FEM analysis of the interaction between a broad embankment and its subsoil

JIANFENG CHEN[1], ZHENMING SHI[2], XIAOYING ZHUANG[3]

[1] *School of Civil Engineering, Tongji University. (e-mail: jf_chen@mail.tongji.edu.cn)*
[2] *School of Civil Engineering, Tongji University. (e-mail: shi_tongji@mail.tongji.edu.cn)*
[3] *School of Civil Engineering, Tongji University.*

Abstract: Broad embankment and its subsoil belong to an interaction object, where they affect each other mutually and deform co-ordinately. In order to study the influencing factors of subsoil's settlement, the paper varies the combination of fill's height, fill's stiffness and subsoil's stiffness and then analyzes these cases by FEM program applying modified Cam-clay model coupling Biot to subsoil and Mohr-Coulomb model to fill. The results show that the settlement of subsoil distinctly correlate with fill's height and fill's stiffness and subsoil's stiffness, which can be concluded as follows: (1) In case of soft subsoil with moderate fill's stiffness, the maximum settlement points occur at the two shoulders of embankment. As the height of loading increases, the location of the maximum settlement points tend to move towards the central part of embankment and its differential settlement to the centre part of the embankment decreases. (2) In case of hard subsoil with moderate fill's stiffness, the two shoulders no longer own the maximum settlement and the differential settlement of subsoil decreases. (3) In case of hard fill with soft subsoil, settlement and differential settlement become smaller. With the increase of loading, the differential settlement decreases significantly.

Résumé: Le large remblai et son sous-sol appartiennent à un objet d'interaction, où ils s'affectent mutuellement et déforment Co-ordinately. Afin d'étudier les facteurs influençants du règlement du sous-sol, le papier change la combinaison de la taille de la suffisance, a rempli rigidité et rigidité du sous-sol et puis analyse ces caisses par le programme de FEM appliquant l'accouplement modifié Biot de modèle d'Came-argile au sous-sol et au modèle de Mohr-Coulomb pour remplir. Les résultats prouvent que le règlement du sous-sol se corrèlent distinctement avec la taille de la suffisance et ont rempli rigidité et rigidité du sous-sol, qui peuvent être conclues comme suit : (1) en cas de sous-sol mou avec la rigidité de la suffisance modérée, les points maximum de règlement se produisent aux deux épaules du remblai. Pendant que la taille des augmentations de chargement, l'endroit des points maximum de règlement tendent à se déplacer vers la partie centrale du remblai et son règlement différentiel à la pièce de centre du remblai diminue. (2) en cas de sous-sol dur avec la rigidité de la suffisance modérée, les deux épaules ne possèdent plus le règlement maximum et le règlement différentiel du sous-sol diminue. (3) en cas de suffisance dure avec le sous-sol mou, le règlement et le règlement de différentiel deviennent plus petits. Avec l'augmentation du chargement, le règlement différentiel diminue de manière significative.

Keywords: embankment, finite element, settlement

INTRODUCTION

Broad embankment and its subsoil belong to an interaction object, where they affect each other mutually and deform co-ordinately. The settlement of subsoil is directly under the influence of the fill's height, the fill's stiffness and the subsoil's stiffness. The Chen, Shi & Shen (2003) have once analysed the settlement of a broad embankment built on soft subsoil by Finite Element Method (FEM) program applying a linear elastic model with Biot coupling. The results showed that settlements at the shoulders of embankment are greater than those at the central part, and as loading increasing, the location of the maximum settlement point tends to move towards the central part of embankment. These results are entirely consistent with the results taken from the Muar experimental embankment in Malaysia and with the 400m-wide embankment built on soft subsoil of Shenzhen airport in China (see Zhang 1999 for further details). With both these substantial engineering embankment projects their observed settlements were measured to be greater at the two sides than at central part of each respective embankment.

The Chen *et al.* (2003) have analysed settlements of an embankment case but by only meshing the subsoil itself and not by considering the embankment and subsoil together as an interacting object. Instead, this paper has assessed several cases with various combinations of fill height, fill stiffness and subsoil stiffness being analysed and in each case the embankment and the subsoil t were meshed together as a whole. This allows a better study on how these factors influence the deformation of subsoil to take place. A FEM analysis of settlements for these cases has been carried out by applying a modified Cam-clay model to subsoil and the Mohr-Coulomb model to fill.

CONSTITUTIVE MODEL

The widely applied modified Cam-clay model is particularly pertinent to calculate the deformation of soft subsoil (Chen, Qin & Shi 2003). Moreover, this model can be coupled together with Biot theory to develop into the coupling Cam-clay & Biot model, which is capable of simulating the coupling aspects associated with subsoil deformation, seepage and consolidation (Qian 1996). Chen *et al.* (2003) have presented a detailed FEM equation derivation of the coupling Cam-clay and Biot model. From this the required input parameters are stress ratio, M; compression index, λ; expansion index, κ; Poisson ratio, ν and coefficient of permeability, k.

As fill is commonly made by compacting gravels, the Mohr-Coulomb model is adopted, which contains two key parameters namely, cohesive strength c and angle of internal friction φ.

FEM ANALYSIS

In the FEM analysis presented in this paper a broad embankment case that is 48.0 m in width with a slope 1:5 has been taken. The subsoil is composed of single soil stratum having gravity = 17.0 N/m^3, vertical coefficient of permeability, $k_v = 1\times10^{-8}$ m/s and horizontal coefficient of permeability, $k_h = 2.4\times10^{-8}$ m/s. The fill's unit weight is 25.0 kN/m^3. In view of the symmetry of embankment, only half width 24.0 m is used in the analysis. The Marc2003 FEM programme was used to undertake the analysis presented in this paper.

To study influences of the variation in combinations of fill height, fill stiffness and subsoil stiffness on the deformation of subsoil, the FEM analysis was carried out for three cases, each with different properties of subsoil and fill. Parameters for these calculation cases are listed in Table 1. For the first case a soft subsoil was adopted, with the second case a hard subsoil was assessed, both having a fill moderate in stiffness placed on top. For the third case, the fill's stiffness was significantly increased however, the subsoil was taken to be soft as with case 1.

Table 1. Mechanical parameters of calculation cases.

Property Index	Subsoil				Fill	
Case	Poisson's Ratio ν	Compression index λ	Expansion index κ	Stress ratio M	Cohesive strength C	Angle of internal friction φ
Case 1: Soft Subsoil	0.4	0.147	0.06	1.05	0	30°
Case 2: Hard Subsoil	0.3	0.06	0.02	1.0	0	30°
Case 3: Stiffer Fill	0.4	0.147	0.06	1.05	15	40°

The model after meshing is shown in Figure 1 and Figure 2 illustrates the curve of loading height versus time used in this analysis. It is assumed that the upper ground was under a free drainage condition and at a 25.0 m depth an undrained boundary existed. The model was constrained for displacement in horizontal direction along left and right side, and for displacement in both horizontal and vertical direction along base as shown in Figure 1.

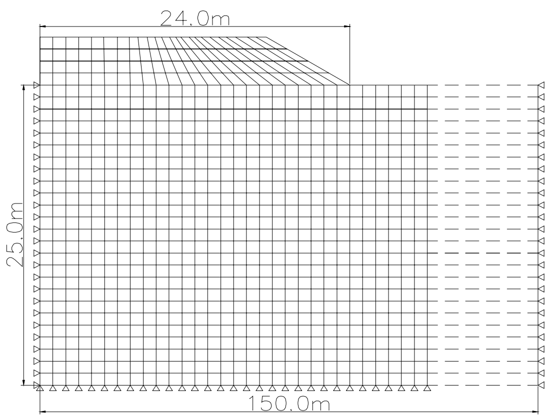

Figure 1. Mesh and boundary conditions used in FEM modelling

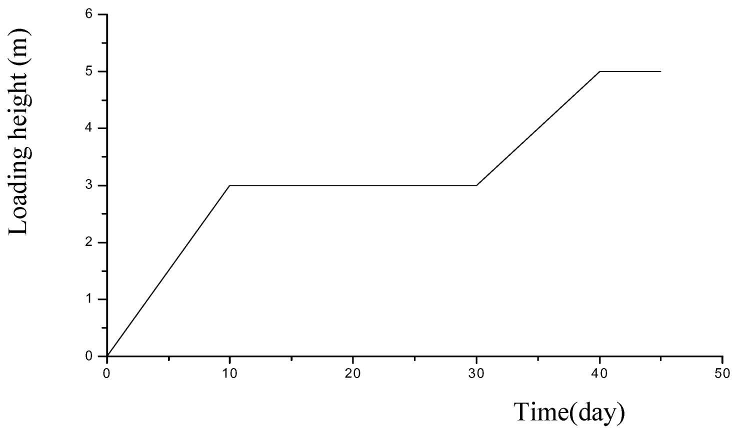

Figure 2. Curve of loading height versus time

Case 1: FEM analysis for case of soft subsoil

Figure 3 and Figure 4 show the distribution of settlements after 10 and 40 days of loading respectively.

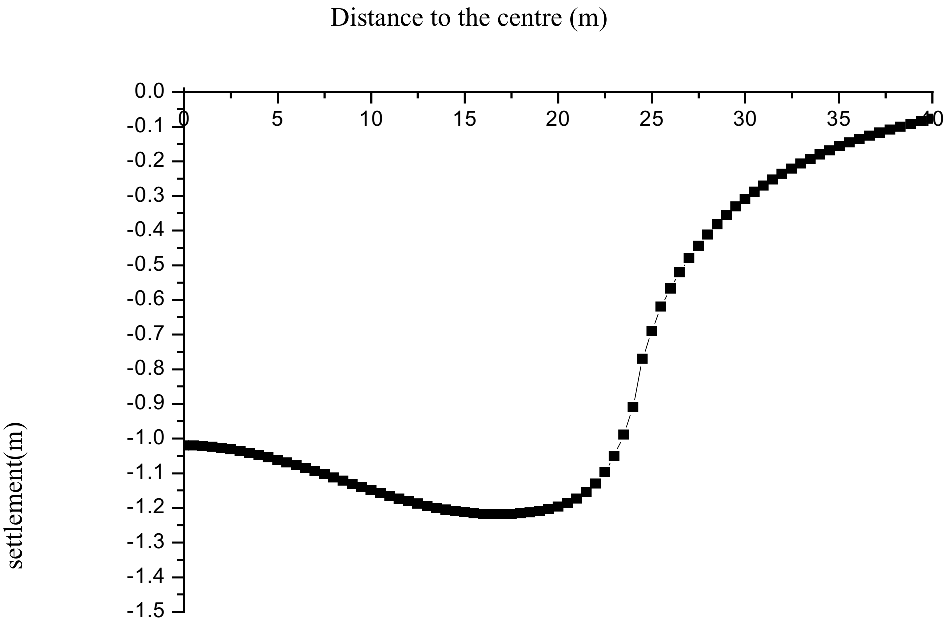

Figure 3. Settlement after 10 days of loading (loading height 3m)

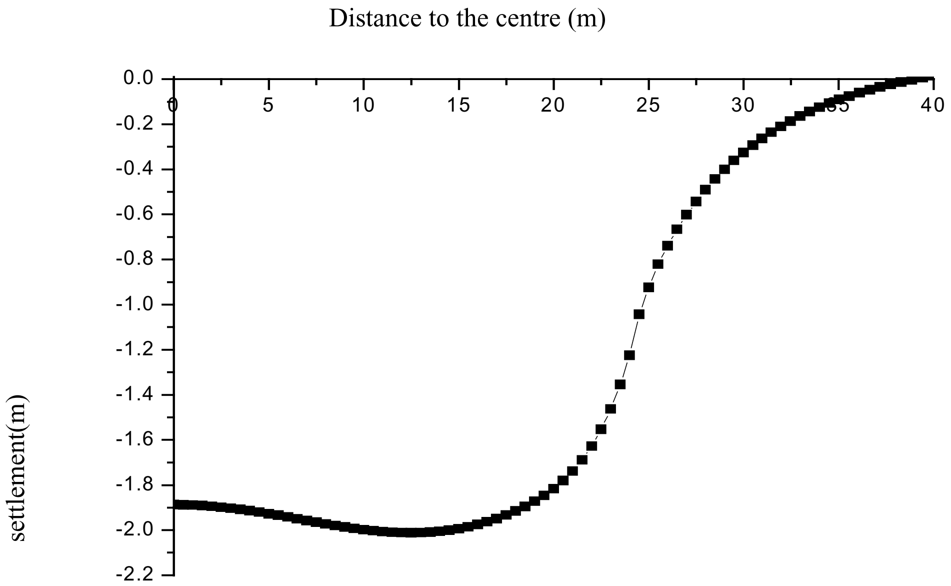

Figure 4. Settlement after 40 days of loading (loading height 5m)

It can be seen from the Figure 3 that when the loading height reached 3.0 m, the point of maximum settlement occurs at about a 17.0 m distance from the central part of the embankment, while its differential settlement relative to the central part is about 20 cm. As the loading height increases to 5.0 metres, the point of maximum settlement shifts to about 14.0 m distance from the central part while its differential settlement relative to the central part is about 10 cm (see Figure 4).

For a very broad embankments built on soft subsoil, the maximum settlement occurs not at the central part of embankment but under the two shoulders, and when loading increases, that maximum settlement points tends to move inward while its differential settlement to the central part decreases. These results are consistent with other embankment cases the authors have analysed using FEM program when applying a linear elastic model with Biot coupling.

Case 2: FEM analysis for case of hard subsoil

Figure 5 and Figure 6 show distribution of settlements after 10 and 40 days of loading respectively.

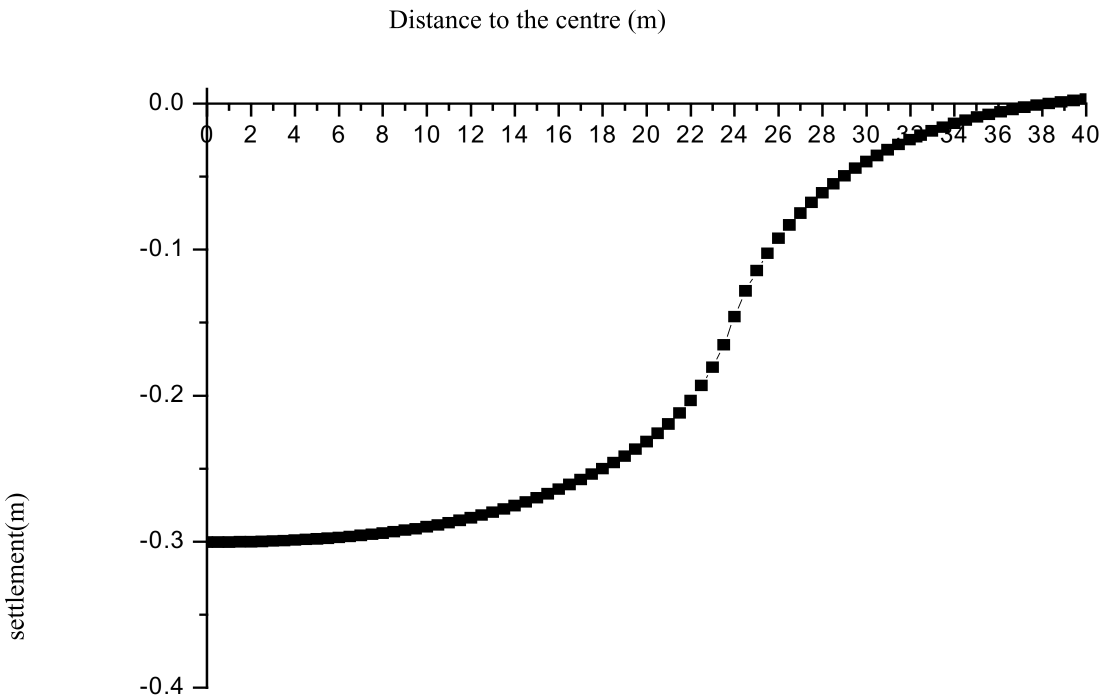

Figure 5. Settlement after 10 days of loading

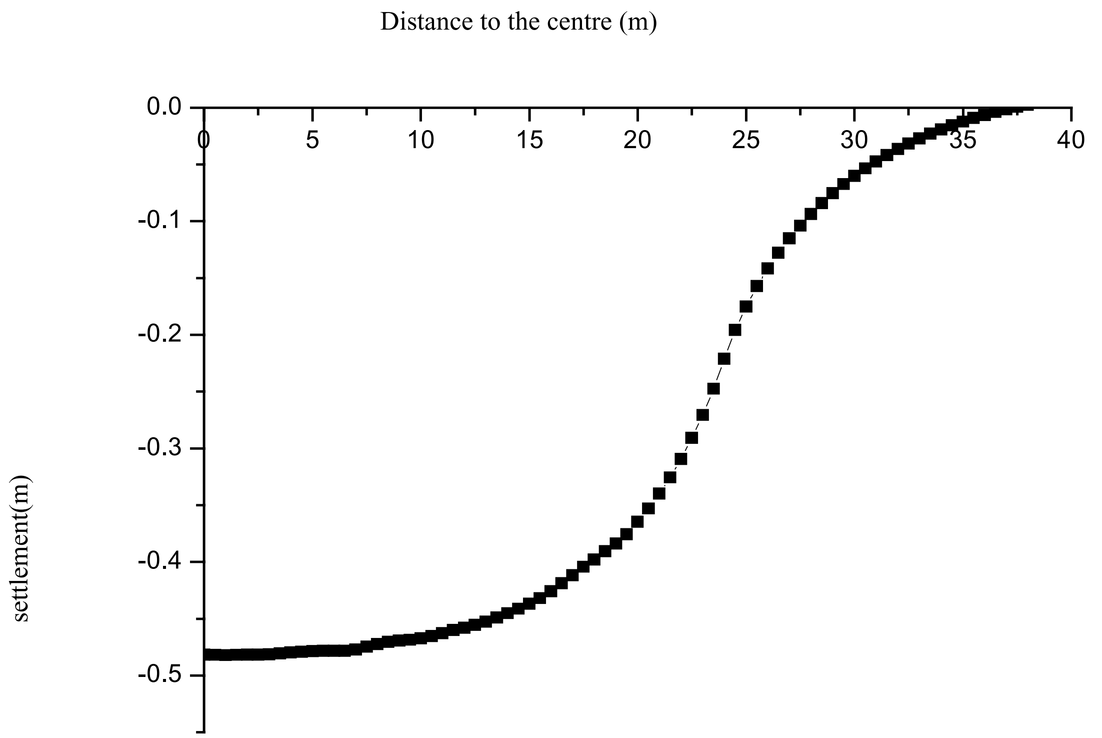

Figure 6. Settlement after 40 days of loading

It can be seen from Figures 5 and 6 that as the subsoil becomes stiffer compared to case 1, the maximum settlement occurs at the central part and no longer under the shoulders of the embankment.

Case 3: FEM analysis for case of stiffer fill

Figure 7 and Figure 8 show distribution of settlements after 10 and 40 days of loading respectively.

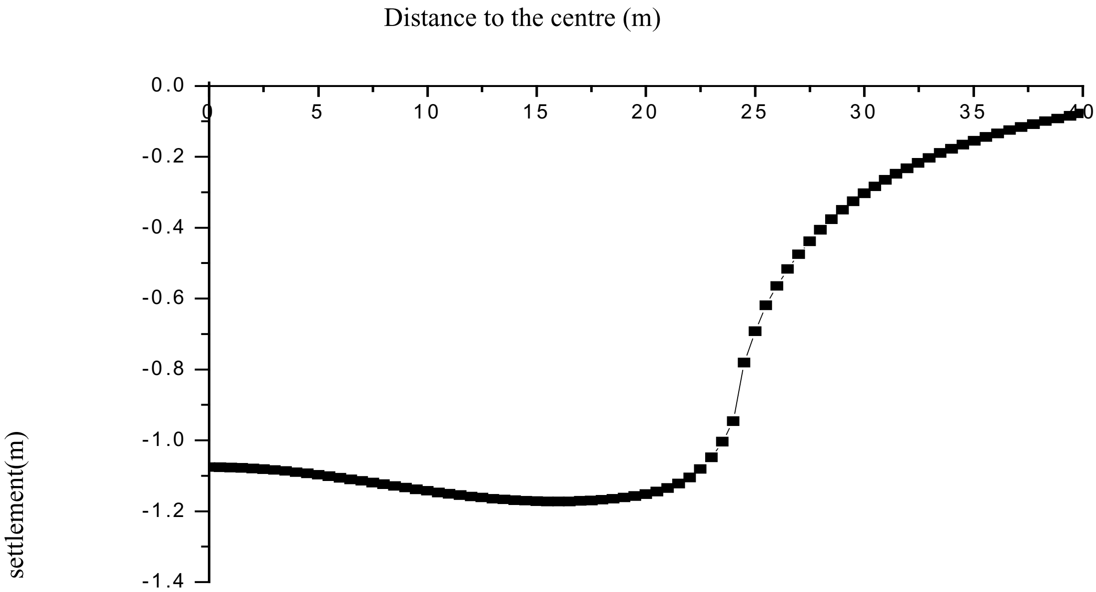

Figure 7. Settlement after 10 days of loading

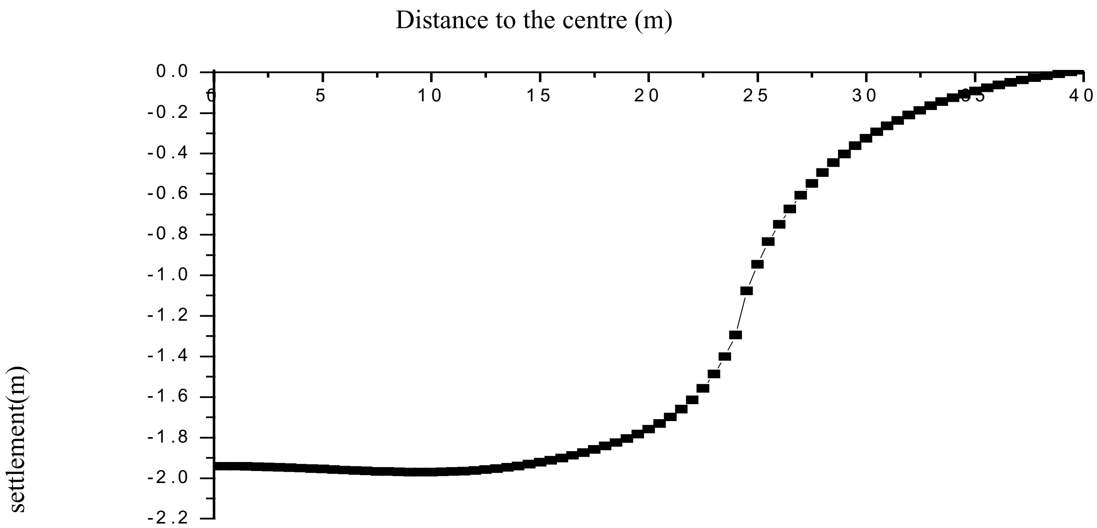

Figure 8. Settlement after 40 days of loading

It can be seen from Figures 7 and 8 that though in this case (case 3) the distribution of settlement is similar to the case 1 on the whole, there are some key differences. When the loading height reaches 3.0 m, the point of maximum settlement occurs at about 16.0 m distance from the central part while its differential settlement to the central part is about 10 cm. As the loading height increases to 5.0 metres, the point of maximum settlement occurs at about a 9.5 m distance to the central part, while its differential settlement to the central part is about 0.3 cm.

These results indicate that an increase in the stiffness of the fill causes a decrease in the settlement and differential settlement, and the decrease in differential settlement can be further promoted as the loading continues to increase.

CONCLUSIONS

By analysing for three broad embankment cases with various combination of fill height, fill stiffness and subsoil stiffness, following conclusions can be drawn:

- In case of soft subsoil with moderate fill stiffness, the maximum settlement points occur under the two shoulders of embankment. As the height of loading increases, the location of the maximum settlement points tend to move towards the central part of embankment and its differential settlement relative to the central part of the embankment decreases.
- When the subsoil becomes harder, the maximum settlement move away from under the shoulders and the differential settlement under embankment decreases.
- By increasing the fill's stiffness, settlement and differential settlement become smaller. With the increase of loading, the differential settlement decreases significantly.
- For a broad embankment with high fill, its settlement is distinctly influenced by such factors as fill height, fill stiffness and subsoil stiffness, and that varying the combination of these factors can lead to various distribution of settlement. Thus, it is improper to judge the settlement pattern of the subsoil by considering the influence of single factor only.

Corresponding author: Dr J.F Chen, School of Civil Engineering, Tongji University, Siping Road 1239, Shanghai, 200092, China. Tel: +86 021 65982771. Email: jf_chen@mail.tongji.edu.cn.

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