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SESSION WORKSHOP NOTES

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"Vessel Collision Design of Movable Bridges", Michael Knott,
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VESSEL COLLISION DESIGN OF MOVABLE BRIDGES

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Introduction

The 1980 collapse of the Sunshine Skyway Bridge crossing Tampa Bay in Florida was a major turning point in the development of vessel collision design criteria for bridges in the United States. As a result of the collision by an empty 35,000 DWT bulk carrier with one of the bridge's anchor piers, 1,300 feet of the southbound main span collapsed and 35 lives were lost in vehicles which fell into the bay.

In the period 1970-74 an analysis of river towboat collisions with bridges in the U.S. documented 811 accidents with bridges, costing over $23-million in damage and 14 fatalities[1].

In the period 1965-1989, an average of one catastrophic accident per year involving bridge collisions by merchant vessels have been recorded worldwide. More than 100 persons died in these accidents and very large economic losses were incurred in repair/replacement costs, lost transportation service, and other damages. More than half of these bridge collisions occurred in the United States.

As a result of these accidents, increased concern over the safety of bridges crossing navigable waterways has arisen and research into the vessel collision problem has been initiated in several countries of the world. In 1983, a "Committee of Ship/Bridge Collisions" appointed by the Marine Board of the National Research Council, Washington, D.C. examined the risks and consequences of ship and barge collisions with bridges in the United States[2]. Included in this committee's report were the following observations:

- No agency or unit of government is responsible for the safety of over water bridges against ship collisions.
- No standards have been developed for the design and construction of bridges to resist ship collisions (with the exception of criteria for fenders to protect railroad bridges).
- Regulatory and institutional activities address parts of the ship-bridge-waterway system, but none addresses the functioning of the system as a whole.

In 1988, a pooled-fund research project sponsored by eleven states and administered by the Federal Highway Administration (FHWA) was initiated to begin addressing the above concerns by establishing a design specification for ship and barge collisions with highway bridges (including movable bridges) crossing navigable waterways. The eleven states included Louisiana, Florida, Minnesota, Alabama, Mississippi, North Carolina, Texas, Washington, California, New York, and Missouri. The FHWA contracted with the consulting firm of Greiner, Inc. to perform the study. This paper summarizes the key findings of the study report entitled "Guide Specification and Commentary for Vessel Collision Design of Highway Bridges" which is currently being reviewed for adoption by the American Association of State Highway Officials (AASHTO)[3].

Study's Purpose

The purpose of the study was to develop design and analysis recommendations associated with ship and barge collision impacts on highway bridges located on navigable waterways. Included in the study was the examination of existing procedures, and the development of new procedures where appropriate, to assess the risk of vessel collision with bridges over navigable waterways, to estimate the cost of such collisions, and to determine the levels of acceptable risk. Also included was the development of design criteria for the design of bridge elements and pier protection systems to protect bridges and motorists during impact.

Summary of Report

The Guide Specification developed during the study establishes design provisions for bridges crossing navigable waterways to minimize their susceptibility to damage from vessel collisions. The intent of the provisions is to provide bridge components with a reasonable resistance capacity against ship and barge collisions. In navigable waterway areas where collision by merchant vessels may be anticipated, the Guide Specification requires that bridge structures be designed to prevent collapse of the superstructure by considering the size and type of vessel, available water depth, vessel speed, structure response, and the risk of collision.

An importance classification system was developed to categorize bridges as either 1) critical, or 2) regular for purposes of determining the risk acceptance and design vessel for impact loadings. The classification is based on Social/Survival and Security/Defense requirements with critical bridges being those that must continue to function after impact from a design vessel whose probability of occurrence is smaller than other, regular bridges.

The Guide Specification is applicable to steel hulled merchant ships larger than 1,000 DWT (deadweight tonnes), and inland waterway barges, although certain special purpose vessels are excluded. The report contains extensive data concerning the dimensions, clearances, and physical characteristics of typical bulk carriers, product carrier/tankers, freighter/container ships, and inland hopper, deck, and tank barges. Essential data for using the Specification's risk procedures includes a description of the vessel traffic passing under the bridge, vessel transit speeds, vessel loading characteristics, waterway and navigable channel geometry, water depths, environmental conditions and bridge geometry.

The Guide Specification contains three alternative analysis methods for determining the risk acceptance criteria and design vessel. Method I is a simple to use semi-deterministic procedure; Method II is a detailed risk analysis procedure; and Method III is a cost-effectiveness of risk reduction procedure. The Guide Specification requires the use of Method II for all bridges unless the special circumstances described in the report for the use of Methods I and III exist. Special circumstances for the former include shallow draft waterways where the marine traffic consists almost exclusively of barges; and for the latter include very wide waterways with many piers exposed to collision and existing bridges to be retrofitted.

The Method II acceptance criteria for vessel collision is based on the bridge importance classification as shown below:

- CRITICAL BRIDGES. The acceptable annual frequency of collapse, AF, of critical bridges shall be equal to, or less than, 0.01 in 100 years (AF=.0001).

- REGULAR BRIDGES. The acceptable annual frequency of collapse, AF, of regular bridges shall be equal to, or less than, 0.1 in 100 years (AF=.001).

The acceptable annual frequency of bridge collapse for the total bridge as determined above shall be distributed over the number of pier and span elements located within the waterway, or within the distance 3xLOA on each side of the inbound and outbound vessel transit paths if the waterway is wide. This results in an acceptable risk criteria for each pier and span element of the total bridge.

The design vessel for each pier or span element shall be chosen such that the annual frequency of collapse due to vessels equal to, and larger than, the design vessel is less than the acceptance criterion for the element.

The annual frequency of bridge element collapse shall be computed using the following equation:

$$AF = (N)(PA)(PG)(PC)$$

where

AF = Annual frequency of bridge element collapse due to vessel collision.
N = The annual number of vessels classified by type, size, and loading condition which can strike the bridge element.
PA = The probability of vessel aberrancy.
PG = The geometric probability of a collision between an aberrant vessel and a bridge pier or span.
PC = The probability of bridge collapse due to a collision with an aberrant vessel.

AF shall be computed for each bridge element and vessel classification. The summation of all element AF's equals the annual frequency of collapse for the entire bridge structure. Detailed guidelines for computing N, PA, PG, and PC are included in the Specification.

The primary area of concern for vessel impact is the central area near the navigable channel defined as a distance of 3xLOA on each side of the centerline of the inbound and outbound vessel transit paths. LOA is the length overall of the Method I design vessel and is also used in Method II as a constant parameter for distributing the vessel impact speed and in determining the geometric probability of collision.

The design vessel impact loading for each bridge component is calculated as follows:

$$\text{Group Load} = \gamma(1.0D + 1.0P)$$

where

γ = Load Factor = 1.0
D = Dead Load
P = Vessel Collision Impact Force

Under the application of the group loading, the piers, substructures, and connections to the superstructure shall be proportioned to prevent the collapse of the superstructure. Damage or local collapse of substructure and superstructure elements is permitted to occur provided that, 1) sufficient redundancy of the remaining structure, or multiload paths, exist in the ultimate limit state to safely prevent superstructure collapse, 2) that the design vessel has been completely stopped or redirected so that no significant damage to the superstructure will result, and 3) that the structure element can be visually inspected and repaired in a relatively straightforward manner.

As an alternative to this ultimate state design, the Guide Specification provides criteria for Load Factor and Service Load Design methods. As an additional alternative, pier protection may be provided for the bridge structure to eliminate or reduce the group loading to acceptable levels.

Empirical relationships for computing an equivalent static impact force associated with a head-on collision of a ship or barge with a rigid body are provided in the Guide Specification. The impact force equations were developed from published research based on physical model studies of the crushing strength of typical ship and barge bows conducted in West Germany. Figures 1 and 2 show typical forces developed for vessel impact of tanker ships and hopper barges (195'x35') using the Specification criteria.

The Specification requires that all portions of a bridge pier or substructure exposed to physical contact by any portion of the design vessel's hull or bow, shall be either protected or proportioned to resist the applied loads. The bow overhang, rake, or flair distance, of ship and barge vessels shall be considered in determining the portions of the pier and substructure exposed to contact by the vessel. Figures 3 and 4 illustrate the ability of modern ships and barges to strike vulnerable bridge piers and columns due to the vessel bow overhang.

Bridge elements exposed to collision can be designed to withstand the impact loads, or a fender or protection system can be developed to prevent, redirect, or reduce the impact loads to non-destructive

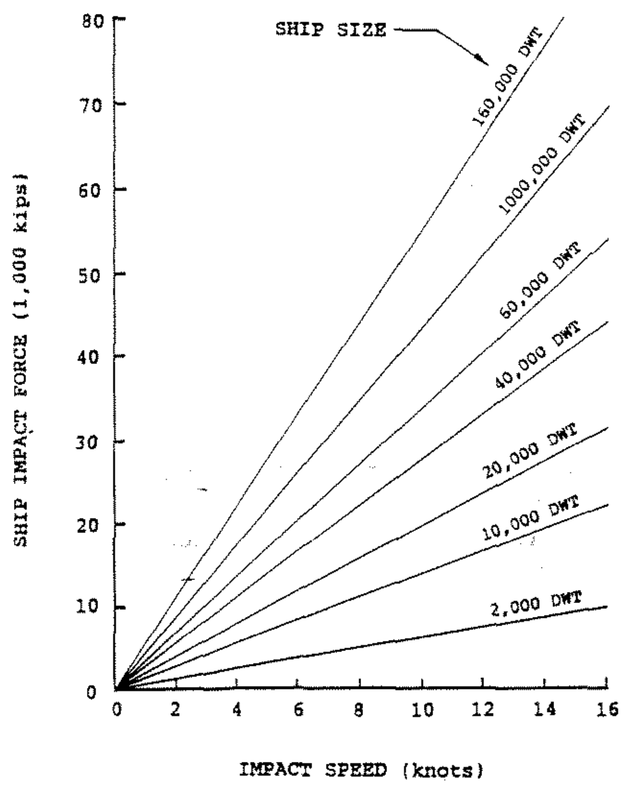

Figure 1. Typical Tanker Ship Impact Forces

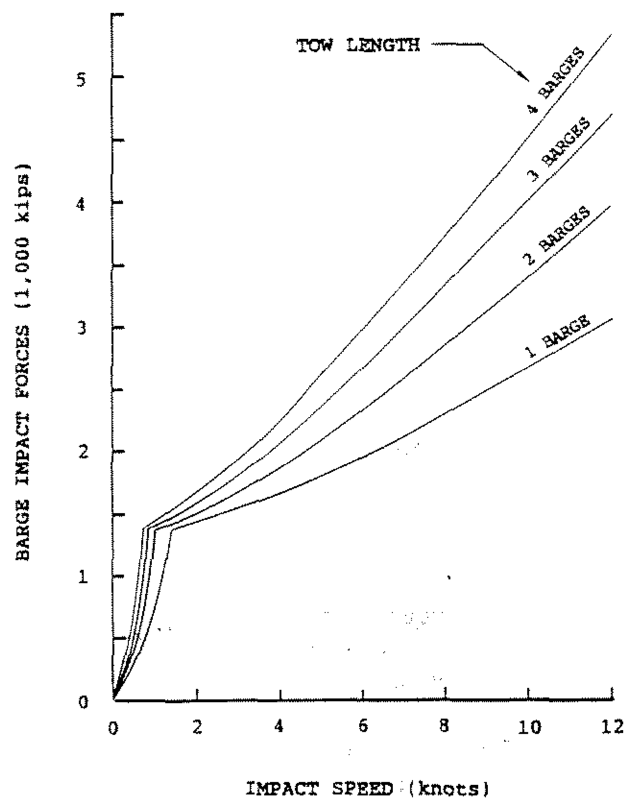

Figure 2. Typical Hopper Barge Impact Forces

levels. The protective structures may be located directly on the bridge (such as a fender), or independent of the bridge (such as a dolphin). Protective structures are usually designed using energy methods in which the vessel impact energy is absorbed by the deformation of the protection structure, the deformation of the vessel's bow, or by a combination of both. Detailed discussions of fender systems, pile supported systems, dolphins, islands, and cable net systems are included in the Guide Specification.

In addition to physical protection systems, the Guide Specification also discusses the use of motorist warning systems to reduce the potential loss of life in the event of a catastrophic vessel collision, and the use of aids to navigation alternatives (including electronic navigation systems) to reduce the probability of vessel collision.

Movable Bridge Protection

Special Guide Specification requirements were developed for the protection of movable bridges because of the numerous accidents that have occurred on these bridge structures. Many of the movable bridges in the U.S. were designed and built in the late 1800's and early 1900's when both the frequency and size of vessels using the waterways were very small compared to the ship and barge vessels today. As a result of their relatively narrow horizontal spans, and the increase in size and frequency of vessels in most waterways today, many movable bridges have a relatively high risk of vessel collision. The machinery in most movable bridges is relatively sensitive to impact, vibrations, and deflections in both the substructure and superstructure. As a result, even minor (non-catastrophic) vessel impacts can disrupt the bridge operations causing bridge closure until repairs are made. The Guide Specification requirements discussed below were developed to give designers specific guidelines in protecting these structures.

Movable bridge piers which house mechanical equipment or support movable machinery should be fully protected from vessel contact by aberrant vessels. There should be no contact of the vessel with the pier when the protection system is in the fully deformed position and the vessel has been stopped. Special consideration must be included for the overhang of raked bows on ships and barges.

The navigation spans of all movable bridges should provide a protection system which prevents vessels from laterally contacting the pier or navigation channel superstructure while the vessel is transiting through the bridge. There should be no contact between the vessel and the pier or span while the protection system is in the deformed position.

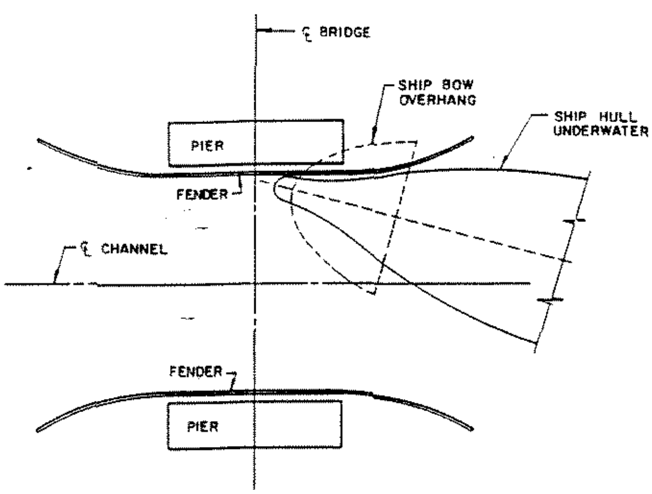

Figure 3. Plan of Ship Bow Overhang Impacting Pier

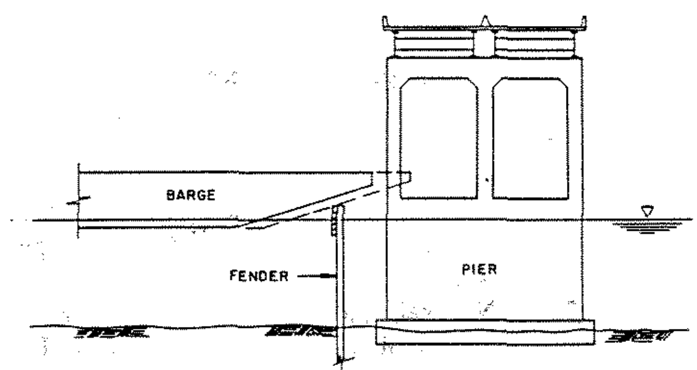

Figure 4. Elevation of Barge Bow Impacting Pier

The superstructure of the movable spans on bascule and swing bridges should be fully protected when they are in an open position. The protection system along the sides of the navigation channel should prevent contact between the vessel and the span in the open position. This is a special concern for bascule bridges in which the movable span leaves in the open position may overhang the pier and are vulnerable to contact by a vessel's superstructure.

Electrical power cables, including submarine cables, should be positioned and supported so as to be fully protected from damage by impact from marine traffic.

Bascule bridge spans are subject to impact damage by marine vessels when spans are in either the open or closed position. Bascule leaves, when in the full open position, should be designed such that an aberrant vessel cannot come into contact with the structure. Although it is impractical to design closed bascule leaves such that marine vessel contact cannot occur, leaf designs should minimize the resultant leaf damage from impacts occurring when the bridge is in the closed or partially open position.

The bridge tender's house should be located such that marine vessel impact will not endanger the bridge tender or bridge controls and operating system.

Mechanical, hydraulic, or electrical systems should not be located on walls susceptible to vessel impact. Precautions should be taken to locate and/or protect drive systems, such as hydraulic systems, drive gearing, motors, and electrical power and control systems from possible damage due to direct or indirect impact damage from marine vessels.

Drive systems for movable bridges should be evaluated to identify single point failures which may result from impact damage. Consideration should be given to providing redundant system elements for single point failures. For those system elements which cannot be fully protected against impact damage, critical items should be conveniently replaceable.

References

1. U.S. Department of Commerce, "Analysis of Bridge Collision Incidents, Volumes I and II," prepared by R. B. Dayton, Operations Research, Inc., May, 1976.
2. National Research Council, Marine Board of the Commission on Engineering and Technical Systems, "Ship Collision with Bridges; The Nature of the Accidents, Their Prevention and Mitigation," prepared by the Committee on Ship-Bridge Collisions, National Academy Press, Washington, D.C., 1983.
3. Federal Highway Administration, "Guide Specification and Commentary for Vessel Collision Design of Highway Bridges (Final Report and Technical Summary)," prepared by M. A. Knott, Greiner, Inc., February, 1990 (DRAFT).