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MODELLING OF RAILWAY TRACK TEMPERATURE REGIME WITH REAL HEAT-TECHNICAL VALUES FOR DIFFERENT CLIMATIC CHARACTERISTICS

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Abstract

High quality of railway track construction is a major priority. One of the quality elements is the resistance to load of railway formation with individual structural layers caused by negative temperatures during the critical freezing period of winter. Numerical modelling allows obtaining more control outputs at different climatic loads. The presented paper shows the load of railway track model with different variants of climate and shows the importance in the designing of the non-transport load under negative temperatures, i.e. observation of transition of the zero isotherm through the layers of railway subgrade. If the subgrade layers of the railway formation are built with high quality and durability then the axis of the track will keep its geometric spatial position during the long-time operation.

Keywords:

Railway engineering;
Layers of railway subgrade;
Numerical modelling of temperature regime;
Heat-technical values;
Zero isotherm.

1 Introduction

The temperature regime in the particular structural layers of the railway track formation is one parameter of a set of characteristics with its assessment, mainly because the built-in materials have to resist the negative temperatures, i.e. then ensure the long-term deformation stability. In the different regions of the country, i.e. railway track location, there are different climatic conditions to which to the thickness of the structural layers and a selection of designed materials with increased of the frost resistance (and of course also to other influences) must be adapted. By numerical modelling the depth of freezing of the formation of railway construction and transition of temperatures through the particular layers of the used construction materials is being determined.

The Department of Railway Engineering and Track Management of Faculty of Civil Engineering at the University of Žilina (DRE-FCE-UNIZA) for a long time has been monitoring own made models of track in 1 : 1 scale since the year 2003 [1]. During the winter periods we observe the temperature values in the structural layers on points of the measurement positions and progressions of temperatures under different temperature loads in cold weather during freezing period are also detected. The values of numerical modelling by using the SV-HEAT SoilVision system [2] we can compare it with the measured values, but the advantage of the numerical modelling is that we can observe the model under different temperature loads [3].

The paper presents the results at the specified input climatic conditions from two models of long-term research at our department; the third model is a combination of them. Two more models are modelled under a climate with very cold weather. The paper presents models loaded with minimum temperatures at high minimum values of the frost index I_F = -600 to -800 °C, which occur in our region Žilina, possibly Poprad, approx. 1 - 2 times in 30 years.

2 Climatic characteristics

On the basis of long-term research activities we use input data from some of the winter periods since 2013. The key to selecting there were two winter characteristics obtained, i.e. MODEL 1 – will be loaded by climatic temperatures of the period with the highest frost index during the reporting period from 2003 to 2017 [4], which is presented by the winter 2005/2006. MODEL 2 - climate from the period when the greatest depth h_F of freezing construction layers was obtained and it was in winter 2011/2012 since 2003 [5]. The temperature load of the MODEL 3 was created by the combination of the lowest minus temperatures from MODEL 1 and MODEL 2 (Table 1 and Fig. 1). MODELS 1 to 3 are characteristic for the winter period of our regional area of Žilina for last 14 years (here also a global warming of the Earth plays partial influence).

Table 1: MODEL 1 to 3, years 2003 - 2017 at DRE-FCE-UNIZA – basic climate choice for modelling.

WINTER	$T_{M,air}$	$T_{M,air}$	$I_{F,air}$	$I_{F,sur}$	h_F	**Characteristics of the winter period**	**Snow**
	max °C	**min °C**	**-°C**	**-°C**	**m**		**m**
2005/06 MODEL1	5.7	-16.7	388	248	0.82	the highest frost index (I_F^{max}, $I_{F,surface}^{max}$)	0.05
2011/12 MODEL2	4.9	-15.2	238	207	0.89	the maximum depth of freezing (h_F^{max})	0.05
2005/12 MODEL3	climate T_s model 1+2		375	Table 4		combination of MODEL1 and MODEL2	0.10

For purpose of subsequent modelling, we used the model with railway subgrade TYPE 2, which is processed in the Canadian software SV-HEAT [2]. All the following model situations are the same in terms of dimensions, material-technical characteristics of the layers, etc. [6]. In this proposed process of modelling, we can see the behaviour of the temperatures transition under different climatic loads. We expand our consideration to the MODEL 4, i.e. to our model built in laboratory, to which we will apply the climatic conditions of the mountain areas of the High Tatra Mountains, for the Poprad region. In the given location the frost index throughout the winter is usually I_F = -500 °C and more, in our particular case in the winter 1995/1996 it was I_F = -600 °C, Table 2. To illustrate the phenomenon we use the MODEL 5, which is based on the MODEL 3 + 30 % up of the temperature, e.g. climate for frost index I_F = -800 °C, which generally occurs in long cycles of freezing with higher impact of frost (Table 2).

Table 2: MODEL 4 and 5, years 2003 - 2017 at DRE-FCE-UNIZA – further climate settings for modelling.

WINTER	$T_{M,air}$	$T_{M,air}$	$I_{F,air}$	$I_{F,sur}$	h_F	**Characteristics of the winter period**	**Snow**
	max °C	**min °C**	**-°C**	**-°C**	**m**		**m**
MODEL4	climate T_s model 4		600	Table 4		original climate Poprad in 1995/96	0.15
MODEL5	climate T_s model 5		800	Table 4		combination MODEL3 + 30 % Žilina - Slovakia + 30 %	0.20

The frost index I_F is the sum of the negative daily temperatures T_s during the winter period (each period begins when the first four days have minus temperatures). The average daily temperature T_s is calculated daily from four daily measurements of $T_s = (T_{7am} + T_{2pm} + 2.T_{9pm})/4$, measured at 7 am, 2 pm and 9 pm. Particular detailed graphs for T_s are shown in Fig. 1 and Fig. 2. The snow cover right in the track is in the individual models according to the Table 1 and Table 2 (we cannot ignore the fact that the train ride prevents the formation of snow layer higher than the railheads).

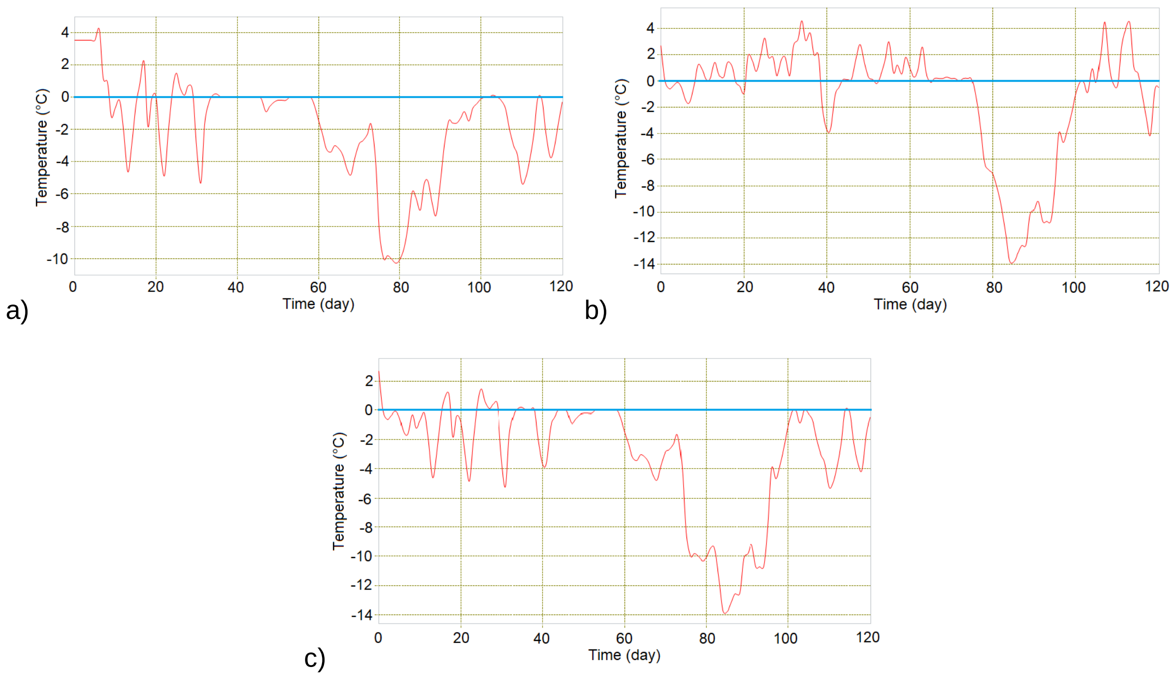

Fig. 1: Average daily temperature T_s of MODEL 1 to 3 (120 days) - climatic loads.

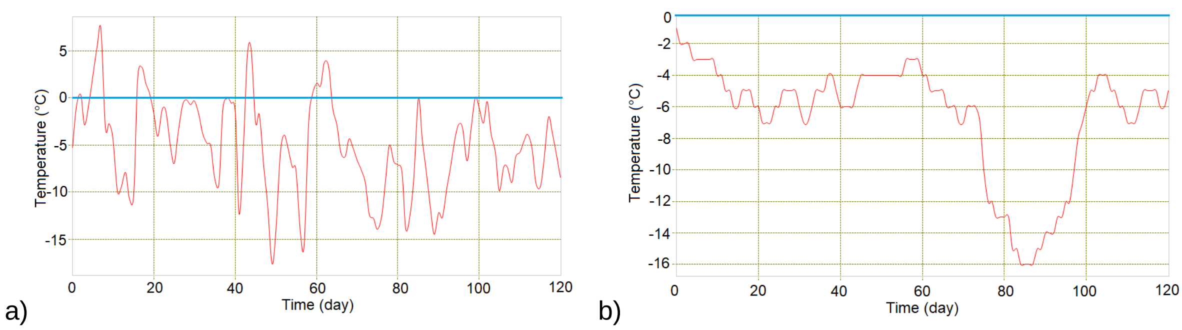

Fig. 2: Average daily temperature T_s of MODEL 4 and 5 (120 days) - climatic loads.

The winter periods of each investigated winters of our research represent the duration of the 120 days period when frosts are expected, i.e. in the dates from November to March "10.11.(year$_i$)" to "10.3.(year$_{i+1}$)".

Northern Slovakia is situated at altitudes from 320 to 400 m above the sea level (Height system Balt settlement - Bpv.) with railway lines, such as the location of Žilina, where the presented models are built in the north of our country. The area of the town of Poprad is also in the north of the country (below the High Tatra Mountains at altitudes from 650 to 750 m above the sea level the Poprad railway station is located). To illustrate the height differences of the Slovak Republic, we will also mention Bratislava – the capital city of Slovakia, located at the height from 120 to 170 m above the sea level. Climate temperatures, which are now in the north of the country, were in the south about 25 to 40 years ago (global warming). For these reasons, it is necessary to consider at which altitude a railway line is built and which climate load the railway formation will resist (the research is focused on the winter periods and mainly freezing of the railway subgrade layers).

3 Model loaded with minus temperatures

The models are based on the built-in railway formation of the track in the "in-situ" DRETM laboratory [7] using SV-HEAT SoilVision [2]. The subbalast layers of the railway formation were modelled as the TYPE 2 of the railway subgrade with a protective gravel-sand layer under the track bed (the reason for its building-in is to increase its resistance to low freezing temperatures and also to improve the water regime of the layers).

If the TYPE 1 of subgrade without protective layer was used, the railway subgrade could freeze at low I_F values and we would have to consider its rebuilding to TYPE 2 in the given section of the track. In this paper, all climate changes are modelled already on the TYPE 2. Finally, we can conclude that with higher climatic loads due to external minus temperatures, we will also have to consider the TYPE 2 as partly freezing, because this sand-gravel protective layer have been freezing (at I_F = -600 °C and especially at I_F = -800 °C). It would be convenient to consider a greater thickness of the protective layer up to 600 mm. One of other types of standard subgrades, TYPE 3 to TYPE 6, with other layers and structural elements, such as geotextile, geogrid, geocomposite, panels, asphalt, various stabilizing layers and so on, should be used in the structural design of the railway track to ensure non-freezing of railway substructure (these structures have also other properties, for example from the point of view of traffic load, and so on). The designer within designing can change the thickness of the particular layers and their structure by choice of built-in materials.

Better structure of the railway substructure, without various undesirable deformations and transformation from this inconvenient non-transport load from minus temperatures, can carry a better rail track (the traffic load from the axial pressures and the dynamics caused by the rail vehicles run are checked during the designing of the structural layers of the railway formation). The long-term sustainability of the correct geometric position of track and railway track objects will increase, and then the track will not require frequent refurbishment. TYPE 2 model is presented in Fig. 3 (it also applies to multi-line track with small changes in the course of temperatures in layers - stronger core of rail formation at high embankments and cuttings).

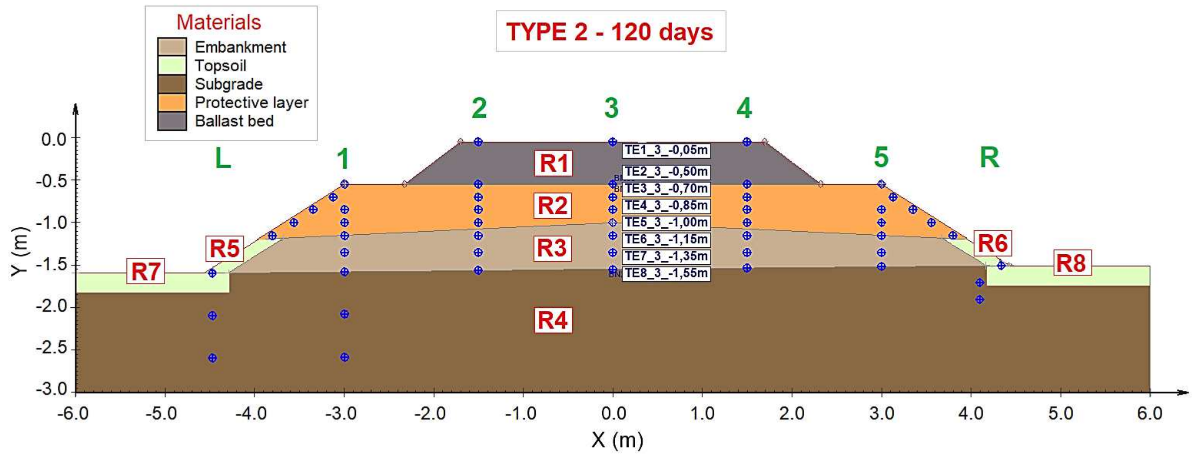

Fig. 3: Numerical model of subgrade profile TYPE 2 - part of railway track.

The railway track is modelled in the form of the construction areas R_i (Fig. 3), i.e., of the particular layers in which the required structures of the materials with heat-technical parameters are built-in. The particular values of the technical characteristics of the model materials were determined by the laboratory tests at the accredited laboratory at the Department of Railway Engineering (DRE). The heat-technical characteristics of the materials of the subgrade of TYPE 2 from the “in situ” model have been inputted to our modelling (Table 3), [6], and [8], where: λ - thermal conductivity, ρ - soil dry density, c - specific heat capacity, T_{ef} and T_{ep} - temperatures of freezing and thawing of the material, and W - material humidity.

Table 3: Heat-technical characteristics of the layers of the railway subgrade model TYPE 2.

R_i	Material	λ	ρ	c	T_{ef}	T_{ep}	W
		J/(day.m.C)	kg/m^3	J/(kg.C)	°C	°C	%
R1	Track bed	58147	1908	980	-0.01	-0.5	1.3
R2	Protected layer FPL	145853	2045	1246	-0.01	-0.5	5.4
R3	Embankment	116166	2129	1216	-0.01	-0.5	5.5
R4	Railway subgrade	78710	1646	1495	-0.05	-1.5	18.0
R5 - R8	Topsoil	120960	1800	1000	-0.01	-0.5	20.0

4 Analysis of modelling results

During the simulations of modelling, the results were analysed from the first day of the climate load (temperatures) automatically. At all given positions, analysis of freezing of the layers were performed simultaneously with the FlexPDE module in the system SV-HEAT [2]. For visual demonstration the positions of temperature measurement "TE_5_3_-1.00m" in Fig. 5 (the spatial position is in Fig. 3) are chosen, which is located at the decisive level of the railway substructure. The results presented in the figure are only after the complete analysis of the track model.

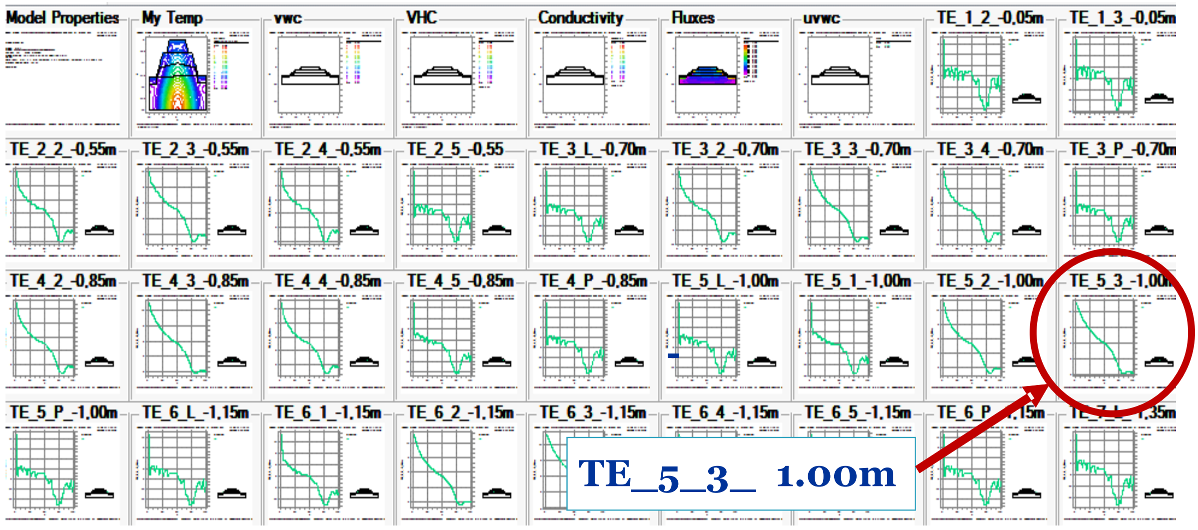

Fig. 4: Thermal analysis of the whole model and position “TE_5_3_-1.00m“ – FlexPDE [2].

In the discussion we will analyse the course of temperatures at a specific point “TE_5_3_-1.00m” (level in Fig. 3), which is located at the level of the railway substructure. In this case, we expect that the layer is not disturbed by the minus temperatures (i.e. we observe zero isotherm - 0 °C) in the railway formation. Fig. 5 shows the results of temperature analysis after all climatic loads of MODEL 1 to 5 (Figs. 1 and 2).

Fig. 5 shows that in the MODEL 1 and 2 the freezing of the formation of the railway track subgrade does not occur on this point, but in the MODEL 3 its boundary is attacked by the zero isotherm (0 °C limit). MODEL 4 and 5 show that under the given climatic loads (I_F = -600 °C and I_F = -800 °C), the layer of the embankment of the railway formation under the protective layer will also be frozen (FPL - its thickness h_{FPL} = 0.45 m).

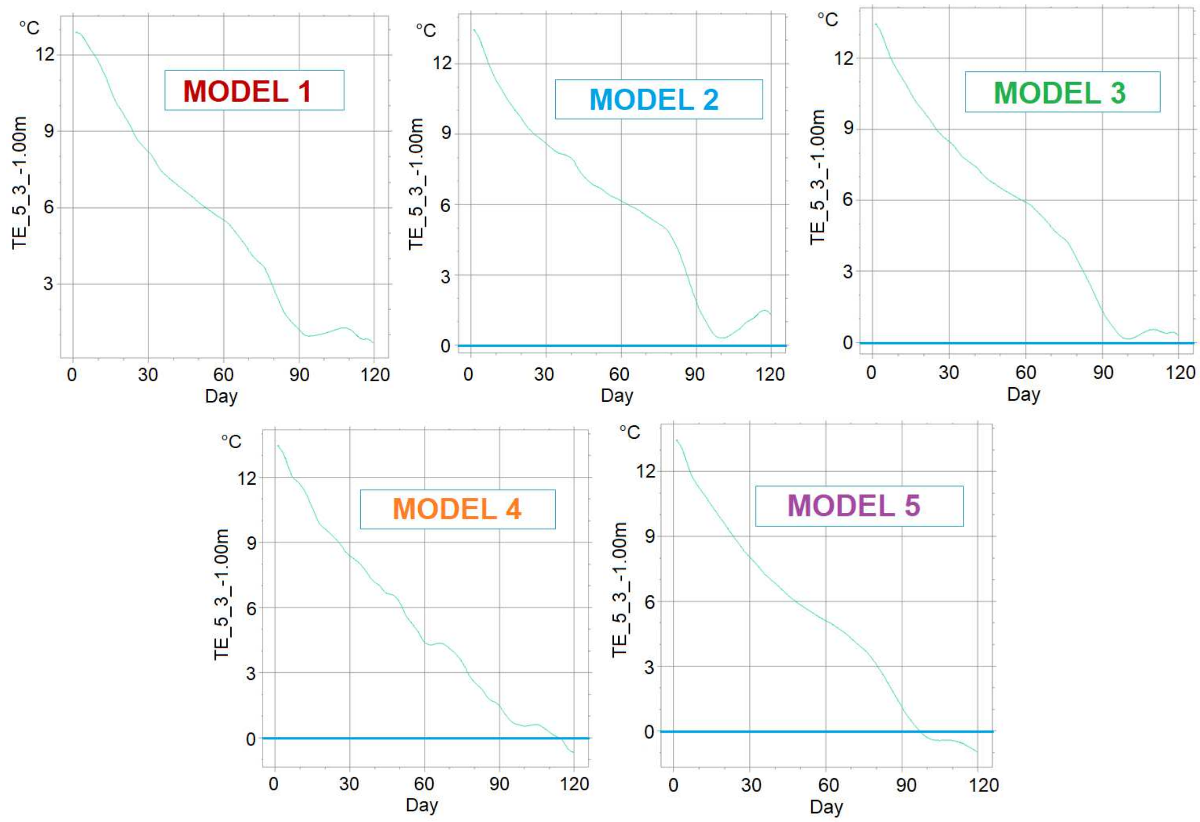

Fig. 5: The courses of the temperatures at the position “TE_5_3_-1.00 m” (Fig. 3): MODEL 1 to MODEL 5.

For this reason, it is necessary to protect the subgrade surface by adding new structural layers (geo-textiles, geo-materials, other material layers, etc.), or by increasing the thickness h_{FPL} of the current protective sand-gravel layer, to ensure the required transition of temperatures through each layer of the railway body. Otherwise, we consider them to be partially freezing or unsuitable. The main task of the research was to find the maximum depth of freezing, i.e. the position of the zero isotherm, not only check of the individual measurements on positions during the analysis (eventually comparison with the temperature values from points of practical measurements “in-situ” on real models built by our department, [4]).

5 Results of the analysis and conclusions

Track modelling can be done in 2D or 3D SV-HEAT system [2]. The railway track is a transport construction of a line character and therefore we will do the analysis in 2D in the characteristic cross-section profile, because the whole section has the same character of the composition of the structural layers of the railway formation (the track in the longitudinal direction may be composed of consecutive multiple types of subgrade). In our case, the type of railway subgrade TYPE 2 is used throughout the track stationing. Similar considerations apply to the multi-line track (linking multiple analysed views next to each other).

Basically, from the analysis of the presented climate loads of the models it results (during 120 days of the winter period) that MODELS 1 to 3 are compliant with their temperature ranges up to frost index value of I_{F120} ≤ -375 °C, where freezing of structural layers occurred up above the subgrade formation (whole railway bed and partly the protective sand-gravel layers), the depths of freezing were h_{MODEL1} = 0.60 m, h_{MODEL2} = 0.70 m, h_{MODEL3} = 0.95 m, Fig. 6.

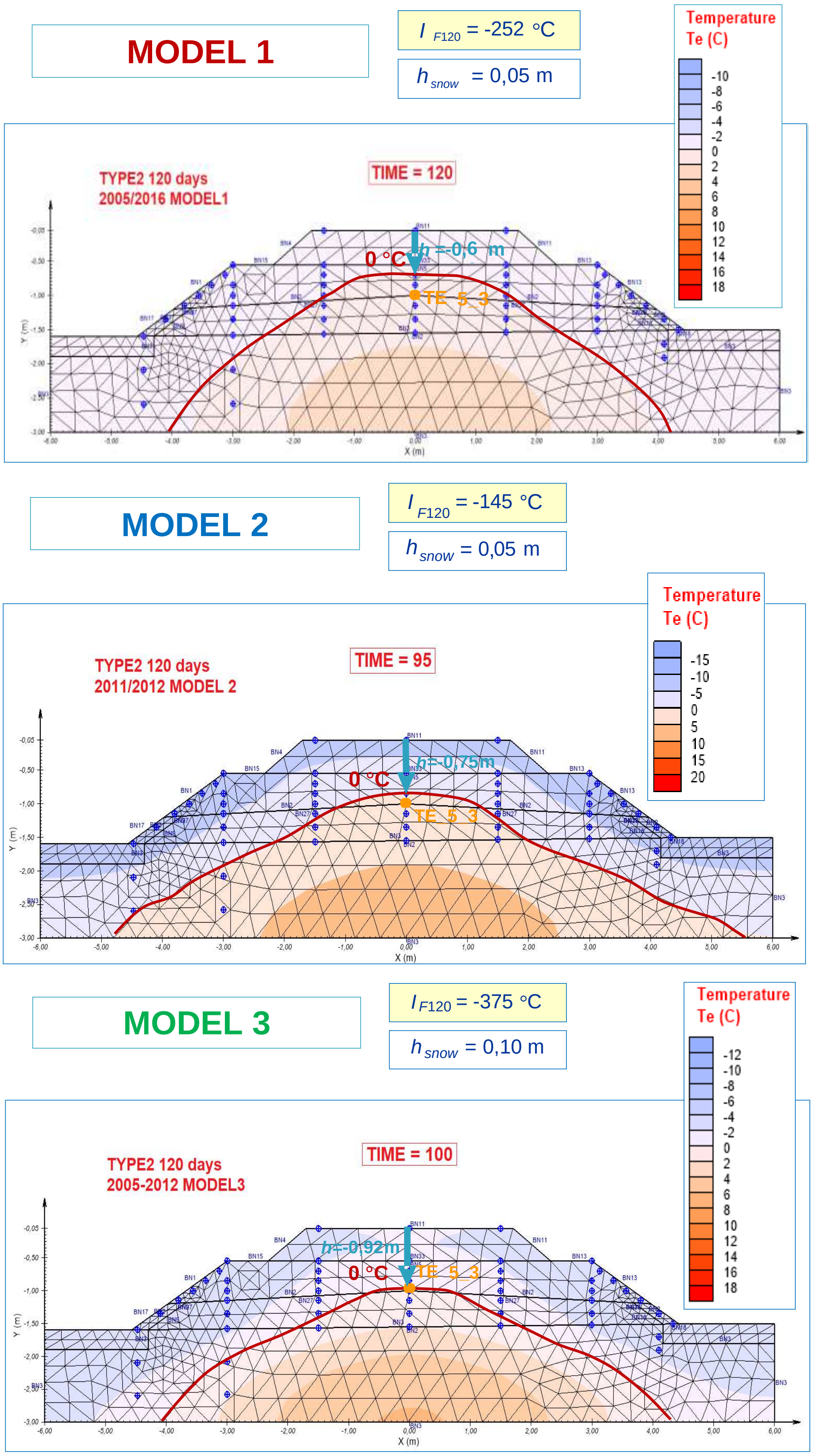

Fig. 6: Visualization of analysed results of modelling MODEL 1 to 3 – satisfactory.

Due to the effect of increased frost on structure in climate MODELS 4 and 5 with I_{Fp120} = -600 °C and I_{Fp120} = -800 °C freezing of subgrade formation occurs in the analysed position „TE_5_3_-1,00m“, which is evident in Fig. 7. The depths of freezing are h_{MODEL4} = 1.20 m and h_{MODEL5} = 1.35 m. We can consider these structures to be partially freezing, or unsatisfactory (in the future, the railway formation will require more frequent interventions in maintenance of the track geometry, i.e. increase of maintenance costs during track operations on railway track, also [9] and etc.).

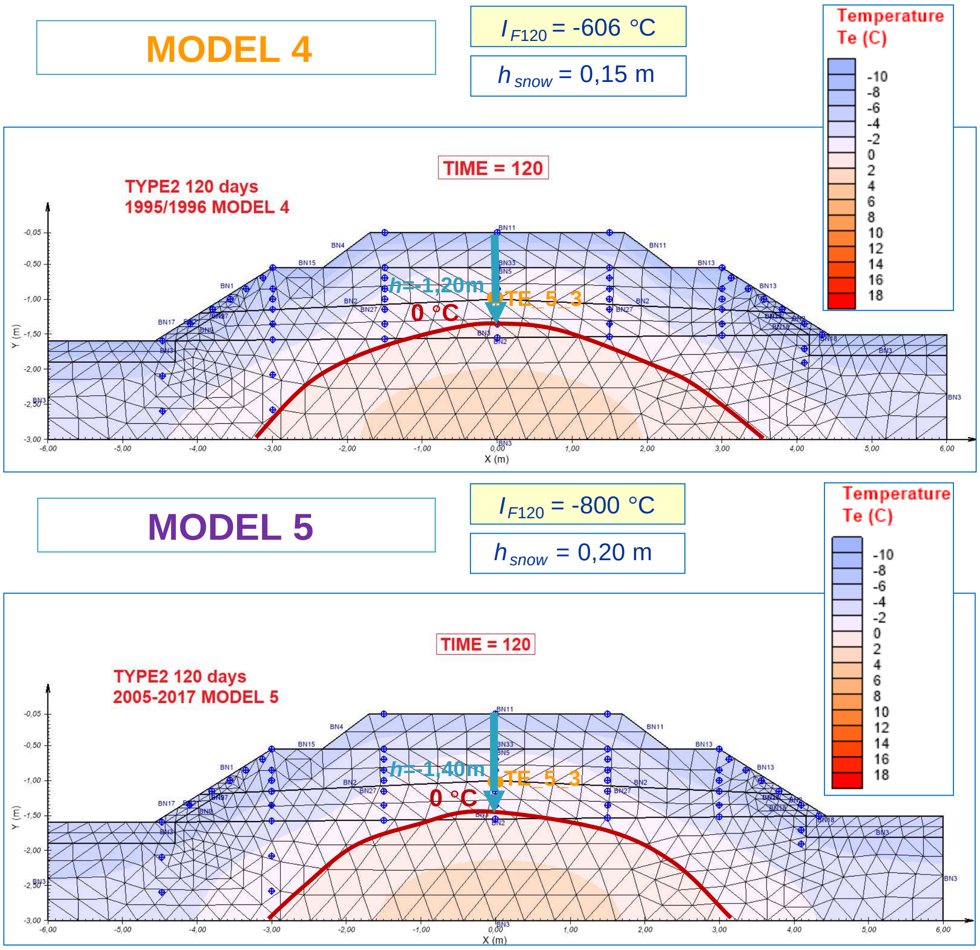

Fig. 7: Visualization of analysed results of modelling MODEL 4 and 5 – unsatisfactory.

Table 4: Depths of freezing h_F under different climatic loads.

MODEL	$I_{F,air}$	**Climatic load**	**Depth of snow**	**Depth of freezing h_F**	
				$n_F = 1$ $I_{F,air} = I_{F,surf}$	$n_F = 0.85$ $I_{F,air} \neq I_{F,surf}$
	-°C	**Climate type**	**m**	**m**	**m**
MODEL1	400	Clima1 (Fig. 1a)	0.05	0.65	0.40
MODEL2	250	Clima2 (Fig. 1b)	0.05	0.86	0.72
MODEL3	375	Clima3 (Fig. 1c)	0.10	0.94	0.78
MODEL4	600	Clima4 (Fig. 1d)	0.15 0.20	1.20 0.91	0.93 0.63
MODEL5	800	Clima5 (Fig. 1e)	0.20 0.25	1.45 1.14	1.09 0.80

In the case if the structures remained in these compositions of the layers and with the modelled thickness of the partial layers (MODEL 4 and MODEL 5 with high freezing index I_F = -600 to -800 °C), there may be deformations of railway subgrade, which also result in unacceptable behaviour of the layers above it, such as on the railway bed R1, on the protective sand-gravel layer R2, and so on. Subsequently, a disintegration of track geometry will occur (unsustainable horizontal and vertical position of the rail axis). The more the layers of the railway subgrade with the materials R1 to R4 will be deformed, the costs of repairing and reconstructing the section of the track will be increased

(Table 4). These criteria are also integrated in the standard STN 73 6360-2: 2015 [10] as degrees: AL - assessment limit, IL - intervention limit (repair), and in the worst case as IAL – immediate action limit.

On the contrary, if we increase excessively the thickness of layers (i.e. overdesign), thereby we increase the investment costs for building the new lines, the reconstruction, the modernization or building of high-speed lines. The higher is the designed track speed, the higher are the quality requirements imposed on rail formation construction, and this applies in the context of non-transport load under minus temperatures, too.

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