Testing the Suitability of the Reinforced Foam Concrete Layer Application in the Track Bed Structure

Libor Izvolt¹, Peter Dobes¹, Martin Mecar¹

¹ Faculty of Civil Engineering, Department of Railway Engineering and Track Management, University of Žilina, Slovakia, Univerzitná 8215/1, Žilina, Slovakia
peter.dobes@fstav.uniza.sk

Abstract. The paper describes experimental activity carried out at the Department of Railway Engineering and Track Management of the Faculty of Civil Engineering, University of Žilina. It focuses on assessing the suitability of the application of thermal insulation material (the reinforced foam concrete layer) in the track bed structure. Within the experimental measurements, the traffic load (static load component) and non-traffic load (the effect of climatic factors) were monitored. The experimental measurements were carried out on individual segments of the experimental field, differing in thickness of reinforced foam concrete layer and deformation resistance of the subgrade sub-surface.

1. Introduction

Foam concrete (FC) as one of the lightweight concrete modifications has been known in the construction industry for more than 30 years. This building material contains closed void pores that significantly reduce its bulk density and thermal conductivity, but still has good mechanical strength. The basic components of the foam concrete mixture are cement, water, technical foam, additives and admixtures. Based on their ratio in the mixture, other modifications of the foam concrete can be achieved. Nowadays, many modifications of the foam concrete mixture and its reinforcement by many components are being tested abroad. The most interesting modifications of foam concrete include low bulk density modifications (from 300 to 700 kg.m⁻³), which make foam concrete known as FC 300 or FC 700 [1].

The research of the Department of Railway Engineering and Track Management (DRETM) has long been focused on the issue of the resistance of the track bed due to effects of climatic influences. Based on the assumed properties and positive results of the reinforced foam concrete layer mentioned in [1-6], we decided to test its properties in the area of the Experimental stand DRETM [7]. For this purpose, a real model of a railway track bed with a reinforced foam concrete layer was built. The necessary material to build the experimental field (model of railway track bed with built-in reinforced foam concrete layer) was provided by iwtech Ltd.

The experimental field represents the real structure of the railway track bed designed according to TNŽ 73 63 12 "The design of structural layers of subgrade structures" [7]. However, it should be noted that a part of the sub-ballast layer (or protective layer) is replaced by the foam concrete thermal insulation layer (FC 600) reinforced with the basalt reinforcing mesh type ORLITECH MESH [8].

The geometrical and structural arrangement of the layers of the railway track bed can be observed in figure 1.
Figure 1. Experimental field layout and cross-section (its segmentation and the location of the static load tests)

The experimental field is divided into three segments (segment A, B, C) of the same geometric arrangement. Segments A and B are characterized by higher deformation resistance (static deformation modulus) at subgrade sub-surface level \( E_{0,\text{sub}} \geq 40 \text{ MPa} \) and segment C is characterized by lower deformation resistance at subgrade sub-surface level \( E_{0,\text{sub}} < 15 \text{ MPa} \). Different deformation resistance of the subgrade sub-surface was used to identify the impact of the reinforced concrete layer to increase the deformation resistance (static deformation modulus) of the entire track bed structure. The experimental field - segment A differs from segment C by the built-up layer of ballast bed on the surface of the sub-ballast layer because segment A also serves to monitor the effects of climatic factors (rain, snow, frost) on the depth of freezing of the track bed structure.

The monitoring of the thermal regime of the tested structure (segment A) was carried out using the built-in Pt 1000 temperature sensors (red dots in figure 1). The monitoring of the water regime of individual structural layers of the track bed (in segment A) was carried out by means of a built-in protective tube of 2 m length (cyan rectangle in figure 1) in which the actual moisture was verified by moisture probe type TRIME PICO IPH T3 [9].

Given the fact that deformation resistance of 5 to 8 MPa was achieved at the level of the original subgrade surface, the crushed stone aggregate layer was placed on subgrade of low deformation modulus (0.35 m thickness at segment A and B, respectively 0.15 m at segment C. This modification enabled to achieve the required deformation resistance of approximately 40 MPa (segment A and B), respectively 15 MPa (segment C) on the surface of the crushed aggregate layer, which is designated as a subgrade sub-surface in the track bed structure. In order to ensure the separation and partial reinforcement of the bottom surface of the reinforced concrete layer, a geotextile Geofiltex 63/20 T of weight 200 g.m\(^2\) was placed at the level of the subgrade sub-surface. On the geotextile, there is a layer of foam concrete (FC 600) reinforced at its bottom and over the entire area with basalt reinforcing mesh type ORLITECH MESH with aperture dimensions of 100 x 100 mm.
2. Characteristics of the experimental measurements
Within the experimental measurements on the experimental field, plate load tests (PLTs) were carried out which allowed to identify the deformation resistance in the individual levels of the track bed structure (original subgrade surface, subgrade sub-surface, surface of the reinforced foam concrete layer and sub-ballast upper surface). In addition, the thermal regime was monitored and evaluated for the purpose of assessing the resistance of the tested structure due to the non-traffic and partly also the traffic load (its static component). It is assumed that the application of the reinforced concrete layer to the track bed structure will not only increase its thermal resistance (a suitable solution in the case of frost-susceptible subgrade surface), but also its deformation resistance (a suitable solution in the case of low deformation resistance of subgrade surface). By identifying the achieved parameters of the individual characteristics of reinforced foam concrete layer incorporated in the track bed structure in the area of both the traffic and non-traffic load, the prerequisites for establishing criteria for making a safe and economical design of a railway track bed structure with a built-in reinforced foam concrete layer were created.

2.1. Determination and assessment of deformation resistance of the tested structure
Plate load tests on individual construction layers of the railway substructure body were carried out according to the methodology stated in TS4 "Track substructure - Annex 6" [10] using a rigid 300 mm diameter loading plate. For both load cycles, a maximum contact stress of 0.2 MPa was used, which is the standard stress used on the Railways of the Slovak Republic (ŽSR) for the substructure body layers, [11]. The deformation characteristics measurements were made on the surface of the individual structural layers of the experimental field, namely on the original subgrade surface, subgrade sub-surface (crushed aggregate layer), on the reinforced foam concrete layer and at the level of the sub-ballast upper surface (crushed aggregate layer – protective layer of reinforced foam concrete). The measured value was the static deformation modulus $E_{si}$, which was determined from the relationship:

$$E_{si} = \frac{1.5 \cdot p \cdot r}{y} \text{ (MPa)},$$

where $p$ is contact stress under the loading plate (MPa), $r$ loading plate diameter (m), $y$ the total average settlement of the load plate found in the second cycle (m).

The static modulus values $E_{si}$ of the individual structural layers of the experimental field were determined in two phases, during the construction of the experimental field in 2017 and then after two winter periods (2017/2018 and 2018/2019). Figure 2 depicts the measured values of the static deformation modulus $E_{si}$ at the levels of the individual structural layers of the experimental field - segments A and B, which were determined during its construction (in 2017) and subsequently after two winter periods (in 2019). Figure 3 depicts the measured values of the static deformation modulus $E_{si}$, which were determined at the same levels of the individual structural layers and for the same time periods but in the experimental field - segment C. It should be noted that segment C differs from segments A and B by lower deformation resistance at the level of subgrade sub-surface $E_{0,sub} < 15 \text{ MPa}$ ($E_{0,sub} \geq 40 \text{ MPa}$ for segments A and B) and greater reinforced foam concrete layer - 150 mm thick (segments A and B - only 100 mm thick).

The experimental field - segment A also serves to monitor the water and thermal regime to provide the necessary input parameters for future numerical modelling. Segment A, as the only one between all segments of the experimental field, was not dismantled after the 2 winter periods in question, and therefore the measurement of the static deformation modulus $E_{si}$ was not realized.
Figure 2. Measured values of static deformation modulus $E_{si}$ in segments with higher deformation resistance (segments A and B) at the level of subgrade sub-surface ($E_{0,sub} \geq 40$ MPa) - left (measured values during construction - year 2017) and right (measured values after two winter periods - year 2019)
Figure 3. Measured values of static deformation modulus $E_s$ in segment with lower deformation resistance (segment C) at the level of subgrade sub-surface ($E_{0,sub} \geq 40$ MPa) - left (measured values during construction - year 2017) and right (measured values after two winter periods - year 2019).

2.2. Assessment of the resistance of the tested structure due to climatic load effects

The resistance of the track bed structure due to effects of climatic factors (non-traffic load) is guaranteed by the design of its sufficient thickness to prevent the penetration of zero isotherm below the frost-susceptible subgrade surface. The determination of the position of zero isotherm in the track bed structure allows 5 temperature sensors Pt 1000 (see figure 1), which are built into individual structural layers of the experimental field - segment A. These sensors are located in the axis of segment A and measure the real temperature in their particular locations, every 30 minutes.

Climatic characteristics are monitored by a separate temperature sensor, which continuously records the air temperature 2.0 m above the terrain surface. Table 1 demonstrates the identified climatic characteristics ($\theta_{s,\text{max}}$ - maximum mean daily air temperature during the winter period, $\theta_{s,\text{min}}$ - minimum mean daily air temperature during the winter period, $\theta_m$ - average annual air temperature, $I_F$ - air frost index, $I_{FS}$ - air frost index on the measuring profile surface – ballast bed surface, $D_F$ – depth of freezing of the track bed structure) in the monitored winter periods (2017/2018 and 2018/2019).

| Winter period | $\theta_{s,\text{max}}$ (°C) | $\theta_{s,\text{min}}$ (°C) | $\theta_m$ (°C) | $I_F$ (°C, day) | $I_{FS}$ (°C, day) | $D_F$ (m) |
|---------------|-----------------|-----------------|----------------|----------------|----------------|------------|
| 2017/2018     | 8.1             | -11.2           | 9.0            | 107            | 98             | 0.69       |
| 2018/2019     | 7.1             | -11.3           | 10.3           | 124            | 97             | 0.49       |

It should be noted that during both winter periods, the snow cover was removed from the surface of the model of railway track (experimental field – segment A), in order to simulate the maximum frost
effect on the materials incorporated in the track bed structure. This means that the depth of freezing of the track bed structure $D_f$ as well as the surface frost index value $I_{FS}$ have not been influenced by the thermal insulation properties of the snow cover.

Although the air frost index value during both monitored winter periods represented only about 25% of the design value of the air frost index for the Žilina territory ($I_{FD} = 470 \, ^{\circ}C$, day), on the basis of which the structural design of the track bed of the experimental field was performed, a significant zero isotherm penetration into the tested structure can be observed due to the removal of the snow cover and course of the winter period 2017/2018. The comparison of the individual climatic characteristics of the two recorded winter periods it can be visible in figures 4, 5 and 6.

**Figure 4.** Graphic representation of the course of mean daily air temperatures and the air frost index (left – winter period 2017/2018, right – winter period 2018/19)

**Figure 5.** Graphic representation of the course of mean daily air temperatures and the air frost index on the ballast bed surface – segment A (left - winter period 2017/18, right - winter period 2018/19)

**Figure 6.** Graphic representation of the course of the depth of freezing of the track bed structure – segment A (left – winter period 2017/18, right – winter period 2018/19)
3. Conclusions

The Department of Railway Engineering and Track Management (DRETM) has been involved in research activities including the problem of experimental monitoring of the suitability of incorporation of various thermal insulating materials (lightweight clay aggregate - liapor, extruded polystyrene slabs - styrodur, liapor concrete and foam concrete) into the railway track bed structure since 2016 [6, 11, 12]. The thermal insulation materials in question are monitored not only in terms of their resistance due to climatic factors, but also in terms of their impact on increasing the deformation resistance of the entire track bed structure.

From the results presented in subsection 2.1, it can be stated that the reinforced foam concrete layer is suitable for increasing the deformation resistance of the track bed structure. For the case of a new railway track construction and assuming a sufficiently resistant subgrade surface ($E_0 \geq 40$ MPa), it is possible to achieve at the level of the sub-ballast upper surface approximately doubled value of the static deformation modulus (approx. 80 MPa), already for 100 mm thickness of the reinforced foam concrete layer (experimental field - segment A and B). It should be noted that the measurements of the static deformation modulus values on the surface of the reinforced foam concrete layer $E_{si}$ were carried out after 28 days of hardening of the foam concrete (figure 2 - left). In the case of performing static load tests after 2 winter periods (figure 2 – right), the static deformation modulus values measured on the reinforced foam concrete layer surface were cca 40 to 100 % higher. In order to protect the surface of the reinforced foam concrete layer prior to the pressing of the ballast bed fr. 31.5/63 mm, a crushed aggregate protective layer fr. 0/31.5 mm was placed on its surface (figure 1 - segment A, B). At the time of experimental field construction, the reinforced foam concrete protective layer provided an increase in the static deformation modulus $E_{si}$ of about 15 to 25 %.

The experimental field – segment C is characterized by a low static deformation modulus value at the level of the subgrade sub-surface ($E_{0,sub} < 15$ MPa) and by the incorporation of a thicker reinforced foam concrete layer in the track bed structure (layer thickness is 150 mm). The results from the experimental measurements carried out on the individual structural layers of the body of the track substructure (segment C) are presented in figure 3. Figure 3 (left) shows a more than 10 times increase in the static deformation modulus values (the difference between the values measured at the level of the subgrade sub-surface and the level of the reinforced foam concrete layer surface). It should be noted that the measurements of the static deformation modulus values on the surface of the reinforced foam concrete layer $E_{si}$ were carried out after 28 days of hardening of the foam concrete (as in the case of segments A and B). In the case of the measurement of the static deformation modulus values after 2 winter periods (figure 3 - right), the static deformation modulus values measured on the surface of the reinforced foam concrete layer were of about 40 to 80 % higher.

Subsection 2.2 of this text was aimed at assessment of the reinforced foam concrete layer resistance incorporated in the railway track bed due to climatic factors. According to [8], a 0.45 m thick protective layer from the crushed aggregate fr. 0/31.5 mm is required in the railway track bed for the Žilina region (design air frost index $I_{FD} = 470$ °C, day). In the experimental field - segment A, this structure was replaced by a 100 mm thick reinforced foam concrete layer and a 150 mm thick crushed aggregate layer fr. 0/31.5 mm (thickness reduction of overall track bed structure of 200 mm). In two winter periods recorded so far, the achieved air frost index value $I_F$ was only about 25 % of the design frost index value, it is not possible to solidly confirm sufficient resistance of the tested structure due to frost effects (despite the fact that the increased frost effects were caused by removing each snow cover). However, it is interesting to note that despite the lower value of the air frost index $I_F$ achieved in the winter period 2017/2018, the depth of freezing of the track bed structure was increased by 0.20 m than in the winter period 2018/2019 (see table 1). This difference probably caused a different course of the winter periods in question (number and intensity of frost periods). In the winter period 2017/2018, the value of the air frost index $I_F$ was achieved in a shorter period under the influence of several mean daily air temperatures $\theta_0$ below -10 °C and lower average annual air temperature $\theta_0$s (lower by 1.3 ° C than in the winter period
2018/2019). There was less accumulated heat in the track bed structure, and so the frost could penetrate faster in the structure.

As part of the further experimental activities of DRETM, it is necessary to verify the thermal insulation effects of the track bed structure with built-in reinforced foam concrete layer due to more adverse climatic factors and to test the resistance of the structure to traffic load, especially dynamic effects, from the real traffic density of the railway track.

Acknowledgment(s)
The presented results are the partial results of solving the VEGA grant project 1/0275/16 “Structure optimization of sleeper subgrade due to non-traffic load aspect”.

References
[1] J. Vlcek, M. Drusa, W. Scherfel, and B. Sedlar, Experimental investigation of properties of foam concrete for industrial floors in testing field, World Multidisciplinary Earth Sciences Symposium, vol. 95, pp. 1-8, 2017.
[2] G. Yakovlev, J. Kerienen, A. Gailius, and I. Girniené, Cement based foam concrete reinforced by carbon nanotubes, Materials Science [Medžiagotyra], vol. 12(2), pp. 147-151, 2006.
[3] J. Hulimka, R. Krzywoń, and A. Jędrzejewska, Laboratory Tests of Foam Concrete Slabs Reinforced with Composite Grid, International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures, vol. 193, pp. 337-344, 2017.
[4] M. Decký, M. Drusa, K. Zgútová, M. Blaško, M. Hájek, and W. Scherfel, Foam Concrete as New Material in Road Constructions, World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium, vol. 161, pp. 428-433, 2016.
[5] V. Valašková, J. Vlček, and M. Drusa, Experimental and computational dynamic analysis of the foam concrete as a sub-base layer of the pavement structure, 14th International Conference on Vibration Engineering and Technology of Machinery, vol. 211, pp. 1-6, 2018.
[6] M. Drusa, J. Vlcek, W. Scherfel and B. Sedlar, Testing of Foam Concrete For Definition of Layer Interacting With Subsoil In Geotechnical Applications, International Journal of Geomate, July 2019, Vol.17, Issue 59, pp.115-120, Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.59.8293
[7] P. Dobeš, L. Ižvolt, and S. Hodáš, Examining the influence of railway track routing on the thermal regime of the track substructure – experimental monitoring, 16th Scientific and Technical Conference, Transport Systems, Theory & Practice, 2019 (in press).
[8] www.orlimex.cz/kompozity, online: 04/2019
[9] Trime Pico-profile manual, online 05/2019, https://s3.amazonaws.com/mesystemsccwp/wp-content/uploads/2017/09/Manual_TRIME-PICO-IPH1.pdf
[10] Slovak railway regulation TS4, Track substructure - Appendix 6, GR ŽSR, Slovakia. Validity from 07/2018 [in Slovak]
[11] TNŽ 73 6312, The design of structural layers of subgrade structures, GR ŽSR, Slovakia. Validity from 08/2005 [in Slovak]
[12] P. Dobeš, L. Ižvol, M. Mečár, and J. Malachová., The determination of values of the specific heat capacity of the selected thermal insulation materials used in track bed structure, 26th R-S-P Seminar, vol. 117.