ALTERNATIVE SELECTION STUDY
for
Tsunami Evacuation Pedestrian Bridge
over Ecola Creek
City of Cannon Beach, Oregon

July 20, 2011

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Purpose

The purpose of this report is to evaluate the feasibility of seven possible emergency bridge alternatives for providing an evacuation route for the north end of the city of Cannon Beach across Ecola Creek in the event of an earthquake and subsequent tsunami. The seven alternatives have been identified by the City of Cannon Beach through its Emergency Preparedness Committee and other citizen input. OBEC Consulting Engineers has been retained to study the feasibility of each of the alternatives.

Tsunami evacuation is a component of the City of Cannon Beach addendum to the Clatsop County multi-jurisdictional Natural Hazards Mitigation Plan. The plan is an effort to increase the community's protection from natural hazards including earthquake, flood, tsunami, and geologic instability such as landslide, liquefaction, and subsidence.

Project Background

A new bridge will serve as a Tsunami Evacuation Route for the downtown core, public elementary school, and bible school. The shortest evacuation route for the north downtown area, including the schools, is across Ecola Creek and up Fir Street to reach elevations above predicted maximum tsunami wave heights. Currently, evacuation by this route can be completed in approximately five minutes by using the N. Elm Avenue/Fir Street Bridge. However, it is unlikely that this bridge will withstand a large earthquake or tsunami. Because the availability of this bridge in an emergency is uncertain, evacuation exercises conducted by the City and schools use a route that runs south on Spruce Street to Sunset Boulevard before heading east to higher ground. During practice exercises it takes 22 minutes in ideal conditions to reach safe ground using this route, which is unacceptable. A new bridge across Ecola Creek is needed for emergency evacuation.

Figure 1: Area Map

Evaluation of the alternatives will include design requirements, advantages and disadvantages, fatal flaw analysis, and estimated project costs. The evaluation of bridge alternatives must also include evaluation of soil liquefaction and relative earthquake amplification in addition to earthquake and tsunami hazards. All of the above hazards have been identified as "highest" probability at the Ecola Creek site by the Oregon Department of Geology and Mineral Industries (DOGAMI).

Evacuation Bridge Alternatives

It is assumed that all the emergency evacuation bridge alternatives will be located approximately 30 feet west of the existing road bridge for two reasons: 1) if an earthquake occurs that causes the existing bridge to fail, the structure will not strike the new bridge directly; and 2) if the initial tsunami wave comes on land, the existing bridge will fail to the east, away from the new bridge. Additionally, the proposed alignment lands on public non-park lands on both ends of the bridge, minimizing right-of-way issues.

Figure 2: Proposed Bridge Location

The City of Cannon Beach has identified the following bridge alternatives for further study.

A) Floating pontoon bridge, assumed to be timber construction with a 6-foot-wide deck. For the purposes of the alternative selection study, the bridge ends would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site. The interior supports of the bridge would be on pontoons floating in the creek. The bridge would not be designed to resist a tsunami wave.

B) Fixed timber bridge with a 6-foot-wide deck. For the purposes of the alternative selection study, this bridge would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site. The bridge would not be designed to resist a tsunami wave.

C) Fixed prestressed concrete pedestrian bridge with 12-foot-wide deck. In accordance with minimum national design standards for pedestrian bridges and eligibility for federal and/or state funding, the desirable bridge deck width is 14 feet and the minimum allowable deck width is 12 feet. A 12-foot deck will be assumed for the purposes of this analysis for maximum economy. The bridge substructure would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site. To the extent possible, the bridge superstructure will also be designed to withstand a large earthquake and generated tsunami wave.

D) Replace the western half of the existing road bridge with a new concrete bridge on the same alignment, with a 10-foot-wide downstream sidewalk for tsunami evacuation. In accordance with minimum national design standards for bridges and eligibility for federal and/or state funding, the desirable half-width of bridge deck is 27 feet out-to-out (1-foot combined traffic/pedestrian rail, 10-foot sidewalk, 4-foot shoulder, and 12-foot travel lane). The bridge substructure would be founded on driven pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site. To the extent possible, the bridge superstructure will also be designed to withstand the large earthquake and generated tsunami. The remaining east half of the existing bridge would be replaced as a future project.

E) Replace the existing road bridge with a new concrete bridge on the same alignment, with 10-foot-wide downstream sidewalk for tsunami evacuation. In accordance with minimum national design standards for bridges and eligibility for federal and/or state funding, the desirable bridge deck width is 44 to 49 feet out-to-out (1-foot combined traffic/pedestrian rail on each side, either a 5-foot or 10-foot sidewalk on one side and a 5-foot sidewalk on the other side, two 4-foot shoulders, and two 12-foot travel lanes). The bridge substructure would be founded on driven pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site. To the extent possible, the bridge superstructure will also be designed to withstand the large earthquake and generated tsunami.

F) Fixed timber suspension bridge with minimum 6-foot-wide bridge. For the purposes of the alternatives selection study, this bridge will be considered at a lower and a higher elevation to mitigate tsunami loading. However, this bridge will need to withstand the initial large earthquake.

G) Quantitatively evaluate the existing bridge for serviceability at Magnitude (M) 5 through 7 and M8/9 earthquake levels and evaluate potential usability of piling in the event of loss of superstructure only. This alternative would investigate the potential of using the existing bridge piling for rapid reestablishment of a pedestrian link to the city after collapse of the existing superstructure. The bridge is 44-feet out-to-out (1-foot combined traffic/pedestrian rail on each side, two 5-foot sidewalks, two 4-foot shoulders, and two 12-foot travel lanes).

The bridge site is shown in the following photo looking east upstream on Ecola Creek. The new bridge would be located in front of the existing bridge. The school is shown to the right (south of the existing bridge).

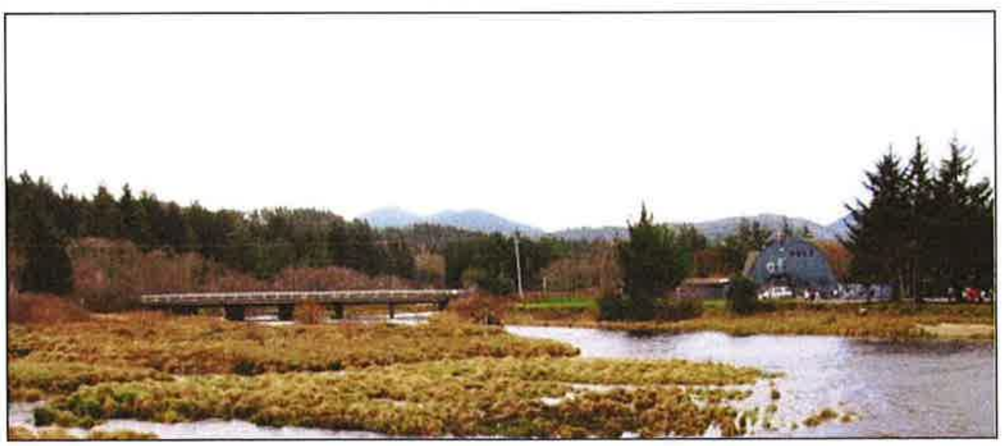
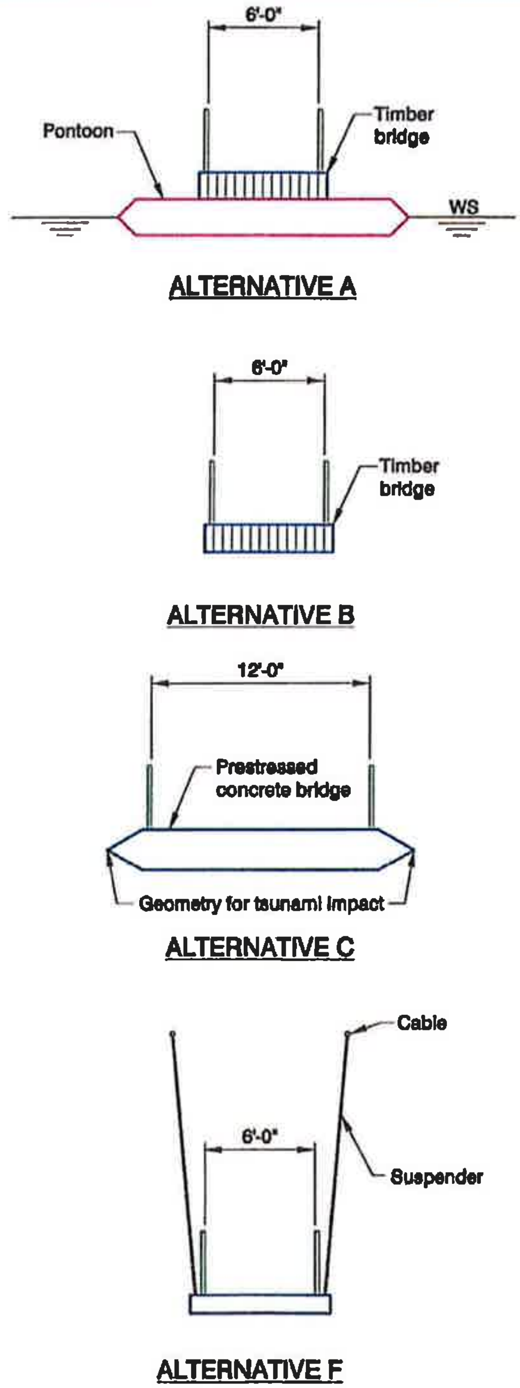


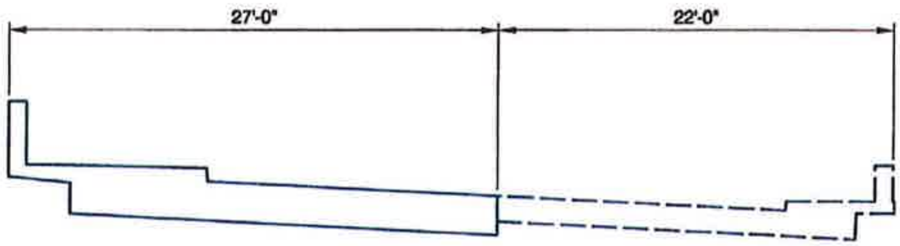
Figure 3: Bridge Site

Typical sections of the bridge alternatives are shown in Figures 4 and 5.

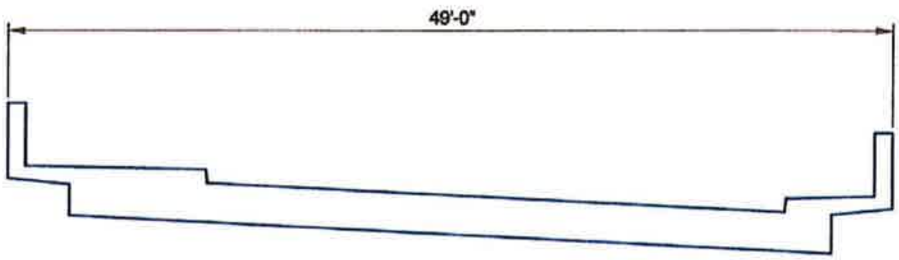


NEW PEDESTRIAN BRIDGE ALTERNATIVES

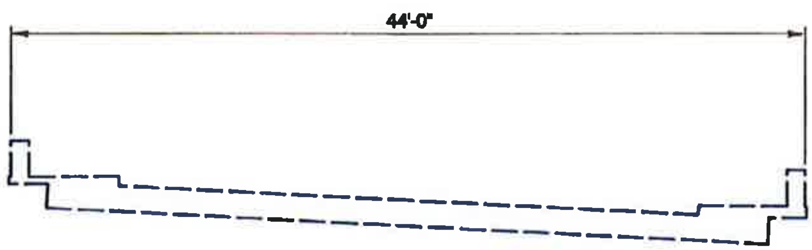
FIGURE 4



ALTERNATIVE D



ALTERNATIVE E



ALTERNATIVE G

ROAD BRIDGE ALTERNATIVES

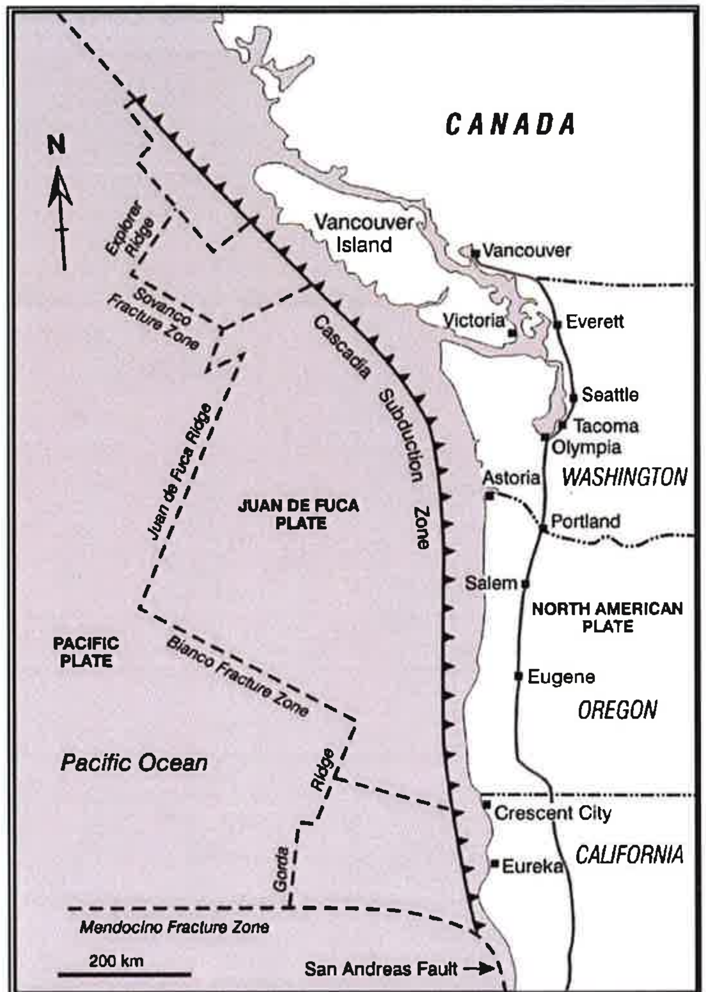
FIGURE 5

Coastal Seismicity

The Cascadia Subduction Zone, which lies off the Oregon coast, is the primary source of seismic activity in the region. At this major subduction fault, the Juan de Fuca plate slides beneath the North American plate at a rate of up to 4 centimeters (1.5 inches) per year. Geological records show that when these two plates suddenly slip, the Cascadia Subduction Zone is capable of producing massive earthquakes with a magnitude exceeding 9.0.

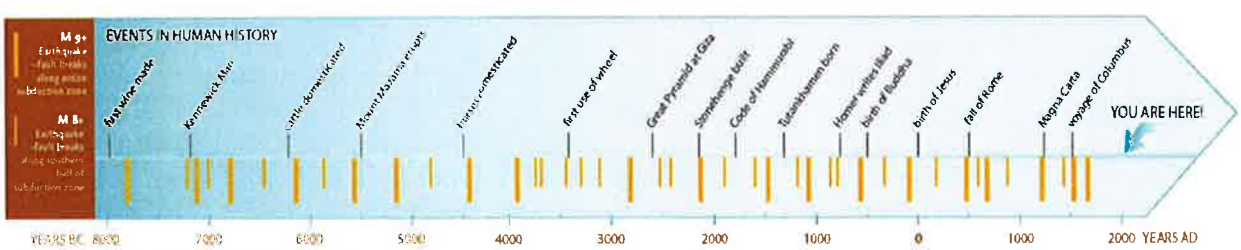
The last major earthquake along the Cascadia Subduction Zone is known to have occurred in January of the year 1700, well before European settlers had arrived on the west coast. Historical records in Japan show that the tsunami created by this massive earthquake (estimated to have been between M8.7 and M9.2) made its way across the Pacific Ocean, causing widespread damage along the Japanese coast.

By studying and carbon dating soil layers, geologists have determined that at least 40 large-scale subduction zone earthquakes have occurred over the past 10,000 years. The recurrence interval of these quakes averages 250 years. The following is a timeline diagram of the M8 and M9 earthquakes along the Oregon coast.



Source: Adapted from the Cascadia Region Earthquake Workgroup (2005)

Figure 6: Subduction Zone Map



Great earthquakes off the coast of Oregon have occurred 40 times over the last 10,000 years, ranging in size from magnitude 8.0 to over 9.0. This graph charts these mega-quakes over this period beginning in 8000 BC and shows they occur, on average, about once every 250 years. Evidence found in coastal marshes (below) shows the last great earthquake occurred in 1700 AD.

Figure 7: Timeline of Earthquakes off Oregon Coast

The M9 and larger earthquakes on this diagram represent a rupture of the entire 2,000-kilometer Subduction Zone, and the M8 earthquakes represent ruptures on the south half of the Subduction Zone along the Oregon coast. Additionally, a number of smaller earthquakes have occurred as a result of partial fault ruptures, ruptures on the northern half of the zone, and intra-plate ruptures (crustal earthquake). The City has asked what effect these small earthquakes would have on the existing road bridge; Alternate G, the possible reuse of the existing bridge substructure after an earthquake, addresses that possibility.

Earthquake Hazard at Cannon Beach

Engineering design for earthquake hazards is generally conducted using a probabilistic approach. Based on seismic hazard maps produced by the U.S. Geological Survey (USGS) and DOGAMI, the bridge design code and Oregon Department of Transportation (ODOT) stipulate that all new bridges be designed for two different seismic hazards. For the smaller hazard, which is defined as an earthquake that has a 10-percent chance of exceedance in the next 50 years (500-year return interval earthquake), the bridge is designed to remain serviceable. For the larger hazard, which is defined as an earthquake that has a 5-percent chance of exceedance in the next 50 years (1,000-year earthquake), the bridge is designed to not collapse.

Based on the great importance of the tsunami evacuation route, OBEC recommends designing the bridge to not collapse in an earthquake that has a 2-percent chance of exceedance in the next 50 years, if possible with current bridge construction. This hazard level is the highest level mapped and represents an earthquake with a return period of 2,500 years. It also includes design consideration of an M9.3 earthquake, the largest believed possible off the coast of Cannon Beach. Site-specific analyses of the forces generated by this hazard were calculated for the proposed city hall evacuation building and are discussed further in the Geotechnical Site Conditions section of this report.

Tsunami Hazard

As seen on March 11, 2011, when a M9 earthquake occurred off the coast of Japan, the potential for a tsunami often poses a great risk after a large earthquake. In a subduction zone earthquake, the top plate (which has slowly bulged upwards as a result of friction with the lower, subducting plate) releases suddenly. This release of energy causes a huge mass of water to abruptly lift upward; as this mass spreads, an abnormally large wave is formed, which can travel great distances and at great speeds.

The Oregon coast is vulnerable to tsunami from both near-source earthquakes originating in the Cascadia Subduction Zone and distance-source tsunamis originating from much larger distances; e.g., the Alaska quake in 1964 and the 2011 Japan earthquake.

Because of the risk of a tsunami at Cannon Beach, a number of studies have been conducted to determine the inundation zones of both near-source and distance-source tsunamis. Evacuation routes have been established, and the existing road bridge and proposed new pedestrian bridge are part of the evacuation route for the north end of the city.

DOGAMI conducted one of the studies for tsunami inundation risk in Cannon Beach. The map that was produced for this study, below, shows the inundation area for a number of possible tsunami probabilities; 50-percent, 70-percent, 90-percent, and 99-percent lines correspond to wave heights of 29 feet, 36 feet, 52 feet, and 100 feet, respectively.

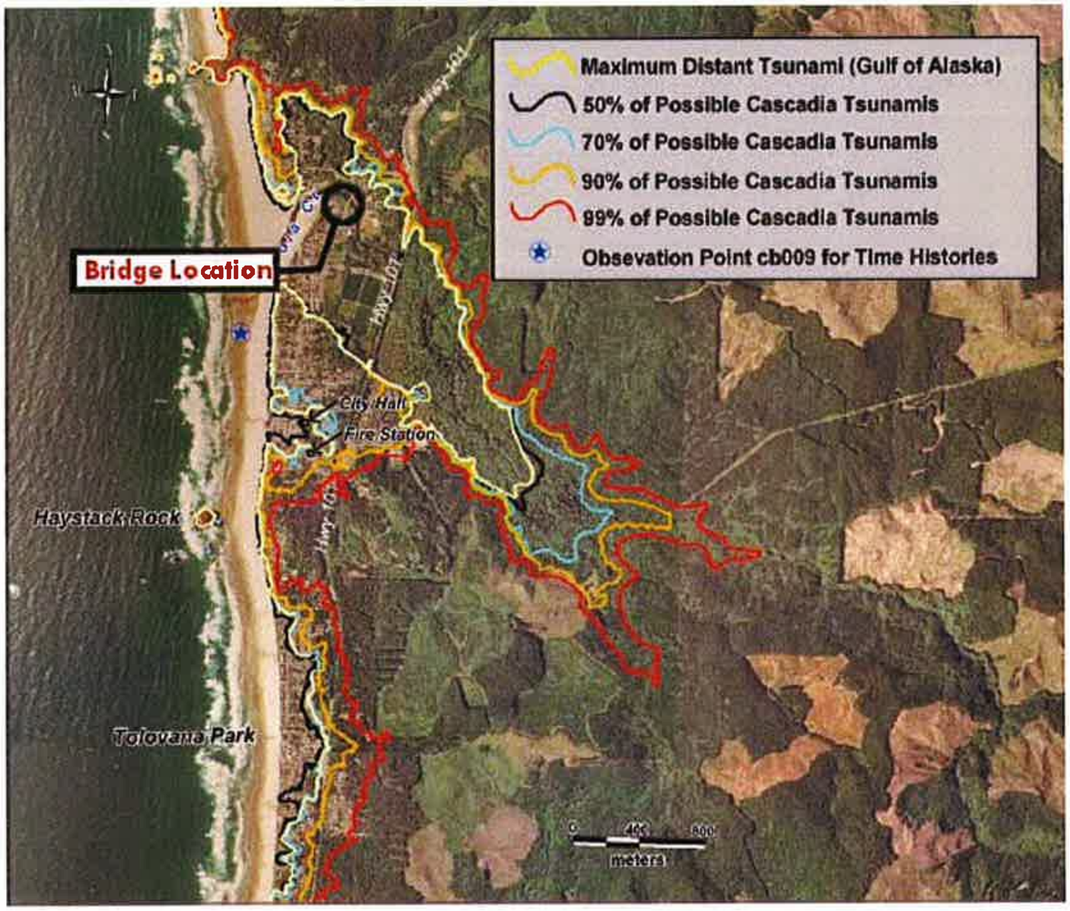


Figure 8: Inundation Area Map

Although Japan has been designing for tsunamis for decades, in the United States tsunami-resistant design is not as far advanced. Currently, none of the major building or bridge design codes in the United States address the risk of tsunami. However, some design guidelines can be found in FEMA report P646 "Guidelines for Design of Structures for Vertical Evacuation from Tsunamis," and in the City and County of Honolulu Building Code. Each of the pedestrian bridge alternatives will be qualitatively evaluated for tsunami resistance.

Geotechnical Site Conditions

An in-depth geotechnical investigation was conducted by Chinook GeoServices, Inc. in May 2011 for the City of Cannon Beach as part of a feasibility study for a proposed new city hall building as a Tsunami Evacuation Building (TEB). Although the site of the investigation is approximately 1 mile south of the proposed pedestrian structure, subsurface conditions are believed to be similar, based on the relative geological hazard maps prepared by DOGAMI. The Chinook GeoServices report will be used as the basis of geotechnical considerations for the emergency evacuation bridge until more detailed investigations are completed for this project.

This report indicates that borings at the city hall site showed medium stiff to soft silt and clay in the top 25 feet, followed by medium dense to very dense sand layers extending down to 100 feet where the borings encountered siltstone bedrock. Analysis also indicated that liquefaction could occur in the top 75 feet of the soil profile. Liquefaction-induced settlement was estimated at 9 to 15 inches in the upper 75 feet, and between 1 and 4 feet of lateral spreading could occur. A site-specific seismic hazard study was also conducted as part of the Chinook GeoServices report. The study identified the site as soil class "E" (the poorest of the possible soil types) and offered a recommendation to use site-specific values of Sms and Sm1 equal to 1.24g and 1.62g, respectively for the maximum credible earthquake required by the International Building Code (IBC), which governs the design and construction of buildings. Following are Figures 3 through 6 from DOGAMI showing relative hazard maps of the proposed bridge.

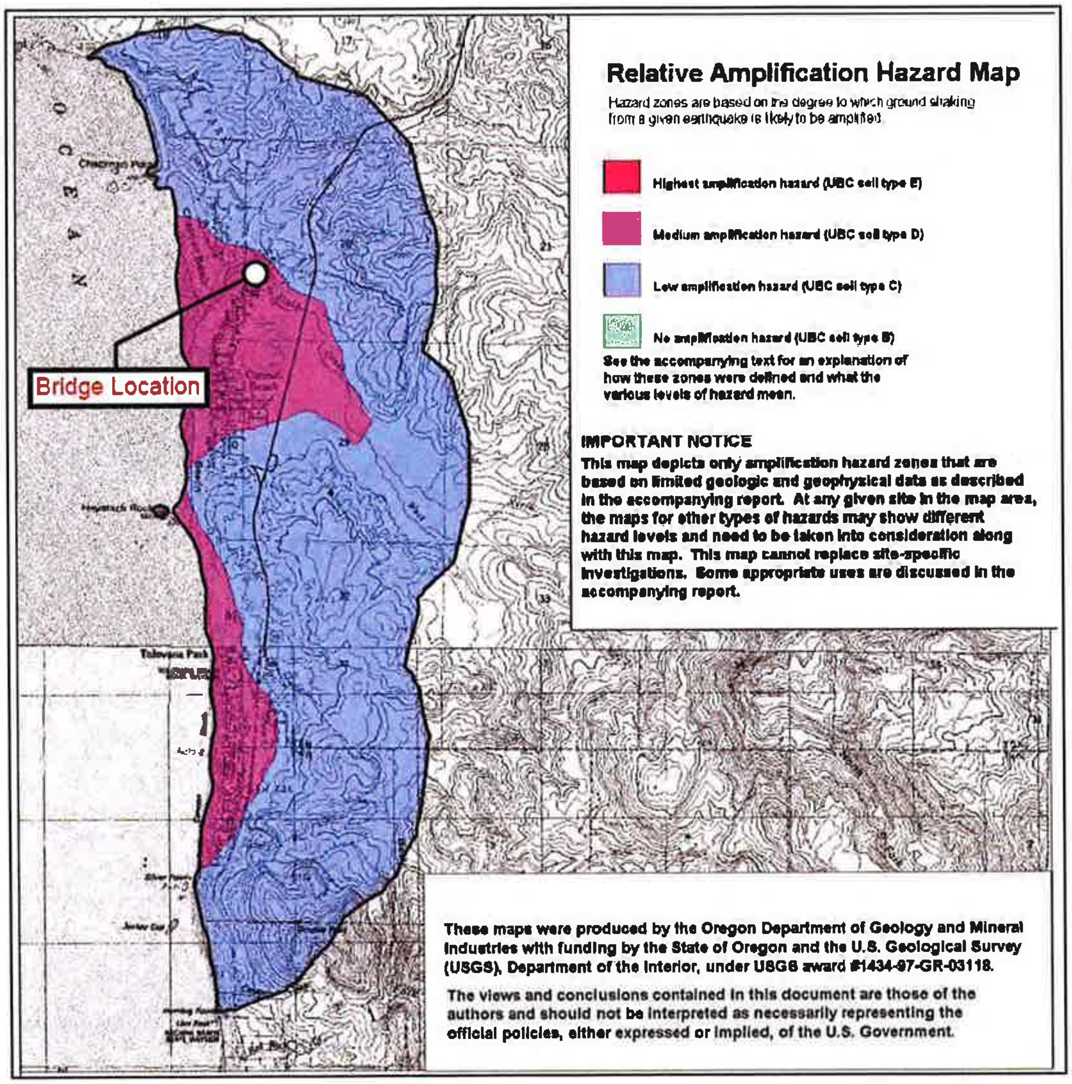


Figure 9

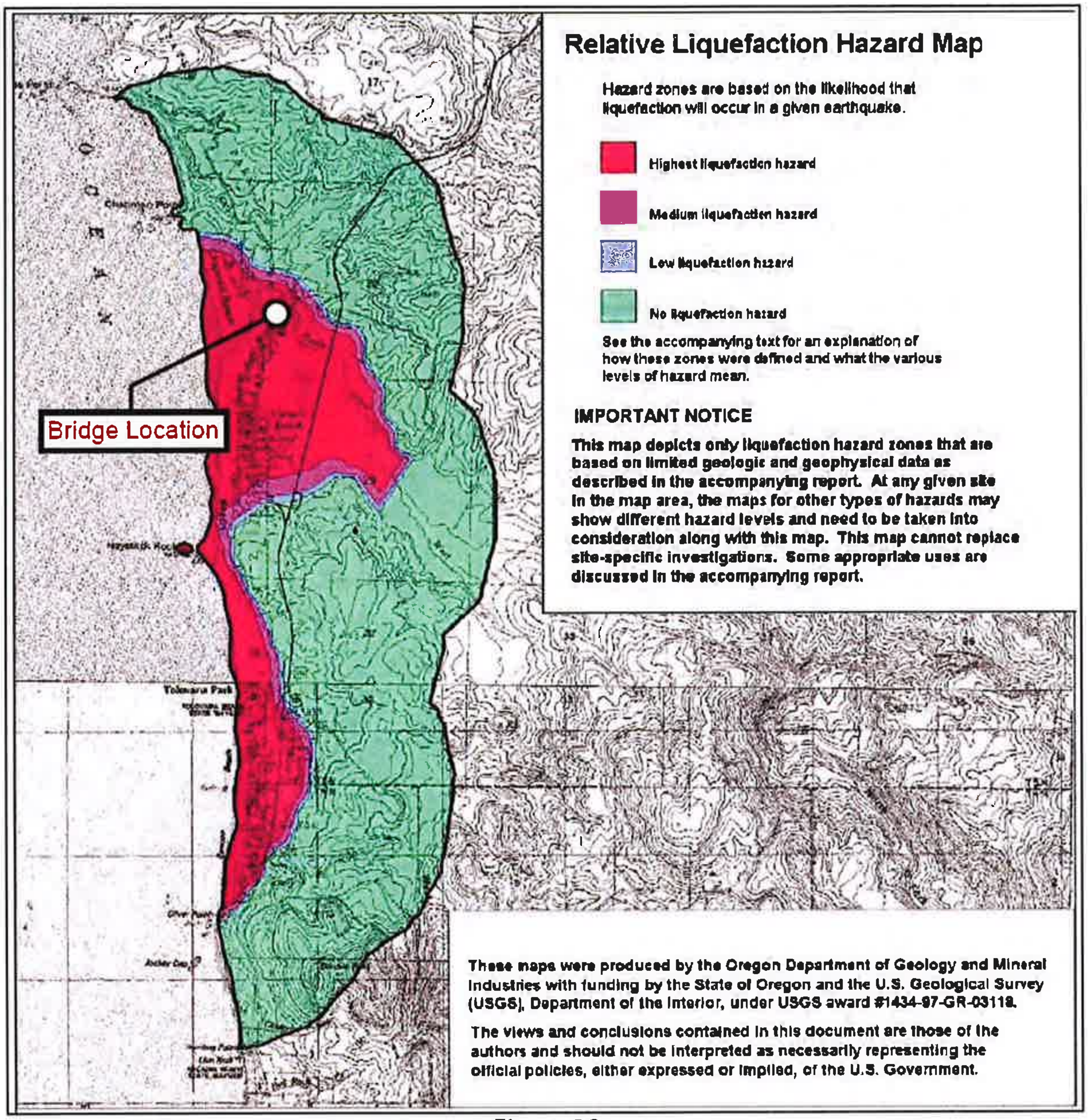

Relative Liquefaction Hazard Map
Hazard zones are based on the likelihood that liquefaction will occur in a given earthquake.
Highest liquefaction hazard
Medium liquefaction hazard
Low liquefaction hazard
No liquefaction hazard
See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
IMPORTANT NOTICE
This map depicts only liquefaction hazard zones that are based on limited geologic and geophysical data as described in the accompanying report. At any given site in the map area, the maps for other types of hazards may show different hazard levels and need to be taken into consideration along with this map. This map cannot replace site-specific investigations. Some appropriate uses are discussed in the accompanying report.
Bridge Location
These maps were produced by the Oregon Department of Geology and Mineral Industries with funding by the State of Oregon and the U.S. Geological Survey (USGS), Department of the Interior, under USGS award #1434-97-GR-03118.
The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Figure 10

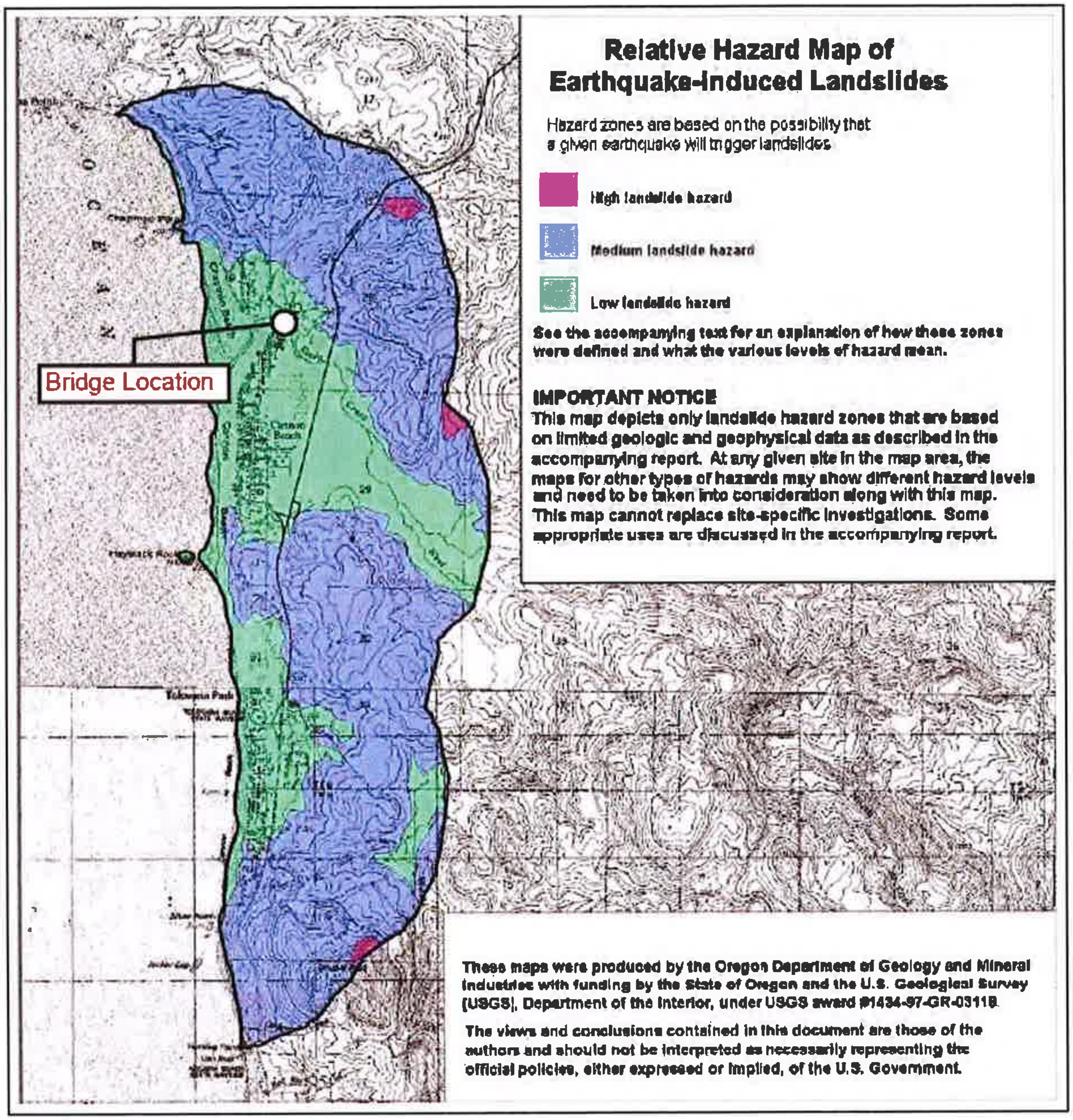

Relative Hazard Map of
Earthquake-Induced Landslides
Hazard zones are based on the possibility that
a given earthquake will trigger landslides
High landslide hazard
Medium landslide hazard
Low landslide hazard
See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
IMPORTANT NOTICE
This map depicts only landslide hazard zones that are based on limited geologic and geophysical data as described in the accompanying report. At any given site in the map area, the maps for other types of hazards may show different hazard levels and need to be taken into consideration along with this map. This map cannot replace site-specific investigations. Some appropriate uses are discussed in the accompanying report.
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Figure 11

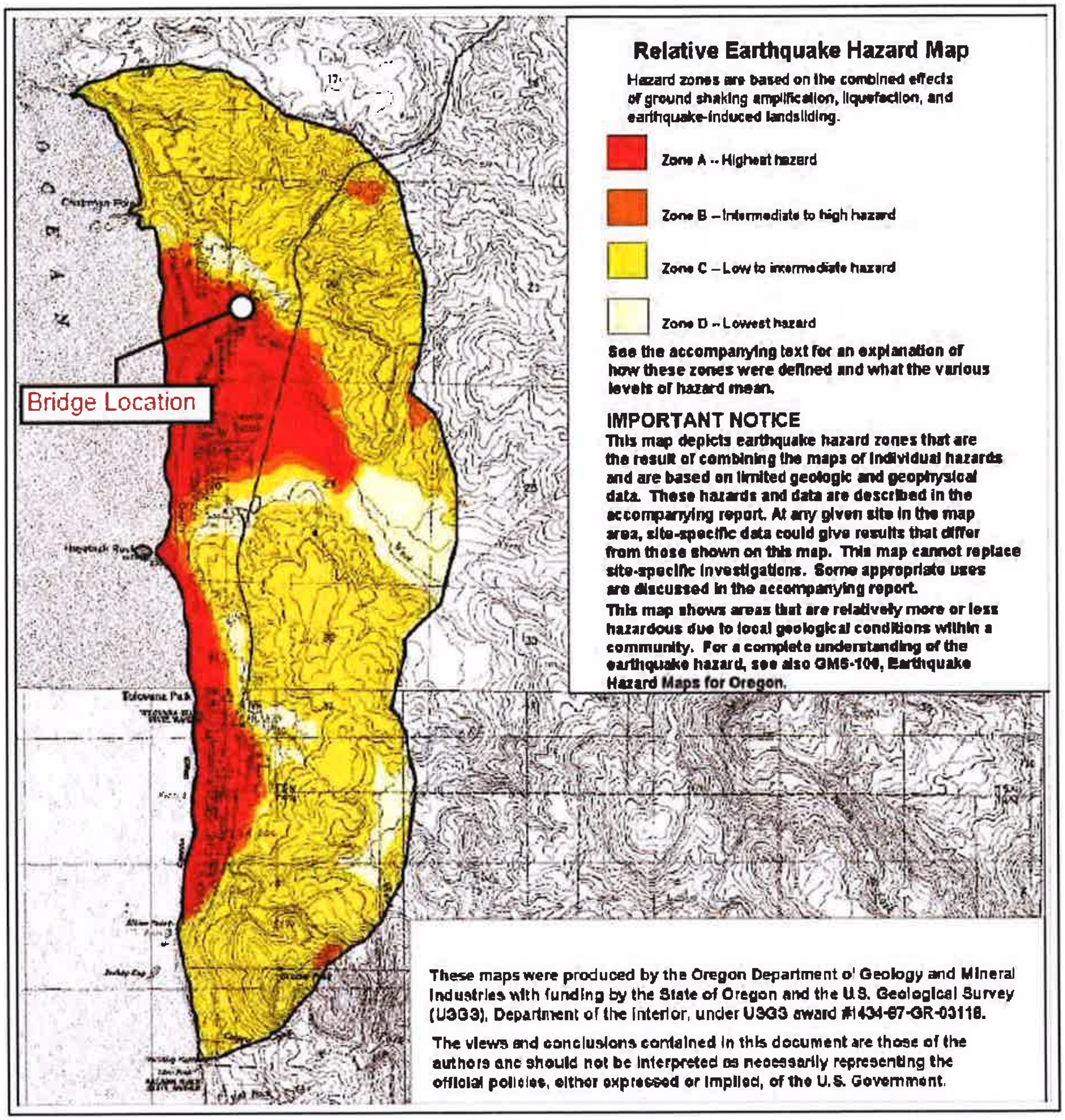

Figure 12

These relative geologic hazard maps show that the bridge site is subject to high earthquake amplification, lateral spreading of soils, and soil liquefaction hazard. For these reasons, all the proposed evacuation bridge alternatives must have durable, earthquake-resistant deep pile foundations to ensure the bridge survives the large earthquake and is able to serve the intended purpose as an emergency tsunami evacuation structure over Ecola Creek.

Pedestrian Level of Service

If a major emergency occurs within the city of Cannon Beach, thousands of people could be affected, possibly necessitating a large-scale evacuation. The scope and urgency, whether it is a partial or full evacuation, depends on the scale of the emergency. In the case of a near-source earthquake, once individuals evacuate their buildings they face the immediate threat of tsunami. Therefore, timely evacuation of people upland from the approaching danger is essential. City evacuation routes would be used, and use of the new emergency evacuation bridge would be crucial.

In the event of an emergency, evacuation bottlenecks, such as at the bridge, are of particular concern. For the purposes of this alternative selection study, established pedestrian movement calculations are used to evaluate the proposed bridge widths. Pedestrian behavior must be analyzed to calculate the capacity of the bridge. Characteristics such as walking speed, spacing between pedestrians, and mix of pedestrians (able-bodied, disabled, elderly, and children) affect the density of pedestrians using a pathway. The Highway Capacity Manual (HCM) has identified six different classes for pedestrian level of service (LOS) on a pathway, as shown below.

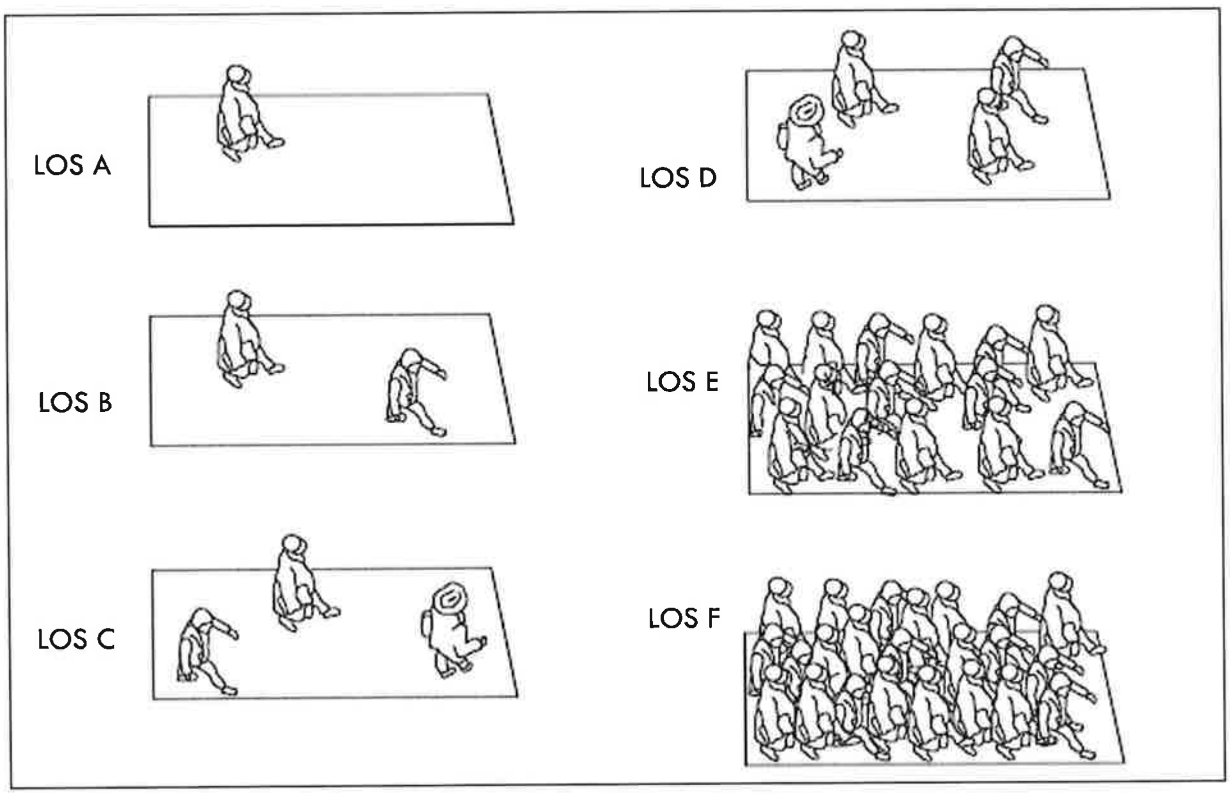

Figure 13: Level of Service Classes

Under LOS A conditions, pedestrians are free to walk at their desired pace and do not have to adjust their movements in reaction to other pedestrians. In the subsequent LOS categories, freedom of movement becomes increasingly restricted by other pedestrians, and walking speeds are decreased until pedestrians are spaced so closely as to be touching others, and they can only shuffle forward at a very slow pace (see LOS F). During an evacuation, pedestrians would most likely encounter LOS E or F depending on the bridge deck width.

At LOS E virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range forward movement is possible only by shuffling, and there is insufficient space for passing slower pedestrians. Design volumes approach the limit of walkway capacity, with some stoppages of flow.

At LOS F all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Flow is sporadic and unstable, and complete stoppages are possible.

On a narrow bridge (4-foot effective surface for a 6-foot wide bridge deck) people would be spaced very closely, walking speeds would be restricted, and pedestrians would not have much freedom to pass others.

The time required to enter the bridge depends on the number and flow rate of pedestrians, and the width of the pathway. The flow rate is defined as the number of people who pass a point during a given amount of time. The Highway Capacity Manual states that pedestrians in LOS E typically space themselves at 8 to 15 square feet per person and exhibit a flow rate of 15 to 23 persons per minute per foot. For this analysis, a spacing of 10 square feet per person and a flow rate of 18 persons per minute per foot are used. These are typical values used in large evacuation studies.

The calculation for number of persons that can use the bridge per minute has two components: 1) the time it takes all pedestrians to enter the bridge; and 2) the length of time before a tsunami arrives, predicted to be approximately 30 minutes. The flow rate used is 18 persons per minute per foot. This method was used to account for the bottleneck restricting flow. The maximum flow rate achievable is determined by the width of the bottleneck. A wider bottleneck allows more people to pass a point on the pathway at the same time and increases the capacity of the pathway. The following equation is used to calculate the time it takes people to flow onto a pathway:

$$Occ = Q*W$$

Where Occ=number of people, Q=flow rate, and W=effective width of bridge deck

Therefore, for a 6-foot-wide bridge (4-foot effective): Occ = (18)(4) = 72 persons/minute

If 15 minutes is available, theoretically 1,080 people can cross the bridge in that time. If there are delays in reaching the bridge due to earthquake-caused hazards such as downed power lines, people may arrive in a more condensed time period. In that scenario the level of service could quickly deteriorate to LOS F, and the number of people crossing the bridge could be greatly reduced with the bridge seriously under capacity.

When a similar analysis is made with a typical multiuse two-way bridge with a 12-foot-wide deck, capacity appears to be adequate for the arrival of up to 216 evacuees per minute.

Bridge gradeline (up or downhill slope of bridge) also affects level of service. The Americans with Disability Act (ADA) limits bridge slopes to a maximum of 5 percent, which is suitable for all classes of pedestrian usage during an evacuation.

New Bridge Design Criteria

The proposed bridge is intended to serve as a pedestrian bridge facility on a day-to-day basis as well as for emergency tsunami evacuation. New bridge design criteria are based on the following. The criteria below apply to both bridge sub and superstructure.

- American Association of State Highway Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities*, 1999
- Oregon Department of Transportation (ODOT) *Oregon Bicycle and Pedestrian Plan.*
- Americans with Disabilities Act (ADA)
- AASHTO *Load and Resistance Factor Design (LRFD) Bridge Design Specifications, Guide Specifications for Design of Pedestrian Bridges*, 2007
- ODOT *Oregon Standard Specifications for Construction*, 2008
- ODOT *Highway Design Manual*, 2002
- ODOT *Bridge Design and Drafting Manual* (BDDM), 2007

Using the above noted references, the minimum design criteria for a bridge with federal or state funding are as follows:

- Based on the *Guide for the Development of Bicycle Facilities* and the ADA, the minimum desirable bridge width is 10 feet with 2-foot rail shy distance, or 14 feet out-to-out. The design criteria also allow a 12-foot-wide bridge deck as the minimum acceptable standard. Since the funding for this project may be limited, bridge recommendations are provided for a 12-foot width only. Although a narrower bridge is allowable, federal or state funding may be available only for standard width bridge decks.
- The bridge structure will be designed in accordance with the AASHTO *LRFD Bridge Design Specifications*. The design pedestrian load is 85 pounds per square foot, and an H-10 (10,000 pound gross weight emergency vehicle such as police, ambulance, etc.) is used as an alternate live load. The design will include an allowance of 25 pounds per square foot for future wearing surface.
- The deck of the bridge will be constructed entirely above the 100-year flood elevation, in accordance with FEMA and ODOT design practices.
- The bridge will be designed to withstand a 1,000-year interval earthquake without collapse, in accordance with FEMA and ODOT design practices.

Special provisions for Tsunami Inundation Zones are as follows:

- The bridge will be anchored to resist, without collapse, a 2,500-year interval earthquake.
- Consideration will be given to detailing the bridge to withstand a high level of tsunami wave theoretically.
- Excellent tsunami resistance is offered by bridges constructed of precast and/or cast-in-place concrete spans made continuous to promote response to earthquake and wave forces, and anchored to concrete-filled steel pipe piles. As shown in the typical deck sections, the leading edges of concrete decks can be pointed with a steel nosing to more easily slice tsunami debris swept past the bridge. In addition, the leading edges of substructure piping will be further braced and armored with a steel nosing to similarly slice debris.

For all new bridge alternatives, a durable driven pipe pile foundation is assumed at all ends and interior bents to resist large magnitude earthquakes so the bridge is intact for tsunami evacuation after the earthquake event. For the purposes of this study, the piles are assumed to be 12- or 16-inch-diameter pipe piles driven to 25 feet below estimated soil liquefaction level, depending on the alternative considered.

Rating Criteria

To determine the suitability of the emergency evacuation structure, each of the seven alternatives has been evaluated based on seven criteria. The chosen criteria are Project Cost, Environmental/Permitting, M8/9 Earthquake Response, M5/7 Earthquake Response, Tsunami Response, Pedestrian Level of Service, and Durability, Maintenance, and Longevity.

Project Cost	Environmental /Permitting	M8/9 Earthquake Response	M5/7 Earthquake Response	Tsunami Response	Pedestrian Level of Service	Durability/ Maintenance/ Longevity

The rating criteria are defined as follows:

Project Cost

This criterion rates overall cost in comparison to the other alternatives, including costs for construction, engineering design, environmental permitting, and contingencies. It is assumed that project development (design and construction engineering, contract administration, etc.) and environmental permitting are 20 percent and 10 percent of construction, respectively. In addition, due to the schematic nature of alternative development, a construction contingency of 25 percent is included in each estimate.

For all new bridge alternatives, it is assumed that the bridge substructure is founded on driven steel pile foundations designed to withstand a large earthquake and accompanying geological hazards – soil liquefaction, soil lateral spreading, and amplification. Because the interior bents are over water, the steel pile bents must be driven from a work bridge structure, the cost of which is similar for Alternates B through E. Environmental/Permitting costs are similar for all new bridge alternatives.

For new bridges with concrete superstructures (Alternates C, D, and E), the bridge superstructure will also be designed to resist the significant tsunami wave resulting from an M8/9 earthquake, to the extent possible.

Environmental/Permitting

This criterion rates environmental impacts in comparison to the other alternatives, including impacts to wetlands and riparian zone, use of pressure-treated timber over water, and other factors. No wetland delineation report has been prepared for the site; however, wetlands and riparian zones are present on both ends of the bridge. Minimum environmental permitting will include coordination with the US Army Corps of Engineers (ACOE) and Oregon Division of State Lands (DSL), which will require a joint Section 404 Clean Water Act fill permit. The permit will likely require environmental studies, including a biological assessment (BA) on the effects and impacts of the project on threatened and endangered species such as fish and mammals. National Marine

Fisheries Service (NMFS), US Fish and Wildlife Service (USFWS), and Oregon Department of Fish and Wildlife (ODFW) would then coordinate a biological opinion (BO) regarding the effect on listed species. This process dictates measures that would be required by the project to protect listed species and would verify the viability of the proposed project. Clatsop County land use regulations also require obtaining state and federal permits/approval and minimizing riparian zone impacts.

In addition, any new bridge alternative will require a building permit to ensure it is safe to carry the intended structure and pedestrian loadings.

M8/9 Earthquake Response

This criterion rates how well the new bridge alternatives respond to a Cascadia Subduction Zone earthquake.

M5/7 Response

This criterion rates how well the new bridge alternatives and the existing road bridge respond to an earthquake of lesser magnitude than the Cascadia Subduction Zone earthquake. This magnitude earthquake would generally be caused by small intercrustal fault lines and is not likely to control the design of any new structures. Earthquakes of this size would generally not have the required energy or location to generate a tsunami risk. This criterion is mainly used to evaluate and rate the existing road bridge at the site.

Tsunami Response

This criterion rates how well the new bridge alternatives and the existing road bridge respond to a tsunami induced by a distant-source earthquake (lesser magnitude than the Cascadia Subduction Zone earthquake) and near-source Cascadia Subduction Zone earthquake. All new timber bridge alternatives (Alternates A, B, and F) have negligible tsunami resistance. The superstructures of the new concrete bridge alternatives (Alternates C, D, and E) will be designed and detailed to withstand the significant tsunami wave resulting from an M8/9 earthquake, to the extent possible.

Pedestrian Level of Service

This criterion rates how well the new bridge alternatives allow safe and effective pedestrian egress in the event of a tsunami or other emergency requiring evacuation. Bridge width dictates capacity and level of service (LOS) for pedestrian use. Gradeline geometry must meet minimum ADA criteria for a safe bridge deck slope.

Durability/Maintenance/Longevity

This criterion rates the durability of the bridge alternative, the likely lifespan of the bridge, and the total life cycle costs as a result of required maintenance and upkeep.

Rating Summary

Each site has been assigned a rating for each of the eight criteria. The five ratings that are being used in this report are *Superior*, *Acceptable*, *Neutral*, *Undesirable*, and *Unacceptable*. A summary rating table for each of the six alternatives follows. Alternate G, evaluation of the existing bridge, has not been rated for these criteria.

Alternative Ratings Matrix

Alternative	Project Costs	Environ./ Permitting	M8/9 Earthquake Response	M5/7 Earthquake Response	Tsunami Response	Pedestrian Level of Service	Durability/ Maintenance/ Longevity
A Floating Pontoon Bridge	Acceptable	Neutral	Undesirable	Neutral	Un-acceptable	Un-acceptable	Undesirable
B 6-Foot-Wide Timber Bridge	Acceptable	Neutral	Acceptable	Acceptable	Un-acceptable	Un-acceptable	Undesirable
C 12-Foot-Wide Concrete Bridge	Neutral	Acceptable	Acceptable	Superior	Acceptable	Superior	Superior
D Replace West Half Of Existing Bridge	Undesirable	Acceptable	Acceptable	Superior	Neutral	Superior	Superior
E Replace All Of Existing Bridge	Undesirable	Acceptable	Acceptable	Superior	Neutral	Superior	Superior
F 6-Foot-Wide Suspension Pedestrian Bridge	Neutral	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Undesirable

Rating of Alternatives

Alternate A: Floating Pontoon Bridge

This alternative is assumed to be timber construction with a 6-foot-wide deck and 60-foot timber spans, which is reasonable for timber construction. For the purposes of the alternative selection study, the bridge ends would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying geological hazards. The interior supports of the bridge would be on pontoons floating in the creek. The bridge would not be designed to resist a tsunami wave.

<u>Project Cost</u> – Estimated cost of this alternative is $796,000 (cost estimate shown in detail in Table 1). Because this bridge has a lower cost than the most expensive alternative, this alternative is rated as *Acceptable*.

Environmental/Permitting – The superstructure for this alternative is assumed to be timber, similar to Alternate B, in keeping with the desire for a reasonable bridge cost. Environmentally, treated timber construction over rivers and creeks is not allowed unless additionally sealed. Environmental regulating agencies may also object to having pontoons in the water. Because of these issues, this alternative is rated *Neutral.*

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs this alternative is not anticipated to survive a wave or water surge of any kind. For this reason, this alternative is rated *Undesirable.*

M5/7 Earthquake Response – In a smaller earthquake event, the response of the bridge is unknown and is rated *Neutral.*

Tsunami Response – The tsunami response of this alternative will be particularly poor due to the flexible pontoons located at the water surface. This means any small tsunami or wave surge may damage or destroy this structure. Therefore, this alternative is rated *Unacceptable.*

Pedestrian Level of Service – This alternative is assumed to be 6 feet wide, similar to the Alternate B. Pedestrian LOS for this structure will be E or F, and not adequate to move a large number of evacuees in a short period, as required. In addition, because the pontoon bridge needs to accommodate variable water surface levels from tide and flooding, it is anticipated that the pontoon bridge gradeline will sometimes exceed a safe slope and not meet ADA criteria. The deck may also be slippery when wet, adding to safety concerns with this alternative. For these reasons, this alternative is rated *Unacceptable.*

Durability/Maintenance/Longevity – Because the superstructure is timber, it will have a shorter lifespan and require more maintenance than concrete superstructure alternatives. Therefore, this alternative is rated *Undesirable.*

Alternate B: Fixed Timber Bridge with 6-Foot-Wide Deck

This alternative is assumed to be timber construction with a 6-foot-wide deck and 60-foot timber spans, which is reasonable for timber construction. For the purposes of the alternative selection study, this bridge would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying geological hazards. The bridge would not be designed to resist a tsunami wave.

Project Cost – Estimated cost of this alternative is $1,047,000 (cost estimate shown in detail in Table 1). Because this bridge has a lower cost than the most expensive alternative, this alternative is rated as *Acceptable.*

Environmental/Permitting – The superstructure for this alternative is assumed to be timber, similar to Alternate A, in keeping with the desire for a reasonable bridge cost. Environmentally, treated timber construction over rivers and creeks is not allowed unless additionally sealed. Therefore, this alternative is rated *Neutral.*

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs, this alternative is anticipated to survive because it is built on durable, earthquake-resistant steel pile foundations driven to depth. For this reason, this alternative is rated *Acceptable*.

M5/7 Earthquake Response – In a smaller earthquake event, this bridge is anticipated to respond adequately. For this reason, this alternative is rated *Acceptable*.

Tsunami Response – The tsunami response of this alternative will be particularly poor because of the low lateral strength resistance of the superstructure and structure depth. Therefore, this alternative is rated *Unacceptable*.

Pedestrian Level of Service – This alternative is assumed to be 6 feet wide, similar to the Alternate A. Pedestrian LOS for this structure will be E or F, and not adequate to move a large number of evacuees in a short period, as required. For this reason, this alternative is rated *Unacceptable*.

Durability/Maintenance/Longevity – Because the superstructure is timber, it will have a shorter lifespan and require more maintenance than concrete superstructure alternatives. Therefore, this alternative is rated *Undesirable*.

Alternate C: Fixed Prestressed Concrete Pedestrian Bridge with 12-Foot-Wide Deck

The superstructure of this alternative is assumed to be precast concrete construction made continuous laterally to resist a large tsunami wave and debris force. The deck is assumed to be 12 feet wide supported on 60-foot spans, which is reasonable for strong, relatively slender precast concrete members. The bridge substructure would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying geological hazards. The bridge would also be designed for maximum theoretical tsunami forces.

In keeping with minimum national design standards for pedestrian bridges and eligibility for federal and/or state funding, the desirable bridge deck width is 14 feet and the minimum allowable deck width is 12 feet. For the purposes of this analysis, a 12-foot deck will be assumed for maximum economy.

Special provisions for tsunami loading include:

- Steel armored and pointed leading and trailing deck edges to split lateral tsunami-driven debris (schematically shown in typical deck section in Figure 1).
- Braced and armored points on leading and trailing support pile edges to split lateral tsunami-driven debris.
- Structure made laterally continuous end to end to provide lateral loading load-path in addition to lateral resistance of pile bents.
- Breakaway railings to present a streamlined bridge profile toward tsunami.
- Minimized deck width to reduce uplift wave pressure on underside of deck.
- Especially robust lateral and vertical uplift connections between sub and superstructure.

Project Cost – Estimated cost of this alternative is $1,714,000 (cost estimate shown in detail in Table 1). Because the cost of this bridge is somewhat less than for the most expensive alternative, this alternative is rated as *Neutral*.

Environmental/Permitting – Environmentally, this is the most common type of bridge permitted over rivers and creeks, and the environmental process for permitting this bridge is well known and predictable. For this reason, this alternative is rated *Acceptable*.

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs, this alternative is anticipated to respond well because the substructure and superstructure support each other, and are designed and constructed to durable earthquake standards. For this reason, this alternative is rated *Acceptable*.

M5/7 Earthquake Response – In a smaller earthquake event, this bridge is anticipated to respond well. For this reason, this alternative is rated *Superior*.

Tsunami Response – The tsunami response of this alternative will be particularly effective compared to timber construction. With the additional design features indicated above, the superstructure and structure depth should be very resistant to tsunami loading. Therefore, this alternative is rated *Acceptable*.

Pedestrian Level of Service – This alternative is assumed to be 12 feet wide, and pedestrian LOS for this structure will be very high. The deck surface is hard and non-slip, and adequate to move a large number of evacuees in a short period, as required. For this reason, this alternative is rated *Superior*.

Durability/Maintenance/Longevity – Because the superstructure is concrete, it will have a long useful life and require little maintenance in service. Therefore, this alternative is rated *Superior*.

Alternate D: Replace Western Half of Existing Road Bridge with New Concrete Bridge on the Same Alignment with a 10-Foot-Wide Downstream Sidewalk for Tsunami Evacuation

In accordance with minimum national design standards for bridges and eligibility for federal and/or state funding, the desirable half-bridge deck width is 27 feet out-to-out (1-foot combined traffic/pedestrian rail, 10-foot sidewalk, 4-foot shoulder, and 12-foot travel lane). Note that a 5-foot sidewalk is possible as a less expensive option for this alternative, giving a bridge deck width of 22 feet out-to-out. The bridge substructure would be founded on driven pile foundations designed to withstand a large earthquake and accompanying geological hazards. To the extent possible, the bridge superstructure will also be designed to withstand the large earthquake and resulting tsunami. The remaining east half of the existing bridge would be replaced as a future project.

The superstructure of this alternative is assumed to be precast concrete construction made continuous laterally to resist a large tsunami wave and debris force. The deck is assumed to be supported on 60-foot spans, which is reasonable for strong, relatively slender precast concrete members. The bridge substructure would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site.

Project Cost – Estimated cost of this alternative is $2,929,000 (cost estimate shown in detail in Table 1). Because the cost of this bridge is relatively expensive and no state or federal funding appears to be available for this project, this alternative is rated as *Undesirable*.

Environmental/Permitting – Environmentally, this is the most common type of bridge permitted over rivers and creeks, and the environmental process for permitting this bridge is well known and predictable. For this reason, this alternative is rated *Acceptable.*

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs, this alternative is anticipated to respond well because the substructure and superstructure support each other, and are designed and constructed to durable earthquake standards. For this reason, this alternative is rated *Acceptable.*

M5/7 Earthquake Response – In a smaller earthquake event, this bridge is anticipated to respond well. For this reason, this alternative is rated *Superior.*

Tsunami Response – The tsunami response of this alternative may not be as effective as a 12-foot-wide concrete pedestrian bridge (Alternate C) because its greater width may be more susceptible to uplift force and more likely to trap debris from a tsunami. Therefore, this alternative is rated *Neutral.*

Pedestrian Level of Service – This alternative is assumed to be 27 feet wide, and pedestrian LOS for this structure will be very high. The deck surface is hard and non-slip, and adequate to move a large number of evacuees in a short period, as required. For this reason, this alternative is rated *Superior.*

Durability/Maintenance/Longevity – Because the superstructure is concrete, it will have a long useful life and require little maintenance in service. Therefore, this alternative is rated *Superior.*

Alternate E: Replace Existing Road Bridge with New Concrete Bridge on the Same Alignment with 10-Foot-Wide Downstream Sidewalk for Tsunami Evacuation

In accordance with minimum national design standards for bridges and eligibility for federal and/or state funding, the desirable bridge deck width is 49 feet out-to-out (1-foot combined traffic/pedestrian rail on each side, 10-foot sidewalk on one side and 5-foot sidewalk on the other side, two 4-foot shoulders, and two 12-foot travel lanes). Note that it is possible to have 5-foot sidewalks on both sides of the bridge as a less expensive option, giving a deck width of 44 feet out-to-out. The bridge substructure would be founded on driven pile foundations designed to withstand a large earthquake and accompanying geological hazards. To the extent possible, the bridge superstructure will also be designed to withstand the large earthquake and resulting tsunami to some extent.

The superstructure of this alternative is assumed to be precast concrete construction made continuous laterally to resist a large tsunami wave and debris force. The deck is assumed to be supported on 60-foot spans, which is reasonable for strong, relatively slender precast concrete members. The bridge substructure would be founded on driven steel pile foundations designed to withstand a large earthquake and accompanying soil liquefaction, soil lateral spreading, amplification, and relative earthquake hazard at the site.

Project Cost – Estimated cost of this alternative is $4,757,000 (cost estimate shown in detail in Table 1). Because this bridge is the most expensive alternative and no state or federal funding appears to be available for this project, this alternative is rated as *Undesirable.*

Environmental/Permitting – Environmentally, this is the most common type of bridge permitted over rivers and creeks, and the environmental process for permitting this bridge is well known and predictable. For this reason, this alternative is rated *Acceptable.*

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs, this alternative is anticipated to respond well because the substructure and superstructure support each other, and are designed and constructed to durable earthquake standards. For this reason, this alternative is rated *Acceptable*.

M5/7 Earthquake Response – In a smaller earthquake event, this bridge is anticipated to respond well. For this reason, this alternative is rated *Superior.*

Tsunami Response – The tsunami response of this alternative may not be as effective as a 12-foot-wide concrete pedestrian bridge (Alternate C) because its greater width may be more susceptible to uplift force and more likely to trap debris from a tsunami. Therefore, this alternative is rated *Neutral.*

Pedestrian Level of Service – This alternative is assumed to be 49 feet wide, and pedestrian LOS for this structure will be very high. The deck surface is hard and non-slip, and adequate to move a large number of evacuees in a short period, as required. For this reason, this alternative is rated *Superior.*

Durability/Maintenance/Longevity – Because the superstructure is concrete, it will have a long useful life and require little maintenance in service. Therefore, this alternative is rated *Superior.*

Alternate F: Fixed Timber Suspension Bridge with Minimum 6-Foot-Wide Bridge

For the purposes of the alternatives selection study, this bridge will be considered at a lower and higher elevation to mitigate tsunami loading. However, this bridge will need to withstand an initial large earthquake.

This alternative is assumed to be timber construction with a 6-foot-wide deck and 300-foot timber main span supported on structural steel towers on durable earthquake-resistant driven steel pile foundations. The anchorages of the main cables would extend back 75 feet on land at each end of the bridge, and are mass concrete supported on durable earthquake-resistant driven steel pile foundations. All foundations would be designed to withstand a large earthquake and accompanying geological hazards.

Analysis of this alternative included investigating a higher/longer suspension bridge option and a lower/shorter suspension bridge option. In comparing the two options, the higher/longer bridge has numerous disadvantages. The tsunami path is approximately 2,500 feet wide at the mouth of the creek, and it is not possible to place the towers of the higher/longer bridge outside of the tsunami path. Therefore, it does not make sense to consider the higher/longer bridge, as it will not be tsunami resistant even if placed partially above a lower level tsunami. In addition, the right-of-way requirements and logistics of siting the higher/longer bridge are not feasible. For this reason, only the lower/shorter bridge option is considered in this analysis.

Project Cost – Estimated cost of this alternative is $1,608,000 (cost estimate shown in detail in Table 1). Because the cost of this bridge is somewhat less than for the most expensive alternative, this alternative is rated *Neutral.*

Environmental/Permitting – The superstructure for this alternative is assumed to be timber, similar to Alternate B, in keeping with the desire for a reasonable bridge cost. Environmentally, treated timber construction over rivers and creeks is not allowed unless additionally sealed. Because this bridge has no piers in the water, it has environmental permitting advantages. For these reasons, this alternative is rated *Acceptable*.

M8/9 Earthquake Response – In an extreme earthquake event, if land subsidence, liquefaction, or lateral spreading occurs, this alternative is anticipated to survive because it is built on durable, earthquake-resistant steel pile foundations driven to depth. For this reason, this alternative is rated *Acceptable*.

M5/7 Earthquake Response – In a smaller earthquake event, this bridge is anticipated to respond adequately. For this reason, this alternative is rated *Acceptable*.

Tsunami Response – The tsunami response of this alternative will be particularly poor because of the vulnerability of the towers and the potential for debris carried by a tsunami to get caught on the main cables at the tower anchorages. Therefore, this alternative is rated *Unacceptable*.

Pedestrian Level of Service – This alternative is assumed to be 6 feet wide, similar to the Alternate A. Pedestrian LOS for this structure will be E or F, and not adequate to move a large number of evacuees in a short period, as required. For this reason, this alternative is rated *Unacceptable*.

Durability/Maintenance/Longevity – Because the superstructure is timber, it will have a shorter lifespan and require more maintenance than concrete superstructure alternatives. Therefore, this alternative is rated *Undesirable*.

Alternate G: Quantitatively Evaluate Existing Bridge for Serviceability of Approximately M5 through M9 Earthquakes and Potential Usability of Piling in the Event of Loss of Superstructure Only

This alternative would investigate the potential of using the existing bridge piling for rapid reestablishment of a pedestrian link to the city after the event. The existing bridge is 44 feet out-to-out and was constructed in 1964 as a replacement for an older bridge in this location, which was destroyed by a tsunami generated by the Alaska earthquake of 1964.

The bridge has seven spans of 30 feet for an overall length of 210 feet. The superstructure consists of preast prestressed concrete bridge slabs set side by side and tied together with transverse steel tie rods. The substructure consists of timber pile bents with piles driven to approximately Elevation -40, according to the as-built records for the bridge, which is within the soil liquefaction zone determined from the city hall geotechnical study. The timber piles support a 16-inch square timber pile cap, and the interior bent piles are braced by timber "X" bracing. The concrete slab superstructure is held to the timber caps by drift pins between the slabs and the caps. The drift pins have low lateral resistance to tearing out the sides of the cap. For this reason and others, the existing bridge is vulnerable to failure in earthquakes that cause relative movement between the substructure and superstructure.

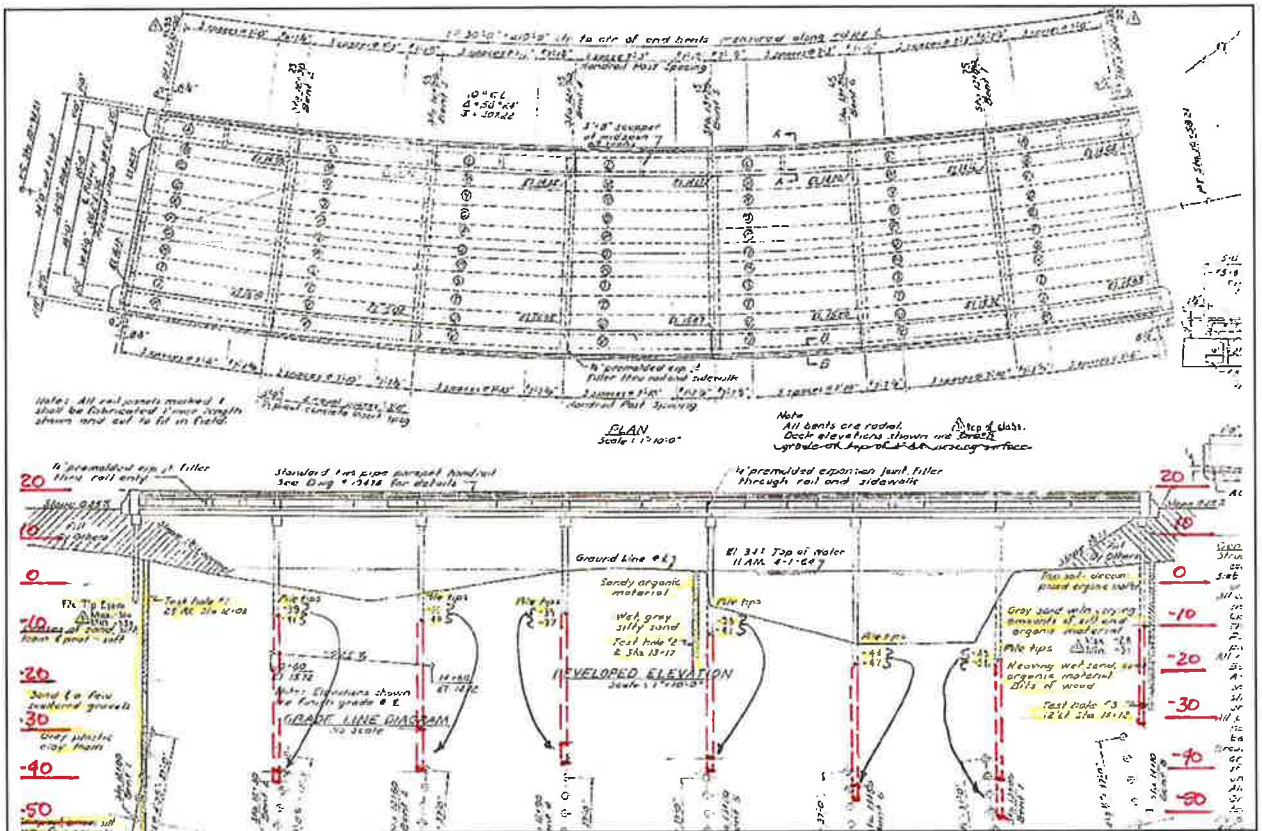

Figure 14: General Arrangement of the Existing Ecola Creek Bridge

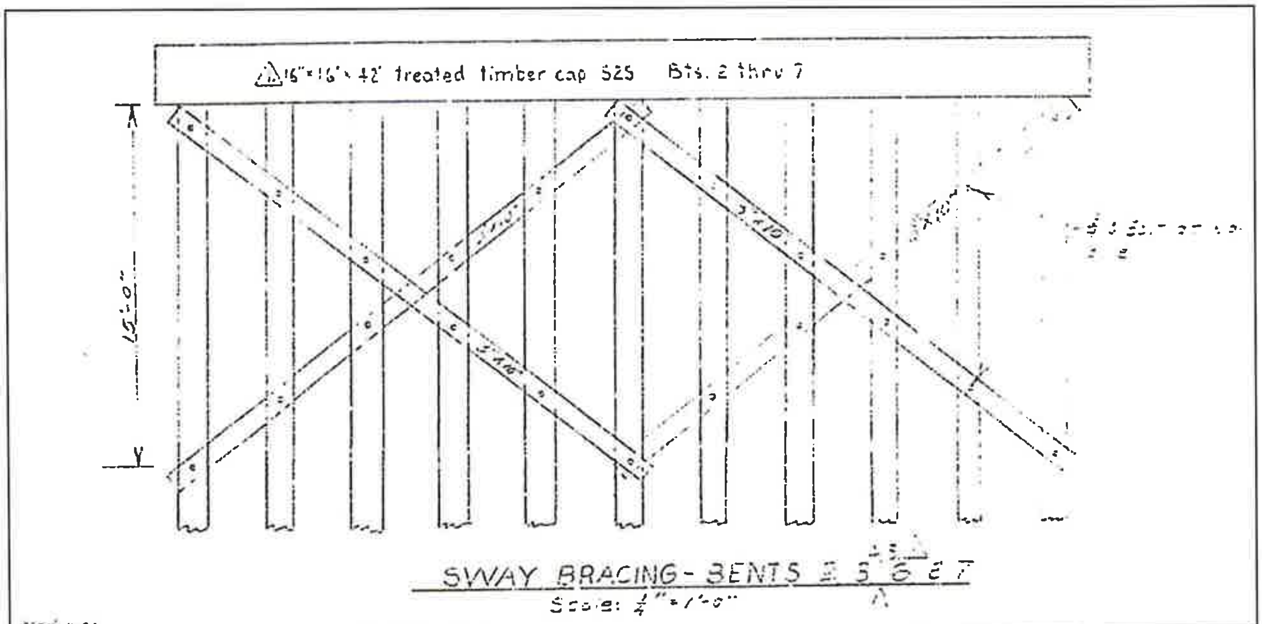

Figure 15: Interior Timber Pile Bents with Timber "X" Bracing

Because of the age and construction of the existing bridge, it is likely vulnerable to failure in a relatively small earthquake. The bridge has little resistance to being pulled off its bents during an earthquake; however, the exact condition, amount of deterioration, and strength of the timber pilings and caps, bracing, and bracing connections are unknown. It is likely the existing timber substructure would not be usable to rapidly establish a transportation link after a bridge collapse.

The photo, right, shows the bridge site after the 1964 tsunami. As can be seen, there are a few remaining bents. It is possible the tsunami lifted and floated the timber bridge superstructure off the bents, leaving some intact. The existing concrete bridge is much heavier than the old bridge. If an earthquake causes the current bridge to fail, it is more likely to fail vertically, flattening the existing timber substructure and diminishing its potential for immediate reuse.

Figure 16: The tsunami generated by the 1964 Great Alaskan Earthquake (M9.2) caused over $250,000 dollars in damage and destroyed the Ecola Creek Bridge in Cannon Beach.
Photo Source: Oregon Department of Geology and Mineral Industries

<u>Conclusion</u>

OBEC is aware it has been difficult for the City to determine which alternatives should be considered and to understand the advantages and disadvantages of each. All the alternatives described in this report have been requested by the City based on citizen input, and there are no other alternatives that OBEC would recommend. The rating matrix presented here has been created based on logical rating criteria that can be used to fairly evaluate all the alternatives. It is hoped this report and rating analysis gives the City the information needed to evaluate the alternatives and select the best outcome to meet the goals for this project.

TABLE

TABLE 1

Cannon Beach Tsunami Evacuation Bridge Alternatives Cost Estimate

Bridge Data	6' - Wide Floating Pontoon Bridge A	6' - Wide Timber Bridge B	12' - Wide Concrete Bridge C	Replace West Half of Existing Bridge D	Replace All of Existing Bridge E	6' - Wide Suspension Pedestrian Bridge F
Estimated Bridge Length	300	300	300	300	300	75/300/75
Max. Span Length	60	60	60	60	60	150/75
Width	6	6	12	27	49	6
Steel Pile Bents	2	6	6	6	6	4
Piles/Bt (Estimated Length 100' Each)	3	3	4	6	9	6

Estimated Bid Items Temporary Features and Roadwork	Price	Unit	A Qty	A Cost	B Qty	B Cost	C Qty	C Cost	D Qty	D Cost	E Qty	E Cost	F Qty	F Cost
Mobilization		LS	1	$63,000	1	$68,000	1	$108,000	1	$196,000	1	$319,000	1	$107,000
Erosion Control		LS	1	$10,000	1	$15,000	1	$15,000	1	$20,000	1	$20,000	1	$10,000
Road Work/Sidewalks		LS	1	$60,000	1	$60,000	1	$60,000	1	$100,000	1	$200,000	1	$60,000
Structures														
Bridge Removal		LS							1	$116,000	1	$185,000		
Temp. Work Bridge 240' long x 20' wide	$ 50	SF	3600	$180,000	4800	$240,000	4800	$240,000	4800	$240,000	4800	$240,000		
Furnish Pile Driving Equipment		LS	1	$50,000	1	$50,000	1	$50,000	1	$50,000	1	$50,000	1	$50,000
Furnish PP 12 x 0.5" Wall Piles	$ 31	FT	600	$18,841	1800	$56,524								
Furnish PP 16 x 0.5" Wall Piles	$ 42	FT					2400	$102,000	3600	$152,000	5400	$228,000	2400	$102,000
Drive PP Steel Piles	$ 1,000	EACH	6	$6,000	18	$18,000	24	$24,000	36	$36,000	54	$54,000	24	$24,000
Steel Pile Caps/Bent	$ 8	LB	1500	$12,000	5400	$43,200								
Concrete Foundation/Walls	$ 900	CY	10	$9,000	10	$9,000	60	$54,000	110	$99,000	190	$171,000	50	$45,000
Pontoons	$ 25,000	EACH	4	$100,000										
Reinforced Concrete Bridge End Panels	$ 300	SY	40	$12,000	40	$12,000	80	$24,000	180	$54,000	330	$99,000	40	$12,000
Wire Rope	$ 15	LB											16800	$252,000
Structural Steel	$ 10	LB											30000	$300,000
Timber Superstructure	$ 60	SF	1800	$108,000	1800	$108,000							1800	$108,000
Concrete Superstructure	$ 110	SF					3600	$396,000	8100	$891,000	14700	$1,617,000		
Project Development Costs														
Design Engineering (15%)				$95,000		$102,000		$161,000		$294,000		$478,000		$161,000
Environmental Permitting (Lump Sum)	$ 50,000	LS		$50,000		$50,000		$50,000		$50,000		$50,000		$50,000
Construction Engineering (15%)				$63,000		$102,000		$161,000		$294,000		$478,000		$161,000
Contingencies (25%)				$158,000		$170,000		$269,000		$489,000		$796,000		$268,000
Total Project Cost				$796,000		$1,047,200		$1,714,000		$2,929,000		$4,757,000		$1,608,000