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Research Article

Numerical Analysis of Effect of Back Berm in Road Engineering

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Abstract: Based on the nonlinear finite element method, the basic characters of road engineering reinforced with back berm are studied. It is found that there is no influence on maximal vertical settlement and distribution of vertical settlement in the scope of original embankment by back berm, only the vertical settlement of foundation under back berm enlarged by back berm. The lateral displacement of embankment could be reduced by back berm, which reduced further by width of back berm enlarged. The stability of embankment increased rapidly with the width of back berm enlarged. But when the width of back berm reach a critical value, the stability of embankment is no more increased with the width of back berm enlarged. In order to utilize land effectively, the width of back berm should not be bigger than the critical value. The critical value of width of back berm could be calculated with the corresponding parameters of road engineering. There is almost no influence on stability of embankment by gravity of back berm. It is suggested to fill the back berm by the soil with big cohesive strength and big internal friction angle.

Keywords: Back berm, lateral displacement, stability, vertical settlement

INTRODUCTION

Stability and settlement are the key control problems of road engineering on soft soil foundation. Big lateral displacement, swelled at toe of slope and slipped of embankment usually happened at embankment on low bearing capacity of foundation (Chai and Miura, 2002; Zhou *et al*., 2010; Wei *et al*., 2010). The value of lateral displacement of embankment is a key parameter to estimate and control the stability of embankment, which effected the vertical settlement and stability of embankment (Sakai *et al*., 2003; Liu *et al*., 2008; Wei *et al*., 2010).

There are lots of methods, such as geotextile, anti-slide pile and foundation treatments, could be used to improve the settlement and stability of embankment according to different engineering geology and environmental condition. Sometimes, back berm also could be used to enhance the stability of embankment if need (Zhang *et al*., 2007). Back berm is a method filling earth or stone at some scope near toe of embankment, which prevent the soil extruded at toe of embankment, characterized with easy construction, need no special construction machinery, short time of construction, low cost and obtain ray materials locally, always favored by engineers.

Such as Qian-zi-dang soft foundation of Jin-Yi road engineering, which has been designed as an extra bridge with length of 560 m originally, optimized as a bridge with length of 100 m and 460 m embankment with back berm later, which obtained good economic effects by reducing the engineering cost of 1500 ten thousand RMB (Zhang and Wu, 2004). Jia-Keng tunnel at Longyou-Lishui-Longquan express highway of Zhejiang province is a typical shallow buried and non-uniform pressed tunnel. In order to improve the stress state of tunnel opening, the residues during tunnel excavation has been heaped at the left side of platform upside tunnel opening as back berm, which released the stress concentration in adjacent rock of tunnel and enhanced the stability of tunnel (Wang *et al*., 2010). In the first-stage construction of Hai-cang road engineering, back berm has been created at both sides of road with lots of riprap stones, which reduced the lateral displacement and rate of displacement greatly and enhanced the critical height of embankment effectively (Yan *et al*., 2003).

In the code of road engineering, the height of back berm is suggested at 1/2 of the height of embankment, while the width of back berm should be calculated by stability analysis of embankment (JTJ 017-96, 1997). Therefore, it is significant to study the influence of width of back berm on stability of embankment. Based on nonlinear Finite Element Method (FEM), the effect

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Table 1: Parameters of each layer

Soil layer	Gravity/(kN/m^{-3})	Cohesive strength/(kPa)	Internal friction angle φ/(^{0})	Young's modulus E_0/(MPa)	Poisson's ratio
Embankment	20.5	8.0	11.0	6.0	0.33
Clay Ⅰ	19.0	17.0	25.0	9.0	0.28
Clay Ⅱ	18.5	6.0	11.0	4.3	0.35
Clay Ⅲ	19.5	31.0	17.5	10.1	0.30

of back berm has been systematically studied in this study, the vertical settlement, lateral displacement and stability of embankment have been analyzed, which aims to provide some references on application of back berm in road engineering.

MODEL OF FINITE ELEMENT MTHTOD

Now a typical model of embankment with back berm is to be analyzed, the width of top of embankment is 26.0 m, the height of embankment is 4 m and the ratio of slope of embankment is 1:1.5, as showed in Fig. 1. Back berm with height of 2.0 m at both sides of embankment is to be used. The ratio of slope of back berm is the same as that of embankment, the width of back berm marked as *L*. According to reconnaissance of geology, the foundation of embankment is composed by 3 soil layers, whose parameters are showed in Table 1. The parameters of back berm are the same as that of embankment. Due to the symmetrical characteristic of embankment, half part of embankment could be analyzed.

Clay I is a thin soil layer under ground surface. The strength of clay I is bigger than that of clay II and clay III. Thus, clay I is a hard shell soil on the top of clay II and clay III.

The domain of FEM model should be large enough to eliminate the influence of boundary. Thus, the area of FEM model including 11.0 m thickness of foundation, 26.0 m apart from the toe of embankment, as showed in Fig. 1.

This problem could be simulated as plane strain model, foundation and embankment could be simulated with Mohr-Coulomb failure criterion. The vertical settlement and lateral displacement fixed at bottom of model and lateral displacement fixed at both sides of model. The mesh of FEM is divided by 15 nodes triangle element, the mesh of embankment without back berm is showed in Fig. 2. According to the code of highway engineering of China, the material of back berm should be the same as embankment. The construction process could be simulated by activating the mesh of embankment and back berm.

The friction between each soil layers could be simulated with interface element by parameter R_{inter}. R_{inter} = 1.0 indicated that there is no glide between each soil. The real value of R_{inter} could be measured by tests, but need much resource and fee. In fact, the specific value of every parameter of embankment could be impacted by the exact value of R_{inter} from 0 to 1.0, but the regularity of every parameter remain the same with different value of R_{inter}. Therefore, it is assumed that there is no glide between each soil with R_{inter} = 1.0 in this study, as the same simplified by other researchers.

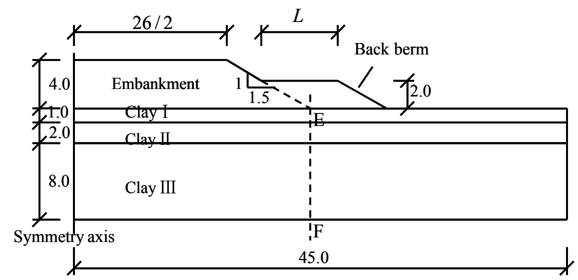


Fig. 1: Model of the embankment (unit: m)

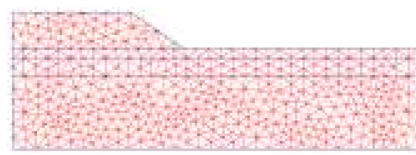


Fig. 2: Mesh of FEM with *L* = 0 m (elements: 874)

The stability of embankment is to be studied with shear strength reduction of FEM (Dawson *et al*., 1999; Manzari and Nour, 2000; Wan *et al*., 2010), that is, the intensive parameters c, ø of each layers soil should be reduced by coefficient F_{trial} simultaneously:

$$c_r = \frac{c}{F_{trial}},\ \phi_r = \arctan\left(\frac{\tan\phi}{F_{trial}}\right) \tag{1}$$

where, c_r , ϕ_r is reduced cohesive strength and internal friction angle, respectively? The model analyzed by FEM with reduced parameters, if embankment arriving limiting equilibrium state judged by some criterion (Liu *et al*., 2005), the safety factor of embankment equal the value of coefficient F_{trial}. Otherwise, the model should be recalculated with new reduced parameters until embankment arriving limiting equilibrium state. Lots of researches indicated that it is reliably and feasibly to analyze stability of embankment with shear strength reduction of FEM (Liang and Liu, 2003; Dai *et al*., 2009).

RESULT OF FEM CALCULATION

Character of vertical settlement of embankment: The isoline of vertical settlement of embankment with *L* = 0, 4 and 6 m of back berm are showed in Fig. 3 respectively. It can be found that there is no influence on the vertical settlement of original scope embankment by back berm. The back berm enlarged the value of vertical settlement under the slope of embankment.

The vertical settlement at top surface of foundation is showed in Fig. 4. It is obviously that maximal

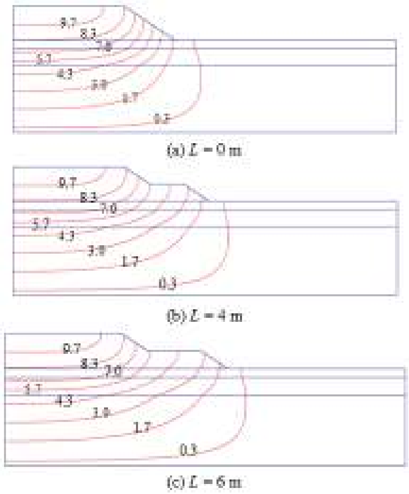


Fig. 3: Vertical settlement of embankment (unit: cm)

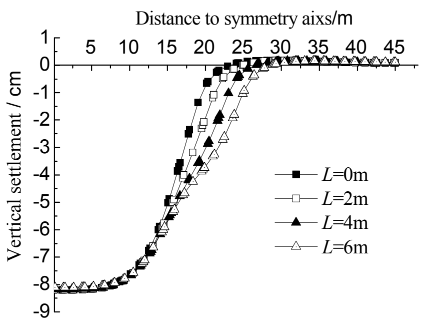


Fig. 4: Vertical settlement at original top surface of foundation

vertical settlement, about 8.2 cm, obtained at axis of embankment and back berm has no influence on the maximal vertical settlement of embankment. There is little hump at the toe of embankment. The vertical settlement under back berm increased with the width of back berm increased. In a certain degree, the construction of embankment is controlled by maximal value of vertical settlement and lateral displacement and its rate, which would not be controlled by filling of back berm, due to the deformation induced by back berm is little.

Lateral displacement of embankment: The isoline of lateral displacement of embankment with L = 0, 4 and 6 m of back berm are showed in Fig. 5. It can be found that the maximal lateral displacement of embankment obtained in the clay Ⅱ under toe of embankment, the corresponding value are 2.1, 1.7, 1.5 cm with L = 0, 4, 6 m back berm, respectively. Thus, the lateral displacement could be reduced by back berm effectively.

The lateral displacement of vertical surface EF is showed in Fig. 6. It can be found that the lateral displacement decreased with width of back berm

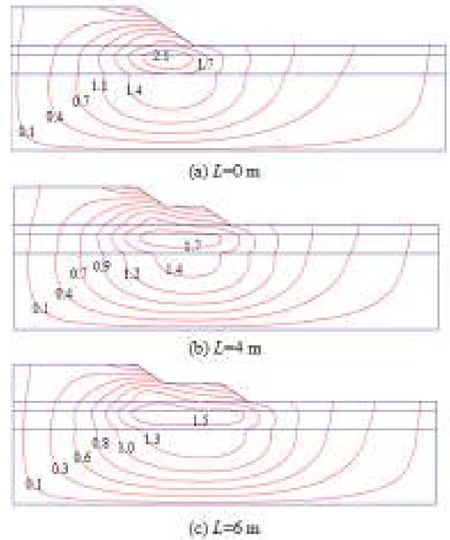


Fig. 5: Lateral displacement of embankment (unit: cm)

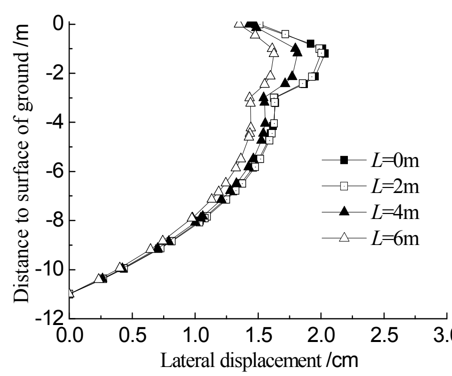


Fig. 6: Lateral displacement at vertical surface of EF

increased. The lateral displacement of embankment with back berm of L = 2 m is maybe the same as that of embankment without back berm, which indicated that the lateral displacement of embankment could not be reduced with short width of back berm. Therefore, there is a reasonable interval value of width of back berm according to different condition of embankment.

Stability of embankment: The relationship between safety factor of embankment and width of back berm is showed in Fig. 7. The safety factor of embankment without back berm is 1.18, less than 1.20 which representing the minimum requirements of code, so the stability of embankment should be enhanced by reinforcement. The stability of embankment increased with width of back berm increased, which indicated it is effectively to enhance stability of embankment with back berm. But the stability of embankment arrived at 1.80 and no more increased when width of back berm bigger than 4.0 m, so there is a limitation of width of back berm according to different condition of embankment.

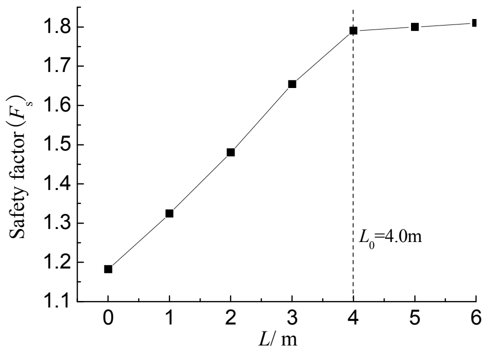


Fig. 7: Relationship between safety factor of embankment and width of back berm

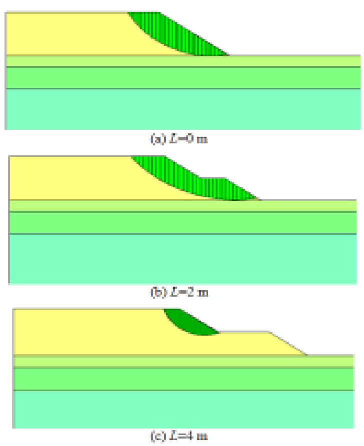
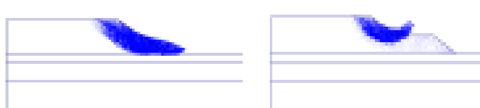


Fig. 8: Failure surface of embankment

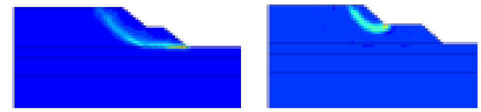


(a) L = 0 m (b) L = 5 m

Fig. 9: Total incremental displacements of embankment

In order to utilize land resources effectively and reduce the space of back berm, the width of back berm should be less than the limitation value. The limitation value of width of back berm could be defined by the condition of embankment, which obtained L_0 = 4.0 m in the example of this study provided

The failure surface of embankment is showed in Fig. 8. The failure surface is a curved surface through the toe of embankment when width of back berm less than 2.0 m. Due to clay I is a hard shell soil with high strength, the failure surface of embankment could hardly through clay I. With increasing of width of back berm, the toe of embankment has been effectively "protected" by back berm and failure surface more and more hardly across at toe of embankment. When width of back berm bigger than 4 m (L≥4 m), the position of failure surface has been changed, only through at top of back berm, as showed in 8 (c).



(a) L = 2 m (b) L = 5 m

Fig. 10: Maximal shear strain of embankment

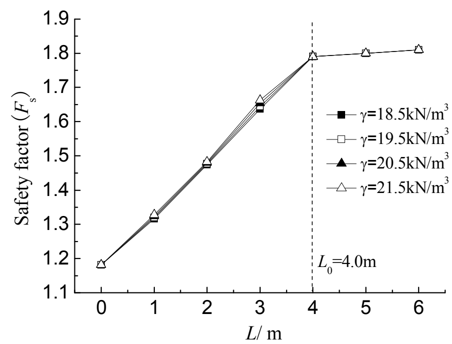


Fig. 11: Influence of gravity of back berm on stability of embankment

The total incremental displacements of embankment and the maximal shear strain of embankment are showed in Fig. 9 and 10 respectively. It can be found that the volume of soil to be slipped including the toe of embankment when width of back berm less than 4 m (L<4 m). When width of back berm bigger than 4 m (L≥4 m), the toe of embankment has been "protected" by back berm effectively and the slipping surface changed and cross the top of back berm, as showed in Fig. 9b and 10b. That is, the characters of embankment mutated or changed when width of back berm bigger than 4 m.

In a certain degree, the potential failure surface located at the position of the maximal shear strain of embankment. It is no use to enhance stability of embankment any more by increasing the width of back berm when which bigger than the value of limitation.

Sensitivity analysis of parameters of back berm: In a certain degree, it is economically to use local materials to fill the back berm, such as in mountainous area block stone and reduced stone is to be used, while in plain country clay and sand is to be used. That is, there is big difference in the parameters of different filling, so it is worth to study the sensitivity of parameters of back berm on stability of embankment.

The influence of gravity, cohesive strength and inner friction angle of back berm on stability of embankment are showed in Fig. 11 to 13. It can be found that the stability of embankment increased with cohesive strength or internal friction angle of back berm increased, especially when the width of back berm at L = 2.0~3.0 m. Therefore, it is suggested to use the filling of back berm with big cohesive strength and internal friction angle in embankment. But the gravity of back

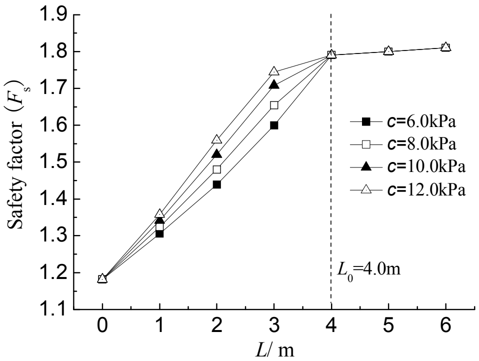


Fig. 12: Influence of cohesive strength of back berm on stability of embankment

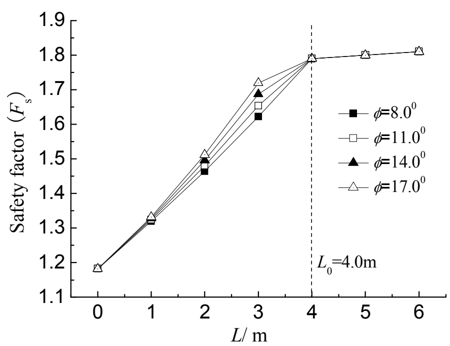


Fig. 13: Influence of internal friction angle of back berm on stability of embankment

berm has no influence on the stability of embankment basically. When the width of back berm bigger than 4.0 m, all the parameters of back berm have no influence on the stability and failure surface of embankment, due to the stability of embankment no more increased when width of back berm bigger than 4.0 m.

Back berm need much land, which could hardly be used at population concentrated area. In order to economize the land resource and utilize the platform of back berm, farming could be carried out at back berm and off-set facility of road could also be set at back berm.

CONCLUSION

- There is no influence on the vertical settlement of original scope embankment by back berm. And the back berm has some influence on the vertical settlement at slope of embankment. The vertical settlement under back berm increased with the width of back berm increased.
- The lateral displacement of embankment decreased with width of back berm increased, which could be reduced by back berm effectively.
- The stability of embankment increased with width of back berm increased. But there is a limitation of width of back berm, the stability of embankment no more increased when width of back berm bigger than the limitation. In order to utilize land resources effectively and reduce the space of back berm, the width of back berm should be less than the limitation value.
- The stability of embankment increased with cohesive strength or internal friction angle of back berm increased, but the gravity of back berm has no influence on the stability of embankment. It is suggested to use the filling of back berm with big cohesive strength and internal friction angle in embankment. All the parameters of back berm have no influence on the stability and failure surface of embankment when the width of back berm bigger than the limitation value.

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