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Interaction Between Widened and Existing Embankment on Soft Soils

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Abstract: The most cost effective choice to improve existing highway capacity is to widen the existing highway embankments, but adding a new embankment adjacent to the old one may result in a series of geotechnical engineering issues including excessive differential settlement occurring between the existing and the widened embankment which will subsequently cause longitudinal pavement cracks, drop off or even local or global instability of embankments especially those on soft soils. Therefore, how to minimize the differential settlements and prevent severe cracks is of great concern when widening the existing embankments. The interaction between the existing and the widened embankment was analyzed to explore the influence of the starting time to widen on the additional settlement in the existing embankment. The development of transverse stress in the pavement and the evolution of the pavement slope were also investigated. In the view of reducing differential settlement and pavement tensile stress caused by widening in the embankment, a most suitable time to begin widening was proposed.

Key words: Embankment, widening, differential settlement, pavement stress, pavement slope, soft soils

INTRODUCTION

The rapid development of China's economics makes it urgent to widen the existing highways to meet the increasing highway transportation demand (Jia *et al*., 2004; Liu *et al*., 2007; Huang *et al*., 2004; Gao *et al*., 2004). However, adding a new embankment adjacent to existing embankment will cause some geotechnical engineering problems such as additional settlement in the existing embankment and differential settlement between the widened and the existing embankment (Deschamps *et al*., 1999; Wang and Huang, 2004). This will, in turn, cause additional tensile stress in the pavement. When the stress exceeds the strength of the pavement materials, pavement cracking is unavoidable. And rain water will subsequently filter through embankment fill and cause further damages, even local and/or global instability, especially for those embankments on soft soils. The excessive differential settlement between the widened and the existing embankment may also change the pavement slope designers expected. How the settlement, the stress and the slope of the embankment develop prior to and after the widening is therefore of great importance in highway embankment widening projects (Meng *et al*., 2007; Han, 2006; Qian *et al*., 2003). However, little attention has been paid to the issue. In this study, the interaction between the existing and the widened embankment was analyzed by using a commercial FEM program to explore the evolution of the settlement, the stress and the slope in the existing embankment as well as in the widened embankment, the effect of the starting time to begin widening was mainly investigated. Based on the analyses, a most suitable time to start widening was proposed.

NUMERICAL MODEL

For simplicity, only the symmetric widening method on both sides of existing embankments was considered herein (Fig. 1). The existing embankment which has a height of 4.0 m, a top width of 26 m and a bottom width of 38 m, consists of a 0.3 m thick concrete-asphalt layer, a 3.2 m thick gravel-clay mixture and a 0.5 m thick crushed stone base. The widening embankment has a same height and configuration as the existing embankment which was widened an additional lane of 4.5 m on both sides and the original side slope geometry maintained unchanged.

The soft foundation soil below the embankment consists of 1.5 m thick crust and 25 m thick soft clay which is underlain by perfectly rigid base layer.

When conducting numerical analysis in this study, the concrete-asphalt layer was considered as no-porous elastic material. Both the embankment fill and the foundation soils were considered as Mohr-Coulomb materials. The material parameters are listed in Table 1.

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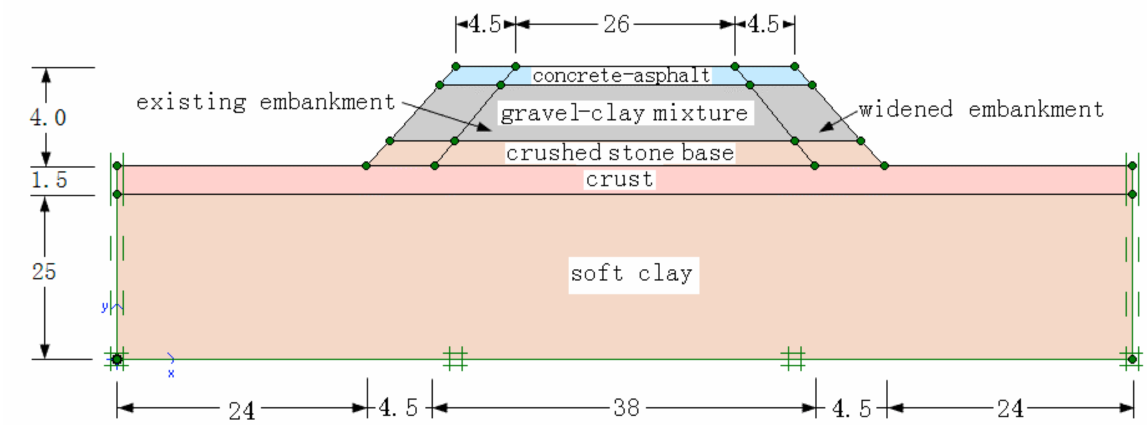

Fig. 1: Numerical model (unit: m)

Table 1: Physical and mechanical parameters of the materials

Materials	γ_d [kN/m^3]	γ_{sat} [kN/m^3]	k [m/d]	E_s [Mpa]	υ	c [kPa]	φ [°]	Ψ [°]
Concrete- asphalt	23	23	-	1000	0.17	-	-	-
Gravel-clay mixture	20	24	1.00000	30	0.25	5	30	0
Crushed stone	20	23	1.00000	40	0.25	0	32	5
Crust	16	18	0.00015	6	0.25	15	20	0
Soft clay	14	17	0.00065	4	0.35	10	15	0

The top of the perfectly rigid base layer was taken as the bottom boundary without any displacements. The side boundaries within the depth of the foundation soils can freely slide only along the vertical direction and the rest boundaries are free in displacements. Except for the side boundaries within the foundation soils depth and the bottom boundary, other boundaries are permeable. The underground water level is just at the top of the crust. The construction sequence of the embankment was simulated as 8 equal instant fillings and each filling was followed by a 2.5-day of consolidation. After the embankment filling, the excess pore pressures in the soils were allowed to dissipate to no more than 1 kPa.

RESULTS AND ANALYSES

Figure 2a plots the embankment settlements caused by the widening which was conducted 3 years after the existing embankment has been used. It can be seen that soil heaved not only beyond the widening embankment but also at the middle range of the existing embankment at the early stage of reconsolidation. After 30 days of reconsolidation, the maximum heave at the center of the existing embankment and the maximum heave beyond the new embankment were 11.5 and 12.5 mm, respectively while the maximum settlement reached 71 mm under the crest of the new embankment, i.e., the maximum differential settlement between the existing and the widened embankment base was 83.5 mm. With the continuous reconsolidation, the heave decreased and transformed into settlement nearly 180 days after the widening. It can also be seen that the settlements of the embankment became stable after 3 years of reconsolidation and the maximum settlement and the maximum differential settlement reached 114 and 84.9 mm, respectively.

Figure 2b shows the development of the embankment settlements caused by the widening which was conducted 5 years after the existing embankment has been used. Obviously, heave occurred at the middle range of the existing embankment base as well as the range beyond the new embankment. Similarly, after 3 years of reconsolidation, the settlements also became stable while the final settlements are less than that shown in Fig. 2a. In this situation, the maximum settlement and the maximum differential settlement were 98 and 84.8 mm, respectively, both are smaller than that shown in Fig. 2a. This suggests that the settlements caused by the widening can be reduced by adding the new embankment after a longer time since the construction of the existing embankment.

Figure 3a plots the pavement stress induced by the widening which was conducted 3 years since the existing embankment has been used. It can be seen that tensile stress developed in the existing pavement and compressive stress in the widening pavement. The maximum tensile stress occurred approximately at a distance of 9.5 m away the embankment center while the

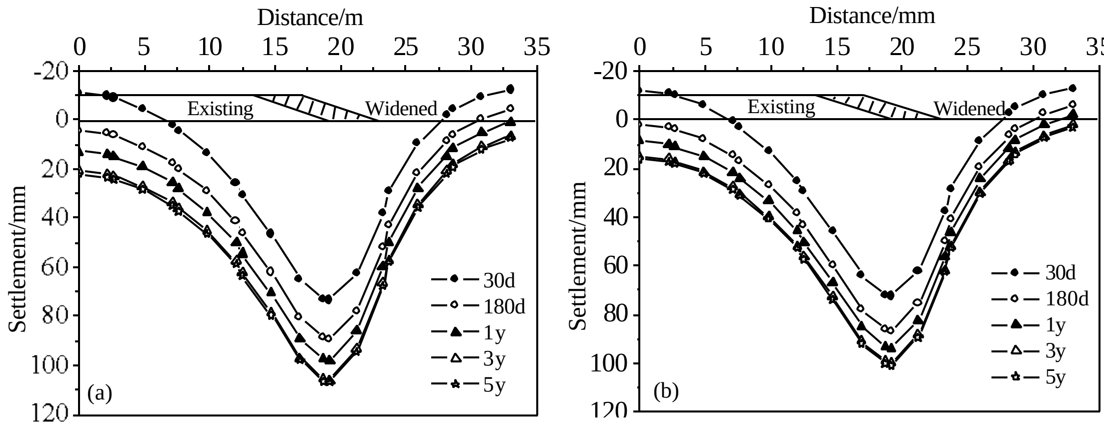

Fig. 2(a-b): Development of the embankment settlement induced by widening

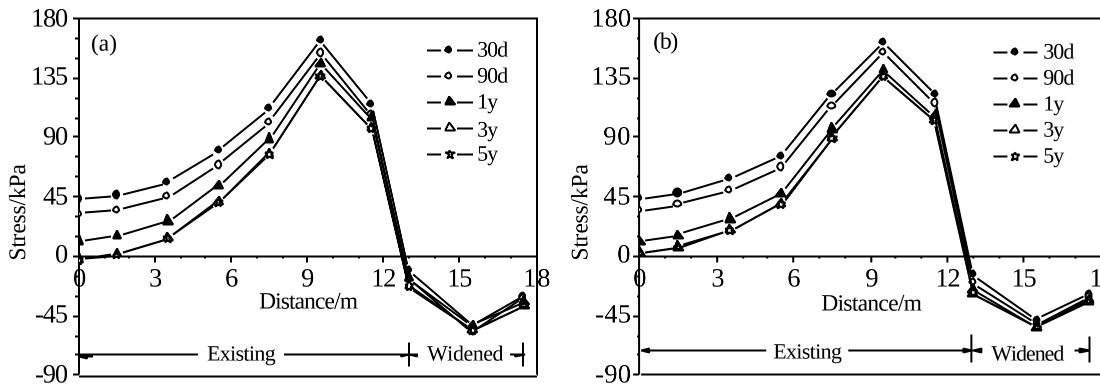

Fig. 3(a-b): Variation of the pavement stress caused by widening

maximum compressive stress located nearly at the mid of the widening lane. It can also been seen from Fig. 3a that the tensile stress in the existing pavement decreased with the continuous reconsolidation. For example, the maximum tensile stress decreased from 165 kPa 30 days after the widening to 135 kPa 3 years after the widening. On the other hand, the pavement compressive stresses in the widening pavement changed little with the continuous reconsolidation and its maximum value nearly remained at a value of -60 kPa.

Figure 3b shows the pavement stresses induced by the widening which was conducted 5 years since the existing embankment has been used. Obviously, the characteristic of the pavement stress is the same as that shown in Fig. 3a and also, both the tensile stress in the existing pavement and the compressive stress in the widened pavement became stable after 3 years of reconsolidation while their maximum values are slightly smaller than that shown in Fig. 3a.

The phenomena observed from Fig. 3 that the pavement stresses induced by widening after 3 years or 5 years are nearly same suggests that it is suitable to begin widening 3 years after the existing embankment has been used.

The development of the existing pavement slope prior to and after the widening is shown in Fig. 4. It can be noticed that under its self weight, the existing pavement slope increased from 0.88 to 0.93% a year later and remained nearly unchanged thereafter and instantly jumped to a negative value of -0.19% as soon as the beginning of the widening, i.e., adverse slope occurred in the existing pavement induced by widening. The slope will reach -0.33% after 180 days of reconsolidation and remained almost unchanged since then.

Figure 5 depicts the variation of the existing pavement slope after the widening. When the existing embankment was widened 3 years since it was put into use, its slope turned into a negative value of -0.19% after

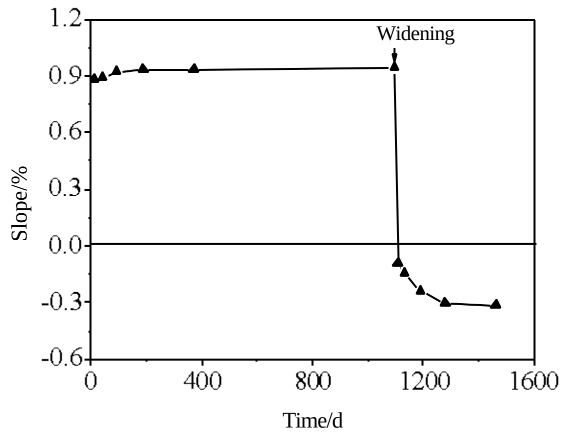

Fig. 4: Evolution of the existing pavement slope

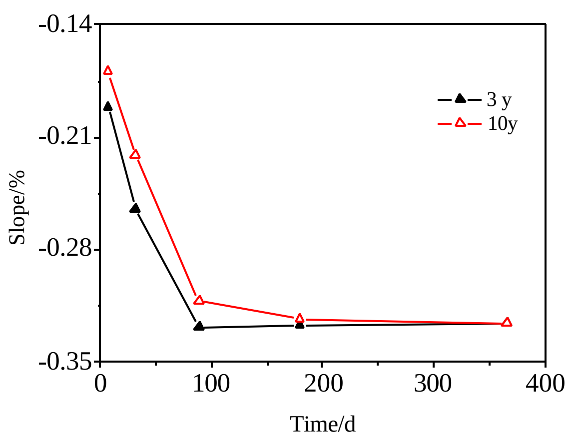

Fig. 5: Influence of widening time on the existing pavement slope

7 days of reconsolidation and increased to -0.25% after 30 days reconsolidation and then remained almost unchanged at a value of -0.33% after 90 days of reconsolidation. But for the embankment which was widened 10 years since it was put into use, its slope turned into a negative value of -0.17% after 7 days of reconsolidation and increased to -0.22% after 30 days reconsolidation and then remained almost unchanged at a value of -0.33% after 90 days of reconsolidation. Obviously, the existing pavement slope will be slightly smaller if the widening is conducted more lately.

CONCLUSION

The interaction between the widened and the existing embankment was analyzed and the following conclusions can be drawn. Additional settlements will be induced in the existing embankment by the widening while the additional settlements can be reduced by adjusting widening time. For the situation discussed in this study where the thickness of the soft foundation is 25 m, there exists a most appropriate time of 3 years since the existing embankment has been put into use to begin widening. Tensile stress will be induced within the existing pavement by widening and cracks will subsequently appear on the pavement when the tensile stress exceeds the tensile strength of the pavement material. In the view of reducing pavement tensile stress induced by widening, it is suitable to widen the existing embankment after 3 years of consolidation. The existing pavement slope prior to widening will firstly increase, then decrease slightly and finally remain unchanged. Adverse slope of the existing pavement will occur as soon as the beginning of the widening. It is recommended to widen later to reduce the pavement adverse slope and some measures should be adopted to smooth the pavement.

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