Innovative Solutions for Roadbed Reinforcement on 303-331 km of Adnikan Detour at Bureya Reservoir

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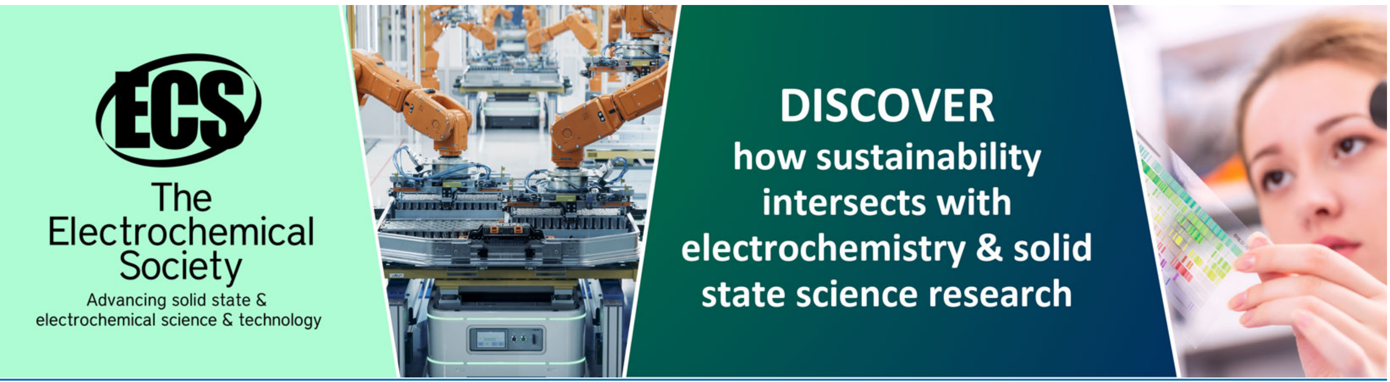

Innovative Solutions for Roadbed Reinforcement on 303-331 km of Adnikan Detour at Bureya Reservoir

S M Zhdanova[1] and O A Neratova[1]

[1]Far Eastern State Transport University, Khabarovsk, Russia

Abstract. The role of innovative technical solutions that are both effective against roadbed deformations and ecological friendly is at rise for new road constructions, renovation of current roads, the Baikal-Amur Mainline (BAM) and Yakutian Mainline (YM) in particular. The task is complicated by a perspective increase of heavy trains and ongoing climate change that must be taken into account for the roads on permafrost and ice-bearing soils. The author's experience shows the effectiveness of "natural process assistance" approach in solving the above mentioned tasks [1]. The technical solutions are aimed to be economically reasonable, easily producible and adopted in different conditions.

1. Introduction

To solve the sophisticated tasks put forward by the government for the industry it is necessary to obtain a set of information for ultimate and long-term solutions for roadbed exploitation on permafrost. It requires a development of complex measures covering a systemic-functional approach to diagnostics, long-term forecasting, an analysis of current, prospective and developed designs and technologies that can be patented and used. This complex must comprise all stages starting from project feasibility study and include all stages of projecting and exploitation to emergency situations. The multifunctional tested stabilization methods that are theoretically and design confirmed should be taken into account when developing the complex of measures [2].

Two basic documents, the Russian Federation Transport Strategy 2030 and the Presidential Address to the Federal Assembly "On national objectives and strategic tasks for the Russian Federation development 2024" pose the challenges for Russian scientists and engineers, that is to develop the infrastructural complex of Russian rail roads and to bring the Northern Latitudinal Railway and the Far Eastern Railway Vostochny Poligon to the ten top companies according their achievements in this aspect.

The permafrost roadbed operational data and multi-year researches carried out by the engineers of FESTU confirm that the roadbed deformations on poor run-off sections are directly relevant to the drainage malfunction or insufficient number of discharge facilities [3,4].

However, the ultimate complex of environmental protection measures connected with the rail road construction must provide both rational utilization of water and earth resources and stability of engineering structures during their construction and operation.

The challenges of transport development in uninhabited northern territories are the following:

- demographic problems, absence of industries and territory unsettledness;
- absence of infrastructure and social conditions for workers;
- labor intensity in both construction works and data collecting (model input) for projection that must provide long-term and safe traffic operation;

- ignoring scientific research results;
- vulnerable character of natural environment (underground icing, permafrost degradation, thermakarst, etc.) and ignoring of nature conservation measures that are necessary to provide for a rational utilization of water and earth natural resources as well as stability of engineering structures during their construction and operation.

Nowadays, Russian Federation has the lowest index of road density among industrially developed countries which is more true for its northern territories, 5 km of rail roads per 1,000 sq.km [5] .

The roadbed loses its stability mostly due to heave-icing or suffusion deformations in adverse natural and climatic conditions, engineering geological conditions and freeze soil conditions.

The soil filtering deformation is soil structure decomposition up to its complete destruction that takes forms of suffusion, uplifts appearing under the influence of the hydrodynamic pressure at forced flow of underground waters. It is determined by the virtual slope and a ratio of soil fraction volume and its diameter.

Consequently, certain projecting nature conservation measures are necessary to be planned on the basis of multi-optional calculations and freeze process forecasting for construction and exploitation of railway engineering complex on the target area of development.

It is also obvious that the track is built on a specific ridge-and-valley topography characterized by a high seismic activity and is operated in the adverse nature conditions changing over time, such as permafrost degradation, geological changes and highly varying hydro-geological conditions. These factors contribute to development of different soil physical and geological processes.

The problem of road exploitation in adverse frozen soil conditions is their long-term deformability. For example, this index on the Baikal-Amur Mainline railway keeps average at about 33% from 1990s; the same figure is true for the Amur-Yakutia Mainline.

The main reasons for the embankment long-term instability are:

• defects in designing that do not meet the requirements for water discharge facilities on a great number of sites. The original designs for catchment-basin combination, barrier elimination, etc., lead to geofailures;

• water-bearing ground as the drainage maintenance and regulation structures are generally neglected until their noticeable malfunction; the ground waters are taken into account when ice or aufeis mound has appeared;

• disproportion of rail- and automobile road coaxial alignment as well as absence of common surface design between the roads provoke hollows that eventually are filled with waters, and consequently undermine temperature humidity conditions in adjacent areas and the structure bases;

• when eliminating deformations, the effects are in the focus rather than causes;

• the problem of different diagnostic methods is in variable interpretation of data;

• the technical standard base is not updated making the regulation weak; the BAM, a leader in fighting with permafrost deformations, has the same technical standard base that dates back to the beginning of the road construction time, 40 years ago;

• ignoring the results of scientific research; absence of the industrial standards for design solutions on permafrost results in a single-option designation of anti-deformation measures. Thus, a database of innovative developments that can be patented is necessary.

2. Modern approach to solutions for problems of roadbed exploitation on BAM

The researches of the last decades have detailed the causes of deformations in the roadbed on permafrost. This data helps develop complex stability measures that find their application on the BAM and the AYM and many are patented.

It is obvious that the main cause of line structure instability is water invasion and overwatering of the territory where the structures are located.

From the experience of FESTU engineers, the problems of roadbed reinforcement can and should be solved with the perspective of the “nature facilitative approach” the solutions of which have already been introduced:

- the roadbed designs that cause minimum changes for the freeze-soil and hydraulic conditions characteristic for the construction site;
- the design structural elements that are made from the materials and the characteristics of which can control freeze and hydraulic processes in soils of the roadbed in the territory. These materials are rocks, highly organic and clay soils, and others of the same kind that can be used for slope paving or layers of different thickness in mass of the embankment;
- smaller size of water discharge facilities, and preference of cross drainage to longitudinal ones; on the sections where marshes are adjacent to frozen slopes the longitudinal drainage is located minimally 5 m away from the slope foot.

The basic principles of rational utilization of the construction development site on permafrost are transformation of landscape within balanced thermoregulation; targeted stabilization of engineering and geological processes, frozen ground in particular, in the embankment of earth structures and adjacent areas; and minimize capital and maintenance cost.

Natural process of the embankment stabilization on permafrost goes on very slowly. From observations of experimental embankments, we know that the talik zones appear after 13-25 years in soils of third and fourth categories of thermal setting. In the Zabaikalye Territory and the BAM, the bottom line of the talik zone is formed 3.5-5.5 m deep from the day surface when the embankment is 1.5-4.0 m high. The talik is a healing transition layer rectifying or damping the temperature regime between permafrost and engineering structures. The thermophysical calculations for the structures of more than 20 years under operation must take into consideration the influence of the transition layer, talik, on further thermodynamic equilibrium in hydro-technical structures [6].

The most vulnerable areas are at the foot of the embankment. The heat loss in soils is considerably less there than in the embankment itself. After the talik zone has been formed, the moisture pressing-out from the subgrade and the plastic extrusion of weak soils take place in a thaw layer between the seasonal freezing and permafrost.

The thermodynamic equilibrium takes place in the hydro-technical structure after 20-25 years of the embankment filling and provides the best condition for a road innovation (second tracks, double-track inserted sections, etc.) without a harmful effect on the embankment of the first line. The period of stabilization can be enhanced through the temperature regime control. For example, cooling and vented structures or heat-insulating designs can be used for this purpose.

The thermodynamic equilibrium is usually broken due to the absence of small artificial structures at the places where the roadway crosses small ravines, hollows and coning surfaces These sections with a small longitude inclination (less than 1%) are usually characterized by a malfunction of longitudinal drainage facilities located along the embankment.

When the discharge facilities do not work properly, ground and surface waters run off to the foot zone along low sections of the relief, such as an outlet of gulley, hollow or deep pressure sink. In summertime, water goes through the roadway freely without a considerable impact on a solid state of soil mass. The time of temperatures below zero is a period when water-thermal regime is disrupted due to uneven freezing of foot zones and narrowing of water-course cross-section that is characterized by a forced flow.

As a result, usually at the beginning of November, at the places where a road comes over gullies, hollows or deep pressure sinks, on the one hand the soil particles are taken out from draining soil of the roadbed and subgrade; on the other hand, when the foot zone of the roadbed is completely frozen, the hollows in the roadbed are filled with water which freezes and expands in volume, thus producing heaves and icing mounds (injected ice) in the roadbed. In spring, the opposite processes, such as soil collapses, funnels of collapse, slope washing-out, etc., take place. This makes an earth structure to deform [6].

All these phenomena are of a little prediction and jeopardize safety and continuous train traffic.

Therefore, it is evident that some complex solutions that eliminate the causes of the above mentioned deformations in the embankment simultaneously are necessary as all of them are connected with the causes of one origin.

Thus, the results of the research are important because knowing the causes of deformations on permafrost, their amount and a period of existence can help to develop anti-deformation measures and documentations for their introduction in the northern areas.

New materials including the geosynthetic ones have been used recently to provide new technically designed and economical solutions.

On the basis of carried out multi-year researches, the following conclusions are made: restoring the thermodynamic equilibrium in the earth technical structures depends on many factors, such as natural climatic, vibro-dynamic loading and others, that cause a long-term settlement of soil. In particular, the direct correlation between certain types of deformations, e. g. heaving or roadbed settlement, and natural climatic areas of their occurrence is found out, Besides, the selection of anti-deformation measures should take into account the principle stabilization mechanism of the geotechnical system "roadbed-subgrade" and provide its fast stabilization. In addition, justification of design choices should be based on vibro-dynamic loading as an inevitable and negative factor for the geotechnical system, that is supposed to increase with the traffic capacity rise in the conditions of heavy-freight traffic and possible road renovation (double-track inserted sections, side tracks, etc.).

For the period from 2012 to 2014, the testing computer-aided point APM-01 installed on Bestuzhevo Station registered that the subgrade soils on permafrost had undergone the following considerable changes for a 30-year period of the road operation [7]:

- the temperature in the subgrade soils keeps permanently above zero at the depth of 12 m;
- the permafrost remains in unchanged conditions beyond the embankment area from the field side;
- the level and direction of ground-water runoff change;
- the soil grain size in the subgrade changes.

The environmental protection measures must include a complex of administrative, designing and technological solutions.

On the sections of frozen floury soils where the longitudinal gradient is greater than 0.04, the side ditches must be reinforced immediately after construction to avoid gullying. Free water discharge must not be allowed at these sections.

To eliminate the causes and prevent prospective roadbed settlement it is necessary to provide the runoff from trapped sections in adjacent areas using water discharge. Repairs of existing water drains should be carried out applying new technical solutions. The places of filtering can be equipped with drainage slots or cross-section berm filling according to FESTU patents.

3. Development of environmental protection measures to control the stability of roadbed and adjacent territory

The roadbed structure depends on the grade line that marks the top of the subgrade relative to its slopes and the original ground along the center line according to horizontal level in the area.

Deformations in the roadbed occur in the following conditions:

- unsatisfactory response to rolling stock operation due to the soil capacity of the existing permanent way;
- unsatisfactory protection of roadbed soils from the impact of climatic, engineering and geological factors, such as slides, mudflow or flooding.

According to the position of structural elements, the railway line can be divided into the following types:

- embankments, when the roadway is made by filling at places lower than the grade line, and the height of which is increasing at bridge and viaduct approaches;
- cuts, when the roadway is made by soil excavation to design elevation and the sod line level is lower than the ground;
- sidehill cuts or sidehill fills, when the subgrade is lower than the ground level on the one side and higher than the ground on the other side;
- zero levels.

Many researches of the roadbed in severe climatic conditions, permafrost in particular, show that the roadway condition depends significantly on its direction relatively to cardinal points.

The analysis of the Vostochny Polygon, the BAM, sections shows that the most favorable conditions for exploitation, projection and reinforcement measures are at the rail road sections along the meridian and less favorable north-east and north-west directions. However, the least favorable are sections directed latitudinally, and it is connected with uneven freezing of the roadbed on the north and south sides which has a negative effect on stability of slopes the roadbed itself.

Thus, on the Vostochny Polygon, the sections Ust'-Nyukzha – Talyma, Larba – Tynda, Tynda – Unaha, Dipkun – Verkhnezeisk, Tungala – Dugda and Tuyun – Alonka have a longitudinal direction, while the sections Olekma – Ust'-Nyukzha, Verkhnezeisk – Tungala, Tungala – Isa and Alonka – Novy Urgal have a meridian direction.

It is reasonable to divide the roadway into analogous components to provide its state assessment, stability or instability. The components are considered analogous if they are roadway continuous sections of the same type located on genetically homogeneous subgrades of equal coefficient of stability and water discharge conditions.

Below, there are developed designs that provide a free run-off through the embankment at cryogenic deformation conditions.

The design for surface and underground water discharge (Patent # 2618108 RF – a two-step drainage system on permafrost from FESTU) is used in adverse natural climatic, engineering and geological conditions for construction and reconstruction of the line structures on the sections where water wash-out and filtering in the roadway take place mainly on permafrost or seasonal deep freezing soils.

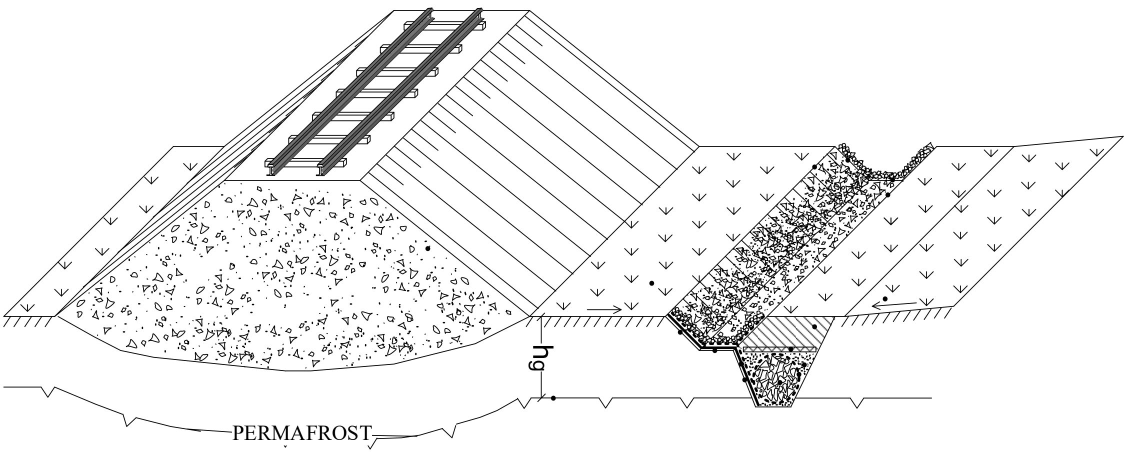

Figure 1. Two-step drainage system on permafrost.

In 2015-2016, a survey of four roadbed sections according to the agreement between FESTU and the Amur-Yakutian Rail Road in the Sakha Republic was carried out on the branch Nerungri Station – Tamarak Junction of the Berkakit – Tommot – Yakutsk Line (11-12 km, 28km and 58-59 km). The branch had speed limit restrictions of 25-40 km/h for the train traffic during almost the whole period of operation.

The earth structure on weak soils: the design is also developed in accordance with scientific research specification.

Fig.2 shows the structure developed by FESTU for draining swampy areas adjacent to the roadbed along the deformed sections, the branch Izvestkovaya – Urgal, BAM.

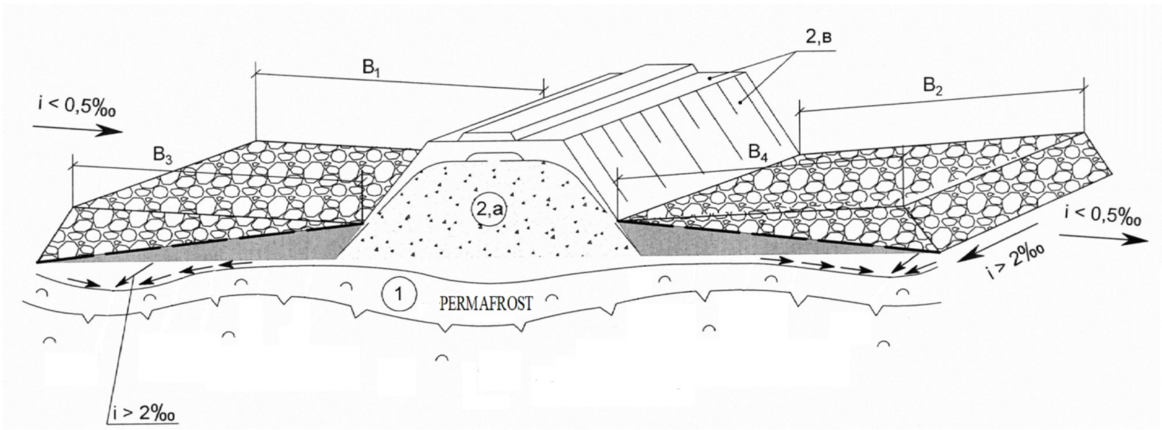

Figure 2. Earth structure on weak soils, FESTU patent # 2706152 RF.

The earth structure on weak soils consists of the embankment and cantledge prisms of rock of various cross-section that are aimed to drain and reinforce the embankment foot zones. The prisms are placed on both high and low sides of the embankment along its grade line, their size increasing in the run-off direction. Their specific feature is different masses and angled cross-sections with the apexes being at the distance equaled the berm's width. The prism of a bigger mass is placed on the high side, while the prism of a smaller mass is placed on the low side. The prisms are mounted on water-stop berms of an angled shape and made of clay soil. The berms are filled on both sides of the embankment and covered with synthetical nonwovens, the prisms' apexes being placed on the slopes.

Having been introduced before, the anti-deformation technical solutions are tested and used effectively in most cases.

FESTU offers a number of new technical solutions enforcing drainage, reinforcement and soil consolidation that are combined in a complex together with water discharges, thus providing an artificial run-off area and other of this kind for soil dewatering and consolidation.

Fig. 3 show a universal structure for the embankment stabilization at the Izvestkovaya – Urgal railway line. It shows the design for controlling the roadbed stability in the conditions of the Vostochny Polygon.

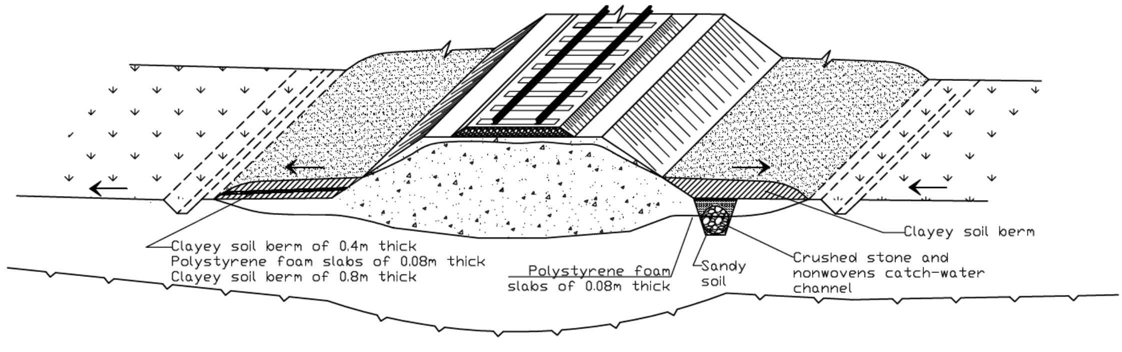

Figure 3. Technical solution for roadbed reinforcement; Izvestkovaya-Urgal railway line, 328-330 km.

The design for discharging surface and ground waters (Patent # 2553738 developed by FESTU).

The design for discharging surface and ground waters contains a longitudinal trench along the railway slope and at least one at a side cross trench: one on a low side of the road and one on the high side; both being perpendicular to the road. Besides, both cross trenches are located in one cross-section of the lower relief.

The longitudinal and cross trenches are made to the depth of seasonal freezing and filled with draining soil. Each cross trench is covered with thermal insulation layer. The design is used on the Amur-Yakutian Mainline, 58-59 km.

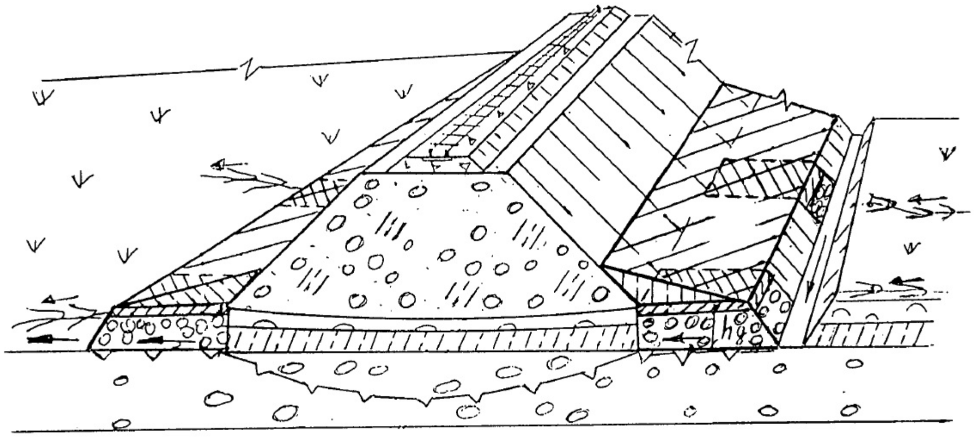

Figure 4. Design for discharging surface and ground waters.

4. Conclusions

1. Modern common features of deformations in technical structures at the Vostochny Polygon are mostly connected with changes in ground water run-off and filtration.
2. The most vulnerable areas of the embankment are its foot zones. Heat loss in the foot zone soils takes more time than in the embankment itself. Water release in the subgrade, and the plastic uplift of weak soils takes place in a thawing layer on the border between seasonal freezing and permafrost after the talik zone has been formed.
3. There is a number of new technical solutions developed by the FESTU engineers that facilitate drainage, strengthening and reinforcement of soils. These measures are combined with installation of water discharge facilities and provide an artificial run-off area for soil drainage and its reinforcement. This is proved by a developed model for controlling the embankment stability at the railway line Izvestkovaya-Urgal, the Vostochny Polygon [8-10].

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