Preliminary results of geodetic diagnostics of transition areas of ballastless track

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Abstract. Construction of ballastless track is usually used in high-speed railway, which is suffered by high traffic load. The main reason is to reduce the maintenance costs of the railway line, although the initial costs of its construction are incomparably higher than with the classic construction. From the point of view of long term deformation analysis of railway track, the critical point of such the type of the construction seems to be the place of its completion and transition to the classical the railway superstructure. In terms of dynamic effects, it is a place with a change in stiffness and therefore a special attention is paid to its diagnostics.

1. Introduction

A railway track with a classic construction is considered to be such a track whose rail grate is placed in a gravel bed. In modernized lines, this classic structure is often replaced by an unconventional structure in which the rail grate forms a monolithic structure, or is placed on a concrete or asphalt construction layer. Such a construction of the railway superstructure is called ballastless track and is characterized by the use of transverse sleepers in a modified shape [1]. The Faculty of Civil Engineering of the University of Žilina carries out a comprehensive diagnostics of the spatial position of the ballastless track in the Turecký vrch tunnel and its surroundings, in order to detect the behaviour of such a structure during operational load. The diagnostics includes geodetic measurements, the task of which is to check the geometrical parameters of the railway line and its spatial position. For the reason to ensure the required accuracy and reliability of results, the precise geodetic technology was used such as robotic theodolites, 3D laser scanners, GNSS receivers and digital levels. The geodetic solution resulted in a deformation analysis of the given railway structure in order to define the height and positional displacements of both tracks. The main goal of the research task is to define the potential spatial changes of the track in its most critical sections, in the so-called transition areas of the track, represented by the transition between ballastless track and classical track. From the point of deformation analysis, the very interesting places of the new railway construction seems to be the transition area between tunnel and open railway line and places built on bridges. Because, the observation technology and evaluation methodology have been already presented in previous studies [1], [2], [3], this paper is devoted to the results publication especially those that deal with analysis of deformations arising in the transition sections of ballastless track.
2. Characteristics of railway locality

The Turecký vrch railway tunnel is the first tunnel in Slovakia designed and implemented according to technical specifications defined for unconventional lines. The total length of the tunnel is 1775 m and the tunnel tube of the excavated section has a length of 1738.5 m. The tunnel is followed by concave sections of the southern portal in the length of 25 m and the northern portal in the length of 10 m. The double-track is designed for a speed of 200 km/h, with opposite curves with a radius of 2000 m. Due to the complex directional conditions and bridge structures located immediately behind the northern portal, the ballastless structure is established not only in the tunnel itself, but on the northern side of the tunnel in the length of 800 m. The total length of the built ballastless structure is up to 4480 m of track. Due to the difference in the stiffness of the subsoil (tunnel bottom, bridge and railway bottom of the earth body), the system of ballastless structure is modified, which is reflected in the thickness of the concrete structure and also in its reinforcement [4].

3. Measurement of spatial track position

The diagnostics of the ballastless track in Turecký vrch locality was realized in the railway section km 102.360 000 – 102.530 000, of southern portal of the tunnel and in the section km 104.200 000 – 104.820 000 of its northern portal. The project of geodetic monitoring started in 2012 and continued firstly in half-yearly intervals and then in annual time measuring cycles, depending on the behaviour of the railway structure under traffic loading. In order to ensure high accuracy, a separate measurement of the position and height of the track was performed. The position of the track was determined by discrete and continuous measurements by done by robotic theodolites and the height was measured by digital levels. An essential part of geodetic measurements is the control of positional and height stability of the reference system, represented by railway benchmarks, which results in the definition of its accuracy, from which the a priori accuracy of the measurement is derived. Geodetic observation of particular points was realized on both of track’s sides in the defined distances of the longitudinal direction (approx. every eight track node). The spatial changes of the track was related to the axis of the right rail string to maintain the accuracy and explicitness of the results and also because of the mutual comparison of the discrete values.

4. Analysis of positional track changes

Positional measurements were performed with universal robotic theodolites TRIMBLE S8, TRIMBLE VX, with a defined angular accuracy of ± 0.3 miligons and a distance accuracy of 1 + 1 ppm and 1 + 2 ppm. The reference system consists of railway benchmarks signalled by portable reflective foils and stakeout points stabilized by screws on the feet of electric poles. The stability of the reference points was determined by checking the relative position of the both types of marks. The control of the geometrical position of the particular observation cycles. Diagnostics of positional changes of the railway structure is performed by statistical hypothesis testing. The positional changes are tested by a simplified null hypothesis, defined by the following criteria:

- If the positional change is less as a-priori positional accuracy, then null hypothesis is confirmed and the motion of the structure is not proven
- If the positional change is less as twice a-priori positional accuracy, then null hypothesis cannot be confirmed and a positional change of the structure can be assumed
- If the positional change is greater as twice a-priori positional accuracy the positional deformation is statistically significant and the null hypothesis is rejected, which means that there is a probability of a positional change of the structure

By analysing the accuracy of measurements realized in particular observational cycles, the accuracy of determining the transitional track change is defined by value of standard deviation 0.022 m.

5. Analysis of height track changes

Height reference network consists of twenty benchmarks permanently stabilized in the concrete bases of electric poles. The process of checking the stability of the height reference network consisted of
estimating the parameters of the regression line, constructed by the differences of height changes (superelevations) between the first and the i-th measurement cycle, determination of outliers and estimating the a-priori accuracy of the network applying numerical solutions according to Marčák [5] and Rousseeuw [6]. When evaluating the results, the height shift of the track is considered significant, in case of exceeding the critical limits, which represent twice the a priori standard deviation of height.

6. Analysis of results

Due to the use of a special device for signalling the position of particular points, relative to the outer side of the rail, special attention was paid to the elimination of the pointing error. The process of evaluation of the positional measurements confirmed the expected value of pointing error in the transverse direction ± 2 mm and in the longitudinal direction ± 20 mm. For this reason, the transverse track displacement in the particular measuring cycles was related to the defined directional parameters of both tracks and the longitudinal track displacements were not defined due to the exceeded the value of the targeting uncertainty. The average value of the transversal shifts as well as the relevant accuracy characteristics of the measurements are introduced in the table 1. The value of the reliability intervals of the particular measurements was defined by using probability value α=0,05 and coefficient \( t_{\alpha/2} \) represented the quantile of Student distribution by assuming normal distribution of the measurement errors.

| Observation cycles | Southern portal | Northern portal |
|--------------------|-----------------|-----------------|
|                    | Track 1 | Track 2 | Track 1 | Track 2 |
| 10.2012            | 4,8 mm   | 3,2 mm   | 4,4 mm  | 5,0 mm |
| 04.2013            | 2,7 mm   | 3,1 mm   | 3,0 mm  | 5,9 mm |
| 10.2013            | 3,0 mm   | 5,6 mm   | 3,6 mm  | 3,6 mm |
| 05.2014            | 2,9 mm   | 3,2 mm   | 3,2 mm  | 3,8 mm |
| 03.2015            | 7,5 mm   | 5,3 mm   | 3,2 mm  | 3,9 mm |
| 03.2016            | 4,2 mm   | 3,8 mm   | 1,7 mm  | 3,8 mm |
| 03.2017            | 2,9 mm   | 3,0 mm   | 4,0 mm  | 6,8 mm |
| 04.2018            | 5,7 mm   | 4,1 mm   | 4,2 mm  | 4,0 mm |
| 06.2019            | 4,6 mm   | 4,5 mm   | 3,8 mm  | 4,1 mm |

The accuracy of height changes of ballastless track is defined by the value of unit height standard deviation obtained by precise levelling. The particular values of the unit standard deviations are introduced in table 2 for every measurement cycle.

There were four critical sections in the northern portal of the tunnel “Turecký vrch”:

- Transition area between tunnel and river bridge in km 104.260 000 – 104.285 000,
- Railway bridge in km 104.280 000 – 104.300 000,
- Railway bridge in km 104.585 000 – 104. 600 000,
- Transition area between the slab track and the ballasted track in km 104.720 000 – 104.745 000.

A demonstration of time dependency of the positional and height changes of the particular points laying on the transition area between the ballasted track and the slab track in the observed area of the northern portal is in figures 1 and 2.
### Table 2. Unit height standard deviations of ballastless track precise levelling

| Observation cycles | Southern portal Track 1 | Track 2 | Northern portal Track 1 | Track 2 |
|--------------------|--------------------------|---------|--------------------------|---------|
| 10.2012            | 0.26 mm                  | 0.30 mm | 0.41 mm                  | 0.41 mm |
| 04.2013            | 0.42 mm                  | 0.25 mm | 0.32 mm                  | 0.45 mm |
| 10.2013            | 0.34 mm                  | 0.41 mm | 0.33 mm                  | 0.22 mm |
| 05.2014            | 0.40 mm                  | 0.41 mm | 0.50 mm                  | 0.18 mm |
| 03.2015            | 0.25 mm                  | 0.20 mm | 0.42 mm                  | 0.46 mm |
| 03.2016            | 0.19 mm                  | 0.21 mm | 0.31 mm                  | 0.34 mm |
| 03.2017            | 0.22 mm                  | 0.24 mm | 0.38 mm                  | 0.34 mm |
| 04.2018            | 0.25 mm                  | 0.20 mm | 0.44 mm                  | 0.37 mm |
| 06.2019            | 0.35 mm                  | 0.24 mm | 0.38 mm                  | 0.40 mm |

**Figure 1.** Time dependency of transversal shifts of transition area between ballastless and classical track.

**Figure 2.** Time dependency of height changes of transition area between ballastless and classical track.
7. Conclusions
The main aim of monitoring the spatial position of the ballastless track in locality Turecký vrch is to determine its behaviour influenced by the traffic load. Since, nine observation cycles have been realized in one kilometre long area of both southern and northern portal of tunnel. The paper is devoted to the analysis of the accuracy and positional and height changes arise in critical sections of observed ballastless track, from which the special attention is devoted to the transition area between ballastless track construction and classical track. The track behaviour of this section is displayed in the figure 1 and 2. The measurement results processed so far show small positional and height changes of track, especially at points laying in the critical sections. The changes of spatial position of the other particular points did not confirm so far. The research task focused on the diagnostics of geometric parameters of ballastless track will continue by comparing discrete measurements with the point cloud applications obtained by 3D laser scanner and GNSS continual technique, to find out accuracy, reliability and efficiency of the use of the particular geodetic methods. The ambition of such a geodetic monitoring ballastless track is in contribution to the decision-making processes that are part of the regular inspections and maintenance of the railway line.

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