Progress Report

June 30, 2007

PROPOSAL TO THE FEDERAL HIGHWAY ADMINISTRATION

TASK ORDER DTFH61-06-T-70006

FOR THE DEVELOPMENT OF
GUIDE SPECIFICATIONS FOR BRIDGES VULNERABLE TO COASTAL STORMS
AND
HANDBOOK OF RETROFIT OPTIONS FOR BRIDGES VULNERABLE TO COASTAL STORMS

by

Modjeski and Masters, Inc.

with

Moffatt and Nichol, Inc.
Ocean Engineering Associates, Inc.
D'Appolonia, Inc.
Dr. Dennis R. Mertz

INTRODUCTION

We received Notice to Proceed on this Work Order on August 14, 2006.

This report covers work done in June, 2007.

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TASK 1 – MEETINGS

A meeting with the full Task force was held in the office of North Carolina DOT in Raleigh, NC on June 12 and 13. The minutes for this meeting are attached as Attachment A.

The team had several phone conferences to discuss the preparation for the June meeting with the Task Force. In addition, several other conference calls concentrated on the calibration process.

TASK 2 – REVIEW, SUMMARIZE, AND AUGMENT LITERATURE

Work on Task 2 is essentially complete. The deliverables for this Task have been submitted and have been accepted by the Task force. Some refinements may be incorporated when transferring the information developed in this task to the final report of the project.

TASK 3 – REVIEW AND SUPPLEMENT ONGOING FORCE STUDIES

Work on Task 3 is essentially complete. Extensive computer runs were conducted during June to determine the coefficients to be used in the force equations. In addition to OEA, Moffatt Nichol offered to make about 12 high-end computers available to make additional runs overnight. The FHWA and the Panel gave the team permission to invoice for Task 3.

TASK 4 – COMPILE AND CATALOG RETROFIT OPTIONS

Work on Task 4 is essentially complete. The deliverables for this Task have been submitted and have been accepted by the Task force. Some refinement may be incorporated when transferring the information developed in this task to the final report of the project.

TASK 5 – PERFORM ANALYTICAL STUDY OF RETROFIT OPTIONS

No progress to-date. A proposal was submitted to the FHWA to reduce this task and divert resources to Tasks 3 and 6. We received the FHWA's approval of this proposal.

TASK 6 – DEVELOP A GUIDE SPECIFICATION AND A RETROFIT HANDBOOK FOR ADOPTION BY AASHTO

TASK 6A - GUIDE SPECIFICATION

The Task Force agreed to the team's request that the 90% submission of the Guide Specification be moved from July 15th to August 15th.

The calibration process required for determining the wave force load factors has been initiated. The load factors will be calibrated based on the failure state of tension failure in an anchor bolt due to wave loads on the structure. For this condition, the vertical force, horizontal force and moment arm, and moment are calculated based on the parametric equations developed for the specification. Data from the ASCE flood study is used to determine the parameters of the random variables used for the wind speed and water surge height. Basic bridge parameters are assumed to allow an anchor bolt force to be calculated. The resistance of the anchor bolt will be treated as a random variable, with the properties determined from available test results.
A method has been charted using Monte Carlo simulations to obtain the distributions of anchor bolt force given the parametric equations and the random natures of the inputs. Once the parametric equations have been finalized, the first calibrated load factors can be determined.

TASK 6B - RETROFIT HANDBOOK

A 50% submission of the Retrofit Manual was made on May 15th. A supplemental submission for the proposed Cost Assessment Model was made on May 29. A condensed version of the glossary of the terms used in coastal engineering was also submitted on May 29. These documents were attached to prior progress reports. We have not received comments on these documents to-date..

TASK 7 – DEVELOP FINAL REPORT AND RECOMMENDATIONS FOR FURTHER STUDIES

No progress

TASK 8 – PREPARE EXECUTIVE SUMMARY AND PRESENTATION MATERIALS

No progress

FUTURE WORK – NEXT MONTH

1. Finalize the tables of the force equations coefficients
2. Continue working on the issues raised during the June 12-13 meeting

3. Continue formalizing the specifications to implement the method of calculating wave forces on superstructure and the associated specifications provisions

4. Update the Retrofit Manual

SCHEDULE

See schedule below.

SCHEDULE

TASK	Date shown in Work Plan	PROPOSED COMPLETION DATES
Notice to Proceed	September 1, 2006	
Kickoff Meeting	December 4,5,6, 2006	
Task 2	December 15, 2006	Done
Task 3	December 15, 2006	May 31, 2007
Task 4	January 26, 2007	Done
Task 5	On hold pending resolution of proposal to the FHWA	
Task 6 50% Draft Specification and Manual 90% Draft Specification and Manual 100% Draft Specification and Manual Interim Report Tasks 2 to 6	 February 15, 2007 May 31, 2007 August 15, 2007 July 15, 2007	 Done August 15, 2007 October 15, 2007 September 15, 2007
Task 7 Draft Final	 June 30, 2007 September 15, 2007	 August 31, 2007 November 15, 2007
Task 8 – Executive Summary Draft 4 to 6 page summary Final 4 to 6 page summary	 June 30, 2007 August 31, 2007	 August 31, 2007 October 31, 2007
Task 8 – 13 hour slides Draft Final	 November 30, 2007 January 31, 2008	 January 31, 2008 March 31, 2008

Total hours spent per task to-date

To-Date Work Hours by Task

Modjeski and Masters, Inc.

FHWA Project on
Development of Guide Specifications for Bridges Vulnerable to Coastal Storms
and
Handbook for Retrofit Options for Bridges vulnerable to Coastal Storms

Labor Costs

Category	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	task 8
John M. Kulicki	94	56	18		97		
Wagdy G. Wassef	21.5	12.5	44		33.5		
Tim Stuffle	149	16	233.5	1			
Tom Rogers	50.5						
Don Miller		1		2.5			
Jeff Forest				39			
Don Price	25						
Sherood Herb			95				
Tom Murphy					139		
Zolan Prucz					7		
Subtotal	340	85.5	390.5	42.5	276.5		

Moffatt & Nichol

FHWA Project on
Development of Guide Specifications for Bridges Vulnerable to Coastal Storms
and
Handbook for Retrofit Options for Bridges vulnerable to Coastal Storms

Labor Costs

Category	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	task 8
Mike Knott / John Headland	8				40		
Jeff Shelden	37	180	45		131.5		
Paul Tschirky	19.5	13			7		
Graphics / CAD / Admin					1		
Subtotal	64.5	193	45	0	179.5		

OEA, Inc.

FHWA Project on
Development of Guide Specifications for Bridges Vulnerable to Coastal Storms
and
Handbook for Retrofit Options for Bridges vulnerable to Coastal Storms

Labor Costs

Category	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	task 8
Subtotal	52	528			153		

D'Appolonia, Inc.

FHWA Project on
Development of Guide Specifications for Bridges Vulnerable to Coastal Storms
and
Handbook for Retrofit Options for Bridges vulnerable to Coastal Storms

Labor Costs

Category	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	task 8
Jim Withiam			5				
Ed Voytko			4.5				
Colleen Campbell			20.75				
Subtotal			30.25				

Attachment A

Minutes of the June 12-13 Meeting

Harrisburg, Pennsylvania
July 5, 2007

MEMORANDUM

TO: Modjeski and Masters, Inc.

RE: JUNE 12 and 13, 2007 MEETING MINUTES – DTFH61-06-T-70006

PN2560

The June12 and 13, 2007, meeting of the above-captioned project was held in the offices of the North Carolina Department of Transportation in Raleigh, North Carolina. The following were in attendance:

Wave Vulnerability Task Force

Greg R. Perfetti	NCDOT
Rick Renna	FDOT
Joseph Krolak	FHWA
Firas Ibrahim	FHWA
David L. Kriebel,	U.S. Naval Academy
Spencer Rogers,	North Carolina Sea Grant
Jerry Dimmagio	FHWA (Attended 6-12-07 only)
Joe Krolak	FHWA
Shoukry El-Nahal	FHWA
Lex Collins	FDOT
Kevin Flora	Caltrans
David Henderson	FHWA (Attended 6-13-07 only)

Project Team

John Kulicki (M&M)	
Wagdy Wassef (M&M)	
Tom Murphy	Modjeski and Masters
Max Sheppard	OEA
Phil Dompe	OEA
Jeff Shelden	Moffatt Nichol

PRESENTATIONS AND DISCUSSIONS

- The meeting started with Dr. Kulicki presenting an overview of April meeting presentations and decisions. A copy of the minutes of the April meeting was sent to all task members earlier.

- **Discussion on Wallingford Method:**

    - The fact that different force calculation methods do not converge to the same answer was discussed
    - Mr. Shelden explained that Wallingford is unclear as to what coefficients should be used. It looks at a bridge as components, as opposed to an entire structure. Wallingford looks at very long wave lengths, does not include variable forces on structure across the width as waves pass. Depending on the coefficients chosen, it can be very similar to Modified Kaplan. Not including the wave period is still an issue with Wallingford. In addition, the effect of air entrapment is not included.
    - It was requested that the Project Final Report includes a discussion of how Wallingford, with careful selection of coefficients, can produce forces comparable to those produced using Kaplan's method in some cases and to clearly state the cases Wallingford method does not give accurate results, e.g. in case of short wave periods.
    - The case of tsunamis was discussed. It was concluded that probably Kaplan and Wallingford will converge for tsunamis as the wave length and period in this case are long.
    - Dr. Kreible asked that the original Wallingford equations to be included in the project report for use in the situations they are applicable to, e.g. in a Tsunami situation. They will be included in the report.

- Mr. Rick Rena made a presentation on FL work. It was indicated that Florida is moving ahead with Phase 3 which is Level III analysis of Tampa Bay bridges followed by statistical analysis.

- The idea of using load modifiers to account for the level of analysis conducted was discussed. It was stated that this is analogous to the approach used in scour analysis. As the level of analysis increases, conservativeness decreases. The consensus was that it is acceptable for the lower level of analysis to be conservative.

- The selection of the values of the load modifiers was discussed. It was decided that these values will be based on the results of Florida Phase 3 study. However, in case these results are not available in time for inclusion in this project, values determined by experts in the field may be used as interim values. The FHWA agreed to sponsor such a meeting if needed. It was suggested that the following should attend:

Rick Renna
David L. Kriebel
Spencer Rogers
Robert (Tony) A. Dalrymple

Later, when more scientifically-developed load modifiers become available, they can be incorporated in the AASHTO agenda item.

- Dr. Sheppard made a presentation entitled FDOT update (copy attached as Attachment A). This presentation gave an overview of the work done in Florida (Phase I: Develop Screening, and, Phase II: Improve on Procedures). A discussion on the selection and value of the Criticality Index (CI) and Vulnerability Index (VI) took place. The Task Force requested that the retrofit manual state that the selection of these values is a management issue and educate the user on the implications of this determination (judgment and prudence)

  - A question was raised regarding AASHTO's possible vote on the retrofit manual. The consensus was that it is not a ballot item. The subcommittee can/will vote to endorse the retrofit manual, but not adopt. The manual could be published as an FHWA document.

- Dr. Sheppard made a presentation entitled Wave Force Prediction Update (copy attached as Attachment B). The following was presented/stated
  - New equations were developed after last submission
  - In all cases checked, the most critical case is Maximum vertical force with concurrent horizontal and movement. Other cases, i.e. maximum horizontal force or maximum moments with other concurrent effects, did not control. It should be noted that the "critical case" above relates to the pull-off of anchor bolts which appears to be the dominate failure mode. Other failure modes such as bolt shear do not seem to control.
  - Steeper waves, i.e. waves with higher (H/Wave length) ratio, produce less vertical slamming force and more Quasi static vertical force but they produce higher horizontal slamming force with less Quasi static horizontal force.
  - New equations were shown. Wave steepness is included in the coefficients. The coefficients are expected to be linear functions of the number of girders. Slamming force will ultimately need to be included based on I-10 experience. Dynamic response may also need to be looked at.
  - It was suggested that it may be possible to take the dynamic effects as a percentage of the quasi static effect.
  - The need to keep force contributions separate to maintain understanding of the underlying physics of the problem was discussed.
  - Dr. Shepard indicated that he will use a calibrated hammer technique to find the natural frequencies of load cells and test set-up and then filter out the response. He will also use pressure grids to better define the slamming force without going through the set-up or load cells.

- A question on how the horizontal force accounts for depth of girder was raised. Dr. Sheppard indicated that it is included in coefficients in the equations. He also indicated that there is a need to test more girder depths to be sure that accurate results are obtained for all girder depths.
- Results indicate that high resolution analyses are required. OEA is using approximately 12 computers. Moffatt Nichol will provide another dozen or so computers to work at night.
- A question was raised regarding whether the shape of girder have an effect on the magnitude of the forces (or only the depth and flange width). Dr. Sheppard indicated that it is not yet clear. He also indicated that if only the depth matters, the tables of the coefficients can be simplified.
- Forces on a bascule pier are not related to Max's equations, other equations in the specifications could be used.

- Jeff Shelden made a presentation on three trial examples for wave force analysis on coastal bridges using the 50% specifications. Some issues relate to specifications were discussed including. The following was discussed/stated:
  - FEMA maps may be inconsistent (include different components that are not the same every where)
  - FHWA will discuss how and where more detailed guidance will be provided (HEC 25 being prepared or a stand alone document for bridges).
  - A discussion on the role of the Ocean Engineer took place.
  - Based on the results for the three bridge examples included in the trial calculations, the following issues were discussed:
    - Some revisions to the specs were discussed including correcting equation and what wind speed (3 sec gusts were used) should be used. Adjustments to wind speed to account for the required duration to produce the waves were discussed.
    - Adding a limit on wave heights based on water depth "near the face of the bridge" was proposed to determine what depth to use in the equations. It was proposed to use the shallowest point in the last 10% or 20% of the fetch length near the bridge.
    - Rational ways to be used in determining the fetch length were discussed. The goal is to eliminate the possibility of using a long fetch that is highly unlikely due to the small angle of wind attack along this fetch.

- Dr. Kulicki discussed the project schedule. The 90% specifications submission was moved from July 31 to August 15th while the 100% submission is still October 15th.

- The 50% Specifications were discussed. Some questions were raised concerning the following:

  - The source of substructure wave force equations: Equations are standard equations (Morrison's equations) and were not developed in this project

    - Loads on pile groups are not extremely accurate. Graduate students in the University of Florida will look at pile groups in the Fall.
    - Cyclic load resistance in foundations is important but has not been addressed. It was recognized that adequate information may not exist in the literature. The Task Force requested that commentary stating that "Fatigue and high uplift are not well documented."

- Members of the Task Force indicated that other parties are interested in getting on board with this work. The project team welcomed the cooperation of others as long as they work toward confirming the results and broadening the applicability of the equations. If others are trying to develop different methods, this may be a waste of available resources.

- The project team asked the Task Force about the depth of the slab bridges to be included in the development of the wave force equations. The Task Force requested that 21 and 36 inches be used. The 36 inches may also be considered to represent adjacent box girders.

- A discussion of the design storm to be used for setting the grade took place. A general consensus to design for 100 year event and check survivability for 500 year event was reached. It was suggested to design for factored water elevation of the 100 year event with some freeboard (Guidance to be provided) then check for 500 year unfactored or with lower load factor.

- The comments from the Task Force on the 50% submission will be sent to the team 6-30-07.

- The Task force requested that wording indicating the specifications are applicable to important/critical bridges and that normal/typical bridges can be excluded. The goal is to eliminate the need for waivers from the FHWA for a typical bridge. Dr. Kulicki suggested including language indicating "specifications shall apply to important structures and may be applied to other structures at the discretion of the owner."

- The Task Force will arrange for another test drive of the specifications after the 90% submission. Some additional states will be involved. M&M will discuss with Greg what examples (mostly type of girders) to be used.

- Dr. Mertz made a presentation on the calibration of the specifications.

    - A Discussion of limit states and which one is appropriate for coastal bridges took place. The Task Force requested that a discussion of the limit states be included in the final report.
    - Calibrations will be within the level of detailed and short comings similar to the LRFD specs.

- The Task Force requested that language allowing the bridge owner to use lower β for evaluation be added to the specifications.

- Final Report:
  - Revisit literature search and finalize state-of-the-art
  - Explain how decisions were made, why the method was selected.
  - Append specs and retrofit manual
  - Include a list of needed future work.

- In light of the length of time the computer runs are taking, the team asked about the possibility of revising the project schedule. The Task Force indicated that the only hard deadline is the AASTHO date, other items (report) are somewhat flexible.

WAGDY G. WASSEF

Attachment A

FDOT Work Update
By
Dr. Max Sheppard

FDOT WORK UPDATE

June 12, 13, 2007

D. Max Sheppard

Phil Dompe

Justin Marin

OEA, Inc.

Projects

- Wave Tank Testing
- Theory Development
- Design Curves
  - Changed to Parametric Equations developed under FHWA/AASHTO contract
- Pilot Study
  - Phase I
  - Phase II
- Met/Ocean Joint Probability

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

Wave Tank Tests

- Flat Deck Tests
  - Test instrumentation and support model structure
  - Gain insight into magnitude and nature of forces and moments
- Bridge Decks with Girders
- Bridge Decks with Girders and Overhangs
- Bridge Decks with Girders and Overhangs and Rails

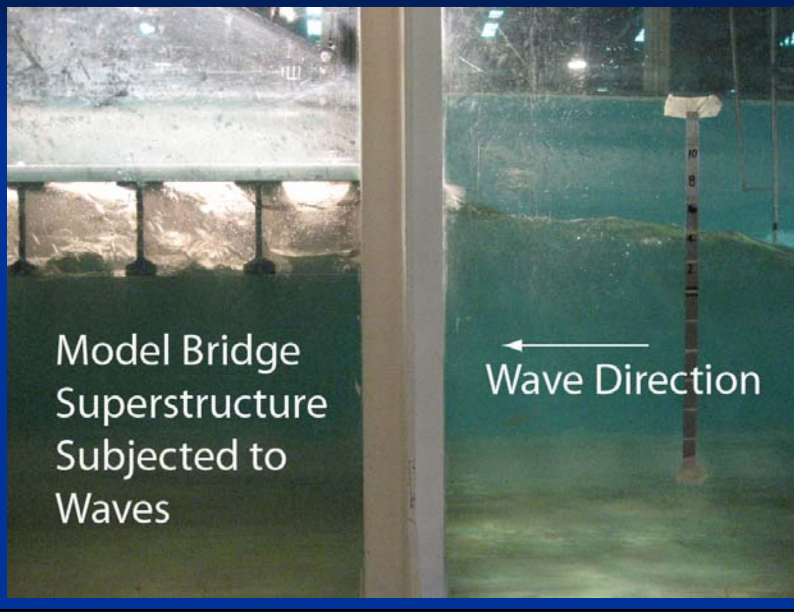
Wave Tank Tests

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

Test Setup

Model Support Structure

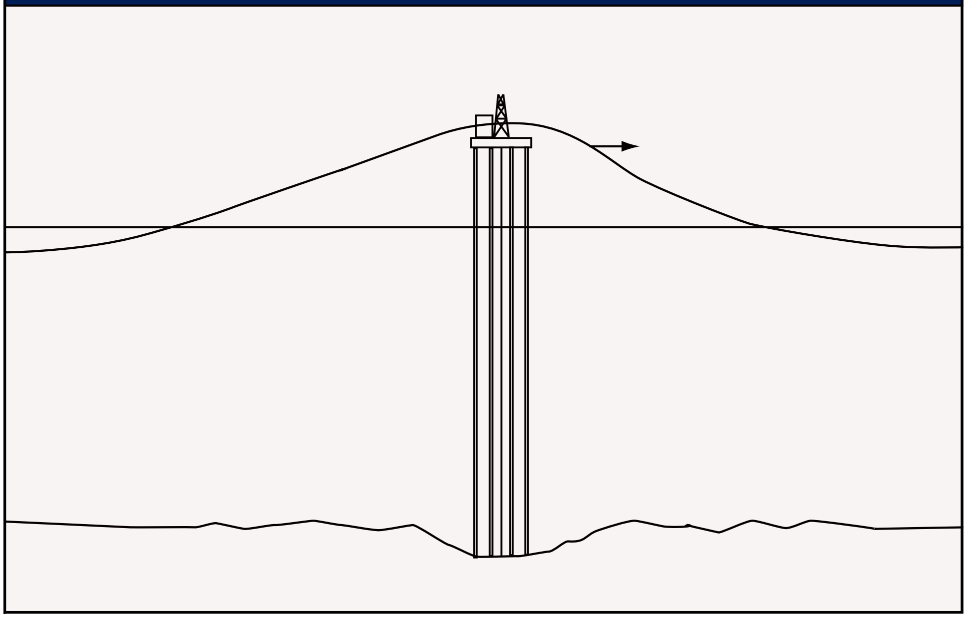
Span With Girders



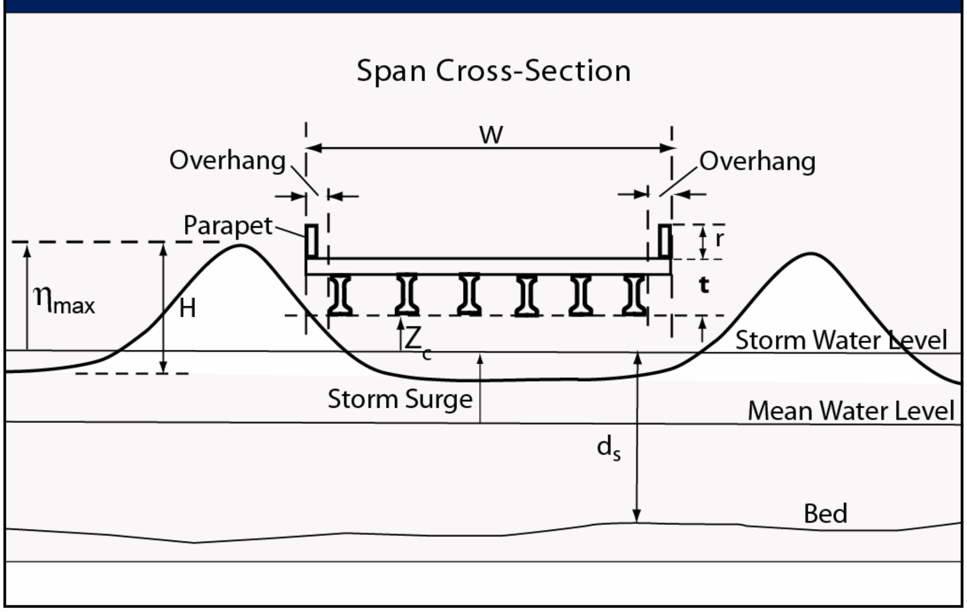
Wave Load Theory

- Existing Theory for Offshore Platforms
  - Structure shapes and size relative to wave parameters significantly different from bridge superstructures
  - Wave parameters (heights and lengths) different for coastal bays and waterways than open gulfs/oceans
- Theory had to be modified and extended

Offshore Platforms/Ocean Waves



Bridge Spans/Bay Waves



Modified Kaplan Equations

- Forces Composed of "Quasi-Static" and Slamming
  - Quasi-Static frequency ~ wave frequency
  - Slamming – short duration
    - Magnitude of vertical slamming force decreases with wave steepness

Modified/Extended Kaplan Method

Qusi-Static Force

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

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

Modified/Extended Kaplan Method

Qusi-Static Force

$$F_v = F_{inertia}\ F_{cam} + F_{drag} + F_{buoyancy}$$

$$= \frac{d(\text{mass x } V)}{dt} + \frac{1}{2}\rho\, L\, W\, C_d\, V\, |V| + F_{buoyancy}$$

$$\frac{d\left[(\rho\forall + m_a)V\right]}{dt} = \frac{\rho d\forall}{dt}V + \rho\forall\frac{dV}{dt} + \frac{dm_a}{dt}V + m_a\frac{dV}{dt}$$

Modified/Extended Kaplan Method

Qusi-Static Force (cont.)

$$\frac{d\left[(\rho\forall + m_a)V\right]}{dt} = \left(\frac{\rho d\forall}{dt} + \frac{dm_a}{dt}\right)V + (\rho\forall + m_a)\frac{dV}{dt}$$

Modified/Extended Kaplan Method

$$m_a \equiv \text{ added mass} = \frac{\pi\ \rho\ l(t)\ b(t)^2}{4\sqrt{1+\left(\frac{b(t)}{l(t)}\right)^2}}\left(C_1 + C_2\frac{h(t)}{b(t)} + C_3\sqrt{\frac{h(t)}{b(t)}}\right)$$

$\rho \equiv$ Density of Water

$b \equiv$ Wetted Span Width

$l \equiv$ Span Length

$h \equiv$ Wetted Span Height

$t \equiv$ Time

$\forall \equiv$ Displaced Volumn of Water

$V \equiv$ Vertical Velocity

Modified/Extended Kaplan Method

- Forces Have to be Integrated Over Wetted Portion of Structure at each Time Step
- Results in Time History of Horizontal and Vertical Forces and Moments
- Used to Perform Numerical Experiments to Produce Data for Parametric Equations

Pilot Study
Phase I

Phase I Objectives

- Develop Screening Criterion
- Apply to potentially vulnerable bridges in pilot study area
- Determine which bridges needed further analysis

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

Procedure Outline

- Using USGS quad maps, NOAA charts, etc. identify bridges with possible problems (large fetch lengths)
- Obtain bathymetry over fetch lengths and in vicinity of bridges (quads, charts, other)
- Obtain 100 year hurricane landfall wind speeds (or land fall wind speed of maximum storm of record)

Procedure Outline

- Using best information available (FEMA, etc.) obtain 100 year storm surge elevations at bridge sites
- Estimate probability wind direction aligns with the Fetch
- Using empirical equations for estimating Significant Wave Height, Hs, and Peak Period, Tp, in USACOE Shore Protection Manual, estimate these parameters at the bridge sites

Procedure Outline

- Estimate peak wave crest height (adjust for uncertainty in prediction methods)
- Add crest height to storm surge elevation to obtain peak water elevation
- Obtain bridge dimensions and elevations

Procedure Outline

- Determine bridge importance (Criticality)

  1. Minor impact to economy or emergency needs if closed (alternative routes exist)
  2. Medium impact if closed - may lead to a barrier island but an alternative route exists
  3. Major impact if closed – only road to a barrier island, evacuation route with no reasonable alternatives
  4. Extreme impact if closed – Interstate or major economic connector (detour very long)

Procedure Outline

- Original Procedure
  - Based on parameters perceived important

$\frac{\eta_{max}}{z_c}$	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

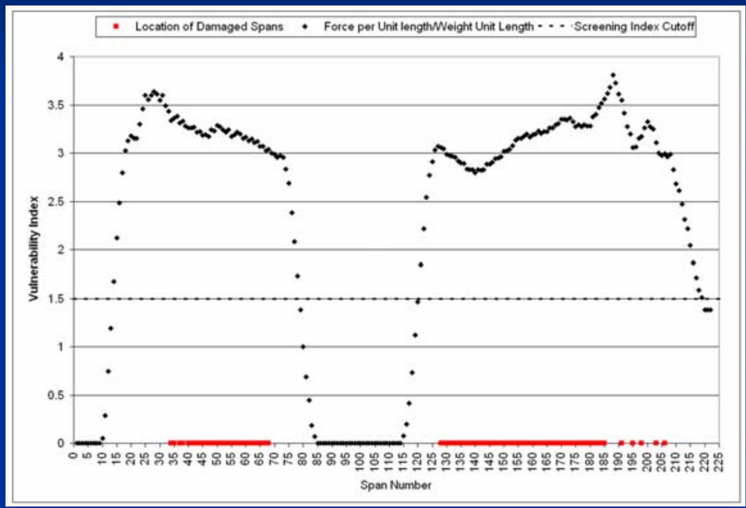
Procedure Outline

- Updated Procedure
  - Advances in our understanding of the wave/structure interaction
  - Actual bridge failures due to wave loads
  - Availability and ease of use of the parametric equations

Procedure Outline

- New Procedure
  - Vulnerability Index based on forces and resistance
    - Forces from Parametric Equations
    - Resistance from span weight
    - Divide Wave Force per unit length by span weight per unit length
  - Screening cutoff value
    - Incipient motion/failure (Force/Resistance = 1)
    - Application to the failure of I-10 over Escambia Bay during Hurricane Ivan
    - Bridge Criticality

Procedure Outline



Procedure Outline

Span	Vulnerability Index $VI \geq 0$	Criticality Index $1 \leq CI \leq 4$	Further Analysis Required
	$VI \geq 1.5$	$CI \geq 1$	Further Analysis
	$1 \leq VI < 1.5$	$CI \geq 2$	Further Analysis
	$0.6 \leq VI < 1$	$CI \geq 3$	Further Analysis
	$0.2 \leq VI < 0.6$	$CI \geq 4$	Further Analysis
	$0.0 \leq VI < 0.2$	$CI \geq 1$	No Further Analysis

Summary

- Identified 53 bridges for screening
- Original screening procedure identified 28 bridges requiring additional analysis
- New screening procedure identified 29 bridges requiring additional analysis

Pilot Study
Phase II
(Level II Analysis)

Phase II Objectives

- Improve Met/Ocean Parameters
- Compute Storm Surge/Wave Forces and Moments on Bridges needing Further Analysis (from Phase I study)
- Compute Bridge Superstructure Response to Surge/Wave Loads/Moments
  - To be performed by FDOT and Consultants
- Test and Revise Screening Criterion

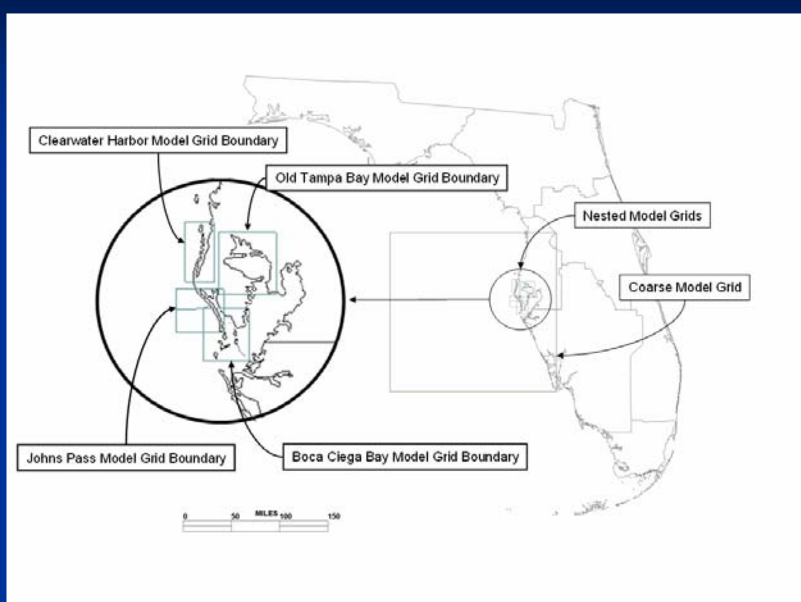
Phase II Procedure

- Update Screening Procedure
- Update Wave and Storm Surge Data
  - Water Surface Elevation
  - Wave Modeling
- Wave Force Calculations

Wave Parameter Improvements

- Wave Modeling
  - Swan
  - Nest Grids
  - Wave Height
  - Wave Period

Wave Parameter Improvements



Phase II Procedure

- Wave Force Calculations
  - Modified Kaplan (Parametric Equations not ready in time to use)
  - 100% and 0% Air Entrapment
  - Maximum Forces and Moments
  - Associated Forces and Moments

Example Results

Bridge #	Span#	Maximum Positive Vertical Force								
		Maximum Positive Vertical Force (kips)	Associated Horizontal Force (kips)	Associated Moment about the Leading Edge (ft-kips)	Associated Moment about the Trailing Edge (ft-kips)	Associated Resultant Force (kips)	Associated Vertical Force without Slamming Force (ft-kips)	Associated Moment about the Leading Edge without Slamming Force (ft-kips)	Associated Moment about the Trailing Edge without Slamming Force (ft-kips)
150036N	3	201	1	4134	-4618	201	201	4134	-4618
150036N	4	205	2	4184	-4727	205	205	4184	-4727
150036S	2	194	0	4009	-4426	194	194	4009	-4426
150036S	4	194	0	4019	-4446	194	194	4019	-4446
150036S	5	192	0	3989	-4386	192	192	3989	-4386
150038	3	337	68	4346	-7433	344	237	3675	-6761
150038	7	327	72	3873	-7054	335	212	3098	-6279
150038	30	102	83	525	-2550	132	56	214	-2240
150038	38	402	86	3280	-6954	411	158	1645	-5320
150043	2	2037	21	23052	-31623	2038	148	1308	-9879
150043	5	1767	19	19953	-28545	1767	149	1328	-9920
150049	4	211	169	1226	-5176	270	174	1031	-4980
150049	6	10	39	14	-347	40	10	14	-347
150049	20	75	128	197	-2059	149	69	167	-2029
150049	22	299	77	2045	-4498	309	165	1395	-3848
150052	4	33	20	188	-405	38	8	46	-264
150052	7	14	11	76	-169	17	3	18	-110
150052	12	49	19	281	-579	52	11	66	-365
[illegible]	1	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Met/Ocean Joint Probability

- Examined Four Hurricane Hindcasts
  - Ivan
  - Katrina
  - Frances
  - Jeanne
- Provided Limited Insight into Limitations of Long Duration Wind Directions

Met/Ocean Joint Probability

- Best Hope is that FDOT will Sponsor Level III Analysis of Pilot Study Area
  - Pilot study area contains wide range of conditions
  - Could determine the difference between "100-Year" analysis and more accurate Level III analysis
  - Can develop Load Adjustment Factors as functions of wind and wave fetch segments

Met/Ocean Joint Probability

- If Level III Analysis is not Performed or it is not Initiated In Time for this Study:
  - Use data collected thus far to estimate Load Adjustment Factors

Attachment B

Wave Force Prediction Update
By
Dr. Max Sheppard

Wave Force Prediction Update

June 12, 13, 2007

Max Sheppard
Phil Dompe
Justin Marin

OEA, Inc.

Outline

- Background
- Issues with Wave Forces on Horizontal Structures
- Parametric Equation Development
  - Vertical forces
  - Horizontal forces
  - Moments
- Comparison Between 1) Measured, 2) Modified Kaplan, and 3) Parametric
- Parametric Equations Applied to I10 –Escambia Bay Bridges

Background

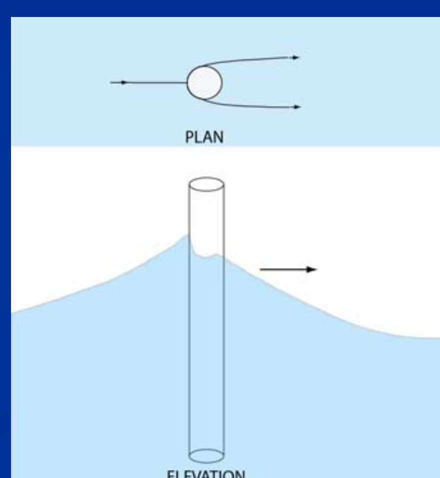
- Objectives
  - Examine and evaluate existing and evolving methods for predicting storm surge and wave loading on bridge superstructures
  - Decide on the best available method
  - Formulate the method/equations such that it is suitable for inclusion in an AASHTO specification and perhaps similar documents
- Approach
  - Make use ongoing work supported by the Florida DOT
  - Expand to include conditions in other states
  - Develop parametric equations for forces and moments

Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Vertical Pile

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

$$F_H = \frac{C_d}{2} \rho D V |V| + C_m \rho \left(\frac{\pi D^2}{4} \right) \frac{dV}{dt}$$



Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure

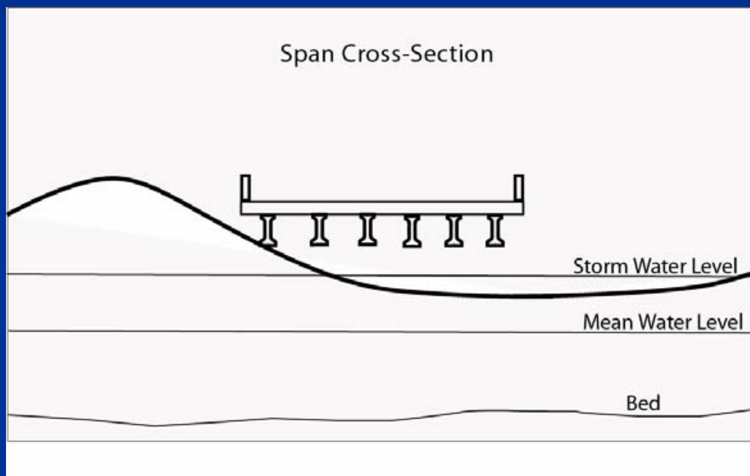
$$F_V = F_{Drag} + F_{Inertia} + F_{CAM} + F_{Buoyancy}$$

$$F_V = \frac{C_d}{2} \rho D V |V| + C_m \rho \left(\frac{\pi D^2}{4} \right) \frac{dV}{dt} + F_{CAM} + F_{Buoyancy}$$

Subaerial Span

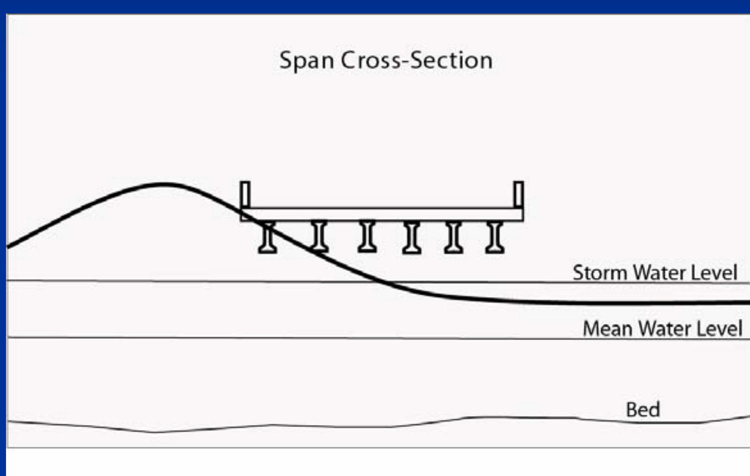
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



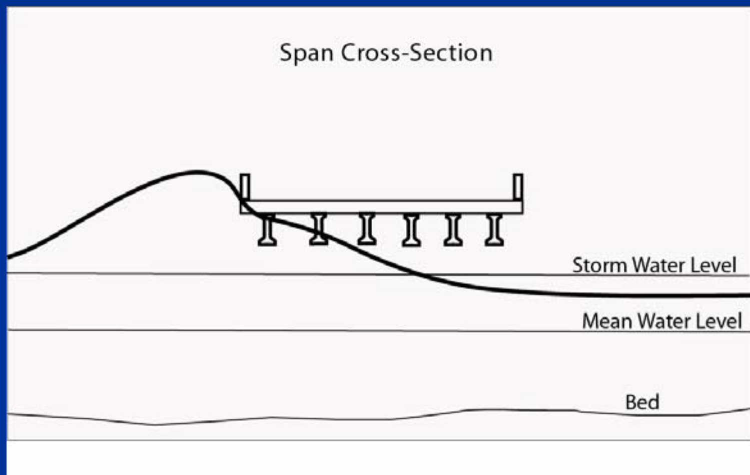
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



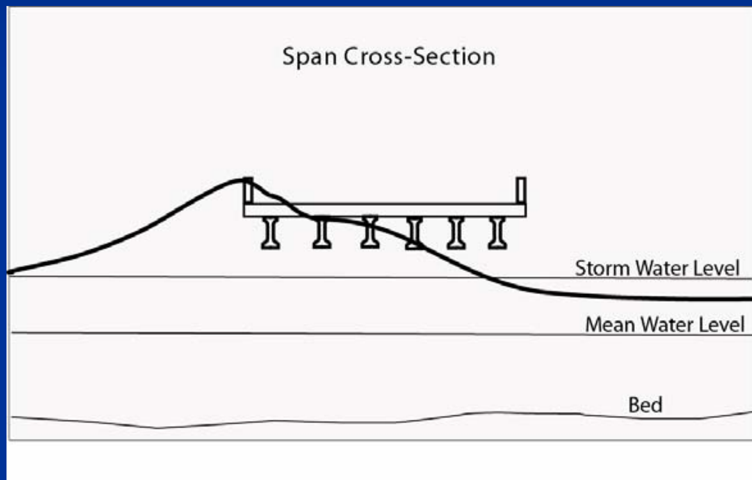
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



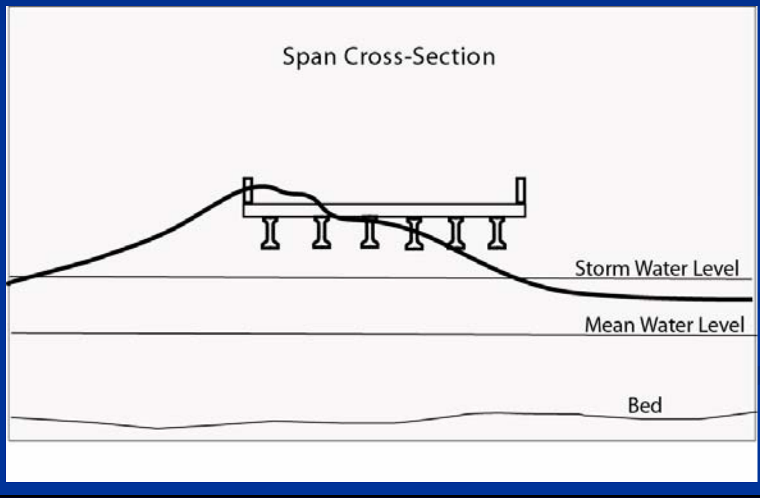
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



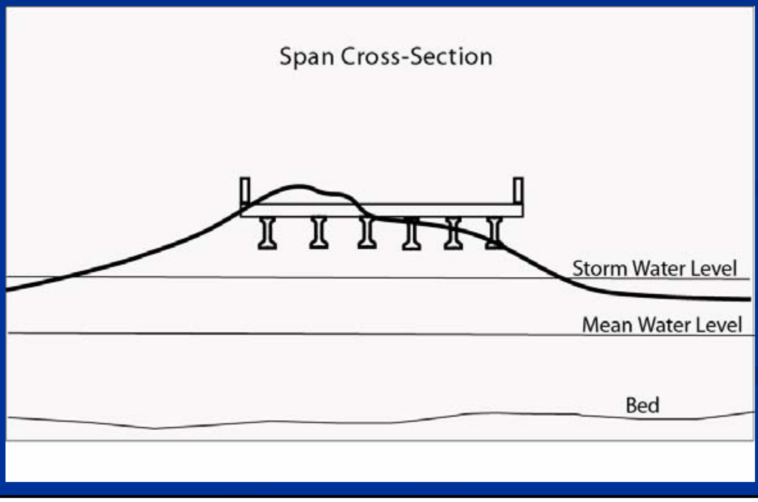
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



Issues With Wave Forces on Horizontal Structures

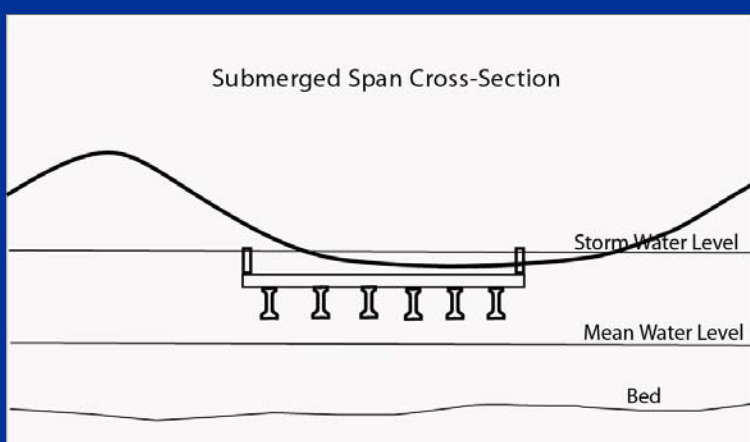
- Consider Wave Forces on a Horizontal Structure



Submerged Span

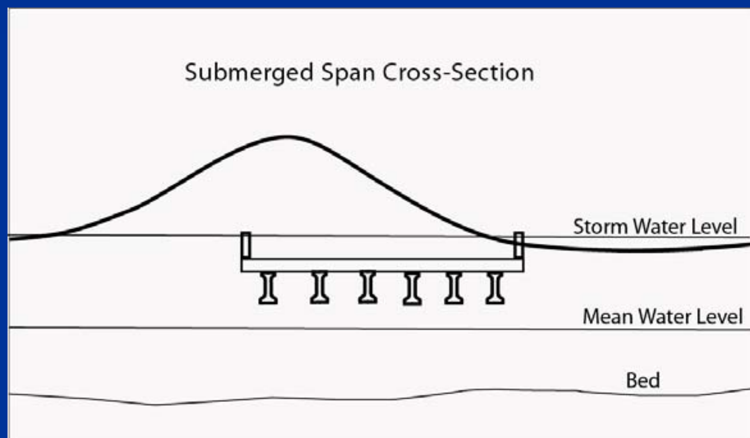
Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



Issues With Wave Forces on Horizontal Structures

- Consider Wave Forces on a Horizontal Structure



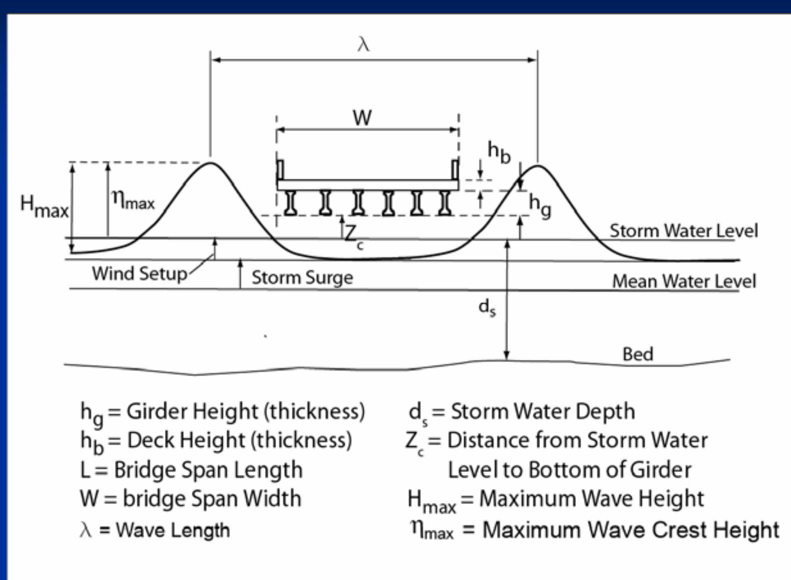
Drag and Inertia Coefficients

- Coefficients Change with Water Level Relative to Deck Level
- Using Coefficients that Fit Subaerial Data Over Predict Submerged Data
- Variable Coefficients Will Be Incorporated
  - Will most likely reduce computed vertical forces on submerged structures

Parametric Force and Moment Equations

- Wave Forces are Dependent on:
  - Water and wave parameters
    - Water depth
    - Wave height and period
  - Structure location and shape
    - Low member height above storm water level
    - Type of span, width, length, etc.

Definition Sketch



Parametric Vertical Force Equations

$$\frac{F_V}{F_Z^*} = A \times \left(\frac{W}{\lambda}\right)^B + F_{Slamming}$$

where

$$A = f_1\left(\frac{Z_c}{\eta}\right) = C_{z1}\left(\frac{Z_c}{\eta}\right)^2 + C_{z2}\left(\frac{Z_c}{\eta}\right) + C_{z3},$$

$$B = f_2\left(\frac{Z_c}{\eta}\right) = C_{z4}\left(\frac{Z_c}{\eta}\right)^2 + C_{z5}\left(\frac{Z_c}{\eta}\right) + C_{z6},$$

$$C_{zi} = f_3\left(\frac{H}{\lambda}\right), \text{ and}$$

Parametric Vertical Force Equations

$$C_{z1} = 6661.7\left(\frac{H}{\lambda}\right)^3 - 1314.7\left(\frac{H}{\lambda}\right)^2 + 79.6\left(\frac{H}{\lambda}\right) - 1.30$$

$$C_{z2} = -31.7\left(\frac{H}{\lambda}\right)^2 - 0.6\left(\frac{H}{\lambda}\right) - 0.15$$

$$C_{z3} = -40.67\left(\frac{H}{\lambda}\right)^2 + 8.37\left(\frac{H}{\lambda}\right) - 0.076$$

$$C_{z4} = 6577.8\left(\frac{H}{\lambda}\right)^3 - 1449.9\left(\frac{H}{\lambda}\right)^2 + 94.9\left(\frac{H}{\lambda}\right) - 1.054$$

$$C_{z5} = -116.36\left(\frac{H}{\lambda}\right)^2 + 20.97\left(\frac{H}{\lambda}\right) - 0.90$$

$$C_{z6} = 64.14\left(\frac{H}{\lambda}\right)^2 - 8.62\left(\frac{H}{\lambda}\right) - 0.95$$

Parametric Vertical Force Equations

$$F_z^* = \gamma_w \; W \; (\eta - Z_c)$$

where

η = Height of wave crest above storm water elevation,

Z_c = Low member height above storm water elevation,

γ_w = Specific weight of water, and

W = Width of span

λ = Wave length

and

$$F_{Slamming} = f\left(\frac{H}{\lambda}, \frac{W}{\lambda}, \frac{Z_c}{\eta}\right)$$

Parametric Horizontal Force Equations

$$\frac{F_H}{F_z} = \left[I + J\left(\frac{Z_c}{\eta - Z_c}\right)\right]^2 \qquad \left(\frac{Z_c}{\eta - Z_c}\right) \geq -2$$

$$\frac{F_H}{F_z} = [I - 2.0\,J\,]^2 \qquad \left(\frac{Z_c}{\eta - Z_c}\right) < -2$$

$$I = K_1\left(\frac{H}{\lambda}\right)^3 + K_2\left(\frac{H}{\lambda}\right)^2 + K_3\left(\frac{H}{\lambda}\right) + K_4$$

$$J = K_5\left(\frac{H}{\lambda}\right)^3 + K_6\left(\frac{H}{\lambda}\right)^2 + K_7\left(\frac{H}{\lambda}\right) + K_8$$

Parametric Horizontal Force Equations

$$K_1 = 7.02\left(\frac{W}{\lambda}\right) - 6.17$$

$$K_2 = -10.96\left(\frac{W}{\lambda}\right) + 10.00$$

$$K_3 = 4.67\left(\frac{W}{\lambda}\right) - 4.48$$

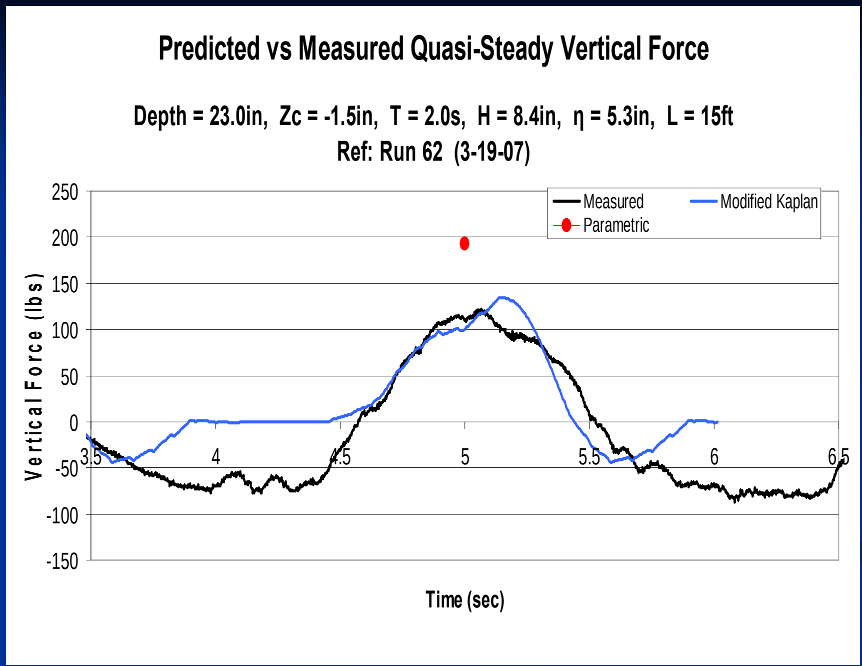
$$K_4 = 0.348\left(\frac{W}{\lambda}\right) + 0.89$$

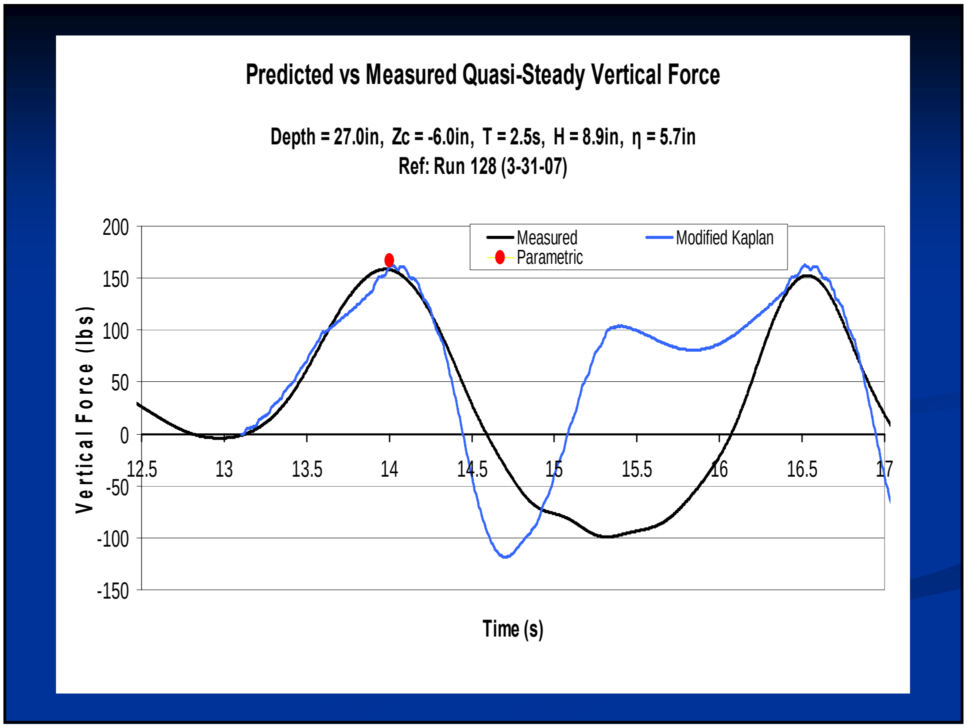
$$K_5 = -1.69\left(\frac{W}{\lambda}\right) - 2.29$$

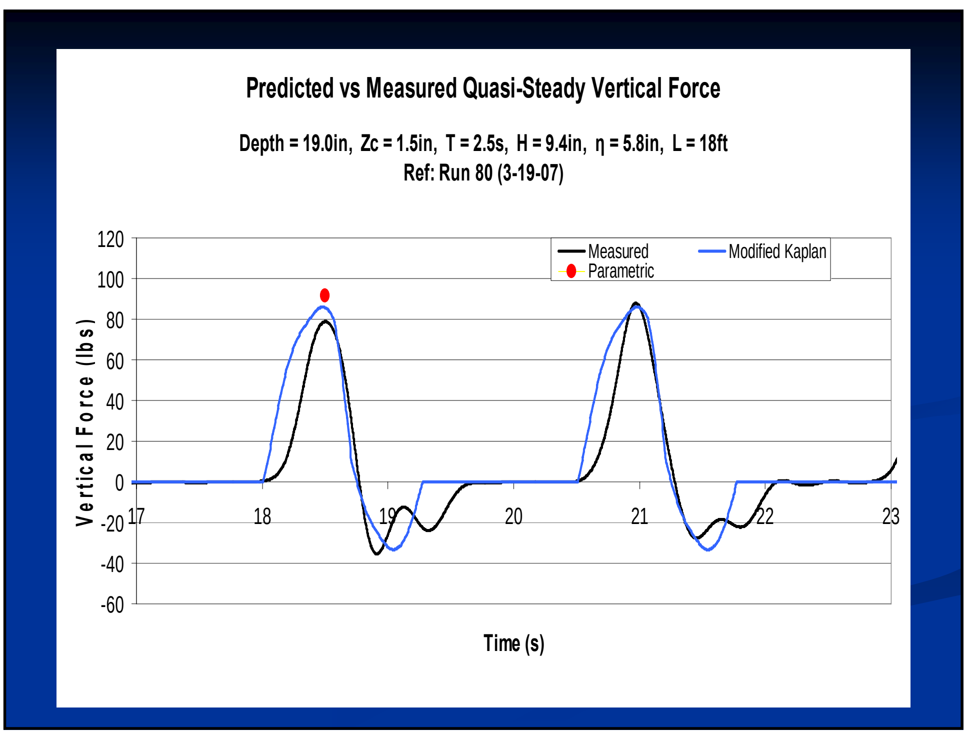
$$K_6 = 2.29\left(\frac{W}{\lambda}\right) + 4.42$$

$$K_7 = -0.69\left(\frac{W}{\lambda}\right) - 2.54$$

$$K_8 = -0.04\left(\frac{W}{\lambda}\right) + 0.59$$




Predicted vs Measured Quasi-Steady Vertical Force
Depth = 27.0in, Zc = -6.0in, T = 2.5s, H = 8.9in, η = 5.7in
Ref: Run 128 (3-31-07)
Measured
Parametric
Modified Kaplan
Vertical Force (lbs)
200
150
100
50
0
-50
-100
-150
12.5
13
13.5
14
14.5
15
15.5
16
16.5
17
Time (s)


Predicted vs Measured Quasi-Steady Vertical Force
Depth = 19.0in, Zc = 1.5in, T = 2.5s, H = 9.4in, η = 5.8in, L = 18ft
Ref: Run 80 (3-19-07)
Measured
Parametric
Modified Kaplan
Vertical Force (lbs)
120
100
80
60
40
20
0
-20
-40
-60
17
18
19
20
21
22
23
Time (s)