Bridge Design for Marine Vessel Collision

Zolan Prucz, Ph.D., P.E.
Modjeski and Masters, Inc.

2007 Louisiana Transportation Engineering Conference
Baton Rouge, Louisiana
• Factors Involved
• Historical Developments
• Current Design Practice
• Recommendations
RISK OF VESSEL COLLISION

I-40 Bridge, Webbers Falls, OK, May 26, 2002

BRIDGE CHARACTERISTICS

WATERWAY CHARACTERISTICS

VESSEL TRAFFIC CHARACTERISTICS

NAVIGATION CHARACTERISTICS
Historical Developments

Design Criteria for Vessel Collision

Prior to 1980: Criteria was limited to special projects and movable bridge fenders

1980 – 1984: Increase in awareness and research efforts


## Vessel Collision Accidents Since 1980

<table>
<thead>
<tr>
<th>Year</th>
<th>Bridge</th>
<th>Cause</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>Almo Br., Sweden</td>
<td>weather</td>
<td>8</td>
</tr>
<tr>
<td>1980</td>
<td>Sunshine Skyway Br., FL</td>
<td>weather</td>
<td>35</td>
</tr>
<tr>
<td>1982</td>
<td>Lorraine Br., France</td>
<td>weather</td>
<td>7</td>
</tr>
<tr>
<td>1983</td>
<td>Volga River RR, Russia</td>
<td>human error</td>
<td>176</td>
</tr>
<tr>
<td>1984</td>
<td>Causeway Br., LA</td>
<td>human error</td>
<td>0</td>
</tr>
<tr>
<td>1987</td>
<td>Sidney Lanier Br., FL</td>
<td>human error</td>
<td>0</td>
</tr>
<tr>
<td>1993</td>
<td>Claiborne Ave., LA</td>
<td>human error</td>
<td>1</td>
</tr>
<tr>
<td>1993</td>
<td>CSX RR Br., AL</td>
<td>human error</td>
<td>47</td>
</tr>
<tr>
<td>2001</td>
<td>Port Isabel, TX</td>
<td>human error</td>
<td>8</td>
</tr>
<tr>
<td>2002</td>
<td>Webbers Falls, OK</td>
<td>medical cond</td>
<td>12</td>
</tr>
</tbody>
</table>
Causes of Accidents

• 70% Human Error (misunderstandings, insufficient information, bad maneuvering, alcohol or drugs, lack of skill, attention or sleep)

• 20% Mechanical Failure (engine, steering, navigation instruments)

• 10% Extreme Environmental Conditions (winds, currents, fog, rain)
Current Design Practice

Method I (AASHTO Guide)
1. Collect vessel and waterway data
2. Select design vessel and compute collision loads

Method II (AASHTO Guide, AASHTO LRFD)
1. Collect vessel, navigation, waterway and bridge data
2. Perform probability based analysis and select pier capacities
AASHTO Method II

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

AF = Annual Frequency of Collapse
N = Annual Number of Vessels
PA = Probability of Vessel Aberrancy
PG = Geometric Probability
PC = Probability of Collapse

AF acceptable: < 0.0001 for Critical Bridges
< 0.001 for Regular Bridges
Annual Number of Vessels, \( N \)

Number of vessels \( N \), grouped by

- Type
- Size and shape
- Loading condition
- Direction of traffic

Adjusted for the water depth at each pier
Probability of Vessel Aberrancy, PA

$$PA = (BR) \ (R_B) \ (R_C) \ (R_{XC}) \ (R_D)$$

**BR** = Aberrancy base rate

**$R_B$** = Correction factor for bridge location

**$R_C$** = Correction factor for parallel current

**$R_{XC}$** = Correction factor for cross-currents

**$R_D$** = Correction factor for vessel density
Correction factor for bridge location, $R_B$

Waterway Regions for Bridge Location
Geometric Probability, PG

• Models the location of an aberrant vessel relative to the channel
• Quantifies the conditional probability that a vessel will hit a pier given that it is aberrant
• Accounts for the lower likelihood of an aberrant vessel being located further away from the channel
Geometric Probability Model

Normal Distribution with $\sigma = \text{LOA}$

Geometric Probability of Pier Collision
Probability of Collapse, $PC$

Reduces AF by a factor that varies from 0 to 1

\[
P_C = \begin{cases} 
0.1 + 9(0.1 - H/P) & \text{if } 0.0 \leq H/P < 0.1 \\
(1.0 - H/P)/9 & \text{if } 0.1 \leq H/P < 1.0 \\
0.0 & \text{if } H/P \geq 1.0 
\end{cases}
\]

where:

$H$ = resistance of bridge component (kips)
$P$ = vessel impact force (kips)
Probability of Collapse Distribution (PC)
Ship Collision Force on Pier, $P_S$

$$P_S = 8.15 \ (DWT)^{1/2} \ V$$

$P_S$ = Equivalent static impact force (Kips)
DWT = Deadweight tonnage (Tonnes)
$V$ = Vessel collision velocity (Ft/sec)
Figure Shows Typical Ship Impact Forces

Ship Impact Force, $P_S$
Barge Collision Force on Pier, $P_B$

\[
P_B = 4,112(a_B)(R_B) \quad \text{for } a_B < 0.34
\]
\[
P_B = (1,349+110a_B)(R_B) \quad \text{for } a_B \geq 0.34
\]
\[
a_B = [(1+KE/5,672)^{1/2} - 1](10.2/R_B)
\]

$P_B$ = Equivalent static impact force (Kips)
$a_B$ = Barge bow indentation (ft)
$R_B$ = Ratio of barge width (ft) to 35 ft
$KE$ = Barge collision energy (K-ft)
Barge Tow Impact Force, $P_B$

Crushing Load Level: 35 Ft Wide Barge 1,350 k

Figure Shows Typical Hopper Barge (35 ft wide) Impact Forces
Recommendations

• Use a Comprehensive Approach
  – Reduce Likelihood of Vessel Aberrancy near a Bridge
  – Reduce Bridge Element Exposure to Aberrant Vessels
  – Reduce Consequences of Vessel Collisions

• Reduce Sensitivity of Design to Small Changes in Assumptions
Reduce Likelihood of Vessel Aberrancy

• Vessel and Vessel Navigation Aspects
  – Navigation practices and regulations
  – Aids to navigation
  – Vessel identification and monitoring

• Bridge and Bridge Location Aspects
  – Locate bridge away from bends, locks, docking facilities and other bridge crossings
  – Align bridge perpendicular to channel
  – Maximize horizontal and vertical clearance
Lake Pontchartrain Collision Avoidance System
Reduce Likelihood of Vessel Aberrancy

• Vessel and Vessel Navigation Aspects
  – Navigation practices and regulations
  – Aids to navigation
  – Vessel identification and monitoring

• Bridge and Bridge Location Aspects
  ➢ Locate bridge away from bends, locks, docking facilities and other bridge crossings
  – Align bridge perpendicular to channel
  – Maximize horizontal and vertical clearance
March 17, 1997 25 - Barge Tow Collision with the US 190 Bridge, Baton Rouge
February 2, 2007 - Barge Tow Collision with the US 80 Bridge, Vicksburg
April 4, 1998 Collision M/V Anne Holly with the Eads Bridge

April 26, 1984 Collision M/V Erin Marie with the Poplar Str. Bridge

April 2, 1983 Collision M/V City of Greenville with the Poplar Str. Bridge

April 4, 1998 Collision M/V Anne Holly with the Eads Bridge
April 4, 1998 Collision of the M/V Anne Holly with the Eads Bridge
Reduce Likelihood of Vessel Aberrancy

• Vessel and Vessel Navigation Aspects
  – Navigation practices and regulations
  – Aids to navigation
  – Vessel identification and monitoring

• Bridge and Bridge Location Aspects
  – Locate bridge away from bends, locks, docking facilities and other bridge crossings
  – Align bridge perpendicular to channel
  ➢ Maximize horizontal and vertical clearance
Recommendations

• Use a Comprehensive Approach
  – Reduce Likelihood of Vessel Aberrancy near a Bridge
  ➢ Reduce Bridge Element Exposure to Aberrant Vessels
  – Reduce Consequences of Vessel Collisions

• Reduce Sensitivity of Design to Small Changes in Assumptions
Reduce Bridge Element Exposure

• Limit Number of Piers Exposed to Vessel Contact
• Account for Riverbed Profile Changes and Scour
• Limit Physical Access to Piers
• Prevent Access to Protruding Underwater Pier Corners
• Provide Adequate Horizontal and Vertical Clearance
Reduce Bridge Element Exposure

• Limit Number of Piers Exposed to Vessel Contact

➢ Account for Riverbed Profile Changes and Scour

• Limit Physical Access to Piers
• Prevent Access to Protruding Underwater Pier Corners

• Provide Adequate Horizontal and Vertical Clearance
Mississippi River
Gulf Outlet Bridge
Pier Protection Study
May 28, 1993 Collision of the M/V Chris with the Claiborne Ave Bridge
Reduce Bridge Element Exposure

- Limit Number of Piers Exposed to Vessel Contact
- Account for Riverbed Profile Changes and Scour
  ➢ Limit Physical Access to Piers
  - Prevent Access to Protruding Underwater Pier Corners
  - Provide Adequate Horizontal and Vertical Clearance
New Pier Protection
Reduce Bridge Element Exposure

- Limit Number of Piers Exposed to Vessel Contact
- Account for Riverbed Profile Changes and Scour
- Limit Physical Access to Piers
  - Prevent Access to Protruding Underwater Pier Corners
- Provide Adequate Horizontal and Vertical Clearance
September 27, 1996 Collision of the Julie N Tanker with the Million Dollar Bridge
Reduce Bridge Element Exposure

- Limit Number of Piers Exposed to Vessel Contact
- Account for Riverbed Profile Changes and Scour
- Limit Physical Access to Piers
- Prevent Access to Protruding Underwater Pier Corners

➢ Provide Adequate Horizontal and Vertical Clearance
Recommendations

• Use a Comprehensive Approach
  – Reduce Likelihood of Vessel Aberrancy near a Bridge
  – Reduce Bridge Element Exposure to Aberrant Vessels
  ➢ Reduce Consequences of Vessel Collisions

• Reduce Sensitivity of Design to Small Changes in Assumptions
Reduce Consequences of Collision

• Provide Stronger Piers
• Check Both Global and Local Pier Capacity
• Provide Redundancy
• Limit the Extent of Damage
• Provide Adequate Detailing
• Protection of Public and Environment
January 10, 1988 Collision of the Turpial with the Huey P. Long Bridge
Reduce Consequences of Collision

- Provide Stronger Piers
  ➢ Check Both Global and Local Pier Capacity
- Provide Redundancy
- Limit the Extent of Damage
- Provide Adequate Detailing
- Protection of Public and Environment
Check Global and Local Pier Capacity
May 9, 1980 Summit Venture Collision with the Sunshine Skyway Bridge
May 3, 1987 Ziema Bialostoka Vessel Collision with the Sidney Lanier Bridge
Reduce Consequences of Collision

• Provide Stronger Piers

• Check Both Global and Local Pier Capacity

➢ Provide Redundancy

• Limit the Extent of Damage

• Provide Adequate Detailing

• Protection of Public and Environment
January 14, 1989 Barge Tow Collision with U.S. 98 Bridge, Pensacola, FL
Reduce Consequences of Collision

- Provide Stronger Piers
- Check Both Global and Local Pier Capacity
- Provide Redundancy
  - Limit the Extent of Damage
- Provide Adequate Detailing
- Protection of Public and Environment
May 9, 1980 Summit Venture Collision with the Sunshine Skyway Bridge, FL
May 26, 2002 M/V Robert Y. Love Tow Collision with the I-40 Bridge, OK
October 13, 1987 Tillawook Tug and Barge Collision with the Coos Bay Bridge
Reduce Consequences of Collision

• Provide Stronger Piers
• Check Both Global and Local Pier Capacity
• Provide Redundancy
• Limit the Extent of Damage
  ➤ Provide Adequate Detailing
• Protection of Public and Environment
May 26, 2002 M/V Robert Y. Love Tow Collision with the I-40 Bridge, OK
- Spalling of column concrete cover
- Loss of long. reinforcing bar anchorage
- Loss of hoop splice capacity
Reduce Consequences of Collision

• Provide Stronger Piers
• Check Both Global and Local Pier Capacity
• Provide Redundancy
• Limit the Extent of Damage
• Provide Adequate Detailing

➢ Protection of Public and Environment
Motorist Warning Systems

May 26, 2002 I-40 Bridge Accident

May 9, 1980 Sunshine Skyway Bridge
Protection of Environment
Recommendations

• Use a Comprehensive Approach
  – Reduce Likelihood of Vessel Aberrancy near a Bridge
  – Reduce Bridge Element Exposure to Aberrant Vessels
  – Reduce Consequences of Vessel Collisions

➢ Reduce Sensitivity of Design to Small Changes in Assumptions
Reduce Sensitivity of Design to Small Changes in Assumptions

• Vessel Speed
• Pier Strength / Impact Load
• River Stage and Riverbed Profile
• Vessel and Traffic Characteristics
Sensitivity to Vessel Speed and Pier Strength / Impact

- **Left Graph**: Shows the relationship between tow length and barge impact forces (1,000 KIPS) as a function of impact speed (knots). Lines represent different numbers of barges. The graph indicates how the impact force increases with speed and number of barges.

- **Right Graph**: Displays the probability of collapse (PC) as a function of the ratio of ultimate bridge element strength to vessel impact force.
Sensitivity Analysis for Annual Frequency of Pier Collapse, AF

Required Pier Capacity, H

Pier AF
Reduce Sensitivity of Design to Small Changes in Assumptions

- Vessel Speed
- Pier Strength / Impact Load
- River Stage and Riverbed Profile
- Vessel and Traffic Characteristics
Sensitivity to River Stage

River Stage

P/H

GLOBAL CAPACITY

LOCAL CAPACITY

1.0
Reduce Sensitivity of Design to Small Changes in Assumptions

• Vessel Speed
• Pier Strength / Impact Load
• River Stage and Riverbed Profile

➢ Vessel and Traffic Characteristics
Summary

- Use a Comprehensive Approach
  - Reduce Likelihood of Vessel Aberrancy near a Bridge
  - Reduce Bridge Element Exposure to Aberrant Vessels
  - Reduce Consequences of Vessel Collisions
- Reduce Sensitivity of Design to Small Changes in Assumptions