Replacement of Fender System at I-10 Mississippi River Bridge

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DWT = 96,315 Tonnes
Loa = 798 Feet
B = 137 Feet
Scope of Work

- Study Alternatives for Fender Repair or Replacement
- Develop Fender Selection and Design Criteria
- Prepare Plans and Specifications for the Selected Fender Alternative
Factors Involved

OVERALL BRIDGE “AF”

BRIDGE CHARACTERISTICS

WATERWAY CHARACTERISTICS

VESSEL TRAFFIC CHARACTERISTICS

NAVIGATION CHARACTERISTICS

FENDER DESIGN CRITERIA
Overall Risk to the Bridge ("AF")

**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 I

Design Vessel for Critical Bridges
• > 50 passages per year, or
• > 5% of the total number of passages

Design Vessel for Regular Bridges
• > 200 passages per year, or
• > 10% of the total number of passages
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
- Accounts for Pier Protection
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

\[ PC = 0.1 + 9(0.1 - H/P) \quad \text{if } 0.0 \leq H/P < 0.1 \]
\[ PC = (1.0 - H/P)/9 \quad \text{if } 0.1 \leq H/P < 1.0 \]
\[ PC = 0.0 \quad \text{if } H/P \geq 1.0 \]

where:

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

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

$P_S$ = Equivalent static impact force (Kips)

DWT = Deadweight tonnage (Tonnes)

$V$ = Vessel collision velocity (Ft/sec)
Ship Impact Force, $P_S$

Figure Shows Typical Ship Impact Forces
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
Factors Involved

OVERALL BRIDGE “AF”

BRIDGE CHARACTERISTICS

WATERWAY CHARACTERISTICS

VESSEL TRAFFIC CHARACTERISTICS

NAVIGATION CHARACTERISTICS

FENDER DESIGN CRITERIA
Bridge and Existing Fender Characteristics

Layout and geometry

Pier Capacities
Pier Geometry Findings:

- The pier columns could be exposed to ship deck contact and the criteria for the new fender should address prevention of access to the columns.

- The top of the distribution block forms an underwater shelf which could damage ship hulls and the criteria for the new fender should address prevention of protruding underwater ledges.
Pier Capacity Findings:

- The capacity of the pier to vessel collision is governed by the local capacity of the pier columns.

- The capacity of the pier shaft to resist collision loads in the longitudinal direction is relatively high and therefore a stronger and more rigid fender structure can be used to minimize repair and maintenance costs and to reduce the likelihood of vessel contact with the pier columns.

- The capacity of the pier to resist collision loads in the transverse direction is limited by the sectional capacity of the pier shaft at its base elevation. A weaker fender could reduce collision load levels but its deformation would have to be minimized to prevent contact with the pier columns.
## Pier Lateral Capacities (kips)

<table>
<thead>
<tr>
<th>Loading Direction</th>
<th>Longitudinal</th>
<th>Transverse</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foundation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caisson</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sliding</td>
<td>148039</td>
<td>351957</td>
</tr>
<tr>
<td>Overturning</td>
<td>78240</td>
<td>76592</td>
</tr>
<tr>
<td><strong>Sectional Capacities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section EL -19.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moment</td>
<td>80060</td>
<td>19544</td>
</tr>
<tr>
<td>Interface Shear</td>
<td>75921</td>
<td>75921</td>
</tr>
<tr>
<td>Shear</td>
<td>64062</td>
<td>42708</td>
</tr>
<tr>
<td><strong>Controlling Capacity</strong></td>
<td>64062</td>
<td>19544</td>
</tr>
</tbody>
</table>

## Localized Capacities

<table>
<thead>
<tr>
<th>Loading Direction</th>
<th>Longitudinal</th>
<th>Transverse</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pier Columns</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface Shear</td>
<td>9734</td>
<td>9734</td>
</tr>
<tr>
<td>Shear</td>
<td>5113</td>
<td>5113</td>
</tr>
<tr>
<td><strong>Base Shear</strong></td>
<td>5113</td>
<td>5113</td>
</tr>
</tbody>
</table>
Existing Fender System Characteristics
Existing Fender System Attributes

1. Reduction of the impact loads imparted to the vessel and the pier.
2. Prevention of potential sparks during collisions.
3. Ability to redirect, absorb energy and reduce loads on the pier during lower energy collisions and during impacts at an angle with the pier.
Factors Involved

OVERALL BRIDGE “AF”

BRIDGE CHARACTERISTICS

WATERWAY CHARACTERISTICS

VESSEL TRAFFIC CHARACTERISTICS

NAVIGATION CHARACTERISTICS

FENDER DESIGN CRITERIA
Waterway Characteristics and Docking Facilities

Bridge View Looking Downstream
Bridge View Looking Upstream
River Stage Daily Variations

Mississippi River at Baton Rouge (01160) From 01/01/1987 To 05/31/2007

Record High: 47.28
Flood Stage: 35
Bankfull: 29
Low Water Reference Plane: 2.57
Record Low: -0.07

Stage in Feet

Gage Zero = 0 Ft. NGVD
River Velocities at Baton Rouge Gage

River Velocity at Baton Rouge Gage (Mile 228.4) at 60% Depth

![Graph showing river velocities at Baton Rouge Gage](image-url)
Docking Facilities Near the Bridge

**East Bank Facilities**
A. Casino Rouge  
B. Capitol Fleet Landing Area  
C. Passenger Dock  
D. USS Kidd  
E. Belle of Baton Rouge Casino  
F. Old Baton Rouge City Wharf (Abandoned)  
G. McKinney Fleet and Barge Service Wharf  
L. International Marine Terminals, Moorings

**West Bank Facilities**
H. GBR Port Commission, Dock No. 1 Wharf  
I. GBR Port Commission, Dock Connection  
J. GBR Port Commission, Dock No. 2 Wharf  
K. GBR Port Commission, Petroleum Terminal  
M. GBR Port Commission, Grain Wharf
Vessel Anchorages Near the Bridge
Factors Involved

OVERALL BRIDGE "AF"

BRIDGE CHARACTERISTICS

WATERWAY CHARACTERISTICS

VESSEL TRAFFIC CHARACTERISTICS

NAVIGATION CHARACTERISTICS

FENDER DESIGN CRITERIA
Vessel Traffic Characteristics

Barge Tow Sizes

Common hopper barge tows:
- 35 barges in a 7 long x 5 wide configuration headed upstream and a 5 long x 7 wide configuration headed downstream.

Largest hopper barge tows:
- 49 barges, in a 7 x 7 configuration, 1,585 feet long x 245 feet wide.

Common tanker barge tows:
- 6 barges in a 3 long x 2 wide configuration.
### Largest Ship Sizes at Bridge

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Length (feet)</th>
<th>Breadth (feet)</th>
<th>Light Draft (feet)</th>
<th>Loaded Draft (feet)</th>
<th>Highest Fixed Point (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>810</td>
<td>110</td>
<td>19</td>
<td>44</td>
<td>161</td>
</tr>
<tr>
<td>Foreign</td>
<td>946</td>
<td>144</td>
<td>22</td>
<td>56</td>
<td>170</td>
</tr>
</tbody>
</table>

### Ship Characteristics by DWT Category

<table>
<thead>
<tr>
<th>DWT Category</th>
<th>Length (feet)</th>
<th>Breadth (feet)</th>
<th>Loaded Draft (feet)</th>
<th>Bow Depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000 to 24,999</td>
<td>200 to 525</td>
<td>30 to 81</td>
<td>4 to 31</td>
<td>24 to 70</td>
</tr>
<tr>
<td>25,000 to 49,999</td>
<td>525 to 664</td>
<td>81 to 103</td>
<td>31 to 39</td>
<td>70 to 79</td>
</tr>
<tr>
<td>50,000 to 74,999</td>
<td>664 to 771</td>
<td>103 to 120</td>
<td>39 to 45</td>
<td>79 to 86</td>
</tr>
<tr>
<td>75,000 to 99,999</td>
<td>771 to 860</td>
<td>120 to 134</td>
<td>45 to 50</td>
<td>86 to 91</td>
</tr>
<tr>
<td>100,000 to 124,999</td>
<td>860 to 939</td>
<td>134 to 146</td>
<td>50 to 54</td>
<td>91 to 96</td>
</tr>
<tr>
<td>125,000 to 133,000</td>
<td>939 to 962</td>
<td>147 to 150</td>
<td>54 to 56</td>
<td>96 to 97</td>
</tr>
<tr>
<td>DWT Category</td>
<td>Downbound Trips</td>
<td></td>
<td>Upbound Trips</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------</td>
<td>---</td>
<td>---------------</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>No (loaded)</td>
<td></td>
<td>No (loaded)</td>
<td></td>
</tr>
<tr>
<td>1,000 to 24,999</td>
<td>545 62.2%</td>
<td></td>
<td>603 64.4%</td>
<td></td>
</tr>
<tr>
<td>25,000 to 49,999</td>
<td>183 20.9%</td>
<td></td>
<td>182 19.4%</td>
<td></td>
</tr>
<tr>
<td>50,000 to 74,999</td>
<td>80  9.1%</td>
<td></td>
<td>83  8.9%</td>
<td></td>
</tr>
<tr>
<td>75,000 to 99,999</td>
<td>56  6.4%</td>
<td></td>
<td>57  6.1%</td>
<td></td>
</tr>
<tr>
<td>100,000 to 124,999</td>
<td>11  1.3%</td>
<td></td>
<td>11  1.2%</td>
<td></td>
</tr>
<tr>
<td>125,000 to 133,000</td>
<td>1   0.1%</td>
<td></td>
<td>1   0.1%</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>876 100.0%</td>
<td></td>
<td>937 100.0%</td>
<td></td>
</tr>
</tbody>
</table>
Ship Size Distribution Plot

DWT Category

Number of Trips

- 1,000 to 24,999
- 25,000 to 49,999
- 50,000 to 74,999
- 75,000 to 99,999
- 100,000 to 124,999
- 125,000 to 133,000

Legend:
- Downbound
- Upbound
Factors Involved

- Overall Bridge “AF”
- Bridge Characteristics
- Waterway Characteristics
- Vessel Traffic Characteristics
- Navigation Characteristics

Fender Design Criteria
Navigation Conditions and History of Accidents

Main Hazards to Navigation:

- High volume of through traffic combined with local vessel movements at nearby docks and anchorages

- During medium to high water river stages, currents make navigation difficult carrying vessels in the channel span towards Pier 5
AIS provides precise information on ship identification, position, speed and heading to a vessel traffic control center and to other AIS-equipped vessels.
Mariners departing Port Commission Dock No.2 are advised to use extreme caution when turning vessels downstream. Strong currents (over 7 knots) associated with high water have caused vessels departing this facility to be set down upon the fender system of the bridge, causing extensive damage. Moving vessels well above or below the bridge before turning downstream is advised.”
<table>
<thead>
<tr>
<th>Accident Number</th>
<th>Date</th>
<th>Location of Damage</th>
<th>Baton Rouge Gage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/12/77</td>
<td>South end of the Pier 5 fender system</td>
<td>23.08</td>
</tr>
<tr>
<td>2</td>
<td>5/27/77</td>
<td>North end and the east side of the Pier 5 fender system</td>
<td>10.00</td>
</tr>
<tr>
<td>3</td>
<td>12/5/77</td>
<td>West side of Pier 5 fender system</td>
<td>22.12</td>
</tr>
<tr>
<td>4</td>
<td>3/5/79</td>
<td>North end and east side of the Pier 5 fender system</td>
<td>29.43</td>
</tr>
<tr>
<td>5</td>
<td>6/14/82</td>
<td>Green navigation light was torn off</td>
<td>27.37</td>
</tr>
<tr>
<td>6</td>
<td>12/21/01</td>
<td>North end of the Pier 5 fender system</td>
<td>31.70</td>
</tr>
<tr>
<td>7</td>
<td>2/10/07</td>
<td>West side of the Pier 5 fender system</td>
<td>26.09</td>
</tr>
</tbody>
</table>
May 27, 1977 - M/V Gulf Solar
December 21, 2001 – M/V Ace G
Feb 10, 2007

- M/T Kition

DWT = 96,315 Tonnes
Loa  = 798 Feet
B    = 137 Feet
Fender Criteria

- Requirements and Attributes
- Evaluation Scenarios
- Performance Requirements
- Design Vessels
- Material Selection Criteria
Requirements and Attributes

1. Prevention of vessel access to the pier columns.
2. Protection of vessels from contacting underwater “shelf”.
3. Adequate strength, stiffness and energy absorption cap.
4. Elimination of sparks upon vessel impact.
5. Abrasion resistance and low coefficient of friction.
6. Low initial cost.
7. Ease of construction.
8. Ease of repair and replacement of damaged parts.
9. Durability and low maintenance costs.
Evaluation Scenarios

• Both barge and ship impacts at various angles and directions
• Both minor (low energy) but frequent collisions and potential for major (high energy) but rare collisions.

Performance Requirements

• Damage due to minor collisions should be limited and easily repairable
• Damage due to major collisions should be repairable at a reasonable cost
Design Vessels

- 6 - Hopper Barge Long Tow at 14.7 ft/sec
  \[ P_{\text{head-on}} = 5,000 \text{ kips}; \ P_{\text{sideways}} = 3,200 \text{ kips} \]

- 3 - Tanker Barge Long Tow at 14.7 ft/sec
  \[ P_{\text{head-on}} = 5,600 \text{ kips}; \ P_{\text{sideways}} = 3,800 \text{ kips} \]

- 100,000 DWT Ship at 14.7 ft/sec
  \[ P_{\text{head-on}} = 37,800 \text{ kips}; \ P_{\text{sideways}} = 18,900 \text{ kips} \]
Material Selection Criteria

- Requirements for the high energy but rare collision scenarios
- Requirements for the low energy but frequent collision scenarios
- Durability and ease of installation and repair

Composite Marine Timber Wales

- Low coefficient of friction
- High abrasion resistance
- Durable
\[ \eta = \frac{\text{absorbed collision energy}}{\text{initial ship's energy}} \]

**Coefficient of Friction (\( \mu \))**

- Steel - steel \( \sim 0.15 \)
- Steel - concrete \( \sim 0.35 \)
- Steel - wood \( \sim 0.65 \)
General Categories of Pier Protection

- Independent Systems
  - Sheet Pile Dolphins
  - Artificial Islands
  - Floating Systems
- Semi-Independent Systems
- Pier-Supported Systems
- Guide Fender Systems
Fred Hartman Bridge, Houston Ship Channel
San Mateo Hayward Bridge, CA
Honshu-Shikoku Bridge, Japan
ENLARGED DETAIL AT-X

SECTION AT A-A REFER PLAN IN FIG-'26'
Zuari Bridge, India
Alternative Fender Concepts Considered

A. Floating fender tied to the subshaft
B. Fender supported by the top of the subshaft
C. Fender supported on the face of the subshaft above water
D. Fender supported by the “shelf” on top of the distribution block
A. Floating Foam Filled Fenders
Attributes

• Effective for frequent low energy sideways berthing scenarios.
• Installation is relatively easy and the initial cost is relatively low.

Shortcomings

• Relatively soft with the energy absorption capacity rated at about 60% compression. Not effective in preventing vessel access to the pier columns and the underwater pier “shelf”.
• Little capacity in the longitudinal direction, ineffective and easily damaged after collisions at an angle.
• High maintenance costs of hardware.
B1. Gravity Type Fenders

Gravity Suspended Fenders
B1. Gravity Type Fenders

Attributes

- High energy-absorption and large impact load reductions can be achieved over long travel distance.

Shortcomings

- There is a need for large displacement for the fender to be effective.
- A strong supporting structure is required.
- Heavy equipment is necessary for installation and replacement.
- High initial and maintenance costs.
- Supporting structure can be damaged by ship’s overhang.
B2. Fixed Fender Supported on the Top of the Subshaft
B2. Fixed Fender Supported on the Top of the Subshaft

Attributes

• Underwater work is minimized.

Shortcomings

• The main supporting structure at the top of the subshaft is exposed to impact by ship’s overhang.
• Difficult fabrication of the many elements involved.
• Can be easily damaged during less severe collisions.
• Relatively high maintenance and repair costs.
Alternative Fender Types Evaluated

- **Alternative 1** – Steel Pipe Fender
- **Alternative 2** – Full Height Precast Concrete Cells
- **Alternative 3** – Steel Pipes with Brackets and Precast Concrete Modules
- **Alternative 4** – Steel Pipes with Full Depth Precast Concrete Modules
- **Alternative 5** – Full Depth Precast Concrete Modules
Alternative 1 – Steel Pipe Fender

Attributes

- Relatively simple installation.
- Relatively low initial cost.

Shortcomings

- Low strength in the longitudinal direction.
- Difficult fabrication of the brackets due to varying geometry and need to match existing geometry.
- Can be easily damaged during less severe collisions.
- Relatively high repair costs.
Alternative 2 – Full Height Precast Concrete Cells

Attributes

• Relatively fast installation.
• Not likely to be damaged during collisions.
• Satisfies performance requirements for the nose sections of the fender.
• Low maintenance costs.

Shortcomings

• Difficult fabrication of the cells due to varying geometry and need to match existing geometry.
• Requires higher capacity cranes.
• Difficult repairs and relatively high repair costs.
Alternative 3 – Steel Pipes with Brackets and Precast Concrete Modules

Attributes

• Satisfies performance requirements for both the nose and the side sections of the fender.
• Damaged concrete modules can be replaced.

Shortcomings

• Difficult fabrication of the brackets due to varying geometry and need to match existing geometry.
• Difficult repair of the steel pipes and brackets if they too get damaged.
Alternative 4 – Steel Pipes with Full Depth Precast Concrete Modules

Attributes

- Satisfies performance requirements for both the nose and the side sections of the fender.
- Damaged concrete modules can be replaced.

Shortcomings

- Difficult fabrication of the temporary brackets and modules due to varying geometry and need to match existing geometry.
- Difficult repair of the steel pipes if they too get damaged.
Alternative 5 – Full Depth Precast Concrete Modules

Attributes

• Satisfies performance requirements for both the nose and the side sections of the fender.
• Damaged concrete modules can be replaced.

Shortcomings

• There is more effort involved in the erection of the bottom concrete modules.