TASK DOCUMENT

TASK 6 - GUIDE SPECIFICATION AND RETROFIT MANUAL
TASK 6a – 90%GUIDE SPECIFICATIONS

August 17, 2007

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

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Possible Organization and Content for Coastal Specifications

~~(Article Numbers Relate to LRFD Specifications)~~

August 17, 2007

1. SCOPE

These specifications shall apply to bridges deemed to be important by the owner, and may be applied to other structures at the discretion of the owner. In making a decision as to which bridges qualify for treatment under these specifications, the screening concepts of the Handbook of Retrofit Options for Bridges Vulnerable to Coastal Storms should be used as a guide. Evacuation and rescue/recovery of the affected area should be a prime consideration when considering a system of bridges serving a coastal area. The effect on the local economy should also be considered.

2. DEFINITIONS

Not all of the definitions herein have been used in these specifications. They are, however, part of the lexicon of coastal engineering and may be useful when reading literature in the field.

ASTRONOMICAL TIDE
The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences.

BATHYMETRY
The measurement of water depths in oceans, seas, and lakes; also information derived from such measurements.

BUOYANCY
The resultant of upward forces, exerted by the water on a submerged or floating body, equal to the weight of the water displaced by this body.

DATUM
Any permanent line, plane or surface used as a reference datum to which elevations are referred.

DEPTH
The vertical distance from a specified datum to the sea floor.

DESIGN STORM
A hypothetical extreme storm whose waves coastal protection structures will often be designed to withstand. The severity of the storm (i.e. return period) is chosen in considering the acceptable level of risk of damage or failure.

DESIGN WAVE CONDITION
Usually an extreme wave condition with a specified return period used for the design of coastal works.

DURATION, MINIMUM
The time necessary for steady-state wave conditions to develop for a given wind velocity over a given fetch length.

EBB CURRENT
The movement of a tidal current away from shore or down a tidal stream.

EBB TIDE
The period of tide between high water and the succeeding low water; a falling tide.

FETCH LENGTH
The horizontal distance (in the direction of the wind) over which a wind generates seas or creates a wind setup.

FETCH-LIMITED
Situation in which wave energy (or wave height) is limited by the size of the wave generation area (fetch).

FLOOD CURRENT
The movement of a tidal current toward the shore or up a tidal stream.

FLOOD TIDE
The period of tide between low water and the succeeding high water; a rising tide. (See Figure II-5-16)

HIGHEST ASTRONOMICAL TIDE (HAT)
The highest level of water which can be predicted to occur under any combination of astronomical conditions. This level may not be reached every year.

HINDCASTING
In wave prediction, the retrospective forecasting of waves using measured wind information.

HURRICANE
An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 33.5 m/sec (75 mph or 65 knots) for several minutes or longer at some points. TROPICAL STORM is the term applied if maximum winds are less than 33.5 m/sec but greater than a whole gale (63 mph or 55 knots). The term is used in the Atlantic, Gulf of Mexico, and eastern Pacific.

IRREGULAR WAVES
Waves with random wave periods (and in practice, also heights), which are typical for natural wind-induced waves.

JOINT PROBABILITY
The probability of two (or more) things occurring together.

JOINT RETURN PERIOD
Average period of time between occurrences of a given joint probability event.

MEAN HIGH WATER SPRINGS (MHWS)
The average height of the high water occurring at the time of spring tides.

MEAN HIGHER HIGH WATER (MHHW)
The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

MEAN SEA LEVEL (MSL)
The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. MSL is not necessarily equal to MEAN TIDE LEVEL. It is also the average water level that would exist in the absence of tides.

MEAN TIDE LEVEL (MTL)
A plane midway between MEAN HIGH WATER and MEAN LOW WATER. MTL is not necessarily equal to MSL. Also HALF-TIDE LEVEL.

MONOCHROMATIC WAVES
A series of waves generated in a laboratory, each of which has the same length and period.

NUMERICAL MODELING
Refers to analysis of coastal processes using computational models.

OVERTOPPING
Passing of water over the top of a structure as a result of wave runup or surge action.

PARTICLE VELOCITY
The velocity induced by wave motion with which a specific water particle moves within a wave.

PHYSICAL MODELING
Refers to the investigation of coastal or riverine processes using a scaled model.

PROBABILITY
The chance that a prescribed event will occur, represented by a number (p) in the range 0 - 1. It can be estimated empirically from the relative frequency (i.e. the number of times the particular event occurs divided by the total count of all events in the class considered).

REFRACTION (of water waves)
The process by which the direction of a wave moving in shallow water at an angle to the contours is changed: the part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours.

RETURN PERIOD
Average period of time between occurrences of a given event.

RISK ANALYSIS
Assessment of the total risk due to all possible environmental inputs and all possible mechanisms.

SCOUR
Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

SEAS
Waves caused by wind at the place and time of observation.

SHOALING
Decrease in water depth. The transformation of wave profile as they propagate inshore.

SIGNIFICANT WAVE HEIGHT
The average height of the one-third highest waves of a given wave group.

SIGNIFICANT WAVE PERIOD
An arbitrary period generally taken as the period of the one-third highest waves within a given group.

SOUNDING
A measured depth of water. On hydrographic CHARTS, the soundings are adjusted to a specific plane of reference.

STORM SURGE [TO BE REVISED]
A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a hurricane also includes that rise in level due to atmospheric pressure reduction as well as that due to wind stress. See WIND SETUP.

SWELL
Wind-generated waves that have traveled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch (SEAS).

TIDE
The periodic rising and falling of the water that result from gravitational attraction of the Moon and Sun and other astronomical bodies acting upon the rotating Earth.

TSUNAMI
A long-period water wave caused by an underwater disturbance such as a volcanic eruption or earthquake. Commonly miscalled "tidal wave."

UPLIFT
The upward water pressure on the base of a structure or pavement.

WATER DEPTH
Distance between the seabed and the still water level.

WATER LEVEL
Elevation of still water level relative to some datum.

WAVE
A ridge, deformation, or undulation of the surface of a liquid.

WAVE CREST
The highest part of a wave.

WAVE DIRECTION
The direction from which a wave approaches.

WAVE FREQUENCY
The inverse of wave period.

WAVE HEIGHT
The vertical distance between a crest and the preceding trough.

WAVE PEAK FREQUENCY
The inverse of wave peak period.

WAVE PEAK PERIOD
The wave period at which the wave energy spectrum reaches its maximum.

WAVE SETUP
Superelevation of the water surface over normal surge elevation due to onshore mass transport of the water by wave action alone.

WAVE STEEPNESS
The ratio or wave height to wavelength also known as sea steepness.

WAVE TRANSFORMATION
Change in wave energy due to the action of physical processes.

WAVE TROUGH
The lowest part of a wave form between successive crests. Also that part of a wave below still-water level.

WAVE LENGTH
The horizontal distance between similar points on two successive waves measured perpendicular to the crest.

WEIBULL DISTRIBUTION
A model probability distribution, commonly used in wave analysis.

WIND SETDOWN
Drop in water level below the still water level on the windward ends of enclosed bodies of water and semi-enclosed bays.

WIND SETUP - LOCAL
On reservoirs and smaller bodies of water, the vertical rise in the still-water level on the leeward side of a body of water caused by wind stresses on the surface of the water.

WIND WAVES
(1) Waves being formed and built up by the wind. (2) Loosely, any wave generated by wind.

3. NOMENCLATURE

(To be taken from where lists and consolidated in final draft)

4. GENERAL

4.1 Storm Clearance

Wherever practical, the vertical clearance of highway bridges should be sufficient to provide at least 3 ft. of clearance over the 100-year design wave crest elevation, which includes the design storm water elevation.

For bridge spans where this vertical clearance is not possible, other design strategies may be considered including those identified in Article 4.2. Bridges located with less than 3 ft. of clearance over the design wave crest elevation shall be designed assuming a minimum of 1 ft. intrusion into the wave. Wave effects on substructure shall be investigated in accordance with the provisions of Article 6.2.3.

C4.1

Setting vertical elevations to keep as much of the structure as possible above the design wave crest elevation clearly decreases the vertical and horizontal surge and wave-induced forces. Additional freeboard beyond that indicated in this article should be considered due to the large uncertainty in the basic wave and surge data needed to determine the design wave crest elevation.

4.2 Design Strategies for Coastal Storms

4.2.1 General

Regardless of the design strategy chosen for a particular bridge, early input from a coastal engineer to clarify coastal issues and scope for the bridge should be considered.

C4.2.1

Further discussion on the credentials recommended for a coastal engineer, and a list of some conditions which require more extensive involvement of a coastal engineer are provided in C6.2.1.

4.2.2 Avoidance

The provisions of Article 4.1 shall apply.

4.2.3 Force Mitigation

Where it is not possible to provide the vertical clearance recommended in Article 4.1, the following may be considered to reduce the wave forces acting on the superstructure:

- Setting the vertical elevation as high as practical
- Using open or sacrificial parapets
- Venting the potential cells that could entrap air creating increased buoyancy forces
- Using large holes in concrete diaphragms or framed cross-frames and end diaphragms on concrete superstructures to promote venting and the exchange of trapped air between spans
- Using continuous superstructures to increase the reactive force of individual spans
- Using solid or voided slab bridges to reduce buoyancy forces

C4.2.3

Some of the force mitigation measures specified in this article are based on observations of the response of structures to coastal hurricanes.

At Lake Pontchartrain Bridge in Louisiana, 14,000 ft of parapet were broken off. This performance suggests that either a shorter overhang or the use of a parapet that would respond inward in a sacrificial manner, while still providing the required traffic barrier resistance outward, could reduce the amount of area exposed to the waves. This response could also promote inundation which reduces the total wave force to be resisted.

Calculated estimates of the effect of entrapped air on the vertical wave forces on the Lake Pontchartrain I-10 Bridge and the Escambia Bay I-10 Bridge have shown that the vertical force can be substantially reduced if the amount of air entrapped between the beams can be reduced. Calculations based on venting the cavities formed by beams and diaphragms on selected spans from those two bridges indicated that it was not practical to drill deck holes to vent air entrapped by waves. Holes could be effective in reducing the amount of air entrapped when the still water elevation is between the bottom of the beams and the bottom of the deck. This behavior occurs because the surge effects that create the still water elevation occur over a much longer time frame than wave action.

The use of large holes in concrete diaphragms, framed cross-frames and end diaphragms, or concrete partial depth diaphragms can be effective in venting entrapped air and allowing the exchange of trapped air between spans. Figure C1 shows the area of hole necessary to permit evacuation of a volume of air for different times.

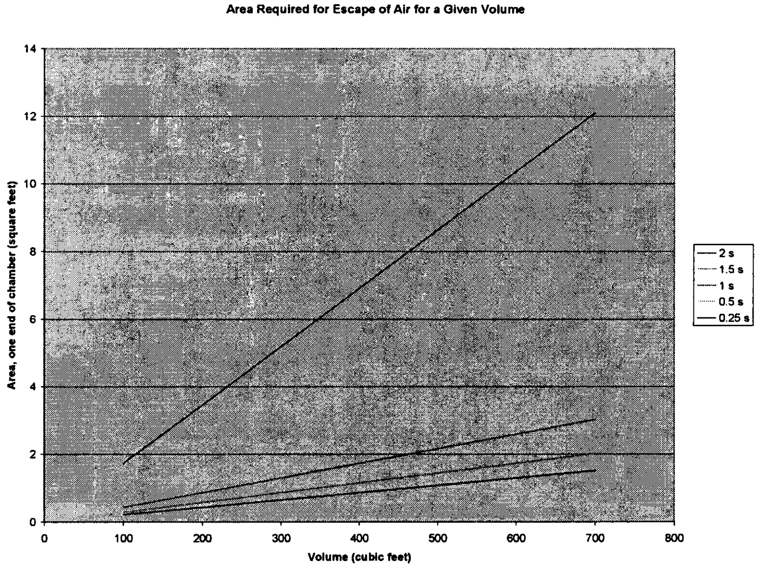

Figure C4.2.3-1 – Venting Requirements

Figure to be replaced with one using vertical wave velocity as basis.

Continuous superstructures appear to have benefits due to the three-dimensionality of the waves because storm waves have finite crest lengths. Therefore, the chance of multiple spans being struck by design waves at the same time is small. Thus, the ability of the structure to resist vertical and horizontal forces are increased through continuous spans.

The use of slab bridges may be especially appropriate to raise some spans sufficiently to avoid wave forces such as those near the ends of bridges which have grade constraints.

4.2.4 Force Accommodation

4.2.4.1 General

Design for coastal storms may be based on any of the strategies identified herein. Design and detailing should achieve an engineered response involving avoiding wave loads, accommodating the full loads, accommodating partial loads with superstructure damage or loss above a chosen load, or submergence. The engineered responses other than avoidance should be predicted using design parameters and the methods outlined herein, and designed to protect the substructure so that it can be reused if the superstructure is lost.

C4.2.4.1

In recent cases where the superstructure was lost but the substructure remained largely re-usable, it was possible to re-open bridges with either temporary superstructures or permanent superstructures in much less time, and at much lower cost than if the substructure had been functionally destroyed by the combination of forces transmitted from the superstructure and those applied directly to the substructure. Therefore, design to protect the substructure is recommended herein.

Where partial or complete force accommodation is provided, there may be significant upward forces due to hydrodynamic and hydrostatic (buoyancy) effects, which may cause a reversal of the normal moments and shears. This requires investigation.

4.2.4.2 Design for the Full Wave Loads

The structure may be designed to resist the loads calculated in accordance with the provisions specified in Articles 6.2.3 and 6.3.

4.2.4.3 Fusing for Partial Loads

Where design for the full wave loads specified in Articles 6.2.3 and 6.3 is not justified by the construction cost impacts or the importance of the bridge, the Owner may design the superstructure to break away from the substructure at less than the full loads.

C4.2.4.3

Various concepts for fusing parts of structures to dissipate the energy of seismic events have been considered and applied. Many of these applications used plastic bending deformation to create the fuse effect. This concept is not necessarily applicable to the coastal storm situation because the amount of deformation would have to be considerable. The concepts of fusing that are applicable to the coastal storm situation involve units designed to fail in tension or separate in some manner to allow the superstructure to float free, thus preserving the substructure for future use.

4.2.4.4 Sacrificial Superstructure

Superstructures may be designed to separate from the substructure either under the action of vertical forces, which include buoyancy as determined herein, horizontal forces, or any combination thereof. Where this strategy is used, the design and details shall ensure that separation occurs only when the forces associated with the 100-year design event are exceeded.

C4.2.4.4

Sacrificial superstructures are a variation of the fusing for partial loads specified under Article 4.2.4.3. In some cases where it is not possible to elevate structures or to resist the loads in an economical and safe way, it may be necessary to sacrifice low level spans, and replace them after the storm.

Past experience has shown that freed, i.e. separated, superstructure units have caused damage to substructure.

4.2.5 Submersible Superstructures

Spans may be designed to be totally inundated at the design wave crest elevation, provided they can be designed to resist the forces caused by wave crest elevations (including storm water levels) lower than the 100-year design values.

C4.2.5

Submersible structures may have application in low level approach structures similar to situations were sacrificial superstructures are also applicable. Wave forces will tend to be smaller once the structure is totally submerged in the water. Submersible heavy structures with small volumes of voids, which reduce the buoyancy, may be a cost effective solution in some cases.

5. LOAD COMBINATIONS

The following Strength Limit State Load Combination shall be considered for bridges vulnerable to wave or surge forces associated with coastal storms:

$$\gamma_d DC + \gamma_d DD + \gamma_d DW + \gamma_d EL + \gamma_{wave} WA \qquad (5\text{-}1)$$

where:

DC = dead load of structural components and nonstructural attachments
DD downdrag
DW = dead load of wearing surfaces and utilities
EL = accumulated locked-in force effects resulting from the construction process, including the secondary forces from post-tensioning
WA = wave forces F_v, F_s, F_H and M_t specified in Articles 6.2.2 and 6.2.3
γ_d = minimum load factors for dead loads as specified in Article 3.4.1 of the *AASHTO LRFD Bridge Design Specifications*
γ_{wave} = load factors on wave forces

For values of η_{wave}-$Z_c > 4$, the load factor for wave loads, γ_{wave}, shall be taken as 2.25.

Work is ongoing to determine the appropriate value for η_{max}-Zc < 4

C5.1

Since dead loads generally resist the wave loads, consideration should be given to whether DW can be reasonably expected to be in place for design event.

6. FORCES ASSOCIATED WITH COASTAL STORMS

6.1 [Add Air Entrapment]

6.2 Hydrodynamic Loads and Design Parameters

6.2.1 General

The provisions of this article shall be taken to apply to bridges located in areas where they may be impacted by storm events.

Information required for establishment of structure vertical alignment and determination of coastal storm forces on the structure should include as a minimum:

- Bridge location within the water system
- Bridge elevation

- Structure dimensions, shape and orientation relative to the water body
- Bathymetry of the water body
- Fetch length orientation relative to the bridge location
- Fetch and fetch angle segment for waves
- Fetch and fetch angle segment for local wind setup/setdown
- Design wave height and period (wave length)
- Design wind velocity
- Design storm water level composed of: (1) astronomical tide, (2) storm surge created by reduced atmospheric pressure, wind stress on water surface and wave setup, and (3) local wind set-up/set-down
- Design current velocity

[Figure to illustrate fetch angle segment for waves and wind setup/setdown. - Max]

Determination of the appropriate design parameters may proceed according to the three levels of analysis specified in Article 6.3. Determination of which level to use shall be based on the replacement value and importance of the structure under consideration, and site-specific parameters such as the complexity of the water boundaries and bathymetry, quantity and quality of meteorological/oceanographic data for the site, etc. A Level I analysis (Article 6.3.2) may be used initially to determine if a more sophisticated analysis is necessary. Alternatively, Level I may be bypassed when the conditions at a particular site and/or the importance of the bridge clearly indicate that a higher level of analysis is appropriate.

Input from a qualified coastal engineer experienced in the determination of these design parameters shall be obtained for Level I analyses. Level II and Level III analyses shall be performed by a qualified coastal engineer experienced in the determination of these design parameters.

C6.2.1

The load factors presented in Article 5 are based on a design event that is assumed to be a one in one-hundred year (referred to here as one hundred year) event. For the Level I and Level II analyses discussed in Articles 6.3.2 and 6.3.3, the initial definition of such an event is the 100-year return period wind velocity combined with the 100-year return period wave height (and period), the 100-year return period water level and the 100-year return period current speed. However, due to the fact that these parameters are not necessarily 100% correlated for coastal storm events, this definition may yield results that are conservative, and in many cases may be too conservative. How much greater depends primarily on site-specific parameters. Therefore, load modifiers are presented in Articles 6.2.2.6 and 6.3.3.7 for Level I and Level II, respectively, based on site-specific parameters that are illustrated by examples.

The forces exerted on a bridge superstructure by elevated water levels and waves depend on all the quantities that govern the magnitudes of these parameters as identified in this article, as well as the size, shape and elevation of the superstructure. The most accurate way to estimate 100-year loads for an important or expensive bridge is with a Level III analysis where the forces on the superstructure produced by the most significant storms at that location are recreated (hindcasted) and an extremal analysis is performed. The purpose of the Level III analysis is to better ascertain the design parameters. The Level III analysis will require more extensive data collection and the use of more sophisticated computer numerical and/or analytical modeling techniques available to the coastal engineering community as discussed in Article 6.3.4.

The criteria to establish suitable credentials in coastal engineering are not fully developed at this time. Until such time as a consensus on certification is reached, the following statement developed by the Florida DOT may be considered.

> "A Coastal Engineer must hold a M.S. or Ph.D. in Coastal Engineering or a related Engineering field and/or have extensive experience (as demonstrated by technical publications in technical journals with peer review) in coastal hydrodynamics, wave mechanics, and/or sediment transport processes. If computer modeling of storm surge, waves, etc. is required, demonstrated expertise/experience in this area is also required."

Conditions that typically require direct attention by a Coastal Engineer are listed below:

- Hydraulic analysis of complex geometry tidal water bodies,

- Hindcasting of historical hurricane events,
- Determination of design wave parameters,
- Analysis of inlet or channel instability, either vertically or horizontally,
- Prediction of potential wave scour at bridges and seawalls,
- Design of countermeasures for wave induced erosion/scour at bridge abutments and approaches,
- Prediction of barrier island overtopping and channel cutting,
- Design of countermeasures for inlet instability, wave attack, or channel cutting,
- Prediction of global coastal sediment transport or design of countermeasures to control global sediment transport,
- Assessment of wave loading on bridges and other structures,
- Determination of design hurricane parameters,

6.2.2 Hydrostatic and Hydrodynamic Forces and Moments on Superstructure

6.2.2.1 General

The following contributors to hydrostatic and hydrodynamic loads on superstructures shall be considered as appropriate:

- Buoyancy
- Drag and inertia forces
- Forces associated with added mass
- Vertical slamming forces

The vertical force shall be considered to be sum of two parts referred to herein as 1) the quasi-static force and 2) the slamming force.

The equations for forces and moments given herein were developed around the trailing edge of the girders, as shown in Figure 1, and calculations of force effects on the structure shall start with the forces assumed to be applied at the trailing edge. The value of M_t shall be taken as specified in Article 6.2.2.5.

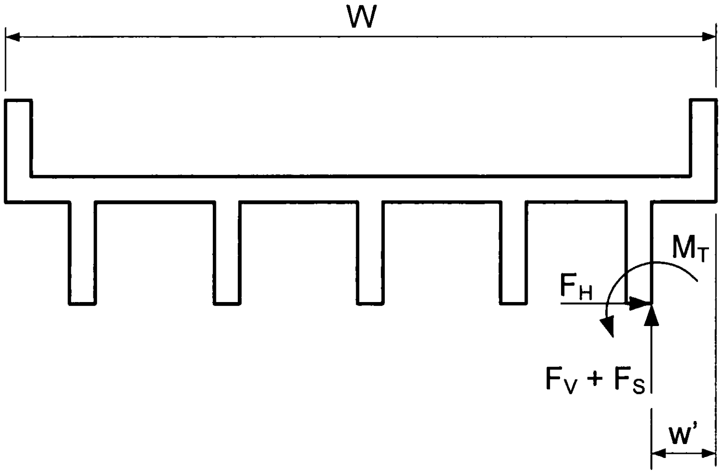

Figure 6.2.2.1-1 – Location of Forces and Moments

Where Equation 1 is not satisfied, the structure is above the wave zone and, therefore, the wave forces need not be determined.

$$\frac{Z_c}{\eta_{max}} \leq 1.0 \qquad (6.2.2.1\text{-}1)$$