Construction method and equipment of stone column in Israel Ashdod port

Youdei Feng
CCCC Second Harbour Engineering Co., Ltd., Wuhan 430040, China
Corresponding author: xiangliang@shecltd.com.cn

Abstract. According to the technical requirements of stone column for improvement of foundation of Ashdod Port in Israel, this paper studies the solutions to achieve stone column construction under strong wave condition. Based on the research of different construction methods and equipment of stone column, combined with the analysis of work efficiency, jack-up platform is put forward, which solves the technical problem of construction of stone column under the condition of long periodic wave surge.

1. Project profile
Ashdod Port is Israel Project is located 50km south of the capital Tel Aviv, construction areas include main breakwater extention 120m and LEE breakwater revetment 480m with stone column of quantity 110,000 m³.

2. Project characteristics and technical requirements
Although the widely used stone column composite foundation has effectively solved the problem of weak bearing capacity of the foundation under soft soil structure [1], due to the restriction of the offshore environment of this project, the traditional construction method and equipment will face the problem of less operation window period and low work efficiency, and it is difficult to meet the requirements of the construction period.

The difficulties and technical requirements of the project are as follows.

2.1. Adverse sea condition
The monsoon period is from November to March of the following year, and the non-monsoon period is from April to October in the project area.

The monsoon period is long accompanied by heavy storms. According to the statistics from 1992 to 2014, there was a gale every 10 days on average, with each gale lasting for 3-5 days and the maximum wave height up to 5m. However, last year, there was a gale every 7 days on average, and there were two major storms with the maximum wave height up to 10m.

The non-monsoon period is the construction period. Although there is no major storm, but the wave characteristics are obvious, are typical long period surge. According to the observation, the number of days with effective wave height below 0.5m is less than 27%, the number of days with effective wave height below 0.7m is less than 55%, the number of days with effective wave height below 1.0m is less than 75%, and the maximum period is more than 10s.
To sum up, the harsh meteorological conditions have brought many difficulties to the overwater construction of stone column, which are mainly shown as follows:

1) Although there are construction Windows with effective wave height below 0.7m intermittently in monsoon period, frequent ship dispatching is needed to avoid storms, resulting in great safety risks;
2) The maximum effective wave height of traditional construction ship is 0.7m. Through analysis, the effective working time window only accounts for half of the whole construction period, which greatly affects the construction efficiency of the whole project.
3) Long period surge waves will lead to the difficulty of ship positioning and high requirements on the mooring system;
4) Long-period surges lead to large plane movement and fluctuation of the ship, which has a great impact on the positioning of gravel conduit.

2.2. Large quantity and short schedule
According to the requirements of the technical specifications, the replacement rate of the plane area of the stone column is 0.13. According to the requirements, the diameter of the stone column is 0.9 m, the spacing is 2.35m and the equilateral triangle is arranged in this project. Among them, the average depth of the main breakwater stone column is 12m, and the number of stone column is about 3500. The average depth of Lee breakwater stone column is 18m, and the number of stone column is about 4900.

According to the overall construction schedule, the construction time of the main breakwater is March 20 to July 17, 2016, a total of about 120 days, all in the non-monsoon construction period; The Lee revetment breakwater was constructed for approximately 360 days from July 18, 2016 to July 12, 2017, including the monsoon period from November to March of the following year. Combined with the meteorological conditions in Section 2.1, the meteorological window analysis during the construction period is carried out. Using the traditional method, a total of three sets of stone column equipment are needed and the meteorological window with wave height below 1m is selected to meet the requirements of the construction period.

2.3. Poor geological condition
The geological investigation report shows that the strengthened soil layer of the main breakwater is a loose sand layer, and the number of penetration hits is 5 ~ 8, which belongs to the soft soil layer. The surface layer of Lee breakwater is compact-tight sand (UMS layer), and the number of penetration hits reaches 80, which belongs to the hard soil layer. The hardness of the same engineering geological conditions is different, and the surface of LEE breakwater is hard, which brings great difficulties to the selection of vibroflot equipment.

3. Construction method of stone column offshore
The reinforcement mechanism of stone column varies with the type of foundation soil. The main functions of stone column in sandy and silty soil foundation are compaction, vibration compaction and anti-liquefaction. The functions of stone column in cohesive soil foundation are mainly displacement and drainage. At present, the main treatment methods of gravel piles on water include immersed tube method and vibroflotation method.

Vibrating immersed tube crushed stone pile is a foundation treatment method that fills a certain grade of crushed stone into the pile pipe after forming holes in the soft foundation and compacts it with vibration to form a larger diameter and compacts the pile body composed of crushed stone.

In the vibroflot method, the stone column is used to lift the vibroflot with a crane and start the submersible motor to drive the eccentric block, so that the vibroflot will vibrate at high frequency. At the same time, the high pressure water pump is started to make the high pressure water injection. Under the action of vibroflot, the vibroflot will gradually sink into the design depth of the soil. Comparison of advantages and disadvantages of the two methods is shown in Table 1.
Table 1. Comparison between the immersed tube method and vibroflotation method for stone column construction

| Construction method | Immersed tube method | Vibroflotation method |
|---------------------|----------------------|-----------------------|
| 1. It is difficult to penetrate the geological hard layer by using vibrating hammer to vibrate and sink pile pipe; 2. The completion rate of the vibrating hammer directly affects the construction efficiency of the immersed pipe method; 3. Floating ship construction is more affected by waves, which requires frequent movement of ship position, and the submerged tube is easy to be damaged; 4. Need auxiliary support frame. | 1. High pressure water is used to assist vibration and subsidence, which has good geological adaptability; 2. Mobile and flexible; 3. Complete sets of vibroflot equipment are independent of each other during construction; 4. The equipment cost is relatively high; 5. Vibroflot method uses the bottom vibroflot to excite vibration, and the compactness is better. |

As can be seen from the above table, the biggest advantage of vibroflot method is that it adopts complete sets of vibroflot equipment and the construction is more flexible. Vibrator equipment main components including vibrator, feed tube, silo, etc., which inspires device as the core, the use of rotating eccentric force, when the phone is switched on to produce a certain frequency and amplitude of horizontal vibration, the use of vibration to rubble of vibroflotation compaction, as shown in the figure below for typical vibration equipment assembly drawing.

4. Equipment of offshore vibroflotation stone column construction

4.1. Traditional construction equipment

4.1.1. Barge modification scheme. This method is a stone column ship temporarily assembled by square barge and vibroflot equipment. It is the most commonly used method for the construction of stone column. It can be divided into two reconstruction schemes: 1) using barge as carrier and using crawler crane to hoist vibroflot for construction; 2) A pile driving frame is installed on the barge, and the vibroflot is hoisted by the pile driving frame for construction (figure 1).

The application of this method to stone column construction has the following characteristics:
1) Good reconstruction, short reconstruction period and good economy;
2) Due to the large amount of reconstruction, it is necessary to recalculate hull stability, structure, equipment layout and mooring system, etc.; In addition, it is necessary to design the feeding equipment and support frame.
3) Poor wind and wave resistance, less operating window.

4.1.2. Transformation of compacted sand pile ship. The construction technology and principle of compacted sand pile and vibroflotation stone column have some similarities. This method has been successfully applied in the reclamation project construction of Zhuangyuan Aogang District, Wenzhou. Moreover, the compacted sand pile ship is widely used in the middle delivery system and has rich engineering experience [2]

The application of this method to stone column construction has the following characteristics:
1) The compacted sand pile ship has its own pile frame, so it only needs to replace the pipe bottom with a vibroflot, so the amount of transformation is small and the transformation period is short;
2) The cost of compaction sand pile ship is high, the rental price is not low, and the cost is higher than that of barge transformation;
3) The problem of poor wind and wave resistance also exists with the barge reconstruction scheme.

4.1.3. Summary. Through the analysis of the above two schemes, it can be seen that it is feasible to use the traditional floating ship as the carrier to carry out the construction of the vibroflotation stone column on the water, but it has great limitations when applied to this project, which are mainly manifested in the following aspects:
1) The positioning accuracy of the vibroflot is directly affected by the transverse, pitching and heave motion generated by the long period surge on the ship;
2) With the increase of wave period and wave height, the impact or interference caused by vibroflot and lifting device will be intensified, or even damage will occur;
3) In terms of safety and accuracy, the construction can only be carried out under the operation window condition with the maximum wave height of 0.7m.

The above two traditional reconstruction schemes are difficult to meet the requirements of the construction period.

4.2. Page Numbers

4.2.1. Overall layout and performance. With a jack-up platform for stone column construction platform, decorate in the upper platform door frame, door frame covering the moon pool and, in certain areas on both sides of the string outside door frame set 3 mobile crane, are decorated in moon pool and outside areas on both sides of the string, driving along the longitudinal mobile door frame, the platform in a single time construction middle moon pool, on both sides of the string in three areas of stone column construction (figure 2).

Figure 1. Transformation scheme of barge into stone column ship

Figure 2. Construction platform scheme of jack-up stone column
The main performance parameters of the jack-up stone column construction platform are shown in Table 2.

Table 2. Main performance parameters of jack-up stone column construction platform

| Item                                | Parameter                                      |
|-------------------------------------|-----------------------------------------------|
| Main Dimension/m                    | 50×42×5 (m)                                   |
| Moon pool size/m                    | 27×19 (m)                                     |
| Platform operating condition        | Wind speed 13.8 m/s, Maximum wave height 2.5 m, period 8s |
| Platform lifting and shifting        | Wind speed 13.8 m/s, Maximum wave height 1.5 m, period 6s |
| conditions                          | Wind speed 36.9 m/s, Maximum wave height 11 m, period 10s |
| Platform storm self-storage condition| Wind speed 36.9 m/s, Maximum wave height 11 m, period 10s |
| Complete equipment for vibroflot     | 4 sets, 3 use and 1 spare                     |

4.2.2. Features and advantages. 1) Eliminate the influence of waves on the construction, greatly increase the operation window, the maximum wave height of 2.5 m can work normally, and can make full use of the operation time in the monsoon period;

2) The platform is equipped with a storage bin (2d storage), and the appropriate window (HS =0.7m) is selected for quick material replenishment to improve the operation capacity;

3) Compared with the traditional construction method, the construction area is wide and the construction efficiency is higher. 210 stone columns can be laid in a single standing platform;

4) Reasonable planning of platform scale and construction sequence can reduce the number of ship shifting and improve the working efficiency;

5) The adoption of the portal crane is conducive to the rapid and accurate positioning of the vibroflot;

6) The platform has strong self-storage capacity. During the construction in monsoon period, it has the ability to withstand wind and waves on site to avoid frequent dispatch;

7) Analyze the efficiency of construction of the platform, it only takes 3 months to complete 3500 stone columns of the main breakwater, and 7.2 months to complete 4900 stone columns of Lee breakwater, which meets the requirements of the construction period.

5. Conclusion

For the improvement soil of the remaining part of the main breakwater of this project, the original scheme adopts excavation and filling. After choosing the scheme of jack-up platform, it can be fully optimized for the soft foundation treatment of stone column, which has high environmental protection performance and can greatly reduce the construction cost.

In the later design, manufacture and use of the platform, there are still the following problems that need to be paid attention to:

1) Selection and use of supporting gravel replenishment ship: gravel replenishment is the key factor to control the construction of gravel pile, and how to choose the appropriate weather window to ensure timely replenishment of the platform is the key;

2) In order to improve the reliability and advancement of construction management, an integrated information management system should be considered to realize the centralized display of the construction process information of three vibroflot equipment under construction at the same time;

3) The geological condition of the platform used in this project is sand layer. Pile boots are considered to be used in order not to damage the gravel piles already constructed. But for silt geology, the proper form of pile leg needs to be further studied.

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