The Influence of Hydrogeological Factors on the Railway Stability in the Areas of Island Permafrost Distribution (by the Example of the Trans-Baikal Railway, Russia)

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Abstract. Changes in the geocryological situation at the road base and in the adjacent territory should be predicted based on an analysis of regional features of the “climate – landscape – cryolithozone – construction” system. These relationships are manifested in various ways across various cryolithozone regions, with these differences being rather poorly understood. In this regard, in 2019, the Melnikov Permafrost Institute (Yakutsk, Russia) and the Northwest Institute of Eco-Environment and Resources of the Chinese Academy of Sciences signed an agreement on joint research work in order to elucidate the evolution of frozen soils, as well as to justify the application of certain measures to stabilise the permafrost environment. These projects aim to study the cryolithozone response along the routes of projected high-speed highways and existing railway tracks. Since 2019, the Institutes’ representatives along with specialists from the Tynda permafrost station (the branch of Russian Railways), North-Eastern Federal University (Neryungri, Russia), Zabtransproekt (Chita, Russia) and the Institute of Natural Resources, Ecology and Cryology of the Siberian Branch of RAS (Chita, Russia) have been investigating individual sections of the Far Eastern and Trans-Baikal railways in Russia. Some areas here are characterised by the continuous distribution of permafrost soils, while others – by island permafrost distribution. These areas share such common features, as the significant lifetime of linear structures (lasting for several tens of years) and the presence of deformations of the railway track, which appeared in the first years after construction. Railway track sections installed in high-temperature frozen soils are of particular interest for monitoring. However, the construction deformations are not always caused by frozen soil degradation. This article presents the results of surveys at one of such objects – a section of the track confined to the Chernovskaya station of the Trans-Baikal railway.

1. Introduction

Chernovskaya is a railway station located on the Trans-Siberian Railway, 25 km from the city of Chita (Figure 1). The station was founded in 1900. Near the station, a brown coal deposit was discovered, which development began in 1907 and continued until 1994. In the early years, coal was mined by open pit mining, later – by mine development and adits [1].
Figure 1. Location of the Chernovskaya station on a map fragment of the Trans-Baikal Railway (marked with a red rectangle) [Compiled by: PV Kashin, www.pereyezd.ru]

The investigated section of the road passes through the lakes conventionally named Verkhnee and Nizhnee (Figure 2). Stagnant Lake Nizhnee had existed before the construction of the railway. Lake Verkhnee was formed as a result of the road construction, which served as a dam preventing the free passage of water to Lake Nizhnee. In the 60s, water from Lake Verkhnee disappeared due to a decrease in the groundwater level as a result of mine drainage. After the termination of the development of coal mines and mine drainage in 1983, the water level in Lake Verkhnee has recovered and continued to grow.

Figure 2. Diagram of the research area based on an image from space

According to archival data, roadbed deformations at the Chernovskaya station have been occurring since the moment of its construction. These deformations are continuous in nature, and the recorded amount of subsidence in some years reach 9 cm. Engineering-geological surveys of the railway were carried out several times by various organisations, resulting in a number of technical solutions (for
example, the installation of seasonal cooling devices at the embankment base). The degradation of permafrost soils was indicated as the main reason for the violation of the roadbed stability. Indeed, the location of the Chernovskaya station is characterised by a high-temperature type of permafrost (minus 0.1 ° C - minus 1.5 ° C) with island distribution [2–7]. The depth of seasonal freezing in the study area reaches 3.5-5 meters, depending on the deposit lithological composition. Permafrost thickness varies from 10 to 30 m. However, the implemented anti-deformation and cooling measures have not led to the stabilisation of the roadbed.

2. Research Methodology
To clarify the reasons for the violation of roadbed stability at the Chernovskaya station in 2019-2020, a set of works was carried out including geophysical research, aerial photography from unmanned aerial vehicles, targeted drilling of wells, well thermometric observations and laboratory determination of thermophysical and deformation-strength characteristics of soils, as well as the analysis of archival materials.

The number and depth of wells were determined taking into account the actual natural conditions at the monitoring site based on the results of reconnaissance work. The wells were drilled at a depth of 20 m with a self-propelled drilling rig operated in a “dry mode” and with compressed air blowing with a diameter of 132-76 mm. In the process of drilling wells, a trip-by-trip description of all encountered soil varieties was carried out. The samples of undisturbed soils were taken from the wells in order to determine their physical properties and thermophysical characteristics. Field documentation, collection, labelling and transportation of soil samples were carried out in accordance with the requirements of the Russian state standard. Based on the results of laboratory tests for wells, a generalised lithological section was constructed, and engineering-geological elements were identified. Geothermal observations in the wells were carried out according to the following scheme: the vertical spacing of the sensors was 0.5 m in the depth interval 0.0–3.0 m and 1.0 m in the interval 3.0–20.0 m.

3. Results and discussions
The conducted well drilling confirmed the previous conclusions about the heterogeneity of the geological structure of the studied area (Figure 3). Thus, along the roadbed, the permafrost roof was observed at a depth of 5.7 m to 13.0 m or was completely absent up to the well bottom (20 m). According to the results of laboratory tests of research samples from wells, soils at the road base were mainly represented by clay material – loam and silt (Figure 4). Dispersed soils making up the embankment base, can turn into a fluid-plastic state with excessive moisture and lose their bearing capacity. For this purpose, hydrogeological conditions at the survey site are rather favourable (Figure 5) [8-11].
Figure 3. Scheme of interpretation of geophysical data in the study area (Scale 1: 5000) (according to the data of DV GeoProekt and the Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences (IPGG SB RAS); well thermometry – the authors’ own data)
For the Figure 1, legend is described to be: Legend: 1 - PFS boundary at a depth of 10 m; 2 - taliks and permafrost degradation front at a depth of 10 m; 3 - lake contours; 4 - axes of railway tracks and stationing; 5 - well; 6 - groundwater filtration paths within lakes; 7 - place of surface water filtration through a railway line; 8 - place of unloading artesian waters into quaternary deposits; 9 - place of groundwater exit to the surface, swamping; 10 - paths and direction of groundwater filtration under the railway track. Geoelectric section on AB line - altitudes, m. Cut of AB line on geophysical data - altitudes, m; distance, m. 1 - watered soils of fluid-plastic consistency; 2 - human-made soils (ballast); 3 - PFS; 4 - groundwater movement direction; 5 - tectonic disturbances; 6 - established groundwater level according to drilling data.

Figure 4. Averaged lithological section of the wells at the Chernovskaya station of the Trans-Baikal railway
Thus, groundwater and lake waters are fed by the unloading underground artesian waters. The unloading apparently takes place into the bottom sediments of the lakes in the lowermost forms of relief (see Figure 3). The fact of artesian water unloading with insignificant pressure is confirmed by the formation of a small lake, which is located 1.5–1.7 m above the water edge of Verkhnee and Nizhnee Lakes. At the same time, a small stream comes out of the lake with a flow rate of 1.2 l/sec.

Thus, the soils under the railway embankment are in a watered state. The flooding of the embankment with stagnant lakes and the filtration of water through the body of the embankment leads to the waterlogging of clay soils at the embankment base and a decrease in their strength properties. Drilling has exposed the layers of soft and fluid-plastic loams, which are squeezed out by sand and gravel ballast from under the embankment base.

The roadbed object can be divided into 3 deformation zones, each having its own distinctive features (Figure 6). Zone 1 (opposite the station building) is characterised by road deformations largely resulting from heaving processes.
Zone 2 is a track section between stagnant lakes with deformations occurring due to the immersion of the embankment body into the underlying soft-plastic loam.

Zone 3 is a track section, which used to be stable in the past. The deformations of the roadbed at the present time are due to the presence of the layers of fluid-plastic loam at the embankment base. Loam decompaction into a fluid-plastic consistency occurs due to constant contact with water through the layers of sand and coal from above and below.

4. Conclusions
The conducted works have confirmed the following. The specific operating conditions of the linear structure under study on permafrost soils make the deformation characteristics differ significantly depending on the type of their source. The existing information about deformations is contradictory, both in terms of the reasons for their formation and their location. For long-term operated structures, the reasons for the violation of the stable state of the track on specific sections of the road, starting from the moment of construction, have not yet been fully analysed and generalised. This feature directly affects the reliability of various forecast models for assessing the state of both the roads after putting them into operation, and the natural processes occurring in their track. Thus, the expansion of the monitoring network to study the interaction of the linear structure under study and permafrost is still a necessity.

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