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Experimental study of the ice loads on multi-piled oil piers in Bohai Sea

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ABSTRACT

For a newly built multi-piled oil pier in Bohai Sea, a series of model tests were performed to evaluate the ice loads acting on the structure and the corresponding pile-group effect. Totally, 6 different ice conditions were considered in model tests, and the ice forces on each pile were measured. A variety of failure modes of ice are observed under different conditions, which result in ice force changing. The measured ice forces on each pile were compared with the computations by the ISO standard. Pile-group effects were thoroughly discussed, including interference effect, sheltering effect, non-simultaneous failing effect and combining influence. Integrated reduction coefficient and non-simultaneous failing coefficient were introduced to describe the influence of these effects. It is shown that between interference effect and sheltering effect the dominant effect for the integrated reduction varies with different piles. Besides integrated reduction, non-simultaneous failing is also investigated for pile-group, and the variation trends of these two effects are opposite as the increasing ice attack angle. Furthermore, the corresponding influence factors on total ice loads were discussed as well.

1. Introduction

With the rapid development of marine transporting and oil exploring activities, large number of oil wharfs have been built up on the shorelines of cold region seas in recent decades. For example, from 2005 to 2015 more than 10 large ports with big oil or gas wharfs were built along the shorelines of Bohai Sea (Fig. 1), which is the northernmost sea of China. To achieve large water depth for giant oil transporting vessels, the oil loading terminal needs to be designed to extend to deep water area through multi-piled oil pier. However, the multi-piled structures are easily subjected to overturning moments due to wind loads, wave loads, ice loads and ship impacts. Consequently, batter piles, which can resist significant lateral loads, are commonly used to support this kind of structure (Fig. 2).

For such piled foundation structures in cold seas, ice loads on the piles give design load for these oil piers. Mainly two types of models for estimating the ice load on single pile have been developed, i.e. analytical models (e.g. Ref. [1]) and semi-empirical models (e.g. Refs. [2–4]). Furthermore, various aspects of ice actions on multi-piled structures were prior investigated analytically and experimentally by scholars (e.g. Refs. [5–9]). These experimental or theoretic studies have given some insightful investigations on the ice load on multi-piled structures. It has been proven by many researchers that the key in

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Fig. 1. Distribution of important ports in Bohai Sea.

Fig. 2. An oil loading terminal in Bohai Sea.

determining ice loads on multi-piled structure is the evaluation of pile-group effect by which the ice load on single pile is reduced.

During the interaction between multi-piled structure and ice sheet, both the ice failure process and the flowing process of broken ice pieces will be significant changed by the pile-group effect. Some experimental and numerical investigations have been carried out on the pile-group effect (e.g. Refs. [10–14]). However, with the increasing complexity of structures, further investigations are needed on different aspects of this effect, as stated in Barker and Sayed [15].

Nowadays, the increasing wharf tonnage leads the oil pier with bigger dimensions and more supporting piles. As shown in Fig. 3, the positioning and postures of the piles become more various. It is naturally to suppose that the pile-group effect on ice loads will exhibit more complex behaviors. Moreover, new events (e.g. the ice jamming within the pile array) may also be induced by such structural characteristics. Therefore, further investigations should be performed to help the engineers in recognizing these variances comprehensively.

The first aim of this paper is to evaluate the ice loads on the multi-piled oil pier of a new oil wharf, which is planned for the Bohai Sea. The second aim is to investigate the pile-group effect. To achieve these aims, a series of model tests were performed. The test results and discussions on the pile-group effect are presented in this paper.