Causes of Roadbed Deformations on Railways in South of Primorsky Region

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Abstract. The Russian Far East is a developing territory that is of a geopolitical importance for the country. A distinctive and significant role play the railroads that comprise 71% of total traffic. This explains a special attention of the state bodies to the railroad maintenance. The target of research is the roadbed deformation on some sections in the south of the Primorsky Region. The roads are built in complex engineering and geological conditions that suppose seasonal flooding and extreme weather conditions which produce some challenges for maintenance. The paper presents the results of field researches, current state data and surveys of hazardous road sections carried out by Far East State Transport University, Khabarovsk, Russia. Some consistent causes of deformation are determined, and the design and technological solutions as well as stability methods are offered for this region.

1. Introduction

The Primorsky Region is characterized by very complicated natural, climatic, engineering and geological, seismic and tectonic conditions which imply a serious risk for transport system functioning. This fact must be taken into account when roads are projected, constructed and exploited. Increasing of traffic and axle loading as well as an introduction of new technologies in transportation must be introduced on the basis of a scientific conception that includes rational usage of the geological environment. This approach should be applied in projection of new and reconstruction of current railway lines as well as a construction of protective structures for elimination the barrier zones to make railroads and automobile roads of the Primorye operate faultlessly and continuously.

The most hazardous and significant natural factors are climatic and geological conditions. They have an impact on road deterioration through torrential monsoon, typhoons, etc., and consequent flooding of territories at these periods causes essential problems in road exploitation due to disturbances of earth stability.

Safety and continuous operation of transport are directly connected with the natural earth structure “environment-roadbed-subgrade” and its condition.

The paper presents the analytical results of geological engineering works, surveys and registrations made at different time periods. Some real cases of the railroad sections in the south of the Primorye are given as samples for description of hazardous processes and phenomena. According to the
researching results received on these sections, the consistency in appearance of settlement deformations, creeps, landslides, etc., is determined in the roadbed. The causes of deformations in the automobile and rail roadbed are researched in the south of the Prymorye to develop effective stability measures for similar projects implemented in places where the above mentioned environmental extremes occur.

2. Hazardous geological processes and phenomena in the south of the Primorsky region

2.1. Hazardous geological processes

The southern part of the territory belongs orographically to the Khasan-Barbash mountainous region and is characterized by hazardous geological processes, such as erosions, landslides and down-falls. Landslides are possible in the river valleys and narrow valleys with steep slopes that have bed slopes and talwegs made of clay formations. The railway line Baranovsky-Khasan was built in 1950-s in accordance with the wartime norms. The line condition is unsatisfactory because the roadbed of the line is a subject for hazardous geological processes in many locations. Engineering geological conditions of area are severe for construction. The embankments built from the local soil undergo slope creeps, and there are many cases of increased slope gradient, settlement and deformations of the culvert inlets and outlets.

The railway line stretches for 50 km along the peripheral part of the Borisov plateau-basalt the slopes of which represent landslide deposits. The conditions in the area enhance the appearance and development of landslide processes. For example, after a period of torrential rains in 2003 and in 2017, there was a slide of land mass followed by a considerable destruction of the roadbed accounting 52 km in total, thus the line was working in emergency conditions for two months in 2017.

The analysis of vulnerable places show that the road is characterized mostly by such deformations as slope creeps, heaving, landslides, the roadbed settlement, etc.

Fig. 1 shows a diagram defining the proportions of different kinds of deformations on the Baranovsky-Khasan line. The diagram is composed on a database obtained with the roadbed automatic control system program.

![Figure 1. Distribution of deformations, Baranovsky-Khasan line.](image)

The reasons of the roadbed instability are connected with the ability of its layers of fine and gravel sands and those of crushed stone to let the precipitation go through to a surface of the embankment clay core. As a result, the soils slide on the slopes along the clay core of the embankment making the structure deformed. Such a structure of the embankment being typical for this railway line enhances the water concentration, thus making the contact place of clayed soil and drainage soils overwet.
Subsequently, the roadbed core being made of clayed soil swells on wetting quickly, so its hard consistency becomes high-plastic and yielding practically skipping the low plastic phase. The strength of soil rehabilitation requires a much more longer period than that between summer precipitation, that is why the clayey soils of the embankment are mostly in a plastic and high-plastic state during the summer time. The subgrade is characterized by low plastic and medium hard consistency that provides quite an acceptable bearing capacity.

Another major cause of deformations in the roadbed are groundwaters. Their levels can significantly decrease or increase due to changes in geological conditions in the area.

The soil contains bound or unbound water, in a vapor phase, or as ice at sub-zero temperatures. When the groundwater moves at above-critical speed, the filtering flow removes soil particles (first, the finest; next, the bigger ones). Subsequently, it leads to the soil loosening and is called a mechanical suffosion.

Along with the above mentioned factors, there is another cause that provokes appearance and development of deformations in the roadbed. The embankments located on hillside, even of little gradient, can be flooded during the periods of rains or snow-melting. However, the hill ditch prevents masses of water to be accumulated at the embankment foot of the upstream slope. Thus, the main cause of embankment deformations is overwetting of the clayey core that leads to settlement of the upper part of the embankment under dynamic forces of the railway traffic, the increased ballast weight and the railway superstructure.

2.2. Natural phenomena

The climatic conditions of the Primorsky region are known for flooding as a major danger in construction and exploitation of infrastructural designs [1,2]. The common methods of flooding prevention is setting a drainage system and subgrade isolation. The consequences of flooding are shown in Fig.2 and Fig.3.
In August 2017, the Far Eastern State Transport University carried out a research on determining the causes of destructions and deformations on some bridges and sections of the roadbed on the Trans-Siberian Mainline and Baranovsky-Khasan Line. The disruption took place as a result of torrential rains and flooding caused by the typhoon Nora on 6-7 August, 2017. Below are some examples of the destructions.

A visual survey of the river crossing on the Baranovsky-Khasan Line, 7th km, shows the following malfunctions: wash-out of piers, abutment #3 wash-out, wash-outs in the approaching embankments. The pier tilt is 3.0 cm to the top, and there is a shift in the same direction of 133 mm that makes an angle of roll in the plane (data date 10/08/2017). There is a tapered wash-out of 6.0 m deep on the top side of the pier, and on the bottom side - another one of 3.0 m deep (Fig.4).

The survey proves a meander character of the riverbed. The artificial structure team carry out qualified reconstruction works including the plane and profile alignment of the deck through its shifting and putting slabs under the bearing on abutment #3. It is additionally recommended to fill the tapered wash-outs at abutment #3 with hard rock and set monitoring observations. In case of long-term deformations, it is recommended to make the piers’ foundation wider and reinforced with the drilled caisson.

The approaching embankments are also reconstructed with some strengthening measures, such as filling the berms with fine-graded soils setting counterberms of rock mass.
The typhoon makes devastating deformations at the river crossing on the 14
th km. Span #1 is washed out. The first factor contributed to this fact is an increase in water accumulation that happens because of elimination of the drainage structure due to rearrangements in the area to give way to a new development of a settlement in the high surface relief. The second factor comes as a result of the first one: overrunning the river high-water mark under the bridge which supposes the maximum probable flood once in 300 years.

![Figure 5. Span #1 wash-out at 14
th km of road.](image)

The first recommendation is to increase the under-bridge clearance to provide the flood discharge over the target design of a 300-year maximum flood probability. The second recommendation is to carry out observation and research works to develop engineering solutions for protection of the river crossing territory.

3. Diagnostic control of rail and automobile road conditions

The works of Far Eastern State Transport University (FESTU) on diagnostics of technical conditions of the railway roadbed are carried out on the section Kuznetsovo-Khmylovskiy according to the methods that have been already tested in similar conditions. The diagnostic device, SDG-M, is developed by Foundation Engineering Research Laboratory, FESTU, and the INKO, LLC, Khabarovsk, and is used to make the traditional survey methods more accurate [2]. The device developers receive four patents and a certificate for their innovation.

The course of the work include some steps, such as a development of a monitoring program, installation of marks for check levelling in the roadbed and berms and monitoring observations according to the developed program.

The section under survey is located on the right bank of the Partizanskaya river, two kilometers away from its estuary within the marine-built terrace which is almost flat with a three-degree gradient in the direction of the America armlet. The terrace is a low swampy plain which is gently undulating in some areas. The terrace is formed due to the sea regression. In a run of wet weather, most of the terrace is covered with water which stagnates at the swampy areas. There are some railway service structures on the territory.

The biggest hydrographical feature of the territory is the Partizanskaya river. In its low course, the river has a wide, somewhere over 4 km, well-developed valley with a number of dead channels and arms. The river bed is irregular and changes its location after torrential floods.

The corrosivity of silt on the section is high, while for high-plastic loam and soft sandy loam it is medium, and for silty sand of fine and average course it is very low. The project design has specified the embankment settlement that equals 60% of the peat layer capacity.

On the section, a layer of sand is covered with loam of 0.6 – 1.5 m thick. The loam consistency is stiff up to 0.4 – 0.5 m in depth under the embankment, whereas it is high-plastic in deeper areas.
The amount of precipitation in July registers its minimum of 150 mm, and the maximum of 520 mm making an average of 300 mm in the whole period. Thus, for the summer period, the settlement on the left side of the embankment has become twice as great as on its right side.

The modernized hardware-software system “SDG-7” helps to control such parameters as vibration displacements within 30 Hz, soil displacement, high-definition thermal and moisture parameters in soil and soil pressure. At the same time, the control is distributed and mobile coming from a mobile working station; data collection, processing and visualization are carried out online. The device is used to make researches on the 14th km of the Khasan-Razdolnoye road (Fig.5).

**Figure 6.** Destructive character of deformations on 14th km of the Khasan-Razdolnoy road.

Before the research, the microrelief is contoured in 0.25, which gives more data about the causes of deformations, in particular:
- in all areas of intensive deformations, there is not only a layer of weak silt soils, but also filtering waters or over-wettings in local low places, such as narrows, hollows, etc.;
- in the areas, there are some uplifts;
- some boiling in the foot area due to soil settlement is observed during a levelling survey. As far as the character of deformations, it is uneven and incrementally increasing in June-July, whereas in September, after the destruction in August, it is smooth as the embankment deformations are temporarily stabilizing.

4. **Conclusions**
1. According to the researches, the causes of roadbed deformations are not only of the natural disaster origin but are also connected with incorrect engineering and geological data involved or determined by an inadequate design.
2. The picture of the kinetic process gives a clear idea about changes in the strain and stress condition in time and helps distinguish the critical points of transition from a stable state to an unstable one. The growth of strains and stresses makes the elastic domain less, while the plastic shift areas increase.
3. The pore water interacting with the soil skeleton moves penetrating through the ground. Its force impact when it flows round the skeleton particles, often called a filtering pressure, can substantially influence the strain and stress state of soils and their strength. The pore water can disrupt the soil structure and remove small soil particles through the pores made by bigger grains of the skeleton, that is so called internal soil wash-out, or suffusion. The pore water sometimes moves all the soil mass out, that is a soil filtering lift phenomenon, or internal soil erosion [3].
4. If the filtering pressure of effluent water is great enough to remove the skeleton particles, the washing-out process (the deep soil, or internal, erosion) starts, and eventually results in appearance of
holes and gullies. In this case, it is reasonable to use reinforcing or reinforced drainage structures [5-12].

5. If the pore water is freely squeezed out on the borders of the deformed massive or water-bearing ground, the soil is considered an open system and requires more drainage devices collecting ground waters (drainage systems) [8-9].

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