Hindcasting Of The Florida Keys For Scour, Emergency Evacuation, and Wave Forces On Bridges

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CORZO CASTELLA CARBALLO THOMPSON SALMAN
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Purpose

- Evaluate the Bridges in the Florida Keys
  - Design Hurricane Stages
  - Design Flows
  - Design Wave Heights
  - Design Scour
- Identify Vulnerable Areas along Evacuation Route
- Wave and Surge Loading on Bridge Decking
- Phase II of the Federally Mandated Scour Evaluation Program

Approach

Task

1. Develop Calibrated Wave and Circulation Models
2. Hindcast Historical Record (>150 Years)
   - Interpolate/Extrapolate to Design Values
     - Surge
     - Wave Height
     - Flow
     - Scour
3. Evaluate Bridges – Scour & Wave Loading
4. Reporting

Task 1

1. Project Initiation - Gather Available Data/Initiate Model Mesh Development
2. Reduce, Analyze, Reconcile, and Assess Available Data
3. Obtain Additional Survey and Geotechnical Data
4. Complete and Calibrate Models

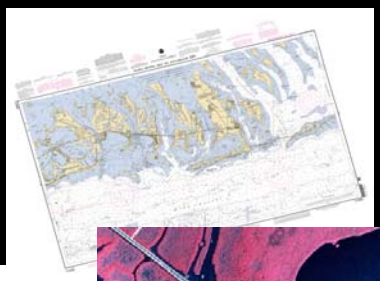
Data Collection

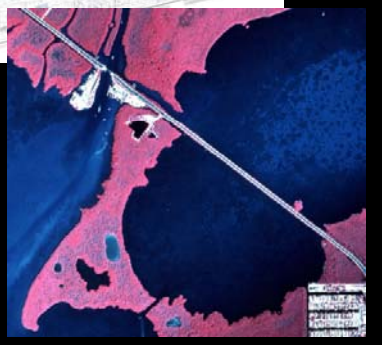
- Aerial Photographs/Maps
- Bathymetry/Topography
  - Existing
  - Acquired
- Geotechnical Data
  - Existing
  - Acquired
- Field Measurements

Data Collection

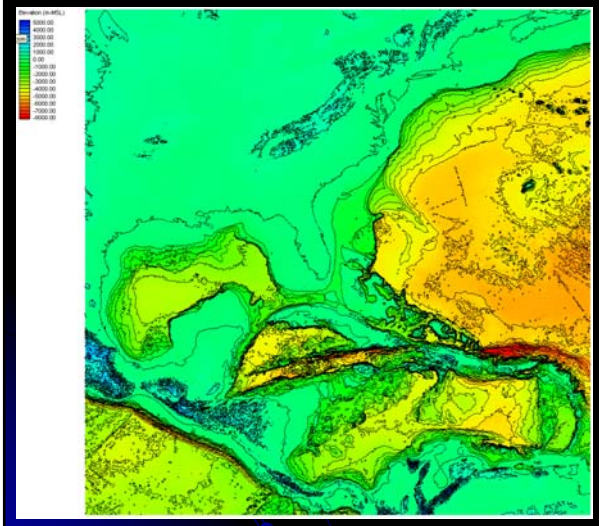
- Bridge Data
- Hurricane Data
  - Wind and Pressure Fields
  - High Water Marks

Aerials/Maps





Bathymetry/Topography



- ETOPO
- Coastal Relief
- Bridge Plans
- USGS Quads

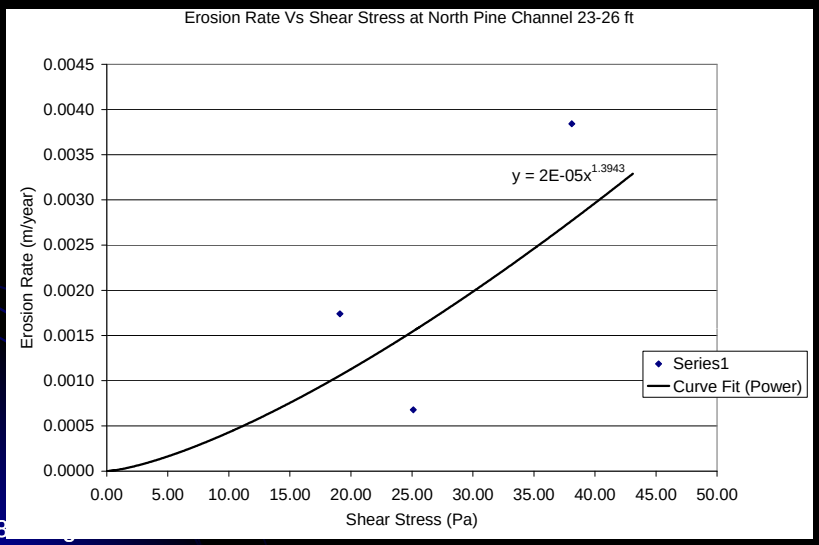
Bathymetry/Topography

- Survey Data Acquired at 25 Crossings
- Offshore Profiles
- US-1 Centerline Survey

Geotechnical Data

- Existing Plans
  - Identify Missing/Unreliable Data
  - Identify “Rule of Thumb” Failure (5 ft, 50 blows/ft)
- Acquired Data
  - Borings at 19 Crossings
  - Testing
    - Unconfined Compressive Strength
    - RETA (Erosion Rate vs. Shear Stress)

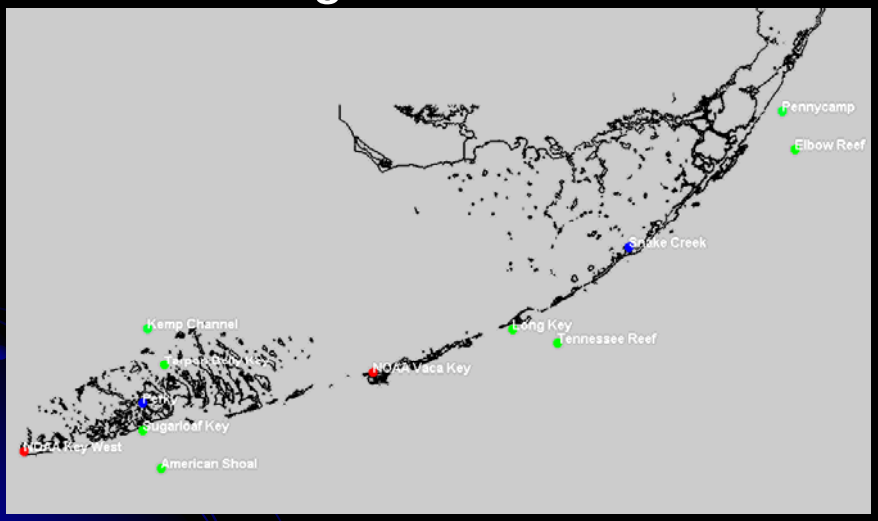
RETA Results



Field Investigation

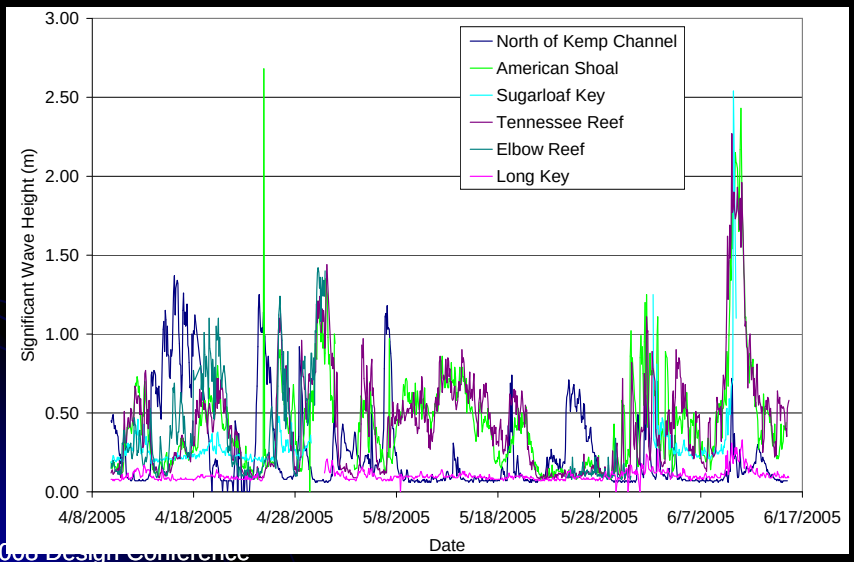
- Obtain Measurements for Calibration
  - Water Surface Elevation
  - Flow Rate
  - Wave Climate
    - Height
    - Period
    - Direction
- Mid-April 2005 to Mid-June 2005

Gage Locations

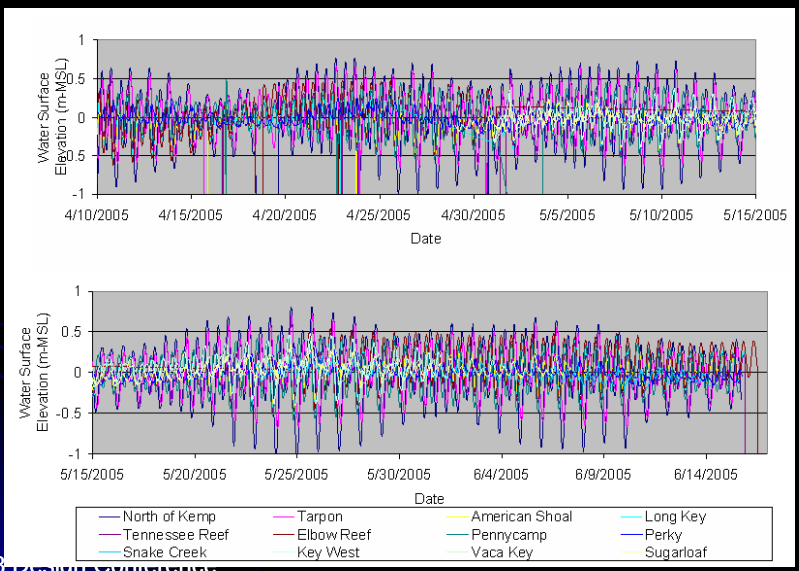


Wave Tide NOAA Gages

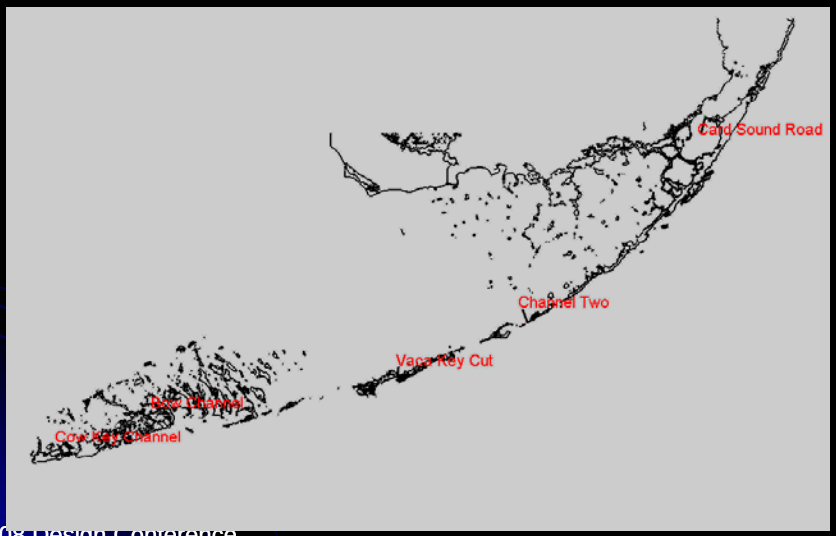
Wave Data

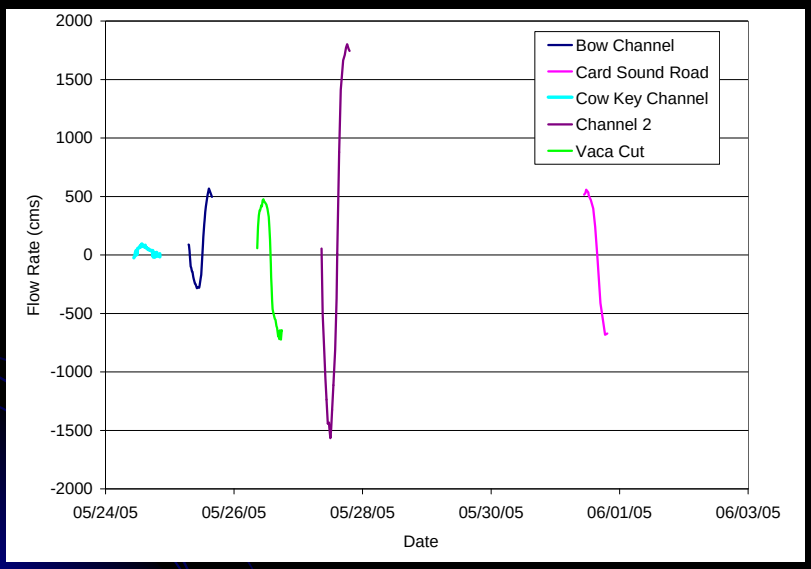


Tide Elevation Measurement



Flow Measurement Locations



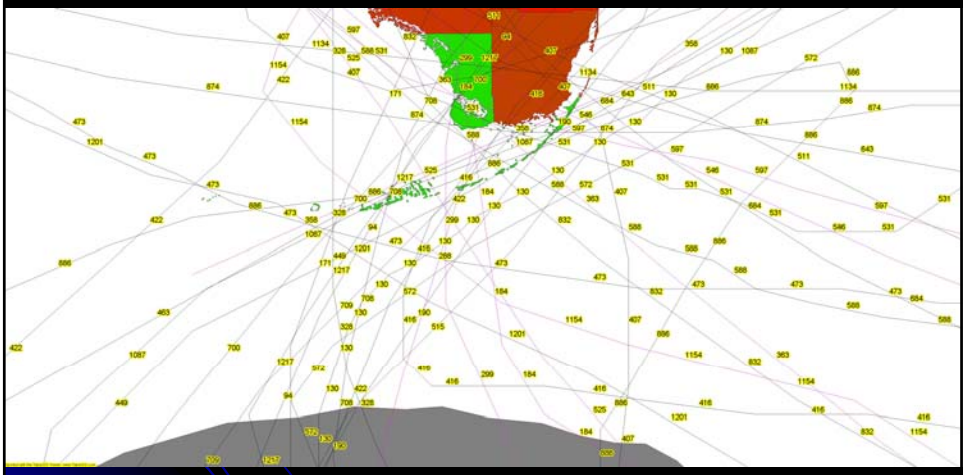


Bridge Data

- General Superstructure Description
- General Substructure Description
- Span Description
- Abutment Description
- General Bed Description
- Detailed Description of Each Pier
  - Station
  - Skew
  - Geometry
  - Tip Elevations

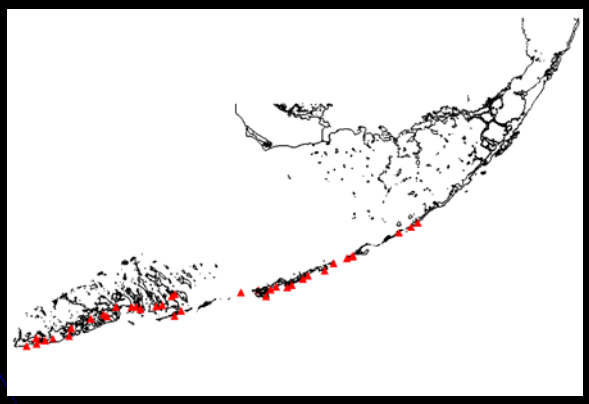
Historical Hurricane Data

- Wind and Pressure Files of Historical Events
- Provides Inputs to Hindcast Simulations
- 1850-2004
- 28 Hurricanes, 9 Tropical Storms



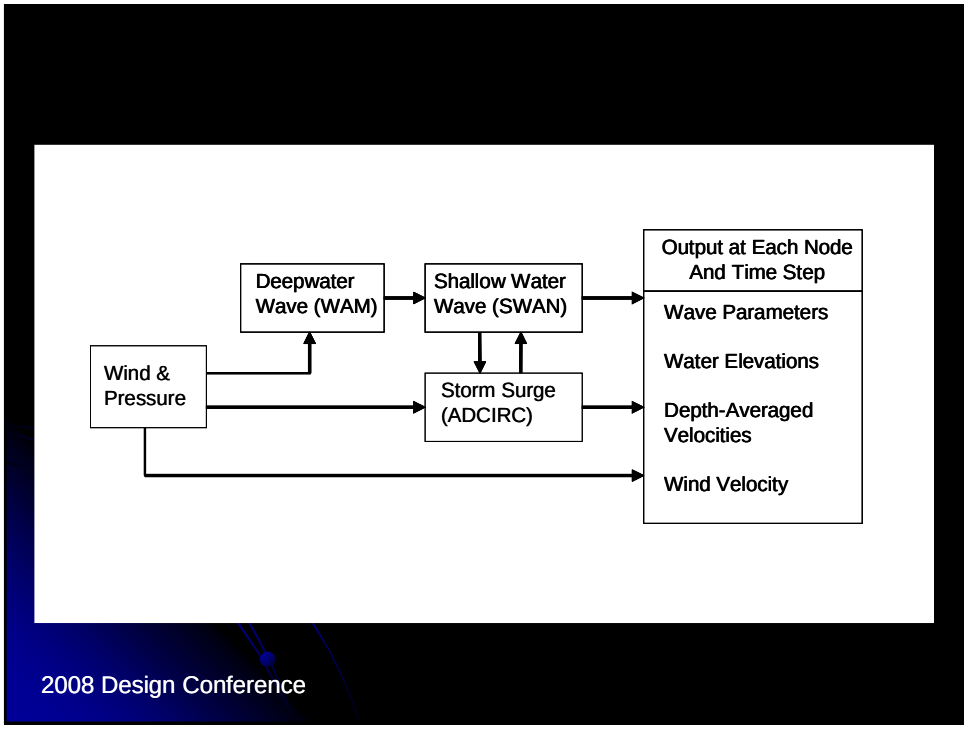
Hurricane High Water Marks

- Georges (1998) Data Set Most Reliable
- USACE



Model Development and Calibration

- Deep Ocean Wave Modeling – WAM
- Coastal Wave Modeling – SWAN
- Tidal Circulation and Surge Modeling - ADCIRC



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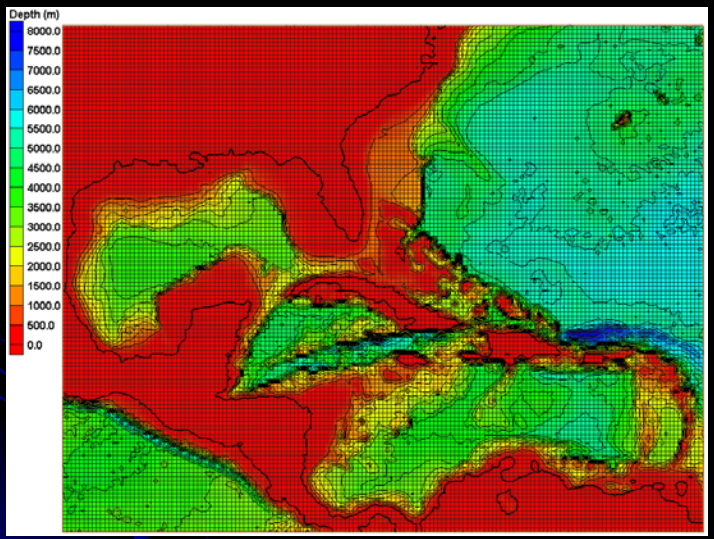
WAM Grid



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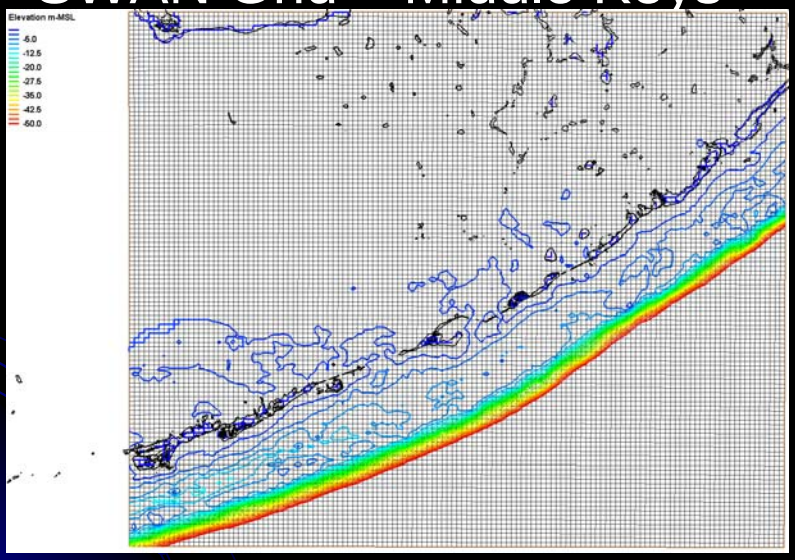
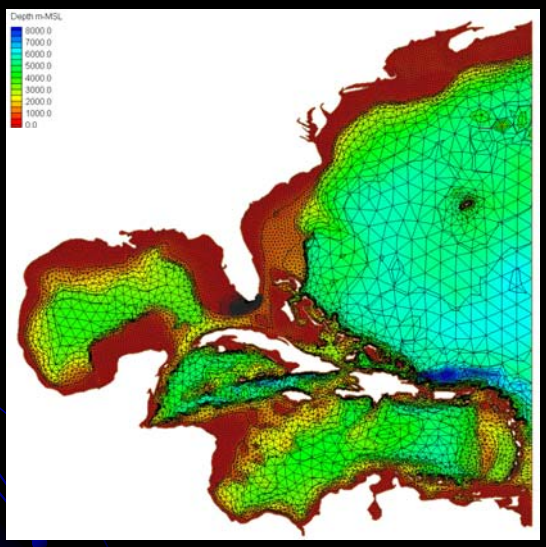
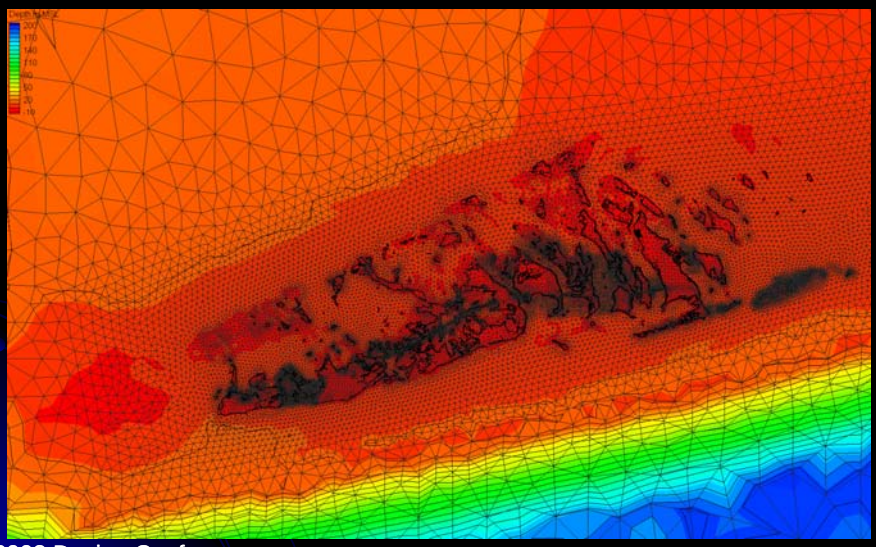
SWAN Grid – Middle Keys



ADCIRC Mesh



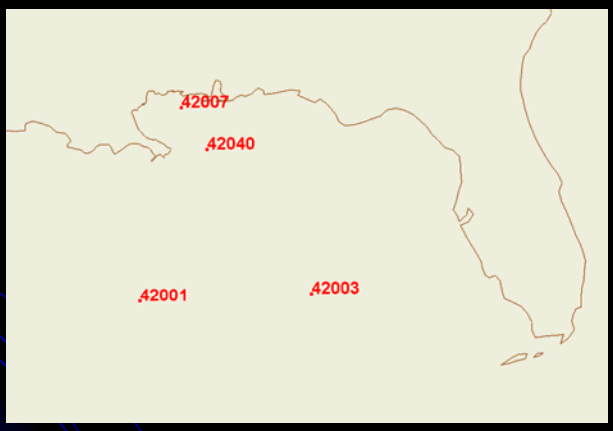
ADCIRC Mesh – Lower Keys



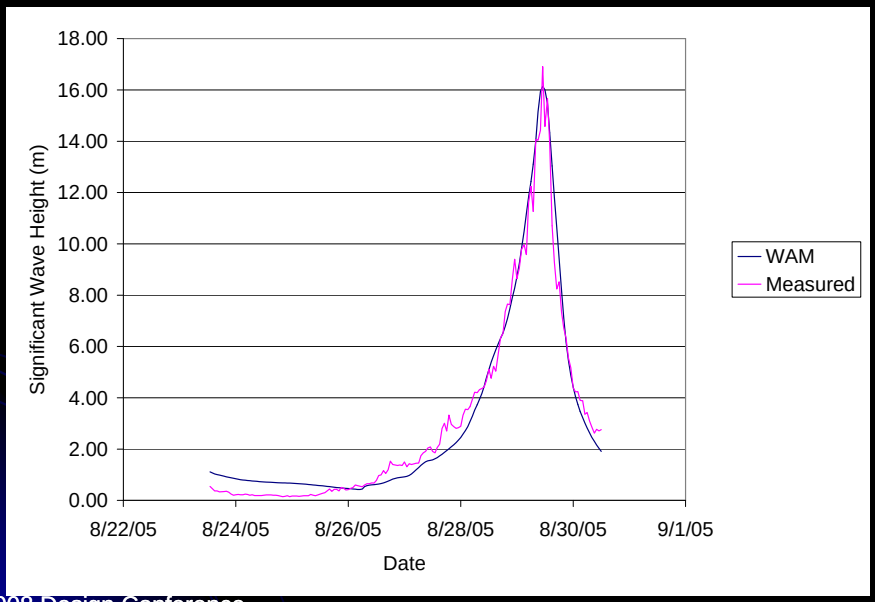
Calibration

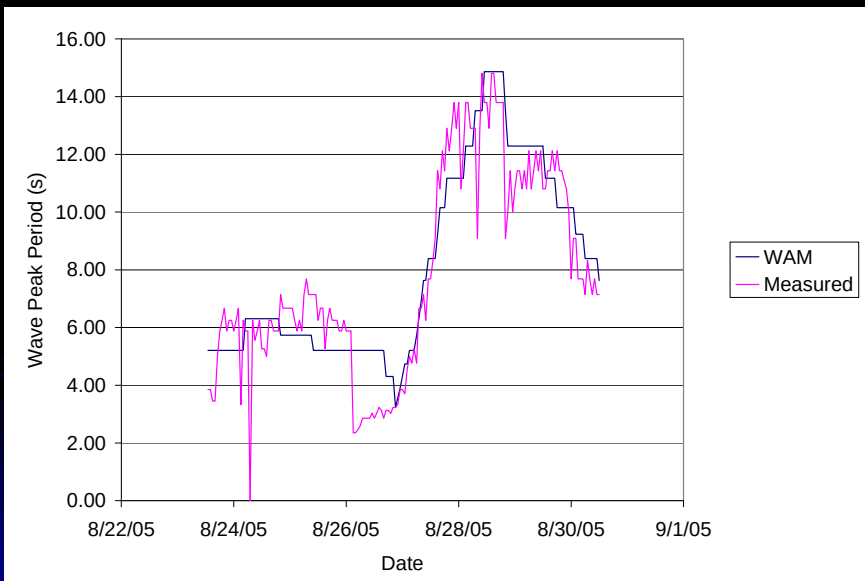
- WAM – Hurricane Katrina Buoy Measurements
- SWAN – Wave Gage Measurements
- ADCIRC – Tide Gage Measurements and Hurricane Georges High Water Marks

WAM Calibration



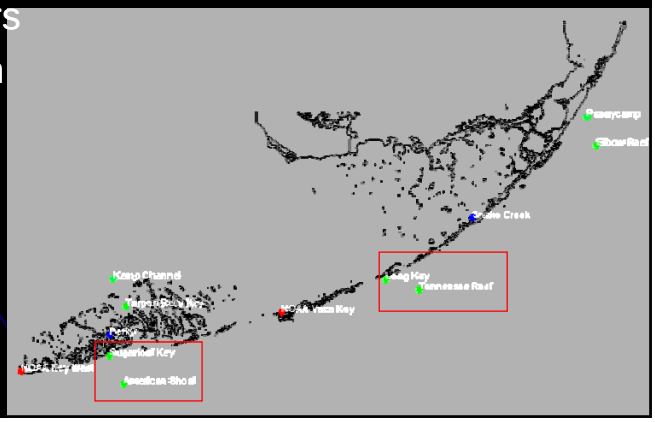
NDBC Buoy Locations



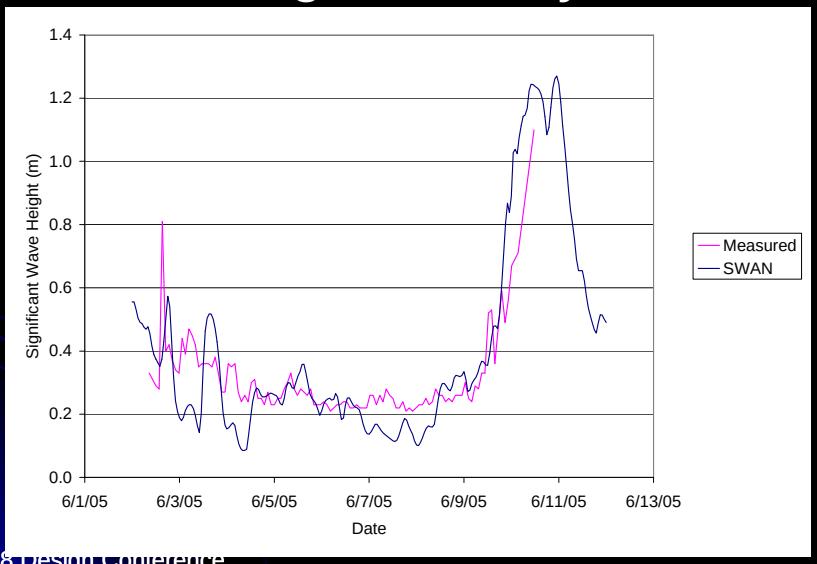


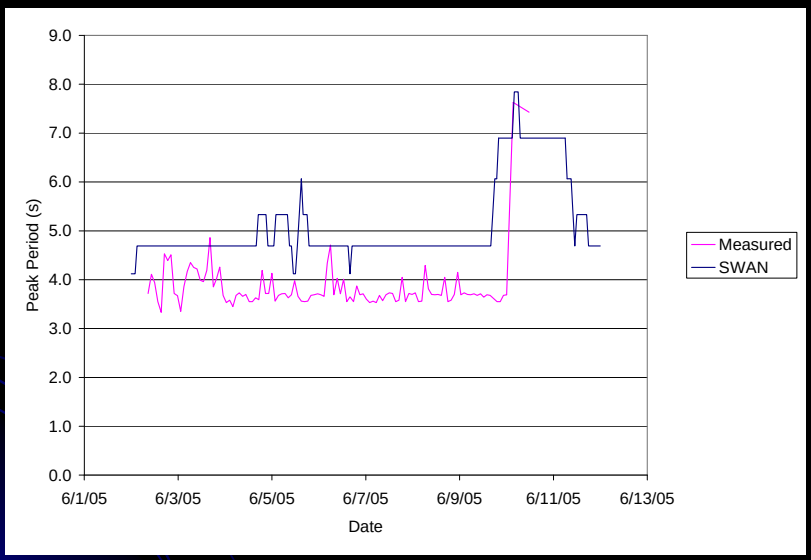
SWAN Calibration

- Only 2 of the 4 Gage Pairs
- Calibration Meshes Test
  - Parameters
  - Resolution



Sugarloaf Key

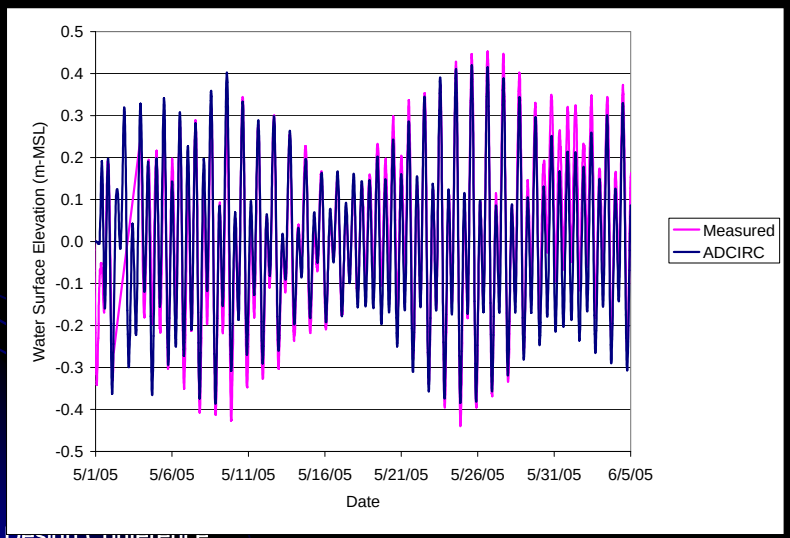




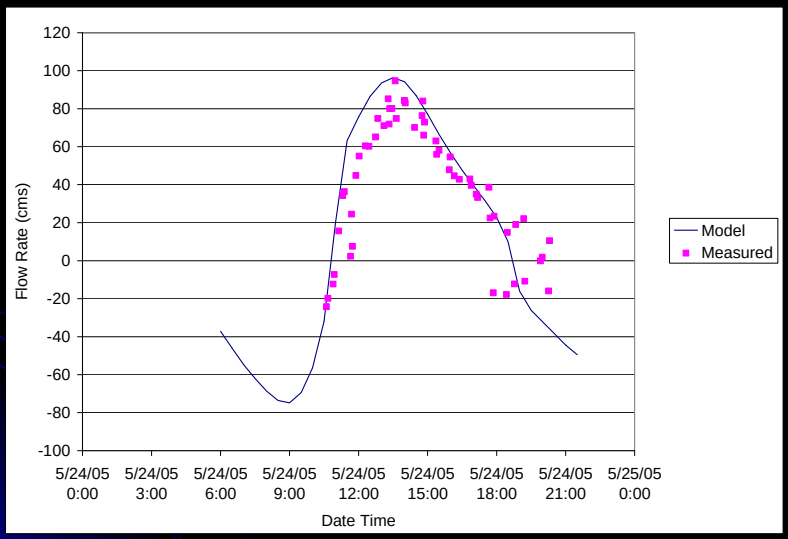
ADCIRC Calibration

- Tidal Measurements
  - Water Surface Elevation
  - Flow Rate
- Hurricane Georges
  - High Water Marks

American Shoal



Cow Key Channel



Hurricane Georges (1998)

High Water Mark Locations

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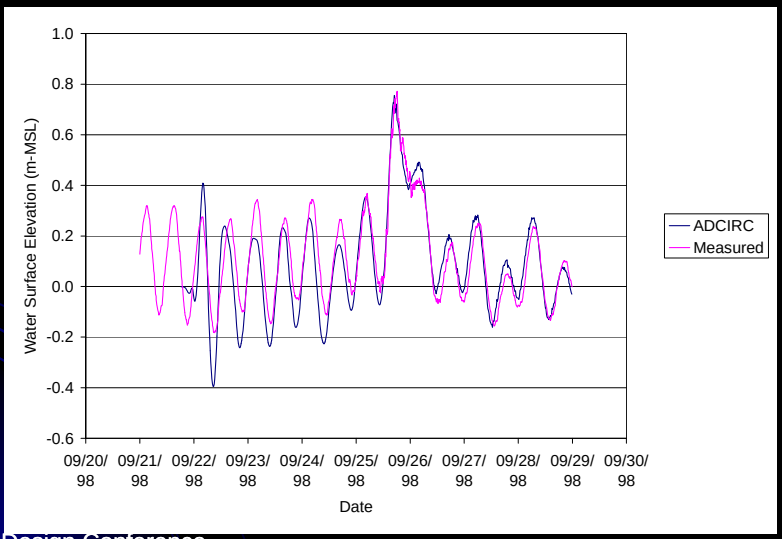
Key West



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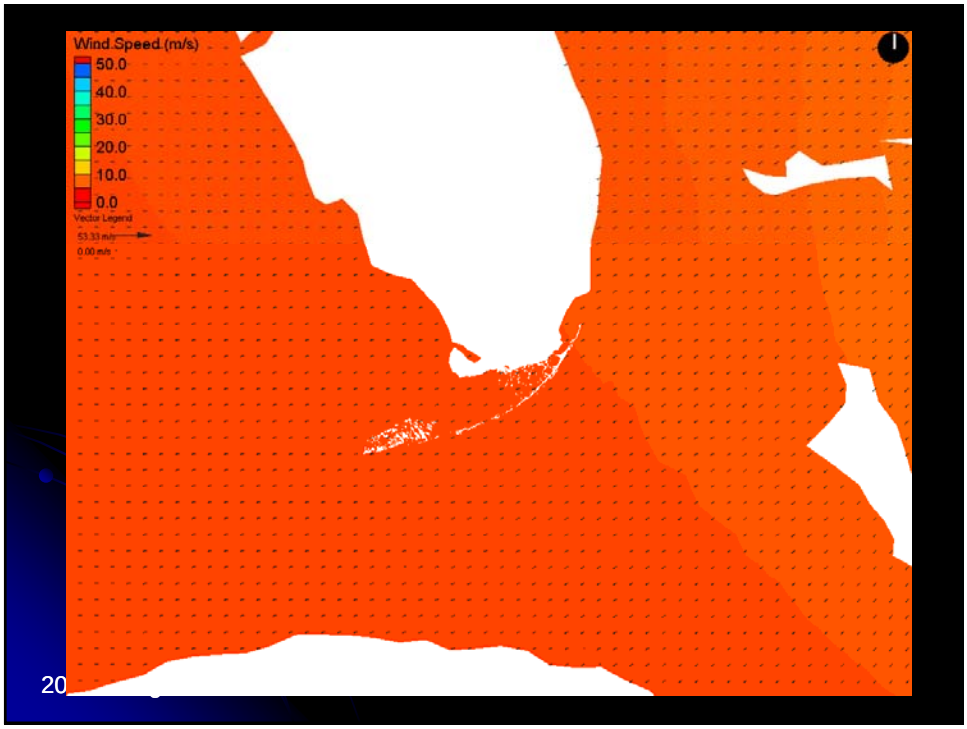
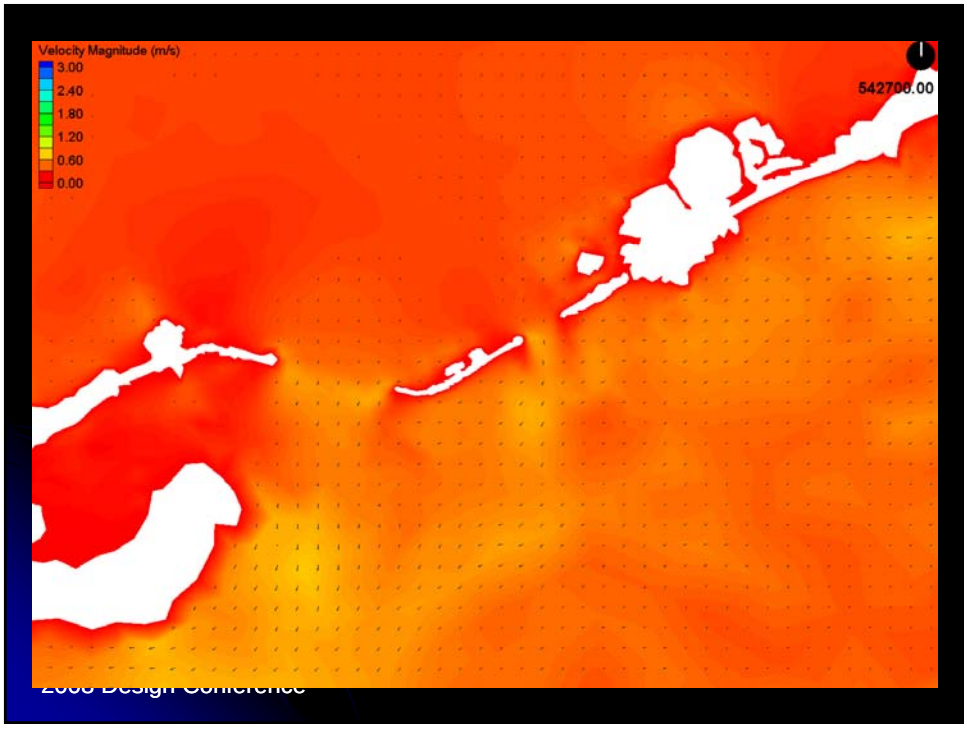
Task 2 Hindcast Historical Record

- Hindcast 37 Storms
- Reduce Data
- Develop Design Values (100- & 500-yr)
  - Flow Rate
  - Wave Parameters
  - Elevations
  - Scour

1935 Hurricane


Wind Speed (m/s)
50.0
40.0
30.0
20.0
10.0
0.0
Vector Legend
53.33 m/s
0.00 m/s


Velocity Magnitude (m/s)
3.00
2.40
1.80
1.20
0.60
0.00
542700.00

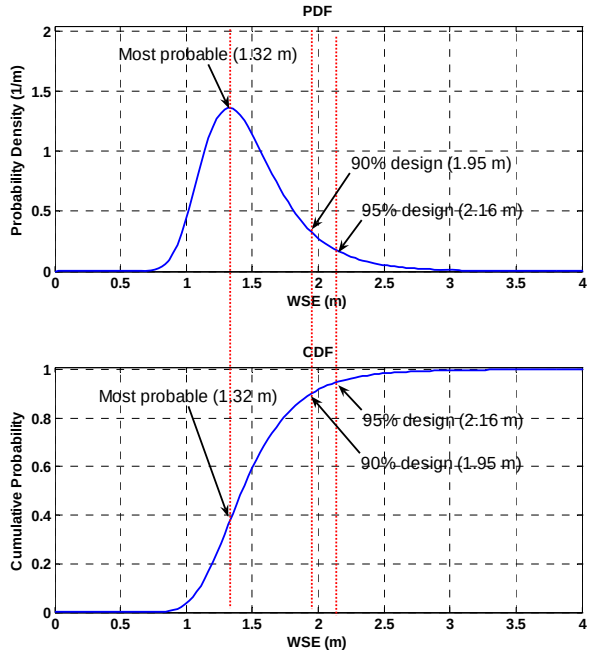
Develop 100- & 500-yr Design Parameters

- Extreme Value Analysis – Ochi (2004)
- Results of Hydrodynamic Model and Scour Calculation Used as “Observations”
- Probability Distributions for “Number of Cyclones in N Years” and “Intensity for Each Parameter (e.g. Wave Height, Scour Depth)”

Choosing The Design Value

- Peak of the Plot Shows the Most Probable Extreme Value
- However It Will Be Exceeded with a Probability Of More Than 50%
- Design Values Should Be Taken Such That the Value Will Not Be Exceeded with a Probability of 90% or 95 %

100-yr Extreme Water Surface Elevation for Bridge 900016



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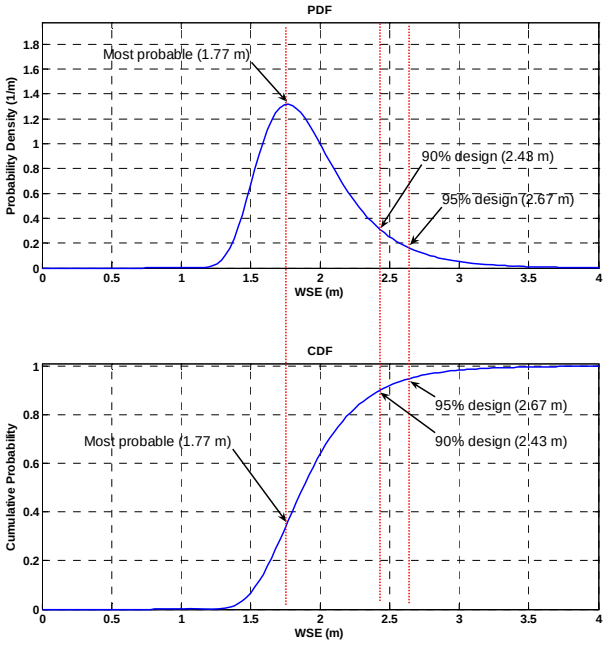
500-yr Extreme Water Surface Elevation for Bridge 900016



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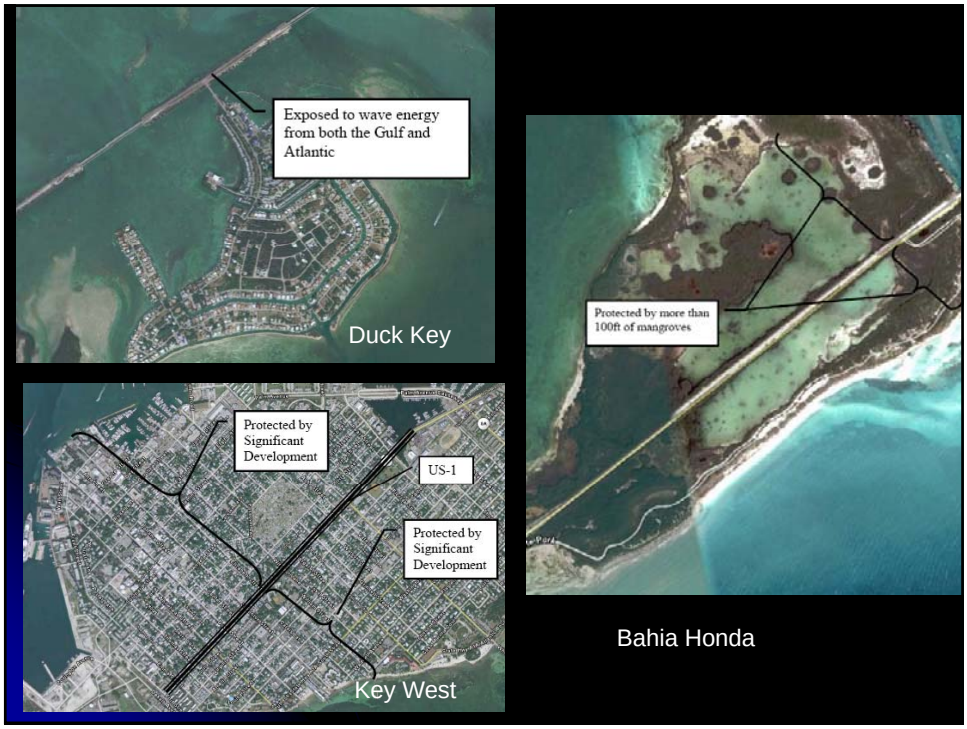
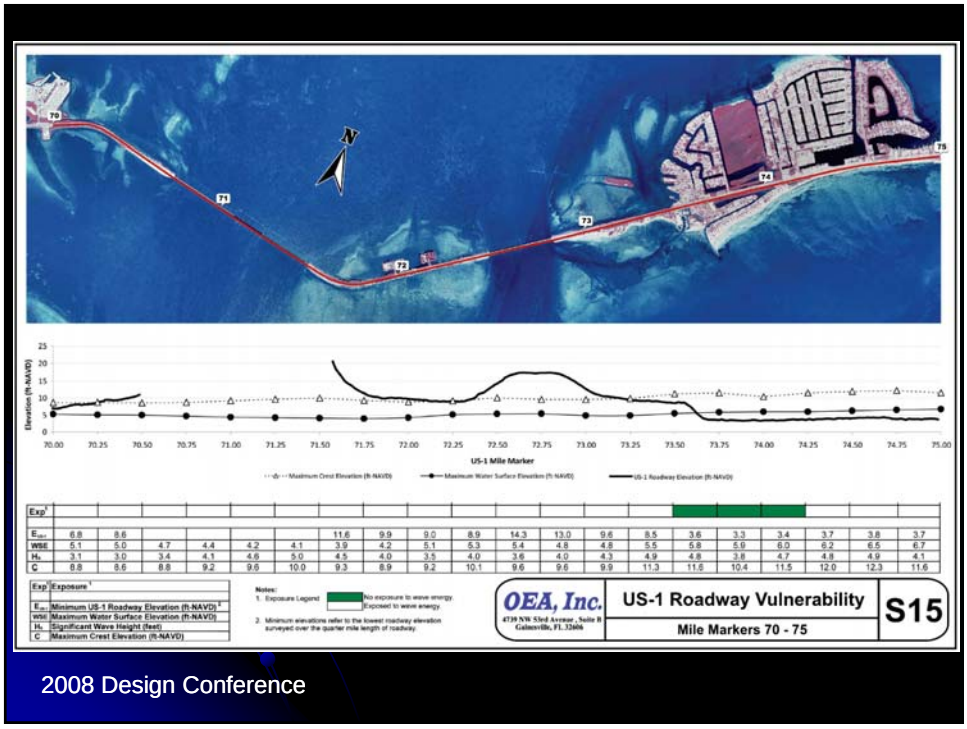
From Modeling Results

- Calculate Design:
  - Wave Heights
  - Water Surface Elevations
  - Scour
- Perform Scour Evaluations
- Identify Vulnerable Roadway Sections
- Calculate Wave Forces

Vulnerability Analysis

- Examined Each ¼ Mile of US-1
- Identified Areas where
  - Surge Elevations at or near the Measured Crown Elevation
  - Significant Wave Energy Offshore
  - Exposure of the Roadway to Wave Energy Entering from Open Waters


Exposed to wave energy from both the Gulf and Atlantic
Duck Key
Protected by more than 100ft of mangroves
Bahia Honda
Protected by Significant Development
US-1
Protected by Significant Development
Key West


US-1 Mile Marker
OEA, Inc.
US-1 Roadway Vulnerability
Mile Markers 70 - 75
S15
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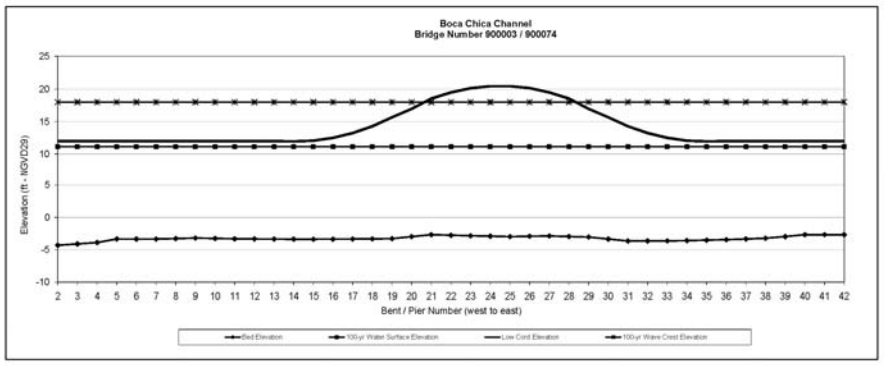
Wave Force Calculation

- Methodology - Developed by OEA Following Method by Kaplan
  - Recently Incorporated by AASHTO
- Inputs:
  - Bridge Superstructure Geometry and Elevations
  - 100-yr (5% Risk) Maximum Wave Heights
  - Wave Periods:
    - Steepness Limited
    - Long Period (14 second)



Bent / Pier # (west to east)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
100-yr Water Surface Elevation (ft - NGVD29)	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Bed Elevation (ft - NGVD29)	-4.3	-4.1	-3.9	-3.3	-3.4	-3.4	-3.3	-3.2	-3.3	-3.3	-3.3	-3.4	-3.4	-3.4	-3.4	-3.4	-3.3	-3.3	-3.0	-2.7	-2.8
Low Cord Elevation (ft - NGVD29)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	11.9	12.0	12.5	13.2	14.3	15.7	17.0	18.6	19.5
100-yr Wave Crest Elevation (ft - NGVD29)	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Delta (ft) *	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.1	6.0	5.5	4.8	3.7	2.4	1.1	-0.5	-1.5

Bent / Pier # (west to east)	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
100-yr Water Surface Elevation (ft - NGVD29)	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Bed Elevation (ft - NGVD29)	-2.9	-2.9	-3.0	-2.8	-2.9	-3.0	-3.1	-3.4	-3.7	-3.7	-3.6	-3.6	-3.5	-3.5	-3.4	-3.2	-3.0	-2.7	-2.7	-2.7
Low Cord Elevation (ft - NGVD29)	20.2	20.5	20.5	20.2	19.5	18.6	17.0	15.7	14.3	13.2	12.5	12.0	11.9	12.0	12.0	12.0	12.0	12.0	12.0	12.0
100-yr Wave Crest Elevation (ft - NGVD29)	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Delta (ft) *	-2.1	-2.5	-2.5	-2.2	-1.5	-0.5	1.1	2.4	3.7	4.8	5.5	6.0	6.1	6.0	6.0	6.0	6.0	6.0	6.0	6.0

Notes:
* Delta is maximum wave crest elevation minus the low cord elevation.
1 Spans 1 through 20 and 28 through 42 are potentially subject to wave impact.

Span	Maximum Horizontal Force (kips)	Maximum Vertical Force (kips)	Maximum Slamming Force (kips)	Maximum Horizontal Force at Maximum Vertical Force (kips)	Maximum Total Vertical Force (kips)
1	45	333	67	21	400
2	82	818	135	46	953
3	83	775	135	43	910
4	84	753	135	42	888
5	89	894	134	41	1028
6	89	895	134	41	1029
7	89	896	134	41	1031
8	89	883	134	40	1017
9	89	871	134	43	1006
10	89	880	134	43	1014
11	89	890	134	40	1025
12	89	893	134	41	1027
13	89	896	134	41	1030
14	87	888	137	42	1025
15	77	884	130	43	1014
16	81	861	103	37	965
17	71	868	64	19	931
18	49	804	25	22	829
19	26	740	5	21	727
20	10	650	2	5	662
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	8	590	3	4	518
29	30	688	17	10	674
30	49	805	25	22	830
31	69	922	64	19	987
32	80	915	104	41	1019
33	84	928	130	44	1059
34	86	926	137	44	1063
35	85	912	135	45	1047
36	85	901	135	42	1036
37	89	894	134	41	1028
38	89	876	134	43	1010
39	91	629	134	39	763
40	83	718	134	43	852
41	83	718	134	43	852
42	83	718	134	43	852
43	83	718	134	43	852

Scour Evaluation

- Rock Scour Calculation
- Scour Rating
- Condition of Abutment Protection
- Recommendations


Lignumvitae Channel
Spanish Harbor Channel
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Harris Gap Channel
Bahia Honda
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Reporting

- Individual Scour and Wave Vulnerability Reports for Each of the 56 Bridges
- Roadway Vulnerability Report
- Final Summary Report

Questions?