Field test on 30,000 kN•m ultra high energy level dynamic compaction on large thickness gravel foundation

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ABSTRACT

A new airport is under construction at somewhere in northern China. The airport is located on a reclaimed 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 15,000kN•m which is called ultra high energy level dynamic compaction. However, the research of ultra high energy level dynamic compaction and engineering examples available for reference are very few. Therefore, field test is necessary before formal construction to determine the improvement energy level and improvement effect. A series of dynamic compaction field tests with different energy levels were carried out. In this paper, dynamic compaction field tests of 30,000kN•m were introduced. In the test, plate load test was carried out to determine the bearing capacity of improved foundation. Stratification settlement monitoring, ultra-heavy dynamic sounding test and multi-channel transient surface wave test were carried out before and after the compaction to reflect the dynamic compaction improvement effect. The field test result shows that after dynamic compaction of 30,000kN•m, the characteristic value of foundation bearing capacity is much larger than 150kpa, which meets the design requirements. Stratification settlement monitoring, ultra-heavy dynamic sounding test and multi-channel transient surface wave test all can reflect the dynamic compaction improvement effect, and the monitoring results are very similar. After dynamic compaction of 30,000kN•m, the improvement effect is obvious in 16m depth, and still exists at 22m depth.

Keywords: ultra high energy level; dynamic compaction; 30,000 kN•m; influence depth

1 INTRODUCTION

Dynamic compaction is a common foundation compaction 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 improvement effect is very good.

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]. Many scholars studied on the dynamic compaction method, such as Nian Tingkai et al. (2010), Zhao Zhendong et al. (2011) and Cai Suode et al. (2015).

In northern China, a new airport is building in a reclaimed island. The foundation is deep gravel layer whose thickness exceeds 20m. The gravel foundation was landfilled one time, therefore its uniformity was poor and it's bearing capacity could not meet the requirements. Builders would improve 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 15,000 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 improvement depth, determine the needed dynamic compaction energy and improvement 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 30,000 kN•m.

2 ENGINEERING SURVEY

The soil layer in the site is divided into four layers from top to bottom. The first layer is marine sediment. The second layer is terrestrial sediment. The third layer is terrestrial sediment and the fourth layer is base rock.

From top to bottom, the first layer contains silt, silty clay mixed sand, silty clay, mud and muddy clay. The average values of SPT blow counts respectively are 1.5, 1.0, 1.0, less than 1.0 and 1.1. The top elevation of this layer is - 13.17 m ～ - 19.94 m.

The second layer contains clay, silt clay, silty soil, silty fine sand. The average SPT blow counts respectively are 7.8, 10.0, 38.8 and 37.4. The top elevation of this layer is -21.57m ～ -36.72m.

The third layer contains clay, silt clay, clay. The average SPT blow counts respectively are 15.0, 17.9 and 18.9. The top elevation of this layer is -38.24～ -73.79m.

The fourth layer contains strongly weathered diabase, moderately weathered diabase, strongly weathered limestone and moderately weathered limestone. All SPT blow counts are larger than 50.0. The top elevation of this layer is - 38.24 m~ - 73.79 m.

Under the test, the first layer was cleared to -15.0m ~ -16.0m. Then filled gravel layer at one time to the elevation of + 4.7m. The test area covers an area of 60m× 60m. The backfilling material is granite gravel from mountain blasting. The gravel volume is very uneven. The weight of the largest block exceeds 100 kg.

The test used the construction technology of three times of point tamping. The tamping point arrangement of the three times of point tamping is shown in Fig.1. The hammer quality is 98.94 tons and the hammer diameter is 2.8 meters. The tamping energy of the first and second times of point tamping is 30,000 kN•m with 30.9 meters falling height. The distance between adjacent tamping points is 12 m. And tamping points arranged in a square shape. The first and second times of point tamping contained 20 attacks ~ 25 attacks. When the average tamping sinking amount of the last two attacks was less than or equal to 300 mm, the point tamping would be finished. The third time of point tamping energy was 15,000 kN•m, and tamping points arranged in a isosceles triangle whose height was 6m and bottom length was 12 m. The third time of point tamping contained 18 attacks ~ 20 attacks. When the average tamping sinking amount of the last two attacks was less than or equal to 200 mm, the third time of tamping would be finished.

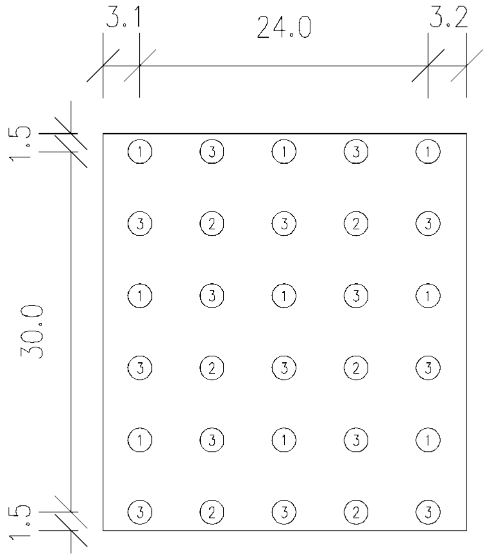

Fig. 1. Tamping point layout.

After three times of point tamping, full tamping which contained 2 attacks ~ 3 attacks was carried out. The tamping energy is 1500 kJ. It is required to tamp and seal the overlapping part, and the overlapping part shall not be less than 1 / 4 of the area of the bottom of the rammer. After the dynamic compaction, the surface layer of the ground is vibrated and rolled by a vibratory roller with an exciting force of 200 kN to 400 kN for 5 to 8 times until there is no wheel track.

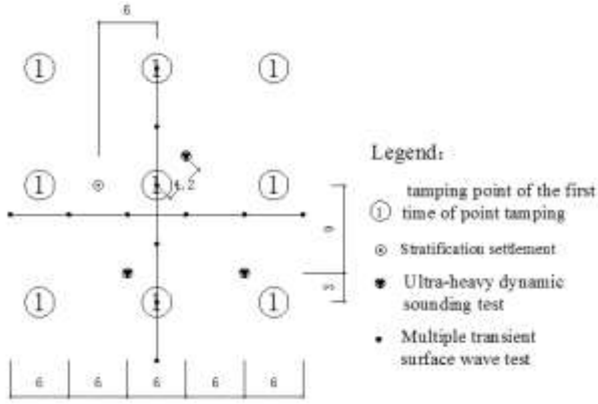

Fig. 2. Layout of monitoring instruments.

According to requirements of the test study, a series of evaluation tasks were carried out before and after dynamic compaction, including stratification settlement observation, ultra-heavy dynamic sounding test, multi-channel transient surface wave detection, static load test et al. the layout of monitoring instruments is shown in Fig.2. Through these projects, the improvement depth could be made clear, the improvement effect could be evaluated and the strength characteristics of the strengthened foundation could be made clear.

3 ANALYSIS OF IMPROVEMENT EFFECT

3.1 Bearing capacity of improved foundation

Plate 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 plate load test, the load-settlement (p - s) curve was obtained, as shown in figure 3. 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 improved foundation meets the design requirement which is 150kPa.

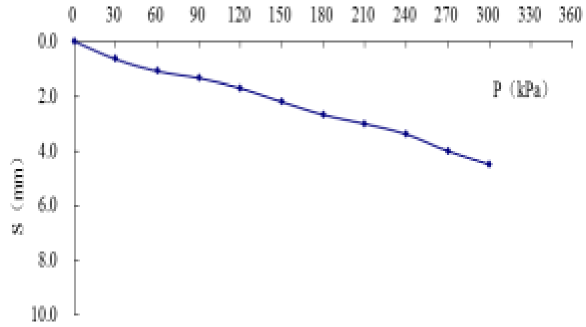

Fig. 3. Settlement vs. load in static load test.

3.2 Analysis of foundation settlement

Fig.4 is stratification settlement curve of foundation after dynamic compaction which was monitored with a group of stratified settler which was embedded 6m away from the center of the tamping point. As can be seen from figure 3, the settlement decreases with increasing depth. Dynamic compaction of 30,000 kN•m has an little influence on the foundation within 22m depth and the influence is significant within 16m depth (the elevation is -11.3m).

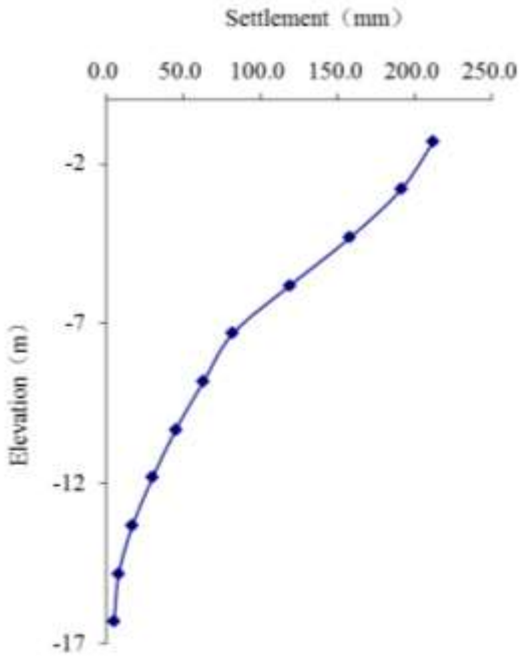

Fig.4. Stratification settlement curve of foundation after dynamic compaction.

3.3 Ultra-heavy dynamic sounding test

Ultra-heavy dynamic sounding test was carried out before and after dynamic compaction in the test. A 120kg drop hammer was used in ultra-heavy dynamic sounding test. The hammer height is 100cm. With the increase of tamping times, the depth of hammer entering into the foundation becomes larger and larger. When the depth achieved 10cm, the tamping times is called N_{120}. The detailed operation process is carried out in accordance with Code for investigation of geotechnical engineering (GB 50021-2017).

The result is shown in figure 5. As can be seen from the figure, at the upper part of foundation, the number of ultra-heavy dynamic sounding test after the compaction has little change compared with that before the compaction. The reason is that the upper part of foundation around the tamping pit is less influenced by dynamic compaction. With the increase of depth, the number of ultra-heavy dynamic sounding increases at first and then decreases. The number of ultra-heavy dynamic sounding test from ground surface to -12m elevation has changed while the ground surface elevation before improvement is + 4.7m. It indicates that the ground from ground surface to the 22m depth is influenced by dynamic sounding. But the increase of the number of ultra-heavy dynamic sounding test of the improved foundation with – 12m elevation downward is far less than the increase at the foundation above – 12m elevation. It means that the foundation depth with obvious improvement effect is about 16.7m.

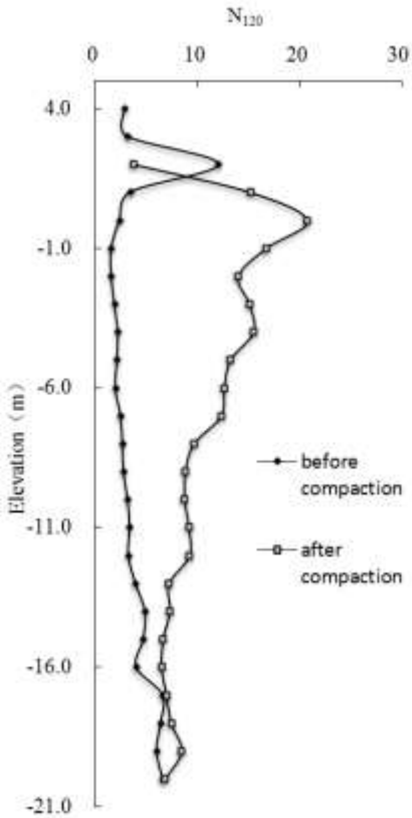

Fig. 5. Hammer number in dynamic sounding test before and after improvement.

3.4. Multiple transient surface wave test

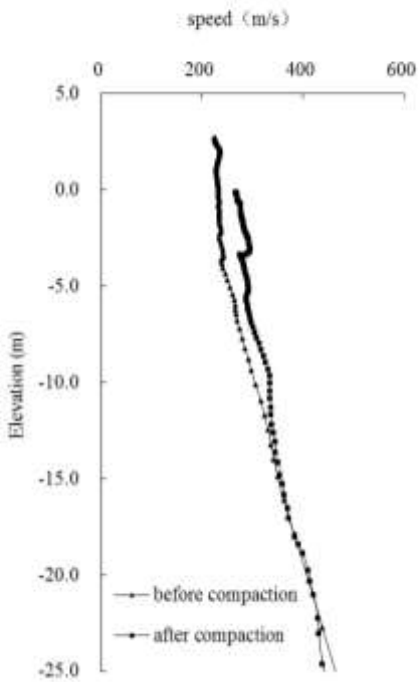

Fig. 6. The curve of multiple transient surface wave before and after the improvement.

Multiple transient surface wave tests were carried out before and after dynamic compaction. The dispersion curves are shown in figure 6. As can be seen from the figure, within the depth range of 16m, the vibration velocity after improvement is obviously higher than that before improvement, which indicates that the foundation has been improved within this depth range. Below the 16m depth, the vibration velocity before and after improvement is basically equal, which indicates that the improvement effect of dynamic compaction at this depth range is not obvious.

4. CONCLUSION

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

(1) After dynamic compaction of 30,000kN•m, the characteristic value of foundation bearing capacity is much larger than 150 kpa, which meets the design requirements.

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

(3) After dynamic compaction of 30,000kN•m, the improvement effect is obvious in 16m depth, and still exists at 22m depth.

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