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"Criteria for the Design of Bridge Fender Systems", Wm.B. Conway,
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CRITERIA FOR THE DESIGN OF BRIDGE FENDER SYSTEMS

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ABSTRACT

The large number of ship and barge collisions with bridges in which existing fender systems failed to provide suitable protection necessitates a reevaluation of our approach to pier protection design. This paper presents an approach philosopy to the selection and design of an appropriate type of fender and pier protection structure. A distinction is made between protection against major vessel collisions where repairable damage to the fender and the pier protection structure is acceptable and protection against minor vessel collisions which should not result in serious damage at each occurrence. Distinction is also made between fixed and movable bridge protection.

INTRODUCTION

In the last decade the number and cost of vessel/bridge accidents has shown a marked increase. Significant efforts have been made to investigate vessel collisions and provide guidelines and standards for their prevention and mitigation. In 1983 a "Committee on Ship-Bridge Collisions" appointed by the Marine Board of the National Research Council, Washington, D.C. [1] studied the causes and the consequences of vessel collisions with bridges spanning navigable coastal waters in the United States. The committee has identified the need for developing uniform standards for the design and construction of bridges to resist vessel collisions and made several recommendations for further investigations. Results of studies on ship-bridge collisions performed all over the world were presented and discussed at the International Association for Bridge and Structural Engineering (IABSE) "1983 Colloquium on Ship Collisions with Bridges and Offshore Structures" held in Copenhagen, Denmark [2]. In the United States, criteria for design against ship collision was developed for several specific bridge projects, as well as at a state level [3]. Design specifications addressing ship collision at a national level have recently been developed for highway bridges [4], and submitted to the American Assocation of State Highway and Transportation Officials (AASHTO) for adoption. At present, guidelines for the design of bridges and pier protection structures against vessel collision are available. They are mainly intended to ensure bridge survival in cases of low probability, major vessel (high energy) collisions. A major collision usually involves plastification of the vessel structure. Most vessel collisions, however, are minor (low energy) and guidelines for minimizing the damage to the vessel and the bridge structure from such collisions are also needed. Provisions for minor vessel collisions must ensure the "serviceability" of the bridge and bridge protection system while the design for major ship collision is intended to ensure bridge integrity during catastrophic vessel collisions. The most common protection against minor vessel collisions is a fender system. This paper presents an approach philosophy to fender design.

DESIGN FOR VESSEL COLLISION - CURRENT PRACTICE

The measures employed today against vessel collision include measures for reducing the risk of collision and measures designed to reduce the consequences of a collision if it occurs. The risk of vessel collision depends on the geometry of the waterway, the location of the bridge and its geometric layout, the type and volume of vessel traffic, the navigational conditions and the provision of aids to navigation and collision warning systems. The consequences of vessel collision are related to the design of the bridge substructure and superstructure. In order to ensure the integrity of the substructure, the following are frequently used:

- o design of bridge piers to withstand collision loads.
- o provision of an independent pier protection structure, also designed against ship collision.
- o provision of a protection system integral with the bridge pier which, together with the pier structure, is designed to resist collision loads.

Current practice for the design of unprotected bridge piers with respect to vessel collision is to select a design vessel and a collision load associated with that vessel [3, 4]. The selection of a design vessel is usually based on a risk assessment model and an "acceptable" probability value of bridge service interruption. The collision loads recommended for design assume head-on collision with an infinitely rigid pier. They are representative of the forces involved in crushing the bow of the design vessel considered. By using these loads in design we ensure that the pier can survive the rare event of a major ship collision.

The consequences of ship collision with a bridge substructure can be reduced by increasing the lateral resistance, providing measures to prevent a span from falling off its bearings and providing adequate structural redundancy. However, the most effective way to ensure the structural integrity of the superstructure is to prevent vessels from reaching it.

PIER PROTECTION SYSTEMS

A wide variety of pier protection systems are used today with various degrees of efficiency. Several types of protective systems have been presented and evaluated in [2, 3, 4]. The American Railway Engineering Association Manual [5] covers design, construction, maintenance and inspection of protective systems for railroad bridges. The most commonly used independent pier protection structures include pile supported systems, dolphins and protective islands. These systems are designed to absorb the collision energy of the design vessel used and stop the vessel before it reaches the pier. The collision energies involved are quite high, and, in the most cases pile supported systems can only provide limited protection. The protection systems which are integral with the bridge piers may consist of steel multi-cell buffers, concrete box buffers or rubber fenders. These systems are designed to absorb part of the impact energy of the design vessel through elastic deformation (rubber fenders) or crushing (concrete box and steel multi-cell buffers) while reducing the force exerted on the pier to acceptable levels. The geometry of the pier and the pier protection must be related to the geometry of the vessels using the particular waterway. The bow overhang at the elevation of the deck, for example, must be prevented from reaching vulnerable bridge elements.

The choice of an appropriate fender protection system must consider factors such as cost, available space, soil conditions, waterway characteristics, vessel traffic and environmental protection requirements. Most pier protection structures are allowed to suffer damage during a major ship collision. The damaged condition of the structure and its repair must be considered at the design stage and during construction. Design weak points ("structural fuses") should be provided so that the extent of damage and the costs of repair can be minimized.

DESIGN FOR MINOR SHIP COLLISIONS

Minor (low energy) collisions are quite frequent. They may result from small vessels hitting the bridge pier or protection structure at low speeds, slow sideways movements of vessels out of control, eccentric impacts at small angles or even barge tows trying to realign by pivoting against the pier protection. Fender systems must be provided and designed so that minor collisions will not damage the vessel, the bridge pier or its protection structure.

FENDER SYSTEMS

Fendering is the most common protective device. Fenders were initially developed for the protection of ships and wharves during mooring operations and designed to remain in the elastic range. They can be attached to the surface of the pier, the surface of an independent protective structure, the surface of a protective structure attached to the pier or on a pile supported system. The materials used are primarily timber and solid rubber.

Fender systems are provided in order to:

- reduce localized damage to the pier or the protection system attached to the pier, such as spalling of concrete surfaces and exposure of reinforcing steel.
- limit damage to vessels in cases of minor collisions.
- prevent sparking upon vessel impacts.
- help reduce vessel collision loads.
- help redirect vessels.

These functions must be clearly defined and addressed both during the design and the construction phase. Fenders shall have sufficient surface area so that the pressures developed during vessel impact will not result in damage to the pier or the pier protection surface, as well as to the vessel's hull. The hull of a vessel is stiffened by longitudinal and transverse ribs. Its strength is determined by the strength of these ribs and their location. In general, the smaller the vessel, the higher the strength of its hull. It is recommended that for minor collisions the resulting pressure be limited to a value between 0.06 ksi to 0.10 ksi depending on the size and the type of the typical vessel considered. Fenders shall be made of material which will not cause sparks during contact with the vessel. Also, they shall be placed so that the hull or other steel parts of the vessel will be prevented from making contact with the bridge structure and causing sparking. The geometry of the vessels (including hull curvatures) in the particular waterway must be taken into account. Data on vessel dimensions may be found in [4]. The surface of the fender must have a low coefficient of friction, so that the loads resulting from eccentric impacts will be reduced. Figure 1 shows the effect of the coefficient of friction on the collision energy transferred to the fender. Using a fender face made of high molecular weight polyethylene, a coefficient of friction (fender face vs. steel) of 0.20 may be obtained.

The shape of the fender arrangement mounted on a pier or pier protection structure shall be such that it could deviate vessels from head-on collision.

Pile supported fenders must be strong in both the transverse and the longitudinal direction in order to be able to redirect vessels approaching at low angles. Similarly to highway traffic barriers, the fender units must have continuity and strength in the longitudinal direction. The beginning and the end of the pile supported fender system must have enough strength to resist the longitudinal reactions at the ends of the fender units during the redirection of the vessel. A detailed review and calculation procedures for pile supported fender systems may be found in [6]. The selection of a typical vessel, approach angle and speed for the analysis must take into account vessel traffic characteristics, existing navigation conditions, weather conditions, geometric layout of the bridge and of the waterway, and the history of vessel collisions at the particular location. The impact scenarios to be investigated shall be based on "most likely" conditions. During minor ship collisions the fenders must remain in the elastic range. Their design shall be such that they could be fast and easily replaceable in case more severe collisions occur. The time for fender repairs must be kept to a minimum since accidents can occur during that time. In order to achieve this, fenders shall be modularized as much as possible.

The design of fenders for movable bridges must receive special attention. Movable bridges are inherently more susceptible to collision damage. Both the risk and the consequences of vessel collision with movable bridges are higher. The superstructure of movable bridges is more exposed to vessel collision than the superstructure of fixed bridges, which provides permanent vertical clearance to vessel traffic. Also, the horizontal clearance of movable bridges is generally smaller than that of fixed bridges. The human factor involved in operating a movable bridge also contributes to the increased risk of collision. Even minor collisions with the piers of a movable bridge may cause jamming or failure of mechanical, hydraulic, or electrical systems and result in interruption of service. The protection system of a movable bridge must prevent vessels from reaching the piers or the bridge superstructure. When determining the location of the protection system, taking into account the actual geometry of the vessels in the particular waterway is of utmost importance. When the protection system cannot prevent contact between the vessel and the pier, the dynamic effects resulting from such a collision must be investigated. A simple model for the analysis of dynamic effects involved in vessel collision is described in [8]. Additional guidelines for movable bridge protection may be found in [4].

SUMMARY

A distinction has been made in this paper between protective structures and fender systems. Protective structures are designed for major vessel collisions and are usually allowed to undergo significant but controlled damage. Fender systems are provided to protect both the ship and the bridge or its protective structure. They must be designed to survive minor vessel collisions with no need for repairs. General criteria for the design of fender systems has been provided.

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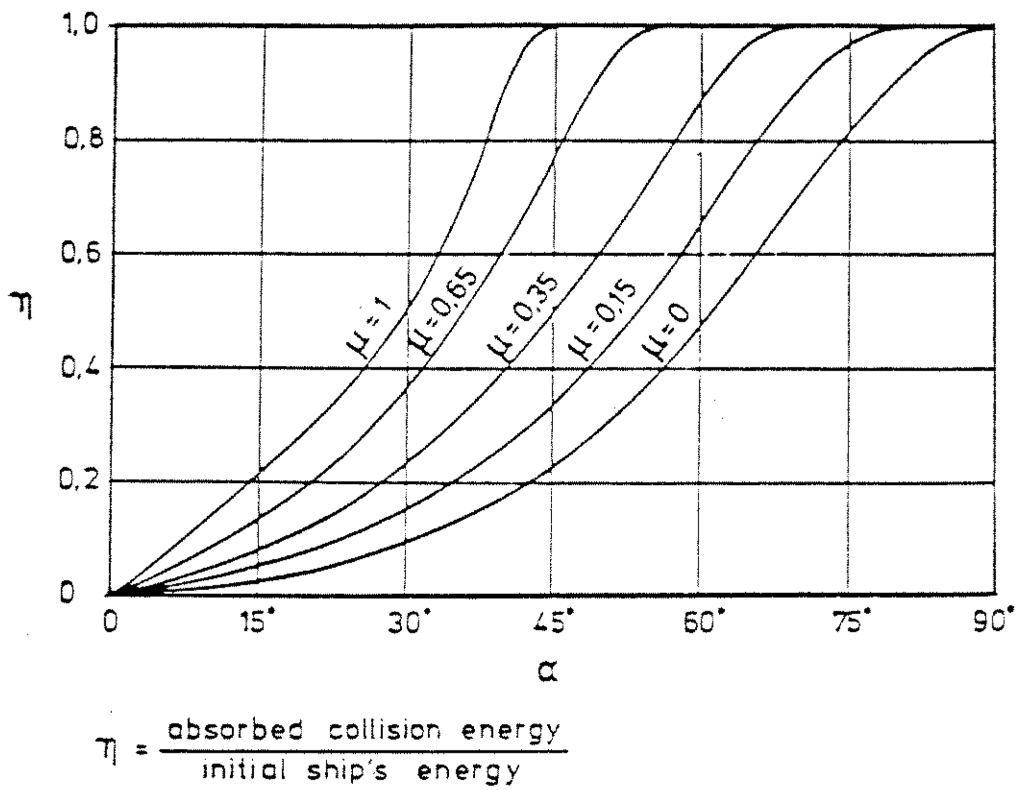

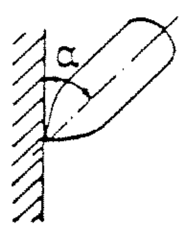

Friction μ

Steel - steel ~ 0,15
Steel - concrete ~ 0,35
Steel - wood ~ 0,65

FIGURE 1 - Part of Collision Energy to be Absorbed by the Ship and/or Pier in Relation to the Collision Angle and the Coefficient of Friction [7].