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Research on Comprehensive Treatment Technology of High Fill and Deep Excavation Special Subgrade of Mountain Highway

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Abstract: The terrain of mountainous areas is high and undulating. This leads to high filling and deep excavation in the construction of mountain roads. The quality and safety risk of high fill and deep excavation construction is greater. If the construction treatment or subsequent treatment is improper, it is very easy to cause engineering diseases. Based on this, this paper takes the characteristics of high fill and deep excavation special subgrade projects in mountainous areas as the breakthrough point to explore the particularity of the project. Then, from the perspective of the disease mechanism of high fill and deep excavation subgrade, this paper analyzes the internal logic of common diseases such as subgrade settlement deformation, slope instability, damage, and destruction. Finally, the paper summarizes the key technologies for the treatment of high fill and deep excavation special subgrade in mountainous areas, and the disease problems and mechanism of anchored high fill and deep excavation subgrade. And it explores the effective disease treatment technology to ensure the high-quality development of Highway Engineering in mountainous areas.

Keywords: Mountain highway; Special subgrade with high filling and deep excavation; Compaction reinforcement technology; Slope reinforcement treatment

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1. Introduction

Against the background of the continuous expansion of China's highway network, the construction projects of mountain roads are increasing. However, due to the undulating terrain, complex terrain structure, and serious and deep weathering of the rock and soil layer in the mountain area, the construction of highway subgrade is more difficult. In order to ensure the safety of highway construction, the subgrade construction needs to adopt the special construction technology of high filling and deep excavation [1]. But the scope of earth excavation and filling construction in this construction process is too large. So the disturbance to the soil is serious, and it will inevitably have a huge and far-reaching impact on the stress of the soil, and then lead to the subgrade disease in the operation of subsequent projects. Moreover, through the statistics of subgrade diseases of highways in mountainous areas, it can be found that the proportion of high fill and deep excavation subgrade diseases is significantly higher (accounting for 78.2%), and the treatment is more difficult. This makes the traditional plain highway subgrade treatment technology unable to meet its treatment needs. Therefore, construction enterprises should explore accurate and efficient treatment technologies in combination with the characteristics of high fill and deep excavation subgrade engineering of mountain highway, so as to improve the stability of high fill and deep excavation subgrade.

2. Characteristics of high filling and deep excavation subgrade engineering in mountainous areas

Due to the influence of geographical location, the terrain difference of high filling and deep excavation subgrade in a mountainous area is large. Moreover, the geotechnical types are complex (refer to **Table 1** for details), which leads to uneven distribution of subgrade stress. Therefore, in order to ensure the quality of highway construction, it is necessary to adopt the method of high filling and deep excavation to ensure the stability of the highway structure. This leads to excessive subgrade filling height (>20m) and excessive excavation depth (more than 15 m). This construction mode will inevitably increase the self-weight of the filled soil, and then increase the stress of the subgrade [2]. At the same time, slope excavation will affect the soil structure, causing soil structure deformation and increasing the risk of slope instability. The soil structure in mountainous areas is also complex, and most of the filling soil is mainly a soil-rock mixture. The uneven size and structure of soil and rock particles not only easily cause the problem of large soil porosity, but also increase the risk of rainwater infiltration, thus increasing the probability of consolidation settlement. In addition, the rainfall in mountainous areas is relatively large, and the long-term scouring and soaking of the basement by rainwater can easily lead to soil softening, further increasing the risk of slope instability. Due to the limited space of highway construction sites in mountainous areas, it is also difficult to carry out some construction technologies. Furthermore, the operation of some large machinery is limited, which leads to the inadequate implementation of subgrade compaction and slope trimming technology. The occurrence of these problems will affect the quality of subgrade construction, so it will increase the incidence of subgrade diseases [3].

Table 1. Characteristics of high filling and deep excavation subgrade in mountainous areas

Type of subgrade	Geotechnical structure	Moisture content (%)
High fill subgrade	Earth-rock mixed soil	18.622.3
Deep excavation subgrade	Weathered mudstone soil	23.527.8
Special subgrade	Expansive soil, soft soil	26.431.2

3. Analysis of the disease mechanism of high fill and deep excavation subgrade

3.1. Disease mechanism of settlement deformation of high fill subgrade

High fill subgrade is prone to settlement and deformation diseases. According to its settlement deformation characteristics, it can be divided into three types: one is instantaneous settlement. It is generally caused by a sudden increase in load, which leads to rapid deformation of the soil, but the deformation elasticity of the instantaneous settlement is large, and there is the possibility of subsequent recovery [4]. The second is a consolidation settlement, which is also the most common settlement disease. It is not elastic and will continue to accumulate. This settlement type is mainly due to the high porosity and self-weight of the high fill subgrade. Combined with external loads, it leads to the continuous and significant reduction of the porosity of the soil. And the amount of settlement formed by different soil layer structures is different. The calculation method of consolidation settlement of high fill subgrade can refer to Formula 1:

$$S = \sum_{i=1}^{n} \frac{\sigma_{zi}}{E_{si}} h_i \tag{1}$$

In the formula: S is the final consolidation settlement of subgrade (mm); σ_{zi} is the average additional stress of soil layer the i-th soil layer (kPa); h_i is the thickness of the i-th layer of fill (m); E_{si} is the compression modulus of the i-th soil layer (MPa); n is the number of filling layers.

It can be seen that the consolidation settlement is directly related to the fill thickness, and the fill thickness of high fill subgrade is larger, so the problem of consolidation compression settlement will be more obvious. The third is secondary consolidation settlement. The settlement occurs after the consolidation settlement is basically stable, which is manifested as a relatively subtle settlement problem.

3.2. Mechanism of instability disease of the deep excavation subgrade slope

The most common disease of deep excavation subgrade in mountainous areas is the instability of the subgrade slope. This is because the deep excavation of the subgrade will cause disturbance to the mountain structure, which will lead to serious and irreversible structural deformation, resulting in cracks in the slope and other problems [5]. At the same time, under the action of external load, it is very easy to cause slope collapse or a landslide. The core cause of slope instability is the loose soil structure, which seriously affects its shear strength, and then leads to the reduction of the safety factor of soil stability. The calculation formula of the stability safety factor can refer to Formula 2:

$$K_s = \frac{\sum ((_i l_i \cos\alpha_i - u_i l_i)\tan\varphi_i}{\sum G_i \sin\alpha_i} \tag{2}$$

In the formula: K_s is the safety factor of slope stability; c_i is the cohesion of the soil (kPa); l_i is the length of the slip arc (m); G_i is the weight of the soil (kN); α_i is the dip angle of the slip arc (°); u_i is pore water pressure (kPa); φ_i is the internal friction angle of soil (°).

The safety factor of the deep excavation slope stability of the mountainous highway needs to reach more than 1.25. Therefore, once the excavation causes disturbance to the soil, resulting in the safety factor lower than 1.25, it is very easy to cause the imbalance of the slope structure. This will lead to a landslide and other risks.

3.3. Damage and development mechanism of water-sensitive subgrade

The water sensitivity of soil in mountainous areas is relatively strong, so the soil in mountainous areas is prone to deformation in the rainy season. This led to cracks in the highway subgrade and slope. At the same time, after rainwater enters the subgrade along the cracks, it will further soften the soil structure and weaken the bearing capacity of the subgrade. The strength calculation of water-sensitive soil can refer to Formula 3:

$$T_f(\omega) = T_{f0} \cdot e^{-k(\omega-\omega_0)} \tag{3}$$

In the formula: $T_f(\omega)$ is the shear strength of the soil corresponding to the water content ω (kPa); T_{f0} is the initial shear strength corresponding to the natural moisture content ω_0 (kPa); k is the water-sensitive attenuation coefficient.

Through the determination of a large number of water-sensitive attenuation coefficients in mountainous areas, it is generally between 0.08 and 0.12, and will increase with the increase of rainfall [6]. Therefore, in the case of high precipitation in the rainy season, the stability of the subgrade soil will continue to decrease significantly, which will lead to damage and other diseases of the subgrade under the impact of rainwater.

3.4. Failure mechanism of subgrade under load

In the operation of the mountain highway, it needs to bear the self-weight and vehicle load, which leads to the continuous increase of subgrade stress. At the same time, the load stress has the characteristics of randomness and repeatability, which affect the recovery ability of the subgrade soil structure. Therefore, when the load is superimposed to a certain extent, it will cause soil deformation. The proportion of high fill and deep excavation subgrade replacement fill is large. Although the construction will carry out strong and repeated compaction on the soil, the control ability of external pressure on the porosity of subgrade soil is limited. Therefore, under the influence of equivalent additional stress of vehicle load, the risk of instability of subgrade is extremely easy to occur [7]. The calculation of the equivalent additional stress of the vehicle load can refer to Formula 4:

$$\sigma_d = 0.75\frac{P}{A}(1+0.12v) \tag{4}$$

In the formula, σ_d is the equivalent additional stress of dynamic load (kPa); P is the vehicle axle load (kN); A is the tire grounding area (m^2); v is the driving speed (km/h).

It can be seen that with the increase in the running time of the highway and the increase in the number of vehicles, the deformation of the subgrade will continue to accumulate. After accumulating to a certain extent, it is likely to cause subgrade damage.

4. Key technology for the treatment of special subgrade with high fill and deep excavation

4.1. Compaction reinforcement treatment technology of high fill subgrade

The probability of settlement deformation of high fill subgrade in mountainous areas is large, and the consequences are serious. In order to effectively prevent subgrade settlement and deformation, comprehensive compaction reinforcement technology should be adopted according to the characteristics of high fill subgrade (**Table 2**). This technology combines compaction, dynamic compaction, and grid reinforcement technology in the construction of ordinary subgrade, and then realizes the reinforcement of subgrade through the complementary technology [8]. First, fine compaction technology is adopted. Before the application of this technology, it is necessary to measure the moisture content of the subgrade (preferably 19%–23%), and personnel can use different compaction standards at different locations. The compaction strength standard of subgrade and upper roadbed is the same, which should reach more than 96%; The compaction strength of the lower roadbed can be properly reduced to more than 94%; The tamping strength of the lower layer of fill shall be controlled above 93%. Secondly, when the filling height of high fill subgrade exceeds 20 m, it is only necessary to strengthen the subgrade structure by dynamic compaction technology. The energy level of compaction shall reach 1200 kN·m. Personnel shall control the distance between adjacent points of compaction at about 4 m, and the number of compaction not less than 8 times. Finally, personnel need to use reinforcement technology. This technology needs to add a geogrid in the subgrade construction, generally adding a layer of grid at an interval of 2 m, and the tensile force of each layer of grid should reach 80 kN/m. Through the setting of a grid, the quality of filling body is improved, and then the settlement of soil body is effectively reduced.

Table 2. Comprehensive compaction reinforcement technology

Disposal plan	Filling height (m)	Average degree of compaction (%)
Fine compaction	22.5	92.3
Fine compaction and dynamic compaction	22.8	95.8
Fine compaction, dynamic compaction, and geogrid reinforcement	23.1	96.2

4.2. Reinforcement and treatment technology of deep excavation subgrade slope

The slope of the deep excavated subgrade in a mountainous area is prone to instability under the scouring of rainwater. In view of this disease, the method of graded excavation can be adopted, supplemented by anchor frame reinforcement and ecological protection technology. This can not only strengthen the slope structure but also optimize the ecological environment. In the graded excavation of the deep excavation slope, the excavation depth of each layer is basically the same (8~10 m). At the same time, the slope shall be determined in combination with the soil structure of the subgrade. Anchor frame reinforcement technology is mainly used in the reinforcement of slopes after excavation, and the full-length bonding anchor reinforcement technology is widely used. In this technology, the drilling depth (4~6 m) and diameter (Φ: 25 mm) of the anchor rod shall meet the construction requirements. In addition, slope protection should be strengthened [9]. The three-dimensional geonet mat can be used as the base of ecological planting protection. This construction method can not only maintain the vegetation, but also buffer the erosion of rainwater on the soil.

4.3. Improvement and treatment technology of special rock and soil subgrade

The area of expansive soil and weathered rock and soil in the mountainous rock and soil layer is large. The high water sensitivity of these soil layers determines that they are prone to landslides and other diseases in the rainy season. Therefore, for special rock and soil subgrade, it is necessary to improve the compactness of soil structure by subgrade improvement to ensure the stability of the soil structure. Firstly, before the construction of special geotechnical subgrade, the indoor proportioning test of construction materials is carried out, and the soil strength and structural stability are taken as the test evaluation criteria. For example, the test comparison results show that the compressive effect of soil in the test group with 5% cement content is the best, so this proportion can be used as the construction standard. Secondly, the improved construction technology is adopted to reduce the water sensitivity of soil structure. For example, the water content of soil can be reduced by crushing and screening of rock and soil, and cement mixing. Then the stability of the soil is improved through the compaction process (compactness ≥ 96%). Finally, the water sensitive attenuation coefficient of soil is controlled within a reasonable range (≤ 0.03), so as to ensure the stability of soil structure [10].

4.4. Supporting technology of the subgrade waterproof and drainage system

The diseases of high fill and deep excavation Subgrade in mountainous areas are directly related to the moisture content of the subgrade. Therefore, reducing soil water content is the key to subgrade prevention and control. To solve this problem, the combined drainage mode of ground interception and drainage, underground drainage, and slope drainage can be adopted to reduce the impact of water on the subgrade. First, surface drainage technology. The core application of this technology is to set intercepting ditches at the top of the slope to intercept the runoff on the ground, so as to effectively prevent the soaking of rainwater on the subgrade. At the same time, concrete pouring drainage ditch and side ditch shall be set to ensure the continuous and stable drainage of water. Secondly, groundwater drainage technology. This technology requires setting a blind ditch (0.8 m wide and 1.0 m deep) underground, and laying gravel and permeable geotextile in the ditch, so as to effectively and quickly dredge groundwater. In addition, the blind pipe is used to connect the filling and excavation junction, so as to improve the drainage capacity of groundwater. Finally, slope drainage technology. Slope drainage is mainly through the design of the horizontal and vertical pipe network at the side of the anchor rod to divert rainwater, and then effectively control the infiltration of rainwater into the base.

5. Conclusion

To sum up, the particularity of the geographical environment of mountainous expressways determines that the subgrade construction method of high fill and deep excavation is required in highway construction. However, the technological limitations of high fill and deep excavation construction lead to the inevitable occurrence of subgrade diseases, and the role of traditional disease management technology in the treatment of high fill and deep excavation subgrade is limited. Therefore, the construction unit needs to try to solve the problem of subgrade disease treatment through the comprehensive application of reinforcement technology, improvement technology, and drainage technology. Integrating the advantages of multiple technologies can improve the compactness of soil structure, reduce soil moisture content, and ensure the stability of subgrade structure. In the future, in the construction of high fill and deep excavation Subgrade of mountain highway, it is also necessary to try to use digital technology to strengthen the optimization of various parameters in the engineering construction and form a targeted treatment scheme.

Disclosure statement

The author declares no conflict of interest.

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