Experimental Monitoring of Moisture Conditions in the Various Types of Track Bed Structure

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Abstract. The principle of designing the railway track structure is based on two baseline assessments. The first assessment verifies the resistance of the railway track structure against the traffic load, which is represented by static and dynamic effects from rail transport. The assessment of railway track structure against the non-traffic load is also important for the correct and relevant design of railway track structure. This load is represented by climatic factors such as frost, water, wind and sunlight. The paper presents the results of experimental monitoring of moisture conditions in the various railway tracks structures. The experimental stand Department of Railway Engineering and Track Management (DRETM) was built for this purpose. The monitoring of thermal regime and water regime of railway track is carried out at this experimental workplace. In the introductory part of the paper are presented individual measuring profiles of the experimental stand DRETM, which were progressively built in a scale 1:1, during the past 7 years. The experimental stand DRETM consists of 6 measuring profiles, which differ from each other by track bed structure and shape of track substructure. The measurement of moisture conditions in individual measuring profiles was performed by a non-destructive method using a TDR test probe. The next part of the paper presents the measured results and the evaluation of the moisture conditions (variation of the moisture conditions) in the individual measuring profiles of the experimental stand DRETM. The final result of this experimental monitoring is represented by the design moisture values of the individual building materials applied to the track bed structure. Subsequently, these moisture values serve for numerical modelling of the non-traffic load on various railway tracks structures.

1. Introduction

The railway line is exposed to various climatic factors during the year, which in many cases negatively affect the reliability and safety of railway operations. Slovak Technical Standard of Railways (TNŽ 73 6312) [1] provides the assessment of the track bed structure against non-traffic load, which is represented by climatic factors (frost, snow and rainfall). The moisture varies in the railway line structure throughout the year, while the amount of moisture in railway substructure body depends on the volume of precipitation, the shape of the railway substructure body (embankment, cut, or a combination thereof), thermal and water regime of track bed. Fluctuation of moisture has a cyclic character during the year, which is called the water regime of track bed. The moisture of the individual built material incorporated in the track bed structure depends mainly on the type of rock, its
density/permeability, climatic conditions, groundwater level and subsoil capillarity. In the case of increased moisture content in the fine-grained (cohesive) soils, which are less permeable to dangerously sensitive to frost, their deformation resistance is reduced. This condition leads to a progressive creation of errors in the structural and geometrical track layout on operating railway line, subsequently it leads to a reduction in its operational safety and reliability.

The Department of Railway Engineering and Track Management (DRETM) has long-term research activities (since 2002) aimed at verification of effect non-traffic load (frost, water, snow cover) on the thermal and water regime of the track bed of the classic railway line structure, (i.e. track skeleton placed on the track ballast) [2]. One of the many sub-tasks of the research is the monitoring of moisture conditions of building materials incorporated in various track bed structures. Knowledge of the real moisture conditions (fluctuations of moisture) of the track bed is a prerequisite for numerical modeling of the thermal regime of track bed in SoilVision software, which requires a number of input characteristics to achieve relevant and correct results.

For realization of the experimental monitoring of the water and thermal regime, The Experimental stand DRETM was built in the campus of the University of Žilina, shows on figure 1.

![Experimental stand DRETM and cross-section of measuring profile no. 1](image)

**Figure 1.** Experimental stand DRETM and cross-section of measuring profile no. 1 [3, 4].

The Experimental stand DRETM consists of two models of railway lines built on a scale of 1:1 differing in the shape of the railway substructure body. The model of railway line in the embankment consists of measuring profiles no. 1 to no. 4 and the model of railway line in the cut consists of measuring profiles no. 5 and no. 6. Configuration of individual measuring profiles of Experimental
stand DRETM as well as structural configuration of cross section of measuring profile no. 1 are shown in the previous figure 1. The individual measuring profiles differ in their track bed structure, while the same measuring elements are incorporated in all measuring profiles. The experimental monitoring of the thermal and water regime is performed using pre-installed temperature sensors and protective plastic tubes that allow non-destructive moisture measurements with the TDR test probe. Figure 1 not only shows the configuration of individual structural layers of track bed, but also the configuration of individual measuring elements in the measuring profile no. 1. Cross sections of other measuring profiles defining their structural configurations referred in [3], [4] and [5].

The purpose of this paper is to present the results of experimental monitoring of moisture conditions in individual building materials, which incorporated to the measuring profiles of the Experimental stand DRETM. The measurements of moisture conditions were started in 2014, when the measuring profiles no. 1 and no. 2 were final built. Measuring profiles no. 3 to no. 6 was progressively built during last 5 years, where the experimental monitoring of the water regime of the track bed structure is also carried out.

2. The experimental monitoring of water regime in models of track bed structures

The measurements of moisture content in individual structural layers of the Experimental stand DRETM are performed by a non-destructive method that uses the principle of time domain reflectometry (TDR). These measurements consist of inserting the TDR test probe TRIME PICO IPH T3 into the TECANAT protective tubes, which have been pre-installed in the individual measuring profiles during the construction of the Experimental stand DRETM. The required depth of insertion of the TDR test probe into the track bed structure corresponds to the center of thickness of the measured structural layer.

In general, structural layers of the railway line consist mainly of coarse-grained (non-cohesive) materials, such as ballast bed and crushed aggregates of different fractions. The TDR test probe is designed to determine moisture in fine-grained (cohesive) materials whose density is up to 1700 kg.m\(^{-3}\) [2], [6]. For this reason, it was necessary to first calibrate the TDR test probe for selected coarse-grained building materials, incorporated into the individual structural layers of the Experimental stand DRETM. A detailed description of the laboratory activities and procedures for performing the calibration is referred in contributions [2], [6] and [7].

2.1. Principle of moisture measurement by TDR test probe

As mentioned above, monitoring of moisture by TDR test probe represents non-destructive way of monitoring using method of time domain reflectometry TDR. Moisture measurement by this device is dependent on the dielectric constant of the material, which represents the ability of the non-conductive material to transport electromagnetic waves. The value of the dielectric constant of solid particles and air is significantly lower than the value of the dielectric constant of water. Table 1 shows the differences between dielectric constants values of individual particles.

| Parameter          | Solid particles | Air | Water    |
|--------------------|-----------------|-----|----------|
| Dielectric constant| 2 - 6           | 1   | 79 - 81  |

The values of dielectric constant referred in Table 1 confirm, that relatively small changes in the saturation of the material by water, have a large effect on the value of dielectric constant of the material and therefore this measurement method can be considered accurate [3]. The following figure 2 shows a measuring device consisting of a TDR test probe TRIME PICO IPH T3 and a handheld device HD2 as well as a protective tube TECANAT in the phase of building measuring profile no. 3.
The principle of time domain reflectometry TDR is based on the fact that the TDR test probe emits electromagnetic waves to its surroundings (radius of 150 mm), where the measuring system of TDR test probe measures the time between sent and reflected electromagnetic wave. This time interval determines the propagation speed of the electromagnetic waves, which is directly influenced by the dielectric constant of the material surrounding the TDR probe. If the propagation speed of wave is lower, the dielectric constant of the soil is higher, and thus the amount of water in the soil is higher [8].

2.2. Monitoring of moisture changes in the structural layers of measuring profiles no. 1 to no. 6

Protective tubes TECANAT was installed into all measuring profiles of Experimental stand DRETM for the determination of moisture fluctuation in track bed during a year. These plastic tubes provide the application and insertion of the TDR test probe into the individual structural layers of the railway line models. Together 20 protective tubes TECANAT are installed into the Experimental stand DRETM, which provides experimental monitoring of moisture in the axis of measuring profile, in the region of embankment (banquet area) and in the region of cut (drainage area). Nowadays, continuous moisture measurements of individual structural layers are performed only in the axis of measuring profiles. In case of extraordinary precipitation, resp. long-term drought, and during the spring melting, measurements are also made in the lateral tubes of the measuring profiles.

The experimental monitoring of moisture performed by the TDR method cannot be implemented in all structural layers of measuring profiles of the Experimental stand DRETM. As shown in the following table 2, measurements of moisture are not performed in the ballast bed fr. 31.5/63 mm, in a leveling layer of sand, in thermal insulation layer from styrodur, in layer from liapor in a loose pile and in liaporconcrete. Structural layers from ballast bed fr. 31.5/63 mm contain a high proportion of air gaps which negatively influence measurements of moisture with the TDR test probe. Also, the structural thickness of layers from liapor in a loose pile, styrodur and from sand is not large enough to determine the amount of moisture using a TDR test probe (minimum material thickness of 150 mm). In the case of the structural layer from liaporconcrete, it was impossible to perform a correct calibration of the TDR test probe. The contribution therefore presents the results of experimental monitoring of moisture in structural layers from crushed aggregate fr. 0/31.5 mm, crushed aggregate fr. 0/63 mm and the subsoil of Experimental stand DRETM, which forms from clay with admixture of river gravel (F6=C1). The depths of the individual measurements by the TDR test probe
probe (shown in table 2) are clearly defined, wherein the center of measurement segment of the TDR test probe must correspond to the center of the measured structural layer. Table 2 shows an overview of the continuous monitoring of the moisture content of individual building materials in the individual depths of the measuring profiles of the Experimental stand DRETM.

**Table 2.** Moisture measurement structure of building materials incorporated into The Experimental stand DRETM.

| Material                        | Thickness [mm] | Depth [mm] | Material                        | Thickness [mm] | Depth [mm] | Material                        | Thickness [mm] | Depth [mm] |
|--------------------------------|----------------|------------|--------------------------------|----------------|------------|--------------------------------|----------------|------------|
| Ballast bed fr. 31.5/63 mm      | 500            | Not measured| Ballast bed fr. 31.5/63 mm     | 500            | Not measured| Ballast bed fr. 31.5/63 mm     | 500            | Not measured|
| Crushed aggregate fr. 0/31.5 mm | 450            | 725        | Crushed aggregate fr. 0/31.5 mm | 150            | 610        | Crushed aggregate fr. 0/31.5 mm | 450            | 765        |
| Crushed aggregate fr. 0/63 mm   | 550            | 1225       | Styrodur 2800 CS                | 50             | Not measured| Clay                           | Subgrade       | 1300       |
|                                |                |            | Sand                            | 100            | Not measured| Liapor concrete                | 150            | Not measured|
|                                |                |            | Clay                            | Subgrade       | 1500       | Clay                            | Subgrade       | 1100       |

Continuous monitoring of moisture of incorporated materials of the Experimental stand DRETM is performed with a periodicity every two weeks. The contribution presents the results of experimental monitoring of moisture corresponding to the period from 5. 9. 2018 to 24. 5. 2019, which define the course of the water regime during the winter period 2018/2019. Figure 3 shows monitoring of moisture using TDR test probe in the measuring profile no. 1 of the Experimental stand DRETM.

**Figure 3.** Experimental monitoring of moisture in measuring profile no. 1 of Experimental stand DRETM [Pieš, 2019].
The time interval between the individual measurements of moisture was determined based on previous results and experiences from the experimental monitoring of moisture in [3], [4]. This monitoring evidences that in a shorter time period (than two weeks) there were no significant changes in the moisture values of the incorporated building materials. The results of experimental monitoring of moisture for the time period from 5. 9. 2018 to 24. 5. 2019 are processed in the form of graphical curves, where the individual curves define the humidity variation in the structural materials of the individual measuring profiles. Figure 4 to figure 6 show the results of experimental monitoring of moisture in structural layers from crushed aggregate fr. 0/31.5 mm, crushed aggregate fr. 0/63 mm and clay with admixture of river gravel (F6=CI).

**Figure 4.** Course of moisture in crushed aggregate fr. 0/31.5 mm of individual measuring profiles [Pieš, 2019].

**Figure 5.** Course of moisture in crushed aggregate fr. 0/63 mm of individual measuring profiles [Pieš, 2019].

**Figure 6.** Course of moisture in clay with admixture of river gravel (F6=CI) of individual measuring profiles [Pieš, 2019].
The graphical moisture courses of crushed aggregate fr. 0/31.5 mm (figure 4) shows that the moisture values in the measuring profile no. 1 ranged from 5.1 % to 6.3 %. Moisture values in measuring profiles no. 3 to no. 6 ranged from 1.8 % to 3.4 %. These moisture values are almost twice as low as the moisture values determined in the measuring profile no. 1. This fact is caused by the gradual building of individual measuring profiles of the Experimental stand DRETM. Measuring profile no. 1 was built first and crushed aggregate 0/31.5 mm incorporated in this structure, contained a higher proportion of fine-grained particles than the crushed aggregate fr. 0/31.5 mm applied into other measuring profiles.

Figure 5 shows graphical moisture courses of crushed aggregate fr. 0/63 mm, which has been incorporated into measuring profiles no. 1 and no. 2, where it forms the body of the embankment of a railway line model. The moisture values of crushed aggregate fr. 0/63 mm ranged from 2.7 % to 4.7 %. Figure 4 as well as figure 5 show, that the amount of moisture was increased approximately about 0.8 % on average in the structural layers from crushed aggregate fr. 0/31.5 mm and crushed aggregate fr. 0/63 mm, in the period of spring thawing (from 5. 2. 2019 to 13.3. 2019).

The graphical moisture courses shown on figure 6 represent the fluctuation of moisture in the railway line subgrade, where the moisture values of clay with admixture of river gravel (F6=CI) ranged from 19.2 % to 20.9 %. Figure 6 also shows that the fluctuation of moisture in the subgrade of railway line models was more moderate (without major fluctuations) during the winter period 2018/2019 than in the case of the upper structure layers of track bed constructed from coarse-grained materials.

3. Conclusions

TDR test probe TRIME PICO IPH T3 is designed primarily to detect amount of moisture in fine-grained materials. Nevertheless, even the coarser grain size of the monitored material did not affect the accuracy of the individual measurements during the calibration as well as during the experimental monitoring of moisture on the Experimental stand DRETM. The boundary conditions such as sufficient compaction to remove unwanted air gaps, not exceeding the maximum saturation of material and sufficient insertion of the TDR test probe into the monitored building material, are basic preconditions for performing correct measurement of moisture by TDR technology. By observing these boundary conditions and performing a high-quality calibration of the TDR test probe, it is possible to achieve high accuracy of the measured values of moisture.

The moisture measurement by TDR test probe in comparison with laboratory determination of moisture [9], where samples of test materials need to be taken directly from individual structures of the Experimental stand DRETM, is simple and fast, without any undesirable destructive interference into models of railway lines. Thanks to the pre-installed protective tubes TECANAT, measurements of moisture can be performed in various depths of the track bed structure without disturbing it.

Based on the results of the experimental monitoring of moisture in the Experimental stand DRETM, the average moisture values of the tested building materials were determined for period from 5. 9. 2018 to 24. 5. 2019. These average values of moisture are presented in table 3.

Table 3. Average moisture values of tested materials [Pieš, 2019]

| Material          | Crushed aggregate fr. 0/31.5 mm | Crushed aggregate fr. 0/63 mm | Clay (subgrade) |
|-------------------|----------------------------------|-------------------------------|-----------------|
| Moisture [%]      | 4.2                              | 3.7                           | 20.1            |

Average moisture values of the tested building materials from table 3 will be used as input parameters for the numerical modelling of the thermal regime in the SoilVision software, which should result in the determination of the freezing depth of the track bed structure during affect different climatic factors.
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