Design of Energy Absorbing Structures for Barge Collision Protection of Bridge Piers

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Summary

The design of bridge structures against barge collision generally relies on the assumption that flexible protection systems absorb the kinetic energy of the vessels by means of elastoplastic deformation. For large tows, however, protection systems become massive structures with considerable stiffness and yield loads that may become larger than that of the barge bow.

The present paper shows a study of a flexible protection system for a bridge in Argentina, consisting of groups of drilled shafts. The barge tow is modeled in the analyses by means of a multiple degree of freedom non linear model, whereas the protection structure is represented by its equivalent load deflection curve and mass, obtained in a separate nonlinear pushover analysis.

Results show that there are several sources of energy absorption, namely: elastoplastic deformation of impacted structure, yielding of barge bow, and friction. The analyses results show how different components of energy absorption are affected by the stiffness and yield load of the impacted structure.

Keywords: barge, bridge, collision, impact, vessel.

1. Energy demands

The energy demands are given by the kinetic energy of the barge tow (plus added hydrodynamic mass, e.g., AASHTO 2005) that is expected to impact the protection structures. For the present study, the maximum energy demand considered corresponds to a 4x4 barge tow at a velocity of 5.3 m/sec (downstream), W = 403 MNm. An intermediate energy demand of W = 155 MNm, due to a 4x4 tow at a velocity of 3.3 m/sec (upstream), and a minimum of W = 71 MNm, due to a single row of 4 barges at a velocity of 4.5 m/sec (downward), are also considered in the analyses.

Table 1: Number of shafts for each scenario

Total Energy (MNm)	Effective Energy (MNm)	Shafts needed	Shafts Adopted
71	71	3.5	3.0
155	116	5.8	6.0
403	302	15.0	15.0

It is seen in Table 1 that the number of shafts proposed for the low energy demand scenario appears to be less than what would be required in order to fully absorb the energy demand. In what follows, actual energy absorption analyses are carried out in order to evaluate the mechanisms involved in the energy absorption process.

2. Dynamic model

The protection structure is modeled by means of a nonlinear spring, which shows an elastic unloading behavior defined by the initial stiffness of the load-deflection curve. The inertia of the protection structure is modeled as lumped mass, defined as the total cap mass. Energy absorption in the protection structure is given by the area under the load deflection curve, where it is noted that a small portion of the total energy is recoverable through the unloading curve.

Barge-structure interaction is modeled by means of a nonlinear representation of the load-deflection behavior of the protection structure, the load-deformation behavior of the barge bow that becomes in contact with the structure upon collision, and the two dimensional interaction within the barge tow (Luperi et al. 2011).

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3. Results

3.1 Flexible structure

As the yield load of the structure is less than the yield load of the barge bow, it could be concluded that, from a static point of view, the barge bow would not yield, whereas energy absorption would only take place in the protection structure. Nevertheless, the inertia of the cap plays a role in the force balance, and the actual forces can be evaluated by means of the dynamic model.

Dynamic model results indicate that there is a 14% energy absorption in the barge bows, as the reaction load of the structure is increased above its yield load due to the inertia of the pile cap.

3.2 Intermediate structure

The yield load of the barge bows for this case is greater than the yield load of the structure. From a static point of view, it could be concluded that the barge bows would not yield, and that the energy dissipation would take place in the protection structure. However, as for the case of 3 shafts, the inertia of the pile cap tends to increase the interaction forces, and the actual behaviour is represented by means of the nonlinear dynamic model.

It is seen that the barge tow breaks away and the portion of the kinetic energy which is not absorbed is 44.5 MNm (29%), which is consistent with the preliminary assumptions in Table 1. The remaining 110.5 MNm are absorbed in plastic work at barge bow, 12.8 MNm (8%), plastic work at the protection structure, 80.5 MNm (52%), friction between barges, cap, and plastic work of lashings, 17.2 MNm (11%). Hence, it is seen that there are several energy absorption components, which can be evaluated through dynamic analyses.

3.3 Rigid structure

The yield load of the structure for this case exceeds the yield load of the bows by about a factor of two. Hence, from a static point of view, the protection structure would not undergo significant yielding, whereas the energy absorption would mainly take place in the barge bows.

Dynamic analysis results show that the residual kinetic energy after the impact yields 114.0 MNm (28%), hence the energy to be absorbed is 289.0 MNm, which is consistent with the simplified assumption in Table 1. In this case, the structure only absorbs 2% of the kinetic energy. Maximum loads on the shafts, however, are 68% greater than the yield load of the barge bows, due to dynamic effects.

4. Conclusions

It is seen that there is a significant contribution of energy absorption by the barges, even for cases where the yield load of the structure is less than the yield load of the barge bows. Dynamic effects tend to increase the force on the barge above the yield load of the structure due to the inertia of the cap. Dynamic effects also affect the behavior of the impacted structure, by increasing the maximum reaction loads above the yield load of the barge tow.

It is seen that there is a transition in the energy absorption mechanisms from a situation where energy is mostly absorbed by the structure (84% for flexible structure) to a case where most of the energy is dissipated in the barge bows through both friction and plastic work (66% of total for a rigid structure).

For a rigid structure (i.e., yield load of structure significantly greater than barge bow), the maximum reaction is 64% larger than the yield load of the barge bow. This is of particular importance for design of structures against impact of barge flotillas. It should be noted that AASHTO LRFD (2005) does not explicitly indicate impact factors for the loads developed at the barge bows.

5. References

AASHTO (2005), "AASHTO LRFD BRIDGE DESIGN SPECIFICATION"

Luperi, F. J., Pinto, F. y Prato C. A. (2011); "Modelación de Impacto de Conjuntos de Barcazas Contra Pilas de Puentes". Memorias del ENIEF 2011, Vol XXX, págs. 1221-1237. Argentina.