FEM analysis of the high-pile wharf retrofitting at the Shanghai Port

Pengyu Zhu1,2, Yonglai Zheng1,4, Zhuorui Wu1 and Shuxin Deng3

1 College of Civil Engineering, Tongji University, Shanghai 200092, China;
2 Shanghai International Port (Group) Co., Ltd, Shanghai, 200080;
3 School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China.
4 zyll@tongji.edu.cn

Abstract. A high-pile wharf retrofitting project at the Shanghai Port is analyzed by using the general finite element software–ANSYS. The finite element models of the high-pile wharves are built. The forces and displacements before and after retrofitting are compared. The results show that the internal force and overall displacement get smaller after adding a batter pile in front of the wharf. The on-site strain monitoring verifies the effect of the high-pile wharf retrofitting. The FEM analysis and on-site strain monitoring can also be helpful to the stability analysis during the operating period.

1. Introduction

High-pile wharves have good adaptability to soft soil foundation and are widely applied in China. In the past three decades, a lot of high-piled wharves have been constructed[1,2].

When analyzing the high-pile wharf structure, the common method is to simplify the wharf as a lateral row frame firstly. Then the traditional plane calculation model is taken to calculate the stresses and deformations of each element. If both the size and the stiffness of beams, plates, and piles are small, this method can be convenient to analysis the force states of the wharf structures. However, if the size and stiffness of these structures are large, the deficiency of this method will come to light, due to the increasing deep flexural members[3].

Another method is to consider the high-pile wharf as a whole and the finite element method can be applied to analyse the stresses and deformations of the whole system[4,5]. In this way, spatial problems of the wharf structures can be easily analyzed. Xie et. al.[1] built the finite element models of the high-piled wharf in the general finite element software–ANSYS to investigate the lateral loading behavior. Li and Liu[6] applied the spatial finite element method to analyze covered type structure of sheet piles wharf structure and analyzed the earth pressure, designated displacement at tie rods and constraint conditions of wall base. Su et al.[7] developed a seismic 3D finite element analysis framework for pile supported wharf structures and the resulting pile axial forces, shear forces, and bending moments are thoroughly analyzed. Wang and He[8] combined the finite element method (FEM) and theoretical analysis method to analyze the structural property, bearing behavior and failure mode of the all-vertical-piled wharf in offshore deep water.

In the present paper, a high-pile wharf retrofitting project at the Shanghai Port is analyzed by using the general finite element software–ANSYS. The finite element models of the high-pile wharves are built. The forces and displacements before and after retrofitting are compared. Based on these results,
the effect of the high-pile wharf retrofitting project is evaluated. The results can also be helpful to the stability analysis during the operating period.

2. Background

Currently, the main wharf structure at Shanghai Port is high-pile beam-slab wharf, the shelf space is generally 6~12m, the fragment length is generally 60~70m. The upper structure is composed of plant, longitudinal beam, cross beam, and berthing member, the substructure is a pile foundation. Pile foundation arrangement is determined by the use requirements, geological conditions, and other factors. The combination type of straight pile and inclined pile or cross pile is adopted in Shanghai Port, but part of the wharf prefers to all-vertical-piled due to some restrictions. Pre-stressed squared pile, PHC pipe pile, steel pipe pile, and bored pile are mainly adopted in the pile foundation of the high-pile wharf.

The frame spacing of the high-pile beam-slab wharf at Shanghai Port is 7m. Each frame shelf arranges 13 or 14 concrete piles with the size of 600 x 600. The upper structure of wharf is cast-in-place pile cap node. Department of beams and longitudinal beams are non-prestressed cast composite beams, prefabricated cast laminated panels. SUC1000H (RH) rubber fender is used in front of the wharf, with the spacing of 14m. SA800H arch rubber fender is used in the frame between drum type rubber fender. The natural soil surface is -11.50~ -12.50m in front of the wharf.

As shown in Figure 1, a Φ800mm steel pipe pile in the middle of every span in front of the wharf and the connection beam is added to improve the ability to resist horizontal force. Connection beam and two ends of the frame are cast in place node connection.

Figure 1. High-pile wharf structure before (left) and after (right) retrofitting.

3. FEM analysis and results

3.1. FEM modeling

In this paper, the international general program ANSYS finite element analysis software is used for modeling and analysis. Wharf structure model uses a full spatial entity unit in order to ensure high accuracy of the analysis. The unit is SOLID45 space hexahedral element with high precision. The model contains nearly 200,000 units as shown in Figure 2. Simulation parameters are shown in Table 1.

Only the horizontal forces are considered in the present study because the wharf retrofitting is for the increase of the ship load. So the simulation conditions are the wharf mechanical analysis under ship strike actions (horizontal load, no vertical load), before and after retrofitting. The form of ship berthing is 100-thousand-ton container ship with the length of 346m and the width of 45.6m. The draft of the ship is 14.5m.
Table 1. Simulation parameters of high pile wharf structures.

| parameters components | concrete | Young's modulus (MPa) | Density(kg/m³) | Poisson's ratio |
|------------------------|----------|-----------------------|----------------|----------------|
| Beams                  | C40      | 3.25×10⁴              | 2500           | 0.167          |
| Piles                  | C50      | 3.45×10⁴              | 2500           | 0.167          |

3.2. Results
As shown in Figure 3, the overall trend of beam bending moment is consistent before and after retrofitting. The bending moment of the beam focused on the front end, the positive bending moment is concentrated at the second pile cap nodes in the riverside, and the negative bending moment is concentrated in the front of the beam by the berthing member. The value of positive bending moment gets smaller after retrofitting, and the maximum value of the negative bending moment (located at the top of the berthing member) is basically consistent before and after retrofitting. But the negative bending moment after retrofitting at the first beam pile cap node and between the first and the second node is significantly less than the value before retrofitting.

As plotted in Figure 4, the overall trend of beam shear force is consisting before and after retrofitting but has local slight variation. The beam shear force distributes in the whole frame, and the maximum
value of the shear force occurs between the first pile cap and the second pile cap, the minimum value of the shear force occurs between the second pile cap and the third pile cap. After retrofitting, the positive shear force appears in the first pile cap where adding a foundation pile (negative shear stress before retrofitting). The value of beam shear force after retrofitting is less than the value before.

Horizonal displacement diagram before and after retrofitting is shown in Figure 5. The upward displacement of beam appeared between the first node and the third node of the pile cap, and the downward displacement appeared between the third node and the fifth node of the pile cap. The maximum upward vertical displacement occurs between the first node and the second node of the pile cap, and the maximum downward vertical displacement occurs in the site of berthing member. The value of vertical displacement changes little after retrofitting. Beam horizontal displacement decreases slightly after retrofitting.

The internal force and overall displacement get smaller after retrofitting of adding a batter pile in front of the wharf. The internal force (the bending moment of beam and pile force) and the horizontal displacement are reduced under the horizontal force after retrofitting.

4. On-site monitoring results
Sensors with semiconductor strain gauge and arched strain gauge are applied for on-site strain monitoring. Sensors are connected with the static strain data acquisition system, and then through the data mining system and its software function, the data is sent out by the wireless transmission module. Stress monitoring system to complete the statistics of the monitoring data, analyzing the stress variation in the defining period.

Due to the construction of transformation taking a long time, it is difficult to guarantee the experiment under the same ship collision. Therefore, as far as possible to arrange a similar tonnage of 2 ships collision, and asked the impact angle and speed as close as possible.
The site test of wharf structure is difficult, and the accuracy of the test is higher. Site conditions are more complex, more interference factors, the impact of the ship is uncertain. Therefore, it is difficult to capture the ideal test conditions, and there are some errors in the two impact conditions. In this paper, through the comparison of the strain before and after the same test point, it is concluded that the internal force of the pier is partially changed.

As shown in Figure 6, when the ship hit the monitoring point at a certain time point of the strain generated mutation, the strain is around 13 µε before retrofitting, and it is only 6 µε after retrofitting. Due to the impact of ship impact force, the strain value produced by the monitoring point after retrofitting of the wharf is less than that of the former. From the measured data, we can see that the front edge of the wharf has been added an inclined pile, and the internal force of the beam has been reduced.

Figure 6. Strain diagrams at the bottom cross beam before (black) and after (red) retrofitting.

5. Conclusions
The general trend of the plane stress analysis and spatial analysis is consistent, and the result of the space computation is less than that of the plane stress. The plane stress analysis only considers the internal force of the frame, and the internal force of the other bent frame cannot be calculated after the load acting on the frame. The plane stress analysis considers the main function of the beam system in the whole stress system of the wharf, and the effect of the panel on the whole structure is not considered. While space is calculated by the panel as the overall stress system, the transfer of the force, the panel also appears larger stress. The result of field monitoring is basically in agreement with the theoretical calculation, but it cannot be a system of comparable data due to other factors such as the measurement accuracy.

By analyzing the structural stress of a wharf in Shanghai port before and after retrofitting, it can be seen that under the same horizontal load, the internal force of the structure is significantly smaller than that of the former. By increasing the inclined pile way can make the berthing capacity of the pier improved. In this paper, the method of combining theoretical calculation data and measured data to compares the value of internal force before and after the reconstruction.

Site monitoring is a long-term process. More effective monitoring data can provide a comparison of the on-site monitoring data with spatial calculation results, which can be a theoretical guidance to similar terminal upgrade.

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