Study on Settlement Deformation Characteristics of Reinforced Soil Subgrade

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Abstract. Based on a high fill subgrade in Indonesia, this paper uses finite element software to simulate the settlement deformation characteristics of high fill subgrade under the condition of reinforced cushion. The calculation results show that although the existence of the reinforced cushion cannot significantly reduce the foundation settlement, it has obvious effect in ensuring the stability of the shoulder. The stability safety factor of the 9m high roadbed with the reinforced cushion layer increases by about 0.2. It is suggested that the reinforced soil cushion can be used as a reinforcement measure to ensure the stability of the shoulder when high-fill roadbed construction is carried out on soft soil foundation.

1. Introduction
Subgrade filling is one of the important reasons that lead to the stability of embankment body. During the construction of high fill subgrade, because the geological environment is soft soil, which contains not only silt, organic soil, swamp soil and other inferior soil, the filling and compaction processes are carried out without thorough treatment, which makes the subgrade itself problematic. Another example is that in the filling process, coarse-grained soil is not used for filling according to the design requirements, but the soil in the surrounding environment is transported here and filled. Most of these soils contain dead bodies of animals, insects, roots, sods and other substances. These substances, as filling materials, will form humus in the ground and sludge in case of water, which will not only fail to support the high-filled subgrade, but also lead to instability of the subgrade.

Reinforced soil technology is widely used in slope supporting structures, but the understanding of how much the reinforced soil of high fill subgrade plays in settlement and stability is not very consistent in the industry. This paper takes the finite element simulation calculation of settlement and slope stability of a reinforced soil high fill subgrade in Indonesia as an example, and illustrates the application effect of reinforced soil on high fill subgrade through the calculation results.

2. Project overview
The first phase of a highway project in Indonesia has a total length of 178km. The road section is hilly. The road section is mainly filled with embankment. Most of the roads are filled with paddy fields.
Villages are densely covered and the terrain is flat. It is a plain area. The whole line adopts asphalt concrete pavement structure, with 4 lanes in both directions and large traffic flow in some sections.

In this analysis, the duration of embankment construction is 180 days and the duration of pavement construction is 90 days. If the residual settlement is still very high, it is suggested to increase the duration of road embankment construction to reduce the post-construction settlement.

The calculation parameters are shown in Table 1.

| Soil | γ(kN/m³) | γd (kN/m³) | c (kN/m²) | φ (°) | ν | E(kN/m²) | K (m/day) |
|------|----------|-------------|-----------|-------|---|----------|-----------|
| 1    | 15       | 11          | 15        | 0     | 0.3 | 3000     | 8.6e-4    |
| 2    | 16       | 12          | 40        | 0     | 0.3 | 8000     | 8.6e-4    |
| 3    | 17       | 14          | 100       | 0     | 0.3 | 20000    | 8.6e-4    |
| 4    | 17       | 14          | 100       | 0     | 0.3 | 40000    | 8.6e-4    |
| 5    | 17.8     | 14.8        | 22.8      | 19.2  | 0.3 | 3400     | 0.01      |

3. Simulation Analysis and comparison

177 + 750 boreholes are selected for calculation. The depth of foundation soil in this section is 60m, and the roadbed is filled with 7m according to the data. PLAXIS 3D is used for simulation analysis in this calculation. The calculation can completely simulate the three-dimensional effect of subgrade and analyze the anti-sliding and reinforcing effect of geotextile in subgrade. The calculation model is shown in Figure 1.

![Figure 1 Settlement model of rigid foundation](image)

![Figure 2 Total settlement after normal operation](image)

(1) There is geotextile in actual engineering

This time, the construction project of subgrade sealing layer filling and rolling is simulated, the influence of consolidation time of subgrade soil during the construction process is considered, and the influence of loading load on the settlement of subgrade after the trial operation of highway is analyzed. According to the calculation, the settlement of subgrade is 5cm after the completion of the filling construction of the first layer of subgrade, the total settlement of subgrade and pavement is 19.6cm after the completion of the construction, and the total settlement of subgrade is about 26cm after the normal operation of highway.

In the simulation analysis, it is considered that the construction steps of the actual embankment are filling soil layer by layer, laying reinforcement and rolling until the top surface of the embankment. The number of units in the calculation domain is increased step by step to simulate the filling process step by step. The displacement increment and stress increment of each unit are calculated by the self-weight load of each newly added unit. And accumulate step by step, finally determine the displacement field and stress field in reinforced embankment when the construction is completed.

In addition, in order to analyse the influence of geotextile on subgrade settlement and subgrade slope stability, the subgrade safety factor is calculated. The calculation results of subgrade stress concentration points are shown in Figure 3, and the subgrade slip arc shape with geotextile is shown in Figure 4. According to the calculation, it can be found that the stress concentration point of high fill subgrade is divided into two parts, one part is in the range of 5-10m below the road surface, and the
other part occurs at the junction of the subgrade slope toe and the original road surface. If the subgrade is too high or the road surface load is too large, shear damage will occur at the subgrade slope toe. Drainage and anti-filtration measures should be taken, and anti-pressure at the slope toe should also be done for soft soil subgrade.

(2) there is geotextile in actual engineering

In order to compare the influence of geotextile on shoulder stability, only the safety factor of shoulder anti-sliding stability is calculated in this calculation. The nephogram of shoulder anti-sliding stability strain without geotextile is shown in Figure 5. According to the calculation, under the condition of geotextile, the subgrade is easy to generate circular arc through sliding surface, which will lead to instability of subgrade under the condition of excessive load. Fig. 6 is the calculation results of subgrade settlement and subgrade slope stability safety factor with and without geotextile respectively. Through calculation and comparison, it is found that incorrect geotextile has little influence on the total settlement of subgrade, but geotextile is more capable of verifying the integrity of subgrade for settlement during construction, increasing the settlement of round subgrade soil during construction, and has strong effect on improving the stability of subgrade slope.

4. Comparative analysis of calculation results

On the whole, the maximum principal stress equivalent nephogram increases with the increase of fill depth and is the maximum at the bottom of the foundation. However, in the reinforced part, the maximum principal stress value decreases compared with the unstiffened embankment. This shows that the interaction between geogrid and fill can reduce the maximum principal stress in embankment.

The minimum principal stress is the largest at the bottom of the foundation. Stress concentration occurs at the contact part between the fill and the grid, especially at the upper and lower parts of the whole reinforced area, which indicates that this phenomenon occurs due to the difference in mechanical properties between the fill and the reinforcement.

The equivalent nephogram of shear stress shows that the shear stress after reinforcement appears within a certain range on both sides of embankment, which indicates that geogrids need not be arranged in the whole soil body when designing geogrid positions, and the engineering requirements can be met only by arranging geogrids in the range where plastic zones occur.
The equivalent nephogram of plastic zone shows that the depth and range of reinforced plastic zone are obviously smaller than that of unreinforced embankment. The plastic zone of unreinforced embankment is at the bottom of foundation, while the reinforced plastic zone occurs at the junction of reinforced zone and unreinforced zone, and the range is much smaller.

The safety factor of reinforced embankment is about 6% higher than that of unreinforced embankment. The graph of deformation increment shows that reinforced embankment and unreinforced embankment effectively reduce stress concentration and block the occurrence of circular arc failure of shoulder stability.

5. Conclusion
Through the numerical simulation of high-filled reinforced earth embankment under static action, the following conclusions are obtained:

(1) Using finite element method, the earth embankment reinforced with geogrid is divided into a system of soil layer, geogrid and the interface between them. Duncan-Chang model is adopted for the stress-strain relationship of soil, and Goodman element without thickness is used for the interface simulation, which can better reflect the working performance of such reinforced earth embankment. The use of geogrid in high-filled embankment can reduce the maximum principal stress in embankment, make full use of the strength of geogrid and fill itself, effectively improve the strength and stability of embankment, and reduce the deformation of embankment and foundation.

(2) The shear stress after reinforcement appears within a certain range on both sides of embankment, which indicates that the tensile strength of geogrid should be paid attention to in the design. At the same time, when designing the location of geogrid, it is not necessary to arrange geogrid in the whole soil body. As long as the geogrid is arranged in the plastic zone, the engineering requirements can be met. It is necessary to arrange a certain number of layers of long-span tendons, but it is not necessary to arrange all the long-span tendons according to deformation analysis.

(3) The use of geogrid can reduce embankment settlement and embankment cross-section difference, and improve the integrity and consistency of embankment. It is effective to use finite element method to simulate and analyze reinforced high embankment, and the results of theoretical analysis are consistent with previous research results.

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