Preliminary White Paper
on
Tsunami Evacuation Buildings (TEBs): A New Risk Management Approach to *Cascadia Earthquakes and Tsunamis*

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Shirahama Tsunami Evacuation Structure. Photo by Professor Nobuo Shuto

Executive Summary

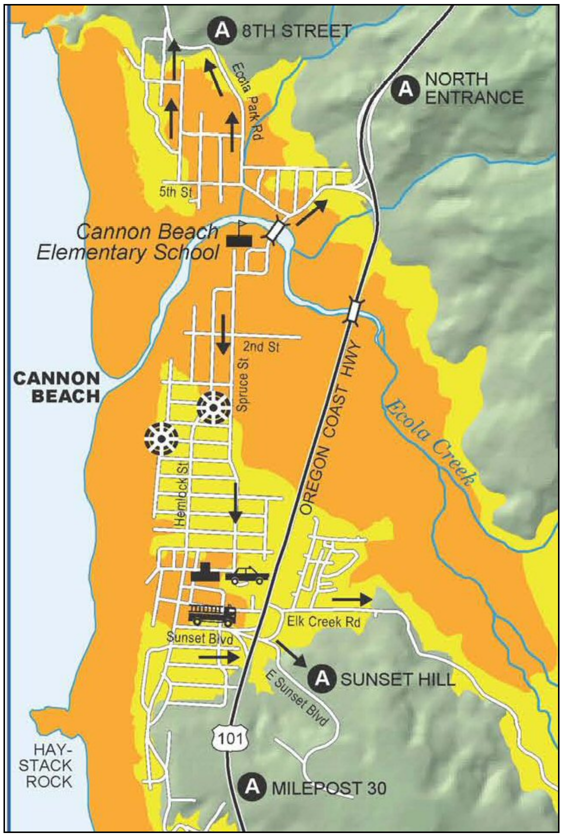
This white paper is a working document that discusses the need for tsunami evacuation buildings (TEB) as new risk management approach to the Cascadia earthquake and tsunami. Taking its starting point from FEMA P646 Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, it looks at how this conceptual approach would work for rebuilding the Cannon Beach City Hall as a TEB. Preliminary design, technical and social issues are considered, including tsunami dissipator to deflect wave energy away from the TEB and geotechnical and structural design to survive a magnitude 9 earthquake and near field tsunami. Many issues remain unresolved, including the need to determine tsunami evacuation scenarios, foundation conditions, funding challenges, and many more.

Chapter 1. Introduction on Tsunami Risk Management

Yumei Wang, PE

Background

Low lying coastal communities along the Pacific Northwest are at-risk of near-field (local) tsunami inundation generated by Cascadia Subduction Zone (CSZ) earthquakes. These communities were developed long before scientists understood the existing tsunami hazards. As such, about 100,000 residents are in the tsunami inundation hazard zone each day in Oregon. Some of these 100,000 people are in the high hazard portion of the inundation zone nearest to ocean and river channels with long travel distances to safe, higher elevation land. In addition, many of these communities attract tourists who come to visit the ocean beaches, which are high risk areas. Coastal communities have been responding to the tsunami risk by developing emergency operation plans that include establishing evacuation routes and areas, and educational outreach programs.



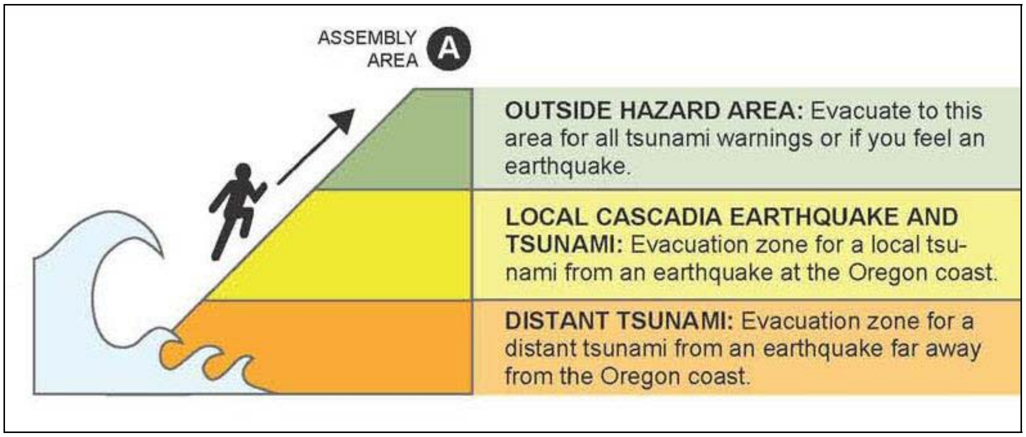


Figure 1-1a and 1-1b: Portion of Cannon Beach tsunami evacuation map and index (DOGAMI, 2008)

In 2009, new generation tsunami inundation maps will be issued for Cannon Beach, Oregon (CB). Using improved scientific data and methods (i.e. post 2004 Sumatra), the tsunami hazard maps will show greater risk hazards from Cascadia generated tsunamis than previous maps. The 2008 CB evacuation map shows much of the downtown, the elementary school, fire station, police station and city hall at risk from distant and local tsunamis (Figure 1-1a and 1b) In addition, vulnerability studies have shown that certain populations such as visitors and elderly are also particularly at risk. It should also be noted that the people will be disoriented from the earthquake and that evacuation times before the tsunami arrive range from 10-30 minutes for Cascadia events. The increased tsunami risk has meant that Cannon Beach and other coastal communities can no longer rely solely on the strategy of evacuation to higher ground but must look at tsunami evacuation buildings, structures and berms.

Tsunami Evacuation Buildings (TEBs)

Tsunami evacuation buildings (TEBs) can be an important element to insuring that schools, essential facilities, and government buildings are able to meet their everyday purposes, and continue to function after the earthquake and tsunami. While this approach has not been done in the United States, it has been done in Japan (See Cover Page Photo).

People who cannot safely evacuate the tsunami inundation zone should be able to evacuate to a TEB. An estimated dozen or more TEBs should be available in Oregon alone. TEBs must be able to withstand prolonged strong shaking and may be reinforced concrete structures with deep scour-resistant foundations and a minimum of two stories (Figure 1-2). The lowest story should be open space on the ground floor to allow for water and debris passage. Or, the lowest floor may be designed to be sacrificial, such as with break away walls. The elevation of the bottom of the second story should be higher than the anticipated tsunami inundation elevation. The roof may be designed for general purposes, such as for parking or recreation space. It may also be designed for emergency purposes, such as for evacuees, heliport, emergency storage of food or medical supplies, emergency generator, emergency vehicles and so on. Energy dissipation or deflection structures may be designed to protect the TEB by reducing tsunami force and scour effects. In addition, TEB design should accommodate rapid ingress by foot traffic during tsunamis and be readily identifiable to evacuees. Accommodation must also be made for wheelchair access. TEBs should allow for a minimum area per evacuee depending on its purpose, such as 0.5 sq m. Because tsunamis are rare, TEBs should serve a daily purpose.

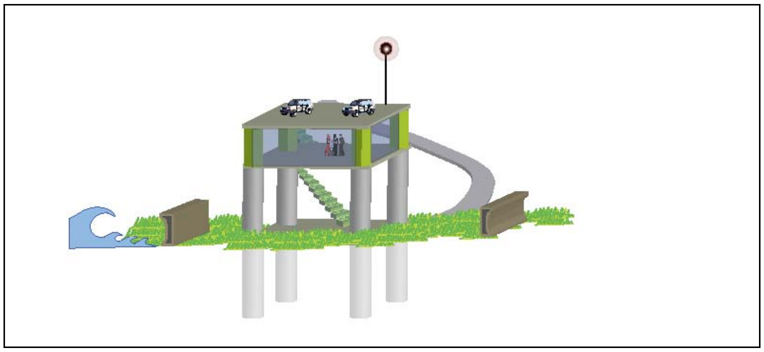


Figure 1-2. Schematic Design of Tsunami Evacuation Building (TEB)

Cannon Beach City TEB and Design Team

The existing Cannon Beach City Hall is expected to be critically damaged during a local and distant tsunami. Replacing city hall with a TEB would allow the community to accommodate evacuation needs and rely on its continued function. A new Cannon Beach City Hall TEB would serve as a demonstration project for other coastal communities with high tsunami risks.

In order to better understand elements needed to construct a City Hall TEB, an ad-hoc design committee was formed. The design team members of the committee include engineers, an architect, and scientists and are listed in the Appendix. This design team has developed this preliminary white paper on the Cannon Beach City Hall TEB's conceptual design and has identified a number of issues that need to be addressed.

Chapter 2. Cannon Beach City Hall/TEB Design Considerations

Jay Raskin, AIA

Cannon Beach is a small community located on the northern Oregon coast eighty miles west of Portland. The city has a full time resident population of 1,690 that is augmented by around 3,000 part time residents. Tourists visiting the city can range from several thousand to tens of thousands on any given day. Economic activity is centered on tourism. The city has high risk factors for tsunami's because a majority of the population and economic activity is located in the tsunami inundation zones as well as many visitors who also tending to gather in the tsunami inundation zones. In addition, the cities population has a fairly high percentage of retirees. See Figure 2-1.

Cannon Beach, a Tsunami Ready community, has been active in preparing for the Cascadia subduction zone earthquake and tsunamis as well as distant tsunami's. Starting in the 1990's the Cannon Beach Rural Fire District installed a series of siren/loudspeakers to warn visitors of approaching distant tsunami's and started tsunami education efforts. The City of Cannon Beach joined in these efforts by establishing the Emergency Preparedness Committee which developed an Emergency Operations Plan, identified evacuation routes and areas, created on-going community outreach and education programs, established shelter sites (along with seismic evaluations of the shelters), as well as other recommendations to the City to strengthen emergency response. The Fire Station was relocated to high ground in 1994 and contains the Emergency Operations Center (EOC) for the community.

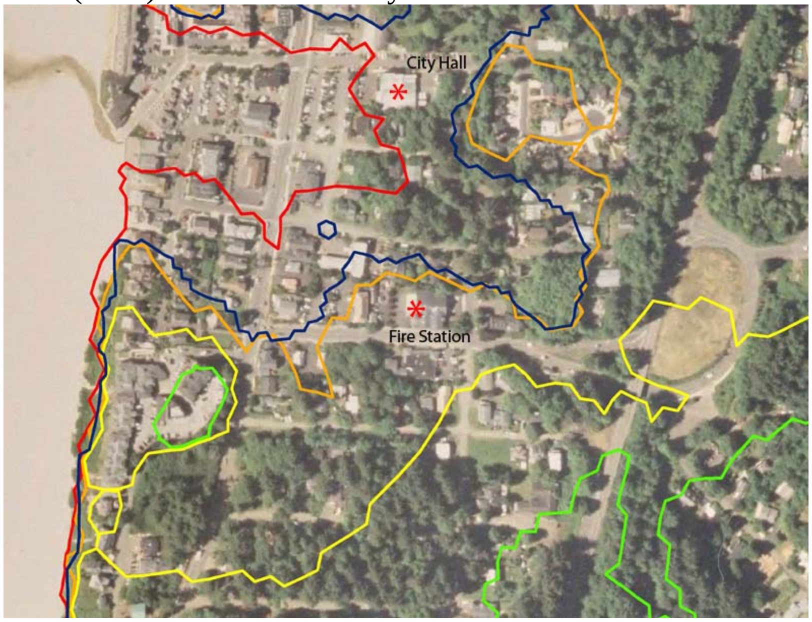


Fig. 2-1 Inundation Confidence Levels, Cannon Beach Inundation Mapping Study, DOGAMI (2008)

Cannon Beach then turned its attention to relief and long term disaster recovery. It was aided in this effort by a workshop funded by the Cascadia Earthquake Emergency Workgroup (CREW.org), in which Oregon Natural Hazards Workgroup, Oregon Emergency Management and USGS that brought community leaders, the school district, utility companies, health care providers, and the business community together. Out of this workshop, the City created the “Prepare for Emergency Recovery Committee” (PERC), a staff committee focused on relief and immediate post disaster recovery efforts, and the Long Term Disaster Recovery Committee, which is an advisory committee looking developing pre-disaster mitigation strategies. One important result of this process was the realization that continuity of governance is essential and that this was problematic with the existing City Hall, which was vulnerable to both earthquakes and tsunamis.

New City Hall/Tsunami Evacuation Building

The decision to look into rebuilding the existing City Hall as a Tsunami evacuation building was due both to the lack of availability of an alternate site above the inundation zone and to the fact that it was well situated to provide refuge to residents and visitors in the Downtown and Midtown areas, both highly populated and vulnerable areas. It is also very visible from a major beach access. .

The existing building is 9,000 square feet and, if replaced, is large enough to provide refuge to at least 800-1,000 people on the second level and possible roof terrace.

Figure 2-2 Cannon Beach City Hall/TEB conceptual Design Ecola Architects, PC (2008)

Design Considerations

The conceptual design that was developed incorporated the primary elements of a TEB. (See Figure 2-2) The building was raised on columns to allow water pass beneath the structure. The second floor level was set to be above not only the most likely tsunami event, but most of the rare tsunami events as well. A roof terrace was designed to provide additional refuge area and as a safety factor for inundation depth. Exterior stairs were placed as a very visible design feature to make the building readily identifiable as a tsunami refuge. The lower level is open to provide parking. The building also was designed to serve other functions so that the lower level can shelter the Farmers Market and the roof terrace is a public open space where Haystack Rock is visible. Accessibility is being planned for with the use of elevators designed to be functional after the earthquake. Emergency power and supplies will also be included. Strategies for wave energy dissipator to reduce tsunami actions on the TEB can be provided for in the parking lot in front of City Hall.

Zoning Ordinances

The conceptual design must meet of the City's zoning ordinances. These ordinances included providing off street parking, setting the building back from the residential zone south by 20 feet, providing landscaping, and a building height limit of 28'. The conceptual design showed that all zoning ordinances can be met except for the 28' height limit. This would require a variance from the City, but is considered an acceptable request given the nature of the project. The City also has as Design Review requirement so that the aesthetics of the building must be acceptable to the community.

ADA Accessibility

ADA accessibility is a requirement for public buildings. The most straightforward solution is providing at least one elevator to the building, built to a high seismic resistance standard and provided with emergency power to insure function after the earthquake. The option of an accessible ramp was examined and, at this stage, it was determined that not enough space was available for the length of ramp required, especially if the ramp had to reach to the roof terrace as well. Large ample stairs were provided on the exterior of the building that met ADA standards

Aesthetics

The building has to readily identifiable as a refuge for a tsunami. The conceptual design solution was to make the stairs to the upper level and to the roof terrace a very distance and visible part of the design. The stairs were placed on the south side of the building and made very visible to people evacuating along Hemlock Street, the main street in town. The City of Cannon Beach has design review for commercial and public buildings so any design also has to meet the design review guidelines. An initial attempt to meet these guidelines included have a gable roof over part of the roof and using cedar shingles, which are a common siding material in town. One design element that needs further study is creating an attractive ground story. This level will need to be used for parking in order to meet the zoning ordinances for off street parking. However, a possible secondary use of the covered area for the new Cannon Beach Farmer's market may provide additional design parameters to create a pleasing space under the building.

Other Considerations

Relocating City Hall had been considered as an alternative when its vulnerability was first realized. This thinking changed when it became evident that there was not suitable available land within the City limits, or in close proximity. The existing location of City was good for its proximity to the citizens and providing them services. Relocating the

City Hall would have required mitigating effects on the daily lives of the citizens and was deemed as not feasible.

Chapters 1 and 2 References

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Chapter 3. Tsunami Dissipation Wall for Cannon Beach City Hall

Javier F. Moncada

Introduction

Seawalls, bulkheads and revetments are coastal structures that are used to protect shoreline land from erosion due to rising sea levels and waves. The shoreline structures are constructed of structural soil fill, geotextile fabric, large stones, steel, reinforced concrete or some combination of these materials. The optimal structure type is determined by the predicted water levels, wave climate, material availability and soil classifications.

Shoreline placed seawalls may have significant short and long term environmental impacts. Short term water quality can be decreased from construction activity. Long term sand circulation and displacement can affect habitat for marine life. Seawalls may limit beach access and may be intrusive on the shoreline views.

Reinforced concrete seawalls can withstand higher wave forces than soil revetments and stone bulkheads. They are designed to absorb breaking wave energy or reflect waves seaward or upward.

In order to design a tsunami dissipation wall that reduces the tsunami actions the TEB, we adpat the foregoing design concept of seawalls. When tsunamis propagate inland, wave fronts can take the shape of either a bore or surge. These destructive waves can carry debris, such as logs, creating high impact loads and cause extensive damage to wooden and unreinforced masonry structures. To dissipate some of this tsunami energy, the Canon Beach City Hall vertical tsunami evacuation building will have two reinforced concrete seawalls along the west and east sides of the buildings.

Objective

The primary objective of the tsunami dissipation walls is to reduce some of the tsunami energy and debris forces by wave front upward deflection and debris damming. The more wave and debris energy that can be absorbed or dissipated by the wall prior to reaching the building, the less robust the building will need to be. The seawall is not intended to completely prevent tsunami inundation of City Hall, but merely to dissipate some of the tsunami energy.

Environment

More investigation is required to determine the exact location of the tsunami seawall relative to the Canon Beach City Hall. An estimate of the tsunami seawall location is near the building and approximately 700 ft from shore. No environmental impacts are anticipated at this time and the wall is not expected to limit beach access.

Tsunami Seawall Design Considerations

City Hall will have two pile supported reinforced concrete walls. The ocean side west wall is rendered in Figure 3-1 and the landward east wall is rendered in Figure 3-2. Both of these figures are conceptual and are modified figures from the Shore Protection

Manual. The west wall is a combination stepped and curved face and the east wall is a curved faced only.

The curved face of the wall will reflect the wave energy upward, causing the tsunami to reflect some of its destructive energy before reaching the building. The wall will absorb impact and damming debris forces. The west wall will dissipate wave energy from the run-up and the east wall will dissipate wave energy from the drawdown. The rip rap will resist scour from the run-up and drawdown. Greater scouring has been observed to occur during drawdown.

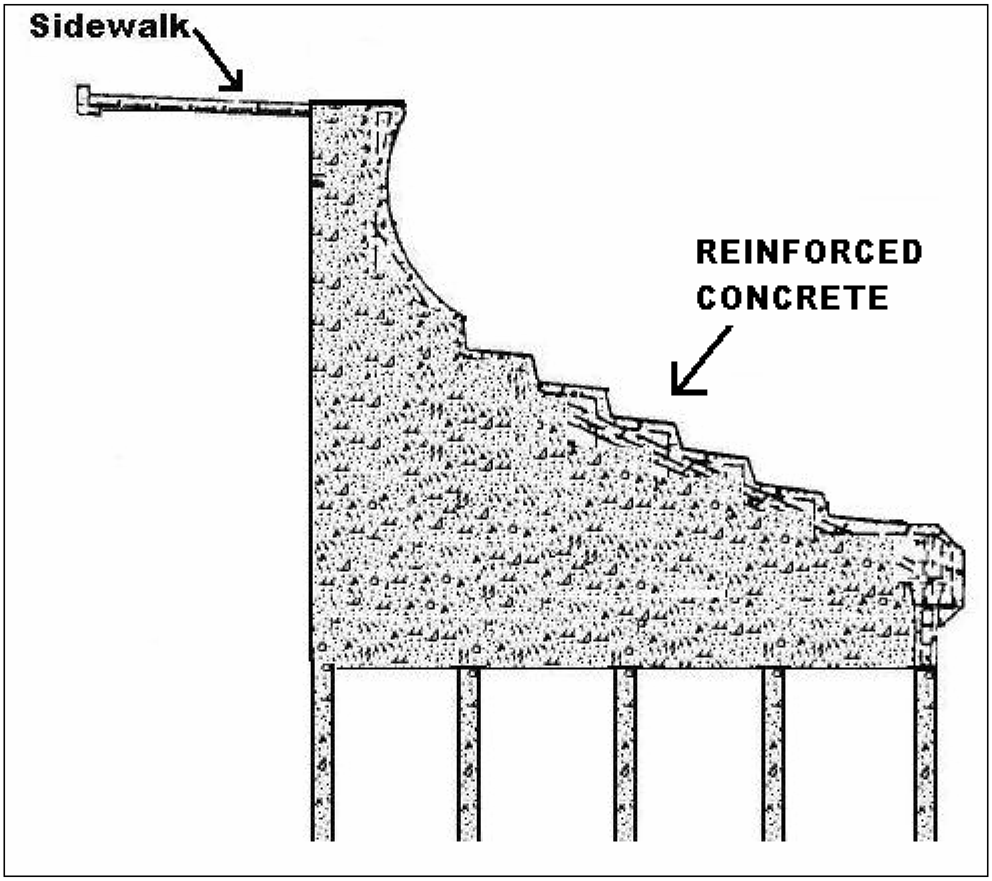

Figure 3-1: Combination stepped and curved face pile support seawall, modified from Figure 6-2, SPM II, proposed City Hall west tsunami wall. NTS

The seawalls will be constructed of steel reinforced concrete. The west wall would be best located in the parking lot where a natural grade difference already exists.

Conclusion

To build and design an effective and efficient tsunami seawall for Canon Beach, more information is needed about the expected tsunami wave and the soil types below the walls. The design tsunami wave shape, velocity, height and frequency will govern the forces needed to design the seawalls. Local soil classification is needed to determine pile depths and width of wall.

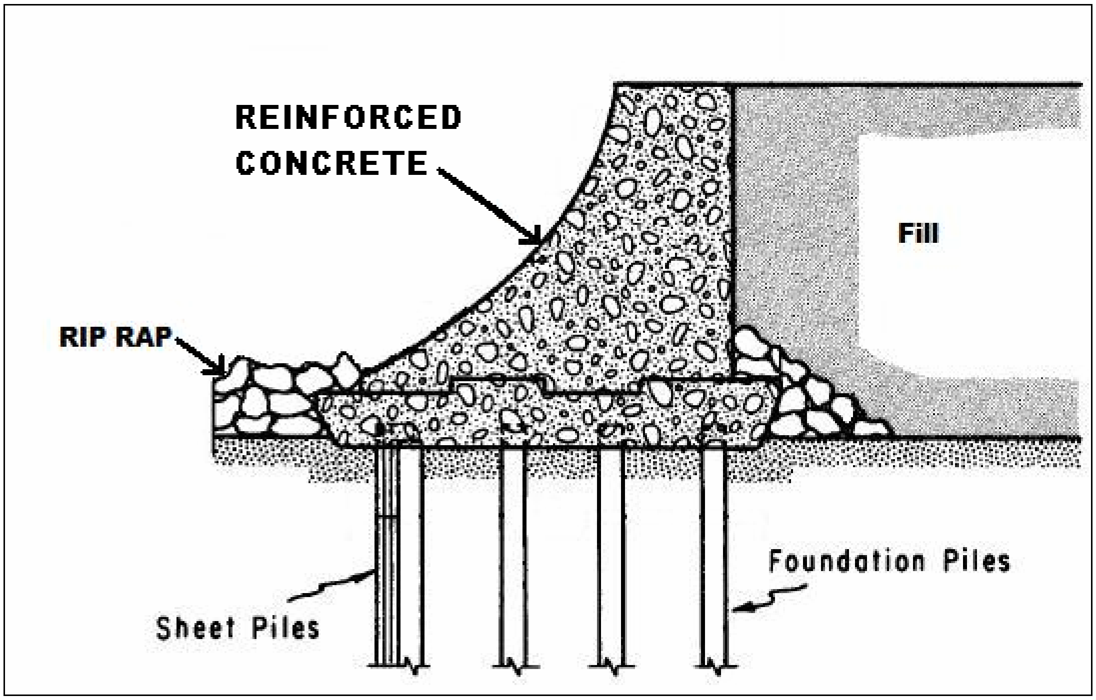

Figure 3-2: Pile supported, reinforced concrete curved face seawall, modified from Figure 6-1 SPM II, proposed east City Hall tsunami wall. NTS

Chapter 3 References

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Design of Coastal Revetments, Seawalls, and Bulkheads, USACE June 1995

Shore Protection Manual Volume II (SPM), 1984, Coastal Engineering Research Center, USACE

Chapter 4. Cannon Beach City Hall/TEB Structural Design Considerations,

Kent Yu, PhD, PE

Cannon Beach is located on the seismically active Oregon coast. It is likely affected by tsunamis and strong seismic shaking generated by a Cascadia Subduction earthquake. In order to function as a refuge from tsunami, the proposed Cannon Beach City Hall/Tsunami Evacuation Building (TEB) must remain usable following a major seismic event. This, in turn, requires the building to retain most of its pre-earthquake lateral-force resistance, experience little nonstructural damage, and be capable of resisting expected tsunami loading effects. The building should be designed using performance-based earthquake engineering principles to meet Immediate Occupancy performance objectives for the maximum considered earthquake (MCE) seismic event. At the MCE event, the building shall retain sufficient lateral strength to resist forces associated with the 2,500 year tsunami.

Seismic Performance Objective

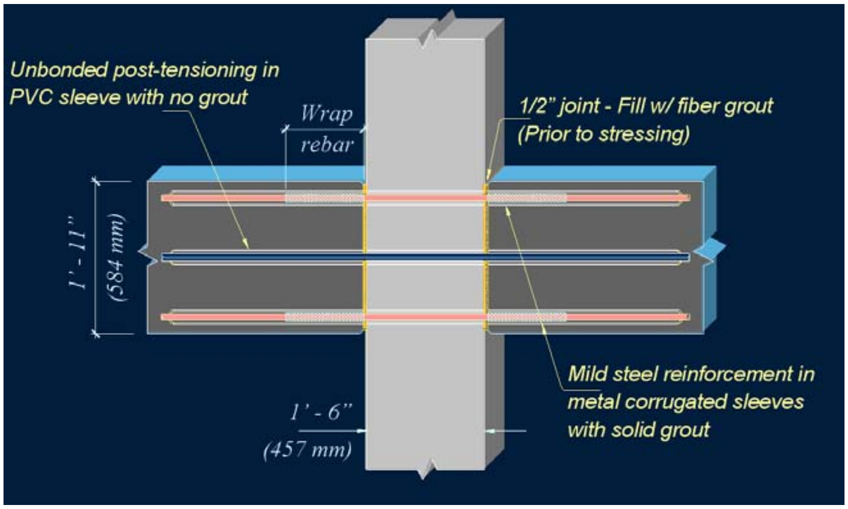
There is limited guidance available to explicitly address required seismic performance of a TEB structure. FEMA P646 (2008) recommends that such structure be designed to meet Immediate Occupancy performance (as defined in ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings*) for the Design Basis Earthquake (DBE) and Life Safety performance for the Maximum Considered Earthquake (MCE). However, we feel that this recommended performance requirement couldn't guarantee the usability for a tsunami if the building experience significant structural damage at the MCE level, with inadequate lateral resistance for a tsunami. A building that experiences substantial structural damage or out of plumb may be considered as Life Safe. However, it can not be re-usable without substantial repair.

To make evacuees feel comfortable entering the TEB and remaining in the structure during the aftershocks, the structure is expected to remain plumb with limited structural damage (especially near stairs and ingresses) that does not require any repair work prior to being occupied. Since a tsunami evacuation building is expected to remain functional and perhaps, be used for emergency response and/or medical care for a period of time, it is important to have higher-level performance of nonstructural components with limited damage. For the TEB, we feel that it is more appropriate to design the building to meet Immediate Occupancy performance level for the MCE event. As part of the design process, it is essential to perform verification analyses to ensure the performance objective is met using available performance-based earthquake engineering techniques such as ASCE/SEI 41-06.

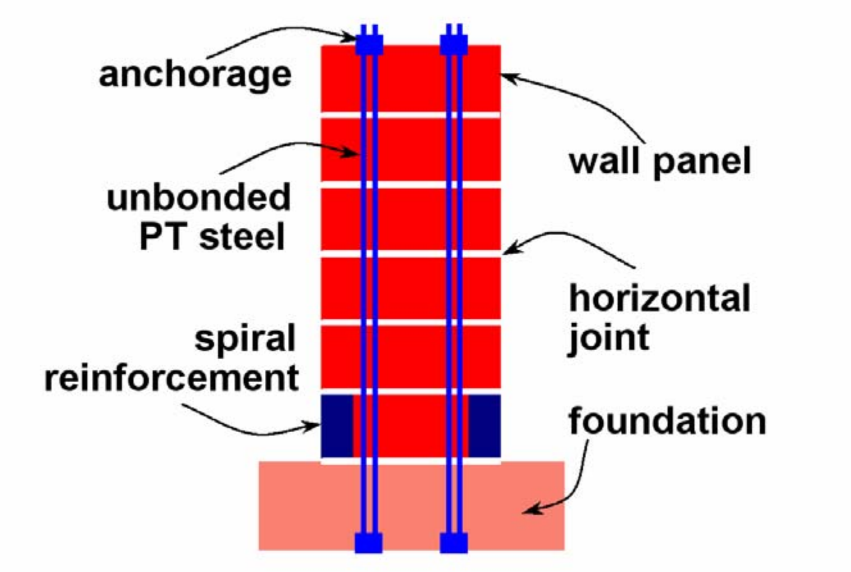
Structural System and Design Consideration

Seismic Design Consideration

There are several structural systems founded on deep piles that can achieve the required seismic performance and allow tsunami debris to flow through at the lower levels and keep the hydrodynamic loads to a minimum: steel frames with dampers, post-tensioned reinforced concrete frames [Figure 4-1(a)], and post-tensioned concrete shear walls [Figure 4-1(b)]. The post-tensioned reinforced concrete frames and post-tensioned concrete shear walls rely on the post-tensioning tendons to re-center the structure to its pre-earthquake position. When properly designed, the building with these systems tends to have limited residual displacement even for the MCE event. Since the steel structure is more prone to corrode in the coastal environment, post-tensioned concrete frames or a combination of concrete frames with concrete shear walls parallel to the direction of anticipated tsunami flow are more suitable for the TEB, and also compatible with the planned function at the ground level of either parking or farmer's market.



(a) Post-tensioning hybrid concrete frame (Sritharan et al. 2000)



(b) Post-tensioning concrete shear wall (Restrepo and Rahman 2007, Scheottler et al 2009)

Figure 4-1 Lateral-force Resistance Systems

Figure 4-2 shows a conceptual layout of lateral-force resistance system for the Cannon Beam TEB. It is expected that the site would likely experience liquefaction during the seismic shaking, which could result in differential settlement of ground soil. Also, significant scouring due to tsunami is likely to occur at the site. To minimize the undesirable effects of liquefaction induced differential settlement and scouring on structural system, pile foundation is recommended as shown in Figure 4-3 to support the columns of both seismic and gravity frames. Pile caps are interconnected with grade beams and ground slab to ensure lateral forces can be distributed to all the piles.

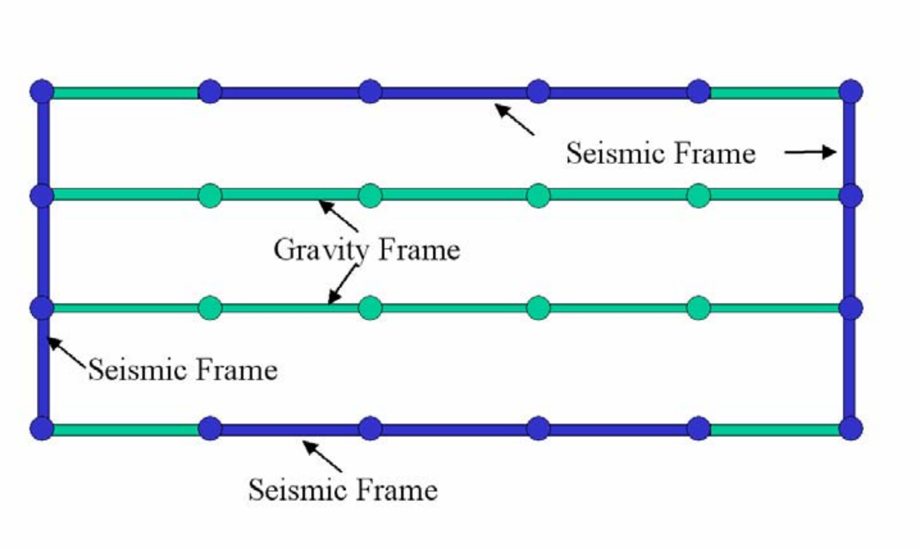


Figure 4-2 TEB Seismic System Layout: Plan view

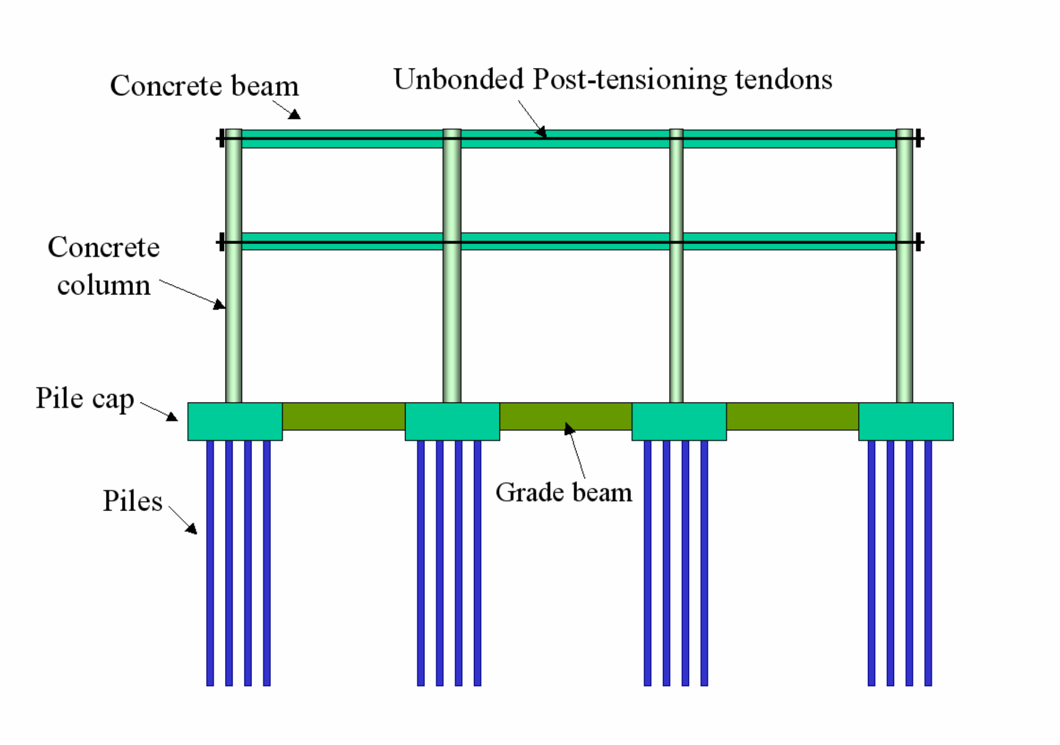


Figure 4-3 Typical Post-tensioning Concrete Frame Elevation

Tsunami-Resistant Design Consideration

The concrete columns in the lower level are designed with circular cross-sections to minimize hydrodynamic loads and impact loads associated with waterborne debris.
At the city hall site, the tsunami inundation depth is estimated to range from 6 feet at the most likely tsunami to 15 feet to 30 feet in rare events. Both the second level and a roof terrace are planned for refuge. Given the uncertainty involved in the tsunami modeling and estimate, if the first story height is set unconservatively low, the water run-up could potentially exceed the first story height, wash away the contents in the second story, and pose buoyancy and hydrodynamic uplift force on the 2nd floor concrete slab, as well as the excess moments on the column structures Thus, the design team must exercise care to properly set the story height for the first story.

The concrete floor framing and slab at the 2nd and the roof levels will be designed to accommodate refuge live load. The slab to beam connection at the ground and the 2nd floor levels need to be strong enough to resist any potential buoyancy and hydrodynamic uplift forces on the slab.

In case that "break away" wood stud walls are used in the building, we will detail the connections with a fuse at the top and sides to minimize the hydrodynamic loads on the building structure (Yeh 1997). Due to uncertainties involved in the estimate of impact forces associated with waterborne debris, the TEB design will incorporate considerations of the "tie force" strategy and the "miss column" strategy in the design to reduce the potential for progressive collapse if one column is severely damaged (FEMA P646).

Other Considerations for Post-Earthquake Response

After a major seismic and tsunami event, the city hall is expected to function for relief and post disaster recovery. It is important to ensure that the nonstructural systems including ceiling, communication system, fire suppression system, M/E/P distribution lines and tall furnishings are properly braced to reduce the falling hazards and reduce the potential for loss of function. Seismic design shall follow the recommendations contained ASCE 41-06.

Chapter 4 References

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Chapter 5 Geotechnical and Scour Considerations

Marcella M. Boyer, P.E., G.E.

Introduction

This chapter summarizes the deep foundation, earthquake and tsunami considerations for the proposed Tsunami Evacuation Building (TEB). Residual liquefaction, caused by cyclic shear stress and momentary liquefaction (enhanced scour) are defined. Tsunami scour issues are discussed.

Deep Foundation Considerations

Subsurface conditions on the site of the existing Cannon Beach City Hall are not specifically known, but we have reviewed geotechnical engineering reports from nearby sites. The reports from nearby sites show variable layers of subsurface soils. The subsurface soils generally consist of fill underlain by layers of silt with varying amounts of clay and organics, gravel and sand. The layering is generally not similar between borings. Perched groundwater could be present at depths as shallow as 6 feet. Static groundwater can be present at depths as shallow as 13 feet based on nearby well logs on file with the state, although it has been encountered at depths as deep as 30 feet.

The highly variable subsurface conditions reported in the vicinity are typical of coastal lagoon, fluvial and shoreline alluvial deposits. Therefore, it would not be appropriate to extrapolate the subsurface conditions due to likely rapid lateral and vertical subsurface changes. Current thought is that the fill under the TEB location may be thicker than adjacent sites because of the possible presence of a preexisting drainage that has been filled. The depth of the fill will be unknown until borings can be advanced at the proposed building location. Regardless of the thickness of fill at the site, it is our opinion that deep foundations will be necessary for the TEB that is proposed for Cannon Beach because of the potential ground response to a Local Cascadia Subduction Zone (CSZ) Earthquake. The foundations would need to extend into firm material below anticipated seismic (residual) liquefaction and/or enhanced scour depths. The firm material could consist of dense beach sand, consolidated dune sand, dense gravel or bedrock or the Quaternary Marine Terrace Deposits that are mapped in the area.

Many of the concrete structures survived the tsunami inundation in the 2004 Sumatra Tsunami. Therefore, we recommend deep concrete foundations be used for the TEB. Deep foundations are necessary so that uniform support for the structure is provided during and after a local earthquake and during an after both the distant and local tsunami event. Integrated grade beams could be added to create a stiffer system that better resist earthquake ground shaking.

Earthquake Considerations

A Local CSZ Earthquake (up to Mw = 9) would create high lateral soil forces on the foundations and residual liquefaction of the underlying saturated loose to medium dense sand/silty soils. Residual liquefaction occurs when saturated deposits of loose to medium dense, cohesionless, sands and silts, are subjected to strong earthquake shaking. If these saturated deposits cannot drain rapidly during cyclic loading, there will be an increase in pore water pressure. With continuing oscillation, the pore water pressure can increase to the value of the overburden pressure. The shear strength of a cohesionless soil is directly proportional to the effective stress, which is equal to the difference between the overburden pressure and the pore water pressure. Therefore, when the pore water pressure increases to the value of the overburden pressure, the shear strength of the soil reduces to that of a liquid (zero), and the soil deposits turn to a liquefied state. Dynamic total and differential settlement would occur as a result of liquefaction. Deep foundations could be used to extend below the depth of the liquefied soil. Ground improvement techniques such as excavation and compaction, in-situ ground densification, grouting, deep soil mixing and/or drainage improvements could be used to reduce or eliminate residual liquefaction and potentially reduce the number and depth of the concrete piles.

Other earthquake hazards include severe ground shaking, lateral spreading and rapid coastal subsidence. Lateral spreading is the downward horizontal movement of soil toward a slope that occurs over or within seismically liquefied soil. Coastal subsidence is defined as a large scale downward movement of the earth’s surface with little or no horizontal movement. This document does not address these other hazards.

Tsunami Considerations

The TEB could be affected by tsunamis from two sources, but the effect on the structure and foundation would be similar. One tsunami source would be the one that occurs because of the Local CSZ Earthquake. In this case, the potential tsunami inundation could occur within a several minutes after the CSZ Earthquake. The second tsunami source would be a distant earthquake that occurs far away from the Oregon Coast without any local earthquake effects. Localized tsunami scour and enhanced tsunami scour would occur for both tsunamis. Deep concrete foundations would extend below the anticipated scour depth.

Tsunami scour is different from scour from other types of wave action. The wave period is long (a few to tens of minutes), the event duration can be 3 hours or longer, and the inundation height could be as high as 10 meters (30 feet) or higher depending on the location with an extreme pore water pressure gradient. The energy from a tsunami event is classified as extreme.

Tsunami Scour Issues and Depth Estimation

Tsunami scour depth is difficult to predict because of the many variables that govern the scour mechanism. The key governing parameters are local geography, flow direction and velocity, the number of piles, the shape, alignment and size of the piles and properties of the soil around the pile. Other factors include the depth of the surge, the proximity to the shoreline and wave breaking height. Current codes (ASCE 7-05) give consideration to scour, but do not provide guidance for calculating the depth of scour.

The Coastal Construction Manual (FEMA 2000) recommends localized tsunami scour be estimated as a percentage of still water depth (wave height) relative to soil type and proximity to the shoreline. However, it is evident that floodwater velocity strongly affects scour depths as summarized in the EERI/FEMA NEHRP 2006 document. See Figures 5-1 and 5-2.

Figure 5-1. Tsunami Scour. Tsunami runup height = 4.1 m, Inundation depth = 0.95m above the floor; Scour depth = 1.2m. Photo provided by Harry Yeh.

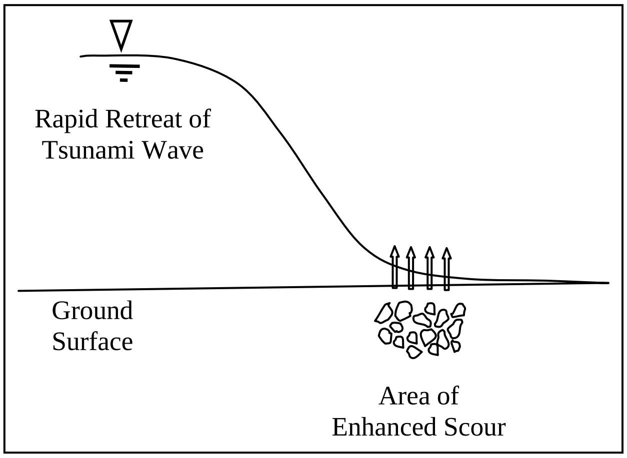

Figure 5-2. Enhanced Scour Sketch produced by Marcella Boyer, P.E., G.E.

Momentary liquefaction (enhanced scour) occurs at the ground surface because the saturated soil is easily transported as a liquid. Studies have shown that enhanced scour can occur at the end of wave drawdown (wave retreat). During and after wave drawdown, the pore water pressure gradients in the near surface soil increases and momentary liquefaction can occur. Momentary liquefaction occurs with the rapid reduction in total vertical stress (loss of wave height) in a soil saturated by water inundation. The shear strength of the saturated soil reduces to zero and the soil behaves like a liquid.

Scour can be reduced by placing gravel, rip rap and/or concrete around the piles. Wave deflection and energy dissipation could also be used to reduce scour.

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Chapter 6. Tsunami Simulator for Cannon Beach

Harry Yeh, Oregon State University, and Tim Fiez, The Gartrell Group

An integrated simulator will be developed to evaluate the effectiveness of the planned City Hall/TEB on the existing Cannon Beach City Hall site. In addition to evaluating the effectiveness of TEB, the simulator will be used as a tool to improve both warning systems and evacuation tactics for the City of Cannon Beach.

Tsunami Scenarios Simulations

A scenario simulator has been developed to support rational tsunami hazard and vulnerability analyses. The simulator integrates three modules: 1) hydrodynamic numerical simulation of tsunami propagation and runup, 2) warning transmission simulation, and 3) evacuation simulation. Although the hydrodynamic simulation is deterministic, the other two components are probabilistic.

Hydrodynamic simulation models for tsunami generation, propagation, and runup have been used often in practice (e.g., Titov & Synolakis, 1998; Lin, et al., 1999; Imamura, 1996). While the numerical algorithm itself is considered adequately accurate (e.g. Yeh, et al. 1995), it remains difficult to determine practical tsunami-source conditions. Fortunately, Oregon has just completed a thorough investigation to estimate the most credible tsunami source for the Cascadia events; their study is an extension a previous study (Priest, 1997) coupled with geological paleo-tsunami deposit data (Priest, 2008). Furthermore, Zhang and Baptista (2008) have conducted detailed numerical simulations specifically for the inundation in Cannon Beach. Hence, this best suitable numerical output data will be utilitzed for the development of the scenario simulator.

The warning transmission module models both official (“broadcast”) and informal (“contagion”) processes. The informal network (person-to-person oral communications) is the primary method of warning transmission, since official warnings (processed by government authorities and transmitted by loudspeakers, route alert vehicles, radio, and TV) are relatively slow in responding to a locally generated tsunami and might be totally destroyed by the earthquake causing the tsunami. In the model, informal communications are controlled by four parameters: 1) the number of households, 2) the distances among households, 3) the delay in initiating contact, and 4) preferential contacts . The preferential contacts are based on a probabilistic biased network model (e.g. Rapoport, 1979; Fararo,1981; Skvoretz, 1985). In addition, there are control parameters distinguishing “normal” days from those with stressed conditions during disasters. For example, the number of contacts is larger during disasters, the communication distances between contacts are shorter, and the preference parameter is weaker. A majority of control parameters must be determined based on demographic data. Fortunately, thorough collections of such data are available for Cannon Beach (Wood, 2007),. Additional parameters control the loudspeaker warning system (loudspeaker locations, audible distances, audience share, announcement frequency, and timing), route alert vehicles such as police cars and fire engines (routes and speeds, dispatch timing, audible distance, and audience share), and radio/television (audience share, announcement frequency, and timing).

Evacuation simulation is modeled in two steps: 1) individuals' decision-making and preparation processes for evacuation, and 2) the actual evacuation process. The first step reflects:

- the number of repeated warnings received (and from which channels)
- evacuation actions taken by neighbors and friends
- location of the household
- prior knowledge and/or experience of tsunamis
- time to evacuate after the decision is made

. The current model only simulates the evacuation of individuals moving on foot toward the closest shelters or high ground, but other evacuation methods (e.g., motor vehicles) and potential setbacks (road blockage, bridge failure, etc.) can be incorporated in the simulator in the future.

The integrated simulator uses a GIS framework to produce an animation of the tsunami runup (typically occurring in multiple waves), warning transmission patterns, and individuals' protective responses. Figure 6-1 shows how the components interact. To evaluate the overall outcome, the program determines 1) the number and spatial distribution of households receiving a warning, 2) the temporal distribution of those warnings, 3) the cumulative effects of informal communication (oral and telephone) patterns, and 4) number of casualties. Tsunami fatalities in the simlulations are determined with a newly developed casualty model (Yeh, 2009) that is based on whether a person can remain standing within the tsunami flow, with the considerations of age and gender differences. Figure 6-2 shows an example of the animated display for the scenario simulator.

As stated earlier, the development of the tsunami scenario simulator will not only provide quantitative evaluations for the effectiveness of the Cannon Beach tsunami shelter (i.e. reduction in casualties), but will be useful in identifying the effects of hazard mitigation measures (such as seawalls), emergency response resources (e.g., number and capacity of evacuation routes, locations of tsunami shelters) and emergency response procedures (e.g., amount of forewarning and routing of route alert vehicles).

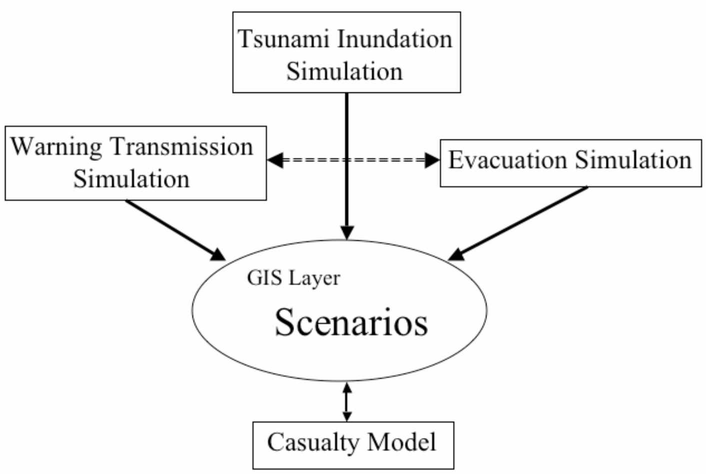

Figure 6-1. Schematic representation of the integrated tsunami scenario simulator

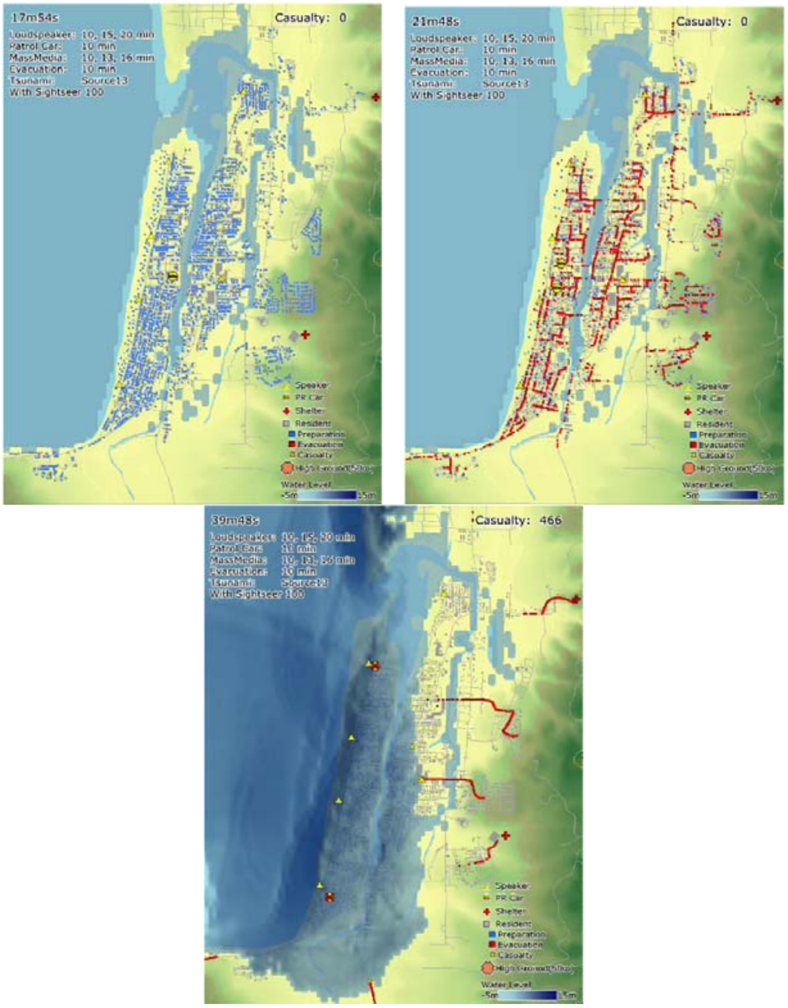

Figure 6-2. An example of animated tsunami scenario simulation. Note that the casualty numbers are shown in the upper right corner.

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Chapter 7 Next Steps

This preliminary white paper includes conceptual design concepts for the future Cannon Beach City Hall TEB. It provides the basis for a future feasibility study and case history that could include subsurface exploration, tsunami evacuation modeling, further development of the conceptual design to allow for preliminary structural design, further development of tsunami wave dissipation design, cost scenarios, and more. The goal of the future studies would be to test the feasibility of a TEB in real situations, which will better allow coastal communities to understand the many technical, social, design, and cost implications. This in turn, will allow coastal communities to develop appropriate and comprehensive tsunami evacuation and mitigation strategies.

A future feasibility study could address a number of major issues involved with constructing new tsunami evacuation buildings. The results from such a feasibility study would be useful for any tsunami prone community. These issues, among others, involve:

- Multi-hazard issues, including design level earthquake and design level tsunami
- Performance based goals and reliability, including ATC 58 and ATC 64
- Scientific uncertainties
- Engineering uncertainties
- Wave energy dissipation structures, including on and off site structures and impacts
- Multi-use and function issues including livability, including pre- and post-tsunami functionality
- Structures with various footprints, heights, and area
- Local zoning issues
- Social issues, including evacuation routes and education associated with evacuation buildings, and protection for vulnerable populations
- Design and construction costs
- Funding assistance

A feasibility study could include a bracketed range of earthquake design levels, tsunami design levels, varying inundation heights, and various performance levels on different soil and foundation types. For example, a building designed for MCE could be evaluated with inundation heights of 5-10 ft, 10-15 ft, 15-20 ft, 20-25 ft, and 25-30 ft for life safety, immediate occupancy, and fully operational conditions.

A number of communities in the Pacific Northwest are considering tsunami refuges. A feasibility study would provide information that would be immediately useful for the construction of a future TEB demonstration projects.

Appendix
Ad-hoc Design Team for Cannon Beach Tsunami Refuge

A conceptual design for a new Cannon Beach City Hall that would serve as a community tsunami evacuation building (TEB) was developed by this ad hoc design team. The design team includes engineers and architects with expertise in risk management, tsunami evacuation modeling, structural engineering, geotechnical engineering, wave energy dissipation engineering, architecture, computer programming and local design considerations (listed below). The conceptual design for a new tsunami evacuation building is largely based on the FEMA 646 publication. It will be shared on September 28 and 29, 2009, at a field trip and workshop, which is being sponsored by the Cascadia Region Earthquake Workgroup (CREW.org) and others.

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Focus area: The building is designed using performance-based earthquake engineering principles to meet Immediate Occupancy performance objective for the MCE seismic event. After the MCE event, the building shall retain sufficient lateral strength to resist forces associated with the 2500-year tsunami.