Attachment A

Meeting Booklet Prepared by Florida DOT

AASHTO/FHWA WAVE TASK FORCE

Gainesville, Florida
December 5 & 6, 2006

Table of Contents

Tentative Schedule for Dec. Kickoff Meeting (11-30-06)

When: Dec 4, 5 & 6– to be finalized next week
Where: Gainesville – FDOT will supply vans and meeting room for one day
Contact person in Wm's office: Linda Ryan (Linda.ryan@dot.state.fl.us)

Dec 4 – Team meeting

1:30 – 5:30 PT Meets

- Scope adjustments
- Discussion of K and W methods
- Other candidates?
- Basis for a choice
- Further define roles and responsibilities

Dec 5 –Joint Meeting

8:30 -12 Combined meeting

- Introductions
- Review of minutes from last meeting
- Presentation on Risk Analysis by Steve Ernst of FHWA 90 minutes
- Intro to wave tank visit - Max
- How does project fit in big picture? What is already available?
- What other work is underway at state and federal level?
- Philosophy

12 -1 Lunch
1PM Leave for U of F wave tank
3:30 Return to meeting

- Review of progress on related FDOT projects.- Max and Dennis
- Task Force presentations
- Progress on Tasks 2,3, 4 and 6
  - Status of Lit Survey and Damage Types – JMK
  - Wave loads – JMK, Max, Jeff
  - Retrofit concepts – Wagdy
  - Possible basis for design cases – Jeff and all
  - Cost effectiveness memo by Mike Knott – reported by Jeff

5:00 Adjourn

Dec 6

8-4:30 Meet with TF

- Continue progress on Tasks 2,3 and 4 - continued
- TF feed back and direction
- Scope/Work Plan
- Expectations
- Products
- Set date for next combined meeting

Minutes from the
October 20, 2006
Teleconference / Meeting
To discuss work plan for contract
<u>DTFH61-06-T-70006</u>

The meeting was opened by taking roll call. In attendance were:

Wave Vulnerability Task Force

William N. Nickas (FDOT)
Mitchell K. Carr (MDOT)
Greg R. Perfetti (NCDOT)
Rick Renna (FDOT)
David R. Henderson (NCDOT)
Kevin Flora (CALTRANS)
Tom Everett (FHWA)
Kornel Kerenyi (FHWA)
Firas Ibrahim (FHWA)
(Tony) Robert A. Dalrymple, Johns Hopkins University
David L. Kriebel, Department of Naval Architecture & Ocean Engineering
Spencer Rogers, North Carolina SeaGrant

Contractors

John Kulicki (M&M)
Wagdy Wassef (M&M)
Max Sheppard (OEA)
Jim Withiam (D'Appolonia)
Jeff Sheldon (M&N)
Dennis Mertz (Mertz)

The first item discussed was the review of the proposed work plan. John Kulicki chaired the discussion on the work plan.

Technical Approach:

The Contractor points out that the focus of this study will be typical prestressed concrete and steel multi-girder bridges and slab bridges. The guidance developed will be mainly for fixed bridges. The loads developed can also be applied for variable deck girders. An estimate of forces on pile groups and other substructure elements will be included. Tsunamis and damage from floating debris will not also be considered.

Task 1 – Kick off and Project Meetings:

The contractor discussed the expanded version of a kick off meeting early December, with three objectives:

- Hold an internal team meeting to determine what information has been assembled;
- Meet with the Task Force for 2 days to discuss our progress and remaining work.
- Visit the Dr. Sheppard's wave tank tests at the University of Florida

The contractor will attend the project close-out meeting with the Task Force, and make a presentation to 2007 and 2008 SCOBS meeting. Pooled fund states not on the task force will be also invited to the close-out meeting.

Task 2 – Review, Summarize, and Augment Literature:

The contractor is in the process conducting a literature review, and summarizing and cataloging damages on bridges and structures resulting from coastal storm hydrodynamic events, and will augment this work with additional data and information as required. A request for information was sent to all of the coastal states and to a variety of other agencies. The Project Team also decided to make personal contacts in order to expedite collection of some of this information.
Back-calculating structural resistance from forensic data will be done mainly for I-10 across Escambia Bay and I-10 across Lake Pontchartrain because there have been sufficient data already developed for these two bridges by team members MN and OEA. Various failure modes will be analyzed and cataloged. Back-calculating forces from observed structural movements will not be included. The damage reports do not include details of horizontal and vertical deck movements. The contractor will also investigate phasing between wind set-up and storm surge to analyze failure modes. Commonsense engineering approach will be used to conduct these investigations.

Task 3 – Review and Supplement Ongoing Force Studies:

The contractor will focus on 3 wave prediction methods:

- Improved HR Wallingford wave force equation
- Modified Kaplan procedure developed by Max Sheppard
- Wave force equations developed by Scott Douglass

The slamming forces are included in all three methods. For the modified Kaplan procedure slamming forces will be incorporated in the plots of non-dimensional parameters. Phasing of quasi-static force and slamming forces was also discussed.

Task 4 – Compile and Catalog Retrofit Options

The contractor received the unpublished new Seismic Retrofit Manual from the FHWA and reviews that for potential details of interest. The contractor was asked to compile a retrofit option matrix including pros and cons for the meeting in December.

A discussion followed on using depth limited barriers on a bay bottom to break waves and to reduce wave forces. To explore the idea reshaping the superstructure to gain less drag and create more down-pull force will not be perused. Hold downs will be reviewed critically as a retrofit option, because they tend to move and not solve the problem. Elastic tie downs will not be considered.

Task 5 – Perform Analytical Study of Retrofit Options

The contractor briefly discussed the goal of this task to put the more promising retrofit options into a model and subject them to hindcast wave loads. The model will not include a dynamic analysis. The model will also include tying simple supported spans together.

Task 6 – Develop a Guide Specification and a Retrofit Handbook for adoption by AASHTO

Task 6a - Guide Specification

The contractor discussed the layout of the proposed guide specifications including a multi level approach, prioritization and a screening technique. Max Sheppard will develop a screening methodology similar to the FDOT screening model including a importance characteristic. The prioritization depends on many factors such as security issues. The task forces suggested including Steve Ernst (FHWA) into this discussion. Various load factors will be associated with different levels of analysis. Level I one will be used in the screening technique.
A discussion on the issue of a national hazard map indicating wave forces and their probability was conducted. The discussion also included the joint probability wind/wave/surge analysis.

Task 6b - Retrofit Handbook

The outline of the retrofit hand book was attached to the work plan and most of the issues discussed for the guide specifications apply for the retrofit handbook.

The second item discussed was Max Sheppard's progress report including:

Wave Tank Tests and Data Analysis

- Acquired data from tests with deck only
- Theory compares well with experimental data
- Determined relationship between duration and magnitude of slamming force and wave properties and structure elevation
- In process of adding slamming force to quasi-stationary force in equations
- Will be adding girders within two weeks and starting tests

Surge/Wave Vulnerability Screening, Loading Calculations Structure Response and Retrofit
Phase I - Screening

- Initial screening completed

Phase II

- Changes and improvements to screening procedure
- Completed all wave modeling
- Extracted required bridge information for I-10 Escambia Bay Bridge
- Extracted water elevation, and wave height/period information from hindcast solution files for I-10 Escambia Bay during Hurricane Ivan
- In position to test different predictive equations once Modified Kaplan Equations are ready

Joint Probability Analysis

- Progress report distributed to team members and task force
- Wind (hindcast) data from four significantly different hurricanes have been examined and trends observed
- Hurrican Ivan hindcast models being rerun to separate wind setup, and storm surge and waves
  - Examine phase as a function of location in bay system
- Might run Ivan along a different path (probably not time for FDOT deadlines)
- Most likely there is weak or no dependence of phase between storm surge and wind setup.
- Use Goda method for dealing with remaining service life of bridge??

December Meeting:

Tom Everett was asked to contact Steve Ernst to participate in the December Kickoff Meeting in Gainesville, FL.

MODJESKI and MASTERS, INC.

Harrisburg, Pennsylvania
November 7, 2006

MEMORANDUM

TO: Modjeski and Masters, Inc.

RE: <u>OCTOBER 20, 2006 MEETING MINUTES – DTFH61-06-T-70006</u> PN2560

A meeting on the above-captioned project was held on October 20, 2006, as joint in-person and conference call meeting hosted at the National Academy's Keck building. A Wave Task Force roster is attached indicating those that were present at the meeting and those who attended by telephone. One individual, Joseph Krolak, was not able to participate. From the research team, Drs. Wassef, Mertz, Withiam, Sheppard, and Kulicki attended (Wassef and Kulicki in person) as did Mr. Jeff Shelden. An agenda for the meeting is attached.

ADMINISTRATIVE ITEMS

Mr. Nickas advised the group that the December meeting in Gainsville will take place. The Florida DOT will provide two 12-person vans to shuttle people back and forth from the airport and back and forth to various sites during the meeting. Members of the Task Force should make their arrangements through Linda Ryan at Florida DOT. All flights by the Task Force Members must be made through the FHWA. Members of the Task Force may select their own flights, but the actual ticket has to be arranged by the FHWA. Advise Dr. Firas Ibrahim of flight requirements.

REVIEW OF WORK PLAN

Technical Approach

Regarding the Scope issues in the third paragraph of the Work Plan:

- It was decided that tsunamis would not be included.
- Damage from floating debris would not be considered, but a reference to ASCE-7 and the Vessel Collision Specification could be placed in the commentary, as well as in our report on the project.

- The project will deal primarily with wave forces on beam slab bridges, including buoyancy; and wave forces on the structural components of movable bridges, but not on the electrical and mechanical features.
- Dr. Sheppard indicated that the procedures he is working on will work with configurations other than prismatic beams and decks, but we will not have experimental work on superstructure shapes other than prismatic beams and decks.
- Regarding wave forces on pile groups, Dr. Sheppard also advised that there is relatively little data and not much known about pile groups. A first cut approximation can be done with the understanding that more work will have to be done in the future.

Task 1 – Meeting in September

The three objectives of the meeting in December, starting at the third paragraph of Task 1 in the Work Plan, were generally agreed upon. With respect to the last paragraph under Task 1, we should indicate that the project closeout meeting with the Task Force may also include the pooled fund states.

Task 2 – Literature Survey, etc.

Regarding the discussion in the second paragraph, we should indicate that two distinct actions were observed, depending on the particularities of wave action at several sites. In Mississippi, it was reported that some of the spans appeared to ratchet off the piers indicating repetitive periods of vertical and horizontal forces. In some locations, it appeared that the superstructures were displaced in more or less one movement. Discussions also considered the span that was moved about 220 feet on the Bay St. Louis Bridge in Mississippi primarily as a function of current. The Project Team needs to be cognizant of these separate actions and be sure that both are addressed.

It was also reported that I-10 over Escambia Bay in Florida experienced a ratcheting effect and that Mississippi Bridges may have been inundated for a longer period of time allowing them to move in one movement. The peak current velocities at the US 90 bridges in Mississippi were much higher than those at the I-10 Escambia Bay bridges.

For the I-10 Escambia Bay bridges the peak storm water level was approximately at the low member elevation whereas most of the spans on the US 90 bridges were submerged. Vertical slamming forces occur when the low member elevation is above the trough of the waves.

The Popps Ferry Bridge also appeared to have had the ratcheting movement. The Pops Ferry Bridge runs North and South, whereas the US 90 Bridge, which suffered major damage, spans East to West.

Mitch Carr confirmed that one of the rolling leaf bascule bridges had in fact been shifted on the track and that a bascule pier had been cracked.

The Project Team has been combining its literature survey into a list of resources collected with an indication of who had been reading them and a place to add some comments about important aspects found in the various reviews. An in-progress copy is appended to the minutes of the meeting and will be part of future progress reports. It is hoped that members of the Task Force who are aware of additional papers that should be reviewed will advise us.

Task 3 – Review of the Supplement Ongoing Force Studies

With respect to the three or four currently available and wave force prediction methods identified in the third paragraph, the Project Team indicated that we have now settled on the following four wave force methods:

- HR Wallingford-Exponential
- HR Wallingford-Linear
- Kaplan as modified by Dr. Sheppard
- The Scott Douglas method

There are questions as to whether the HR Wallingford-Linear will be available in a timely manner due to publication procedures. Moffatt & Nichol will attempt to speed up the availability of this information through personal contact with Mr. William Allsop. The Project Team is prepared to use some of the honorarium money to work with Mr. Allsop to make this information more available to us.

It was pointed out that the Wallingford methods:

- Were developed primarily for ocean platforms which are different from our problem in that the ratio of the wave length to the width of the structure is quite different for piers compared to bridges, and
- Submerged structures were apparently not investigated.

Task 4 – Compiling Catalog Retrofit Options

The following comments were made relative to the general outline shown under the second paragraph of the work plan:

- Superstructure continuity may be useful where there are skewed waves such that there is a longitudinal component of the wave force.
- Fuses to protect the substructure should probably be forced based rather than displacement based.
- There was some interest in shaping the cross-section to produce a downward hydrodynamic force in a fashion analogous to the way bridges are designed for wind. Experimental work on this aspect is outside the Scope, but this could be mentioned in the report for possible future work.
- We need to separate the technical issues from those involving a business decision. This might relate in particular to the use of Dr. Sheppard's screening approach, which would be technical, versus a management approach dealing with prioritization, one feature of which would be the result of screening.

- There was a question as to whether we can give guidance on the boundary conditions or analysis methods to be used with various retrofit options.
- There was discussion about the possibility of using a submerged breakwater reef that might be built for other purposes, such as the promotion of fish life. Issues included how far away from the bridge this might be, how big it might be, how do you design it, whether it creates depth limited waves, etc. There was also reservation as to whether the reef would be functional during a hurricane event when we needed it most.

The Task Force asked for copies of the wave model used in Dr. Sheppard's study of Escambia Bay which included SWAN, ADCIRC, and other software. Mr. Renna will provide the wave models (these have already appeared in the email).

It was pointed out that if we used remaining life in Dr. Sheppard's evaluation screening method, this could affect the choice of a design storm which might create a circular process. This also related to the question of technical decisions versus business decisions. The initial reaction to this approach was somewhat negative, but subsequent discussions indicate that this should be given more thought and consideration.

Task 5 – Perform Analytical Studies of Retrofit Options

This topic was reviewed and no additional comments were forthcoming.

Task 6 – Develop Guide Specification and Retrofit Handbook for Adoption by AASHTO

The Project Team's approach was discussed, including the fact that we have now started a memorandum (Mr. Shelden) to compare various existing specifications for wave loads in terms of the load cases investigated, as well as consideration as to whether the Goda method of using two times the design life was the wave recurrence interval.

The remaining tasks were reviewed briefly and little further discussion took place on these items.

RETROFIT HANDBOOK – PRELIMINARY OUTLINE (9/19/06)

This preliminary outline was attached to the Work Plan was reviewed and it was pointed out that regarding importance, a formula by Texas should be reviewed as a means of prioritization, as should work currently underway by the FHWA.

TABLE OF VALUES

A table of proposed partial payments had been appended to the work plan. This can now be disregarded as the FHWA has decided not to permit partial payments.

MILESTONE SCHEDULE

A schedule was appended to the Work Plan oriented towards achieving the objectives along the lines of the original schedule proposed in the RFP. There was some discussion as to the importance of getting a quality product even if the schedule had to slip a little bit.

It was also pointed out that some of the milestone events are contingent upon the completion of other projects underway by the Florida DOT. Some adjustment of interim milestone dates may still be required.

REVIEW OF THE SEPTEMBER 30, 2006 PROGRESS REPORT

This document was reviewed and there were no questions or comments that need to be addressed.

UPDATE ON PROGRESS

The Team reported that we have continued to work on all of the items identified in our September 30th progress report as work to be done in this month. This included the following:

- Collecting and reading various references from the Literature Survey.
- Beginning to look at alternative specification presentations, including ASCE 7, API, LRFD, LADOTD, Lake Pontchartrain criteria.
- Dr. Sheppard continues to evolve the screen process, which we expect to use in the Retrofit Manual.
- Work continues at the University of Florida in the wave tank.

UPDATE OF RELATED FLORIDA DOT PROJECTS

Wave Tank Tests and Data Analysis

- Have data from tests with deck only
- Theory compares well with experimental data
- Have determined relationship between duration and magnitude of slamming force and wave properties and structure elevation
- In process of adding slamming force to quasi-stationary force in equations
- Will be adding girders within two weeks and starting tests

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Phase I - Screening

- Initial screening completed

Phase II
- Have made changes (hopefully improvements) to screening procedure
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- Extracted required bridge information for I-10 Escambia Bay Bridge
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Joint Probability Analysis
- Progress report distributed to team members and task force
- Wind (hindcast) data from four significantly different hurricanes have been examined and trends observed
- Hurricane Ivan hincast models being rerun to separate wind setup, and storm surge and waves
  - Examine phase as a function of location in bay system
- Might run Ivan along a different path (probably not time for FDOT deadlines)
- Most likely there is weak or no dependence of phase between storm surge and wind setup.
- Use Goda method for dealing with remaining service life of bridge??

REVIEW OF PROPOSED AGENDA FOR DECEMBER MEETING

An opportunity to review this agenda and comments on it was provided. No significant additions or deletions were proposed.

OCTOBER PROGRESS REPORT

It was decided that the Minutes of the Meeting would serve as October's Progress Report.

for JOHN M. KULICKI

JMK:WGW:dml

encl.
as

ATTACHMENT 1

Wave Vulnerability Task Force Roster
Oct. 20, 2006 Project Meeting
"T" indicates attendance by telephone
"P" indicates attendance in person

AASHTO Partners	
State Bridge Engineers	**Hydraulics Engineers**
Mr. William N. Nickas, Chair **P** State Structure Design Engineer Florida Department Of Transportation Mitchell K. Carr **T** Bridge Design Engineer Mississippi Department of Transportation Greg R. Perfetti **T** State Bridge Design Engineer North Carolina Department of Transportation	Rick Renna **P** State Drainage Engineer Florida Department of Transportation David R. Henderson **T** North Carolina Department of Transportation State Hydraulics Engineer Kevin Flora **T** California Department of Transportation State Hydraulic Engineer
FHWA Partners	**Subject Matter Experts (Consultant/Academia)**
Tom Everett, Vice Chair **P** Federal Highway Administration Kornel Kerenyi **P** Federal Highway Administration Joseph Krolak **Absent** Federal Highway Administration Shoukry Elnahal **T** Federal Highway Administration	(Tony) Robert A. Dalrymple **T** Department of Civil Engineering Johns Hopkins University David L. Kriebel, Professor **T** Director, Ocean Engineering Department of Naval Architecture & Ocean Engineering Spencer Rogers **T** North Carolina Seagrant
FHWA Support Staff	
Firas Ibrahim **P** Federal Highway Administration	

ATTACHMENT 2

Agenda – Oct 20 Meeting DTFH61-06-T-70006

1:00 Call to Order
Roll Call
Administrative Comments
Task Force Membership
Other
1:10 Review of Work Plan
Scope
Task Force Expectations
3:10 Review of 9/30 Progress Report
3:20 Update on Progress
3:30 Update of Related FDOT Project
3:55 Review proposed Agenda for Dec. Meeting
4:00 Need for 10/31 Progress Report
4:01 Adjourn

DRAFT WORK PLAN

SUBMITTED TO THE FEDERAL HIGHWAY ADMINISTRATION

TASK ORDER RFP 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.

September 25, 2006

TECHNICAL APPROACH

While recent hurricanes are named herein, the term "coastal storm" is broader than" hurricane" in that it implies any storm that involves a combination of wind, wave, and/or surge. Thus, a "Nor'Easter" is considered a coastal storm.

Our focus will be on assembling available information into a practice-oriented specification and retrofit handbook. Time and resources will not allow for a major research effort.

The structure-type focus of this study will be typical prestressed concrete and steel multi-girder bridges and slab bridges. Although some of the guidance to be developed may be useful for the analysis of segmental concrete or movable bridges, specific design specifications or retrofit concepts for these types of bridges will not be developed. Similarly, while tsunamis are a wave event, they will not be specifically covered. Damage from floating objects will not be considered.

Our approach to Tasks 1 through 8 in the Prospectus follows.

Task 1 – Kick off and Project Meetings

The RFP states that the contractor's key technical and other appropriate staff shall meet with FHWA and other staff at the FHWA Office of Bridge Technology, the National Highway Institute in Washington, DC, the contractor's facilities, or at other locations to be determined by the Government for one one-to-two day meeting to discuss the overall approach, contractor proposed work plan and schedule, deliverables, and details of this project.

Furthermore, the RFP states that the contractor shall also be required to meet with the Government and review task force for one or more 1 or 2-day project technical meetings with the Government and review group to resolve any on-going technical issues that arise during development. While some meetings will require only one person, some will require 2 or 3 to attend. These meetings will be scheduled as needed during the project.

We will hold an expanded version of a kick off meeting, part of which would be intra Team, in early December, with three objectives:

- Hold an internal team meeting to determine what information has been assembled. Discuss what additional information we need, and promote cooperation on some critical Tasks such as Tasks 3 and 5 on which so much of the rest of the project depends;
- Meet with the Task Force for 2 days to discuss our progress and remaining work, further clarify expectations and identify areas where the Task Force may be able to provide input, especially for Tasks 2 and 4, and to discuss objectives and deliverables.
- Visit the wave tank at the University of Florida and review findings with Dr. Sheppard.

A preliminary agenda for this meeting is attached.

Due to the difficulty in scheduling a kick off meeting shortly after NTP, the Team held a two-day meeting on September 18 and 19. Items discussed included clarifying responsibilities, discussions on the Wallingford and modified Kaplan methods and plan on how a decision will eventually be made as to wave force calculation method, and an exchange of views on the form some of the deliverables might take. The agenda for that meeting is attached.

A meeting has also been scheduled for Oct 20th which will be attended by representatives of the Team and the Task Force with telephone access to other members of both groups.

We expect that one or more additional meetings of the full team will be beneficial. As the very least we expect the wave experts from MN and Dr. Sheppard to meet occasionally regarding Tasks 3 and 5.

We expect to attend a project close-out meeting with the Task Force, and make a presentation to 2007 and 2008 SCOBS meeting.

Task 2 – Review, Summarize, and Augment Literature

Conduct a literature review, and summarize and catalog damages on bridges and structures resulting from coastal storm hydrodynamic events, and augment this work with additional data and information as required.

This Task shall also include back-calculating structural resistance from forensic data made available from damage inspections and bridge plans. These studies will be done for I-10 across Escambia Bay and I-10 across Lake Pontchartrain because there have been sufficient data already developed for these two bridges by team members MN and OEA. The Project Team will use simple, commonsense engineering to conduct these investigations. For example, the capacity of anchor bolts, bumper blocks, diaphragm connections and similar details might be an indicator of the applied forces that were either exceeded or not exceeded. Likewise, seismic analogies such as the capacity design approach might be used to estimate substructure shear capacity. Some studies of substructure behavior using complex soil structure software maybe necessary. Soil-structure-hydrodynamic interaction issues for that type of analysis would involve geotechnical, coastal and structural experts. This information will then be used to assess the wave force prediction methods in Task 3 and Task 5.

We will compile a catalog of damages from post-event condition assessments and literature reviews already conducted by some of the coastal states. Some of the literature reviews by others are soon to be completed or have been completed quite recently. It should not be necessary to update these data. We will review selected relevant published papers and reports. We will contact those directly involved with some of the post Katrina, Rita, and Ivan bridge damage surveys; including some of the coastal states which made presentations on bridge damage. As a minimum, we will review reports as exist on the following:

- A literature survey being done for TxDOT
- ASCE Katrina survey
- "Wave Forces on Bridge Decks," report by University of South Alabama
- Investigation for U.S. 90 at Biloxi, MS
- Investigations for U.S. 90 Bay St. Louis, MS
- Investigations for I-10 across Escambia Bay, FL
- Investigations for I-10 across Lake Pontchartrain, LA

From a geotechnical/substructure perspective, we will review the information compiled to identify the type and severity of storm-related damage (e.g., scour and unacceptable foundation movements), foundation type and pier configuration, and foundation soil conditions.

When reviewing damage incurred by some bridges, we will also look for information on bridges, both highway and railroad, that experienced significant storm surge and wave loading, but suffered little damage for use in other tasks.

<u>Task 3 – Review and Supplement Ongoing Force Studies</u>

Studies are ongoing characterizing loads structures encounter from coastal storm events. Information from these studies will be reviewed and supplemented by the work by others for applicability to this study.

We will review work currently underway by researchers at various universities. We presume that members of the Task Force will assist in making information available to us where their agency is funding the work and that they will facilitate release of preliminary findings from state DOT's University researchers and their contract staff. This effort should involve multiple universities and we propose to pay selected faculty an honorarium to spend some time discussing their work to either facilitate understanding of published work or gain insight into unpublished work. This is included in the contract cost proposal.

Task 3 will be limited in effort and schedule. In order to be consistent with the focus of this project, we expect to do a limited synthesis of 3 or 4 currently available wave and surge prediction and wave force prediction methods involving comparative calculations for similar data sets, and two well defined case studies. Recent hindcasts of wave and surge to be used in this project will be:

- I-10 across Escambia Bay, FL
- I-10 across Lake Pontchartrain, LA

We will concentrate efforts on evaluating the modified Kaplan procedure currently being investigated and evaluated by Dr. Sheppard (University of Florida/OEA, Inc.), and procedures outlined by HR Wallingford in "Piers, Jetties and Related Structures Exposed to Waves: Guidelines for Hydraulic Loadings." A discussion of the applicability, merits and shortcomings of these two approaches will be presented in the Final Report. Presentations at the September 18th and 19th Team meeting started this dialogue which will be continued and be the subject of presentation at the joint meeting in December. We will document some of the basis for recommending a particular method or methods in the Commentary of the Design Specification. These methods will be used to estimate the loading on spans of the two bridges identified above which were damaged during Hurricane Ivan or Katrina (for which surge and wave hindcasts have already been developed by team members MN and OEA).

Once a method for estimating wave forces has been obtained, it may be possible to produce plots of non-dimensional parameters involving moments and vertical and horizontal wave forces; water and wave parameters, and structure parameters. If these plots can be developed, they will be included as one of the products of this study.

Task 4 – Compile and Catalog Retrofit Options

Compile and catalog retrofit options developed for other hazards that may have potential for applicability to mitigate bridge damage resulting from this hazard.

We will review the 1995 Seismic Retrofit Manual and the not yet released new seismic retrofit manual compiled by MCEER for details and concepts that may be applicable to the coastal bridge problem. We will also collect concepts being considered by the coastal states by personal contacts with the State Bridge Engineers in the appropriate states. Structural concepts may be organized as:

- Risk Mitigation
  - Superstructure
    - Continuity
    - Venting
    - Hold downs
    - Barrier modification
    - Sacrificial spans
    - XXX
    - XXX
  - Substructure
    - Capacity enhancement
    - Ductility enhancement
    - XXX
  - Synergy issues

Options for foundation retrofit may include types of ground improvement to stabilize soils near pier foundations and the addition of structural elements to foundations (e.g., micropiles) that provide reserve axial, lateral and torsional resistance and which can be installed under emergency conditions to facilitate bringing a critical structure back into service relatively soon after a storm event.

After a critical evaluation of concepts, ideas and strategies that seem to be most implementable will be input for the retrofit Manual to be written in Task 6.

Task 5 – Perform Analytical Study of Retrofit Options

Conduct an analytical study to determine behavior of bridges under loads identified under Tasks 2 and 3 and with applicable retrofit options identified under Task 4.

Our approach is to reality-check hindcast wave force estimates from recent hurricanes for limited sections of two bridges against the apparent behavior observed in the field as gathered in Task 2 and using the previously performed wave and surge hindcasts developed in Task 3. Using the calculated forces and the structural assessment of resistance from Tasks 2 and 3, we will assess some of the more promising retrofit options identified in Task 4. If a given retrofit option changes the load paths in a structure the revised structural actions will have to be considered. Similarly, if a retrofit option changes the dynamic characteristics we will have to discuss the potential significance with the Task Force before proceeding with major structural analysis. This potential seems remote, so we have based our cost proposal on assuming that the structure is rigid. Dynamic analysis is not included in this proposal.

Viable options for foundation retrofit may be analyzed using FB-MultiPier. FB-MultiPier is a nonlinear finite element analysis program that can analyze multiple bridge pier structures interconnected by bridge spans subjected to a full range of AASHTO-load types in static- or dynamic-analysis modes. Each pier structure is composed of pier columns and a cap supported on a pile cap and piles/shafts with nonlinear soil. This analysis program couples nonlinear structural finite element analysis with nonlinear static soil models for axial, lateral and torsional soil behavior.

Loads for this task will be generated by OEA using whatever method is selected to be advanced for the specification and reviewed by MN and MM.

Task 6 – Develop a Guide Specification and a Retrofit Handbook for adoption by AASHTO

Task 6a - Guide Specification

The Project Team will develop a multi-level, performance-based guide specification and commentary. A design event of a given minimum probability of occurrence will be the basis of force determination. Needed statistical data describing the uncertainty on the load side will be recommended by MN and OEA. Starting with load factors and load combinations in API RP2A (which has an LRFD format) and ASCE 7, load factors will be developed to provide levels of reliability comparable to other limit states in the AASHTO LRFD. Monte Carlo simulation will be used to by DRM and MM to confirm the choice of load and resistance factors. The outcome of the calibration will be reviewed by the Team before presentation to the Task Force. Advancement to AASHTO should be a consensus of the Team and Task Force. The API and ASCE load specifications will also be a starting point for required provisions other than just the load factors.

Thus, the coastal input will be based on the same recurrence for all sites, but the magnitude of the associated parameters and the resulting force estimate will be site specific. The level of coastal input will be dependent of the required analysis level and vary from use of available standard data to comprehensive numerical modeling by experienced Coastal Engineers. Use of more sophisticated and accurate technique for the more expensive and important bridges may involve the use of numerical models to hindcast winds, waves and storm surges and their joint probability. The guidelines will also include the site specific criteria that must be considered in the analyses (i.e. surge elevation, wave period, wave height, etc.) Additionally, guidance and procedures will be provided concerning combining wave and surge loadings with other potential load cases such as live load, wind load, scour and vessel impact. Levels of analysis may take the form below:

> Level I – force calcs using data from screening analysis by reference to Spec where possible (surge from FEMA, Fetch from mapping, wind from ASCE 7, Wave height from Shore Protection Manual 84)
>
> Level II – improve some data based on coastal engineering and repeat force calc
>
> Level III – Improve as much data as possible using coastal numerical modeling, statistical analysis, structural dynamics, model studies, advanced geotechnical modeling.

At this time, we expect that a menu of levels of analysis we will developed similar to Table 4.7.4.3.1-1 in the seismic criteria in the LRFD Specifications. Hazard, vulnerability, importance and construction cost are likely discriminators in such a table. It is reasonable to expect that some, or possibly all, of the performance levels in the specifications will require that the storm surge and wave characteristics and their interaction with wind and current, be determined by a qualified coastal engineer for use by the bridge engineer.

We have considered the issue of a national hazard map indicating wave forces and their probability, and it is the collective judgment of the Team that due to the site specific nature of both the storm surge and especially the waves, a comprehensive national map of the type described in the RFP is not possible. In fact, developing anything more advanced than the FEMA surge maps is also beyond this project. Similarly, there seems to be little chance of developing a research statement for another agency to prepare such a map. If conditions change during the life of this project to make either a map or a map-development project more variable, it can be discussed with the Task Force at that time to see if there is a satisfactory way to proceed.

In lieu of the national map, we will prepare guidelines and procedures on how to produce the storm surge and wave conditions at a bridge site for a given probability event. These guidelines will include more than one procedure starting with a relatively simple one for use with small, less important bridges. A simple procedure may involve using existing FEMA storm surge maps and ASCE-7 design wind speeds. Even these relatively simple tools address the issue of the probability of an event of a given size affecting a given site in that wind speed and surge height correspond to a return period. Thus the difference in coastal storms affecting New Jersey and Florida, for example is addressed to some degree. This information could be used with basic Corps of Engineers wave hindcasting techniques to determine the design conditions for determination of forces on the bridge.

We will prepare guidance for a bridge designer to use the wave/surge/current/wind information to determine if the structure has sufficient vertical clearance for the superstructure to be unaffected, and if not to determine the structural response for these loads. We will identify design strategies as part of the design guidance.

Ideally, the Guide Specification should address the joint probability of the current, surge, wave and wind, and possibly scour and vessel impact. It is very unlikely that the maximum of each event will occur simultaneously. Similarly, there should be some recognition of the fact that a wave/surge arriving at a bridge may not be precisely aligned with the direction of a pier to produce maximum damage. The vessel collision specifications contain an analogous concept, i.e., that not all vessel collisions with a bridge pier are maximum direct hits; many are glancing blows – see LRFD Article 3.14.5.4 and Commentary. The information required to do a rigorous joint probability wind/wave/surge analysis is extremely rare if it exists at all at this time. A study currently underway by OEA, Inc. for the FDOT District 6 for the Florida Keys will, when completed, provide the information needed for this type of analysis for that area but not in time to affect this project. In this project, approximate techniques will be used in an attempt to produce estimates of these joint probabilities. However, the joint probability issue may be found to be so site specific and/or data dependent that it is not amenable to treatment by such simple methods as Turkstra's rule. If this is found to be the case we will outline procedures and criteria for conducting site specific evaluations of joint actions.

<u>Task 6b - Retrofit Handbook</u>

There is a need for the Retrofit Manual to have a programmatic component. Therefore, the Project Team will develop guidance on a suggested screening and prioritization process. Since the focus of the project is to utilize available information, at least as a starting point, we will be guided by processes similar to those used in seismic design and/or security assessments. We will also consider the Draft 3-level approach presented by Florida as discussed at the SCOBS meeting in Utah as a possible screening tool as well as other methods that we identify in Task 2. We anticipate that the recommended ranking procedure will place heavy emphasis on evacuation and recovery issues and will consider programmatic issue such as scheduled maintenance or replacement.

The screening process developed in Task 6 will have options for early dismissal of bridges which have either such low hazard levels or low vulnerability as to not warrant further consideration. Criteria may involve site issues such as small fetch or other protection from surge and/or wave. Height of structure or weight/buoyancy might also be factors for early exemption from further study. Some of these characteristics have already been used in available security, coastal and seismic screening processes.

The Project Team will prepare guidance for dealing with the bridges found to need retrofit or replacement in two levels: strategies and possible details. Strategies could range from do nothing and accept the risk, stockpiling replacement spans or temporary bridging, or installing retrofits, through replacement of lifeline structures.

We will present retrofit concepts identified in Task 4 found to be effective and practical for the types of low-level bridges found in coastal areas in a concept graphic with a list of advantages and caveats that the Project Team and the Task Force determine to be necessary. Caveats may include the necessity to investigate the load path all the way into the foundations, improve ductility to assure that the implied structural response is obtainable, or use built-in fuses. The handbook will include a general methodology for design and retrofit, but detailed design procedures and example calculations will not be provided. The RFP indicates that the Government and task force will help identify feasible strategies, and we welcome that input.

Findings of this Task (for each milestone submittal) will be presented to the Government and AASHTO/FHWA Task Force.

The Project Team will develop a cost assessment model to evaluate the benefit/cost associated with potential retrofit investments for long or lifeline bridges requiring special attention. MN will take the lead in developing the cost assessment model. We anticipate that the cost-effectiveness procedure will be similar to the Method III Benefit/Cost analysis contained in the *AASHTO Guide Specification and Commentary for Vessel Collision Design of Highway Bridges (1991)*. The cost of retrofit measures will be compared with the benefits associated with avoiding the major quantifiable costs associated with bridge collapse, including replacement and detour costs associated with traffic having to use alternative routes after a potential collapse event. The risk associated with the collapse event will be included in the benefit/cost analysis procedures.

A preliminary draft outline for the Retrofit Manual is attached.

Task 7 – Develop Final Report and Recommendations for Further Studies

Based on findings of Tasks 2 - 5, the Project Team will prepare a final comprehensive report with findings supporting the items described in Task 6. In addition, the report will contain a plan for further study including any experimental work under a separate phase of work. The project findings will be presented to the AASHTO/FHWA Task Force.

While MM will take the lead, MN will contribute the summary of analysis of load calculation procedures and will review the rest of the document. The presentation will be shared by MM, MN and OEA.

Task 8 – Prepare Executive Summary and Presentation Materials

We will prepare a 4-6 page executive summary and presentation materials for managerial briefings. The briefing materials will be limited to a one hour presentation. MM will take the lead assisted by DRM. The executive summary will be reviewed by MN, OEA and DAP.

We propose to delay the preparation of the technology transfer material until after the other tasks are nearly complete, and to negotiate a fee for that work when the extent of prepared information from other tasks that can be used directly as presentation material can be more accurately assessed. No costs for preparation of that material is included in this proposal.

The requirements for monthly reporting and the deliverables are detailed in the RFP. These requirements are not repeated herein but will be fulfilled by our team.

A proposed schedule of values and milestone schedule follows.

Tentative Agenda for Dec. Joint Meeting

8-17-06

When: Dec 4, 5 & 6– to be finalized next week
Where: Gainesville – FDOT will supply vans and meeting room for one day
Contact person in Wm's office: Linda Ryan (Linda.ryan@dot.state.fl.us)

Dec 4 – Team meeting

1:30 – 5:30 PT Meets

- Scope adjustments
- Discussion of K and W methods
- Other candidates?
- Basis for a choice
- Further define roles and responsibilities

Dec 5 –Joint Meeting

8 - 9 Separate meetings of Task Force (TF) and Project Team (PT)
9 -12 Combined meeting

- Introductions
- How does project fit in big picture? What is already available?
- What other work is underway at state and federal level?
- Summary of work to date – review of progress reports
- Philosophy

12 -1 Lunch
1PM Leave for U of F wave tank
3:30 Return to meeting

- More on progress
- Expectations
- Products

5:30 Adjourn

Dec 6

8-5 Meet with TF

- TF feed back and direction
- Scope/Work Plan
- Set date for next combined meeting

5:00 PM - Leave

Agenda for September 18-19 Team Meeting

Monday Noon -5:30 (w/working lunch)

- Tentative contract terms (30 min)
- How to invoice for work done (30 min)
- Comment on the partial payment schedule sent recently which we need to offer to FHWA. (15 min) Any comments as far??
- Results to date from request for information. (15 min)
- Mike Knott – cost assessment, other thoughts (30 min)
- Max Sheppard – review of current related projects and how they will feed into this project (45 min)
- Presentations on Kaplan, Wallingford, FDOT screening, discussion of Douglas report (60 min to 90 min))
- Prepare a list of current thinking on the types of information necessary to get to bridge loadings and where we think it might come from----eg winds, fetch, tides, surge height, wave height etc. (Do MN or OEA already have this from other work?) (30 to 45 min)

From OEA's wave and surge vulnerability report March 2006

The six steps in the procedure are as follows:

1. identify potential bridges
2. establish the 100-year water surface elevation at each bridge – FEMA flood maps or local data
3. determine the fetch length and the average water depth over the fetch for each bridge - mapping
4. determine the 100-year wind speed and direction for each bridge - NOAA
5. determine the maximum design wave height at each bridge – USACoE??
6. determine the elevation and configuration of the superstructure for each bridge. - Plans

- Free discussion on where we think this is going---what might the deliverables look like.

Tuesday 8:30 – 5:00 (w/working lunch)

- Free discussion continues
- Expand our revised tech proposal, which you all have, into a "work plan". Need more specificity. Any premeeting work on this would be good. Most of us have more that 2 days (16 hours??) for a type 1B meeting so there is some time available to work on this. For that matter, time could be charged to the actual tasks on the basis that we are defining and planning the work.
- Start to list major headings for spec and handbook
- List topics for OCT 20 meeting.

    1. Work Plan
    2. Table of values
    3. Lump sum by Task

4. Receipts?
5. Formats for invoices.

- Review agenda for Dec meeting, attendance list (to Linda ASAP), lab tour time requirements.

Retrofit handbook – Preliminary Outline (9/19/06)

Purpose
Terminology
Examples of past storm damage – MM, started
Screening existing inventory (no force calc) – WGW & Max, start Nov.
- Overview of process
- Hazard Identification
  - Storm recurrence
    - Needed data and source – six steps from FDOT
    - Site and fetch
    - Wind
    - Bathymetry
    - Surge & Still water elev (tide, storm surge
  - Vulnerability scoring
    - Based on FDOT process – add programmatic features to FDOT process

Prioritization of bridges requiring further analysis by risk (OVI or similar, see next page) - MM
Analysis of bridges not screened out – MN, start now
- Level I – force calcs using data from screening analysis by reference to Spec where possible (surge from FEMA, Fetch from mapping, wind from ASCE 7, Wave height from Shore Protection Manual 84)
- Level II – improve some data based on coastal engineering and repeat force calc
  - XX
  - XX
- Level III – Improve as much data as possible using coastal numerical modeling, statistical analysis, structural dynamics, model studies, advanced geotechnical modeling.

(Note Level structure probably in design spec and referenced in Manual)

- Cost assessment model - MK, now
- Prioritization of bridges requiring mitigation by risk (OVI or similar)

Retrofit Strategies for existing bridges - WGW
- Management Issues
  - Risk acceptance
    - Temporary bridges
    - No action
    - Incident management plan
  - Risk transfer
  - Risk avoidance
    - Alignment relocation
    - Grade change

Structural changes
Collateral improvements (combined benefits)
Concept Synergy – management level
Engineering Issues
Risk Mitigation
Superstructure
Continuity
Venting
Hold downs
Barrier modification
Sacrificial spans
XXX
XXX
Substructure
Capacity enhancement
Ductility enhancement
XXX
Geotechnical
site remediation
XXX

Synergy issues

Excerpt from Blue Ribbon Panel Report on Bridge and Tunnel Security

The risk, *R*, to the facility is determined following an approach similar to that developed for seismic retrofit and can be expressed as follows:1

$$R = O \times V \times I$$

where,

***O* = Occurrence:** In the general form of the risk equation, this factor is hazard oriented and will change with the nature of the hazard. In the context of this report, the occurrence factor approximates the *likelihood* that terrorists will attack the asset. It includes target attractiveness (from the perspective of the threat), level of security, access to the site, publicity if attacked, and the number of prior threats. Input into this factor typically comes from the law enforcement and intelligence communities familiar with threat and operational security measures.

***V* = Vulnerability:** In the general form of the risk equation, vulnerability is an indication of how much the facility or population would be *damaged or destroyed* based on the structural response to a particular hazard. In the context of this report, vulnerability is the likely damage resulting from various terrorist threats (weapon type and location). It is a measure of expected damage, outcome of the event, expected casualties, and loss of use, all features of the facility itself. Input into this factor typically comes from engineering analysis and expertise.

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1 The proposed approach is consistent with the approach suggested by the TSA and with approaches currently used by entities that have completed or are performing risk assessments.

***I* = Importance:** Importance is a characteristic of the facility, not the hazard. In principle, importance is the same for any hazard. Importance is an indication of *consequences* to the region or nation in the event the facility is destroyed or unavailable. Is the facility on an evacuation or military mobilization route; is it likely to be used by first responders to emergencies; what is its historic and associated significance; what is its peak occupancy? Input into this factor typically comes from owners, operators, users, and beneficiaries of the facilities, often governmental sources, and will use factors similar to those used in the first tier prioritization.

This formula properly expresses the interaction among the three factors. Dominant factors magnify risk; negligible factors diminish it. Other formulas, such as models that add the factors, fail to account for their interactive effects. For example, in the absence of a threat (O=0), the risk should be zero as this model provides; additive models would have a residual risk. In the multiplicative model, eliminating any one factor to zero (or near zero) reduces the risk to near zero (e.g., low importance leads to low risk regardless of other factors).

The countermeasures that reduce the risk associated with an asset may be designed to reduce the occurrence factor (e.g., make the asset less accessible), the vulnerability factor (e.g., harden the facility to reduce damage), or the importance factor (e.g., add redundant facilities to reduce dependence on the asset)

Existing structures are different from new structures.

Task Order DTFH61-06-T-70006

Table of Values

Task	2	3	4	5	6 50%	6 90%	6 100%	7 75%	7 100%	8 75%	8 100%
Start	15-Aug	15-Aug	15-Sep	1-Dec	1-Dec			1-Mar		1-Jun	
End	15-Dec	15-Dec	26-Jan	2-Mar	15-Feb	31-May	15-Aug	30-Jun	15-Sep	30-Jun	31-Aug
Total	$64,791	$104,00 6	$57,254	$95,450	$121,637			$77,843		$18,272	
Invoice											
31-Oct	25%	25%									
30-Nov	60%	60%	30%								
31-Dec	100%	100%	60%								
31-Jan			100%								
28-Feb				85%	35%						
31-Mar				100%							
30-Apr											
31-May						75%					
30-Jun								60%		60%	
31-Jul											
31-Aug							100%				100%
30-Sep									100%		

Milestone Schedule

TASK	RFP COMPLETION DATES	PROPOSED COMPLETION DATES	
Notice to Proceed	September 1, 2006	September 1, 2006	
Kickoff Meeting	2nd week in September 2006*	December 4,5,6, 2006	
Task 2	December 15, 2006	December 15, 2006	Jan 15
Task 3	December 15, 2006	December 15, 2006	Feb 28
Task 4	January 26, 2007	January 26, 2007	3/31
Task 5	March 2, 2007	March 2, 2007	4/15
Task 6			
50% Draft Specification and Manual	December 31, 2006	February 15, 2007	4/30
90% Draft Specification and Manual	May 31, 2007	May 31, 2007	7/31
100% Draft Specification and Manual	August 15, 2007	August 15, 2007	10/15
Interim Report Tasks 2 to 6	July 15 2007	July 15 2007	9/15
Task 7			
Draft	June 30, 2007	June 30, 2007	8/30
Final	September 15, 2007	September 15, 2007	9/15
Task 8 – Executive Summary			
Draft 4 to 6 page summary	June 30, 2007	June 30, 2007	8/31
Final 4 to 6 page summary	August 31, 2007	August 31, 2007	10/31
Task 8 – 13 hour slides			
Draft	June 30, 2007	November 30, 2007	Jan 31/2008
Final	September 30, 2007	January 31, 2008	March 31/2008

DRAFT WORK PLAN

SUBMITTED 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.

September 25, 2006

TECHNICAL APPROACH

While recent hurricanes are named herein, the term "coastal storm" is broader than" hurricane" in that it implies any storm that involves a combination of wind, wave, and/or surge. Thus, a "Nor'Easter" is considered a coastal storm.

Our focus will be on assembling available information into a practice-oriented specification and retrofit handbook. Time and resources will not allow for a major research effort.

The structure-type focus of this study will be typical prestressed concrete and steel multi-girder bridges and slab bridges. Although some of the guidance to be developed may be useful for the analysis of segmental concrete or movable bridges, specific design specifications or retrofit concepts for these types of bridges will not be developed. Similarly, while tsunamis are a wave event, they will not be specifically covered. Damage from floating objects will not be considered.

Our approach to Tasks 1 through 8 in the Prospectus follows.

Task 1 – Kick off and Project Meetings

The RFP states that the contractor's key technical and other appropriate staff shall meet with FHWA and other staff at the FHWA Office of Bridge Technology, the National Highway Institute in Washington, DC, the contractor's facilities, or at other locations to be determined by the Government for one one-to-two day meeting to discuss the overall approach, contractor proposed work plan and schedule, deliverables, and details of this project.

Furthermore, the RFP states that the contractor shall also be required to meet with the Government and review task force for one or more 1 or 2-day project technical meetings with the Government and review group to resolve any on-going technical issues that arise during development. While some meetings will require only one person, some will require 2 or 3 to attend. These meetings will be scheduled as needed during the project.

We will hold an expanded version of a kick off meeting, part of which would be intra Team, in early December, with three objectives:

- Hold an internal team meeting to determine what information has been assembled. Discuss what additional information we need, and promote cooperation on some critical Tasks such as Tasks 3 and 5 on which so much of the rest of the project depends;
- Meet with the Task Force for 2 days to discuss our progress and remaining work, further clarify expectations and identify areas where the Task Force may be able to provide input, especially for Tasks 2 and 4, and to discuss objectives and deliverables.
- Visit the wave tank at the University of Florida and review findings with Dr. Sheppard.

A preliminary agenda for this meeting is attached.

Due to the difficulty in scheduling a kick off meeting shortly after NTP, the Team held a two-day meeting on September 18 and 19. Items discussed included clarifying responsibilities, discussions on the Wallingford and modified Kaplan methods and plan on how a decision will eventually be made as to wave force calculation method, and an exchange of views on the form some of the deliverables might take. The agenda for that meeting is attached.

A meeting has also been scheduled for Oct 20th which will be attended by representatives of the Team and the Task Force with telephone access to other members of both groups.

We expect that one or more additional meetings of the full team will be beneficial. As the very least we expect the wave experts from MN and Dr. Sheppard to meet occasionally regarding Tasks 3 and 5.

We expect to attend a project close-out meeting with the Task Force, and make a presentation to 2007 and 2008 SCOBS meeting.

Task 2 – Review, Summarize, and Augment Literature

Conduct a literature review, and summarize and catalog damages on bridges and structures resulting from coastal storm hydrodynamic events, and augment this work with additional data and information as required.

This Task shall also include back-calculating structural resistance from forensic data made available from damage inspections and bridge plans. These studies will be done for I-10 across Escambia Bay and I-10 across Lake Pontchartrain because there have been sufficient data already developed for these two bridges by team members MN and OEA. The Project Team will use simple, commonsense engineering to conduct these investigations. For example, the capacity of anchor bolts, bumper blocks, diaphragm connections and similar details might be an indicator of the applied forces that were either exceeded or not exceeded. Likewise, seismic analogies such as the capacity design approach might be used to estimate substructure shear capacity. Some studies of substructure behavior using complex soil structure software maybe necessary. Soil-structure-hydrodynamic interaction issues for that type of analysis would involve geotechnical, coastal and structural experts. This information will then be used to assess the wave force prediction methods in Task 3 and Task 5.

We will compile a catalog of damages from post-event condition assessments and literature reviews already conducted by some of the coastal states. Some of the literature reviews by others are soon to be completed or have been completed quite recently. It should not be necessary to update these data. We will review selected relevant published papers and reports. We will contact those directly involved with some of the post Katrina, Rita, and Ivan bridge damage surveys; including some of the coastal states which made presentations on bridge damage. As a minimum, we will review reports as exist on the following:

- A literature survey being done for TxDOT
- ASCE Katrina survey
- "Wave Forces on Bridge Decks," report by University of South Alabama
- Investigation for U.S. 90 at Biloxi, MS
- Investigations for U.S. 90 Bay St. Louis, MS
- Investigations for I-10 across Escambia Bay, FL
- Investigations for I-10 across Lake Pontchartrain, LA

From a geotechnical/substructure perspective, we will review the information compiled to identify the type and severity of storm-related damage (e.g., scour and unacceptable foundation movements), foundation type and pier configuration, and foundation soil conditions.

When reviewing damage incurred by some bridges, we will also look for information on bridges, both highway and railroad, that experienced significant storm surge and wave loading, but suffered little damage for use in other tasks.

<u>Task 3 – Review and Supplement Ongoing Force Studies</u>

Studies are ongoing characterizing loads structures encounter from coastal storm events. Information from these studies will be reviewed and supplemented by the work by others for applicability to this study.

We will review work currently underway by researchers at various universities. We presume that members of the Task Force will assist in making information available to us where their agency is funding the work and that they will facilitate release of preliminary findings from state DOT's University researchers and their contract staff. This effort should involve multiple universities and we propose to pay selected faculty an honorarium to spend some time discussing their work to either facilitate understanding of published work or gain insight into unpublished work. This is included in the contract cost proposal.

Task 3 will be limited in effort and schedule. In order to be consistent with the focus of this project, we expect to do a limited synthesis of 3 or 4 currently available wave and surge prediction and wave force prediction methods involving comparative calculations for similar data sets, and two well defined case studies. Recent hindcasts of wave and surge to be used in this project will be:

- I-10 across Escambia Bay, FL
- I-10 across Lake Pontchartrain, LA

We will concentrate efforts on evaluating the modified Kaplan procedure currently being investigated and evaluated by Dr. Sheppard (University of Florida/OEA, Inc.), and procedures outlined by HR Wallingford in "Piers, Jetties and Related Structures Exposed to Waves: Guidelines for Hydraulic Loadings." A discussion of the applicability, merits and shortcomings of these two approaches will be presented in the Final Report. Presentations at the September 18th and 19th Team meeting started this dialogue which will be continued and be the subject of presentation at the joint meeting in December. We will document some of the basis for recommending a particular method or methods in the Commentary of the Design Specification. These methods will be used to estimate the loading on spans of the two bridges identified above which were damaged during Hurricane Ivan or Katrina (for which surge and wave hindcasts have already been developed by team members MN and OEA).

Once a method for estimating wave forces has been obtained, it may be possible to produce plots of non-dimensional parameters involving moments and vertical and horizontal wave forces; water and wave parameters, and structure parameters. If these plots can be developed, they will be included as one of the products of this study.

Task 4 – Compile and Catalog Retrofit Options

Compile and catalog retrofit options developed for other hazards that may have potential for applicability to mitigate bridge damage resulting from this hazard.

We will review the 1995 Seismic Retrofit Manual and the not yet released new seismic retrofit manual compiled by MCEER for details and concepts that may be applicable to the coastal bridge problem. We will also collect concepts being considered by the coastal states by personal contacts with the State Bridge Engineers in the appropriate states. Structural concepts may be organized as:

- Risk Mitigation
  - Superstructure
    - Continuity
    - Venting
    - Hold downs
    - Barrier modification
      - Breakaway
      - Open
    - Sacrificial spans
    - XXXXX
    - XXXXX
  - Substructure
    - Capacity enhancement
    - Ductility enhancement
    - Add earwalls (1ft) to piers
    - Add Shear keys to piers
    - Strengthen with tie beams, bracing, shafts or piles
    - XXX
  - Synergy issues

Options for foundation retrofit may include types of ground improvement to stabilize soils near pier foundations and the addition of structural elements to foundations (e.g., micropiles) that provide reserve axial, lateral and torsional resistance and which can be installed under emergency conditions to facilitate bringing a critical structure back into service relatively soon after a storm event.

After a critical evaluation of concepts, ideas and strategies that seem to be most implementable will be input for the retrofit Manual to be written in Task 6.

<u>Task 5 – Perform Analytical Study of Retrofit Options</u>

Conduct an analytical study to determine behavior of bridges under loads identified under Tasks 2 and 3 and with applicable retrofit options identified under Task 4.

Our approach is to reality-check hindcast wave force estimates from recent hurricanes for limited sections of two bridges against the apparent behavior observed in the field as gathered in Task 2 and using the previously performed wave and surge hindcasts developed in Task 3. Using the calculated forces and the structural assessment of resistance from Tasks 2 and 3, we will assess some of the more promising retrofit options identified in Task 4. If a given retrofit option changes the load paths in a structure the revised structural actions will have to be considered. Similarly, if a retrofit option changes the dynamic characteristics we will have to discuss the potential significance with the Task Force before proceeding with major structural analysis. This potential seems remote, so we have based our cost proposal on assuming that the structure is rigid. Dynamic analysis is not included in this proposal.

Viable options for foundation retrofit may be analyzed using FB-MultiPier. FB-MultiPier is a nonlinear finite element analysis program that can analyze multiple bridge pier structures interconnected by bridge spans subjected to a full range of AASHTO-load types in static- or dynamic-analysis modes. Each pier structure is composed of pier columns and a cap supported on a pile cap and piles/shafts with nonlinear soil. This analysis program couples nonlinear structural finite element analysis with nonlinear static soil models for axial, lateral and torsional soil behavior.

Loads for this task will be generated by OEA using whatever method is selected to be advanced for the specification and reviewed by MN and MM.

<u>Task 6 – Develop a Guide Specification and a Retrofit Handbook for adoption by AASHTO</u>

<u>Task 6a - Guide Specification</u>

The Project Team will develop a multi-level, performance-based guide specification and commentary. A design event of a given minimum probability of occurrence will be the basis of force determination. Needed statistical data describing the uncertainty on the load side will be recommended by MN and OEA. Starting with load factors and load combinations in API RP2A (which has an LRFD format) and ASCE 7, load factors will be developed to provide levels of reliability comparable to other limit states in the AASHTO LRFD. Monte Carlo simulation will be used to by DRM and MM to confirm the choice of load and resistance factors. The outcome of the calibration will be reviewed by the Team before presentation to the Task Force. Advancement to AASHTO should be a consensus of the Team and Task Force. The API and ASCE load specifications will also be a starting point for required provisions other than just the load factors.

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> Level II – improve some data based on coastal engineering and repeat force calc
>
> Level III – Improve as much data as possible using coastal numerical modeling, statistical analysis, structural dynamics, model studies, advanced geotechnical modeling.

At this time, we expect that a menu of levels of analysis we will developed similar to Table 4.7.4.3.1-1 in the seismic criteria in the LRFD Specifications. Hazard, vulnerability, importance and construction cost are likely discriminators in such a table. It is reasonable to expect that some, or possibly all, of the performance levels in the specifications will require that the storm surge and wave characteristics and their interaction with wind and current, be determined by a qualified coastal engineer for use by the bridge engineer.

We have considered the issue of a national hazard map indicating wave forces and their probability, and it is the collective judgment of the Team that due to the site specific nature of both the storm surge and especially the waves, a comprehensive national map of the type described in the RFP is not possible. In fact, developing anything more advanced than the FEMA surge maps is also beyond this project. Similarly, there seems to be little chance of developing a research statement for another agency to prepare such a map. If conditions change during the life of this project to make either a map or a map-development project more variable, it can be discussed with the Task Force at that time to see if there is a satisfactory way to proceed.

In lieu of the national map, we will prepare guidelines and procedures on how to produce the storm surge and wave conditions at a bridge site for a given probability event. These guidelines will include more than one procedure starting with a relatively simple one for use with small, less important bridges. A simple procedure may involve using existing FEMA storm surge maps and ASCE-7 design wind speeds. Even these relatively simple tools address the issue of the probability of an event of a given size affecting a given site in that wind speed and surge height correspond to a return period. Thus the difference in coastal storms affecting New Jersey and Florida, for example is addressed to some degree. This information could be used with basic Corps of Engineers wave hindcasting techniques to determine the design conditions for determination of forces on the bridge.

We will prepare guidance for a bridge designer to use the wave/surge/current/wind information to determine if the structure has sufficient vertical clearance for the superstructure to be unaffected, and if not to determine the structural response for these loads. We will identify design strategies as part of the design guidance.

Ideally, the Guide Specification should address the joint probability of the current, surge, wave and wind, and possibly scour and vessel impact. It is very unlikely that the maximum of each event will occur simultaneously. Similarly, there should be some recognition of the fact that a wave/surge arriving at a bridge may not be precisely aligned with the direction of a pier to produce maximum damage. The vessel collision specifications contain an analogous concept, i.e., that not all vessel collisions with a bridge pier are maximum direct hits; many are glancing blows – see LRFD Article 3.14.5.4 and Commentary. The information required to do a rigorous joint probability wind/wave/surge analysis is extremely rare if it exists at all at this time. A study currently underway by OEA, Inc. for the FDOT District 6 for the Florida Keys will, when completed, provide the information needed for this type of analysis for that area but not in time to affect this project. In this project, approximate techniques will be used in an attempt to produce estimates of these joint probabilities. However, the joint probability issue may be found to be so site specific and/or data dependent that it is not amenable to treatment by such simple methods as Turkstra's rule. If this is found to be the case we will outline procedures and criteria for conducting site specific evaluations of joint actions.

Task 6b - Retrofit Handbook

There is a need for the Retrofit Manual to have a programmatic component. Therefore, the Project Team will develop guidance on a suggested screening and prioritization process. Since the focus of the project is to utilize available information, at least as a starting point, we will be guided by processes similar to those used in seismic design and/or security assessments. We will also consider the Draft 3-level approach presented by Florida as discussed at the SCOBS meeting in Utah as a possible screening tool as well as other methods that we identify in Task 2. We anticipate that the recommended ranking procedure will place heavy emphasis on evacuation and recovery issues and will consider programmatic issue such as scheduled maintenance or replacement.

The screening process developed in Task 6 will have options for early dismissal of bridges which have either such low hazard levels or low vulnerability as to not warrant further consideration. Criteria may involve site issues such as small fetch or other protection from surge and/or wave. Height of structure or weight/buoyancy might also be factors for early exemption from further study. Some of these characteristics have already been used in available security, coastal and seismic screening processes.

The Project Team will prepare guidance for dealing with the bridges found to need retrofit or replacement in two levels: strategies and possible details. Strategies could range from do nothing and accept the risk, stockpiling replacement spans or temporary bridging, or installing retrofits, through replacement of lifeline structures.

We will present retrofit concepts identified in Task 4 found to be effective and practical for the types of low-level bridges found in coastal areas in a concept graphic with a list of advantages and caveats that the Project Team and the Task Force determine to be necessary. Caveats may include the necessity to investigate the load path all the way into the foundations, improve ductility to assure that the implied structural response is obtainable, or use built-in fuses. The handbook will include a general methodology for design and retrofit, but detailed design procedures and example calculations will not be provided. The RFP indicates that the Government and task force will help identify feasible strategies, and we welcome that input.

Findings of this Task (for each milestone submittal) will be presented to the Government and AASHTO/FHWA Task Force.

The Project Team will develop a cost assessment model to evaluate the benefit/cost associated with potential retrofit investments for long or lifeline bridges requiring special attention. MN will take the lead in developing the cost assessment model. We anticipate that the cost-effectiveness procedure will be similar to the Method III Benefit/Cost analysis contained in the *AASHTO Guide Specification and Commentary for Vessel Collision Design of Highway Bridges (1991)*. The cost of retrofit measures will be compared with the benefits associated with avoiding the major quantifiable costs associated with bridge collapse, including replacement and detour costs associated with traffic having to use alternative routes after a potential collapse event. The risk associated with the collapse event will be included in the benefit/cost analysis procedures.

A preliminary draft outline for the Retrofit Manual is attached.

<u>Task 7 – Develop Final Report and Recommendations for Further Studies</u>

Based on findings of Tasks 2 - 5, the Project Team will prepare a final comprehensive report with findings supporting the items described in Task 6. In addition, the report will contain a plan for further study including any experimental work under a separate phase of work. The project findings will be presented to the AASHTO/FHWA Task Force.

While MM will take the lead, MN will contribute the summary of analysis of load calculation procedures and will review the rest of the document. The presentation will be shared by MM, MN and OEA.

Task 8 – Prepare Executive Summary and Presentation Materials

We will prepare a 4-6 page executive summary and presentation materials for managerial briefings. The briefing materials will be limited to a one hour presentation. MM will take the lead assisted by DRM. The executive summary will be reviewed by MN, OEA and DAP.

We propose to delay the preparation of the technology transfer material until after the other tasks are nearly complete, and to negotiate a fee for that work when the extent of prepared information from other tasks that can be used directly as presentation material can be more accurately assessed. No costs for preparation of that material is included in this proposal.

The requirements for monthly reporting and the deliverables are detailed in the RFP. These requirements are not repeated herein but will be fulfilled by our team.

A proposed schedule of values and milestone schedule follows.

Tentative Agenda for Dec. Joint Meeting

8-17-06

When: Dec 4, 5 & 6– to be finalized next week
Where: Gainesville – FDOT will supply vans and meeting room for one day
Contact person in Wm's office: Linda Ryan (Linda.ryan@dot.state.fl.us)

Dec 4 – Team meeting

1:30 – 5:30 PT Meets

- Scope adjustments
- Discussion of K and W methods
- Other candidates?
- Basis for a choice
- Further define roles and responsibilities

Dec 5 –Joint Meeting

8 - 9 Separate meetings of Task Force (TF) and Project Team (PT)
9 -12 Combined meeting

- Introductions
- How does project fit in big picture? What is already available?
- What other work is underway at state and federal level?
- Summary of work to date – review of progress reports
- Philosophy

12 -1 Lunch
1PM Leave for U of F wave tank
3:30 Return to meeting

- More on progress
- Expectations
- Products

5:30 Adjourn

Dec 6

8-5 Meet with TF

- TF feed back and direction
- Scope/Work Plan
- Set date for next combined meeting

5:00 PM - Leave

Agenda for September 18-19 Team Meeting

Monday Noon -5:30 (w/working lunch)

- Tentative contract terms (30 min)
- How to invoice for work done (30 min)
- Comment on the partial payment schedule sent recently which we need to offer to FHWA. (15 min) Any comments as far??
- Results to date from request for information. (15 min)
- Mike Knott – cost assessment, other thoughts (30 min)
- Max Sheppard – review of current related projects and how they will feed into this project (45 min)
- Presentations on Kaplan, Wallingford, FDOT screening, discussion of Douglas report (60 min to 90 min))
- Prepare a list of current thinking on the types of information necessary to get to bridge loadings and where we think it might come from----eg winds, fetch, tides, surge height, wave height etc. (Do MN or OEA already have this from other work?) (30 to 45 min)

From OEA's wave and surge vulnerability report March 2006

The six steps in the procedure are as follows:

1. identify potential bridges
2. establish the 100-year water surface elevation at each bridge – FEMA flood maps or local data
3. determine the fetch length and the average water depth over the fetch for each bridge - mapping
4. determine the 100-year wind speed and direction for each bridge - NOAA
5. determine the maximum design wave height at each bridge – USACoE??
6. determine the elevation and configuration of the superstructure for each bridge. - Plans

- Free discussion on where we think this is going---what might the deliverables look like.

Tuesday 8:30 – 5:00 (w/working lunch)

- Free discussion continues
- Expand our revised tech proposal, which you all have, into a "work plan". Need more specificity. Any premeeting work on this would be good. Most of us have more that 2 days (16 hours??) for a type 1B meeting so there is some time available to work on this. For that matter, time could be charged to the actual tasks on the basis that we are defining and planning the work.
- Start to list major headings for spec and handbook
- List topics for OCT 20 meeting.

    1. Work Plan
    2. Table of values
    3. Lump sum by Task

4. Receipts?
5. Formats for invoices.

- Review agenda for Dec meeting, attendance list (to Linda ASAP), lab tour time requirements.

Retrofit handbook – Preliminary Outline (9/19/06)

Purpose
Terminology
Examples of past storm damage – MM, started
Screening existing inventory (no force calc) – WGW & Max, start Nov.

- Overview of process
- Hazard Identification
    - Storm recurrence
        - Needed data and source – six steps from FDOT
        - Site and fetch
        - Wind
        - Bathymetry
        - Surge & Still water elev (tide, storm surge
    - Vulnerability scoring
        - Based on FDOT process – add programmatic features to FDOT process

Prioritization of bridges requiring further analysis by risk (OVI or similar, see next page) - MM
Analysis of bridges not screened out – MN, start now

- Level I – force calcs using data from screening analysis by reference to Spec where possible (surge from FEMA, Fetch from mapping, wind from ASCE 7, Wave height from Shore Protection Manual 84)
- Level II – improve some data based on coastal engineering and repeat force calc
    - XX
    - XX
- Level III – Improve as much data as possible using coastal numerical modeling, statistical analysis, structural dynamics, model studies, advanced geotechnical modeling.

(Note Level structure probably in design spec and referenced in Manual)

- Cost assessment model - MK, now
- Prioritization of bridges requiring mitigation by risk (OVI or similar)

Retrofit Strategies for existing bridges - WGW

- Management Issues
    - Risk acceptance
        - Temporary bridges
        - No action
        - Incident management plan
    - Risk transfer
    - Risk avoidance
        - Alignment relocation
        - Grade change

Structural changes
Collateral improvements (combined benefits)
Concept Synergy – management level
Engineering Issues
Risk Mitigation
Superstructure
Continuity
Venting
Hold downs
Barrier modification
Sacrificial spans
XXX
XXX
Substructure
Capacity enhancement
Ductility enhancement
XXX
Geotechnical
site remediation
XXX

Synergy issues

Excerpt from Blue Ribbon Panel Report on Bridge and Tunnel Security

The risk, *R*, to the facility is determined following an approach similar to that developed for seismic retrofit and can be expressed as follows:1

$$R = O \times V \times I$$

where,

***O* = Occurrence:** In the general form of the risk equation, this factor is hazard oriented and will change with the nature of the hazard. In the context of this report, the occurrence factor approximates the *likelihood* that terrorists will attack the asset. It includes target attractiveness (from the perspective of the threat), level of security, access to the site, publicity if attacked, and the number of prior threats. Input into this factor typically comes from the law enforcement and intelligence communities familiar with threat and operational security measures.

***V* = Vulnerability:** In the general form of the risk equation, vulnerability is an indication of how much the facility or population would be *damaged or destroyed* based on the structural response to a particular hazard. In the context of this report, vulnerability is the likely damage resulting from various terrorist threats (weapon type and location). It is a measure of expected damage, outcome of the event, expected casualties, and loss of use, all features of the facility itself. Input into this factor typically comes from engineering analysis and expertise.

1 The proposed approach is consistent with the approach suggested by the TSA and with approaches currently used by entities that have completed or are performing risk assessments.

***I* = Importance:** Importance is a characteristic of the facility, not the hazard. In principle, importance is the same for any hazard. Importance is an indication of *consequences* to the region or nation in the event the facility is destroyed or unavailable. Is the facility on an evacuation or military mobilization route; is it likely to be used by first responders to emergencies; what is its historic and associated significance; what is its peak occupancy? Input into this factor typically comes from owners, operators, users, and beneficiaries of the facilities, often governmental sources, and will use factors similar to those used in the first tier prioritization.

This formula properly expresses the interaction among the three factors. Dominant factors magnify risk; negligible factors diminish it. Other formulas, such as models that add the factors, fail to account for their interactive effects. For example, in the absence of a threat (O=0), the risk should be zero as this model provides; additive models would have a residual risk. In the multiplicative model, eliminating any one factor to zero (or near zero) reduces the risk to near zero (e.g., low importance leads to low risk regardless of other factors).

The countermeasures that reduce the risk associated with an asset may be designed to reduce the occurrence factor (e.g., make the asset less accessible), the vulnerability factor (e.g., harden the facility to reduce damage), or the importance factor (e.g., add redundant facilities to reduce dependence on the asset)

Task Order DTFH61-06-T-70006

Table of Values

Task	2	3	4	5	6 50%	6 90%	6 100%	7 75%	7 100%	8 75%	8 100%
Start	15-Aug	15-Aug	15-Sep	1-Dec	1-Dec			1-Mar		1-Jun	
End	15-Dec	15-Dec	26-Jan	2-Mar	15-Feb	31-May	15-Aug	30-Jun	15-Sep	30-Jun	31-Aug
Total	$64,791	$104,006	$57,254	$95,450	$121,637			$77,843		$18,272	
Invoice											
31-Oct	25%	25%									
30-Nov	60%	60%	30%								
31-Dec	100%	100%	60%								
31-Jan			100%								
28-Feb				85%	35%						
31-Mar				100%							
30-Apr											
31-May						75%					
30-Jun								60%		60%	
31-Jul											
31-Aug							100%				100%
30-Sep									100%		

Milestone Schedule

TASK	RFP COMPLETION DATES	PROPOSED COMPLETION DATES
Notice to Proceed	September 1, 2006	September 1, 2006
Kickoff Meeting	2nd week in September 2006*	December 4,5,6, 2006
Task 2	December 15, 2006	December 15, 2006
Task 3	December 15, 2006	December 15, 2006
Task 4	January 26, 2007	January 26, 2007
Task 5	March 2, 2007	March 2, 2007
Task 6		
50% Draft Specification and Manual	December 31, 2006	February 15, 2007
90% Draft Specification and Manual	May 31, 2007	May 31, 2007
100% Draft Specification and Manual	August 15, 2007	August 15, 2007
Interim Report Tasks 2 to 6	July 15 2007	July 15 2007
Task 7		
Draft	June 30, 2007	June 30, 2007
Final	September 15, 2007	September 15, 2007
Task 8 – Executive Summary		
Draft 4 to 6 page summary	June 30, 2007	June 30, 2007
Final 4 to 6 page summary	August 31, 2007	August 31, 2007
Task 8 – 13 hour slides		
Draft	June 30, 2007	November 30, 2007
Final	September 30, 2007	January 31, 2008

THE AASHTO GUIDE METHOD

For Bridge, Tunnel, And Highway Infrastructure Terrorism-related Risk Management

Purpose of the AASHTO Guide

The Guide was developed as a tool for State DOTs to:

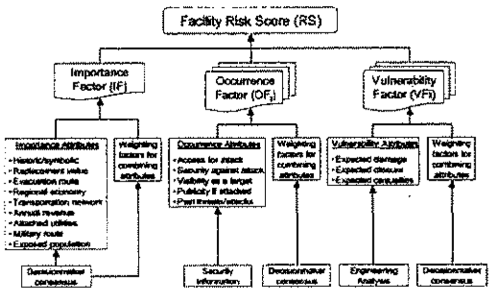
- Assess the vulnerabilities of physical assets such as bridges, tunnels, roadways, and inspection and traffic operation facilities
- Develop possible countermeasures to deter, detect, and delay the impact of threats to such assets
- Determine the capital and operating costs of such countermeasures
- Improve security operational planning for better protection against future acts of terrorism

AASHTO Guide Format

- "How to" Guide, not research report format
- Two volumes:
  1. *Guide*: Brief Introduction, methodology overview, six steps, and illustrative examples
  2. *Appendix*: Background, copies of worksheets, acronyms, bibliography, individuals contacted, and illustrative practices
- Six step methodology including:
  - Objective
  - Approach
  - Illustrative example

Components of Risk Management in Assessing an Individual Facility

(Ref: Blue Ribbon Panel on Bridge and Tunnel Security, FHWA/AASHTO, 2003)



Risk Management Orientation

(from seismic retrofit practice)

Risk = "Criticality" (a technical given) X Threat (an uncontrollable externality) X Vulnerability (controllable)

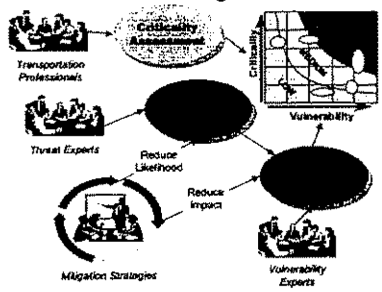
- Vulnerability = f {threat – countermeasures}
- Owner policy implications:
  - control risk with countermeasures
  - recognize cost/risk trade-offs

Risk Assessment Typically Occurs in 3 Major Phases:

1. Pre-Assessment
2. Assessment
3. Post-Assessment

Phase 1: Pre-Assessment

Assemble the risk management team



Phase 1: Pre-Assessment

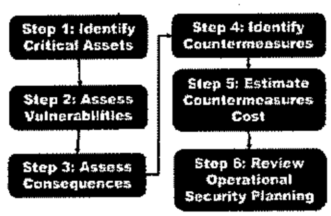
- Conduct team training exercises
- Make contact with external organizations
- Plan and schedule the risk management process
- Collect the required resources

Required Resources and Level of Commitment

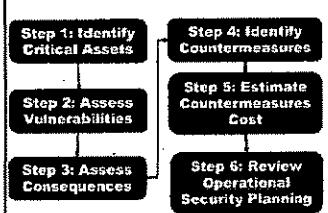
- Asset Data
  National Bridge Inventory System
  Hydrologic Data
- Threat Data
  Meteorologists
  Seismologists
  Coastal Flood Experts
- Vulnerability Data
- Consequence Data
- Countermeasures Data
- Cost Data
- Policies, Plans, and Procedures
- Personnel (interviews)
- Geographic Information Systems (maps, drawings)

Phase 2: Assessment

Conduct Steps 1 to 3 of Risk Management



Phase 3: Post-Assessment



- Conduct Steps 4 to 6
- Develop a strategy for implementing the recommended countermeasures:
  - Cost-benefit analyses
  - Trade-off studies
  - Procuring equipment and services

Overview of the 6 Step AASHTO Risk Management Process

Step 1 - Critical Asset Identification *Objectives*

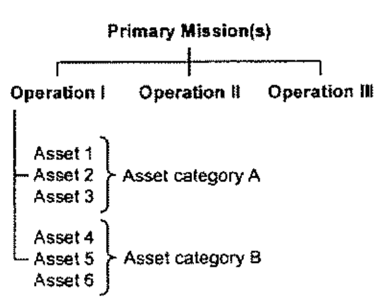
- Produce prioritized list of highway transportation assets for vulnerability analysis and countermeasures evaluation
- Provide consistent, repeatable, credible, well-documented process with complete audit trail of individual and collective judgments
- Ensure that domain expertise is leveraged efficiently

Step 1a – Create an all-inclusive list of critical assets

- "Which assets enable us to achieve our mission?"
- Critical transportation assets fall into 4 categories:

INFRASTRUCTURE	*FACILITIES*	*EQUIPMENT*	*PERSONNEL*
• Arterial Roads • Interstate Roads • Bridges • Overpasses • Barriers • Roads Upon Dams • Tunnels	• Chemical Storage Areas • Fueling Stations • Headquarters Buildings • Maintenance Stations/Yards • Material Testing Labs • Ports of Entry • District/Regional Complexes • Rest Areas • Storm Water Pump Stations • Toll Booths • Traffic Operations Centers • Vehicle Inspection Stations • Weigh Stations	• Hazardous Materials • Roadway Monitoring • Signal & Control Systems • Variable Messaging System • Vehicles • Communications Systems	• Contractors • Employees • Vendors • Visitors

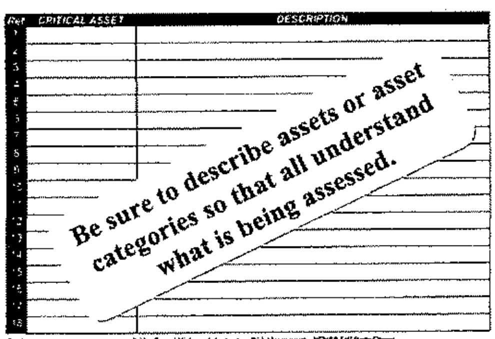
Critical Asset Relationships



Observations About Candidate Critical Assets

- Group similar assets into a single asset category where all of the individual assets have similar physical and functional characteristics and would likely require similar countermeasures.
- Define assets at the greatest level that would be destroyed during an attack.
- Recognize that your mission goes beyond simply operating and maintaining the physical assets that you own and operate.

Candidate Critical Asset List



Step 1b – Critical Asset Factors

- Factors should be relevant to the location and circumstances and represent a team perspective.
- Focus on identifying the minimum set of Critical Asset Factors that will address major concerns.
- Factor values or weights should reflect the priorities and concerns of the area or region.
- Critical Asset Factors and the values they are assigned should remain constant throughout the vulnerability assessment; changes will require a re-evaluation of critical assets.

Step 1b – Establish Critical Asset Factors

"What are the factors that would cause an asset to be critical to the successful performance of our mission?"

- *Deter/Defend Factors*
  - A. Ability to Provide Protection
  - B. Relative Vulnerability to Attack
- *Loss and Damage Consequences*
  - C. Casualty Risk
  - D. Environmental Impact
  - E. Replacement Cost
  - F. Replacement/Down Time
- *Consequences to Public Services*
  - G. Emergency Response Function
  - H. Government Continuity
  - I. Military Importance
- *Consequences to the General Public*
  - J. Available Alternate
  - K. Communication Dependency
  - L. Economic Impact
  - M. Functional Importance
  - N. Symbolic Importance

Step 1b – Weight Critical Asset Factors

	Critical Asset Factor	*Value*
A.	Ability to Provide Protection	1
B.	Relative Vulnerability to Attack	2
C.	Casualty Risk	5
D.	Environmental Impact	1
E.	Replacement Cost	3
F.	Replacement/Down Time	3
G.	Emergency Response Function	5
H.	Government Continuity	5
I.	Military Importance	5
J.	Available Alternate	4
K.	Communication Dependency	1
L.	Economic Impact	5
M.	Functional Importance	2
N.	Symbolic Importance	1

1. Minimally important to our mission
2. Little importance to our mission
3. Moderate importance to our mission
4. Very important to our mission
5. Critical to the success of our mission

Modified Critical Asset Factor List

Critical Asset Factor	*Factor Value*	*Brief Description*
Casualty Impact		The potential for loss of or serious injury to human life associated with an attack on the asset, both internal and external (e.g. due to an explosion, chemical attack, or catastrophic failure/collapse of the asset)
Economic Impact		The extent to which loss of and/or serious damage to the asset (including secondary effects) would affect the livelihood, resources, or wealth of individuals and businesses in the area, state, region, country, or around the world
Emergency Response Function		The role the asset plays in emergency response, either in direct services or in enabling access to emergency services, including gaining access to affected locations and evacuating people from affected locations.
National Strategic Importance		The contribution that the asset makes to maintaining national and regional security and government continuity
Business Continuity		The extent to which loss of and/or serious damage to the asset would adversely impact the ability of the owner or operator to continue to provide services and maintain needed command and control.
Replacement Cost		The capital investment required to replace the asset, including related site restoration/preparation, construction, and related replacement and repairs to support infrastructure
Environmental Impact		The acute and/or chronic effects (including secondary effects) loss of the asset would have on the environment resulting in significant property damage due to toxic substances or destruction of protected areas

Step 1c – Prioritize the all-inclusive list of critical assets

- Enter the critical asset values (0 or 1) into the table and calculate the total score for each asset
- The total score (x) will be used to calculate the criticality of each asset (X) in step 3
- Apply a screening threshold to determine the most critical assets

CRITICAL ASSET	CRITICAL ASSET FACTOR														TOTAL SCORE (x)
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
Asset 1															
Asset 2															
Asset 3															
Asset n															

Illustrative "Upper Bound"Conditions for Applying Factors to Assets

LABEL	FACTOR	CRITERIA FOR APPLYING FACTOR TO ASSETS
A	Casualty impact	Casualties (deaths and injuries) likely to exceed X people
B	Economic impact	Economic impact is national and long-term resulting in business failures, significant job losses, and market downturns
C	Emergency response functions	Major (hours) delays or impediments to emergency response functions either due to loss of critical response assets, risks to emergency response personnel, or loss of critical evacuation routes or methods
D	National Strategic Importance	Significant potential loss of assets needed to support military deployment or execution of military operations resulting in concerns about national security, significant potential for loss of government continuity of operations resulting from loss of asset and/or related secondary effects
E	Business Continuity	Loss of all or significant portion of assets and capabilities needed to carry out the mission of transporting goods and/or people within, through, or to/from the region
F	Replacement cost	Replacement cost in excess of $x
G	Environment impact	Acute and/or chronic environmental damage resulting significant property damage due to toxic substances or destruction of protected areas, including long-term (years) or permanent closure of facilities or tracts of land.

Step 2b: Assign vulnerability factors to the critical assets

VULNERABILITY FACTOR	DEFINITION
Visibility and Attendance	Awareness of the existence of the asset and the number of people typically present
Access to the Asset	The availability of an asset to ingress and egress by a potential threat element
Site Specific Hazards	The presence of materials that have biological, nuclear, incendiary, chemical, or explosive properties in quantities that would expend initial response capabilities if compromised

Step 2b – Assign vulnerability factors to the critical assets

	VULNERABILITY FACTOR and DEFAULT VALUE		DEFINITION
Visibility and Attendance	LEVEL OF RECOGNITION (A)	1	Largely invisible in the community
		2	Visible by the community
		3	Visible Statewide
		4	Visible Nationwide
		5	Visible Worldwide
	ATTENDANCE/ USERS (B)	1	Less than 10
		2	10 to 100 (Major incident per FEMA)
		3	100 to 1000
		4	1000 to 5000
		5	Greater than 5000 (Catastrophic incident per FEMA)
Access to the Asset	ACCESS PROXIMITY (C)	1	Asset with no vehicle traffic and no parking within 50 feet
		2	Asset with no unauthorized vehicle traffic and no parking within 50 feet
		3	Asset with vehicle traffic but no vehicle parking within 50 feet
		4	Asset with vehicle traffic but no unauthorized vehicle parking within 50 feet
		5	Asset with open access for vehicle traffic and parking within 50 feet
	SECURITY LEVEL (D)	1	Controlled and protected security access with a response force available
		2	Controlled and protected security access without a response force
		3	Controlled security access but not protected
		4	Protected but not controlled security access
		5	Unprotected and uncontrolled security access
Site Specific Hazards	RECEPTOR IMPACTS (E)	1	No environmental or human receptor effects
		2	Acute or chronic toxic effects to environmental receptor(s)
		3	Acute and chronic effects to environmental receptor(s)
		4	Acute or chronic effects to human receptor(s)
		5	Acute and chronic effects to environmental and human receptor(s)
	VOLUME (F)	1	No materials present
		2	Small quantities of a single material present
		3	Small quantities of multiple materials present
		4	Large quantities of a single material present
		5	Large quantities of multiple materials present

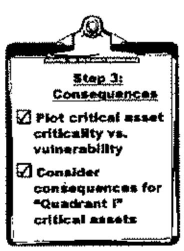
Step 2c – Score the vulnerability factor for each critical asset

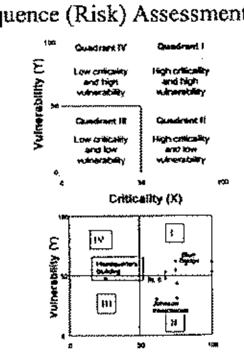
- Calculate the vulnerability factor (y) which will be used to calculate the vulnerability coordinate (Y) in Step 3

$$(y) = (A*B) + (C*D) + (E*F)$$

CRITICAL ASSET	VULNERABILITY FACTOR											TOTAL SCORE (y)
	(A)	*	(B)	+	(C)	*	(D)	+	(E)	*	(F)	
	1-5	*	1-5	+	1-5	*	1-5	+	1-5	*	1-5	
Asset 1												
Asset 2												
Asset 3												
Asset 4												
Asset n												

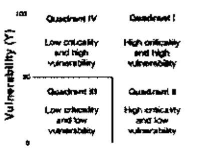
Step 3 – Consequence (Risk) Assessment





Step 3a – Plot critical asset criticality versus vulnerability

- Calculate the criticality (X) and vulnerability (Y) coordinates for each quadrant using x and y values derived in Steps 1 and 2



$X = \text{Criticality} = (x/C_{max}) * 100$

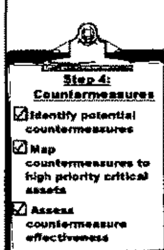
$Y = \text{Vulnerability} = (y/75) * 100$

- Cmax is the maximum possible Criticality value (Cmax = 43 for the default values in Step 1)

Step 3b – Consider consequences for Quadrant 1 critical assets

- Begin with assets in the upper right corner of the matrix and work toward the origin.
- Review what makes Quadrant I assets critical and vulnerable, paying particular attention to the consequences associated with the loss of these assets.
- Use this information in the next step to assist in identifying appropriate countermeasures.

Step 4 - Countermeasures



Example: Maryland's Countermeasures

- Built-in monitors on bridges
- Motion detection devices below bridges
- Increased armed security
- Regular checking of truck traffic
- Application of X-ray technology
- Improved training for toll collectors and other tunnel personnel
- Enforcement of HAZMAT requirements
- Increased lighting
- CCTV cameras for surveillance
- No-fly zones around bridges
- Suspension cable protection
- Patrol boats under and around bridges

Example: Texas's Potential Countermeasures for Bridges

- Eliminate parking areas beneath bridge
- Restrict ingress and egress routes from adjacent areas
- Provide additional lighting
- Limit/monitor access to plans of existing bridges
- Install motion sensors or other active sensors
- Install surveillance cameras
- Apprise local law enforcement officials of critical bridges
- Provide column protection
- Provide pass-through in concrete median barriers
- Install advance warning system

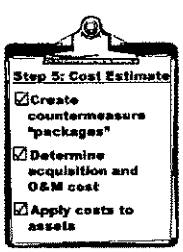
Step 4b – Map countermeasures to high-priority critical assets

- Using the countermeasures in Step 4a, along with countermeasures determined by the team, map the countermeasures to the critical assets falling into Quadrant 1

Step 4c – Assess countermeasure effectiveness

- Assesses how well the application of the countermeasure reduces either the potential for or consequences of attacks on assets given specific threats and vulnerabilities
- After applying countermeasures, re-score Steps 1 and 2 to determine whether or not the proposed countermeasures shift the consequences (Step 3) into a lower quadrant

Step 5 - Cost Estimation



COUNTERMEASURE DESCRIPTION (Partial List)	COUNTERMEASURE FUNCTION			ESTIMATED RELATIVE COST (H/M/L)		
	Deter	Detect	Defend	Capital	Operating	Maintenance
Increase inspection efforts aimed at identifying potential explosive devices as well as increased or suspicious potential criminal activity.	✓			L	L	L
Institute full-time surveillance at the most critical assets where alternate routes are limited or have not been identified.	✓	✓		H	H	H
Eliminate parking under any of the most critical type bridges. Elimination of the parking can be accomplished through the use of concrete barriers.	✓			L	L	L
Place barriers in such a way as to eliminate areas of access where a vehicle could be driven right up to the asset.	✓		✓	L	L	L
Install security systems with video capability at all DOT facilities.	✓	✓		H	M	L

Step 5a – Create countermeasure "packages"

- In many cases, combinations of countermeasures will needed to achieve the desired vulnerability reduction
- Package countermeasures in ways that make sense operationally and from a vulnerability reduction perspective
- Once viable packages are identified, their unit costs should be determined using standard life cycle costing methods

Step 5b - Determine acquisition, operation, and maintenance cost of proposed countermeasures

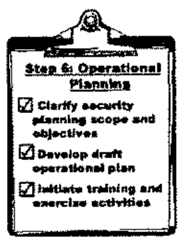
- The guide provides a tool for assigning preliminary costs to each countermeasure listed. The ranges are subjective and depend on many variables

	Sample Countermeasure Relative Cost Range		
	Capital Investment	Annual Operating Cost	Annual Maintenance Cost
L	<$100K	<$50K	<$25K
M	$100K to $500K	$50K to $250K	$25K to $100K
H	>$500K	>$250K	>$100K

Step 5c – Apply costs to assets

- State DOTs can group the assets by type (similar to the categories listed in Step 1) and extend the unit price for the appropriate countermeasures to the number of critical assets in each category

Step 6 – Security Operational Planning



- 6a – Clarify security planning scope and objectives
- 6b – Develop a security operational plan
- 6c – Initiate training and exercise activities

Risk Management for Terrorist Threats to Bridges and Tunnels

Risk Management

Risk Equation

Risk Management

Risk Equation

❖ $R = O * V * I$

- R = Risk
- O = Occurrence
- V = Vulnerability
- I = Importance

Risk Management

Occurrence Factor

- Occurrence – Likelihood of a threat occurring against a component
  - General likelihood of threat happening
  - Likelihood of threat being used against component
  - Target attractiveness
  - Access to component

Risk Management

Vulnerability Factor

- Vulnerability – Resistance of a component to a threat

Risk Management

Importance Factor

- Importance – Importance of the component to the bridge
  - Structural
  - Historic / symbolic
  - Repair cost
  - Time out of service

Risk Management

Risk Equation

- Unique to each component for each threat
- $R_{i,j} = O_{i,j} * V_{i,j} * I_j$
  - i = threat
  - j = bridge component

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Process

- Identify components
- Identify weighting factors
- Identify occurrence factors
- Identify vulnerability factors
- Identify importance factors
- Calculate risk

U.S. Department of Transportation Federal Highway Administration — Risk Management — ERDC

Process (con't)

- Identify mitigation strategies
- Reevaluate occurrence and vulnerability factors
- Recalculate risk
- Compare risk from baseline to one with mitigation

U.S. Department of Transportation Federal Highway Administration — Risk Management — ERDC

Threats

Types of Threats

- Explosive
  - Vehicle-Bourne Improvised Explosive Device (VBIED)
  - Hand-Emplaced Improvised Explosive Device (HEIED)
- Non-Explosive
  - Non-Explosive Cutting Device (NECD)
  - Vehicular Impact
  - Fire

Risk Equation

- $R_{i,j} = O_{i,j} * V_{i,j} * I_j$
  - R = Risk
  - O = Occurrence
  - V = Vulnerability
  - I = Importance

$+b^2=c^2$

Risk Equation

❖ $R_{i,j} = O_{i,j} * \mathbf{V}_{i,j} * I_j$

- R = Risk
- O = Occurrence
- **V = Vulnerability**
- I = Importance

Risk Management

Vulnerability

❖ $V_{i,j}$ – relative vulnerability of a given component, *j*, given the occurrence of the threat, *i*

- Software available to help get this information
  - BlastX (Army Corps of Engineers)
  - BEL (FHWA)

Risk Management

Vulnerability – VBIED

❖ VBIED for component destruction

- 1.00 = ≤ 500 lb
- 0.90 = 501 – 3,000 lb
- 0.50 = 3,001 – 5,000 lb
- 0.30 = 5,001 – 10,000 lb
- 0.10 = 10,001 – 30,000 lb
- 0.05 = 30,001 – 60,000 lb
- 0.00 = N/A or can withstand above

Risk Management

Vulnerability – HEIED

- HEIED for component destruction
  - 1.00 = ≤ 5 lb
  - 0.95 = 6 – 10 lb
  - 0.70 = 11 – 50 lb
  - 0.20 = 51 – 100 lb
  - 0.10 = 101 – 500 lb
  - 0.05 = > 500 lb
  - 0.00 = N/A or can withstand above

Vulnerability – NECD

- Time to sever component
  - 1.00 = < 30 seconds
  - 0.50 = 30 – 60 seconds
  - 0.10 = 1 – 3 minutes
  - 0.05 = > 3 minutes
  - 0.00 = N/A or can withstand above

Vulnerability – Vehicle Impact

- Vehicle size for component destruction
  - Land-based vehicles
    - 1.00 = Car or SUV
    - 0.75 = Panel van (H-20)
    - 0.50 = Semi-truck (HS-20)
    - 0.00 = N/A or can withstand above

Vulnerability – Vehicle Impact

- Vehicle size for component destruction
  - Water-based vehicles
    - 1.00 = Small vessel
    - 0.75 = Typical vessel
    - 0.50 = Large vessel
    - 0.00 = N/A or can withstand above

Risk Management

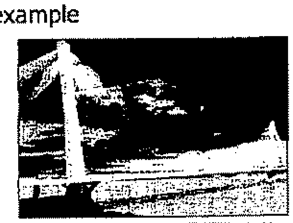
Vulnerability – Fire

- Time for component to lose strength
  - 1.00 = < 5 minutes
  - 0.75 = 5 – 10 minutes
  - 0.50 = 11 – 15 minutes
  - 0.25 = 16 – 30 minutes
  - 0.00 = N/A or can withstand above

Risk Management

Exercise

- Determine the vulnerability factors for the example



Risk Management

Risk Equation

- $R_{i,j} = \mathbf{O_{i,j}} * V_{i,j} * I_j$
  - R = Risk
  - **O = Occurrence**
  - V = Vulnerability
  - I = Importance

$+b^2 = c^2$

Occurrence

- $O_{i,j}$ – relative probability of a threat, *i*, actually occurring a against a given component, *j*
- Attributes
  - General likelihood of threat happening
  - Likelihood of threat being used against component
  - Target attractiveness
  - Access to component

Occurrence

- $O_{i,j} = \Sigma(wf_k * a_k)$
  - wf = weighting factor
  - a = attribute

$+b^2 = c^2$

General Likelihood of Threat Happening

- Likelihood that terrorists prefer this type of threat
- Ask "How likely are terrorist to use this threat in your region?"
- Based on counter-terrorism intelligence
- Same regardless of component under consideration
- Weighting factor = 0.10

Risk Management

General Likelihood of Threat Happening

- 1.00 = Very likely
- 0.75 = Likely
- 0.50 = Somewhat likely
- 0.25 = Slightly likely
- 0.00 = Not likely

Risk Management

Likelihood of Threat Being Used Against Component

- If component is attacked, likelihood that this type of threat would be used
- Ask "How likely would a terrorist use threat to destroy this component?"
- Do not consider access
- Do not consider required threat
- Weighting factor = 0.25

Risk Management

Likelihood of Threat Being Used Against Component

- 1.00 = Very likely
- 0.75 = Likely
- 0.50 = Somewhat likely
- 0.25 = Slightly likely
- 0.00 = Not likely

Risk Management

Target Attractiveness

- Likelihood that terrorist will recognize that component is critical to structural stability
- Ask "How attractive is this component to the bridge?"
- Independent of threat type
- Weighting factor = 0.10

Risk Management

Target Attractiveness

- 1.00 = High
- 0.75 = Medium
- 0.50 = Low
- 0.25 = Very low
- 0.00 = Not attractive

Risk Management

Access to Component

- Ease of getting threat in the vicinity of the component
- Ask "How easy is it to get to the component before a capable response occurs?"
- Access time vs. response time
- Do not consider time to carry out attack
- Do not consider standoff distances
- Weighting factor = 0.55

Access to Component

- 1.00 = Completely accessible, RT » AT
- 0.75 = RT probably > AT
- 0.50 = RT ≈ AT
- 0.25 = RT probably < AT
- 0.00 = Completely denied, RT « AT

- RT = Response time   AT = Access time

Risk Management

Mitigation

- Implement measures which are appropriate and effective for a particular risk, yet economical and do not interfere with a bridge's operation

Risk Management ERDC

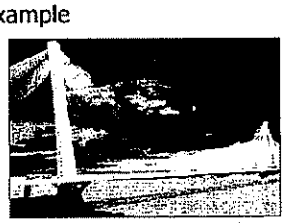
Defense Priority

- First priority
  - Prepare to respond and recover
- Second priority
  - Deter, deny, detect
- Third priority
  - Defend with standoff
- Fourth priority
  - Defend with structural hardening

Risk Management ERDC

Exercise

- Determine the mitigated relative risk for the example



Risk Management ERDC

Risk Management for Terrorist Threats to Bridges and Tunnels

by Shay K. Burrows, P.E[1]. and Steven L. Ernst, P.E.[2]

Introduction

Bridges and tunnels are vulnerable to terrorist threats. Military tacticians have for centuries used available technology to destroy or preserve vital crossings, commercial demolition experts routinely demonstrate the effectiveness of explosives to remove structures, and a captured Al-Qaeda training manual shows ways to destroy bridges with improvised devices. Though this vulnerability is well-understood, what is less well known is the answer to this question: What do we do to protect a vulnerable transportation system that is so important to the local, national and world economy?

The Federal Highway Administration (FHWA) began to answer this question shortly after the attacks of September 11, 2001 through a cooperative effort with the US Army Corps of Engineers (USACOE). The USACOE leveraged years of experience with military munitions and tactics for using explosives to destroy bridges to establish a foundation for how to make structures more resistant to attacks.

There are five components to an effective defense that prevents bridges from being attacked or enables them to survive an attack. Owners must first prepare to respond and recover from a potential attack. This requires working with police departments and fire departments, operation centers, maintenance personnel, engineers, and others. With this preparation in-hand, owners can start thinking on the four "Ds" of defense; Deter, Deny, Detect, and Defend. Here are some examples:

- Deter – make the terrorists know you are watching. Install visible security measures, such as CCTV cameras, signs, etc., provide routine security patrols, and improve visibility of critical locations with adequate lighting and by removing vegetation and other obstructions.

- Deny – don't allow access to critical locations. Secure access hatches and doorways, provide area control with fencing or bollards, and prevent explosives from being placed in small inconspicuous locations.

- Detect – catch them in the act. Install and monitor CCTV cameras and intrusion alarms.

- Defend – prevent a progressive collapse from an attack. Provide sufficient "stand off" distance to critical locations or improve member redundancy with hardening or adding additional load paths. Stand-off can be achieved

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permanently or temporarily during an elevated threat level or specific threat against the bridge.

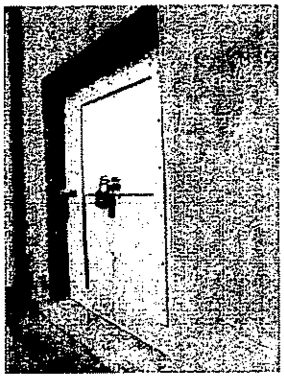


Figure 1: Secured access hatch

Figure 2: Fencing to deny access to critical locations

Figure 3: Bollards to provide permanent stand-off

Because protective measures are expensive, it is essential to have a cost-effective approach to manage the risk in an environment of multiple hazards. Component-level risk management provides a way to analyze the impact of the security threats to vulnerable bridge components and help the owner focus spending on those low-cost improvements most likely to reduce risk. The goal is to manage risk, understanding that it is not possible to entirely eliminate risk from terrorists whose goal is to create catastrophic economic and social consequences.

Component-level Risk Management

This component-level risk management methodology is founded on the basic risk equation used for other extreme events; Risk = Occurrence x Vulnerability x Importance, or R=OVI. There are six steps needed to complete this analysis and determine a base risk for each component.

1. Identify the critical bridge
2. Assemble a project team
3. Compile the threats
4. Identify the bridge's components
5. Quantify occurrence, vulnerability, and importance factors
6. Calculate the base risk

1. Identify the critical bridge. The bridge under consideration should be deemed by the owner to be critical. That means that a risk analysis such as the AASHTO method[3] has

[3] American Association of State Highway and Transportation Officials (AASHTO), 2002, *A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection*, prepared by SAIC, Washington, DC. Available online at www.transportation.org.

determined that this facility is at high risk relative to other assets, considering such factors as loss of life, economic consequences including user cost and replacement cost, threat assessment, and general vulnerability.

2. Assemble a project team. A multi-disciplinary project team is necessary to perform a component-level analysis and requires experts in bridge design, maintenance, and construction, emergency response professionals (fire, police, and rescue), blast and weapons-effect designers, threat assessment experts, local, state and federal government stakeholders, and others who might provide information or analysis. The team must gather and analyze data from sources such as inspection and maintenance records, traffic studies, design drawings, load rating calculations, and emergency response capability and response times. The data will be supplemented with information gained from site visits and interviews with responders and users. This detailed information will help the team determine values for the threats to each component, the vulnerability of each component to every possible threat, and the importance of each component to the structure.

3. Compile the threats. Not all threats are effective to destroy a bridge component or to damage it sufficiently to cause instability leading to a bridge failure, and some threats, such as airplane impact or military weapon attack are very difficult to prevent or protect against. Only those threats that are controllable, plausible, and serious enough to cause catastrophic damage should be considered in this methodology. The terrorist threats we consider are: Vehicle- or vessel-borne improvised explosive devices (VBIED), hand-emplaced improvised explosive devices (HEIED), non-explosive cutting devices (NECD), vehicle or vessel impact (VI), and fire. Other threats can be added depending on site-specific threat information.

4. Identify the bridge's components. The team must determine which components are important using engineering analysis done by design experts who must determine collapse mechanisms and conditions that may keep a bridge out of service for and extended time. For this determination, the design expert should involve all stakeholders to define the degree of risk that is acceptable. One might ask the question, "Should we consider damage that causes no collapse or should we set the threshold at easily repairable damage?"

It may be necessary to consider components more than one time, based on location, function, traffic configuration or other considerations. Consider a stay cable for example. At deck level the stay cable is exposed to vehicular traffic, but at the connection to the tower, it is far away from and relatively invulnerable to a vehicle bomb. Because the total risk to the cable will be different based on location, the analysis requires separate components for the cable at these two locations. Applying this concept over the entire bridge will result in many components to be matched against every threat.

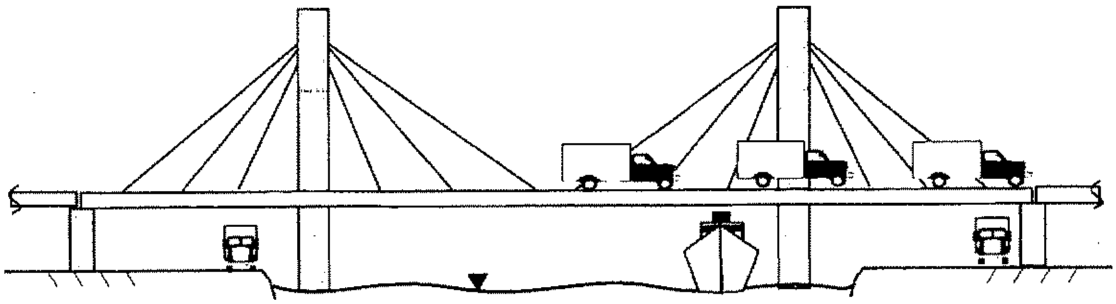


Figure 4: Example bridge showing components to consider

5. Quantify occurrence, vulnerability, and importance factors. The occurrence (O), vulnerability (V), and importance (I) factors can be related to the threats considered, the components identified, or a combination of both. The occurrence factor captures the likelihood of each threat being used to attack each component. The vulnerability factor is a measure of the resistance of each component to each threat under consideration. The importance factor captures the importance of the component to the bridge, structurally, historically, and due to its cost and time to repair. Each of the values for O, V, and I is a number between 0 and 1.

6. Calculate the base risk. Multiplying the O, V, and I factors together will determine the base risk (R) for each component and threat combination. Its value will also be a value between 0 and 1. It is important to note that risk can never be entirely eliminated (it cannot be 0), though it can be very low. Also, the base risk score is not a determination of absolute risk, rather it can be used to measure relative risk. The combinations that result in the highest scores are at more risk than the ones with lower scores.

Mitigation

It is reasonable to concentrate protective measures on those things that can reduce the scores for those components at highest risk. Mitigation schemes are applied one at a time, the values that contribute to the risk score are re-evaluated, and a new, mitigated risk score is calculated. The difference between the base risk scores and the mitigated risk scores provides an indication of the relative risk reduction and a measure of benefit from the mitigation measures. This process is done for each protective measure and for reasonable combinations of measures. It is also critical to have good estimates of the cost for each proposed mitigation, so that the benefit from risk reduction can be compared to this cost. It is not reasonable to reduce risk at exorbitant cost. One aim might be to level the risk scores using less expensive measures.

In the end, only the owner can decide how much risk to accept and how much money should be invested to protect against terrorism. These investments must be considered along with multiple hazards that may impact their infrastructure, and this methodology provides a way to prioritize for decision-makers a reasonable list of projects and objectives to be included in a spending program. Owners must consider these options in the context of their strategic agenda and within constraints of political and social agendas, understanding that some risk must be accepted and managed.

Acknowledgments

The component-level method described in this article was developed through the efforts of many engineers, threat experts, major bridge owners and operators under the direction of the USACOE. The authors would like to thank the USACOE Engineer Research and Development Center (ERDC) and the USACOE Design Protective Center for their efforts to produce this methodology. Special thanks is extended from the Federal Highway Administration to James C. Ray at ERDC, whose unpublished technical paper forms the basis for the methodology.

Bibliography

American Association of State Highway and Transportation Officials (AASHTO), 2002, *A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection*, prepared by SAIC, Washington, DC.

American Association of State Highway and Transportation Officials (AASHTO), 2003, *Recommendations for Bridge and Tunnel Security*, prepared by the Blue Ribbon Panel on Bridge and Tunnel Security, Washington, DC.

Federal Highway Administration (FHWA), 2006, *First Responder Awareness for Terrorist Threats to Bridges and Tunnels Workshop*, Instructor's Manual.

Federal Highway Administration (FHWA), 2006, *Risk Management to Terrorist Threats to Bridges and Tunnels Workshop*, Instructor's Manual.

Ragsdale, C.T., *Spreadsheet Modeling and Analysis*, Fourth Edition, Thomson South-Western.

Ray, James, 2005, "*Risk Based Prioritization of Terrorist Threat Mitigation Measures on Bridges*," unpublished report.

Sidebar

The Federal Highway Administration has developed two security workshops; one to raise awareness of terrorist threats to bridges and tunnels and another on risk management. These workshops are targeted to State highway agencies and other bridge and tunnel owners. The Risk Management for Terrorist Threats to Bridge and Tunnels workshop is 1 1/2 –days long and is designed to give engineers and managers the understanding to develop a cost-effective risk management plan for a structure using a component level analysis. More specifically, students will learn to identify strengths and weaknesses of bridge and tunnel components, the damage to be expected for terrorist threats, and how to analyze the risk of each component to a specific threat. The First Responder Awareness to Terrorist Threats for Bridges and Tunnels workshop is 1/2–day long and is designed to give "First Responders", such as law enforcement personnel, inspectors, and other emergency responders, an overall awareness of terrorist threats and structural vulnerabilities.

Contact Shay Burrows at (410) 962-6791 or shay.burrows@dot.gov and Steve Ernst at (202) 366-4619 or steve.ernst@dot.gov for more information.

Attachment B

Revised Meeting Agenda

<u>Tentative Schedule for Dec. Kickoff Meeting</u> (11-30-06)

When: Dec 4, 5 & 6– to be finalized next week
Where: Gainesville – FDOT will supply vans and meeting room for one day
Contact person in Wm's office: Linda Ryan (Linda.ryan@dot.state.fl.us)

~~Dec 4 – Team meeting~~

~~1:30 – 5:30 PT Meets~~
- ~~Scope adjustments~~
- ~~Discussion of K and W methods~~
- ~~Other candidates?~~
- ~~Basis for a choice~~
- ~~Further define roles and responsibilities~~

<u>Dec 5 –Joint Meeting</u>

8:30 -12 Combined meeting
- Introductions
- Review of minutes from last meeting
- Presentation on Risk Analysis by Steve Ernst of FHWA
- Coastal Eng 101
- Intro to wave tank visit - Max
- Possible basis for design cases – Jeff and all

12 -1 Lunch
1PM Leave for U of F wave Tank
3:30 Return to meeting
- How does project fit in big picture? What is already available?
- What other work is underway at state and federal level?
- Philosophy
- Review of progress on related FDOT projects.- Max and Dennis
- Task Force presentations
- Progress on Tasks 2,3, 4 and 6
  - Status of Lit Survey and Damage Types – JMK
  - Wave loads – JMK, Max, Jeff
    - Basis of decision
    - Wallingford, Douglas and Modified Kaplan
    - Test matrix
  - Screening Process Update
  - Review Retrofit Manual Outline
  - Retrofit concepts – Wagdy
  - Cost effectiveness memo by Mike Knott – reported by Jeff

5:00 Adjourn

<u>Dec 6</u>

8-4:30 Meet with TF
- Continue progress on Tasks 2,3 and 4 - continued

- TF feed back and direction
- Scope/Work Plan
- Expectations
- Products
- Set date for next combined meeting

Attachment C

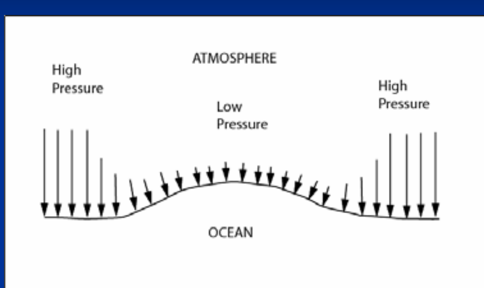
Dr. Sheppard's Presentation on:
Terms and Definitions

Background

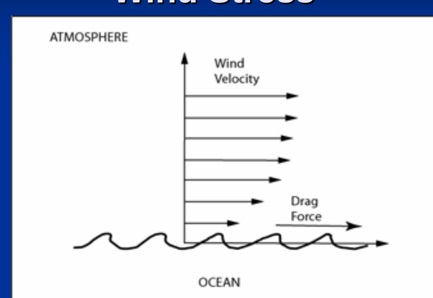
- Storm Surge
- Wind Setup
- Wind Waves
- Wave Loading

Storm Surge

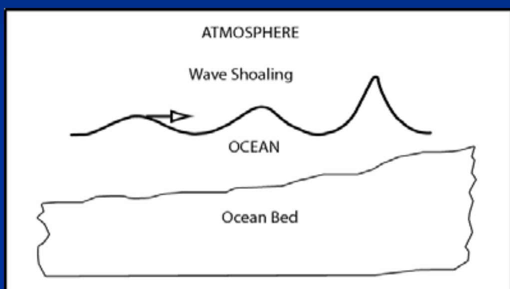
Storm Surge Mechanisms
Low Pressure



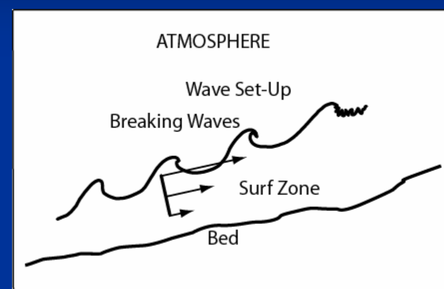
Storm Surge Mechanisms
Wind Stress



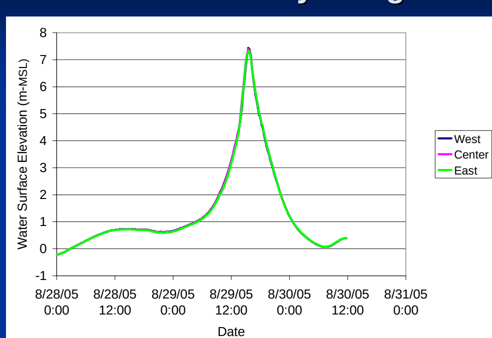
Storm Surge Mechanisms
Wave Shoaling



Storm Surge Mechanisms
Wave Setup

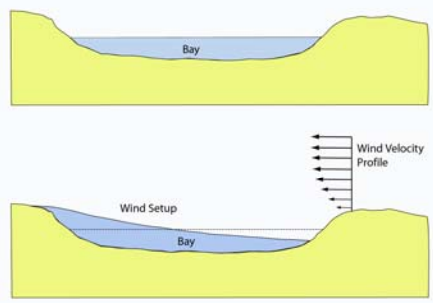


Katrina Storm Surge
Saint Louis Bay Bridge



Wind Setup

Wind Setup



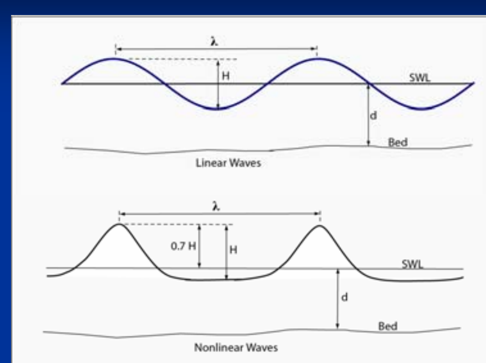
Wind Setup in a Bay

Wind Waves

Wind Generated Waves

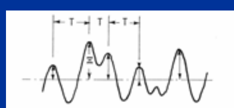
- Definitions:
  - Wave Height – Distance from trough to crest
  - Significant Wave Height – Average height of 1/3 highest waves
  - Wave Period – Time required for one wave to pass a fixed point
  - Peak Period – Period of waves with most energy

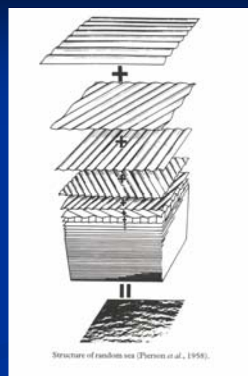
Wind Generated Waves



Wind Generated Waves

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





Wind Waves

Height and Period (Length) Depend on:

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

Wave Height Limitations

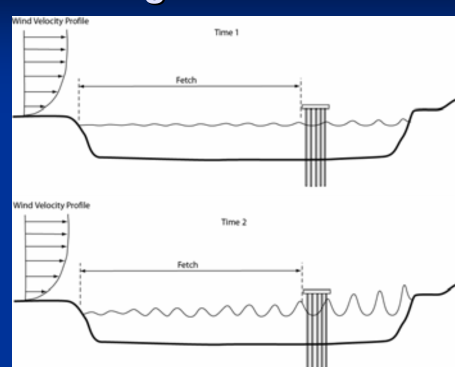
- Water Depth:

  $H \le 0.7\, d_s$

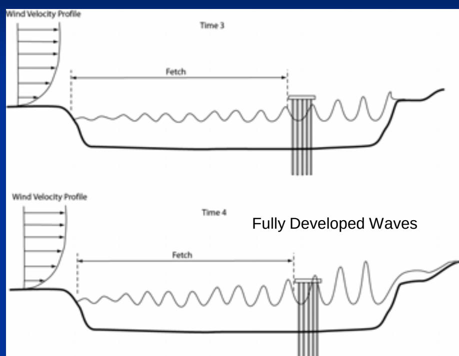
- Wave Steepness

  $H \le 0.020\, g\, T^2\, [\tanh(kd_s)]^2$

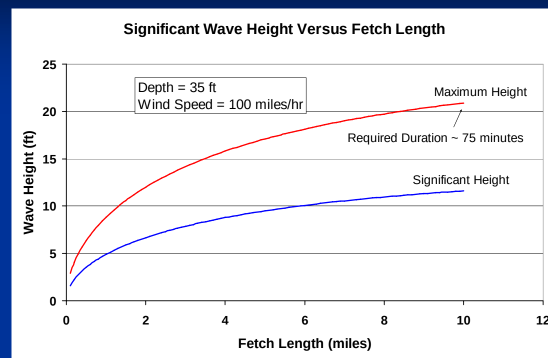
Fetch Length – Wind Duration



Fetch Length – Wind Duration



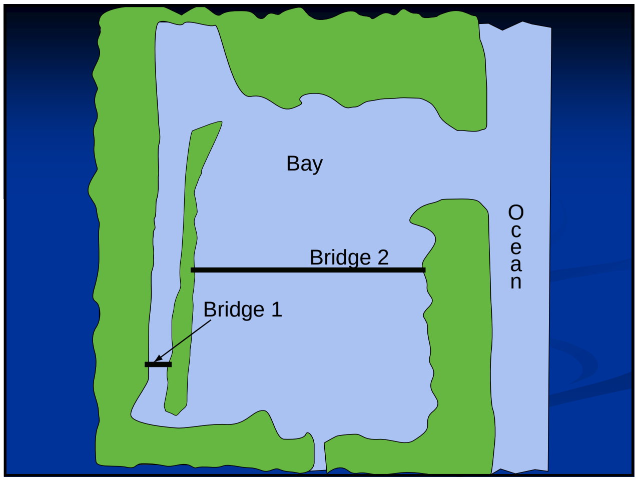
Influence of Fetch Length

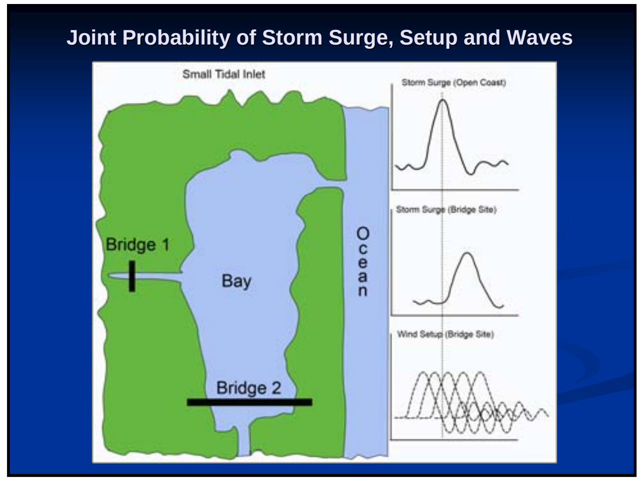


Water Level - Wave Parameter Issues

Water Level - Wave Parameter Issues

- Design Event
  - Storm surge
  - Wind setup
  - Wave height and period
- Joint Probability
- SITE SPECIFIC


Bay
Bridge 2
Bridge 1
Ocean


Joint Probability of Storm Surge, Setup and Waves
Small Tidal Inlet
Storm Surge (Open Coast)
Storm Surge (Bridge Site)
Wind Setup (Bridge Site)
Bridge 1
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Bridge 2
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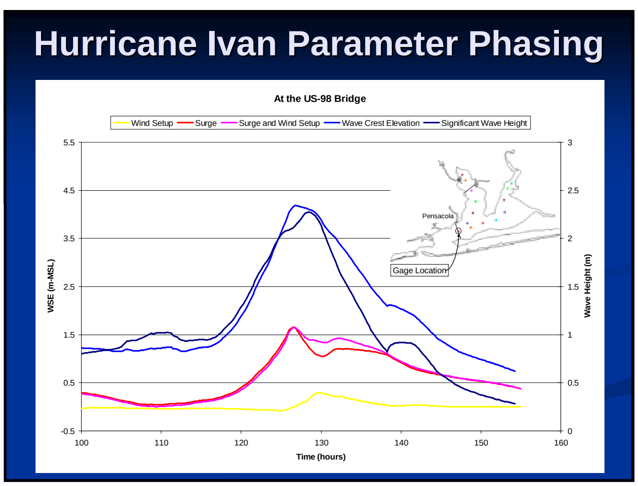
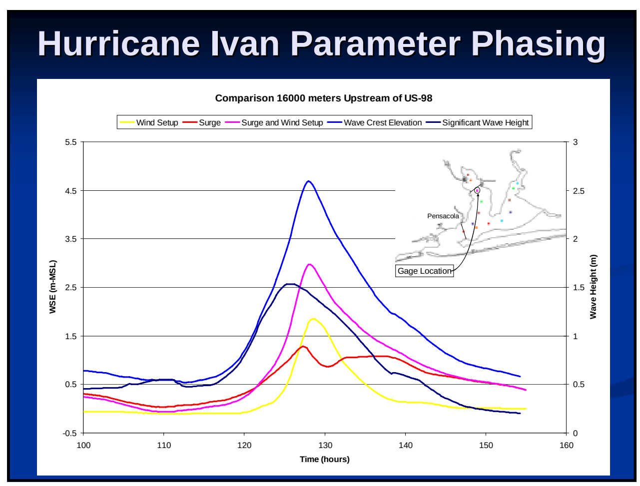

Hurricane Ivan Parameter Phasing
At the US-98 Bridge
Wind Setup
Surge
Surge and Wind Setup
Wave Crest Elevation
Significant Wave Height
WSE (m-MSL)
Wave Height (m)
Time (hours)
Pensacola
Gage Location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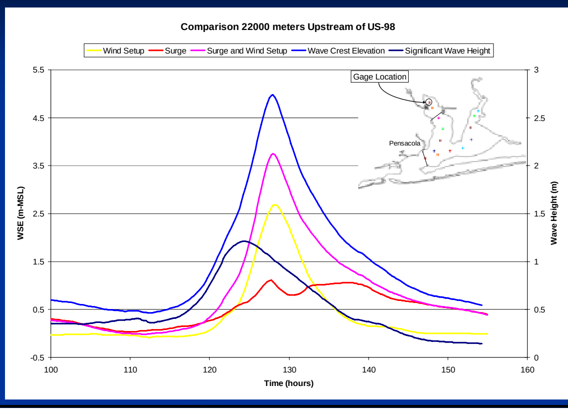
Hurricane Ivan Parameter Phasing



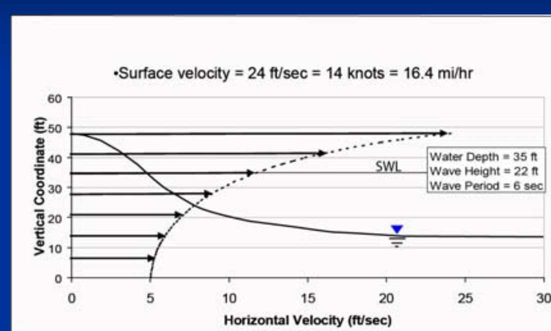
Water Level - Wave Parameter Issues

- Example – Particular Location
  - 100 year event (1% probability each year)
    - Storm surge (FEMA, other)
    - Wind setup
    - Wave height and period
- Joint Probability

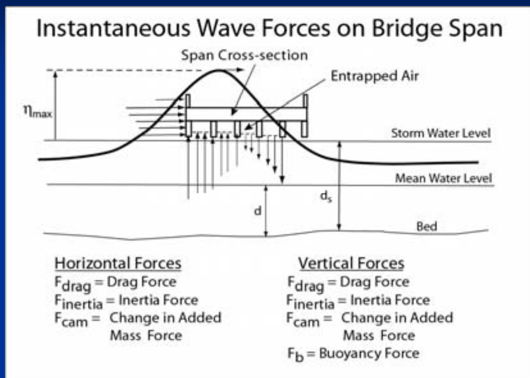
Storm Surge/Wave Forces

- Storm Surge/Wave Forces Depend On:
  - Water elevation
  - Wave heights and periods
    - Water particle velocity
    - Water particle acceleration
  - Structure shape, dimensions, and elevation relative to the storm water level

Horizontal Velocity Profile Under A Wave Crest - Example



Surge/Wave Forces



Force and Moment Calculations

- Four Methods Being Considered
  - Modified Kaplan - DMS
  - Wallingford I - JS
  - Wallingford II - JS
  - Douglas - JS

Attachment D

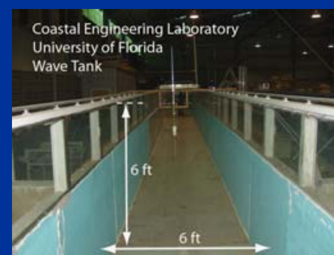
Dr. Sheppard's Presentation
On
Laboratory Testing in U of FL

Wave Tank Tests

- Need 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



Test Setup

Test Setup

Phase I Test Sequence

- Bridge Deck Only Tests (completed)
  - Generic flat deck structure
  - Test instrumentation
- Bridge Deck with Girders (in progress)
  - Common bridge superstructure design
  - Potential for air entrapment – increased buoyancy
  - Increased horizontal forces

Phase I Wave Conditions

- Non Breaking Monochromatic Waves
  - Wave period
  - Wave height
  - Water depth
  - Deck elevation relative to storm water surface
- Random waves
  - Significant wave height
  - Peak period
  - Water depth
  - Deck elevation relative to storm water surface

Phase II Test Sequence
(proposed)

- Slamming Force Tests
  - Modified instrumentation to determine
    - Magnitude
    - Duration
    - Spatial extent
  - More rigid model support structure

Phase II Wave Conditions

- Non Breaking Monochromatic Waves
  - Wave period
  - Wave height
  - Water depth
  - Deck elevation relative to storm water surface
- Random waves
  - Significant wave height
  - Peak period
  - Water depth
  - Deck elevation relative to storm water surface

Phase III Test Sequence
(proposed)

- Bridge Deck with Girders
  - Common bridge superstructure design
  - Potential for air entrapment – increased buoyancy
  - Increased horizontal forces

Phase III Wave Conditions

- Breaking Monochromatic Waves
  - Wave period
  - Wave height
  - Water depth
  - Deck elevation relative to storm water surface

Preliminary Laboratory Tests Measured and Predicted Forces

Attachment E

Dr. Sheppard's Presentation
On
Methods of Calculating Wave Forces

Wave Forces on Bridge Decks

D. Max Sheppard
OEA, Inc.
University of Florida

Phil Dompe
OEA, Inc.

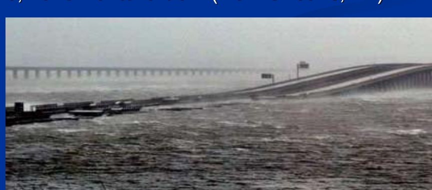
Justin Marin
University of Florida

Outline

- Motivation For, Objectives OF Study
- Background
- Wave Loading Problem
  - Screening criterion – existing bridges
    - Design event
      - Environmental parameters
  - Wave force and moment computation
  - Structural response
  - Retrofit options – existing bridges
- 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

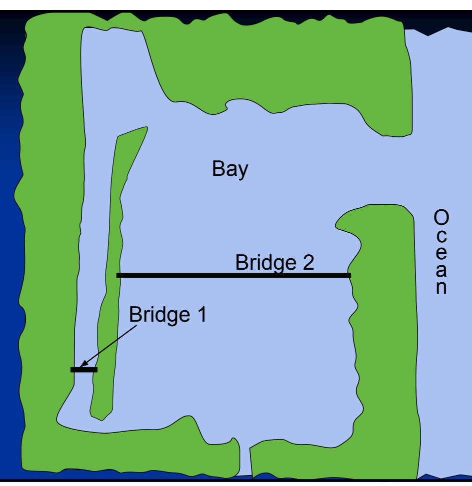
Objectives of Florida and National Projects

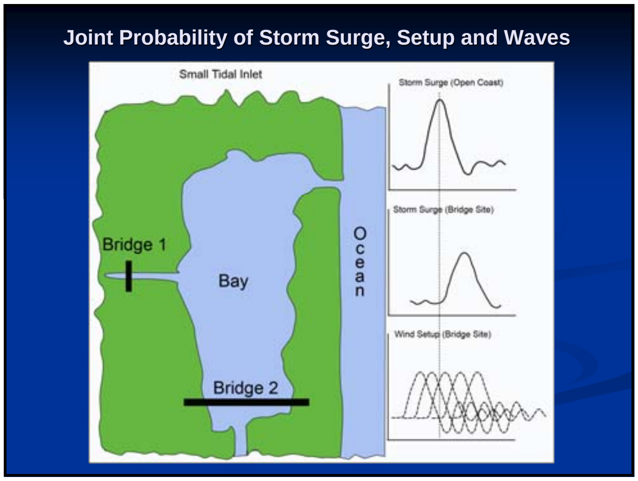
- Develop screening criterion
- Develop different level methods for establishing design surge, setup and wave parameters
- Develop/adopt method for estimating surge-wave forces and moments on bridge decks
- Develop retrofit options for existing bridges

Water Level - Wave Parameter Issues

Water Level - Wave Parameter Issues

- Design Event
  - Storm surge
  - Wind setup
  - Wave height and period
- Joint Probability
- SITE SPECIFIC

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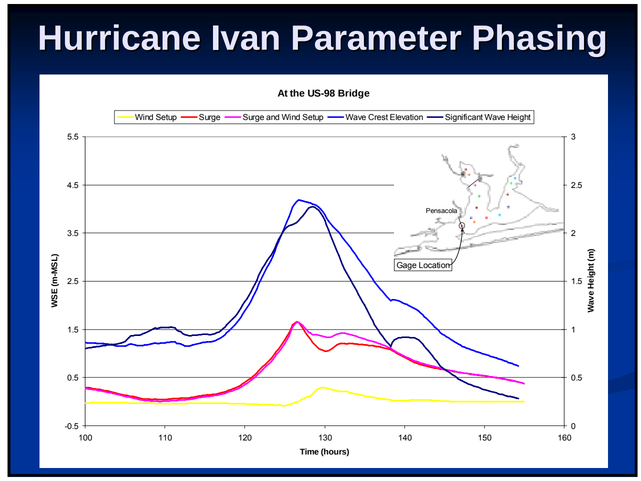
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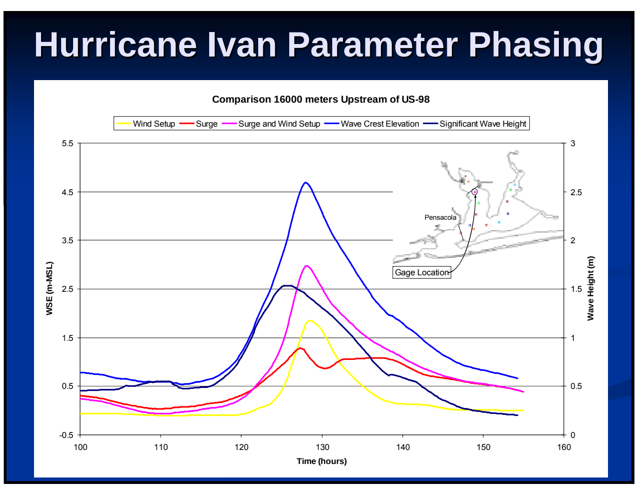
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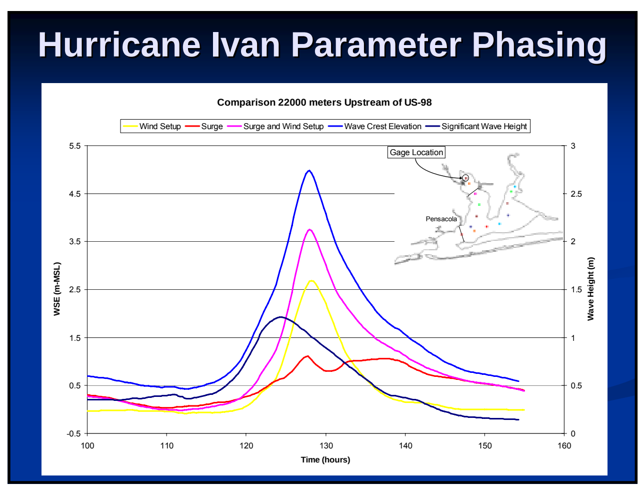
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Surge and Wind Setup
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Pensacola
Gage Location

Water Level - Wave Parameter Issues

- Example – Particular Location
  - 100 year event (1% probability each year)
    - Storm surge (FEMA, other)
    - Wind setup
    - Wave height and period
- Joint Probability

Storm Surge/Wave Forces

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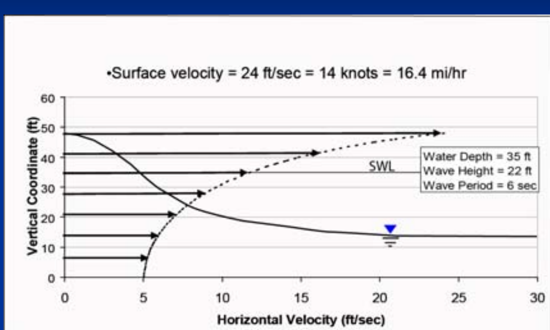
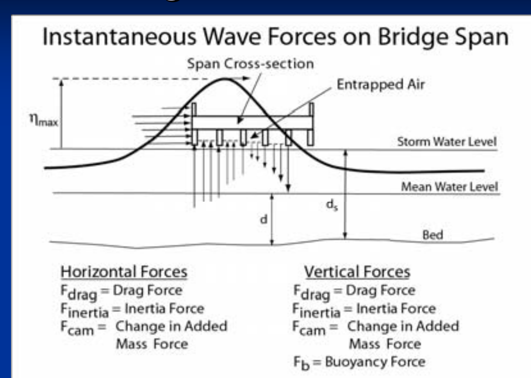
  - Structure shape, dimensions, and elevation relative to the storm water level

Horizontal Velocity Profile Under A Wave Crest - Example



Surge/Wave Forces



Force and Moment Calculations

- Four Methods Being Considered
  - Modified Kaplan - DMS
  - Wallingford I - JS
  - Wallingford II - JS
  - Douglas - JS

Wave Forces
Modified Kaplan Method

Kaplan Method

- Extension of Morison Equation Approach
  - Add mass time dependent

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

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

Kaplan Method

$$F_{Drag} \propto \rho A|V|V$$

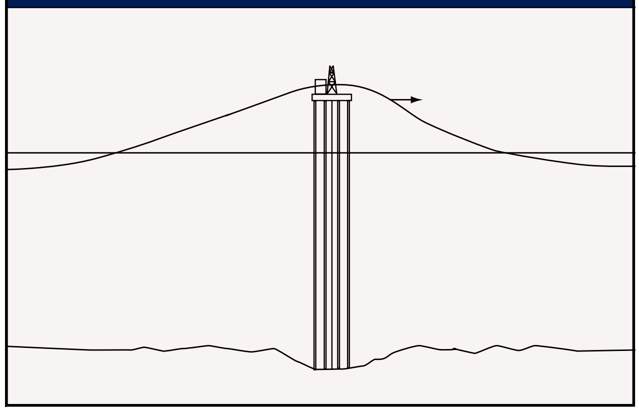
$$F_{inertia} \propto \frac{d[m(t)V(t)]}{dt} = \frac{dm(t)}{dt}V + m\frac{dV(t)}{dt}$$

$$\frac{dm(t)}{dt} \equiv \text{cam} \equiv \text{change in added mass}$$

Kaplan Method

- Developed for Offshore Platforms
  - Small structures relative to wave lengths
  - Flat plate decks
  - Long waves (low frequency) T ~ 14 -18 sec (wave lengths ~ 960 ft to 1440 ft)

Kaplan Method

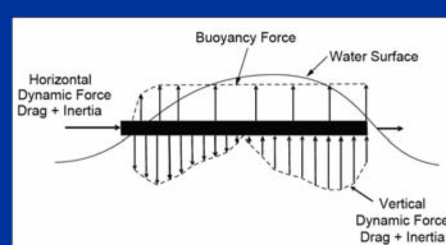


Modified/Extended Kaplan Method

- Developed for Bridge Super Structure Shapes
  - Girders – possible air entrapment
- Shorter waves T ~ 4 - 8 sec (wave lengths 80 ft to 225 ft)
  - Larger velocity and acceleration gradients
  - Larger buoyancy force gradients
  - Larger change in added mass components

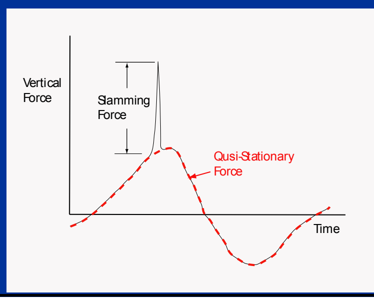
Modified/Extended Kaplan Method

- Moments as well as forces essential to computing structural response



Modified/Extended Kaplan Method

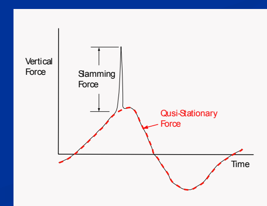
- Vertical Force
  - Qusi-stationary force
  - Slamming force



Modified/Extended Kaplan Method

- Slamming Force
  - Magnitude?
  - Duration?
  - Spatial distribution?
- These Questions Must Be Answered

Before its Impact on Structural Response Can Be Determined



Modified/Extended Kaplan Method

Qusi-stationary Force

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

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

Modified/Extended Kaplan Method

Qusi-stationary Force

$$F_v = \frac{d(m_a V)}{dt} + F_{drag} + F_{buoyancy}$$

$$= \frac{d(m_a V)}{dt} + \frac{1}{2}\rho\, L\, w\, C_d\, V\, |V| + F_{buoyancy}$$

$$\frac{d(m_a V)}{dt} = \frac{dm_a}{dt} V + m_a \frac{dV}{dt}$$

Modified/Extended Kaplan Method

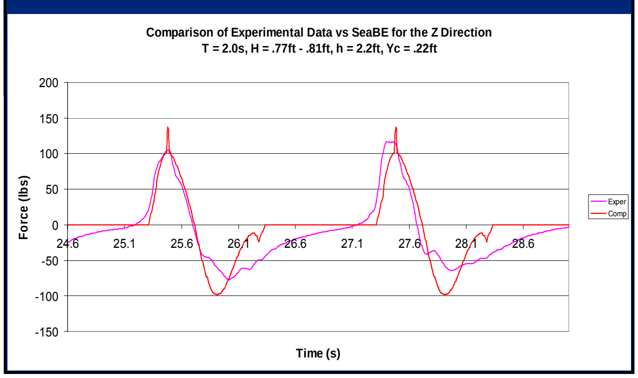
$$m_a \equiv \text{ added mass} = \frac{\pi\,\rho\,l(t)\,b(t)^2}{4\sqrt{1+\left(\frac{b(t)}{l(t)}\right)^2}}\left(C_1 + C_2\frac{h(t)}{b(t)} + C_3\sqrt{\frac{h(t)}{b(t)}}\right)$$

$\rho \equiv$ Density of Water
b $\equiv$ Wetted Span Width
l $\equiv$ Span Length
h $\equiv$ Wetted Span Height
t $\equiv$ Time

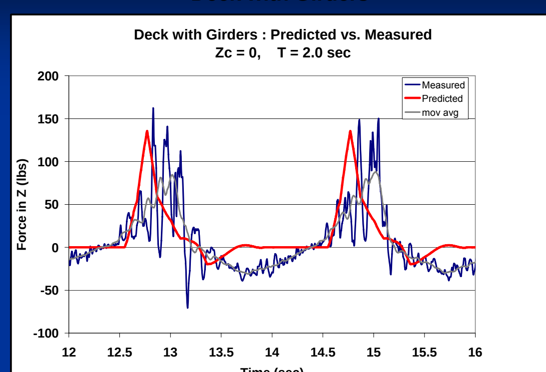
Modified/Extended Kaplan Method

- Need Laboratory Data to Determine Drag and Inertia Coefficients
- Wave Tank Tests at Coastal Engineering Laboratory at University of Florida

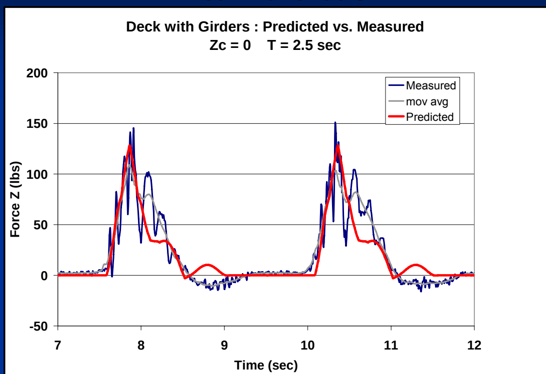
Measured & Computed Vertical Force
Earlier Results for Deck Only



Measured & Computed Vertical Force
Deck with Girders



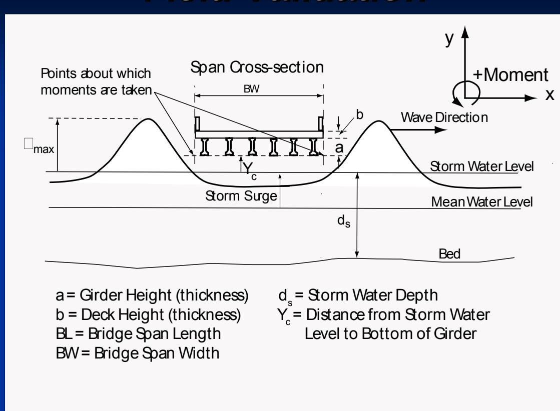
Measured & Computed Vertical Force
Deck with Girders



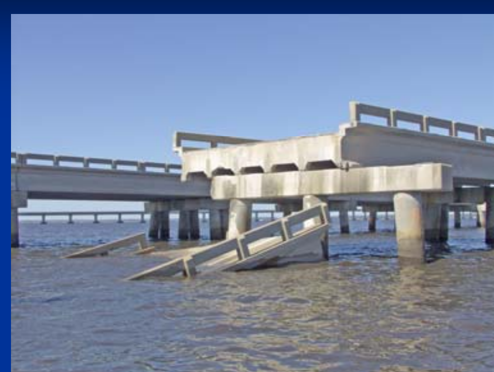
Field Validation

- I-10 Escambia Bay Bridges - Ivan
- I-10 Lake Pontchartrain Bridges – Katrina
- Hurricane Hindcasts Exist for Both Bridges
- Damage Information Exists

Field Validation



I-10 Escambia Bay - Ivan



I-10 Escambia Bay - Ivan

I-10 Escambia Bay Bridge Spans

- Approximate Maximum Resistive Forces and Moments
  - Maximum Vertical Force = Weight + Tie-Downs = 238 + 328 = - 566 kips
  - Maximum Moment about Lower Trailing Edge = (238 x 17.5) + (164 x 32.5) = 9,495 ft kips

I-10 Escambia Bay Bridge Spans

Vertical Force		
Span	Modified Kaplan	
	Force (kips)	Resistive Force (kips)
122	454 to 735	566
130	956 to 1,513	566

Moment about Trailing Edge		
Span	Modified Kaplan	
	Moment (ft-kips)	Resistive Force (ft-kips)
122	-4,784 to -7,667	9,495
130	-9,861 to -16,105	9,495

Summary

- Objectives
  - Develop screening criterion
  - Develop different level methods for establishing design surge, setup and wave parameters
  - Develop/adopt method for estimating surge-wave forces and moments on bridge decks
  - Develop retrofit options for existing bridges

Summary

- Challenges
  - Determining design parameters
    - Joint probability of storm surge, wind setup, wave parameters
  - Determining wave forces and moments
  - Identifying/Developing retrofit options

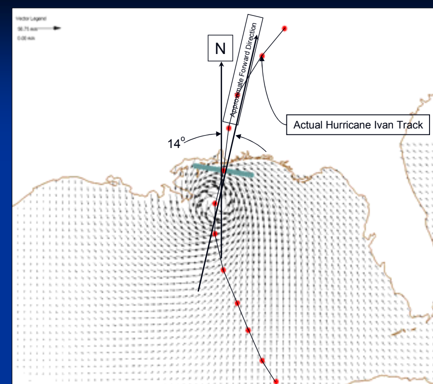
Summary

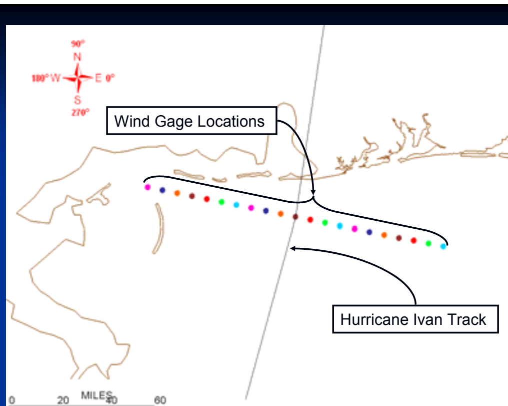
- Progress
  - Progress on Screening Criterion
  - Ready to start comparisons of different methods for computing wave forces and moments
  - Generating information needed to analyze joint probability of environmental parameters
  - Work initiated on retrofit options

Questions, Comments

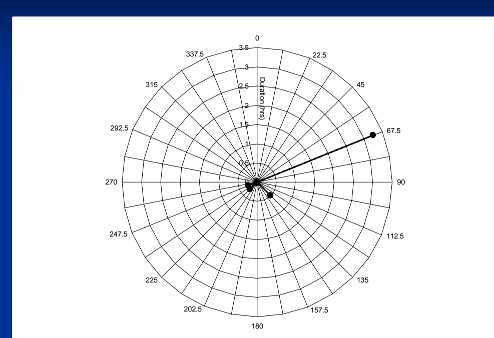
Improve Wind Alignment Criteria

- Based on durations for wind directions from hindcast events
- Update hurricane path statistics



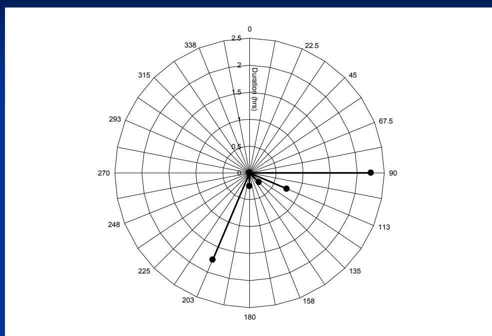


Landfall at the Eye of the Hurricane (Angle Relative To Path)



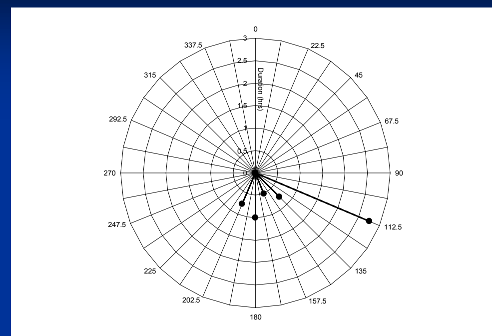
Duration Wind Speed Exceeds 75% of Maximum Wind Speed

Landfall 12.6 Mile to the Right of Forward Motion (Angle Relative To Path)



Duration Wind Speed Exceeds 75% of Maximum Wind Speed

Landfall 25.1 Miles to the Right of Forward Motion (Angle Relative To Path)



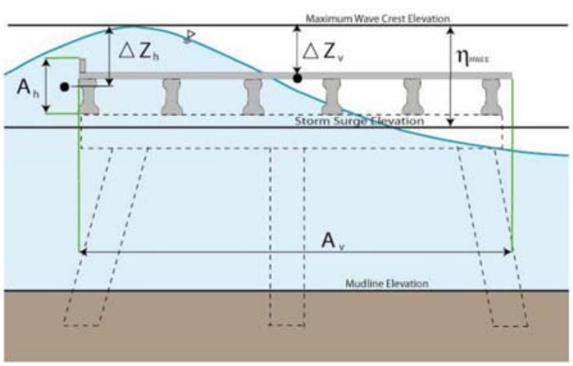
Duration Wind Speed Exceeds 75% of Maximum Wind Speed

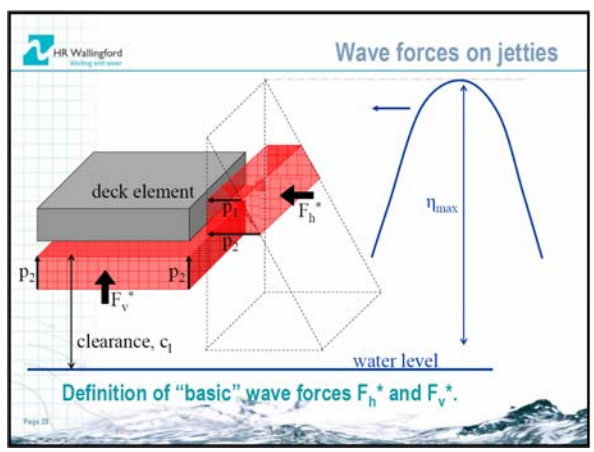
Attachment F

Mr. Shelden's Presentation
On
The Basis of Existing Codes,
Wallingford's Method, and,
Proposed Design Criteria

Huntington Beach Pier, California
(1988 Storm)

Catalina Island Ferry Terminal, 1960's
Hs= 10 feet, Tp = 7 sec, Still Intact





$$F^*_v = \int_{b_w}\int_{b_l} p_2 \cdot dA \cong b_w \cdot b_l \cdot p_2 \quad (1)$$

$$F^*_h = \int_{b_w}\int_{c_l}^{\eta_{max}} p_{hyd} \cdot dA = b_w \cdot (\eta_{max} - c_l) \cdot \frac{p_2}{2} \quad \text{for} \quad \eta_{max} \le c_l + b_h \quad (2)$$

$$F^*_h = \int_{b_w}\int_{c_l}^{c_l+b_h} p_{hyd} \cdot dA = b_w \cdot b_h \cdot \frac{(p_1 + p_2)}{2} \quad \text{for} \quad \eta_{max} > c_l + b_h \quad (3)$$

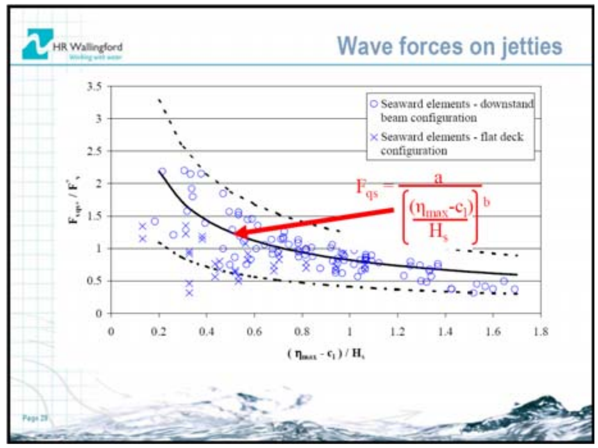
where

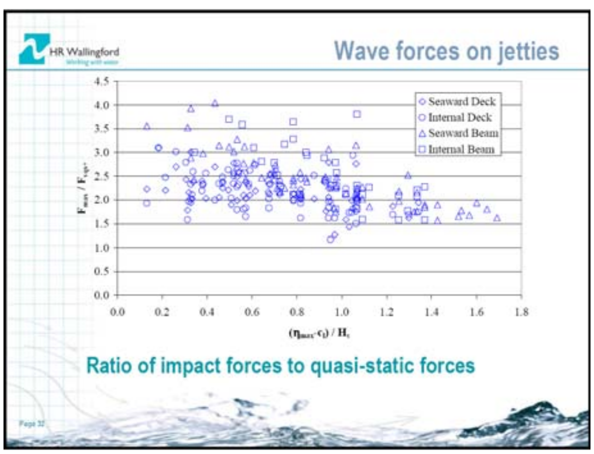
$$p_1 = [\eta_{max}\ \tilde{n}\ (b_h+c_l)]\cdot\rho g \quad (4)$$

$$p_2 = (\eta_{max}\ \tilde{n}\ c_l)\cdot\rho g \quad (5)$$

and

p_1, p_2 pressures at top and bottom of the element
b_w element width (perpendicular to direction of wave attack)
b_h element depth
b_l element length (in direction of wave attack)
c_l clearance (distance between soffit level and still water level, SWL)
η_{max} maximum wave crest elevation (relative to SWL).





Proposed Design Approach

- Load Factor Equation
  - (1.25 or 0.9)DC + (1.5 or 0.65)DW + (?)WS + (?)SC + (?)WV
- Force=f(Surge,H,a,b)
- Need COV for Surge & H for Monte-Carlo Simulation
- Ref: PIANC Working Group No. 12 "Uncertainty Related to Environmental Data and Estimated Extreme Events," Burcharth, et.al

Proposed Design Approach

- Uncertainty
  - – Errors in Calculation Methods
  - – Extreme Value Analysis
- Recommend COV 0.3
- Recommend 100-year Event as Basis
  - – 100-yr surge w/ associated wave, wind, scour
  - – 100-yr wave w/ associated surge, wind, scour

Proposed Design Approach

- Three Levels of Analysis
  - – Level I: Existing Data – may be too conservative (FEMA, ASCE-7)
  - – Level II: Intermediate – Refine items with greatest uncertainty or conservatism
  - – Level III: Extensive numerical modeling and statistical analyses