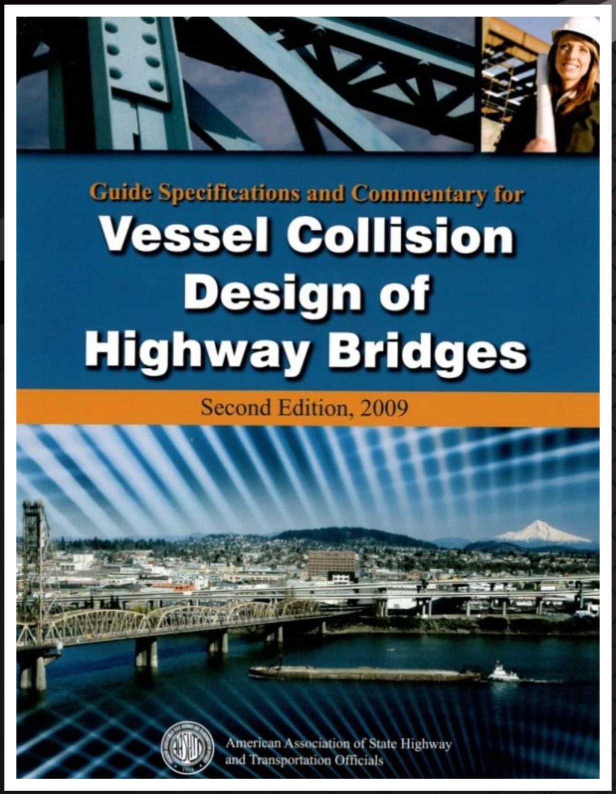



*AASHTO Code*

# SHIP & BARGE COLLISIONS WITH BRIDGES

## General Overview

moffatt & nichol

*Michael Knott, P.E.*

*Dr. Eric Nichol, P.E.*

*Mikele Winters, P.E.*

*Western Bridge Engineers' Seminar*

*September 4-6,2013*
*Bellevue, WA*

# Background

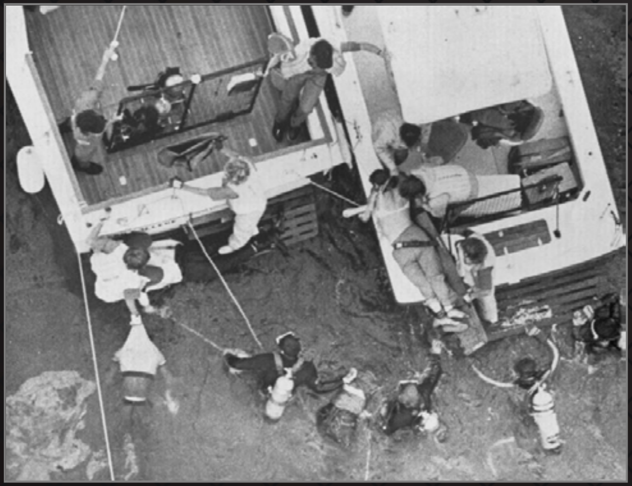
- Accidents do happen …
  - It's Only A Matter of Time (Risk)
  - Knott's Rule: If You Build It … They *Will* Hit It
- 36 Major Collapses since 1960 Due to Vessel Collisions
  - 18 Collapses in the U.S.
  - 340+ Fatalities
- 250+ Minor Vessel Collisions/Year

**Major Bridge Collapses in the U.S.**

| Bridge Location | Year | Fatalities |
|---|---|---|
| Lake Ponchartrain, LA | 1964 | 6 |
| Chesapeake Bay Bridge, VA | 1970 | 0 |
| Sidney Lanier Bridge, GA | 1972 | 10 |
| Chesapeake Bay Bridge, VA | 1972 | 0 |
| Lake Ponchartrain Bridge, LA | 1974 | 3 |
| Pass Manchac Bridge, LA | 1976 | 1 |
| Benjamin Harrison Bridge, VA | 1977 | 0 |
| Union Avenue Bridge, NJ | 1977 | 0 |
| Berwick Railroad Bridge, LA | 1978 | 0 |
| Sunshine Skyway Bridge, FL | 1980 | 35 |
| Hannibal Railroad Bridge, MI | 1982 | 0 |
| Lake Ponchartrain Bridge, LA | 1984 | 0 |
| Bonner Bridge, NC | 1990 | 0 |
| Judge Seeber Bridge, LA | 1993 | 1 |
| Bayou Canot RR Bridge, AL | 1993 | 47 |
| Queen Isabella Bridge, TX | 2001 | 8 |
| I-40 Bridge over Ark. River, OK | 2002 | 13 |
| Popps Ferry Bridge, MS | 2009 | 0 |
| Eggner Ferry Bridge, KY | 2012 | 0 |

# Background

- People do die … Really!
  - If it happened to you ….
    You wouldn't like it either



# Background

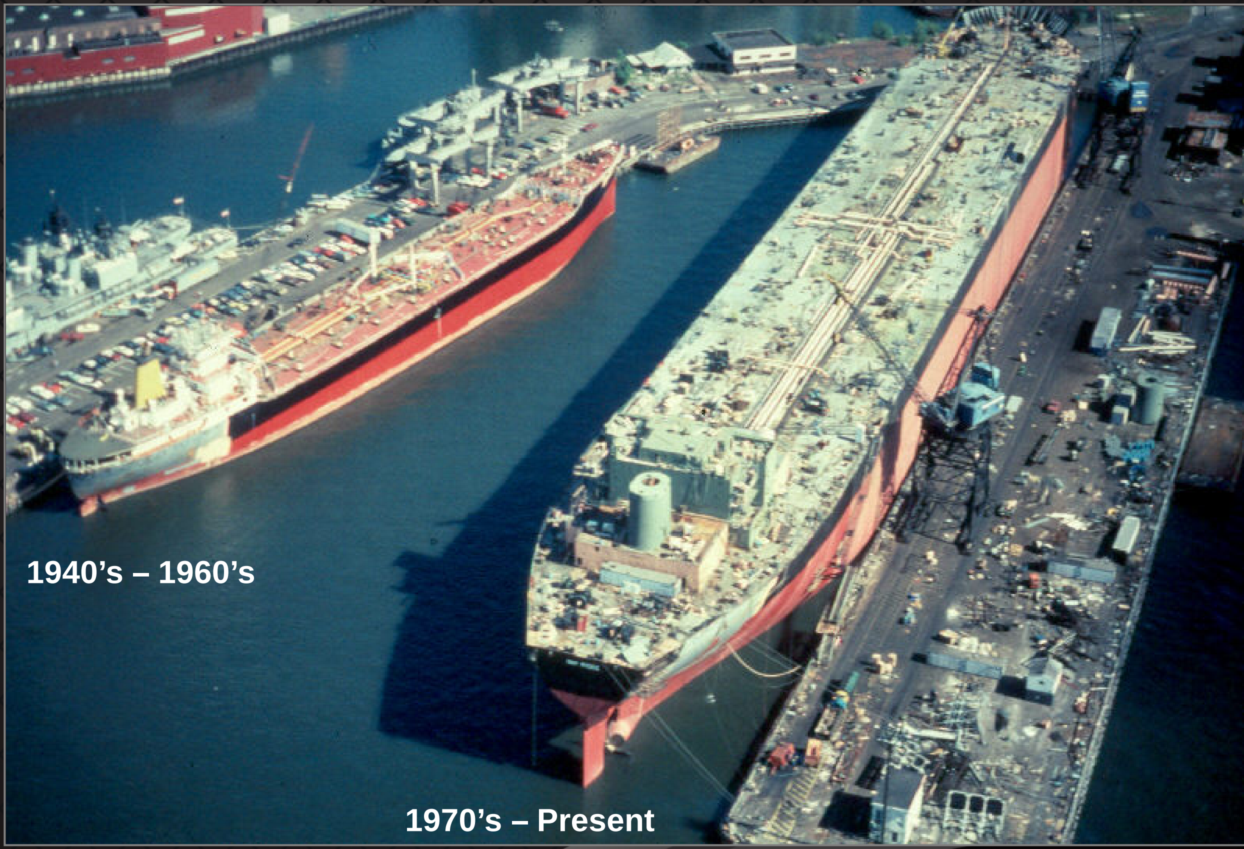
- Oil spills from accidents do occur … Really!

Barge Collision with Swing Bridge Fender System

Ship Collision with San Francisco – Oakland Bay Bridge Main Pier Fender System

# Background

- Modern Vessels Are Longer & Wider Than In The Past



# Background

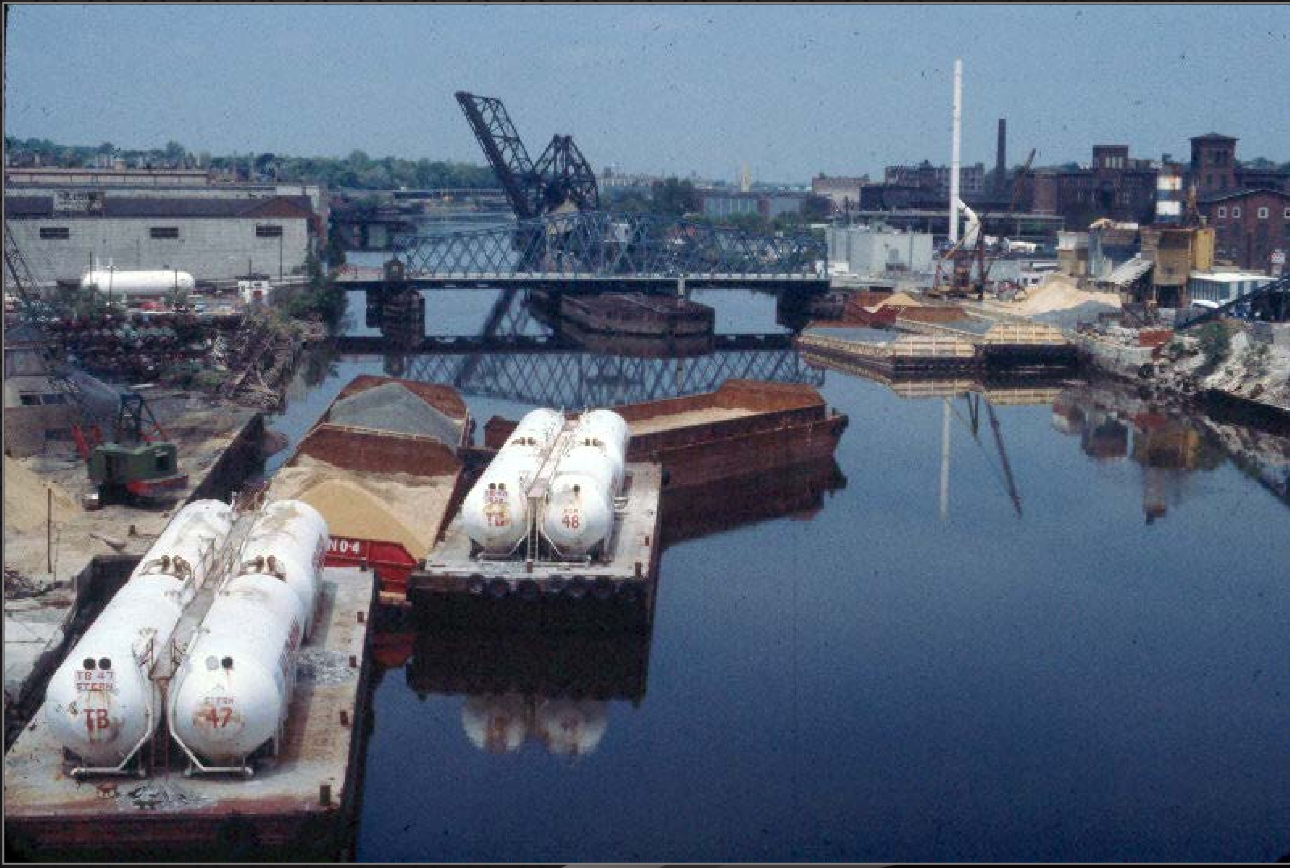
- Many older "Long Span" bridges … aren't long enough for today's larger vessels

# Background

- Many bridge openings are too narrow for today's larger/wider ships and barge tows

# Background

- Bridges are often located near congested marine terminal facilities



# Background

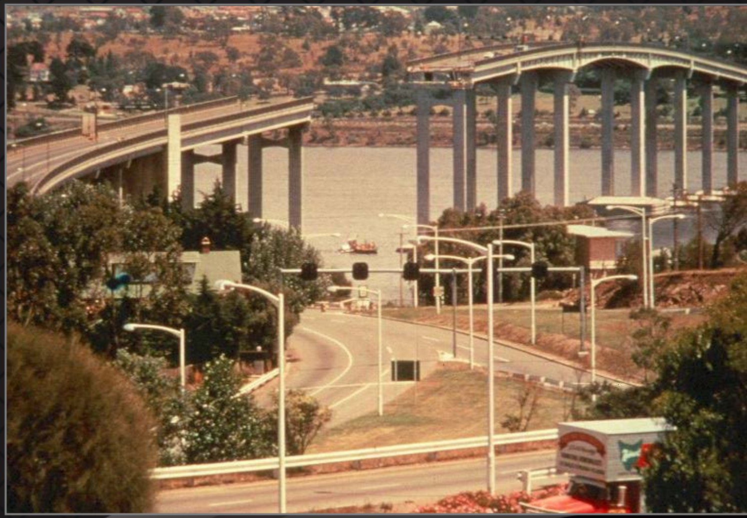
- Too many bridges over navigable waterways in some locations

# Background

- Frequency of ship & barge traffic has increased in many harbors and channels

# Background

- Vessels Get In Trouble Due to ...
  PILOT ERROR
- Some Causes ...
  - Inattentiveness
  - Drunkenness/Tiredness
  - Crew Misunderstandings
  - Poor Judgment
  - Violate Navigation Rules
  - Incorrect Evaluation
    of Wind/Current Conditions



# Background

- Vessels Get In Trouble Due to …
  MECHANICAL FAILURE
- Some Causes ...
  - Engine Failure
  - Steering Failure
  - Other Mechanical & Electrical Equipment Failures

# Background

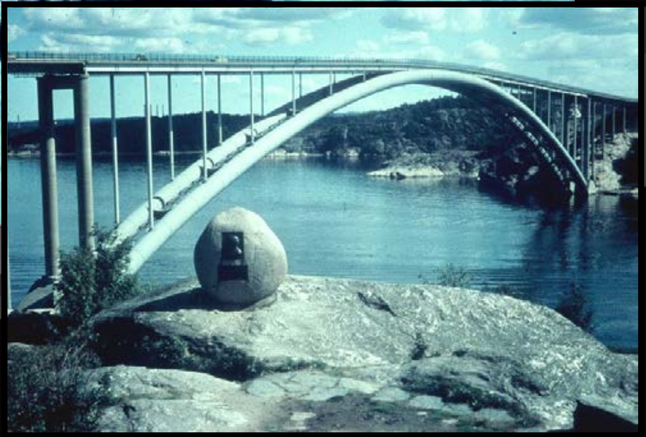
- Vessels Get In Trouble Due to … ADVERSE ENVIRONMENTAL CONDITIONS
- Some Causes ...
  - Poor Visibility (Rainstorm, Fog)
  - High Density of Ship & Barge Traffic
  - Strong Currents
  - Wind Squalls
  - Poor Navigation Aids
  - Awkward Channel Alignments

# *Sunshine Skyway Bridge*

*Tampa Bay, FL (1980)*

# *Tjörn Bridge*

*Almo Sound, Sweden (1980)*



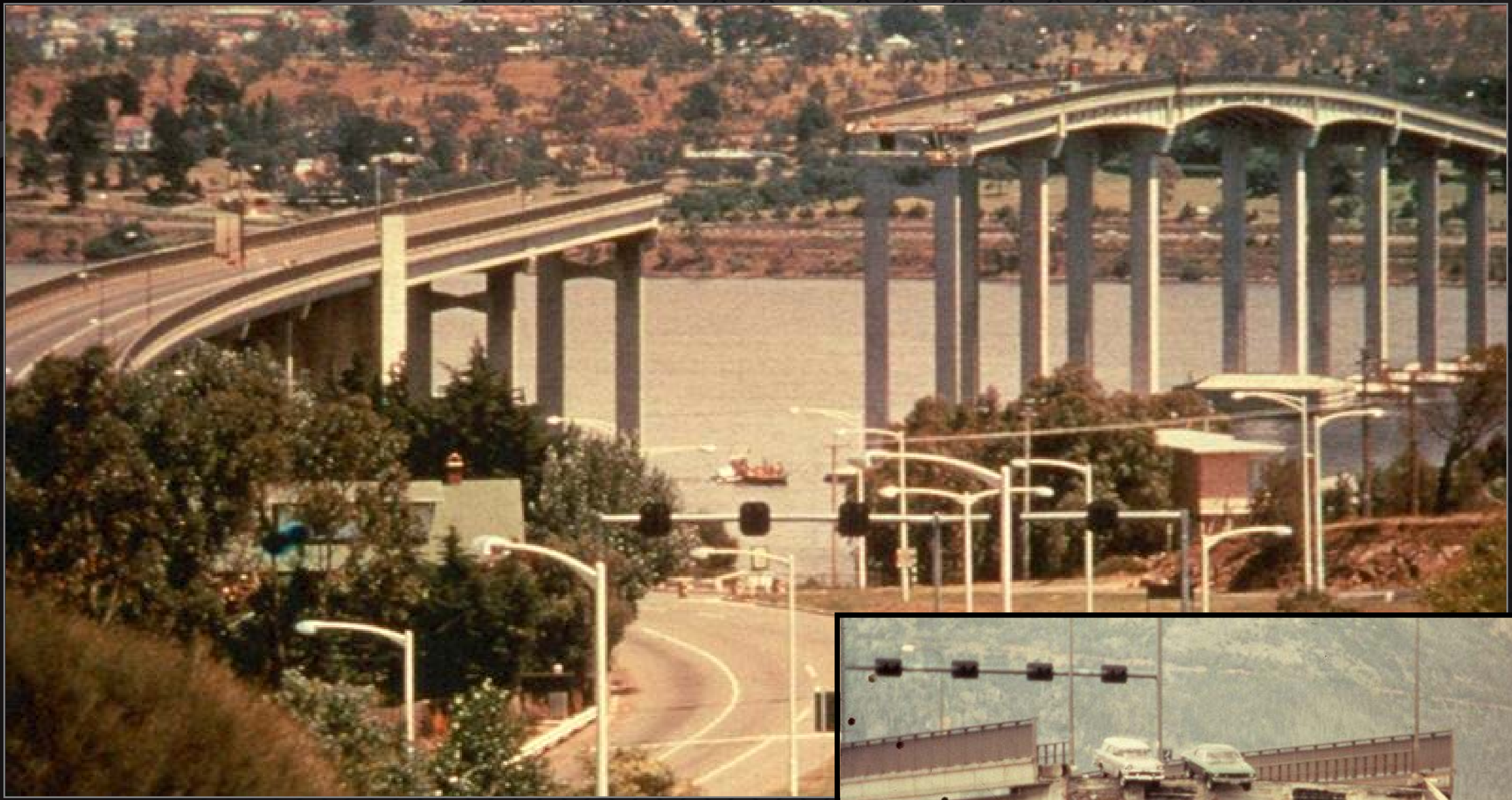
# ***Ulyanovsk Railway Bridge***

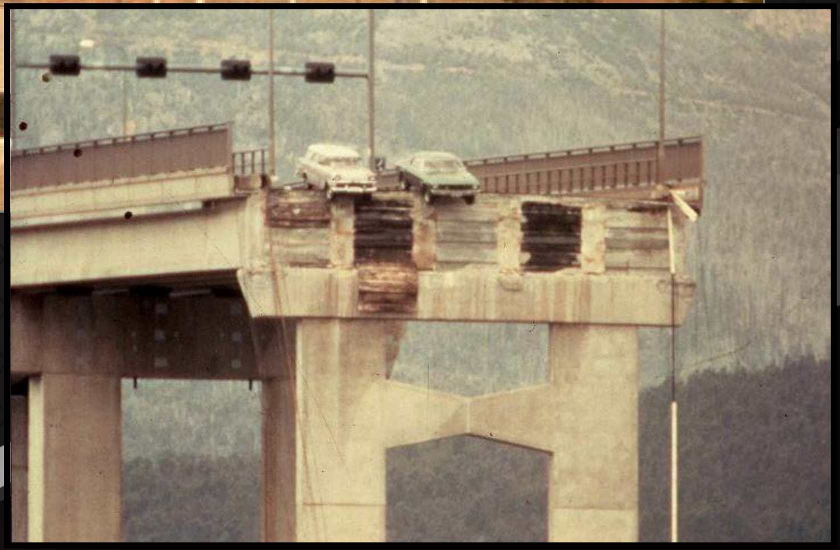
*Volga River, Russia (1983)*

**177 Fatalities when top deck of cruise ship was “decapitated”**

# *Tasman Bridge*

*Derwent River, Hobart, Australia (1975)*





# *Benjamin Harrison Bridge*

*James River, Hopewell, VA  (1977)*

# Sidney Lanier Bridge

*Brunswick, GA (1983)*


# Bonner Bridge

*Oregon Inlet, NC (1990)*

# Claiborne Ave. Bridge
*New Orleans, LA (1993)*

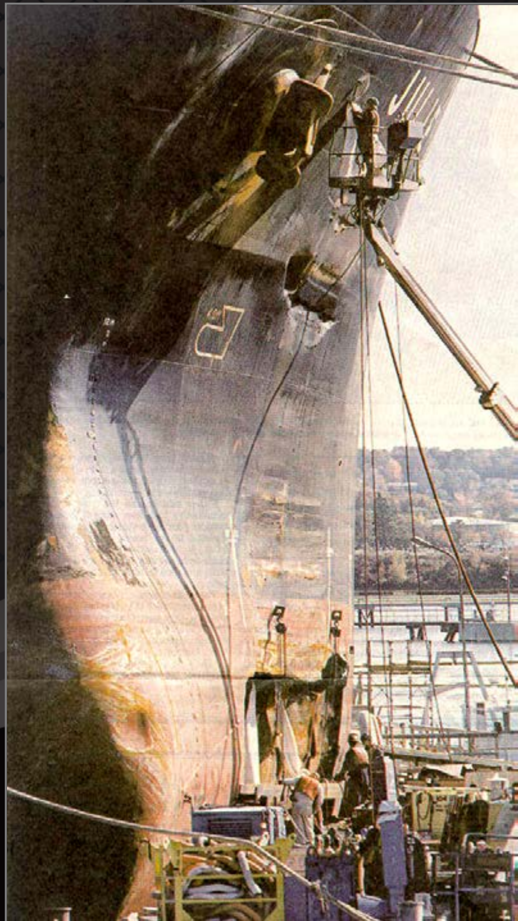
# Bayou Canot RR Bridge

*Mobile, AL (1993)*

# *Million Dollar Bridge*

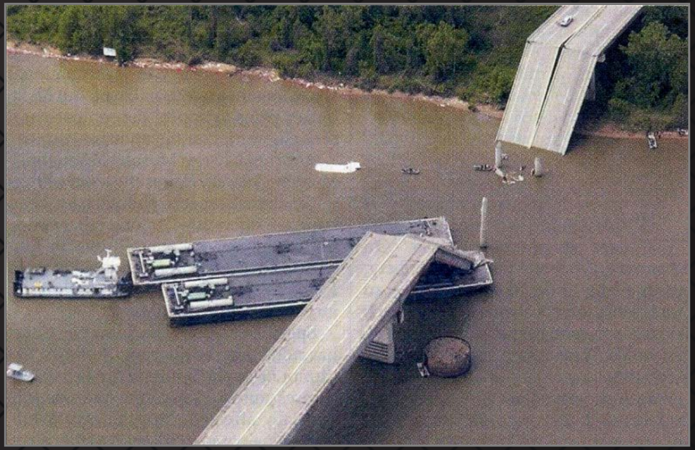
*Portland, Maine (1996)*

- Tanker Ship Accident (LOA=560’, Width=85’)
- Double Leaf Bascule Bridge (Horizontal Navigation Clearance = 95’)
- 170,000 Gallons of Fuel Oil Spilled



# *Queen Isabella Bridge*
## *South Padre Island, TX (2001)*

# I-40 Bridge over Arkansas River
## *Webber Falls, OK (2002)*



# *Popps Ferry Bridge*

*Biloxi, Miss (March 2009)*

"There's 35,000 cars a day that goes across this bridge," A.J. Holloway said.  "How there wasn't a car on there, or a vehicle, or a school bus at that time (7:20 AM), on that span, is just amazing to me."

# ***Eggner Ferry Bridge***

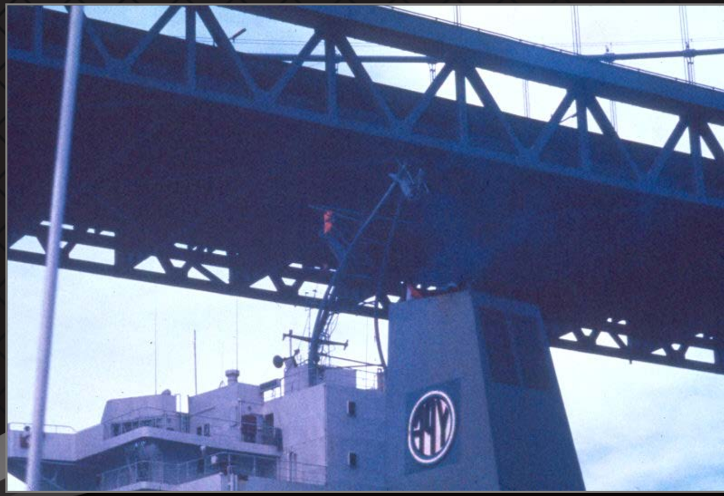
*Marshall, KY (January 2012)*

# Movable Bridges

- Get hit fairly often … (like magnets to vessels)

# Mast Collisions

- Occur frequently – but are usually not catastrophic



# Legal Things You Should Know …

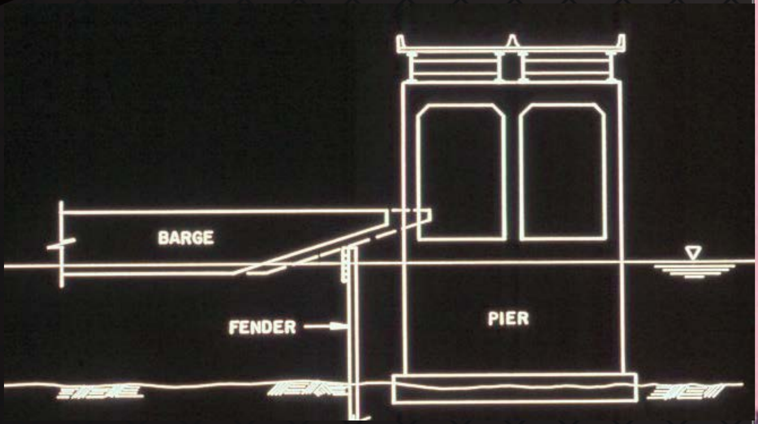
- Bridges Are ***Obstructions*** to Marine Navigation
- Mariners Have the Right of Way … ***Not Motorists***
- Bridges Must Provide for the ***Reasonable*** Needs of Navigation
- Bridges *are* ***Permitted*** to be Built as Obstructions to Navigation by the USCG
- Bridges ***Must*** be Maintained in Accordance with USCG Permits

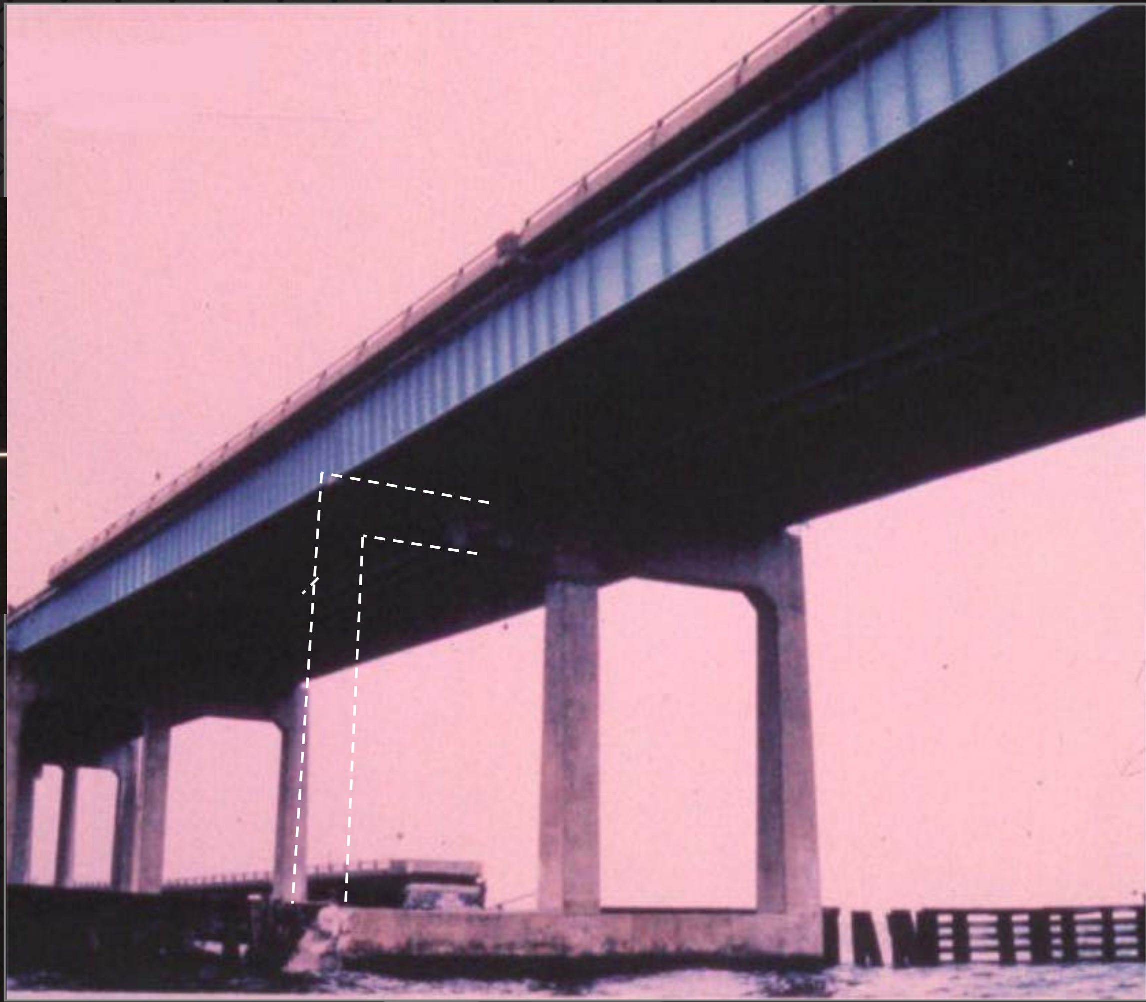
# Collision Code Purpose

- "In navigable waterway areas, where vessel collision by merchant ships and barges may be anticipated, bridge structures shall be designed to *prevent collapse of the superstructure* by considering the size and type of the vessel, available water depth, vessel speed, and structure response."
  - Significant damage, even failure, of secondary members is permitted as long as redundant load paths exist and the superstructure does not collapse
- "Bridges over a navigable waterway meeting the guide specification criteria, *whether existing or under design*, should be evaluated as to its vulnerability to vessel collision in order to determine prudent measures to be taken for its protection."

# Pensacola Bay Bridge

*Florida (1989)*

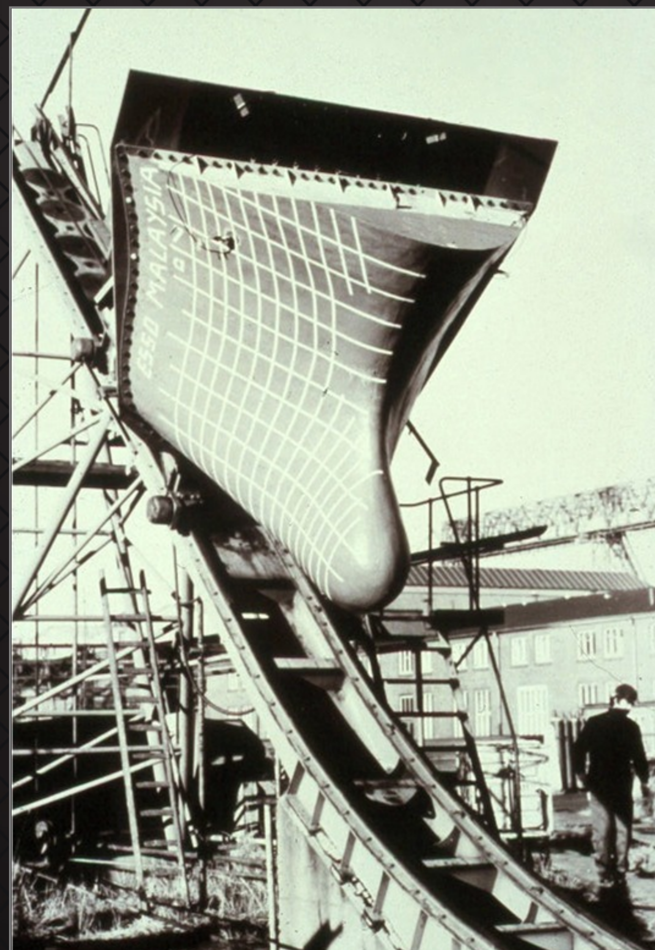


**Bridge Superstructure Survived Due To Structural Redundancy**

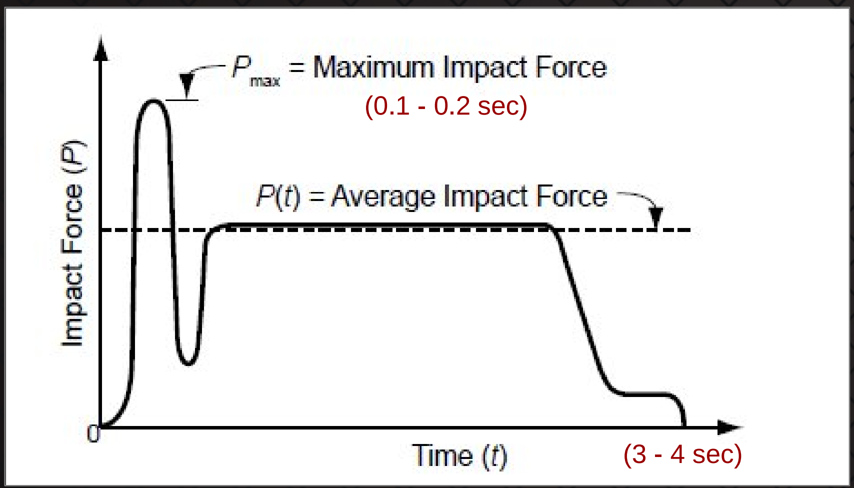
# Ship Collision Force on Pier

- Woisin's large-scale dynamic model tests

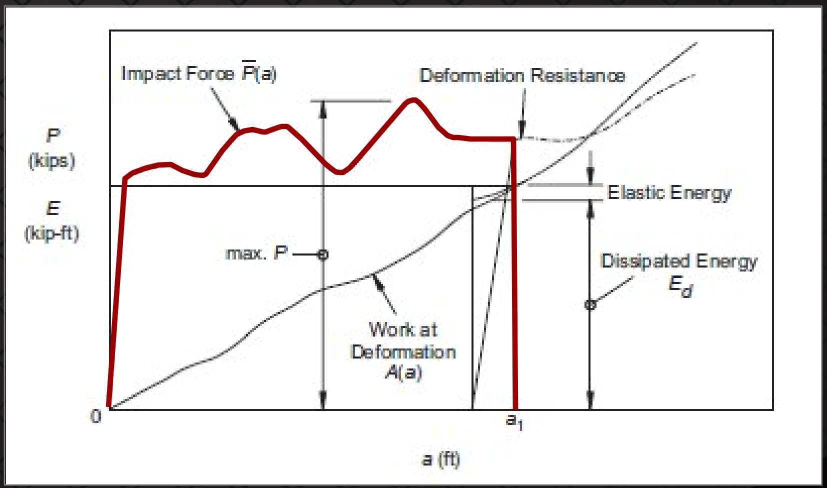



# Ship Collision Force on Pier

- Typical impact data from Woisin




Average Impact Force vs. Time (t)

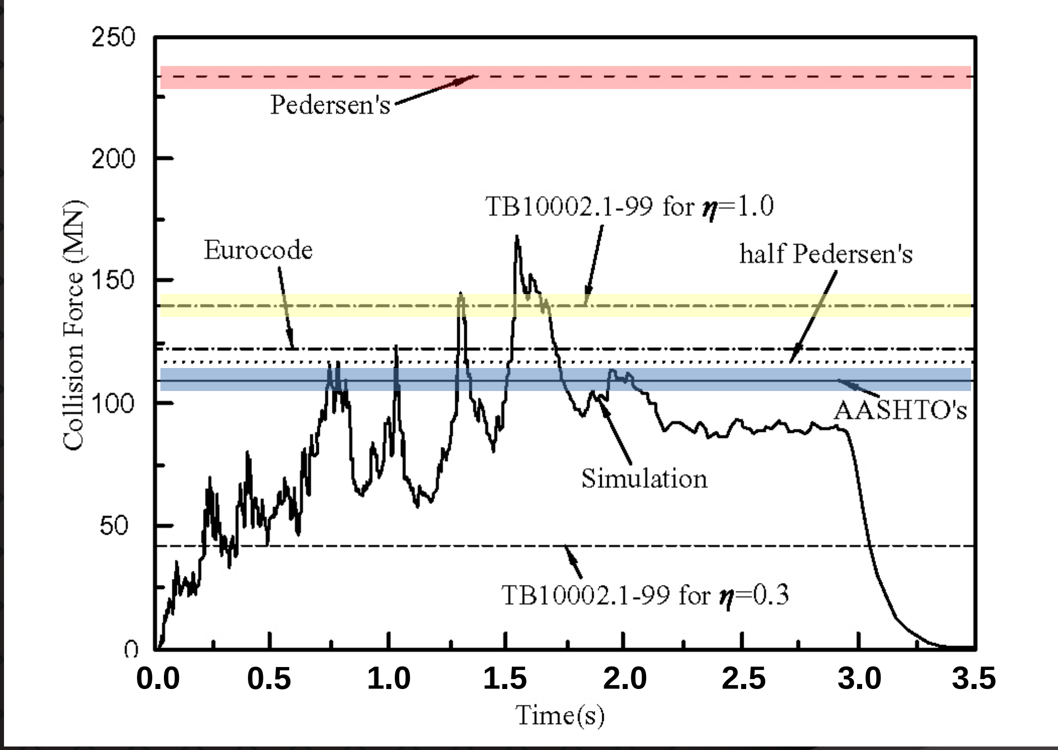



Average Impact Force vs. Bow Crushing Length (a)

$$\overline{P}(t) = (1.25)\overline{P}(a)$$

# Ship Collision Force on Pier

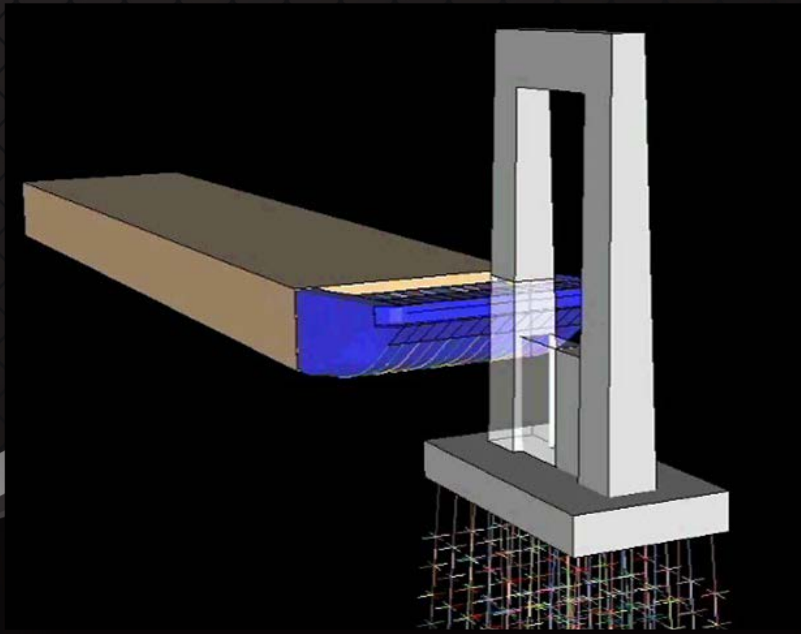
- Guide Commentary contains discussion of differences
  in ship collision forces between AASHTO, German, Asian, and Danish research




Comparison of ship impact forces for 50,000 DWT Bulk Carrier (Tongji Univ., Shanghai, China)

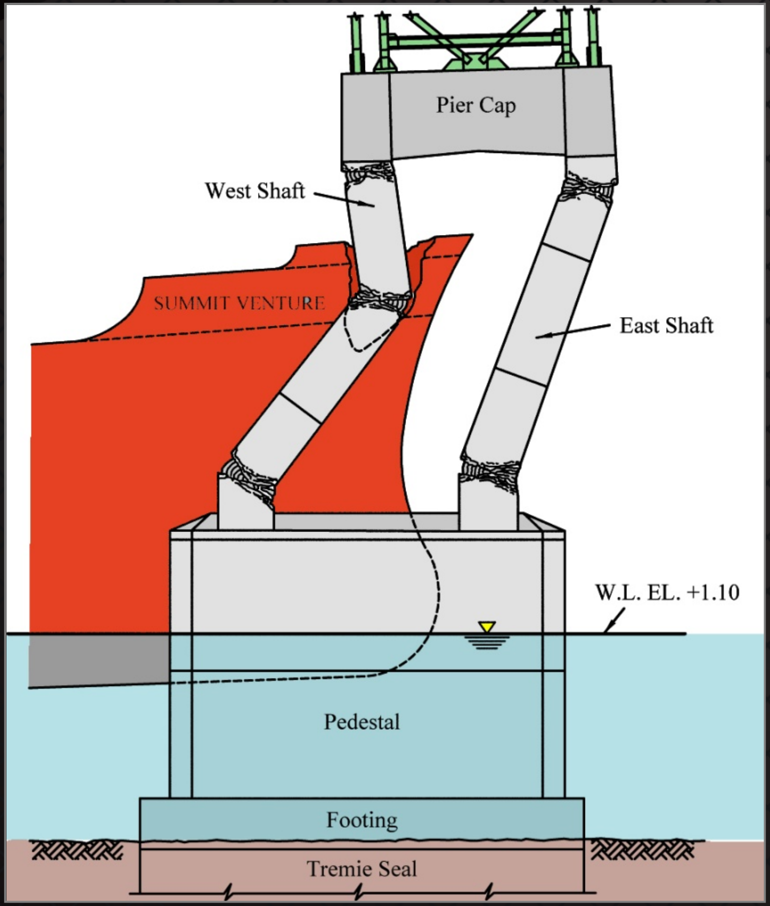
# Barge Collision Force on Pier

- Full scale barge impact testing by Florida DOT used by the University of Florida (2006) to develop and calibrate a FEM barge collision numerical model
  - St. George Bridge across Apalachicola Bay

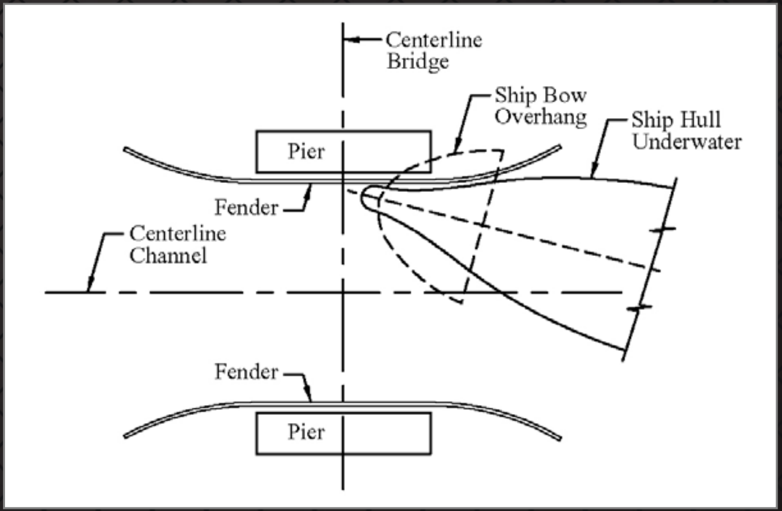


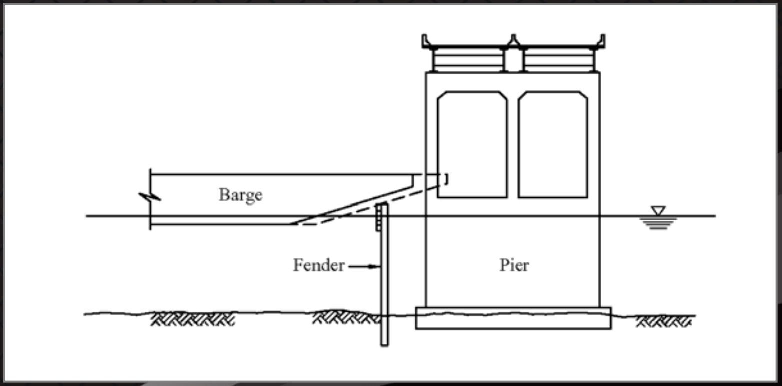
# Location of Impact Forces

- Examples of vessel bow overhang impact




Sunshine Skyway Bridge Collapse



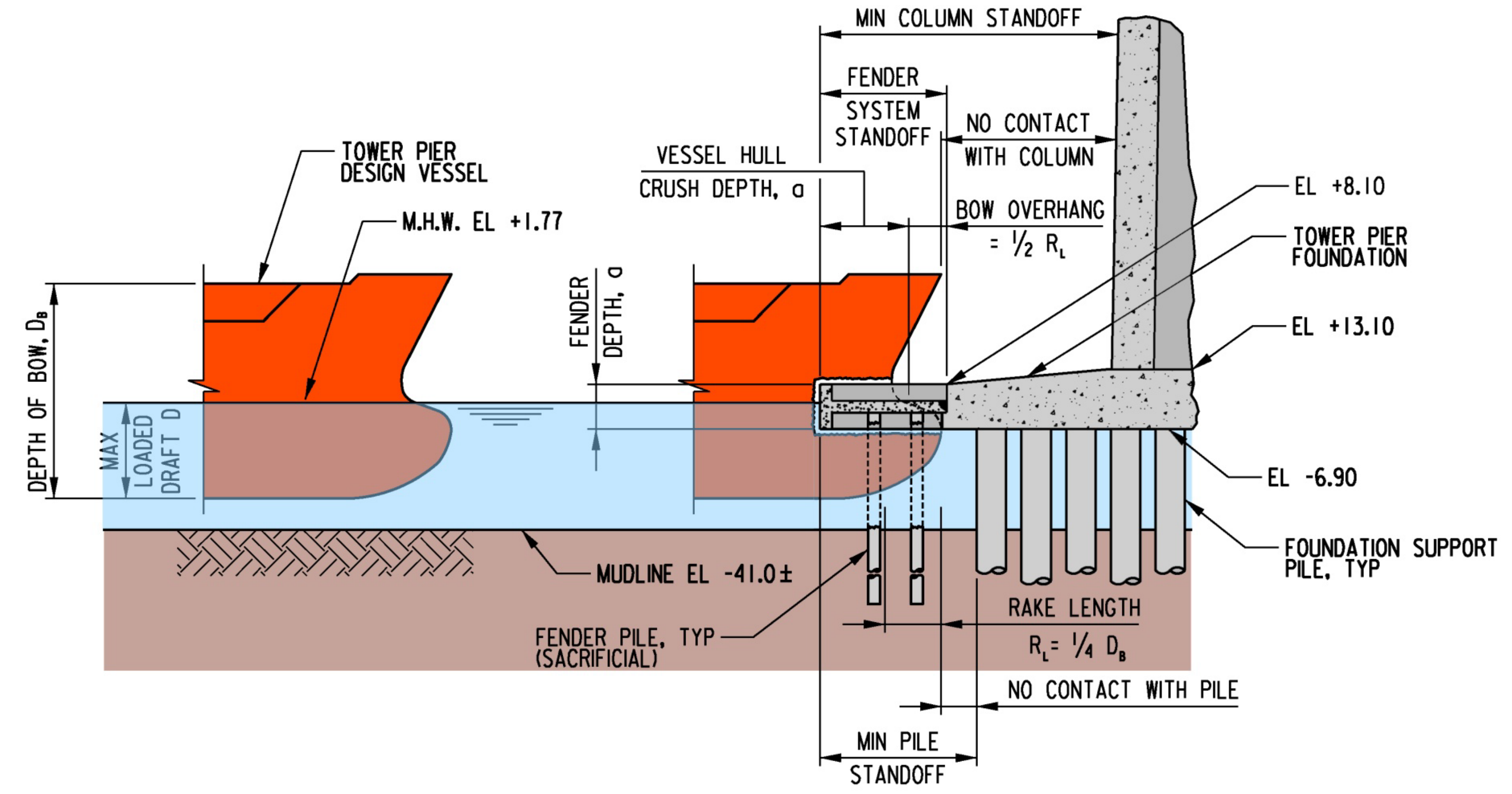
# Location of Impact Forces

- Example of ship bow overhang


Container Pier Accident

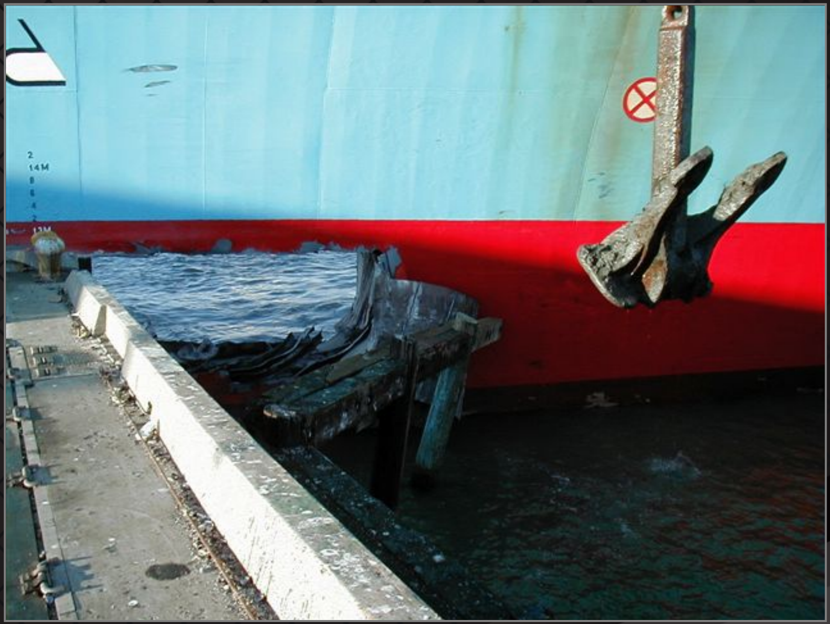
# Location of Impact Forces

- Local Bow Crushing During Impact



# Location of Impact Forces

- Local Bow Crushing During Impact

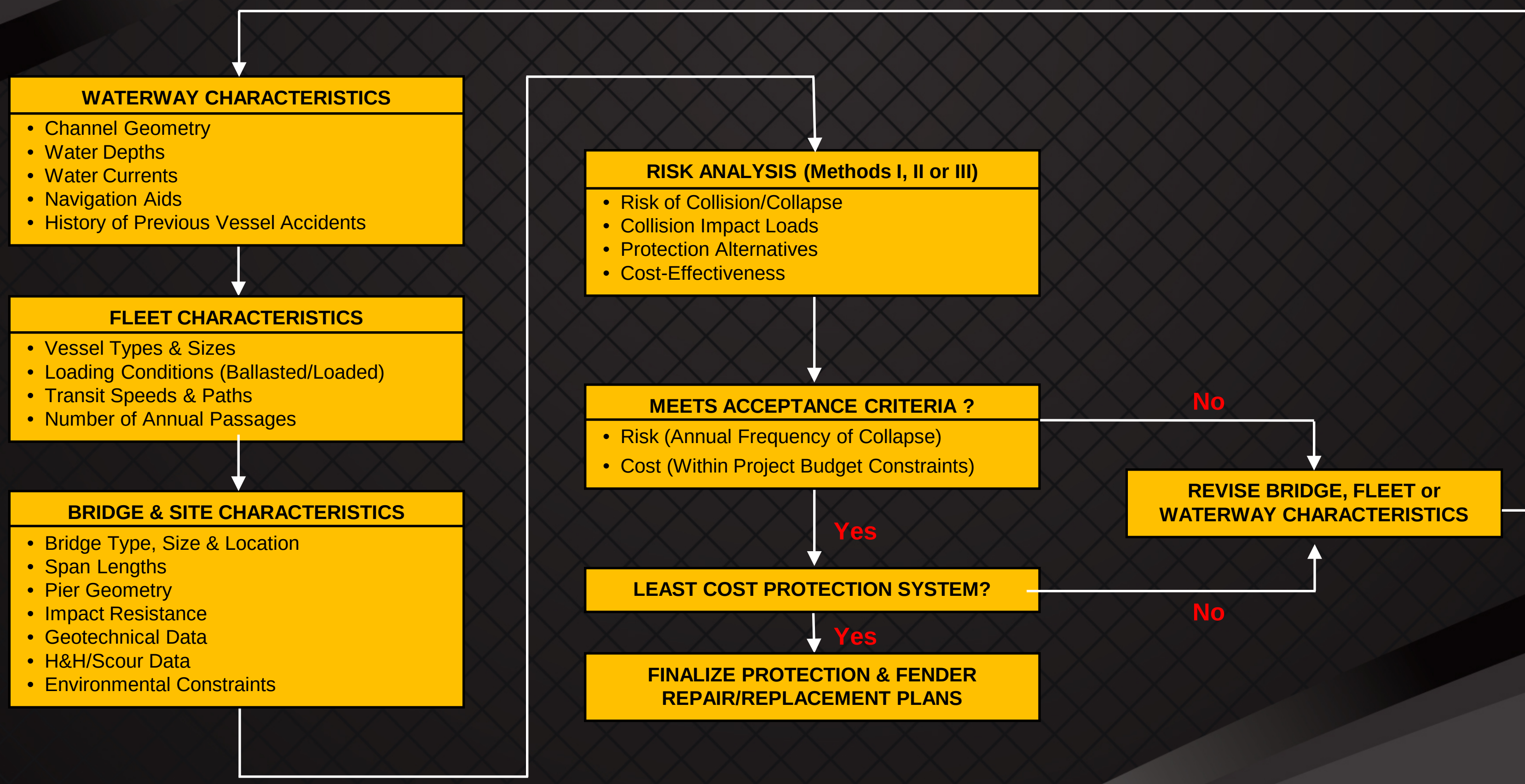



Container Pier Accident

# Bridge Analysis Options

- AASHTO provides three alternative analysis methods for determining the design vessel for each bridge component in the structure in accordance with a two-tiered risk acceptance criteria.
  - Method I is a simple to use semi-deterministic procedure
    - Limited to Barges in Shallow Draft Waterways
  - Method II is a detailed risk analysis procedure
    - Required for Ships in Deep Draft Waterways
  - Method III is a cost-effectiveness of risk reduction procedure
    - Based on a classical benefit/cost analysis
- Risk Acceptance Criteria
  - Critical Bridges: Risk of Collapse 1 in 10,000 years
  - Typical Bridges: Risk of Collapse 1 in 1,000 years

# Overview of Risk Analysis Procedure



# Annual Frequency of Collapse

- The annual frequency of bridge element collapse shall be computed by:

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

  - where,

AF = Annual frequency of bridge element collapse due to vessel collision
N = Annual number of vessels classified by type, size, and loading condition which can strike the bridge element
PA = Probability of vessel aberrancy
PG = Geometric probability of a collision between an aberrant vessel and a bridge pier or span
PC = Probability of bridge collapse due to a collision with an aberrant vessel
PF = Adjustment factor to account for potential protection of the piers from vessel collision due to upstream or down stream land masses, or other structures, that block the vessel from hitting the pier.

# Annual Frequency of Collapse

- Relatively straightforward analysis using programs like Excel or MathCAD to automate the repetitive analysis process
  - Setup for Each Specific Project
- Total bridge AF is the sum of the individual component AF's (piers exposed to collision)

Downbound Vessels

| AF |
|---|
| .... |
| .... |
| .... |
| .... |

Upbound Vessels

| Vessel Type | N | PA | PG | PC | PF | Growth Factor | AF |
|---|---|---|---|---|---|---|---|
| ……. | … | … | … | … | … | …. | …. |
| ……. | … | … | … | … | … | …. | …. |
| ……. | … | … | … | … | … | …. | …. |
| | | | | | | Total AF All Vessels | …. |

**Pier 1**

**+ (PLUS)**

Downbound Vessels

| AF |
|---|
| .... |
| .... |
| .... |
| .... |

Upbound Vessels

| Vessel Type | N | PA | PG | PC | PF | Growth Factor | AF |
|---|---|---|---|---|---|---|---|
| ……. | … | … | … | … | … | …. | …. |
| ……. | … | … | … | … | … | …. | …. |
| ……. | … | … | … | … | … | …. | …. |
| | | | | | | Total AF All Vessels | …. |

**Pier 2**

**+ (PLUS)**

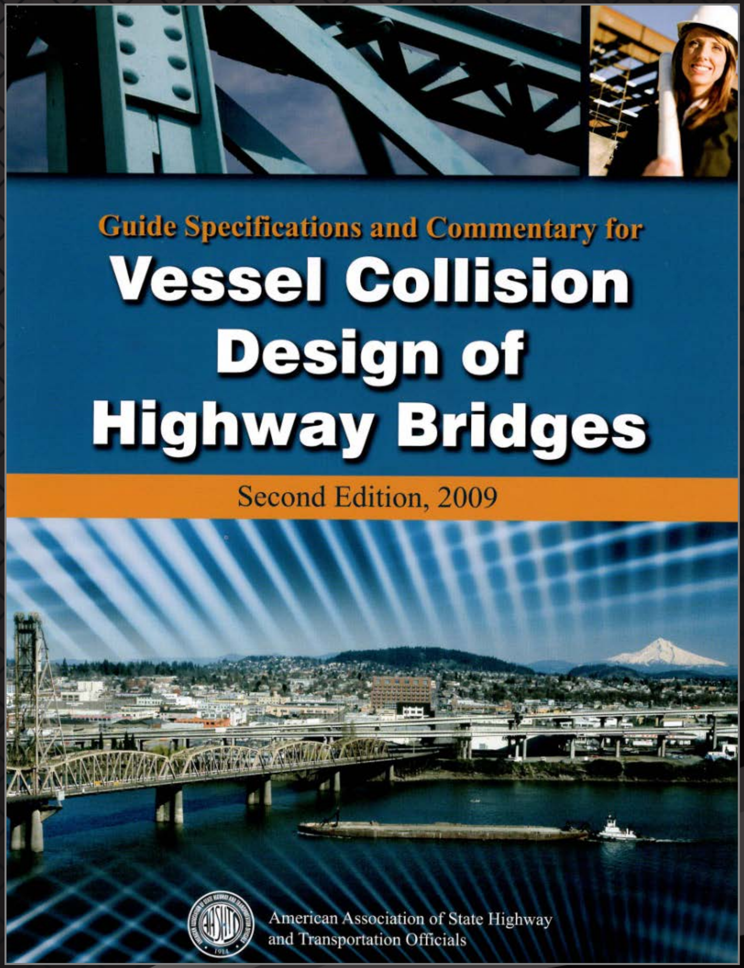
**Pier 3 + Pier 4 + Pier 5 … etc. = Sum of All Pier AF's**

# Annual Frequency of Collapse

- Once the input data has been developed and the risk analysis tables have been generated, the program can be used several ways:
  - If the ultimate resistance strength of the piers has been computed (ex. an existing bridge), you can solve for AF and determine if it meets the risk acceptance criteria
  - You can back-solve the ultimate pier strength needed for each pier (ex. a new bridge) by setting the AF for each pier to the risk acceptance criteria
  - The strength of setting up the analysis in this manner is the ability to ask "what if …" questions
    - Different pier locations, span lengths, etc.

# Bridge Protection Alternatives

- AASHTO Code
  - Substructure Provisions
  - Concrete & Steel Design
  - Physical Protection Systems
    - Fenders
    - Pile supported systems
    - Dolphins
    - Islands
    - Floating structures
  - Movable Bridges
  - Motorist Warning Systems
  - Aids-to-Navigation



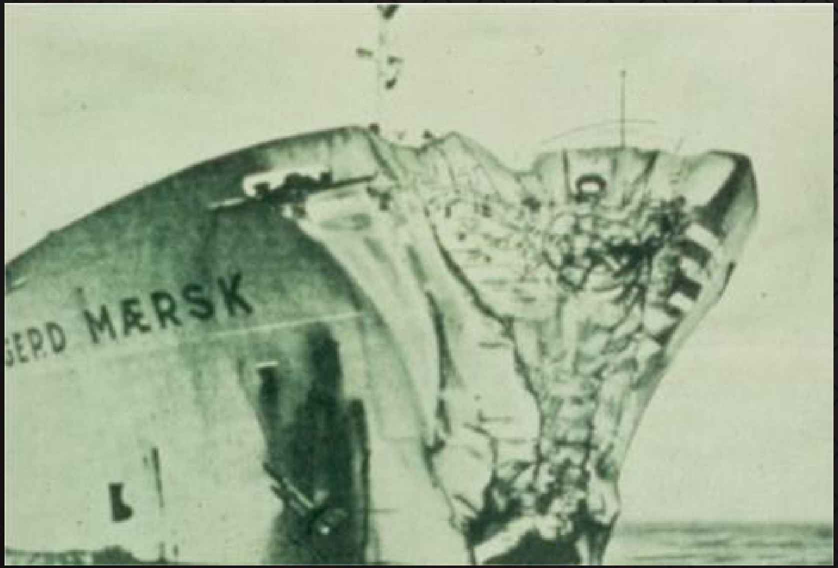
# Bridge Protection Examples

- Design Bridge for Full Impact Force
- Fender Systems
- Pile-Supported Structures
- Protection Islands

# Newport Bridge

*Crossing Narragansett Bay, Rhode Island (1981)*

- 31,800 DWT tanker hits main tower of suspension bridge at approximately 6 knots
- Minor damage to bridge pier
- Vessel bow crushed in 11 feet




# *Luling Bridge*

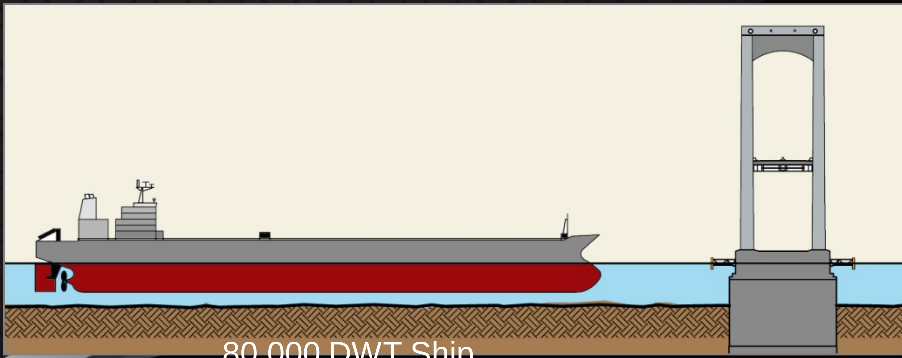
*New Orleans, Louisiana*

- Piers designed to withstand vessel impact forces (50,000 kips)

# *Throgs Neck Bridge*

*Crossing the East River, New York City*

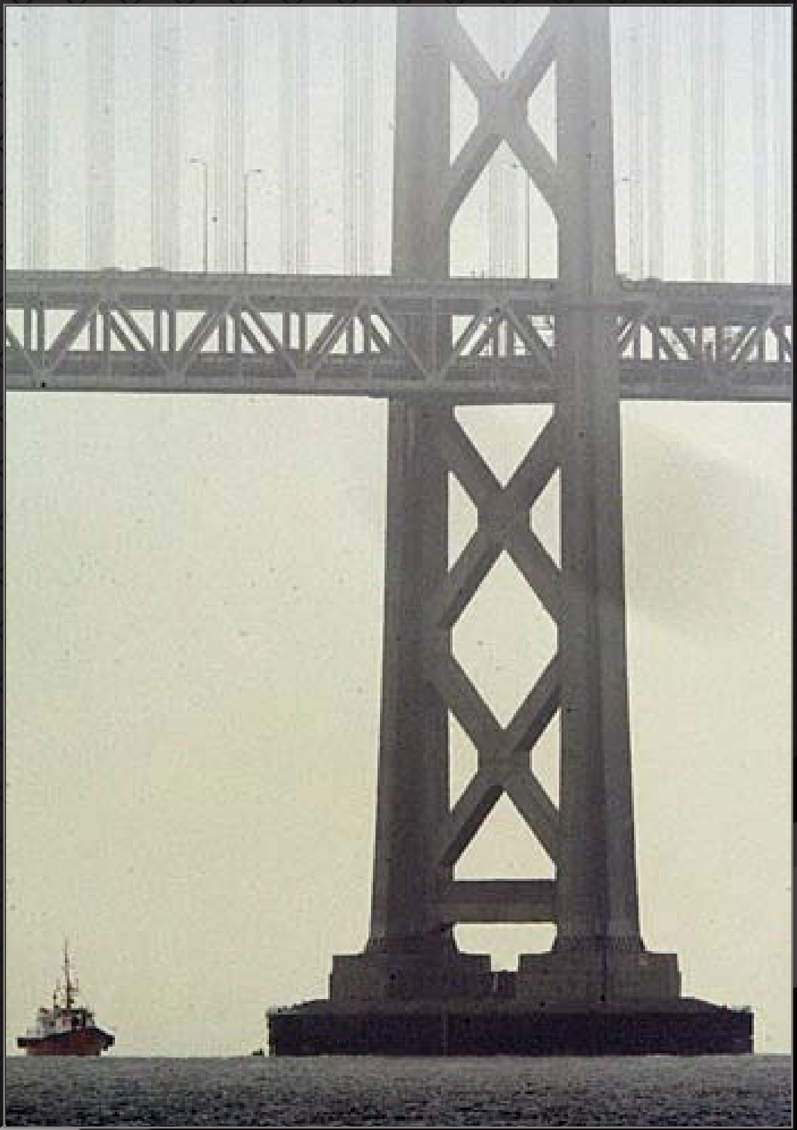
– Steel Framed Fender System



80,000 DWT Ship

# San Francisco / Oakland Bay Bridge

*Fender / Footing Accident (2007)*

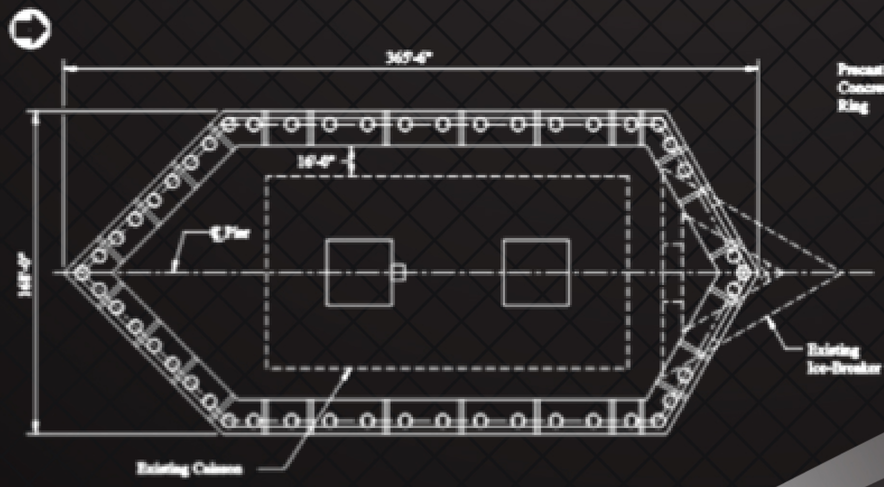
# *East Bay Bridge*

*San Francisco – Oakland, California*

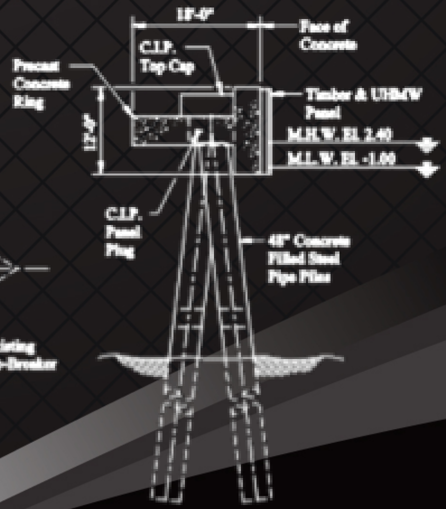
- Concrete fenders used around perimeter of piers
  - Piers also designed to withstand barge impact forces

# *Tappan Zee Bridge over Hudson River*

*Tarrytown, New York*



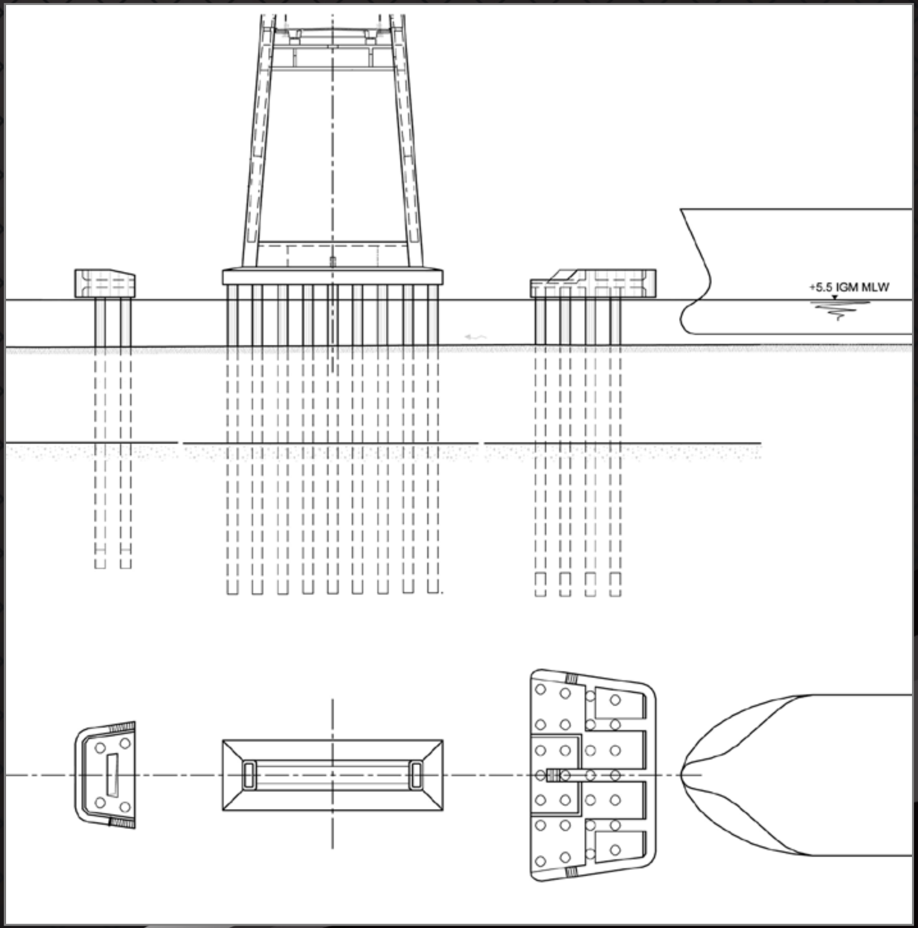

PLAN



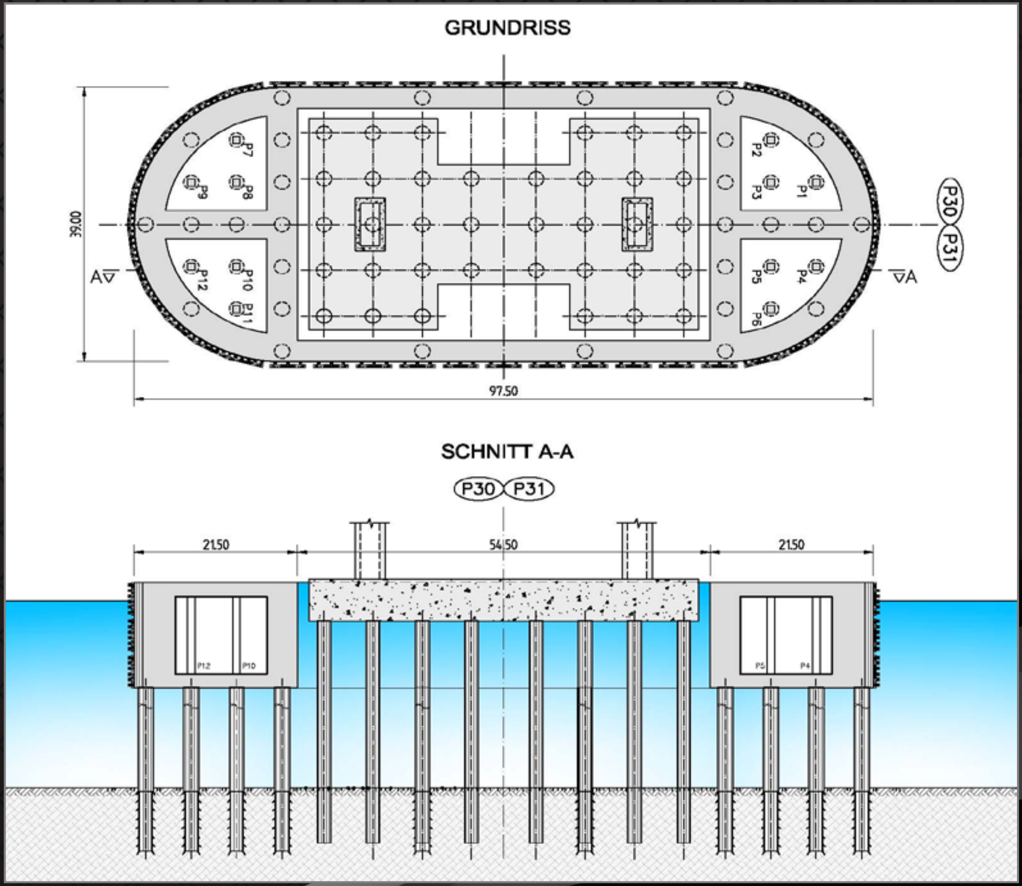

SECTION

# Rosario - Victoria Bridge
*Crossing the Paraná River, Argentina*

– Pile Supported Structure System



– Pile Supported Structure System



# *Sunshine Skyway Bridge*

*Tampa Bay, Florida*

# *Sunshine Skyway Bridge*

*Tampa Bay, Florida*

# Dames Point Bridge

*Jacksonville, Florida*

# Sunshine Skyway Bridge

*Tampa Bay, Florida*

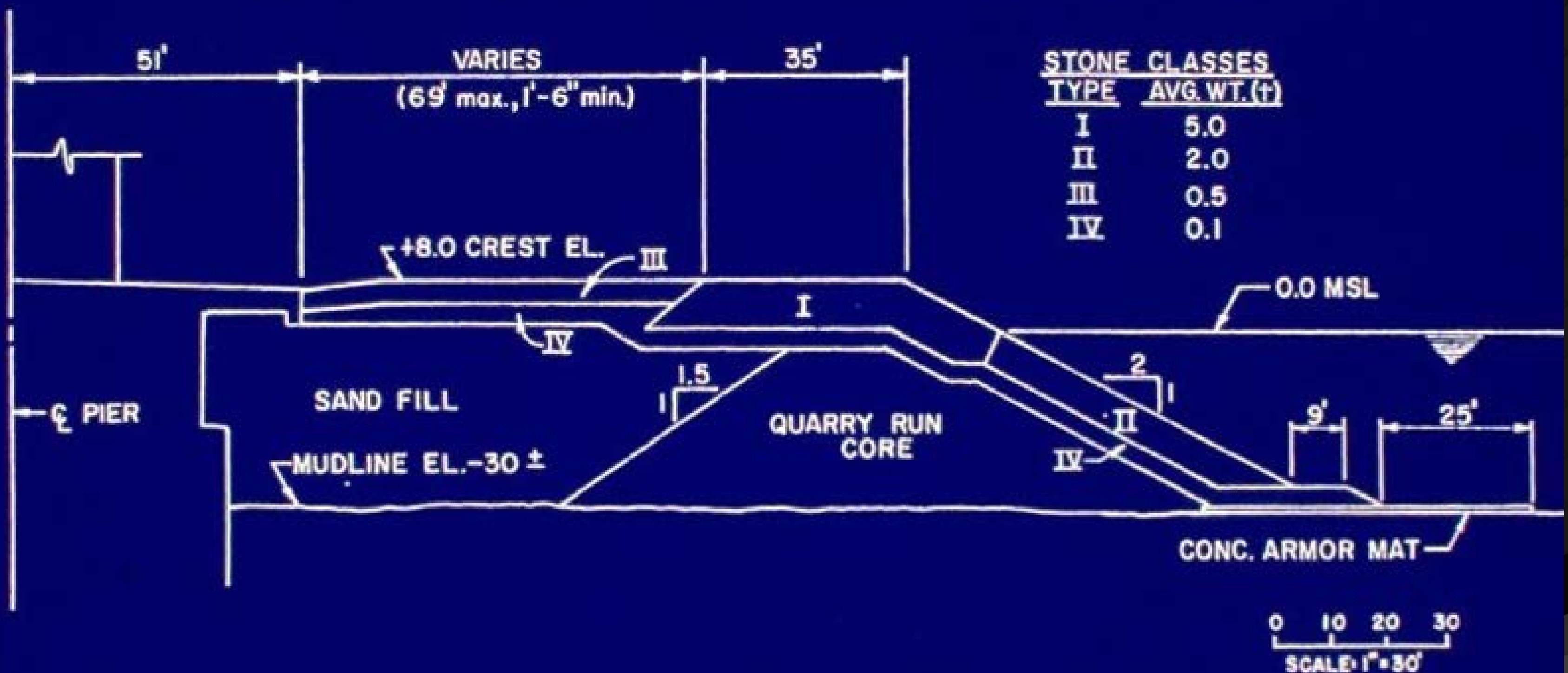



Figure 4: Section thru Main Pier Island.

# Sunshine Skyway Bridge

*Tampa Bay, Florida*

# Sunshine Skyway Bridge

*Tampa Bay, Florida*

# Houston Ship Channel Bridge

*Baytown, Texas*

## ***Dames Point Bridge***
*Jacksonville, Florida*

# Arthur Ravenel Jr. Bridge

*Crossing the Cooper River, Charleston, SC*

# *Sidney Lanier Bridge*

*Crossing the Brunswick River, Brunswick, GA*

# *Orwell River Bridge*

*Ipswich, Suffolk, England*

# Vessel Collision Summary

- Let's Learn From The Past
- Bridges Over Navigable Waterways Need:
  - Better Planning
  - Longer Spans
  - Stronger Piers
  - Better Protection
  - Better ATN

- Vessel Collision Requirements are now Mandatory under LRFD Bridge Design Code
- Engineering Judgment and Specialized Skills are Required to Design Pier Protection Systems
  - Plastic / Non-Elastic / Sacrificial Structures

# Final Thoughts

- Extreme Events will Usually Control the Design of Most Major Bridges
  - Vessel Collision
  - Earthquakes
  - Storm Surge & Waves (Post Hurricane Katrina / Sandy Damage)
  - Scour from Extreme Flood Events
- Terrorist Attacks (Post 9/11 World)
  - Hijacked Vessel Used as a Weapon Against Landmark Bridges & Critical Transportation Links
  - Confidential Studies Conducted by DOT's
- Design of New Bridges for One Extreme Event Usually Improves the Performance Response to Other Extreme Events

# THANK YOU FOR PARTICIPATING!

Vessel Collision Design of Highway Bridges

moffatt & nichol

*Western Bridge Engineers' Seminar*

*September 4-6,2013*
*Bellevue, WA*