Assessment of the Stability of Linear Structures in Transitional Natural Regions of the Yakutia Permafrost Zone

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Abstract. The operational reliability of individual road or railway sections represents a function of their initial state, cargo intensity, road maintenance, and, most importantly, the interaction of structures and materials of the roadbed with the environment. A lack of connections between factors affecting the reliability of the railway sector, as well as the random nature of these factors, requires systematic research using specialized techniques. The development and application of such techniques is of particular importance for ensuring the stability of roads in natural regions of a transitional type. The significance of carrying out an assessment of local geological, soil, permafrost and other conditions in such regions is demonstrated on the example of investigating the impact of cryogenic weathering and seismic hazard on the stability of the Amur-Yakutsk Mainline.

1. Introduction

Despite extensive experience in the construction and operation of railways and roads in permafrost zones, the interest in the stability of such systems is still growing. Due to the specific operating conditions of linear structures installed in permafrost soils, deformations here are determined by the nature of their sources. As a result, information on such deformations is frequently contradictory in terms of both their location and origin. Factors affecting the stability of individual road sections remain to be comprehensively analysed and generalized. The multifactorial influence of the environment on linear structures in harsh climatic conditions impedes a reliable differentiation of destructive processes by the level of severity [1-7]. This affects the reliability of prognostic models used to assess both the state of roads in the long term and the natural processes occurring in their lane.

A serious challenge in the development of prognostic models for assessing road stability consists in the problem of identifying processes occurring in the areas where roads border with natural regions of different types (e.g., at the junction of engineering and geological landscapes). In these areas, the unevenness of deformations, rather than their absolute values, presents particular danger. In addition, the operational reliability of transport facilities suffers from insufficient attention at the design stage to existing information on the natural and climatic conditions of certain regions. This frequently leads to additional expenses on road maintenance and reconstruction.

Therefore, it is important to study specific geological, soil, permafrost and other conditions in natural regions with harsh conditions using specialized research techniques. This paper is aimed at...
assessing the impact of cryogenic weathering and possible seismic hazard on the stability of the Amur-Yakutsk Mainline (AYaM).

2. Research methods and results
The assessment of cryogenic weathering impact was carried out at the sections of the Tommot-Kerdem railway (figure 1) having the same embankment design (dimensions, soil composition in the body of the embankment, etc.), although located at the junctions of the engineering and geological landscapes: upper part of the slope ↔ bottom of the river valley.

![Figure 1. Amur-Yakutsk Mainline on the map of Russia: 1 – Amur-Yakutsk Mainline; 2 – Tommot-Kerdem railroad; 3 – localities; 4 – water bodies; 5 – study sections.](image)

According to the analysis of field data conducted in 2008–2017, the climatic conditions in the railway line were conducive to intensive cryogenic weathering [8, 9]. The impact of cryogenic weathering here is manifested in the disintegration of coarse-grained soils used as a building material for the upper structure of the embankment and other elements of the railway.

The conducted analysis shows that the highest degree of destruction was characteristic of the embankment located at the bottom of the river valley. The destruction of the embankment rocks occurred by splitting. For comparison, the prevailing destruction process in the area passing through the upper part of the slope was desquamation. The number of rock freezing and thawing cycles (the main factor in cryogenic weathering) on the embankment surface in the river valley comprised 115 cycles during the year, which was 11–17% higher compared to this value in the road section on the upper part of the slope.

A subsequent research stage was the examination of rock samples for determining their frost resistance. It is known that conventional techniques for frost resistance determination analyse rocks having undergone 25 freezing and thawing cycles, without taking into account the actual load of the rock as part of embankment (e.g., in a highly humid or arid environment, in contact with ice, etc.) [10-16]. However, for the railway sections under study, the average number of freezing and thawing cycles on the land surface exceeded 25 cycles significantly. The conducted laboratory tests revealed that, for the rocks composing the upper structure of the embankment in the river valley, the strength value decreased by 27% following 200 cycles of alternate freezing and thawing. This parameter decreased by 18% for the rock samples from the embankment in the upper part of the slope. It should be noted that, according to the CP-622 ‘Technical conditions for planning preventive repairs of engineering
structures of Russian railways’ [17], the overhaul frequency for drainage ditches reinforced with rocky soil, rock dumping and gabions comprises 8–10, 5 and 7 years, respectively. However, the data on the rock destruction intensity obtained for the railway section in the river valley indicates that maintenance works in this section should be conducted in earlier periods. This, ultimately, leads to a decrease in the traffic speed of trains.

During the observation period of 2 years, the number of railway track deformations associated with the disintegration of rocks under the influence of cryogenic weathering in the upper part of the slope was almost 2 times lower as compared to the section at the bottom of the river valley (9 versus 5 deformations). In the former case, the disintegration of coarse rocks composing the upper structure of the embankment acted as an independent negative factor in the violation of the roadbed stability. Thus, crushing of large rock fragments under the influence of freeze-thaw temperatures leads to the subsidence of the levelling layer as a result of its compaction. In the latter case, the cryogenic weathering of rocks composing the upper structure of the embankment and other elements of the railway track activated additional unfavourable cryogenic processes. A change in the granulometric composition of soils, in some cases, fundamentally transforms the temperature regime both in the roadbed and the base. Thus, grinding of coarse clastic fragments in rock dumping leads to void colmatation and alternating heat transfer processes. In general, the deformations identified at the sections under study included hill waste, caving, fill washout, subsidence of the embankment upper layer, washout and berm erosion (figure 2).

![Figure 2](image_url)

**Figure 2.** Deformations in the railway embankment at the bottom of the river valley caused by additional or exclusive influence of cryogenic weathering.

Similar to the study of cryogenic weathering, an assessment of possible seismic hazard for the Amur-Yakutsk Mainline was carried out at the junction of the engineering and geological landscapes of a shallow bluff and a floodplain river terrace [18]. Seismological studies were conducted at the sections of the Berkakit-Tommot railway (see figure 1). Accelerographs were installed according to the scheme in Figure 3. Stations 001 and 002 were located on the bluff and the floodplain river terrace, respectively. During observations, high-amplitude seismic signals from two types of sources were recorded, including a passing freight train and an industrial explosion at the Neryungri coal mine. The results showed that seismic intensity increases in the transition sections from the bluff to the floodplain river terrace. In other words, the heterogeneity of the soil strata at the junction of landscapes causes a growing increase in the amplitude of ground motion.
3. Conclusion
Unfortunately, extensive experience in the construction and operation of railways and roads does not eliminate the negative effects of deformations, frequently of an emergency nature, associated with cryogenic and other phenomena. In this regard, regular monitoring should be seen as a criterion of the reliability and trouble-free operation of geotechnical systems. Monitoring observations are key to elucidating the nature of processes occurring in the impact zone of engineering objects at the borders of different natural regions, thus permitting characterization of external and internal changes in the roadbed in the long term (e.g., after several decades of operation for long-operated railroads of the Amur-Yakutsk Mainline).

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