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EXPERIMENTAL MONITORING OF TRANSITION ZONES IN RAILWAY TUNNELS

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Abstract

The expert research activity of transition zones of tunnels is one part of the overall set of these places on the railway line. Typical places where the stiffness of the railway changes are the portals of tunnels, where undesirable deformations occur during the operation of trainsets due to the changes in materials. In the places of the portals, there can be a ballastless track or slab track (with concrete bearing layer) or classic structure with a railway ballast. The paper presents long-term research on monitoring height changes in these sections. The results of the expert activity will be the basis for the subsequent proposal of new measures, i.e. changes to built-in objects or modification of the materials of structural layers in a given place of the transition zone.

Keywords:

Railway engineering;
Transition zone;
Tunnel portals;
Long-term monitoring;
Height deflections.

1 Introduction

Places on the railway line where two sections with different types of materials connect to each other cause a lot of shocks from the wheels of the trains. If they are not treated, i.e. effective anti-measures designed, for example, a height change in the geometrical position of the track level may occur, which is dependent on unwanted movements and deformations of these structure parts built into the railway track in this section. If they are not treated, i.e. designed effective countermeasures, for example, a height change in the geometrical position of the track level may occur. This change is dependent on unwanted movements and deformations of these structural parts built into the railway track in this section. These places are called transition zones, i.e. the stiffness of the railway track objects in a given place changes, usually "step change". The transition from a classic gravel track with a trackbed to a ballastless track and vice versa is treated by designs with different reinforced-concrete tubs, wedges, boards, and different types of materials in the structural layers, or by bonding and cementing them in order to increase the stiffness of the track.

A similar transition occurs in the places of tunnel portals, where the foundation of reinforced concrete blocks of their portals are in front/behind the tunnel. A classic track structure with a gravel bed can be designed here, as well as a ballastless track. Alternatively, the ballastless railway will be located only in the tunnel tube between the portals, and further, the classic railway line continues.

Sections of the double-track railway tunnel named „Turkish Hill“ (in Slovak „Turecky Vrch”) with its northern and southern portals in Trencianske Bohuslavice were selected for the purpose of expert and monitoring activities as part of the research tasks. Research measurements have been taking place regularly since 2013, but the presented research focuses on the years 2016-2023. In the set of in-situ measurements in the track, there are 4 tunnel transition zones on the main trans-European corridor “*Va*” Bratislava – Zilina for the design line speed at V = 160 km/h, the tunnel is designed for a speed of 200 km/h.

2 Current state

Tunnels on railway lines are in various stages of construction, i.e. for example, they are already in operational practice, current construction, or the design stage before their construction. Monitoring and expertise at the Department of Railway Engineering (DRE) are dedicated to existing tunnels, and based on research findings, measures will be proposed in the places of transition zones, in our case, the railway body with objects in the parts of the portals of the tunnels. Therefore, the acquired knowledge is needed, which will enable the design of more resistant transition zones for railway traffic, so that these objects absorb shocks from the wheels of train sets and the geometric position of the track (GPT) is long-term sustainable in direction and especially its required height course. In these places, there is a tendency for a longitudinal height wave as a permanent deformation, which causes a "jumpy" change in the stiffness of the railway objects. For example, this is the transition of a classic rail bed vs. a ballastless track, transition points of tunnels, bridges, and various infrastructure objects. Increased stability in a given place of the transition zone will ensure a reduction of financial costs during maintenance in the operation of the track (a ballastless reinforced-concrete track also presents a complication when modifying GPT in operation) and there is also no wear and tear of parts on rolling stock on this undesirable wavy track.

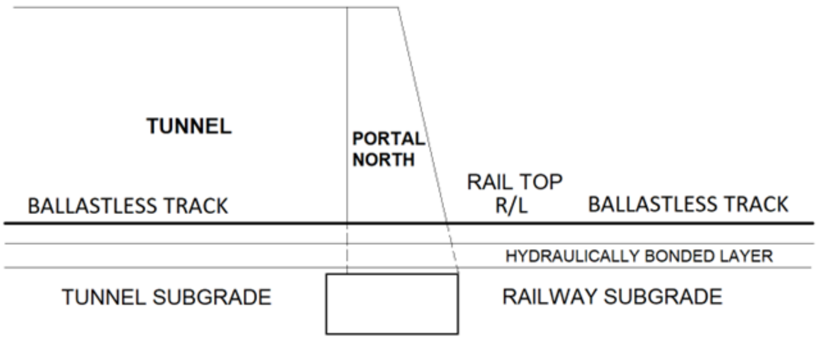
The research issue is also addressed at the international level, for example, the authors Wang, Markine, and Shevtsov [1] deal with the analysis of the dynamic behavior of the railway line in transit zones, where tunnels are also mentioned. The differential settlement and dynamic stress of the layers of the adjacent tunnel to the track are solved in Shan, Zhou, and Shu [2], the track is in embankments, simulations in 3D, and calculations within the FEA finite element method. Measures in transition zones are addressed by Wang and Markine [3], where test results show that adjustable fasteners are effective in mitigating track degradation in transition zones. The authors Hu, Zhang, Wen, and Wang [4] investigated the dynamic responses of transition zones of high-speed railways with different types of structural layers.

Numerical research on the dynamic performance of the tunnel-bridge transition with a deep-buried pile-plank structure is in the work by Li, Wei, Chen, and He [5]. Other authors Paixao, Varandas, and Fortunato [6] are working on research into the dynamic behavior of objects in transition zones as part of long-term monitoring, including tunnels. The issue of the railway track on the embankment near the tunnel within the ballastless carriageway is also presented in Ramos, Correia, Calcada, and Connolly [7]. The authors Chumyen, Connolly, Woodward, and Markine [8] deal with the effects of improving the layers of the railway body and auxiliary additional rails in transition zones (railway tracks, tunnels, bridges, etc.). Evaluation of short-distance subgrade transitions in transition zones using pile-slab structures for high-speed lines is discussed in Li, et al. [9].

Monitoring and experimental measurements have also been carried out in the in-situ laboratories of the Department of Railway Engineering (DRE) since 2003 as part of the subgrade freezing on two test multi-stands (stand I. 2003-2016, stand II. 2013-2023). Due to the practical monitoring of transition zones, expert measurements began directly on the transition zones in Trencianske Bohuslavice (2012-2023) and Trencin (2017-2023) on the railway line of the corridor "*Va*" Bratislava - Zilina. A number of research papers on the topic were published in the Department of Railway Engineering, for example by the authors Hodas, Izvoltova, Chromcak, and Bacova [10] in the framework of monitoring the geometric position of tracks in the area of transition zones of ballastless track, tunnels, bridges, etc. Another scientific work is the solution of securing structural layers of transition zones against their freezing by Hodas, Pultznerova, and Izvoltova [11]. The research of the DRE department is covered by grant VEGA 1/0084/20 (2020-2023) by Izvolt, et al. [12]. Based on the research tasks of the DRE department, a university textbook by the authors Izvolt, and Hodas [13] on the design, construction, reconstruction, and modernization of railway lines and stations was published.

3 Tunnel transition zones

Typical places of transition zones are parts of tunnel portals. The expert measurements were carried out in the tunnel where the ballastless track is located. At the northern portal of the "Turkish Hill" tunnel, the ballastless track is continuous and continues into the railway line further, Fig. 1a. On the opposite side of the southern portal, the ballastless track ends at the end of the tunnel, and the track changes to a classic one with a track bed. But in this place, a transition zone "reinforced-concrete tub" with a terminal block is also inserted, where the ballastless track ends according to Fig. 1b.



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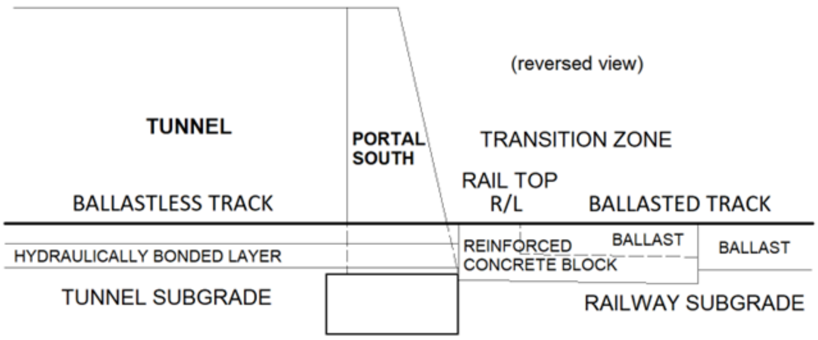


(b)

Fig. 1: Structural parts and layers in tunnel transition zones: (a) Continuous ballastless track; (b) Ballastless track in the tunnel and ballasted track out of the tunnel.

These places change their rail track stiffness from concrete bearing layer to ballast or simply put, there are places where it is necessary to carry out new designs of transition zone components, for example within the submitted new research project VEGA 1/0246/24 by the authors Hodas, et al. [14].

4 Methods and monitoring

Experimental in-situ measurements of the geometrical position of the track were carried out by a continuous method using a KRAB measuring trolley [15] with a measuring step of the longitudinal deflection of both rails R/L (right/left rail) of 250 mm. Transition zones of the tunnel selected and marked according to track number ZA1, ZA2 towards Zilina and BA1, BA2 towards Bratislava (of the double-track tunnel near Trencianske Bohuslavice city) are shown in Fig. 2. When evaluating the results, the BA1 and BA2 zones were reversed in the opposite direction in order to compare the relevant data in one direction, the so-called "jump" from the tunnel tube to the track. On the southern portal, we will also take into account the added classical transition zone in the track (Fig. 8 and Fig. 9).

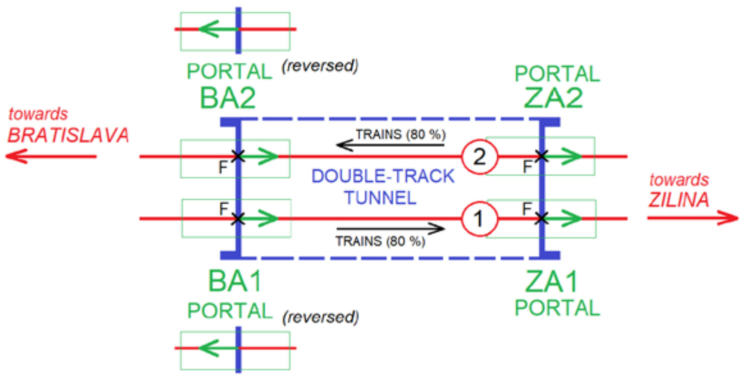


Fig. 2: Transition zones of tunnel – sections of inspections.

In the research, we are dealing with the monitoring of height changes, as they are decisive, and the task is to eliminate the longitudinal height changes, where the curve can resemble the shape of a sinusoid (the resulting values are in Fig. 4 to Fig. 9). Longitudinal deflections were measured at the top of the rails R/L as the top of the rail head, Fig. 3. Between the right R and the left L rails is the height dependence of the superelevation – cant *D*, or the height deformation as the height deviation *Δh*, or both. *LH* is longitudinal height deflections on rail top R (LH_Dyn_R) and top L (LH_Dyn_L).

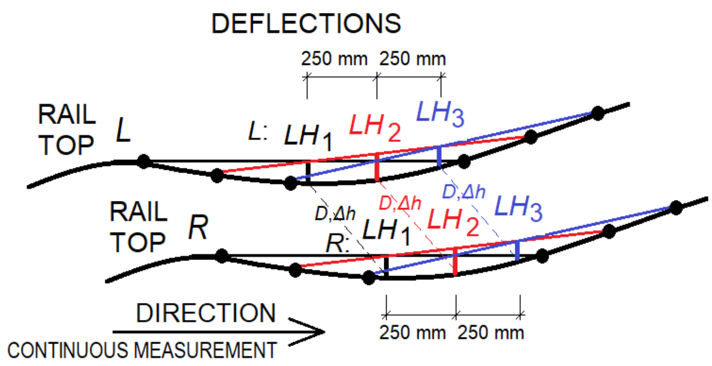


Fig. 3: Track deflections of monitoring sections – top of rails R/L.

5 Expertise results and discussion

Based on the inspection and measurements of the modernized railway lines, it can be stated that it is possible to increase the quality of the track in the area of transition zones of tunnels. Driving at increased speed along these transition zones and their subsequent sections will be more reliable, more comfortable, and safer without unnecessary swaying of train sets. Despite compliance with permissible deviation values in the structure and operational deviations by [16] and [17], it is possible to increase the stiffness of the railway in transition zones.

The obtained results of height deflections are diverse, it depends on the structures and layers in the transition zones, as well as on the quality of the subsoil (rocky, high embankment, etc.) and the quality of the construction work performed. It is best if, for a specific transition zone, all these elements are reliably designed and built, and the transition zone then keeps its shape (height deflection) in the original long-term sustainable state. The monitoring results point to all these possibilities.

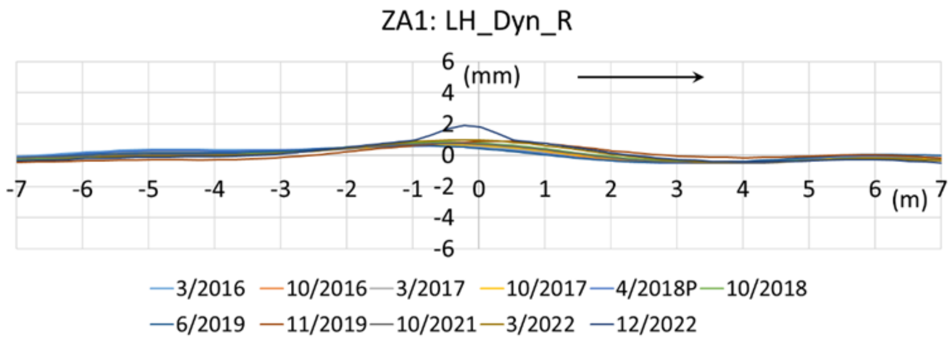
The resulting curves are referenced to the zero point "F" (Fig. 2), from which the deflections of both rails R/L are examined in lengths of ±7 m, i.e. the total section of this influence on the place of the transition zone. In the resulting curves, the prevailing direction of travel of train sets along the track is also indicated by the sign "→" (approx. 80%) in the figures.

5.1 North portal - transition zone

Expertise 2016-2022 confirmed the quality of the transition zone on the north side of the tunnel. On track No. 1 (ZA1) from Fig. 4, a very mild height wave is recorded, on the rail R the wave is larger in 12/2022, but this must be verified only with subsequent measurements in 2023. The left rail L does not show it. Behind the point F (0, 0) there is a slight pushing of materials into the railway body with less stiffness, which, on the other hand, also causes the R/L gradient to rise at this point F.

Track No. 2 (ZA2) is practically level without unwanted height deformations, Fig. 5. We can conclude that the results prove a stable track gradient in the transition zones of both tracks. The reason may also be the bedrock, continuous ballastless track, and the following bridge object behind the tunnel. Monitoring and measurements of the zones of bridge objects are in Hodas et al. [18].

From all the figures with the curves of the rails R/L deflections in Fig. 4 to Fig. 9, it follows that the measurement method of continuous measurement by the KRAB device [15] reliably captures the height wave (±1 mm) during repeated measurements in a time interval of half a year or after a whole year. The condition is that the KM position is correctly adjusted during measurements.



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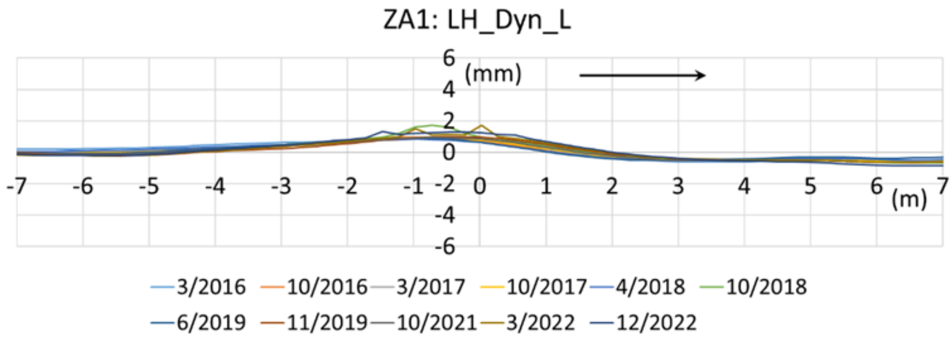

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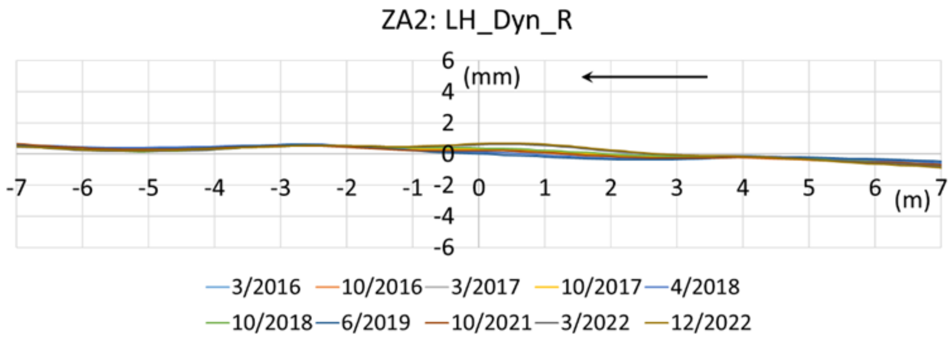
Fig. 4: Inspection of track geometry quality of tunnel portal – longitudinal height deflections (LH) of the track axis No. 1 toward Zilina: (a) rail top R; (b) rail top L.



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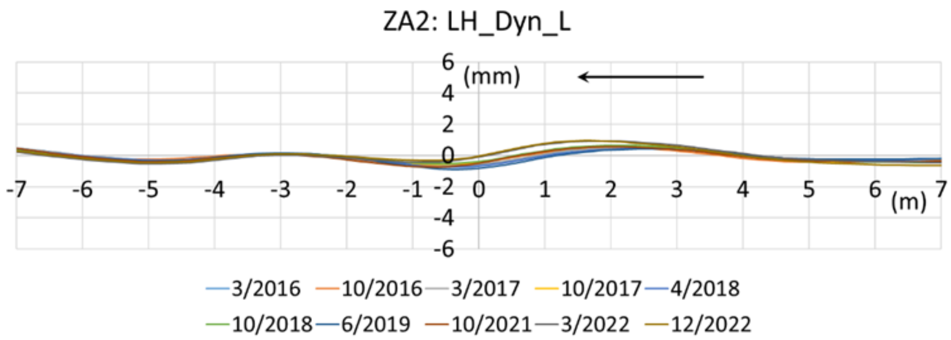

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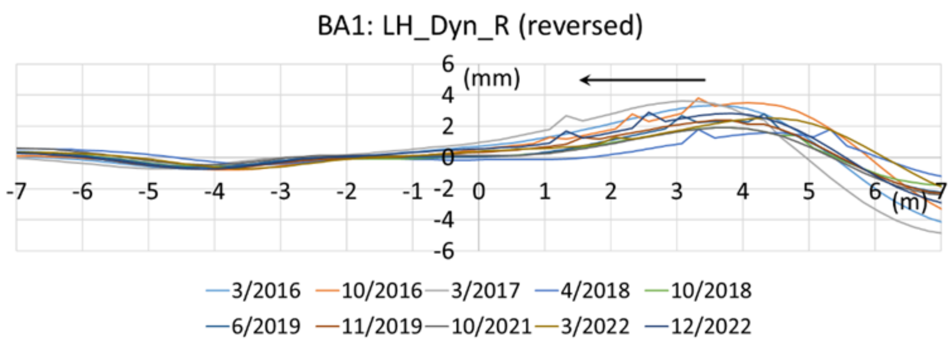
Fig. 5: Inspection of track geometry quality of tunnel portal – longitudinal height deflections (LH) of the track axis No. 2 toward Zilina: (a) rail top R; (b) rail top L.

5.2 South portal - transition zone

The southern portal represents a construction challenge, since in addition to the transition zone of the tunnel, there is also the final reinforced concrete block of the transition zone of the ballastless track. The stiffness of the railway track is rapidly changed here from a reinforced concrete track to a gravel track with a ballast bed. From figures Fig. 6 and Fig. 7, it is clear that the height waves of this problem are shifted approx. 5 m behind the tunnel portal. The reason is the iron-construction concrete block of the transition zone, 5.18 m long, along which there is still a ballasless track. The presented height wave as a "jump" into a material with less stiffness (ballast bed) is captured with a height course of the wave -4 to -6 mm. As this material is twisted or bent into the lower layers of the subgrade and is also extruded and pushes the reinforced concrete block upwards by +2 to +4 mm. This is a classic problem of these sections of the track, not only in the tunnels. Both R/L rails in particular tracks (BA1, BA2) behave identically here.



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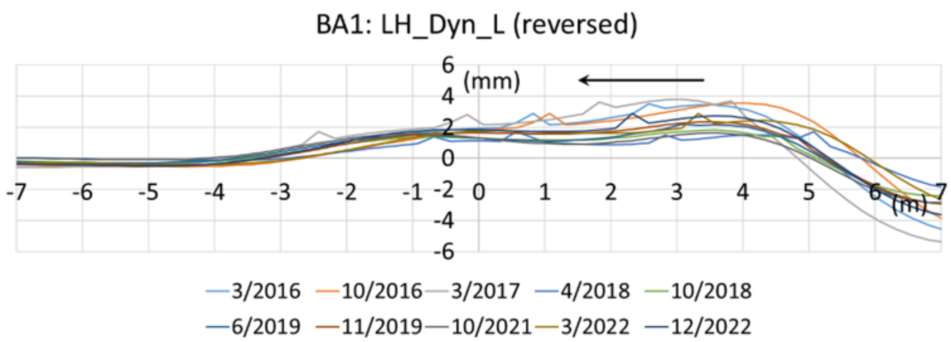

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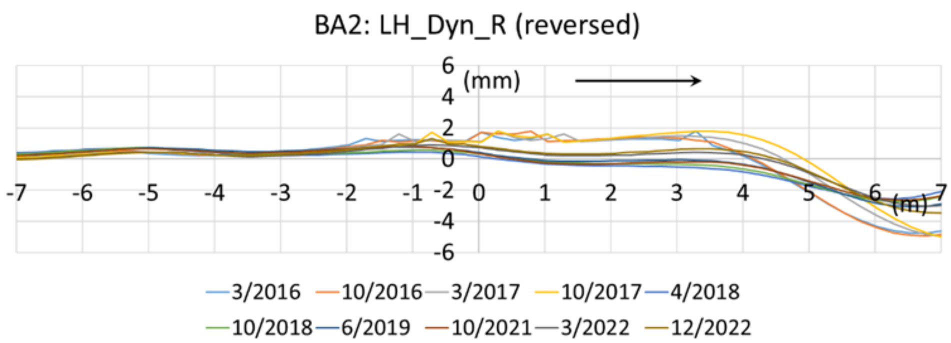
Fig. 6: Inspection of track geometry quality of tunnel portal – longitudinal height deflections (LH) of the track axis No. 1 toward Bratislava: (a) rail top R; (b) rail top L (reversed).



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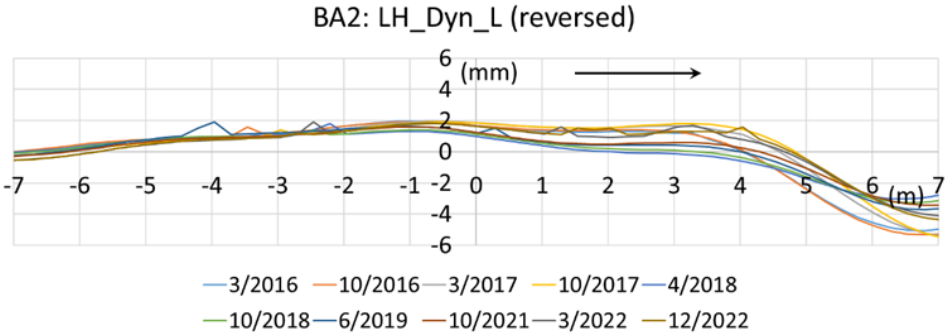
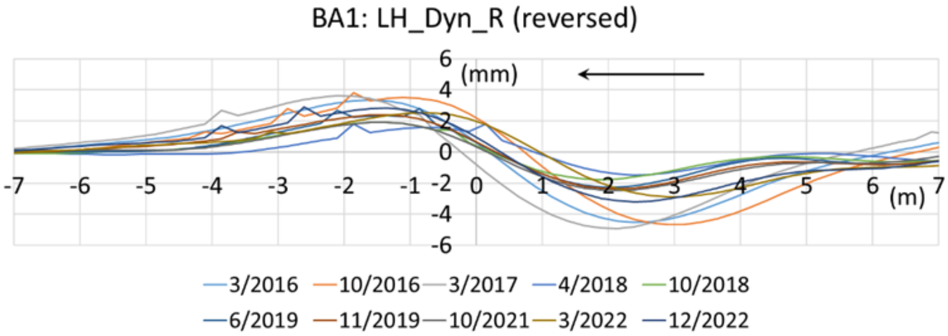


(b)

Fig. 7: Inspection of track geometry quality of tunnel portal – longitudinal height deflections (LH) of the track axis No. 2 toward Bratislava: (a) rail top R; (b) rail top L (reversed).

The critical point is point F in these zones of changes of objects in the profile (Fig. 2), all monitored height deflections show curves directly in the reinforced concrete bath in the classic transition zone, for the transition to the ballast bed in Fig. 8 (BA1) and Fig. 9 (BA2). A relevant contribution will be to include these results of monitoring in the framework of inspections and continuous measurements in the application of these new solutions of transition zones as part of their modification and thereby ensure the smooth passage of train sets at these rigidly different points of the track. Many years of experience with the modernization of railway lines show in this case as well that it is a long-term spending of financial resources for the maintenance of the geometrical position of the track. The mentioned phenomenon also affects the structure of rolling stock traveling along these transition zones.



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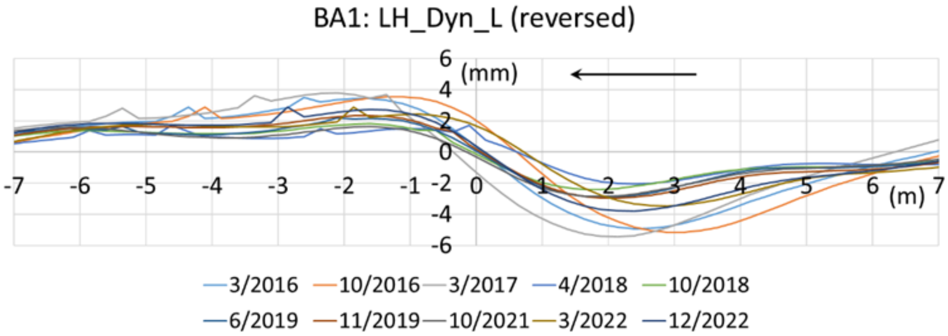

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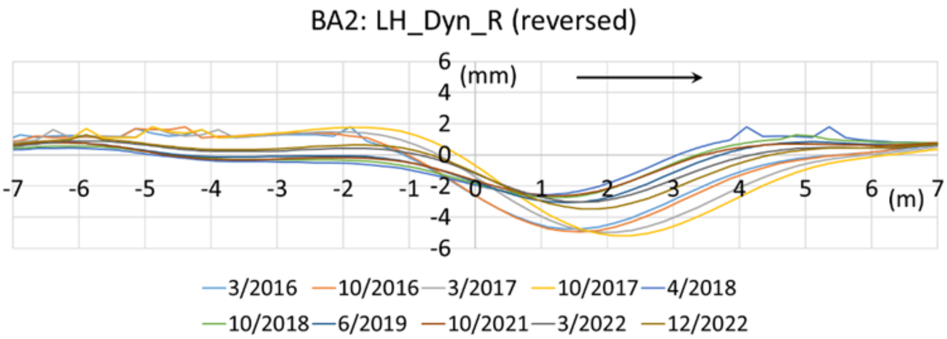
Fig. 8: Inspection of track geometry quality of transition zone – longitudinal height deflections (LH) of the track axis No. 1 toward Bratislava: (a) rail top R; (b) rail top L (reversed).



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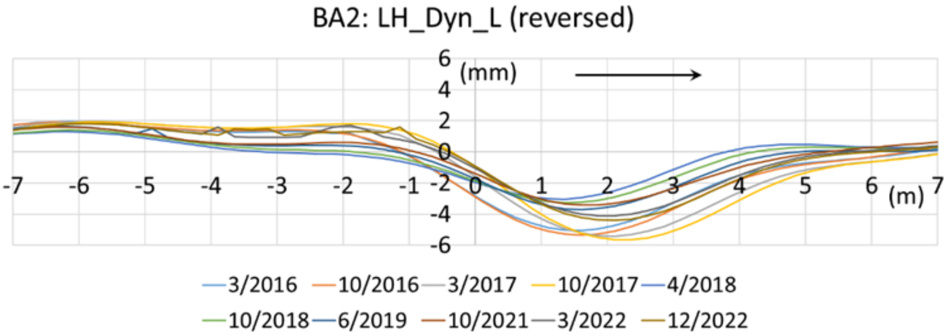

(b)

Fig. 9: Inspection of track geometry quality of transition zone – longitudinal height deflections (LH) of the track axis No. 2 toward Bratislava: (a) rail top R; (b) rail top L (reversed).

6 Conclusions

In the years of solving research tasks, a set of in-situ measurements was completed on test sections on the "*Va*" rail line within the European railway corridors. Sections were determined that correspond to transition zones where there is a sudden change in the stiffness of the rail track. During these measurements, it was proven that undesirable faults and deficiencies in the geometry of the track (mainly the height course) arise in these places.

On the basis of these proposals, numerical modeling of adequate structural elements for these transition zones (objects of the railway superstructure and substructure) will be solved, for example within the submitted new proposal of the research project Hodas et al. [14], with additional support [19]. During the comparisons, possible modifications will be proposed in order to optimize the gradual gradation of the railway stiffness in the transition zone. New criteria will be created for future designs of transition zones, in this case, tunnel ones.

For this reason, it is also necessary to pay attention to objects that closely follow the tunnels at the portals, such as bridges, transitions of ballastless tracks vs. classic ballasted track, embankment culverts, etc.

The final designs will guarantee the long-term reliability of the track geometry. Last but not least, one must not forget about the high-quality execution of construction works, which could complicate the achieved new proposals for transition zones. A fundamental question is also the construction of high quality subsoil under the railway body. The higher the speed of the train set, the more demanding structural elements will be required in the transition zones.

Acknowledgement

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