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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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PROBLEM SOLUTION FOR EXPLOITATION OF ROAD STRUCTURES AT THE RUSSIAN FAR EAST NORTHERN AREAS

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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 Baikal-Amur Mainline (BAM) and Amur-Yakutsk Mainline (AYaM) in particular. The permafrost-bound problems of a railway construction and operation are described. The aim of the research is to find the solutions for a stable work of railroads in the conditions of increased freight traffic and a growing road deformability. Some experimental sections on the above mentioned roads are determined after the monitoring observations, and new reinforcement structures are installed. The solutions are offered taking into account the causes of the problems. The problems that cause the increased deformability are solved with a combination of traditional and new methods suggested by the authors who also offer the devices invented to do the research. Some of the authors' developments for the subgrade stabilization in the frost heave, thermokarsts, polygonal-veined ice formation and aufeis conditions are given as they are applied at real working projects. The reliable work of the reinforcing structures for 10 to 18 years and more proves the effectiveness of the solutions. The authors' 30-year experience of survey, monitoring and software development for the areas with above mentioned problems can be useful for the specialists working in the similar conditions.

Keywords: exploitation problems; roadbed; causes of deformations; cryogenic process; theoretical substantiation

1 Introduction

The ways of problem solutions for construction and exploitation of the roadbed in the severe conditions of northern areas in the Russian Far East are updated every time in cases of a perspective increase in density of freight traffic, a transport infrastructure development, or a construction of a new project in similar conditions. It is directly related to a large-scale program "The Strategy of the Russian Federation Railway Transport Development (2030)" adopted by the Russian government [1]. The strategy forecasts an increase in traffic on the Baikal-Amur Mainline (BAM) and a completion of the railway line to Yakutsk. The growth of industrial production as well as a development of transport nodes adjacent to the Pacific coast and some mineral deposits in the area are considered perspective. The increased traffic requires a development of railway infrastructure including not only reconstruction of the existing lines, but also a construction of the new ones [2]. However, the task seems a great challenge in the northern areas. The absence of industrial production, fundamental infrastructure units and social conditions for workers are accompanied with a low density of lines (5 km per 1,000 sq. km). Vulnerable natural conditions (almost 80 % of the Russian Far East territory is located on permafrost) influence the deformability of all the structures during their whole life cycle and create difficulties in transport development of the region [3-7].

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The Baikal-Amur Mainline was put into operation more than 30 years ago. For two following decades the roadbed had not been maintained properly that consequently led to a considerable water encroachment to its subgrade. The roadbed water encroachment caused the permafrost degradation, and its line achieved the depth of an active zone, that is 10-12 m. The permafrost degradation was accompanied by the roadbed deformation, long-term and uneven subsidence. In these circumstances, the underground base runoff was disrupted (on the sides the permafrost line remained the same, while in the subgrade the thawing basin appeared). So, a deformation type has changed, and now a mechanical suffusion is prevailing [7-10]. The process has been observed, and the authors conducted field, laboratory and theoretical researches during this time period. The monitoring investigations are organized on the 7 BAM sections and 5 sections of the Amur-Yakutsk Mainline (Berkakit-Tommot-Yakutsk). On the results of the research work some constructive and technological solutions have been developed, patented and introduced. These new practical achievements have been applied at about 15 projects. Nine of them have been introduced on the BAM and the Amur-Yakutsk Mainline as a complex solution of the roadbed reinforcement that meets the aim of the research. The section of 115-116 km of the Yakutsk lines has been under operation for 12 years, and its reinforcement is described in the paper. The methods of theoretical monitoring are developed, the causes of deformations are determined and new solutions are offered on the data base received in the field research of the real projects. The field and laboratory check studies prove the effectiveness of the carried out measures and an appropriateness of the reinforced roadbed design as well as the programming theoretical approach.

2 The theoretical and practical background of the research methods.

Some results of the preceding to this project long-term researches are taken as a theoretical calculation basis to develop technological and design solutions for the roadbed reinforcement in the places of frost-thaw sinkholes on the section of the Amur-Yakutsk Mainline (115-116 km of the Oganyor-Tayozhny section). The researchers are carried out in two different directions. The main direction that has formed a theoretical basis is connected with the frozen ground studies. They include the processes and phenomena taking places in weak soils, the mechanisms and triggers of permafrost thawing during the roadbed construction. The natural climatic phenomena, moisture filtering and vibro-dynamic factors has also been taking into account as producing a destructive effect on the geotechnical system “the roadbed-its subgrade”. The researches are carried in the field and the laboratory setting with the help of both common and specially developed methods and monitoring devices [7-9]. The common monitoring devices for a soil condition research include surface marks, thermometric borings and sediment gauges. The borings are done into certain cross sections of the roadbed body at the depth of 10-12 m with hermetic cap cylinders (Fig. 1).

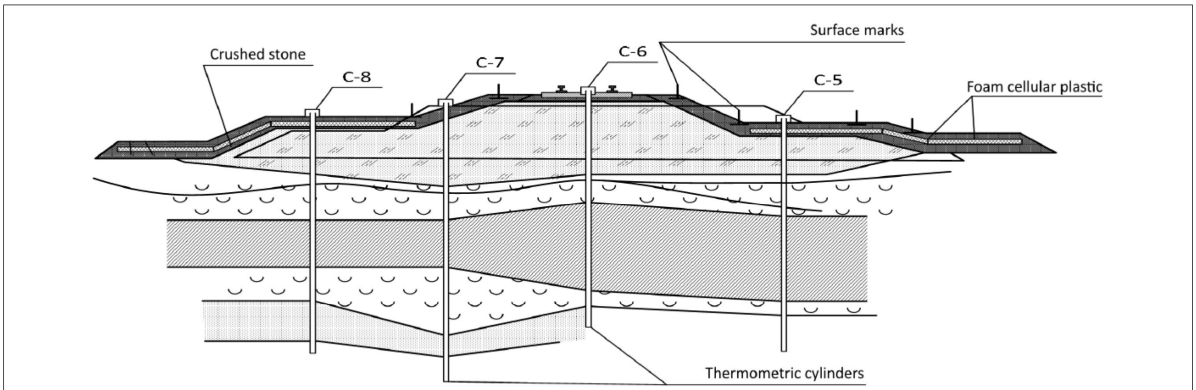

Figure 1 Surface marks and thermometric borings in experimental cross section

Fig. 2 shows an intensity decrement diagram of a roadbed deformation in a high-temperature permafrost for the soils of different thermostability (1 category – stable; 2 category – unstable, slightly deformable; 3 category – unstable, deformable; 4 category – unstable critically deformable; 5 category – damage stability. The data are given as a result of multiyear surveys. The method of temperature regime survey in the borings using strings and gauges is used to trace the dynamics of temperature changes in embankments and their subgrades. The measurements and the level survey are carried out according to a research program at the appointed periods: monthly in the first 3 years, then twice a year in spring and autumn. The results of the temperature measurements reveal the dynamics of the seasonal processes that take place (Fig. 3).

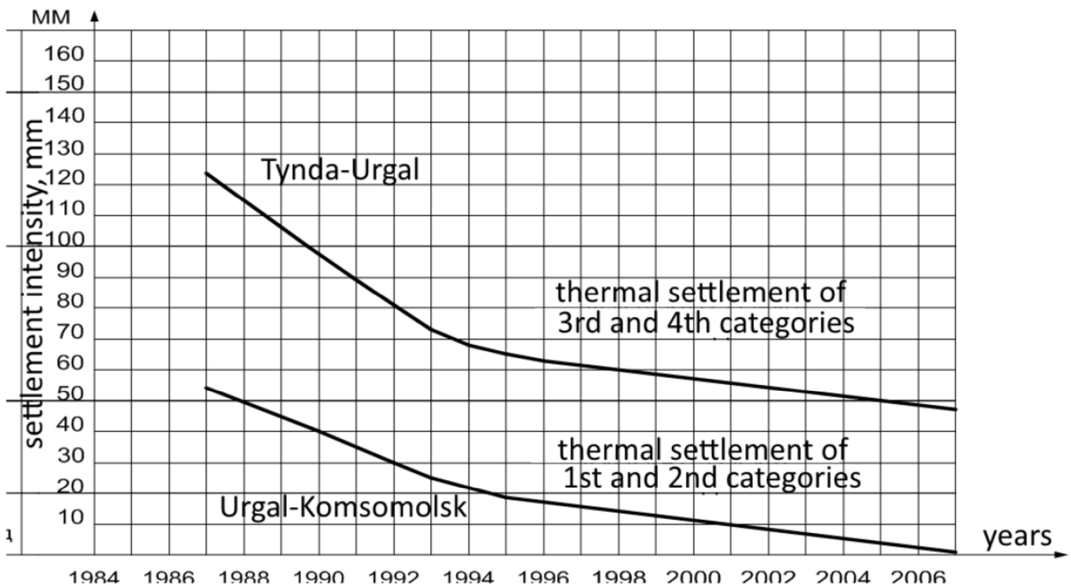

Figure 2 Intensity decrement diagram of embankment deformation on BAM, Tynda-Urgal section

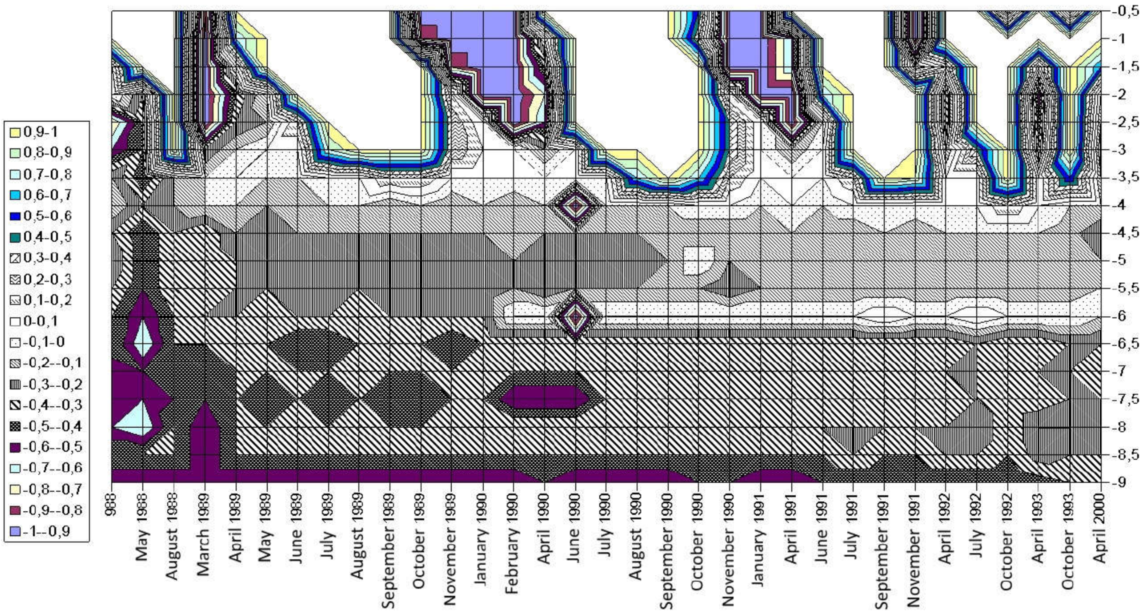

Figure 3 Temperature measurements analysis in a multiyear cycle (shows the authors' method of the 3D).

In addition, the research of frozen soil processes includes another common method of determining the permafrost line – the method of dynamic and static penetration tests. These works are done to control the regime survey of the permafrost location and to determine the permafrost line in the experimental cross sections where the thermometric cylinders are not installed. Thus, all the above mentioned measurements are done before 2003.
Besides the common ways of research, some special methods of physical modeling of processes in soil are used in particular for the lateral horizontal and oblique movements of weak soil in the embankment foot zone (plastic deformations). The shift meter, a devise to measure displacements, is designed on experimental sites. It is patented and introduced on the working projects at the BAM including the considered site at 116 km. The total number of the shift meters installed is 13, and their observations considerably increase the accuracy of the research adding more parameters to a seasonal deformability research in multiyear cycle. The shift meter is included into the Technical Standard Regulations. Fig. 4a shows a graphical chart of the shift meter's plate displacements. Another device, an experimental design of mobile diagnostic system for weak soil subgrades, was developed in 2001-2004. It has been using to conduct on-line experimental and theoretical researches of thermal and humidity conditions of the roadbed subgrade. The recent years researches have helped make the physical model of appearing and developing additional cryogenic deformations in the roadbed and embankments on weak soils more precise including the permafrost thawing under vibro-dynamic loading (Fig. 4b) [8, 9].

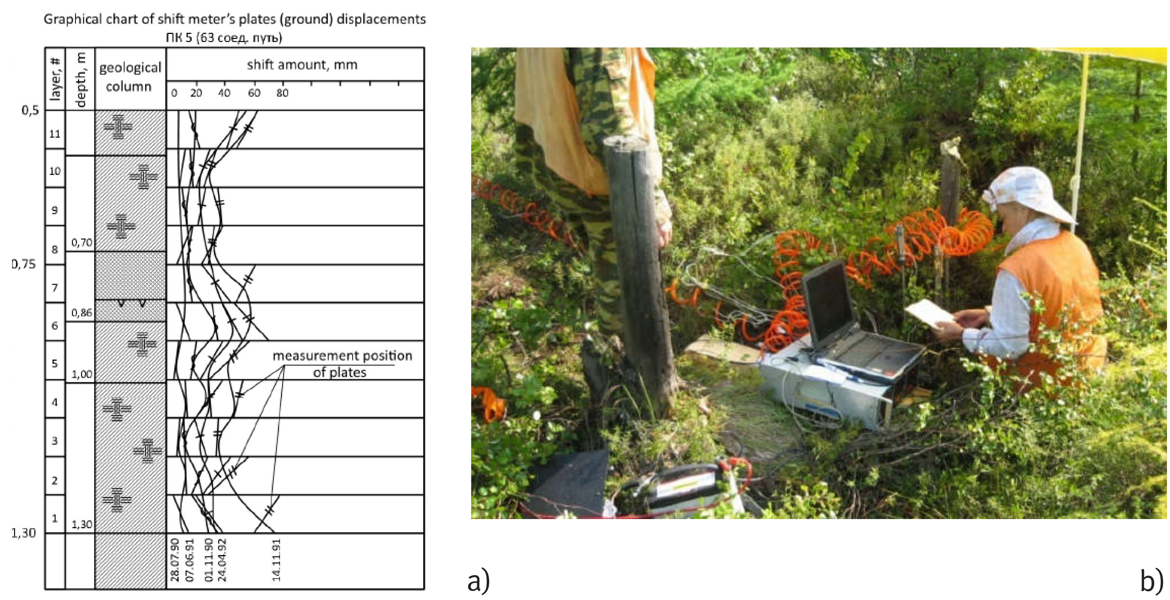

Figure 4 a) Graphical chart of shift meter's plates displacements; b) Permafrost thawing diagnostics on site at vibro-dynamic (train) loadingwith mobile system.

The practical direction of the research is connected with the influence of introduced and patented technologies and structures on the system stability when soil thawing and the subgrade sediment occur. On the basis of these researches the developed structures are tested in real conditioned at the experimental sites. The physical modeling is individual according to a task set. Along with this a complex of thermal isolation measures for the roadbed structures, nonwoven fabric and soil reinforcing compositions are tested.
Thus, the multiyear natural and laboratory researches revealing the character and parameters of the processes and phenomena have resulted in the methods and theoretical substantiation of strength, bearing capacity and stability of a geotechnical system. The complex of new calculation methods for reinforcing structures is created [10].

3 Research and practice results on providing the roadbed stability in the conditions of permafrost and cryogenic deformations.

The solution of the project task on a substantiation of the roadbed reinforcing measures at 115-116 km of the Oganyor-Tayozhny section (the Amur-Yakutsk Mainline) is carried out on the basis of qualitative assessment of the bearing capacity, strength and the stability of the “roadbed-subgrade” geotechnical system and its elements. The calculation assessment schemes of the stress and strain condition of the existed system and its elements are used taking into account the accepted designs. The first scheme is used to find out the karst-forming processes, while the other is used to find out the bearing capacity and stability, i.e. the given strength, the soil bearing capacity and the system stability [11-12].
The sequence of the actions is the following. First, the calculation schemes are used for carrying out the model task solutions considering the impact of the main external factors influencing an interaction of the system elements and the subgrade (Fig. 5a).The calculation is carried out for the safe zone of 3.2 m, while making it thicker can lead to a total destruction of the whole roadway. The calculations done prove the zone insufficient without additional measures, because in case of a crack the factor of safety becomes k = 0.84, while the norm is k = 1.25. The soil condition above the crack’s cave is at its extreme limit that provoke a collapsing sinkhole (Fig. 5b).

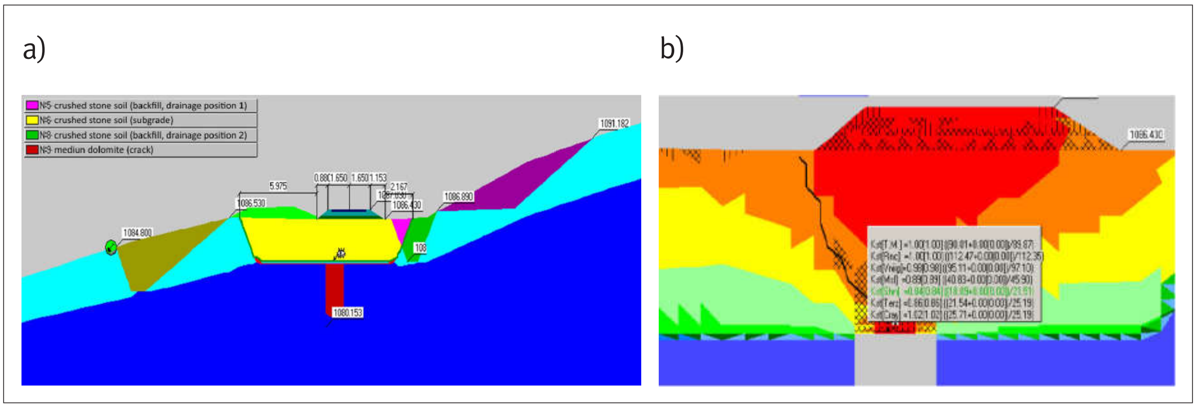

Figure 5 a) Geomechanics model of “track-roadbed” system; b) Modeling results of an open through-thickness fissure of 1.0 m wide at $k_{st}[Shn]_{min}$ = 0.84<$[k_{st}]$ = 1.20

To realize the project solutions and provide an operational safety a variant of a small alternative way around is suggested. The new operation way is possible after a reinforcement of its subgrade and the roadbed filling. The point is that it is possible to reinforce the alternative way subgrade at a continuous traffic. To provide the stability of the subgrade the geogrid of the SS30 type is used for the reinforcement. The geogrid installation lessens the soil layer up to 2.0 m and provides a necessary coefficient (Fig. 6).

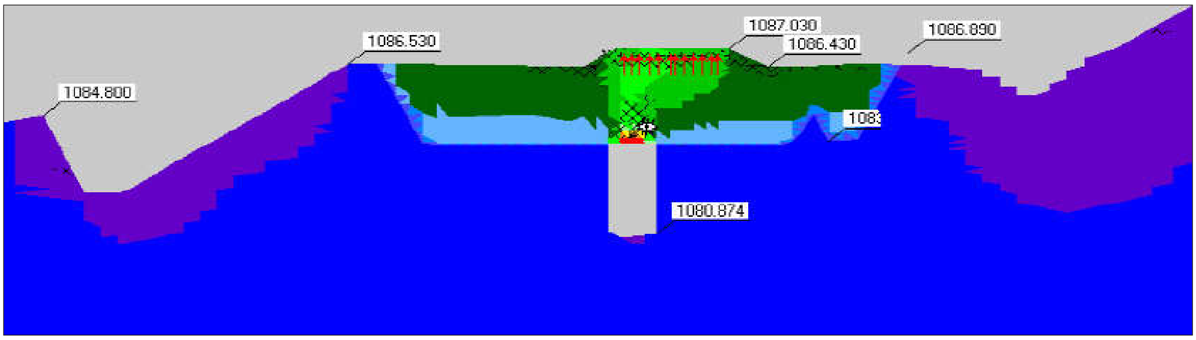

Figure 6 Modeling results of applying train loading to reinforced subgrade of roadbed

When applying train loading, the soil above the dome comes to its limit state, and the geogrid material is completely tensile N_{max} = 29 kN/m which is quite below its limit of N = 40.0 kN/m. A protecting drainage with a watertight barrier and a thermal isolation against the outer air (Fig. 5a, green on the left) is arranged to catch the underground water from karsted areas and remove the suffusion.

It is set up along the new way axis from a high end and on the side ditch axis from the right side of the subgrade. The calculations prove that in this case the necessary roadbed stability is provided when an open through-thickness fissure of 1.0 m wide occurs. A tenacious and flexible fixture of clay soil armed with a mineral composition mixture is set up to provide the strength and prevent an overwetting in the roadbed soils. The fixture is additionally armed with a geogrid which is laid with a gradient of 0.03 in the field direction.

Thus, the safety zone supported by the reinforced subgrade provides the necessary nondestructive stability at the operational loads [13].

4 Conclusions

The multiyear researches carried out by the authors in the northern parts of the Russian Far East include the traditional and developed methods, programs and diagnostic devices, for a design-basis justification of the technical solutions. On the basis of the research data some new solutions for elimination the causes of continuous deformations in the roadbed and its stabilization are found, patented and introduced as 15 new structural designs on the BAM and the AYaM. The researches carried out with the designed mobile diagnostic system and software help specify the physical model of appearance and development of different kinds of the roadbed deformations on a thaw permafrost under the influence of natural conditions, overwetting and vibro-dynamic loading.

The results are proved by providing a continuous and non-failure traffic after applying the reinforcing measures on the BAM section with termo-and-karst formation. All the measures have proved their efficiency from 8 to 18 years.

The field researches on the BAM conducted in 40 years after its construction and on the AYaM after 30 years confirm the 70 % of permafrost has lowered to the active zone depth (10-12 m). The cryogenic problems such as aufeis, heave, suffusion and others are characteristics of the roadbed zone, while on both sides of it the permafrost works in ordinary regime.

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