SEISMC PERFORMANCE DESIGN CRITERIA FOR OREGON DOT

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Abstract

Oregon is in a unique position geologically that has resulted in a lack of major earthquakes that would lead to retrofitting bridges. While Oregon has had no major damaging earthquake in recorded history, the State is vulnerable to a very large subduction zone event in the next 50 years, according to scientists at Oregon State University. Since many of the bridges have not been retrofitted, Oregon has established a performance design criteria that is intended to allow mobility and continuity through "backbone" lifeline system of highways to allow rescue after an event and economic recovery in a minimum amount of time. This paper describes the studies that led to the development of the criteria and how the design criteria are applied to new and retrofitted bridges.

Introduction

Oregon's Seismic Performance Design Criteria has been developed in direct response to the seismic risk specific to Western Oregon and the vulnerability of our current bridge infrastructure. During our recorded history since the early 1800's Oregon has had very low seismicity. However, scientists have concluded that Oregon is at risk for a very large subduction zone event with a predicted return period of 300-500 years, the last one occurring in January 1700. A Cascadia subduction zone earthquake with a magnitude of 8.0 or greater will hit Oregon; the question is when, not if. Such an earthquake will cause an unparalleled economic and human catastrophe for the state of Oregon because of the lack of preparation and lack of resiliency of the highway network.

A preliminary assessment has found that Oregon bridges have seismic vulnerabilities similar to those damaged in previous earthquakes, deficiencies such as insufficient column reinforcement, insufficient foundation capacity, non-stable bearings, inadequate superstructure seat width, and presence of liquefiable soils. ODOT adopted the 2006 FHWA Retrofit Manual in April 2010. After an evaluation process, some of the details included in this manual (Figures 11–14) have been selected as good solutions for retrofitting Oregon bridges. Because of our state's unique seismic situation, ODOT is currently evaluating the performance of these retrofit details under a very strong and very long shaking event, such as a M9.0 Cascadia subduction zone earthquake. This evaluation process is not expected to invent new retrofit details, but it should identify any need to refine the existing ones.

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The vulnerabilities of Oregon bridges are complex and differ from bridge to bridge and from site to site. Some bridges are prone to more than one type of seismic deficiency, and a few may need to be replaced. ODOT has already conducted research and investigation to develop the best approach for mitigating the problem. Worldwide experience has shown that while we are not knowledgeable enough to predict the exact time that an earthquake will strike, we can be proactive to save lives and speed up the recovery process. The following figures illustrate common seismic damage and recommended methods of mitigation or retrofitting for bridges.

Unfortunately, in its current state, the transportation system will be of little help in facilitating emergency response and long-term recovery after a Cascadia subduction zone quake. A magnitude 8.0 or greater quake will cause widespread disruption of Oregon's transportation system, making rescue operations difficult, if not impossible. Most bridges in western Oregon will suffer serious damage or destruction in a major seismic event because they were built before the existence of modern seismic codes. In addition, dozens of unstable slopes and pre-existing deep slides will fail during the extended three minutes or more of shaking produced by a large Cascadia event. Virtually all major highways will be closed in the immediate aftermath of a quake; it will take months to open many highways—and years before mobility is fully restored.

In the meantime, Oregon's trade-based economy will falter due to severe limitations on moving people and goods. Experience with other large-scale disasters around the world shows that many firms will fail within the first few months, while others will move outside Oregon to avoid collapse; many that remain will struggle to maintain access to markets, resources and workers due to the lack of mobility on major highways.

Given the economic impacts, the question is: what can Oregon do to increase the resilience of our highway system so we can be prepared to rescue our citizens and recover our economy in the face of this inevitable reality?

Fortunately, there are ways to keep the highway system functional after a quake. Seismic retrofitting of bridges is a well-developed and well-understood practice that has been extensively accomplished in Oregon's neighboring states of California and Washington. Due to the more frequent occurrence of earthquakes in those states, departments of transportation there have received significant seismic retrofit funds to mitigate impacts to their infrastructure.

Unlike its West Coast neighbors, Oregon has not experienced a large, damaging earthquake during the modern era, and our knowledge of the locations of faults and the geological history of major events is quite recent. In comparison to California and Washington, Oregon's earthquakes are much less frequent, but when they hit they are much larger and more damaging. In the absence of significant retrofitting, the highway system will not be functional immediately after a major seismic event and will cause sizable economic losses—estimated at $355 billion over the course of seven years

Pre-emptive seismic retrofitting could lessen the economic losses by 10 to 24 percent, depending on the level of seismic investment in the system. This translates into reducing the loss by $35 to $85 billion.

As part of the statewide effort to make the Oregon highway system seismically resilient, ODOT's responsibility has become clear: retrofit all seismically vulnerable bridges and address unstable slopes on key lifeline routes in a strategic and systematic program to allow for rescue and recovery following a major earthquake.

- Many bridges along Oregon state highways are in relatively good condition, with many years of remaining service life, absent a major seismic event, and could benefit from a stand-alone retrofit project.
- Some bridges are not good candidates for seismic retrofit due to structural and other condition issues. Most of these bridges were built in the 1950s and 1960s, and many were built over poor soils which can amplify the seismic forces the bridge must endure during a seismic event.
- Other bridges will need to be replaced within the next several decades, and it makes no sense to retrofit a bridge only to replace it within a decade; for these structures, replacement will be more cost-effective in the long term.
- Still other bridges will need significant rehabilitation work, and there would be significant cost benefits to combining retrofit and repair projects.

In order to establish the most cost effective investment plan, ODOT conducted additional studies on key lifeline routes to identify long term bridge needs and to develop a program level assessment of bridge improvement needs.

The Oregon Seismic Lifeline Routes (OSLR) study is designed to address Policy 1E, Lifeline Routes, of the 1999 Oregon Highway Plan, which states: "It is the policy of the State of Oregon to provide a secure lifeline network of streets, highways, and bridges to facilitate emergency services response and to support rapid economic recovery after a disaster." The report summarizes a newly developed study methodology to help prioritize system management measures at a corridor level. In addition to the facility and geophysical data addressed in earlier studies, this study added new considerations, including connections to population areas; locations of hospitals, fire stations, energy utilities, fuel storage facilities, and sites of other essential materials and services; and connections to other modes that will be important in a major emergency, such as airports, ports, and freight routes. In this way, the OSLR study looks at vulnerabilities, key connections, and roadway capacity to identify routes that need to be made more resilient to facilitate response after an event.

The design event for this study is a major Cascadia subduction zone earthquake with likely related events, including tsunami, landslides, liquefaction of soils, and dam failures. The reason for focusing on this event is that it would have regional to multi-state impacts and would require a multi-state and federal response. Not only would it have significant impacts on the surface transportation system, requiring mobilization of many levels of emergency response, its effects would also be far-reaching. The result of the OSLR work, completed in April 2012, is a recommended, regional, corridor-level Oregon Seismic Lifeline System.

The study area is the geographic region of the state most susceptible to a seismic event and related impacts: generally, the populated areas along the Interstate 5 corridor and locations to the west of it. Although Klamath Falls is outside of the vulnerability area for a subduction zone earthquake, it is included in the study due to its proximity to active crustal faults. The area east of I-5 to U.S. 97 was also included in the study area, because access to the east side of I-5 is necessary to connect to emergency response services that will likely be staged at the Redmond Municipal Airport. In addition, the U.S. 97 corridor will be critical to support economic recovery.

All Oregon state highways within the study area were considered. The process started with the selection of a subset of those highways that appeared to be good candidates for lifeline routes. The list of possible routes went through a triage process to increase the efficiency of the OSLR project and to decrease the effort required to analyze the data along each route. State highways west of U.S. 97 were selected for inclusion in the evaluation because they had one or more of the following characteristics:

- Likely ability to promote safety and survival through connections to major population centers with survival resources.
- Currently used as a strategic freight and/or commerce route.
- Connection between seismically vulnerable areas and one or more of the following key destinations of statewide significance identified by ODOT Maintenance as critical for surface connection to interstate resources:

    - I-84 east of Biggs Junction and U.S. 20 east of Bend
    - The California border on I-5 and on U.S. 97
    - Crossing the Columbia River into southwestern Washington
    - A port on the Columbia or Willamette River and one port on the coast
    - Portland International Airport and Redmond Municipal Airport

State highways in western Oregon that were not selected are considered important to the overall transportation system and local emergency response and recovery. For the purposes of this study, however, they were not considered to be good candidates for identification as statewide lifeline routes, because they do not connect major population centers, do not connect to destinations of statewide significance, or, in downtown Portland, are not considered primary facilities.

Economic Assessment of Seismic Damage from a 9.0 Cascadia Subduction Zone Event

Once the lifeline routes were identified, ODOT conducted an economic study of the impact to the State Gross Economic product using the statewide traffic and land use model. The study of economic benefits of a state highway seismic program demonstrated that if the full retrofit program (Stages 1 - 5) is completed prior to a major Cascadia seismic event, Oregon would avoid the loss of $84 billion to the state's economy. This avoidance of loss equates to a rate of return of 16, when compared to the investment needed to do seismic retrofits. The latest recommended program includes needed replacement and rehabilitation work, so the costs of the program have increased somewhat. This would result in a slightly lower, but still very high rate of return. The costs avoided in losses to the economy will remain the same, and may potentially be higher, since replacement bridges are expected to perform better than retrofitted bridges in a seismic event.

Cost of Seismic Retrofit Program of Bridges and Slides/Slopes – $5.0 B

Benefit Cost
16

Proportion of Total Economic Loss Avoided - $84.0 B

Combining selective bridge replacements and bridge rehabilitation work with seismic retrofit of bridges will result in cost savings on project design, construction, project management, and reduced user delay cost when compared to undertaking a separate rehabilitation and replacement program. The effect, when combined with mitigation of unstable slopes, is a cost-effective program that improves the overall condition and resiliency of Oregon's key lifeline routes. By keeping bridges open to commerce that would otherwise decay and restrict the movement of freight, the proposed program will have significant benefits to Oregon's economy even if we avoid a major earthquake.

The seismic risk used for bridge design and retrofit is defined by hazard maps of ground acceleration values. The maps combine multiple regional sources of ground shaking using a Probabilistic Seismic Hazard Analysis (PSHA). Each source has a different intensity, probability of occurrence, and distance to a specific location. One key source of ground shaking in a PSHA is from the Cascadia Subduction Zone (CSZ); however, a CSZ earthquake can have significantly different ground motion estimates as a stand-alone event than what is captured in the values derived from a PSHA.

For seismic evaluation of bridges in Oregon, two cases are considered: ‘no collapse’ for large earthquake shaking and ‘serviceability’ for more frequent smaller earthquake shaking. ‘No collapse’ is expected to result in severe damage without complete collapse; ‘serviceability’ requires little or no damage so the bridge remains functional. The ground acceleration used in design for the ‘no collapse’ and ‘serviceability’ cases at a specific location would have two different values derived from PSHA hazard maps for a 1000-year return period and 500-year return period respectively.

For ‘no collapse’, the CSZ earthquake dominates calculated PSHA acceleration values along the coast, but has a diminishing contribution further inland. Consequently, actual ground acceleration inland from a CSZ event may exceed the PSHA values, which means designers, following current seismic design code, may be under-designing for collapse prevention in certain parts of the state. For ‘serviceability’, the less frequent CSZ would have little contribution when considering low level earthquakes. For this reason ODOT adopted higher hazard than recommended in the FHWA Seismic Retrofit Manual in an effort to recognize some CSZ influence for serviceability. Doing this also raised the contributions from other earthquake sources across the state within the PSHA calculation. Consequently, designers following the current ODOT guidelines for serviceability could be over-designing to meet ‘serviceability’ performance.

For cases where actual acceleration correlate with PSHA values, the increased duration of a CSZ earthquake may result in more damage than expected. Numerical simulations using data from recent subduction earthquakes have shown that more damage occurs from the increased duration of shaking as compared to non-subduction earthquakes of the same peak acceleration. However, this result is being experimentally verified by Portland State University.

Provided that a CSZ earthquake is considered the most likely earthquake source in the next 50 years and that many of the important lifeline routes are most affected by a CSZ earthquake, the use of the CSZ event as the serviceability design value will assure that bridge safety, mobility, and retrofit decisions are made using the best estimate of seismic demand on our bridges.

One of the reasons for ODOT selecting 1000 year serviceability design event instead of the 500 year was to compensate for the unknown duration effects of the subduction zone. Duration effects are not captured by the single acceleration design value used by the code.

Rebuilding a bridge under normal conditions is usually a routine operation for planners, engineers, and construction companies. Data from previous projects that are similar in scope provide the information needed to estimate the cost and time for constructing new projects. Designers and builders usually have a clearly defined approach when it comes to construction methodologies and techniques for building certain types of bridges. Depending on the size and location of a project, it may take as little as a year or two to construct small bridges on routes with low Average Daily Traffic (ADT), and up to more than a decade to construct big projects on busy routes.

By contrast, facing a post-earthquake situation with tens or even hundreds of bridges in need of immediate replacement will be very challenging. Every single step of the process to replace these structures will encounter new circumstances and involve many unknown factors, which usually determine the cost and timeframe for building a bridge.

Some of the questions that need to be answered are:

- What is the capacity of the bridge engineering community for designing replacement bridges or repairs in an emergency situation?
- What contractors will be available to construct this many bridges?
- Will we have adequate construction materials to supply these projects?
- Realizing there will be many other structures in need of repair or replacement at the same time, what reconstruction has the first priority?

It is well understood how difficult it will be for the state to recover economically after a Cascadia subduction zone earthquake if several bridges along the state's most critical routes collapse or suffer major damage. Having multiple impassable bridges within a given highway corridor poses a big problem for the bridge building industry as well. After the earthquake, many bridge sites will be very difficult to access or will not be accessible at all to normal construction equipment. Restricted access will prevent or delay the repair or reconstruction of many bridges. The process of rebuilding our bridges and thus rebuilding the state's transportation network will follow the corridor approach, sequentially opening longer sections of connected highways identified as priority lifeline routes.

Repairing or replacing many damaged bridges along Interstate 5 after an earthquake will take varying amounts of time depending on which structures are damaged and the type of damage. While the access to bridge sites will likely be more direct along Interstate 5 (compared to other routes), the design and construction process will not be an easy task due to demands on resources and the need to respond to widespread damage. Mainline bridges, especially those over large rivers, will be more problematic than the roadway overpasses. The size of the majority of bridges crossing waterways along I-5 is significant (see Figure 4). The design effort for one of them will take several months for a permanent crossing. Additionally, construction of bridges of this size has typically taken multiple years to complete. That time could be reduced under emergency conditions, especially if traffic is diverted and the contractor has unlimited use of the site.

Normally, the replacement structure will be larger and designed to higher standards than the one it replaces. This has usually been achieved by using precast elements and heavy weight machinery. It is unknown how well precast yards will be able to handle the large demand for their products or whether there will be enough excavators and cranes to cover the statewide need. Temporary bridges owned by the state and those possibly available for loan or purchase will not span the distances needed for crossing our larger rivers. Fortunately, many of the larger mainline bridges on I-5 have received at least a Phase 1 seismic retrofit. In order to have the desired level of resiliency, however, they will need to be strengthened with a Phase 2 seismic retrofit.

Reconstruction of smaller bridges will also not be immediate, even under emergency procedures, especially around the larger metropolitan areas like Portland. Many of these “simple” structures cross local streets, and the presence of traffic on these streets can significantly delay reconstruction.

Overpasses on I-5 have not been retrofitted to any level and are therefore likely not only to be damaged beyond use, but to block access along the mainline. Emergency removal of debris may restore temporary access along the mainline, but access to intersecting routes will take much longer. While it is known that most of these medium size bridges across the state’s main routes are seismically vulnerable, planning to retrofit them is unrealistic given current economic constraints. Even though many will be impassable after the earthquake, we believe they will have minimal impact on the traffic on these routes themselves. On the other hand, reconstruction of these overpasses will have a significant impact on the main routes. There is not an easy way to build a bridge over a busy highway and inside a busy metropolitan area. Most of these bridges are multi-span structures and usually contain an interior bent between traffic lanes. Repairing or rebuilding these bridges will be very difficult without significant traffic disruption (see Figure 5).

The situation is even worse for replacing damaged bridges on routes connecting I-5 to coastal cities. While the design process for many of these bridges can start at the same time (assuming enough structural engineers are available), constructing them will depend on accessibility. Access to bridge sites will be very difficult and almost impossible for most areas, because there are few detours available. In areas where each bridge must be dealt with consecutively, the time for complete corridor restoration would be multiplied.

Rebuilding U.S. 101 along the coast after a Cascadia subduction zone earthquake will most likely require a national mobilization. There will not be sufficient local workforce or contractors available, and local suppliers may not be operational for a period of time after a catastrophic event. Access to a few bridge sites may be accomplished from waterways, but the majority of structures along this corridor will be hard to reach. The timeline to rebuild the entire U.S. 101 route after a Cascadia subduction zone earthquake will depend on the magnitude of the overall damage to roadway.

Design Criteria

ODOT bridges are currently designed to at least meet the national bridge design standards established by AASHTO. This includes all standards related to seismic bridge design. Under these code requirements, bridges are primarily designed to meet a life-safety performance standard, which means the bridge has a very low probability of collapse when subjected to earthquakes that are most likely to occur over the life of the structure.

The level of ground shaking used in the design is associated with earthquakes that on average could occur approximately every 1000 years. Even under the high design level of shaking, the bridge could likely suffer some amount of structural damage which would require repair. Like any natural event, an even larger earthquake could occur, resulting in larger movements than bridges are designed for. Bridge damage could be extensive enough to require complete replacement. This design philosophy is used because it would be too expensive to design bridges for the highest possible, but very rare, earthquake. ODOT seismic bridge design also includes a check for the lower level earthquake event that occurs more frequently, on average approximately every 500 years. Under this lower level of shaking, the bridge is designed to withstand earthquake loads with minimal damage, such that the bridge is assumed to be opened to emergency vehicles within 72 hours after an event. The inclusion of this additional lower level ("serviceability") design is above the standard performance requirements prescribed by the AASHTO code. The intent is to design for the CSZ event, which has a return period of 300-500 years and would cause catastrophic impacts, such as loss of life and severe injuries to citizens and losses to the economy for 8 – 10 years after such as event.

ODOT requires all new bridges to be designed for two-level performance criteria as follows:

(1) 1000-year "Life Safety" Criteria: Design all bridges for a 1000-year return period earthquake (7% probability of exceedance in 75 years) under "Life Safety" criteria. To satisfy the "Life Safety" criteria, use Response Modification Factors from LRFD Table 3.10.7.1-1 using an importance category of "other".

(2) 500-year "Operational" Criteria: In addition to the 1000-year "Life Safety" criteria, design all bridges to remain "Operational" after a 500-year return period event (14 percent probability of exceedance in 75 years). To satisfy the "Operational" criteria, use Response Modification Factors from LRFD Table 3.10.7.1-1 using an importance category of "essential". When requested in writing by a local agency, the "Operational" criteria for local bridges may be waived.

Long Span Bridges: LRFD 3.10.1 states that the seismic provisions of that manual are applicable for bridges with spans not exceeding 500 ft. For seismic design of bridges with spans exceeding 500 feet, consult with the Seismic Design Standards & Practice Engineer to discuss whether special analysis and design procedures are warranted.

Example Long Span Bridge Design Criteria

Safety Evaluation – Structural Components

The Safety Evaluation Earthquake (SEE) for structural evaluation corresponds to a mean return period of 2,500 years. In this earthquake, the bridge can be designed for "no collapse".

The basic approach is to design the bridge components to the following behavior levels under the safety evaluation earthquake:

Piers / Columns: Repairable Damage
Superstructure and Pier Caps: No Damage
Piles/Drilled Shafts: Minimal damage
Pile / Shaft Caps: Minimal damage
Bearings and Shear Keys: Repairable damage.
Expansion Joints: Significant damage.

4.2.2 Safety Evaluation – Geotechnical Considerations

The Safety Evaluation Earthquake (SEE), corresponding to a mean return period of 2500 years, shall be used to evaluate the following geotechnical issues:

- Performance of the structure foundations, considering both axial and lateral bearing resistance and deformation, considering the soil behavior before it liquefies and after it partially or fully liquefies, including effects of liquefaction induced settlement and down drag forces.
- Impact of lateral soil movement caused by seismic inertial forces, loss of shear strength due to liquefaction, or both, on the performance of the structure foundations.
- Impact of abutment fills on the structure performance.

If liquefiable soils are determined to be present, and it has been determined that they will in fact liquefy under the design earthquake for the site, the soil shall be stabilized to protect the bridge from collapse due to lateral deformation and down drag caused by the liquefaction, or the structure shall be designed to withstand the forces and moments resulting from the lateral and vertical movements caused by the liquefaction.

Functional Evaluation

The Functional Evaluation Earthquake (FEE) will correspond to an event with a mean return period of 500 years. For this event, the performance level will be "Minimal Damage", with no permanent offsets for all structural elements. For reinforced concrete elements, "Minimal damage" for the FEE event shall be based on the member strengths determined using the strain limitations given in Section s 1.4.52 and 1.4.3. Expansion joints can potentially see "repairable damage" as defined by the manufacturer's provided ratings.

"Minimal damage": Although minor inelastic response may occur, post-earthquake damage is limited to narrow cracking in concrete, no apparent permanent deformations, damage to expansion joints that can be temporarily bridged with steel plates and inconsequential yielding of secondary steel members. Permanent offsets should be avoided, except that permanent offsets of the foundations are permissible if the strain limits specified in Section 1.4 of this document are not exceeded. Permanent offsets of the foundations will be permitted only if they do not prevent immediate use of the bridge subsequent to the SEE event.

"Repairable damage": Inelastic response may occur, resulting in concrete cracking, reinforcement yield, minor spalling of cover concrete and minor yielding of structural steel. The extent of damage should be sufficiently limited such that the structure can be restored essentially to its pre-earthquake condition without replacement of reinforcement or replacement of structural members. Repair should not require closure.

"Significant damage": Although there is minimum risk of collapse, permanent offsets may occur in elements other than the foundations. Damage consisting of concrete cracking, reinforcement yielding, major spalling of concrete, and deformations in minor bridge components may require closure to repair. Partial or complete replacement of secondary elements may be required in some cases. Secondary elements are those which are not a part of the gravity load resisting system.

Performance Assessment

The seismic performance of the bridge shall be assessed by comparing estimated structural demands on components with estimated structural capacities of those components. Capacities are calculated using parameters defined in following section.

Allowable Concrete Strain Values

Normal weight concrete
Allowable strains in normal weight concrete shall be:
Piers and Columns (Average extreme fiber strains in plastic hinge):
FEE event €cFEE = 0.005
SEE event €cSEE = 75% €cu

where €cu is the ultimate concrete strain according to the Mander's equations. (Priestley, 1996).

Piles, Drilled Shaft and Pile/Shaft Caps (Maximum extreme fiber strains in potential plastic hinge):
FEE event €cFEE = 0.005
SEE event €cSEE = 0.01

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4.5.2 Allowable Reinforcement Strain Values

Table 4 5 Allowable strains in reinforcing steel shall be:

Reinforcement	€sFEE	€sSEE	€su	€sh
Piers and Columns (Average extreme fiber strains in plastic hinge)				
Main Bars No. 9			0.12	0.0125
Main Bars No. 10			0.1209	0.0115
Main Bars No. 11	0.015	1/2 €su	0.096	0.0115
Main Bars No. 14			0.096	0.0075
Main Bars No. 18			0.096	0.0050
Piles, Drilled Shaft and Pile/Shaft Caps (Maximum extreme fiber strains in potential plastic hinge)				
Confinement Bars No. 3 – 9	0.015	0.02	0.12	0.0125
Main Bars No. 9 10 – 11			0.1209	0.0100115
Bars No. 11	0.09	0.0115		
Bars No. 14	0.09	0.0075		
Bars No. 18	0.09	0.0050		

Where:

€su = the steel strain at ultimate stress for Grade 60 (A706A706) reinforcement

€sh= Grade 50 Onset of strain hardening strains

Seismic Retrofit Criteria

Until now, ODOT has only been able to perform Phase I retrofitting only when other rehabilitation is needed on a specific bridge. Our current approach provides a moderate level of protection for isolated retrofitted bridges at a cost that is consistent with the current Bridge Program funding level. Since complete retrofit carries a much higher cost, this type of phased approach maximizes the benefit gained from each retrofit dollar spent.

The design philosophy for earthquake retrofit is similar to that of a new bridge. Where reasonable, retrofits are designed such that the bridge will be serviceable for a moderate earthquake and provide collapse prevention (life-safety) in a large earthquake. However, it is not always possible to retrofit a bridge to the desired level without complete replacement. Even under the best circumstances, a new bridge designed and built according to today’s standards would perform better than a retrofitted bridge.

ODOT has revised the FHWA Seismic Retrofit Criteria in the Seismic Retrofit Manual for bridge importance and service life categories as follows (changes shown in bold underlined type:

EARTHQUAKE GROUND MOTION	BRIDGE IMPORTANCE and SERVICE LIFE CATEGORY					
	Standard			**Essential**		
	ASL 1	**ASL 2**	**ASL 3**	**ASL 1**	**ASL 2**	**ASL 3**
Lower Level Ground Motion **14** percent probability of exceedance in 75 years; Return period is about **500** years.	PL0[4]	**PL2**	**PL2**	PL0[4]	**PL2**	PL3
Upper Level Ground Motion 7 percent probability of exceedance in 75 years; Return period is about 1,000 years.	PL0[4]	PL1	PL1	PL0[4]	PL1	PL2

Conclusions

1. The addition of a functional performance level design event will allow Oregon bridges to serve a critical rescue purpose and an economic recovery purpose after a major subduction zone event.

2. Bridge performance is controlled by limiting loading conditions and deflections that keep materials from being overstressed at the functional performance level event.

3. Significant savings in economic losses can be achieved by adopting a performance level that assures economic recovery can be achieved after a major earthquake event.

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