Applied Ocean Research 32 (2010) 49–57

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Centrifuge modeling of an offshore water-intake project under ice loading

Liming Hu*, Min Zhao, Jialiu Pu

State Key Laboratory of Hydro-Science and Engineering, Department of Hydraulic Engineering, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 18 December 2009
Received in revised form
24 March 2010
Accepted 5 May 2010
Available online 4 June 2010

Keywords:
Centrifuge modeling
Sheet pile wall
Ice loading
Marine soil
Water-intake project
Thermal power plant

ABSTRACT

Sheet pile is a potential structural type for an offshore water-intake project for a thermal power plant in China because of its advantages of low cost and easy construction. However, the soil in offshore areas is under-consolidated and has a high water content. Therefore its bearing capacity is low, and the safety of water-intake structures under various loads is of major concern. Consequently the centrifuge modeling technique was used to study the stability of a structure in terms of its deformation, stress distribution, and bearing capacity under ice loading. The results show that the sheet pile structure works well under certain ice loads, and the earth pressure acting on the passive side contributes most of the bearing capacity. The lateral displacement of the structure increases significantly when the ice load exceeds the critical load. The position of the ice load has an obvious effect on the mechanical behavior of the structure, although increasing the structure's embedded depth cannot improve the bearing capacity significantly.

1. Introduction

The water-intake structure is a significant component of an offshore power plant for obtaining once-through cooling water. An open diversion channel is always employed in a water-intake structure in China, and sheet pile is useful for such a structure because of its advantages of low cost and easy construction. The sheet pile is usually embedded in soft marine soil, which is always under-consolidated and has a high water content, low strength, high compressibility, and low permeability. Furthermore, the loads acting on a sheet pile structure are complicated, which include earth pressure, storm waves, ocean currents, and floating ice. Therefore, lateral displacement is prone to occur, which results in dysfunction and even global failure of the structure.

The Dongying power-plant project is in the Yellow River delta, close to the Bohai Sea, in Shandong Province, China. The first phase of the project includes two 1000 MW thermal generators. The water-intake structure is an important part of the power plant. In the preliminary design, this sheet pile structure is 4 km long, extending into the sea, with an embedded depth of 20 m in soft marine soils. A plan layout of the water-intake structure is shown in Fig. 1, and the cross section of the sheet pile and geological strata is shown in Fig. 2. The physical and mechanical properties of the marine soils were determined by in-situ tests including static cone penetration tests (CPT), standard penetration tests (SPT), as well as field vane shear tests (VST), and conventional geotechnical laboratory tests of undisturbed soil samples including physical properties, compression, consolidation, and triaxial and direct shear tests [1]. The water-intake structure is a double sheet-pile wall system consisting of a 7.5-m-long structural element. In the Bohai Sea, floating ice is one of the major loads acting on offshore structures in winter. Therefore, inclined ice-breaking piles are designed for attachment to the sheet pile system in order to break the floating ice and reduce the ice load acting on the sheet pile structure.

However, such a structure had not been designed before for a water-intake project. A conventional sheet pile wall is often used in foundation engineering, which is a temporary structure, and the load is mostly from earth pressure. For a permanent water-intake structure, various loads in the oceanic environment must be considered for its safety, especially during construction. Floating ice is one of the major concerns, and its loading rate, direction, as well as frequency play a significant role on the intensity of the acting loads on the offshore structure [2]. For this project, the ice load reaches the largest value the first time it acts on the water-intake structure.

In reality, the actual ice load is dynamic in nature. There is an ice breaking system in the design of the water-intake system to break the floating ice and reduce the acting load on the water-intake structure. The ice load is very intense when it acts on the wall the first time. After ice breaking, the load becomes much less. Focus has therefore been on investigating how much ice load the wall can stand, and providing the reference for the design of such an ice breaking system including spacing, cross section and strength of inclined piles, without taking the dynamic nature of the ice load

* Corresponding author. Tel.: +86 10 62797416; fax: +86 10 62785593.
E-mail address: gehu@tsinghua.edu.cn (L. Hu).

0141-1187/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apor.2010.05.001

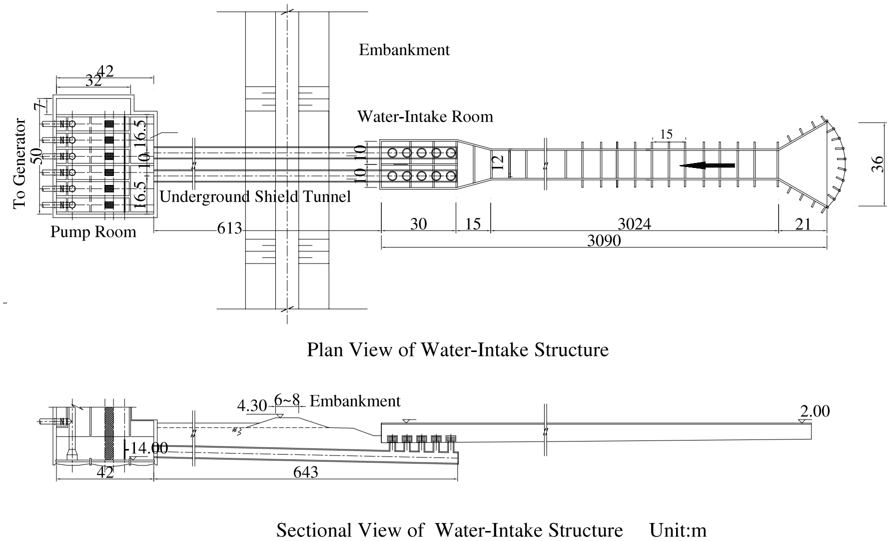

Fig. 1. Layout of the water-intake structure for Dongying power plant (Unit: m).

into account. In this study the load applied on the wall by the piston system is therefore assumed to be static. Accordingly, the possible degradation of soil strength under repetitive ice loads have not been addressed in this study, but could be considered in the further investigation by a dynamic loading system.

Furthermore, the condition of the offshore area is complex because the soil is multilayered, and most of the layers are soft and of low bearing capacity.

Many offshore structures have been built on soft ground, and much research has been undertaken on the mechanical characteristics of soft marine soils [3–6]. However, the design theory for the interaction between structure and soils is not well developed because of the nonuniformity and complexity of marine soils. The centrifuge modeling technique appears to be a powerful physical modeling tool for geotechnical engineering. A 1/N scale model tested at a centrifugal acceleration N times the earth's gravity undergoes stress conditions identical to those of the prototype [7]. The soil mass deformations are similar, and the failure mechanism of the soil model is the same as the prototype. Centrifuge modeling tests were conducted to investigate the soil–structure interaction behavior such as a retaining wall during excavation, sheet pile wall, pile groups and deep foundation system under lateral loading [8–13].

In this study the interaction behavior between the soil and sheet pile structure was simulated using the centrifuge modeling technique, and the safety of the water-intake structure under ice loading is discussed in the light of the Dongying power plant project. The in-situ ground condition was modeled using soil from the project site. The ice load was simulated by an increasingly applied load. The functional mode of the structure and ground soil was monitored simultaneously. The effects of different loading positions and different embedded depths on the mechanical behavior of the structure were investigated.

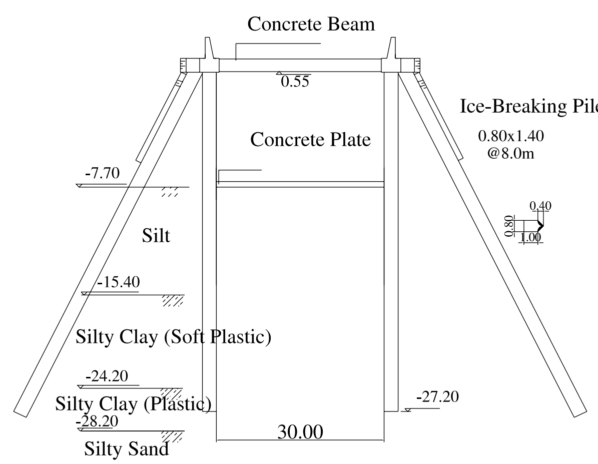

Fig. 2. Typical cross section of the sheet pile and geological layers at the site (Unit: m).

Fig. 3. Centrifuge facility at Tsinghua University.

2. Materials and facilities

2.1. Centrifuge facility

Centrifuge tests were conducted in the geotechnical centrifuge laboratory at Tsinghua University, shown in Fig. 3. The centrifuge payload capacity is 50 g-ton, with an arm length of 2.5 m and a maximum acceleration of 250g. An acceleration of 100g was adopted in this study.

The scaling laws between the centrifuge model and the prototype are presented in Table 1 [14]. The mechanical properties and geometrical dimensions for the centrifuge model need to comply with the scaling laws to adequately simulate the prototype behavior.