ATLANTIS PRESS

Advances in Engineering Research, volume 170

7th International Conference on Energy and Environmental Protection (ICEEP 2018)

Experimental study on 18000 kN•m ultra high energy level dynamic consolidation on large thickness gravel foundation

Jianbao Fu[1,2,3,4a],Ruiqi Zhang[1,2,3,4b] , Jian YU[1,2,3,4c]

1. Tianjin Port Engineering Institute Co., Ltd. of CCCC First Harbor Engineering Co., Ltd., Tianjin 300222, China

2. CCCC First Harbor Engineering Company Ltd., Tianjin 300461, China

3. Key Laboratory of Port Geotechnical Engineering, Ministry of Communications, PRC, Tianjin 300222, China

4. Key Laboratory of Tianjin Port Geotechnical Engineering, Tianjin 300222, China

[a]276339170@qq.com, [b]zhangruiqi@tpei.com.cn, [c]yujian@tpei.com.cn

Keywords: dynamic consolidation, ultra high energy level, gravel foundation

Abstract:A new airport is building at somewhere in northern China. The airport is located on an artificial island which is filled with gravel. Because the foundation is filled at one time and the thickness exceeds 22m, it should be consolidated. The designer supposed to use dynamic compaction method. The dynamic compaction energy may exceeds 15000kN•m which is called ultra high energy level dynamic consolidation. However, the research of ultra high energy level dynamic consolidation and engineering examples available for reference are very few. Therefore, field test is necessary before formal construction to determine the reinforcement energy level and reinforcement effect. A series of dynamic compaction field tests with different energy levels were carried out. In this paper, dynamic compaction field tests of 18000kN•m was introduced. It the test, flat load test was carried out to determine the bearing capacity of reinforced foundation, and deep settlement monitoring, layered settlement monitoring, ultra-heavy dynamic penetration test and multi-channel transient surface wave test were carried out before and after the consolidation to reflect the dynamic compaction reinforcement effect. The field test result shows that after dynamic consolidation of 18000kN•m, the characteristic value of foundation bearing capacity is much larger than 150kpa, which meets the design requirements. Deep settlement monitoring, layered settlement monitoring, ultra-heavy dynamic penetration test and multi-channel transient surface wave test all can reflect the dynamic compaction reinforcement effect, and the monitoring results are very similar. After dynamic consolidation of 18000kN•m, the reinforcement effect is not obvious in the range of 4m on the surface layer of the foundation, but obvious in the range of 4m to 14m, and still exists at 22m depth.

Introduction

Dynamic compaction is a common foundation consolidation treatment method. In the late 1960s, it was first put forward by Menard technology company in France. Dynamic compaction method uses lifting equipment to lift the heavy hammer to a certain height, and then makes it fall freely to generate great impact energy and compact the foundation, thus improving the strength of the foundation.

From November 1978 to early 1979, the research institute of the first navigation bureau of the Ministry of communications (now Tianjin Port Engineering Institute Co., Ltd.) and its cooperative units carried out experimental study of dynamic compaction method in Tianjin Xingang No.3 highway for the first time in China. On the basis of preliminary understanding of this method, experiments were carried out on fine sand foundation of coal yard of Qinhuangdao wharf from August to September, 1979, and the foundation reinforcement effect is very good[1].

Dynamic compaction method has many advantages, such as wide application range, simple equipment, convenient construction and easy operation. It is widely used to strengthen various types of foundations such as sandy soil, silty soil, collapsible loess and crushed stone soil [1-4].

In northern China, a new airport is building in an artificial island. The foundation is deep gravel layer whose thickness exceeds 20m. The gravel foundation was landfilled one time, therefore it's uniformity was poor and it's bearing capacity could not meet the requirements. The builders would reinforce the gravel foundation by high energy level dynamic compaction. The dynamic compaction energy level required to consolidate such a deep gravel foundation is very huge, and it is likely to exceed 15000 kN•m. Then it will be called ultra-high energy dynamic compaction. However, there is no stipulation on dynamic compaction exceeding 12,000 kN•m in current norms in China, and there is little research on ultra-high energy dynamic compaction all over the world. Only few projects used ultra-high energy dynamic compaction. Therefore, it is necessary to study on the relationship between dynamic compaction energy and reinforcement depth, determine the needed dynamic compaction energy and reinforcement effect before the formal implementation. Then dynamic compaction tests with different dynamic compaction energy were carried out. Due to the limitation of layout, this paper only introduced dynamic compaction test with 18000 kN•m.

Engineering survey

The seabed surface elevation of the test area is -5.0m ~ -6.0m. The foundation below the seabed surface is relatively uniform on the whole. Along the depth, the soil layer can be divided into three layers. The first layer is soft soil layer of marine sediments. The second layer is clay and silty clay layer deposited by land-sea interaction. The third layer is clay and silty clay layer of continental deposits. The thickness of the first layer gradually increases from south to north, with a layer thickness of 9m to 16m. The land area within the test area is formed by dredging and filling technology. After removing the surface marine soft soil layer, the ground gravel soil is replaced to an elevation of + 4.7m. The test area covers an area of 120m× 60m.

The test used the construction technology of three times of point ramming and one time of full ramming. The ramming energy of the first and second times of point ramming is 18,000 kN•m. The distance between adjacent ramming points is 10 m. And ramming points arranged in a square shape. The first and second times of point ramming contained 18 attacks ~ 20 attacks. When the average ramming sinking amount of the last two attacks was less than or equal to 300 mm, the point ramming would be finished. The third time of point ramming energy was 8000 kN•m, and ramming points arranged in triangles whose two straight sides are 10m and 5m long. The third time of point ramming contained 14 attacks ~ 16 attacks. When the average ramming sinking amount of the last two attacks was less than or equal to 200 mm, the full ramming would be finished. After ramming each time, the site should be smoothed and shall be filled up to the handover elevation. Then one general tamping shall be carried out, with tamping energy of 1500 kN•m and 2 attacks ~ 3 attacks. Finally, the site was rolled by vibratory roller for 5 ~ 8 times until there is no wheel trace.

According to the test requirements, carried out a series of detection projects were before and after dynamic compaction, including surface settlement observation, layered settlement observation, deep settlement plate observation, rammed settlement measurement, ultra-heavy dynamic penetration test, multi-channel transient surface wave detection, static load test and other detection projects. Through these projects, the reinforcement depth could be made clear, the reinforcement effect could be evaluated and the strength characteristics of the strengthened foundation could be made clear.

Analysis of reinforcement effect

Bearing capacity of reinforced foundation. Flat load test was carried out in the test area after dynamic compaction. The test adopted 1.0m× 1.0m steel plate, and the loading method adopted the relative stability method of graded maintenance load settlement. The loading process is divided into 10 grades. The maximum load is 300kPa. The test was carried out in strict accordance with the relevant requirements in “Technical code for ground treatment of buildings” (JGJ 79-2012).

The design bearing capacity of the foundation is 150kPa. According to result of flat load test, the load-settlement (p - s) curve was obtained, as shown in figure 1. As can be seen from the figure, there is no damage phenomenon of the foundation when the loading reach 300kPa. So the characteristic value of the bearing capacity of the foundation is far greater than 150kPa. It means that the bearing capacity of the reinforced foundation meets the design requirement which is 150kPa.

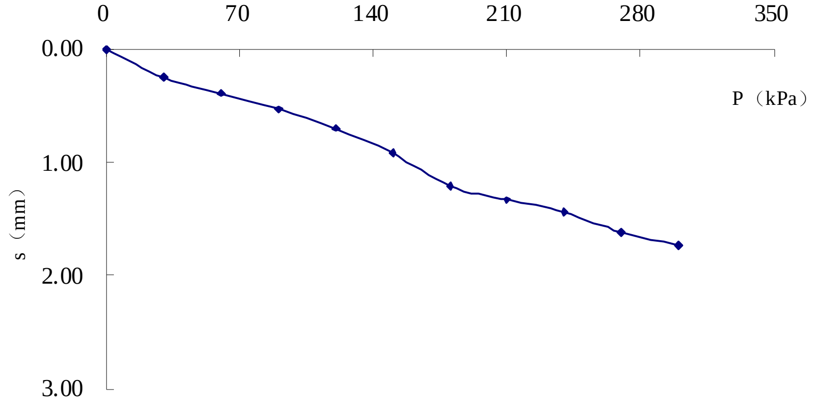

Fig. 1 Settlement vs. load in static load test

Analysis of foundation settlement. As can be seen from table 1, the settlement of the foundation mainly occurs between the surface and 12m depth. After two times of dynamic compaction, the average compression amount of soil in the depth range of 12m below the surface is about 27 cm / m, the average compression amount of soil in the depth range of 12m to 16m is 3.3 cm / m, and the average compression amount of soil in the depth range of 16m to 20m is 0.45 cm / m. The result indicates that dynamic compaction of 18000 kN•m has an influence on the foundation within 20m depth and the influence is significant within 12m depth.

Table 1 Monitoring results of deep foundation settlement

Depth of observation point [m]	Settlement after the first tamping [cm]	Settlement after the second tamping [cm]	Total settlement of dynamic compaction for two times[cm]
12	16.7	15.8	32.5
16	6.4	6.7	13.1
20	1.2	0.6	1.8

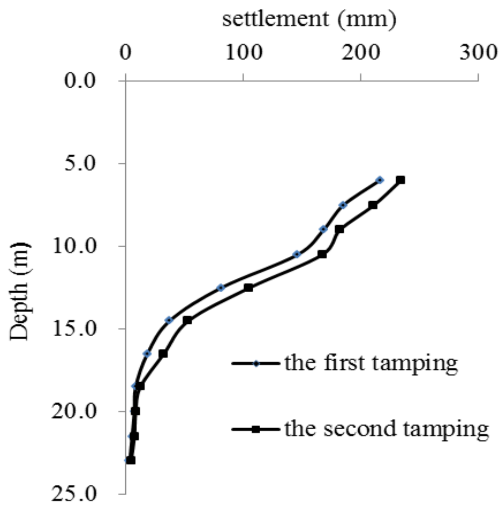

Fig. 2 Layered settlement curve of foundation after dynamic compaction

Layered settlement instrument was embedded in the test to monitor the deep layered settlement of foundation soil caused by the first and second time of point ramming. The monitoring results are shown in figure 2. As can be seen from figure 2, there is settlement from the ground surface to 22m depth and the settlement decrease with the increase of depth. At about 14m depth, there is an inflection point. The influence of dynamic compaction to the foundation is significant within 14m depth.

Ultra-heavy dynamic penetration test. Ultra-heavy dynamic penetration test was carried out before and after dynamic consolidation in the test. The result is shown in figure 3. As can be seen from the figure, at the upper part of foundation, the number of ultra-heavy dynamic penetration test after the consolidation has little change compared with that before the consolidation. The reason is that the upper part of foundation around the ramming pit is less influenced by dynamic compaction. With the increase of depth, the number of ultra-heavy dynamic penetration increases at first and then decreases. The number of ultra-heavy dynamic penetration test from ground surface to -17m elevation has changed while the ground surface elevation before reinforcement is + 4.7m. It indicates that the ground from ground surface to the 22m depth is influenced by dynamic penetration. But the increase of the number of ultra-heavy dynamic penetration test of the reinforced foundation with - 9m elevation downward is far less than the increase at the foundation above - 9m elevation. It means that the foundation depth with obvious reinforcement effect is about 14m.

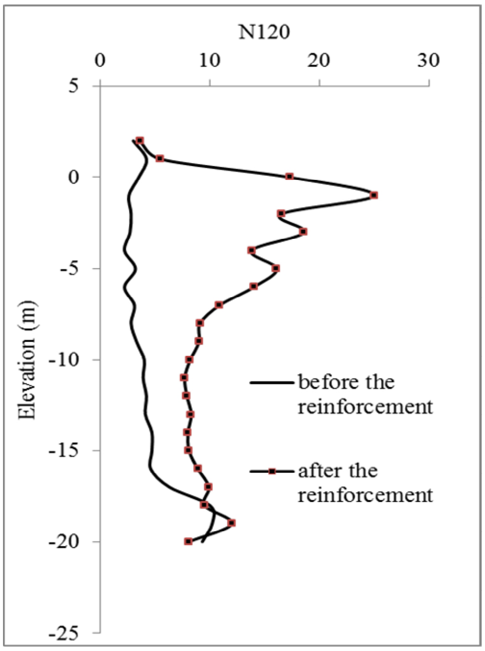

Fig. 3 Hammer number in dynamic penetration test before and after reinforcement

Multiple transient surface wave test. Multiple transient surface wave test was carried out before and after dynamic consolidation. The dispersion curves are shown in figure 4. As can be seen from the figure, the vibration speed after reinforcement is less than that before reinforcement within the top 4m depth, which indicates that the foundation has not been reinforced in this depth range. This phenomenon is the same as the standard penetration monitoring results. Within the depth range of 4m ~ 14m, the vibration velocity after reinforcement is obviously higher than that before reinforcement, which indicates that the foundation has been reinforced within this depth range. Below the 14m depth, the vibration velocity before and after reinforcement is basically equal, which indicates that the reinforcement effect of dynamic compaction at this depth range is not obvious.

Conclusion

Through dynamic consolidation test on large thickness gravel foundation, the following conclusions are obtained:

(1) After dynamic consolidation of 18000kN•m, the characteristic value of foundation bearing capacity is much larger than 150 kpa, which meets the design requirements.

(2) Deep settlement monitoring, layered settlement monitoring, ultra-heavy dynamic penetration test and multi-channel transient surface wave test all can reflect the dynamic compaction reinforcement effect, and the monitoring results are very similar.

(3) After dynamic consolidation of 18000kN•m, the reinforcement effect is not obvious in the range of 4m on the surface layer of the foundation, but obvious in the range of 4m to 14m, and still exists at 22m depth.

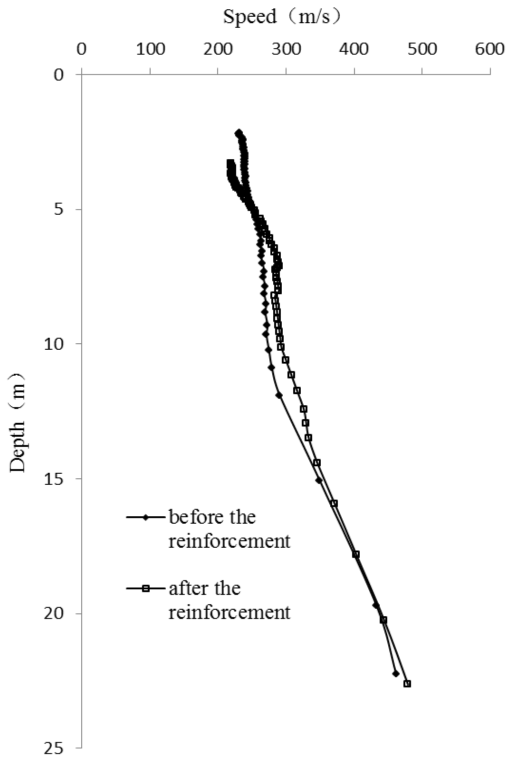

Fig. 4 The curve of multiple transient surface wave before and after the reinforcement

References

[1] YE Guo-liang,XU Bin-bin. Reinforcement mechanism of dynamic compaction and its literature review [J]. China Harbour Engineering, 2015, 35(4): 1-5. (in China)

[2] NIAN Ting-kai,LI Hong-jiang,YANG Qing, et al. Experiment of high energy dynamic compaction with 15 000 kN•m on a rubble[J]. Rock and Soil Mechanics fills site underlain by soft interlayer in coastal area, 2010, 31(3): 689-694.(in China)

[3] Zhao Zhendong,Zhao Xiangyu. Application study on the treatment of gravel soil foundation by using high energy level dynamic consolidation [J]. Geotechnical Investigation, 2011, (10): 29-32. (in China)

[4] Cai Suode, He Ming, Xue Qingkun, et al. Application research on foundation reinforcement by dynamic compaction[J]. Petrochemical Design, 2015,32(2) 45 - 47. (in China)

[5] Technical code for ground treatment of buildings（JGJ79-2012）[S].