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Displacement analysis of single pile in soft soil with ground load

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Abstract: *The pile will have a large lateral displacement in soft soil under the role of heaped load. Based on Biot consolidation theory, combined with a certain highway project, a three-dimensional FEM model was established, the process that the soil lateral load deformation lead to the pile side displacement was simulated. On the ground of the former result, the influence factors for the displacement of pile top and the pile displacement field distribution are analysed. The results shows that, the building load area, load grade and the distance from loading area to pile have a major influence on the pile side displacement. On the other hand, the load on pile top have a very small contribution for stability of anti-side displacement. The buildings nearby the area of pile foundation should be given attention in practical engineering.*

Keywords: *soft clay; super-long pile; highway project; building load; pile side displacement*

1. Introduction

At present, China's highways are mainly distributed in the southeast, and coastal highways account for a large proportion. The coastal beach area is dominated by soft soil, which has the characteristics of weakness, low strength, high compressibility, low permeability, and easy plastic rheology [1], which brings great difficulties to the foundation treatment of road construction projects. Therefore, for coastal sections with deep soft soil layers, pile foundations are mainly used to meet post-construction settlement and stability requirements [2]. However, if the highway pile foundation is in the reclamation section and buildings need to be built in the reclamation area after the completion of the construction, the building load will be transmitted to the pile body through the soil layer around the pile, which will cause a large vertical additional settlement and lateral displacement [3], which will cause the road surface to crack or even break. At present, most of the researches on piles in deep and soft foundations focus on active piles, and less on passive piles under soil filling and building loads [4].

Based on the Biot' consolidation theory [5], considering the situation that the super long single pile in coastal beach reclamation area is subjected to unilateral building load after construction is completed, a three-dimensional elastic-plastic finite element model is established to analyze the influence of different building load area and different distance on pile foundation deformation and displacement, which can provide references for the future plan of coastal beach reclamation area.

2. Problems description and calculation model

2.1. Finite element model

Part of a coastal expressway project passes through the coastal beach area, which is intended to pass by pile-support viaduct. The bridge sections have similar basic geological conditions and are located in coastal reclamation areas. The upper part is soft soil with a thickness of about 30m. It is mainly silt and silty clay with poor properties. The middle part is mainly thick subclay and clay. Hard plastic and soft plastic alternately appear. The lower part is hard plastic clay and gravel, pebble layer.

Using the finite element software ABAQUS [6], a three-dimensional model was established based on the geological data of the bridge pile foundation and the relevant dimensions of the pile foundation provided during the construction design stage. The center of the cross section of the pile was used as the

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origin, and the horizontal soil boundaries were taken as X = ± 100m, Y = ± 100m, the direction of gravity is the Z-axis direction, and the soil is taken from 0 to 100m; a circular pile with a diameter of 2m is used. The pile is 90m long, and the buried depth is 77m. It is driven into the holding layer (round gravel and silt layer) and the depth is 2m. The specific three-dimensional finite element model is shown in Figure 1.

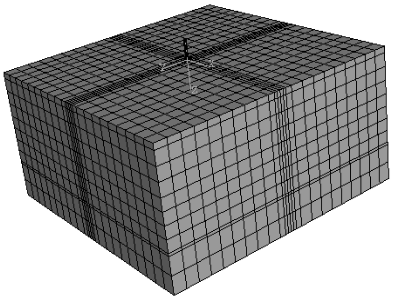

Figure 1 Finite element model

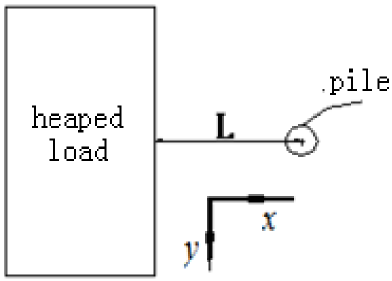

Figure 2 Building loads and the relative positions of piles

The building load is loaded on one side, and the working conditions are based on the distance from the building load to the pile (as shown in Figure 2), L=10m, 20m, 30m. For each distance, two building load areas of 100 (10 × 10) m2 and 200 (10 × 20) m2 are considered. At the same time, two pile top loads of 0 and 4700kN (the design load under traffic condition) are considered, a total of 12 kinds of working conditions.

2.2. Selection of calculation parameters

The soil is considered as an elastoplastic body, and the Mohr Coulomb model is adopted as the constitutive model [7], and the elastic body simulation is adopted as the pile [8]. The building load is unilateral loading, from 0 to 100kPa in 10kPa levels; the load cycle of each level is 15 days, and the entire building construction period is 150 days. The bottom boundary of the model is a full displacement constraint, and the surroundings are horizontal constraints. The perimeter and bottom boundaries are undrained boundaries, and the upper surface is the drainage boundary except for the area of the building load [9][10]. The calculation parameters of pile and soil are shown in Table 1.

Table 1: Calculation parameters of pile and soil

Layer/Pile	Depth(m)	E(MPa)	ν	γ(kN/m3)	C(kPa)	φ(°)	Permeability Coefficient(m/s)	
							Horizontal	Vertical
Silt Clay	30	2	0.35	17.9	12.0	2.5	3×10^{-8}	3×10^{-8}
Silty Clay	75	25	0.25	20.0	65.0	20.0	10×10^{-8}	10×10^{-8}
Gravel and Silty Sand	80	6,500	0.20	25.3	10.0	35.0	2×10^{-4}	2×10^{-4}
Clay	100	25	0.25	22.1	65.0	20.0	8×10^{-8}	8×10^{-8}
Pile	77	30,000	0.17	24.0	/	/	/	/

3. Analysis of the influence of bilateral building load on displacement field of single pile foundation

As shown in Figure 3, point M at the top of pile is selected as the calculation point to calculate the change in the x-direction displacement of the pile foundation caused by building load during the building period. Meanwhile, the x-direction displacement of pile body OP line in Figure 3 after the end of loading is analyzed.

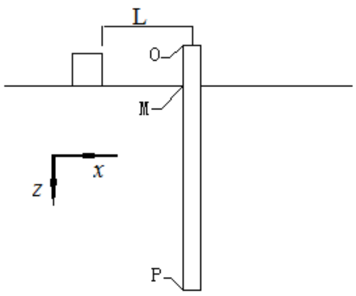

Figure 3: Schematic diagram of the calculation point location

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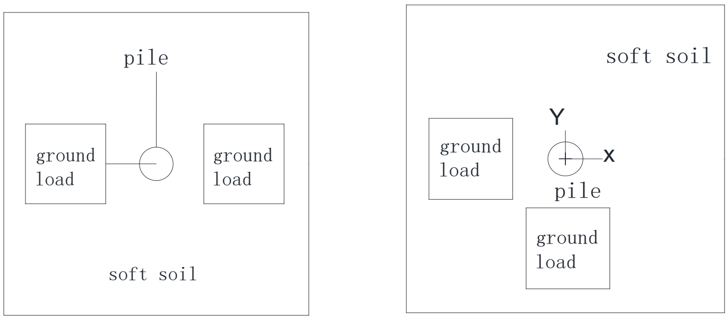
The building load on both sides of a single pile can be divided into two types of working conditions. See Figure 4 for details.



(a) Condition 1 (symmetrical load) *(b) Condition 2 (asymmetrical load)*

Figure 4 Top view of two different working conditions areas of building load on both sides of single pile

3.1. Lateral displacement analysis of piles under symmetrical load on both sides

It can be seen from Figure 5 that the horizontal displacement of point M starts to decrease under the second side load, but the decrease value of point M is smaller than its the horizontal displacement under the first side load. The decrease value of the horizontal displacement of point M under the second side load does not change much with the distance change between the building and the pile, but the increase value of the horizontal displacement of point M under the first side load changes greatly with the distance change between the building and the pile, so the final horizontal displacement of point M decreases with the increase of the distance from the building to the pile. The maximum horizontal displacement is 12.51mm. The horizontal displacement of point M is basically 0 with load on its both sides at the same time.

As can be seen from Figure 6, when the load is on the second side, the horizontal displacement of the pile at each depth is smaller than that with the first load. The maximum horizontal displacement of each depth of the pile is not fixed with the first side load, while it is stabilized at the top of the pile when the load is on the second side, and decreases along the depth direction of the pile top, with the maximum displacement of 24.03mm. It is basically 0 when it is close to the pile top for 10m. The horizontal displacement of each depth of the pile is basically 0 under load on its both sides at the same time.

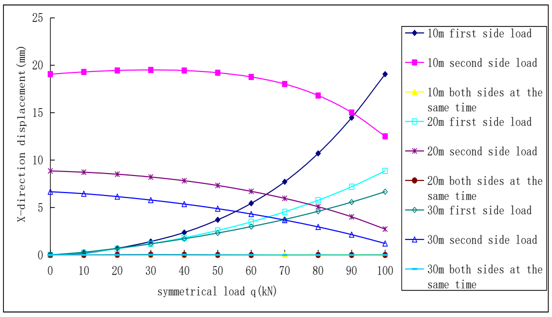


Figure 5: X-direction displacement of point M under symmetrical load on both sides

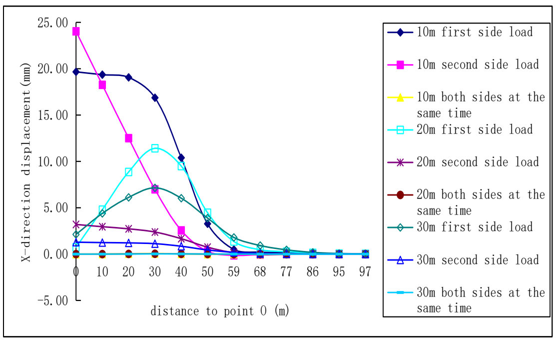


Figure 6: X-direction displacement of the pile side under symmetric load on both sides

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3.2. Lateral displacement analysis of piles under asymmetric load on both sides

The lateral displacement caused by the asymmetric load on both sides does not lie on the same straight line with the change of the load. It can be divided into X-direction displacement and Y-direction displacement. X-direction displacement is the horizontal displacement direction under symmetrical load on both sides.

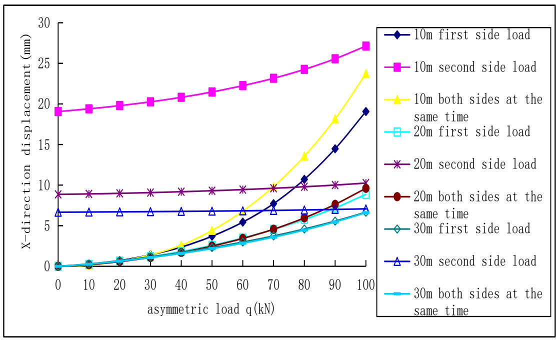

Figure 7 X-direction displacement of point M under asymmetric load on both sides

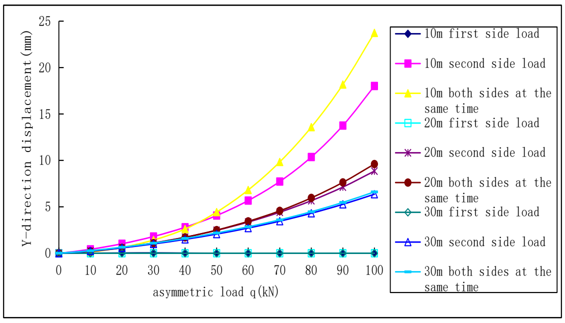

Figure 8 Y-direction displacement of point M under asymmetric load on both sides

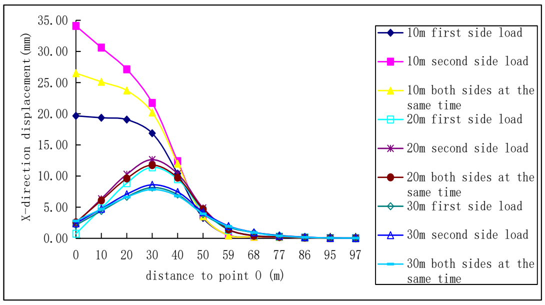

Figure 9 X-direction displacement of the pile side under asymmetric load on both sides

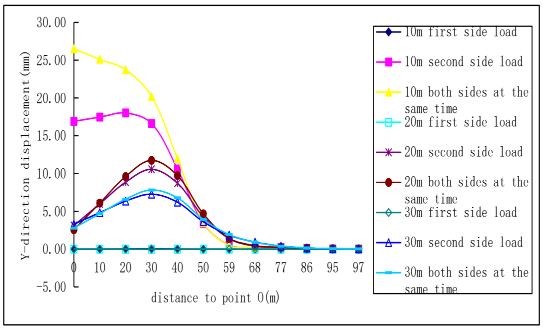

Figure 10 Y-direction displacement of the pile side under asymmetric load on both sides.

It can be seen from Figure 7 that the X-direction displacement of point M begins to increase with the growth of the load on the first side (X side), and continues to increase with the growth of the load on the second side, but the increase rate becomes smaller, resulting in the maximum X-direction displacement of 27.13mm. When both sides are loaded at the same time, the X-direction displacement of point M increases with the growth of the load, but the x-direction final displacement of point M is smaller than that of point M with non-simultaneous load on both sides, and the maximum X-direction displacement is 23.73mm.

What can be seen from Figure 8 is that the Y-direction displacement of point M is basically 0 under the load on the first side (X side), and increases with the growth of the load on the second side. The maximum Y-direction displacement is 18.02 mm. However, the increase rate is slightly larger than that of the X-direction with load on the first side (X side). When both sides are loaded at the same time, the Y-direction displacement of point M increases with the growth of the load, but the Y-direction final displacement of point M is larger than that of point M with non-simultaneous load on both sides, and the maximum Y-direction displacement is 23.74mm.

It can be seen from Figure 9 that the maximum X-direction displacement at each depth of the pile is not fixed to a certain depth under the load on both sides, but the maximal displacement points are basically the same with the load on both sides. No matter the both sides are loaded at the same time or not, the regularities of X-direction displacement at each depth of the pile top are the same. But under the load on both sides at the same time, the final X-direction displacement at each depth of the pile top is less than that under non-simultaneous load on both sides. In the case of non-simultaneous load on both sides, the maximum X-direction displacement at each depth of the pile is 34.10 mm, on the top of the pile. In the case of loading on both sides at the same time, the maximum X-direction displacement is 26.51 mm, on the top of the pile too.

It can be seen from Figure 10 that the Y-direction displacement at each depth of the pile is basically 0 under the load on the first side (X side), and increases with the growth of the load on the second side. However, the increase rate is slightly larger than that of the X-direction with load on the first side (X side). Under the load on both sides at the same time, the Y-direction displacement regularity is the same as the regularity of Y-direction displacement with load of the second side. But with load on both sides at the same time, the final displacement of the Y-direction points is larger than that with non-simultaneous load on both sides. In the case of non-simultaneous load on both sides, the maximum Y-direction displacement at each depth of the pile is 18.02mm, at a distance of 20m from the top of the pile. In the case of loading on both sides at the same time, the maximum Y-direction displacement is 26.51 mm, the maximum displacement in the Y-direction is 26.51mm, on the top of the pile.

4. Conclusion

The lateral load area of the building, the load level, the distance from the load zone to the pile, and the load on the top of the pile all have certain effects on the lateral movement of the pile foundation in soft soil:

(1) The building area and load grade have a great influence on the lateral displacement of the pile foundation. At the same distance, the lateral movement of the pile foundation increases nonlinearly with the increase of the building area or load grade. Therefore, the construction of large-scale buildings and high-rise buildings near the pile foundation should be avoided as much as possible. At the same time, the buildings in the project planning should be synchronized and symmetrically constructed as much as possible.

(2) The horizontal displacement of the pile gradually decreases with the increase of the building load distance. If the distance from the building area to the pile is too small, it will cause a large lateral displacement of the pile. For the engineering situation analyzed in this paper, it is suggested that the distance from the building area to the pile foundation is more than 15m.

In this paper, the drainage consolidation of soil under building load is also considered based on the Biot's consolidation theory in the whole analysis process. Due to the small permeability coefficient of the silty soil, the soil consolidation is slow, and there is a very large excess pore water pressure in the soil layer, which dissipates slowly. Therefore, the soil consolidation has little effect on the lateral displacement of the pile foundation during the simulated construction period. However, with the extension of time, the consolidation process will continue, which can be further studied. At the same time, the analysis of this paper is only for the case of a single pile. In the actual project, the highway pile foundation should be a group of piles. The next step will be a more in-depth analysis and research on the lateral displacement and deformation of the group piles under the building load.

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References

[1] Li Youyun, Liu Baojian, Xie Yongli. Influences of Permeability and Consolidation Settlement. On Structure of Soft Clay [J]. Chinese Journal of Rock Mechanics and Engineering, 2006, 25(2): 3587-3592.
[2] Yin J. H. & Graham J., Elastic visco-plastic modeling of the time-dependent stress-strain behavior of soils [J]. Canadian Georechnical Journal, 1999, 36(4), 736-745.
[3] Ellis E. A, Springman S. M. Full-height piled bridge abutments constructed on soft clay [J]. Geotechnique, 2001, 51(1): 3-14.
[4] M. F. Bransby, Sarah Springman, 3-D Finite elementmodeling of piles groups adjacent surcharge loads [J]. Computers and Geotechnics, 1996, 19(4): 301-324.
[5] Xu Shuping, Liu Zude. Application of Biot's consolidation theory to improving soft ground by preloading method [J]. Rock and Soil Mechanics, 2003, 26(2): 307-310.
[6] Sun Jizhu, Gao Hui. Soft soil foundation consolidation analysis with ABAQUS software [J]. Rock and Soil Mechanics, 2007, 28(10), 919-922.
[7] L. T. Chen, H. G. Poulos, Piles subjected tolateral soil movement [J]. Journol of Geotechnical and Geoenviromental Engineering, ASCE, 1997, 123 (9) :802-811.
[8] Boulanger. R. W, Curras. C. J, Kutter. B. L, et al, Seismic soil-pile-structure interaction experiments and analyses [J]. Journal of Geotechnical and Geoenvironmental Engineering, 1999, 125 (9): 750-759.
[9] Chen Jianyun, Hu Zhiqiang, Lin Gao. 3D seismic re sponse study on large scale underground group caverns [J]. Chinese Journal of Geotechnical Engineering, 2001, 23(4): 494-498.
[10] Peng Senliang, Wu Jimin, Wei Jihong. Study of Dynamic Impact of Preloading Rate under Tidal Environment on Soft Soil Consolidation [J]. Site Investigation Science and Technology, 2009, (3): 13-15.