TSUNAMI DESIGN CRITERIA AND LOAD CASES OF ASCE 7-16 CHAPTER 6, TSUNAMI LOADS AND EFFECTS

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Abstract

The ASCE 7 Tsunami Loads and Effects provisions utilize probabilistic hazard analysis, tsunami physics, and fluid mechanics, integrated into a comprehensive set of structural design provisions. Procedures for tsunami inundation analysis are based on using mapped values of Offshore Tsunami Amplitude or the Runup and Inundation Limit shown in the ASCE Tsunami Design Geodatabase. There are two procedures available for determining the flow depth and velocities at a site. The Energy Grade Line Analysis takes the Runup elevation and Inundation Limit indicated on the Tsunami Design Zone map as the given solution point of a hydraulic analysis along the topographic transect from the shoreline to the Runup point. The two-dimensional (2D) Site-Specific Inundation Analysis develops a time history of tsunami scenario(s) matching the specified probabilistic Offshore Tsunami Amplitude.

The ASCE 7 provisions for tsunami loads and effects enables a set of analysis and design methodologies that are consistent with tsunami physics and implemented using hydraulic engineering principles. Once the tsunami flow conditions of inundation depth and flow velocities at a project site are determined, these parameters are then used to determine structural loading and scour effects for which the building or structure must be designed. The ASCE 7-16 Standard also prescribes the various hydrostatic and hydrodynamic loading conditions that must be considered when designing the overall structural system and individual structural members for the tsunami flow conditions at the project site. These loads include:

- i) Uplift due to buoyancy
- ii) Hydrostatic lateral loads
- iii) Gravity load of water retained on elevated floors
- iv) Hydrodynamic drag on the structural system and individual structural components
- v) Hydrodynamic effects of bores
- vi) Hydrodynamic uplift
- vii) Impact loads due to waterborne debris

In this paper, we indicate the terms formally defined in the ASCE 7 Chapter 6 Tsunami Loads and Effects provisions with capitalization, consistent with what is editorially done for such terms in the ASCE 7 Standard Chapter 6 itself.

Keywords: tsunami engineering; ASCE 7; hydrostatic loads; hydrodynamic loads; debris impact loads

1. Introduction

The ASCE 7 provisions for Tsunami Loads and Effects [1] implements a unified set of analysis and design methodologies applicable within the Tsunami Design Zones based on Probabilistic Tsunami Hazard Analysis. Procedures for tsunami inundation analysis are based on using geocoded values of Offshore Tsunami Amplitudes or Runups and Inundation Limits shown in the ASCE Tsunami Design Geodatabase. Structural loads are based on tsunami physics of the flow, and capacity criteria for the basis of design are structural ultimate strengths.

.2. Probabilistic Tsunami Hazard Analysis

Historical records alone do not provide a sufficient measure of the potential threat of future tsunamis. To achieve structural reliability, engineering design must consider the occurrence of tsunamis greater than the historical record, based on the scientific assessment of the underlying seismicity and slip potential of tsunamigenic subduction zones. Accordingly, for the tsunami design provisions developed by ASCE, Probabilistic Tsunami Hazard Analysis (PTHA) generated large stochastic catalogs of tsunami waveforms directly from the source mechanisms in accordance with logic tree probabilities for each possible subduction source mechanism (e.g., event magnitude, slip distribution and extent of rupture), consistent with their estimated plate convergence rates and seismic efficiencies.

The basics of PTHA for a region involve integration over the range of tsunamigenic sources of varying extents and recurrences, as follows:

1. Tsunamigenic subduction zones (and non-subduction seismic thrust faults) are discretized into a compiled system of rectangular subfaults each with corresponding tectonic parameters.
2. A statistically weighted logic tree approach is used to account for variations in the model parameters for tsunamigenic earthquake occurrence probabilities from tectonic, geodetic, historical, and paleo-tsunami data, and estimated plate convergence rates. Source model characterization for probabilistic tsunami events include:
    a. Recurrence of the subduction zone sources
    b. M_{max} of the subduction source regions
    c. Coupling ratio (what proportion of long-term plate convergence is released in seismic tsunamigenic events)
    d. Scaling Relationships of M_w to average slip and area of rupture
    e. Slip Distribution (asperity of slip rather than uniformity)
    f. Extent of Rupture
    g. Near-field regional subsidence
3. Tsunami waveform generation is modeled by decomposing a tsunami that is generated by an earthquake into a linear combination of individual tsunami waveforms from a set of subfaults that make up the earthquake's total rupture in location, orientation, and rupture direction and sequence.
4. Tsunamis from the source region are propagated to 100 meter depth near the coast line using the linear shallow water wave equations that take into account spatial variations in seafloor depth.
5. The highest offshore tsunami amplitudes are determined at 100m depth for the nominal design level exceedance of 2,475-years, and incorporating a statistical lognormal sigma allowance in recognition of inundation modeling uncertainty.
6. Seismic sources and their associated moment magnitudes (M_w) that together contribute at least 90% to the net offshore tsunami hazard at the site under consideration are disaggregated.

PTHA results are given as Offshore Tsunami Amplitudes. The ASCE Standard defines the Offshore Tsunami Amplitudes (not the peak to trough tsunami height) of the Maximum Considered Tsunami (MCT) above the ambient sea level at a standardized offshore depth of 100 meters. The Offshore Tsunami Amplitude and associated waveform parameters then constitute the probabilistically referenced design wave amplitude for any Hazard Consistent Tsunami used for inundation analysis. These offshore amplitudes were then used to run nonlinear inundation models to determine the Runup elevation and Inundation Limit that defines the Tsunami Design Zone, TDZ, and runup elevations. The disaggregated sources were used to generate Hazard-Consistent Tsunami scenarios that were propagated towards the coastlines.

The Tsunami Design Zone is the area vulnerable to being flooded or inundated by the MCT, which is taken as having a 2% probability of being exceeded in a 50-year period with the aforementioned additional statistical lognormal sigma allowance in recognition of inundation modeling uncertainty. The MCT is the design basis event consisting of the inundation depths and flow velocities during the stages of in-flow and out-flow most critical to the structure. Key parameters controlling tsunami design criteria are illustrated in Figure 1. They include the Inundation Depth, the (maximum horizontal) Inundation Limit, and the Runup elevation. Inundation Depth is the depth of tsunami water level with respect to the local grade plane. Inundation Limit is the maximum horizontal extent of the inundation zone relative to the shoreline. Runup elevation is the elevation above reference datum at the tsunami Inundation Limit. The Runup locations for the MCT are used to define the Inundation Limit boundary of the Tsunami Design Zone.

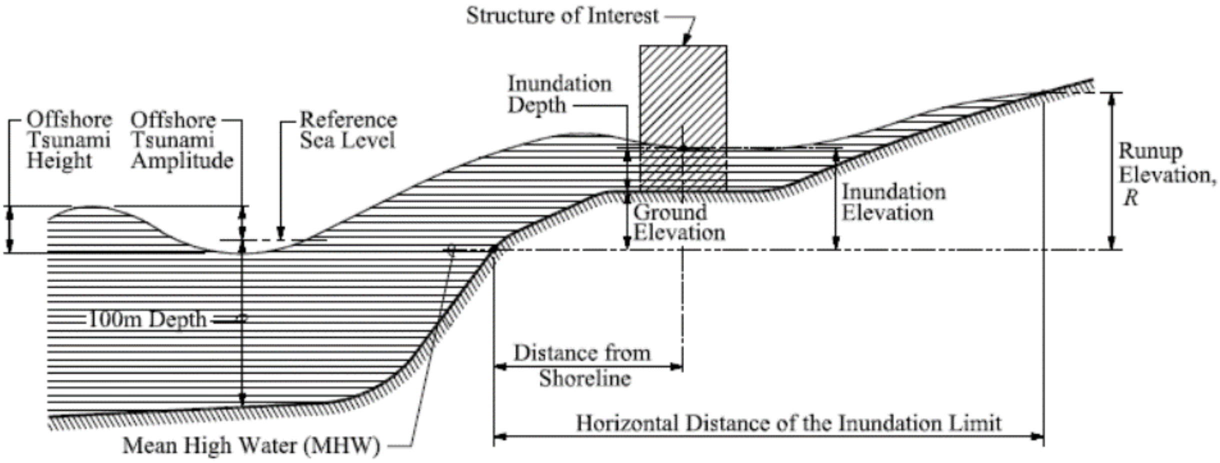

Fig. 1 Tsunami Inundation Terminology of ASCE 7 [1]

.3. Analysis of Design Inundation Depth and Flow Velocity

In order to design structures for tsunami loading, it is necessary to determine the flow depth and velocity at the project site during the Maximum Considered Tsunami (MCT). Tsunami inundation analysis procedures for determining the flow depth and velocities at a site utilize either the Offshore Tsunami Amplitudes or the Runups and Inundation Limits, all available from the ASCE 7 Tsunami Design Geodatabase. The Energy Grade Line Analysis takes the Runup elevation and Inundation Limit indicated on the Tsunami Design Zone as the given solution point of a hydraulic analysis along a topographic transect from the shoreline to the Runup point. The Energy Grade Line Analysis (EGLA) is a prescriptive method that has been developed to produce design flow parameters appropriate for use in engineering design for structural integrity. A key benefit of the EGLA approach is that it results in statistically conservative design values for hydrodynamic forces, relative to site-specific modeling results. The EGLA is always performed for Tsunami Risk Category II, III and IV structures. The two-dimensional Site-Specific Inundation Analysis utilizes the Offshore Tsunami Amplitudes as input for a numerical simulation of a Hazard Consistent Tsunami Scenario(s) on a high-resolution digital elevation model of nearshore bathymetry and onshore topography. Site-Specific Inundation Analysis is performed for Tsunami Risk Category IV structures unless the Energy Grade Line Analysis shows the inundation depth to be less than 12 ft. (3.7 m) at the structure. Site-Specific Inundation Analysis is not required for, but may also be used for Tsunami Risk Category II and III structures. The options for the analysis of design inundation depth and flow velocity are shown in Table 1.

Table 1. Inundation Depth and Flow Velocity Analysis Procedures where Runup is mapped

Analysis Procedure using the ASCE Tsunami Design Geodatabase	**Tsunami Risk Category (TRC) Structure Classification**			
	TRC II	TRC III	TRC IV (excluding TVERS)	TRC IV - Tsunami Vertical Evacuation Refuge Shelter (TVERS)
Energy Grade Line Analysis	✓	✓	✓	✓
Site-Specific Inundation Analysis	Permitted;	Permitted;	✓ Required if EGLA inundation depth ≥ 12 ft (3.7 m)	✓

✔ indicates a required procedure

The EGLA relies on input of a known Runup point (or alternatively, a known inundation depth at a point along the transect) obtained from the ASCE Tsunami Design Geodatabase. The coastal area terrain is approximated by the use of one-dimensional linear transects across a composite bathymetric / topographic profile. The basic idea behind the method is that the hydraulic energy of the flow can be approximated as a quasi-steady sum of the potential and kinetic flow energy, as measured by the flow depth and velocity head. At the shoreline, where ground elevation is zero, the energy grade line is located at a height above the water surface equal to the velocity head. At the Runup, the velocity and hydraulic energy is zero and accordingly the energy grade line intersects the ground topography. In between the shoreline and the runup limit, the incremental slopes of the energy grade line can be established using appropriate expressions for energy losses due to bottom friction, wave breaking, and turbulence of the advancing flow [2]. The EGLA procedure is based on hydraulic flow principles applied along a terrain profile modeled as linearly sloped segments, using Manning's coefficient for equivalent terrain macro-roughness to account for the friction slope of the energy grade line of the flow (illustrated in Figure 2). The Energy Grade Line Analysis incrementally determines the variation of inundation depth and maximum flow velocity across the inland profile using Eq. (1) and Eq. (2). Because there is only one energy equation but two unknowns, depth h, and velocity, u, it is necessary to use a relationship between these two to solve the problem; velocity is assumed to be a function of inundation depth, calibrated to the Froude number that is prescribed to decay gradually based on distance from the shoreline along the transect, calculated according to Eq. (3).

Where the tsunami waves shoal either over long and mild seabed slopes, or encounter abrupt seabed discontinuities such as fringing reefs, short-period waves called solitons are generated on the front edge of the much longer period tsunami waveform. (Shoaling refers to the increase in wave height and steepness caused by a decrease in water depth. Under the conditions described above, a series of solitons can be generated; the tsunami research literature describes this phenomenon as "soliton fission".) "Soliton fission" in the nearshore regime can often lead to the occurrence of tsunami bores, in which the soliton waves break. These waves have higher wavespeed and more impulsive impact on structures, and carry a 1.5 factor increase of lateral force. The Froude number coefficient, α , in Eq. 3 is 1.0 except where tsunami bores occur, in which case it is increased to a value of 1.3.

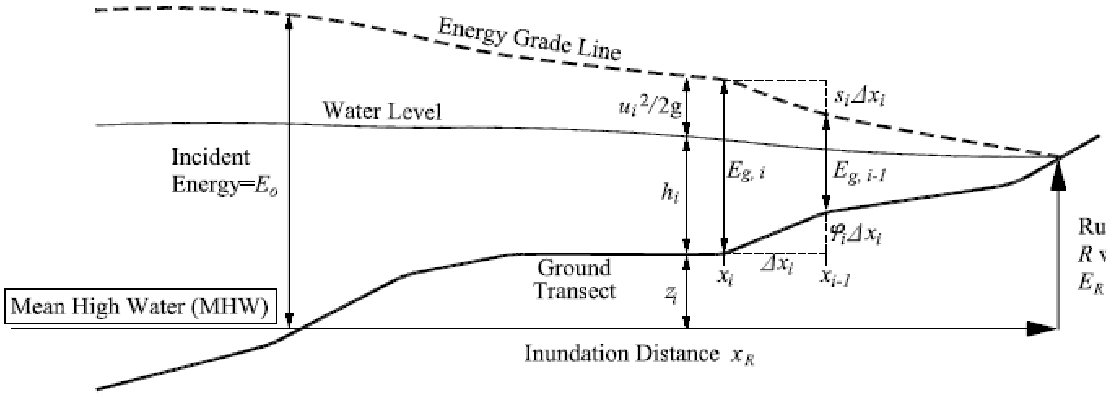

Fig. 2 Illustration of the Energy Grade Line Analysis of Overland Flow Depth and Velocity

$$E_{g,\,i+1} = E_{g,i} + (\varphi_i + s_i)\,\Delta x_i \tag{1}$$

where

$E_{g,\,i}$ = Hydraulic Head at point $i = h_i + u_i^2/2g = h_i\,(1+0.5\,F_{ri}^2)$

h_i = Inundation depth at point i

u_i = Maximum flow velocity at point i

φ_i = Average ground slope between points i and $i+1$

F_{ri} = Froude Number = $u/(gh)^{1/2}$ at point i

$\Delta x_i = x_i - x_{i+1}$ the increment of horizontal distance, which shall not be coarser than 100 ft (30.5 m) spacing

x_i = Horizontal distance inland from shoreline at point i

s_i = Friction slope of the energy grade line between points i and $i+1$, is calculated per Eq. 2

$s_i = (u_i)^2/((1.49/n)^2 h_i^{4/3})$ $= g\,F_{ri}^2/((1.49/n)^2 h_i^{1/3})$ U.S inch-pound units. (2)

$= g\,F_{ri}^2/((1.00/n)^2 hi^{1/3})$ S.I. units

and where

n = Manning's coefficient of the terrain segment being analyzed

E_R = Hydraulic head of zero at the point of Runup

Froude number is given as

$$F_r = \alpha\left(1 - \frac{x}{x_R}\right)^{1/2} \tag{3}$$

A Site-Specific Inundation Analysis determines the 2-dimensional flow and directionality effects that the linear transect analysis of the Energy Grade Line Analysis cannot render. This simulation modeling is required to evaluate a detailed flow time history for the design of Tsunami Risk Category IV structures. Site-Specific Inundation Analysis is required to utilize a more detailed spatial digital elevation model of bathymetry and topography, together with one of the NOAA-benchmarked 2D inundation model software codes to determine the time history of flow depth and velocity parameters for the site[3]. The analysis input must use Hazard Consistent Tsunami(s) that matches the Offshore Tsunami Amplitudes for the region given in the

ASCE Tsunami Design Geodatabase. This analysis method is particularly useful in evaluating more complicated bathymetry, inland flow diversion, and amplification around local hills and valley features. These additional bathymetric and topographic effects that may adversely affect the local inundation depth and flow velocities. Topographic amplification of flow velocity would be explicitly determined in a Site-Specific Inundation analysis. This evaluation is particularly important for Tsunami Vertical Evacuation Refuge Structures.

Because the EGLA is expected to provide conservatively safe flow characteristics, it is used for establishing the minimum flow velocities for design even when a site-specific analysis is performed. The reason for these safeguard design restrictions is that the tsunami model validation standard, NOAA OAR PMEL-135[3], presently does not validate flow velocities over land, and based on NOAA PMEL workshop comparisons, some numerical inundation models could potentially underestimate flow velocities. Therefore, simulation precision in such software should not be mistaken for reliable accuracy for engineering design. Urban environments may channel and significantly amplify flow velocities. In urban environments with buildings at densities that may reduce tsunami Runup, the flow velocities determined by a “bare-earth” Site-Specific Inundation Analysis for a given structure location may not be taken as less than 90% of those determined in accordance with the Energy Grade Line Analysis method based on urban macro-roughness. For other terrain roughness conditions, the Site-Specific Inundation Analysis flow velocities determined at a given structure location shall not be taken as less than 75% of those determined in accordance with the Energy Grade Line Analysis method.

.4. Load Cases

Normalized depth and depth-averaged flow speed prototypical time-history graphs are provided to define three load cases that are required to be satisfied in structural design, as shown in Figure 3. When the EGLA is used, the graphs are intended to capture the likely combinations of depth and flow that would occur during the rising and falling phases of tsunami inundation. Site-Specific Inundation Analysis may yield different time history results based on a site’s particular topography.

The three cases of tsunami loading required to be considered are defined by the inundation depths and the associated velocities:

1. The minimum initial combination of hydrodynamic force with buoyant force shall be evaluated at an inundation depth not exceeding the maximum inundation depth nor the lesser of one-story or the height of the top of the first story windows.
2. Two-thirds of maximum inundation depth when velocity is near maximum, in each direction.
3. Maximum water depth when the flow velocity is assumed to be at one-third of maximum, in each direction.

5. Tsunami Structural Loads and Effects

Structural design of buildings and structures include requirements for the following tsunami effects [4]. The design limit state is the design strength capacity of structural members.

- Hydrostatic Forces
  - Unbalanced Lateral Forces at initial flooding
  - Buoyant Uplift based on displaced volume
  - Residual Water Surcharge Loads on elevated floors
- Hydrodynamic Forces
  - Drag Forces – on the entire structure as well as on its individual components
  - Lateral Impulsive Forces of Tsunami Bores
  - Hydrodynamic Pressurization by Stagnated Flow
  - Shock pressure effect of entrapped bore impulse
- Waterborne Debris Impact Forces

    - Poles, passenger vehicles, medium boulders
    - Shipping containers, boats apply if structure is in proximity to hazard zone
    - Extraordinary impacts of ships apply in proximity to Risk Category III & IV structures
- Scour Effects
    - General Erosion
    - Local Scour and soil pore pressure softening effects on the foundation

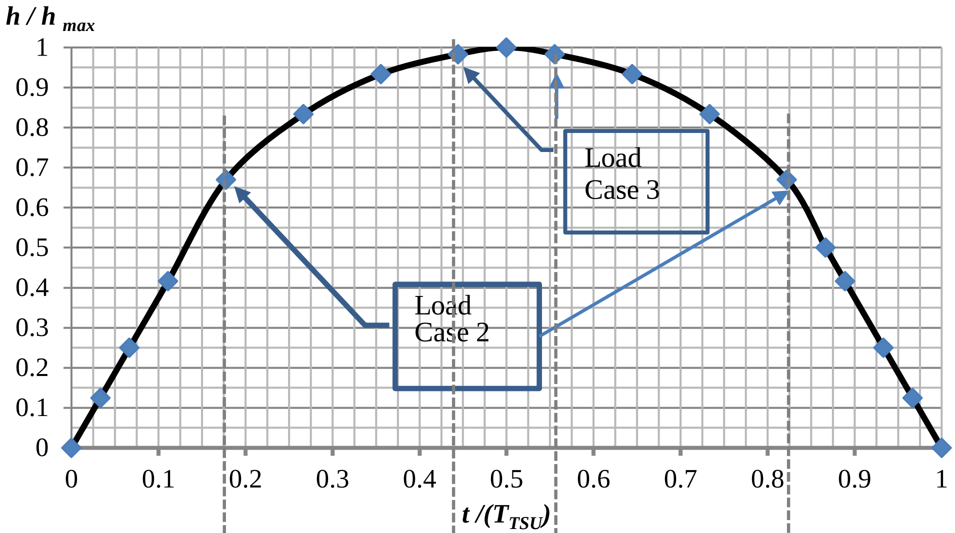

Fig. 3(a) Normalized Inundation Depth vs. Normalized Time

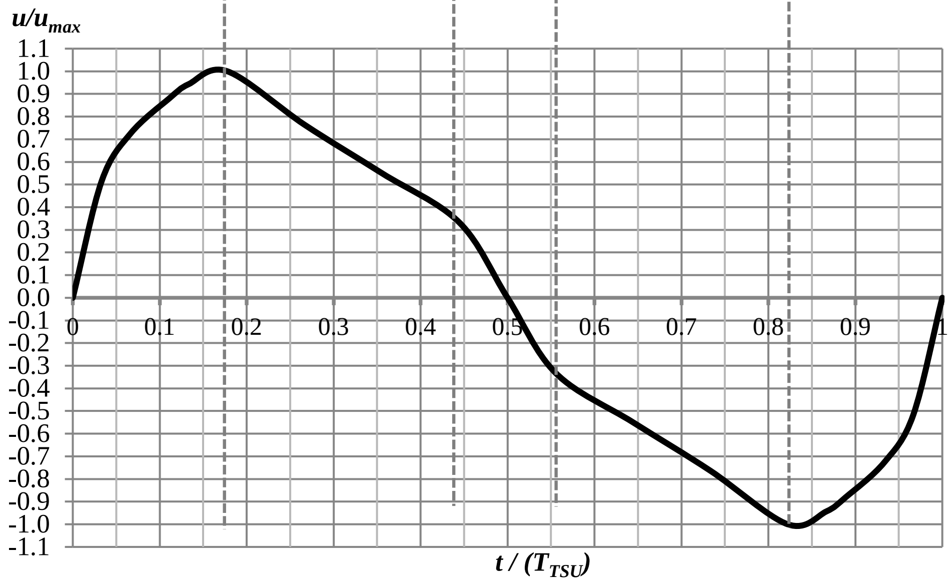

Fig. 3(b) Normalized Flow Velocity vs. Normalized Time

5.1 Hydrostatic Loads

Reduced net self-weight due to buoyancy should be evaluated for all inundated structural and non-structural elements of the building. Uplift due to buoyancy should include enclosed spaces without breakaway walls that have opening area less than 25% of the inundated exterior wall area. Buoyancy should also include the effect of air trapped below floors, including foundation slabs, and in enclosed spaces where the walls are not designed to break away. All windows, except those designed for large missile wind-borne debris impact or blast loading, shall be permitted to be considered openings when the inundation depth reaches the top of the window pane.

5.2 Hydrodynamic Loads

Fluid flows generate hydrodynamic loads on objects that obstruct the free –field flow. The overall drag force developed either by in-coming or out-going flow on the building or structure must be resisted by its lateral-force-resisting system. Likewise, lateral hydrodynamic pressure loads are applied on the projected area of all structural components (as well as enclosure and appurtenance assemblages) that exist below the inundation flow depth. The lateral hydrodynamic load given by Eq. 4 is the hydrodynamic drag for tsunami loading.

$$F_{TSU} = \frac{1}{2}\rho_s C_d b(h_e u^2)\, I_{tsu} \tag{4}$$

in which

ρ_s = the minimum fluid mass density= $k_s\, \rho_{sw}$, the fluid density factor multiplied by the mass density of seawater,
C_d = the drag coefficient for the building component,
b = the width perpendicular to the flow,
h_e = the inundation depth,
u = the flow velocity and
I_{tsu} = tsunami importance factor. I_{tsu} is the Tsunami Importance Factor and is given as an assigned constant for each Tsunami Risk Category.

Bore impact forces on walls should be considered as an amplified force equivalent to 150% of the hydrodynamic drag.

5.3 Debris Impacts

Tsunamis can transport a large volume of debris. Virtually anything in the flow path that can float given the inundation depth or which cannot withstand the water flow can become waterborne debris. Common examples are trees, wooden utility poles, cars, and wood-framed houses and portions thereof. Some non-floating debris, such as boulders and dislodged pieces of concrete, can also be transported by tumbling if the flow is strong enough. Waterborne debris impact is applied to any perimeter structural element of the gravity-load-carrying system within the inundation depth at the site. The impacts of a 1,000-lb. (452kg) log , a floating passenger vehicle, and a submerged tumbling boulder or concrete mass debris (weighing 5,000-lb., or 2267 kg) are assumed to impact perimeter vertical structural components of the gravity-load-carrying system. The ubiquity of 1) logs and/or poles; 2) passenger vehicles; and 3) boulders and concrete debris requires the assumption that these will impact the structure if the inundation depth and velocity make it feasible. Table 2 summarizes the requirements for design, especially the threshold inundation depths at which level (or greater) it is required to consider each debris impact type.

Table 2. Conditions for which Design for Debris Impact are Evaluated

Debris	**Buildings and Other Structures**	**Threshold Inundation depth**
Poles, logs, passenger vehicles	All	3 ft (0.91 m)
Boulders and Concrete Debris	All	6 ft (1.8 m)
Shipping Containers	All those determined to be within the debris hazard region	3 ft (0.91 m)
Ships and/or barges	Tsunami Risk Category III Critical Facilities and Category IV near ports	12 ft (3.6 m)

Debris impact forces by large objects such as shipping containers and ships are applicable depending on the location of the structure and potential debris in the surrounding area that would be expected to reach the site during the tsunami. To determine the extent of the debris impact hazard region around a port, harbor, or shipping container yard, an empirical approach is based on the amount of available debris and the flow depth in the vicinity, along with other significant structures that may be between the origin of debris and the structure being designed [5].

The basic idea of the graphical empirical procedure (illustrated in Figure 4) is to find a 45° circular sector with an area equal to 50 times the combined plan area of the debris, such that the debris, once disbursed, would have an average concentration (i.e., ‘area density’) of 2%. First, an arc of the debris impact hazard region for inflow shall be drawn as follows: one arc and the two radial boundary lines of the 45° sector defines a circular sector region with an area that is 50 times the total sum debris area of the source, representing a 2% concentration of debris. The inland boundary of the inflow sector may be terminated at the threshold inundation depth given in Table 2. Second, because the debris can be transported towards the shoreline on drawdown, the debris impact hazard region for outflow shall be determined by rotating the circular segment by 180° and placing the center at the intersection of the centerline and the arc that defines the 2% concentration level. Buildings and other structures contained only in the inflow sector shall be designed for strikes by a container and/or other vessel carried with the inflow. Buildings and other structures contained only in the reversed second sector shall be designed for strikes by a container and/or other vessel carried in the outflow. Buildings and other structures contained in both sectors shall be designed for strikes by a container and/or other vessel moving in either direction; in this bi-directional sectored region, there is a greater probability of receiving a colliding impact. The most severe effect of impact loads within the inundation depth should be applied to the perimeter gravity-load-carrying structural components located on the principal structural axes perpendicular to the inflow or outflow directions.

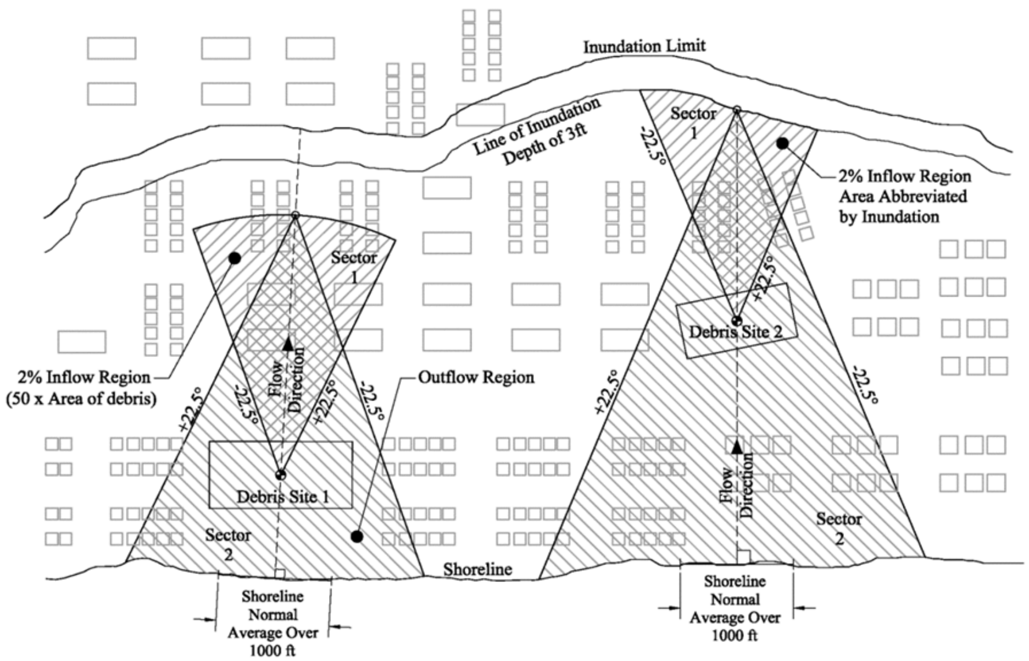

Fig. 4 Illustration of Determination the Floating Debris Impact Hazard Region for Shipping Containers

The impact forces depend on the impact velocity, which is assumed to be equal to the flow velocity for floating debris [6]. The points of application of the impact force, which is assumed to be a concentrated force, shall be chosen to give the worst case for shear and moment for each structural member that should be considered within the inundation depth and the corresponding flow velocity. The nominal maximum instantaneous debris impact force, F_{ni} , is determined in accordance with Eq. 5:

$$F_{ni} = u_{\max} \sqrt{k m_d} \quad (5)$$

The design instantaneous debris impact force, F_i , is then calculated in accordance with Eq. 6:

$$F_i = I_{TSU} C_o F_{ni} \quad (6)$$

where,

I_{tsu} is the importance factor
C_o is the orientation coefficient, equal to 0.65 for longitudinal objects
u_{max} is the maximum flow velocity at the site occurring at depths sufficient to float debris
k is the effective stiffness of the impacting debris or the lateral stiffness of the impacted structural element(s) deformed by the impact, whichever is lesser. The ASCE provisions have tabulated values of stiffnesses to be used for common debris objects.
m_d is the mass W_d /g of the debris. The ASCE provisions have tabulated values of mass to be used for common types of debris objects.

The impulse duration for elastic impact shall be calculated from Eq. (7) in which the impact force is constant, resulting in a rectangular force–time history:

$$t_d = \frac{2 m_d u_{max}}{F_{ni}} \quad (7)$$

The instantaneous loads from the impact scenario cases need not be combined with other tsunami-related loads such as hydrodynamic forces, which are sustained.

6. Reliability against Failure for Structures Designed in Accordance with ASCE 7

The tsunami structural reliabilities have their basis in a parametric analysis performed using Monte Carlo simulation by Chock, et al., (2016b) [7]. The reliabilities for tsunami are for the inundated structural elements to prevent failure from hydrodynamic loading during the maximum considered tsunami (MCT), with explicit consideration of the variation of the hazard curve according to relative position from the shoreline. Probabilistic limit-state reliabilities were computed for representative structural components carrying gravity and tsunami loads, utilizing statistical information on the key hydrodynamic loading parameters and resistance models with specified tsunami load combination factors. The prescriptive design criteria for waterborne debris impacts and foundation scour are not probabilistic, and therefore these effects are not included in Table 3. The new ASCE 7 tsunami design provisions will result in a design with a level of reliability for structural components generally equivalent to or exceeding the (absolute and the conditional) targeted reliabilities for other types of other extraordinary load cases such as seismic effects.

Table 3. Target Reliability (Conditional Probability of Failure) for Structural Elements Given the Occurrence of the Maximum Considered Tsunami

Tsunami Risk Category	**Conditional Probability of Failure Caused by the Maximum Considered Tsunami Hydrodynamic Pressure**
I	Not Applicable
II	10%
III	5%
IV	3%
Tsunami Vertical Evacuation Refuge Structure	1%

7. Summary

The ASCE 7 provisions for Tsunami Loads and Effects implements a unified set of analysis and design methodologies applicable within Tsunami Design Zones based on Probabilistic Tsunami Hazard Analysis. Procedures for tsunami inundation analysis are based on using geocoded values of Offshore Tsunami Amplitudes or Runups and Inundation Limits shown in the ASCE Tsunami Design Geodatabase. There are two procedures available for determining the flow depths and velocities at a site. The Energy Grade Line Analysis takes the Runup elevation and Inundation Limit indicated on the Tsunami Design Zone map as the given solution point of a hydraulic analysis along the topographic transect from the shoreline to the Runup point. Then normalized depth and depth-averaged flow speed prototypical time-history graphs are provided to define three principal load cases. The two-dimensional (2D) Site-Specific Inundation Analysis develops a time history of tsunami scenario(s) matching the specified probabilistic Offshore Tsunami Amplitude, so that a complete time history of flow depth and associated velocity vectors is determined for the site and its surrounding area. Once the flow depth and velocity are determined by either method, structural loads are based on tsunami physics of the flow, and capacity criteria for the basis of design are structural ultimate strengths. Procedures for the calculation of hydrostatic, hydrodynamic, and waterborne debris forces are given. When the ASCE 7 tsunami provisions are used for design, an explicitly determined structural reliability objective would be achieved that explicitly accounts for inherent uncertainty.

7. Acknowledgements

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8. Copyrights

9. References

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