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Manufacturing and evaluation of Large-scale Composite Bumper System for bridge pier protection against ship collision

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ABSTRACT

An innovative Large-scale Composite Bumper System (LCBS) for bridge piers against ship collision was recently proposed at Nanjing Tech University. The modular segment of LCBS is made of Glass Fiber-Reinforced Polymer (GFRP) skins, GFRP lattice webs, Polyurethane (PU) foam cores and ceramic particles in which Vacuum Assisted Resin Infusion Process (VARIP) is adopted in the manufacturing process. This novel bumper system offers several remarkable advantages, such as: self-buoyancy in water, modular fabrication of segments, efficiency for on-site installation, excellent corrosion resistance, as well as ease in replacing damaged segments. In this paper, the manufacture procedures as well as the installation process of LCBS were introduced. An in-depth analysis of performance evaluation of LCBS was then conducted for a real cable stayed bridge using a nonlinear explicit dynamic finite-element analysis program (LS-DYNA). The simulation results indicated that LCBS can effectively increase the impact time of ship-bridge collision, and reduce the peak collision forces to a non-destructive level, leading to a good effect in energy dissipation. The results suggest that LCBS is an effective bumper system for protecting bridges and ships in ship-bridge collisions.

1. Introduction

Ship collision with bridge piers is one of the most frequent accidents in waterborne traffic. In view of the large variations of deadweight tonnage and approach speed, ship-bridge collisions may cause not only tragic loss of many lives but also severe damage to the bridge [1–3]. Despite of efforts in proper planning of bridge siting and navigation channel layout, and assessment of collision risk with reference to acceptable criteria, ship-bridge collisions still are a constant threat to bridges over water. According to Federal Highway Administration (FHWA) in USA, the collision damage of a vehicle or a ship impacting a bridge is the third cause of bridge failure/collapse, following the first two causes which are flood and overweight vehicles [4]. There were globally 34 major bridge collapses caused by ship-bridge collisions between 1960 and 2007 with a total loss of 346 lives (e.g., Sunshine Skyway Bridge in USA in 1980) [5,6]. In China, growing traffic requirements result in the increase in the construction of major bridges across large expanses of water, there were also many ship-bridge collisions occurred in recent years. In 2007, Guangdong Jiujiang Bridge was impacted by a cargo ship, resulting in tragic loss of nine lives and the collapse of partial bridge. 200 m of the bridge deck was severely damaged and fell into the river [7]. Since that accident, the Collision Avoidance Special Rectification Activities were launched by Ministry of Transport of China to ensure bridge safety. Thus, the protection of bridge piers against ship collisions is of importance and increasingly draws research attention. The bridge anti-collision facilities need to be properly designed to prevent the failure of bridge piers and to enhance the safety of bridge structures.

In the past two decades, several types of anti-collision facilities have been developed based on the basic principles of energy absorption and momentum buffering. 18 bridge anti-collision facilities were tested by Svensson [8]. Voyiadjis et al. [9] reviewed the existing six major types of anti-collision facilities for bridge piers used in USA and other countries. Each kind of anti-collision facilities has distinctive characteristics and working conditions. In recent years, steel fender facilities have been more commonly used in China than other types of anti-collision facilities [10]. The floating framed-steel fender facilities have been incorporated onto bridge piers with substantial water level variations, such as Huangshi Bridge on the Yangtze River. The fender system absorbs ship impact loads by elastic and plastic deformation of its own mem-

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bers. But the fender system has major drawbacks such as high rigidity of its constituent materials, high initial cost, poor corrosion resistance and high maintenance requirements [11].

Fiber-reinforced polymer (FRP) composites are particularly attractive for anti-collision structures due to their exceptional material properties, such as high strength and high stiffness, lightweight, excellent corrosion resistance and good cushioning performance [12–14]. Recently, research attentions have been drawn to develop composite structures incorporating with FRP for effective energy dissipation [15–24]. Foam-core sandwich panels (Fig. 1a), which consist of two GFRP skins and Polyurethane (PU) foam core, were tested under quasi-static compression and showed that the foam core is of importance in energy absorbtion [25,26]. However, the foam-core sandwich panels had very low stiffness and peak strength due to the low strength and stiffness of the foam core. They are not suitable for bridge anti-collision facilities, as there will be huge impact force and energy release during the collision. A new type of foam-filled lattice composite panel, proposed by the authors' research group (Fig. 1b) [26–28], consists of not only two GFRP skins and PU foam core, but also GFRP lattice webs. Experimental results showed that [26], compared to the foam-core sandwich panels without lattice webs (Fig. 1a), the GFRP lattice webs can increase the peak load of approximately 1600% during the quasi-static compression test. However, there are difficulties to manufacture large-scale foam-filled lattice composite panel (e.g., 3.5 m in thickness) using integral molding method. Therefore, the foam-filled lattice composite panel are not suitable to be directly used as bridge anti-collision facilities. Based on existing research of foam-filled lattice composite panels (Fig. 1b), an innovative Large-scale Composite Bumper System (LCBS) (Fig. 1c) was recently proposed by the first author and the third author as bridge anti-collision facilities. LCBS consists of six or more large-scale cylindrical segments connected by large-scale joints and pins. The cylindrical segment is made of GFRP skins, GFRP lattice webs, PU foam cores and ceramic particles, in which Vacuum Assisted Resin Infusion Process (VARIP) is adopted in the manufacturing process. The cylindrical segment can be looked as 3 dimensional foam-filled lattice composite panel, which is rolled into a cylindrical hollow tube and filled with ceramic particles. This novel bumper system offers several advantages, such as: self-buoyancy in water, modular fabrication of segments, efficiency for on-site installation, excellent corrosion resistance, low maintenance requirements, as well as ease in replacing damaged segments. This novel anti-collision bumper system has already been installed for more than 10 bridges in China since 2010.

In this paper, the rationale for this novel anti-collision bumper system together with its expected advantages is discussed. The manufacture procedures as well as the installation process of LCBS were firstly introduced. An in-depth analysis of performance evaluation of LCBS was then conducted for a real cable stayed bridge using a nonlinear explicit dynamic finite-element analysis program (LS-DYNA). Typical collision cases for bridge piers installed with LCBS or without LCBS herein are investigated via numerical simulations. The maximum impact force and impact duration were compared for these cases. Energy dissipation characteristics of the LCBS were also discussed in detail.

2. Project overview

2.1. RunYang Yangtze River Bridge

LCBS was applied in the RunYang Yangtze River Bridge in 2012. The RunYang Yangtze River Bridge, which is located on the Yangtze River in Jiangsu province of China, has of two branches: the suspension bridge in south branch and the cable-stayed bridge in north branch. The main bridge towers of the suspension bridge are located on the south land and the Shiyezhou islet, so there is no risk of ship-bridge collisions. However, the north cable-stayed bridge is the secondary navigable spans with its main towers located in the river, which have high risks of ship-bridge collisions (Fig. 2). The object of this paper is to prevent the ship-bridge collisions of the north cable-stayed bridge. The cable-stayed bridge has two main towers, double cable planes and steel box girders, with span arrangements as follows: 175.4 m + 406 m + 175.4 m (Fig. 2). The south and north towers are both pre-stressed concrete structure in the form of vase-shape (Fig. 3a). The two towers are 143.026 m and 146.888 m in height measured from the pile cap to the tower top, respectively. The whole bridge is designed with 104 stay cables. The tower cap is supported by 24 bored piles with the diameter of 2.5 m.

The two main towers of the north cable-stayed bridge have been under high risks of accidental ship-bridge collisions since its opening in 2005. The tonnage and speed of ships have been increased since then. So it is crucial to install anti-collision facilities for the bridge piers against a potential ship-bridge collision.

The large-tonnage ships passing through the navigation channel in the north branch mainly include 3000 dead weight tonnage (DWT) container ships and oil tankers with a total weight of 4500 ton (i.e., 1500 ton of self-weight and 3000 ton of cargo weight) and a conventional navigation velocity of 3.0 m/s. According to the ship-collision statistical data, the 3000 DWT oil tanker was chose as the representative ship.

2.2. LCBS for bridge piers

Considering structural characteristics of bridge piers and anti-collision demand and impact force, LCBS was designed with a circular cross section that can move up and down with the change of water level. As shown in Fig. 3a, each bridge tower has two piers and LCBS is installed surrounding each bridge pier.

As shown in Fig. 3b, the LCBS surrounding the bridge pier was assembled with 2 straight modular segments and 4 elbow-shaped segments by 6 pairs of concave and convex joints. Each joint connects the two adjacent modular segments by 2 high-density polyethylene (HDPE) bolts with a diameter of 240 mm. The modular segments are very easy to be replaced due to the sim-

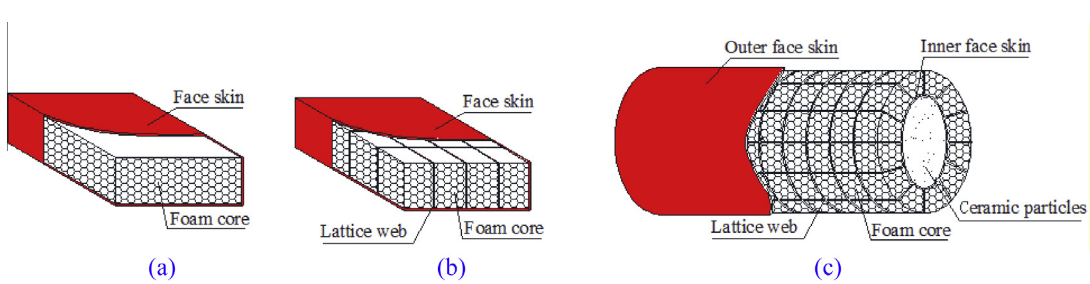

Fig. 1. Energy-absorbing structures: (a) foam-core composite sandwich panel, (b) foam-filled lattice composite panel, and (c) cylindrical segment of LCBS.