United States Nuclear Regulatory Commission

Protecting People and the Environment

JAPAN LESSONS-LEARNED PROJECT DIRECTORATE

JLD-ISG-2012-06

Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment

DRAFT Interim Staff Guidance

November 14, 2012

PURPOSE

This interim staff guidance is being developed to describe to stakeholders methods acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for performing tsunami, surge, or seiche hazard assessments in response to NRC's March 12, 2012 request for information issued pursuant to Title 10, Code of Federal Regulations, Part 50, Section 54 (10 CFR 50.54).

BACKGROUND

- March 2011 events at the Fukushima Dai-ichi nuclear power plant

- NRC established a senior-level agency task force referred to as the Near-Term Task Force (NTTF) which conducted a systematic and methodical review of the NRC regulations and processes.

- Commission direction and the Consolidated Appropriations Act, Public Law 112-074, was signed into law on December 23, 2011. Section 402 of the law requires a reevaluation of licensees' design basis for external hazards.

- NRC issued a request for information to all power reactor licensees and holders of construction permits under 10 CFR Part 50 on March 12, 2012.

- March 12, 2012 50.54(f) letter includes a request that respondents reevaluate flooding hazards at nuclear power plant sites using updated flooding hazard information and present-day regulatory guidance and methodologies.

GUIDANCE FOR PERFORMING A SURGE OR SEICHE HAZARD ASSESSMENT
(ENCLOSURE 1)

CONTENT

Section 1- Guidance Fformat and Historical perspective

Section 2 – Acceptance Criteria

Section 3 – Surge Hazard Assessment

Section 4 – Seiche Hazard Assesement

Section 5 - Wave and Inundation Effects for Surge and Seiche

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SECTION 1: HISTORICAL PERSPECTIVE

1979 – NOAA introduces concept of Probable Maximum Hurricane (PMH): “A hypothetical steady-state hurricane having a combination of values of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location” [National Weather Service (NWS) Technical Report 23]

2005 - In response to Hurricane Katrina, NRC formed a storm surge research program focused on developing modern, risk informed, hazard assessment techniques and additional guidance through cooperation with the National Oceanic and Atmospheric Administration (NOAA) and United States Army Corps of Engineers (USACE).

2007 – NRC emphasis on PMH characteristics was superseded by the adoption of the Probable Maximum Storm Surge (PMSS) hazard assessment.

SECTION 1: HISTORICAL PERSPECTIVE (cont'd)

2009 - USACE Engineer Research and Development Center/Coastal and Hydraulics Laboratory (ERDC CHL) was tasked by the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research (RES) to review the NOAA Technical Report NWS 23 ("Meteorological Criteria for Standard Project Hurricane (SPH) and Probable Maximum Hurricane (PMH) Wind fields, Gulf and East Coasts of the United States") and the NRC Regulatory Guide 1.59 ("Design Basis Floods for Nuclear Power Plants").

ERDC CHL review finding(s):

Several assumptions in the PMH described in NWS 23 are not consistent with the current state of knowledge. RG 1.59 ocean model limited by restrictions and simplifications given the computer resources available in the early to mid-1970's.

Recommended that a modern coupled system of wind, wave, and coastal circulation models that properly define the physical system and include an appropriate non-linear coupling of the relevant processes be adopted.

SECTION 2:
ACCEPTANCE CRITERIA

Existing Regulatory Guidance:

- ***10 CFR Part 50***, "Licensing of Production and Utilization Facilities." General Design Criterion 2 (GDC2)

- ***10 CFR Part 100***, "Reactor Site Criteria"

- ***NUREG-0800,*** "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)" **(2007)**

- ***NUREG/CR-7046***, "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America" **(2011)**

- ***Regulatory Guide 1.59***, "Design Basis Floods for Nuclear Power Plants," Revision 2 **(1977)**

- ***Regulatory Guide 1.27***, "Ultimate Heat Sink for Nuclear Power Plants," Revision 2 **(1976)**

SECTION 2:
ACCEPTANCE CRITERIA (cont'd)

Existing Regulatory Guidance (cont'd):

- ***Regulatory Guide 1.102,*** "Flood Protection for Nuclear Power Plants," Revision 1 **(1976)**
- ***Regulatory Guide 1.206,*** "Combined License Applications for Nuclear Power Plants," **(2007)**
- ***ANSI/ANS-2.8-1992,*** "American National Standard for Determining Design Basis Flooding at Nuclear Reactor Sites," **(1992)**
- ***JLD-ISG-2012-05***, Integrated Assessment ISG **(2012)**.

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SECTION 2: ACCEPTANCE CRITERIA (cont'd)

Updates to Guidance:

- This ISG is consistent with practices by other federal agencies.
- In current practice for storm surge, other federal agencies no longer use the "probable maximum" or "standard project" terminology. However, NRC guidance uses these terms.
- In this ISG, the "probable maximum" terminology referenced in NUREG-0800, Regulatory Guide 1.59, Regulatory Guide 1.206 and ANSI/ANS-2.8-1992 is not used. Instead, the terms "simulated" and "design basis" are used as defined in the Appendix (Glossary):

Design Basis Flood (DBF)
Simulated Hurricane (SH)
Simulated Wind Storm (SWS)
Simulated Storm Surge (SSS)
Design Basis Storm Surge (DBSS)

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SECTION 2: ACCEPTANCE CRITERIA (cont'd)

Updates to Guidance (cont'd):

The determination of the storm surge from the one-dimensional models and DBSS estimates using the associated simplified methods provided in Appendix C of Regulatory Guide 1.59 (1977) are not considered acceptable and are not currently used for new reactor application storm surge hazard assessments.

The current practice in storm-surge modeling is based on the use of coupled hydrodynamic ocean circulation and wave models, both driven by a planetary boundary layer (PBL) model that provides the atmospheric forcing (see next slide).

The meteorological input for atmospheric forcing provided in NWS 23 (1979) is still acceptable for licensing decisions when coupled with NOAA or USACE storm surge models.

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SECTION 2: ACCEPTANCE CRITERIA (cont'd)

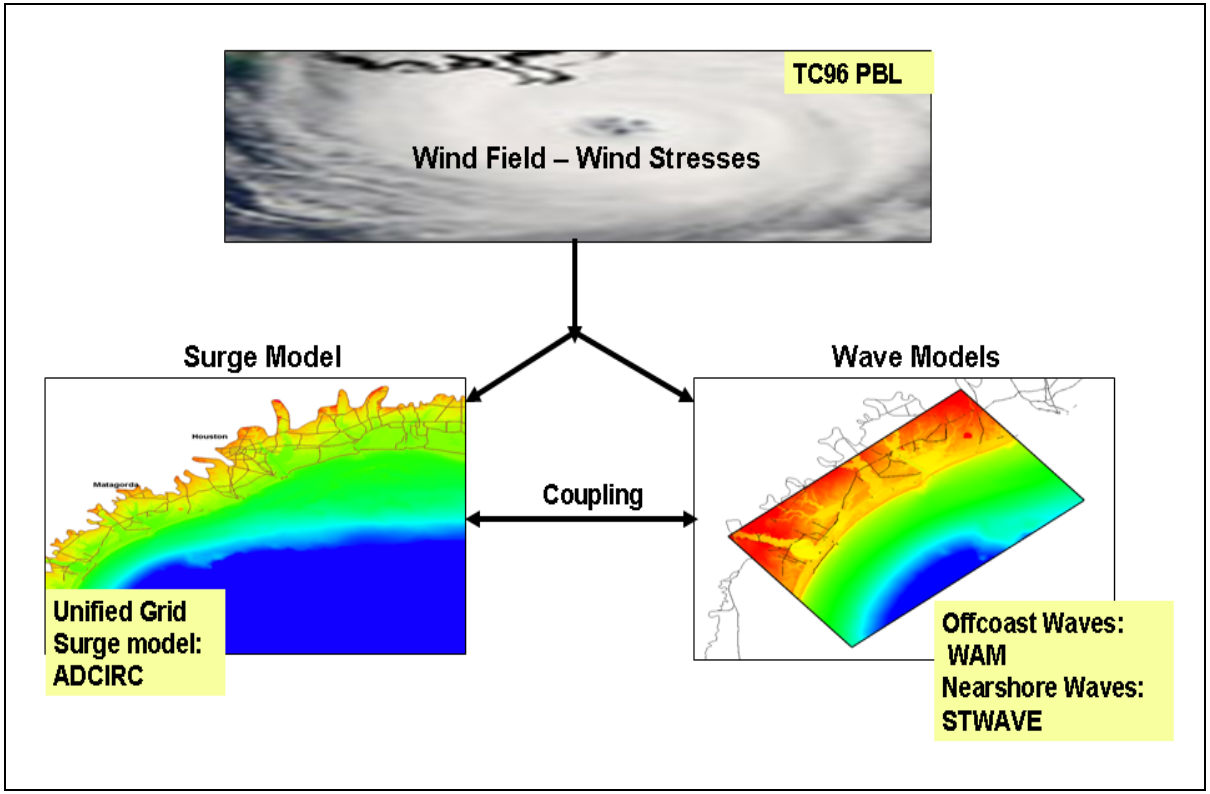

Figure 1: Storm surge modeling system (Resio et al., 2012)

SECTION 3:
SURGE HAZARD ASSESSMENT

Section 3.1 - Overview

Section 3.2 – Meteorological parameters

Section 3.3 – Surge parameters

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Overview:

Probabilistic-only and the deterministic-only approaches to the estimation of very low-probability storm surges have their strengths and deficiencies, depending on the safety hazard assessment objective.

The NRC currently uses a deterministic-only approach in conjunction with the hierarchical hazard approach (HHA) for storm surge hazard assessments.

Other federal agencies join the two approaches to provide some advantages over either approach implemented independently. For example, the USACE has developed a probabilistic-deterministic methodology for storm surge hazard assessment that can be combined with the HHA to provide a DBSS with risk information.

This ISG is consistent with practices by other federal agencies.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

1 Definition or refinement of meteorological parameters for hurricanes as well as extra-tropical storms and squall lines, as applicable [ISG Section 3.2]

2 Definition or refinement of surge parameters including antecedent water levels (astronomical tides, initial rise, and sea level rise), as applicable [ISG Section 3.3.2]

3 Computation of surge water levels using meteorological and surge parameters [ISG Section 3.3.3]

4 Evaluation of wave and inundation effects [ISG Section 5]

5 Surge elevation < Site elevation?

No

Yes

6 Can variables & parameters be further refined?

Yes

No

7 Storm surge assessment complete

Figure 2: Storm Surge Hierarchical Hazard Assessment

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 1 (Section 3.2- Meteorological Parameters):

Storm surge can result from several different types of storms (e.g., tropical cyclones, extra-tropical cyclones, squall lines, and hybrid storms).

The historical record for each storm type appropriate for the region should be examined to determine estimates for extreme winds.

This detailed analysis of historical storm events in the region should be augmented by simulated storms parameterized to account for conditions more severe than those in the historical record, but considered to be reasonably possible on the basis of meteorological reasoning.

Four techniques are considered in this guidance for simulated storm generation:

- Probable Maximum Hurricane (PMH)
- Joint Probability Method (JPM)
- ANSI/ANS-2.8-1992
- Empirical Simulation Technique (EST)

SECTION 3: SURGE HAZARD ASSESSMENT (cont'd)

Step 1- Meteorological Parameters (cont'd):

Hurricane Parameters

Probable Maximum Hurricane (PMH) [Deteministic]**-**

NOAA NWS Technical Report 23 (Schwerdt et al., 1979) describes the PMH method in detail. PMH meteorological parameters, as described in NUREG-0800 Section 2.4.5, define the physical attributes of the PMH to derive wind fields that can serve as input into an atmospheric model. Storm surge model simulations are performed with numerous combinations of PMH parameters to obtain the highest design basis storm surge (DBSS) at the site (Deterministic).

The PMH parameter values in NWS 23 were based on data from historical hurricanes from 1851 to 1977. A detailed site/region specific hurricane climatology study should be provided to show that the PMH parameters are consistent with the current state of knowledge (e.g., storm size; Hurricane Katrina and Hurricane Sandy).

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 1- Meteorological Parameters (cont'd):

Hurricane Parameters

Joint Probability Method (JPM) [Deterministic-Probabilistic] **-**

The JPM has been used for simulating hurricanes since the late 1960's. The JPM approach is a simulation methodology that relies on the development of statistical distributions of key hurricane input parameters (central pressure, radius of maximum winds, translation speed, and heading) and sampling from these distributions to develop model hurricanes.

Simulation methods such as JPM are widely used for coastal flood frequency analysis primarily because of the unavailability of sufficient historical record from which to derive frequencies by more conventional means, such as gage analysis. For this reason, JPM is widely used in coastal flood studies performed by the USACE and FEMA.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 1- Meteorological Parameters (cont'd):

Extra-tropical and Squall Line Parameters

ANSI/ANS-2.8-1992 [Deterministic]:

Provides detailed guidance on extra-tropical windstorms and squall lines.
For the Great Lakes, a set of fixed criteria of extra-tropical storm parameters is provided in lieu of a meteorological study.

A moving squall line should be considered for the locations along Lake Michigan where significant surges have been observed because of such a meteorological event. The possible region of occurrence includes others Great Lakes.

A detailed site/regional specific meteorological study should be conducted to identify applicable mechanisms and to verify that the ANSI/ANS-2.8-1992 assumptions reflect the most severe meteorological parameters.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 1- Meteorological Parameters (cont'd):

Extra-tropical and Squall Line Parameters

Empirical Simulation Technique (EST) [Deterministic-Probabilistic]:

The EST approach has been used for simulating storms since the late 1990's. Unlike hurricanes, extra-tropical storms are not easily represented by a set of storm parameters. EST estimates for a site are based entirely on the historical storms and flood levels observed at that site. Alternate life cycles are simulated by assuming that storm occurrence follows a stochastic process and by implementing a bootstrap resampling from the set of observed events to construct synthetic records.

Simulation methods such as EST are widely used for coastal flood frequency analysis primarily because of the unavailability of sufficient historical record from which to derive frequencies by more conventional means, such as gage analysis. For this reason, EST is widely used in coastal flood studies performed by the USACE and FEMA.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 2 (Section 3.3.2 - Surge Parameters):

Datums -With the exception of the Great Lakes that use regional datums, elevations should be documented as NAVD88.

Antecedent Water Levels – Prior to running the storm surge models, potential Additions to the initial water level must considered, For example, antecedent water level is the sum of the stillwater depth, 10 percent exceedance high tide, initial rise and long term sea level rise:

Astronomical Tides - High tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over a continuous 21-year period.

Initial Rise - For locations where the 10 percent exceedance high spring tide is estimated from observed tide, a separate estimate of the initial rise is not necessary.

Sea Level Rise - Long term sea level rise should be derived for the expected life of the nuclear power plant based upon the trend in site/regional tide gage station data.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 3 (Section 3.3.3, Surge Water Levels):

This section provides guidance on methods for the computation of surge water levels using SLOSH(Sea, Lake, Overland Surge from Hurricanes) and ADCIRC (ADvanced CIRCulation) storm surge models:

ADCIRC

The ADCIRC model was developed at the USACE Dredging Research Program as a family of two- and three-dimensional finite element-based models. The model can simulate tidal circulation and storm-surge propagation over very large computational domains while simultaneously providing high resolution in areas of complex shoreline configuration and bathymetry.

The USACE hurricane modeling system used for a NRC Research storm surge study (NUREG/CR 7134) combined various wind models (TC96 PBL), the WAM offshore and STWAVE nearshore wave models, and the ADCIRC basin to channel scale unstructured grid circulation model.

SECTION 3:
SURGE HAZARD ASSESSMENT (cont'd)

Step 3 (Section 3.3.3, Surge Water Levels):

SLOSH

SLOSH was developed by NOAA to forecast real-time hurricane storm surge levels on continental shelves, across inland bodies of water and along coastlines, including inland routing of water levels.

Modification of storm surges due to the overtopping of barriers (including levees, dunes, and spoil banks), the flow through channels and floodplains, and barrier cuts/breaches are included in the model. SLOSH also incorporates an Atmospheric model for tropical cyclones.

NOAA has developed the Extra-Tropical Storm Surge Model (ET-Surge; NOAA, 2012d) that can use a separate planetary boundary wind model in conjunction with a modified SLOSH model to predict storm surge based on large extra-tropical storms as opposed to the tropical storms that SLOSH was originally developed

SECTION 5:
SURGE HAZARD ASSESSMENT (cont'd)

Step 4 (Section 5, Wave and Inundation Effects Associated with Surge or Seiche):

This section deals with the wave dissipation phase where surge and seiche wave action can directly impact the site:

Coincident Wave Heights- Calculation of wind waves that can occur coincidentally with the storm surge or seiche stillwater level. The current practice in storm-surge modeling is the use of coupled hydrodynamic ocean circulation and wave models, both driven by a planetary boundary layer (PBL) model that provides the atmospheric forcing (Figure 1). Guidance also provided by the USACE coastal engineering manual (CEM).

Inundation – Inland penetration of flood wave. Inundation effects are typically available from standard surge models.

SECTION 5:
SURGE HAZARD ASSESSMENT (cont'd)

Step 4 (Section 5, Wave and Inundation Effects Associated with Surge or Seiche) cont'd:

Drawdown (Low Water Level) -Drawdown may be an issue when safety related structures/equipment (e.g., UHS intakes) depend on water sources that have the potential to be impacted by storm surge or seiche. Numerical models such as ADCIRC and SLOSH provide a visual/quantitative estimation of low water level conditions.

Hydrostatic and Hydrodynamic Forces - The determination of the hydrostatic and hydrodynamic forces is required when storm surge/seiche flood levels impinge on flood protection or safety-related SSCs. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of hydrostatic and hydrodynamic forces. For coastal structures, the USACE CEM provides guidance on hydrostatic and hydrodynamic forces.

SECTION 5:
SURGE HAZARD ASSESSMENT (cont'd)

Step 4 (Section 5, Wave and Inundation Effects Associated with Surge or Seiche) cont'd:

Debris and Water-Borne Projectiles - The determination of the effect from debris and water-borne projectiles must be considered when storm surge/seiche flood levels impinge on flood protection or safety-related SSCs. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of debris and water-borne projectiles.

Effects of Sediment Erosion or Deposition - The determination of the impact of sediment erosion and deposition must be considered when storm surge/seiche flood levels impinge on flood protection, safety-related SSCs and foundation materials. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of the effects of sediment erosion and deposition.

SECTION 4:
SEICHE SURGE HAZARD ASSESSMENT

Seiche is an oscillatory wave generated in lakes, bays or gulfs as a result of seismic or atmospheric disturbances and with a period ranging from a few minutes to a few hours. The oscillatory modes for the body of water in question should be calculated from a variety of potential sources. Sources to consider include: (1) local or regional forcing phenomena such as barometric pressure fluctuations, strong winds, rapid changes in wind direction, and surge associated with passage of local storms; and (2) distant but large forcing mechanisms such as distant storms, tsunami, or earthquake-generated seismic waves.

For bodies of water with simple geometries, modes of oscillation can be predicted from the shape of the basin using analytical formulas.

However, most natural bodies of water have variable bathymetry and irregular shorelines and may be driven by a combination of forcings. For such bodies, seiche periods and water surface profiles should be determined through the use of numerical models.

GUIDANCE FOR PERFORMING A TSUNAMI HAZARD ASSESSMENT
(ENCLOSURE 2)

CONTENT

Section 1- Guidance Format and Historical perspective

Section 2 – Acceptance Criteria

Section 3 – Tsunami Hazard Assessment

Section 4 – Wave and Inundation Effects of Tsunami

SECTION 1:
HISTORICAL PERSPECTIVE

In response to the **2004** Indian Ocean tsunami, the NRC coordinated a tsunami safety study in **2005** with the National Tsunami Safety initiative conducted by NOAA.

The NRC tsunami hazard study was conducted by the Pacific Northwest National Laboratory (PNNL) and the Pacific Marine and Environmental Laboratory (PMEL) which is a part of NOAA. This early effort resulted in the publication of two documents. They were NUREG-CR 6966 (**2008**), which was published in final form in March 2009, and NOAA Technical Memorandum OAR PMEL-136, “Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites” which was published in **2007**.

In **2006**, the NRC also initiated a long-term research tsunami research program. This program, which includes cooperative work with the United States Geological Survey (USGS) and NOAA,was designed both to support activities associated with the licensing of new nuclear power plants in the U.S and to support development of new regulatory guidance. This research program has resulted in several publications and made important contributions to tsunami modeling approach and standards.

SECTION 2:
ACCEPTANCE CRITERIA

Regulatory Guidance:

Uses same guidance provided in surge and seiche hazard assessment with the following exceptions**:**

Regulatory Guide 1.59 (1977) briefly mentions tsunami as a source of flooding but does not provide guidance on tsunami hazards.

NUREG/CR-6966, "Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America", provides present-day methodologies and technologies that can used to estimate design-basis floods at nuclear power plants for tsunami hazards **(2009).**

SECTION 2: ACCEPTANCE CRITERIA (cont'd)

Regulatory Guidance (cont'd):

NOAA Technical Memorandum OAR PMEL-135 ("Standards, Criteria, and Procedures for NOAA Evaluation of Tsunami numerical Models") and **NOAA Technical Memorandum OAR PMEL-136** ("Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites"). These documents form the basis of the 2007 tsunami-related updates to NUREG-0800.

USGS **(2009)**, "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts: an updated Report to the Nuclear Regulatory commission," Atlantic and Gulf of Mexico Tsunami Hazard Assessment Group.

Updates to Guidance - In current practice for tsunami hazard assessment, other federal agencies such as USACE, NOAA and FEMA no longer use the "probable maximum" or "standard project" terminology. However, existing NRC guidance continues to use these terms. This document is consistent with practices by other federal agencies. In this ISG, the term design basis tsunami (DBT) replaces probable maximum tsunami (PMT).

SECTION 3:
TSUNAMI HAZARD ASSESSMENT

Historical Tsunami Data

Reviews should be conducted of historical tsunami data, including NUREG-0800 mappings and interpretations, regional records, eyewitness reports, and recently available tide gauge and real-time bottom pressure gauge data (NUREG-0800 and RG 1.206). NUREG/CR-6966 provides further details and additional guidance.

Source Generator Characteristics

A regional or site specific literature survey and assessment of tsunamigenic sources sh
be performed to determine if a tsunami poses a hazard to the site. The survey and assessment should include all potential near-field and far-field sources and mechanisms that could generate tsunami.

Nuclear power plant sites located near the ocean should consider hazards from oceanic tsunami. Inland sites should consider the possibility of tsunami-like waves generated in water bodies within the region (e.g., due to hill-slope failure or seismic sources). Any relevant paleo-tsunami evidence should also be assessed.

SECTION 3: TSUNAMI HAZARD ASSESSMENT (cont'd)

Tsunami Model Initial Conditions:

Datums

Uses same guidance provided in surge and seiche hazard assessment

Antecedent Water Levels

Uses same guidance provided in surge and seiche hazard assessment for high tides, initial rise and sea level rise.

Tsunami Propagation Models

This section describes the tsunami propagation phase with a discussion of the state-of-the-art tsunami models currently used by NRC, industry and other federal agencies.

SECTION 3:
TSUNAMI HAZARD ASSESSMENT (cont'd)

Tsunami Propagation Models

The shallow-water equation models have been shown to be reasonably accurate throughout the evolution of a tsunami, and are widely used. However, these models lack the capability to simulate dispersive waves, which could be the predominate features in landslide-generated tsunami, and for tsunami traveling a long distance.

Several higher-order depth-integrated wave hydrodynamics models (Boussinesq models) are now available for simulating non-linear and weakly dispersive waves, such as COULWAVE (Cornell University Long and Intermediate Wave Modeling Package, 2002) and FUNWAVE (Fully Nonlinear Boussinesq Wave Model, 2000). The major difference between the models is their treatment of moving shoreline boundaries.

SECTION 4:
WAVE AND INUNDATION EFFECTS OF TSUNAMI

The same general guidance provided in surge and seiche hazard assessment for inundation, wave runup, drawdown, hydrostatic/hydrodynamic forces, debris and water-borne projectiles, and effect of sediment erosion and deposition applies for the tsunami hazard assessment.

Note that the wave characteristics (period, and wave length) of a tsunami differ from the wind driven storm surge waves which may generate different hydrodynamic and hydrostatic forces on structures. As a result of the March 2011 tsunami, this has become an active area for further research.