

Numerical research on soft clay foundation reinforcement phase settlement

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Abstract. The reinforcement phase settlement of soft clay foundation is a difficult problem with great practical meaning. This paper analysed the reinforcement phase settlement of dredger fill foundation based on an engineering case. The development of settlement and pore pressure variation within the foundation reinforcing treatment period is calculated with finite element software. The finite element analysis results are compared with the in-site test results, and the reinforcement phase settlement development feature is concluded.

1. Introduction

The settlement feature involves with both the foundation layers' physical property and the foundation reinforcing treatment. The distribution of foundation layers, features of each soil layer, and the foundation reinforcing treatment are modelled in numerical simulation model [1-3]. The development of settlement is calculated, and the finite element analysis (FEA) model is calibrated with the in-site test results.

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2. Project Profile

The project is road engineering in some area of Tianjin Port. The design road is 282 m long and 40 m wide, and the foundation treatment area is about 24161 m². Vacuum combined with surcharge preloading is used in foundation treatment practice. The vacuum load is 85 kPa, lasting for 110 days. The draining boards are set into square shape with 0.8 m intervals and 15 m deep. Table 1 shows the soil properties of each layer.



Table 1. Parameter of soil properties

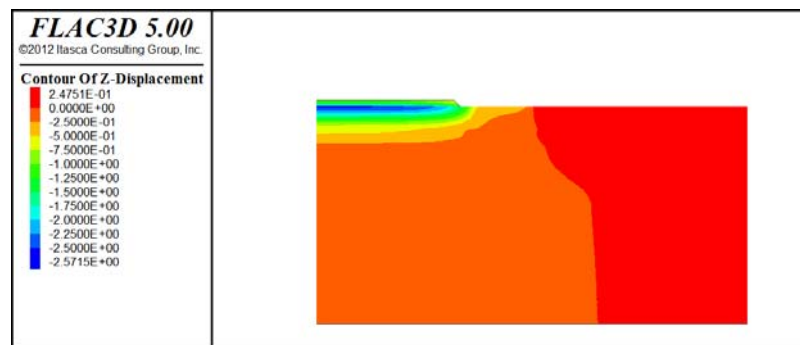
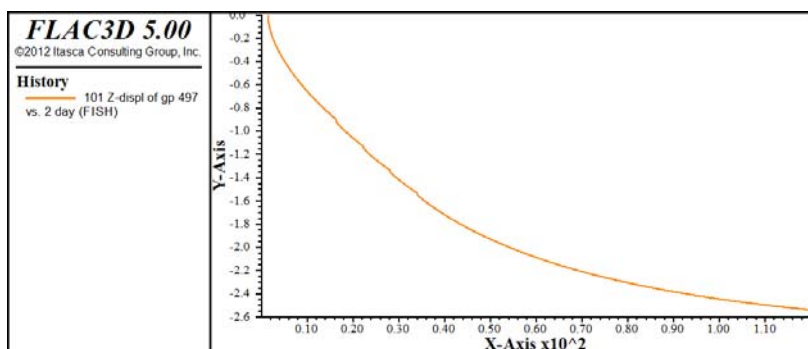
Layers	Thickness (m)	Saturated unit weight (ken/m ³)	Shearing strength	
			Cohesion c (kappa)	Internal friction angle ϕ (°)
Dredged mud	6.1	17.5	11.91	9.38
Muddy- salty clay	2.2	17.8	12.81	9.67
Mud	2.7	16.8	12.75	9.57
Muddy clay	7.8	17.7	12.98	11.18
Salty clay	6.2	19.4	19	4.11
Silt fine sand	35	19.9	19	4.11

The surface settlement, layer settlements and pore water pressure monitoring devices are set in foundation reinforcement phase to obtain key index in foundation treatment quality assessment.

3. FEA model

The finite element analysis (FEA) is proposed with the FLAC 3D software. The soil layers and the foundation reinforcing process are model based on the engineering case. For calibrating the key parameters in the FEA model, the simulation settlement is compared with the in-site test result.

Figure 1 shows the settlement of the whole foundation in foundation reinforcing treatment. Figure 2 shows the surface settlement curve in foundation reinforcing treatment.

**Figure 1.** Foundation settlement distribution in reinforcing treatment process**Figure 2.** Foundation surface settlement curve in reinforcing treatment process

As Figure 1 shows, the foundation is consolidated in the reinforcing treatment process, and the settlement distributes widely and heavily in the whole foundation. The total settlement in foundation reinforcing treatment is 2.572 m. The settlement concentrates under the hydraulically-filled mud layer. Figure 2 illustrate that the soil almost finish consolidation in the later stage of reinforcing treatment process.

Figure 3 shows the comparison between FEA calculation results and the in-site settlement data.

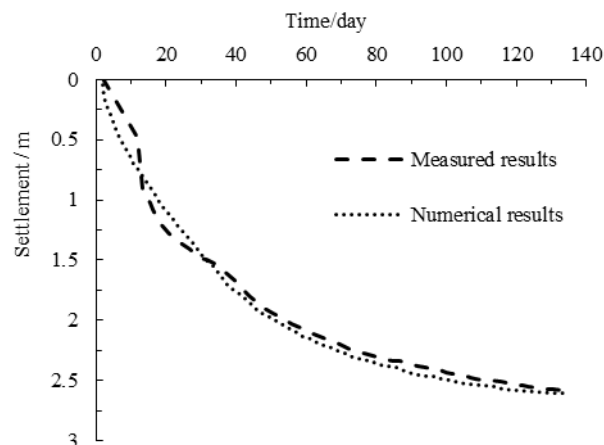


Figure 3. Comparison between the FEA results and the in-site settlement

As Figure 3 illustrated, the FEA results have some different comparing with in-site settlement. This is due to the in-site monitor data missing in plastic drains setting phase. The FEA results almost equal to the in-site monitor data in the later phase. The key parameters of FEA model is suitable for simulating this case and can modeling foundation deformation well.

The parameters used in FEA model are displayed in Table 1.

Table 2. Parameters used in simulation

Soil layers	Thickness(m)	Elasticity modulus (MP)	Poisson's ratio	Permeability coefficient (cm/s)		
				Vertical coefficient	Lateral coefficient	Equivalent Vertical coefficient K _{ev}
Hydraulically-filled mud	6.1	0.57	0.2	2.15E-07	2.95E-07	3.83E-6
Mucky salty clay	2.2	6.45	0.24	6.67E-07	4.56E-07	1.85E-6
Mud	2.7	1.14	0.2	2.85E-07	4.37E-07	1.14E-6
Mud clay	7.8	3.52	0.28	1.64E-07	3.38E-07	5.53E-6
Salty clay	6.2	8.86	0.34	2.7E-08	3.27E-08	—

4. Results and analysis

The calibrated FEA model is used to calculate the settlement reinforcing treatment period. Figure 4 shows the pore pressure distribution in the foundation reinforcing treatment period.

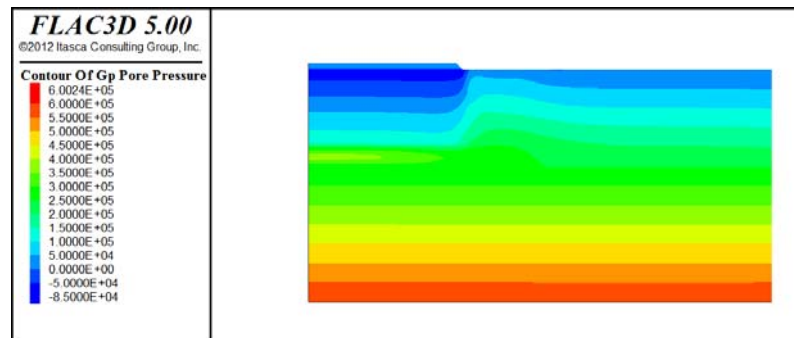


Figure 4. Pore pressure distribution when foundation reforming treatment finished

Figure 4 shows that the pore pressure is significant lower than the hydrostatic pressure due to the vacuum loading in the foundation reinforcing treatment. The surface pressure is -85 kPa , and the pressure increases with the increasing depth within the plastic drains setting area. There are much positive pore pressure below the plastic drains setting area. This phenomenon shows that the soil layer below the plastic drains setting area is under-consolidated.

Figure 5 shows the dissipation of pore pressure in different depths within the plastic drain setting area.

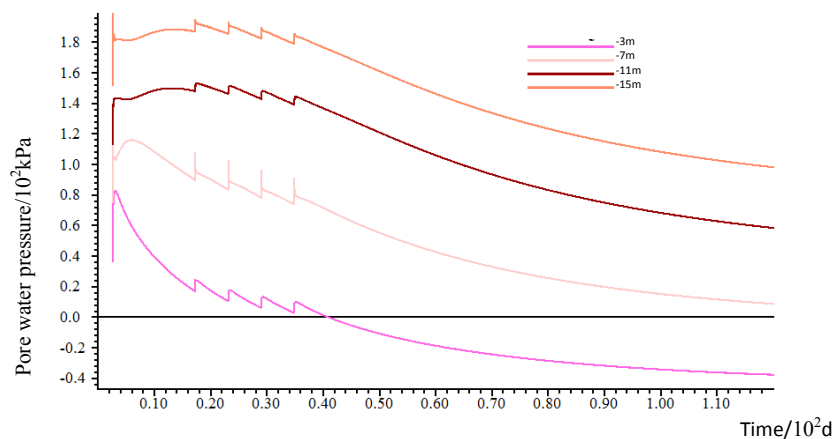


Figure 5. Dissipation of pore pressure in different depths

Figure 5 shows the pore pressure is dissipated significantly with foundation reinforcing treatment going on in different depths (-3m , -7m , -11m and -15m) within the plastic drains setting area. The consolidation degree is very high, and the foundation reinforcing effect is remarkable in the late stage of foundation reinforcing treatment.

Figure 6 shows the dissipation of pore pressure of soil layer under the plastic drains setting area (-23 m below the ground surface).

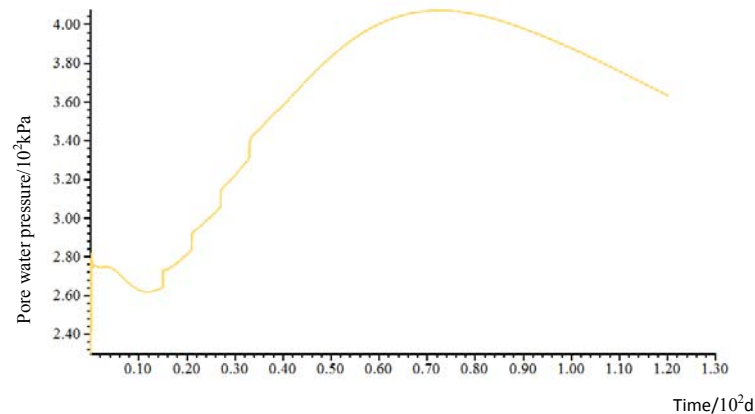


Figure 6. Dissipation of pore pressure in soil layer below plastic drains setting area

As shown in Figure 6, the dissipation of pore pressure in soil layer below plastic drains setting area is slow. The soil layer below plastic drains setting area has no fast drainage channels, and the pore pressure cannot dissipate quickly. This soil layer is effected little by negative pressure load, therefore the pore pressure increases linearly with the increasing depth. The pore pressure reaches the peak value 70 days after applying negative pressure load then decreases to 362 kappa. The excess pore pressure is 132 kappa, and the soil layer is in unconsolidated state. The excess pore pressure distributes in the low permeability salty clay layer (as shown in Figure 7). Therefore, the settlement after foundation reinforcing treatment is mainly caused by consolidation of this layer.

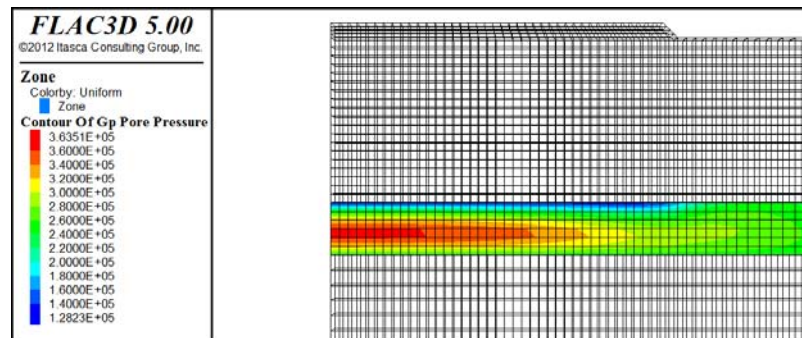


Figure 7. The excess pore pressure distribution when reinforcing treatment finished

5. Conclusion

This paper analyzed the settlement of an engineering case in Tianjin Port. The finite element method and in-site test are both proposed to calculate the settlement development. The main conclusions are as followed.

- (1) The finite element simulation model established in this paper is calibrated with the in-site data, and the model can be used to predict the settlement.
- (2) The plastic drains can improve the foundation reinforcing treatment effect.
- (3) The settlement after foundation reinforcing treatment is mainly caused by consolidation of the layer below the plastic drains setting area.

Acknowledgments

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