



## INFLUENCE OF PLANUM BEARING CAPACITY ON TRACK STRUCTURE

Slavko Živković<sup>1</sup>, Stjepan Lakušić<sup>2</sup>

<sup>1</sup> Croatian railways, Croatia

<sup>2</sup> University of Zagreb, Faculty of Civil Engineering, Croatia

### Abstract

The demand for improvement of the quality of railway transport, primarily regarding comfort and traffic speed, initiated numerous railway administrations to modernize their railway lines. The mentioned requirement motivated a large number of experts to consider the problem of track maintenance, all with the purpose of increasing safety and reducing the maintenance costs, particularly for classical track structures (tracks with the railway bed). Regarding maintenance of tracks, it is not sufficient to direct the attention only to maintenance of the superstructure. Installation of good quality rails, fastening systems, railway sleepers and ballast will have little effect if the substructure of tracks does not have a corresponding bearing capacity. Degradation of the substructure causes settlement of the track structure, and this mostly influences the deterioration of the track geometry. Due to the mentioned, during maintenance and reconstruction planning, the substructure must be considered equally important as the superstructure, because the instabilities of the track are most often the consequence of the planum deformations. The paper presents the research of the effects of the track substructure bearing capacity on behaviour of the track structure. Researches were carried out on the network of Hrvatske željeznice (Croatian Railways) (on the two-track railway Ivankovo – Vinokovci, Pan-European Corridor X) in the period from 2003 to 2008. Within the five-year research, continued measurements of settling of the tracks were made on selected measurement points, along with measurements of the track geometry. On the basis of processing of the data measured and the analyses carried out, it was ascertained to what extent does the bearing capacity of the substructure (subballast), expressed by the stiffness modulus, influence the behaviour of the track structure.

*Keywords: subballast, ballast track, planum deformations, maintenance*

### 1 Introduction

Soil base, as integral part of geotechnical structures of the subballast of railway lines is always loaded along the same lane and therefore damages of planum and subsoil are of specific shape, deformations in cross and longitudinal direction. Material type of these elements is much more subject to changes compared to the elements of track permanent way, especially its most jeopardized part – planum. Compaction of materials in these layers caused by traffic load must remain within the scope of elastic deformations. Damages of the planum generally occur due to several different impacts and they typically occur due to the following:

- Way of construction of the subballast (inappropriate types of material, unsuitable construction methods, insufficient and uneven fill compaction, noninstallation of protective layer – sub-base of loose materials);

- poor maintenance (irregular track maintenance and occurrence of significant mistakes in grade level, untimely disposal of rain and other waters from planum, non-maintenance of drainage ditches, cutting slopes etc.).
- increase of traffic, axle weights and speeds.

## 2 Description of tested section Ivankovo-Vinkovci

In terms of traffic, the railway line M105 Novska – Vinkovci – Tovarnik – state border – (Šid) belongs to x pan-European railway corridor and simultaneously it is very important line for mixed long-distance railway transport between the central and east Croatia, Figure 1.

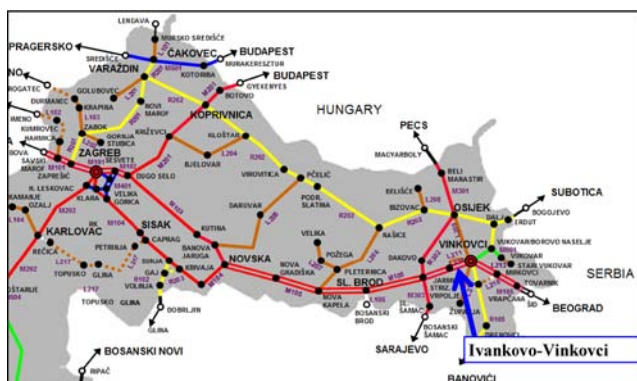


Figure 1 Map of a part of the Croatian Railway network

It is a typical lowland railway line located in the Pannonian plain in the region of Sava river. The right, north track of the section Ivankovo – Vinkovci was built in 1878 and the left, south one was built in 1928. Almost the entire line is built on the low embankment and rests on the clay base. These clays are mainly of high, medium and low plasticity which required, due to their specific properties, required repairs on the line. Maximum permitted train mass along the entire line is D<sub>4</sub> (225 kN/o and 80 kN/m). The present maximum allowed speed is 100km/h (just to mention, the track is designed for the speed of 160km/h). Total transport realised at the section in 2008 amounted to 4.25 mil. gross tons per track.

### 2.1 Track reconstruction at the Ivankovo – Vinkovci section

The section was reconstructed during 2003. The old permanent way and a part of soil material to the new-designed planum elevation were removed, Figure 2. Protective sub-base layer was made of crushed stone which was transported by trucks from the quarry. Neighboring track was used for supply and installation. The layer has thickness of 40cm, and it is compacted by a vibrating roller, Figure 3. Before placing geotextile, the soil bearing capacity on the planned and compacted planum were tested by measurement of stiffness modulus. According to final design, the required stiffness modulus on the planum is 15 MN/m<sup>2</sup>. Testing of stiffness modulus was also made on the protective sub-base. The requested stiffness modulus of the protective layer is 40 MN/m<sup>2</sup>. Results of testing of stiffness modulus of the planum and sub-base are shown in Figures 4 and 5.



Figure 2 Works at the planum level



Figure 3 Works at protective layer level

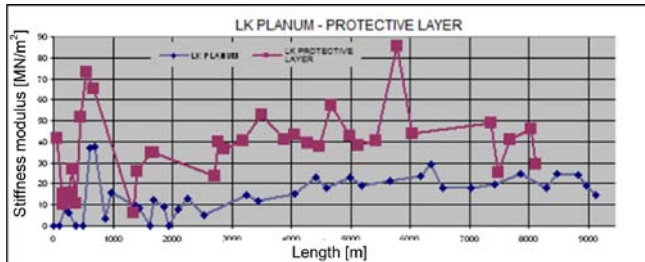


Figure 4 Results of stiffness modulus testing, left track

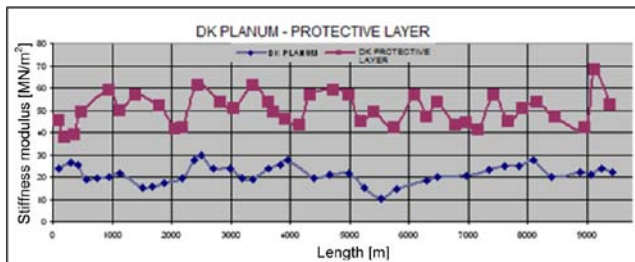


Figure 5 Results of stiffness modulus testing, right track (DK)

## 2.2 Construction of permanent way

Along the whole section continuous track was installed. Tracks type 60E1 were installed, having strength of 900 N/mm<sup>2</sup>, prestressed reinforced concrete sleepers, produced by Vibrobeton Vinkovci. Tracks are fixed by rail clips SKL-1 (on concrete sleepers) and rail clips SKL-2 and ribbed base plates on the parts with wooden sleepers. Sleepers are built in the ballast track 30cm thick under the sleeper bottom face. Designed axis distance of the 2-track line is 4m. After complete reconstruction, the line is controlled by track vehicle intended for measurement EM-120, and measurements are made twice per year, in spring and autumn. The line condition is shown by TQI (Track Quality Index). The following parameters are included to calculate TQI:

- track longitudinal profile (stability), average (relative), PROFILE<sub>av</sub>;
- curvature of track planarity on the measuring base of 6m, CsURV6m;
- track width, WIDTH;
- track height ratio and track superelevation (relative) SUPER;
- average (relative) track direction DIRECTION<sub>av</sub>.

### 2.3 Description of measuring points selected for research

The tested section Vinkovci – Ivankovo is a part of electrified 2-track railway line meaning that there are contact network columns on the right and left side. On the top side of the column concrete foundation there are two built-in permanent points which are connected to marks by a levelling. These points served as references for monitoring of the track settlement with special attention to spots where stiffness modulus was tested. In monitoring of displacement in interaction “wheel – track – sleeper”, spots with “extreme” values of stiffness modulus” were observed. In addition to standard structure, the track settlement was monitored at the part of a bridge where ballast track is built in the bridge concrete slab.

### 3 Calculation of track deflection

Calculation of deflection of long continuous beam on elastic base loaded in one point is made by expression, according to [2]:

$$z = \frac{Q \cdot \beta}{2 \cdot U} e^{-\beta|x|} (\cos(\beta \cdot |x|) + \sin(\beta \cdot |x|)), \eta(x) = e^{-\beta|x|} (\cos(\beta \cdot |x|) + \sin(\beta \cdot |x|)) \quad (1)$$

Accordingly, it should be taken into account that axle weight is present in all calculation methods. Number, layout and axle weight for which calculation is made, are taken into account in calculation adopted at DB (according to Eisemann) which has the influence line as the basis (derived by Zimmerman), [2]:

$$z = \frac{Q \cdot \beta}{2 \cdot U} \eta(x) e^{-\beta|x|}, \beta = \sqrt[4]{\frac{U}{4EI}}, \eta(x) = \eta(x_1) + \dots + \eta(x_n) \quad (2)$$

Where:  $\eta(x)$  is replaced with  $\eta_1(x)$ ,  $x_1, \dots, x_n$  are distances from the relevant observed spot to an axle. In our case, the train consisting of electric locomotive HŽ 1141 and three passenger wagons type BI is observed, Figure 6.

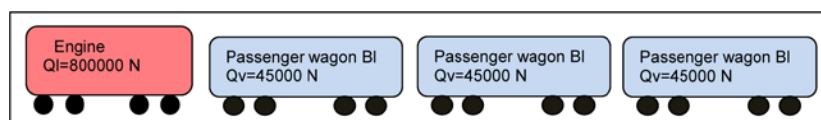


Figure 6 A usual passenger train

From expressions (1) and (2), calculation was made for long continuous beam on elastic base according to scheme shown in Figure 6 for deflection  $z$ . Computation was made for coefficients of the base  $c=0.05, 0.1$  and  $0.3 \text{ N/mm}^3$ . Dynamic coefficient is determined according to Eisemann analytical equation (the running top condition  $\delta = 0.2$ , condition of track in use, level of estimate reliability = 1 for a statistical confidence level of 68.3% of the base stress was adopted according to [5]. Diagram of the sleeper displacement under the locomotive axle was obtained by field measurements (Figure 7) and by calculation shown in Figure 8.



Figure 7 Deflection measurement (left: track in embankment, km 0+371; right: track on the bridge, km 5+398)

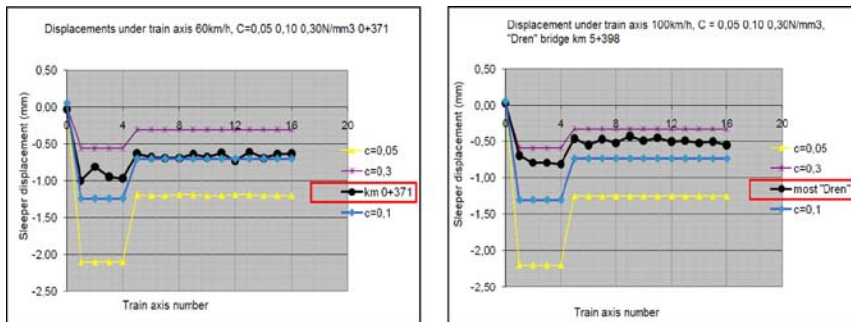


Figure 8 Sleeper deflection under axes, results obtained by measurements and calculations

## 4 Analysis of measurement results

### 4.1 Track settlement

The average values of deflection on the spots of measured stiffness moduli are presented in Figure 9. The applied maintenance in the observed periods is identical for both sections of the line.

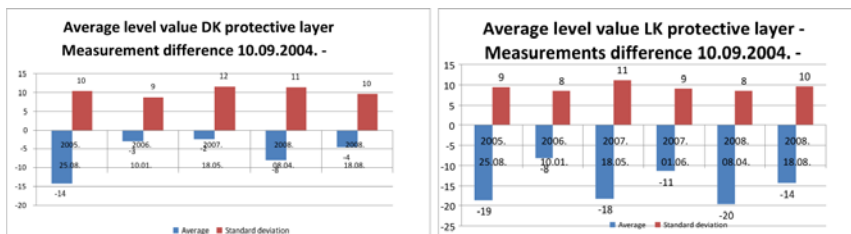


Figure 9 Average value of grade level settlement (mm), left-right track (LK-DK)

Correlation coefficients of “stiffness modulus and track settlement” (correlation coefficient A) and track settlement. In two consecutive measurements (correlation coefficient B) are shown in Table 2. The value of correlation coefficient for “stiffness modulus and settlement” is below 0.5 which indicates that there is no correlation between the analysed items. Correlation of “displacement” of two consecutive measurements has the value approaching 1 indicating to

continuous settlement trend on observed location and high correlation level. Coefficients are calculated on the basis of 35 measuring points.

**Table 1** Correlation coefficient of measure parameters /settlement, stiffness modulus)

SECTION OF RAILWAY LINE VINKOVCI – IVANKOVO	Right track 4.14 mil. gross tons		Left track 3.98 mil. gross tons	
	Planum	Protective layer	Planum	Protective layer
	10/09/2004 – 25/08/2005			
Stiffness modulus [MN/m <sup>2</sup> ]	21.16	50.16	14.95	37.67
Displacement difference [mm]	-16.4 (-15.2)	-14.2 (-15.2)	-18.5 (-18)	-18.1 (-18)
Correlation coefficient "A"	0.06	-0.15	0.08	0.32
Correlation coefficient "B"	0.82	0.83	0.75	0.81

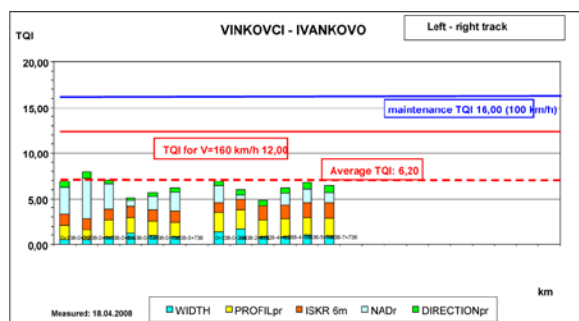
  

SECTION OF RAILWAY LINE VINKOVCI – IVANKOVO	Right track 5.46 gross tons		Left track 4.31 gross tons	
	Planum	Protective layer	Planum	Protective layer
	18/05/2007 (01/06/2007) – 08/04/2008			
Stiffness modulus [MN/m <sup>2</sup> ]	21,16	50,16	14,95	37,67
Displacement difference [mm]	-6,2 (-5,6)	-5,5 (-5,6)	-9,4 (-8,2)	-8,2 (-8,2)
Correlation coefficient "A"	0,05	0,22	-0,23	-0,09
Correlation coefficient "B"	0,93	0,95	0,93	0,97

Values in brackets refer to total settlement of the section

## 4.2 Analysis of parameter data of measuring vehicle for selected track sections

Graphic presentation of Track Quality Index  $TQ_{IU}$  shown in Figure 10 for the mentioned sections of the line indicates the average value of 6.20. Kilometer position 0+000 corresponds to the actual kilometre position 156+762.



**Figure 10** Track Quality Index ( $TQ_{IU}$ )

## 4.3 Analysis of the sleeper displacement for a usual passenger train

Analysis of the sleeper displacement caused by the passenger train axles is given for two testing locations km 0+371 (Ms planum = sinking, Ms protective layer = 10.8 MN/m<sup>2</sup>), km 5+938 the bridge structure "Dren" (Ms planum = concrete base, ballast track without protective layer). Figure 11 shows position of LVDT sensors (Linear Variable Differential Transformer

sensors), at measuring of deflection. LVDT 1 and LVDT 2 sensors are positioned on two sleepers as shown in Figure 11. The place of ancillary support, “measurement plane” was positioned at the foundation of the contact network column, i.e. the bridge slab. Data on the displacement measurements are given for usual (characteristic) train shown in Figure 6. Results of measurements of the track structure deflection are shown in Figure 12. Taking into account the very nature of the problem of oscillation of the track structure in traffic and possible condition of the track, measuring results for the analysed measuring position and calculation results show good correlation as shown in Figure 8.

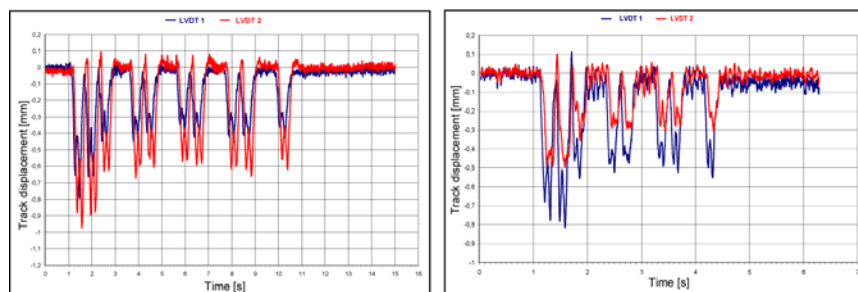


Figure 11 Position of LVDT sensor on tracks



Figure 12 Results of measurement (left km 0+371, right km 5+938-bridge “Dren”)

## 5 Conclusion

Stiffness modulus is determined as the measure of quality of production of the planum and protective layer. Correlation coefficients indicate that this modulus is not a good measure for predicting the behaviour of track structure. Therefore, the question arises of defining parameters which will describe in the best way behaviour of the track structure during the period of use. Measuring vehicles, as the method of monitoring give certain image on the track condition, and they can be, conditionally, used in maintenance at the moment when limit values for c category tracks are exceeded. Optimal range within which maintenance should be performed is in within the A and c or B and c category [1]. The question is how to predict the right moment for carrying out of maintenance works. In mechanical regulation of the line, decision must be made in relation to: total track settlement, total traffic volume and time of utilisation. All three information, either individually or together, can be a condition for work performance. The goal is to avoid unnecessary and excessive use of machinery for mechanical regulation of tracks at those sections where it is not necessary. It is necessary to prepare a rulebook-guidelines adjusted to actual traffic needs and quality of the analysed track, especially during the periods of smaller volume of transport and recession. Development and possibilities of various new

measurement methods, not used so far in maintenance of railway tracks, could serve as a significant element in determination of quality of new built and existing railway lines.

## References

- [1] Uputa za provjeru geometrijskog uporabnog stanja kolosijeka tračničkim mjernim vozilom tehničko mjernih karakteristika EM-120, Hrvatske željeznice, Zagreb, 2005.
- [2] Development of a methodology for calculating stresses in track components, University of Pretoria etd – Naude, F P, 2005.
- [3] Švaljek I, Kožulj T, Bošnjak M, Tehničko-eksploatacijski pokazatelji i značajke vučnih vozila Hrvatskih željeznica, Zagreb, 2003.
- [4] Kontrolna ispitivanja donjeg stroja pruge, IZVJEŠĆE br. 4 43 00 -08/04, IGH Osijek, 2004.
- [5] Esveld Coenraad, Modern Railway Track 2<sup>nd</sup> Edition