Stability Analysis of High Filled Steep Slope Embankments in Weak Soil Layers

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Abstract. In order to ensure the safety of high filled steep slope embankments in weak soil layers, it is extremely necessary to conduct stability testing research on them. Therefore, a stability analysis study on high filled steep slope embankments in weak soil layers is proposed. Taking a main road in a certain city as the research object, based on clarifying the treatment plan for high filled steep slope embankments in weak soil layers, different backfill soil samples from weak soil layers were taken as independent variables. Combined with practical application requirements, different strength load tests were designed, including 1 preload, 4 cyclic loads, and 1 overload. The compression rebound curve was analyzed to draw conclusions. Under the same load action, Properly reducing the content of large particles in the particle size distribution of backfill soil samples in weak soil layers can improve the stability of embankments; The stability of backfill embankments in weak soil layers is inversely proportional to the load strength under different loads; Balancing the particle size distribution of backfill soil samples in weak soil layers can maximize the stability of embankments.

Keywords: soft soil layer; high fill steep slopes; embankment stability; backfilling soil samples; strength load; compression rebound curve.

1 Introduction

In the process of road construction, in order to meet the requirements of straight and smooth routes for easy driving, it is inevitable to have a large number of roadbed excavation projects, forming a large number of road cutting slopes[1]. Recently, many high-grade highways that use soft soil layers and high fill embankments have experienced damage phenomena such as settlement, pavement layer cracks, slope swelling, collapse, and even overall surface sliding or instability of embankments during the construction process after completion, resulting in project delays and significant economic losses. The reasons for the failure of high filled embankments in weak soil layers are multifaceted[2]. In addition to subjective factors such as careless construction and geological exploration, as well as objective factors such as the complexity and variability of geological conditions, changes in environmental conditions, and

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changes in stress caused by filling [3], uneven settlement, overall instability, and insufficient understanding of the mechanism of embankment failure during or after the construction of high filled embankments in weak soil layers [4], as well as the current imperfect stability design methods, It is also the main reason for the failure of high filled embankments in weak soil layers [5]. Therefore, in order to solve the key issues in the design and construction of embankment stability, avoid uneven settlement of embankments, ensure smooth traffic, and ensure the safety of pedestrians and vehicles, it is necessary and urgent to conduct research on the stability of high filled embankments in weak soil layers [6]. Among them, literature [7] combines the main influencing factors and their relationships on the overall stability of embankments, selects six important influencing factors of road cut slopes, establishes a comparable embankment stability calculation model based on orthogonal method, clarifies the sensitivity and influence relationship of each influencing factor, and determines seismic force, embankment slope slope, ground slope The specific impact of the friction angle of the foundation soil on the overall stability of the embankment. Based on the embankment engineering of a section of the Inner Mongolia Railway in reference [8], a coupled model of rainfall seepage stress for unsaturated soil embankments was constructed. By inverting the saturation, pore water pressure, and deformation process of the embankment slope under rainfall environment, it was concluded that with the increase of rainfall time, the saturation, pore water pressure, and deformation range of the surface soil of the embankment showed a progressive trend. On this basis, this article proposes a study on the stability analysis of high filled steep slope embankments in weak soil layers.

2 Project Overview

This article takes the main road of a certain city as the research object, with a designed speed of 50km/h and a red line width of 45-60m. In the roadbed design stage of sloping road sections, fill embankments with ground cross slopes steeper than 1:5 are considered as sloping embankments. Based on the specific conditions of steep and sloping road sections such as geotechnical properties, hydrological conditions, steep and gentle cross slopes, and filling height, combined with various indicators provided by geological survey data, slope embankment reinforcement design is carried out on the basis of stability calculation to avoid sliding of the slope embankment. An analysis was conducted on the distribution of weak soil layers in the filling roadbed of the project, mainly located in the following locations: K3+100~K3+575 full section embankment, K4+028~K4+220 full section embankment, and K4+560~K5+050 full section embankment. According to the survey report data, the upper part mainly consists of a plain fill layer and a silty clay layer, while the lower part consists of a mudstone layer. Some sections of the silty clay layer pass through paddy fields, so there is a high water content, and very few sections have a small amount of muddy silty clay. For the above road sections, the main treatment method is to replace and fill with embedded crushed stones.

3 Design of Treatment Scheme for High Fill and Steep Slope Embankment in Soft Soil Layer

3.1 Soft soil subgrade replacement and filling treatment plan

For ordinary road sections, the standard replacement depth is 1.0-2.0m, and the specific replacement material is rubble. The corresponding construction requirements are as follows:(1) The gravel filling material should have a good gradation, a uniaxial saturated compressive strength of no less than 20MPA, a maximum particle size of no more than 50cm, and be free of plant residues, garbage, and other debris. The mud content should not exceed 10%, and the compaction quality should be controlled according to a porosity of no more than 24%.(2) The thickness, optimal moisture content, and number of compaction passes for layered compaction and rolling of the cushion layer are determined based on on-site tests of compaction equipment and design requirements[9].(3) The width and thickness of the cushion layer should meet the design requirements, and the compaction degree of the cushion layer should be inspected layer by layer and meet the compaction degree requirements[10].

3.2 Treatment of embedded stones

The soft soil in the second half of the road is mainly composed of soft plastic to plastic and plastic to hard plastic silty clay. Based on the geological survey report, when the thickness of the soft soil is greater than 3.0m, the upper 2.0 soft soil is excavated, and the soil is compacted with block stones embedded in it. Then, the stones are replaced and filled to 0.5m above the groundwater level, and high-quality soil is used for filling. The size of the rubble varies with the consistency of the soft soil.

4 Test Plan for High Fill and Steep Slope Embankments in Soft Soil Layers

4.1 Pretreatment of Backfill Soil Samples for High Fill and Steep Slope Embankments in Soft Soil Layers

This paper studies the relationship between backfill soil samples and slope stability in different soft soil layers, based on the treatment plan for steep slope embankments with high filling in soft soil layers designed in two parts.

According to the principle of compression test, when the volume of backfill soil particles remains unchanged, the cross-sectional area of the soil sample remains unchanged, and the height occupied by solid soil particles remains unchanged, it can be obtained from the geometric deformation relationship

$$\frac{H_0}{1+e_0}=\frac{H_0-\Delta h}{1+e} \tag{1}$$

$$e = e_0 - \frac{\Delta h}{H_0}(1 + e_0) \tag{2}$$

Among them, H_0 represents the initial height of the backfill soil sample, Δh represents the compression amount of the backfill soil sample under load P, e_0 represents the backfill soil sample of the initial backfill soil sample, and e represents the dynamic deformation modulus of the backfill soil sample.

In order to control the variables, this article adopts the equal substitution method to treat the oversized particle materials in the backfill soil samples of weak soil layers. Figure 1 shows the specific screening results.

Fig. 1. Sieving composition of backfill soil samples in weak soil layers

The calculation method for the control standards during the screening stage can be expressed as:

$$p_i = \frac{100 - p_m}{p_m - p_5}(p_{0i} - p_5) + p_{0i} \tag{3}$$

Among them, p_i represents the percentage of particles with a certain size passing after substitution, p_5 represents the percentage of particles with a particle size of 5mm passing the sieve in the original soil sample screening test, p_m represents the percentage of particles with a particle size of 75mm passing the sieve in the original soil sample screening test, and p_{0i} represents the percentage of particles with a certain size passing the sieve in the original soil sample screening test.

4.2 Design of Backfill Soil Sample Scheme for High Fill and Steep Slope Embankment in Soft Soil Layers

After processing, the particle size distribution curves of the backfill soil samples from three groups of weak soil layers are shown in Figure 2.

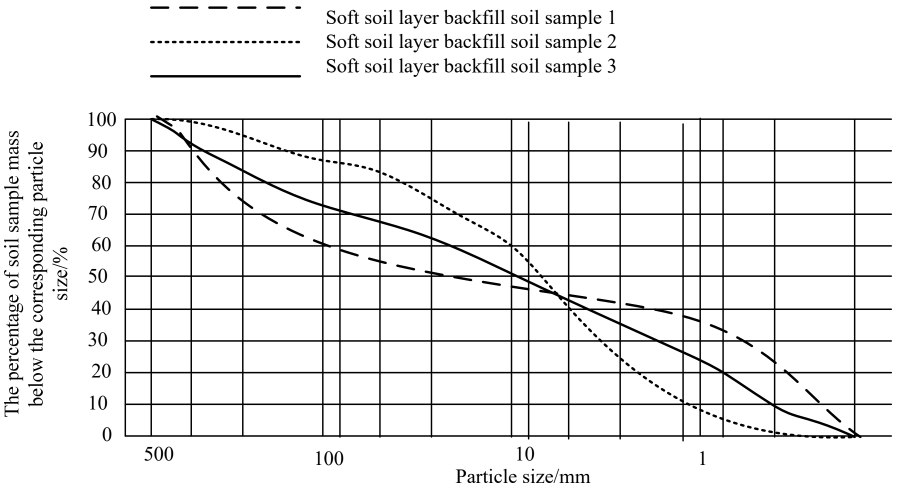


Fig. 2. Particle size distribution curve of backfill soil sample in weak soil layer

In the specific load stage, in order to better simulate the load characteristics of the actual operating stage, a load execution plan as shown in Table 1 was set up.

Table 1. Stability Test Load Action Plan

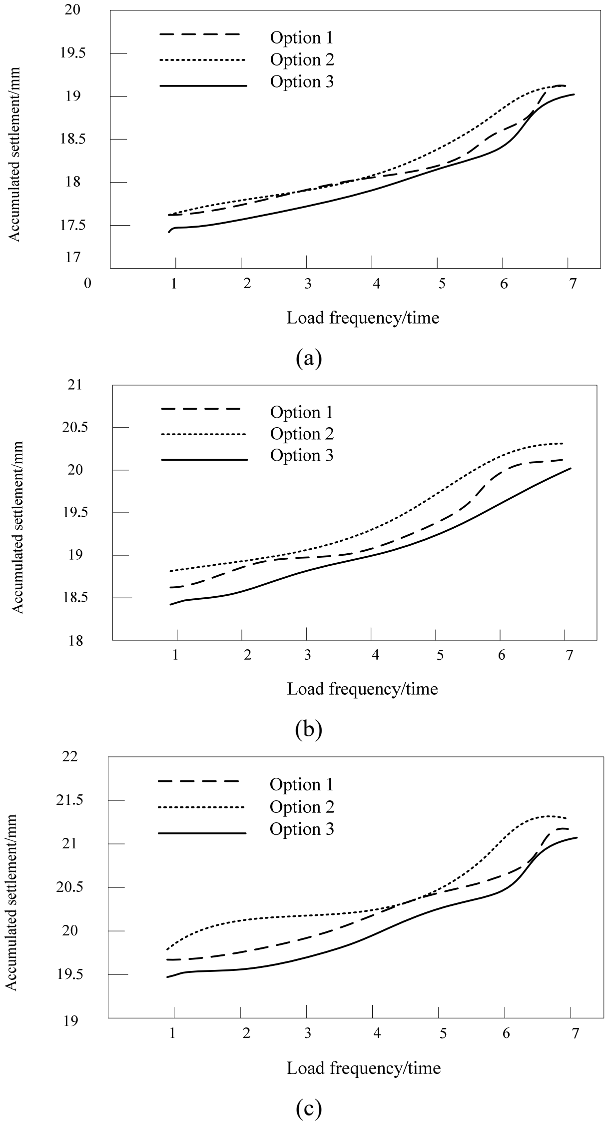
Load mode	Load strength/kPa	Load frequency/T
Preload	300	1
cyclic loading	400	4
overload	500	1

On the basis of the above, analyze the stability of high filled steep slope embankments in soft soil layers under different backfill soil sample conditions.

5 Stability analysis

Compression rebound tests were conducted on the backfill soil sample schemes of high filled steep slope embankments in soft soil layers, including 1 preload, 4 cyclic loads, and 1 overload. Under three sets of soft soil layer backfill soil samples, the 7 compression rebound curves of the embankment are shown in Figure 3. Among them, (a) in Figure 3 represents Scheme 1 for backfilling soil in weak soil layers. Scheme 2 and Scheme 3 respectively undergo compression rebound curves of 1 100kPa preloading+4 200kPa cyclic loading+1 overload of 300kPa constant load 12h+1 cyclic load of 300kPa. (b) in Figure 3 represents Scheme 1 for backfilling soil in weak soil layers.

Scheme 2 and Scheme 3 respectively undergo compression rebound curves of 1 300kPa preloading+4 400kPa cyclic loading+1 overload of 500kPa constant load 12h+1 cyclic load of 500kPa, In Figure 3, (c) represents the compression rebound curves of Scheme 1, Scheme 2, and Scheme 3, which have undergone 1 pre compression of 500kPa, 4 cyclic loading of 600kPa, 1 overload of 700kPa, and a constant load of 12h and 1 cyclic load of 700kPa, respectively.



(a)

(b)

(c)

Fig. 3. 7-fold compression rebound curve of embankment under different load intensities

From Figure 3, it can be seen that the compression curves of different soft soil layers with high filling and steep slope embankment backfill soil sample schemes all show an upward "convex" shape, and significant settlement occurs after preloading and the first loading; The rebound curves are all concave in shape. In the initial stage of unloading, the rebound deformation is very small, almost zero, and it is basically not until the last 1-4 levels of load that significant rebound deformation occurs. Moreover, after unloading, it is impossible to return to the deformation state before loading, indicating that the deformation generated by the three groups of soft soil layers with high fill and steep slope embankment backfill soil sample schemes under load consists of two parts: elastic deformation and plastic deformation; When an equal amount of load is added, a smaller preloading load acts on the backfill soil sample, resulting in a more significant compression effect. Under multiple actions of the same cyclic load, the compression effect on the backfill soil sample is not significant. The first preload unloading is completed, and the cyclic loading and subsequent overloading cyclic loading are carried out. The compression curve will return to the extension line of the first compression curve.

6 Conclusion

Based on the research on the stability analysis of high fill and steep slope embankments in weak soil layers in this article, the following conclusions can be drawn:

(1) Under the same load, appropriately reducing the content of large particles in the particle size distribution of backfill soil samples in weak soil layers can provide stability for embankments;

(2) The stability of backfill embankments in weak soil layers is inversely proportional to the load strength under different loads;

(3) Balancing the particle size distribution of backfill soil samples in weak soil layers can maximize the stability of embankments.

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