TECHNOLOGY DIGEST
TD-12-010
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Redirection Concept to Protect Railroad Bridge Piers from Barge Impacts

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Summary

Texas Transportation Institute/Texas A&M College Station has developed a barge redirection system to protect railroad bridge piers. The prototype concept was developed under funding from the Association of American Railroads' (AAR) Affiliated Laboratory Strategic Research Initiative Program monitored by the AAR Technology Scanning Committee. The redirection system concept presented herein is simply an anchored barge placed near a bridge pier requiring protection. This redirecting barge can be moored into the riverbed using mooring chains and thus provide a soft response yet using similar inertia of the errant barge. The size and location of placement of the barge would be determined by simulating probable barge encroachment scenarios given site-specific constraints and relevant environmental data.

Bridges over navigational water are exposed to errant barge collisions. The bridge piers are not necessarily designed to withstand such a high kinetic energy impact exerted by the large mass of a barge. Although many protective devices are available and used to handle such impact events, many of them rely on limited energy absorption and bearing on a special structure or on the bridge pier itself. In addition to the safety concerns of a bridge pier impact, there are the additional concerns of long-term outages to repair the damage. Damage to a major river crossing bridge may hinder the ability of a railway to serve its customers for many months.

The finite element program LS-DYNA was used to evaluate the performance of the pier protection system through simulation. Six different impact cases were selected for simulation. These cases were based on the angle of encroachment of an errant barge and the point of impact on a redirecting barge. These initial collision simulations of the barges tested the feasibility of the proposed concept. In the simulations, site-specific restraints were not taken into account, but reasonable limits for barge velocity, barge draft, etc. were included. The simulation results are considered to be representative of actual barge-bridge protection crash behavior. The barge models were developed from typical barge dimensions. The barge simulations were correlated with full-scale testing. The bridge protection barge anchoring assumes rigid connections, which will make the predictions of forces more conservative than actual behavior.

In some of the collision simulations (i.e., frontal impact), the errant barge was rebounded from the redirection barge, and in other cases (i.e., side impacts) the errant barge was successfully redirected away. Overall, the simulations confirm the feasibility of the protection system concept with the conditions aforementioned. However, because of the generic assumptions of the initial simulation, more work is needed to understand the effects of river geometry, river velocity, and other restraints on this proposed redirection concept. Approval of such a pier protection system would be needed from the government agency responsible for maintaining each waterway for navigation.

INTRODUCTION

Impact loading events such as a ship or a barge colliding with a railroad bridge pier have both safety and economic consequences on the public and on the rail industry. The objective of this research is to develop redirection concepts to prevent or reduce damage to a bridge pier undergoing impact loading. Safety will be improved by adding a protective structure to bridge piers for bridges deemed at risk of being hit by a vessel.

Approximately 26,000 dry cargo barges, 3,000 tanker barges, and 1,200 towboats operate today on 25,000 miles of inland waterways in the United States. A barge tow consisting of one tug and 15 attached barges has a 22,500-ton or 800,000-bushel capacity, the equivalent of 188 train cars or 726 semitrucks. The 1,200-foot-long barge tow carries as much coal or grain as 1.9 miles of trains or 23.8 miles of semitrucks. Inland barge tows carry approximately 13 percent of the nation's freight.

These barges/flotillas can pose a risk to the integrity of bridges spanning inland navigable waterways. Impact events involving vessels against bridge piers have caused significant damage and loss of life all around the world. From 1960 to 1998, 30 major bridge collapses occurred worldwide because of ship collisions, resulting in 321 fatalities.[1] Half of these 30 bridge collapses occurred in the United States.

On Sept. 14, 2003, the M/V Brownwater V departed Brownsville, Texas, pushing four loaded hopper barges ahead of it, lined up single file in a straight line. At midnight, the pilot took the helm. The 800-foot tow successfully cleared the Long Island swing bridge at 1:45 a.m. on Sept. 15, but 15 minutes later it struck the Queen Isabella Causeway Bridge approximately 375 feet west of the channel almost head-on. The collision caused two 80-foot sections of the bridge to collapse. Figure 1 shows the bridge after the collision.

Figure 1. Queen Isabella Causeway (Texas)

Vessel collision accidents with bridges do not necessarily result in collapse of the structure, but can still cause significant damage. A study of river towboat collisions with bridges in U.S. inland waterways from 1970 to 1974 reported 811 accidents with bridges with a cost of $23 million in damages and 14 fatalities.[1] On average, 35 vessel collision incidents are reported every day to U.S. Coast Guard Headquarters in Washington, D.C.[1]

U.S. Coast Guard and American Waterways Operators identified 2,692 barge–bridge collisions in the United States between 1992 and 2001 and reported 900 bridges (34 percent of collisions) requiring alteration, replacement, etc.[2,3]

A variety of factors can affect a vessel-pier bridge impact event including the following:[1]

- Waterway geometry, water stage fluctuations, current speeds
- Vessel geometry, speed, and loading conditions
- Weather conditions
- Navigation procedures, hazards to navigation
- Bridge location, geometry, size, and stiffness
- Bridge protection systems

Barge Redirecting Concept

The proposed concept is to place an anchored barge near a bridge pier requiring protection. The size and location of placement of the barge is determined by simulating probable barge encroachment scenarios given site-specific constraints and relevant environmental data.

Initial impact simulations of the barges tested the feasibility of the proposed concept. In the simulations, site-specific restraints were not taken into account, but reasonable limits for barge velocity, barge draft, etc. were included. The necessary components of the simulation were the impacting (errant) barge, the redirecting (protection) barge, and the mooring chains that are used to anchor the redirection barge. (Once the initial simulations are completed and reviewed, the conditions of the simulation can be adjusted easily for site-specific information.)

The two barges used in the simulation were developed from dimensions provided by a previously conducted test by the Florida Department of Transportation (FDOT).[4] The structural bracing within the simulation model was simplified from the FDOT drawings to reduce the overall time of the barge impact simulation. The overall dimensions for the impacting barge were 151 by 50 by 12.5 feet with a weight of 1,088,000 pounds. Figure 2 shows the simulation barge.

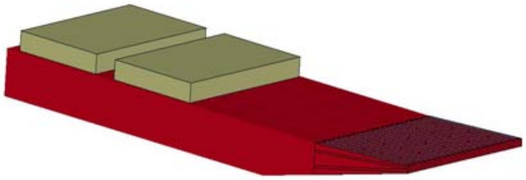

Figure 2. Impacting Barge Simulation Model

The redirecting barge was created by flipping over the impacting barge and removing its payload. The sides of the barge were flared out to a 45-degree angle from the vertical to allow for better utilization of water vertical resistance as it tries to lift the impacting barge. The overall dimensions for the redirecting barge were 131 by 59 by 12.5 feet with a weight of 667,000 pounds. Figure 3 shows the redirecting barge.

Figure 3. Redirecting Barge Simulation Model

To simulate the buoyancy effect of water on the barges, 66 and 78 nonlinear springs, spaced appropriately, were used on the impacting and redirection barges, respectively. These submerged springs were kept vertical beneath the barges by constraining their rotation in all directions. The stiffness of each buoyancy spring is the product of the tributary area associated with each spring and the density of water. Nonlinear curves were applied to the springs with this derived stiffness value, and all tensile forces applied to the spring resulted in a force of zero, or zero stiffness.

To account for the draft of the barge, initial offsets had to be applied to the springs. The total weight of the barge was divided by the sum of the effective stiffness to get the initial displacement or draft. The impacting barge had an initial draft of 3.5 feet, and the redirecting barge had a draft of 1.5 feet. Dynamic effects were tested with an allowable ±3 inches of vertical barge movement.

Different mooring chain sizes and layouts were designed for the necessary load transferred from the barge impact to the ground. The final design chosen for mooring chains consisted of seven rows of five chains (along the length of the barge) and five rows of five chains (along the width) each 25-feet-long. Figure 4 shows this configuration. The chain chosen for simulation was 1 ¾-inch diameter open medium link chain with 10 links in each chain. This chain has a proof load of 80,000 pounds and a breaking load of 161,000 pounds.

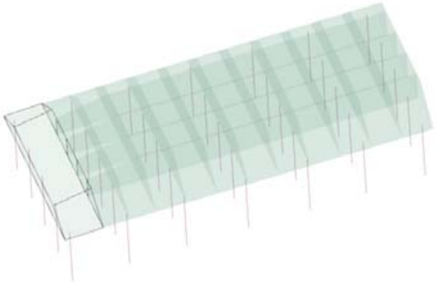

Figure 4. Mooring Chain Layout

In creating the nonlinear loading curve for the chain, any compressive displacement was assumed to yield a force of zero. In addition, each of the 10 chain link sections per total length of chain was assigned zero force for the first 2 inches of displacement to allow play in the links during tensioning. After this point, the chain starts to apply a linear tensile force equal to a predetermined chain stiffness value, K. Although some of the forces experienced in the simulation are greater than the breaking load, the simulation neglected the fact that the soil or footing will yield under impact, and the full force will not be taken through the chains.

The barge impact simulation cases were defined by the impact location on the redirecting barge and the impact angle of the impacting barge with respect to the length of the redirecting barge. The impacting barge has a defined speed of 5 mph, and the redirecting barge begins from rest. The simulation cases were as follows:

Case 1. Location: Front Corner, 0-degree angle

Case 2. Location: Front Corner, 15-degree angle

Case 3. Location: Front Corner, 25-degree angle

Case 4. Location: Side (Midway), 15-degree angle

Case 5. Location: Side (Midway), 25-degree angle

Case 6. Location: Side (Quarter Length), 25-degree angle

Figure 5 shows barge impact Case 6.

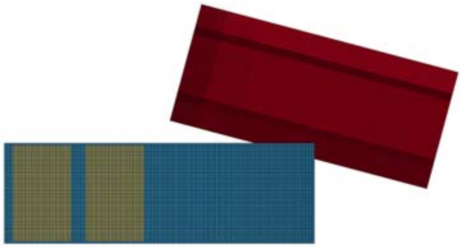

Figure 5. Barge Impact — Case 6

From the results of the simulations, each case showed the redirecting barge successfully redirected (i.e., moved downstream avoiding the protected pier) or rebounded (i.e., moved upstream from the protected pier) the impacting barge after contact. In Cases 1 through 3 the impacting barge rebounded after impact, and in Cases 4 through 6 the impacting barge redirected away from the redirecting barge at angles between 20 to 30 degrees from its initial position.

Figure 6 shows the path the deflected barge moved (from left to right) from the point of impact to its current position for Case 6.

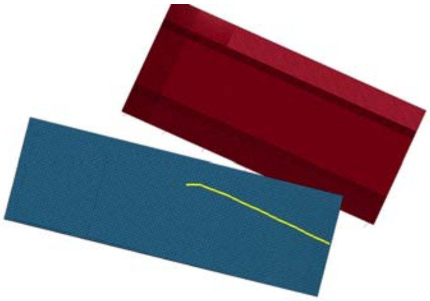

Figure 6. Point Trace of Case 6 Simulation

During all of the impact cases, the maximum displacement of the redirecting barge from its original position was approximately 12.6 feet, which is the key value to determine the location around the bridge where the pier barge needs to be placed. To avoid collision with the bridge pier during impact, the redirecting barge needs to be placed at the maximum displacement it could possibly exhibit. However, if that value for displacement is too high, then river width and the window of contact for errant barges need to be considered.

For all simulation cases where the impacting barge has rebounded after impact, the maximum axial force in the mooring chains easily reaches the proof load (80,000 pounds) of the 1¾-inch mooring chains. However, the riverbed within the simulation is defined as a rigid body, which means the soil of the riverbed should absorb some of the axial forces from the mooring chain due to weakness of the soil under tensional forces. Therefore, the maximum force values of the simulation may not reflect the values found in reality.

Overall, the simulations show that the barge protection concept is feasible, and further research on river conditions, river and bridge geometry, etc. can be continued. For example, if a bridge had more than one pier, the errant barge could potentially be redirected from one pier by the protection system into the second pier. So, it would be necessary to examine the spacing of the bridge piers and conduct a study on the exit angle of the errant barge, which would then be used to determine the appropriate placement of the protection system.

CONCLUSION

A novel yet simple concept of protecting bridge piers from errant barge impact is presented. The concept is simply to place an existing barge with mooring chains to redirect an errant barge from a path toward a bridge pier or other navigational infrastructure. Finite element simulation was used to verify that this concept has the desired functionality. The simplicity of the concept makes it easy to construct and remove if needed, and it does not require additional expensive structural elements to be implemented.

In addition, the simulation showed that this concept would work at different impact angles and positions on the redirecting barge. However, because of the simplicity of the initial simulation, more work is needed to understand the effects of river geometry, river velocity, flotilla, and other variables that were not researched in this feasibility study. Approval of such a pier protection system would be needed from the government agency responsible for maintaining each waterway for navigation.

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