STRENGTHENING OF ROADBED BASE ON VERY ICY PERMAFROST SOILS

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ABSTRACT

Deformation of roadbeds on permafrost soils are connected with permafrost degradation in the roadbed base (there are about 70% of such deformations along the Bajkal-Amur Main Line). The main task in providing roadbed stability is to prevent permafrost degradation. There are several methods of strengthening roadbed base on very icy permafrost soils which are based on the regulating warming and cooling. These lead to lowering of the average annual soil temperature and prevention of permafrost degradation. They are: constructing sheds to protect from sun and precipitation; snow cleaning and embankment painting; use of plastic cover; fulfillment of ventilation pipes and special constructions for cold accumulation. New technical solutions are protected by patents. On the basis of the patents, projects and scope documents for building pilot-experimental roadbed sections of Amur-Yakutsk Main Line were developed. Maintaining permafrost conditions in road beds simplifies construction, reduces expenses for track building and exploitation by using typical embankment constructions; not needing additional embankment width or height; not using expensive stone filling or a large amount of cooling pipes. It helps to increase railway reliability and efficiency.

INTRODUCTION

Roadbed deformation in permafrost soils is primarily caused by permafrost degradation in the roadbed base. This type of deformation accounts for about 70% of deformation along the Baikal-Amur Railway (Belozerov, 1993 and Yakovlev, 1992).

Typical mitigating measures to ensure roadbed stability on either a weak base or those subsiding under thaw, primarily include: making the embankment wider and higher, lifting tracks on ballast, constructing berms, filling the embankment with rock, cutting out ice-saturated bed soil and replacing it with drainage material compacted layer-by-layer, etc. (Fyodorov, 1977). These measures are of a passive nature because they are aimed primarily at overcoming the consequences of permafrost degradation. In addition, they require great expenses for track construction and maintenance and they do not solve the problem of ensuring roadbed stability on very icy permanently frozen soil (Bushin, 1992 and Yakovlev, 1992).

Obviously, there is a necessity to develop active arrangements to ensure roadbed stability on very icy permafrost soils aimed at the elimination of the basic cause of the deformation; to prevent permafrost degradation in the roadbed base.

In co-authorship with a group of specialists, we have developed several methods of strengthening roadbed bases on very icy permafrost soils. These methods are based on either the adjustment of the ratio of cooling and warming factors with the purpose of reducing average annual soil temperatures and to preserve them in the permanently frozen state (Kondratyev, 1992; Kondratyev, et al., 1992a; 1992b; 1992c; 1993a; and 1993b), or are based on preventative removal of ice-masses (ice lenses) from a permanently frozen base and filling the resultant cavities with a high density soil (Kondratyev and Broid, 1994).

STRENGTHENING BY SNOW CLEANING AND PAINTING

The method of strengthening a roadbed base by the means of snow cleaning and painting is patent No. 1764371.

In zones of perennially frozen soils subjected to subsidence under thawing, embankments are constructed according to a technique envisaging preservation of base soils in a perennially frozen state. Swaths are cut in winter time without stumping out; a moss-vegetation cover is maximally preserved; the embankment first layer is filled "from the head" not allowing the vehicle traffic on a natural base; the embankment is compacted layer-by-layer.

In the first half of winter (from the moment of appearing a stable snow cover to the moment of heat flow sign inversion) the snow is regularly removed from the roadway, embankment slopes and parts of adjoining territories. The moment of heat flow sign inversion is established according to the data of the nearest weather station when the air daily average temperature becomes steadily higher than that of the soil surface. The width of a strip near the embankment to be cleaned from snow should be, as a rule, more than the width of the embankment side surface, however, it should not exceed the thickness of a layer of soil yearly temperature fluctuations for a naked surface.

In spring after snow melting the embankment slopes of southeastern and western exposures as well as the top track structure are painted white. The painted surface should adequately reflect solar radiation in the spring-summer period, therefore if 60% of the protected surface becomes dirty, it should be repainted.

A positive effect is achieved owing to the fact that elimination of the snow heat insulating influence in the cold period intensifies a heat flow from the embankment body and base into atmosphere - their intensive cooling takes place.

Essential increase of albedo (α) of the surface coated with new ($\alpha=75\%$) or old ($\alpha=55\%$) white paint as compared to the natural surface ($\alpha=25\%$) and, particularly, to the track surface blackened with coal dust and fuel oil ($\alpha=6\%$) decreases the quantity of absorbed solar radiation, reduces summer warming of the roadbed and its base. Intensifying winter cooling and lessening summer warming preserve the track base in the frozen state. Prevention of permafrost degradation in the roadbed base rules out development of its perennial settlement.

The use of this method allows to simplify the roadbed design and to reduce track building and maintenance costs; to use standard components; to avoid making reserves by the embankment height and width; not to use stabilizing berms, the costly and not always effective rockfill for roadbeds; to reduce the volume of a draining material and to replace it by a cheaper ordinary non-frost susceptible soil. Owing to this the road capacity and the track component service life will increase.

STRENGTHENING BY SUN-PRECIPITATION PROTECTIVE SHEDS

The method of strengthening of a roadbed base by using sun-precipitation protective sheds is patent No. 1740555.

Making a sun-precipitation protective shed over the embankment prevents a warming effect of direct solar radiation and summer precipitation as well as drastically increases winter cooling and hindering heat insulation of the embankment with a snow cover.

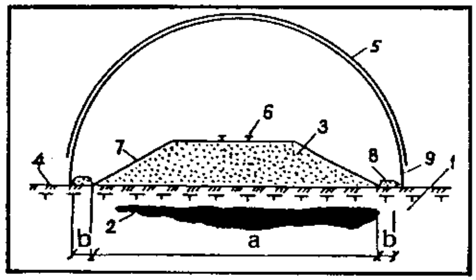


Fig. 1. Schematic diagram of a railway track with sun-precipitation protective shed roof of a convex shape

A schematic diagram of rail track is presented in Fig. 1-3. At roadbed sections with the base from very icy soils 1 or with inclusion of underground ice 2 an embankment 3 of the ordinary design is filled without removal of moss-vegetation cover 4. Sun-precipitation protective shed 5 is built additionally. The shed design is selected with regard to the geographic latitude and local climatic conditions, slope exposures and embankment height. The roof profile should be convex (Fig. 1) of a single-pitch or ridge (Fig. 2 and 3) shape. The shed should protect the railway top structure 6, embankment slopes 7 and a part of adjoining territories 8 including water retaining banks against rain and direct solar radiation in spring and summer, as well as prevent accumulation of snow in winter. For this purpose the sheds lower part has air holes 9 facilitating snow carrying out by an air flow beyond the rail track during passage of trains or at snow storm. The shed width should be not less than a sum of cross dimensions of the embankment (a) and water-retaining banks (b) at meridional direction of the track and not less than a sum of cross dimensions of the main formation level (c), the embankment southern slopes (d) and the water-retaining bank (b) in case of the latitude orientation. The shed height and the embankment optimum height determined by the results of heat engineering analyses for concrete route sections. The above clearance should be included into the shed internal space.

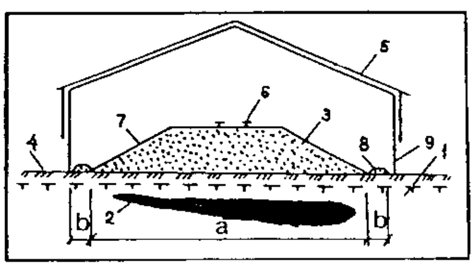


Fig. 2. Schematic diagram of a railway track with sun-precipitation protective shed ridge roof

Sheds can be built not only over embankment sections but also over zero vertical alignments and in recesses.

A positive effect is achieved owing to the fact that the shed rules out a warming influence of the snow cover, summer precipitation infiltration and direct solar radiation being principal factors of permafrost degradation and roadbed subsidence.

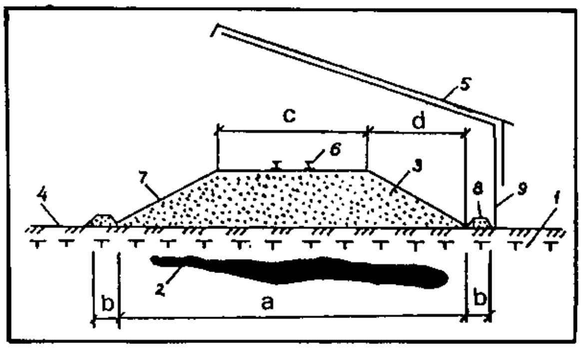


Fig. 3. Schematic diagram of a railway track with sun-precipitation shed simple roof

While retaining high strength properties of frozen base soils within the whole period of a railway service the necessity in additional anti-deformation measures no longer arises, the embankment design is simplified, the track throughput capacity and the track component service life are increased.

STRENGTHENING BY MEANS OF COOLING PIPES

The method of strengthening of roadbed base by means of cooling pipes is patent No. 2010919.

Strengthening of roadbed base is achieved by the fact that due to location of the cooling pipe system in the embankment bottom part the base soils are preserved in a perennially frozen state. The embankment design with the cooling system is explained in Fig. 5 and 6.

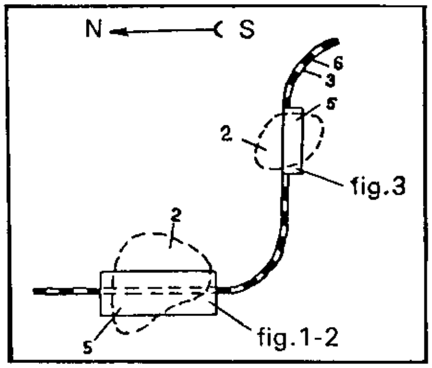
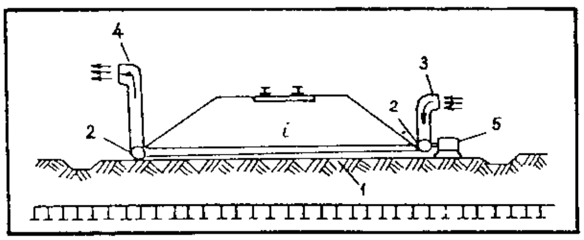


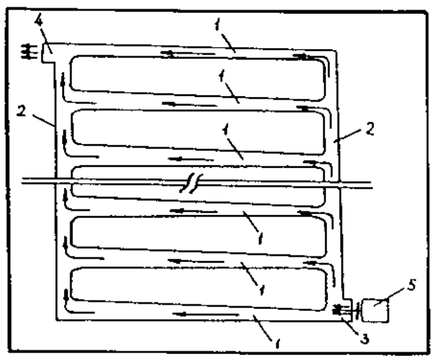
Fig. 4. Dependence of shed design on embankment slope exposures

The cooling system consists of one or several rows of cooling pipes 1 laid across the embankment and used for passing a coolant (cold or cooled air, air-gas mixture) by natural or forced ventilation. The pipe diameter, spacing and the number of rows are determined by heat engineering analysis. Ventilation is performed by means of trunk pipes 2, inlet 3 and outlet 4 connections. To intensify natural ventilation the holes of inlet and outlet connections are located on different levels. This is facilitated by laying the pipes with a gradient to the roadbed bottom part or by the use of tapered pipes. In case of forced ventilation fran 5 is additionally installed. This allows, when necessary, to perform additional cooling in summer with air-gas mixtures, e.g., air-nitrogen one, and to ensure the roadbed stability even in abnormally warm years.



← Fig. 5. Embankment design with cooling pipes

Fig. 6. Cooling system in plan →



STRENGTHENING WITH THE TERRAIN, ACROSS GRADIENT, USING A FILM COVER

The method of strengthening of roadbed base at sections with the terrain cross gradient using a film cover is Patent No. 1807173.

At hill side sections to preserve roadbed base soils in a perennially frozen state it is necessary to prevent a warming effect of not just solar radiation and atmospheric precipitation but also of the surface and above-permafrost waters running downhill to the embankment.

The effect of the surface and above-permafrost waters is prevented by making an anti-filtration cover (Fig. 7) from polymer film 1 on the boundaries of frozen core 2 with draining prism 3 and berm 4 from the top side. For reliable conservation of the frozen core and very icy base 5 of the embankment berm is constructed of heat-inflating 6 and anti-filtration 7 layers and is cut into the base to the depth exceeding the thickness of a seasonally melting layer 8. The embankment slope from the bottom side is trended with rockfill also facilitating conservation of the frozen core and the embankment base; in case of the slope southern exposure the rock material should have a natural or specially created light-reflecting color. The training prism base should have a gradient towards the bottom side for meteoric water run-off.

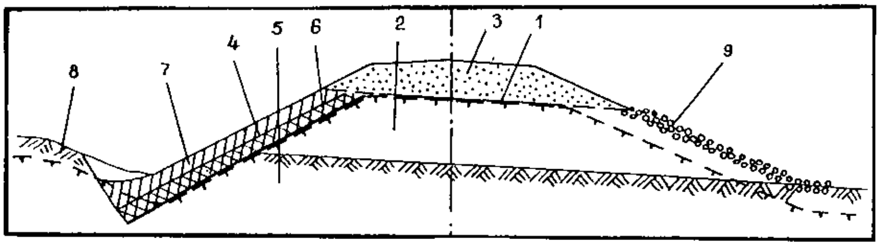


Fig. 7. Embankment design with a film cover

STRENGTHENING WITH THE TERRAIN, ACROSS GRADIENT, USING COLD ACCUMULATION DEVICES

The method of strengthening of roadbed base at sections with the terrain cross gradient using cold accumulation devices is patent application No. 93057489.

The main drawback of the design with anti-filtration polymer film cover is high labor intensity in conditions of railways being in service and restriction of use primarily in new construction. The below design lacks this drawback.

Prevention of the warming effect of surface and above-permafrost waters at hillside sections is achieved by making an anti-filtration cover from frozen soils (Fig. 8) using cold accumulation devices 1 like Long, Gapeyev, Makarov, etc., thermopiles placed from the top side of embankment 2.

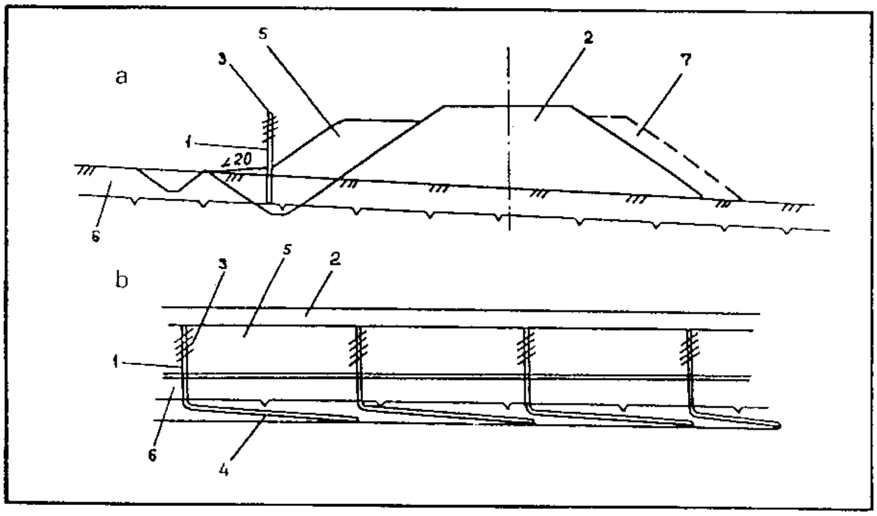


Fig. 8. Embankment design with a cold accumulation device: a) cross section; b) longitudinal section

The devices air heat exchanger 3 is installed vertically while a soil one 4 - along the embankment at angle of 95-100 degrees to the vertical. For reliable conservation of the frozen and very icy embankment base an anti-filtration berm 5 is built being cut into the base for the depth exceeding the thickness of seasonally melting layer 6. The embankment slope from the bottom side is strengthened with rockfill 7 also facilitating conservation of the embankment frozen core and base in case of the slope southern exposure the rock material should have a natural or specially created light reflecting color.

STRENGTHENING BY SUBSTITUTING VERY ICY MASSES WITH HIGH DENSITY SOILS

The method of strengthening of roadbed base by substitution of very icy masses for high density soils is patent application No. 94022236.

In some cases, particularly at sections with the soil temperatures close to 0°C, it can be advisable instead of continuous maintaining negative temperatures during a railway operation to take preventative measures on replacing very icy masses by a soil mass not subsiding under thawing. A method of breaking down and removing very icy permafrost soils or ice deposits in the roadbed base is offered using a hydrodynamic technique through special wells which are also used to fill the emerging cavities with a thawed soil having required properties, e.g. sand (Fig. 9). In this case hazardous settlements of the embankment are ruled out under any thermal effects and changes in environment.

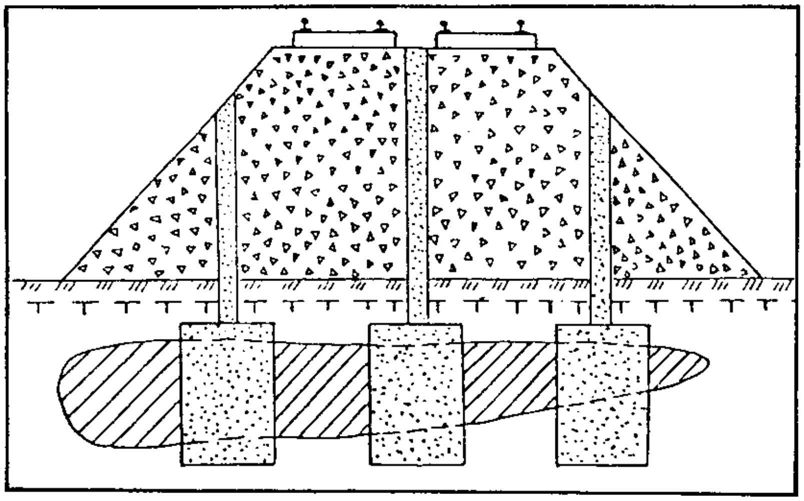


Fig. 9. Strengthening of roadbed base by substitution of very icy soils for non-subsiding soil mass

DISCUSSION

On the basis of the above technological concepts with the purpose to test their efficiency in operation conditions and to try out the techniques Mosguiprotrans designs pilot-experimental roadbed section of Berkakit-Tommot-Yakutsk Railway being under construction now. The Baikal-Amur Railway also started to use some of them, particularly, snow cleaning.

Roadbed deformations caused by perennial thawing of permafrost soils in its base occur also in Canada and Alaska. For instance, D.W.Hayley points out in his paper (Hayley, 1988) that during all 60 years of operation of the Hudson Railway the embankment settlements due to base soil thawing and bridge failures due to frost heaving were constant problems. In order to stabilize subsidence at two test sections 7 km long, 400 heat pipes 9-11 m long were placed along the roadbase. In Alaska in 1985-86 D.P.Zarling and A.W.Braley (Zarling, Braley, 1986) conducted tests for development of the most extreme methods of roadbed treatment (cooling highway slopes in permafrost areas). Three methods were tested.

The first method consisted in building a timber and plywood shed on the road slopes to shade the soil during summer and to protect it against eviction of snow as a heat-insulating cover in winter. There were two test sections. At the first one seven sheds were built over the southern slope, each 9.6 m long and 3.6 m wide there allowing to cover 25.2 m. Along and 9.6 m. Across the embankment. At the second section the shed was 4.2 by 7.2 m. In the both cases the sheds were raised above ground by 0.6 m.

The second method consisted in periodic (once a month during the winter) snow cleaning of the highway berm section 6 by 21 m in size.

The third method consisted in installing thermosiphons on the embankment slopes with evaporator 10.5 m long and radiator 1.4 m long.

Sheds have proved to be most effective. According to D.Zarling and A.Braley, they can be adequate for cooling embankments by 3-5 degrees during a few years. Snow cleaning also appeared to be of considerable use however, it may require greater efforts in the years of heavy snowfalls.

SUMMARY

The Alaska experience proves favorable outlooks for development of strengthening techniques for roadbed base on permafrost soils based on adjustment of the cooling and warming factor ratio with the purpose to reduce the average annual temperature of soils and to preserve them in a perennially frozen state.

Our technological concepts seem to be more effective since a shed covers not only the embankment slope as in D.Zarling's and A.Braley's tests but the whole roadbed; snow cleaning is carried out only when the heat flow goes into the atmosphere while in the summer period the heat flow towards the ground is decreased by light-reflecting painting.

We are ready to cooperate with companies and experts in practical application of the inventions and in optimization of the strengthening techniques for roadbed bases on very icy soils in various regions of Russia and other countries.

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