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Settlement Control Technology of High Filled Soil-Rock Embankment in Alpine and High-Altitude Areas

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Abstract: China's infrastructure has gradually achieved large-scale development, and transportation construction has also shifted from east to west, transitioning from plains to mountainous areas. High-fill embankments of different sizes in mountainous areas are unavoidable, and the settlement of high-fill embankments is usually the most concerned issue in high-fill projects. According to the current research of highway projects, most of the high embankments in mountainous areas are soil-rock mixed embankments or rock-filled embankments, and their post-construction settlements are directly related to construction technology and the type of filler used. In this paper, the problems in the settlement control of earth-filled embankment and related factors are analyzed in detail. The settlement control technology of high-fill embankment in high-cold and high-altitude areas is also discussed, so as to ensure the overall quality of high-fill embankment.

Keywords: High-altitude and cold areas; High soil-rock embankment; Settlement control technology

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1. Introduction

The scale of highway network in China has been increasing, and road traffic has gradually shifted from rolling terrain to hilly terrain. Especially after the development of western China was initiated, the development of road traffic has been heading towards the western mountains. Western China is dominated by hilly terrain. Compared with plain areas, the geological conditions are more complex, with harsh working environments, making road construction difficult. Therefore, due to limited resources, it is inevitable to use soil-rock mixture to fill the embankment. The soil-rock filling material is made of a mixture of soil and rock. The particle diameter is larger than that of the soil filler with less cohesion. It is quite different from the soil filler in terms of mechanical properties and structure.

2. Problems in settlement control of high-fill soil-rock embankment in cold and high-altitude areas

2.1. Permafrost

Frozen soil refers to all kinds of ice-containing soil and rocks, which can usually be divided into permafrost, seasonal frozen soil and short-term frozen soil. Permafrost has certain rheological properties and is more sensitive to temperature. Alpine and high-altitude areas, often situated in permafrost regions, typically fall within the inland alpine climate zone. These areas are characterized by an extended freezing period, abundant sunshine, and significant temperature fluctuations between day and night. The roads in the study area generally have seasonal frozen soil, which gradually starts to freeze from October and melts gradually from April of the following year, with the maximum thickness of the frozen layer being 0.9–1.5 m.

Seasonally frozen soil is when the soil is frozen in winter and thaws in spring. Weak frost heave, no frost heave, frost heave, and strong frost heave are the main types of seasonal frozen soil, and thaw collapse, strong thaw settlement, thaw settlement, weak thaw settlement, and no thaw settlement are the five types of settlement of seasonal frozen soil. During the freezing process, the mechanical properties of the frozen soil will change sharply with the decrease of temperature, and the strength of the soil layer will decrease significantly after the frozen soil thaws. Frost heave and thaw settlement are important causes of common faults in subgrades containing frozen soil. According to existing data, frost heave and thawing account for 15% and thaw settlement account for 85%. Frost heave is mainly caused by raised cracks on the subgrade, frost heave mounds and ice cones, etc. Thaw settlement is mainly composed of longitudinal and transverse cracks, slope deformation, pavement damage, etc.[1]. Therefore, in the construction and management of seasonal frozen soil regions, the adverse effects of thawing and frost heaving on road structures and subgrades should be studied.

2.2. Geological disasters

2.2.1. Debris flow

The landforms in the alpine and high-altitude areas are more complex, with large differences in height. Most of the slopes exceed 30°, with higher peaks and lower canyons, and most of the canyons are surrounded by mountains. It is conducive to the convergence of rivers. The middle reaches of the river are relatively narrow and steep, while the lower reaches of the river are dominated by open canyon terraces, which are conducive to the accumulation of clastic materials. This area is mainly composed of schist and thin crystals, where soft and hard joints and beddings are developed. Due to the geological changes and weathering in the geological history period, the rocks are generally in a broken state, which is the main reason for the debris flow in this area.

2.2.2. Slope body

Slopes in cold and high-altitude areas are more prone to disasters, which can be divided into two types: rocky unstable slopes and soil unstable slopes. The foot of slopes that are close to the river bank are usually unstable, and its bottom is easily damaged and deformed by the erosion of the river. Most of the rocks are quaternary gravel soil and loose slope silt, which can easily lead to deformation and instability of the slope during excavation. Unstable rocky slopes are mainly concentrated on both sides of the valley and the steep slope area of the mountain. The original slope height is about 20–50 m, and the slope is about 50°–60°. There are mainly strongly weathered rocks here, and there are one or two sets of tension cracks of varying lengths with low current stability. Landslides are prone to occur, and the slope may become unstable due to heavy rain, which may lead to disasters such as landslides and collapses. Most of the unstable slopes are far away from the road, so the road is less impacted.

3. Factors affecting the settlement control of high-fill soil-rock embankments in high-cold and high-altitude areas

3.1. Construction quality

3.1.1. Porosity

Studies showed that the porosity inside the foundation will change with time due to rainfall, which is related to the erosion of a small amount of fine aggregate layer inside the foundation. The investigation of a certain kind of embankment foundation filled with soil and stone shows that there are many fine-grained substances in the interlayer of piled slope rock mass[2]. Although the soil-rock mixed road has high strength, the particles in the roadbed will be rearranged under the vibration of the vehicle load, and the fine-grained substances in the roadbed will settle. As a result, the void ratio of the roadbed gravel filling increases and the subgrade becomes less stable. In order to eliminate the change of void ratio caused by the migration of particulate matter in the soil-rock mixed fill embankment, the root problem must be solved. When permafrost thaws, the change of pores is also an important factor for soil fusion. Generally, the porosity that subsides due to uneven melting is called the optimal void ratio, and the optimal void ratios of some frozen soils are shown in Table 1.

Table 1 The measured optimal void ratio of representative frozen soils

Filler	Optimal void ratio e_{md}
Sandy soil	0.55
Pebble gravel soil with silt and clay content greater than 12%	0.35
Clay and loam	0.65
Pebble gravel soil with silt and clay content less than 12%	0.40
Gravel clayey soil	0.40

3.1.2. Degree of compaction

If the degree of compaction of the subgrade pavement does not meet the design standards, it will be difficult to compact the border areas on both sides of the embankment. In addition, the side slopes on both sides are eroded and infiltrated by rainfall, and partial settlement often occurs here. During the construction process, the height difference between the edge of the subgrade and the middle position increases, and in severe cases, cracks between the subgrade and the edge of the subgrade will occur, and staggered platforms and subsidence will also occur during the construction process. Because there is a gap under the lane, the rainwater can seep from the gap to the base layer. During heavy traffic, the lane would be affected and the road surface will be damaged[3].

3.2. Filler

3.2.1. Soil quality

In various types of embankments, as long as they have a certain strength and can form a stable filling by tamping, they can be used as embankment materials. Different soil-rock mixture will have different effects on embankment settlement. For example, roadbed mixed with rock materials has better drainage and permeability due to its high density and strength. Therefore, its post-construction settlement is much smaller than that of stone packing, which has lower water permeability.

Soils with different properties have different thaw-sedimentation coefficients. It has been found through several experiments that the relationship between the thawing characteristics of various soils is as follows: sandy gravel soil < heavy clay < silty clay; under the condition of water saturation, the thawing coefficient of the coarse-grained frozen soil increases with the increase of silt viscosity, and when its composition exceeds 12%, the thawing coefficient will increase rapidly. Therefore, 12% is an important value of the viscous component of the powder[4].

3.2.2. Soil-rock ratio

The rock content in the filler is the soil-rock ratio of the filler. The soil-rock ratio is directly related to the compaction of each layer of the embankment, and then directly related to the settlement of the entire embankment slope. The results show that the maximum dry density of soil-rock mixture changes with the stone content, and this maximum value can be divided into three periods, namely, the slow growth stage, the rapid growth stage, and the gradual decrease stage. The stone content of each stage must be determined through relevant analysis. In addition, under the same stone content, the particle size of the coarse aggregate directly affects the maximum dry density of the soil and stone mixture.

3. 2. 3. Foundation

There are mainly two types of foundations, artificial foundations and natural foundations. Among them, natural foundations are limited by conditions such as soil stress and groundwater level, while the artificial foundations are affected by the treatment method and the soil used. Although the weight of the natural ground itself has basically consolidated the subgrade, but as the construction progresses and the number of applied layers increases, the natural foundation will also settle, and the size of the settlement is directly related to the embankment filling and filling height. In addition, the shape of the foundation will also have a certain impact on the settlement of the subgrade. The settlement of a flat embankment is mainly concentrated in the middle of the roadbed, which is also where the maximum settlement occurs. The momentary subsidence in the middle of the embankment increases with each upward loading, and decreases again in the intermittent stage. However, maximum settlement does not occur at the top of the embankment but close to the slope. The settlement should gradually increase from the inner side of the side slope adjacent to the embankment to the outer side of another free surface[5].

4. Settlement control technology of high-fill soil-rock embankment in cold and high-altitude areas

4. 1. Shallow soft soil construction technology

4. 1. 1. Dredging

To control the sediment of high-fill soil-rock embankment in cold and high-altitude areas, the soft clay in this area was penetrated by using a lightweight dynamic penetrometer, so as to clarify the scope of dredging in this area. When the filling depth of the high-fill embankment exceeds 20 meters, the allowable load should exceed 320 kPa. Since the lightweight dynamic penetrometer does not measure the depth accurately, , if there is still soft soil observed with the naked eye even after penetrating to the supposed soft soil depth, further penetrating experiments should be carried out to determine the depth for soft soil removal. The key is to remove all soft soils. The next step of construction can only be carried out after being checked and accepted by relevant supervisory and management personnel.

4. 1. 2. Temporary drainage

Drainage is a key step in roadbed construction. Water can cause great damage to the roadbed and road surface, and poor drainage will increase the moisture content in the filler, resulting in soft soil. This reduces its strength and stability, causing subsidence or plastic deformation. It is important to keep the moisture content of the foundation at a certain level. Intercepting ditch, diversion ditch, and temporary drainage ditch should be excavated according to the subgrade boundary and land boundary to create an unimpeded drainage system. Temporary drainage pipes must be equipped with permanent drainage pipes, and the water flow cannot be directly discharged to the field to avoid affecting surrounding environment, or else can it cause sediment and erosion. Therefore, the water should be discharged as far away possible.

4.1.3. Paving and leveling

The most important step in embankment construction is the paving of soil-rock filler. The selection of this process can be related to the overall quality of soil-rock filler embankment, and the quality of each layer is related to the settlement of the whole embankment after construction. When lithological materials are used in the fillings, the paving of the subgrade will directly determine the structural form of the subgrade compaction layer, thus having a direct impact on the compaction of the subgrade. It is necessary to select a suitable paving method so that the filler can be evenly distributed among the layers, and the segregation of the filler can be prevented. In this process, strict requirements are put forward for the thickness of the loose layer, the maximum particle size of the filler, and the gradation of the asphalt mixture[6].

In the current subgrade construction, there are mainly three common paving methods:

(1) Progressive paving method

In the progressive paving method, the unloading vehicle unloads the material sequentially on the filling surface from the beginning to the end, and a bulldozer is used to complete the paving and leveling[7].

(2) Backward paving method

In backward paving method, the unloading truck unloads the material on the surface of the rolled layer from the end to the front in a backward manner, thereby forming many compact packing piles; and then paving and leveling is carried out. In general, this method is suitable for fillers with finer particles.

(3) Mixed paving method

In the mixed paving method, the backward paving method is used to unload the material when laying a new layer, thus forming a certain filling pile, and then a bulldozer is used to pave it a certain thickness is achieved. Next, the progressive paving method is used to discharge the material onto paved layer. This method is suitable for applying thicker fillers[8].

Three different paving methods on the same thickness of filling were compared in terms of soil-rock high-fill road, surface smoothness, and compaction. The flatness of the surface was observed with the naked eye, and in the compaction process, the same machinery and compaction method were used, and the degree of compaction and porosity after compaction were tested and compared.

Table 2 shows the comparison of rolling effects between the backward paving method and the progressive paving method under the same compaction method, with a paving thickness of about 70 cm.

Table 2 Comparison of rolling effect between retreat paving method and progressive paving method

Paving method	Compactness (%)	Sedimentation rate (%)	Porosity (%)
Progressive paving method	92.6	9.32	22.7
Back paving method	94.8	9.74	20.1

(3) Key quality control

(1) Cross-section measurement and construction stakeout should be carried out. The stakeout accuracy of high-fill embankments is the primary link and key content of high-fill embankment construction quality monitoring. (2) The original roadbed should be treated and consolidated according to relevant specifications provisions. (3) Strengthen the management of loose laying thickness and cross slope of each layer[9]. (4) Materials that meet the design requirements should be selected, and the maximum dry density and optimal moisture content of the filler should be measured accurately. (5) The high-fill embankment should be started early, but not too early, so that the high-fill embankment has more settlement time[10]. (6) When treating the original surface of the high-fill embankment, the embankment

can be widened correspondingly or built with back pressure slope protection.

5. Conclusion

There are many deficiencies in the construction and management process of high-fill soil-rock embankments in high-altitude and cold areas in China, resulting in self-produced tunnel spoils piling up and the insufficiency of filling materials. Therefore, this paper analyzes the permafrost and geological hazards in the settlement control of high-fill embankments in high-cold and high-altitude areas. Besides, factors that affect the settlement of high-fill embankments, such as construction quality, fillers, and foundations are also explained. The technical requirements for filling layers of high-fill earth-rock embankments are also clarified, so as to provide support for the research and development of high-fill earth-rock embankment settlement control technology in cold and high-altitude areas.

Disclosure statement

The author declares no conflict of interest.

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