Requirements and practice from measuring the deformation resistance of the formation of the railway subgrade of the Slovak railways modernized line Plevník-Drienové-Bytča-Žilina

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Abstract. Deformation resistance of the formation of the subgrade is the main indicator of the quality of the designed structural layers of the subgrade formation. Deformation resistance is determined in Slovak Railways (ŽSR) by a static plate load test and is expressed by the modulus of deformation E_s. The static load test not only verifies the correctness of the design of the type of structural layers of the body of the railway subgrade, but it is also an indicator of the quality of the performed construction works. On modernized ŽSR lines, is designed for subgrade type No. 3 and in the most unfavorable geotechnical conditions also the type of structural layers of the formation of the railway subgrade No. 6. The required value of deformation resistance at the level of the formation of the subgrade is designed with regard to the speed zone of the railway line. ŽSR corridor lines are designed for speeds up to 160 km/h, so they belong to the RP4 speed zone. Such lines also include a section of the ŽSR modernized Plevník-Drienové-Bytča-Žilina line.

1. Introduction

Since 2002, ŽSR has begun extensive modernization of its railway lines. The priority of modernization is the main lines, which are included in the strategic European transport routes TEN-T and railway corridors on the basis of international agreements AGC and AGTC. Three important railway corridors pass through the territory of the Slovak Republic, while the double-track line Považská Teplá-Žilina is a part of corridor no. V. (Venice-Trieste/Koper-Ljubljana-Budapest-Uzhhorod-Lviv). With the integration of the ŽSR network into European transport routes, ŽSR has taken over the obligation to respect international agreements and the resulting technical requirements that are imposed on these lines.

The modernization of railway lines focuses on the modification of stations and trainstops, the building of level crossings and especially on increasing the line speed, where the highest speed of trains reaches 160 km/h after the modernization. The line speed is the basic parameter used to design the type of structural layers of the subgrade body and the required deformation resistance at the level of the subgrade formation.

2. Railway line Plevník–Drienové–Bytča–Žilina

Construction of the modernized line ŽSR Plevní-Drienové - Bytča is an independent investment project of the modernization of the line Púchov-Žilina to a speed of up to 160 km/h, II. stage Považská Teplá (outside) - Žilina (outside). The investment project passes through the districts of Považská Bystrica, Bytča and Žilina. This area is part of the main development axis of Slovakia, through which the corridors of transport and technical infrastructure of supraregional importance meaning. In the draft regulations for territorial development, the project is included as a public benefit measure of the superior transport infrastructure. The structure consists of interstation track sections and railway station structures, which represent separate coherent parts of the project (CPP):

- CPP 48 Považská Teplá – Bytča with trainstop Plevník-Drienové and Predmier,
- CPP 49 Bytča – figure 1,
- CPP 50 Bytča – Dolný Hričov,
- CPP 51 Dolný Hričov,
- CPP 52 Dolný Hričov – Žilina with trainstop Horný Hričov.

Individual CPP were realized as separate buildings. Each of them was designed to be independently feasible and to be able to operate independently also with certain limitations and specifications.

The proposal for the modernization of the railway line makes maximum use of the existing railway formation, taking into account compliance with the required speed parameters, basic conditions for capability and area modification. The technical conditions for the implementation of directional adjustments of the track curves required the necessary deviations in order to achieve its required speed parameters. The necessary track alignments, caused by the required speed parameters, with regard to the existing railway track, have been done in:

- track section Považská Teplá – Bytča, km 176.7 – 177.9 in length 1 200 m,
- track section Bytča – Dolný Hričov, km 187.0 – 189.7 in length 700 m,
- railway station Dolný Hričov, km 190.7 – 191.7 in length 1000 m and km 191.9 – 192.8 in length 900 m,
- track section Dolný Hričov – Žilina, km 195.2 – 196.5 in length 1 300 m.

Figure 1. Railway station Bytča after modernization.

The structure realisation was based on the conditions of maintaining operation in inter-station sections in the exclusion of one of the two railway tracks. The order of implementation of individual CPP was chosen on the basis of close cooperation of the construction contractor (TEBS Association) with the client of the building (ŽSR), the railway administrator of the railways (ŽSR, OR Žilina), building designer (Reming Consult) and building supervision (DEC International), on the basis of approved work procedures and construction organization plan in specified exclusions of railway operation.

The construction procedures and durations of construction took into account the time horizons set by the Ministry of Transport, Posts and Telecommunications of the Slovak Republic due to the efficient drawing of finance. The total length of the modernized section is 22.702 km, 50 613 m of new rail tracks were laid, 44 new rail switches and crossing structures, 9 railway bridges were reconstructed and 7 new railway bridges were built, 5 new underpasses for passengers and the public and 13 113 m of noise bariers [1].

3. Deformation modulus measurements of the subgrade formation

In the conditions of ŽSR, since 1971, the deformation resistance of the structural layers of the railway substructure has been expressed by the value of the deformation modulus determined by a static load test [2]. Determination of deformation characteristics by static plate load test (PLT) with a circular plate is based on the general theory of elastic half-space. In the Slovak Republic, the following normative documents apply to the static plate load test: STN 73 6133 [3], STN 73 6190 [4] and for railway subgrade structures the ŽSR TS4 regulation [5]. The deformation resistance of the plain of the railway subgrade body is characterized by its modulus of deformation determined by a static load test using the methodology specified in the regulation [5]. According to this regulation, the resulting of static modulus of deformation E_{si} is determined from the second of two load cycles - figure 2. One load cycle has a specified 4 load stages, after reaching the maximum specific pressure, the same stepped relief of the plate follows until reaching the zero applied pressure. The graphical course of the static PLT is shown in figure 2. The value of 0.2 MPa was used as the maximum contact stress for both load cycles, which is the standard stress used on ŽSR lines for the formation of the subgrade. The measured quantity was the static modulus of deformation E_{si}, which was determined from modernized line ŽSR Plevní-Drienové - Bytča is an independent building of the relation:

$$E_{si} = \frac{1{,}5 p \cdot r}{y} \qquad (1)$$

where: E_{si} – static modulus of deformation, [MPa],
p – contact stress under the load plate, [MPa],
r – load plate radius, [m],
y – total average settlement of the plate load, [m],

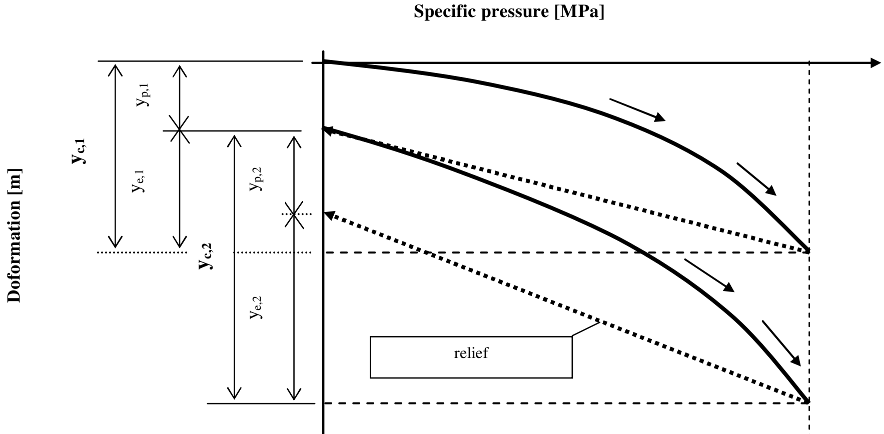

Figure 2. The course of PLT according to the methodology of ŽSR TS4.

Static load tests were performed by employees of the Department of Railway Engineering and Track Management, Faculty of Civil Engineering, University of Žilina. The equipment of the Accredited Laboratory of the Faculty of Civil Engineering, the static load set FROWAG with single-point deformation sensing with a digital indicator IDU25 Mitutoyo and a load plate with a diameter of 0.300 m were used for the measurement.

Static load test at the level of the surface of the formation of the railway subgrade belongs to the basic measurements in situ of the inspection and acceptance process of building. The measurement provides accurate results in a relatively short period of time, other field quality control tests, e.g. compaction degree, last disproportionately longer. This is an important parameter especially in the conditions of ŽSR structures, because the deficiencies found by the control test must be removed immediately in the possesions, for example additionally compacting the tested layer, or replace it with a more suitable material, etc. The static load test at the level of the railway subgrade formation surface is the main acceptance test of the quality control of the railway subgrade structure, it is the basis for taking over the structure works and the permit for the commencement of structure works of the railway superstructure. The prescribed number of static load tests is according to [5], one PLT every 200 m. The minimum required values of the static modulus of deformation of the formation of the subgrade E_s on main railway tracks are specified in the project documentation, namely at least 80 MPa on newly built relocation embankments and at least 60 MPa on existing railways.

4. Evaluation of measurements

On the modernized section of the Plevník-Drienové-Bytča-Žilina railway line, a total of 277 static load tests were performed at the level of the formation of the subgrade, of which 243 load tests in the main railways tracks and 34 static load tests in other tracks in the modernized railway stations Bytča and Dolný Hričov [7]. The results of the average values of the modulus of deformation at the level of the formation of the railway subgrade on particular CPP and tracks are shown in figure 3.

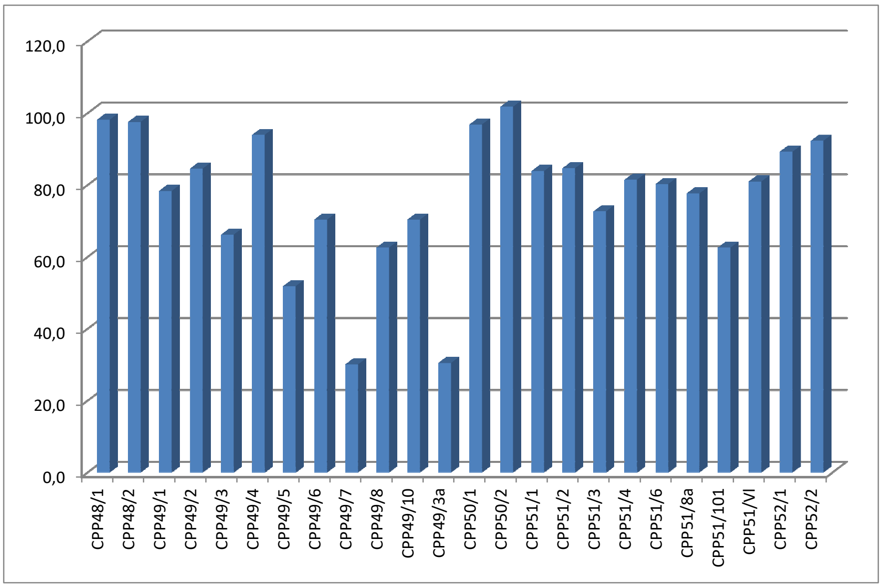

Figure 3. – Overview of the results of the achieved average values of deformation modules in the level of the railway subgrade formation.

As mentioned in the introduction, the modernization of the ŽSR corridor lines focuses mainly on increasing the line speed to 160 km/h.

This line speed applies to the main railway tracks, therefore in the further assessment of the quality of the structure of the modernized line, the measurement results are related only to the main railway tracks. Table 1 shows the average values from the deformation modulus measurements identified in the main railway tracks.

Table 1. Average values of deformation modulus in main railway tracks.

	CPP 48		CPP 49		CPP 50		CPP 51		CPP 52	
Track	1	2	1	2	1	2	1	2	1	2
$E_{s\ average}$ [MPa]	98.1	97.5	78.3	84.5	96.8	101.7	83.8	84.6	89.2	92.2
$E_{s\ reglets}$ [MPa]	113.4	104.3	-	-	98.5	113.8	91.3	91.4	100.2	101.4
$E_{s\ exist}$ [MPa]	93.9	95.9	-	-	96.2	99.2	75.6	79.9	85.1	88.8

In table 1, in addition to the average values of the measured deformation modulus ($E_{s\ average}$), the average values of the deformation modulus measured on the sections with the existing railway formation ($E_{s\ exist}$) and on the sections with the newly built railway formation ($E_{s\ reglets}$), i.e. on relocations of the railway track due to a change of alignment (to achieve its required speed parameters). Graphic course of deformation modules of track No. 1 and 2 in the level of the formation of the railway subgrade of the modernized line Plevník-Drienové - Bytča - Žilina is shown in figures 4 and 5.

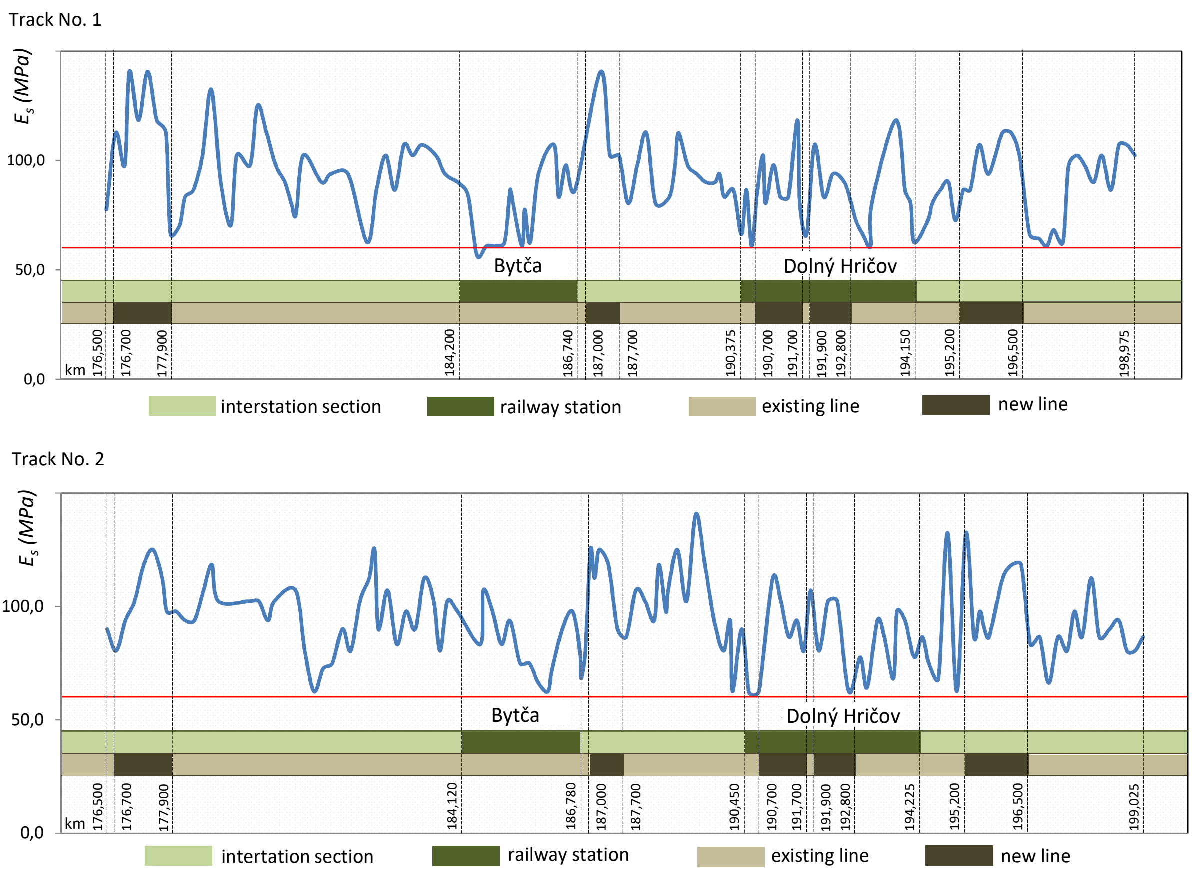

Figure 4. Graphic course of achieved values of deformation modulus of the formation of the railway subgrade surface.

From the measured values of the deformation modulus of the formation of the railway subgrade surface, it is clear that on a newly built railway formation achieves higher values of the modulus of deformation than the modulus of deformation of the formation of the railway subgrade on the existing body. Similarly, the modulus of deformation of the formation of the railway subgrade surface of the modernized railway stations Bytča - CPP 49 and Dolný Hričov - CPP 50 reaches lower values than on the interstation sections - CPP 48, CPP 50 and CPP 52.

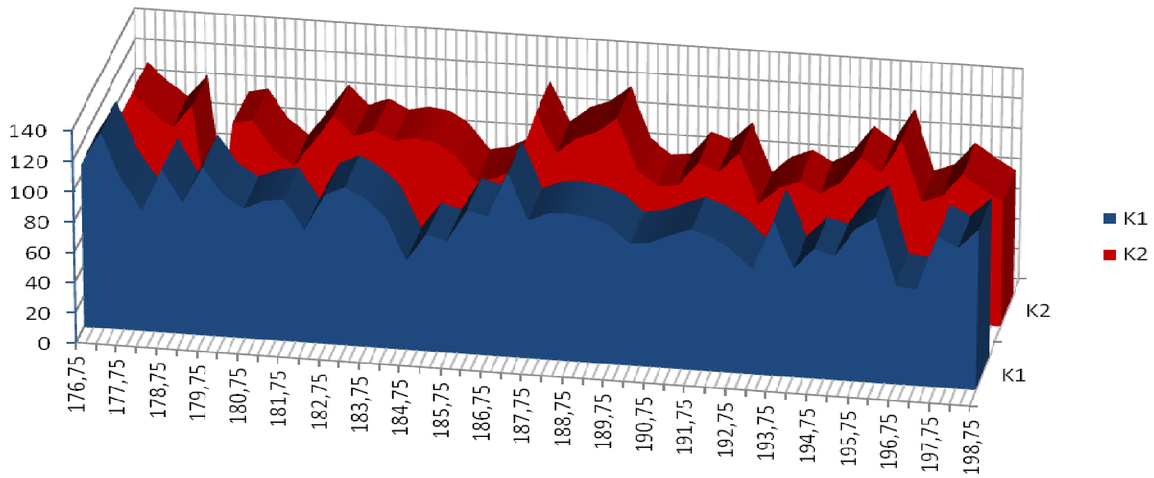

Figure 5. Comparisons of values of deformation modules in the level of railway subgrade formation surface track. No. 1 and track No. 2.

4. Conclusions

At ŽSR, the deformation resistance of the railway subgrade formation surface is determined by the minimum value of the deformation modulus [6]. The design of the structural layers of the body of the railway subgrade is based on the required technical requirements and on the results of the geotechnical survey. The technical requirements are uniquely determined; we propose the required value of the deformation modulus at the level of the surface of the formation of the railway subgrade with regard to the speed zone of the railway line. ŽSR corridor lines are designed for speeds up to 160 km / h, they belong to the RP4 speed zone, for which the minimum values of the deformation modulus are considered.

However, the results of the geotechnical exploration introduce a certain degree of uncertainty into this design, because another important parameter of the design of the structure of the structural layers of the railway subgrade formation is the modulus of deformation of the ground plane determined by a static load test made in borrov and drill hole. The selected number of survey tests may not reveal problem areas of the existing state and these will be revealed only by uncovering the ground plan during the actual realisation. In such a case, it is important that the construction work and the chosen technology respond flexibly to this situation and that appropriate measures are proposed. This was also the case for the structure of the modernized line Plevník-Drienové - Bytča - Žilina, where the project proposed a type of structural layers of the formation of the railway subgrade No. 3 with different thickness of the base layer and different types of geosynthetics. As far as the situation allowed, these were operatively adjusted according to the existing state of the ground plan, and in the most critical places, the type of structural layers of the formation of the railway subgrade was changed to type No. 6, i.e. on the type of structural layers of the formation of the railway subgrade with a stabilized ground plane. From the results of measurements of the deformation resistance of the surface of the formation of the railway subgrade, it is clear that the cooperation of the building contractor, construction designer and construction supervisor was effective and the specified design parameters and the overall quality of the realized building were observed with sufficient reserve.

Acknowledgments
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