Abstract

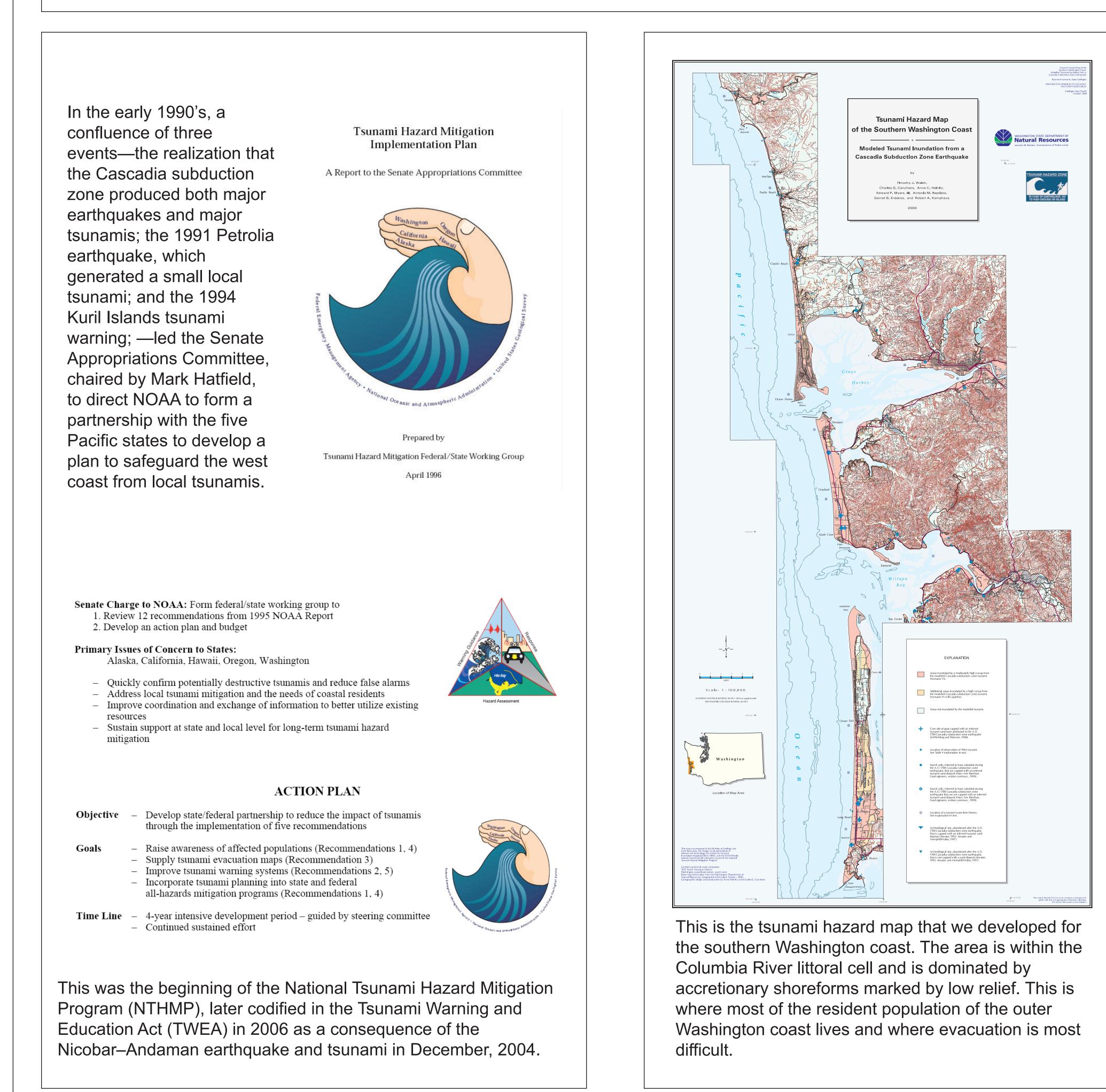
The Washington coast lies adjacent to the Cascadia subduction zone, where a magnitude 9+ earthquake and ensuing tsunami will imperil communities on low-lying spits of the Columbia River littoral cell. Paleoseismic investigations demonstrate that this area has been subject to repeated tsunami attack. Three different numerical models simulating three different earthquake scenarios demonstrate that the communities of Long Beach, Westport and Ocean Shores would be inundated in a few tens of minutes, and sufficiently high ground is generally not accessible in that time.

The National Tsunami Hazard Mitigation Program (NTHMP), a federal-state partnership administered by NOAA, sought to address that issue by developing modeling, siting, load calculation, and structural design guidance for structures to both survive a near field earthquake and be tall and robust enough to be used for local evacuation from tsunamis. The result was entitled "Guidelines for Design of Structures for Vertical Evacuation from Tsunamis" (FEMA P646), published jointly by NOAA and FEMA. It was updated in 2012 to incorporate information from the Tohoku tsunami.

A multi-agency planning team led by University of Washington researchers and graduate students and Washington Emergency Management Division, including Washington Department of Natural Resources, NOAA, FEMA, USGS, county and tribal emergency management officials, created a community-driven process to identify potential sites for vertical evacuation in these at-risk areas.

On the Westport peninsula, the principal site identified was the location of Ocosta Elementary School, which is approximately at the limit of modeled inundation but also at risk from earthquake-induced ground failure of the adjacent protective ridge. Two previous attempts to pass bond issues to replace the school failed. The current plan to replace the school called for making part of the new school a tsunami vertical evacuation structure that could host as many as a thousand people. This time the bond issue passed...by a 70/30 majority.

The gym is designed to be 30 feet above grade and 55 feet above sea level following earthquake-induced subsidence. Its roof will be accessed from the outside of the four corners and will be capable of holding more than 1,000 people. Ground breaking for the new school is scheduled for fall 2014.



The First Tsunami Vertical Evacuation Structure in the United States: Ocosta Elementary School, Washington



WASHINGTON STATE DEPARTMENT OF Natural Resources Peter Goldmark - Commissioner of Public Lands

Division of Geology and Earth Resources David K. Norman - State Geologist

Timothy J. Walsh, Washington Department of Natural Resources John D. Schelling, Washington Emergency Management Division Cale R. Ash, Degenkolb Engineers

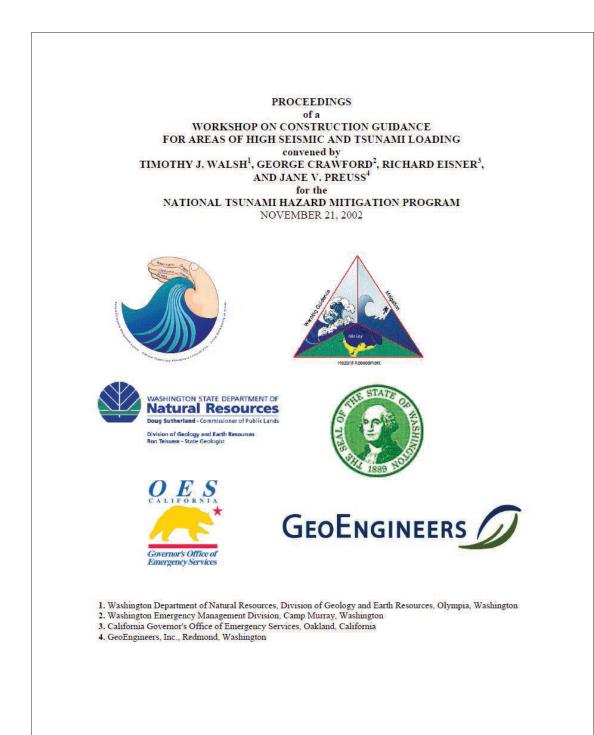
Randall J. LeVeque, University of Washington, Applied Mathematics Loyce M. Adams, University of Washington, Applied Mathematics Frank I. Gonzales, University of Washington, Department of Earth and Space Sciences



Washington Military Departme regency Management Division







On November 21, 2002, George Crawford, Rich Eisner, Jane Preuss, and Tim Walsh held a workshop to investigate whether it was feasible to design facilities to withstand a nearfield M9 earthquake, suffer so little damage as to be attractive for an evacuation refuge, and also be high and resilient enough to serve as a shelter for people in the near-field.

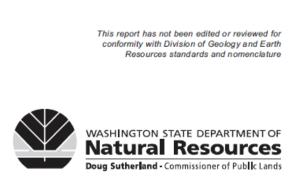


Guidelines for Design of Structures for Vertical Evacuation from Tsunamis



We then formed a partnership with FEMA and the Applied Technology Council to provide building code style guidance for building facilities to withstand a magnitude 9 earthquake and be suitable for vertical evacuation. As demonstrated by the Tohoku tsunami, planning for the right size earthquake is critical.

uctures that Serve as **Evacuation Sites** by Harry Yeh, Ian Robertson, and Jane Preuss WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCE Open File Report 2005-November 200



We contracted with Harry Yeh and Ian Robertson to investigate tsunami damage in which some buildings survived where nearly everything was destroyed. They estimated the forces on the buildings and the features of the survivors that led to their survival. This formed the basis of guidelines for structures in tsunami inundation zones to be used as vertical evacuation facilities.



Vertical Evacuation from **Tsunamis: A Guide for Community Officials**

FEMA P646A / June 2009

FEMA

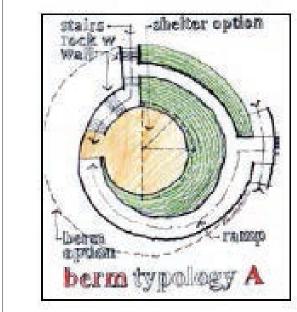
This was accompnied by a guide for community officials to initiate a planning process for vertical evacuation structures

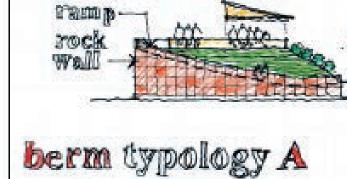
But how to build these? John Schelling, with Washington State Emergency Management Division, launched Washington"s approach to tsunam evacuation in places that have no nearby high ground



Project Safe Haven: Vertical Evacuation on the Washington Coast Grays Harbor County, Washington





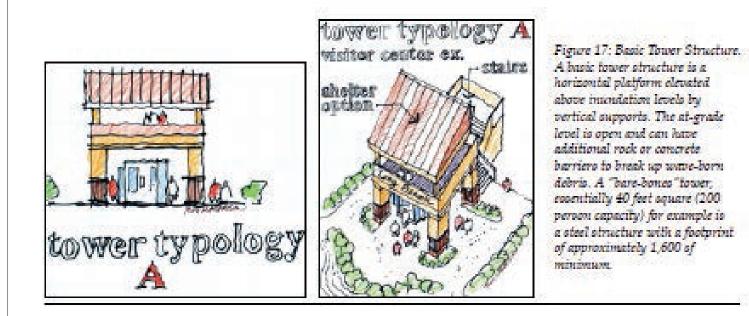


ure 16: Modified Basic Borm Structur basic berm structure can be modified to enhance its visual

appearance and use. There are many variations based on local need and budgets that can add recreational facilities, landscaping and weather rpon local use and context. They generally have open ground level areas, uncovered or covered platfor ith safety fencing. Towers can be used for a variety of functions including visitor centers, in which the

it-grade level acts as sacrificial office, display areas or viewing platforms for scenic and / or wildlife areas, conjunction with community water towers. owers have a smaller footprint than berms for the same number of people. Access to tower structures in be restrictive to physically challenged and aged people if ramps are not included. A berm/tower combination typology has been developed to address limited mobility concerns. The provision of shelters and emergency facilities are optional. COWER TYPOLOGY A: SINGLE TOWER

Single towers may be the most appropriate structure for less costly safe havens where alternative uses ire not feasible and / or land is limited. Alternative uses for towers and at-grade floor area can be accommodated as open space or with sacrificial uses such as shops, information booths, storage areas, etc. Towers can be accessed by stairs, ramps, and mechanical vertical assists in non-emergency situations; and, manual vertical assists (winches, etc.), for emergency events.



After selecting areas for vertical evacuation, Ron Kasprisin (UW) and students led citizens through conceptual designs of vertical evacuation structures that fit into the communities.

Acknowledgments

established without the tireless efforts of Eddie Bernard, recently retired from NOAA. Tsunami inundation superintendent of the Ocosta Shool District, persevered after 2 levy failures to promote this effort and to modeling was also performed in this area by Ed Myers and Antonio Batista at the Oregon Health Sciences convince the voters or her school district to support it. And of course, thanks to the voters of the Ocosta University and by Vasily Titov and colleagues at NOAA's Pacific Marine Environmental Laboratory. Charles School district for their courageous and farsighted vote.

Many people have contributed to all of the efforts documented here. The NTHMP would never have been Wallace of Grays Harbor County has been a continuing source of encouragement, and Paula Akerlund,

UNIVERSITY of WASHINGTON

- Safe Haven Options (from FEMA 646):
- Towers Limited Space **Blocks Views** Few Options for Shelter

Buildings

Expensive Better get it right the first Very Large, Likely to Block Views May require Private Development Incentives for Height?

Berms –

Least Expensive Option Can be Multi-Purpose May be Placed to Limit View Blocking



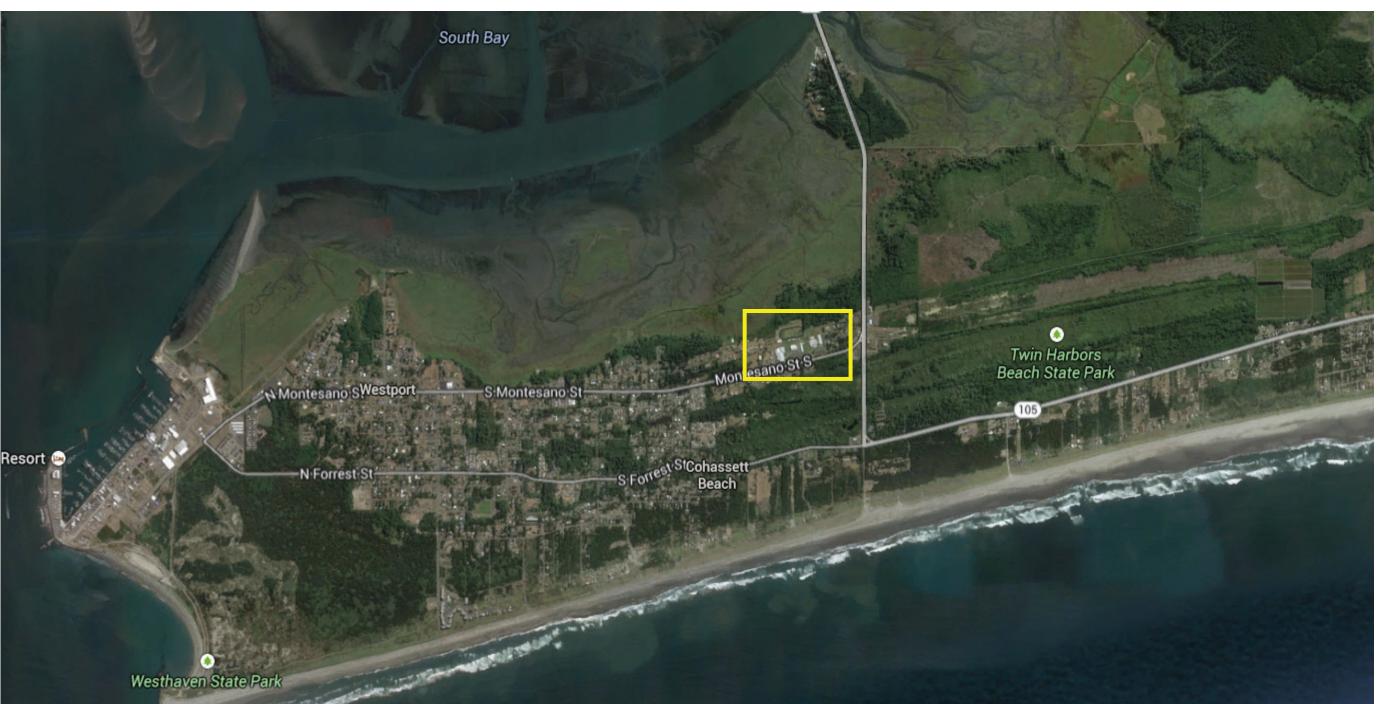
The EARTH and SA







We started by developing walking circles that illustrated how far pedestrians could travel in 20 minutes. This established logical places for vertical evacuation structures to maximize the number of people who could evacuate from an impending tsunami



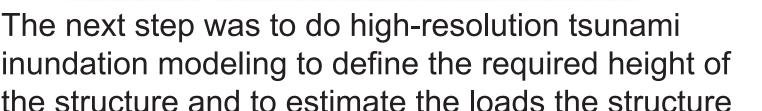
A consistent theme in the Safe Haven process was protecting children by placing vertical evacuation refuges at or near schools. Near Westport, a logical place to build safe haven is at the site of Ocosta Elementary School.

Frank González, Randy LeVeque and Loyce Adams University of Washington

Tsunami Hazard Assessment of the Ocosta School Site in Westport, WA

Final Report: September 11, 2013

Supersedes February 24, 2013 Report

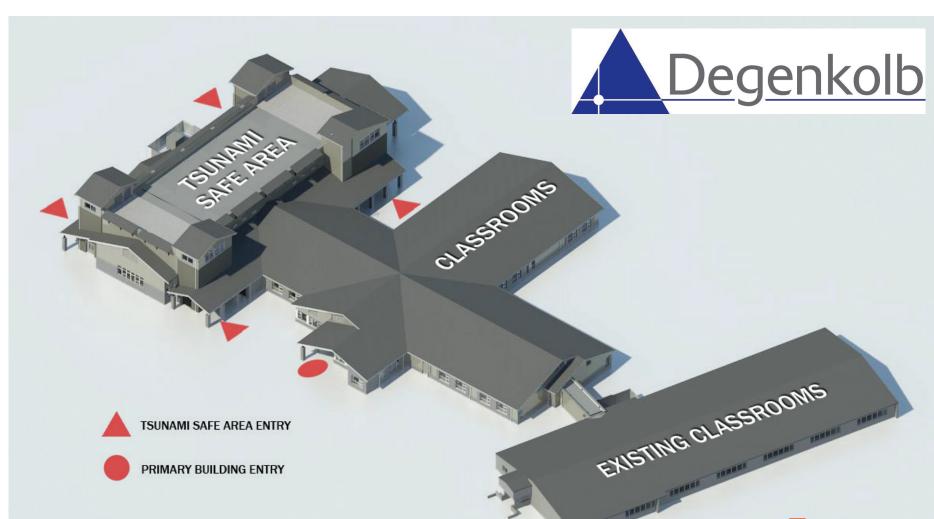


Westport, WA, Google Earth image. Blue rectangle is area of fine resolution GeoClaw

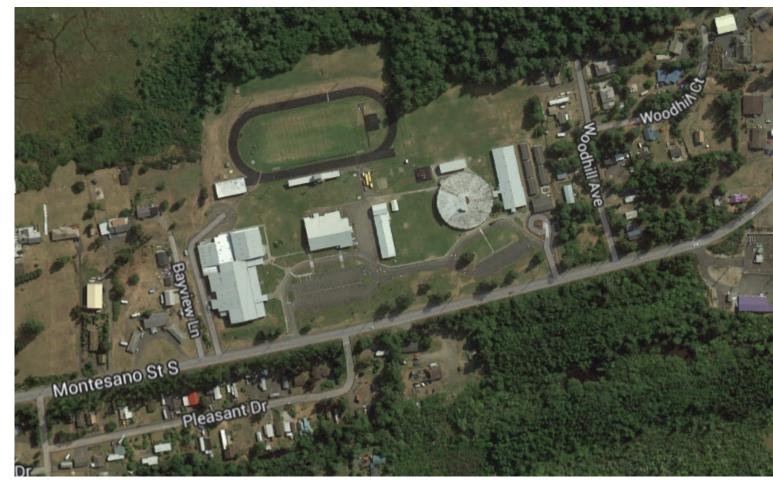
tsunami model grid; white circle encompasses Ocosta School campus.

Study funded by Washington State Emergency Management Division

inundation modeling to define the required height of the structure and to estimate the loads the structure would be designed to resist.

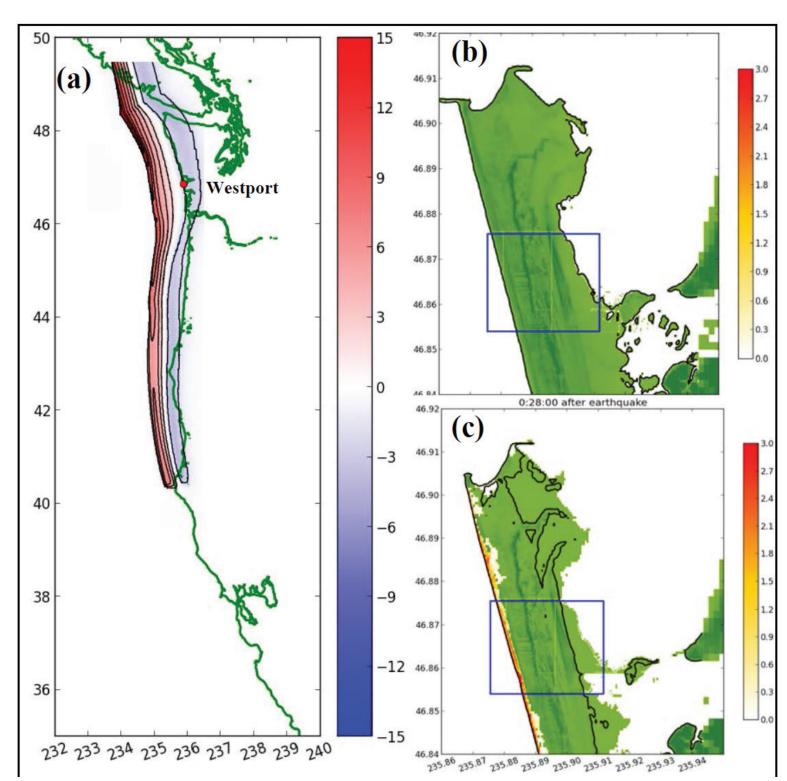


Degenkolb Engineers was retained to design the structural system for the elementary school. The inundation modeling combined with design guidelines resulted in a refuge which is 55 feet above sea level and 28 feet above grade. The roof of the school gymnasium will be the designated safe refuge and it has a capacity for over 1,000 people. Access to the roof is by stair towers at the corners of the gym, which are reached from the outside only, so that people do not have to enter the building and 24/7 access is maintained.

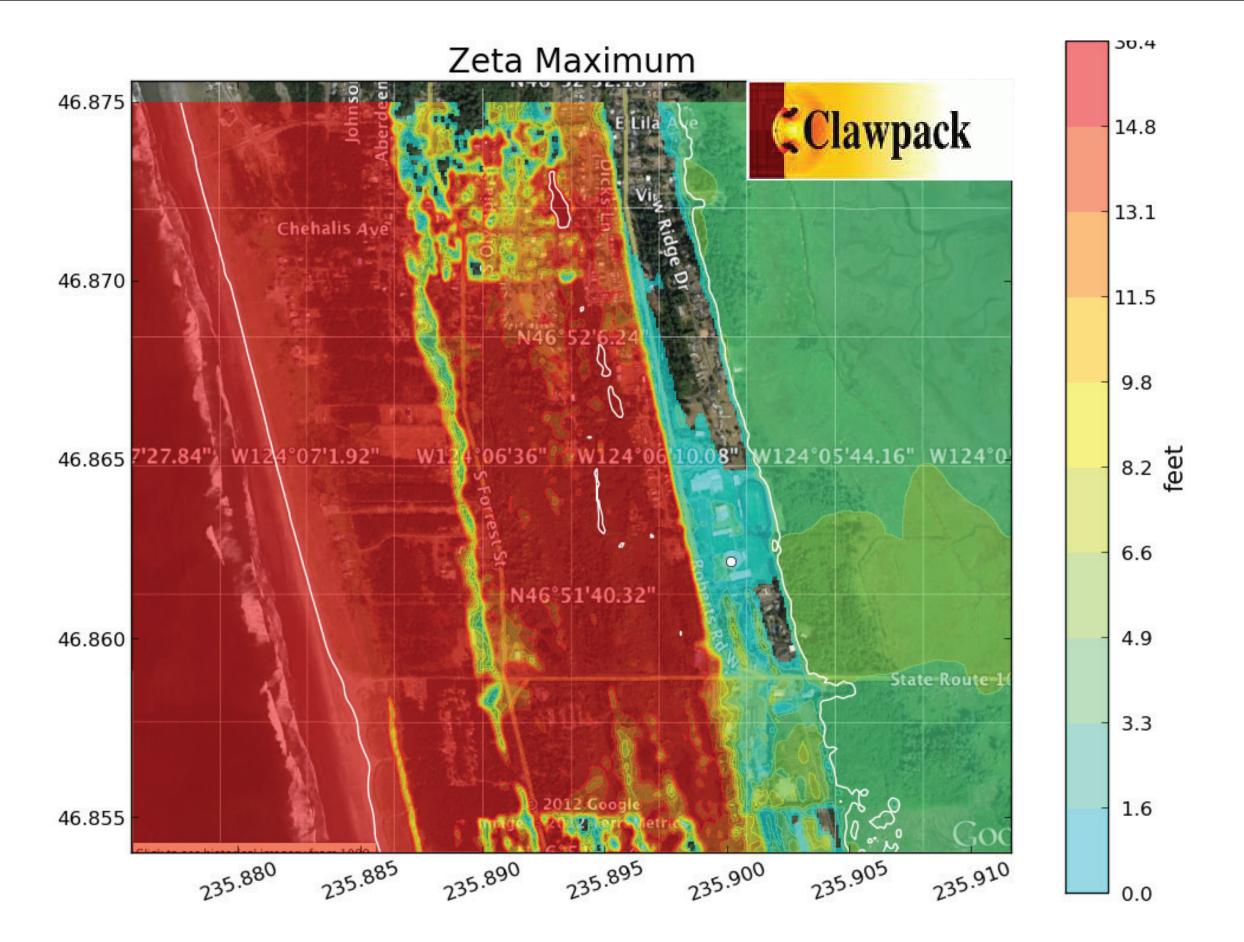


Ocosta Elementary School is an old school that the district has tried twice to replace, but the bond issue failed twice. In April of 2013, another bond issue was on the ballot to replace the school, this time including \$2 million for a wing to be built to FEMA 646 standards.

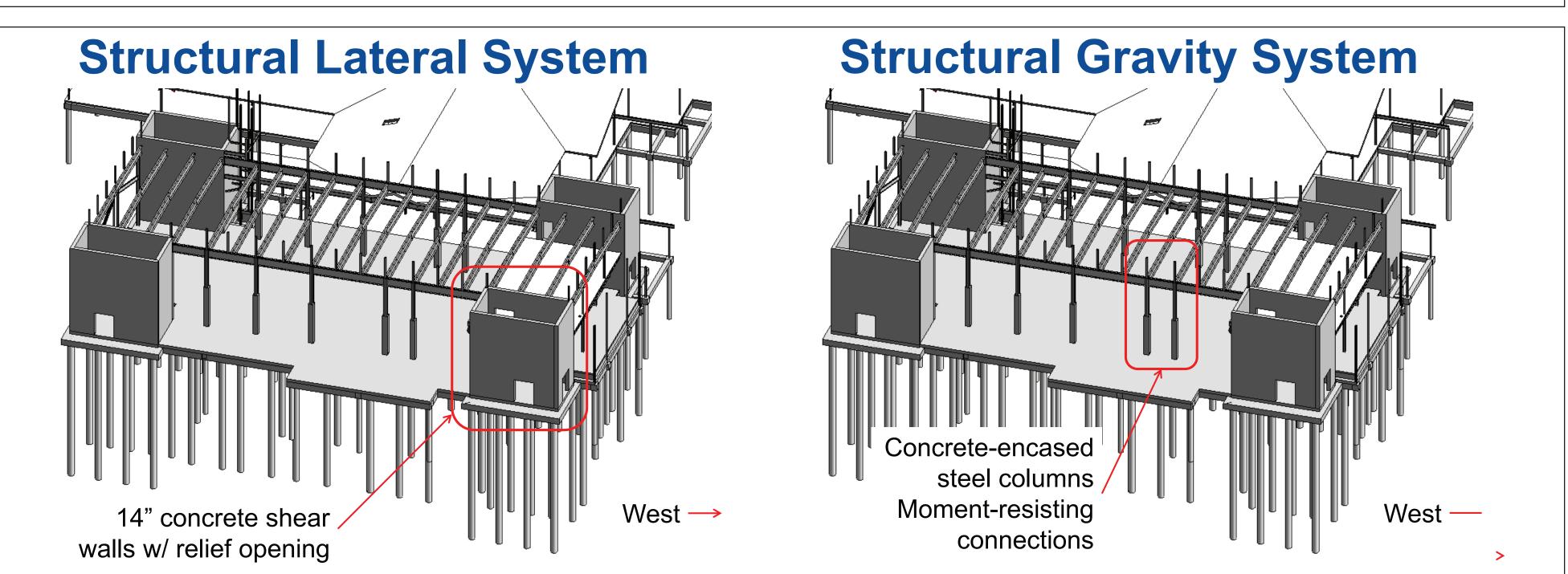
County	Measure	Vote	Vote %
Grays Harbor	Approved	865	69.87%
	Rejected	373	30.13%
Pacific	Approved	197	70.36%
	Rejected	83	29.64%
	Combined Total		
All	Approved	1,062	69.96%
	Rejected	456	30.04%
Total Votes		1,518	100%



We used the GeoClaw modeling software (M. J. Berger, I L. George, R. J. LeVeque and K. M. Mandli, 2011, The GeoClaw software for depth-averaged flows with adaptive refinement, Advances in Water Resources 34, pp. 1195-1206) which has been validated for use by the NTHMP. We modeled an M9 Cascadia earthquake estimated to have approximately a 2,500 year recurrence interval, designated L1 by R. C. Witter, Yinglong Zhang, Kelin Wang, G. R. Priest, Chris Goldfinger, L. L. Stimely, J T. English, and P. A. Ferro, 2011, Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios, Oregon DOGAMI Special Paper 43, 53 p.



The modeling incorporated anticipated coseismic subsidence as part of the initial condition. We also artificially reduced the height of topography to approximate coseismic landsliding, based on the findings of S. L. Slaughter, T. J. Walsh, Anton Ypma, and Recep Cakir, 2014, Landslide and liquefaction maps for the Ocean Shores and Westport peninsulas, Grays Harbor County, Washington: effects on tsunami inundation zones of a Cascadia subduction zone earthquake: Washington Division of Geology and Earth Resources Report of Investigations 38, 26 p, 3 plates.



The details of the structural system are shown above. The gym will be pile-supported, with concrete shear walls and and columns with moment resisting connections. This design resists the maximum considered hydrostatic, hydrodynamic, and impact loads and to guard against progressive collapse.