TRANSPORT PROBLEMS 2021 Volume 16 Issue 2
PROBLEMY TRANSPORTU DOI: 10.21307/tp-2021-036

Keywords: railway track; static plate load test; embankment; transition area

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EVALUATION OF GEOTECHNICAL TESTS (STATIC LOAD TESTS) ON A SELECTED OPTIMISED SECTION OF RAILWAY CORRIDOR NO. Va

Summary. To improve the transport service of every country at the required level, it is necessary to set up appropriate infrastructure, including railways, and the necessary facilities of satisfactory quality. After the establishment of the Slovak Railways (ŽSR), the condition of the railway infrastructure was judged to be unsatisfactory. This situation urgently required optimisation of track sections, which are included in the trans-European corridors. The basic aim of optimisation of the railway network of ŽSR is to build a high-quality, safe and reliable railway, which, due to its excellent quality, will correspond to the standards of advanced European countries and, at the same time, provide interoperability. Due to this, it was necessary to verify the fulfilment of the prescribed quality parameters on the optimised lines, among others, and also bear the capacity of individual structural parts of the sub-ballast layers. To address this aim, this paper deals with optimised corridor no. Va in the Považská Teplá - Žilina section, where the diagnostics of the quality of the sub-ballast layers was conducted. This paper specifically focuses on the evaluation of the determined values of the bearing capacity of the construction layers of the embankments and their foundations as well as the transition areas between the objects of sub-ballast layers and embankments located in the optimised section of the line.

1. INTRODUCTION

The Austro-Hungarian settlement enabled the construction of several main railway lines in the area of contemporary Slovakia after 1867, namely, the so-called Považie Railway. In 1883, a steam railway was introduced into operation on the given track section. A few years later, the advances in notification and signalling technology allowed for a maximum speed of 120 km/h. Positive trends in the development of railway operations were interrupted by World War I and World War II. After the restoration of the Czech–Slovak State Railways (ČSD), several construction interventions, related to the construction of dams on the Váh River, were carried out on the Považie Railway.

However, despite the gradual increase of the operational load on the Bratislava– Žilina– Košice line, including the Považie Railway, there was minimum investment into its development or quality maintenance [1].

A significant change occurred after the birth of the independent Slovak Republic (January 1, 1993), and subsequently, the greenlighting of the project of trans-European multimodal corridors (the decision to optimise the main railway lines in Slovakia). The requirements for the optimised railway line were harmonised through an international AGC agreement (*European Agreement on Main International Railway Lines*) [2].

Under the AGC agreement, three trans-European corridors (Corridor no. IV, Corridor no. Va and Corridor no. VI) cross the territory of the Slovak Republic; the line section Považská Teplá–Žilina is part of Corridor no. Va [3]. The optimisation of the Slovak branch of corridor no. Va started in 2000 and the works were subdivided into 13 stages. The optimisation of the line section related to the train speed of 160 km/h was carried out in 2014– 2017 [4].

This paper focuses on the evaluation of the bearing capacity of the construction layers of embankments and their foundations as well as the transition areas in contact with the objects of the sub-ballast layers (bridges, culverts, underpasses) on the optimised section of the railway line Považská Teplá–Žilina.

The settling and stability of an embankment depend on the bearing capacity of its individual structural layers as well as the subsoil. These are the main geotechnical parameters assessed in the structural design of the embankment, especially in terms of its foundation on low deformation-resistant soil. Abroad, this issue has been researched in several countries, e.g., in Malaysia, where 13 test embankments were built in the Muar Flats complex, and their transverse and vertical deformation characteristics were monitored [5]. In China, an analysis of the deformation characteristics of high embankments based on low deformation-resistant soils was performed. It demonstrated that as the modulus of elasticity of the soft subsoil of the embankment and the new embankment increased, the largest embankment settlements decreased significantly [6]. Research at the Chinese Academy of Sciences focused on the opposite boundary conditions, by monitoring the permanent deformation characteristics of non-cohesive soils in the subsoil of the embankment [7]. In the conditions of the Slovak Republic, the problem of low deformation-resistant subsoil and embankment construction has been studied and reported in [8].

The most critical places on the railway line from the point of view of the resulting different settlements of the structural layers of the sub-ballast layers are the so-called transition areas between the earthwork and the artificial railway structures (bridges, culverts and underpasses). In this area, due to the different stiffness of the subsoil, there is an increased effect of dynamic loading, which can cause smaller or greater degeneration of the track geometry. An optimal proposal of the structural composition of the transition areas is therefore essential, as this eliminates the additional cost of repairing the track geometry to its desired position. Abroad, this issue has also been resolved by several experts. To better understand the physical mechanisms occurring in a typical transition area between the classic railway line without the artificial railway structure and a line section with a built-in culvert, experimental monitoring of the transition area was performed e.g. in the Netherlands [9]. Extensive field measurements of the transition areas created by the crushed stone mixture backfill and their numerical modelling were carried out in Portugal [10-12]. A study of deformation characteristics in the transition area between the embankment and the concrete structure was also performed in Japan [13]. The main problems of transition areas, their alternative design and classification of the most common approaches to the solution of transition areas are presented in a study from Spain [14]. In the conditions of the Slovak Railways, transition areas are designed according to [15].

The aim of this work is to present the experience related to the construction of embankment structures and transition areas obtained in the optimisation of the line section of Corridor no. Va. The obtained deformation characteristics will also serve as input parameters for the subsequent design of various structural compositions of transition areas and their numerical modelling in Simpack software. This paper is a continuation of the paper [16] published in the journal Civil and Environmental Engineering.

2. OVERVIEW OF TESTED MATERIALS AND METHODS OF THEIR DIAGNOSTICS

This chapter will describe the characteristics of built-in materials and methods for verification of the bearing capacity of construction layers of embankments and their foundations, as well as transition areas located on the optimised section of the line.

2.1. Characteristics of material properties of embankments and their transition areas

The earthwork in the embankment is an engineering structure that should be constructed using a suitable filling material, wholly or partially on the terrain surface. The design thicknesses of the individual layers of the embankment depend on the type of filling material and the effectiveness of the available compactor. The construction of a sufficiently deformation-resistant earthwork in the embankment of high-quality, especially coarse (incoherent), soils is one of the prerequisites for ensuring good-quality and safe railways [17].

The section of the Považská Teplá– Žilina railway line has a total length of 22.7 km, 6.1 km of which is constructed on a newly built embankment. New embankments are built to increase the line speed, in turn yielding larger radii of curves, which lead to a new directional path of the original track route. Following the established practice and the contracting authority's requirement to carry out optimisation of the railway line during continuous operation, the respective line was split into 5 coherent parts of a construction (CPC). The locations of individual CPC and newly built embankments (designated E 1–E 5) are demonstrated in Fig. 1.

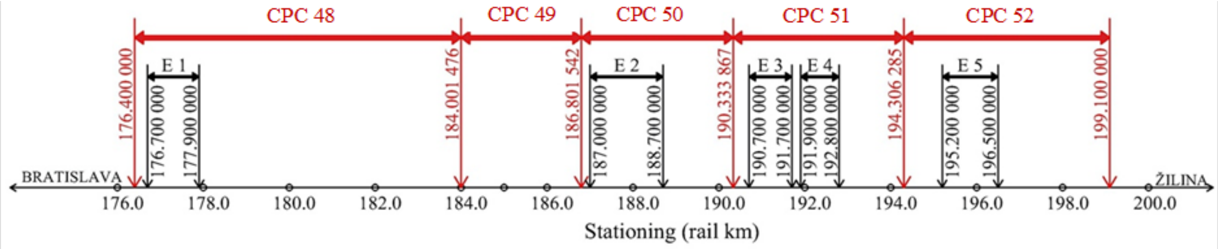

Fig. 1. Locations of individual CPC and newly built embankments [18]

In the geotechnical examination of the sub-ballast layers, which was conducted in 2005, mostly sandy loams (MS2), sands (SP) and clay soils (CG, CI, CL, CS) were identified in the foundation of the embankments. The values of the bearing capacity (acquired by static load tests) on the surface of the foundation bed of the embankments did not satisfy the prescribed value $E_{def2} \geq 25$ MPa. Because of this, a consolidation layer of coarse-grained soils (crushed stone mixture fr. 0/63 mm) with a thickness of approx. 0.5 m was designed in the foundations of all embankments. The consolidation layer is covered in Macrit GTV 50/50 geocomposite and reinforced with Triax TX 160 geogrid. In four cases, the embankments were built from coarse-grained soils fr. 0/63 mm (E 1– E 4) and in one case, an embankment of a sandwich structure (E 5) was constructed. The sandwich structure was built by alternating fine-grained soil obtained from the nearby cut of the railway line with a layer of coarse-grained soil. The prescribed values of bearing capacity at the level of foundation of an embankment and the level of individual construction layers of the embankment are evident from Fig. 2.

The actual values of the bearing capacity of the foundations and the individual structural layers of the embankments in question, measured during the optimisation works of the section of the railway line and their analysis, are the subject of Chapter 3.

In terms of construction quality diagnostics of the construction layers of the track substructure, the measurement methodology described in Chapter 2.2, apart from embankments, also assessed the so-called transition areas. These areas are transitions of the earthwork to the artificial railway structures (bridges, culverts and underpasses). The purpose of the transition areas is to prevent different settlement of structures and to ensure the stiffness gradation of the earthwork towards the artificial railway structure. As a rule, it is recommended to build specially designed and compacted backfills to establish a transition area. In the case of new constructions, optimisation of lines and complex reconstructions of existing lines, the transition area according to [15] should have a length $L = V/2$, but not less than 30 m and a maximum of 80 m.

The location, designation and type of railway artificial structures, where the transition areas were assessed, are presented in Tab. 1.

The subject of research activities of the Department of Railway Engineering and Track Management (DRETM) is also a continuous diagnostic of the track geometry of optimised line sections using the KRAB^{TM} – Light$^{®}$ equipment [20]. Based on the measurements carried out so far, it can be stated [21, 22] that the transition areas are a critical point on the railway line that significantly influence its quality, and, therefore, it is necessary to pay particular attention to them. Several other countries [12, 23-27] are focusing on the design of the optimal composition of the transition areas and their monitoring. This issue is also the subject of the current VEGA grant project (specified in greater detail in the Acknowledgement section) at the DRETM (our workplace).

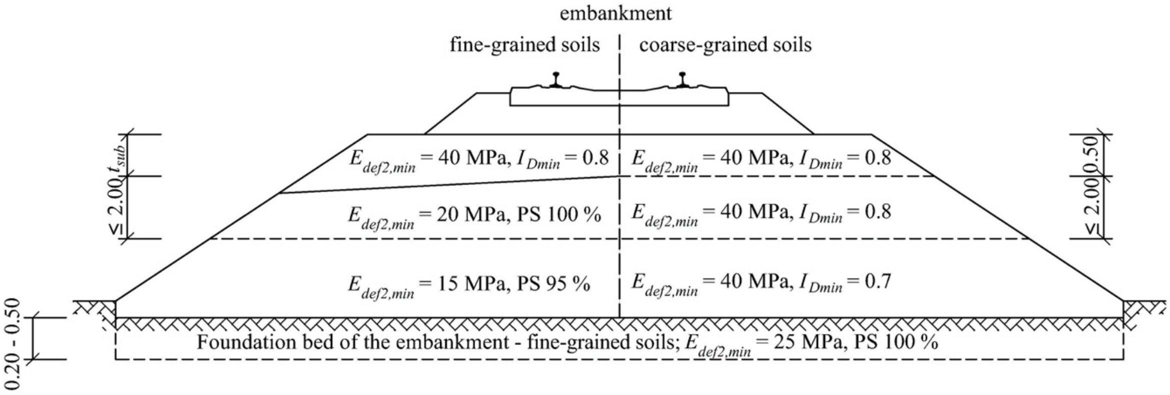

Fig. 2. Prescribed values of the bearing capacity of individual parts of the structure [19]

An example of the transition area and the prescribed value of the bearing capacity of the transition area at the sub-ballast upper surface are shown in Fig. 3.

The values of the bearing capacity of transition areas, determined during the optimisation works of the Považská Teplá–Žilina line section and their analysis, are also specified in Chapter 3.

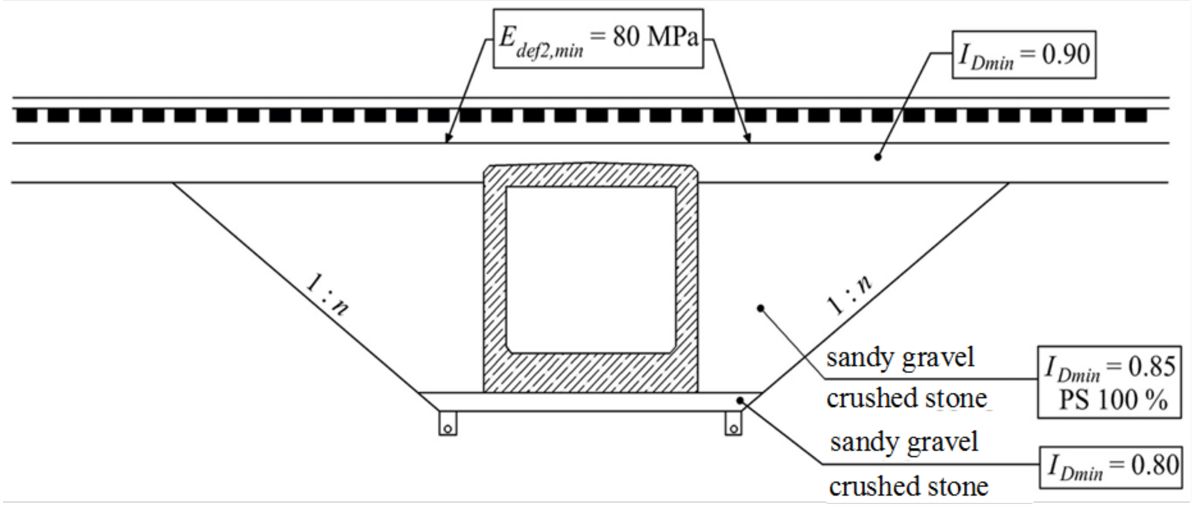

Fig. 3. Example of the transition area for small-length objects [15]

2.2. Methodology of establishing the bearing capacity of embankments and transition areas

The bearing capacity of the foundation and structural layers of embankments as well as the transition areas of the optimised section of the Považská Teplá–Žilina railway line were identified using the equipment shown in Fig. 4.

The static plate load tests (PLTs) on the surface of the foundation bed of the embankment, on the surface of the consolidation layer and on the surface of the last construction layer of the embankment or at the sub-ballast upper surface (transition areas) were conducted in compliance with STN 73 6190 [29]. The bearing capacity measurement of the above-mentioned structural parts of the embankment was conducted in two load cycles with a maximum contact stress value of 0.30 MPa, namely, by gradual (stepped) loading/unloading of a rigid circular load plate with a diameter of 357 mm. The measured values were the static modulus of deformation E_{def} and the quality of compaction of the diagnosed structural layer, expressed by the ratio E_{def2}/E_{def1} [29]. The static modulus of deformation of the structural layers E_{def} was determined according to the following formula:

$$E_{def} = \frac{\pi}{2}.(1 - \mu^2).r.\frac{\Delta p}{\Delta y} \quad (1)$$

where E_{def} – static modulus of deformation (MPa),
μ – Poisson material number determined by the type of test material (-),
r – plate load radius, (m),
Δp – change of contact stress (MPa) and
Δy – change of plate settlement (deformation of the test layer) (m).

Table 1

Location, designation and type of railway artificial structures [18]

Stationing (rail km)	Designation of structure	Type of structure
176.577	SO 48.32.08	culvert
179.125	SO 48.32.11	culvert
179.435	SO 48.32.12	culvert
180.167	SO 48.32.13	culvert
180.667	SO 48.32.14	culvert
181.593	SO 48.32.15	culvert
182.057	SO 48.32.16	culvert
182.795	-	culvert – original state
185.330	SO 49.33.12	underpass
186.942	SO 50.32.10	culvert
187.080	SO 50-32-06	railway bridge
188.942	-	culvert – original state
189.109	SO 50.32.12	culvert
192.835	-	railway bridge – original state

Fig. 4. Static plate load test device [28]

The measurement of the static deformation modulus of the foundation and construction layers of embankments in the section of the railway line was usually carried out every 200 m, or even at a smaller distance in cases of localisation of places with low bearing capacity. In the transition areas, static load tests at the sub-ballast upper surface were conducted in the axis of track axes or separately for each track axis in front of and behind the artificial railway structure (bridge, culvert, underpass).

3. MEASUREMENT RESULTS AND THEIR ANALYSIS

The diagnostics of the bearing capacity of structural parts of embankments, their foundations and transition areas to the railway artificial structures was conducted between June 2014 and April 2017. The values of the static modulus of deformation, measured in individual structural levels of embankments within individual CPC (specified in greater detail in section 2.1 - Fig. 1), were identified following the methodology described in section 2.2. Fig. 5 demonstrates an overview of the values on the surface of the foundation bed of the individual embankments (E 1 - E 5), located in the respective CPC.

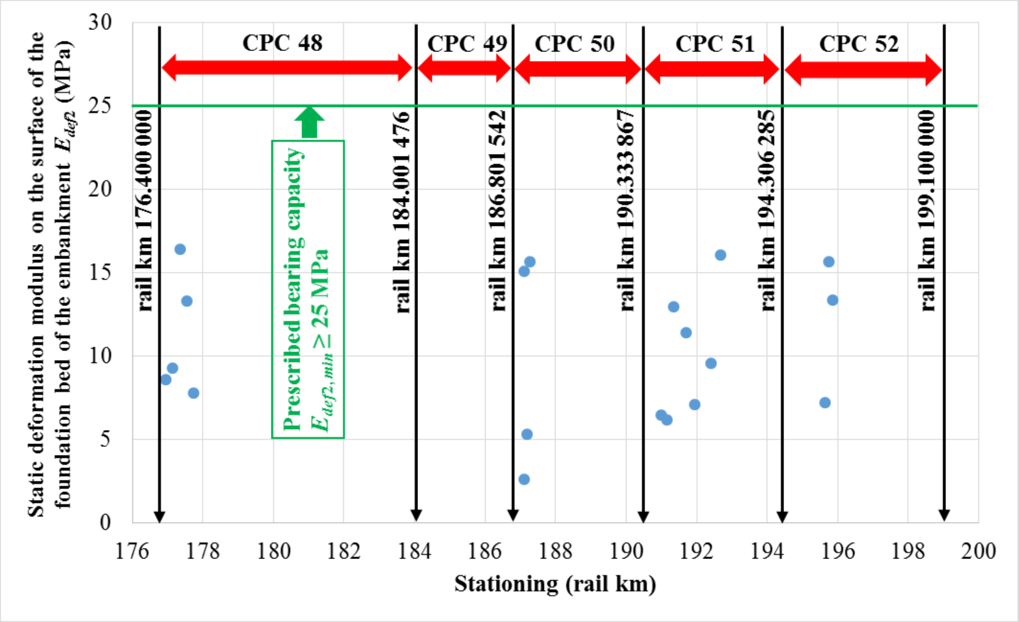

Fig. 5. Determined values of the static deformation modulus on the surface of the foundation bed of the embankments

Fig. 5 shows that the values of the static modulus of deformation on the surface of the foundation bed of individual embankments did not satisfy the prescribed minimum bearing capacity $E_{def2,min} \geq 25$ MPa. In total, 19 values were evaluated, ranging from 2.6 MPa to 16.4 MPa (average value was 10.5 MPa). For this reason, a consolidation layer of crushed stone mixture fr. 0/63 mm, thickness 0.50 m, was established on the surface of the foundation bed of all assessed embankments. Fig. 6 shows a summary of the values of the static deformation modulus on the surface of the consolidation layer of the individual embankments located on the line section in question.

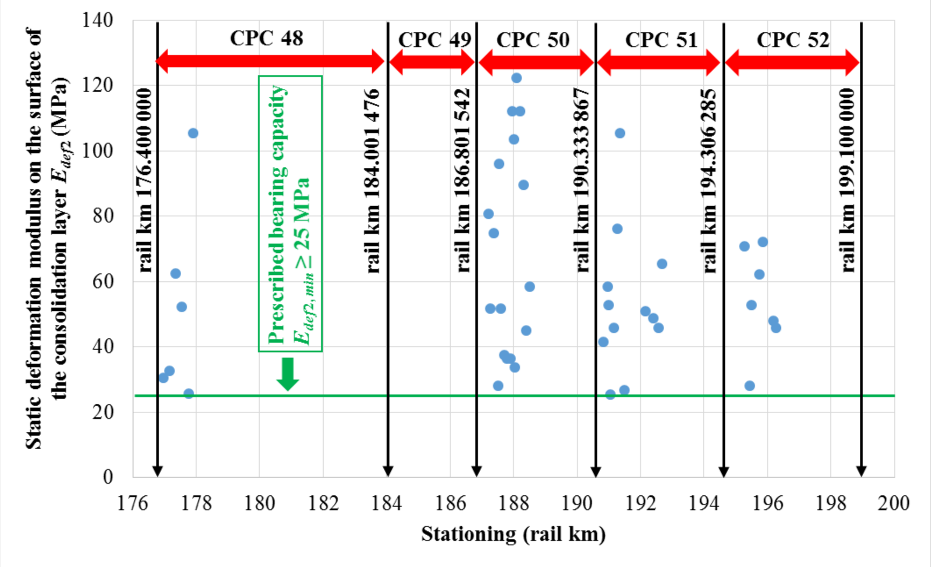

Fig. 6. Determined values of the static deformation modulus on the surface of the consolidation layer of embankments

Fig. 6 shows that the values of the static modulus of deformation on the surface of the consolidation layer of individual embankments already complied with the prescribed minimum bearing capacity $E_{def2,min} \geq 25$ MPa and, therefore, individual structural layers of the embankments could be gradually built. In total, 42 values were evaluated in the analysis, ranging from 25.5MPa to 122.3 MPa (the average value was 59.6 MPa).

In the case of embankments designated E 1–E 4, their structural layers were constructed of coarse-grained soil fr. 0/63 mm and in the case of the E 5 embankment, a sandwich construction (a combination of fine-grained and coarse-grained structural layers of the embankment) was established due to the low bearing capacity of the fine-grained soil used. Fig. 7 and Fig. 8 show a summary of the values of the static deformation modulus on the surface of the top structural layers of the E 1–E 4 embankments, and on the surface of the fine-grained (orange rings) and coarse-grained (blue rings) structural layers of the sandwich construction of the E 5 embankment.

Fig. 7 shows that embankments built from coarse-grained soils are problem free in terms of achieving the required construction conditions (observance of the maximum thickness of individual structural layers) and technological conditions (performing the required compaction). They are also satisfactory in terms of achieving the prescribed bearing capacity of the measured structural layer. In total, 49 values were evaluated, ranging from 42.8 MPa to 162.8 MPa (the average value was 110.0 MPa).

To achieve a reduction in the cost of embankment construction, the project documentation suggested that soil from nearby cutting slopes would be used. This material (clay soil) did not have the optimal properties in terms of the prescribed bearing capacity for its placement in the embankment layers ($E_{def2,min} \geq 20$ MPa). Therefore, it was decided to change the material composition of the embankment layers for a sandwich construction of embankment (a combination of structural layers of fine-grained and coarse-grained soil). The material obtained from the original earthwork of the railway line was used as coarse-grained soil. In total, 34 values were evaluated in the analysis, ranging from 2.8 MPa to 101.1 MPa (the average value was 39.8 MPa). As shown in Fig. 8, despite changing the material composition of the embankment layers (E 5), in some embankment locations, the prescribed bearing capacity was not achieved. Due to this, in this coherent part of a construction (CPC 52), on the surface of the top construction layer of the embankment, lime stabilization of the incorporated fine-grained material had to be additionally established. Based on the experience gained with the sandwich construction, part of the embankment structure, namely, from rail km 195.8 to rail km 196.5, was built only from the coarse-grained material (obtained from the original earthwork) and part of the embankment structure stabilised on its surface (rail km 195.0 – rail km 196.0).

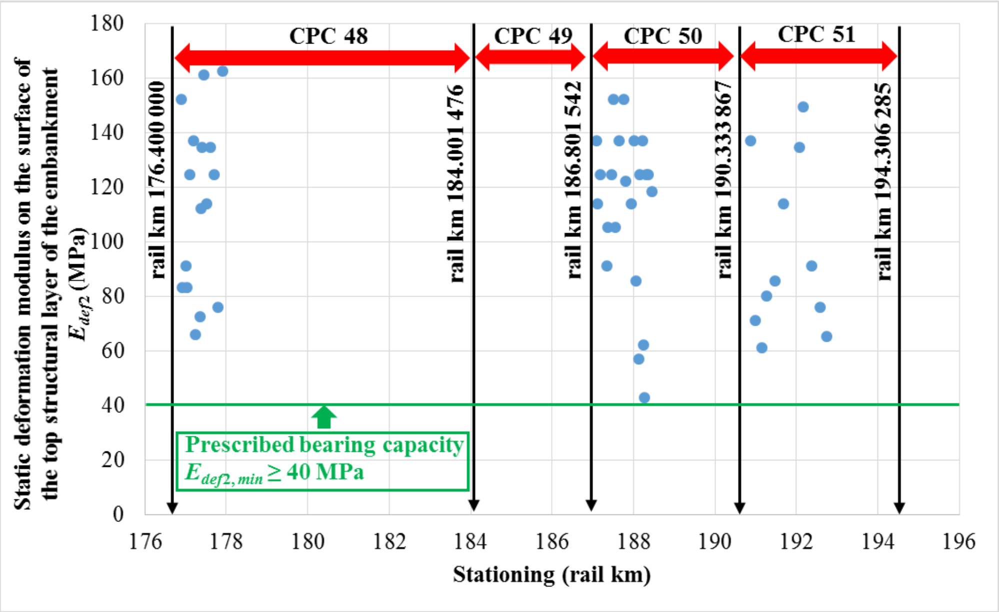

Fig. 7. Determined values of the static deformation modulus on the surface of the top structural layers of the embankments established from coarse-grained soil

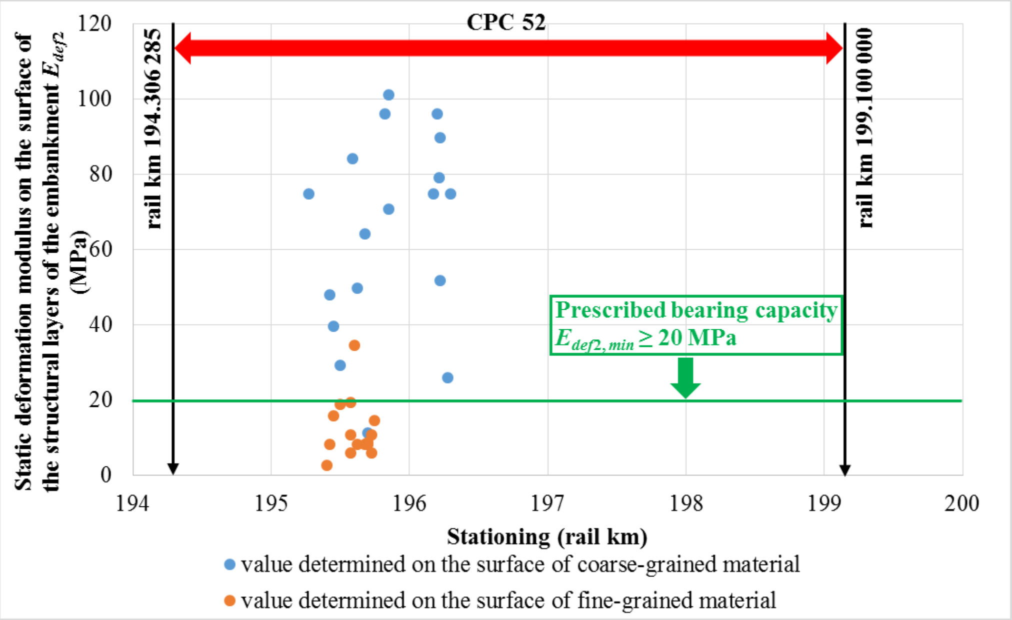

Fig. 8. Determined values of the static deformation modulus on the surface of structural layers of the sandwich embankment

In addition to the identification of compliance with the specified values of the bearing capacity of individual structural parts of embankments, the values of the bearing capacity of transition areas of the artificial railway structures (their location is shown in Table 1) at the sub-ballast upper surface were also measured. Fig. 9 shows a summary of the determined values of the bearing capacity of the transition areas measured at the sub-ballast upper surface.

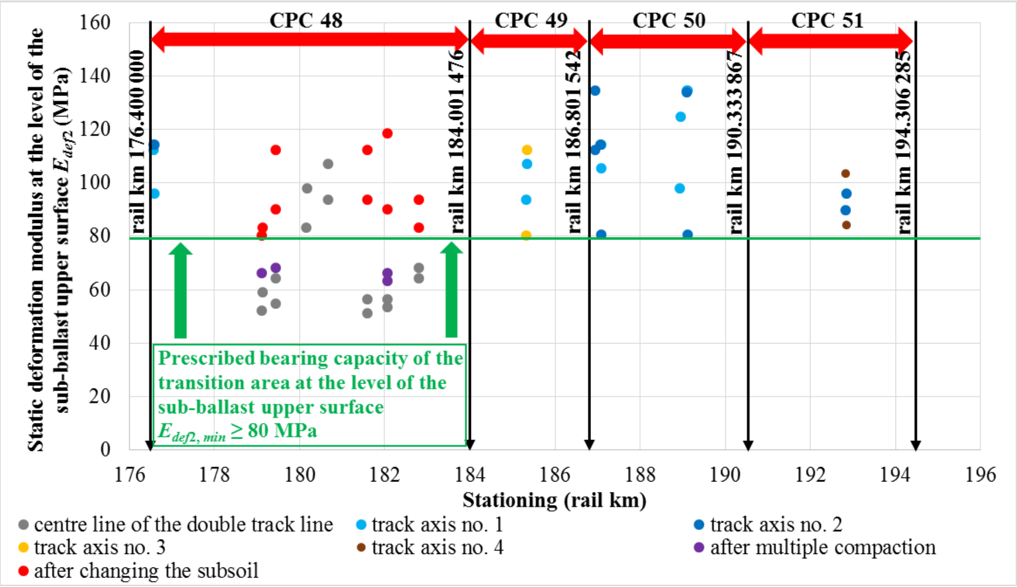

Fig. 9. Determined values of the static deformation modulus of the transition areas of the railway artificial structures measured at the sub-ballast upper surface

Fig. 9 shows that out of the 14 diagnosed transition areas constructed from coarse-grained soil fr. 0/63 mm, up to 5 transition areas did not meet the minimum prescribed value of the static deformation modulus at the sub-ballast upper surface $E_{def2,min} \geq 80$ MPa, even after performing multiple compaction (purple rings). Therefore, a decision was made to change the subsoil of transition areas to coarse-grained soil fr. 0/63 mm and re-diagnose the transition areas in question (red circles). It can be stated that after this treatment, the transition areas in question meet the prescribed minimum bearing capacity. In total, 52 values were evaluated in the analysis, ranging from 51.1 MPa to 134.6 MPa (the average value was 94.2 MPa before subsoil change and 102.9 MPa after subsoil change).

4. CONCLUSIONS

The aim of the construction work on the double-track railway line in the section Považská Teplá – Žilina was to optimise its technical infrastructure as it is part of the European railway corridor no. Va. The optimisation aimed to meet the prescribed parameters in terms of the AGC agreement. This paper presents an overview of the determined values of the bearing capacity of the several embankments, their foundations and transition areas of the artificial railway structures of the optimised section of the respective line in question, which was split into 5 coherent parts of a construction (see Fig. 1).

Following the analysis of the values of the static deformation modulus of the individual structural layers of the embankment, it can be concluded that if the coarse-grained soils are used in the embankment layers and a sufficiently deformation-resistant foundation bed of embankment (consolidation layer construction) is built in, these embankments can be considered problem free (Fig. 7).

On the contrary, the use of fine-grained soils (especially clay soils) in the embankment layers (Fig. 8) causes considerable complications, namely, qualitative (insufficient bearing capacity, considerable settling), technological (dependence of their incorporation on climatic conditions, compaction problems), economic (change of project documentation, additional construction measures), etc.

Drawing on the long-term experience of the DRETM members in quality diagnostics of work conducted on optimised sections of the Slovak Railways infrastructure, this line section also confirms that the geotechnical survey does not always yield relevant information about the subsoil of the railway line and recycled materials (obtained from the original earthwork) used in the sub-ballast layers of the optimised railway line. Subsequently, a non-standard structural composition of the sub-ballast layers (a combination of a sandwich construction of the embankment and its stabilisation) can finally be designed. As part of further optimisation work on the railway line corridor, but also on other lines in the foreign railway administration, it is therefore recommended to carry out a quality geotechnical survey (densifying of the network of measuring points on the line) and construction of embankments primarily from coarse-grained materials.

The experience of DRETM staff with transition areas, which are considered to be one of the most critical places on the railway line based on several years of monitoring of optimised sections, was also confirmed. Following the analysis of the determined values of the bearing capacity of the transition areas at the sub-ballast upper surface, it was shown that out of 14 assessed transition areas, up to 5 did not meet the prescribed value $E_{sub} \geq 80$ MPa (Fig. 9) and the subsoil had to be changed. Ensuring the prescribed bearing capacity of the structural layers and the subsoil of the transition area during its construction is the first step to reducing future failures in the track geometry and the consequent increased track maintenance costs. Another recommendation for ensuring good-quality roadways not only in Slovakia but also abroad is to carry out diagnostics of the bearing capacity of transition areas within their construction.

Finally, it should be noted that this paper expands on and is related to the topics developed in [16]. Further studies of DRETM will analyse the measured values of the bearing capacity of the sub-ballast layers at the sub-ballast upper surface in the optimised section of the railway line Považská Teplá–Žilina. In this way, a coherent overview of the quality of work carried out in this section of the railway line will become available.

Acknowledgement

The presented information is the partial results of solving the VEGA grant project 1/0084/20 "*Numerical and experimental analysis of transition areas of objects of structures of railway superstructures and objects of formation substructure*".

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Received 28.11.2019; accepted in revised form 17.05.2021