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EXPERIMENTAL MONITORING OF THERMAL RESISTANCE OF RAILWAY TRACK CONSTRUCTION

Summary. In the paper the author presents the results of experimental monitoring of the thermal resistance of the railway track construction on a testing stand received during two winter periods. During the winter period 2003/2004 there was 100 – 120 mm thick snow cover on the surface of the rail gravel and during the winter period 2004/2005 the railway track construction without snow cover was monitored.

MONITORING GŁĘBOKOŚCI PRZEMARZANIA KONSTRUKCJI TORU KOLEJOWEGO

Streszczenie. Artykuł prezentuje wyniki badań głębokości przemarzania konstrukcji toru kolejowego przeprowadzonych na doświadczalnym odcinku, które otrzymano podczas obserwacji prowadzonych w dwóch okresach zimowych. Zimą, na przełomie lat 2003/2004, na powierzchni podsypki utrzymywała się pokrywa śnieżna o grubości około 100 – 120 mm. Rok później, w okresie 2004/2005 badana konstrukcja toru nie była pokryta warstwą śniegu.

1. INTRODUCTION

Real loading of a track in operational conditions is miscellaneous. The railway track construction is during its durability loaded not only with transport but also with non-transport loading. Moving railway cars or trains of wagons load the railway track construction – rail *grate*, rail (gravel) bedding and its subgrade with complex force effects of static, quasi-static and dynamic character, which together form so-called **transport loading**. Except these direct force effects the railway track construction is exposed to further effects, mainly weather and climatic conditions (water, frost, solar radiance and wind) influencing the sleeper subgrade, so-called non-transport loading.

It is not possible to omit the influence of weather and climatic factors (the influence of non-transport loading) on the railway track. It influences quality of the track during the whole year. Particularly the influence of frost on the sleeper subgrade construction is one of the main factors of non-transport loading which remarkably affects its quality. The frost in connection with unfavourable water regime causes the rise of volume changes of the sleeper subgrade which results in the railway track construction damages. It follows that the protection of the sleeper subgrade against frost effects has become very important. The sleeper subgrade construction which shows minimum freezing of subgrade surface is best protected against frost effects.

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In the last years there have been changes in climatic conditions; there are not so frost values and snowfalls reached as they were in the beginning of monitoring these values at meteorological stations in Europe. This fact should influence dimensioning of the sleeper subgrade construction taking into consideration the frost effects on the sleeper subgrade construction design. Reached smaller depths of the sleeper subgrade freezing on existing tracks or reduction of the sleeper subgrade construction layers on modernized tracks will cause lowering of maintenance costs or capital costs for building the sleeper subgrade construction.

In this paper the first results of the experimental monitoring of the thermal resistance of construction are analysed. They should prove the assumption that long-run lower average medium temperatures during the winter period can result in more economical sleeper subgrade construction from the point of view of its design and assessment to unfavourable frost effects.

2. CLIMATIC CONDITIONS AND THERMAL REGIME OF SLEEPER SUBGRADE [1]

When searching for reasons and effects of railway substructure damages climatic conditions play a very important role. It is inevitable to quantify them by those characteristics on basis of which their influence on thermal regime of the sleeper subgrade and the depth of its freezing can be expressed.

From this point of view the main climatic characteristics are:

- air pressure,
- air humidity and amount of rain fall,
- air temperature,
- snow cover

The result of the difference in **air pressure** is wind as a horizontal movement of air caused by pressure gradient force. Except global air movement local movement of air plays a very important role. It is caused mainly by articulation of landscape. Air, which gets cooler at night in higher locations, flows into valleys that causes remarkable differences in microclimate.

Humidity is a result of water evaporation into the air. By steam condensation evaporated water returns to the Earth surface in the form of rainfalls and snowfalls. Rainfalls are given by amount and intensity.

Air temperature is one of the most important characteristics of climatic conditions of a particular area. It changes during a day (higher temperatures in the daytime, lower in the night), but mainly during a year (higher temperatures in summer, lower in winter). The course of air temperatures is expressed by the following characteristics:

a) *average day air temperature* T_s [°C]

$$T_s = \frac{T_7 + T_{14} + 2T_{21}}{4}, [^{\circ}\mathrm{C}] \quad (2.1)$$

where T_7, T_{14} a T_{21} are temperatures measured at 7.00 a.m. and 2.00 p.m. and 9.00 p.m. of Greenwich meantime 2m above ground,

b) *maximum air temperature* T_{max} *and minimum air temperature* T_{min} in a day's or year's cycle,

c) *average year air temperature* T_m expressed with the following equation

$$T_m = \frac{\sum_{i=1}^{365} T_s}{365}, \ [^{\circ}\mathrm{C}] \tag{2.2}$$

d) *number of frost days* – days during which minimum air temperature equal to or lower than -0,1°C occurs,
e) *number of ice days* – days during which maximum air temperature equal to or lower than -0,1°C occurs (all-day frost),
f) *frost period* – period with continuous frost or ice days,
g) *frost index* I_m [°C day] – maximum negative value of the sum of average day temperatures in the winter period.

From the above mentioned characteristics the **frost index I_m** is the most common characteristics which is used when considering thermal regime and assessment of the sleeper subgrade from the point of view of its protection against frost. The frost index is not a constant value, but rather changeable. It depends directly on air temperature, which is influenced by many factors. It is possible to express mathematically the influence of individual factors on the size of index only to a certain extent. The more precise determination of the frost index is possible only by *direct measuring of temperatures* at particular meteorological stations.

Thermal regime of the sleeper subgrade is defined as a course of thermal changes of individual construction layers and soil in the sleeper which are caused by solar radiance and air temperature changes in the daytime or during a year. Freezing depth of the sleeper subgrade h_{pr} is a very important characteristics in this sense.

Thermal resistance of the sleeper subgrade is defined as a distance of zero isotherm (0°C) from the surface of rail bedding. The following factors influence the thermal resistance of the sleeper subgrade:

a) temperatures in the winter period characterised most commonly by the frost index I_m,
b) thermal-insulation features of the sleeper subgrade construction layers,
c) condition of subgrade surface soil (humidity w, bulk density ρ, granulometric composition, etc.),
d) thickness of snow cover on the railxay track.

The frost indexI I_m is given by summing up medium day air temperatures T_s in the winter period according to the equation (2.1)

$$I_m = \sum_{t_z}^{t_k} T_s, \ [^{\circ}\mathrm{C.day}] \tag{2.3}$$

In this way a line of sums in °C is received. In the case that temperature value on the surface of the rail construction (surface of the rail bedding) is used instead of the value T_s, the frost index on the surface I_{mp} is received.

3. CHARACTERISTICS OF EXPERIMENTAL MONITORING OF THERMAL RESISTANCE OF SLEEPER SUBGRADE

Direct experimental measurement is one of relatively reliable but also rather time-consuming methods of monitoring the thermal resistance of the sleeper subgrade h_{pr}. In the

case of experimental monitoring of the thermal resistance it is possible to use the following methods:
1) modelling in laboratory conditions,
2) measuring on testing track sections.

The thermal resistance of the sleeper subgrade in experimental measurements is determined by *the level of water freezing in soil* or *zero isotherm position.* The level of water freezing is usually found out by built-in frost meters and the position of zero isotherm is determined from continuous temperature measurements in the sleeper subgrade construction by built-in thermometers.

In 2003 a so-called outer testing stand was built at the Department of Railway Engineering and Track Management (DRETM) to monitor the bearing capacity of the railway substructure construction and the thermal resistance of the most commonly applied sleeper subgrade construction on modernized ŽSR tracks according to the regulation [2] sleeper subgrade of the type No. 3. The aim of monitoring is above all to receive relevant data for technically correct and economical design of the sleeper subgrade construction not only from the point of view of its required bearing capacity but also thermal resistance.

3.1. Description of the outer testing stand of DRETM

The testing stand of DRETM is situated at the Faculty of Civil Engineering, the University of Žilina. It consists of two vertical concrete foundations in which there are two transversal frames from profiles IPE 300. Transversal frames function as a counterweight (buttresses to hydraulic lifter) for realization of static loading tests.

The railway track construction in the testing stand consists of the following construction layers (Fig. 3.1):
- *ballast bedding with thickness* 500 mm, fraction 32 – 63 mm,
- *subbase* 450 mm from broken stone, fraction 0 – 32 mm,
- *bracing geocomposite MACRIT GTV 50/50 B* laid on subgrade surface,
- *subgrade surface built in bilateral transversal gradient 5 %* from sandy clay *(F4 = CS).*

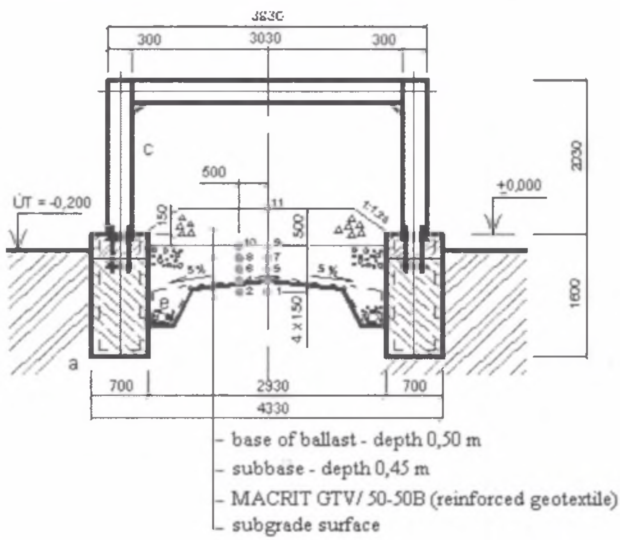

Fig. 3.1. Profile of outer testing stand of DRETM
Rys. 3.1. Profil zewnętrznego stanowiska pomiarowego DRETM

In the construction layers of the testing stand there are 11 resistance thermometers built in vertically (see their placement on the fig.3.1.), which scan temperature in the given surroundings. Thermometers output is recorded automatically to the measuring base ***MS 4***, from which it is possible to remove the measured data to a computer with program ***Comet***.

3.2. Monitored characteristics

Temperatures in the whole profile of the built testing stand construction were monitored during experimental measurements. Measurements realized in the testing stand and presented in this paper are from the period from *22. 12. 2003* to *30. 03. 2005*.

Next monitored characteristics during given period was air temperature measured 2, 0 m above rail bedding surface. According to the relation (2.1) not only medium daytime air temperatures were expressed from measured temperatures T_s, but also frost indices I_m were enumerated according to the relation (2.3).

4. EVALUATION OF EXPERIMENTAL MEASUREMENTS

It is possible to characterize the **winter period 2003/2004** as a very mild winter with maximum medium daytime temperature $T_{s,\ max,\ 03/04} = 13,1$ *°C* and minimum medium daytime temperature $T_{s,min,03/04} = -12,3$ *°C*.

During this winter period the rail bedding surface was almost permanently covered by snow, thickness of which was monitored and maintained with template on the value approximately 100 – 120 mm. The frost index was determined from measured air temperatures $I_{m,03/04} = 168,92$ *°C.day*.

Course of medium daytime air temperatures T_s and frost index I_m is obvious from Fig. 4.1.

The **winter period 2004/2005** was colder and with more snowfalls when compared to the previous one. Medium daytime temperatures reached maximum $T_{s,max,04/05} = 6,6$ *°C* and minimum $T_{s,min,04/05} = -13,4$ *°C*.

During this winter period the snow cover was removed from the stand surface to protect the rail bed against snow and simulate the effect of black frost.

The value of frost index was determined from measured temperatures $I_{m,04/05} = 227,24$ ***°C.day***.

Course of medium daytime air temperatures T_S and frost index I_m is obvious from Fig. 4.2.

Course of medium daytime air temperatures T_s in individual depths of testing stand construction during both monitored winter periods is obvious from Fig. 4.3.

5. PRELIMINARY CONCLUSIONS FROM EXPERIMENTAL MEASUREMENTS

Having evaluated temperature measurements in the testing stand construction it has been found out that zero isotherm did not penetrate below the level of the railway substructure only in the time of winter period 2004/2005. In the winter period 2003/2004 zero isotherm was situated in the lower half of the rail bedding construction layer, near above level of subbase surface. In winter period 2004/2005 the zero isotherm was in maximum depth (about 180 mm under level of subbase surface) in the first half of February. However, the zero isotherm did not reach level of subgrade surface in this season. These results was influenced

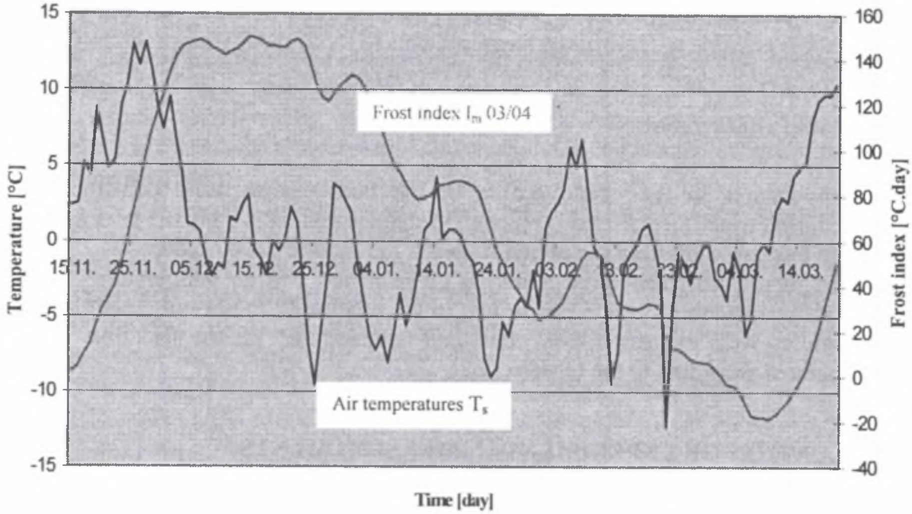

Fig. 4.1. Course of medium daytime air temperatures T_s and frost index I_m in winter period 2003/2004

Rys. 4.1. Przebieg średniej temperatury powietrza T_s oraz wskaźnika I_m w ciągu dnia podczas sezonu zimowego 2003/2004

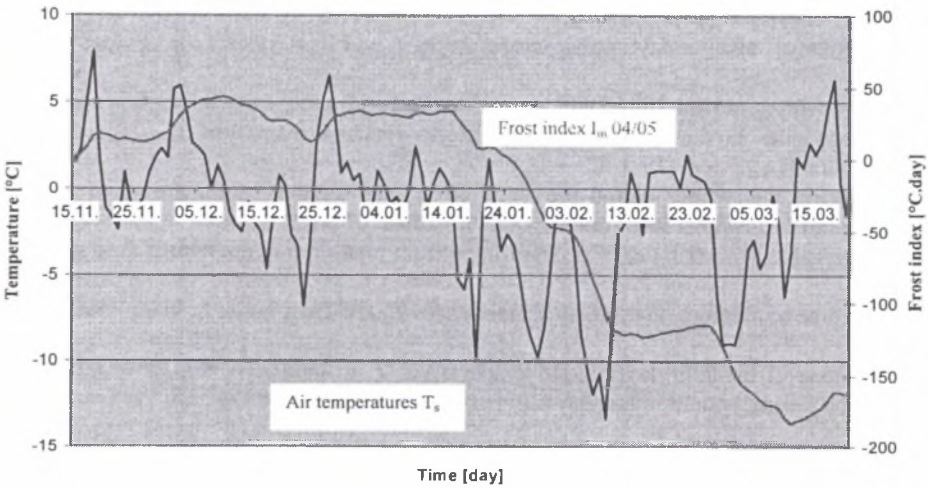

Fig. 4.2. Course of medium daytime air temperatures T_s and frost index I_m in winter period 2004/2005

Rys. 4.2. Przebieg średniej temperatury powietrza T_s oraz wskaźnika I_m w ciągu dnia podczas sezonu zimowego 2004/2005

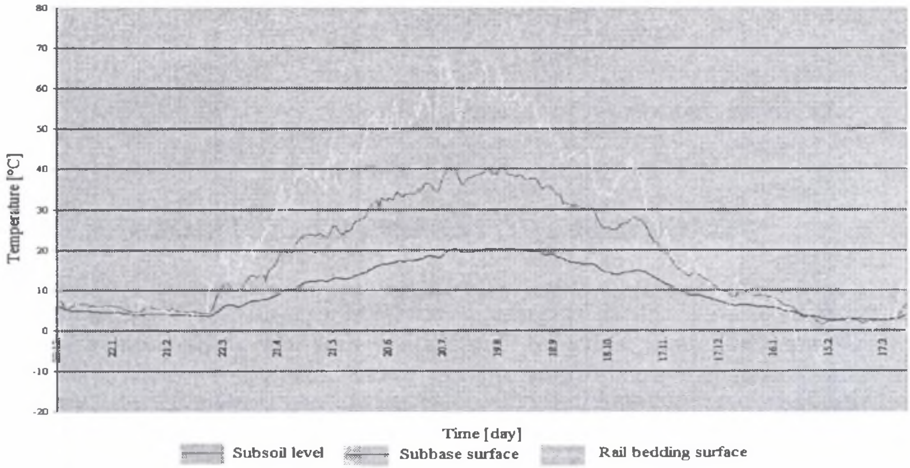

Fig. 4.3. Course of medium daytime air temperatures T_s in individual depths of testing stand construction in winter periods 2003/2004 and 2004/2005

Rys. 4.3. Przebieg średniej temperatury powietrza T_s odczytanej na różnych głębokościach na stanowisku pomiarowym w ciągu dnia podczas sezonów zimowych 2003/2004 oraz 2004/2005

by the snow cover (the winter period 2003/2004), as well as relatively low values of the frost index in both monitored winter periods ($I_{m,03/04}$ = 168,92 °C.day or $I_{m,04/05}$ = 227,24 °C.day), which did not reach even 50% of proposal frost index I_{mn} for Žilina region (I_{mn} = 480 °C.day). With regard to the fact that in the winter period 2004/2005 the higher frost index was reached when compared to the winter period 2003/2004 and the rail bedding surface was during the whole period without the snow cover, it is possible to assume that the thermal resistance of rail gravel layer had a remarkable influence on the position course of zero isotherm and subsequently on freezing of the monitored construction. This assumption is based on the fact that rail gravel material was not influenced by real influences of railway operation; it was not polluted and fully compacted. A high portion of air spaces, absence of microgranular fraction and humidity in the rail bedding formed from the rail bedding material a construction layer of high thermal resistance, or a layer with a small coefficient of thermal conductibility λ which stopped penetrating of zero isotherm into bigger depths of the testing stand construction.

For objective assessment of the sleeper subgrade construction from the point of view of its thermal resistance it is suggested to place the rail bedding from the operating track into the testing stand for the following period, compact it to presupposed volume weight and imbed a rail grate. These measures should provide conditions similar to a real railway track and subsequent relevant values of the thermal resistance of the tested sleeper subgrade type.

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