Development law of lateral displacement of deep soil mass in submerged breakwater

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Abstract. The 12.5m deep water channel project under Nanjing of the Yangtze River is a national key project. Based on the hechangzhou waterway section of the project, combined with the characteristics of water depth, strong wind, rapid flow and high wave, aiming at the problems such as short construction time, difficult instrument embedding, easy damage and low data collection efficiency, field monitoring test is carried out to monitor the foundation of submerged dike structure in the construction process. The lateral displacement of deep soil mass, clear its development law, provide a strong guarantee for safe construction.

1. Introduction
With the rapid development of China's economy, deep-water wharf, inland waterway, breakwater and other projects are more and more extended to the deep water. The construction of the project is faced with the situation that the natural environment is getting worse and worse, the foundation condition is getting worse and worse, and the construction difficulty is also increasing. In order to ensure the smooth progress of deep-water project, it is necessary to carry out on-site monitoring, real-time monitoring of key nodes, and grasp their operation status. However, due to the characteristics of deep water engineering, such as deep water depth, large current and no directional period, it is difficult to monitor on-site. Especially in the period of big waves, how to realize continuous real-time monitoring and master the changes of foundation and foundation during the construction process at any time is an important challenge.

In this paper, based on the hechangzhou waterway section of the project, combined with the characteristics of water depth, strong wind, rapid flow and high wave, aiming at the problems such as short construction time, difficulty in embedding instruments, easy to be damaged and low data collection efficiency, field monitoring test is carried out to monitor the lateral displacement of deep soil mass in the construction process of submerged dike structure foundation, so as to clarify the development law of the period, so as to ensure the safety of construction Workers provide strong support.
2. Profile of the engineering case

Two flat submerged dikes crossing waterway section were installed in the waterway improvement engineering of He chang zhou waterway section. The submerged dike 1# locates at 2100 m downstream of a built-up submerged dike, and the submerged dike 1# locates at 1000 m downstream. The elevation of dike crown varies much. The sections connecting to two shore sides are +4.0 m and +6.0 m, while the elevation of dike crown in the deep-water channel is -18.0 m. Three GK-4600 type settlement monitors were installed in each cross-section of the dike, and the locations of monitors are shown in Fig.1.

![Figure 1. Locations of settlement monitors in a cross-section of the submerged dike](image)

The monitoring lasted from March 4, 2016 to December 18, 2016, and the construction of submerged dike main structure finished before June, 2016.

3. Testing results

According to the measured monitoring data, the lateral displacement time curve of deep soil mass is shown in Fig.2. The statistics of displacement and maximum displacement rate of each monitoring point are shown in Table 1. The statistics of displacement rate of each monitoring point in different construction stages are shown in Table 2. The proportion of displacement to total settlement during construction is shown in Table 3.
Figure 2. Lateral displacement time curve of deep soil mass

Table 1 Statistics of displacement and maximum displacement rate of each monitoring point

| Sensor depth (m) | 0   | 2   | 4   | 6   | 8   | 10  | 12  | 14  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Total settlement (mm) | 7.5 | 6.0 | 5.4 | 5.7 | 0.2 | 0.2 | 0.4 | 0.2 |
| Maximum displacement rate (mm/d) | 0.93 | 1.52 | 0.93 | 0.67 | 0.29 | 0.40 | 0.27 | 0.20 |

Table 2 Statistical table of displacement rate at different construction stages at different depths

| Sensor depth (m) | 0   | 2   | 4   | 6   | 8   | 10  | 12  | 14  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Maximum displacement rate (mm/d) | Main construction period 0.9 | 1.5 | 0.9 | 0.7 | 0.3 | 0.4 | 0.3 | 0.2 |
| Completed in 3 months 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| Completed in 6 months 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| Completed in 9 months 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average displacement rate(mm/d) | Main construction period 0.09 | 0.10 | 0.08 | 0.09 | 0.05 | 0.05 | 0.02 | 0.01 |
| Completed in 12 months 0.02 | 0.01 | 0.01 | 0.01 | -0.01 | -0.01 | 0.00 | 0.00 | 0.00 |
Table 3  Statistics of displacement proportion in construction period

| Sensor depth (m) | 0  | 2  | 4  | 6  | 8  | 10 | 12 | 14 |
|------------------|----|----|----|----|----|----|----|----|
| Displacement of main construction period (mm) | 3.1 | 3.2 | 2.3 | 2.7 | 1.2 | 1.3 | 0.4 | 0.2 |
| Total settlement (mm) | 7.5 | 6.1 | 5.4 | 5.7 | 1.5 | 1.6 | 0.6 | 0.3 |
| Proportion of displacement in construction period (%) | 41.0 | 52.4 | 41.9 | 46.9 | 80.3 | 84.1 | 66.7 | 52.9 |

During the construction of the main structure of the submerged dike, the deep lateral displacement of the foundation soil is very small, the maximum displacement value is 7.5 mm, and the maximum displacement rate is 1.52 mm / d.

Under the same load, the lower the strength, the larger the lateral deformation, and the higher the strength, the smaller the lateral deformation. With the increase of soil depth, the additional stress gradually decreases, the strength of foundation soil increases, and the soil mass on the surface of the foundation displaces to both sides. The lateral deformation decreases with the depth, so the displacement decreases gradually.

4. Conclusions
Based on the in-site tests, the development of lateral displacement of deep soil mass in submerged breakwater can be obtained. The main conclusions are as followed.

- During the construction of the main structure of the submerged dike, the deep lateral displacement of the foundation soil is very small, the maximum displacement value is 7.5 mm, and the maximum displacement rate is 1.52 mm / d.
- With the increase of soil depth, the additional stress gradually decreases, the strength of foundation soil increases, and the soil mass on the surface of the foundation displaces to both sides. The lateral deformation decreases with the depth, so the displacement decreases gradually.

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