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Determination of hurricane-induced barge impact loads on floodwalls using dynamic finite element analysis

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ABSTRACT

During hurricane events, moored barges are at risk of being propelled by high winds and impacting flood protection walls in the vicinity. Cities like New Orleans, Louisiana are at particular risk for such hazards, due to the preponderance of canals and moored barges throughout the city combined with high hurricane risk. Unfortunately, limited information is available to estimate the magnitude of barge impact loads for the design of floodwalls. In this paper, forces associated with hurricane-wind-propelled barge impacts on floodwalls are quantified using high-resolution dynamic finite element simulations. Such simulations account for highly nonlinear material deformation in the impacting barge, nonlinear soil response, and dynamic interaction between the barge, wall, and soil. The paper presents force histories for a variety of representative impact scenarios which can be used directly in dynamic analysis of floodwalls. Additional guidance is provided for employing the force results in static design scenarios.

1. Introduction

The city of New Orleans, Louisiana, USA is located near the mouth of the Mississippi River on the coast of the Gulf of Mexico, and large portions of the city have been constructed at or below sea level. Consequently, New Orleans is at significant risk of water intrusion resulting from both seasonal river flooding and hurricane-induced storm surges. Thus, the city and many surrounding areas are protected with an extensive system of earthen levees and concrete floodwalls that are designed and maintained by the U.S. Army Corps of Engineers (USACE). During hurricanes, these floodwalls are subjected to loads from elevated storm surges, waves, wind, and wind-propelled debris. After Hurricane Katrina directly struck New Orleans in 2005, it was observed that numerous river barges, which had been moored throughout the city waterways, broke loose from their moorings and were propelled through the channels by hurricane winds. Thus, floodwalls throughout New Orleans—and any region where this scenario can occur—are at risk of being damaged by impact from aberrant, wind-propelled barges (Fig. 1).

Given the severe consequences associated with the barge impact hazard, the goal of the current study was to quantify barge impact loads on typical floodwalls using high-resolution dynamic finite element analysis. Loads quantified by this study can be used to design new floodwalls or to assess the need for protecting or replacing existing infrastructure in flood-prone areas.

2. Background

Following a number of structural failures resulting from barge and ship collisions, significant research effort has been devoted to quantifying loads associated with barge impact with various waterway structures. For bridges, design codes in the U.S. [1] and Europe [2] prescribe barge impact loads and related design requirements. Ongoing research is being carried out to further refine the U.S. code procedures by developing more accurate predictions of impact loads [3–5] and improved analysis procedures [6,7]. However, these procedures are not readily adapted to analyzing floodwalls subjected to wind-driven barge impact, primarily because they were derived assuming that head-on impact will occur between the barge bow (front portion) and bridge pier. In contrast, during a hurricane, an unrestrained wind-driven barge could impact a floodwall at any angle, permitting impact by the bow, stern (rear portion), or side of the barge.

Research focused on barge impact forces on other waterway structures has been conducted by the USACE. Specifically, studies were previously undertaken to quantify barge impact loads on semi-rigid walls—such as those surrounding locks—by means of a series of full-scale barge flotilla impact experiments [8,9]. The

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Fig. 1. Aberrant barges that impacted New Orleans area floodwalls during Hurricane Katrina. *Source*: U.S. Army Corps of Engineers.

two USACE studies culminated in design provisions and load prediction equations, referred to as ETL 1110-02-563 [10], which pertain to barges colliding with lock wall structures. However, impact loads predicted using the USACE ETL equations could be overly conservative when applied to barge impacts with floodwalls, because floodwalls are much more flexible than the relatively rigid wall structures considered in the ETL provisions [10]. Furthermore, similar to the bridge design procedures described above, impacts from the barge stern or barge side are not considered in the ETL provisions. Given the limitations of applying existing analysis methods to the problem of hurricane wind-driven barge impacts on floodwalls, the current study was undertaken to quantify impact loads for a variety of feasible impact conditions using finite element impact simulations.

3. Finite element model features

In order to perform contact-impact analyses of barge collisions, finite element (FE) models of a typical jumbo hopper barge, and two USACE floodwalls were developed for analysis using the LS-DYNA code [11]. The barge finite element model was developed based on detailed structural drawings that were provided to the authors by a barge manufacturer.

3.1. Jumbo hopper barge

The most common type of barge traversing U.S. waterways—including those surrounding New Orleans—is the jumbo hopper barge. Thus, throughout this study, a jumbo hopper barge measuring 59.4 m (195 ft) long and 10.7 m (35 ft) wide was used for all impact simulations.

3.1.1. Structural modeling

As illustrated in Fig. 2(a), the jumbo hopper barge is divided into three zones along its length: bow, hopper, and stern. Watertight bulkheads, spaced at 12.3 m (40.5 ft) intervals along the hopper region, act to compartmentalize the barge. The entire barge structure was modeled using more than 900,000 nonlinear

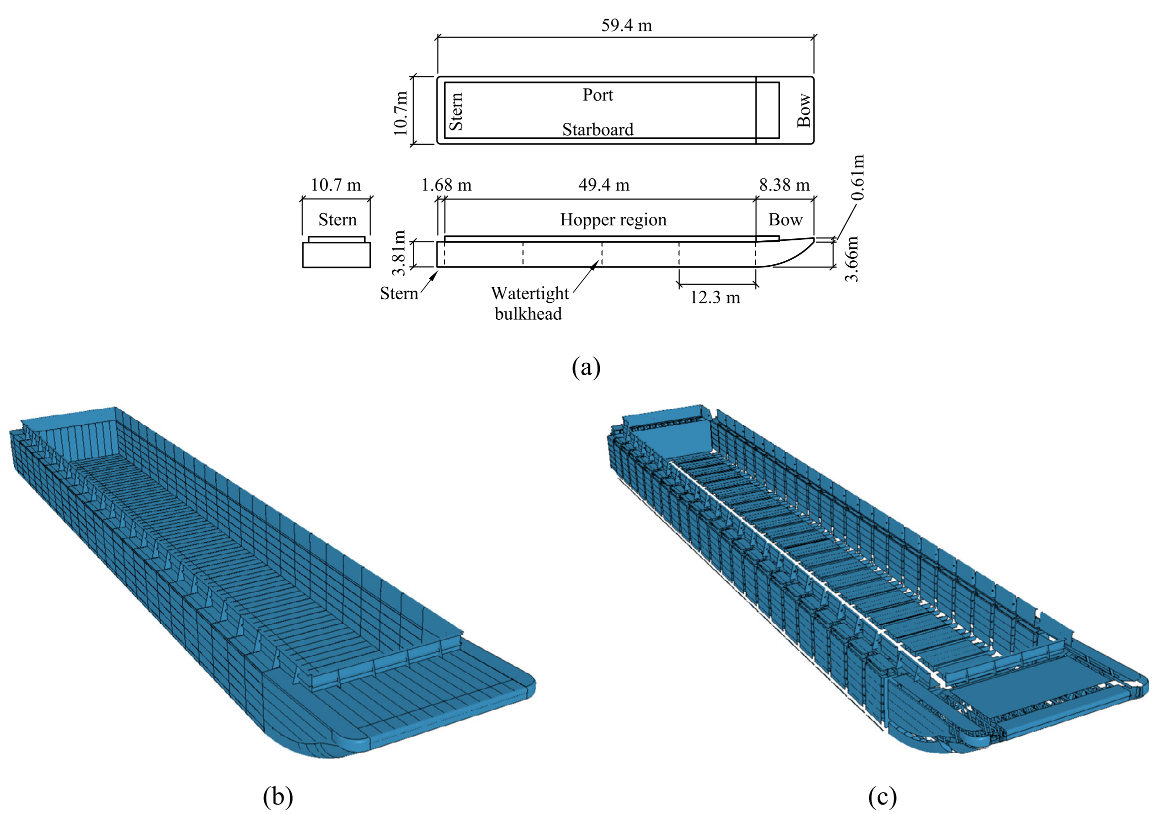

Fig. 2. Jumbo hopper barge FE model (mesh not shown for clarity): (a) schematic plan and elevation view; (b) perspective view; (c) exploded view.