Engineering Structures 173 (2018) 481–494

Contents lists available at ScienceDirect

Engineering Structures

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

Calibrations of numerical models by experimental impact tests using scaled steel boxes

J.J. Wang, Y.C. Song, W. Wang*, J. Li

State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, China

ARTICLE INFO

Keywords:
Vessel impact
Protective structures
Anti-collision device
Finite-element simulations
Impact tests

ABSTRACT

The bridge piers located in navigation waterways are susceptible to vessel impact. In order to protect bridge piers from vessel impact, different kinds of protective structures have been developed. As one of such protective structures, the flexible anti-collision device with a steel outer periphery surrounding the bridge pier is frequently used in bridge designs against vessel impact. The mechanical properties of such steel anti-collision devices subjected to vessel impact loadings often need to be investigated by means of finite-element simulations using numerical models, the accuracy of which is critical. The objective of this paper is to conduct a group of hammer impact tests using scaled steel boxes and use the experimental results to validate the numerical models. Such numerical models with sufficient prediction accuracy can be further extended for applications to the design of the steel anti-collision devices subjected to vessel impact loadings.

1. Introduction

The rapid growth of trade and development of bridge construction technologies have led to the constructions of an increasing amount of bridges spanning over navigation waterways. These bridges are often susceptible to vessel impact due to the increase of vessel transportation volume. It was pointed out by Manen and Frandsen [1] and Larsen [2] that at least one major vessel-bridge collision accident of serious consequences occurred each year on average in the past. The protection of bridge piers from vessel impact is thus of vital importance in bridge designs.

The impact processes between the vessels and bridge piers were substantially investigated previously using finite-element simulations by many research institutions around the world [3–9]. The vessel impact energy is generally largely transformed into the internal energy of the vessel and the pier through plastic deformations after impact. In order to alleviate or even avoid the damages to the bridge pier during such impact, protective structures of different types such as dolphin structures [10–12], artificial islands [13] and guiding structures [14], are currently extensively used in bridge designs against vessel impact. However, these protective structures often suffer from problems such as high cost, installation difficulties and maintenance problems. To conquer these deficiencies, a new type of flexible floating anti-collision device with a steel outer periphery surrounding the bridge pier is developed and frequently used in China for bridges such as the Yangtze River Highway Bridge located in Hubei Province, China [15], the Zhanjiang Bay Bridge located in Guangdong Province, China [16], the Xiangshan Bridge located in Zhejiang Province, China [17], etc. The finite-element simulation is currently the main strategy for investigating the mechanical properties of such steel anti-collision devices subjected to vessel impact loadings. However, the vessel impact is a complex and highly non-linear dynamic process, which is challenging to be predicted with sufficient accuracy by finite-element simulations. The validation of the numerical models necessitates the conduction of experimental impact tests using either scaled or full-scale models, which have attracted much scientific attention.

The earliest ship impact tests were conducted by Minorsky in 1959 [18], and an empirical formula was proposed to describe the relationship between the deformed steel volume and the absorbed impact energy based on the data obtained from the twenty-six impact tests. Woisin conducted a total of twenty-four impact tests using scaled ship models from 1967 to 1976 [19] for the sake of protecting nuclear-powered ships from collision against other ships. An empirical formula was developed accordingly to quantify the equivalent impact force based on the ship size and impact velocity. Meir-Dornberg once conducted the dynamic loading with a drop hammer and the static loading on barge models of reduced-scale in 1983 to quantify the barge impact loading during impact [20]. Based on the data obtained from the impact tests, the empirical formulas in terms of the impact energy for calculating the barge bow crushing depth and barge impact force were

---

* Corresponding author.
E-mail address: dwsjzri@gmail.com (W. Wang).

https://doi.org/10.1016/j.engstruct.2018.06.100
Received 30 March 2018; Received in revised form 19 June 2018; Accepted 26 June 2018

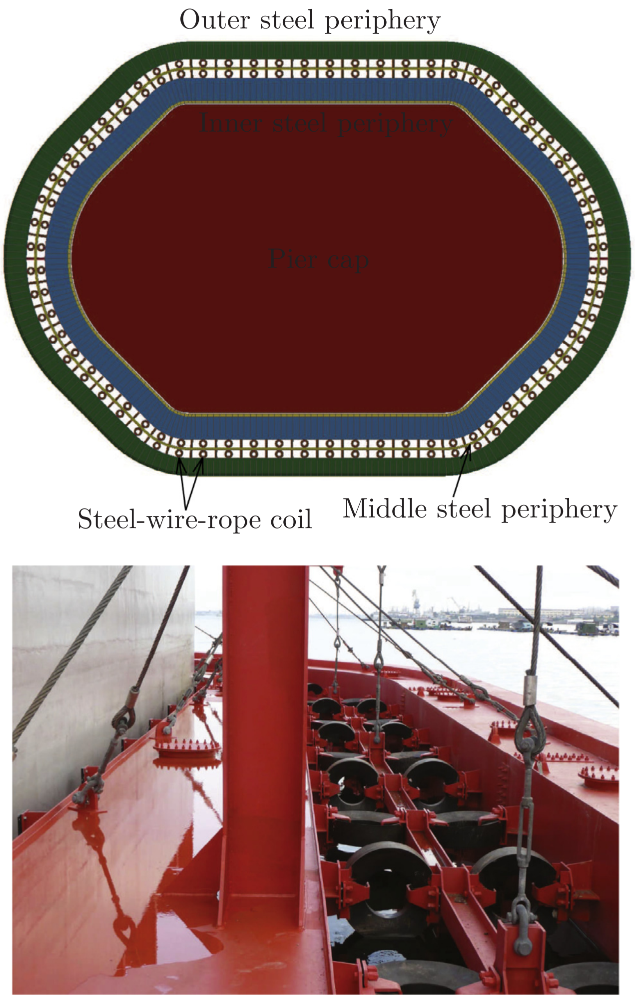

Fig. 1. Configuration of the steel anti-collision device adopted by Zhanjiang Bay Bridge located in Guangdong Province, China [15,26].

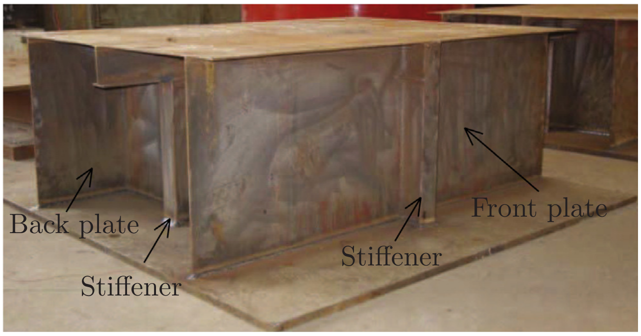

Fig. 2. Configuration of the scaled steel box.

developed. The Association for Structural Improvement of the Shipbuilding Industry of Japan carried out extensive collision and grounding tests to investigate the structural crashworthiness of double-side structures of tankers and the failure mechanism of ship structures when ground occurs [21]. Numerical finite-element models of the impact tests were developed and validated by Paik [22]. In 2004, University of Florida conducted a full-scale experiment of barge impact on the old St. George Island Causeway Bridge [23–25]. This is the first full-scale test of barge impact on bridge piers which serves as a benchmark for illustrating the physical phenomena involved in real barge-pier impact events.

However, the existing experimental impact tests regarding vessel impact are mainly focused on the structure of the vessels whilst the experimental studies on the steel anti-collision devices subjected to vessel impact loading are still very limited. This paper thus aims to conduct a group of hammer impact tests using three scaled steel boxes to investigate the mechanical properties of the steel boxes under different impact scenarios. The experimental results are then used to validate the numerical models developed in this paper. The length and failure strain of the elements for the numerical models are carefully determined by correlative studies. The numerical models after detailed model validations may be further extended for applications to the design of the steel anti-collision devices subjected to vessel impact loadings.

2. Experimental impact tests

During a vessel impact, a portion of the impact energy is transformed into the residual kinetic energy of the vessel while the rest of the impact energy is dissipated through the plastic deformations of the vessel and the impacted structure. In order to protect both the bridge pier and the vessel, the flexible steel anti-collision devices have been designed, as shown in Fig. 1. Such devices have an excellent energy-dissipation capacity and can absorb a large amount of energy during impact, thus the energy absorbed by the vessel and the pier can be much reduced and consequently both the pier and the vessel can be protected. As full-scale experimental impact test is expensive and mostly unrealistic to be conducted, reliable numerical models are often needed to predict the complex phenomenon involved in the vessel impact process with sufficient accuracy. Based on this concept, the hammer impact tests of different energy levels are conducted here using three scaled steel boxes of the same configurations. The damages to the steel boxes during impact are recorded and analysed, and the experimental results are used as the benchmark for validating the numerical models developed in this paper.

2.1. *Configurations of the experimental equipment*

In total three impact tests labelled as 1#, 2# and 3#, respectively, are conducted here using three scaled steel boxes of the same configurations, as shown in Fig. 2. The overall dimension of the scaled steel box is 1400 mm in length, 1000 mm in width, and 500 mm in height. The scaled steel box is composed of welded steel plates of 4.62 mm in thickness. The cross-sectional configurations and dimensions of the scaled steel boxes are provided in Fig. 3.

The impact tests are conducted on the drop hammer impact machine which is comprised of the top guiding plate, the bottom guiding plate, the drop hammer located between the two guiding plates and the impacting steel block attached to the bottom guiding plate, as depicted in Figs. 4 and 5. The drop hammers are 1400 mm in diameter and the 1# drop hammer and 2# drop hammer are 663 mm and 503 mm in height, respectively.

Before each impact test, the drop hammer is raised to the prescribed height and then falls freely until it impacts on the scaled steel box, as shown in Fig. 6. The mass, impact height and impact velocity of the