ASSESSING OREGON’S SEISMIC RISK

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Abstract

The State of Oregon has unique seismic risks associated with its location adjacent to the Cascadia Subduction Zone. The nature and probability of this risk are examined. Because this risk was only recently identified, most of the state’s bridges are designed for little or no seismic loads, and thus require a comprehensive program of seismic retrofit. Divided into Phase 1 (superstructure) and Phase 2 (substructure), the retrofit needs have been identified with respect to structure vulnerability and criticality, and work has been proposed and prioritized to account for cost-effectiveness and lifeline classification.

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Seismic concern from historical evidence.

The state of Oregon is bordered by Washington to the north, California to the south and the Pacific Ocean to the west. Oregon’s coastline is an eclectic collection of shear rock cliffs, flat sandy beaches, mountainous sand dunes and tidal marshlands.

Its rugged beauty along the coastline and into the Cascade mountain range, can be attributed to the action of plate tectonics directly off of the coastline in the Pacific Ocean.
The movement of the Juan de Fuca Plate under the North American Plate creates the “Cascadia Subduction Zone”. Subduction Zone earthquakes are greater in magnitude, affecting a much larger area than the crustal type earthquakes that are the common experience of California. The Cascadia Subduction Zone, along a 1600-km long plate boundary, is capable of generating a Magnitude 8 or 9 earthquake (Richter scale).
Numerous soil test holes have been evaluated along the coastline, in an effort to evaluate the magnitude and frequency of significant events. Tsunami sediment layers and carbon dating have been used to develop this approximate strain history.

The sediment layers used to construct the history, correlate to a major tsunami event recorded in Japan, in January 27, 1700. It’s been 300 years since the last Cascadia Subduction Zone Earthquake. Based on this historic and geologic evidence, a major subduction zone earthquake could occur at any time.

The impact of a subduction zone earthquake is different from the crustal earthquake in the fact that the potential magnitudes are higher. The area affected is much larger in the subduction zone event because the entire length of the plate boundary is involved. In the Oregon portion, this could affect approximately 70% of the state’s 6500 bridges.

**Design considerations**

ODOT’s designs have always met the basic AASHTO criteria. Designs prior to 1958 did not account for seismic loading, because the impact of Plate Tectonics was not yet fully understood. Designs between 1958 and 1974 included a seismic design force equal to 2-6% of the structure weight. Bridges designed during the time frame from 1975 to 1989 were designed for seismic forces of up to 12% of the structure weight. It was not until 1989, and the Loma Prieta earthquake in the San Francisco Bay area, that a more sophisticated structural analysis and ductile reinforcing details for seismic forces, became a part of mainstream bridge design in Oregon.
Due to the small number of recorded seismic events in Oregon, the available bedrock acceleration maps available prior to 1990 indicated lower seismic loads. In 1995, a consultant study assessed more realistic ground accelerations and developed site specific, probability-based bedrock acceleration contour maps to aid in seismic design. The 500-year peak ground acceleration map shown below was established as a rational design loading for most bridges. Generally the risk of seismic exposure increases westward along the entire length of the state. The peak ground acceleration ranges from 0.05g in the eastern regions of the state to 0.60g along the southern coastline.

![500-Year Peak Ground Acceleration Map](image)

Figure 6

Oregon’s state-owned bridge inventory contains about 2600 bridges, many of which are multi-span pre-cast/pre-stressed concrete beam bridges and cast-in-place post tensioned bridges. With these types of structures, two failure mechanisms have been identified from vulnerable detailing:

The first failure mechanism would engage when the motion from the earthquake causes the bridge’s superstructure to separate from the substructure. A typical bridge designed prior to extensive seismic detailing would not have an available beam seat greater than 300 mm for seismic movement in the longitudinal direction. Additionally, the beam seat would not have shear lugs designed to resist much, if any, transverse direction seismic force.
The following photo from the 1994 Northridge earthquake illustrates this type of failure.

When the superstructure spans collapse, this portion of the travel route immediately becomes unusable and inhibits emergency access. This type of damage can take several months to rebuild. If on a critical freight route, the loss to Oregon businesses would be many times the cost of the repair.

Typical seismic retrofit details to prevent this type of failure include longitudinal cable restraints and the addition of concrete or steel shear lugs for transverse force restraint. This type of seismic retrofit is referred to as a “Phase 1” seismic retrofit.
Examples of Phase I Seismic Retrofit

Figure 9

Figure 10

Figure 11
The second failure mechanism would engage when the motion from the earthquake which causes the bridge’s substructure to collapse from the seismic force. Similar to the superstructure design shortcomings of earlier typical bridge design, substructures (columns in particular) were not designed to resist the intense forces experienced in a seismic event. Structures built before 1975 are particularly vulnerable due to their lack of seismic design detailing. These earlier designs typically contain multiple column redundancy, but do not contain adequate column confinement reinforcement and vertical bar splices and anchorage. The column’s confinement reinforcement was typically #13 or #16 reinforcing hoops at 300 mm.

The following photo from the 1971 San Fernando earthquake illustrates the type of failure that is likely to occur with these earlier designs.

Substructure collapse or partial collapse requires careful engineering judgment regarding the compromise of structural integrity the remaining load carrying capacity. With each aftershock, the structural integrity can change along with the safety designation.

In addition to columns, the foundation of the bridge is also susceptible to seismic loads in excess of the design loads. Foundation failures may not be readily detectable with the damage hidden by overburden.

Substructure seismic retrofit is referred to as a “Phase 2” seismic retrofit and, for certain bridges, can exceed the replacement cost of the structure.
Due to insufficient funding, ODOT has not performed any Phase 2 seismic retrofit at this time. In the future, this type of work will involve footing strengthening and column jacketing to increase ductility.

![Seismic Retrofitting Freeway Structures](image)

**Figure 13**

In rare cases, it has proven cost-effective to install seismic isolation bearings to absorb seismic energy without the need for substructure strengthening.

![Seismic Retrofitting Freeway Structures](image)

**Figure 14**
Seismic retrofit can greatly increase the resistance of bridges to earthquake damage. The degree of seismic resistance in a design is a trade-off of risk reduction vs. cost. ODOT’s strategy is to do Phase I Retrofit before Phase 2 to quickly reduce risk to as many bridges as possible.

No amount of retrofit investment can assure absolutely no damage from a Subduction Zone Earthquake.

Figure 15
**Route Priority Analysis**

Lifeline routes were identified, using Emergency Response and Economic Recovery as criteria. Routes in the State have been categorized into four priority levels. They are as follows:

**Priority 1:** *Essential* for Emergency Response in the first 72 hours after the seismic event

**Priority 2:** *Desirable* for Emergency Response in the first 72 hours, or *Essential* for Economic Recovery in the months following the seismic event

**Priority 3:** Other Emergency Response Routes that are the only access serving relatively few people, and all NHS (National Highway System) Routes

**Priority 4:** Non-lifelines

**Total Retrofit Need**

Priority routes were matched up with peak ground acceleration levels to establish corridors for proposed bridge seismic retrofit. Lifeline routes are given the highest priority and matched to the lowest acceleration threshold.

For superstructure seismic retrofit, the numbers of bridges and the approximate cost of Phase 1 retrofitting are as follows:

- 145 bridges are on routes with a priority 1 and a peak ground acceleration of greater than 0.12g. The approximate cost is $40.6 million.

- 178 bridges are on routes with a priority 2 and a peak ground acceleration of greater than 0.12g. The approximate cost is $49.5 million.

- 30 bridges are on routes with a priority 3 and a peak ground acceleration of greater than 0.15g. The approximate cost is $9.3 million.

- 44 bridges are on routes with a non-lifeline and a peak ground acceleration of greater than 0.18g. The approximate cost is $4.2 million.

The Phase 1 seismic retrofit effort would include 397 bridges at a total of $103.6 million.
For Phase 2 substructure seismic retrofit, the numbers of bridges and the approximate cost are as follows:

- 345 bridges are on routes with a priority 1 and a peak ground acceleration of greater than 0.15g. The approximate cost is $177.5 million.
- 391 bridges are on routes with a priority 2 and a peak ground acceleration of greater than 0.18g. The approximate cost is $225.4 million.
- 22 bridges are on routes with a priority 3 and a peak ground acceleration of greater than 0.25g. The approximate cost is $10.7 million.
- No bridges are on routes that are not a lifeline.

The Phase 2 seismic retrofit effort would include 758 bridges at a total of $413.6 million.

In summary, Oregon has 1155 state-owned bridges (46% of the DOT’s inventory) that require seismic retrofit, at a total cost of $517.2 million. If the Phase 1 and Phase 2 seismic retrofit were to be spread over a twenty year period, the approximate cost would be $26 million per year.
References

**Figure 1:** Photo by Richard L. Groff, P.E., Oregon Dept. of Transportation.

**Figure 2:** Photo by Orrin Russie, Oregon Dept. of Transportation.


**Figure 4:** USGS Topinka, USGS/Cascades Volcano Observatory 1999, modified from Tilling, 1985, Volcanoes: USGS General Interest Publication, URL: [http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_plate_tectonics_cascades.html](http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_plate_tectonics_cascades.html)

**Figure 5:** Conceptual diagram by Martha Sartain & Richard L. Groff, P.E., Oregon Dept. of Transportation.

**Figure 6:** State of Oregon Dept. of Geology & Mineral Industries, from GMS-100, Earthquake Hazard Maps for Oregon, edited by I.P. Madin & M.A. Mabey. based on *Seismic Design Mapping State of Oregon*, prepared for Oregon Dept. of Transportation by Geomatrix Consultants, January 1995. URL: [http://sarvis.dogami.state.or.us/store/gifs/eq5_2500.gif](http://sarvis.dogami.state.or.us/store/gifs/eq5_2500.gif)

**Figure 7:** Bridge 53-1964F Interstate 5/California Route 14 Interchange, North Connector, 1994 Northridge, CA Earthquake (photographer Mark Ascheim), Northridge Collection, Earthquake Engineering Research Center, University of California, Berkeley. URL: [http://www.eerc.berkeley.edu/cgi-bin/equiis_detail?id=6972](http://www.eerc.berkeley.edu/cgi-bin/equiis_detail?id=6972)

**Figure 8:** Bridge 08590C, Marquam Bridge Ramp. Photo by Dennis Carlson, P.E., Oregon Dept. of Transportation.

**Figure 9:** Bridge 08589B, Undercrossing Pacific Highway Connection No 3. Photo by Dennis Carlson, P.E., Oregon Dept. of Transportation.

**Figure 10:** Bridge 08590D, Northbound Marquam Bridge Ramp. Photo by Dennis Carlson, P.E., Oregon Dept. of Transportation.

**Figure 11:** Bridge 08590Y, Northbound Marquam Bridge Ramp Connection to Water Ave. Photo by Dennis Carlson, P.E., Oregon Dept. of Transportation.
Figure 12: Image No. S4382, Freeway structures near interchange between Interstates 5 and 210, 1971 San Fernando, CA Earthquake (photographer Karl V. Steinbrugge), Steinbrugge Collection, Earthquake Engineering Research Center, University of California, Berkeley. URL: http://www.eerc.berkeley.edu/cgi-bin/eqiis_detail?id=4115

Figure 13: Conceptual drawing from CalTrans Jan. 1995

Figure 14: Bridge 02444A, Hood River Bridge. Photo by Hormoz Seradj, P.E., Oregon Dept. of Transportation

Figure 15: Conceptual diagram by Martha Sartain & Richard L. Groff, P.E., Oregon Dept. of Transportation.