Session 8

Phil Dompe

Ocean Engineering Associates Inc.

Screening Existing Bridges for Vulnerability to Wave Attack

Topic Description

Screening Existing Bridges for Vulnerability to Wave Attack:
The presentation describes a method for screening existing bridges for vulnerability to wave attack. The methodology uses available data to rank bridges according to their potential vulnerability to wave attack. The methodology was developed as part of a pilot study, the second phase of which currently underway.

Speaker Biography

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

Session 8

Max Sheppard

Ocean Engineering Associates, Inc.

Screening Existing Bridges for Vulnerability to Wave Attack

Topic Description

Screening Existing Bridges for Vulnerability to Wave Attack:
The presentation describes a method for screening existing bridges for vulnerability to wave attack. The methodology uses available data to rank bridges according to their potential vulnerability to wave attack. The methodology was developed as part of a pilot study, the second phase of which currently underway.

Speaker Biography

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

A Method for Screening Existing Bridges for Surge/Wave Loading Vulnerability

D. Max Sheppard
OEA, Inc.
Philip Dompe
OEA, Inc.

2006 DESIGN CONFERENCE
Designing For More Than Bridges and Roads

OEA, Inc.

Study Motivation

- Recent bridge failures attributed to storm surge and wave loading
  - I-10 over Escambia Bay - Hurricane Ivan
  - US 90 over Bay St. Louis - Hurricane Katrina
  - US 90 over Biloxi Bay - Hurricane Katrina
  - I-10 over Lake Pontchartrain - Hurricane Katrina

Study Motivation

- Need for procedure to identify coastal bridges that are susceptible to significant wave loading during a design probability storm

Study Objectives

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

This Presentation

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

Presentation Outline

- Screening Procedure Framework
- Procedure Outline
- Example Application
- Pilot Study Phase II
- Further Analyses

Screening Procedure Framework

- Use Existing Data/Information
- Include Quantities on which Wave Forces Depend:
  - Approximate wave heights and periods
  - Storm surge elevations
  - Wind alignment with fetch probabilities
  - Bridge superstructure elevation
  - Bridge span type
- Include Bridge Importance
  - Evacuation route
  - Minor bridge with easy detour

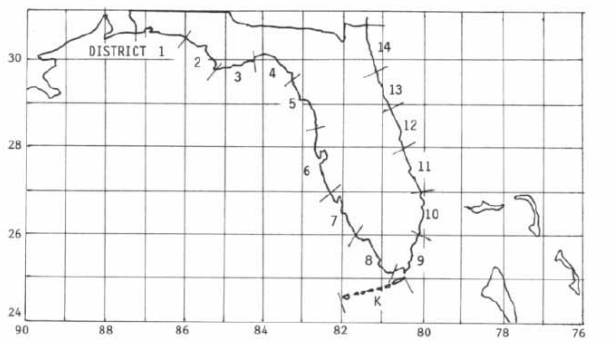
Procedure Outline

- Using USGS Quad Maps, NOAA Charts, etc. Identify Bridges with Possible Problems (large fetch lengths)
- Obtain Bathymetry Over Fetch Lengths and in Vicinity of Bridges (quads, charts, other)
- Obtain 100-Year Wind Speeds (or wind speed of maximum storm of record)

Procedure Outline

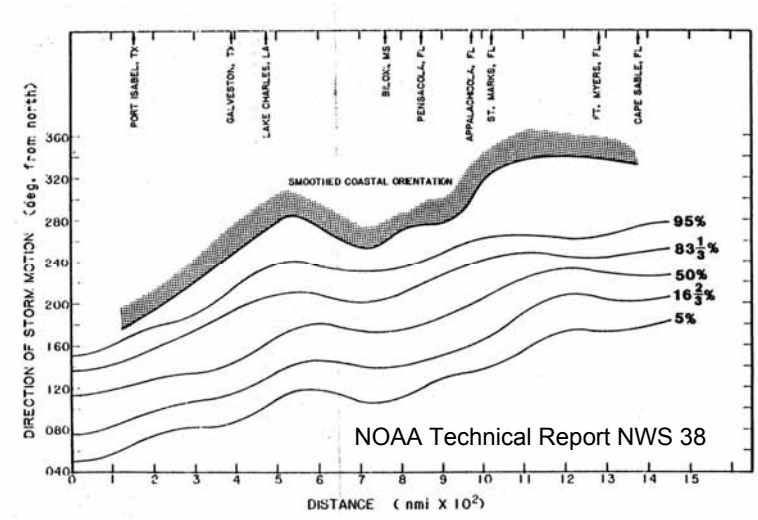
Wind Speed

- Ochi, M.K. 2004 Prediction of Hurricane Landfall Wind Speed along the Florida Coast: Statistical Analysis of NOAA HURDAT Data.



Procedure Outline

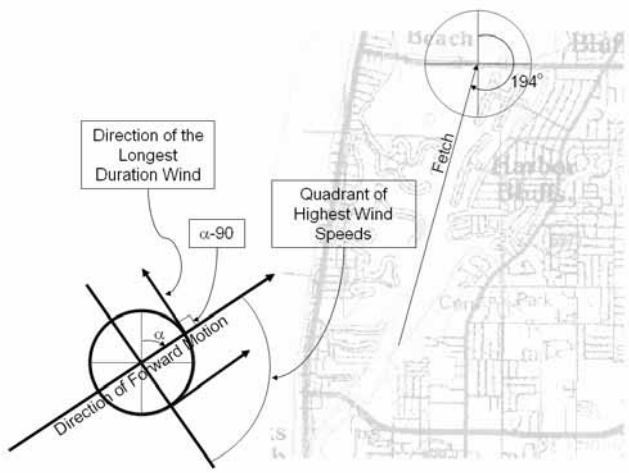
- Estimate Probability of Wind Direction



NOAA Technical Report NWS 38

Procedure Outline

- Estimate Probability of Wind Direction



2006 Design Conference

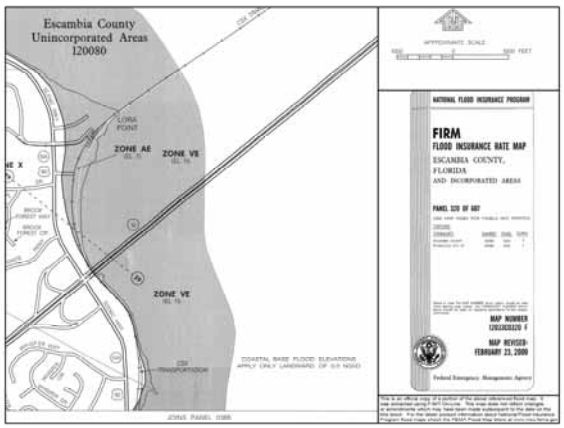
Procedure Outline

- Using Best Information Available (FEMA, etc.) Obtain 100-Year Storm Surge Elevations at Bridge Sites

2006 Design Conference

Procedure Outline

FEMA



Procedure Outline

- Using Empirical Equations for Estimating Significant Wave Height, Hs, and Peak Period, Tp, in USACOE Shore Protection Manual, Estimate these Parameters at the Bridge Sites

$$\frac{gH}{U_A^2} = 0.283 \tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{\tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right]}\right\}$$

$$\frac{gT}{U_A} = 7.54 \tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right] \tanh\left\{\frac{0.0379\left(\frac{gF}{U_A^2}\right)^{1/3}}{\tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right]}\right\}$$

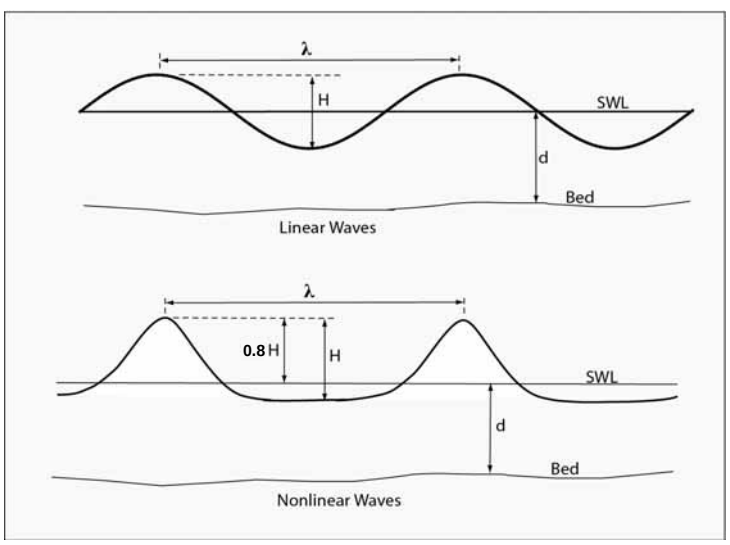
$$U_A = 0.71U^{1.23}$$

Procedure Outline

- Estimate Peak Wave Crest Height (adjust for uncertainty in prediction methods)

$$H_{\max} = 1.8 \times H_{sig}$$

Procedure Outline



Procedure Outline

- Estimate Peak Wave Crest Height (adjust for uncertainty in prediction methods)

$$\eta_{\max} = 0.8 \times H_{\max}$$

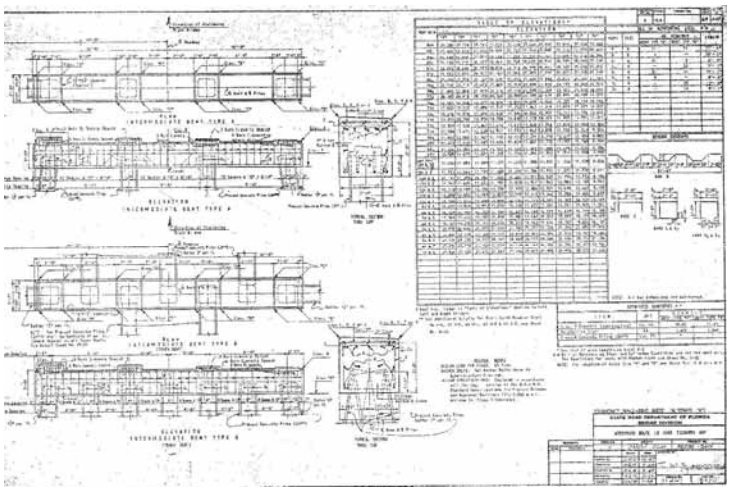
Procedure Outline

- Add Crest Height to Storm Surge Elevation to Obtain Peak Water Elevation

Maximum Elevation = η_{max} + Storm Surge Elevation

Procedure Outline

- Obtain Bride Plans (member elevations)

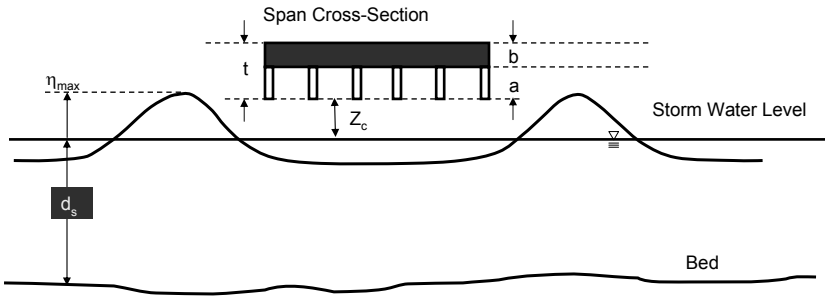


2006 Design Conference

Procedure Outline

- Determine (Crest Elevation/Deck Elevation)

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

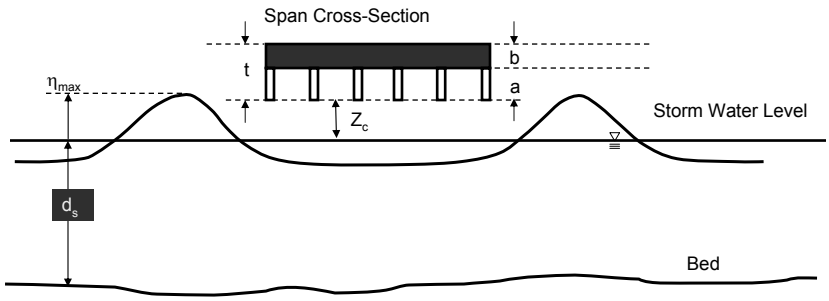


2006 Design Conference

Procedure Outline

- Determine Importance of Air Entrapment

$$\frac{a}{b}$$

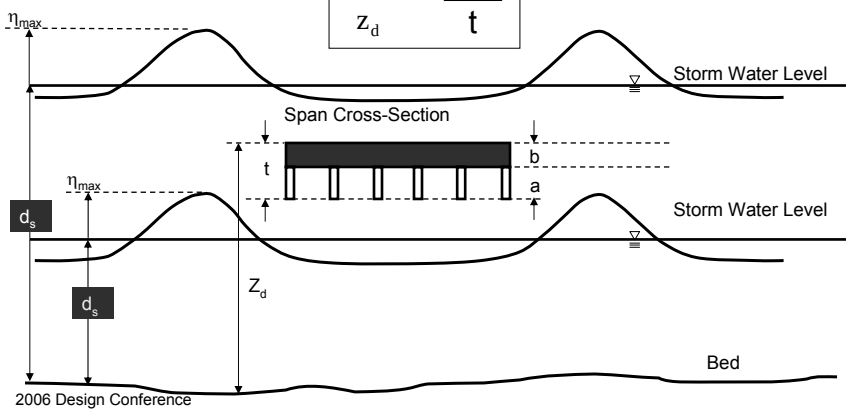


2006 Design Conference

Procedure Outline

- Determine the Affect of Storm Surge Elevation Relative to the Deck Elevation

$$\frac{d_s}{z_d} \qquad \frac{\eta_{max}}{t}$$



2006 Design Conference

Procedure Outline

- Determine Bridge Importance (Criticality)

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

Procedure Outline

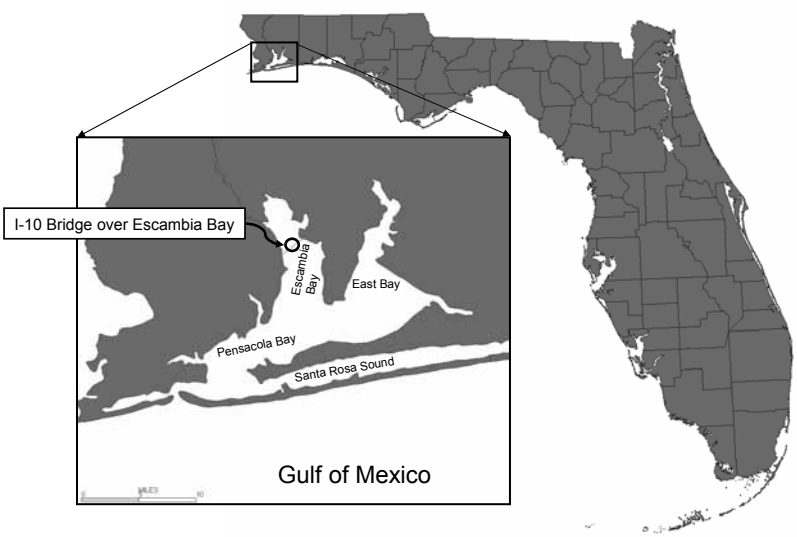
- Span Type
  - Single span
  - Continuous span

Procedure Outline

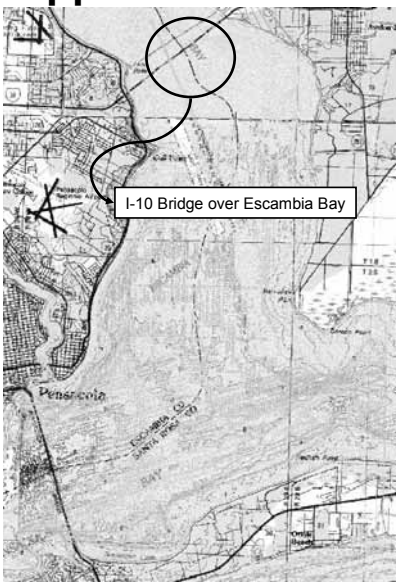
$\frac{\eta_{max}}{z_s}$	W	Wind Direction Probability	P	$\frac{d_s}{z_d}$	SS	$\frac{\eta_{max}}{t}$	E	Buoyancy $\frac{a}{b}$	B	Span Type	S	Criticality	C
( ) < 0	1	0.8 – 1.0	1.0	$\frac{d_s}{z_d} > 1.2$	2	$0.1 < \frac{\eta_{max}}{t} \le 0.5$	1	0 < ( ) < 1	0	single	1	1	0
0 < ( ) < 1	0	0.6 – 0.8	0.8	$1.2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

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

Example Application of the Procedure

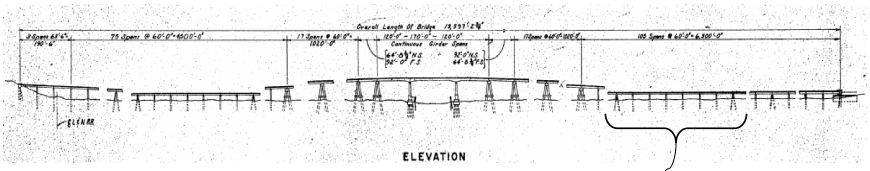


Example Application of the Procedure



2006 Design Conference

Example Application of the Procedure



Damaged Sections

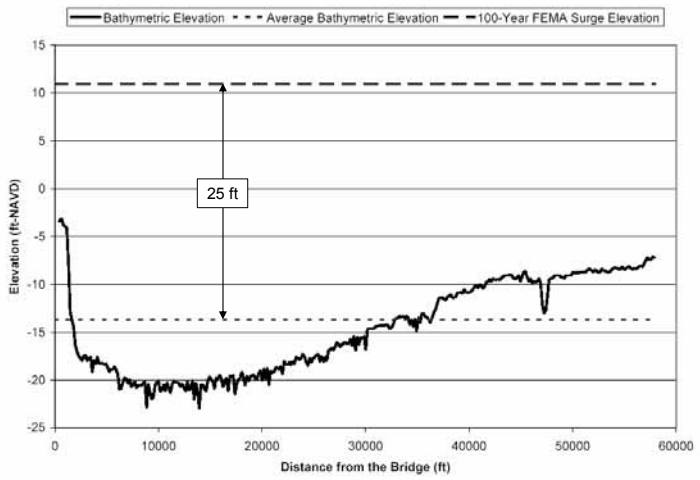
2006 Design Conference

Example Application of the Procedure

1. Extract the Fetch Length and Average Water Depth from the USGS Maps and Bathymetry

Example Application of the Procedure

Example Application of the Procedure



Example Application of the Procedure

1. Extract the Fetch Length and Average Water Depth from the USGS Maps and Bathymetry

   Average Depth = 25 ft
   Fetch Length = 11 miles

Example Application of the Procedure

2. Estimate the 100-year Significant Wave Height from the *Shore Protection Manual* (USACE, 1984) and the *Coastal Engineering Manual* (USACE, 2003)

   U = 120 MPH
   g = 32.2 ft/sec
   d = 25 ft
   F = 11 miles

Example Application of the Procedure

$$U_A = 0.71 U^{1.23}$$

$$\frac{gH}{U_A^2} = 0.283 \tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{\tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right]}\right\}$$

$$\frac{gT}{U_A} = 7.54 \tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right] \tanh\left\{\frac{0.0379\left(\frac{gF}{U_A^2}\right)^{1/3}}{\tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right]}\right\}$$

Example Application of the Procedure

- Adjusted Wind Speed

$$U_A = 0.71U^{1.23}$$

$$= 214.1 \text{ MPH}$$

Example Application of the Procedure

- Significant Wave Height

$$\frac{gH_s}{U_A^2} = 0.283 \tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{\tanh\left[0.53\left(\frac{gd}{U_A^2}\right)^{3/4}\right]}\right\}$$

$$H_s = 11.6 \text{ ft}$$

Example Application of the Procedure

- Peak Wave Period

$$\frac{gT}{U_A} = 7.54 \tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right] \tanh\left\{\frac{0.0379\left(\frac{gF}{U_A^2}\right)^{1/3}}{\tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right]}\right\}$$

T = 6.3 sec

Example Application of the Procedure

3. Convert Significant Wave Height to Maximum Wave Height

H_{max} = 1.8 X 11.6 = 21 ft

Example Application of the Procedure

4. Compare Maximum Wave Height to Depth Limited Wave Height

H_{depth} = 0.78 X 17.5 ft

= 13.7 ft > 21 ft

Therefore use H_{depth} = 13.7 ft

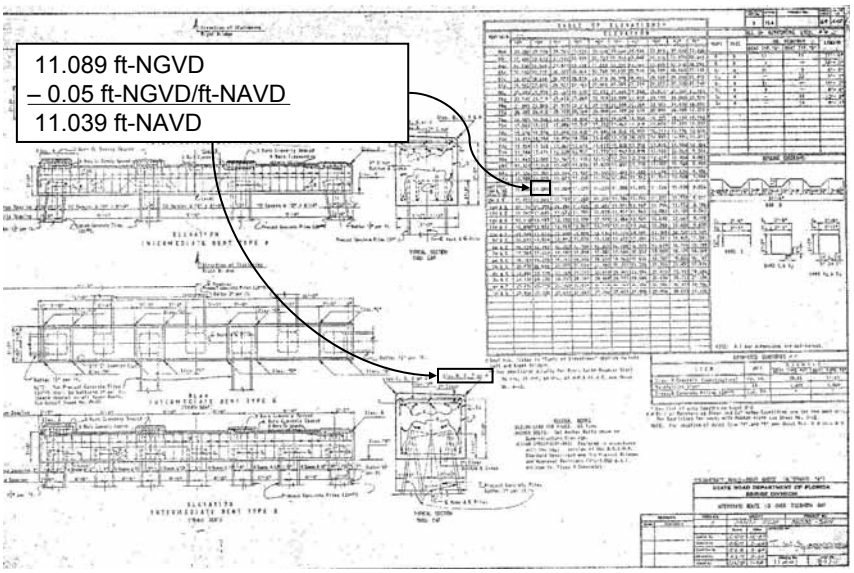
Example Application of the Procedure

5. Calculate Maximum Wave Crest Elevation by Adding 70% of the Wave Height to the 100-Year SWL

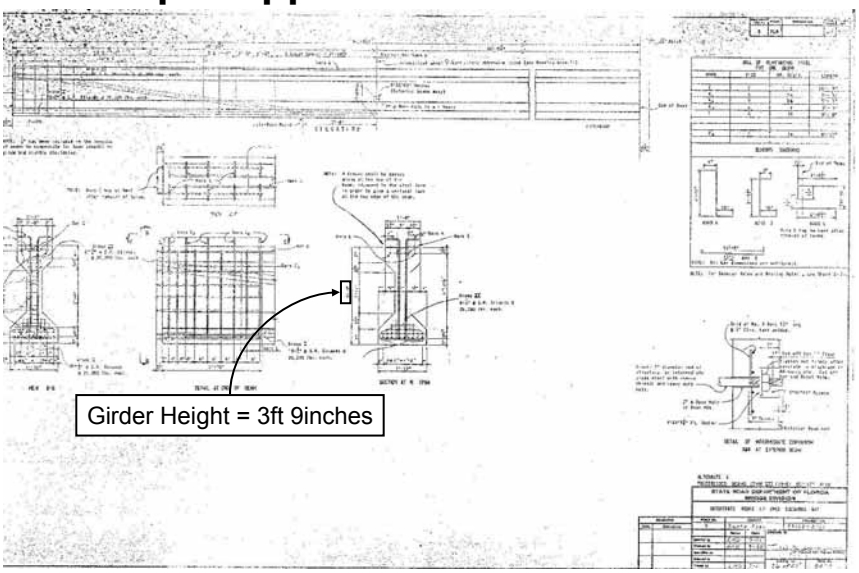
η_{max} = 0.80 X 13.7 ft + 11 ft-NAVD

= 22 ft-NAVD

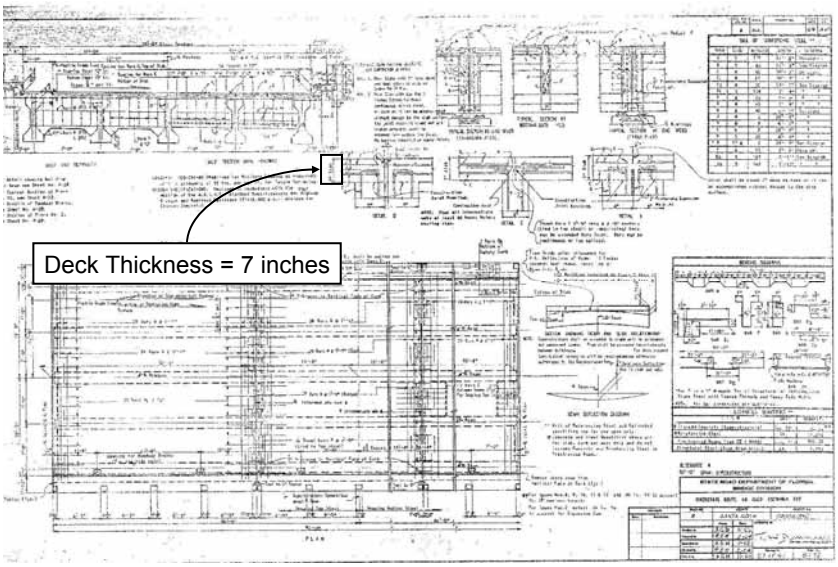
Example Application of the Procedure



Example Application of the Procedure



Example Application of the Procedure



2006 Design Conference

Example Application of the Procedure

$\frac{\eta_{max}}{z_c}$	W	Wind Direction Probability	P	$\frac{d_s}{z_d}$	SS	$\frac{\eta_{max}}{t}$	E	Buoyancy $\frac{a}{b}$	B	Span	S	Criticality	C	Wave Vulnerability Index
280.2	**1**	**0.15**	**0.5**	**0.85**	**3**	**2.5**	**3**	**6.4**	**3**	**1**	**1**	**4**	**6**	**8**

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

2006 Design Conference

Pilot Study Phase II

- Storm Surge
  - Improved storm surge information
    - Seek out other storm surge studies
    - Hindcast storm of record
- Wave Parameters
  - Improved wave information
    - Configure and run shallow water wave models
- Structure
  - More detailed structure information
- Surge/Wave and Resistance Forces
  - Compute surge/wave forces
  - Compute structural response

Further Analyses

- For those Bridges Predicted to Fail During Design Probability Examine Possible Retrofit Options
  - Cost/benefit analysis
- Retrofit Options
  - Subject of FHWA – Pooled Fund Study
  - Other studies
- Implement Selected Retrofit

Questions, Comments

2006
DESIGN CONFERENCE

Designing For More Than Bridges and Roads

2006 Design Conference