Structural Engineering Documents

4

Ole Damgaard LARSEN

SHIP COLLISION WITH BRIDGES

The Interaction between Vessel Traffic and Bridge Structures

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

About the Author

Born 1942, Ole Damgaard LARSEN graduated from the Technical University of Denmark in 1965. Most of his professional career has been spent with the Danish consulting engineering company COWIconsult, now as department manager in the transportation division. He has been responsible for the planning and design of a large number of major bridge, tunnel and offshore projects. He has 15 years of expertise in ship collision studies, mainly for the initial conceptual phases of bridge schemes, where fundamental decisions with regard to alignment and overall layout of structures are made. Important projects on which he has worked include the Sunshine Skyway Bridge in Florida, the Great Belt Link in Denmark, the Femer Belt Link between Germany and Denmark and the proposed Gibraltar Strait Crossing between Morocco and Spain. Among other publications, he is co-author of the US-FHWA Guide Specification and Commentary for Vessel Collision Design of Highway Bridges.

Structural Engineering Documents

4

Ole Damgaard LARSEN

SHIP COLLISION WITH BRIDGES

The Interaction between Vessel Traffic and Bridge Structures

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

ISBN 3-85748-079-3
Printed in Switzerland

Publisher:
IABSE - AIPC - IVBH
ETH - Hönggerberg
CH-8093 Zürich, Switzerland

Phone: Int. +41 1-377 26 47
from 27 September 1993:
Int. +41 1-633 26 47

Fax: Int. +41 1-371 21 31

PREFACE

In June 1983 a colloquium on "Ship Collision with Bridges and Offshore Structures" was held in Copenhagen under the auspices of the International Association for Bridge and Structural Engineering (IABSE). The colloquium was initiated by the Danish Group of IABSE with the background of comprehensive investigations in this field in connection with the fixed crossing of the Great Belt in Denmark.

The colloquium brought together bridge and offshore engineers, naval architects, navigational experts, risk assessment specialists, etc. with the view to exchange information on this subject.

After the colloquium, the IABSE Working Commission 1 "Structural Performance, Safety and Analysis", established a Working Group for preparing a guideline or a state-of-the-art report.

Members of the Working Group, appointed originally or during the work, were the following:

- Dr. Yahei Fujii, Electronic Navigation Research Institute, Tokyo, Japan
- Mr. Cornelis Q. Klap, Rijkswaterstaat, Voorburg, The Netherlands
- Mr. Michael A. Knott, Greiner Inc., Richmond, USA
- Mr. Thomas R. Kuesel, Parsons Brinckerhoff, New York, USA
- Mr. Ole Damgaard Larsen, COWIconsult, Copenhagen, Denmark
- Dr. Henrik O. Madsen, Danish Engineering Academy, Copenhagen, Denmark
- Mr. Holger S. Svensson, Leonhardt, Andrä u. Partner, Stuttgart, Germany.

The Working Group was chaired by Ole Damgaard Larsen, who also prepared the present IABSE publication. Yahei Fujii, Thomas R. Kuesel and Michael A. Knott made valuable contributions to the publication.

The development of this publication took its basis from the proceedings of the international colloquium in Copenhagen in 1983.

Since the colloquium, important research has been carried out in connection with development of national codes and standards for bridge design and in connection with planning and design of major bridge projects.

It was decided in 1989 to leave out offshore structures from the publication. The reason was that it was found inexpedient to treat the two types of structures in the same publication.

The final editing of the publication was carried out in the course of 1991, when conclusive data could be made available from the following major projects:

- development of vessel collision guide specifications for the Federal Highway Administration in the USA
- development of vessel collision design criteria for the Great Belt Crossing in Denmark.

This document represents the conclusions of the work as accepted by the IABSE Working Commission 1 at the IABSE annual meeting in St. Petersburg, September 1991.

The Working Group was dissolved at the same occasion and inquiries regarding this publication should therefore be addressed to the IABSE Working Commission 1.

The Working Commission 1 is greatly indebted to the author and much appreciates his efforts.

Johan Blaauwendraad,
Chairman of Working Commission 1

TABLE OF CONTENTS

Page

0.	Preface		
1.	Introduction		1
	1.1	Background	1
	1.2	Validity	6
	1.3	Application	6
2.	Initial Planning		7
	2.1	Siting of Bridge Structure	7
	2.2	Navigation Channel Layout	8
	2.3	Overall Bridge Layout	8
	2.4	Vertical Clearance	9
	2.5	Horizontal Clearance	11
3.	Vessel Traffic		19
	3.1	Traffic Routes	19
	3.2	Passage Statistics	20
	3.3	Vessel Characteristics	21
	3.4	Traffic Forecast	24
4.	Risk Acceptance		27
	4.1	Consequences of Collision	27
	4.2	Disruption Risk Acceptance Criteria	28
	4.3	Fatality Acceptance Criteria	32
	4.4	Optimum Cost Acceptance Criteria	34
5.	Collision Risk		37
	5.1	Collision Risk Model	38
	5.2	Causation Probability	39
	5.3	Geometrical Probability	44
	5.4	Failure Probability	49
6.	Vessel Impact Forces		53
	6.1	Head-on Bow Impact Forces	54
	6.2	Sideways Impact Forces	70
	6.3	Deckhouse Impact Forces	71
	6.4	Local Collision Forces	72
	6.5	Barge Vessel Impact Forces	73

7.	Bridge Design		77
	7.1	Energy Considerations	77
	7.2	Structural Analysis	80
	7.3	Design of Substructure	82
	7.4	Design of Superstructure	83
8.	Prevention Measures		85
	8.1	Aids to Navigation	85
	8.2	Vessel Traffic Regulations	87
	8.3	Vessel Traffic Management Systems	87
9.	Protection Measures		91
	9.1	Fender Systems	91
	9.2	Pile Supported Systems	93
	9.3	Dolphin Protection	95
	9.4	Artificial Island or Reef Protection	95
	9.5	Floating Protection Systems	97
10.	Protection of the Public		101
	10.1	Collision Hazard Detection	101
	10.2	Bridge Traffic Control	102

Appendices 103

A.	Vessel Size and Geometry Data	103
B.	Records of Collision Accidents	113
C.	Selected Literature	119

1. INTRODUCTION

1.1 Background

Any structure established in navigable waters constitutes a hazard to shipping and is itself vulnerable to damage or destruction in the event of vessel collision. Among the most significant structures exposed to this hazard are bridges crossing coastal or inland waterways.

A list of serious accidents recorded during the period 1960-1991 has been included in Appendix B. The list represents an updated version of the records published by Frandsen [1-1] in 1983. The records indicate an average of one serious vessel/bridge collision accident per year worldwide, see Figure 1.1. More than 100 persons died in these accidents and large economic losses were incurred directly in repair or replacement costs as well as indirectly in the form of lost transportation service.

The photos in Figures 1.2, 1.3 and 1.4 from actual collision accidents illustrate the seriousness of the subject. The accidents shown are all briefly described in Appendix B.

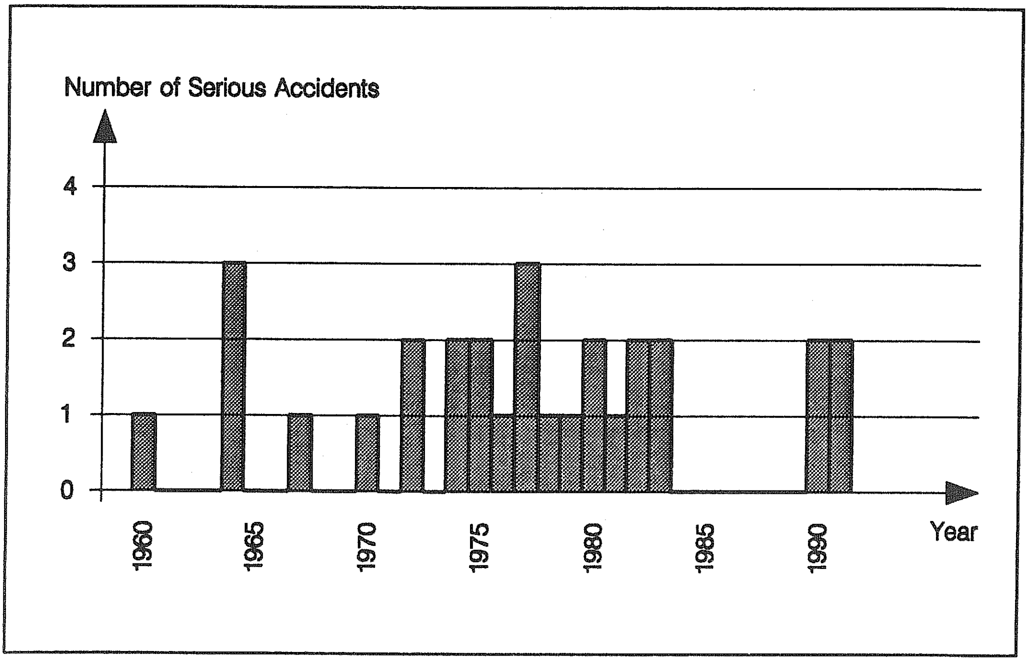

Figure 1.1 The number of serious vessel/bridge collision accidents per year in the period 1960-1991 (32 years).

2. INITIAL PLANNING

As considerations for the interaction between bridge structures and vessel traffic will often influence fundamental decisions such as location and type of bridge crossing, it is essential that the vessel collision aspects are properly investigated as early as possible in the planning process.

A number of important aspects of the bridge design, siting, and aids to navigation can be evaluated by relatively simple means on the basis of the initial knowledge of the waterway and the navigation, applying experience and common sense.

This chapter contains such general considerations concerning the initial planning and layout of the bridge structure and the waterway.

2.1 Siting of Bridge Structure

The purpose of the bridge often determines a specific location. However, minor modifications can normally be introduced and if major problems are identified it might still be possible to consider alternative locations.

For the siting of a bridge crossing, the following aspects, among others, should be considered, ref. [2-1], [2-2], [2-3], [2-13], [2-14], [2-15], and [2-18]:

- Locations with congested navigation should be avoided.
- Locations with difficult navigation conditions (shoals, cross currents, etc.) should be avoided.
- A straight and unencumbered navigation channel approach of adequate length before the bridge-passage should be achieved.
- Adequate distance to locations where berthing manoeuvres take place should be provided.
- The bridge's alignment should preferably be perpendicular to the navigation channel.
- The centre of the navigation span should coincide with the centre line of the navigation channel.
- Locations where bridge piers can be placed in shallow water so that vessels out of control may not reach the bridge structures without first running aground should be preferred.

With regard to the adequate length of unencumbered channel approach, the following empirical estimate has been reported by Shoji et al. [2-18], [2-19], and [2-20] based on analyses of collisions with bridges world-wide: The minimum distance from a bridge line to the position of the nearest turn in the navigation route should be at least 8 L and preferably 20 L, L being the length of the vessel. If the distance is smaller, the turn will influence the navigation at the bridge crossing.

3. VESSEL TRAFFIC

The characteristics of the vessel traffic passing under the bridge should be established in as much detail as possible for the design stage in question. Normally, the traffic characteristics in a specific situation can be established by utilizing available statistics and information from local authorities. On this basis, a forecast should then be made to cover the traffic development during the anticipated life-time of the bridge.

Vessel traffic is conveniently defined in the following terms as described in the subsections below:

- Traffic Routes
- Passage Statistics
- Vessel Characteristics
- Traffic Forecast.

3.1 Traffic Routes

Vessel traffic routes in the vicinity of the bridge should be identified. All routes for which interaction between navigation and the bridge is possible should be considered. Ordinary routes as well as unofficial routes (short cuts etc.) should be identified. An example is shown in Figure 3.1.

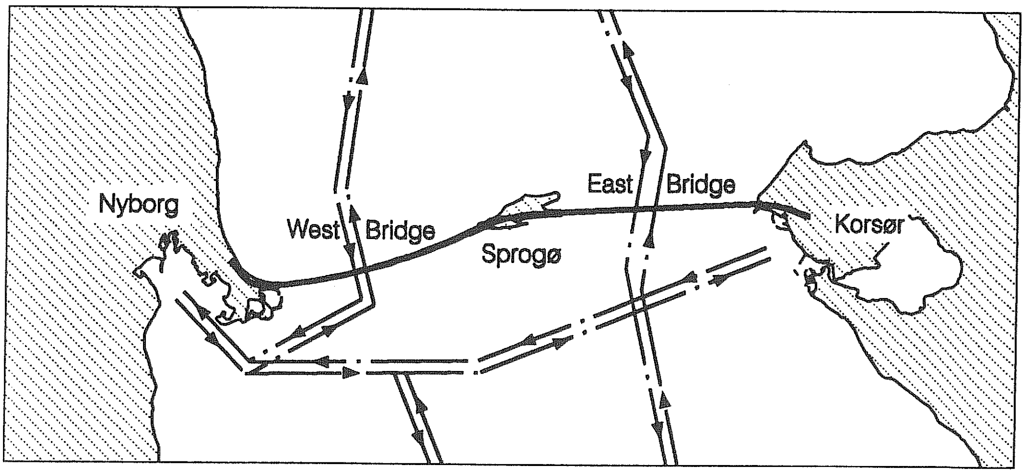

Figure 3.1 Vessel traffic routes in the vicinity of a bridge crossing (based on Olsen et al. [3-4]).

4. RISK ACCEPTANCE

Risk can be defined as the potential realization of unwanted consequences of an event (i.e. the product of the probability of an event and the consequences of the event). Both the probability of occurrence of an event and the magnitude of its consequences are thus involved. References are made to Philipson [4-15], Planeix [4-16], and Rowe [4-17].

Acceptance Criteria can be established either in the form of a predefined set of "Risk Acceptance Criteria" or in the form of "Optimum Cost Criteria":

- Risk Acceptance Criteria are defined as acceptable limits to probabilities of certain unwanted consequences of collision and are expressed in terms of annual frequencies.
  Risk Acceptance Criteria are normally imposed by the Authorities to reflect the willingness of people and society to accept risk. In principle, such criteria do not consider the cost of observing the criteria.
- Optimum Cost Criteria are Acceptance Criteria based on cost-effectiveness analyses comparing the costs of bridge strengthening and protection measures against the benefit of risk reduction. Optimum Cost Criteria may be introduced in cases where it is not economical or technically feasible to design the bridge structures to comply with official Risk Acceptance Criteria. Furthermore, the Optimum Cost Criteria may be used for decisions on whether to reduce the risk to a level below what is required by the Risk Acceptance Criteria, because this can be justified economically.

In order to make the use of the Acceptance Criteria unambigious and efficient they should be implemented together with guidelines on how complying with the criteria shall be documented. These guidelines should cover among others:

- types of collision consequences to be considered
- principles for estimating frequencies of the collision consequences considered
- principles for addressing the uncertainties of the frequency estimates.

4.1 Consequences of Collision

There are a number of different categories of consequences that are associated with a vessel/bridge collision event.

The main consequences may be classified into the following six categories (three categories of direct consequences and three categories of indirect consequences respectively):

5. COLLISION RISK

In general, it is not feasible to design all parts of a bridge structure to withstand worst case loads from ship impact. However, it is possible to estimate frequencies of overloading of bridge structures due to ship impact. With knowledge of the frequencies of overloading, a design can be selected which fulfils certain acceptance criteria as described in Section 4.

Vessel collision accidents to bridge structures are relatively rare and conditions differ from bridge to bridge. Therefore, the estimation of the risk of collision can not be based on vessel/bridge collision statistics alone. Collision risk models, simulating potential collision scenarios are necessary.

In this section practical models for estimating frequencies of ship collisions with bridges are addressed.

When establishing a vessel collision risk model the following approach is recommended:

- The navigation conditions in the vicinity of the planned bridge should be studied, and vessel accident data, i.e. groundings, vessel/vessel collisions, vessel/lighthouse collisions, etc., should be collected.
- Vessel/bridge collision scenarios should be defined and modelled so as to incorporate the particular conditions of the bridge site.
- Subsequently, data for estimation of the parameters to be used in the collision risk model should be collected.

Vessel/bridge collision risk models have been developed by a number of researchers, either for specific projects or for the establishment of general guidelines for bridge designs. State-of-the-art reports have been published in 1983 and 1992, ref. Larsen [5-19] and Olsen et al. [5-32].

Some examples of bridge collision risk models are as follows:

- Establishment of vessel collision load specifications to comply with pre-set bridge disruption acceptance criteria for the proposed Great Belt Bridge Project in Denmark, 1978. The model was developed by CAP-Consult, ref. Frandsen et al. [5-5].
- Assessment of the probability of disruption of the Tasman Bridge in Australia, reconstructed after a vessel collision accident, for the evaluation of benefits of constructing an alternative crossing, the Bowen Bridge, 1978. The model was developed by Maunsell & Partners, ref. [5-26] and Leslie [5-21].
- Assessment of the probability of disruption considering alternative protection measures, of the new Sunshine Skyway Bridge to replace the existing bridge which collapsed due to a vessel collision accident. Models were developed by COWIconsult, ref. Larsen [5-19] and Greiner, ref. Knott et al. [5-16].

6. VESSEL IMPACT FORCES

The determination of the impact load on a bridge structure during a vessel collision accident is very complex as it depends on the vessel characteristics and the bridge structure, as well as the circumstances of the collision accident.

Some important parameters are:

- For the colliding vessel: type, size, shape, speed, loading condition, and strength and stiffness of bow, hull, and deckhouse.
- For the bridge elements in contact with the colliding vessel: size, shape, mass, and lateral resistance characteristics.
- For the collision circumstances: eccentricity of impact and water depth.

Most research has dealt with the ideal case of a vessel colliding with an infinitely rigid and immovable vertical plane wall structure. In this case the kinetic energy of the vessel together with the water surrounding and moving with the vessel is consumed totally through the deformation and crushing of the vessel.

In a less ideal collision event, parts of the energy will be consumed in deformation and crushing of fenders, displacement of bridge pier and bridge superstructure and liberation of energy to the surrounding water.

"Realistic" collision cases therefore involve lower impact forces, longer impact durations and less damage to the vessels than an "ideal" collision case.

Collision impact load definitions are normally required in the following cases as described in the subsections below:

- Head-on Bow Impact Forces
- Sideways Impact Forces
- Deckhouse Impact Forces
- Local Impact Loads.

An additional subsection:

- Barge Vessel Impact Forces

has been included to cover barge vessels which differ substantially from ship vessels and are of particular importance to bridges crossing inland waterways.

7. BRIDGE DESIGN

For bridge design purposes, design forces should be established for at least the following collision load cases:

- collision with the bridge piers and pier shafts, head-on by the vessel bow or sideways by the vessel hull
- collision with the bridge superstructure by the vessel bow, hull, or deck house.

Global forces for design for overall stability as well as local forces for design for local strength of bridge elements are required.

Due to the low probability of collision, the vessel collision load case is traditionally considered to be an accidental action. This means that a reduced level of safety against failure is accepted.

However, two or more levels of vessel collision load assumptions may be introduced in order also to cover lower vessel collision loads which might be experienced more often. As an example, the following three levels of safety, corresponding to collision loads with decreasing levels of probability, might be specified:

- no damage accepted
- minor damage accepted, provided continuous use of the bridge is possible and provided repair work can be effectuated without disturbing the traffic
- major damage or local collapse is accepted, provided the remaining structure has sufficient redundancy to allow repair within a relatively short time (say, 3 months) to a degree that allows re-opening of the bridge for traffic.

7.1 Energy Considerations

In order to determine the consequences of a vessel collision accident, the traditional method is to estimate the amount of kinetic energy available and thereafter determine how this energy is dissipated by displacement, deformation or crushing of the vessel and/or the bridge structure, including attached or free-standing fenders or protective works.

The total kinetic energy KE is:

$$KE = \tfrac{1}{2} \cdot (M_v + M_h) \cdot v^2 \qquad (7.1)$$

where

v = the velocity of the vessel

M_v = is the mass of the vessel

M_h = the hydrodynamic added mass of the water surrounding the vessel and moving with it.

8. PREVENTION MEASURES

Planning and implementation of prevention measures to improve safe navigation in the waterway near a bridge crossing requires close cooperation with the relevant navigation authorities.

Where the matter is of international concern, the national authorities will approach the international authorities, in most cases the International Maritime Organisation (IMO), ref. IMO [8-7].

Prevention or reduction of the frequency of collisions is achieved by providing assistance to navigation. The assistance may differ in extent and level of sophistication, depending on the waterway and the intensity of the navigation. In this connection, inspiration may be obtained from experience within the offshore sector, ref. Vendrell [8-12].

Three levels of assistance are discussed in the following:

- installation of navigational aids on the bridge and in the waterway
- introduction of navigation regulations
- implementation of a vessel traffic management system.

Comments on the effectiveness of the different types and levels of assistance are given in Section 5.2.

8.1 Aids to Navigation

Visual, sonar as well as electronic aids to navigation should be designed to provide safe guidance in most weather conditions.

For installation on the bridge structure, the following types of navigational aids can be considered to provide better detectability:

- colours (fluorescent)
- signs
- high intensity light beacons (flashing)
- range lights
- sound devices (fog horns)
- racon installation at the centre line of the vessel track(s).

An example of installations on a bridge to aid navigation is shown in Figure 8.1.

9. PROTECTION MEASURES

In addition to bridge damage, vessel collisions may result in serious environmental damage such as the spilling of oil and other chemicals. The consequences of a vessel collision may therefore reach far beyond the direct costs of repairing/replacing the vessel and possibly the bridge.

The bridge elements 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 on bridge elements to non-destructive levels.

If the force resistance of the protection system is higher than the vessel crushing force, the bow of the vessel will crush and the impact energy will be primarily absorbed by the vessel.

If the vessel crushing force is higher than the resistance of the protection system, the impact energy will be primarily absorbed by the deflection and crushing of the protection system.

The protection system should be designed not only to protect the bridge structure, but also to protect the vessel and the environment against serious damage. This may be achieved by combining different types of protective systems. Protection systems may be located directly on the bridge structure (such as a bridge pier fender), or independent of the bridge (such as a dolphin). The geometry of the protective structure should be developed to prevent the rake (overhang) of the design vessel's bow from striking and causing damage to any exposed portion of the bridge. Generally, the analysis and design of bridge protection structures requires the use of engineering judgment to arrive at a reasonable solution. Surveys of protection measures can be found in Frandsen et al. [9-5], Knott et al. [9-10], Larsen et al. [9-12], Ostenfeld [9-20], and Saul et al. [9-21], [9-22], and [9-23].

The various types of protective structures commonly used for bridges will be briefly discussed in the subsections below:

- Fender Systems
- Pile Supported Systems
- Dolphin Protection
- Artificial Island or Reef Protection
- Floating Protection Systems.

9.1 Fender Systems

Timber fenders are composed of vertical and horizontal timber members in a grillage geometry attached to the face of the bridge pier, or erected as an independent structure adjacent to the

10. PROTECTION OF THE PUBLIC

To minimize the loss of life which may occur in the event of a catastrophic collapse of a bridge during a vessel collision, bridge user warning systems may be introduced, ref. [10-1], [10-2], and [10-3].

10.1 Collision Hazard Detection

Devices to detect vessel/bridge collision hazards include the following:

- Vessel Impact Vibration Detectors. Placed on bridge piers, these vibration sensors would be capable of distinguishing between normal structural vibrations and movements associated with substantial vessel impacts.
- Continuity Circuits. This electrical system would utilize pairs of conductors terminating with end-of-line devices attached to the bridge superstructure. Collapse of some portion of the bridge deck would interrupt the circuit continuity.
- VHF Radio Link. The use of this device would be in advance of imminent danger, as foreseen by the pilot or master of a vessel which had, for instance, lost steerage. If the mariner anticipated a possible vessel/bridge collision, he would radio the bridge personnel, or other appropriate agency, via VHF marine emergency channel in order to halt traffic on the bridge.

Either of the first two of the above devices could activate traffic control/information systems automatically or through a machine-man-machine interface with the human intermediary verifying hazards before interrupting traffic.

VHF radio units are readily available in the deckhouse of virtually every merchant vessel. The use of such a system would require the installation of a relatively inexpensive VHF set and continuous monitoring by the bridge personnel who could make appropriate traffic control decisions. Virtually any detection device can be electronically linked to traffic control/information equipment in order to automatically warn or stop traffic. However, in actual practice, considerable difficulty can be experienced with false alarms and unnecessary interruptions of traffic.

Included among possible verification methods to be carried out by bridge personnel before traffic control actions are taken, are the following:

- Closed Circuit Television (CCTV). Cameras can be placed strategically to allow personnel at a monitor site to view the bridge main span, the navigation channel, the roadway, or any other feature desired.
- Visual Delineation. The top of the bridge parapet or guardrail would be fitted with a series of reflectors or lights, immediately revealing the collapse of a portion of the bridge superstructure.

Appendix A. Vessel Size and Geometry Data

A.1. Vessel Size Measurements

Dead Weight Tonnage (DWT)

The Dead Weight Tonnage expresses the carrying capacity of a vessel, i.e. the maximum weight in metric tonnes of cargo, fuel, water, stores, etc. on board the vessel when fully loaded.

DWT equals the difference between a vessel's displacement at fully loaded draught and light ballast draught. It is the normal unit for bulk carriers and tankers.

Displacement Tonnage (W)

The Displacement Tonnage expresses the total weight in metric tonnes of the vessel including cargo, fuel, water, stores, etc. The displacement thus depends on the loading condition.

The weight of the ship when in a 'light' or unloaded state, but including the weight of water in boilers and any permanent ballast is called "light displacement". The light displacement weight plus the weight of cargo, fuel, stores, fresh water, and water, ballast is called "load displacement".
W equals the weight of water displaced by a vessel when floating at the specific draught.
W is the normal unit for warships.

The Displacement Tonnage for a fully loaded vessel may be approximated to Dead Weight Tonnage as follows:

- Tankers: DWT = 0.9 x W
- Bulk Carriers: DWT = 0.8 x W
- Container Vessels: DWT = 0.6 x W

Gross Register Tonnage (GRT)

The Gross Register Tonnage expresses the internal volume of a vessel (less certain exempted spaces) measured in cubic feet divided by 100. GRT is thus not a measurement of weight.

GRT is a normal unit for passenger ships and cargo liners and is used as a basis for safety requirements and manning.

The Gross Register Tonnage may be approximated to Dead Weight Tonnage as follows:

- Tankers: DWT = 1.6 x GRT
- Bulk Carriers: DWT = 1.9 x GRT
- Container Vessels: DWT = 0.9 x GRT

Appendix B. Records of Collision Accidents

Serious Vessel Collision Accidents recorded in the Period 1960-1991

1960 Severn River Railway Crossing, England

Vessel	:	Tug pulling two barges each 450 tonnes displacement
Accident	:	Broadside collision with pier
Damage	:	Two spans and one supporting pier collapsed causing five fatalities
Cause	:	Tug pilot's negligence in dense fog
Lit.	:	Peter Mason: "An investigation into the cause of damage to the Severn Railway Bridge". The Structural Engineer No. 2, 1963

1964 Maracaibo Lake, Venezuela

Vessel	:	36,000 DWT loaded tanker
Accident	:	Broadside collision with two piers more than 600 m from the navigational spans
Damage	:	Three spans collapsed
Cause	:	Failure in electrical system affecting steering gear
Lit.	:	Engineering News Record, 1964-04-16 and 1964-12-24

1964 Pontchartrain Lake, Louisiana, USA

Vessel	:	Tug towing two loaded barges
Accident	:	Three trestles were struck by the tug and the two barges
Damage	:	Four spans collapsed, causing six fatalities
Cause	:	Helmsman's lack of attention
Lit.	:	Engineering News Record, 1964-06-25

1964 Pontchartrain Lake, Louisiana, USA

Vessel	:	Tug towing two barges
Accident	:	Tug hit a pile bent
Damage	:	One pile bent was destroyed and two spans collapsed
Cause	:	Tug pilot's inattention (possibly asleep)
Lit.	:	Engineering News Record, 1964-07-30

1967 Chesapeake Bay, Virgina, USA

Vessel	:	Drifting coal barge
Accident	:	Vessel thrown repeatedly against the bridge deck
Damage	:	Six spans were seriously damaged
Cause	:	Barge torn loose from moorings in storm
Lit.	:	Engineering News Record, 1967-12-14

Appendix C. Selected Literature

The literature list is organized in accordance with the sections of the publication:

SECTION 1 - INTRODUCTION

[1-1] Frandsen, A. G.: "Accidents Involving Bridges", IABSE Colloquium on Ship Collision with Bridges and Offshore Structures, Copenhagen, 1983.

[1-2] Frandsen, A. G. and Langsoe, H.: "Ship Collision Problems: I. Great Belt Bridge and II. International Enquiry", IABSE Periodica No. 2, 1980.

[1-3] Frandsen, A. G., Olsen, D., Fujii, Y. and Spangenberg, S.: "Ship Collision Studies for the Great Belt East Bridge, Denmark", IABSE Symposium on Bridges—Interaction between Construction Technology and Design, Leningrad, 1991.

[1-4] Jensen, A. O. and Sørensen, E. A.: "Ship Collision and the Faroe Bridges", IABSE Colloquium on Ship Collision with Bridges and Offshore Structures, Copenhagen 1983.

[1-5] Knott, M. A. and Bonyun, D.: "Ship Collision Against the Sunshine Skyway Bridge", IABSE Colloquium on Ship Collision with Bridges and Offshore Structures, Copenhagen, 1983.

[1-6] Knott, M. A.: "Ship Collision with Bridges", Bulletin of Permanent International Association of Navigation Congresses (PIANC), No. 57, 1987.

[1-7] Knott, M.A. and Larsen, O. Damgaard: "Guide Specification and Commentary for Vessel Collision Design of Highway Bridges", US Department of Transportation, Federal Highway Administration, Publ. No. FHWA-RD-91-006, Dec. 1990.

[1-8] Larsen, O. Damgaard and Benmoussa, C.: "Ship Collision Aspects for Bridge across the Strait of Gibraltar", Third International Colloquium on the Fixed Link Europe-Africa Through the Strait of Gibraltar, Marrakesh, May 1990.

[1-9] Maunsell & Partners and Brady, P. J. E.: "Second Hobart Bridge—Risk of Ship Collision and Methods of Protection", Technical Report prepared for Department of Main Roads, Tasmania, Australia, 1978.

[1-10] Modjeski & Masters, Consulting Engineers: "Criteria for: The Design of Bridge Piers with Respect to Vessel Collision in Louisiana Waterways", Prepared for the Louisiana Department of Transportation and Development and the Federal Highway Administration, New Orleans, July 1985.

[1-11] Norwegian Public Roads Administration: "Report on Vulnerable Bridges Crossing Navigable Waters" (in Norwegian), Oslo, 1982.

[1-12] Olnhausen, W. Von: "Ship Collisions with Bridges in Sweden", IABSE Colloquium on Ship Collision with Bridges and Offshore Structures, Copenhagen, 1983.

[1-13] Ostenfeld, Chr.: "Ship Collisions Against Bridge Piers", IABSE Publications, Vol. 25, 1965.

Structural Engineering Documents

Objective:

Providing in-depth information to the practising engineer by publishing reports of a high scientific and technical level on structural engineering themes.

Fields covered:

Construction materials/ structural analysis/dynamic analysis/construction methods/research/design/ execution/maintenance/ history of construction science and technology/ interaction between structural engineering and other fields (e. g. architecture).

Readership:

Engineers throughout the world who are interested in civil engineering structures: researchers, professors, designers, entrepreneurs, administration and owners' representatives.

Publisher:

IABSE – created in 1929 – is the International Association for Bridge and Structural Engineering, comprising more than 3400 members in 80 countries. A scientific, international, non-governmental and non-profit organisation, IABSE's principal activities are conducting conferences and issuing publications.

Besides the series "Structural Engineering Documents", the IABSE also publishes other series:

"Structural Engineering International"–a quarterly technical journal
IABSE REPORTS
IABSE CONGRESS REPORTS

For further information:

IABSE
ETH-Hönggerberg
CH-8093 Zurich, Switzerland
Fax: Int. + 41 1-371 21 31

Ship Collision with Bridges

The Interaction between Vessel Traffic and Bridge Structures

Any structure in navigable waters constitutes a hazard to shipping and is itself vulnerable to damage or destruction in the event of vessel collision. Worldwide vessel traffic and the average size of vessels continue to increase. At the same time, ever more bridges crossing navigable waterways are being planned and constructed, sometimes with inadequate navigation clearance and/or inadequate protection.

The objective of this publication is to provide information and guidelines for engineers charged with the planning and design of new bridges, navigation channels, and prevention and protection measures. It offers advice on upgrading and retrofitting existing bridges and navigation channels. And it provides the means to evaluate the safety of bridges, vessels, persons and the environment.

After reviewing some basics of navigation and vessel traffic, and considering risk acceptance and collision risk, the publication examines vessel impact forces on bridges and proposes appropriate bridge design criteria. Prevention measures, such as regulations and management systems, and protection measures and systems are also described.

Major international research projects have provided the analytical basis for the publication, including the development of vessel collision guide specifications for the Federal Highway Administration in the USA and the vessel collision design criteria developed for the Great Belt Crossing in Denmark.

Prepared by Ole Damgaard LARSEN, Chairman of the IABSE Working Group "Ship Collision with Bridges", this 132 page publication is a must for any engineer dealing with structures in navigable waters.