



## ADVOCACY FOR TSUNAMI MITIGATION AND PREPAREDNESS OF U.S. SCHOOLS ALONG THE PACIFIC RIM

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### Abstract

High tsunami risk exists for coastal regions in the United States along the Pacific Rim and existing schools located in these regions pose a unique challenge for both mitigation and planning. With a committee of volunteer experts in tsunami hazard assessment and mitigation, a project is currently underway as a part of the Earthquake Engineering Research Institute's *School Earthquake Safety Initiative (SESI)* to identify schools in Tsunami Hazard Zones. The goal of this project is to map schools located in tsunami hazard zones and to advocate for mitigation and planning to reduce school tsunami risk. This paper will document the process used to identify and map at-risk schools in these tsunami zones, and share advocacy and dissemination activities used to reach the school administrators in these regions that could help mitigate risks posed to school children.

The first phase of the project is identifying and mapping schools in the newly released ASCE 7 – 16 Tsunami design zone. This work has identified more than 300 at-risk schools in Alaska, California, Hawaii, Oregon, and Washington. The second phase will consider and conduct various advocacy, outreach and dissemination activities to offer useful and necessary information to school administrators, decision makers, and other stakeholder groups. This is in conjunction with EERI's subprogram, "Creating an Advocacy Network for Improved School Earthquake Safety," supporting similar dissemination efforts. Many existing informational resources reviewed by this project will be discussed, and references will be provided to selected exemplary and relevant resources. In the final phase, the project experts will consider and propose various policy recommendations that can be implemented to enhance mitigation and preparedness for schools in regions susceptible to tsunami hazards. The project is expected to be completed by late 2016 when results on all phases will be presented.

*Keywords: School seismic safety, advocacy, Tsunami, mitigation*

## **1. Introduction to EERI's School Earthquake Safety Initiative & Tsunami Mitigation Subcommittee**

### **1.1 EERI's School Earthquake Safety Initiative**

The School Earthquake Safety Initiative (SESI) is a global and collaborative network of diverse, expert, and passionate professionals committed to creating and sharing knowledge and tools that enable progressive, informed decision making around school earthquake safety. SESI's vision is to serve the world as a leader in the science, public policy, and advocacy of school earthquake safety. [1]

SESI serves stakeholders in school earthquake safety, from children and their parents, to teachers and administrators; from developers and architects, to engineers and builders; from financial institutions and building officials, to government agencies and emergency managers; from civil servants and commissioners, to local politicians and state and federal legislators. We leverage our extensive expertise and reputation to conduct regionally appropriate actions that make a tangible and positive difference in communities around the world, by protecting the lives of all who inhabit school buildings.

### **1.2 SESI Tsunami Mitigation for Schools Subcommittee**

In 2015, following the acquisition of a grant from the Coastal Zone Foundation, SESI commenced its project on tsunami hazard mitigation and disaster preparedness in U.S. schools. For this purpose, SESI launched a subcommittee of expert professionals to identify U.S. schools susceptible to tsunami hazard to then document and disseminate best practices for tsunami mitigation in the U.S. and abroad. The volunteer professionals on this diverse subcommittee include emergency managers from various states with tsunami hazards, structural engineers, policy advocates, school administrators, seismologists, and tsunami experts.

### **1.3 Background on Tsunami Hazards**

Most tsunamis are caused by undersea earthquakes and can also be triggered by landslides that occur above or below the water surface, by volcanic activity and, although rare, from meteorites. There are two sources of tsunamis, local (near-field) tsunamis that originate close to shore, such as from nearby underwater earthquake faults, and distant (far-field) tsunamis that travel across oceans causing impacts thousands of miles from the originating source.

Local tsunamis, usually generated from an underwater, off-shore earthquake fault, can have natural warning signs and can arrive to shore within minutes. Immediate action, such as evacuation to high ground or inland is required even in advance of any official notification. Distant tsunamis are those that originate away from the source location and are often caused by an earthquake. The far-field tsunami waves can travel across oceans to strike a shoreline far from the origin with an arrival time on the order of hours. While natural warning signs exist, official warning systems can be very effective at alerting potentially affected communities well ahead of any danger.

Both types of tsunamis can be dangerous if communities and schools within the shoreline or hazard zone are unprepared. Historically, near-field tsunamis have been responsible for over 70% of tsunami related fatalities as compared to far-field tsunami hazards. [2] Fortunately, with advanced preparation, communities, schools, students, faculty and staff can survive near- and far-field tsunamis. [3]

## **2. Methodology and Approach**

The professionals on the SESI Tsunami Mitigation for Schools subcommittee have conducted a GIS study to identify schools with tsunami risk by overlaying school locations with tsunami hazard zones along the Pacific Coast, Alaska and Hawaii. This study utilizes new and existing tsunami maps along with school databases to

identify schools at risk. The Tsunami Mitigation Committee is also conducting case studies of best practices adopted by schools to reduce their tsunami risk. These best practices, along with mitigation documentation from FEMA and other sources will be compiled and printed as well as digitized. This package will then be disseminated to schools in tsunami hazard zones in order to assist school administrators in disaster preparedness, risk reduction and resilience of their schools. This project is expected to be completed by late 2016 with outreach efforts continuing into 2017.

### 3. Identifying Schools with Tsunami Risk

To preliminarily estimate the number of schools with tsunami risk, SESI received data from USGS Western Geographic Science Center Research Geographer, Dr. Nathan Wood. [4] This multi-state study assessed community vulnerability to natural hazards, and highlighted schools with tsunami hazard in California, Oregon, Washington, Hawaii, and parts of Alaska that were subsequently extracted for SESI to reference. This USGS data was created based on various GIS analyses of tsunami-hazard zones for each state and a 2012 nation-wide business database, and is tabulated in Table 1.

Table 1 – Tsunami Hazard Zones in States

State	Tsunami Hazard Zone
Oregon	L1 scenario zone from DOGAMI
Washington	A combination of Walsh et al 2000 (scenario 1A with asperity) and L1 scenario for Washington from WDNR
California	The state maximum hazard zone in California from CGS
Hawaii	The new extreme inundation zone for Hawaii
Alaska	Maximum tectonically-generated tsunami-hazard zones from AKDGG

This initial data set provided an important starting point for identifying tsunami vulnerable schools. However, because the purpose of the original study was primarily statistical in nature and the data sources were from business records, there existed some inconsistencies found in school facility locations. The discussion of tsunami-vulnerable schools gave basis for further study utilizing ASCE 7-16, which conducted newer studies on tsunami design zones. Additionally, this study did not identify specific locations of schools within a tsunami hazard zone, thus, the subcommittee decided that further study was needed utilizing the newly available information from ASCE 7-16 (described in more detail in the next section).

Under the leadership of Ian Robertson, SESI conducted an independent GIS study to identify vulnerable schools using the ASCE 7-16 Tsunami Design Zone maps that employ a consistent hazard zone methodology across the five western states impacted by tsunamis. Further details on the development of ASCE 7-16 can be found in Section 4. SESI members found school location databases for each state in the study to supplement, update, or replace the baseline data from the USGS study. Table 2 shows the sources for school data used in the study.

Table 2 – Sources of School Location Data by State

Alaska	Alaska Seismic Hazards Safety Commission database from Alaska Department of Education
California	California Department of Education, Public Schools and Districts
Hawaii	Hawaii Emergency Management Agency
Oregon	Oregon Department of Geology and Mineral Industries, Seismic Needs Assessment Project

Washington	Washington Office of Superintendent of Public Instruction, Education Directory
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In order to identify schools located within the ASCE 7-16 Tsunami Design Zones (TDZ), all school GPS locations were imported into Google Earth along with the TDZ maps. All schools that fell within the TDZ were retained in the database, along with schools that straddled the TDZ limit or were within a few hundred meters of the TDZ limit. All other schools were removed from the database. The decision to retain schools close to, but outside of, the TDZ limit is because of the potential for limited access to these schools during and immediately after a tsunami event depending on the location and direction of access roadways. The school locations were cross-checked against Google Earth data layers of public institutions, which occasionally helped to correct errors in the data files. In addition, any private schools or other K-12 institutions that appeared in Google Earth, but were not in the original files, were added to the database. However, it is likely that a number of private and charter schools may not appear in Google Earth or the public school databases, therefore, the total number of private schools will need to be updated once more information is obtained from each state.

Work is still underway to cross-check the database for each state with the official state evacuation maps to determine whether or not every school on the list is indeed in an evacuation zone. Because of the inherent conservatism in the development of the ASCE 7-16 2500-year probabilistic Tsunami Design Zone maps, these generally extend inland beyond current evacuation maps.

#### 4. ASCE 7–2016 Tsunami Design Zones

*ASCE/SEI 7 Minimum Design Loads For Buildings and Other Structures* (often abbreviated as ASCE 7) is a standard that provides the basis for the United States building code, called the International Building Code. It sets minimum requirements for general structural design and includes means for determining dead, live, soil, flood, snow, rain, atmospheric ice, earthquake, and wind loads, as well as their combinations. [5] On regular 6-year intervals, this standard is updated by various committees. During the 2016 update cycle to the new version ASCE 7-16, a new chapter on tsunami design has been incorporated and adopted. SESI decided to use this state-of-the-art information from the new chapter to inform its study.

In an effort to identify all public and private schools in the five western states that are exposed to a tsunami hazard, SESI used the Tsunami Design Zone maps generated for ASCE 7-16 Chapter 6, Tsunami Loads and Effects. These maps were generated based on a 2500-year probabilistic analysis of all earthquake-generated tsunamis in the Pacific Basin. This work was performed primarily by Hong Kie Thio of AECOM and Yong Wei of PMEL, NOAA [6]. The methodology used in this process, and the resulting maps have been reviewed by various interested parties, including the ASCE 7 Tsunami Loads and Effects subcommittee and the ASCE 7 Main Committee. The maps include appropriate levels of uncertainty based on lack of knowledge of the source mechanisms and modeling accuracy.

An additional advantage of these maps for the SESI study, is that they use a consistent methodology to identify tsunami hazard across all states. Tsunami evacuation maps were also considered by the committee, but as their development and adoption occurs at the state level, their assumptions and hazard levels vary. Using consistent, nationally developed maps allowed the data and school lists to be more comparable across states, which was seen as a strong advantage by the subcommittee. The downside of using these maps however, is that they are new and apply only to the design of new structures, while the evacuation maps represent mandated state requirements. Thus, SESI endeavored throughout the project to use both ASCE 7-16 Tsunami Design Zone maps and state evacuation maps where possible.

##### 4.1 Probabilistic Tsunami Hazard Analysis

All of the Pacific basin tsunami sources were considered in the development of 2500-year return period probabilistic off-shore tsunami wave conditions for the ASCE 7-16 design standard. Past reliance on historical tsunamis to define the design level have failed, most notably during the Tohoku Tsunami in Japan, so a probabilistic approach is the only defensible methodology to help estimate future potential tsunamis. The anticipated 2500-year offshore wave heights along the Aleutians, West Coast of North America, and the

Hawaiian Islands run as high as 20 meters in Alaska, but reduce down the West coast of the US. Offshore wave heights are not expected to exceed 15 meters along the coast of Hawaii.

The tsunami sources are fully integrated over seismic sources varying in size and recurrence rate. Uncertainties are included through the use of logic trees and probability distribution functions based on earthquake source predictions by the US Geological Survey, USGS. The results include aleatory uncertainties relating to the lack of understanding about the source mechanism, such as slip distribution and tsunami wave generation, and epistemic uncertainties relating to modeling of trans-oceanic wave propagation. The resulting probabilistic tsunami hazard is primarily expressed in the offshore tsunami amplitude and characteristic period at 100m bathymetric depth along the entire coastline of Washington, Oregon, California and Hawaii, and the southern coastline of Alaska. During generation of the 2500-year offshore wave properties, source disaggregation was recorded for use in generating scenario tsunamis that represent the 2500-year return period event. These data are stored in an online ASCE database [5].

#### 4.2 Tsunami Design Zone Maps

In order to determine the extent of tsunami inundation along the exposed coastlines, the offshore wave heights are used to generate onshore inundation modeling to determine the Tsunami Design Zone (TDZ) and runup elevation. The disaggregated sources were used to generate scenario tsunamis which were propagated toward the coastline of interest. The resulting offshore wave at 100m bathymetric depth must not be less than 80% of the PTHA 2500-year wave amplitudes. The tsunami is then propagated on land using a 60m horizontal grid resolution Digital Elevation Model (DEM) to determine the inundation limit. All land seaward of the inundation limit is in the TDZ. This work was performed by researchers at the NOAA Pacific Marine Environmental Laboratory, PMEL, in Seattle, Washington. It is proposed that the individual states use higher resolution DEM's (10 meter resolution or better) to generate more accurate TDZ data for highly populated regions.

Now that the TDZ maps are officially accepted into the published version of ASCE 7-16, they will likely form the basis for tsunami design requirements in the 2018 version of the International Building Code, IBC 2018. Any category IV (essential and hazardous facilities) and category III (large occupancy) buildings, that fall in the TDZ will need to consider tsunami design in addition to traditional loads such as seismic, wind, etc. A local jurisdiction may also elect to include some taller category II (office, residential, etc.) buildings in the tsunami design requirements so as to provide alternative vertical evacuation options and to provide greater community resilience to tsunami inundation. All low-rise, light framed residential and commercial buildings (category II) and agricultural and storage buildings (category I) will be exempt from tsunami design.

It is therefore important to note that the TDZ maps are *not* tsunami evacuation maps. Each State and County is responsible for developing appropriate tsunami evacuation maps, and most coastal counties in the five western states have evacuation maps in place. It is likely that the TDZ maps will exceed the extent of the evacuation maps, either because of the added margin of error for uncertainty, or because of the vintage of evacuation maps. The TDZ maps have therefore been used for this SESI study only as a starting point to identify schools at potential tsunami risk. The advantage of this approach is that the TDZ maps provide a consistent probabilistic platform for comparison across all five states, whereas the locally generated evacuation maps were often developed based on scenario or historical tsunamis, without much inter-state coordination.

## 5. Mapping Schools with Tsunami Risk

Based on the procedure described in section 3, the number of schools falling within the ASCE 7-16 TDZ in each of the five western U.S. states is given in Table 3. The following sections show a sample of schools in each of these states.

Table 3 – Schools in ASCE 7-16 Tsunami Design Zones

State	Public Schools	Private Schools
Alaska	4	0
California	75	5
Hawaii	73	32
Oregon	9	3
Washington	19	1

### 5.1 Alaska

In spite of its long coastline, Alaska has only a few schools at risk of tsunami inundation. It should be noted that the coastline of Alaska fronting the Bering Sea has a less well-defined tsunami hazard, so the ASCE 7-16 TDZ maps only cover regions along the southern coastline of Alaska. Figure 1 shows the location of two of the four schools in Alaska that fall into, or are close to, the TDZ. Even though Seward High School falls outside the TDZ limit, access to the school will be affected during and immediately after a design level tsunami, so it was included in the list.

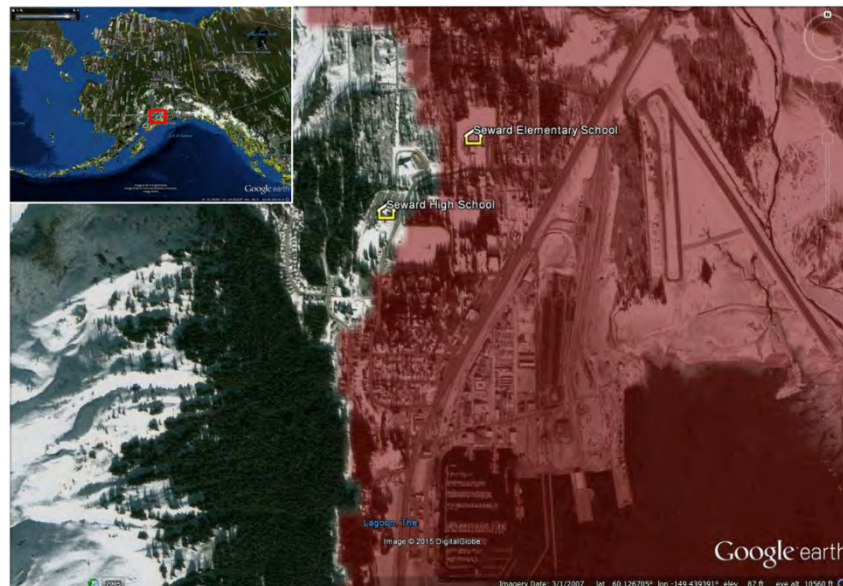


Fig. 1 — Google Earth image showing locations of Seward Elementary and High Schools

## 5.2 California

There are a total of 80 schools in California that fall within or close to the ASCE7-16 TDZ. Figure 2 shows 12 public and 4 private schools identified in or near the TDZ in the communities of Newport Beach and Huntington Beach, Southern California.



Fig. 2 — Google Earth image showing locations of Schools in Huntington/Newport, Southern California

## 5.3 Hawaii

With its concentration of residential centers in the coastal plains, Hawaii has a total of 105 schools (73 public and 32 private) in the ASCE 7-16 TDZ. There are a total of 71 schools in the TDZ on Oahu, 16 in Maui County, and 9 each on the islands of Hawaii and Kauai. The official student population of all of these schools is close to 50,000 students within the TDZ during a regular school day. **Error! Reference source not found.** Figure 3 shows the location of 14 schools in the TDZ in downtown Honolulu on the south shore of Oahu.

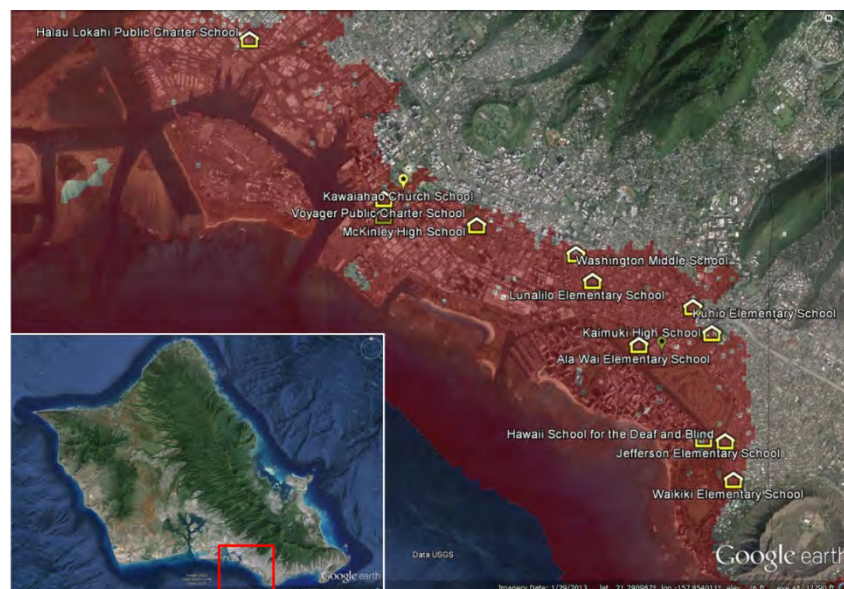


Fig. 3 — Google Earth image of Downtown Honolulu, HI, showing 12 public and 2 private schools in the TDZ

## 5.4 Oregon

There are 12 schools in Oregon that fall within or close to the ASCE 7-16 TDZ. Figure 4 shows the location of schools and the district administrative office in Seaside, Oregon, relative to the TDZ. [7]

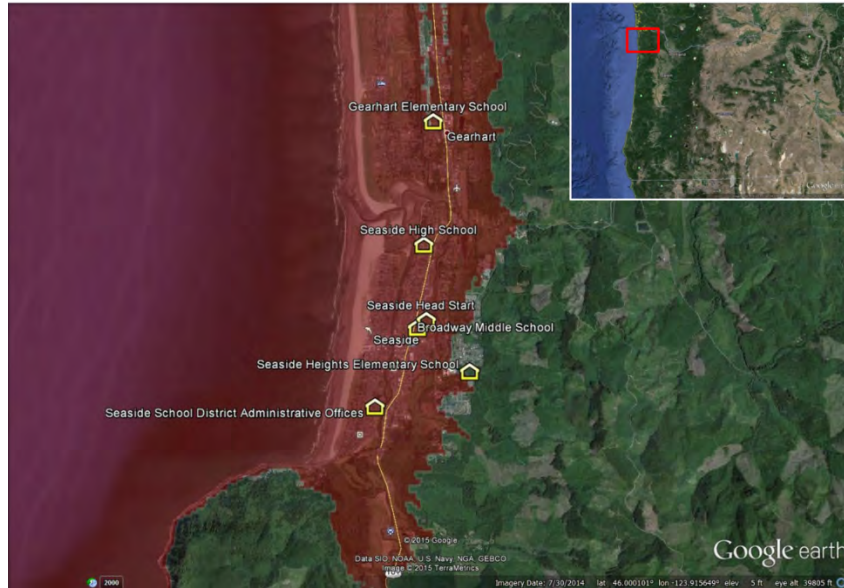


Fig. 4 — Google Earth image of Seaside, Oregon, showing five schools and the district administrative office

## 5.5 Washington

There are 20 schools in the TDZ in Washington State. Figure 5 shows the location of Ocosta Elementary and Junior-Senior High Schools within the TDZ. Construction of a vertical evacuation structure at these schools is described in the next section.

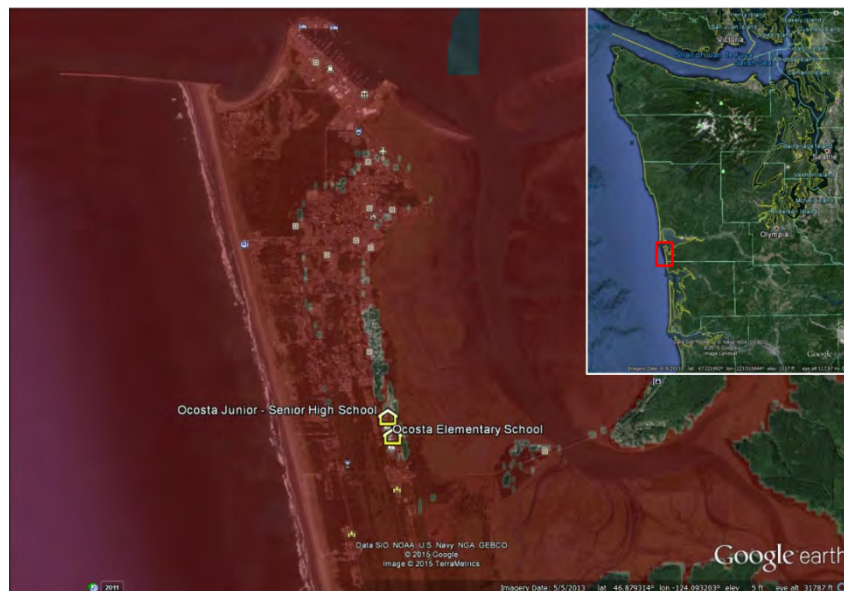


Fig. 5 — Google Earth image showing the location of the Ocosta Schools in the TDZ in Washington State



## 6. Tsunami Mitigation Case Study Examples

The following sections highlight case studies of tsunami hazard mitigation strategies in schools within selected states. These range from physical mitigation to action-based preparedness, and showcase a variety of funding mechanisms and techniques. These case studies are being considered by SESI for use as best practices to share with other schools at-risk. Their varied approaches to managing tsunami hazard risk should provide ideas to school stakeholders and demonstrate that there is no “one-size-fits-all” option to tsunami mitigation.

### 6.1 Lincoln County School District, Oregon: Relocation and Open Space

Lincoln County schools on the Oregon coast had instated district-wide tsunami and evacuation drills, yet administrators were afraid that the age and condition of the buildings may lead to collapse during an earthquake and tsunami event, along with the impending danger of the evacuation routes leading through landslide zones. In 2006, the district reconfigured two schools on high ground to increase capacity for students from two other schools located in a tsunami hazard zone that were later closed. The Lincoln County District was able to finance the 58,000 square foot project through special programs, including the Qualified School Construction Bonds which dispersed \$15 million in federal aid.

The project is part of the first FEMA pre-disaster mitigation project in the nation. FEMA also granted the district \$3 million in exchange for the demolition of the old high school in a tsunami hazard zone to convert the area into open buffer space. A project such as this can only be FEMA-approved when the benefits exceed the cost of the project. In this case, the 11.5 acres of open space near the coast significantly reduced the potential for loss of life and property, affording the school district federal pre-disaster aid monies. The community is now deciding on the future use of the open space, with options including a multi-use community park with an athletic field, theater components, dog parks and community gardens. [8, 9]

### 6.2 Ocosta Elementary School, Washington: Vertical Evacuation Structure

The University of Washington led a multi-agency planning team of researchers, professionals and graduates along with the Washington Emergency Management Division to create a community-driven process to identify potential siting for vertical evacuation buildings in low-lying, risk prone regions on the Washington coast. Near the Westport peninsula, Ocosta Elementary had been identified as most vulnerable, for which two previous bond measures to replace the school had failed.

In 2012, a new bond passed allowing for a \$2 million wing to be built to Ocosta Elementary school using the FEMA P646 standards (Guidelines for Design of Structures for Vertical Evacuation from Tsunamis) [9] and draft versions of the ASCE 7-16 tsunami design provisions. The group considered several Safe Haven Options described in FEMA 646, including Tsunami resistant towers, buildings and berms. A team of professors and students led the citizens through conceptual designs of the vertical evacuation structures appropriate for the communities, ultimately and collectively deciding upon a dual-purpose instructional and safety building engineered by Degenkolb Engineers. The roof of the school gymnasium is designated safe refuge with capacity for over 1,000 people and is accessed from four exterior stair towers, supported by deep foundations anchored 50 feet into bedrock. The project broke ground on January 2015, and is the first tsunami evacuation structure in North America (see Fig 6). [10, 11]



Fig. 6 – Ocosta Elementary School, Proposed Tsunami Evacuation Building [12]

### 6.3 Tsunami Evacuation Guidelines for Schools in Hawaii

In 2012, the Hawai'i Tsunami Education Curriculum Program (HITEC) and the Pacific Tsunami Museum commenced a 3 year-project with funding from the U.S. Department of Education to offer a multi-faceted program for school preparedness. The program develops place-based education for students in grades 4, 6, 8 and 9 on five islands located in high risk tsunami and flooding inundation zones. HITEC prepares students to become first responders for their family and communities with sensitivity to local customs and culture. In doing so, the curriculum includes non-traditional, yet contextually significant, elder knowledge of disaster management and risk mitigation. Students in field-test schools create emergency preparedness and evacuation route fliers to distribute to the community with the guidance of the program managers and teachers. HITEC also provides teacher training and community lectures transmitted live through video conference to participating schools, and pre-recorded web-based courses on tsunami hazard education for school children. Regional scientists offer mentorship for teachers and students as a partnership between tsunami experts and middle schools on the islands.

As of 2012, the program has trained 32 teachers who are field testing lessons with students in 17 schools on five islands. Priority is given to schools located in the tsunami evacuation zones with large numbers of Native Hawaiian students. The Pacific Tsunami Museum provides informal consultations to school principals and their safety committees to assist schools in enhancing evacuation preparedness plans and procedures with lessons learned from previous Pacific coast tsunami events. [13]

## 7. Tsunami Safety Resources

The following paragraphs describe selected resources and guidance documents for schools in tsunami hazard prone regions that SESI can disseminate and share with at-risk schools. Several of the case studies discussed above area also listed below. While some of the resources are more technical in nature, it is envisioned that SESI volunteers can help to explain these resources to interested school administrators to assist stakeholders in both understanding and navigating the many options for enhancing tsunami safety.

*FEMA Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* was updated in 2012 following the Great Tōhoku earthquake and offers general information for vertical evacuation structures and design guidelines. [10]

Kai E'e Hawai'i Tsunami Education Curriculum, Pacific Tsunami Museum. [13]

*National Tsunami Hazard Mitigation Program* is the federal level organization providing guidance for all states with tsunami hazard vulnerability. Included are state and territorial tsunami preparedness websites. [14]

*TsunamiReady® National Oceanic and Atmospheric Administration (NOAA)* is a federal level research and advocacy organization that offers educational resources for students, teachers, and community leaders. [15]

*Earthquake and Tsunami Information and Resources for Schools* by the Washington Military Department and the National Tsunami Hazard Mitigation Program documents activities for educators to prepare school children for tsunami and earthquake hazards. [16]

*Oregon Tsunami Clearinghouse* by the State of Oregon Department of Geology and Mineral Industries provides resources for teachers and students on what to do in preparation and response during a tsunami event. [17]

*Living on Shaky Ground: How to Survive Earthquakes and Tsunamis in Northern California* was developed by the Humboldt Earthquake Education Center at Humboldt State University in 2011. The document promotes earthquake and tsunami readiness for community members including tips on creating a personal disaster preparedness plan and disaster supply kits. [18]

## 8. Next Steps for Advocacy to Schools at Risk from Tsunami

EERI and its volunteers acting through the School Earthquake Safety Initiative are considering a campaign to accomplish the following:

- Conduct outreach to influence and support school administrators responsible for schools in SESI's mapped tsunami hazard zones. This outreach will include dissemination of best practices, information, and model literature that describe example mitigation approaches and preparedness procedures, as well as distribution of digital copies of tsunami inundation zones.
- Advocate for measures to improve community awareness of local tsunami risk by publicizing tsunami inundation zones and issues facing schools. The campaign will also encourage state and local government agencies to integrate inundation zones into land use plans.
- Support policies to reduce tsunami risk to school children and adults. This includes restricting construction of new public and private K-12 schools in tsunami inundation zones unless buildings are designed for tsunami forces, provide adequate evacuation options (both vertical and inland evacuation), and phasing out or relocating existing schools from inundation zones.
- Disseminate information and model literature to publicize and distribute digital copies of tsunami inundation zones to influence school administrators in taking action toward tsunami safe schools and preparedness procedures within susceptible school districts.
- Issue a media advisory on pilot inundation maps and pilot programs with recommendations on actions that responsible organizations can take toward school safety and tsunami risk mitigation.

Through these strategic actions, EERI hopes to mitigate tsunami risk at regional, state and national levels by supporting schools facing tsunami hazard risk, and by providing administrators access to experts and sharing best practices for tsunami risk mitigation.

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