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Evaluation of composite crashworthy device for pier protection against barge impact

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ABSTRACT

Barge impact is a potential hazard to bridge piers located in navigation waterways. Pier protection against barge impact is of vital importance and thus protective structures of different types are currently extensively used in bridge designs. Glass fiber reinforced plastic (GFRP) is a kind of composite that has been widely used in the design of crashworthy devices for many bridges in China. However, many questions regarding the mechanical properties of this composite remain to be answered. In this paper, a series of material property experiments, i.e. tension, compression, bending and shear experiments, are conducted using GFRP samples, based on which the GFRP material parameters are determined. A quasi-static crushing experiment using a scaled composite cylinder is conducted to investigate the failure mechanism of GFRP, epoxy resin and polyurethane foams which comprise the composite section. In addition, a numerical model of the scaled composite cylinder is developed and validated using experimental results. The validated numerical model is then used to evaluate the effectiveness of a full-scale cylindrical crashworthy device with composite section subjected to barge impact.

1. Introduction

Bridge design against barge impact has drawn much attention in the past decade. Similar to wind, earthquake and other extreme loadings, barge impact on bridge structures can possibly lead to catastrophic consequences including human casualties and economic losses. A lot of researches focusing on predictions of impact loadings and dynamic responses of bridge structures subjected to vessel impact were conducted previously by different universities and institutions in the world (Consolazio and Cowan, 2005; Cowan, 2007; Yuan, 2005; Wang and Morgenthal, 2017, 2018a; Wang et al., 2017; Fan and Yuan, 2012; Wang and Yu, 2014; Fan et al., 2011a).

Another critical problem that bridge designs are confronting is how to protect bridge structures from vessel impact, either by completely isolating bridge structures from contact forces using independent protective structures such as dolphin structures (Saul et al., 2001; Knott, 1986), artificial islands (Simonsen and Ottesen-Hansen, 1998), guiding structures (Holger, 2009), etc, or by reducing the damages to bridge structures subjected to vessel impact using shielding devices such as floating crashworthy devices (Chen and Wang, 2006; Lv et al., 2014), CFRP (carbon fibre reinforced polymers) coatings (Sha and Hao, 2015; Pinzelli and Chang, 2001), novel crashworthy devices (Wang and Morgenthal, 2018b), etc. However, independent protective structures often suffer from problems such as high cost, great construction difficulties and occupation of navigation space whilst CFRP coatings are not effective for reducing the maximum impact force and are thus not able to protect the barge during impact (Sha and Hao, 2015). In addition, the change of water level is another challenge to the existing protective structures, as their locations are generally fixed. Due to these problems, flexible floating devices which surround the protected bridge pier have been widely used in China today for bridges such as the Zhanjiang Bay Bridge located in Guangdong Province, China (Chen and Wang, 2006), the Xiangshan Bridge located in Zhejiang Province, China (Lv et al., 2014), the Runyang Yangtze River Bridge located in Jiangsu Province, China (Liu et al., 2013), etc. Such floating devices are often configured by steel structures (Chen and Wang, 2006; Lv et al., 2014; Li and Bao, 2003) which suffer from problems such as large stiffness, corrosion, high cost, etc.

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 plastic deformations of the vessel and impacted structure (Wang and Morgenthal, 2018b). In order to protect both the bridge pier and the vessel, a crashworthy device which is easy to install, maintain and can absorb large portions of impact energy through plastic deformations needs to be developed. In this way, the energy absorbed by the vessel and the pier during impact would be

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Fig. 1. Composite crashworthy devices installed for several bridges in China.

low, and consequently, both the vessel and the pier can remain in the linear range, that is, elastic (undamaged), through the limitation of the force transmitted (Wang and Morgenthal, 2018b). Fiber reinforced composites, e.g. GFRP, are corrosion-resistant, light-weight and high-strength, thus they are easy to maintain and have attracted much attention for applications to floating crashworthy devices (Liu et al., 2013; Mao et al., 2015; Ding, 2012; Zou et al., 2014), as shown in Fig. 1. Such composite floating devices are often used in locations where the water level experiences dramatic changes during the year. No connection components between such devices and piers are needed, thus the effort taken by installing such devices can be much reduced. Due to large flexibility, such devices would undergo large plastic deformations during a high-energy vessel impact and can thus absorb a large amount of impact energy, protecting both vessels and piers.

A lot of quasi-static or dynamic impact experiments were conducted in recent years using scaled models of composite crashworthy devices to investigate the energy-dissipation capacity of the device and the effectiveness of the device for reducing dynamic responses of protected structures subjected to impact (Liu et al., 2013; Fan et al., 2014; Zhou et al., 2016a; Li, 2013; Jin, 2014; Wu et al., 2014). However, such

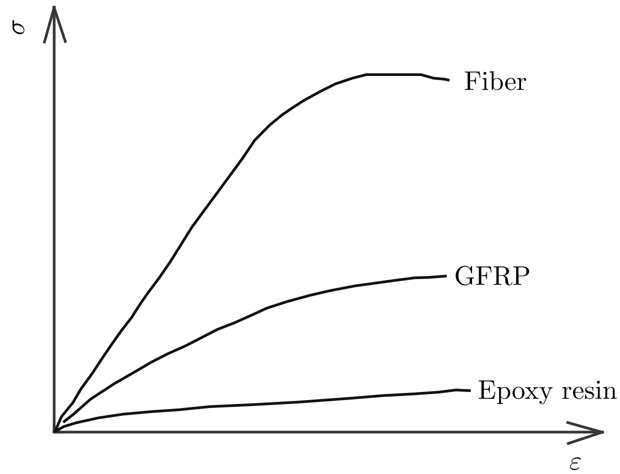

Fig. 3. Stress-strain relationship of GFRP (Zhou et al., 2016b).

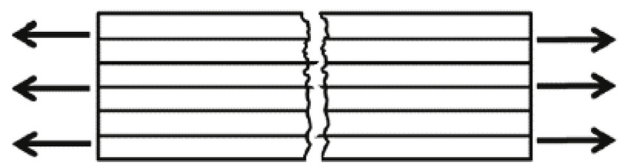

Fig. 4. Tensile failure of glass fibres.

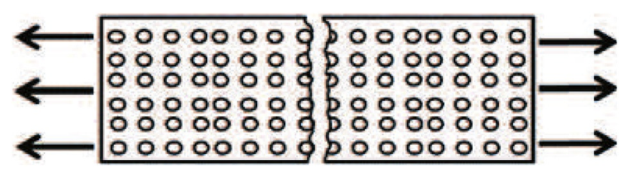

Fig. 5. Tensile failure of epoxy resin.

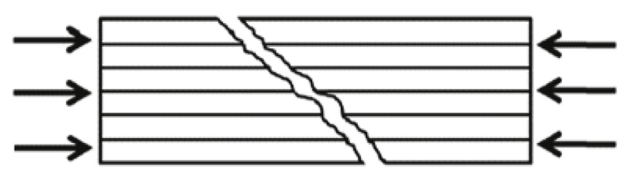

Fig. 6. Shear failure of the GFRP slab when subjected to compressive loading along *x*-axis.

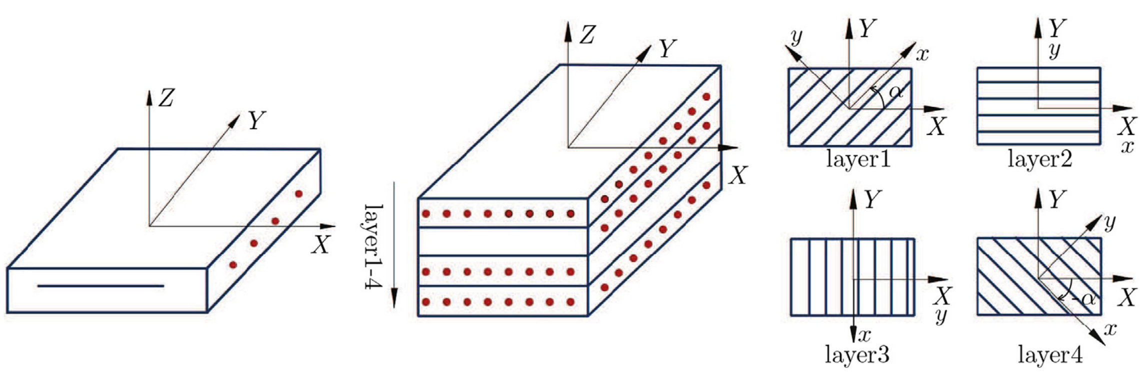

Fig. 2. Layout of the single-layered GFRP slab (left) and the multi-layered GFRP slab (right).