Computational Modelling of Hurricane Wave Forcing on Bridge Decks

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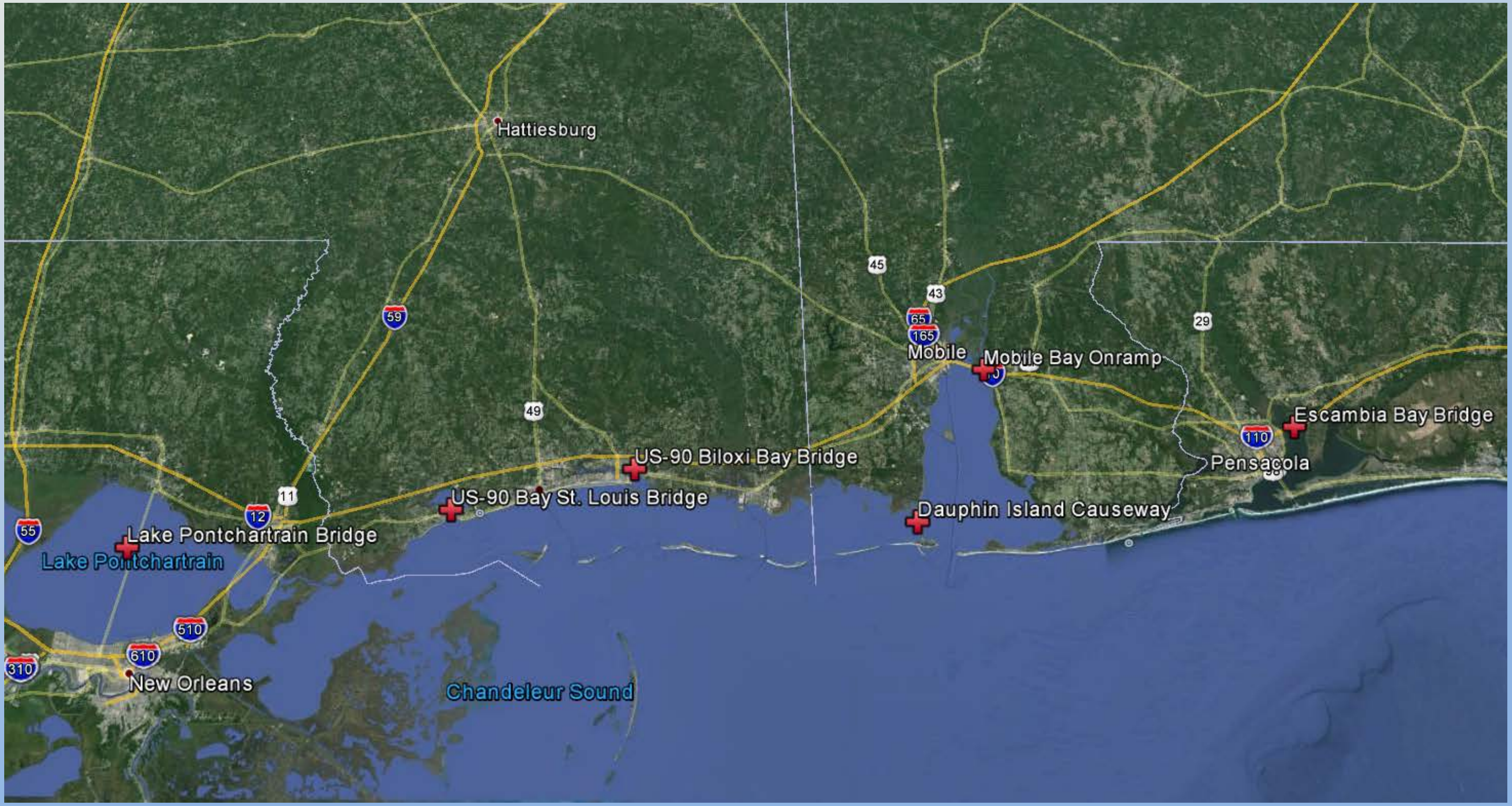
Vulnerable Coastal Bridge Damage Summary (1979 – 2005)



Map of Bridge Failures Due to Hurricanes Since 1979

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Katrina Damage Summary

Mobile Bay Onramp

Lake Pontchartrain Causeway Bridge

Biloxi Bay Bridge

US-90 Bridge

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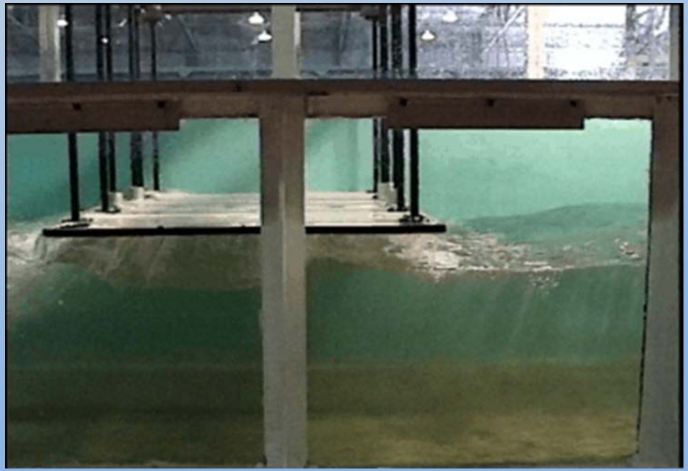
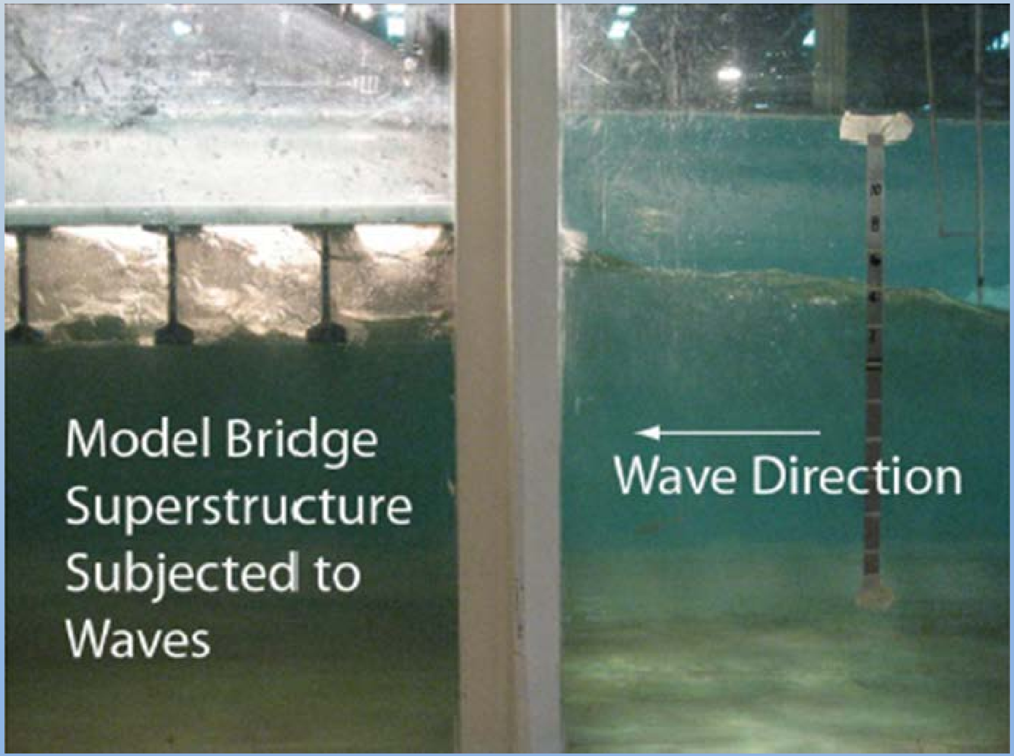
Quantification of Vertical Uplift Forcing





UF Physical Wave Model Photographs

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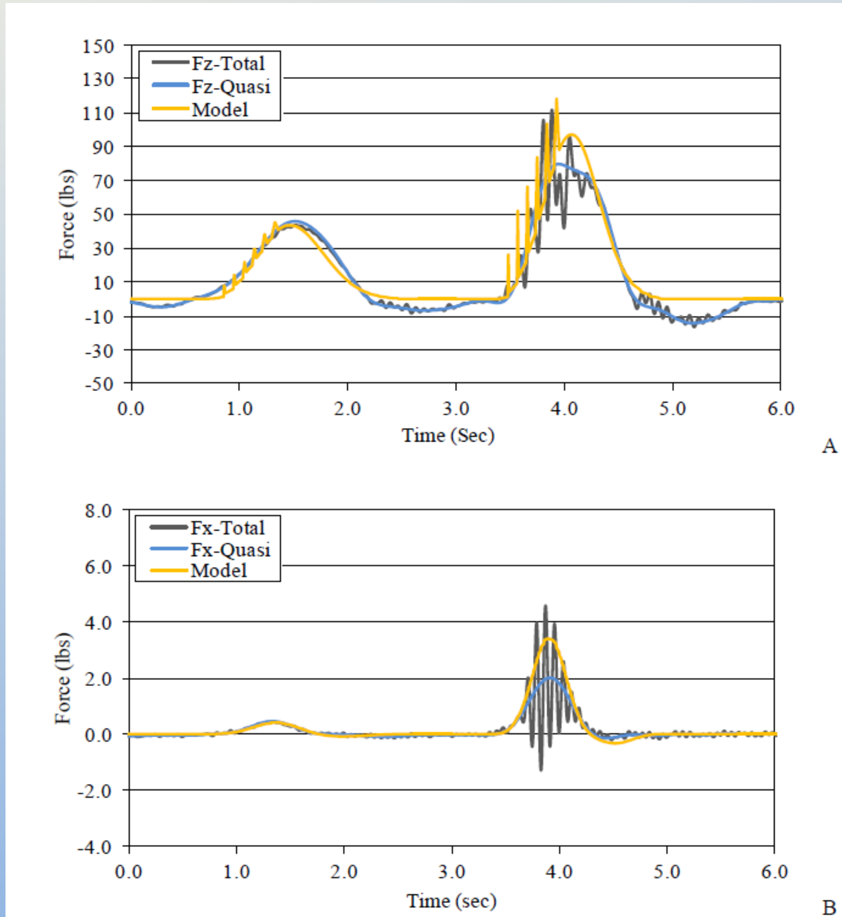
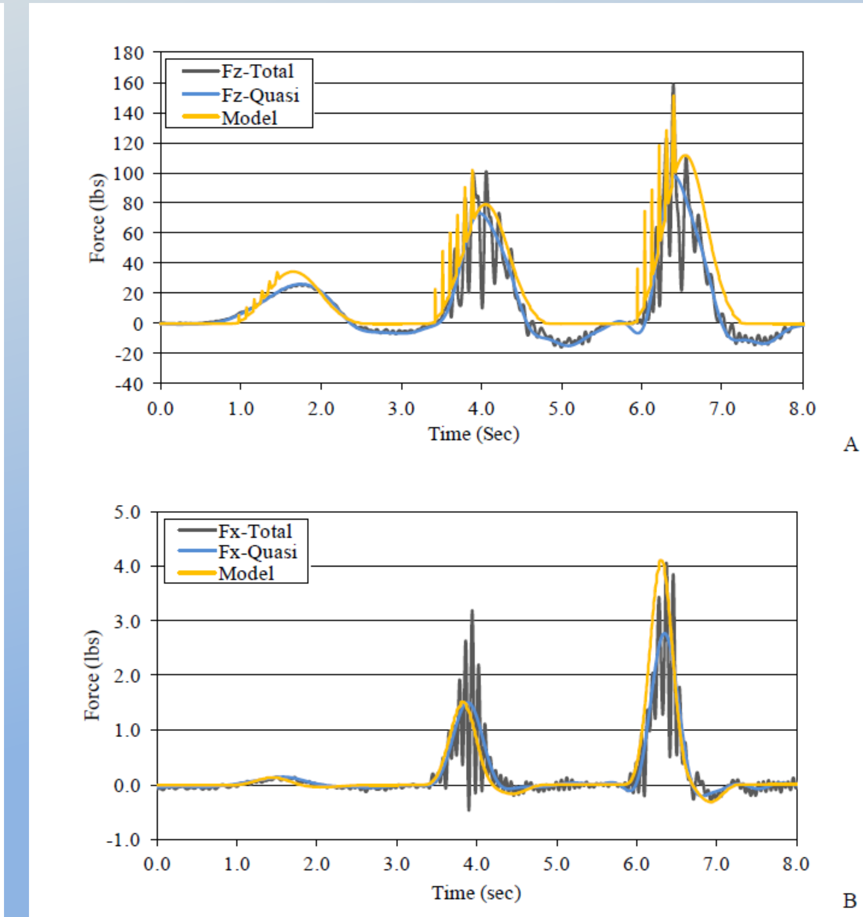
Wave Forcing on Bridge Data

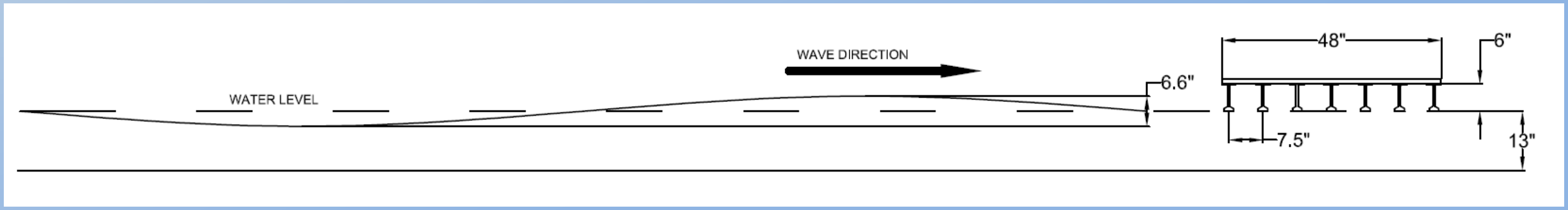




Examples of Wave Forcing on Bridge Physical Data Showing Vertical Forcing (Top Graphs) and Horizontal Forcing (Bottom Graphs)

Computational Model - Questions

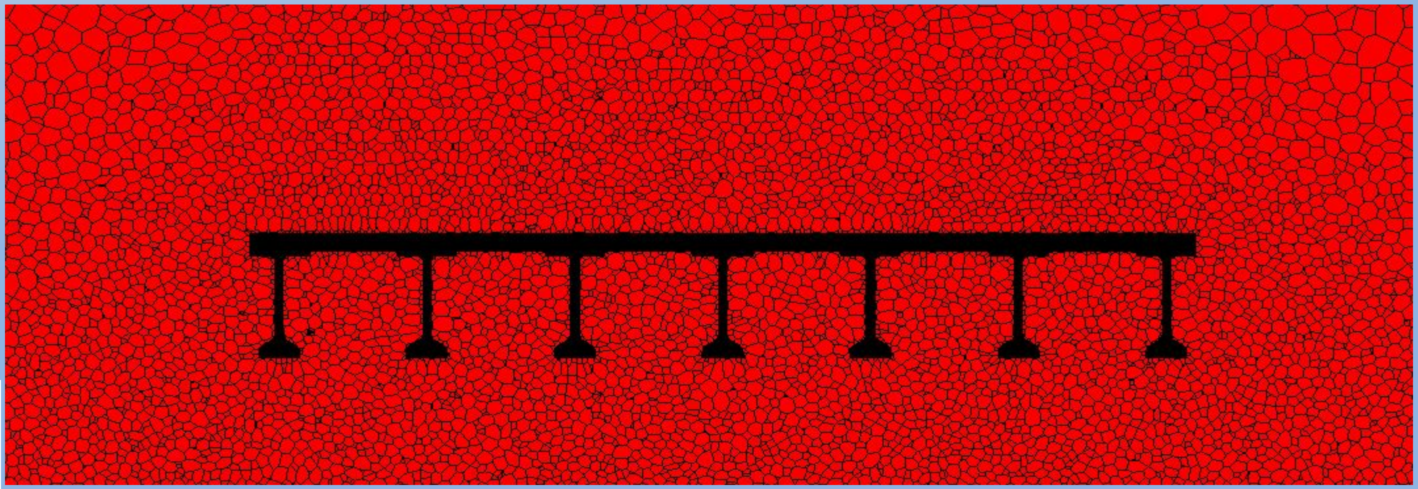
- Can computational model recover Slamming Force?
- “How” to generate waves using computational model?



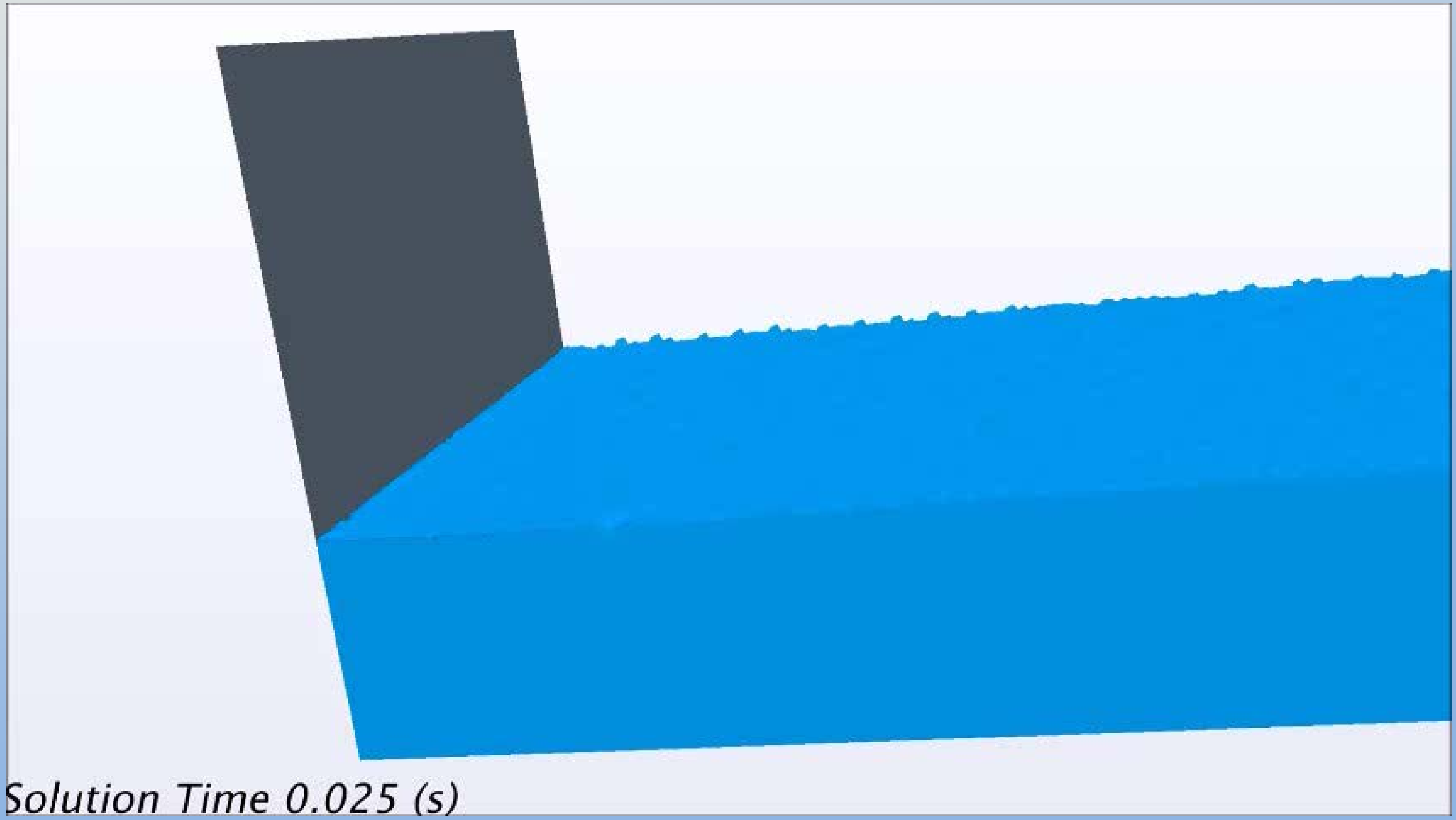
Schematic of Computational Model

Computational Model – Summary

Parameter	Value/Method
Number of Cells	~6.3 Million
Cell Method	Polyhedral
Cell Resolution	~1 cm near deck; 5 cm far from deck
Turbulence Model	k-ε RANS
Wall Closure	All y^+ wall treatment
Wave Generation Method	Varied
VOF Model	Segregated two-phase VOF
Time Step	Implicit unsteady



Wave-Generation Methods (Piston/Mesh Morphing)



Inlet for Piston Model

Wave-Generation Methods (Linear/Fifth Order Wave Theory)

Example of Linear Model

Wave Optimization

- Linear Wave Theory
  - $\eta = \frac{H}{2}\cos(kx - \sigma t)$
  - $\sigma = \frac{2\pi}{T}$
  - $k = \frac{2\pi}{L}$
  - $H =$ Wave Height
  - $x =$ Distance Downstream
  - $t =$ Time
- Piston-Driven Wave
  - $\eta = f(S)$
  - $S =$ Piston Stroke
  - $S = A\sin(Bt)$
  - $A, B =$ Empirically-determined constants

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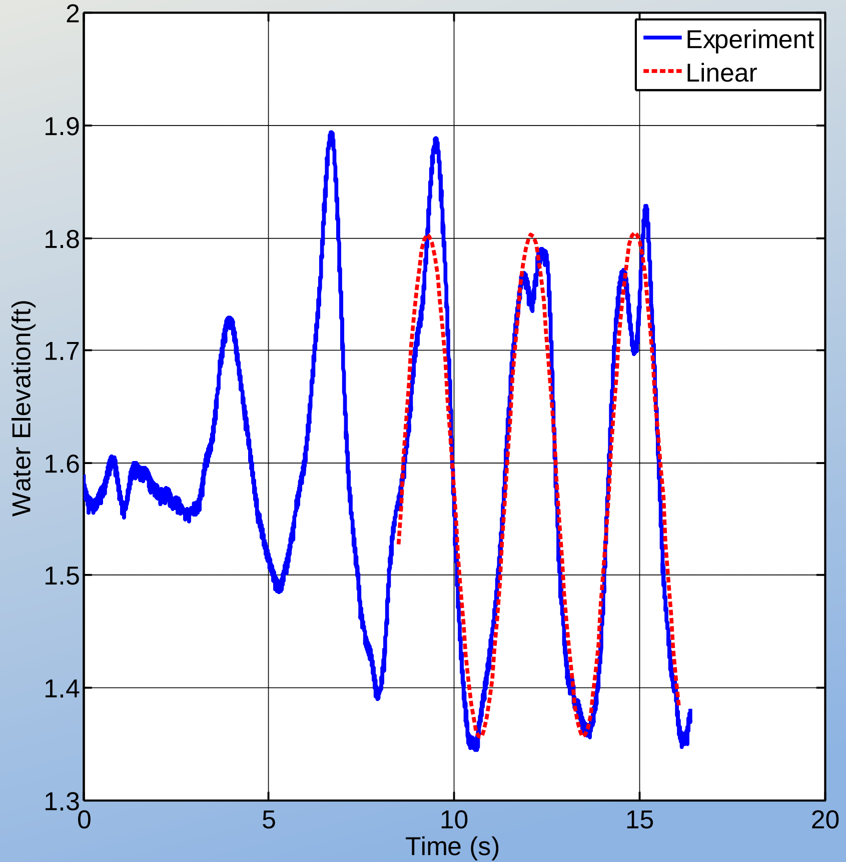
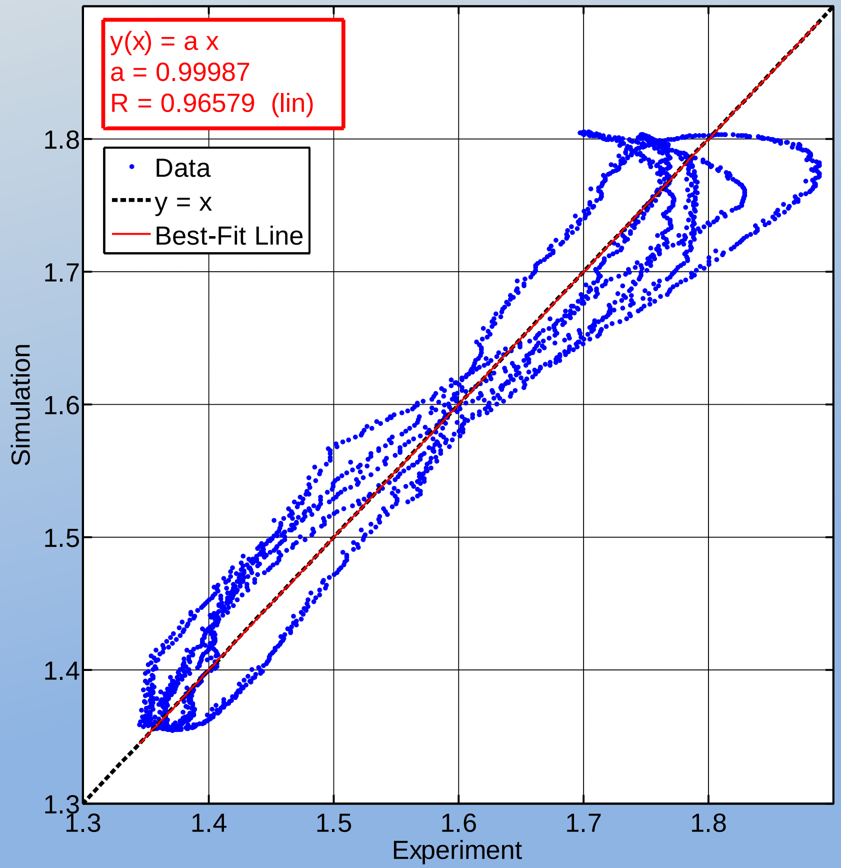
Wave Optimization



Wave Signal From Experiment with Representative Linear Signal Overlain



Example of Regression Technique (Optimized Linear Wave Shown)

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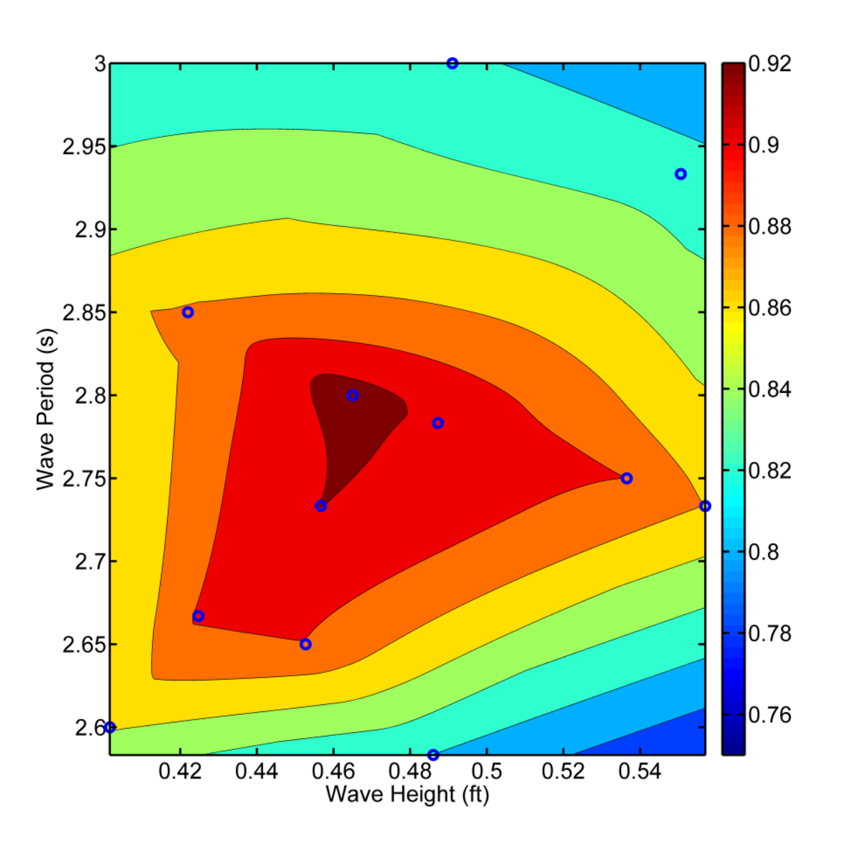
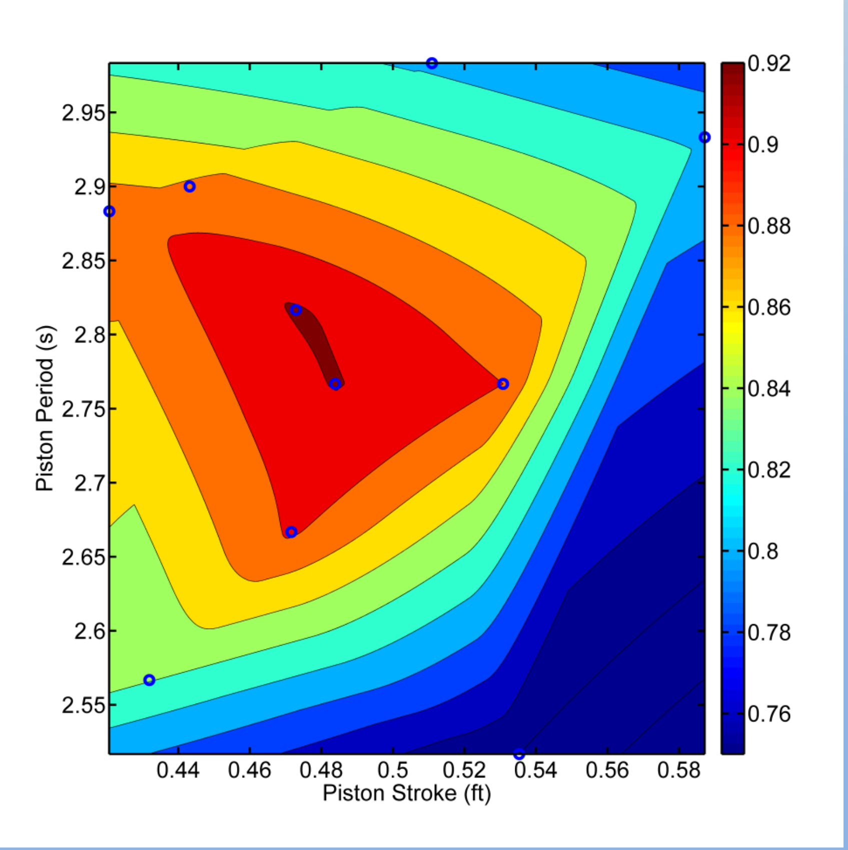
Wave Optimization

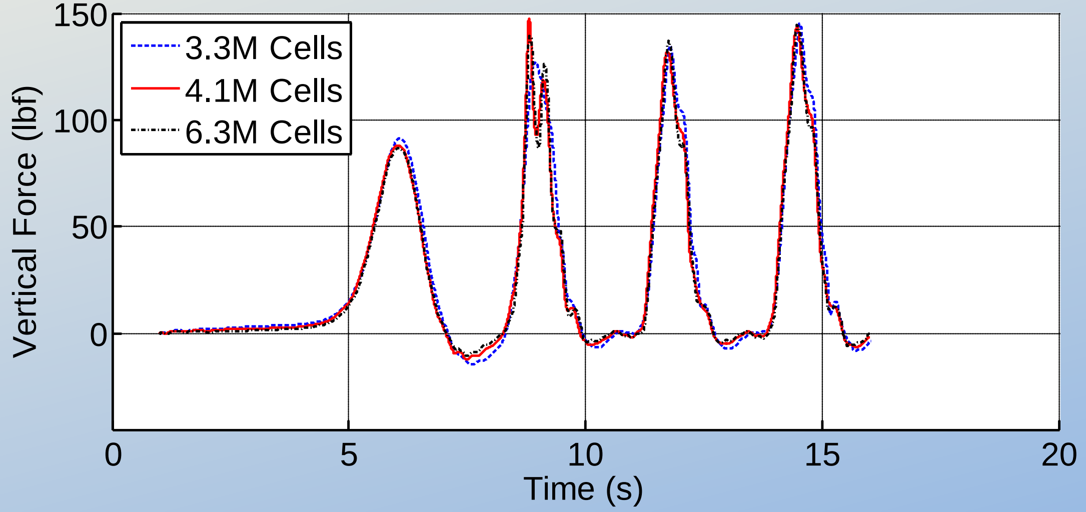


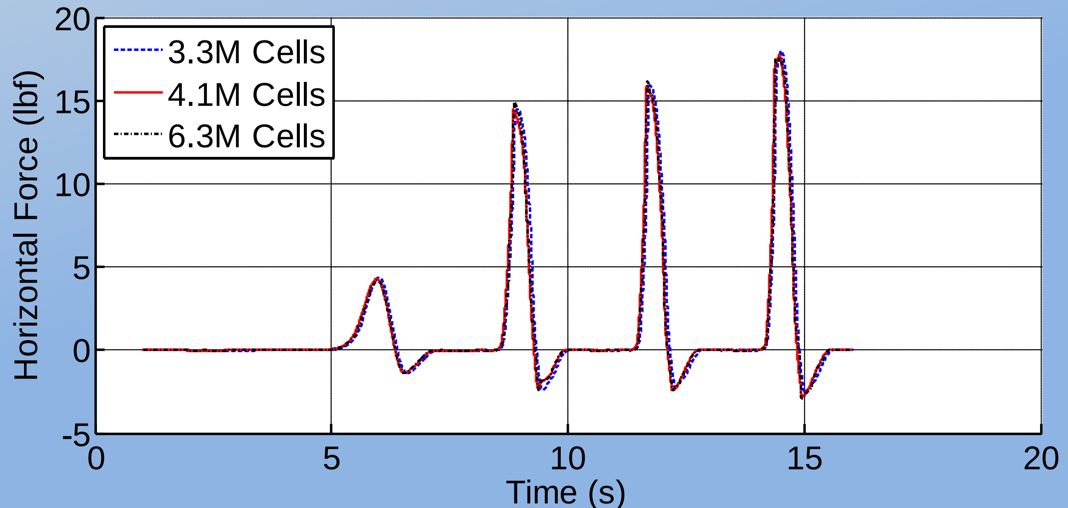
Contour Plots used to Optimize Linear Signal



Contour Plots used to Optimize Piston Signal

Wave Grid Dependency





Integrated Force on Bridge Deck as a Function of Number of Cells for Vertical Force (Top) and Horizontal Force (Bottom)

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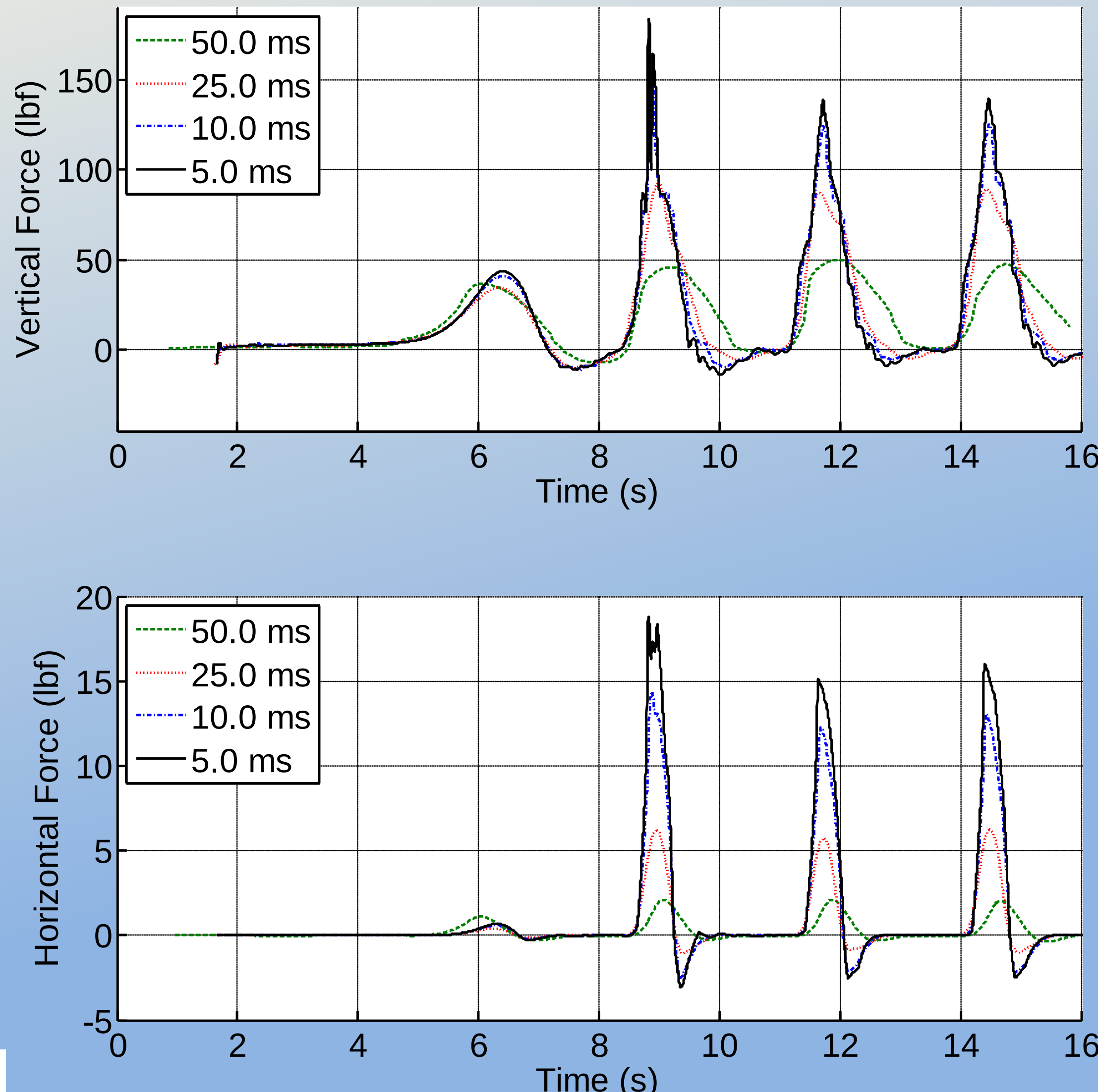
Force Time Step Dependency (Piston)



Integrated Force on Bridge Deck as a Function of Time Step for Vertical Force (Top) and Horizontal Force (Bottom)

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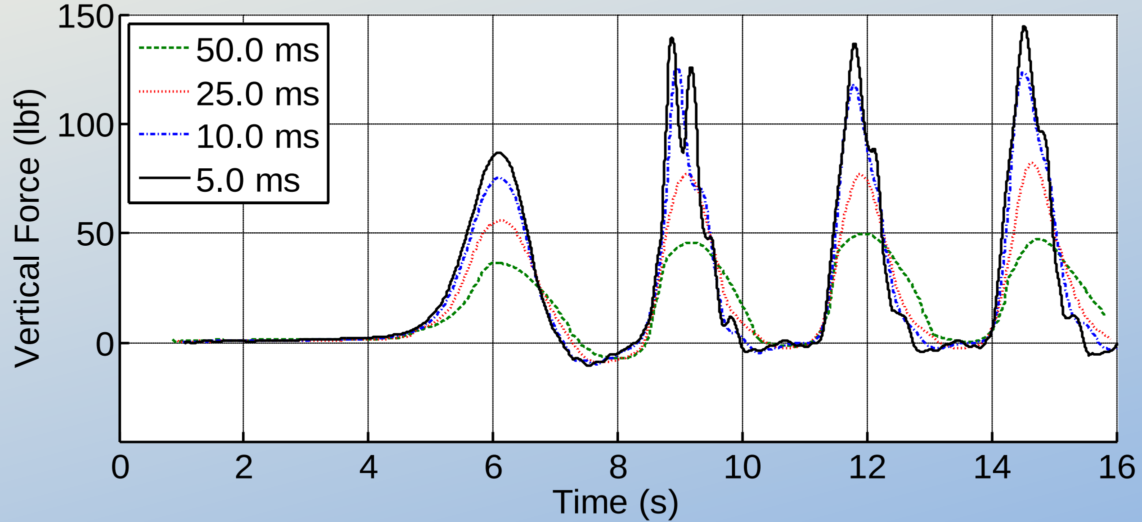
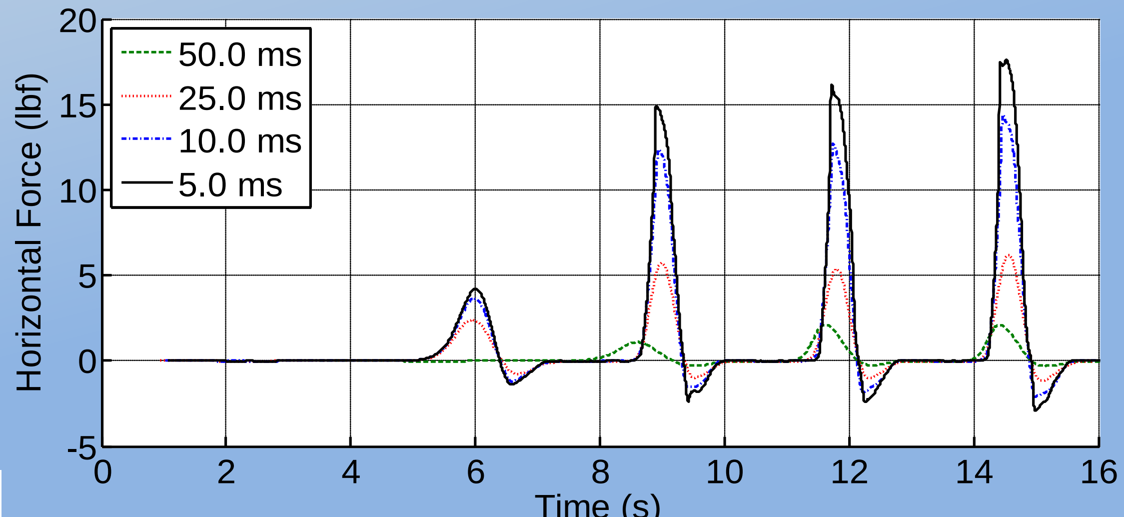
Force Time Step Dependency (Linear)





Integrated Force on Bridge Deck as a Function of Time Step for Vertical Force (Top) and Horizontal Force (Bottom)

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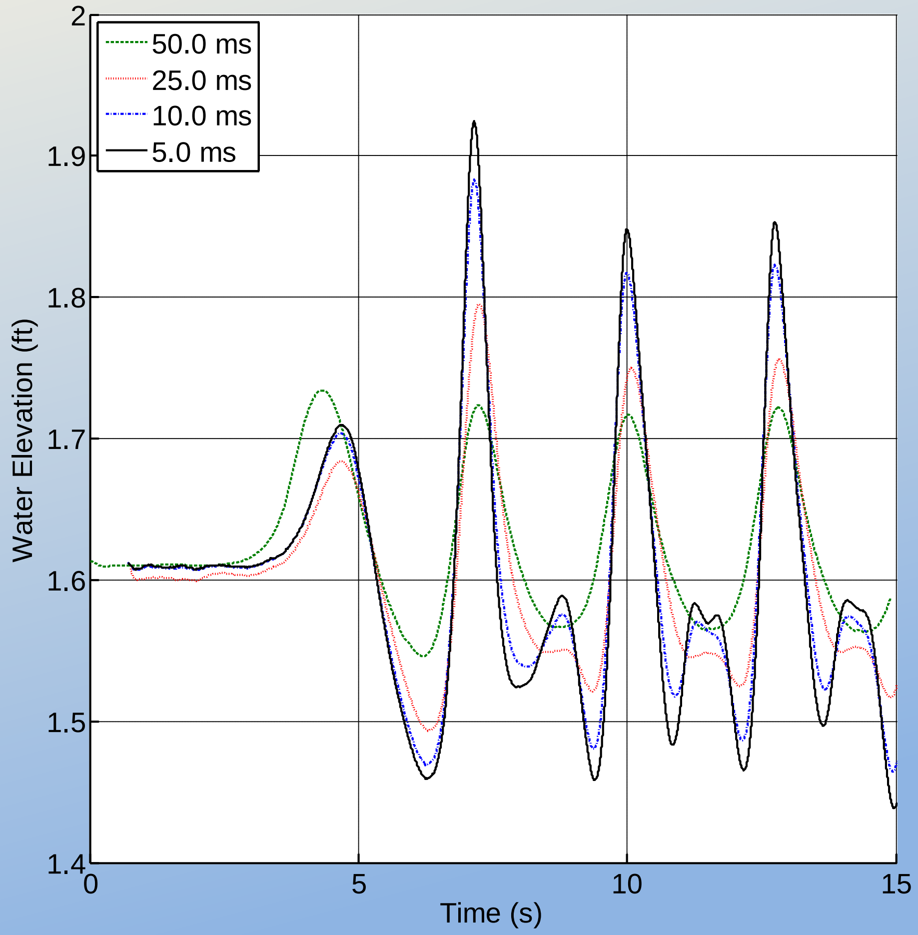
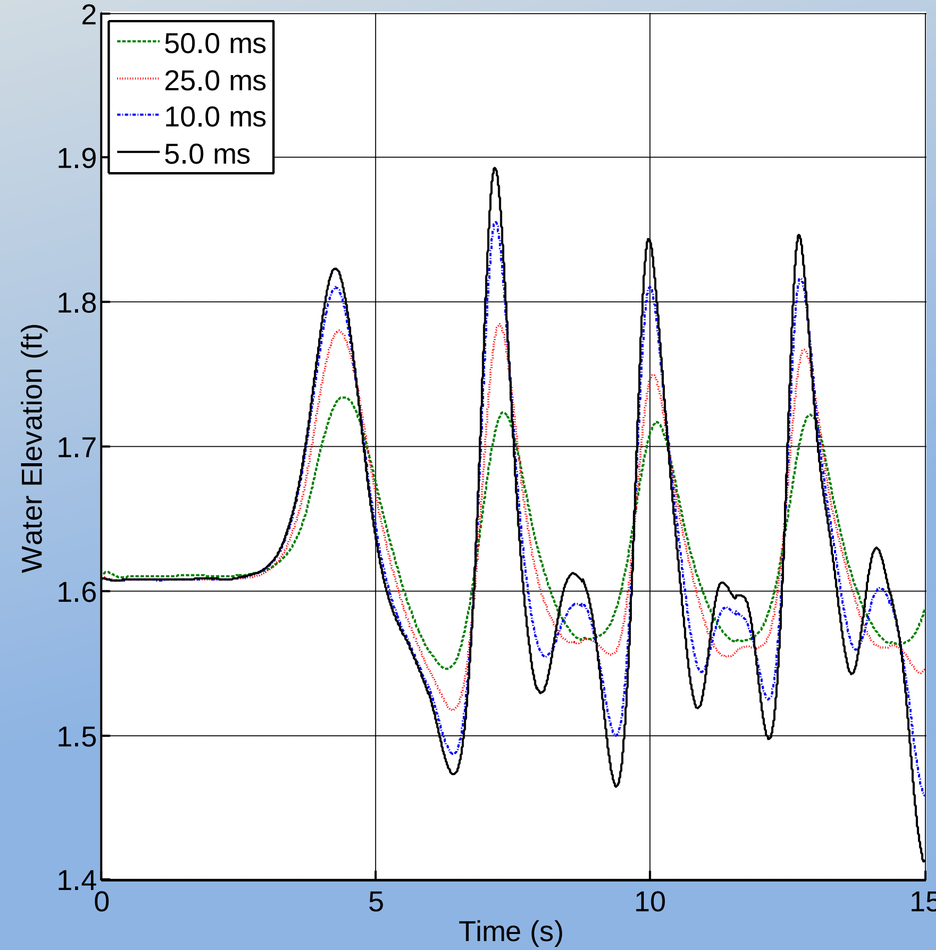
Wave Time Step Dependency





Water Elevation Just Before Bridge as a Function of Time Step for Piston (Left) and Linear (Right)

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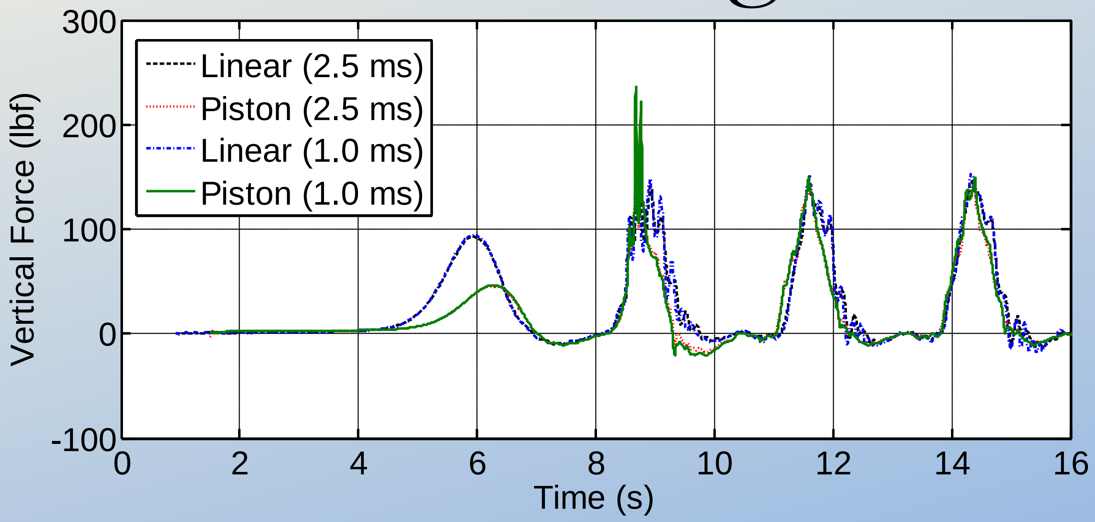
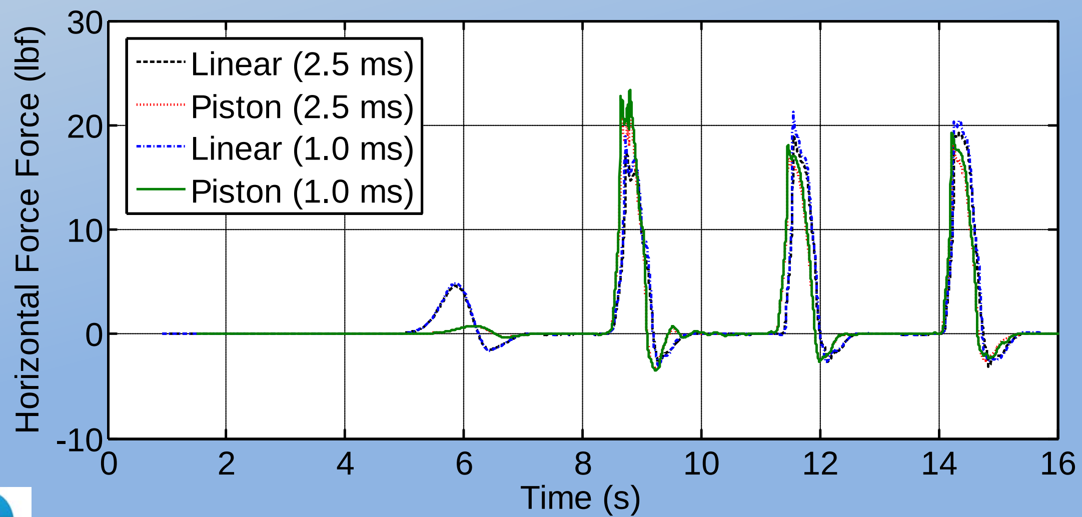
Slamming Force





Integrated Force on Bridge Deck as a Function of Time Step for Vertical Force (Top) and Horizontal Force (Bottom)

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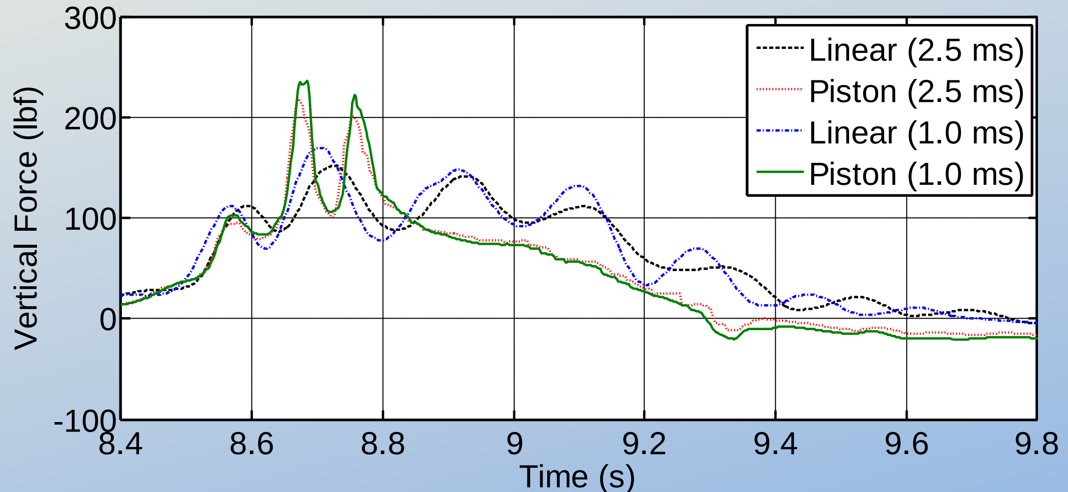
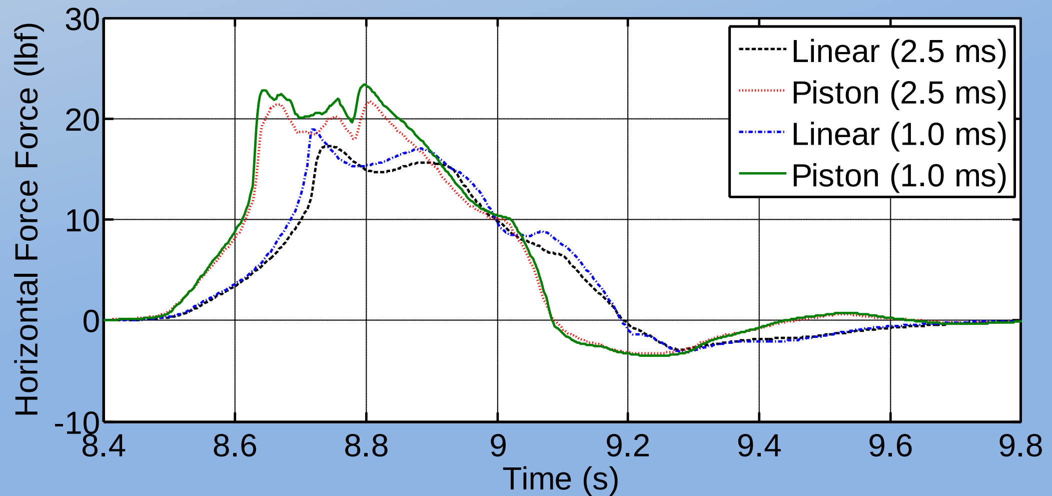
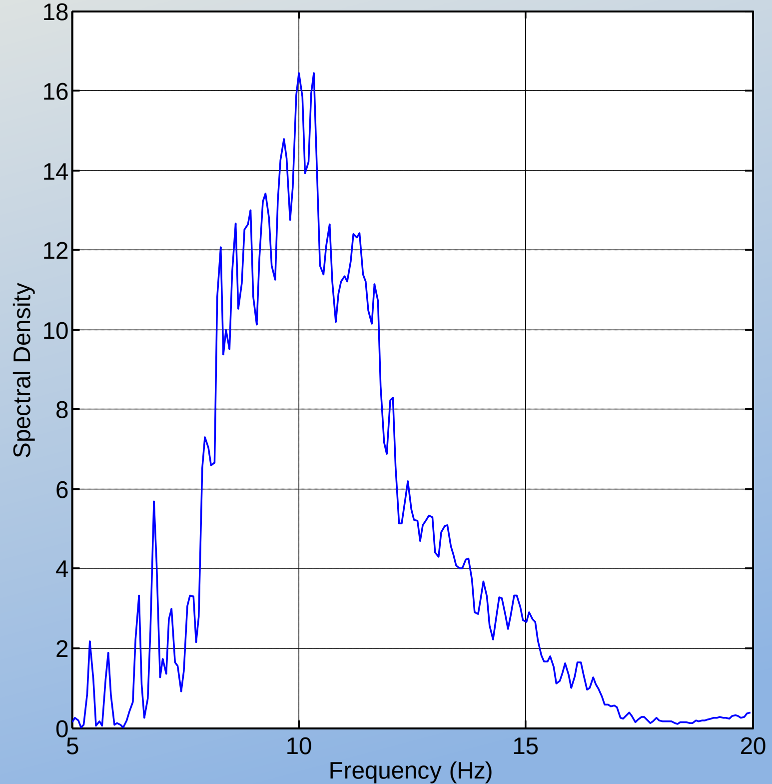
Slamming Force



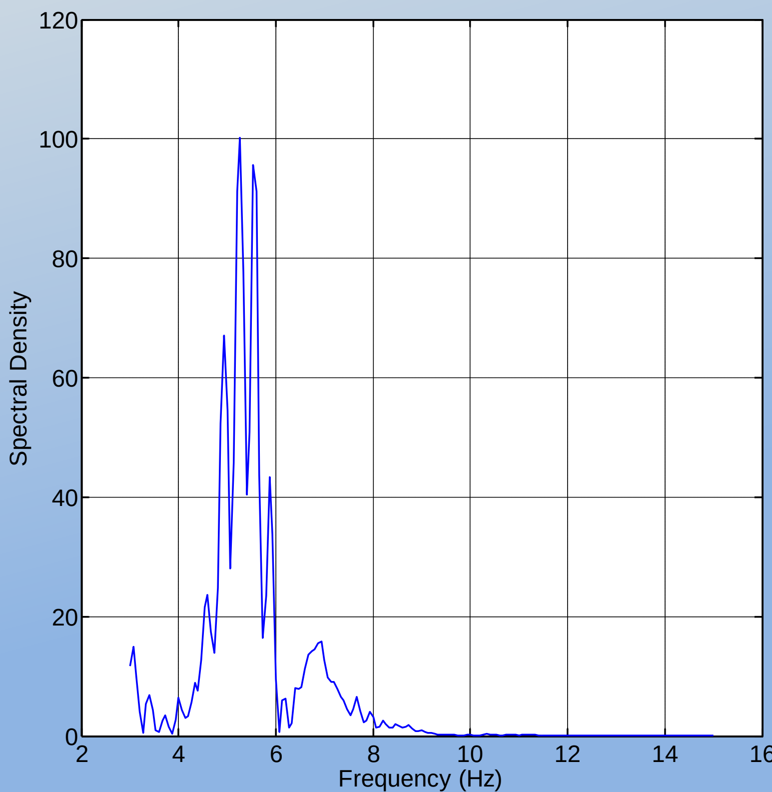


Integrated Force on Bridge Deck as a Function of Time Step for Vertical Force (Top) and Horizontal Force (Bottom)

Spectral Analysis



Spectral Density vs. Frequency for
Piston Method at 1.0 ms



Spectral Density vs. Frequency for
Linear Method at 1.0 ms

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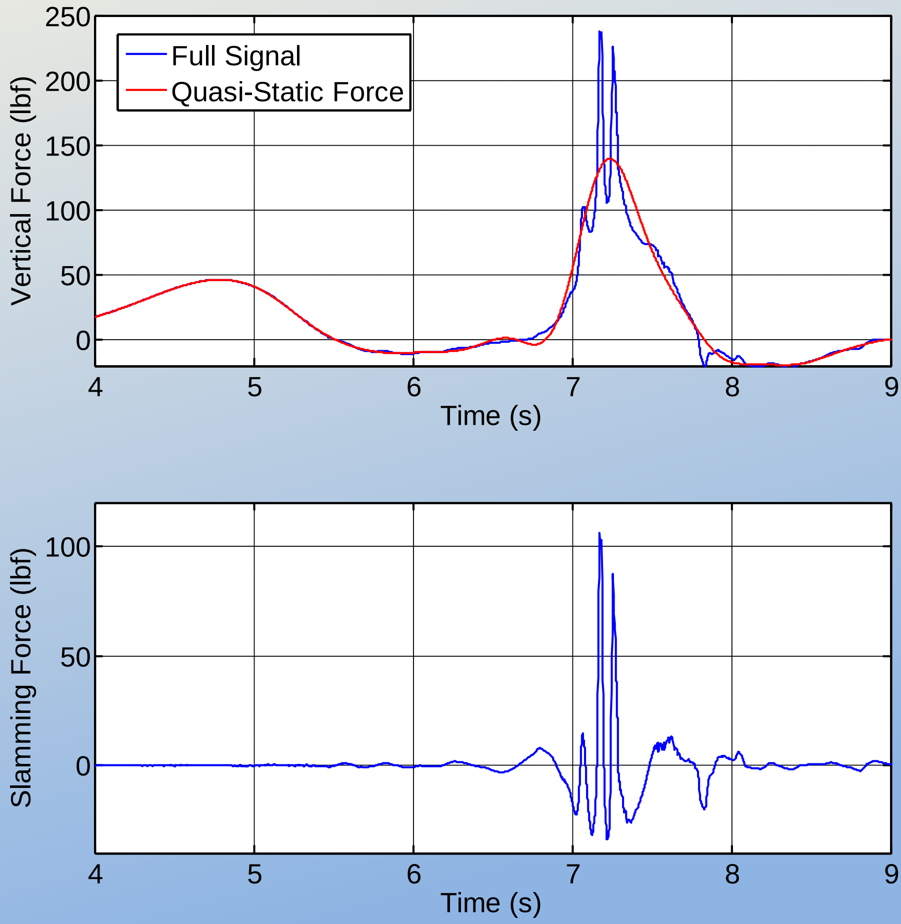
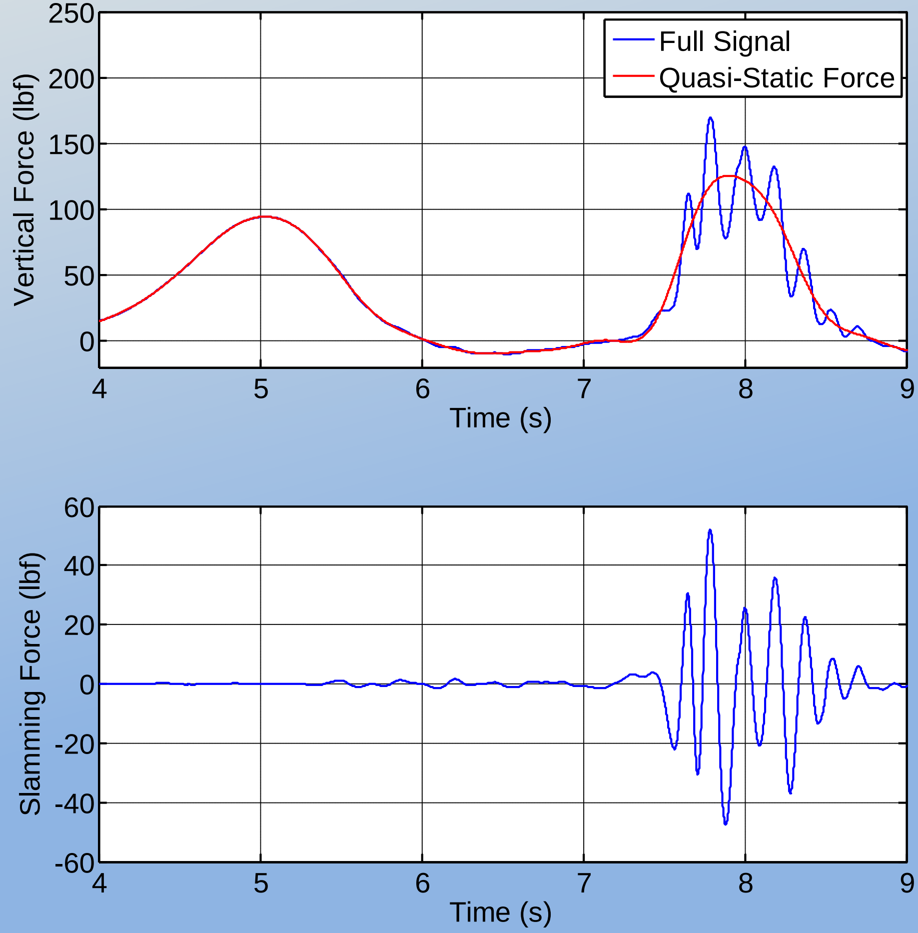
Filtered Signal



Slamming/Quasi-Static Forces for Piston Method



Slamming/Quasi-Static Forces for Linear Method

Comparison With Data (Summary)

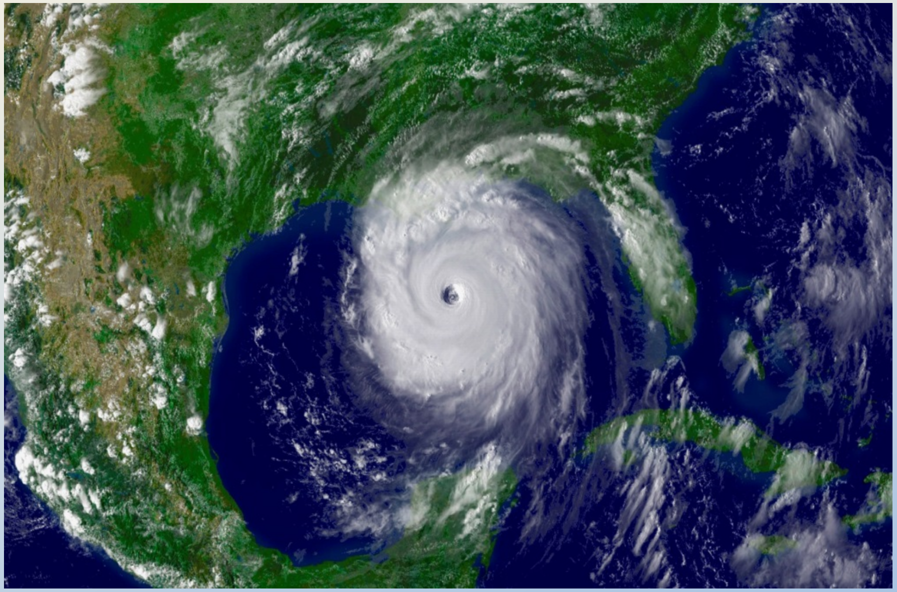
Test Case	Vertical Max	Vertical Min	Quasi Max	Quasi Min	Horiz Max	Horiz Min	Slam
Data	194.99	-35.16	112.81	-26.28	7.96	-2.35	82.17
Piston 2.5 ms	218.40	-17.76	83.41	-22.64	21.70	-3.31	137.02
Piston 1.0 ms	237.88	-20.98	139.55	-19.35	23.38	-3.53	106.04
Linear 2.5 ms	152.12	-10.11	96.38	-20.17	17.30	-2.91	59.55
Linear 1.0 ms	169.74	-9.95	125.54	-9.48	19.01	-3.19	52.13

Comparison With Data (% Error)

Test Case	Vertical Max	Vertical Min	Quasi Max	Quasi Min	Horiz Max	Horiz Min	Slam
Piston 2.5 ms	12.00	49.48	26.06	13.84	172.65	40.66	66.76
Piston 1.0 ms	22.00	40.33	23.70	26.36	193.77	50.03	29.05
Linear 2.5 ms	21.98	71.25	14.57	23.24	117.32	23.82	-27.53
Linear 1.0 ms	12.95	71.70	11.28	69.93	138.76	35.79	36.56

Summary and Conclusions

- Both piston and linear methods can reproduce a vertical slamming component if a small time step is used
- Unclear which method is "better"
  - Piston
    - Quasi-static – high
    - Slamming – low, closer than linear, but wrong number of oscillations
  - Linear
    - Quasi-static – high, but closer than piston
    - Slamming – low, but correct number of oscillations
- Horizontal Force – poorly reproduced for both methods



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