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Stabilization Techniques for Road Lower Structure and Roadbed Constructed on Permafrost Soil

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Abstract. The perspective development of Yamal-Nenets Autonomous District, which is rich in mineral resources is impossible without creation of the road network for communication between settlements, oil and gas fields and transport hubs. Yamal-Nenets Autonomous District is characterized by complex engineering-geological conditions where different geological and geocryological phenomena and processes are being developed causing specific approaches to design and construction of engineering structures to be used. In this regard, an urgent task is to develop constructional solutions making it possible to stabilize the road lower structure and the roadbed, prolong periods between repairs on individual sections and improve operational reliability of roads in general. The paper describes the proposed and implemented constructional and technological solutions to stabilize the road lower structure and the roadbed constructed on permafrost soils. The results of two-year geotechnical monitoring of the road sections with implemented solutions are given.

1 Introduction

Maintenance of roads built on permafrost soils is accompanied by a large number of repairs which are caused by cyclic deformations of the pavement structure and the roadbed. There are lots of causes of such deformations. The main reasons include errors in designing a road being located in severe climatic conditions and changing engineering-geocryological and hydrological conditions during operation. As a result, needed are the additional measures aimed at regulating water-and-temperature conditions of the roadbed and the road lower structure allowing traffic current to be available on the repair area. One such measure is the implementation of various schemes for reinforcing the roadbed and the road lower structure aimed at possible operation of the road during winter and in the period of maximum thawing of the roadbed and the lower structure of the road. Generalized results of research in this area are listed in domestic and foreign literature (Citovich N.A., Stefan I, Krylov M.M., Saltykov N.I., Hakimov X.R., Dalmatov B.I., Kudryavcev V.A., Melamed V.T., Melnikov V.P., Chzhan R V., Aldrich H.P., Paynter H.M., Ershov E.D., Ivanov N.S., Orlov

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V.O., Porhaev G.V., Pchelincev A.M., Tyutyunov I.A., Fedorov V.I., Feldman G.M., Cheverev V.G., Corte A.E., Xu X. and etc.)

2 Literature review

In 2011 a group of researchers from Tyumen State University of Architecture and Civil Engineering (TSUACE) carried out a survey of the road section (PK 593+00 – PK 600+50) "Surgut - Salekhard, Novy Urengoy - Nadym the 1st commissioning and start-up complex: Pangody (km 870) – Pravohettinsky (km 936); the survey was carried out in parallel with the engineering investigations. Photographic images of engineering-geodetic and geological surveys of the previous years were used. The following defects were identified after the analysis of the results obtained (Fig. 1.):

Roadbed

Deformation of the roadbed –vertical movements of the road border

Minor destructions of the roadbed near the head walls of the culverts.

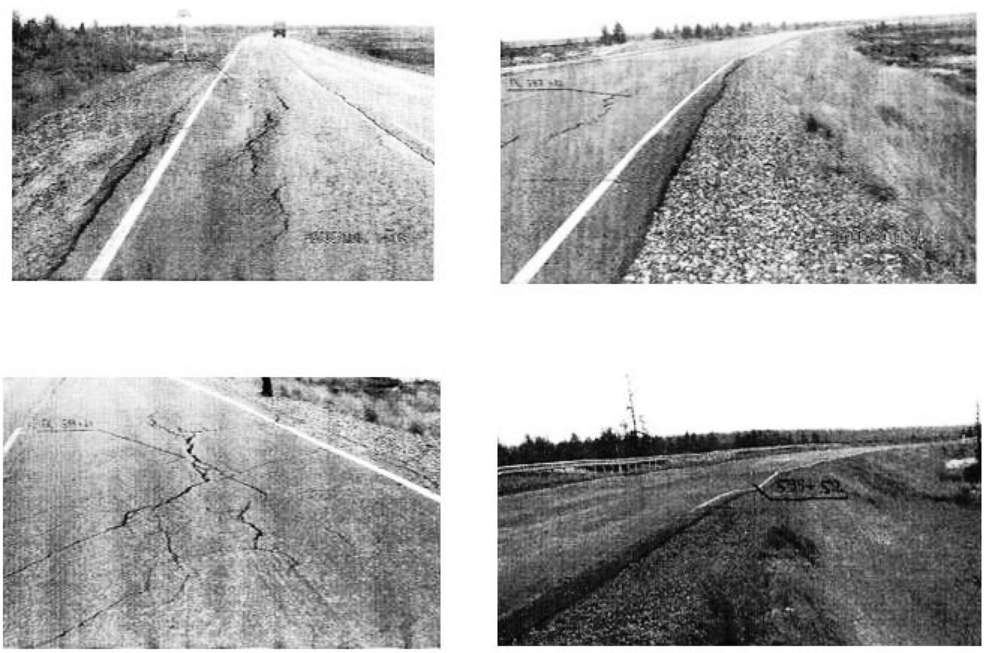

Fig. 1. Defects of the road pavement and the roadbed.

Pavement

Development of longitudinal and transverse cracks could be seen on the surveyed section of the road pavement. Sections with a strong network of cracks were observed in the areas where the roadbed and road borders were deformed.

Cracks generated in the center of the pavement along the axis of the road with 3 cm of growth indicated that vertical movements of the road pavement were accompanied with the horizontal ones toward the slopes. Development of longitudinal cracks up to 23 m in length indicated the possibility of deformation of the roadbed and the road lower structure.

Development of transverse cracks on the surveyed sections of the road pavement indicated vertical movements both along the entire width of the roadbed and pavement and also along the local sections. This type of defect called a hollow spot was accompanied by development of perpendicular cracks thickened on both sides to a maximum vertical movement.

Culverts

Two culverts were constructed on the road section PK 593+00 – PK 600+50. Visible minor deformations of the roadbed slope near the entrant head wall occurred on PK 599+16. One could observe long-standing areas of water in ditches on the right and the left sides of the road indicating the inefficiency of the culverts. Destruction of slopes was not observed. Visual inspection of the defects did not make it possible to identify the causes, but it was possible to determine the direction and nature of roadbed and pavement deforming.

After the results obtained the road was divided into four sections:

Section №1 - PK 594+00 – PK 594+90 - destroyed was the right side of the pavement, the maximum deviation from the design marks was 28 cm. Vertical movements of the left and right sides of the road pavement were observed on PK 594+26 – PK 594+32. The mean value of vertical movements was 20 cm.

Section №2 - PK 596+40 – PK 597+00 - destroyed was the left side of the pavement incorporating two local zones of fracture. The maximum vertical movement on the left side of the pavement was 19cm.

Section №3 - PK 597+20 – PK 597+45 - destroyed was the left side of the pavement and the border. The maximum vertical movement on the left side of the pavement was 23cm.

Section №4 - PK 598+80 – PK 599+90 - identified were the local zones of fracture both on the left side of the pavement and hollow spot edgewise the road structure. On PK 599+46 – PK 599+60, PK 599+20 – PK 599+36 and PK 598+90 – PK 598+80 destroyed were the left sides of the pavements. The maximum deviation of the elevation points from the design marks was 39 cm. On PK 599+18 – PK 598+92 developed were the vertical movements edgewise the road pavement with the maximum value of 30cm.

Engineering-geological surveys resulted in making transverse profiles of the road with engineering-geological cross section view of the specified sections.

On the right side of the road the transverse engineering-geological cross section of section №1 was presented by the medium-sized water-saturated sands with water capacity of up to 2 m in the upper layer, and in the bottom layer - fine water-saturated sands. Permafrost was absent. On the left side of the road the cross section was presented by wet peat with moderate degree of decomposition of up to 1.8 m and icy plastic-frozen peat. The boundary of permafrost was at around 41.90 - 40.80 m, the distance from the daylight surface at 2.35 - 4.50 m. Cracks developed in the right lane of the given section. The absence of permafrost on the right side of the road bottom and the presence of permafrost border on the left side indicated that the road structure rested upon heterogeneous base. The longitudinal cracks along the road axis indicated the boundary separating the lower structure from permafrost soils and the lack of them. Deformations were associated with settlements occurring at the bottom of the right side resulting in horizontal movements of the roadbed structure toward the right slope.

On the right side of the road the engineering-geological cross section of the base on the road section №2 (PK 596+40 – PK 597+00) was presented by fine sands with moderate water saturation capacity of up to 2.1 m and medium-sized sands saturated with water. Permafrost was absent. On the left side of the road the engineering-geological cross section consisted of wet peat with moderate degree of decomposition and saturation capacity of up to 4m, plastic-frozen peat with the saturation capacity of up to 3m and water-saturated sand. The boundary of permafrost was at around 41.60 - 40.00 m, the distance from the daylight surface at 1.35 -. 2.50 m. The pavement had defects in the left lane of the carriageway. Deformations of the roadbed structure and covering of the roadway occurred due to the deformations in the left portion of the roadbed structure resulting from thawing of frozen peat layer. Thawing of the upper layers was worsened by long-standing surface water at the left slope of the road. Engineering-geological cross section of the road lower structure on the road section №3 (PK 597+20 – PK 597+45) was presented by the intermediate layer of medium-sized water-saturated sand with an average degree of water capacity varying from 0.5 to 2.3 m, widely spread throughout the whole structure. From the right side of the road the underlying layers of the engineering-geological cross section were presented by medium-sized water-saturated sand with water capacity of up to 1.2 m, the layer of medium-sized hard-frozen sand with water capacity of up to 2 m and medium-sized water-saturated sand. From the left side of the road the engineering-geological cross section was presented by peat with moderate degree of decomposition saturated with water up to 1.9m of capacity, plastic-frozen peat with moderate degree of decomposition saturated with water up to 2m and the intermediate layer of sandy loams with the capacity of up to 1 m. The bottom layer was presented by water-saturated medium-sized sand. Deformations developed in the left part of the roadbed structure and covering of the roadway. Defects were caused by the presence of weak soil under the left side of the road, i.e. peat with moderate degree of decomposition saturated with water, plastic-frozen peat with the total capacity of 3.5m. On the right side of the road the level of the steady groundwater was 43.7 m at the given section, and on the left side -. 42.3 m. This difference was capable of generating a hydraulic pressure gradient in the soil under the road structure, which often leads to mechanical suffusion and, as a consequence, the destruction of the roadbed structure. Engineering-geological cross section of the road lower structure on the road section №4 (PK 598+80 – PK 599+90) was presented by fine and medium-sized sands with moderate water saturation. Permafrost was absent in the lower structure.

The analysis of the geological-engineering surveys resulted in understanding the possible causes of defects occurring annually on the road pavement and the roadbed:

- Section №1 (PK 594+00 – PK 594+90) - the absence of permafrost on the right side in the lower structure of the road and the presence of permafrost border on the left side indicated that the road structure rested upon the heterogeneous base. Deformations occurred due to settlements in the lower structure from the right side of the road, thus resulting in displacement of the roadbed structure toward the slope;
- Section №2 (PK 596+40 – PK 597+00) – failures in the pavement were due to the deformations in the left side of the roadbed as a result of thawing of the frozen peat layer. The process of thawing in the upper layers was worsened by long-standing surface water at the left slope of the road;
- Section №3 (PK 597+20 – PK 597+45) – failures were caused by the presence of weak soil layers in the lower structure, i.e. peat with moderate degree of decomposition saturated with water and plastic-frozen peat with moderate degree of decomposition. Hydraulic pressure gradient in the soil under the road structure led to mechanical suffusion in the lower structure and the roadbed body.
- Section №4 (PK 598+80 – PK 599+9) – failures were caused by the pressure from the weight of the roadbed and covering of the roadway transmitted onto the weak soil resulting in settlements both in the road lower structure and the roadbed. The slope of the terrain and structure of the road (virage) in the direction of the deformable lane worsened the situation. These factors led to an increase of pressure on the weak soil under the left side of the road and an increase of stresses in the roadbed causing vertical and horizontal deformations of the lower structure and destruction of the left lane pavement of the carriageway.

It was necessary to work out measures to stabilize the road structure and preserve the covering of the roadway on the section "Surgut - Salekhard, Novy Urengoy – Nadym - the 1st commissioning and start-up complex: Pangody (km 870) - Pravohettinsky (km 936)" PK 593+00 – PK 60+50, since the errors were made in designing the road when choosing the type of the transverse cross-section profile of the roadbed, and the engineering-geological features of the road lower structure were not considered [1].

3 Task description

To eliminate the defects developing annually in the roadbed structure and on the pavement it is needed to develop options for constructional and technological solutions to stabilize the road lower structure and the roadbed allowing traffic current to be available on the repair area. The effectiveness of the proposed constructional and technological solutions to stabilize the road lower structure and the roadbed should be assessed by geotechnical monitoring of the section with the realized schemes during the period of three years. Geotechnical monitoring results will allow to evaluate the performance of the structures or develop additional measures aimed at improving their effectiveness, as well as help form the experimental database to develop the technique (forecasting) to calculate temperature, moisture content and the stress-strain state of the object under study. The most effective and efficient measures to stabilize the roadbed and the lower structure of the road are to be used in future on similar problematic sections arising on newly built roads and the existing ones. Preservation of the existing roadbed, covering of the roadway and availability of road traffic during the period of construction works and repairs is the advantage of the developed measures. These measures must agree with the specific features of the engineering-geocryological structure of the roadbed bottom and hydrological conditions [2, 3]. Since the section is located on permafrost, the proposed measures should take into account the peculiarities of construction and design of the roadbed on given sections [4].

Vertical reinforcement of the right side of the roadbed being deformed vertically and horizontally (Fig. 2.) is suggested on section №1 (PK 594+00 – PK 594+90). Reinforcement is performed by vertical placement of the reinforcing material - to a depth of H = 2 m into the roadbed bottom with a hard soil roller l2=2 m in width and h2=0.75 m in height. Its size h1 is chosen so that the roller tilt agrees with the slope of the given transverse profile of the roadbed. The roller is constructed in the sloping part of the roadbed at a distance of l1=8 m from the axis [5]. The soil roller located in the sloping part of the roadbed will block the deformations to be developed in the direction of the slope. To prevent the roller from horizontal movements it is reinforced with the material which is fixed in the bottom with the polyethylene tube 25 mm in diameter. This reinforcement allows horizontal and vertical deformations to be reduced when they occur in the roadbed body and the road lower structure during the period of maximum active layer capacity and prevent further strain on the given section. Geotextile "Geospan TH 80" is used as reinforcement.

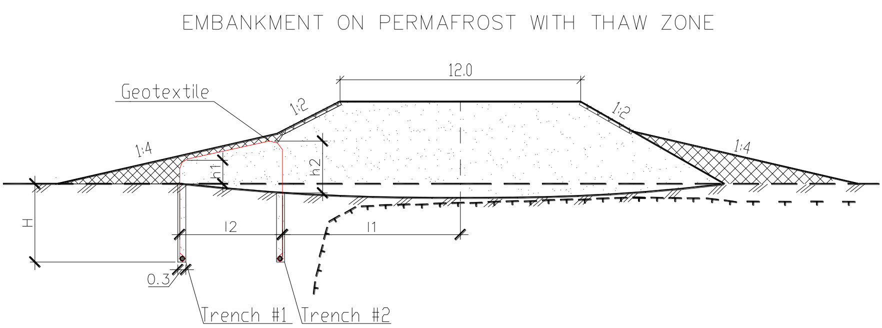

Fig. 2. Constructional and technological solution for roadbed stabilization on road section №1 (PK 594+00 – PK 594+90).

It has been proposed to reinforce the roadbed and the lower structure vertically in the left side of the road on road section №2 (PK 596+40 – PK 597+00) forming a hard soil roller wrapped with the reinforcing material around the outer perimeter (Fig. 3.). Vertical reinforcement is performed to a depth of H = 2 m into the roadbed bottom with the hard soil roller l2=2 m in width and h2=0.75 m in height. The roller size h1 is chosen so that the roller tilt agrees with the slope of the given transverse profile of the roadbed. The roller is placed in the sloping part of the roadbed at a distance of l1=8 m from the axis. The soil roller will reduce the deformations to be developed in the roadbed and the lower structure and prevent penetration of surface water into the body of the roadbed. Lowering of moisture content is achieved by reducing the filtration rate due to the reinforcing material placed vertically which prevents penetration of water into the body of the roadbed and the lower structure of the road. To prevent thawing of weak soil, heat stabilizers TK 32/10 10m in length and 32mm in diameter are added. Heat stabilizers are placed 2m from the outer sides of the reinforced roller. Heat stabilizers will make it possible to raise permafrost level to the daylight surface and reduce the capacity of easily deformable thawed soil layer. Heat stabilizers will allow a cylindrical volume of frozen soil of 1.3 m in radius to be formed for 2 years of operation. Step of 2 meters between the stabilizers allows the vertical frozen soil massif to be formed along the reinforcing elements; that will give additional stability to the road structure [3, 5].

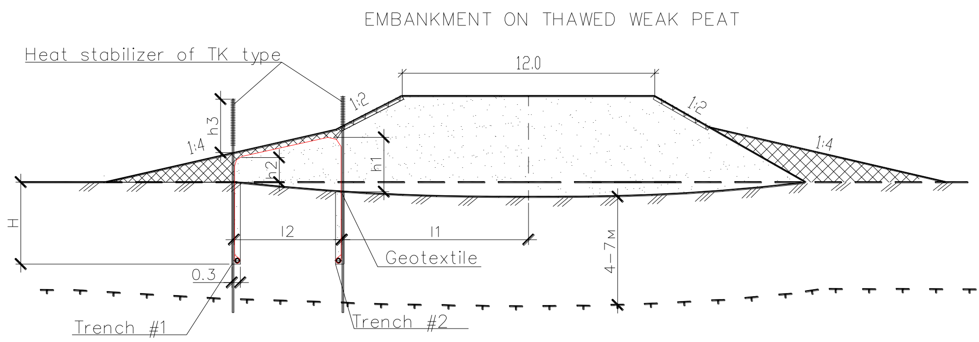

Fig. 3. Constructional and technological solution for roadbed stabilization on road section №2 (PK 596+40 – PK 597+00).

Stabilization technique for the roadbed on section №3 (PK 597+20 – PK 597+45) is identical to that of the section №1 [5]. Unlike section №1 stabilization here is performed on the left side of the road (Fig. 4). The same type of solution used here is connected with performance of vertical reinforcing elements installed at a depth of 2 m into the bottom of the road. The reinforcement wrapping the roller is vertically immersed into the soil below the permafrost making it possible to fix the reinforcement ends rigidly in the permafrost. Besides, lowering of the filtration rate due to vertical placement of the reinforcing material allows moisture-temperature conditions under the roller to be changed and raise the level of permafrost daylight surface [6]. Stabilization of the roadbed structure is carried out due to rigid binding of the reinforcement ends in the permafrost making it possible to reduce deformations in the given section toward the slope.

To ensure stability of the road structure and the roadbed slope on section №4 (PK 598+80 – PK 599+90), the constructional and technological solution has been developed in order to eliminate deformations occurring in the roadbed and the lower structure of the road (Figure 4.).

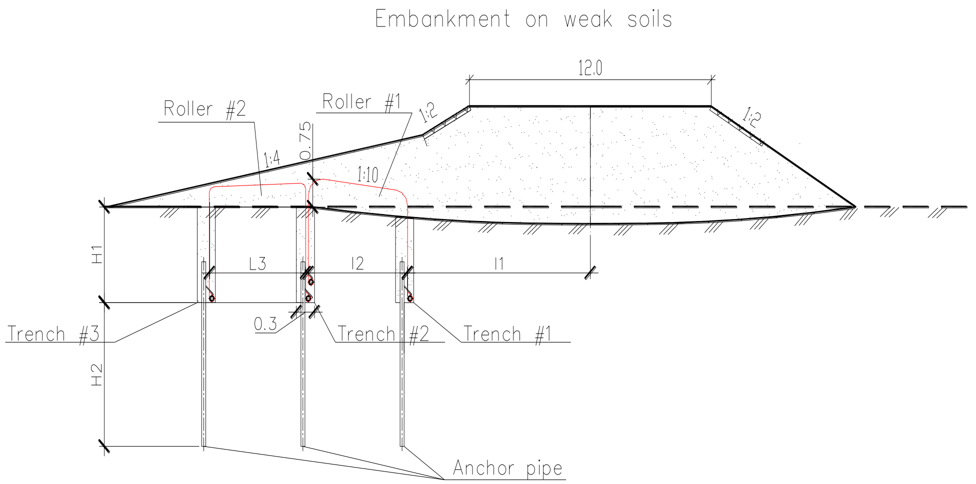

Fig. 4. Constructional and technological solution for roadbed stabilization on road section №4 (PK 598+80 – PK 599+90).

It is suggested to perform vertical reinforcement of the roadbed and the weak lower structure to a depth of H1= 2m with reinforcement to be anchored to steel tubes immersed in the underlying soils to H2=3m. Reinforcement is done with two rollers wrapped with the reinforcing material along their outer surface. Vertical reinforcement is placed in 3 rows with the distance from the axis of l1=6 m, l2=2 m and l3=2 m. A hard soil roller l2,3=2 m in width and h2=0,75 m in height is placed in the sloping part of the roadbed. These vertical rows of reinforcement will prevent soil movement toward the slope. Anchor tubes immersed in the weak subgrade soil to a depth of 3m allow the reinforcing element to be fixed firmly in the design position, and thus increase the stability of the slope and the roadbed structure.

In 2012 the proposed stabilization techniques for the road lower structure and the roadbed constructed on permafrost soils were implemented in the section (PK 593+00 – PK 600+50) - "Surgut - Salekhard, Novy Urengoy - Nadym the 1st commissioning and start-up complex: Pangody (km 870) – Pravohettinsky (km 936) (Fig. 5)..

The effectiveness of the constructional and technological solution to stabilize the roadbed is to be evaluated after the results of geotechnical monitoring of the sections with the implemented solutions during the period of 3 years. Geotechnical monitoring aims at selection and justification of the most rational roadbed on the given section - Novy Urengoy – Nadym - by analyzing the observation results of the stress-strain state and temperature conditions of the road lower structure soils and the roadbed as well as preparing the initial messages for design of road structures using the proposed roadbed.

Fig. 5. Reinforcement of the roadbed and the road lower structure: a) – Section №1 (PK 594+00 – PK 594+90); b) –Section №2 (PK 596+40 – PK 597+00); c) –Section №3 (PK 597+20 – PK 597+45); d) –Section №4(PK 598+80 – PK 599+90).

4 Description of research

Thus, to achieve the purpose when performing geotechnical monitoring and solve the related problems it was necessary to understand the stress-strain state and temperature conditions of the road lower structure soils developing in time [7, 8 and 9].
It was needed to:
- Measure stresses on the vertical platforms in the distinguished points;
- Measure stresses on the horizontal platforms in the distinguished points;
- Measure the vertical movements of soil particles in the road lower structure and its body;
- Measure the vertical and horizontal deformations of the road structure body;
- Measure soil temperature in the embankment base;
- Perform geodetic surveying of the roadbed body.

To monitor temperature conditions of the subgrade soil and the embankment body of the road, 56 thermometric tubes were immersed to a depth of 10 m. Vertical movements of soil layers in the road subgrade and the embankment were measured with 480 deep screw marks. Vertical movements of the marks were recorded by deflectometers made after a dial indicator ИЧ-1. To save measurements and protect instrumentation from adverse climatic factors, protective metal casings were installed above each motion sensor.

Measurement of total stresses and pore pressures were carried out by 480 membrane load cells made after the technique suggested by A.V. Golli. To record sensor readings the following devices were used: automatic meter of deformations ITC-01 and NationalInstruments. General view of the road section (PK 593+00 – PK 600+50) with the installed measuring equipment is shown in Figure 6.

Fig. 6. General view of the road section (PK 593+00 – PK 600+50) with the installed measuring equipment

5 Results

After the results of two-year monitoring of the road sections with the implemented solutions the following conclusions were drawn:

- The first year of geotechnical monitoring showed that such defects as cracks, subsidence and erosion of slopes appeared on the pavement and road borders of each section where stabilization works were carried on the roadbed and the road lower structure. The development of deformation was due to construction and installation works during winter. In maximum thawing of the roadbed and the lower structure of the road in spring and autumn, compaction of subgrade and roadbed soils was carried out using reinforcement (tension). In summer, during the first year of geotechnical monitoring, the pavement, road borders and road slopes were repaired; this was taken as the initial state of the road.

- In the second year of geotechnical monitoring a net of cracks appeared on the section №1 along the whole of the road pavement. Intensive development of deformations occurred due to a permanent flooded area providing water filtration into the body of the roadbed and the lower structure in the period of maximum thawing of the active layer. The level of roadbed flooding in spring was above that of the hard soil roller. In order to prevent water filtration into the body of the roadbed on section №1 it was recommended to develop the project and perform construction and installation works on overburden water removal berms made of non-drain soil on both sides of the road. Subsidence of pavement appeared on the reinforced side of the carriageway indicating that the soil must be further compacted on this section of the road. Constant flooding of the embankment bottom led to intensive development of defects on the given section. Rise of moisture content in the roadbed and the lower structure led to further development of deformations in the form of cracks and subsidence due to the flooding area. The designed drainage systems could not guarantee preservation of the natural hydrological regime of surface waters, and as a result, the frost-thaw flooding area appeared between the railway and the road. This resulted in deterioration of the roadbed frozen state and thawing of subgrade soils.

- In the second year of geotechnical monitoring three transverse cracks were observed on section №2. After measuring temperature on section №2, the negative temperatures were observed in the roadbed body and the lower structure on the left side of the road in 3 - 7 m from the daylight surface. Reduction of temperature of the roadbed soils and the road lower structure as well as its expansion in the underlying soils made it possible to draw a conclusion about the effective operation of the heat stabilizers installed on the given section.

- In the second year of geotechnical monitoring not any defects were revealed on the road pavement and borders on section №3 indicating roadbed and lower structure stabilization.
- In the second year of geotechnical monitoring not any defects were revealed on the road pavement and borders on section №4 indicating roadbed and lower structure stabilization.

Snow deposits up to 1.6-2.3 m cumulating on the slopes of the road and at the foot of the roadbed due to the intense snow ridging and transport by the railway located nearby the sections had a negative effect on the inspected object. Snow deposits cumulating on the slopes of the road and at the foot of the roadbed did not allow the second principle of designing to be realized, since they blocked expansion of the negative temperatures in the roadbed body and the lower structure of the road. In spring, due to the accumulated snow transport, additional moisturizing of the roadbed and the road lower structure occurred.

6 Conclusion

As a result of the research three methods of stabilizing the roadbed and road base on permafrost soil, have been developed, implemented and tested. Application of our research's results will reduce the annual emerging defects in the roadbed and road surfaces.

References

1. Avtomobil'naja doroga na mnogoletnemerzlyh gruntah, R.F. Patent 2522268, MPK7 E 01S03/00 (2015)
2. V.V. Voroncov, A.N.Kraev, M.E.Igoshin, *Nauchno-tehnicheskij vestnik Povolzh'ja*, **2**, 119-123 (2014)
3. V.V. Voroncov, A.N. Kraev, M.E.*, Vestnik Sibirskoj gosudarstvennoj avtomobil'no-dorozhnoj akademii***, 6(40)**, 67-72, (2014)
4. A.N. Kraev, T.V. Permitina, V.A. Zav'jalov, *Aktual'nye problemy stroitel'stva, jekologii i jenergosberezhenija v uslovijah Zapadnoj Sibiri*, 32-40 (2014)
5. M.E. Igoshin, V.V. Voroncov, A.N. Kraev, A.E. Ushakov, *Aktual'nye problemy stroitel'stva, jekologii i jenergosberezhenija v uslovijah Zapadnoj*, 21-28 (2014)
6. V.V. Passek, A.N. Kraev, M.V. Paskov, V.S. Andreev, *Vestnik Tjumenskogo gosudarstvennogo arhitekturno-stroitel'nogo universiteta*, **4**, 89-93 (2015)
7. A.N. Kraev, PhD Thesis (2009)
8. V.F. Baj, A.V. Nabokov, V.V. Voroncov, A.N. Kraev, Vestnik grazhdanskih inzhenerov, **2**, 74-76 (2009)
9. V.F. Baj, L.E. Mal'cev, T.V. Mal'ceva, et al. Jeksperimental'naja ustanovka dlja ispytanija grunta metodom odnoosnogo szhatija, Patent RUS 2213952 (2002)
10. L.E. Mal'cev, T.V. Mal'ceva, V.A. Demin, Neft' i gaz, **2**, 96-102 (2001)
11. A.V. Nabokov, PhD Thesis (2003)
12. V.F. Baj, A.N. Kraev, A.V. Nabokov, Ju.A. Novikov, *Nauchno-tehnicheskij vestnik Povolzh'ja*, **2**, 30-33 (2011)
13. V.F. Baj, T.V. Mal'ceva, A.N. Kraev, *Nauchno-tehnicheskij vestnik Povolzh'ja*, **5**, 108-111 (2014)
14. T. Maltseva, A. Nabokov, A. Chernykh, *Procedia Engineering*, **117**, 239-245 (2015)