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Evaluation of embankment stability on soft ground considering service loads

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Abstract. The stability of road embankment on soft ground is always the highlight during construction. Usually the construction is carried out on the reinforced ground and the degree of reinforcement is influenced by the methods and period. In order to evaluate such influence, changing the compression index is a simple way to represent it. Also the service load can be represented by assigning different bulk density of surcharge. Finite element strength reduction method is used to evaluate the stability of embankment at different stages.

1. Introduction

In the coastal area, due to the high phreatic line there usually is soft ground with high water content and low bearing capacity. Ground reinforcement is necessary before the construction. The typical characteristics of soft ground are high compressibility, low permeability and low shear strength. The void ratio of soft soil is very large (larger than 1). The compression coefficient is around 1.5~2.0MPa⁻¹ and the modulus of compressibility is less than 4MPa. Because the compressibility of soil is greatly influence by its mineral component, the larger the liquid limit is, the greater the compressibility is. The vertical permeability coefficient is usually smaller than 10⁻⁶cm/s. Under the load action, it takes a very long time to reach the high degree of consolidation. The shear strength of soft soil is very small. The drained effective cohesive is smaller than 15kPa and inner frictional angle is smaller than 10.

Table 1. Ground reinforcement method

Method	Principle	Applicability
Replacement	remove the soft soil and replace by proper soil with high shear strength and low compressibility	all kinds of soft ground
Reinforced cushion	install geosynthetics into the ground to improve its stability	all kinds of soft ground
Drainage consolidation	install sand well or plastic vertical drains to expel pore water from the ground	deep, saturated soft ground with low plasticity index
Dynamic compaction	apply impacting force on the ground by heavy hammer to make the soil	soft soil with high permeability



	denser	
Cement mix	rotate soft soil with cement to solidify the ground	all kinds of soft ground

In recent years, the technics of ground reinforcement have been greatly developed, from the drainage consolidation method to geosynthetics, cement mixed method and vibrating method. The usual ground treatment methods are listed in Table 1. After reinforcement, one of the concerning problems is the stability of the road embankment under different load according to the consolidation effect. Therefore, it is necessary to evaluate the influence of serve load and compressibility of soil on the stability of the road embankment on the soft ground.

2. Determination method of stability

In 1955, Bishop[1] proposed another simplified method based on the Swedish method in which the arc-shape slide surface and the equilibrium of the moment are kept while the interaction between two strips is considered. The safety coefficient is represented by the ratio between the resistant shear strength and the actual shear strength on the sliding surface, which is called safety factor of shear stress:

$$F_s = \min(F_s^i) = \min\left(\frac{\tau_f}{\tau}\right) = \min\left(\frac{c_f + \sigma \tan \varphi_f}{\tau}\right) \quad 1)$$

Although the strength reduction method has been widely used in the stability analysis of the slope, the final safety coefficient is always depended on the evaluation criterion of instability. Usually the numerical convergence is taken as the judge criterion, but the influence factors of the convergence of FEM are multiple and it is difficult to explain whether the divergency is attributed to instability or not. Now there are mainly three judge criterions for the instability of the slope: convergence of calculation, run-through of the plastic range and sudden change of characteristic position.

When using strength reduction method for the slope stability, the calculation convergence is usually used as the criterion[2-6]. If the convergent solution cannot be obtained under the designated convergence judgment, the slope loses its stability. For the run-through of the plastic range, some significant shear bands have been observed during the damage of the slope. Similar regulation can be forecasted. If there is run-through plastic deformation in the slope under certain reduction coefficient, such a coefficient can be regarded as the safety coefficient. For the sudden change of characteristic position, the treatment is building the relationship between the displacement of certain point and the reduction coefficient in the FE calculation. If there is a sudden change in the curve, the slope is in a critical state.

3. Calculation results

A FE code called Plaxis3D is used to carry out the strength reduction method. In Plaxis3D, a module called safety analysis can be used for the slope stability analysis. In the calculation, the reduction coefficient is gradually reduced and the total displacement at toe of the slope is also monitored for each reduction coefficient. When the relationship between the reduction coefficient and the total displacement is plotted in the diagram, the safety coefficient is taken as the reduction coefficient if there is no variation even though the total displacement increases. Cam-clay model is used in the calculation. The parameters are listed in Table 2.

TABLE 2. Parameters in the Calculation

Drainage type	Undrained A
Unsaturated bulk density (kN/m ³)	14/16/18

Compression index	0.10/0.12/0.15/0.18
Swelling index	0.02
Equivalent permeability (cm/s)	6.0×10^{-6}

In order to evaluate the influence of service load, the bulk density of surcharge and compression index of soft ground is varying from active and passive aspects. Fig. 1 gives the settlement of the ground under different bulk densities of surcharge. As can be seen, when the bulk density is 14 kN/m^3 the settlement is much smaller than other two densities, while there is no much difference between the settlements when bulk density is 16 and 18. Therefore, it is very useful to decrease the total settlement by reduce the servic load. The settlement at the center of embankment with different compression index is shown in Fig. 2. It is easy to understand that if the soft ground is reinforced under various methods or period the compressibility of final ground might be quite different. It is a feasible way to represent such difference by assign different compression index to the reinforced ground. Obviously, the larger the compression index is, the greater the final settlement is. It can also be noticed that if the compression index is small, the settlement becomes comnvergent soon after the second load and the settlement get stable. However, as the compression index gets greater, namely the soil becomes weaker, the rate of settlement is accelarated.

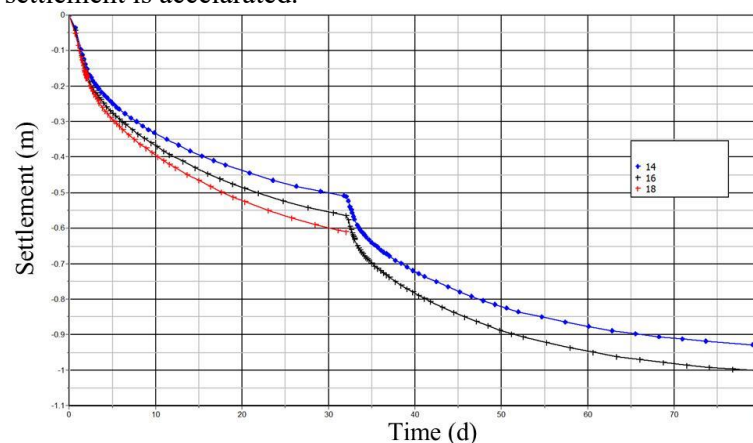


Figure 1. Settlement at the center of bottom surface of embankment under different bulk densities.

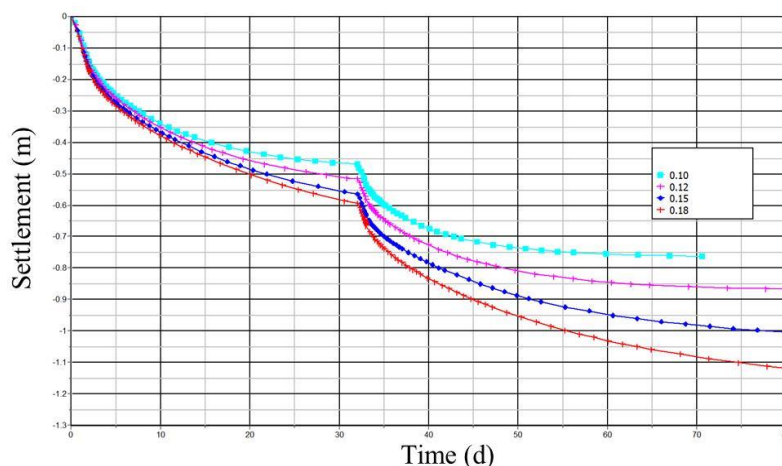


Figure 2. Settlement at the center of bottom surface of embankment under different compression index.

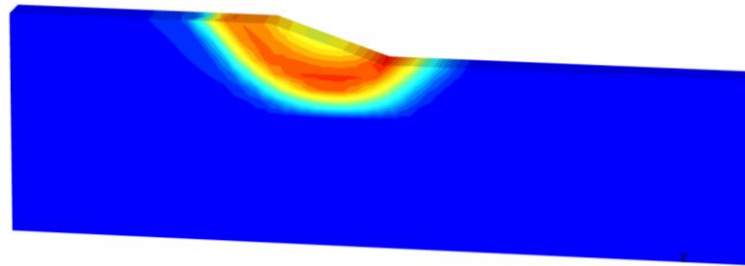


Figure 3. Slide surface inside the embankment.

Fig.3 demonstrates the slide surface inside the embankment when the compression index is 0.18. As mentioned above, when the compression index becomes larger, the rate of settlement also gets greater, which results in the slide surface through the embankment. Therefore, there is a risk that the embankment may lose its stability if the reinforced strength is not enough.

The stability coefficient of embankment at different stages is shown in Fig. 4. As can be seen, the coefficient after the first construction is around 1.07 and then 1.76, 1.12, 1.46 followed by first consolidation, second construction and second consolidation. Due to the consolidation, there is a significant improvement for the stability of the embankment.

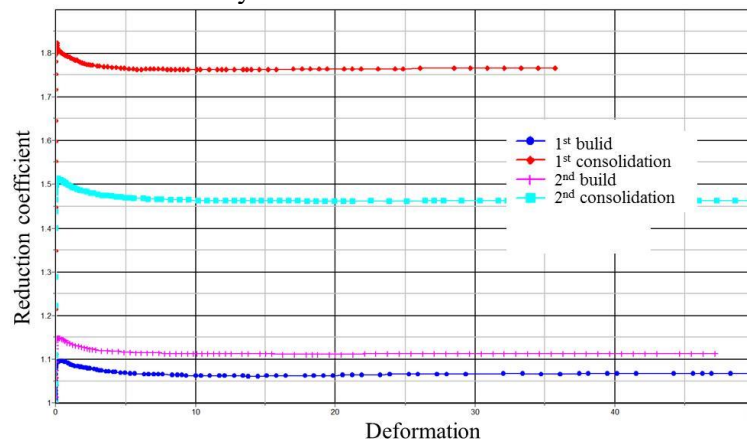


Figure 4. Settlement at the center of bottom surface of embankment.

4. Conclusions

The influence factors on the road embankment are investigated numerically from both active and positive aspects by varying the bulk density of the surcharge and compression index of soft ground. The conclusions are as follows:

1) When the bulk density is small the settlement is much smaller than other two densities. Therefore, it is very useful to decrease the total settlement by reduce the servic load.

2) When the compression index becomes greater, the final settlement also becomes larger. If the compression index is small, the settlement becomes comnvergent soon after the second load and the settlement get stable. However, as the compression index gets greater, the rate of settlement is accelarated.

3) Enough consolidation time is very useful to increase the stability of the road embankment.

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