Full-Scale Barge Impact Experiments

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ABSTRACT

This paper describes the full-scale barge impact experiments recently conducted by the U.S. Army Corps of Engineers (USACE). These experiments were performed by the USAE Waterways Experiment Station to assist in the verification of the current barge impact methodologies being utilized in the design of inland waterway navigation structures. These full-scale experiments utilized four- and fifteen-barge tow configurations. The flotillas were fully ballasted to approximately nine feet of draft and laid out with state-of-the-art instrumentation to record the actual impact force and the behavior of the flotilla during impact. The angles and speeds of the tow at impact during these experiments ranged from 0.5 to 4.1 feet per second, at angles of impact from 5 to 30 degrees. Full-scale experiments were also conducted on a prototype energy-absorbing fendering system designed especially for inland waterway structures. The results from these experiments will be used to further define and develop the barge impact numerical models and assist with design procedures to be used in USACE innovative lock design.

INTRODUCTION

Inland waterway navigation structures at U.S. Army Corps of Engineers (USACE) lock and dam facilities are inherently subjected to "usual" barge impact loads due to transiting flotillas. However, barge impact forces for "unusual" and "extreme events" such as operator error, loss of power, or loss of control have dramatically influenced the current USACE design loads for inland waterway structures. This increase in design loads for barge impact has created a significant increase in the overall costs of navigation structures.

However, the existing analytical models used by the USACE for the analysis and design of barge impact loads have been feared to be very conservative for use in design. With the design trend in the USACE toward building thinner-walled innovative structures that can be of lift-in or float-in construction, the quantification of barge impact forces becomes a critical part in the success of this innovative design. However, the true quantification of the actual force between an inland waterway flotilla and a concrete lock wall has never been directly measured by full-scale experiments.

EXISTING MODEL

The current USACE barge impact design methodology for inland navigation structures is documented in Engineering Technical Letter 1110-2-338 (ETL 338) [1]. The model defined in ETL 338 bases the barge and wall as a single-degree-of-freedom (SDOF) system, as shown in Figure 1. The only input required to this SDOF model is the mass, size (beam and length), velocity, and angle of impact of the flotilla. The ETL 338 model has been developed for both rigid and flexible structures and is based on a constant-pressure coefficient developed by Minorsky [2]. This Minorsky model uses kinetic energy lost to the damage-volume relationship for ship collisions. This model assumes permanent deformation of a ship hull.

However, the model developed in ETL 338 has significant limitations. First, the existing SDOF model does not account for the flexibility of the flotilla during impact on a navigation structure. This flexibility of a tow is accounted for by the lashings (or wires) that tie the flotilla together. The true system is a multi-degree-of-freedom (MDOF) system, as shown in Figure 2.

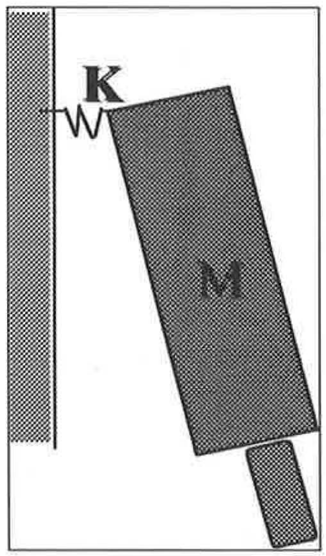

FIGURE 1 Single degree of freedom (SDOF) in ETL 338.

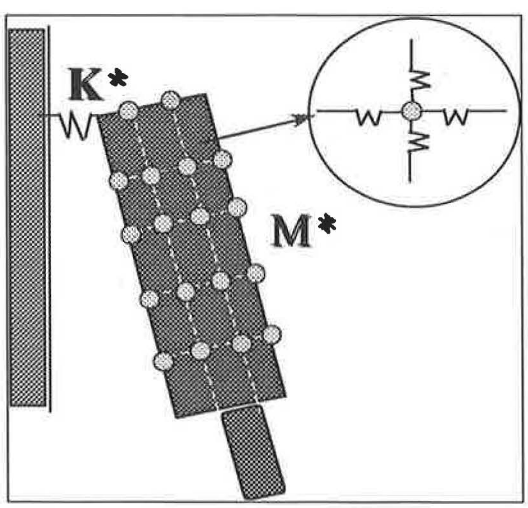

FIGURE 2 True MDOF barge system.

Second, the model is based on permanent deformations of the barge corner. These types of deformations are not typically the norm for inland waterway barges and are very rarely encountered on the inland waterway during most usual, and even most unusual, impact events. Third, the model also requires a correction to the stiffness function, based on the Minorsky coefficient for small angles (less than 2 degrees) and large angles (greater than 80 degrees). This correction has created a limited use of this model for the head-on impacts into bullnoses and protection cells at USACE facilities, as well as very careful interpretation of the resulting impact forces at small angles. Lastly, this model is based primarily on impact research for deep-draft vessels and has had no field verification or validation for typical inland waterway flotillas. These limitations of the model, combined with the consensus that this model produces very conservative design loads, are the prime reason why the USACE has made such a focused effort in performing both prototype and full-scale barge impact experiments.

PROTOTYPE BARGE IMPACT EXPERIMENTS

The prototype barge impact experiments were conducted on an old lock wall at Allegheny River Lock and Dam 2, in Pittsburgh, Pennsylvania. These experiments were termed "prototype" because this type of full-scale experiment using an inland waterway flotilla has never before been attempted. The goals for these prototype experiments were to learn how to quantify and measure barge impact forces, as well as understand the complexity of the barge-wall system during impact. The observations and results from these prototype experiments are discussed and documented further in Patev et al. [3].

These experiments utilized four standard (27 foot by 195 foot) open-hopper rake barges. The barges were drafting at 8 ½ feet and had a combined mass of around 4,000 short tons. The impact experiments were accomplished on a rigid massive concrete wall and on frictionless Ultra-High Molecular Weight (UHMW) plastic fenders. The UHMW fenders were used to investigate the redistribution of the barge energy and direction during impact. Thirty-six impact experiments, twenty-eight on the concrete and seven on the UHMW fenders, were successfully completed and documented.

The experiments utilized 15 different instrumentation devices, recorded on 28 channels on both the flotilla and land wall. The instrumentation included accelerometers and strain gauges on the lead corner barge, as well as clevis pin load cells spliced into the lashings. These clevis pin load cells measured the change in tensile force in the lashing parts upon impact. A multiunit Differential Global Positioning System was also utilized to measure the velocities (normal and tangential), impact angle, and rotation of the flotilla during impact. A high-speed camera (100 frames per second) and a videotape camera were set up to document the interaction of the barge-wall system upon impact. Overall, these experiments were very valuable in providing a better understanding of the dynamics of the barge-wall system and contributed vital data and knowledge that could be utilized for the full-scale barge impact experiments.

FULL-SCALE BARGE IMPACT EXPERIMENTS

The full-scale barge impact experiments were conducted on a lock wall at Robert C. Byrd Lock and Dam (Old Gallipolis Lock), in Gallipolis Ferry, West Virginia. The primary goal for these experiments was to measure the actual impact forces normal to the wall, using a load-measuring device. The focus of these experiments was to obtain and measure the baseline response of an inland waterway barge, quantify an MDOF system during impact, and investigate the use of energy-absorbing fenders. The observations and results from these full-scale experiments are discussed and documented further in Patev et al. [4].

The full-scale experiments used a fifteen-barge commercial flotilla. The barges were jumbo open- hopper rake barges (35 feet x 195 feet) and were ballasted with anthracite coal to a draft of 9 feet. The total mass of the flotilla was approximately 30,000 short tons. The use of the barges and a 2800-horsepower towboat, the MS Jeffery V. Raike, was arranged under a partnership agreement with American Electric Power River Transportation Division, of Lakin, West Virginia. A helper boat was also needed in case of emergency with the prime vessel or breakup of the flotilla during impact. The helper boat, an 1100-horsepower towboat, the MS Quaker State, was supplied by Kahawa River Towing, of Point Pleasant, West Virginia. Figure 3 shows the fifteen-barge tow and helper boat.

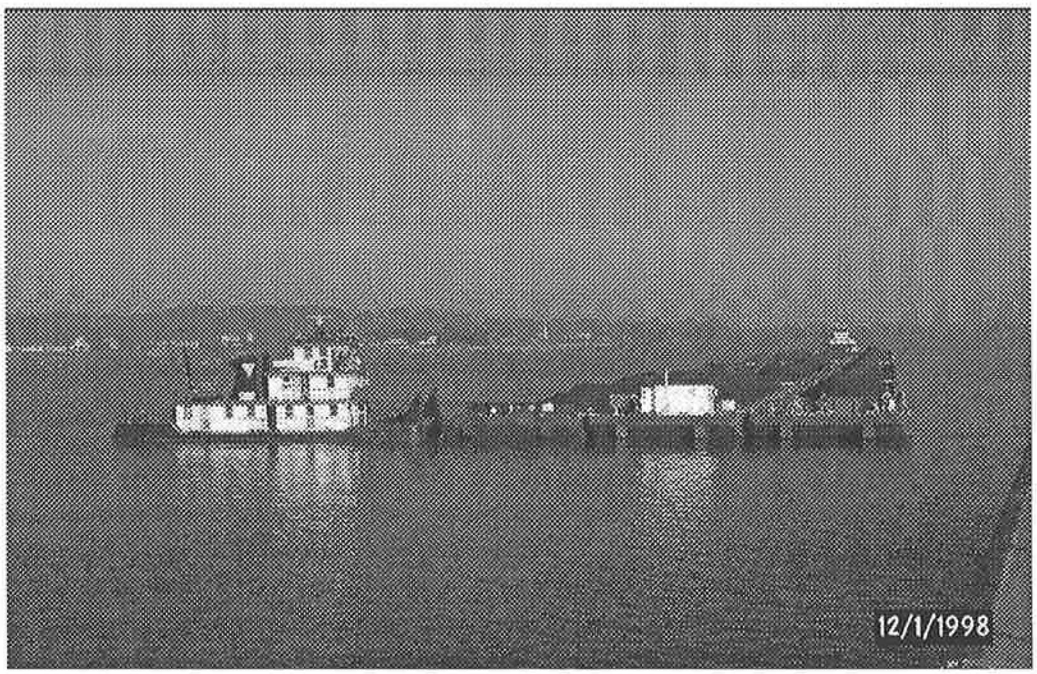

FIGURE 3 Fifteen-barge flotilla used for the full-scale barge impact experiments.

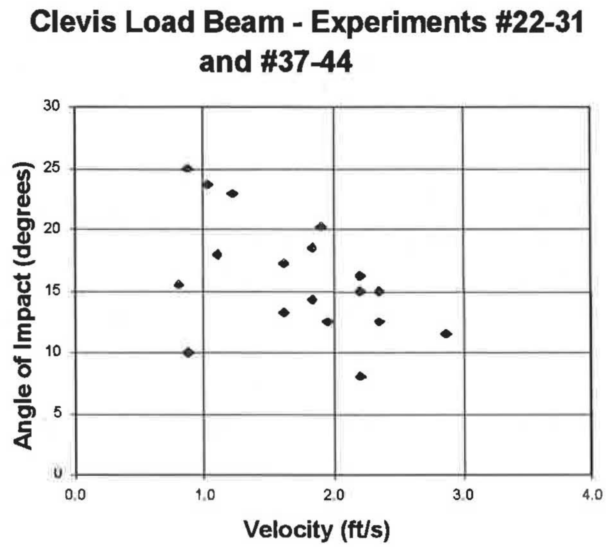

FIGURE 4 Example matrix for impact velocities and angles.

Forty-four impact experiments were successfully conducted on both the rigid concrete upper guide wall (baseline and load-measuring device) and the prototype fendering system (baseline and load-measuring device). A matrix of the required angles and velocities was assembled for the comparison between the baseline and load-measuring experiments on both the concrete and prototype fendering systems. This matrix was successfully filled for each impact case during the forty-four experiments. The final matrix contained angles of impact from 5 to 25 degrees, with velocities of 0.5 to 4 feet per second. An example matrix for velocities and angles for the load beam experiments is shown in Figure 4.

Similar instrumentation used during the prototype experiments was utilized for the full-scale experiments. This included accelerometers (over 12 locations on flotilla), strain gauges, and clevis pin load cells in the lashing parts. The instrumentation data were collected using over 80 channels of instrumentation on both the barge and lock wall. These experiments also utilized a DGPS system on the flotilla to measure the tow velocity, angle, and rotation during impact, as well as high-speed cameras to capture the barge-wall and barge-fender interaction.

In addition, new instrumentation was developed to measure the actual load normal to the barge and wall. This consisted of a load-measuring beam that had two clevis pin load cells capable of measuring up to 1200 kips of force. In addition, a system of PolyVinyl Di-Flouridene (PVDF) sensors was developed at the Waterways Experiment Station as part of a redundant load measurement system on the load beam. An example of the measured impact normal force versus velocity is shown in Figure 5. Additional results from these full-scale experiments are documented further in Patev et al. [4].

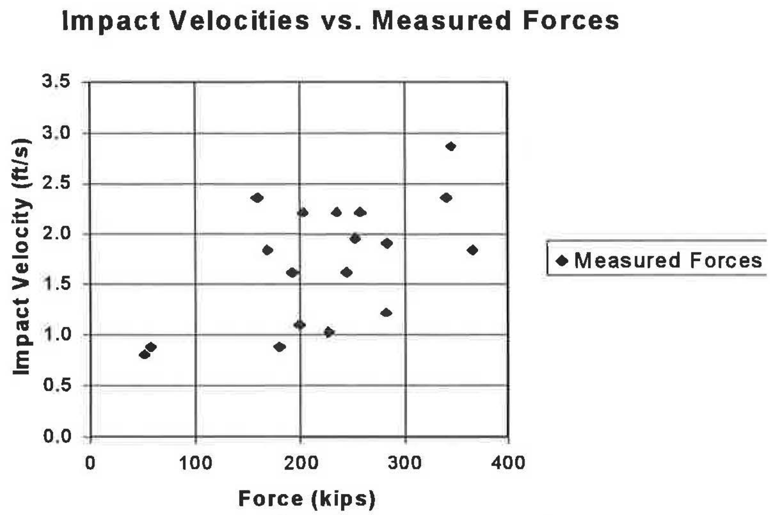

FIGURE 5 Example of measured loads versus impact velocities.

CONCLUSIONS

These full-scale experiments have been very valuable in defining and quantifying barge impact forces as well as documenting the barge-wall and barge-barge interactions during impacts. The information collected from these experiments will be extremely valuable in the verification of the existing SDOF model defined in ETL 388, as well as assisting with further numerical modeling efforts to better define the true MDOF system. These final results should better assist the USACE with the design of innovative structures for barge impact loads.

Additionally, since these full-scale barge impact experiments cover only the elastic range of the barge, these experiments have been very valuable in defining the instrumentation plan for experiments to determine the plastic range of inland waterway barges. These full-scale “crushing” experiments currently are being developed under the Innovations for Navigation Project R&D program at WES and will greatly assist with quantifying the actual crushing strength and performance of the corner and headlog of inland waterway barges.

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