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WAVE FORCE GUIDANCE FOR COASTAL STRUCTURES VULNERABLE TO COASTAL STORMS

Outline

- Background
- Guidance Development
- Method Validation
- Applications
- Summary and Conclusions

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Background

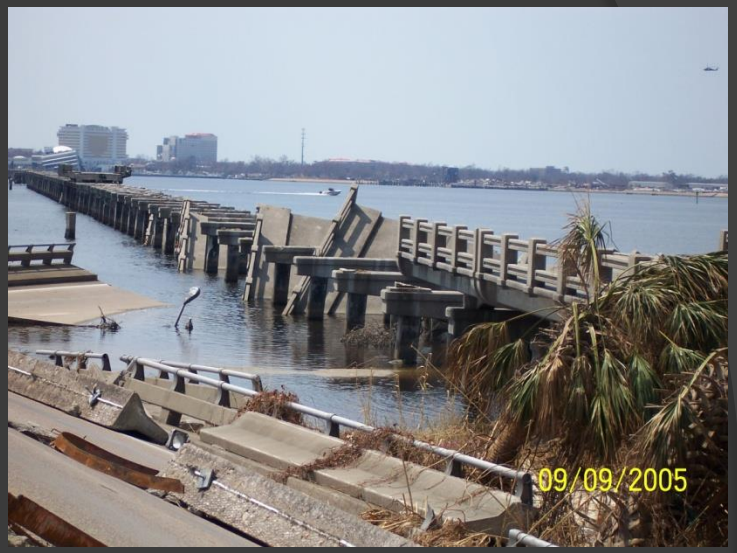

Mobile
Biloxi
Pensacola
Bay St. Louis
New Orleans
Dauphin Island
Cat Island
Petit Bois Island
Santa Rosa Island
I10 - Escambia Bay Bridges
US 90 Biloxi Bay Bridges
US 90 St. Louis Bay Bridges
I10 - Lake Pontchartrain Bridges

Background – Bridge Failures

1 – Pensacola, FL
2 – Bay St. Louis, MS
3 – Biloxi, MS

1

2



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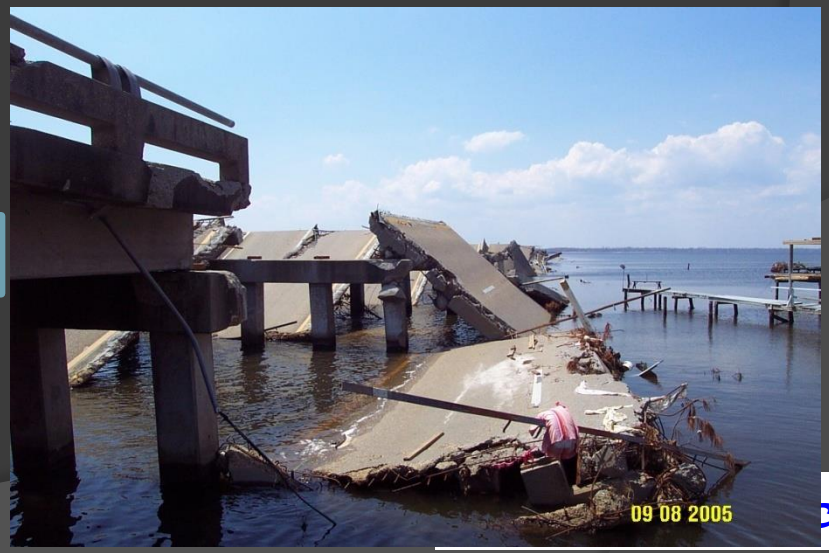
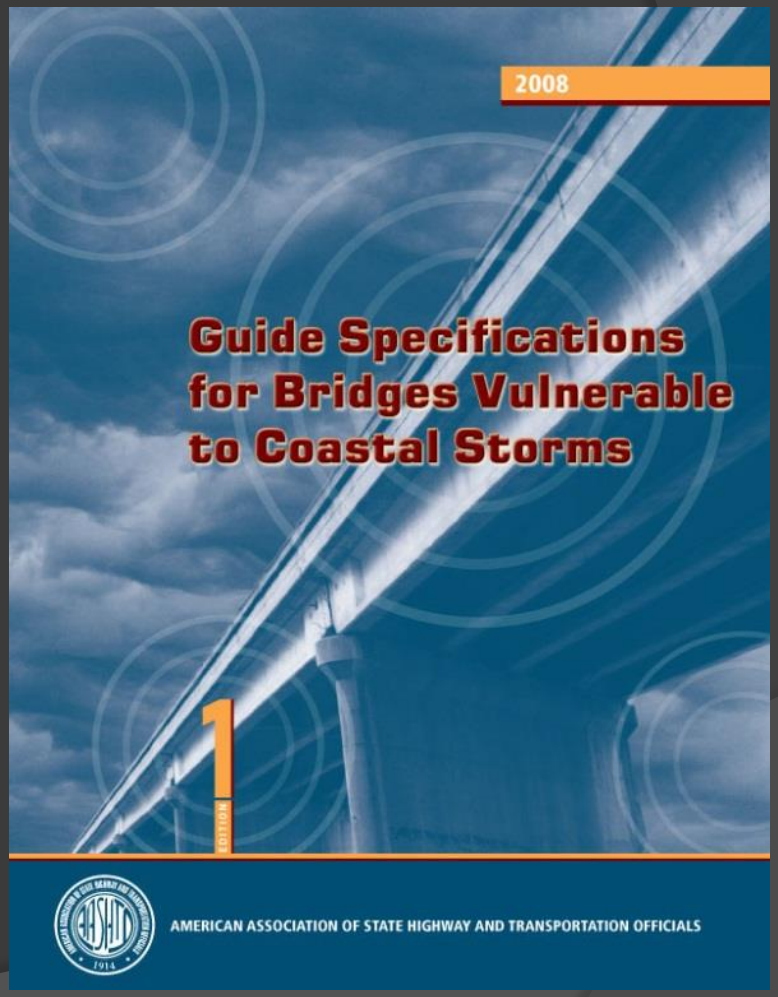


Background – Bridge Failures

1, 2 – I-10 Escambia Bay, FL
3 – Biloxi, MS
4 – I-10 near Mobile, AL

Guidance

- American Association of State Highway Transportation Officials Guide Specifications for Bridges Vulnerable to Coastal Storms
  - Modjeski & Masters Inc. – Prime
  - OEA, Inc.
  - Moffat and Nichol, Inc.
  - D'Appolonia, Inc.
  - Dr. Dennis R. Mertz



Guidance

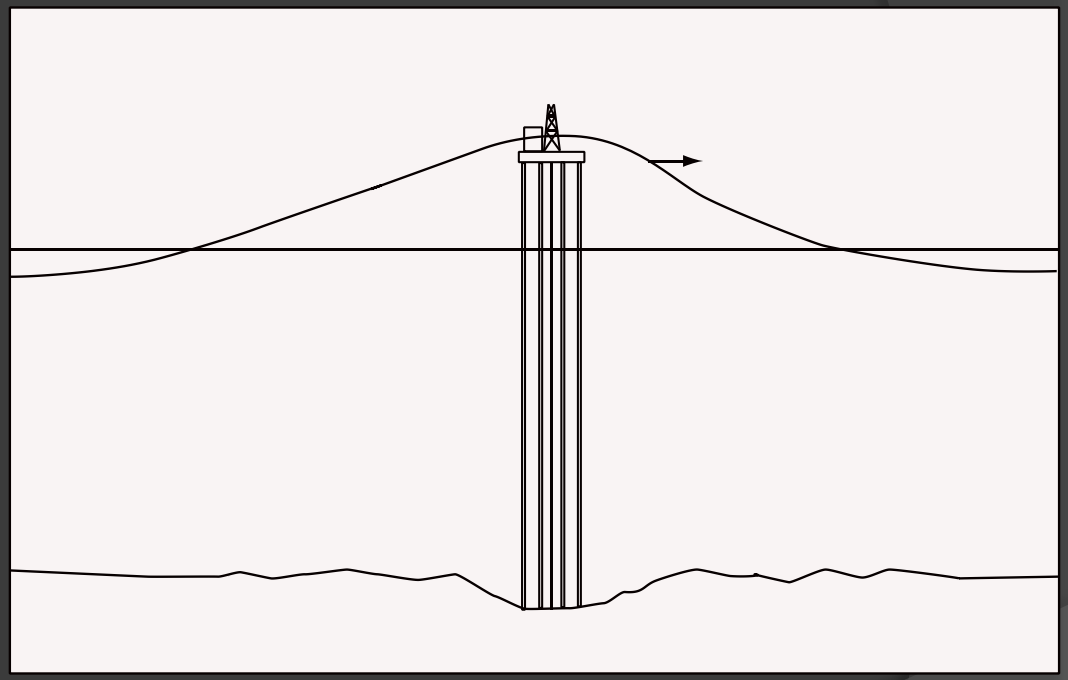
- Avoid wave forces on superstructure
  - Design low member elevation above 100-yr wave crest elevation plus 1 ft freeboard
- Mitigate wave forces
  - Reduce amount of trapped air between beams
  - Use slab spans instead of girders to lessen superstructure depth and reduce trapped air
- *Accommodate wave forces*

Wave Forces

- Significant work on wave loads on *vertical* structures
- Very little work on wave loads on *horizontal* structures
  - Offshore platforms – Kaplan (1995)
  - Open coast piers – H.R. Wallingford (McConnell et al., 2004)
  - Limited laboratory tests
- Objective
  - Develop method for predicting horizontal and vertical wave forces and moments on bridge spans located in coastal and inland waters

Offshore Structures

- Long, large amplitude waves
- Small variations in velocities and accelerations over structure
- Structure has minor effect on wave



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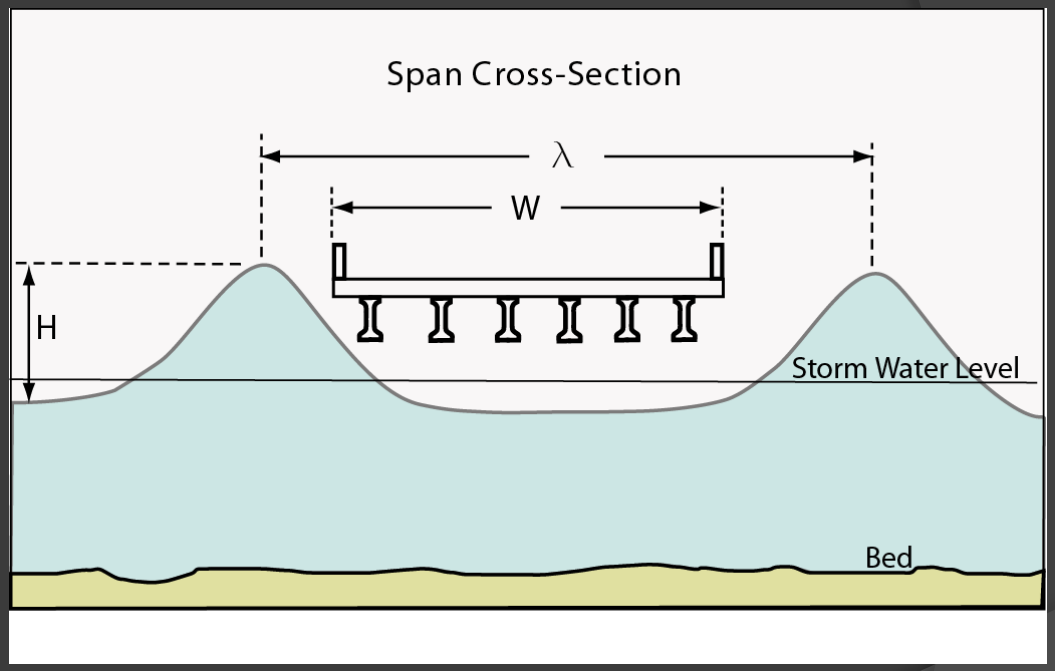
Coastal/Inland Structures

- Short, small amplitude waves
- Large variations in velocities and accelerations over span
- Structure has major effect on wave



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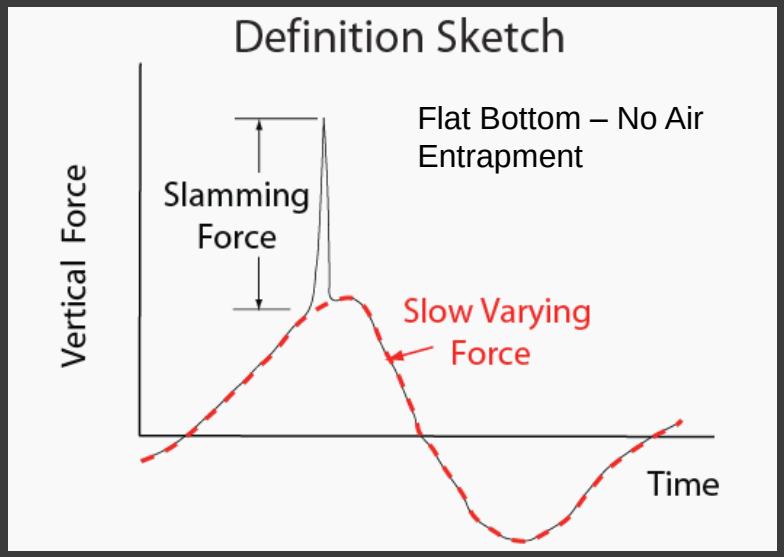
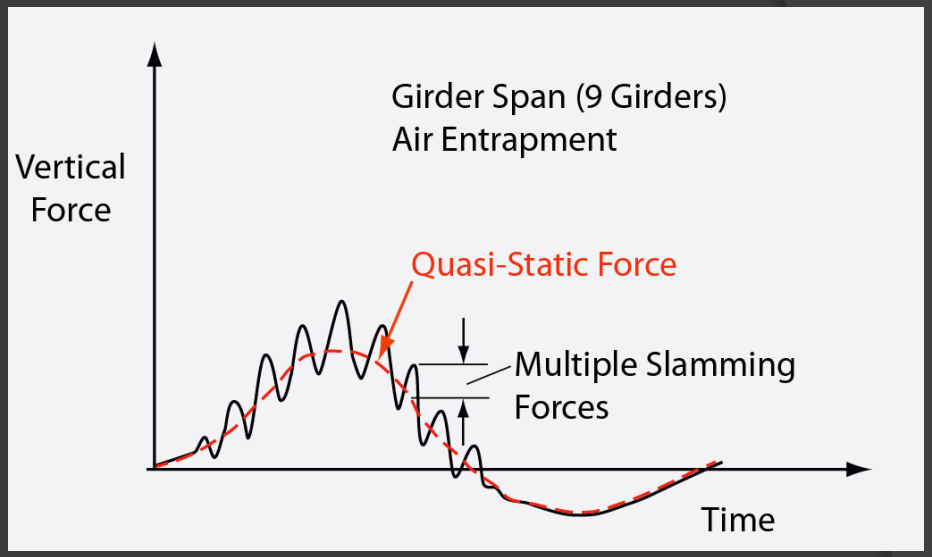
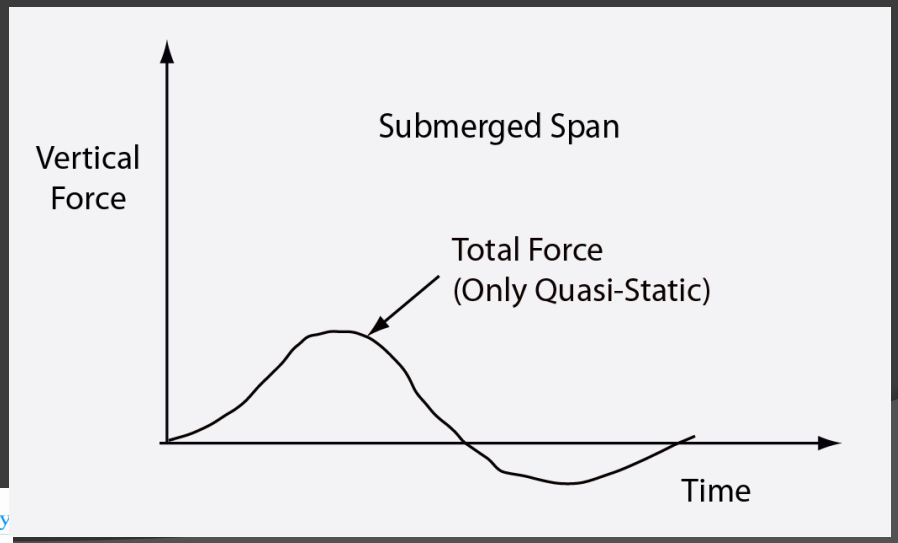
Wave Forces







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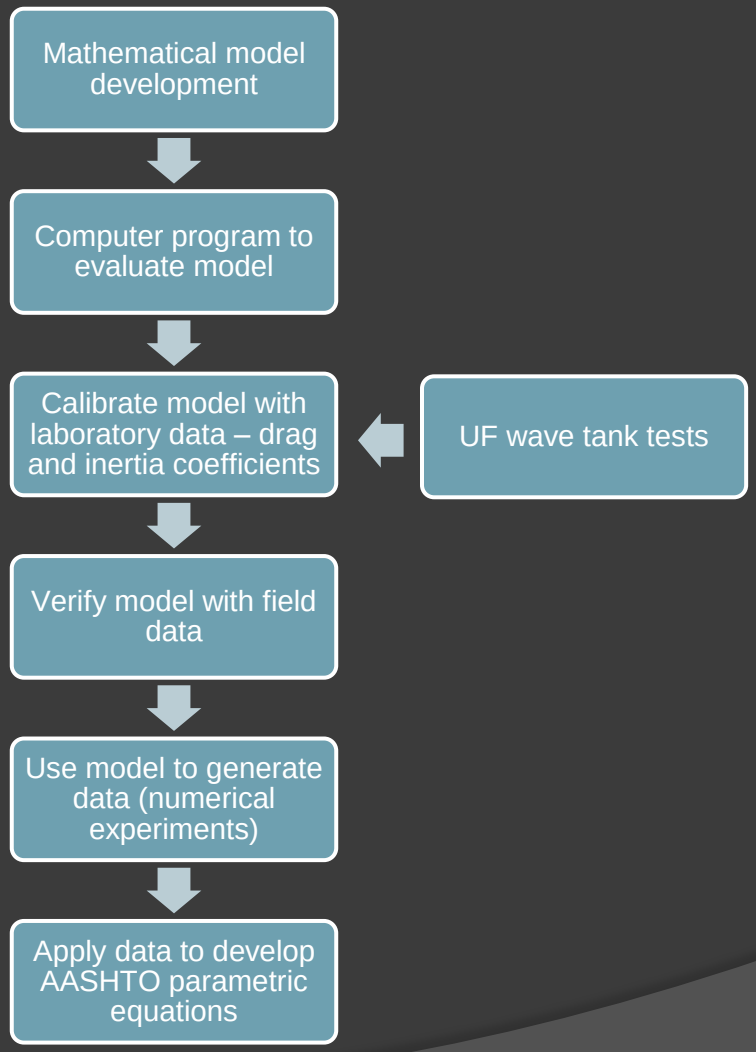
Development Overview



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Mathematical Model

- Developed for Bridge Superstructure Shapes
  - Slab spans
  - Girder spans (possible air entrapment)
- Based on concepts in
  - Morison's equation for wave forces on vertical piles
  - Kaplan's method for wave forces on offshore platform decks

Mathematical Model

Quasi-static + slamming forces

$$F_H = F_{Drag} + F_{Inertia} + F_{CAM} + F_{Slam}$$

$$F_V = F_{Buoyancy} + F_{Drag} + F_{Inertia} + F_{CAM} + F_{Slam}$$

$$F_{Drag} = C_d \frac{1}{2} \rho L w V |V|$$

$$F_{Inertia} = C_{Inertia} \frac{d(m_e V)}{dt} = \left(C_{cam} \frac{dm_e}{dt} V + C_m m_e \frac{dV}{dt} \right)$$

$$F_{Buoyancy} = \rho g \forall$$

where $\forall$ = wetted volume

Mathematical Model

$$m_e = m_s + m_a$$

$$m_{av} = \frac{\rho \pi L W^2}{4\left[1+\left(\frac{W}{b_d}\right)^2\right]^{\frac{1}{2}}}\left[1+\frac{1}{2}\left(\frac{b_d}{W}\right)^{0.4}\right]$$

$$m_{ah} = \frac{\rho \pi L b_d^{\,2}}{4\left[1+\left(\frac{b_d}{W}\right)^2\right]^{\frac{1}{2}}}\left[1+\frac{1}{2}\left(\frac{W}{b_d}\right)^{0.4}\right]$$

Mathematical Model

$$\frac{\partial m_{av}}{\partial t} = \frac{\rho \pi L W^2}{4\left[1+\left(\frac{W}{b_d}\right)^2\right]^{\frac{1}{2}}} \left\{ \left[1+\frac{1}{2}\left(\frac{b_d}{W}\right)^{0.4}\right]\left[2\frac{\frac{\partial W}{\partial t}}{W} - \frac{W\frac{\partial W}{\partial t}}{W^2+L^2}\right] + \left[\frac{1}{5}\left(\frac{b_d}{W}\right)^{0.4}\left(\frac{\frac{\partial b_d}{\partial t}}{b_d} - \frac{\frac{\partial W}{\partial t}}{W}\right)\right] \right\}$$

$\rho \equiv$ Density of water

$W \equiv$ Wetted span width

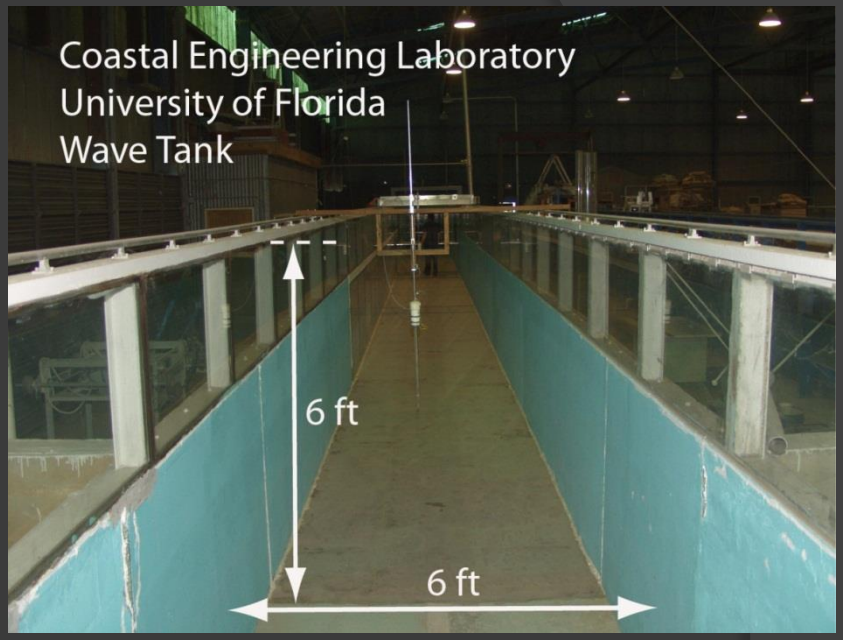
$L \equiv$ Span length

$b_d \equiv$ Wetted span height

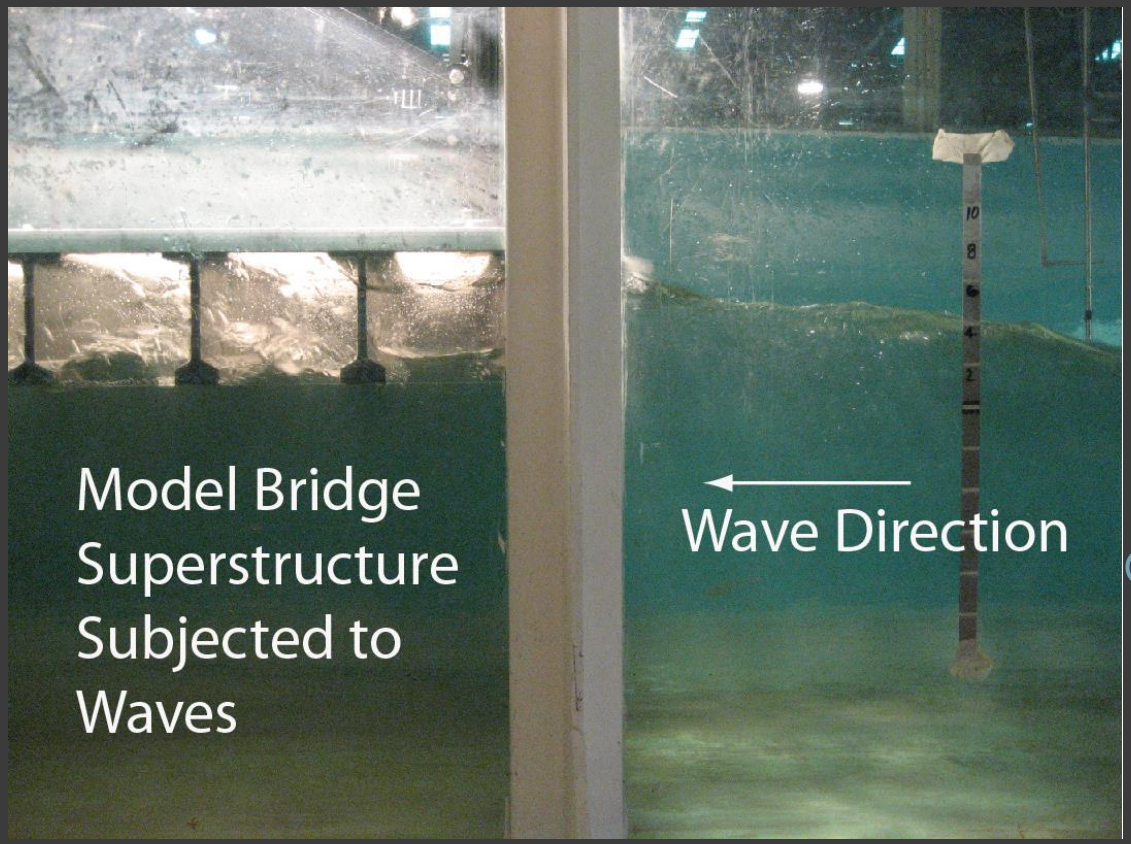
$t \equiv$ Time

Physical Modeling

- Need laboratory data to determine drag and inertia coefficients
- Wave tank tests at Coastal Engineering Laboratory at University of Florida



Physical Modeling



- Testing Conditions
  - Non-breaking, monochromatic waves
  - Varied wave period
  - Varied wave height
  - Varied water depth
  - Varied deck elevation relative to water level
- Test Sequence
  - Flat plate
  - Slab span
  - Girder span

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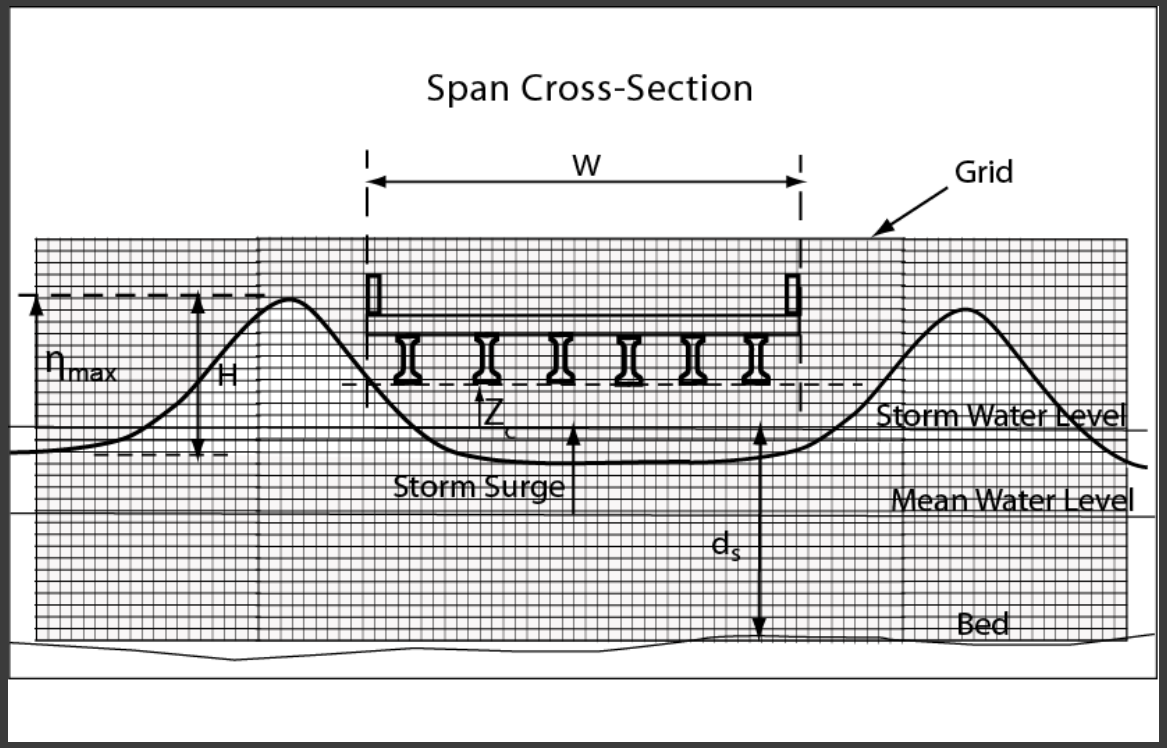
Physics Based Model



- Stream Function Theory computes WSE along the wave and the velocities and accelerations
- Compute wave forces at each time step as the wave(s) propagate past the span

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Physics Based Model

- Input
  - Span dimensions and elevation
  - Water depth at span
  - Water level
  - Wave height and period
- Output
  - Horizontal forces
  - Vertical forces
  - Moment about centroid

Validation – Part 1

- I10 – Escambia Bay Bridges – Hurricane Ivan (2005)
  - Refined Hurricane Ivan hindcast
  - Good span by span damage assessment
- Use PBM with hindcast met/ocean parameters to predict forces on each span
  - Percent air entrapment unknown
    - Compute for 0% and max. % (74%)

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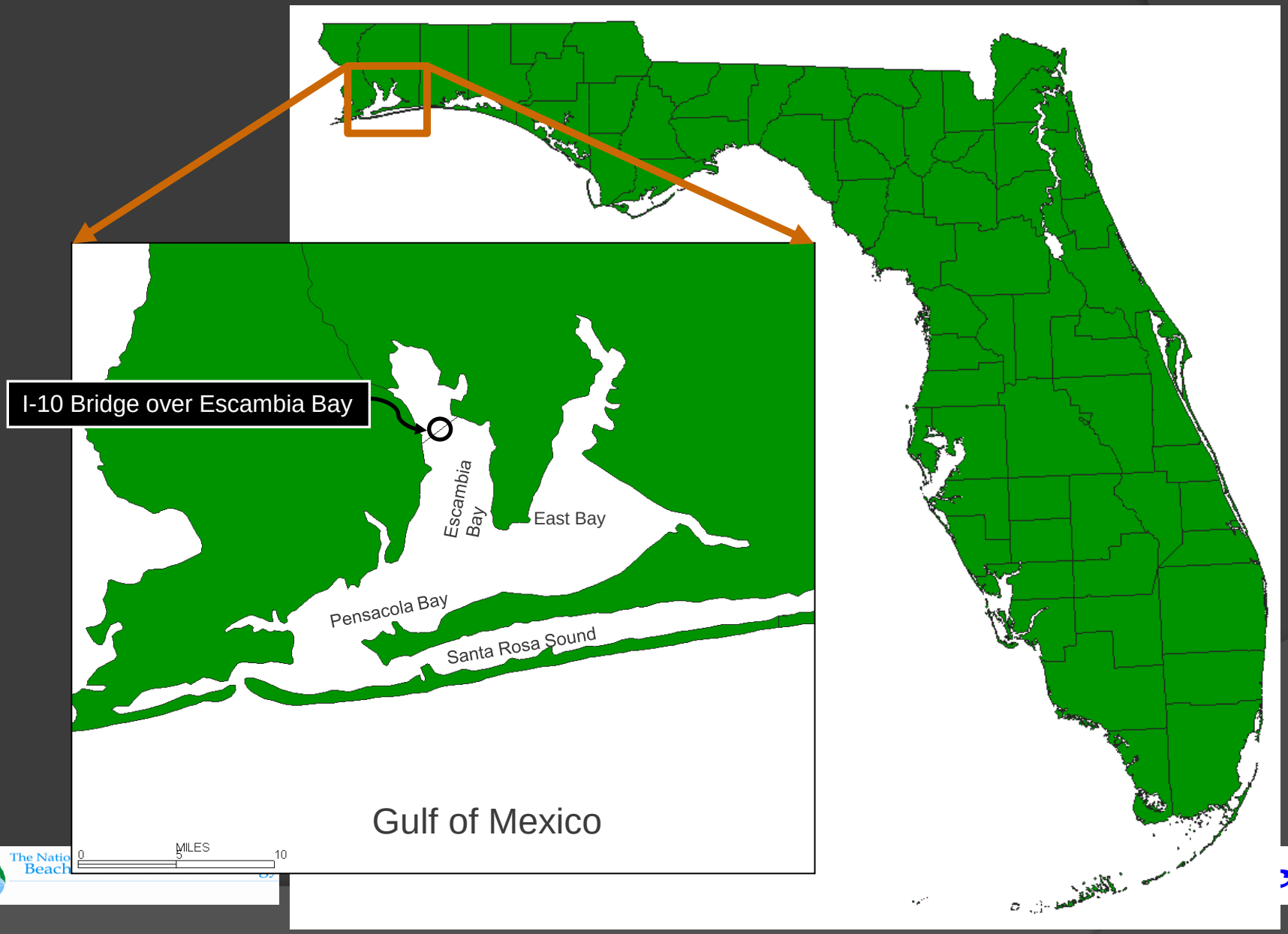
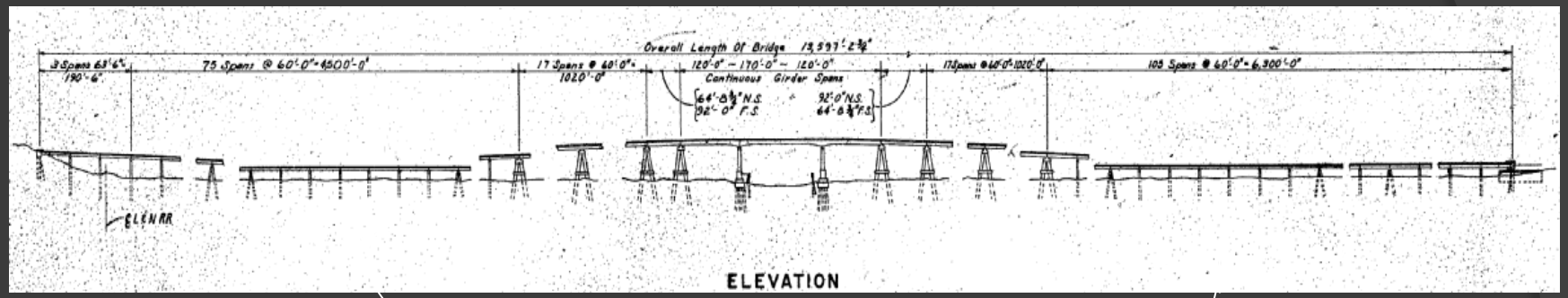
Validation – Part 1



Validation – Part 1



Damaged Sections

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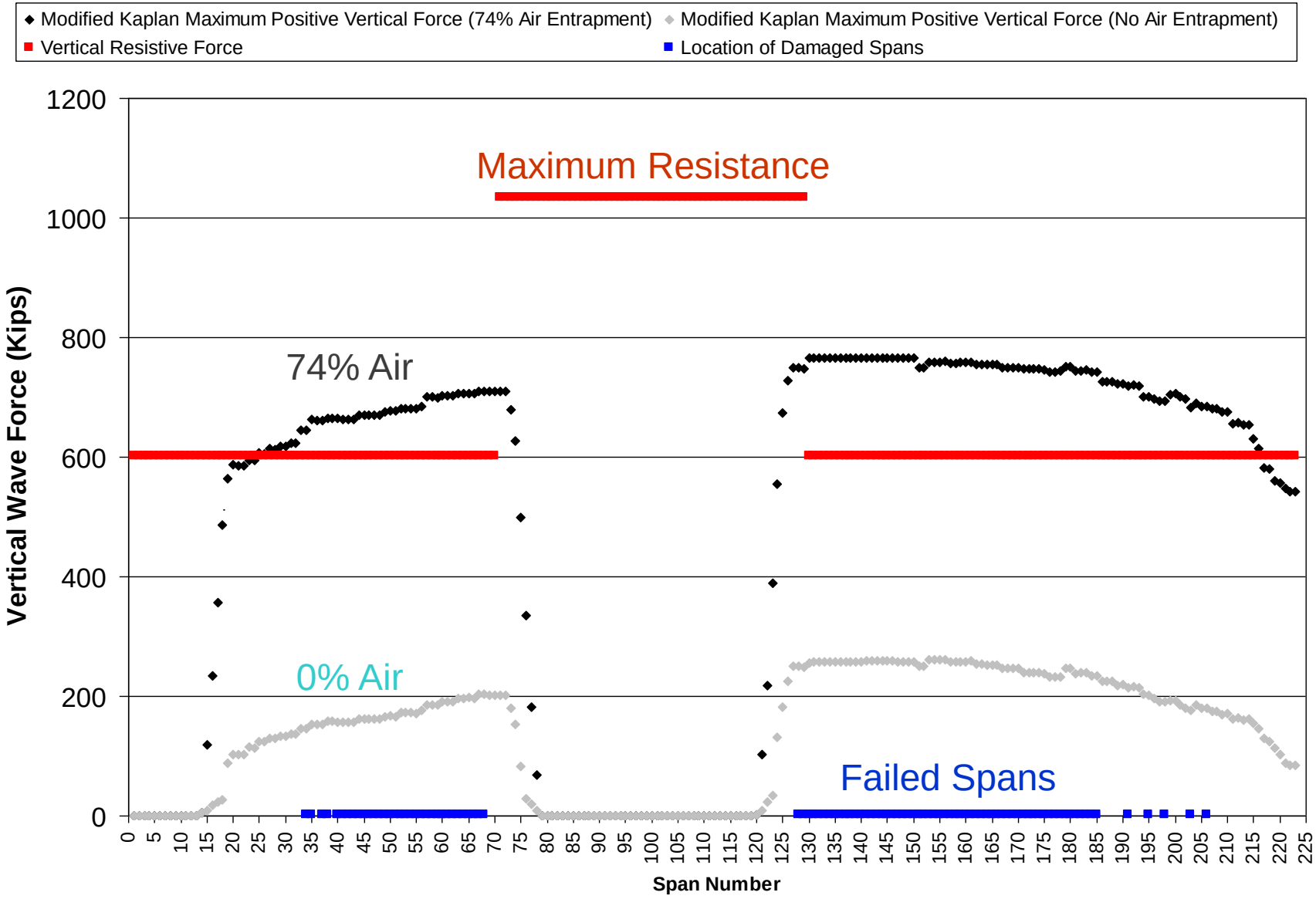
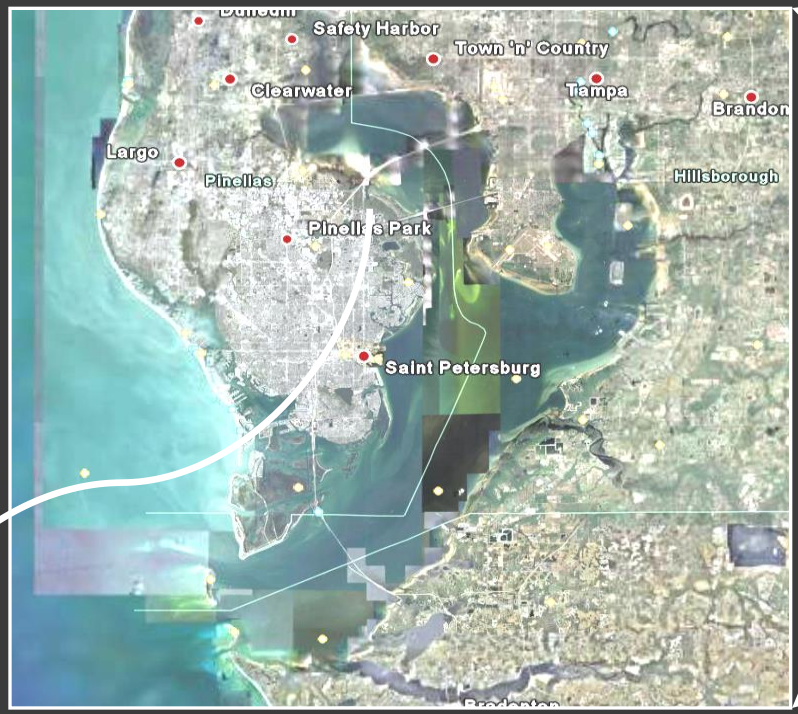
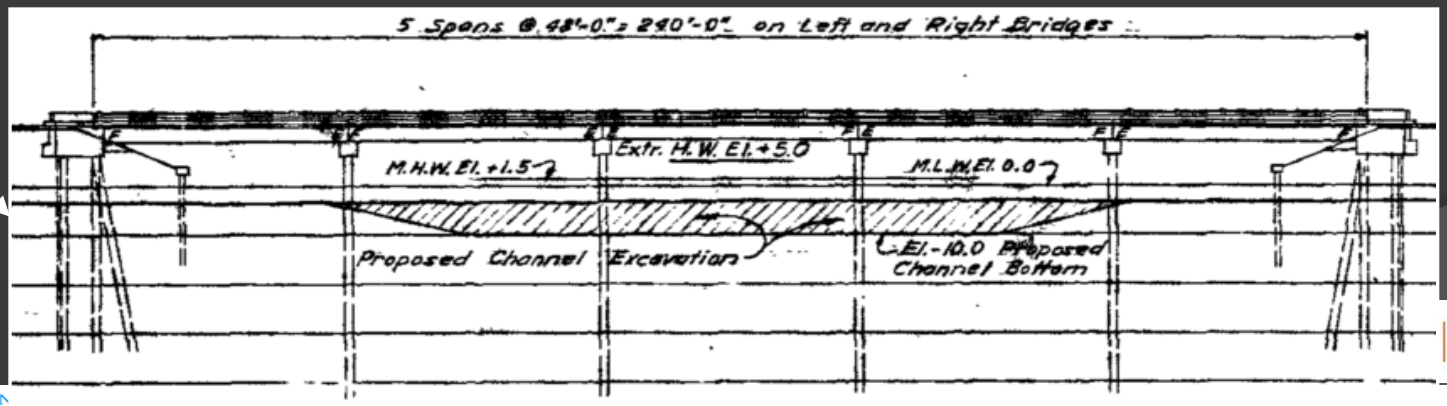

Modified Kaplan Maximum Positive Vertical Force (74% Air Entrapment)
Modified Kaplan Maximum Positive Vertical Force (No Air Entrapment)
Vertical Resistive Force
Location of Damaged Spans
Maximum Resistance
74% Air
0% Air
Failed Spans
Vertical Wave Force (Kips)
Span Number
0
200
400
600
800
1000
1200
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225

Validation – Part 2

- Howard Frankland Approach Bridge – St. Petersburg, FL
  - Constructed 1959
  - Most severe storm since 1959
    - 1968 Hurricane Gladys
  - Met/Ocean Conditions at Site
    - Storm surge + wind setup = 6.8 ft
    - Maximum wave height = 2.7 ft
    - Wave period = 2 sec
  - Clearance = - 0.7 ft

Validation – Part 2





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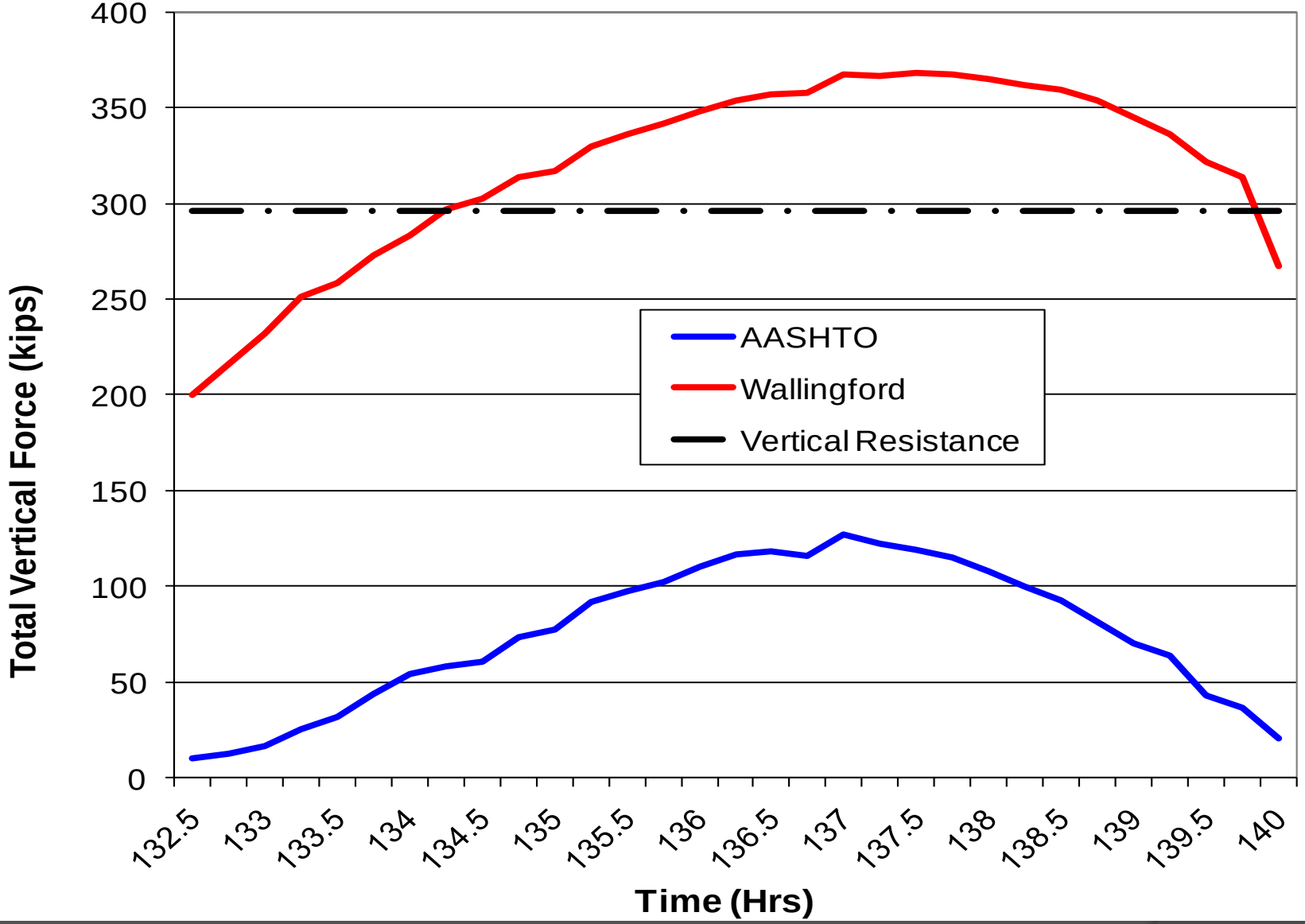
Total Vertical Force



Physics Based Model

- PBM run for a wide range of structure and met/ocean conditions:
  - Structure
  - Span type (slab, girder)
  - Girder type
  - Span width
  - Position relative to water level
  - Water depth
  - Wave height
  - Wave period

Physics Based Model

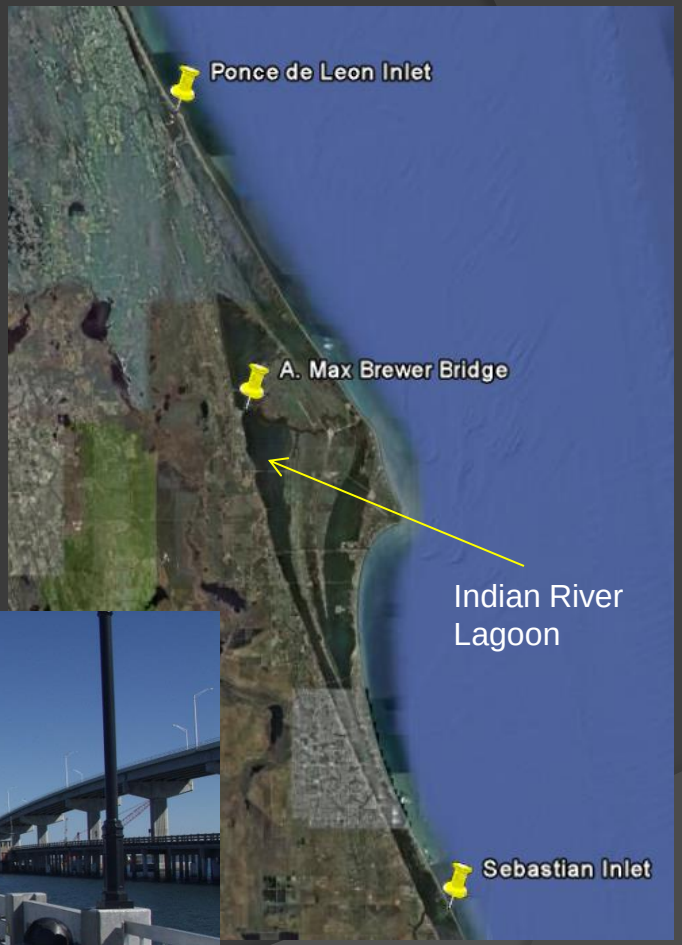
- Data extracted from PBM results
  - Maximum vertical force
    - Associated horizontal force
    - Associated moment
  - Maximum horizontal force
    - Associated vertical force
    - Associated moment
- *Data generated with PBM used to develop parametric AASHTO equations*

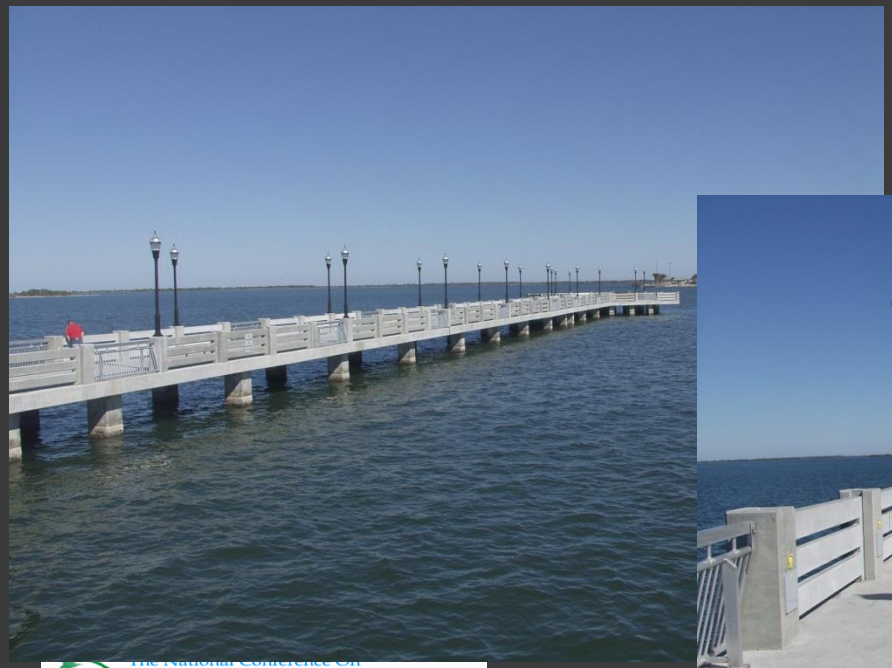
Bridge Applications

- OEA evaluated 100's of coastal bridges in FL and NC as part of wave vulnerability studies
- Some constructed examples:
  - A. Max Brewer Bridge (SR 406 over Indian River Lagoon), Brevard County
  - Flagler Memorial Bridge (SR A1A over ICWW), Palm Beach County
  - US 90 Bridge over Bass Hole Cove (upper Escambia Bay), Santa Rosa County

Pier/Dock Applications

- Titusville Veterans' Memorial Fishing Pier
  - Completed: 2010
  - Engineer: DRMP (OEA)





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Pier/Dock Applications

- Bahia Urbana Waterfront Redevelopment Project Pier
  - Completed: 2012
  - Engineer: Taylor Engineering

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Summary and Conclusions

- AASHTO Guide Specification provides parametric equations for use with *coastal* design
- Bridge, pier, and fixed dock applications
- Conservative load predictions = $$$ retrofit/construct coastal infrastructure
- Non-conservative load predictions = potential loss of structures and lives

Wave Force Guidance for Coastal Structures Vulnerable to Coastal Storms

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