Dynamic Effects of Superstructure Mass during Barge Collisions with Bridges

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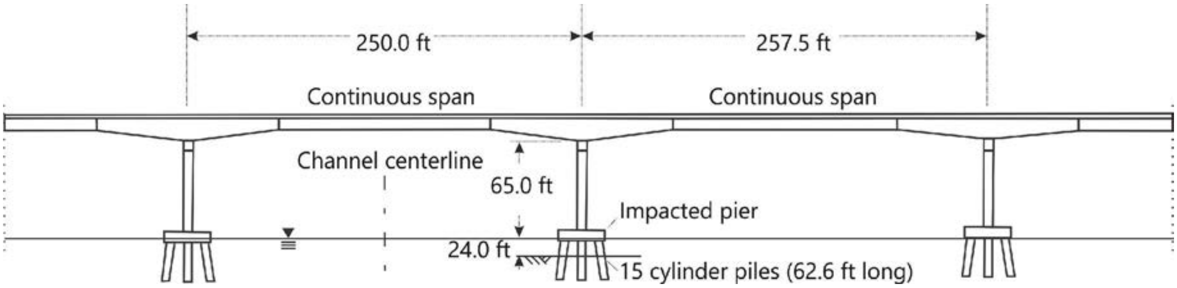
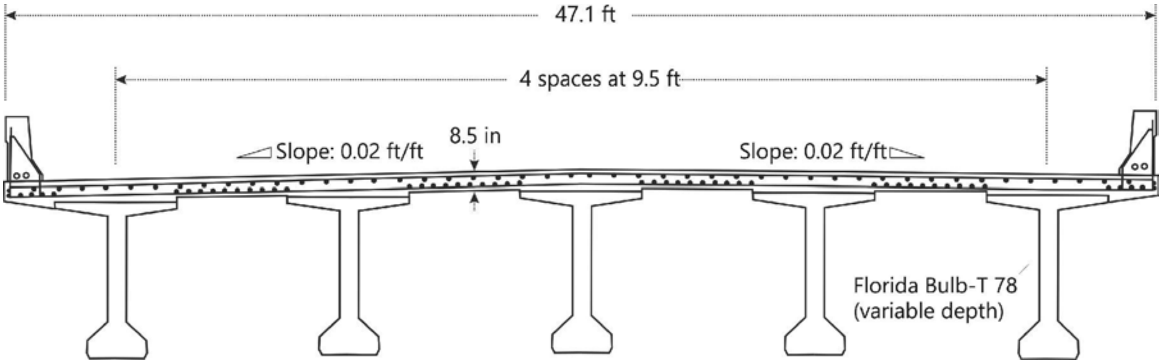


Elevation of channel pier and adjacent spans used in model for barge-bridge collision scenario. All Figures: Bridge Software Institute.



Typical section of superstructure.

During barge-bridge collision events, the superstructure mass of concrete bridges can influence internal forces generated throughout underlying substructures. This article presents a method for dynamically quantifying collision forces and structural demands and applies that method to the analysis of an in-service coastal bridge. The method and tools described here can help engineers in designing concrete bridges that span navigable waterways.

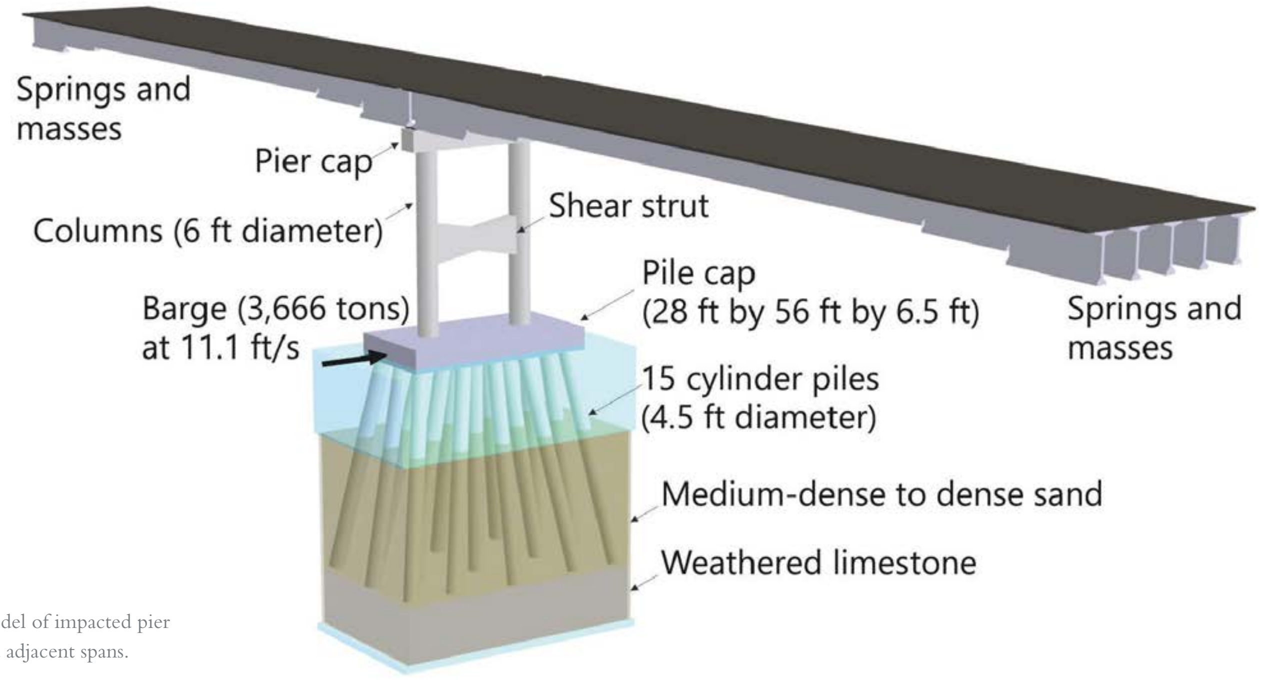
Modeling Barge-Bridge Impact

The St. George Island Bridge is a coastal bridge spanning Apalachicola Bay in northwestern Florida. The southern channel pier supports adjacent 250 ft and 257.5 ft spans. The post-tensioned Florida bulb-tee girders vary in depth from 6.5 ft at drop-in locations to 12 ft above the pier. Both the girders and the 47.1-ft-wide deck are continuous across the pier cap. The five evenly spaced girders each rest on two elastomeric bearings that straddle a cast-in-place shear pin.

For an impact scenario using this structure, a finite-element model of the southern channel pier and adjacent spans (that is, "one-pier, two-span" model) is developed using FB-MultiPier software. In this type of model, all bridge portions more than a span length away from the impacted pier are simplified as springs and lumped masses (spine model), which are positioned at the far ends of the spans. Spring and mass quantities are automatically computed by the program based on a larger bridge model that includes several piers and spans. The simplified "one-pier, two-span" approach allows collision-related design forces to be efficiently computed within a few minutes using ordinary computers, and the accuracy of this method has been verified against more-complex multiple-pier, multiple-span bridge models.[1]

The channel pier contains two 6-ft-diameter pier columns spaced 30 ft apart, which are braced mid-height by a 6-ft-deep shear strut. The 52-ft-long columns are supported at the waterline by a 6.5-ft-thick pile cap. The foundation consists of 4.5-ft-diameter prestressed concrete cylinder piles (14 battered and one plumb) with 10-ft-long reinforced-concrete pile-top plugs. Each of the 62.6-ft-long piles extends through medium-dense to dense sand, and the pile tips bear upon a weathered limestone layer.

Based on waterway traffic local to Apalachicola Bay, a representative collision scenario is formed. It consists of a 3666 ton barge/tug traveling at 6.6 knots (11.1 ft/sec) and striking the 28-ft-wide waterline footing head-on. FB-MultiPier is used to analyze the collision scenario by specifying vessel weight, impact velocity, and impact location, and allowing the software to automatically assign a nonlinear stiffness to represent the impacting barge bow. Both impact forces and bridge internal demands (shears and moments) are computed using this analysis approach, which has been validated against



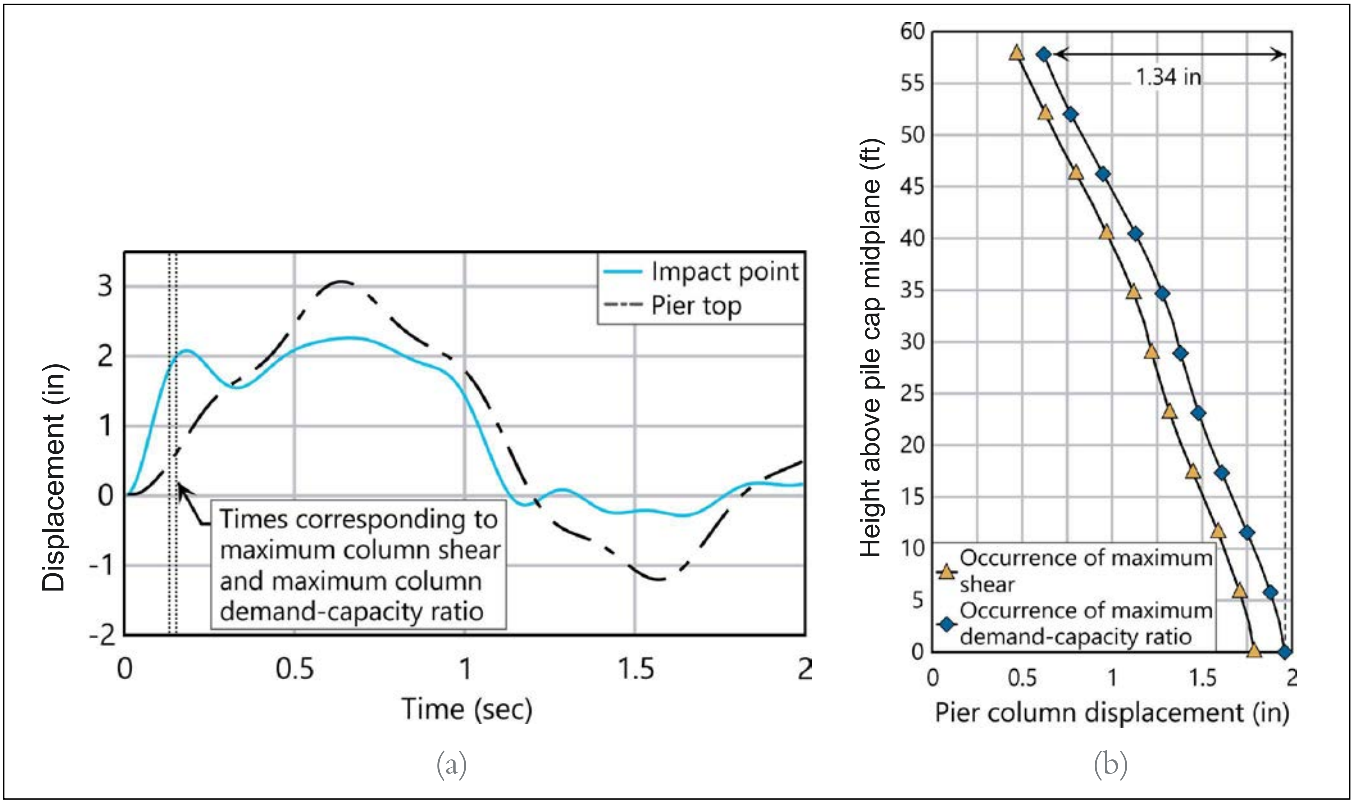
Model of impacted pier and adjacent spans.

full-scale experiments conducted in 2004 on the old St. George Island Bridge before it was demolished.[1,2]

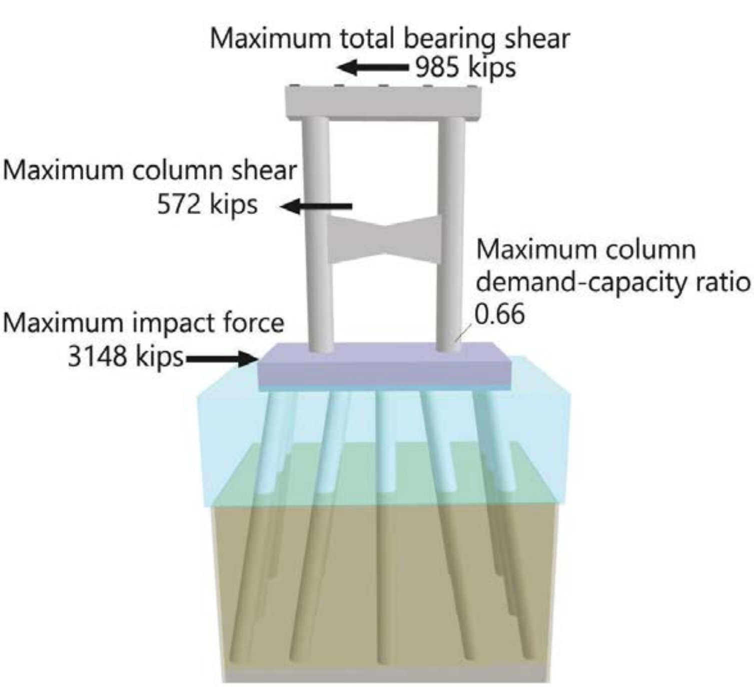
Barge-Bridge Collision Analysis

Using a typical desktop computer, calculation of time-histories of displacements at the impact location and pier top, along with dynamic design forces, is achieved in less than 10 minutes. Analysis results show that primary contact between the barge and pier lasts approximately 1.2 seconds, as indicated by the abrupt reduction in pier column displacements just after 1 second. The maximum impact force of 3148 kip is attained within 0.1 seconds and sustained for an additional 0.9 seconds, while maximum column demands (shear and demand-capacity ratio for axial-moment interaction) occur relatively early, at approximately 0.2 seconds. This phenomenon is due to dynamic amplification of the pier columns' internal forces and is attributable to the mass (inertia) of the concrete superstructure.

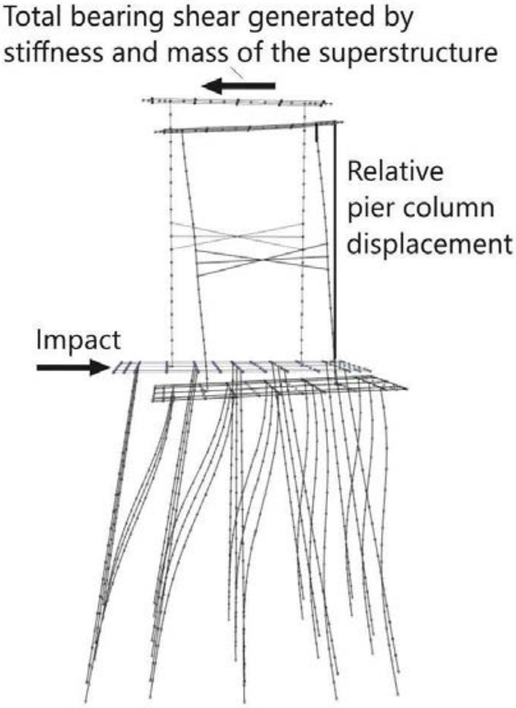
At each point in time, the difference between displacements at the impact point and pier top produces lateral



Dynamic response in the pier columns: (a) Time-histories of displacements at the point of impact and at the pier top; (b) Profiles of column displacements when maximum column shear and maximum column demand-capacity ratio occur.



Maximum internal forces and demands after dynamic amplification.



Deformed shape when maximum demands occur (at maximum differential displacement between bottom of column and top of column).

(flexural) deformation in the columns. When relative lateral deformations reach a temporary maximum (1.34 in.) at approximately 0.1 seconds, internal demands are likewise at peak levels. From the onset of impact to approximately 0.1 seconds, displacement at the impact location increases more rapidly than displacement at the pier top. Motion of the pier top is temporarily prevented (restrained) by both the stiffness and mass of the "one-pier, two-span" concrete superstructure.

The phenomenon of mass-related inertial restraint produces a temporary condition in which displacement at the impact location is larger than that at the pier top. Amplified internal forces corresponding to this condition typically produce maximum structural demands. Importantly, the mass of the concrete superstructure influences both the collision force, 3148 kip, and the structural demand, 985 kip maximum total shear at the superstructure bearings, or 31% of maximum impact force. If the same analysis is carried out with the superstructure stiffness still present, but the superstructure weight (10,783 kip) reduced to near zero, the maximum total shear at the superstructure bearings falls to 656 kip, or 21% of the maximum impact force. Pile shears will then increase accordingly. In most common pier configurations, superstructure mass will draw dynamic impact forces upward toward the superstructure, thus increasing column and bearing design forces, but reducing foundation design forces. Since superstructure mass, which varies from bridge to bridge, influences the proportions of impact force that flow upward (to the bearings) and downward (to the foundation), it is recommended that this mass be included in the determination of controlling design forces for bearings, columns, and foundation elements. Inclusion of superstructure mass can be accomplished either using an efficient dynamic approach of the type described in this article, or using more simplified, but conservative, approximations.

Conclusion

Dynamic barge-bridge collision analysis results demonstrate that both superstructure mass and superstructure stiffness influence the distribution of barge impact forces upward to the bearings and downward to the foundation. Additionally, dynamic amplifications of column forces highlight the importance of incorporating influences such as superstructure mass into bridge design processes. Accounting for the flow of dynamic impact forces through piles, columns, and bearings, including the effect of the mass and stiffness of the superstructure, is an important design consideration for potential collision events.

References

1. Consolazio, G. R., and M. T. Davidson. 2008. "Simplified Dynamic Barge Collision Analysis for Bridge Design." *Transportation Research Record* 2050 (1): 13–25.
2. Consolazio, G. R., R. A. Cook, M. C. McVay, D. R. Cowan, A. E. Biggs, and L. Bui. 2006. "Barge Impact Testing of the St. George Island Causeway Bridge Phase III: Physical Testing and Data Interpretation." Structures Research Report No. 26868, Engineering and Industrial Experiment Station, University of Florida, Gainesville.

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