

Influence of Surcharge Load on the Adjacent Pile Foundation in Coastal Floodplain

Hao Zhang, Kai Sun

School of Civil Engineering, Zhengzhou University, Zhengzhou, 450001

Abstract: In this paper, in order to investigate the behavior of existing piles caused by the horizontal and compression deformation of soft substratum due to backfill surcharge on coastal floodplain, three-dimensional finite element models of piles adjacent to surcharge load were established. The deformation and migration law of soft soil was analyzed. The behavior of single pile and double row pile adjacent to surcharge load were studied, in which the influence of surcharge load location, surcharge pressure, pile stiffness, and pile top constraint conditions were considered. The results show that as the position of surcharge load is closer and the surcharge pressure increases, the response (e.g. deformation and bending moment) is more obvious. With the increase of pile stiffness, the range of passive load is increased. The deformation behavior of pile body under different constraints of pile cap is significantly different. The effect of secondary bending moment caused by pile axial force is obvious and cannot be ignored. If there is a thick soft substratum, it is beneficial to improve the behavior of adjacent piles by using cement mixing pile reinforcement.

Keywords: Soft Soil Foundation; Surcharge Load; Passive Pile; Numerical Analysis

Introduction

In soft soil areas, ground piling often causes lateral displacement of soft foundation soil, causing lateral displacement of adjacent pile foundation and obvious change of bearing capacity of pile foundation. Vertical compressive pile originally controlled by compressive bearing and settlement may be transformed into horizontal bending resistant pile controlled by horizontal additional passive load. According to the classification standard of pile by de beer and 1, this pile is a typical passive pile that bears both the active load of superstructure and the additional passive load caused by lateral displacement of surrounding soil. The engineering behavior of passive pile not only involves the relatively complex interaction between pile and soil in three-dimensional space, but also needs to consider the coupling effect of active and passive loads. If it is not properly evaluated, it will easily lead to serious engineering accidents. For example, a viaduct of a highway junction in Zhangjiagang caused an accident of pier column deviation across the line due to the foundation load of the interchange ramp road^[2]; The partial pile foundation of a super-large high-speed railway bridge (9 ,# and 10 ,#) caused by a large area of one-sided pile load resulted in a serious deviation accident^[3] etc. Especially in recent years, with the rapid development of industrialization and urbanization in coastal areas, reclamation of land from the sea and reclamation of coastal land by roads have become important ways to relieve the shortage of land resources. More and more land reclamation, dumping and reclamation projects have been carried out. However, the current design specifications in China have not yet fully considered the adverse effects of lateral displacement of soil around piles. Therefore, the impact of backfilling and stacking on nearby buildings, especially the impact of stacking on the properties of adjacent piles, has become a hot topic for current research.

Due to the complex and changeable soil quality of soft soil foundation and the different forms of superstructure, it is difficult to draw reliable conclusions by model tests. Finite element numerical model analysis has become an ideal

method to study this problem. Randolph (1981)^[4], Spring Man (1984)^[5] established a two-dimensional numerical model and analyzed the performance of passive piles by plane strain method; Carter (1982)^[6] used axisymmetric method to carry out finite element analysis on passive piles. Wei Rulong (1992)^[7] and Wang Nianxiang (1998)^[8], etc. have studied the interaction between pile and soil in high-pile wharf by using plane finite element method. Chen Fuquan and Min Yang, (2005)^[9] analyzed the influence of pile loading on nearby single and double row piles under different working conditions by using two-dimensional numerical model; Kelesogu (2011)^[10] and others have established a three-dimensional numerical model to analyze the passive loading response of abutment pile foundation during subgrade filling. Zheng Jianlong, (2013)^[11] and others also analyzed the influence of subgrade filling on nearby piles by using a three-dimensional numerical model, but did not involve the influence of pile top constraint in actual engineering.

In this paper, combined with a coastal floodplain backfilling and land reclamation project in Shenzhen, the heaped load is established by using the method of three-dimensional finite element numerical analysis. The analysis model of deformation and stress characteristics of adjacent pile foundation under the action reveals the migration rule of soft soil under the action of pile load, and systematically

This paper analyzes the effect of landfill loading on the pile foundation of the adjacent expressway viaduct in the overbank mud storage area in the project, so as to reasonably evaluate the loading. It provides basis for the influence of adjacent pile foundation.

1. Engineering background and model construction

1.1 Project overview

A coastal floodplain backfilling and land-building project in Shenzhen is located in the northwest coastal area of Bao'an Airport. The original landform of the site is the coastal shoal of the Pearl River Estuary-intertidal zone, belonging to the muddy beach area, and its east side is the alluvial plain landform. The terrain of the site is relatively complex. The original site is mainly composed of fish ponds and rivers, and the surface water body is developed. Figure 1 is a schematic diagram of the plane position of the project. the site area consists of four spoil backfilling areas, a, b, c and d, and the riverside expressway passes through the east side of the site area. Among them, areas a, c and d are the backfilling area of Phase I located on the west side of the viaduct along the Yangtze River. The boundary of the area is about 200 m~230 m away from the viaduct. The maximum width of backfilling area can reach 200 m B and Zone are the second-stage backfilling areas, with the second-stage Shajing Interchange of the Yangtze River Expressway in the area.

It can be seen that the backfilling area in the land reclamation area is large in area and widely distributed, and its impact on the stability of the viaduct along the adjacent riverside expressway cannot be ignored.

According to relevant engineering data, the backfill soil formed on the land area is generally dredged and filled with sand and gravel and backfilled for construction. The basic requirements of soil quality for building muck or spoil are: natural water content is not more than 50%, organic matter content is not more than 10%, and if the stone is contained, the particle size of the stone should be less than 30 cm ,(the particle size is between 2 cm~30 cm and the content should not exceed 10%). The physical and mechanical indexes of the main strata and their rock and soil layers in the site are shown in Table 1. Silt layers (② 1 and ② 2, thickness 12 m~18 m) and organic clay layers (④), thickness 18 m~22 m) with low consolidation, low strength and poor self-stabilization capability are distributed in the site. Consolidation settlement and lateral extrusion are easy to occur under the working conditions of engineering construction and additional load of fill. Therefore, the adverse effects of soft soil on the adjacent bridge foundation should be considered in the backfilling construction of land formation.

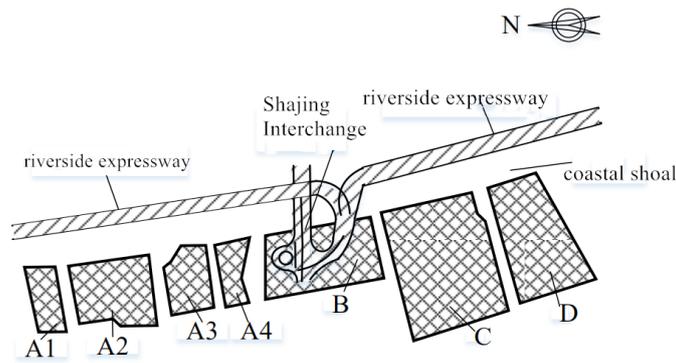


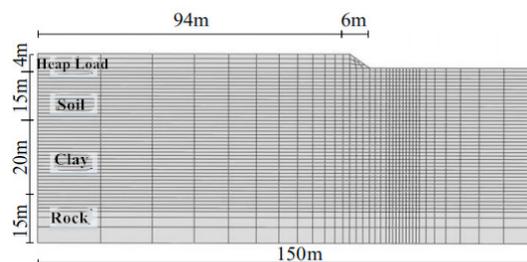
Fig.1 Schematic diagram of the project

Tab. 1 Physical and mechanical indexes of each rock and soil layer

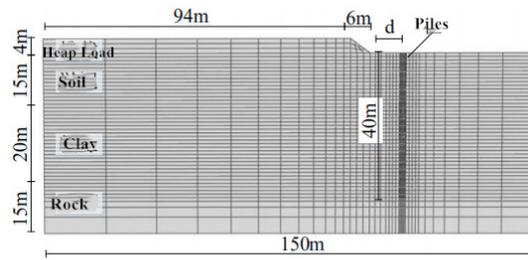
Number	Stratigraphic Name Factor Code	Conditions of Rock and Soil of Layers	value of bearing capacity k/kPa	modulus of compressibility Es/MPa	modulus of deformation Es/MPa	Direct Quick Shear		Consolidated Quick Shear	
						Cohesion c/kPa	Internal Friction Φ/	Cohesion c/kPa	Internal Friction Φ/
①	Artificial Fill(Q ^{ml})	Loose	70	4.0	4.5	8	15	8	15
② ₁	Soil (Q ₄ ^{mc})	Flow	20	1.2	1.2	3	5.3	9.2	6.4
② ₂	Soil (Q ₄ ^{mc})	Flow	35	1.7	1.7	5.8	4.5	12.6	6.3
③	Clay (Q ₃ ^{al+pl})	Plastic	160	5.5	10	30.2	5.6	33.7	9.4
④	Mucky Clay-(Q ₃ ^h)	Flow	60	2.5	2.5	10.5	4.7	19.3	5
⑤ ₂	Silt (Q ₃ ^{al+pl})	Loose(Slightly Dense)	140	/	15	10	12	15	16.3
⑥	Silty Clay (Q ^{pl})	Plastic(Hard Plastic)	200	8.0	22	20.2	18.8	19.8	17.1
⑦ ₁	Gniess (ChF)	Completely Weathered	350	13	70	35	28	35	28
⑦ ₂		Intense Weathered	500	18	180	45	33	45	33

1.2 Finite element model

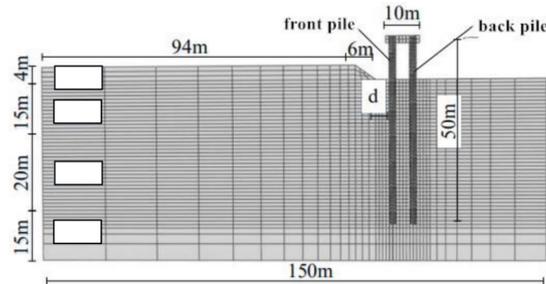
In order to systematically analyze the effect of backfill pile loading on adjacent pile foundations, and in combination with site conditions, pile-free pile loading model, adjacent pile-loading single pile model and adjacent pile-loading bridge pile row model are respectively established, as shown in Figure 2. The total length of the model is 150 m and the width is 60 m. Considering symmetry, the stacking length is taken as 100 m, with slope width 6 m, slope 2/3. In order to facilitate analysis, the strata in the site are simplified into silt layer (15 m thick), clay layer (20 m thick) and hard soil layer/rock layer according to soil layer characteristics. According to the actual engineering design data, the parameters of pile body shall be taken as pile length, pile diameter, pile diameter, pile rigidity and pile body rigidity of 30GPa. Among them, the constraint effect of bridge bearing platform and upper column is considered in the pile arrangement model of adjacent piled bridge. The pile top is provided with length 10m column and bearing platform, front and rear pile arrangement spacing 6m front pile distance $d = 10$ m. The column bearing platform and column are fixedly linked, as shown in Figure 2(c). When establishing the model, the pile and pile are linear elastic bodies, the soil around the pile and the pile bottom are elastic-plastic materials, and obey the Mohr-Coulomb yield criterion. The specific parameters are shown in Table 2.



(a) Pile-up action model without piles



(b) Adjacent stowage single pile model



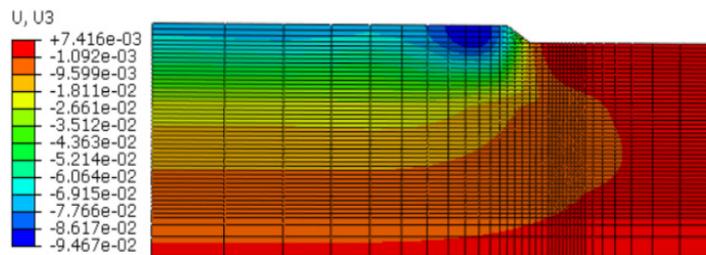
(c) Pile row model of adjacent stowed bridge

Tab.2 Calculation parameters

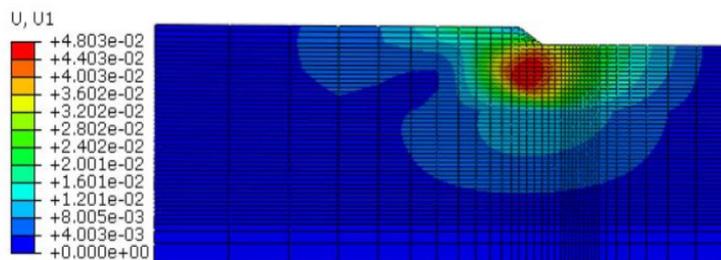
soil layer	density/g/cm ³	elastic modulus /MPa	Poisson's ratio	internal friction angle /°	cohesion/c/kPa	expansion angle /°
heap load	1.5	40	0.3	-	-	-
soil	1.5	15	0.4	6	15	0.1
clay	1.8	80	0.3	10	30	0.1
rock	2.5	200	0.25	33	45	0.1
pile	2.5	30000	0.2	-	-	-

2. Analysis of effect of heap load

As shown in Figure 3, the displacement nephogram of the basement stratum under the designed backfilling and stacking action ($h = 4\text{ m}$, $p = 90\text{ kPa}$). It can be seen that the basement stratum has obvious settlement deformation and lateral displacement under the action of backfilling and stacking.



(a) Sedimentation



(b) Lateral Displacement

Fig.3 Deformation of substratum

Take the toe of the heaped slope as the origin of coordinates, and extract the formation settlement deformation at

different depths, as shown in Figure 4. Under the action of backfilling and stacking, the settlement of the lower stratum is obvious, but the settlement deformation shows a gradually decreasing trend with the increase of soil depth. However, the uplift of the soil in the local area adjacent to the heaped load indicates that the lateral extrusion of the base soil occurs with the occurrence of settlement deformation.

Figure 5 are soil lateral displacement curves at different distances from the heaped load, while keeping the other parameters unchanged, and the total length of the model is established.

250m Pile-free Stacking Model. It can be seen that the lateral displacement of the soil decreases with the increase of the distance from the pile load. When the distance of the pile load is greater than 120 m, the lateral movement of the soil tends to zero. In this project, the distance between the A, area, C, area, D and area from the viaduct of Yanjiang Expressway is more than 200 m .It can be considered that the backfilling and stacking of the viaduct has basically no influence on the pile foundation of the nearby bridge. However, there is Shajing Interchange on the viaduct of Yanjiang Expressway in the B and Field. The influence of backfilling and stacking on the pile foundation of the interchange bridge cannot be ignored in the later construction.

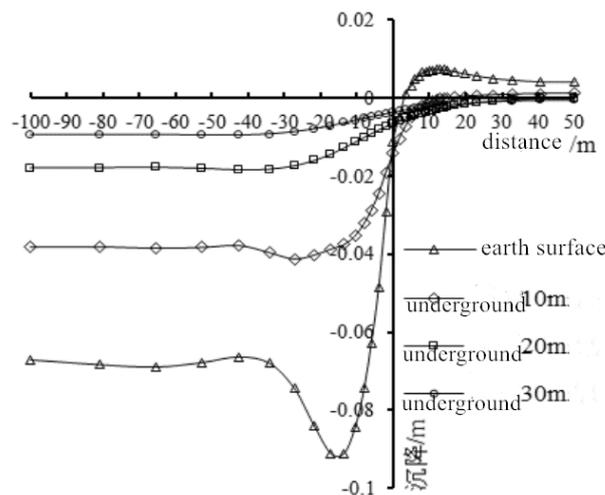


Fig.4 Settlement curves at different depths

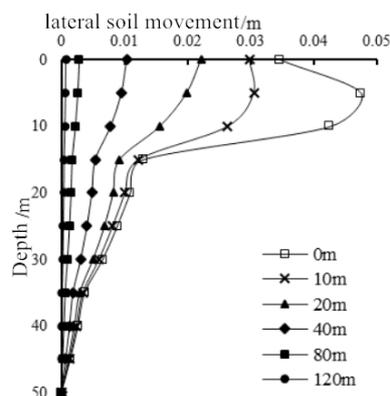


Fig.5 Lateral deformation at different distance from surcharge load

3. Single pile impact response

In order to further reveal the influence of pile loading on the working behavior of adjacent pile foundations, the finite element models of single pile based on adjacent pile loading are compared respectively.

3.1 Heap position

Considering the influence of pile position on pile body behavior, the working conditions of distance from pile $d = 0\text{m}$, 10m , 20m , and 40m are compared and analyzed, and the pile side movement change curve and bending moment

change curve at different pile positions are obtained, as shown in Figure 6. Figure 6(a) is the relationship curves of pile side movement with pile distance from single pile. The lateral displacement of the pile gradually decreases with the increase of the distance from the pile load. When the pile is next to the pile load ($d = 0$ m), the maximum lateral displacement of the pile body is 26.4 mm, which is increased by 48.3%, 1.3%, 7.5%, respectively compared with the maximum lateral displacements of the distances of 10 m, 20 m, 40 m, indicating that the pile load distance has a more obvious influence on the deformation behavior of the pile body.

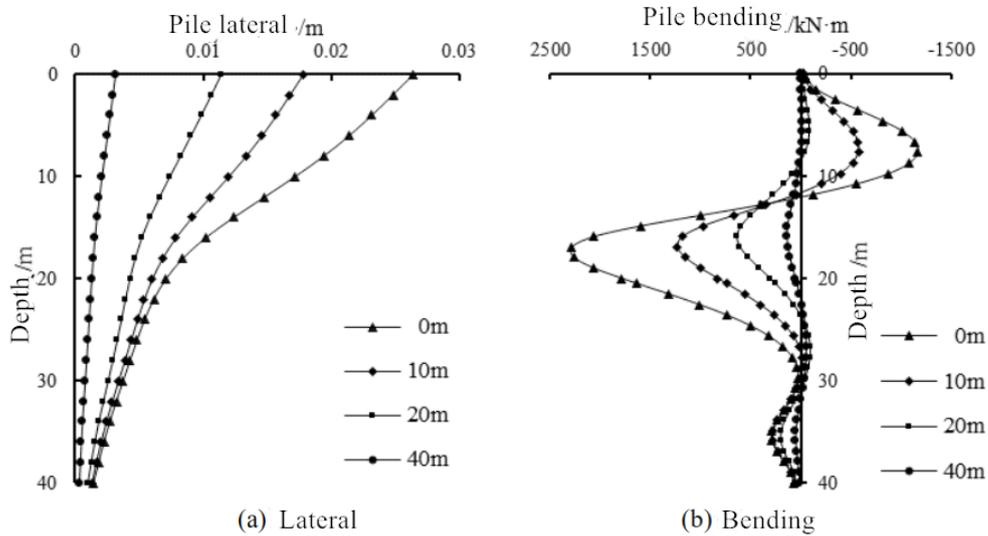


Fig.6 Lateral deformation and bending moment of pile at different distance from surcharge load

Figure 6(b) is the curves of pile bending moment versus pile distance. The maximum bending moment of the pile body is located at the boundary between the silt layer and the clay layer. The maximum bending moment of the pile body is 2264 kN·m, which is further increased by 83.6%, 2.7%, times and 16 times than the maximum bending moments of 10 m, 20 m, 40 m, respectively. The position of the maximum bending moment gradually moves down with the decrease of the stacking distance. The pile force changes obviously and the range affected by the passive load increases.

3.2 Pile stiffness

When the stacking distance is 10 m, keep other parameters unchanged, change the stiffness of the pile body, and analyze the lateral displacement and bending moment variation of the pile body under the stacking load when the pile body stiffness is 1 GPa, 5 GPa, 10 GPa, 20 GPa and 30 GPa.

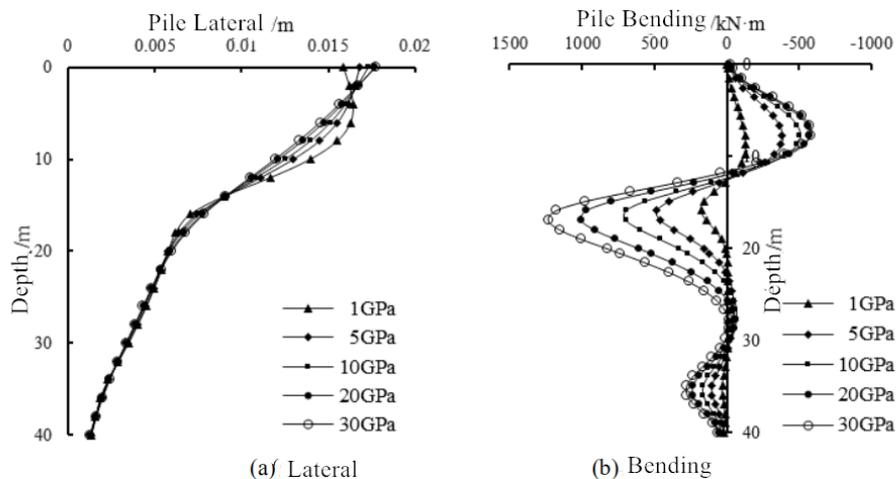


Fig.7 Lateral deformation and bending moment of pile with different stiffness

Figure 7(a) is a curve showing the relationship between the lateral displacement of the pile and the stiffness of the

pile body. it can be seen that when the stiffness of the pile body is greater than 10GPa. The lateral displacement curve gradually decreases from top to bottom, and the maximum displacement of pile body occurs at the top of pile. When the stiffness of the pile body is less than when 10GPa is used, the lateral displacement curve shows parabolic distribution, and the maximum displacement of pile body occurs in the middle of silt layer.

Considering the influence of pile stiffness on the bending moment of pile body, the maximum bending moment of pile body is 1233 kN·m when the pile body stiffness is 30 GPa, which is 22.9%, 77.4%, 1.7%, and 8 times higher than the pile body stiffness of 20 GPa, 10 GPa, 5 GPa, and 1 GPa respectively, indicating that the bending moment of pile body increases with the increase of pile body stiffness. The maximum bending moment value is basically located at the boundary between silt layer and clay layer, and the position of the maximum bending moment value of pile body gradually moves down with the increase of pile body rigidity, and the range affected by passive load increases, as shown in Figure 7(b).

3.3 Heap load level

Considering the influence of the pile load level, the load levels are analyzed as 60kPa ,90kPa ,120kPa ,150kPa and 180kPa respectively. The lateral displacement and bending moment changes of pile body under the pile load are analyzed.

Figure 8(a) is the relationship curves of pile side movement with pile load level. The lateral displacement of the pile mainly occurs in the silt layer, and the maximum lateral displacement is at the top of the pile. The larger the pile load level is, the larger the pile side displacement is. when the load level is 180 kPa, the maximum lateral displacement deformation of the pile body is as high as 9.7 cm, which is increased by 34.7%, 94%, 2%, times and 4.7 times respectively compared with the maximum lateral displacement of the load levels of 150 kPa, 120 kPa, 90 kPa and 60 kPa.

Figure 8 are the curves of pile bending moment versus pile load level. With the increase of the pile load level, the bending moment of the pile body shows an increasing trend. When the load level is 180kPa, the maximum bending moment of the pile body is 8239 kN·m, which is 37.9%, 1, 2.5, times and 6 times higher than the maximum bending moments of the load levels of 150 kPa, 120 kPa, 90 kPa and 60 kPa respectively.

The maximum bending moment of pile body is located at the boundary between silt layer and clay layer, and the position of reverse bending point gradually moves up with the increase of load. The larger the pile load is, the larger the pile affected by pile load.

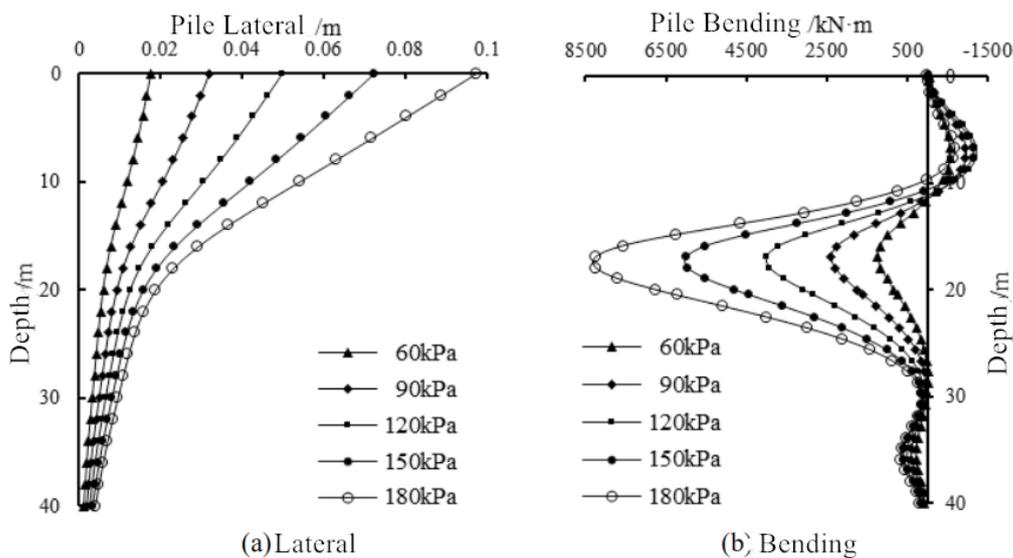


Fig.8 Lateral deformation and bending moment of pile under different surcharge pressure

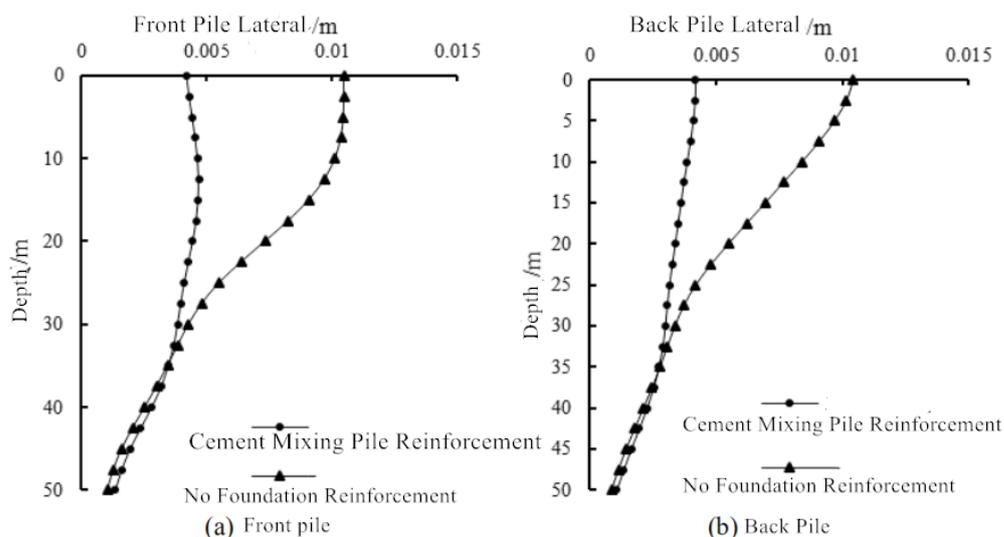


Fig.12 Influence of ground reinforcement on pile lateral deformation

4. Conclusion

In this paper, based on a coastal floodplain backfilling project in Shenzhen, three-dimensional numerical calculation system is used to analyze the backfilling on soft soil foundation

The effect of pile load on adjacent pile foundation is mainly as follows:

(1). Pile position and load level have significant effect. the closer the pile position is, the higher the load level is, the deformation and stress of pile body will be. The more obvious the response is, the sufficient distance (> 120m) should be reserved from the existing pile foundation in the backfill engineering design to reduce the additional load on the pile and the influence of load effect.

(2). The restraint effect of the superstructure adjacent to the pile foundation under the action of pile load is significant, and the bridge pile foundation should be based on different column top. The design checking calculation is carried out under the constraint of bearing, and the “secondary bending moment” effect caused by axial force of pile body is obvious and cannot be ignored.

(3). Foundation reinforcement (cement mixing pile) has a good improvement effect on the soft soil of the foundation, which can obviously reduce the stacking load.

References

1. DEBEER E E. The effects of horizontal loads on piles,due to surcharge or seismic effects[C]//Proc 9th ICSMFE. Tokyo,1977:547-558.
2. Zhang Hao, Shi Minglei, Guo Yuancheng, et al. Displacement characteristics and stress analysis of bridge foundation pile-column under side load [J]. Geotechnical Mechanics, 2017,38(09):2683-2692.
3. Liang Dong, Niu Bin, Gu Mu, et al. Numerical analysis of the influence of large-scale unilateral loading on piers and abutments of high-speed railway bridges [J]. Railway Architecture, 2015(01):39-42.
4. RANDOLPH M F. The Response of Flexible Plies to Lateral Loading [J]. Geotechnique,1981,31(2):247-259.
5. SPRINGMAN S M. Lateral Loading on Pile due to Embankment Construction [D]. Cambring:Cambring University,1984.
6. CARTER J P. Anumerical method fo pile deformations due to nearby surface loads[C]//Proceeding of the Fourth International Conference on Numercial Methods in Geomechanics Edmonton.1982: 811-817.
7. Wei Rulong, Wang Nianxiang, Yang Shouhua. Interaction between pile wharf and bank slope [J]. Journal of Geotechnical Engineering, 1992(06):38-49.
8. Wang Nianxiang. Study on numerical simulation and simplified calculation method of interaction between wharf pile foundation and bank slope [D]. Nanjing: nanjing hydraulic research institute, 1998.

9. Chen Fuquan, Min Yang. Numerical analysis of the behavior of adjacent pile foundations under ground loading [J]. Journal of Geotechnical Engineering, 2005(11):51-55.
10. KELESOGLU M K, SPRINGMAN S M. Analytical and 3D numerical modelling of full-height bridge abutments constructed on pile foundations through soft soils[J]. Computers and Geotechnics, 2011, 38(8):934-948.
11. Zheng Jianlong, Zhang Junhui, Li Xuefeng. Influence of Soft Foundation Bridge Head Subgrade Filling on Abutment Piles [J]. china journal of highway and transport, 2013,26(02):48-55.