# Geotechnical Problems Of The Foundation Of Road Embankments By The Bridge Structures

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**Abstract:** This work presents the geotechnical problems occurring in the interaction area between road embankments and the bridge structures in case a subsoil characterised by complex and complicated geological and engineering conditions. These significant problems that occur during the design, performance and exploitation of the abutment structures, are illustrated on the example of engineering practice in Lower Silesia, concerning a road embankment that constitutes access to the bridge. The results of numerical analyses concerning the process of consolidation of low-strength soils and their impact on the settlements of road embankment indicate the need to carry out such analyses also in the cases, when the soft soils occur in the direct geotechnical layer under the designed embankment. The Authors included in this article a discussion regarding other effective actions and solutions that can be used in the design and performance phase, leading to the elimination or reduction of problems concerning the connection of engineering structures with road embankments, which have been recurring for years, ultimately resulting in the improvement of quality, comfort and safety of road exploitation.

**Keywords:** transport engineering, road embankments, bridge abutments, differential settlements.

## 1 Introduction

Providing an appropriate foundation for the structures of land transport infrastructure constitutes a significant problem for the designers and contractors of works, associated with the construction of new and modernisation of the existing sections of road networks, motorways and bridge structures [12]. During the stage of design, as well as the stage of performance, the extensive tests of load capacity, durability and sensitivity of road structures and bridge structures are carried out. Nevertheless, after completion of the construction works, and sometimes even during them, the damage and destruction of these structures occur very often, resulting from excessive settlements and deformations of road embankments, which in the extreme cases assume the landslide forms.

The most sensitive spot on a road sequence is the connection of bridge structure with the road embankment. Stresses acting on the subsoil under the road embankment base are lower than those occurring under the bridgehead foundation. Moreover, the depth and method of bridgehead foundation significantly differs from the embankment foundation. The possibility of occurrence of the large settlement differences between the exit from the bridge structure and the embankment requires the designers and contractors to apply technical solutions, which enable the minimisation of such adverse effects [3].

Additional adverse condition, which increases the risk of occurrence of excessive differential settlement, is very frequent occurrence of low-strength organic soils within transition zones between the road embankment and the bridge structure [1]. The correct design solutions in regard to embankments located on low-strength geotechnical layer, which occurs in the transition zone of connection of the road with the bridge structure, should eliminate the possibility of occurrence (both during the construction and in the long-term operation) of the problems associated with excessive subsoil settlement. In many design cases, when the low-bearing soils do not directly occur below the level of embankment foundation, while the bridgehead foundation is placed on the piles (or pile-like elements), the possibility of causing significant differences in settlement, through slightly deeper accumulated low-strength or organic soils, is not analysed. Deformations and damages to the road structures may appear some time after the completion of construction, as well as propagate during longer period of time. Most often, it is the result of long-term processes of consolidation of low-strength soils,

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whose pace depends on the properties of given land, as well as on consolidation conditions. Initially, damages in the form of depressions or cracks in the road surface result in the penetration of rainwater into the backfill behind the bridgehead, and subsequently into the embankment subsoil and layers of low-strength soils. This can cause further increases in settlements and propagation of surface damages. Adoption of the appropriate design solutions, which protect against occurrence of deformation and damage, is particularly important in expansion joint area of the bridge structure.

This study presents a discussion regarding the geotechnical problems of foundation and performance of road embankments in the access area to bridge structures, which are placed on a subsoil characterised by complex and complicated geological and engineering conditions. These significant problems that occur during the design, performance and exploitation of earth structures, are illustrated on the example of engineering practice in Lower Silesia, concerning a road embankment that constitutes access to the bridge. Adverse effects in the form of large differences in settlements, as well as surface damages resulting from excessive long-term settlement of the embankment, in the zone of connection of the road with bridge structure, in the conditions of occurrence of the organic soil interlayers in deeper layers of the subsoil, are presented. The design documentation does not include analyses concerning the assessment of soil settlement, including in particular the consolidation settlements of organic soils.

The results of numerical analyses concerning the process of consolidation of low-strength soils and their impact on the settlements of road embankment adjacent to the bridge structure, which are presented in the article, indicate the need to carry out such analyses also in the cases, when the load-bearing soils occur in the geotechnical layer just under the designed embankment. The presented discussion concerning the variants of calculation results may be helpful at the stage of design of the earth structures by the bridge structures. Moreover, the Authors included in this article a discussion regarding other effective actions and solutions that can be used in the design and performance phase, leading to the elimination or reduction of problems concerning the connection of engineering structures with road embankments, which have been recurring for years, ultimately resulting in the improvement of quality, comfort and safety of road exploitation.

## 2 Typical solutions in transition zones that limit the irregularities of settlements

In the typical solutions of bridges with expansion joints at the end of spans, the transition slabs are used [7] as the basic structural solution in transition zones [10]. Their task is to mitigate the consequences of embankment settlements. The length of transition slab depends on the expected settlement of embankment, as well as on the road class. In the case of expressway, the slope of slabs, due to the settlement of embankment, should not exceed 1: 300, while on other roads 1: 200 [4].

In the case of direct foundation of the bridgehead on load-bearing soils - the natural solution consists of the use of concrete transition slab, which replaces the threshold exit from the structure. With a smaller settlement of the embankment in relation to settlement of the bridgehead, the slab is mainly supported by road embankment [3].

However, usually the indirect foundation of the bridgehead is applied (e.g. on reinforced concrete piles), due to restrictive requirements concerning the value of settlements of the bridge supports. In such case, the settlement of bridgehead is significantly smaller than the settlement of embankment - rotation of the transition slab is opposite to the situation of direct foundation. Often, an additional bottom reinforcement of embankment is used, which is dragged in the plan beyond the outline of transition slab and which minimises the occurring settlement differences.

Two above-described cases relate to the load-bearing soil, whose deformation parameters limit the settlement of embankment to a value of 5-10 cm.

In the case of exceeding the given value of displacements of the soil loaded with road embankment or foundation of the structure on low-strength or organic soils - it is necessary to replace the subsoil or to strengthen it. During the construction of bridge structures placed on soft soils usually is applied the reinforcement in the rigid support technology, which allows for high accuracy in settlement estimation (minimum ones, approx. 2-3 cm) - indirect foundation on piles, constrained modulus columns (*CMC*) or soil cement columns (*DSM*). The another way are consolidation techniques (in the long period of time, there are also larger settlements occurring) - embankment overload, with the use of drains or differentiated drainage columns (gravel columns, sand columns in geosynthetic coating, vacuum consolidation, etc. [9].

It is becoming increasingly popular to replace the traditional massive concrete bridgeheads with pillars, behind which the wall of reinforced soil is implemented. The reinforced soil is also used as the ending of embankment, on both sides of the wall bridgehead, or as the side walls of the bridgeheads [8].

Other type of design solutions intended to ensure the continuity of road surface and driving comfort consists of the construction of integrated bridges – structures, in which there are no relative horizontal displacements between spans and bridgeheads, and there are no elements connecting the bridge structure with the embankment. They are single- or multi-span structures with a continuous deck, which is connected to the bridgehead. The bridgehead can be joint-based on the foundation or based on the piles [5, 6]. Soil conditions have a significant role in the design of integrated bridges.

Load-bearing structure of the spans is connected (integrated) with the supports (along with their foundations) without any gaps or other elements (bearings, joints). Also, the deck is connected with access embankments without the use of expansion joints, which ensures full cooperation and appropriate displacement of supports and backfill (embankment soil). Their advantage is the reduction in height of the embankments. In the case of integrated bridges, it is assumed that the embankment will be sufficiently compacted and the transition slabs are not necessary. This requires high accuracy and compaction of the embankment. Moreover, the granulometric composition of the backfill soil must be selected in such manner that it is easily compacted. During performance of embankments directly behind the bridgeheads of integrated bridges, it is also important to form the upper layers of embankment in such manner that a slip plane is created in them, the impact of which would consist of the minimisation of vertical displacements [4].

However, the integrated solutions in bridge engineering are significantly limited by geotechnical conditions. In the case of occurrence of the compressible soil layers (low-strength soils) in the subsoil and in the case of pile lengths greater than 5.0 m, the type of integrated bridge is not applicable.

During the recent years, the publications and design studies have included a number of individual and innovative propositions of the solutions, leading to the elimination or reduction of the foundation problems in regard to the engineering structure adjacent to the earth structure, in access zone to the bridge [6, 8].

# 3 Correct recognition of the foundation conditions of land transport infrastructure structures

The main and necessary element for correct design of the foundation of the bridge structure and road (in the area of transition zones) consists of the proper recognition of geotechnical conditions. It is crucial to determine the actual values of strength and deformation parameters of the soils, especially compressible ones.

Due to the recent use of advanced *in-situ* and laboratory research techniques, the quality of subsoil recognition has significantly improved. However, it is still possible to stumble across documentations without determined geotechnical parameters of organic soils, while the results of geotechnical tests often include errors.

Comments regarding the importance and the rank of geotechnical works are provided in the references [11, 12]. Very often, the scope of research does not correspond to the needs of solved geotechnical problems and the recommendations included in geotechnical standards are not taken into account [15, 16]. Determination of the appropriate scope of soil recognition and the geotechnical parameters obtained in this manner determine the foundation method of bridgeheads, and in the case of indirect foundation, the selection of pile technology and determination of the pile length. Thus, the works associated with soil recognition should be carried out in stages. Initial tests are aimed at determining the foundation method, while the detailed tests are used to design the foundation of the bridge structure and its implementation. Moreover, it is necessary to carry out the tests of subsoil and formed embankments during the construction, as well as to implement continuous geotechnical monitoring.

The fundamental shortcomings of geotechnical documentations result from errors made at the test program stage and during implementation of the test. Incorrect programming of tests results from:

– limitation of the scope of field works, which results in overinterpretation of the obtained information, as well as in geotechnical omissions;
– performance of shallow geotechnical investigations of subsoil of the designed high embankments, which lead to the bridgeheads;
– performance of a large number of shallow test boreholes for the needs of design of the pile foundations;

– incorrect planning of boreholes on the projection of designed supports (omission in the field tests beyond the foundation outline, which constitutes the spot for necessary soil anchorages);
– omission of soft and very soft soils in the subsoil investigations, without providing a detailed description and without determination of their geotechnical parameters.

Errors in the scope of performance of the field tests are usually associated with:
– improper method of making test boreholes, performance of drillings without piping, which gives a distorted image of hydrographic conditions and state of soils (especially cohesive ones);
– lack of precise determination of the range of weak soils (in the plan and with depth);
– ending the drillings in non-load-bearing soils, which makes the tests not useful for the design or leads to significant overdimensioning of the foundation elements.

Errors created at the stage of laboratory tests and development of outcomes result from:
– incorrect collection and limitation of the number of samples for laboratory tests;
– performance of laboratory tests, which do not correspond to the design needs or are not compliant with the requirements of standards;
– lack of shrinkage limit tests in the soils in semi-compacted state, which prevents the appropriate design;
– omission of determination of the characteristics of weak soils (loose fill, organic silt, peat soils), which prevents the appropriate design of their reinforcement;
– failure to apply modern and at the same time more costly methods of soil testing, as well as advanced laboratory soil testing techniques, while replacing them with the use of correlation dependencies, in order to determine the value of geotechnical parameters for design purposes;
– failure to use the direct results of dilatometric tests, pressuremeter tests and CPTU static probe tests for the design (e.g. during the design of pile foundations).

Significant complications in the design and performance of bridge structures may be the result of substantial negligence during recognition of geotechnical conditions, among others in regard to:
– failure to recognise the subsoil of each support (interpolation of results of the subsoil investigations between distant boreholes, which is particularly dangerous in the case of bridge foundation in the vicinity of watercourses, where the variability of subsoil in the plan is significant);
– indication of underestimated soil parameters, significantly weaker than the actual ones (in such case, the designed piles are characterised by too high load-bearing capacity, which may lead to difficulties in implementation, particularly in the case of using prefabricated driven displacement piles) [11, 12];
– adoption of too shallow boreholes in relation to the base depth of designed drilled piles for the bridgehead, in the place of occurrence of the pockets of irrigated sands - after drilling of irrigated layers, the subsequent soil loosening in vicinity of the pile occurs;
– errors in the design and implementation of earth structures, associated with their insufficient compaction, and in order to avoid them, it is necessary to introduce procedures ensuring the performance of continuous and reliable tests of compaction of the formed embankment layers.

# 4 Assurance of appropriate interaction between the embankment and the bridgehead in complex and complicated soil conditions

## 4.1 Structural solutions

The issue of foundation of the engineering structures and subsoil improvement under road embankments is relatively well studied, both in design practice and implementation practice. The correct design and performance of connection of these both structures cause much more problems.

The problems characterised in section 3, resulting from incorrect recognition of the subsoil of bridge and road structures, indicate how the foundation of adjacent engineering structure and earth structure in the bridge access zone are significantly dependent on the degree of complexity of the geological and engineering conditions.

In the case of complex and complicated soil conditions, a number of adverse phenomena may occur in the transition zone between the embankment and the bridge structure. The most important of them is excessive settling of surface on access roads to the structure leads to the creation of the so-called "saddle" (negatively affecting the safety and comfort of driving) and the excessive displacement of bridgeheads, as well as retaining walls made from reinforced soil (which replace the typical reinforced concrete bridgeheads. Also an essential adverse phenomena is an incorrect work of the structure leading to failure, caused by improper performance of subsoil reinforcement or improvement at the contact section of engineering objects with the road embankments [2].

Excessive settling on access roads to the engineering structure (bridge, viaduct, underpass, culvert) usually occurs in the areas with low-strength soils (usually organic) in the subsoil, characterised by high compressibility and in the case of implementation of the "rigid" foundation of an engineering object, e.g. on piles or on a deeply improved subsoil, in the absence of any soil reinforcement under the road frame.

During exploitation, the settling process of organic and low-strength soils, mineral cohesive soils continues for a long time, until the completion of their consolidation [13, 14] or rheological processes, often causing significant deformations and damage to the road surface. In some cases, the displacements of subsoil are so significant that they cause the rotation of transition slabs and cracking of surface at the place of their connection with the structure.

When the subsoil on access roads to such structure is not reinforced, apart from excessive settling of the surface, there is a risk of excessive bridgehead displacement behind the structure. This significantly increases the negative effects of incorrect connection of the structure with the road.

When a road surface is laid directly on the engineering structure, it is not appropriate to allow the occurrence of settlements with sizes similar to the permitted ones for the road structure. In particular, this applies to irregular settlements, which consequently lead to damages requiring the performance of complicated repair of the bridge structure. According to some authors [7, 9, 10], in the case of occurrence of soft soils in the subsoil, it is necessary to implement "rigid" foundation on piles or foundation on deeply improved subsoil (*DSM* columns, *jet grouting*).

Uniform settling of surface on the contact section of the bridge structure and the road can be ensured by appropriately improved subsoil on the access roads to the structure. The so-called transition zones should be implemented - through changing the spacing and length of subsoil improving or reinforcing elements (columns, piles), as well as through combining various improvement technologies.

In the case of construction of the embankment on mineral, non-cohesive or hardly deformable cohesive soils (e.g. semi-compacted soils, hard plastic soils), the settlements occur almost in their entirety during the construction. Settlements amounting to 5-10 cm do not pose a threat to the embankment, however they are important for e.g. retaining walls, whose face is made of concrete elements or reinforced concrete elements (the possibility of cracking).

Among recommendations included in the standard [17], concerning formation of the transition zone between the embankment and the structure (e.g. of a bridge structure), another element that should be mentioned is the use of fine-grained soils intended for formation of the embankments and for the backfill, in order to increase the stiffness of the embankment, as well as deep soil mixing (DSM), in order to increase the stiffness of the geotechnical layers.

In the case of improving or reinforcing the subsoil under road embankments with the use of consolidation methods, it is recommended to gradually introduce rigid elements on the transition sections. Difference in stiffness can be additionally compensated by appropriate geosynthetic mattress structures. In the case of deep improvement of the subsoil under access roads to the bridgeheads, in addition the induction of pressure on the piles will be avoided, because all additional loads will be transferred to the deeper load-bearing layers of the soil layer.

## 4.2 Recommendations concerning the technology of work implementation

Reduction in irregularity of settlements of the embankment and bridge structure in complicated and complex soil conditions can be also achieved by appropriate adjustment of technology to the implementation of works, mainly in the scope of earthworks.

Particular attention should be paid to the implementation of works at the contact section of the embankments and the engineering structures. Most often, the road embankments are constructed faster than the structures. Embankment with the target height is implemented behind the constructed bridgeheads, usually with escarpments with a slope of 1:1.5. Only the so-called bridge backfill are is left. In the case, when low-strength soils (cohesive in plastic/soft plastic state, organic soils) occur in the subsoil, the long-term break between implementation of the embankment's main part and the bridge backfill may cause the occurrence of

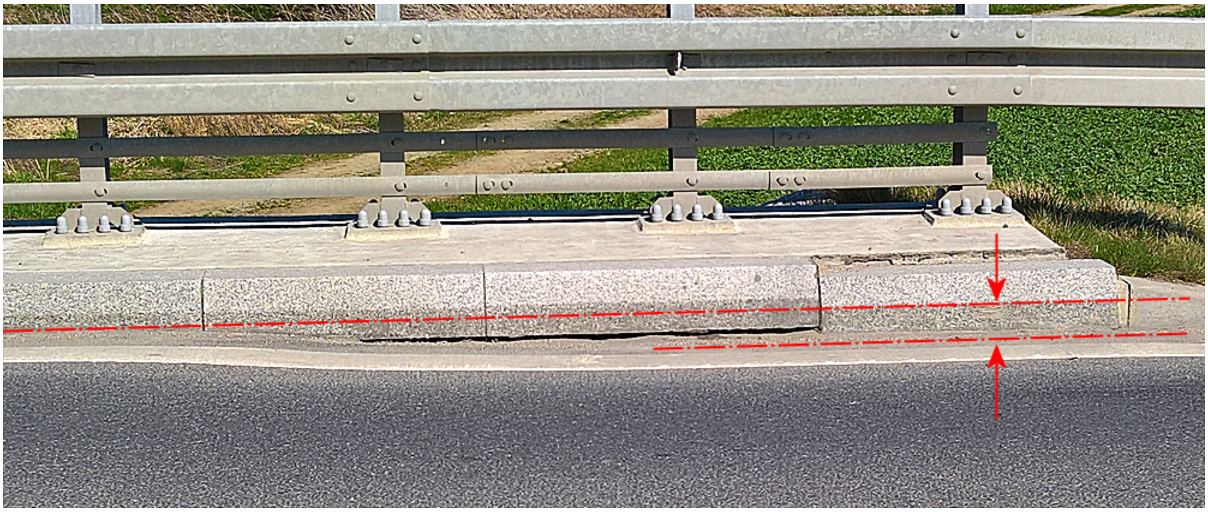

**Figure 1:** Settlements of the bridgehead on the road embankment transition zone.

irregular settlements. After completion of backfill behind the bridgehead (usually after a few/dozen or so months from the embankment construction), the settlement process in this place is just starting, while it can be already in the final stage under the road embankment's main part. In such situation, after implementation of the surface, the consolidation settlement process on the access road to the building is still in progress, which results in creation of the so-called "saddle".

Other additional cause for the formation of excessive settlements on the section immediately adjacent to the structure may be insufficient compaction of the backfills (e.g. resulting from implementation of the embankment with the use of layers with too high thickness). Therefore, the thorough control of the backfill compaction with the use of geotechnical probings is important, and not just the current one performed on the upper surface of subsequent built-in layers. In the case of embankment layers with insufficient parameters, their densification may occur only during exploitation of the road - due to dynamic loading from vehicle traffic.

Also, it is very important to maintain the correct order of works, e.g. premature implementation of piles for the bridge structure in a situation, when the recommended replacement of organic soil with considerable thickness was not performed on access roads to the structure. Moreover, it is necessary to use appropriate work technologies, e.g. safeguards against occurrence of subsoil deformation during implementation of the foundation works.

## 5 Example of damages in the transition zone caused by irregular settlements resulting from consolidation of low-strength layers

For the example illustrating the possibility of damage to the road surface in the transition zone between the embankment and bridgehead, caused by a long-term process of consolidation settlements, the section of a ring road along with the single-span bridge over a local watercourse located in Lower Silesia was selected. Excessive settlements of the embankment with a maximum height amounting to approx. 4.8 m occurred at the contact section of the embankment structure and the bridgehead, behind the transition slab (Fig. 1). Settlements appeared after completion of all works associated with construction of the bridge and the road. Size of these settlements amounted to approx. 5 cm and continued to increase, accompanied by deflection of the road surface, significantly worsening the comfort of driving through the bridge, and moreover, at a distance of approx. 0.5 m from the expansion joint outside the structure, the cracks in the surface appeared, perpendicularly to its axis.

Geotechnical investigation of the subsoil were carried out for the needs of bridge design, which covered four boreholes up to a depth of 12 m, two for each bridgehead. Location of the test sites is presented in Fig. 2. Results of soil recognition at the place of occurrence of the settlements are presented in the form of a geotechnical cross-section in Fig. 3. In one of the boreholes, a complex of organic soils was found at a depth from 1.9 m to 5 m, which was interlayered with thin inserts of other soils, in the form of plastic silts with an organic component content of 11%, as well as stiff organic, interlayered clay with an organic component content of 4.2%. Below to a depth of 12.0 m, there is an accumulation of stiff clay.

During subsoil investigation tests, which were conducted in order to explain the reasons for settlements, the occurrence of organic soils was discovered on both sides of the embankment, which were in worse condition (plastic – soft plastic) than the one specified in the design documentation. The occurrence of low-strength soils was also confirmed under the embankment base with the use of CPTU tests, performed from the embankment crown. In order to carry out laboratory tests of the parameters of shear strength (direct shear test), soil's consolidation properties (oedometric tests) and water permeability, the NNS samples of organic soils and the cohesive soils from layers over and under the organic deposits were collected.

In order to explain the reasons for occurrence of settlements, a variant analysis of the consolidation process was carried out. The subsoil investigation conditions contained in the design documentation, as well as conditions determined during the verification tests were adopted for the calculations. Due to the possibility of drainage effect towards the river in regard to thin interlayers of non-cohesive soils, identified in organic soil layers, several variants of drainage, which has a significant impact on the consolidation process over time, were considered.

The consolidation problem was solved numerically in the finite element method program. Progress of embankment settlement over time, as a result of subsoil consolidation, was determined on the basis of the general seepage equation in fully saturated soil. It comes down to the solving of initial boundary problem under assumption of deformable soil matrix and incompressible fluid, taking into account the evolution of pore water pressures, in accordance with the Terzaghi's theory [13]:

$$\frac{\partial v_z}{\partial z} = \frac{\partial \varepsilon_V}{\partial t}, \tag{1}$$

where: $vz$ – vertical component of seepage velocity, $\varepsilon V$ – volumetric deformation of soil, $z$ – depth axis, $t$ – time.

Seepage velocity in the vertical direction is calculated according to the Darcy's law:

$$v_z = -\frac{k}{\gamma_w} \cdot \frac{\partial u}{\partial z}, \tag{2}$$

where: $k$ – seepage coefficient, $\gamma w$ – volumetric weight of water.

According to Terzaghi's theory of consolidation, the change in volumetric deformation equals the change in vertical deformation:

$$\varepsilon_v = \frac{\sigma'_z}{E_{oed}} = \frac{\sigma_z - u}{E_{oed}}, \tag{3}$$

where: $\sigma'_z$ – vertical component of effective stress, $\sigma_z$ – vertical component of total stress, $Eoed$ – oedometric modulus.

Settlement, dependent on time, is calculated as an integral from the deformation:

$$s = \int_0^H \varepsilon_V dz. \tag{4}$$

The degree of consolidation is determined as:

$$U = \frac{s}{s_f}, \tag{5}$$

where: $s_f$ – final settlement calculated with the assumption of complete dissipation of the excess pore water pressure, with the distribution of stress $\sigma_z$, determined for the final value of subsoil load with the embankment weight.

MES calculation cross-section and the for the consolidation process analyses is presented in Fig. 4. The numerical calculation performed for the simplified "slice-like" model can get very fast results, but they not include the effect of horizontal straining, which were obtained for the full 2D cross-section. The results obtained for the most important calculation variants are presented in Fig. 5, the assumed values of the consolidation parameters for the organic soil are presented in Table 1. Total settlements forecasted on the basis of data contained in the design documentation, amounting to approx. 41 mm are about half smaller than the embankment settlements that actually occurred after completion of the construction. Taking into account the results of verification tests and laboratory-determined values of geotechnical parameters, characterising the consolidation process, in the numerical analysis results in obtaining the total size of embankment subsoil settlement exceeding 110 mm in the calculations. Consolidation pace determined in the numerical model indicates the achievement of 55% consolidation degree after completion of the construction, which means the settlement amounting to approx. 50 mm. It should be

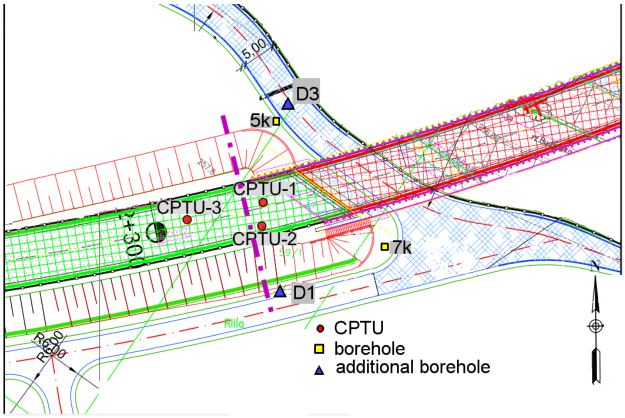


**Figure 2:** Location of test points and the calculation cross-section.

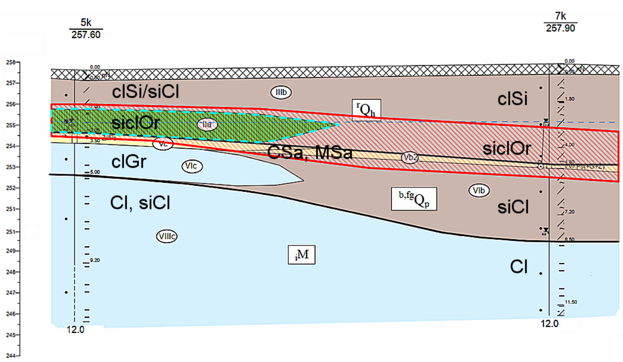


**Figure 3:** Geotechnical cross-section 5k-7k at the place of occurrence of irregular settlements in the transition zone. The zone of organic soil occurrence determined during the subsoil investigations is marked with a diagonal hatching, previous incorrect (incomplete) recognition with a dashed line.

noted that due to the adopted assumptions, it is an assessment of the minimum settlement value.

The above-mentioned example constitutes an illustration of significant errors, shortcomings and negligence, which can occur in the case of complex or complicated soil conditions during design of the solutions in the transition zone between the embankment and the bridge structure. Primarily, the following should be mentioned:

- inaccurate performance of subsoil recognition and incorrect interpretation of soil types, as well as soil states;
- no laboratory tests of geotechnical parameters of the subsoil, which are necessary for the analysis of settlements and consolidation processes, while the parameter values were assumed only based on correlation dependencies;
- erroneous belief (which often occurs in the design practice) that the embankment foundation on the layer of load-bearing soils will ensure good conditions for load-bearing capacity and stability of the road embankment, while in reality it is necessary to consider the entirety of soil conditions, occurring up to the depth of an active zone;
- no settlement analyses were carried out in the design documentation. The possibility of occurrence of excessive and long-lasting settlements, caused by the package of organic soil layers, was not considered. It should be assumed that their impact was omitted, because cohesive load-bearing soils occurred from the ceiling and from the thill.

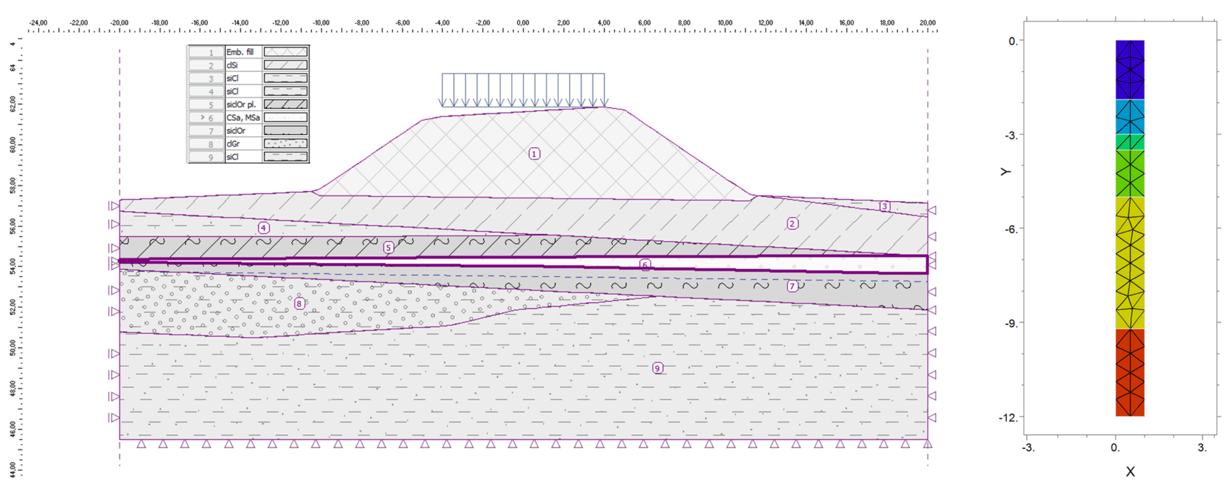


**Figure 4:** MES calculation cross-section for the consolidation process analyses. The possible drainage layer of organic soils was selected. Simplified calculation model is presented on the right side.

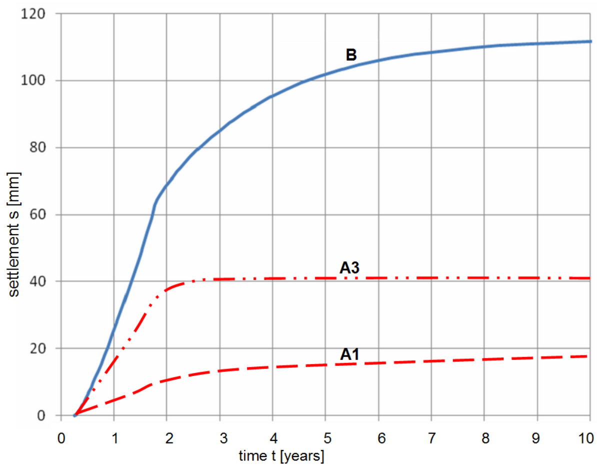


**Figure 5:** Consolidation analysis for the main calculation variants: A1, A3 - minimum and maximum settlement curves determined according to original design data, B - settlement curve determined for the additional geotechnical investigations.

**Table 1:** Consolidation parameters of the organic soil.

| calculation variant | oedometric modulus $E_{oed}$ [MPa] | coefficient of permeability k [m/s] |
|---|---|---|
| A1 | 7,0 | $1,0 \cdot 10^{-7}$ |
| A3 | 7,0 | $1,0 \cdot 10^{-9}$ |
| B | 3,65 | $1,85 \cdot 10^{-10}$ |

## 6 Summary

In the context of presented issues, it can be concluded that the causes of adverse phenomena at contact section of the engineering structure and the earth structure are complex. It is important to correctly select the foundation method of the adjacent engineering structure and the earth structure, in the zone of access roads to the bridge - depending on the correct recognition of the subsoil. The discussed problems, which are associated with the method of work implementation at the contact section of the embankments and the engineering structures, also result from insufficient analysis at the design stage and from incorrect performance. The shortcomings characterised in this article very often overlap in practice.

The practical case presented in this study constitutes an illustration of significant errors, shortcomings and negligence, which can occur in the case of complex or complicated soil conditions during design of the solutions in the transition zone between the embankment and the bridge structure. Especially, it indicates the need to carry out a comprehensive recognition of the subsoil and numerical analyses of the impact of low-strength and organic soils occurring in the subsoil on the behaviour of the designed structure. Such method of procedure is necessary in the case of occurrence of complex or complicated soil conditions up to the depth of the active zone, and not only in direct substrate of the designed road embankment.

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