Recent Advances in Tsunami Design of Coastal Structures

I.N. Robertson
University of Hawaii at Manoa, Honolulu, Hawaii, USA

ABSTRACT: The 2004 Indian Ocean Tsunami initiated a rapid increase in tsunami research, particularly as it relates to the performance of coastal structures during tsunami inundation. The subsequent Chile tsunami in 2010 and Great Japan Earthquake and Tsunami (or Tohoku Tsunami) in 2011 re-invigorated the urgency of developing design provisions for tsunami loading on coastal structures. The culmination of this experimental and theoretical research, and field reconnaissance after damaging tsunamis, resulted in the development of a new Chapter 6 "Tsunami Loads and Effects" in the ASCE7-16 Standard "Minimum Design Loads and Associate Criteria for Buildings and Other Structures". This paper briefly reviews the ASCE7-16 tsunami design provisions. The application of these provisions to the design of new tsunami vertical evacuation refuge structures in Oregon and Washington States, and new multistory residential buildings in Waikiki, Hawaii, will be presented. This paper also introduces recent modifications to the tsunami design provisions approved for the ASCE7-22 Standard published in December 2021. These modifications were prompted by recent laboratory research, observations after the earthquake and tsunami in Palu, Indonesia, and updates to numerical modeling procedures for tsunami inundation.

1 INTRODUCTION

For five years, the ASCE Tsunami Loads and Effects subcommittee worked to develop a new chapter in the ASCE/SEI 7-16 Standard, Minimum Design Loads and Associated Criteria for Buildings and Other Structures. This new Chapter 6, Tsunami Loads and Effects, provides comprehensive provisions for design of coastal structures for tsunami loads, scour and related considerations. These tsunami design provisions now apply to all coastal communities in California, Oregon, Washington State, Alaska and Hawaii. A companion design manual by the author explains the new provisions and demonstrate their application to prototypical reinforced concrete buildings in coastal communities in the Western USA.

2 OVERVIEW OF ASCE7-16 TSUNAMI LOADS AND EFFECTS

2.1 *Tsunami Hazard*

Tsunamis can be generated by a number of natural phenomena, but the most common damaging trans-oceanic tsunamis are caused by subduction zone earthquakes. Local damaging tsunamis can also be caused by thrust or strike-slip faults, aerial or submarine landslides, volcanic explosions, and island flank failures.

2.2 *Tsunami Flow Parameters*

To design structures for tsunami loading, it is necessary to determine the maximum flow depth and velocity at the project site during the 2500-year Maximum Considered Tsunami. These flow characteristics can be determined either by site specific tsunami inundation modeling, or by use of the Energy Grade Line Analysis (EGLA).

2.3 *Structural Design Provisions*

2.3.1 *Tsunami Risk Categories*

ASCE7 defines four Tsunami Risk Categories (TRC). TRC IV includes all essential buildings. TRC III includes large occupancy buildings and critical facilities. TRC I includes buildings that are generally not occupied continuously, and TRC II includes all other buildings, which is the vast majority, including all residential, office, educational buildings, etc. All TRC IV and TRC III buildings and structures, located within the Tsunami Design Zone

(TDZ), must consider the effects of tsunami loading in their design. The local jurisdiction is encouraged to require tsunami design for TRC II buildings with sufficient height to provide emergency refuge for people stranded within the TDZ.

2.3.2 *Tsunami Load Cases*

Three tsunami load cases must be considered, namely a buoyancy check, the maximum flow velocity assumed to occur when the flow depth is 2/3 of the maximum flow depth, and the maximum flow depth with 1/3 of the maximum velocity. Design is required for both incoming and outgoing flow.

2.3.3 *Hydrostatic Forces*

Hydrostatic forces that must be considered in the structural design include buoyancy, unbalanced lateral forces when fluid loads are applied to only one side of a structural element such as a wall, and residual water surcharge loads that can apply to elevated floors during drawdown. Design equations are provided for each of these loading conditions.

2.3.4 *Hydrodynamic Forces*

Hydrodynamic loads include traditional drag forces on both the overall structure and on individual structural elements, lateral impulsive forces due to the initial impact from a tsunami bore on structural walls or other broad structural elements, pressurization of enclosed spaces due to flow stagnation, and shock pressure effects below piers and elevated floors due to entrapped bore conditions. Design equations and procedures are given for each of these conditions.

2.3.5 *Waterborne Debris Impact Forces*

Tsunamis can generate a large quantity of debris, some of which can cause substantial forces when impacting a structural member. ASCE7-16 provisions consider impact from utility poles/logs, shipping containers, passenger vehicles, tumbling boulders/concrete debris, and ships. Impact force equations for all these conditions, except ships, are specified in the provisions.

2.3.6 *Scour Effects*

Sediment transport and scour around building foundations can result in localized and overall structural failure. The ASCE7-16 provisions are based on an empirical expression derived from field observations after numerous past tsunamis.

2.3.7 *Tsunami Vertical Evacuation Refuge Structures*

The design of structures that are specifically designated as tsunami vertical evacuation refuge structures must, of necessity, be more conservative than typical construction. This is particularly important when considering the height of the refuge levels to minimize the potential for overtopping during an extreme event.

3 TSUNAMI VERTICAL EVACUATION STRUCTURES

ASCE7-16 tsunami design provisions have already been applied to several tsunami vertical evacuation structures and multi-story residential buildings. In Westport, Washington, the Ocosta Elementary School constructed a tsunami evacuation area on the roof of a new gymnasium building. In Newport, Oregon, the Oregon State University (OSU) Hatfield Marine Science Center is designed as a three-story research building with a tsunami vertical evacuation refuge on the roof easily accessible via a wide ramp.

4 ASCE7-22 UPDATES

Several significant updates have been made in the 2022 edition of ASCE7. High-resolution Tsunami Design Zone maps have been developed for highly populated coastlines of California, for the Islands of Oahu and Hawaii, and for the Salish Sea region of Washington State. ASCE7-22 now includes clarification as to the use of push-over analysis for tsunami design and assessment of existing structures.

Design expressions are included in ASCE7-22 for the horizontal drag and vertical uplift on horizontal pipelines. Based on field reconnaissance after the Palu Earthquake and Tsunami in 2018, debris damming and impact loads must now be applied to interior columns for certain structures.

Recent laboratory research results have been included in ASCE7-22 with application to scour around vertical elements such as piles. In addition, a method for estimating the depth of soil affected by pore pressure softening has been included in ASCE7-22 for designers to include this effect in their estimates of sediment transport and scour.

5 SUMMARY AND CONCLUSIONS

This paper presents an overview of the Tsunami Loads and Effects Chapter of ASCE7-16 and several examples of its application to the design of tsunami vertical evacuation structures. Enhancements made to these design provisions in the 2022 edition of ASCE7 are introduced with background information.