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Lateral load bearing capacity of offshore high-piled wharf with batter piles

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ABSTRACT

Understanding the lateral load behavior of high-piled wharf is of practical value to structural design, and the horizontal load bearing capacity of the bent is essential to analyzing the behavior of the high-piled wharf. In this paper, finite element models of high-piled wharf are built in a general finite element software–ANSYS to investigate the lateral loading behavior. Parametric analyses have been performed on the working behavior of single pile with varying slopes and section sizes under different load levels. The behavior of bent with batter piles under different lateral loads is discussed. The formulas of lateral load vs. horizontal displacement for single pile and high-piled wharf are formulated and presented in this paper. The numerical simulation results of pile top displacement are found to be in good agreement with those predicted using the theoretical formula presented in this paper. These formulas, which describe the relationship between top displacement and stiffness, inclination and loads, can be useful to determine the horizontal load bearing capacity of the high-piled wharf with batter piles and can realize the real-time safety monitoring of the high-piled wharf for practical application.

1. Introduction

The high-piled wharf structures have been widely applied in ocean engineering and port engineering, evidenced by the many high-piled wharves constructed in the past three decades. The main loads on the high-piled wharf structures are horizontal loads caused by wave load, flow load, wind load and ship impact load (Zhu and Xie, 2015; Xie et al., 2015). While among these loads, the ship load should be the most emphasized for its largest magnitude, especially for the high-piled wharf located in the open sea.

Considering the fact that the lateral load capacity of plumb pile is limited, high-piled wharves with batter piles have been widely used in offshore structures in order to achieve improved lateral load capacity. However, with the development of larger size ships and increasing demand for safety, high-piled wharf is expected to sustain horizontal loads of greater magnitude. The deformation of the wharf structure subjected to horizontal loads has been a main concern to its safe operation and thus considered as an important engineering problem by engineers.

Previous studies on high-piled wharf have been mainly based on theoretical analysis, laboratory tests and the field experiment method. The underlying pile is an important foundation component in the high-piled wharf. The elastic theoretical method proposed by Poulos (1971) is one of the earliest methods for pile foundation analysis, in which the soil is assumed to be ideally homogeneous and isotropic in elastic half space. In the P-Y curve method proposed by Matlock (1970) (where P is the soil resistance along the pile, Y is the lateral deflection of the pile at the same location), the pile behavior under the lateral loads is described using a series of nonlinear curves regarded as the function of the depth along the pile, and also as the representative of the elastic-plastic analysis method. However, these theoretical analysis methods have limitation in practical application due to the complexity of the soil-pile interaction. Several researchers also conducted laboratory experiments and field tests on the high-piled wharf. Pan et al. (2000) studied the stress and the deformation of the pile under horizontal loading by doing scale model experiments. Bonakdar and Oumeraci (2015) conducted a small scale model tests in a 2 m-wide wave flume to investigate the pile group effect on the wave loading of a slender pile and tested different pile arrangement.

With advances in computing technology and finite element analysis software, numerical simulation based analysis methods have been widely employed, and potentially can be used to investigate the effect of a large number of influencing factors of the pile-supported platform under horizontal load. Additionally, numerical study is usually less costly and less time consuming than physical experiments even with small scale model.

Rajashree and Sitharam (2001) conducted finite element analysis of batter piles under lateral load by idealizing the piles as beam elements

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and the soil as elastoplastic spring elements. The nonlinear soil behavior is represented by a hyperbolic relation. The importance of the degradation factor and its effect on the P-Y curves on batter piles are demonstrated.

With the widespread use of pile-supported platform in offshore structures, research works are also reported on the behavior of offshore high-piled wharf under horizontal load. Mostafa and Naggar (2004) studied the response of offshore platform subjected to extreme wave and current loading with varying parameter values. Giannakou et al. (2010) studied the seismic response of batter pile including the “kinematic” pile deformation as well as the “inertial” soil-pile-structure response using three-dimensional finite-element model in which elastic behavior was assumed for the soil, piles and the superstructure. Wang and He (2013) employed a 3-D elastic-plastic finite element model to analyze the load bearing capacity of vertical pile-supported wharf under horizontal loads with pseudo-static method. Fan and Yuan (2014) developed finite element models for ship-structure-soil interactions and identified four interaction phases for the overall flexural failure of the pile-supported platform as initial contact, unloading and free vibration and loading with approximate velocities. Muthukkumaran and Arun (2015) analyzed the soil-structure interaction behavior with varying seabed slope by performing static wave analysis on a typical fixed offshore platform using finite difference method. It is found that the lateral displacement at the pile top increases as the seabed slope increases.

Although the above literature review shows that a few factors have been considered such as the pile length, the stiffness of pile, the load inclination angle and the pile spacing of pile group, few researches on the displacement calculation method of the high-piled wharf under horizontal loads have been done. Therefore, it is of interest to carry out the research on the displacement calculation method for the high-piled wharf under horizontal loads. Theoretical research by Xie (1996) suggested that the problem of analyzing high-piled wharf can be resolved into analyzing bent structure. Determining the working properties of bent structure is the key component in studying the behavior of high-piled wharf.

In the present study, the finite element analysis software package-ANSYS is employed to simulate the deformation of high-piled wharf under the lateral load. The relationship between the lateral load and deformation is expatiated, and the theoretical formula is proposed. The field berthing test is used to investigate the theoretical formula. In this way, the lateral displacement under certain lateral load and the lateral bearing capacity under a limited displacement can be predicted.

2. Numerical model of high-piled wharf: description

2.1. Prototype of bent

As shown in Fig. 1, the section of the beam is an inverted “T” shape. The width of the lower rectangular beam section is 1.20 m, and its depth is 1.10 m. The width of the upper rectangular beam section measures 0.70 m, and its height measures 2.12 m. The base of the piles is assumed to be located at the same elevation. The section size of all the piles is equal to 0.6 m×0.6 m. The free length (i.e., length of the unburied part) of the piles in the vertical direction is 10 m. From left to right, the piles are labeled as #1 to #5 or from #1 to #9 respectively. The horizontal load is assumed to be a static concentrated load and is applied to the centroidal axis of the beam at one time for each loading case. The load direction is pointing to right. The parameters of the soil and the piles are shown in Tables 1, 2. Three different designs of the bent prototype models are showed in Fig. 2(a) to 2(c) respectively.

2.2. Basic assumption in the model

The following basic assumptions are made in the finite element model of the prototype high-piled wharf structures.

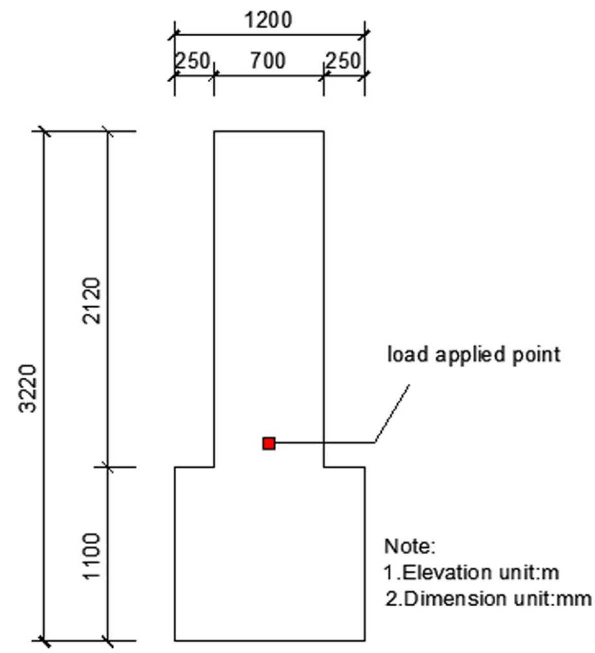

Fig. 1. The section of the beams.

(1) In the model, the soil is assumed to be continuous, homogeneous, and isotropic. The boundary conditions of the soil are given: the bottom surface of soil is constrained in all directions, and the side surfaces of soil are constrained in the horizontal directions.
(2) The elastic modulus and Poisson's ratio of the surrounding soil remain constant with the pile embedded in it.
(3) The pile and the soil are both assumed to behave as elastic-plastic material. The soil follows the Drucker-Prager Yield Criteria, which was also employed in previous study by Wang et al. (2014) as a classical model.
(4) Pile-soil interface is represented with a contact surface, and bottom section of the pile is laid on a horizontal surface.

2.3. Engineering parameters

The parameters of the soil and piles are listed in Tables 1 and 2, respectively. The parameters used for plastic soil behavior is material constant β and yield strength σ_y . $\beta = \frac{2sin\varnothing}{\sqrt{3}\,(3-sin\varnothing)}$, $\sigma_y = \frac{6c cos\varnothing}{\sqrt{3}\,(3-sin\varnothing)}$(ANSYS Help version 16.0, 2014). Where ∅ refers to the internal friction angle, and c refers to the cohesion, the parameters ∅ and c are presented in Table 1.

The compressive strength of the concrete is C40. These engineering parameter values are taken from a real offshore pile-supported structure located in the Yangtze River estuary, China.

2.4. Contact surface setting

In the ANSYS model, the contact surface element is adopted to simulate the pile-soil interaction. In general, the following rules and some research experience are followed to define the target surface and contact surface between the piles and the soil,

(1) The fine mesh surface should be set as the contact surface, and the rough mesh surface should be set as the target surface.
(2) The flat and concave surface should be set as the target surface.
(3) The harder one should be set as the target surface, and the softer one should be set as the contact surface.
(4) The surface with higher order element as base elements should be set as the contact surface, and the surface with lower order element should be set as the target surface.