Study on vibration law of complex foundation of terminal yard under dynamic consolidation

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Abstract. Hard shell layers with different thicknesses are usually distributed on the surface of terminal yard foundation, in order to ensure the safety of surrounding buildings and provide reasonable suggestions for dynamic compaction construction, it is urgent to study the vibration regularity of dynamic compaction. Based on the actual engineering project, this paper systematically studies the vibration law of hard shell foundation under different dynamic compaction construction parameters, it is concluded that: in the stage of hard shell breaking by column hammer, the peak value of vibration velocity is proportional to the thickness of hard shell layer, the peak vibration velocity decreases exponentially with the increase of distance, the minimum safe distance between the site and surrounding buildings is 37m to 58m; when the tamping energy is constant, the peak value of vibration velocity is inversely proportional to the diameter of hammer, on the premise of satisfying the reinforcement effect, large diameter hammer should be preferred; in the stage of flat hammer tamping foundation, the more tamping times, the greater the peak value of vibration velocity, and the amplitude of vibration velocity peak finally tends to be stable; in the stage of column hammer breaking hard shell layer, the peak value of vibration velocity decreases with the increase of tamping number, until the hard shell layer is damaged, the tamping energy is absorbed by the underlying soft clay layer, the peak value drops sharply.

1. Introduction

With the implementation of the 13th five year plan and the development of network intelligence, the port industry has rapidly entered the period of industrial expansion, strengthening the transformation of old terminal yards and promoting the construction of smart terminals are the key development direction of port enterprises. Due to the influence of construction technology, there are hard shell layers on the site surface, and the inhomogeneity of the underlying soil layer are obvious. Therefore, it is difficult to avoid the uneven settlement[1,2] during the use of the site.

Dynamic compaction[3,4] is the most effective method to improve the physical and mechanical properties of foundation, the dynamic compaction vibration has a certain impact on the surrounding buildings, many scholars have carried out research on the regularity of dynamic compaction vibration, L B Lin[5] studied the vibration law of artificial island seawall under dynamic compaction by field test, and summarized the factors influencing the vibration speed; according to the characteristics of dynamic compaction vibration, Z L Lu[6] studied the influence of different compaction energy, compaction number and other parameters on the vibration of the pier nearest to the compaction point,
and the minimum safety distance is given to ensure the building safety; W X Ding\(^7\) analyzed the vibration propagation characteristics by theoretical analysis and numerical simulation, the research results have important reference value for vibration control of surrounding environment during dynamic compaction construction.

At present, the application of dynamic compaction method in the reinforcement of saturated soft soil foundation\(^8\) with hard shell layer is less, and the regularity of foundation vibration is not clear, it is of great significance to conduct in-depth research for guiding the dynamic compaction construction of hard shell layer foundation and ensuring the safety of surrounding environment. Based on a container terminal project, this paper monitors and analyzes the foundation vibration law under different hard shell thickness and different dynamic compaction construction parameters, so as to provide effective reference for the similar project.

2. Project overview

The land area covers an area of 750000 m\(^2\), the site without formal treatment, the road and storage yard are arranged freely and scattered. A 2.0m to 7.0m thick miscellaneous fill structure layer is distributed on the site surface, which is mainly composed of brick, mass concrete and crushed stone, during drilling, local cores are columnar or fragmentary; under the miscellaneous fill, there is a clay layer with a thickness of 2.0m to 6.5m, which is in plastic state, belonging to high compressibility soil, with uneven soil quality, mixed with silt, muddy clay silt and silty clay lens.

The surface soil layer of the site is unevenly distributed, in order to ensure that the site settlement can meet the later use requirements, the dynamic compaction method is selected for foundation treatment, according to the different thickness of miscellaneous fill, the selection range of compaction energy is 1800 kNꞏm to 2600 kNꞏm, the site is reinforced by column hammer for 4 times, and then fully tamped by flat hammer for 6 times, the ramming times of column hammer and flat hammer are 3 to 7 (average 5) and 6 to 8 (average 7) respectively.

3. Field test scheme

3.1. Monitoring instruments and layout requirements

L20-N vibration measuring instrument is used for vibration monitoring, data collection includes three-dimensional amplitude value and main vibration frequency, the maximum value of vibration velocity occurs in Z direction, and the peak value in Z direction is taken for analysis. The layout of instruments should meet the following requirements:

1) The instrument layout selects the site with relatively uniform and representative soil layer.
2) The sensor should be firmly installed and the contact surface should be dense; in order to minimize the distortion caused by the combination with the ground, the buried depth should be at least 3 times of the main size of the sensor, and the original soil should be preferred as the backfill.
3) The sensor should be placed horizontally with X direction pointing to the vibration source.

3.2. Research contents and methods

1) The influence of the thickness of the hard shell layer; The field with hard shell thickness of 2.0m to 6.0m is taken as the test area, the vibration tester under the same tamping number is arranged at the distance of 20m to 70m from the tamping point.
2) The influence of rammer radius; in the test area with 5m thick hard shell layer, rammers with different radius (1.0m, 1.2m, 1.5m) are used to tamp the foundation, and take the peak value of vibration velocity under the same tamping number.
3) The influence law of tamping times; after the hard shell layer is broken by the column hammer, at the end of each full tamping of flat hammer, the vibration sensor is embedded at the place 30m away from the tamping point in each area, observe and analyze the law of vibration peak value.
4) The influence of tamping times of each dynamic compaction; the vibration sensors are embedded 20m away from the compaction point in each area to collect the vibration velocity peak value during the compaction process, and analyze the law of the vibration velocity peak value.

5) Combined with the surrounding environment of the project and the allowable safety standard of blasting vibration, the research results are judged according to Table 1.

Table 1. Allowable standard for vibration safety.

| Protected object category | Safe allowable vibration velocity (cm/s) |
|--------------------------|------------------------------------------|
|                          | f≤10Hz | 10Hz<f≤50Hz | f>50Hz |
| Fresh mass concrete (C20) | 3 days of initial solidification | 3 days to 7 days of solidification | 7 days to 28 days of solidification |
|                          | 1.5-2.0 | 2.0-2.5 | 2.5-3.0 |
|                          | 3.0-4.0 | 4.0-5.0 | 5.0-7.0 |
|                          | 7.0-8.0 | 8.0-10.0 | 10.0-12.0 |

f is the main vibration frequency.

3.3. Analysis of test results

3.3.1. Analysis of the influence result of hard shell thickness

Figure 1 shows the distribution law of the peak vibration velocity at the stage of column hammer breaking the hard shell layer. It can be seen that the thicker the hard shell layer is, the larger the vibration velocity peak value is, and the vibration velocity peak value attenuates with the increase of the distance from the tamping point; when the distance from the tamping point is 70m, the vibration peak value of each test area attenuates to zero, if the dynamic compaction vibration control standard is considered according to the minimum control value of vibration velocity (1.5cm/s) in Table 1, the minimum safe distance range of the test area is 37m-58m (hard shell layer thickness is 2m-6m). Therefore, in order to ensure the safety of surrounding hydraulic structures, corresponding vibration isolation measures should be taken within the safe distance.

3.3.2. Analysis of the influence result of hard shell thickness

Figure 2 shows the distribution of the peak vibration velocity of the foundation with 5m thick hard shell layer under the action of 2000kNꞏm tamping energy, and the radius of the tamping hammer is
1.0m, 1.2m and 1.5m respectively. It can be seen from the figure that under the same tamping energy, the smaller the hammer diameter is, the more intense the foundation vibration is, the larger the corresponding minimum safety distance is, and with the increase of tamping point distance, the more obvious the attenuation of vibration velocity peak value is. Therefore, in the process of dynamic compaction construction, in order to reduce the impact of dynamic compaction vibration on the surrounding buildings under the premise of meeting the foundation reinforcement effect, priority should be given to the use of rammer with larger diameter.

3.3.3. Analysis of the impact of tamping times during each dynamic consolidation

Figure 3 shows the variation law of the vibration velocity peak value of the foundation in each test area at the stage of column hammer breaking hard shell layer. It can be seen that the thicker the hard shell layer is, the greater the peak value of vibration velocity is, and the peak value of vibration velocity in each test area decreases with the increase of tamping number, when the tamping number reaches a certain value, the peak value decreases sharply, which is due to the increase of tamping number, the structure and integrity of the hard shell are gradually destroyed, resulting in the peak value of vibration velocity decreasing, when the ramming reaches a certain extent, the hard shell layer is broken through, resulting in the ramming energy being absorbed and dissipated by the clay layer, and the peak value of vibration velocity drops sharply, the thicker the hard shell layer is, the more times of ramming are needed for the through failure when the hard shell layer is broken by ramming, it can refer to the variation law of foundation vibration velocity, and finish the hammer in time, so as to avoid damaging the structure of soft clay layer.

3.3.4. Analysis of impact result of tamping times

Figure 4 shows the variation curve of the vibration peak value in each test area. It can be seen that the foundation vibration peak value in each area increases in varying degrees after each pass of flat hammer compaction, and the thicker the hard shell layer is, the greater the amplitude of the vibration velocity peak value is; the corresponding compaction times of the maximum amplitude of the peak value in each area are different, for example, the maximum amplitude of the 6m thick hard shell layer appears in the fourth pass of compaction, and the maximum amplitude of the 2m thick hard shell layer appears in the second pass of compaction, then, with the increase of tamping times, the amplitude of peak vibration velocity gradually decreases until it is stable, the reason is that the hard shell layer broken is gradually compacted under flat hammer, and the compactness and structure are gradually increased, under the action of specific compaction energy, the compactness of foundation gradually reaches the peak value and then does not increase, resulting in the rapid growth of peak value in the early stage and finally tends to be stable. Therefore, vibration monitoring can effectively evaluate the
reinforcement effect of foundation soil, and provide the optimization scheme of compaction times for design and construction.

4. Conclusion

(1) In the stage of column hammer breaking the hard shell layer, the thicker the hard shell layer, the more severe the impact of dynamic compaction vibration; the peak value of vibration velocity decays with the increase of compaction point distance, and the thicker the hard shell layer is, the more obvious the attenuation amplitude of vibration velocity peak value is.

(2) The minimum safety distance of the test area is 37m-58m (corresponding to the thickness of hard shell layer is 2m-6m), in order to ensure the safety of surrounding hydraulic structures, corresponding vibration isolation measures within the safety distance should be taken.

(3) Under the same tamping energy, the smaller the hammer diameter is, the stronger the foundation vibration is, and the larger the minimum safety distance is, with the increase of the tamping point distance, the attenuation of vibration velocity peak value is more obvious, on the premise of meeting the foundation reinforcement effect, in order to reduce the impact of dynamic compaction vibration, the larger the hammer diameter should be preferred.

(4) In the stage of column hammer breaking hard shell, the peak value of foundation vibration velocity in each test area decreases with the increase of tamping number, when tamping to a certain extent, the hard shell is broken through, the energy of ramming is absorbed and dissipated by the underlying soft soil layer, and the peak value of vibration velocity drops sharply, therefore, when the column ramming is used to break the hard shell layer, it is necessary to refer to the variation law of foundation vibration velocity, and finish the ramming in time, so as to avoid damaging the structure of the underlying soft soil layer.

(5) In the flat hammer compaction stage, the peak vibration velocity increases in varying degrees after each ramming, the thicker the hard shell layer is, the greater the increase of the peak vibration velocity is; the maximum increase of the peak vibration velocity corresponds to different ramming times, with the increase of ramming times, the increase of the peak vibration velocity gradually decreases until it is stable. Therefore, vibration monitoring can effectively evaluate the reinforcement effect of foundation soil, optimize the best compaction times for dynamic compaction design and construction, and provide reasonable suggestions for ensuring the safety of surrounding buildings in time according to the variation law of vibration velocity peak value.

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