Observed and predicted behavior of embankments and excavation in soft clay

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ABSTRACT: This paper concerns with the predictions and observations of various case studies in soft Bangkok clay. The performance of a full scale test embankment constructed on soft Bangkok clay with Prefabricated Vertical Drains (PVD) at the proposed site of the Second Bangkok International Airport (SBIA) is the first case. Each of the three test embankments was square in plan with a maximum height of 4.2 m, 3H to 1V side slopes and base dimensions of 40 m by 40 m. A coupled consolidation-shear deformation analysis was carried out with FEM using CRISP program incorporating Biot's theory of consolidation and Critical State Soil Mechanics. Good agreements were noted between the measured and predicted settlements as well as the measured and predicted pore pressures. In another case study, the reinforced wall/embankment constructed on soft Bangkok clay consists of 80 degrees inclined gabion facing with hexagonal wire mesh reinforcements on one side and sloping unreinforced sandfill in the opposite side with a total height of 6.0 meters. The numerical simulation based on finite element (FE) analysis under plain strain condition using SAGE CRISP and PLAXIS program were performed to simulate the behavior of the embankment. The results of the numerical simulation reasonably captured the overall behavior of the reinforced soil-wall embankment system on soft ground foundation through good agreement between the field measurements and the simulated values. Finally, the CRISP program was used and FE analysis was carried out for deep excavations in Bangkok. In this case, the strains are small with lateral movement of diaphragm wall in the order of 10 to 50 mm. Thus, the parameters used in the FE analysis were entirely different in contrast from the previous case studies with large strains. Good agreement between measured and predicted values was obtained.

RESUME : Ce document est relatif aux predictions et observations de differents cas d'etudes sur l'argile tendre de Bangkok. Le premier cas concerne la conduite d'un essai en vraie grandeur sur un surelevement construit sur de l'argile tendre de Bangkok avec des drains verticaux prefabriques sur le site presume du deuxieme aeroport international de Bangkok. Chacun des trois essais d'endiguement etaient carres vus de plan, avec une hauteur maximum de 4.2 m et des pentes de cote de 3H sur 1V et des dimensions de base de 40 sur 40m. Une analyse de deformation a ete execute avec FEM utilisant le programme CRISP integrant la theorie de consolidation de Biot et la Mecanique des Sols en conditions critiques. Cela revela une bonne concordance entre les tassements mesures et ceux predits ainsi qu'entre les mesures de pression de pores et celles anticipees. Dans un autre cas d'etude, le mur de renforcement construit sur l'argile tendre de Bangkok, consiste en une face en gabion d'une hauteur totale de 6 metres, avec pente de 80 degres avec des renforcements en fil de treillis de forme hexagonale d'un cote et une pente de sable non renforcee de l'autre cote. La simulation numerique basee sur l'analyse d'elements finis en deux dimensions utilisant le programme SAGE CRISP and PLAXIS fut realisee pour simuler le comportement du mur de renforcement. Les resultats de la simulation numerique refletent de facon raisonable le comportement general du systeme d'endiguement base par une bonne concordance entre les mesures de terrain et les valeurs de simulation. Enfin, le programme CRISP a ete utilise et les analyses sur elements finis furent conduites sur des excavations profondes a Bangkok. Dans ce cas, les deformations sont faibles avec un mouvement lateral du mur diaphragme de l'ordre de 10 a 50 mm. Ainsi, les parametres utilises dans l'analyse sur elements finis etaient completement differents des cas precedents avec larges deformations. Une bonne concordance entre les valeurs mesurees et predites fut obtenue.

1. Introduction

Three types of case histories are presented here in soft Bangkok clay. The first one relates to the Second Bangkok International Airport (SBIA) where the consolidation settlement is the predominant component and the project includes the use of Prefabricated Vertical Drains (PVD) as ground improvement. The second case concerns with reinforced soil embankment with hexagonal wire mesh reinforcement. The third case refers to supported deep excavations for basements of buildings and where the mode of deformation is predominantly undrained. In all cases, the CRISP program (Britto and Gunn, 1987) is used in the numerical analysis and the program uses the Roscoe and Burland version (1968) of the Critical State Theory. In addition, the PLAXIS program (Vermeer and Brinkgreve, 1995) at SBIA has also been applied to simulate for the second case study.

2. Full scale tests of prefabricated vertical drains

Three test embankments (TS1, TS2 and TS3) with 40m x 40m plan dimension and side slopes 3:1 were built at the airport site in SBIA project. These embankments were built on subsoil with PVD installed at spacing of 1.0, 1.2 and 1.5 m, respectively, in a square pattern down to a depth of 12 m. A sand blanket of 1.0 m height was laid on the excavated ground (-0.3 m MSL) prior to the installation of PVD. After the PVD installation, the sand blanket was increased to 1.5 m. Then, clayey sand was used to raise the embankment to 4.2 m (i.e. 75 kPa of surcharge) in stages. During construction, stage I loading was up to 18 kPa. Stage II was taken to 45 kPa, followed by stage III to 54 kPa and stage IV to 75 kPa (4.2 m fill height). For TS 1 embankment with 1.5 m spacing, a 5 m wide and 1.5 m high berm was installed, when the surcharge increased from 45 to 54 kPa. The berm width was increased to 7 m when the surcharge increased from 54 to 75 kPa. For TS2 and TS3, a berm width of 5 m and 1.5 m high was included when the surcharge increased from 54 to 75 kPa. The waiting period was 45 days for TS1 and TS2 with 54 kPa surcharge and this was reduced to 30 days for TS3 which has the closest spacing of PVD. The finite element analysis using the CRISP program was used for the prediction of pore pressures and deformations. The predicted and the

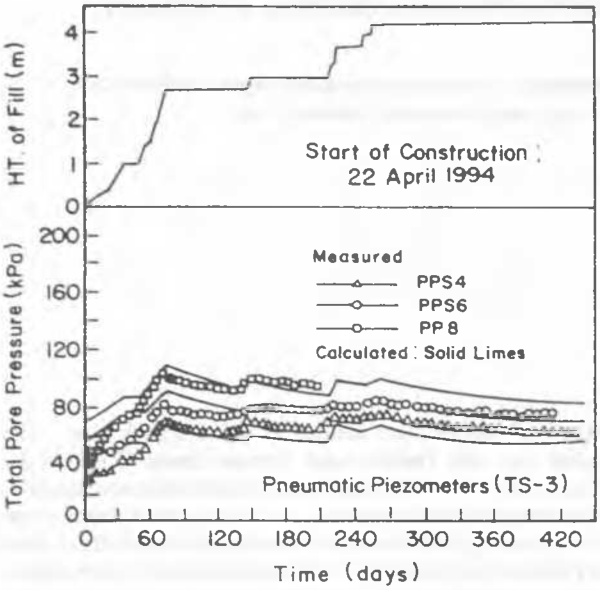

Figure 1 Computed pore pressure from FEM and measured values - TS3

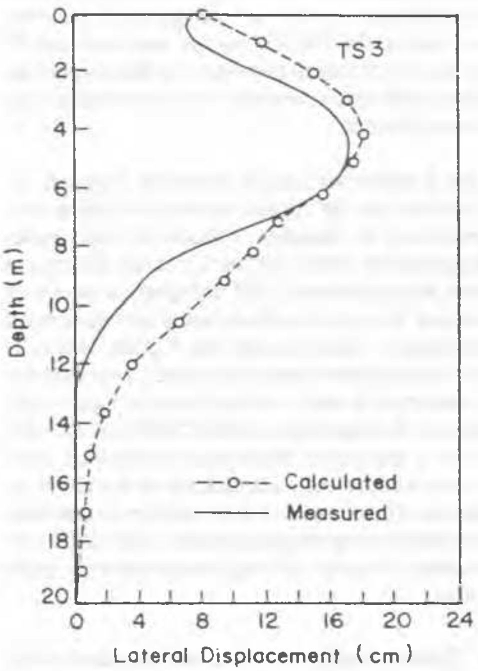

Figure 2. Comparison of computed FEM and measured lateral deformations

observed values as shown in Figs. 1, 2 and 3 are in good agreement.

The soil parameters used in the FEM analysis are given in Table 1. In the theory of Roscoe and Burland (1968) as used in the CRISP program, the values of λ, k and M are used. For the same

Table 1 Soil parameters for FEM analysis for PVD improved ground with embankment surcharge (TS1, TS2 and TS3)

Depth (m)	k	λ	M
0.0-2.0	0.07	0.34	1.20
2.0-7.0	0.18	0.90	0.90
7.0-12.0	0.10	0.50	1.00
12.0-15.0	0.07	0.34	1.20
15.0-18.0	0.02	0.10	1.20

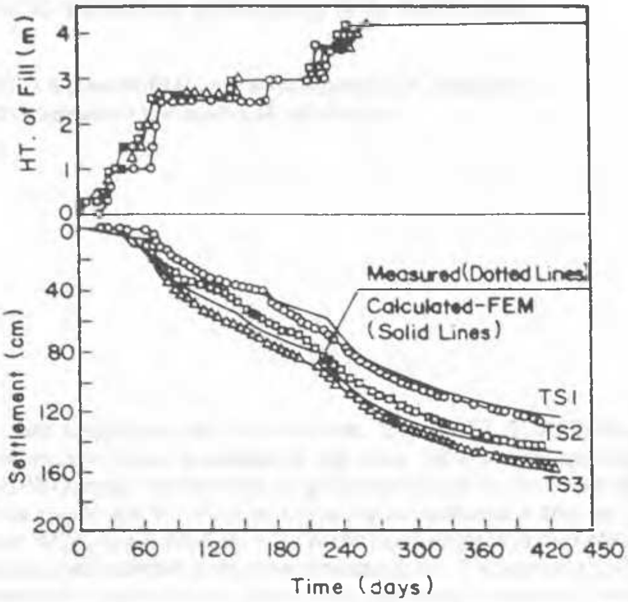

Figure 3 Comparison of computed FEM and measured settlement values – TS1, TS2 and TS3

clay deposits λ, k and M need to be the same for the normally consolidated states. However in Table 1, λ ranges from 0.10 to 0.90; k ranges from 0.02 to 0.18 and M ranges from 0.90 to 1.20.

3. Hexagonal wire mesh reinforced embankment

A fully instrumented test embankment built on soft Bangkok clay was constructed on the campus of the Asian Institute of Technology (AIT), Bangkok, Thailand using the hexagonal twisted wires as reinforcement (Bergado et al, 2000). The embankment was 6.0 m high, 6.0 m long at the top, top width of 6.0 m, and base width of 18.0 m. The wall was divided into two sections along its length. Each section was constructed with the same backfill, silty sand, but with different types of hexagonal wire mesh, namely: zinc-coated and PVC-coated. After 405 days of construction, the embankment was raised by 1 m as an additional surcharge. The gabion facing of the embankment was built with 80 degrees inclination from the horizontal alignment. The side slope and back slope were 1:1. The numerical simulations by finite element method (FEM) under plane strain condition using SAGE CRISP program have been carried out to investigate the behavior of the full scale test embankment. The results were also favorably compared with the previous simulation by Bergado et al (2000) using PLAXIS FEM software.

The elastic, perfectly-plastic Mohr-Coulomb model was used to represent the silty sand embankment fill. The apparent cohesion, c′, and the friction angle, ϕ′, were determined from the large scale direct shear test (Long, 1996). Shear moduli, G, were obtained from the back-analyses using FEM (Long, 1996) by assuming a Poisson's ratio of 0.33. The soil parameters for silty sand are listed in Table 2. The underlying soft Bangkok clay foundation has been divided into 5 layers, i.e., 0 to 2 m weathered crust, 2 to 4 m very soft clay, 4 to 6 m soft clay 1, 6 to 8 m soft clay 2 and 8 to 13 m medium clay. In this study, the elastic perfectly-plastic Mohr Coulomb model obtained from isotropically consolidated undrained tests (CIAU) was used for the overconsolidated weathered crust layer. The Modified Cam Clay model has been widely used for representing stress-strain relationship of the soft Bangkok clay, which is lightly overconsolidated states. The Modified Cam clay model parameters were determined based on one-dimensional consolidation tests as shown in Table 2.

Table 2 Selected parameters for FEM analysis of hexagonal wire mesh reinforced embankment

	Silty sand	Wea-thered clay	Very soft clay	Soft Clay 1	Soft Clay 2	Medium Clay
Model	MC	MC	MCC	MCC	MCC	MCC
Depth (m)	-	0-2	2-4	4-6	6-8	8-13
γ_{bulk} (kN/m^3)	18.0	17.5	15.0	15.0	16.5	19.0
k_x (m/days)	-	0.01	6e-4	8e-5	8e-5	4e-4
k_y (m/days)	-	0.005	3e-4	4e-5	4e-5	2e-4
E_{ref} (kPa)	3082	7000	-	-	-	-
c' (kN/m^2)	10	17.9	-	-	-	-
ϕ' (degree)	30	12.9	-	-	-	-
λ	-	-	0.53	0.51	0.47	0.31
k	-	-	0.13	0.11	0.09	0.07
M	-	-	1	1	1	1
ν	0.33	0.25	0.33	0.30	0.30	0.25

The FE results of SAGE CRISP and PLAXIS have similar behavior and were compared with the measured settlement data of the surface settlement plates as shown in Fig 4. The soil permeability has been assumed to be twice as much in the field condition than the laboratory values due to the presence of the uppermost weathered crust layer on the top of soft clay layer which tends to increase the permeability of soil beneath the test embankment. In addition, the presence of sand lenses and silt seams in the lower part of the soft clay layer also contribute to higher in-situ permeability. The calculated values were consistent with the measured data by using the established average permeability slightly equivalent to twice the laboratory vertical permeability ($2K_{v\,lab}$).

The comparison of FE results using both SAGE CRISP and PLAXIS and the measured lateral displacements are shown in Fig. 5 at 60, 196 and 343 days after the beginning of construction. The calculated wall face lateral displacements underpredicted the measured data in the upper part of the wall due to two reasons. Firstly, as mentioned by Poulos (1972), when good agreement between measured and calculated vertical settlements was obtained, the calculated lateral displacements were greater than those measured. The most significant reasons cited for the differences are the effects of Poisson's ratio, anisotropy and non-homogeneity. Secondly, as reported by Schaefer and Duncan (1988), the differences between measured and calculated lateral displacements in the subsoil immediately after construction are partially due to the influence of inclinometer casing stiffness.

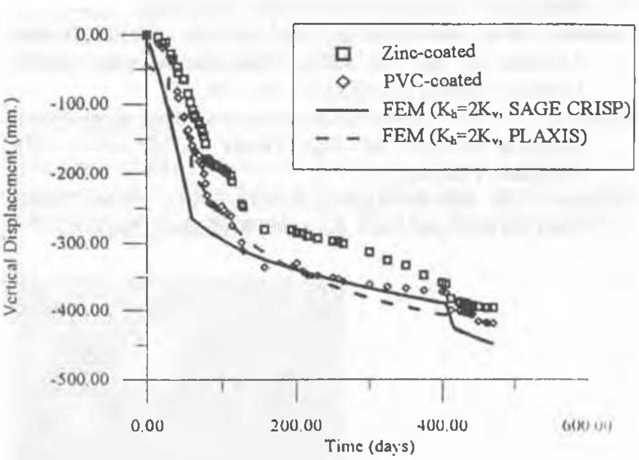

Figure 4 Comparison of measured and predicted surface settlements at 0.45 m depth (middle of the test embankment)

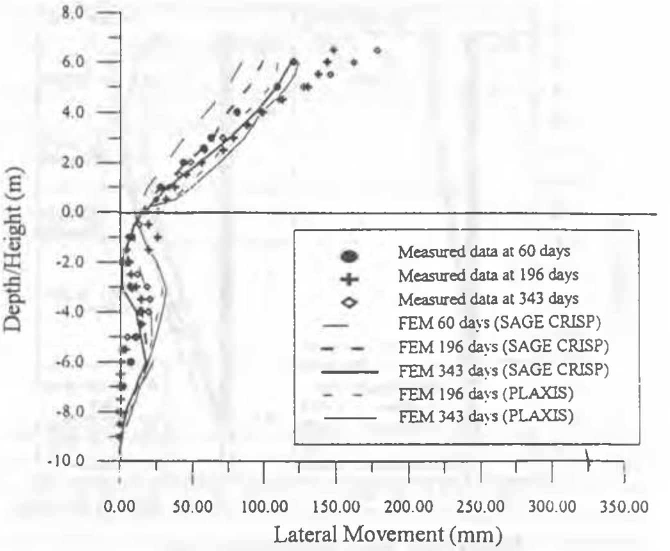

Figure 5 Comparison of measured and predicted lateral displacement profiles

The tension force distributions along galvanized hexagonal wire mesh are shown in Fig 6. The agreement between the FE results using both SAGE CRISP and PLAXIS and the measured data for both types of hexagonal wire mesh at 60 and 240 days were acceptable. The results from the FE analysis underpredicted the field data in the upper part because the upper wall movement at the end of the construction was small. Therefore, the tension forces were not able to develop that much.

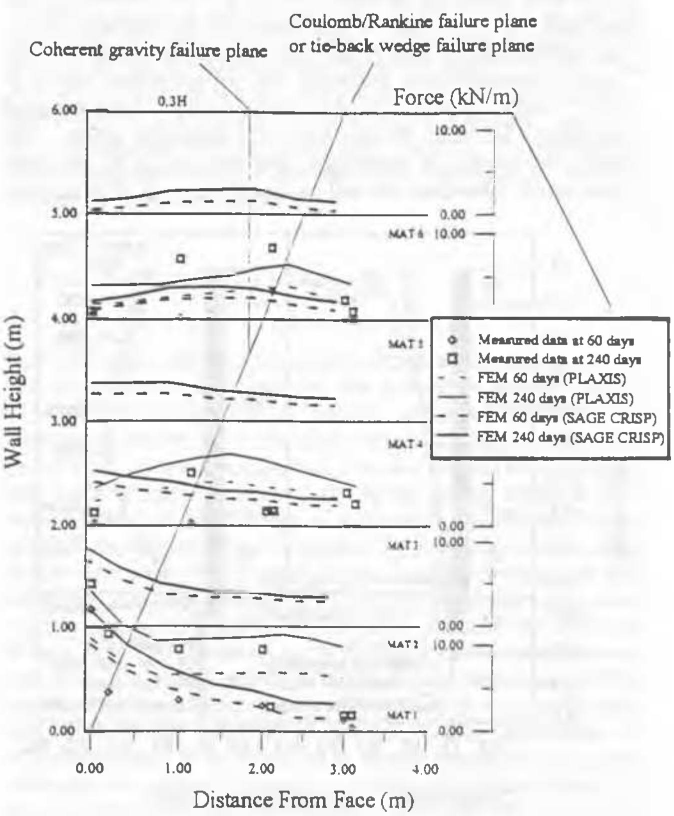

Figure 6 Predicted and measured tensions in galvanized hexagonal wire mesh reinforcement

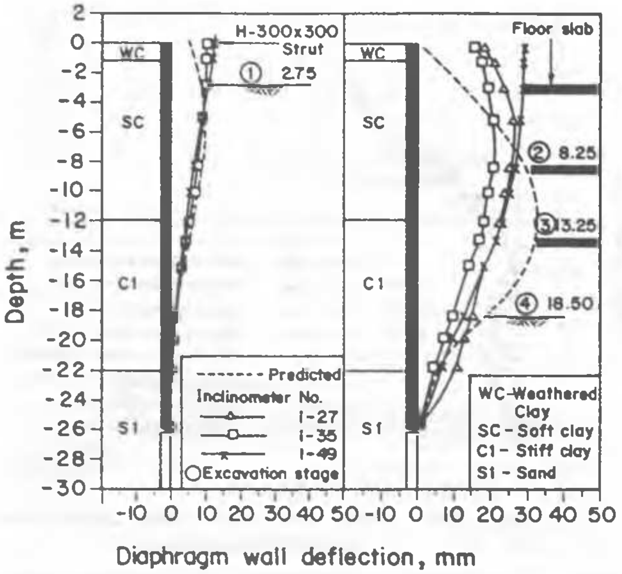

Figure 7 Predicted and measured diaphram wall deflection profiles at site A

4. Deep excavation in Bangkok clay

In this section, the deformation analysis of deep excavations in the Bangkok subsoil is presented. The field data comes from two sites named as A, and B. In site A, a 26.0 m deep, 0.82 m. thick diaphragm wall was used to support an excavation of 18.5 m depth. Barrette piles were installed below the wall to a depth of 50.0 m. Three concrete slabs were constructed by top-down method as supporting system at 2.75, 8.25 and 13.25 m depths (refer Fig. 7). In site B, a 1.0 m thick and 20.0 m deep diaphragm wall was used to support a 16.0 m deep excavation. The bracing system consisted of strut-wales and king posts. The struts were preloaded as shown in Fig. 8. The CRISP program was used and FEM analysis was carried out by Sutabutr (1991). The soil parameters used in the FEM analysis are given in Table 3 and the observed and predicted wall deflections are shown in Figs. 7 and 8 for sites A and B, respectively. There are good agreements between the predicted and measured values. The lateral movements of diaphragm wall from 10 to 50 mm were quite small. Therefore, the soil parameters used in FEM analysis

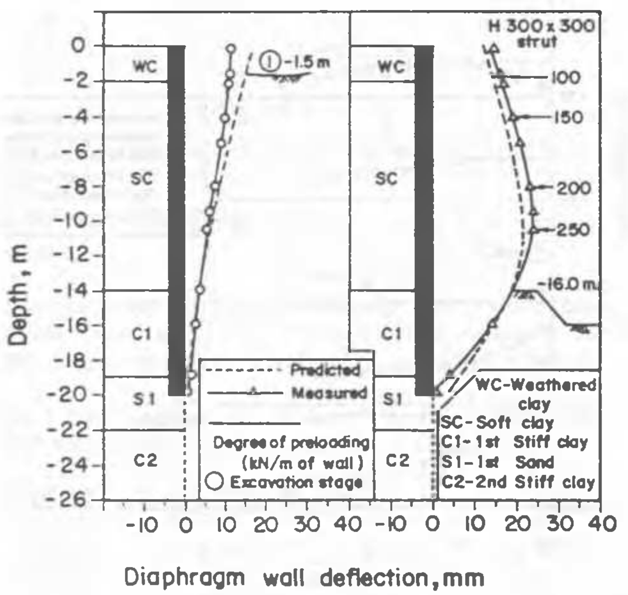

Figure 8 Predicted and measured diaphram wall deflection profiles at site B

Table 3 Soil parameters for FEM analysis for deep excavation in Bangkok clay

Depth (m)	k	λ	M
0.0-2.0	0.053	0.182	1.05
2.0-15.0	0.090	0.358	0.93
15.0-22.0	0.026	0.111	0.88

(see Table 3) are different from the previous values: k ranges from 0.026 to 0.090, λ ranges from 0.111 to 0.358 and M ranges from 0.88 to 1.05.

5. Conclusion

Three case histories in soft Bangkok clay were discussed and presented. At the SBIA site, a couple consolidation-shear deformation analysis was carried out with FE technique using the CRISP program. Good agreement is noted between the measured field data the computed values. For the hexagonal wire mesh reinforced embankment, the FE technique used SAGE-CRISP program was applied in consolidation analysis. The FE results were also favorably compared with the FE technique using PLAXIS program. The results from FE analysis reasonably captured the overall behavior of the reinfocrcement system. In deep excavation case study, the soil parameters used in FE analysis are different from the previous large strain values from the embankments. It appears that for small strain analysis (deep excavation), the use of the CRISP program seem rather not precise. The possibility is to select λ, k and M in such a way that the undrained stress strain curve is predicted well.

6. References

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