Session 38

Max Sheppard

Ocean Engineering Associates, Inc.

Wave Force Research & Existing Bridges Vulnerability to Scouring

Topic Description

Wave Force Research & Existing Bridges' Vulnerability to Wave Loading: An overview of wave forces on bridges and the research currently being conducted at the University of Florida to improve predictive methods is presented. A procedure for identifying bridges that are potentially vulnerable to storm surge and wave loading has been developed and is currently being tested. This screening procedure was developed during the first phase of a pilot study. The tasks involved in the second phase of this study (which is currently underway) are presented as well.

Speaker Biography

Max Sheppard is President of Ocean Engineering Associates, Inc. (OEA, Inc.) and Professor Emeritus in the Civil and Coastal Engineering Department at the University of Florida. His areas of expertise include: bridge scour, coastal hydraulics, sediment transport, coastal structures, and wave loading on coastal and offshore structures.

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Phil Dompe

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Speaker Biography

Philip Dompe is a Senior Coastal/Hydraulics Engineer at Ocean Engineering Associates Incorporated (OEA, Inc.). His areas of expertise are coastal and riverine hydraulics, sediment transport, storm surge and wave modeling, bridge scour, wave loading and design of coastal structures. Mr. Dompe received a B.S. degree in Ocean Engineering from Florida Atlantic University and a Master of Engineering degree in Coastal and Ocean Engineering from the University of Florida; He is a licensed professional engineer in Florida and Mississippi and has 17 years of experience.

Wave Forces Research Existing Bridge Vulnerability

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Presentation Outline

- Wave / Surge Induced Bridge Failures
- Waves and Wave Induced Forces
- Wave Force Research
- Existing Bridges Vulnerability to Storm Surge and Wave Loading
- Summary

Motivation

- Recent Bridge Failures Attributed to Storm Surge/Wave Induced Failures
  - I-10, Escambia Bay (Pensacola, FL)
  - US-90, Biloxi Bay (Biloxi, MS)
  - US-90, Saint Louis Bay (Bay Saint Louis, MS)
  - I-10, Lake Pontchartrain (New Orleans, LA)

Bridge Failures

Pensacola, FL

Bay Saint Louis, MS

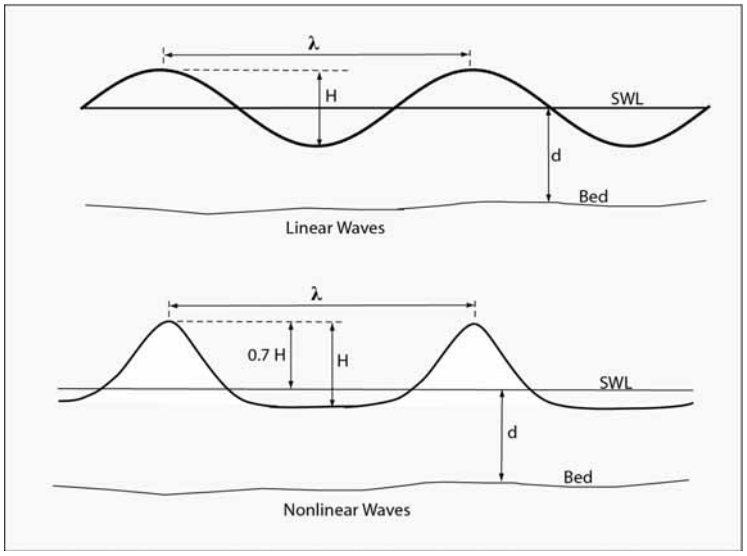
Biloxi, MS

Biloxi, MS

Wind Generated Waves

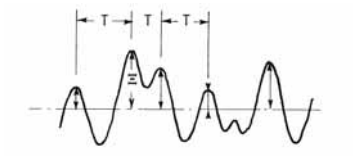
- Definitions:
  - Wave Height – Distance from trough to crest
  - Significant Wave Height – Average height of 1/3 highest waves
  - Wave Period – Time requited for one wave to pass a fixed point
  - Peak Period – Period of waves with most energy

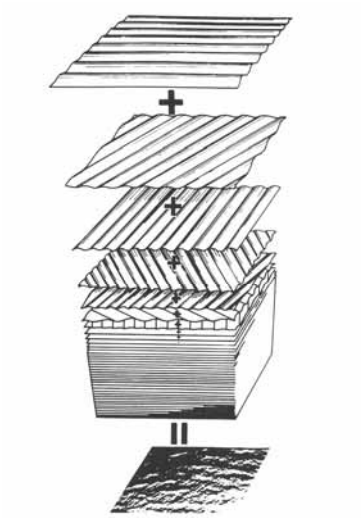
Wind Generated Waves



Wind Generated Waves

Hurricane Wave Field Composed of Waves with Range of Heights and Periods





Structure of random sea (Pierson *et al.*, 1958).

Wind Waves

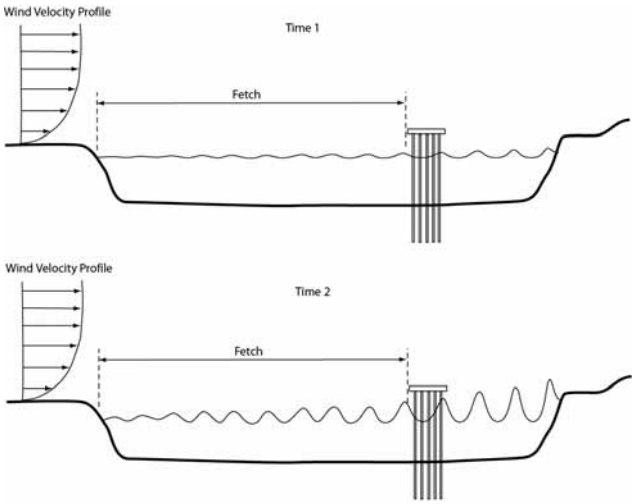
Height and Period (Length) depend on:

- Wind Speed
- Wind Duration
- Fetch Length
- Water Depth

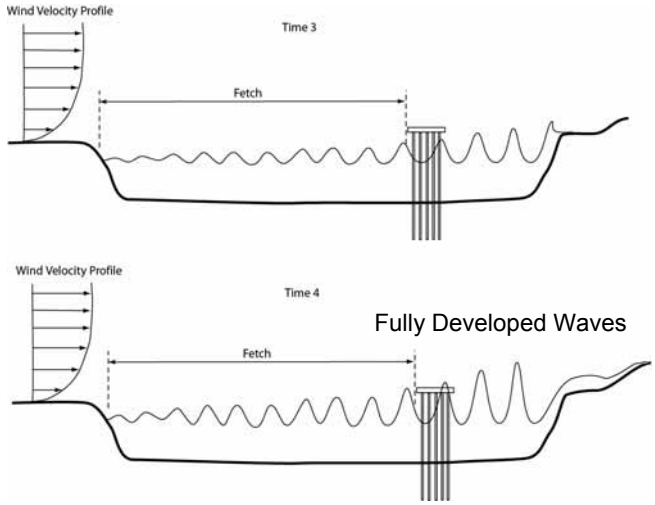
Wave Height Limitations

- Water Depth: $H_{max} < \sim 0.8 \times \text{Depth}$
- Wave Steepness:
  - Deep water
    - $H_{max} < \sim 0.14 \times L_0$
  - Shallow water
    - $H_{max} < \sim 0.082 \times L_0$

Fetch Length – Wind Duration

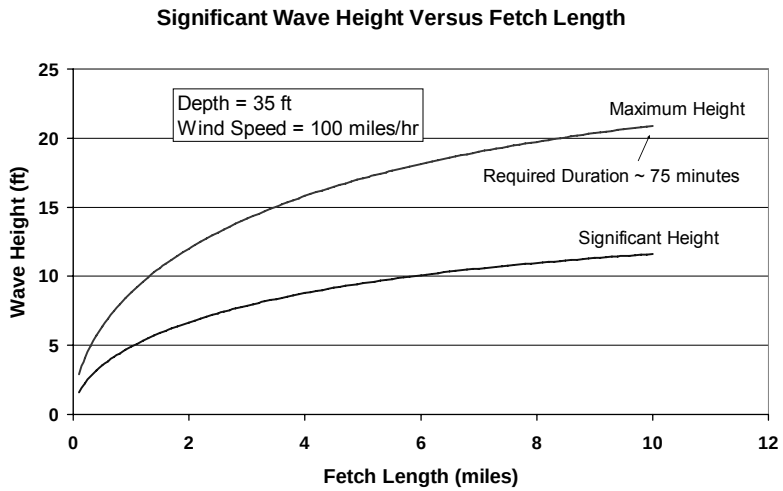


Fetch Length – Wind Duration



Fully Developed Waves

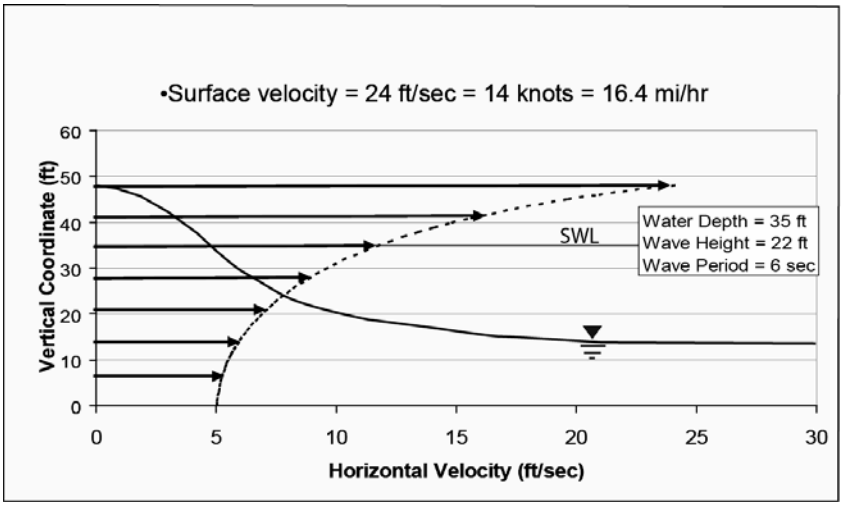
Influence of Fetch Length



Water Velocities and Accelerations in a Wave

- Velocities and Accelerations Can Be Very Large in a Wave
- Drag Forces Function of Velocity Squared
- Inertia Forces Function of Acceleration

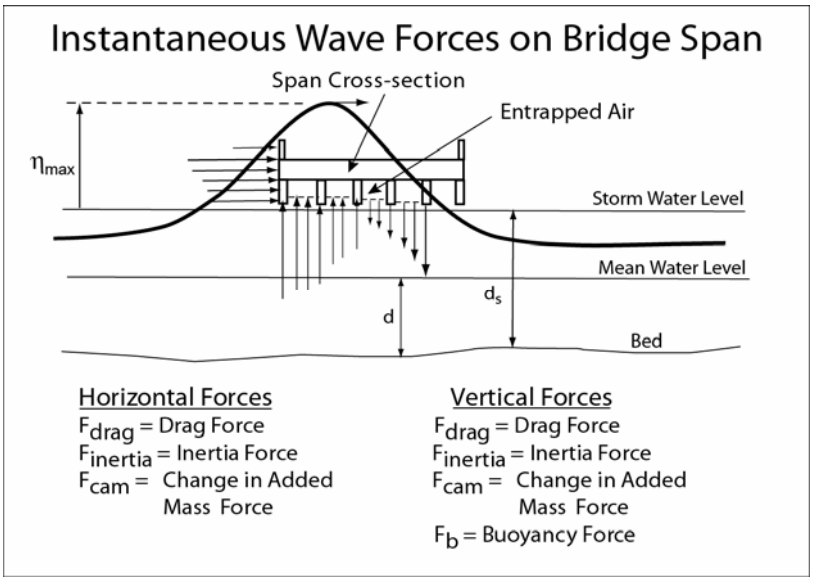
Horizontal Velocity Profile Under A Wave Crest - Example



Storm Surge/Wave Forces

- Storm Surge/Wave Forces Depend on:
  - Storm surge elevation
  - Wave heights and periods
  - Structure shape, dimensions, and elevation relative to the storm surge water level

Surge/Wave Forces



Wave Force Research

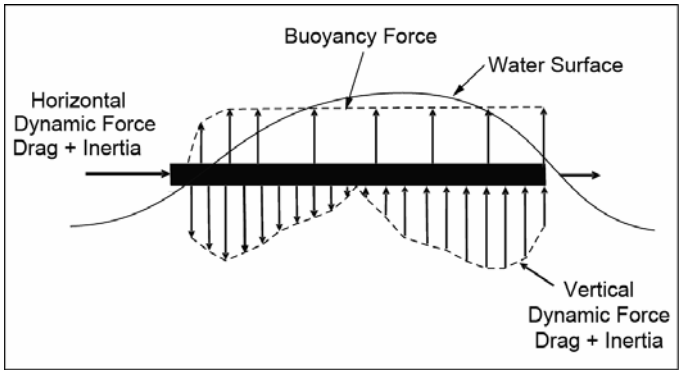
- Research Objective
  - Improve ability to accurately predict surge/wave loading on bridges
- Approach
  - Modify and extend existing theory to include bridge span structures
  - Conduct wave tank tests with instrumented model bridge spans
  - Use field data from Hurricanes Ivan and Katrina to test/verify predictive equations

Wave Force Research

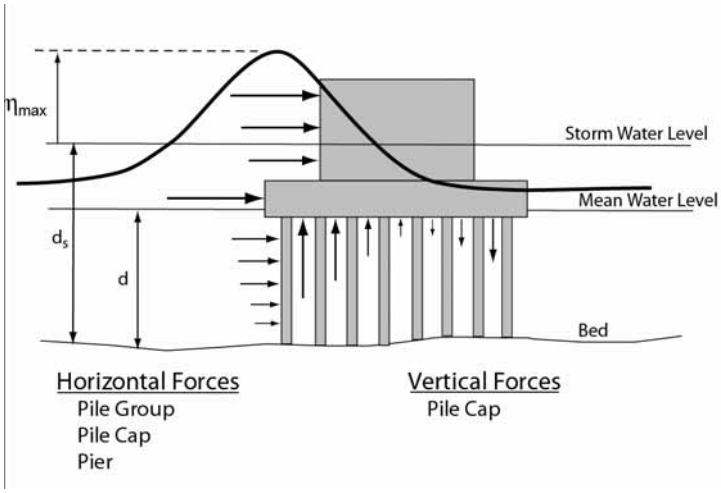
- Theoretical
  - Extending theory to include surge/wave forces on bridge spans

Wave Force Research

- Theoretical
  - Moments as well as forces essential to computing structural response



Wave Force Research

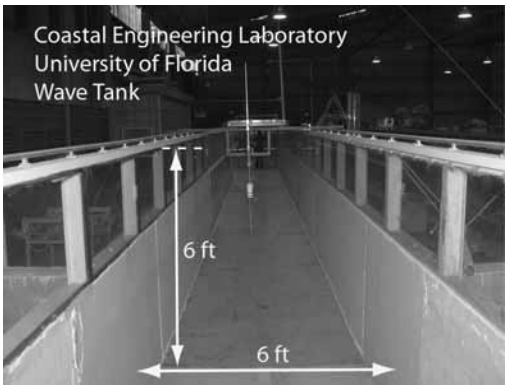


Wave Tank Tests

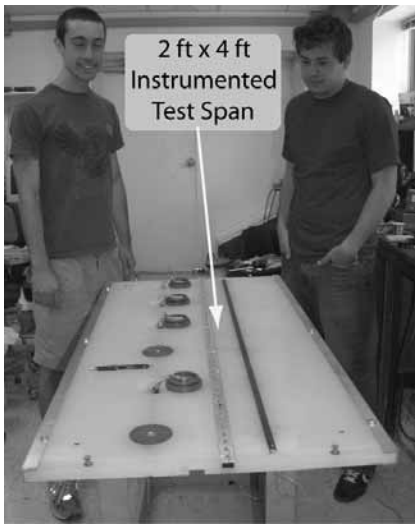
- Sufficient Measurements to Identify Components of Horizontal and Vertical Forces
- Instrumentation
  - Four three-component load cells
  - Pressure transducers on top and bottom
  - Wet/dry sensors on top and bottom

Wave Tank Tests

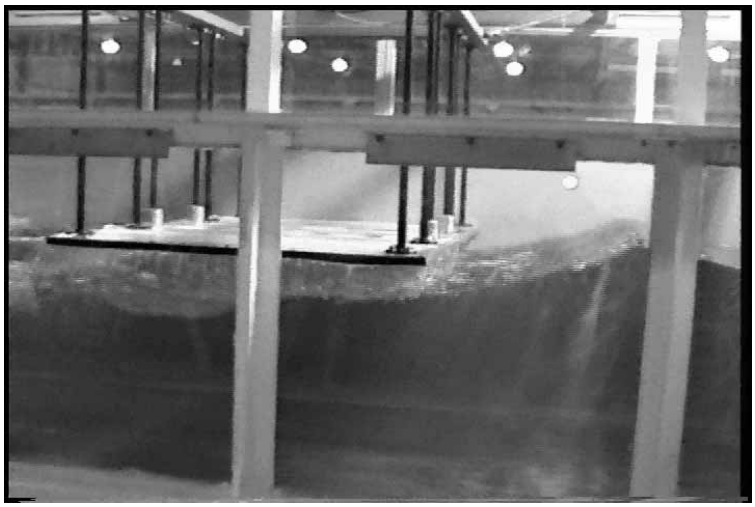
- Wave Tank
  - 6 ft wide x 6 ft deep x 120 ft length
  - Random wave generator



Model Bridge Span



Model Bridge Span



Vulnerability of Existing Bridges to Storm Surge and Wave Loading

Vulnerability of Existing Bridges

- Which coastal bridges are vulnerable to storm surge and wave loading during a design storm event?
- Screening criterion is being developed to identify bridges potentially vulnerable
- Detailed analysis to determine surge/wave induced forces/moments and structural response for potentially vulnerable bridges

Study Objectives

- Develop:
  - A screening criterion
  - A procedure to:
    - Identify all bridges in an area that might possibly be vulnerable
    - Screen out those bridges that DO NOT need further analysis
    - Analyze potentially susceptible bridges
    - Compute surge/wave and resistive forces
    - Compute structural response

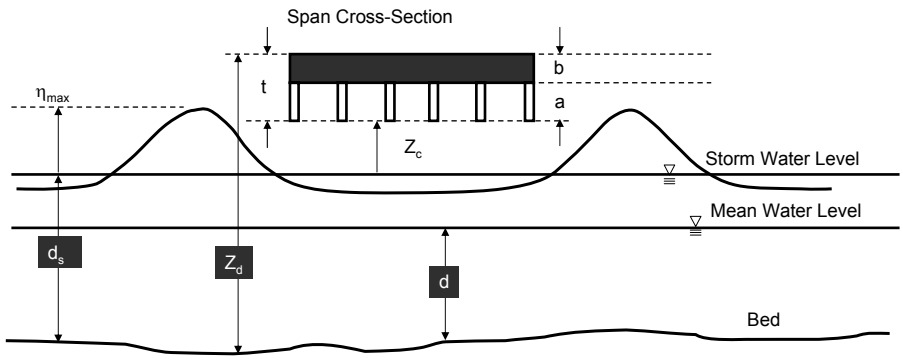
Screening Procedure Framework

- Use existing data/information
- Include quantities on which wave forces depend:
  - Approximate wave heights and periods
  - Storm surge elevations
  - Wind alignment with fetch probabilities
  - Bridge superstructure elevation
  - Bridge span type
- Include bridge importance
  - Evacuation route
  - Minor bridge with easy detour

Screening Criterion

- Quantities Considered
  - Maximum wave heights
  - Probability of maximum wave heights
  - Potential for large buoyancy forces
  - Bridge elevation relative to surge elevation
  - Span type (single, continuous)
  - Importance of bridge

Definition Sketch



Screening Criterion

$\frac{\eta_{max}}{z_c}$	W	Wind Direction Probability	P	$\frac{d_s}{z_d}$	SS	$\frac{\eta_{max}}{t}$	E	Buoyancy $\frac{a}{b}$	B	Span Type	S	Criticality	C
( ) < 0	1	0.8 – 1.0	1.0	$\frac{d_s}{z_d} > 1.2$	2	$0.1 < \frac{\eta_{max}}{t} \le 0.5$	1	0 < ( ) < 1	0	single	1	1	0
0 < ( ) < 1	0	0.6 – 0.8	0.8	$1.2 \ge \frac{d_s}{z_d} \ge 0.8\frac{(z_d - t)}{z_d} = 0.8\left(1 - \frac{t}{z_d}\right)$	3	$0.5 \le \frac{\eta_{max}}{t} \le 1.5$	2	1 < ( ) < 2	1	continuous	0	2	2
1 < ( )	1	0.4 – 0.6	0.6	$\frac{d_s}{z_d} < 0.8\frac{(z_d - t)}{z_d} = 0.8\left(1 - \frac{t}{z_d}\right)$	1	$1.5 < \frac{\eta_{max}}{t}$	3	2 < ( )	3			3	4
		0.0 – 0.4	0.5									4	6

Wave Vulnerability Classification Index = WP(SS+E+B+S+C)
Possible Range 0 to 16
Bridges with Indices ≥ 5 Need Further Analysis

For Bridges Requiring Additional Analysis

- Improved Wave Height, Period Prediction
- Detail Structure Information
- Wave Force and Moment Calculations
- Structure Response Calculations

Bridges Predicted to Fail Under Design Storm Conditions

- Examine Retrofit Options for that Bridge
- Cost Benefit Analysis
- Select Option (note that option may be no action)
- Implement Retrofit Option

Summary

- Surge/Wave Forces Depend On:
  - Surge height
  - Wave height and period
  - Structure shape and size
  - Structure elevation relative to surge elevation
- Wave Height and Period Depend On:
  - Wind speed
  - Wind duration
  - Fetch length
  - Water depth

Summary

- Bridge Vulnerability Screening Procedure Being Developed
  - Determine bridges potentially vulnerable
- Procedure to Determine Storm Surge and Wave Forces and Moments on Bridge Spans and the Structural Response Currently Being Developed
- FHWA – Pooled Fund Study to Examine Retrofit Options to Start in Fall 2006

Questions, Comments

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