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

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APPLIED MATHEMATICS
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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.

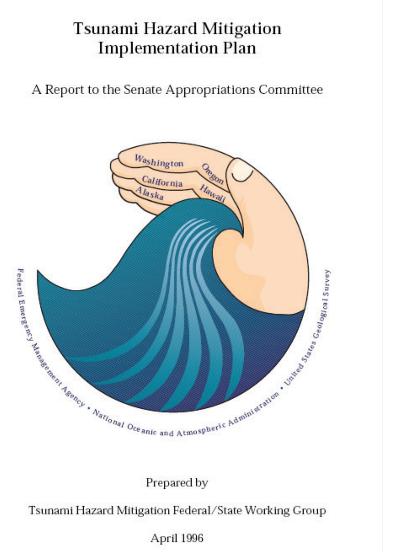
The National Tsunami Hazard Mitigation Program (NTHMP), a federal-state partnership administered by NOAA, sought to address that issue by developing modeling, siting, load calculation, and structural design guidance for structures to both survive a near field earthquake and be tall and robust enough 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.

In the early 1990's, a confluence of three events—the realization that the Cascadia subduction zone produced both major earthquakes and major tsunamis; the 1991 Petrolia earthquake, which generated a small local tsunami; and the 1994 Kuril Islands tsunami warning; —led the Senate Appropriations Committee, chaired by Mark Hatfield, to direct NOAA to form a partnership with the five Pacific states to develop a plan to safeguard the west coast from local tsunamis.


Tsunami Hazard Mitigation Implementation Plan

A Report to the Senate Appropriations Committee

Prepared by

Tsunami Hazard Mitigation Federal/State Working Group

April 1996

Senate Charge to NOAA: Form federal/state working group to
1. Review 12 recommendations from 1995 NOAA Report
2. Develop an action plan and budget

Primary Issues of Concern to States:
Alaska, California, Hawaii, Oregon, Washington

- Quickly confirm potentially destructive tsunamis and reduce false alarms
- Address local tsunami mitigation and the needs of coastal residents
- Improve coordination and exchange of information to better utilize existing resources
- Sustain support at state and local level for long-term tsunami hazard mitigation

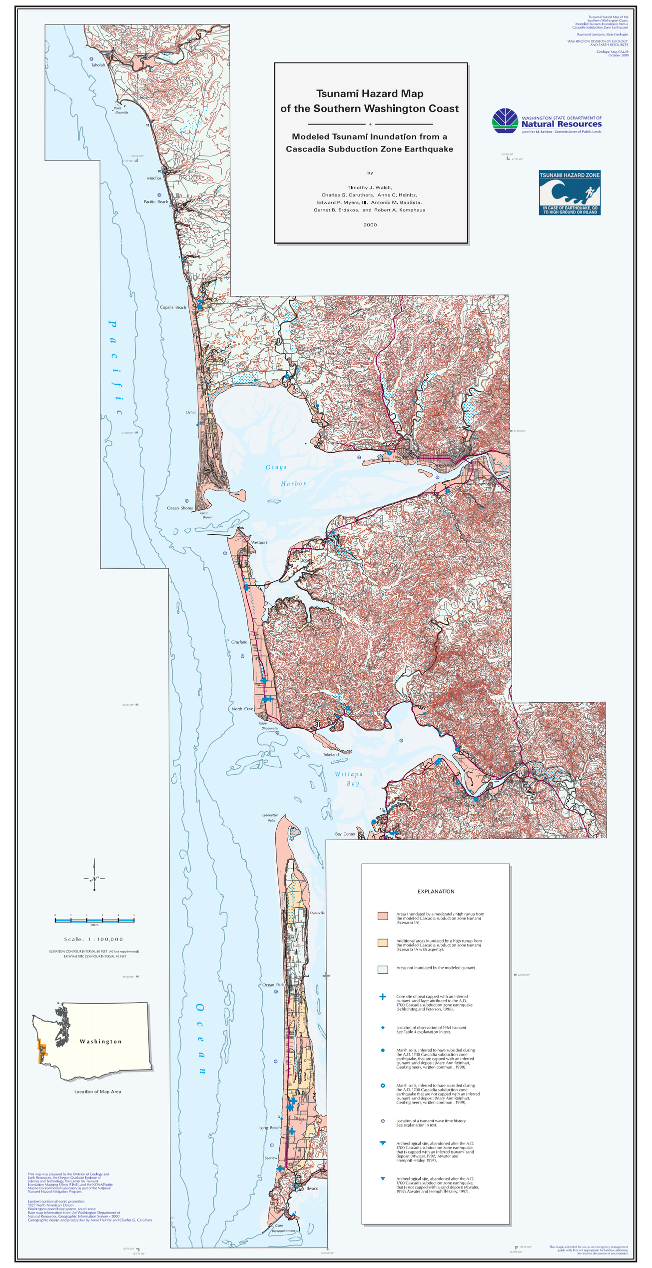
ACTION PLAN

Objective – Develop state/federal partnership to reduce the impact of tsunamis through the implementation of five recommendations

Goals
- Raise awareness of affected populations (Recommendations 1, 4)
- Supply tsunami evacuation maps (Recommendation 3)
- Improve tsunami warning systems (Recommendations 2, 5)
- Incorporate tsunami planning into state and federal all-hazards mitigation programs (Recommendations 1, 4)

Time Line
- 4-year intensive development period – guided by steering committee
- Continued sustained effort

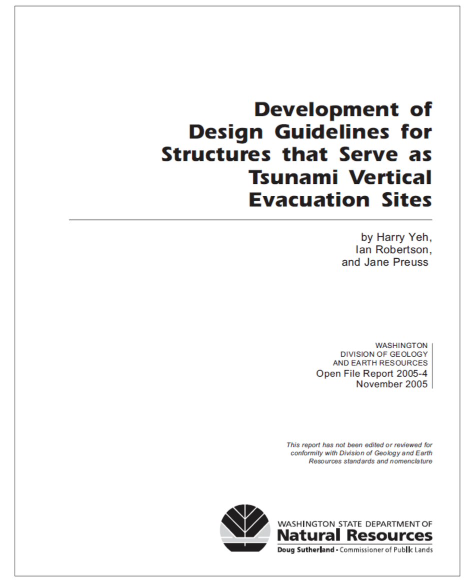
This was the beginning of the National Tsunami Hazard Mitigation Program (NTHMP), later codified in the Tsunami Warning and Education Act (TWEA) in 2006 as a consequence of the Nicobar–Andaman earthquake and tsunami in December, 2004.



This is the tsunami hazard map that we developed for the southern Washington coast. The area is within the Columbia River littoral cell and is dominated by accretionary shoreforms marked by low relief. This is where most of the resident population of the outer Washington coast lives and where evacuation is most difficult.


PROCEEDINGS
of a
WORKSHOP ON CONSTRUCTION GUIDANCE
FOR AREAS OF HIGH SEISMIC AND TSUNAMI LOADING
convened by
TIMOTHY J. WALSH[1], GEORGE CRAWFORD[2], RICHARD EISNER[3],
AND JANE V. PREUSS[4]
for the
NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM
NOVEMBER 21, 2002

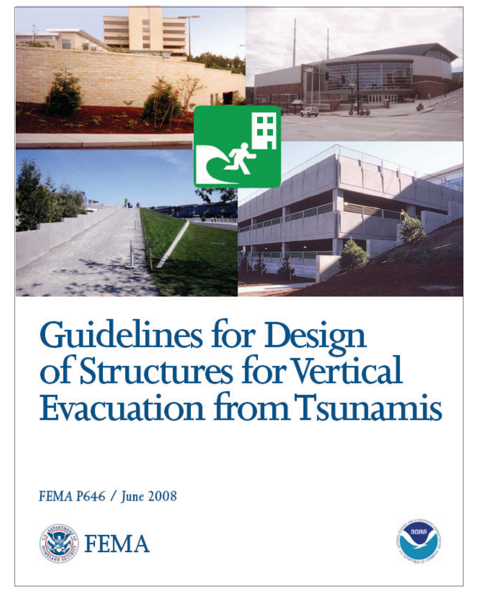
On November 21, 2002, George Crawford, Rich Eisner, Jane Preuss, and Tim Walsh held a workshop to investigate whether it was feasible to design facilities to withstand a nearfield M9 earthquake, suffer so little damage as to be attractive for an evacuation refuge, and also be high and resilient enough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


Development of Design Guidelines for Structures that Serve as Tsunami Vertical Evacuation Sites

by Harry Yeh, Ian Robertson, and Jane Preuss

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Open File Report 2005-4
November 2005

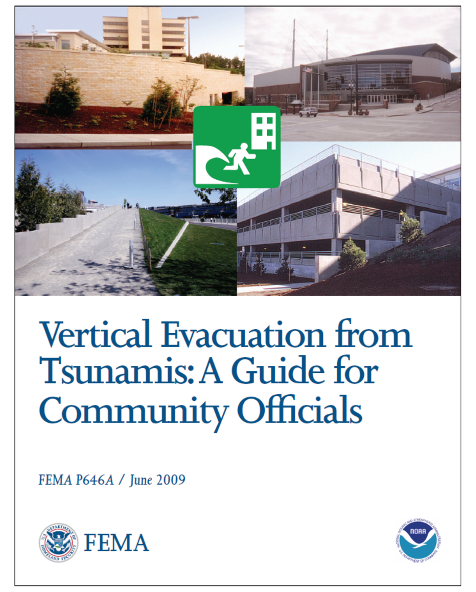
We contracted with Harry Yeh and Ian Robertson to investigate tsunami damage in which some buildings survived where nearly everything was destroyed. They estimated the forces on the buildings and the features of the survivors that led to their survival. This formed the basis of guidelines for structures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


Guidelines for Design of Structures for Vertical Evacuation from Tsunamis

FEMA P646 / June 2008

FEMA

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.

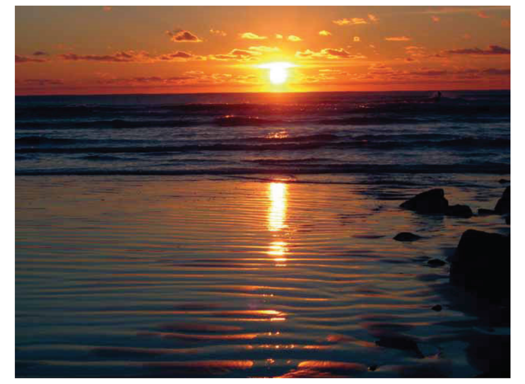

Vertical Evacuation from Tsunamis: A Guide for Community Officials

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 tsunami evacuation in places that have no nearby high ground



Project Safe Haven:
Vertical Evacuation on the Washington Coast

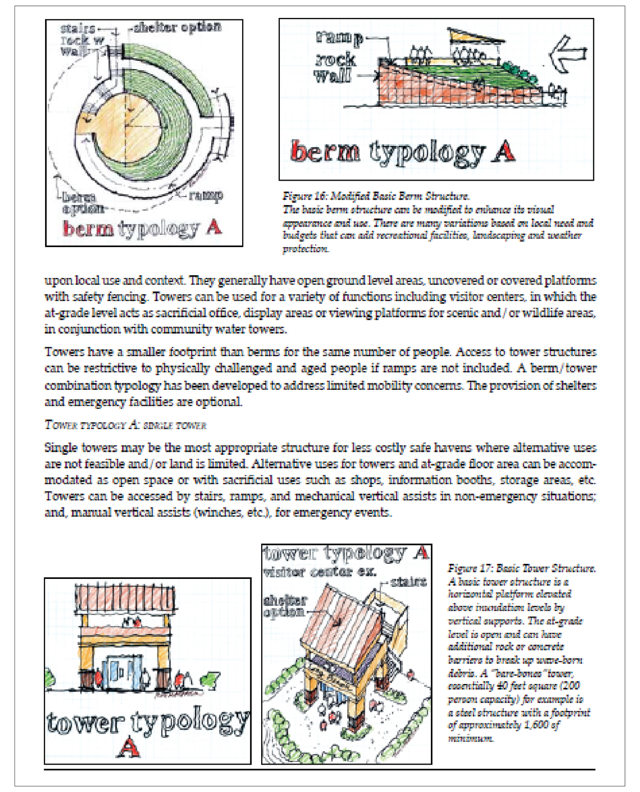
Grays Harbor County, Washington
2011

Safe Haven Options
(from FEMA 646):

Towers –
Limited Space
Blocks Views
Few Options for Shelter

Buildings –
Expensive
Better get it right the first time!
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



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.

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

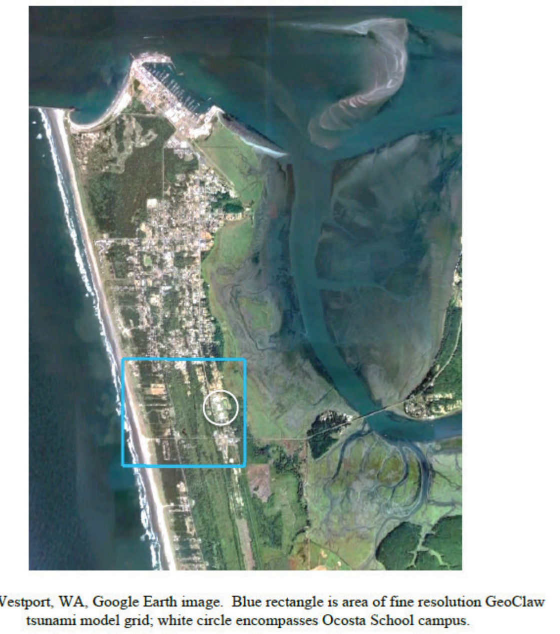
A consistent theme in the Safe Haven process was protecting children by placing vertical evacuation refuges at or near schools. Near Westport, a logical place to build safe haven is at the site of Ocosta Elementary School.

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.

Sch Dist 172 - Ocosta Proposition No. 1 Bonds to Renovate Ocosta Elementary School
*Multi-county race. Results include all counties involved.

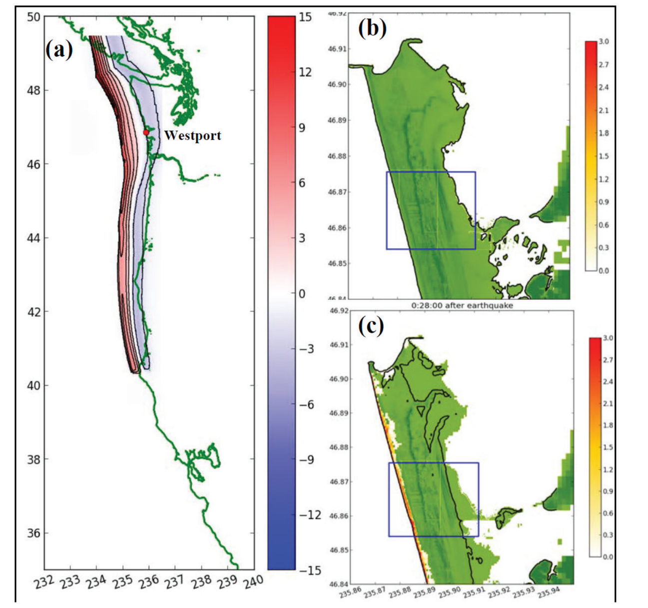
County	Measure	Vote	Vote %
Grays Harbor	Approved	865	69.87%
	Rejected	373	30.13%
Pacific	Approved	197	70.36%
	Rejected	83	29.64%
Combined Total			
All	Approved	1,062	69.96%
	Rejected	456	30.04%
Total Votes		1,518	100%

Tsunami Hazard Assessment of the Ocosta School Site in Westport, WA
Final Report: September 11, 2013
Supersedes February 24, 2013 Report
Frank González, Randy LeVeque and Loyce Adams
University of Washington

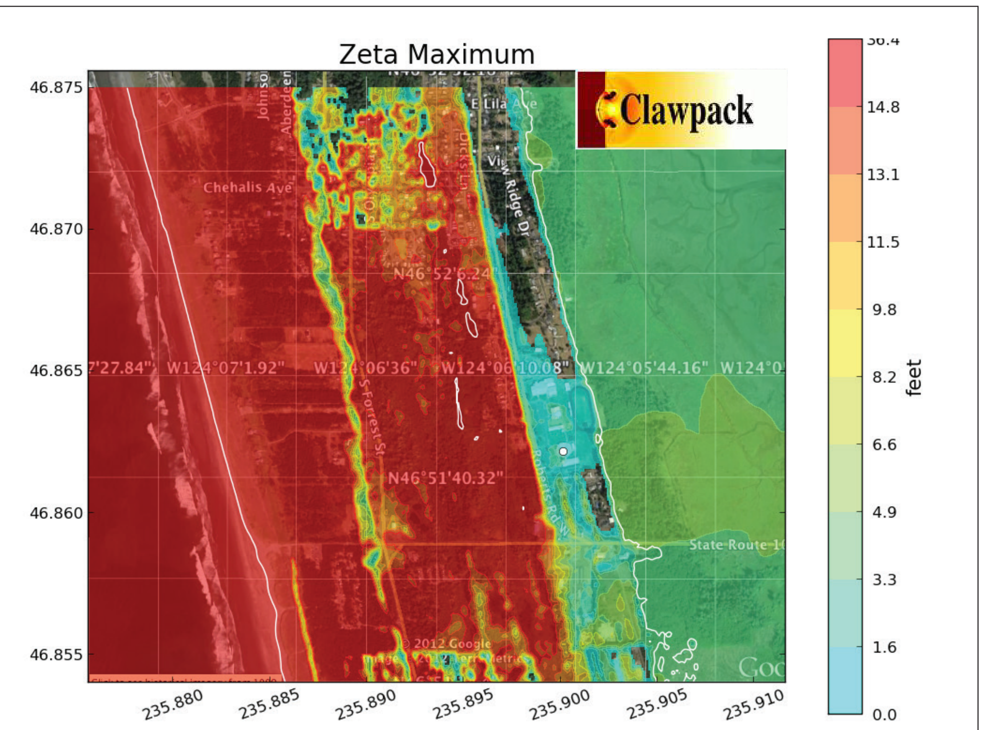


Westport, WA. Google Earth image. Blue rectangle is area of fine resolution GeoClaw tsunami model grid; white circle encompasses Ocosta School campus.
Study funded by Washington State Emergency Management Division

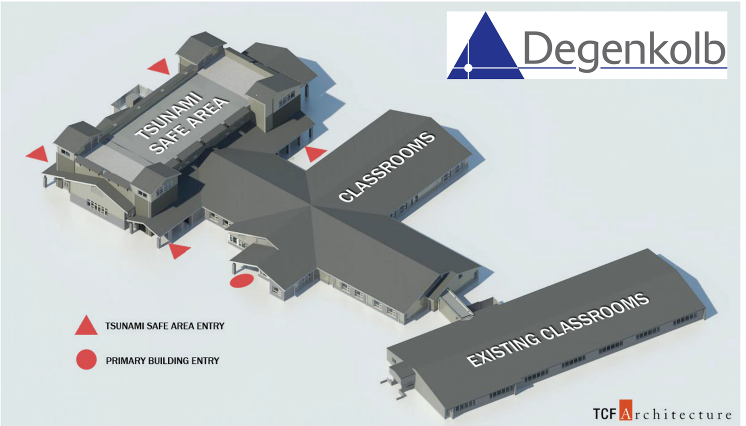
The next step was to do high-resolution tsunami inundation modeling to define the required height of the structure and to estimate the loads the structure would be designed to resist.



We used the GeoClaw modeling software (*M. J. Berger, D. 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.*

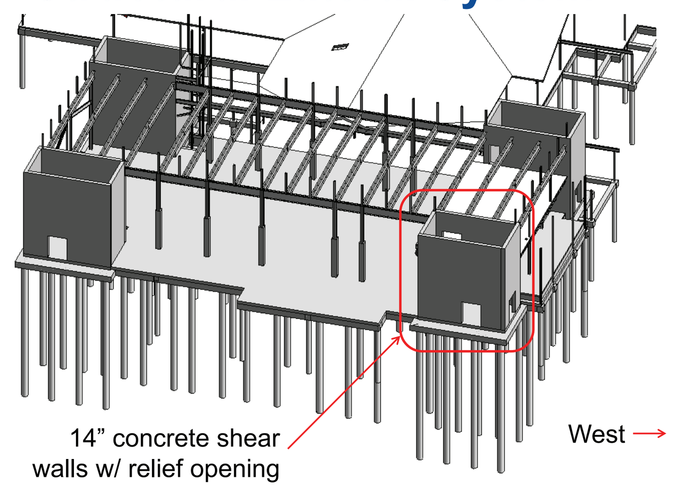


The modeling incorporated anticipated coseismic subsidence as part of the initiial condition. We also artificially reduced the height of topography to approximate coseismic landsliding, based on the findings of *S. L. Slaughter, T. J. Walsh, Anton Ypma, and Recep Cakir, 2014, Landslide and liquefaction 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.*

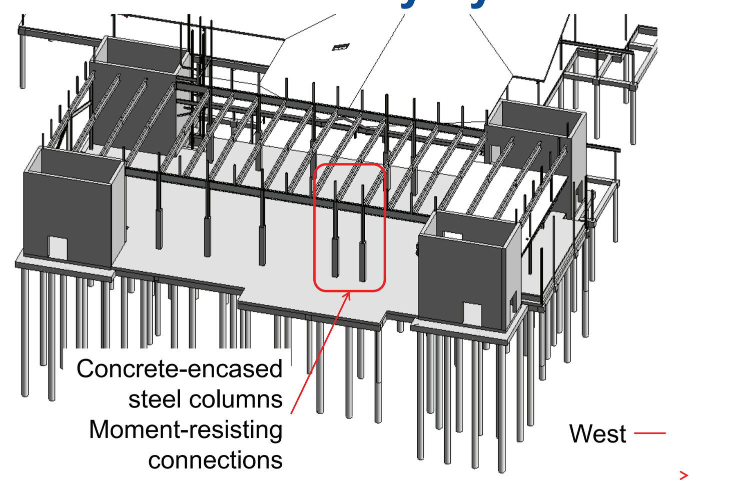


Degenkolb Engineers was retained to design the structural system for the elementary school. The inundation modeling combined with design guidelines resulted in a refuge which is 55 feet above sea level and 28 feet above grade. The roof of the school gymnasium will be the designated safe refuge and it 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.

Structural Lateral System



Structural Gravity System



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.

Acknowledgments

Many people have contributed to all of the efforts documented here. The NTHMP would never have been established without the tireless efforts of Eddie Bernard, recently retired from NOAA. Tsunami inundation modeling was also performed in this area by Ed Myers and Antonio Batista at the Oregon Health Sciences University and by Vasily Titov and colleagues at NOAA's Pacific Marine Environmental Laboratory. Charles Wallace of Grays Harbor County has been a continuing source of encouragement, and Paula Akerlund, superintendent of the Ocosta Shool District, persevered after 2 levy failures to promote this effort and to convince the voters or her school district to support it. And of course, thanks to the voters of the Ocosta School district for their courageous and farsighted vote.