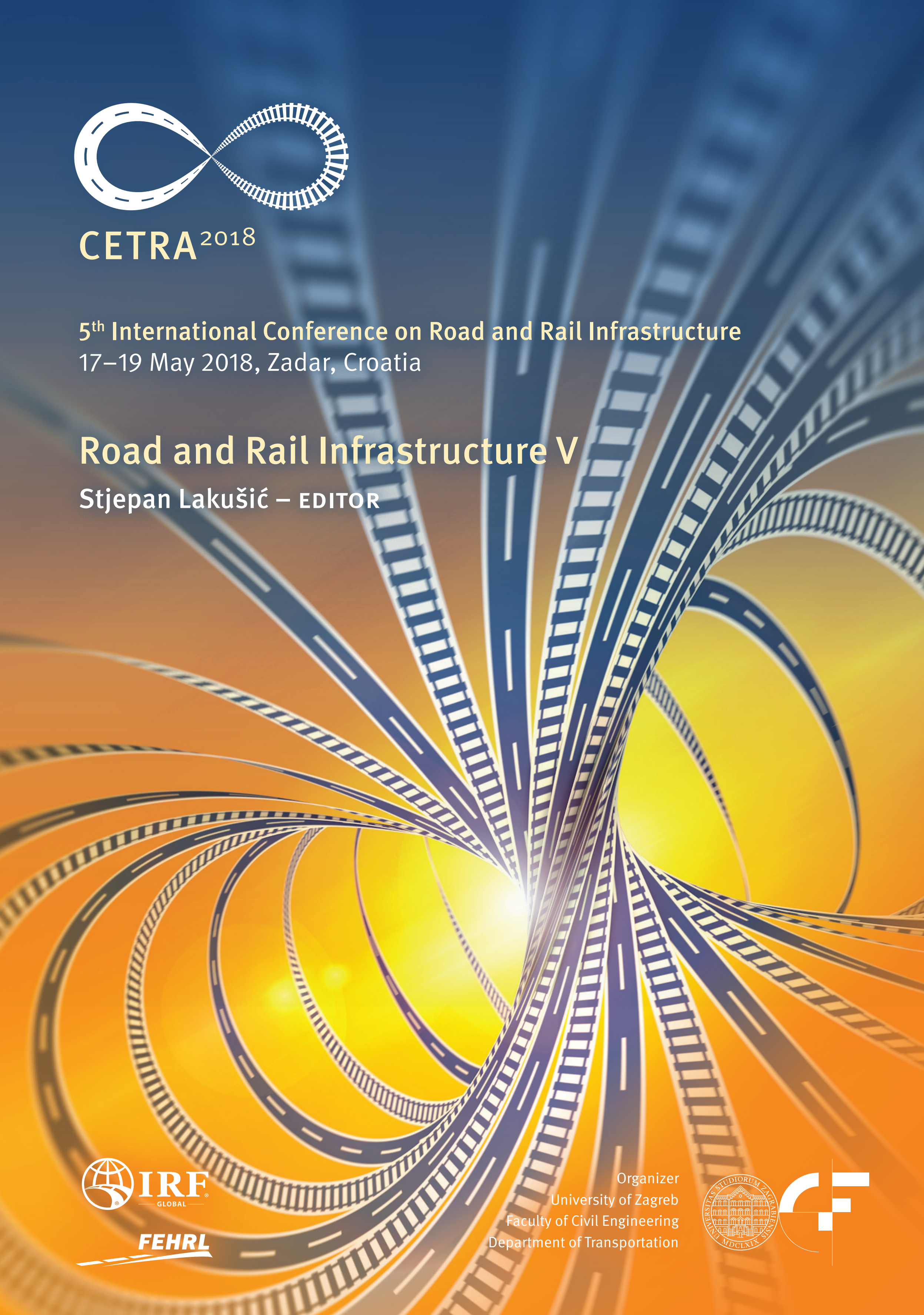

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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ISSUES OF VIBRO-DYNAMIC IMPACT ON ROADBED DEFORMABILITY IN PERMAFROST CONDITIONS

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Abstract

The paper covers some issues of safety and continuous work on railroads at northern parts of the Russian Far East. The most important issue in the trackside is providing the rail roadbed stability. The problems of certain destabilization factors and their impact are not completely solved despite a great amount of publications and standard regulations. The solutions are vital for the permafrost sections where high temperatures occur. It is necessary to eliminate the causes of destabilization promptly and to have a forecast for an assessment of the roadbed repair and maintenance costs in the conditions of increased traffic, under an increased vibro-dynamic impact on the track in particular. It is connected with temperature and humidity abnormalities in permafrost under the vibro-dynamic loads in a multiyear thawing. The most negative effect on the subgrade deformation is produced by a vibro-dynamic impact appearing from class repairs of the track carried out by the maintenance vehicles. The effect enhances during the pre-winter season. The paper covers the experiments with the maintenance vehicles that provide data to be processed in building the "vehicle-track structure-embankment-subgrade" model.

Keywords: *thawed permafrost; temperature and humidity abnormalities; ballast filling; first costs; vibro-dynamic impact*

1 Introduction

The vibro-dynamic impact produced by train traffic on the embankment has been profoundly studied in the USSR and Russia. The results are thoroughly described and widely introduced in providing the roadbed strength [1-4]. However, the features of cryogenic processes in the subgrade soils on permafrost are studied insufficiently. In particular, the processes influenced by the man-made impact such as train loading, track repair works with heavy-duty machine and other anthropogenic factors including the roadbed itself are the causes of an increasing deformability of the roadbed. The authors have been studying these problems in the Foundation Engineering Research Lab (the Far Eastern State Transport University) from 2000 to 2016. The issues are becoming even more actual in the conditions of increasing train traffic, its load intensity and speed on weak permafrost thaw sections. In particular, the deforming sections of the roadbed under survey located on permafrost and drainless marshes (Atyrkan-Amgan, Tuyun-Stlannic, the Urgal nod, Badzhal-Dzhamku) show additional deformation after a general repair of tracks with the heavy-duty machines [5-10]. The problem was shaped at the beginning of the 1990s, and it inspires the aspect of the road structures research that concerns additional causes of the subgrade soils instability on the permafrost.

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2 Research methods for the vibro-dynamic impact on thaw soils in the subgrade

In the framework of the Siberian program the Lab researchers collect the data on class repairs of the previous years on 4 sections of the Far East Railroads Co., Russia. The data processing statistics shows that 70 % of the cases confirm a supposition about a progressing sediment of weak subgrades in the followed after repairs years [7]. This fact gives the grounds for connecting the rolling load impact and the roadbed deformability because of the changes in the subgrade soil consistency. They could happen at the account of a rising temperature in permafrost that increases the soil moisture and thus leads to plastic deformations [5-7].The goals and the research program includes: 1) picking the experimental sites with the conditions relevant to the main researching objectives; 2) obtaining the field data on a level amplitude phase and the soil content changes in the roadbed subgrade; 3) surveying the permanent deformations in the subgrade soils and conducting experiments on determining the natural frequencies of the roadway and the subgrade soils for a refinement of the dynamic model in the "machine-permanent way-embankment-subway" system.
The supposition that the rolling load produces the vibro-dynamic impact is methodically shaped from the following: 1) registration of plastic and permanent deformations of the weak subgrade with a high-frequency EDM Topcon DM-S1 placed on a hard ground; 2) research of high-frequency microseisms in the roadbed subgrade with highly sensitive seismic measuring channel that proves a necessary account of the vibration impact in the energy criterion; 3) research of a transient process in the "embankment-subgrade" system in a range from long-term shifts with the periods of hours and the amplitudes of up to 10 mm to high-frequency microseisms with the periods of up to 0.002 sec and the amplitudes of less than 0.001 mm; 4) impact of different roadway machines and the traffic loading with a registration of plastic and permanent deformations of soils as well as thermal-moisture/moisture-condensate processes and pressure changes in the subgrade soil mass at different times.
A universal roadway machine of a heavy type, the track renewal train VPO-3000, is used in the research. Its technological characteristics and utilization simulate a powerful vibrator affecting the permanent way, the roadbed and its subgrade.
Thus, some issues that concern non-traditional aspects of the vibro-dynamic impact on weak, and especially permafrost thaw, soils of the roadbed subgrade are solved during the method development. They include a necessary study of thermal transformations in the "embankment-subgrade" system, assessment of a technogenic factor of the vibro-dynamic load and an assessment of the roadbed behavior on thaw permafrost soils. The main complex method of monitoring the technical system include the parameter measurements of soil vibrations, pressure in soils, temperature and moisture.

3 Research and practice results

According to a field research the VPO-3000 vibration intensity in the roadbed subgrade is 3-5 times greater than of those from the traffic. Fig. 1 shows the results of instrumental measurements of the permanent deformations development. The field instrumental measurements show that the changes of the thermal and moisture-filtering processes in the embankment-subgrade system are greatly determined by a temporary loading of the track renewal train VPO-3000. This method of researching the transient conditions of the roadbed accounts plenty parameters that help objectively evaluate the overall impact of the traffic and temporary loads during a certain period of time. In general, the method assesses intensity and help to forecast the influence of the traffic freight on the roadbed behavior.
The registration is carried out with the EDM Topcon DM-S1, and the elastic strains are received during the necessary time interval. The EDM is set up at a distance of 30 m from the embankment foot in the experimental cross-section. The observations register movements

of the light reflecting marks driven into the embankment subgrade soil. The EDM's accuracy is 3 cm/km. The essential feature of the method is a synchronous registration of vibration, temperature and moisture measurements. The temperature measurements are taken with special systems customized for the Lab researches [8-12]. The temperature sensors are placed into cylinders in the embankment subgrade to the level of thawing. The cylinders are capped to prevent the influence of the outdoor temperature. The registration is made with a special gauge by a sequential switching between 4 points of observation: 2 on the slope, 1 at the embankment foot and 1 at 5 m aside from the embankment.

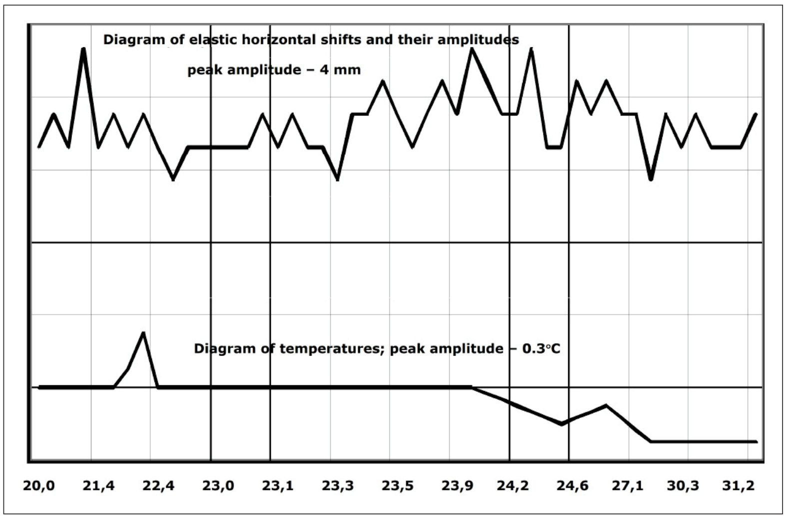

Figure 1 Diagrams of weak soil shifts and temperature measurements

The experimental cross-sections differ in the embankment height, structural dimensions of berms and their materials, conditions of the subgrade soils and hydrological conditions. However, the field researches of the vibro-dynamic impact on the subgrade and embankment soils (Fig. 2) find a consolidation of newly filled ballast prism (1) and the old prism (2); the ballast goes deeper into the roadbed as a result of its "thermal" sediment (3) together with the roadbed column (4), slope zones (5) and the consolidating mid-layers of thaw permafrost (7) in the subgrade (8). The soil mid-layers (6) appear due to the vibration energy absorption. The temperature-moisture imbalance provokes the pore pressure increase (9) leading to plastic shifts (10) and the roadbed soil sediment (11). A temporary equilibrium disturbance of the ballast lines on the slopes take place due to the subgrade plastic deformations (12) along the line of the most intensive vibro-dynamic consolidation of the "embankment-subgrade" system bearing column.

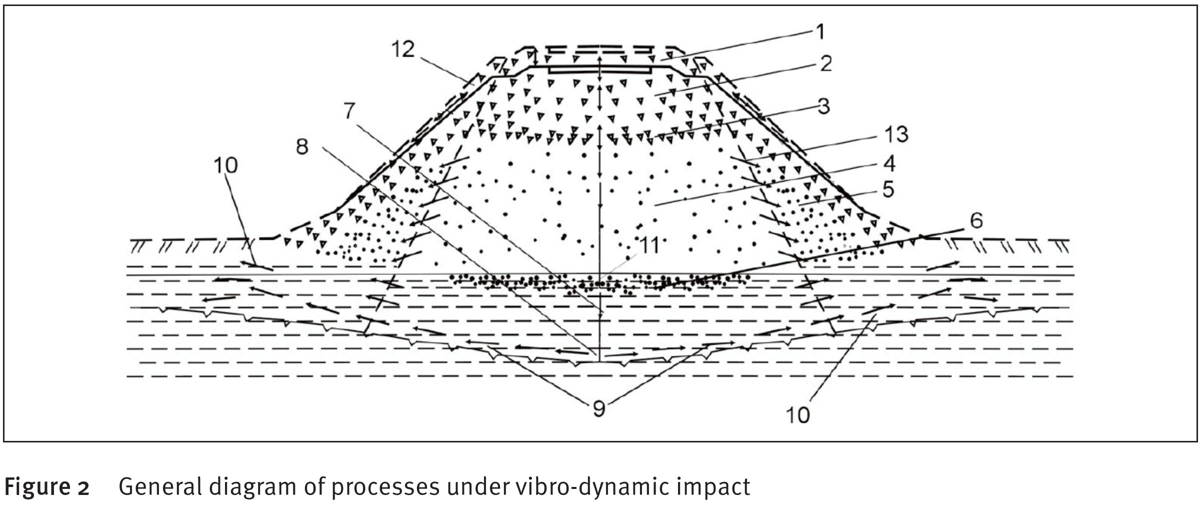

Figure 2 General diagram of processes under vibro-dynamic impact

In addition, it is necessary to note the amplitudes of soil vibro-shifts produced by the VPO-300 machine are 3-4 times greater than those maximums produced by the train traffic and 5 times greater its average level. To provide the subgrade stability when heavy track machines are at their work it is necessary to meet the following main demands: 1) the track repair with this kind of machine should be carried out in a season when the subgrade under the roadway is at its maximum unified condition of high mechanical characteristics (frozen subgrade); 2) the embankment layers to be compressed should be prone to absorbing the vibration energy (the compressing effect is maximal; the vibration transmission is minimal). In general, the problem is the borderline zones (between layers) being the areas of elastic waves reflection/refraction bear local vibro-dynamic loads. On the other hand, it is in the microzones dividing the layers where the soils keep instable. There also happens an intensive local energy absorption which is accompanied by non-elastic forces and the soil particles disruption.
The carried out researches are resulted in a diagnostic system development in a joint project together with researchers from the other company. The diagnostic mobile system is aimed to survey the soil states of the "track-roadbed-subgrade" technical system on the basis of changes in physical parameters. The main idea of the mobile system is to assess the impact and a reaction as well as the intensity of the process parameters [6-8]. The basic modification of the system, SDG-M device, is aimed to measure the parameters of soil vibration, pressure in it, temperature and moisture. The results show the effectiveness of the device. The registered vibro-dynamic process is considered as an external impact factor, train load on soil at the measurement point for example, while the soil reaction is determined on-line through the changes of its temperature, moisture and pressure. The soil pressure can be considered both as an impact or reaction factor. As the impact factor it completes the picture of the vibration process accounting the low frequency band and a relatively static periphery. As the reaction factor it represents an additional index of transformation the kinetic part of the impact energy into the potential energy of the soil reaction. The thermo-dynamic parameters received with the SDG-M device show the permafrost temperature under the berm at the end of August is below zero (-0.1 °C/-0.2 °C), the temperature of the vapor-liquid phase decreases by 0.027 °C › 0.02 and the specific conductivity decreases by 0.45 %. In general, the permafrost and the embankment itself are instable. Fig. 3 shows the diagrams of the temperature and conductivity parameters monitoring in the roadbed subgrade on permafrost.

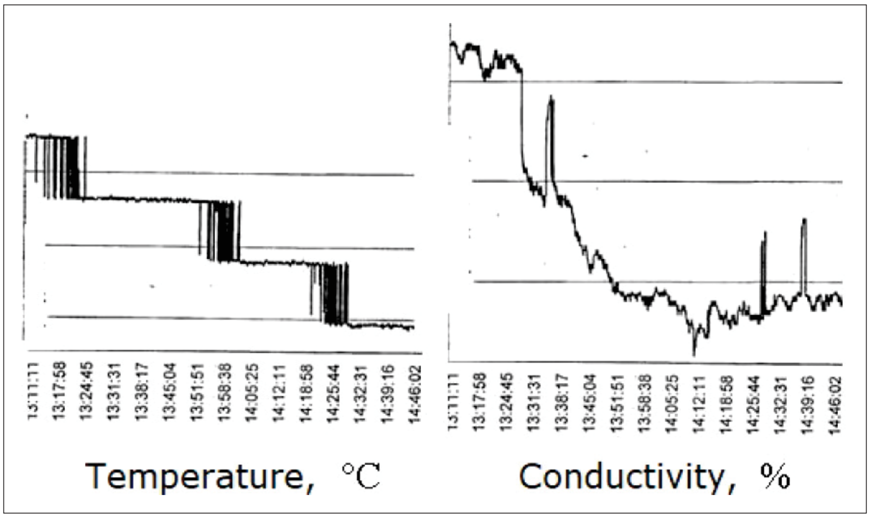

Figure 3 Diagrams of temperature and conductivity after train run

4 Calculation methods of assessment the rolling load impact on subgrade permafrost

The calculation method for the embankment stability on a permafrost subgrade is developed by the authors Gorchkov N. I. and Krasnov M. A. [13, 14] to assess an influence of an increasing vibro-dynamic load that is applied to the thaw subgrade soils. A licensed software program GenIDE32 for a stage-by-stage calculation assessment of the roadbed stability is used to solve applied problems of geotechnics in a framework of the "structure-geoenvironment" model system. This type of problems is solved on the basis of the Finite Element Method, and the incremental plasticity as well as the Mohr-Coulomb yield criterion are used to build the soil rheological model.

For a new construction the qualitative assessment of the "track-subgrade" system as far as its deformability, strength, bearing capacity and the element stability can be carried out according to the following applied scheme: 1) the calculation of the initial stress and strain state in the subgrade system; 2) consequent modeling of the railway track construction process; 3) application of the surface transport load.

The same is true as far as the system under operation. Every modeling stage includes the stress and strain assessment and analysis of the system or its elements according to the requirements of current standard regulations. The Lab monitoring data concerning location of the permafrost frost-thaw lines for the period of more than 40 years are used in modeling. The calculation modelling of a roadbed reinforcement where the permafrost thaw in the subgrade has caused deformations is given below. The cross-section schemes account the rolling stock surface loading of one rail gauge on the track formation as a strip load of 210-220 kN/m according to the requirements for the calculation of railroad track structure. As one running meter includes two sleepers, the calculation is done for the rolling stock distributed load of 110 kN/m. The load point is the sleeper's lower surface.The stability assessment results of the roadbed on the thaw weak soils at the 3163 km section is given as an example. The roadbed is substantially deformed in the process of exploitation. The main project dimensions of the roadbed cross-section are the following: the width of the ballast prism is 3.10 m, the depth of the ballast prism is 0.25 m, the roadbed width is 6.40 m, the height is 2.70 m and the ratio of slope is 1:1.5. In the period of exploitation, the ratio has changed, and a small counter dam is filled.

5 Geomechanical model of "track-subgrade" system, railway milestone 8+00 (embankment height: h=2.70 m)

According to the data of the lab research results the following types of soils can be traced in the embankment subgrade (from top to bottom): frozen peat (thawed on top); frozen peaty clay-loam (high-plastic and fluid-plastic when thawed); sandy loam (plastic when thawed); frozen granite-gneiss (thawed to the right of the enbankment central axis). To follow the track stabilization program the calculations are carried out for the system before the improvement and after improvement. The initial strain in the subgrade is determined for the system model with the exploitation characteristics of the embankment. The calculation results of applying the body forces (gravitation) and the vibro-dynamic load are shown on Fig. 4 and Fig. 5. The stability condition for both cases is k_{st} [Shn] = 1.32 › [k_{st}] = 1.20 on Fig. 4 and k_{st}[Shn] = 1.12 ‹ [k_{st}] = 1.20 on Fig. 5. In the first case the vibro-dynamic load application can result in instability of the right slope.

When the vibro-dynamic load is applied to the system with a variable profile reinforced counter dam, the system stability is k_{st} [Shn] = 1.22 › [k_{st}] = 1.20 (Fig. 6)

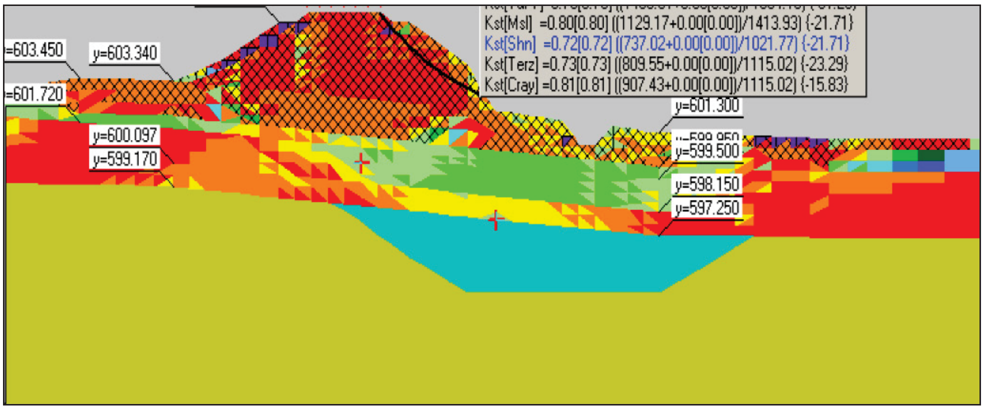

Figure 4 Results of transport loading (before improvement); k_{st}[Shn] = 1.12 ‹ [k_{st}] = 1.20

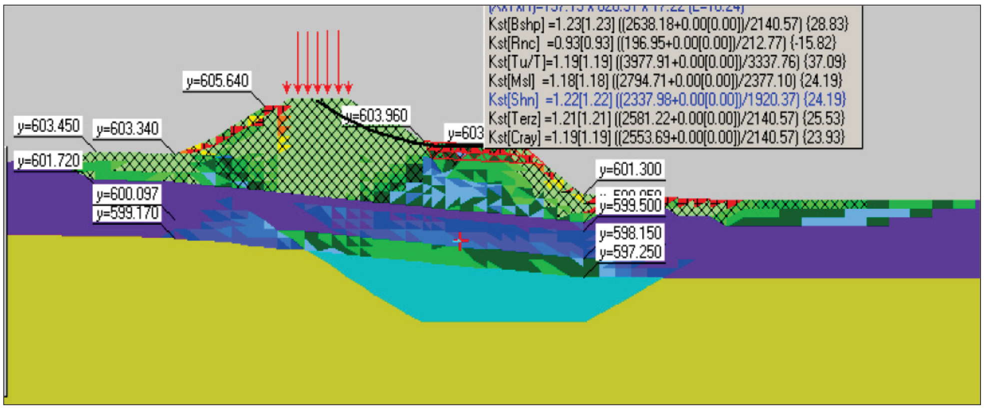

Figure 5 Results of transport loading in reinforced counter dam; k_{st} [Shn] = 1.22 › [k_{st}] = 1.20

6 Conclusions

1) The field and theoretical modeling researches on the particular deformed sections of the roadbed are confirmed by the geophysical, geological, electric-contact dynamic sound and other methods.
2) A complete picture in a time domain of elastic and permanent soil deformations in the embankment subgrade as well as the vibration, thermal and moisture processes at a sequential impact of different side track machines and train loads is clear. It makes possible to forecast and take into account additional working expenditures for planning the maintenance / repair works and their seasons / time frameworks to provide the track stability.
3) The system of soil diagnostics including the mobile devices (SDG-M) and the soil state forecast for the “track-roadbed-subgrade” developed in a joint Lab project registers at a measurement point the vibro- and thermo- dynamic parameters of soils under the outer impact and the train load. The soil reaction to the load impact is assessed by the index changes of temperature, moisture and pressure.
4) The calculation method for the embankment stability on a permafrost subgrade is developed to assess an influence of an increasing vibro-dynamic load influencing the thaw subgrade soils. A licensed software program GenIDE32 for a stage-by-stage calculation assessment of the roadbed stability is used to solve applied problems of geotechnics in a framework of the “structure-geoenvironment” model system.
5) The Foundation Engineering Research Lab (Far Eastern State Transport University) has the monitoring data concerning location of the permafrost frost-thaw lines at different projects and different stages of their exploitations that are used in modeling of structures on permafrost.

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