Designing for Cascadia Earthquakes: Oregon Resilience Buildings

Alice Wiewel\(^1\), Yumei Wang\(^2\) and Qisong “Kent” Yu\(^3\)

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The State of Oregon is designing two high-performance, low-energy buildings to withstand an expected magnitude 9 Cascadia earthquake and serve as centers of government operation following the disaster. Oregonians rely on state services that, if delayed or unavailable, will hinder the state’s ability to quickly recover from a natural disaster or emergency. In order to provide the continuity of critical government functions, DAS’s vision is to construct a resilient office building complex, Oregon Resilience Buildings (ORB) 1 & 2, with the explicit performance objective to be operational immediately after an earthquake or another potential disaster. In normal operational mode, the building will house one or more state agencies and may provide “swing space”. In the post-disaster mode, building tenants will be for those State agencies with a critical role in providing continuity of government. The resilient office building will need to operate at 150% normal occupancy 24-hours-a-day, seven-days-a-week, when in post-disaster operational mode. The office building will incorporate a seismically resistant base isolation system, an independent storm and sanitary sewage system, hook-up connections for emergency mobile communication units, as well as domestic potable water from an existing ground water wells. Occupants will use on-site emergency supplies stored in the basement. Energy strategies such as the use of laptops and increased range of indoor temperatures will limit demand. Incorporating these resilience elements into the ORB 1&2 design has been estimated to be within 2 percent of previous study’s estimated cost for a conventional Class A office building and parking garage.

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The State of Oregon is designing two high-performance, low-energy buildings to withstand an expected magnitude 9 Cascadia earthquake and serve as centers of government operation following the disaster. Oregonians rely on state services that, if delayed or unavailable, will hinder the state’s ability to quickly recover from a natural disaster or emergency. In order to provide the continuity of critical government functions, DAS’s vision is to construct a resilient office building complex, Oregon Resilience Buildings (ORB) 1 & 2, with the explicit performance objective to be operational immediately after an earthquake or another potential disaster. In normal operational mode, the building will house one or more state agencies and may provide “swing space”. In the post-disaster mode, building tenants will be for those State agencies with a critical role in providing continuity of government. The resilient office building will need to operate at 150% normal occupancy 24-hours-a-day, seven-days-a-week, when in post-disaster operational mode. The office building will incorporate a seismically resistant base isolation system, an independent storm and sanitary sewage system, hook-up connections for emergency mobile communication units, as well as domestic potable water from an existing ground water wells. Occupants will use on-site emergency supplies stored in the basement. Energy strategies such as the use of laptops and increased range of indoor temperatures will limit demand. Incorporating these resilience elements into the ORB 1&2 design has been estimated to be within 2 percent of previous study’s estimated cost for a conventional Class A office building and parking garage.

Introduction

Disasters including the magnitude 9.0 Great East Japan Earthquake and Tsunami in 2011, Hurricane Sandy in 2012, and Hurricane Harvey in 2017 have underscored the devastating impacts that natural disasters can inflict at a local, regional, state, and multi-state level. In 2013, the Oregon Seismic Safety Policy Advisory Commission submitted a report to the 77th Legislative Assembly titled the Oregon Resilience Plan: Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami (ORP). The ORP discusses risks faced by Oregon citizens from an impending Cascadia Subduction Zone earthquake and accompanying tsunami, and identifies gaps in the state of Oregon need to fill for resilient infrastructure [1].

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The ORP outlines steps that can be taken over the next 50 years to bring the state closer to resilient performance through a systematic program of vulnerability assessments, capital investments in public infrastructure, new incentives to engage the private sector, and policy changes that reflect current understanding of the Cascadia threat [1]. ORP serves as the State’s roadmap on building resilience for future Cascadia earthquakes, addressing proactive actions that the State of Oregon’s Department of Administrative Services (DAS) is taking in response to ORP recommendations. These include planning for continuity of state government and assisting with recovery and reconstruction of statewide communities from a future Cascadia earthquake.

Like the federal General Services Administration (GSA), DAS is the primary provider of office space for a large proportion of the state’s approximately 40,000 employees. If a Cascadia earthquake were to occur today, none of the DAS state-owned buildings in Western Oregon would likely remain operational to provide government services. It is expected that use of DAS buildings would be impaired by a combination of damage to building structural components (steel frame, concrete shear walls, etc.), nonstructural components (cladding, sprinkler system, elevators, etc.), and the local utility systems that supply the buildings (electricity, water, wastewater, etc.). It could easily take 30 days or significantly longer to make sufficient repairs to reoccupy damaged buildings (if repair is even practical), and reestablish utility services. In many cases, it could be far longer—potentially over 3 years [1].

State Governance and Statewide Recovery

Oregonians rely on many services provided by the State government. If these services are delayed or unavailable, the ability of the State to recover quickly from a disaster and rebuild its communities will be in jeopardy. In order to provide for continuity of critical government functions and recover and rebuild Oregon, DAS will need to design and construct new buildings that exceed the requirements set forth in the state building codes.

DAS is planning to build Oregon Resilience Buildings (ORB) 1 & 2, which will be two high-performance, low-energy buildings capable of withstanding an expected magnitude 9 Cascadia earthquake. ORB 1&2 will serve two primary purposes: 1) provide the State of Oregon’s continuity of governance after an expected Cascadia earthquake, and 2) build needed capacity that accelerates execution of deferred maintenance and modernization projects by providing the option for temporary, or swing, office space. Currently, no existing state-owned office buildings are designed and constructed to be operational after a Cascadia disaster, and the State has a deficiency of office and parking space (www.oregon.gov/das/Financial/Facplan).

The ORB 1&2 building complex will be located on two surface parking lots, referred to as the yellow lot and the red lot, on the State Capitol Mall in Salem, Oregon (Figure 1: Capitol Mall Map). ORB 1&2 will serve as a state government office building and parking structure under normal conditions and as the center of government operation following a Cascadia disaster. In normal operational mode, the ORB 1 will house one or more State agencies. Among other uses, this resilient office building could serve as swing space, for example, either for the executive branch or for Legislature if the State Capitol were to be being seismically retrofitted.
During a Cascadia disaster, both buildings would function in tandem “off the grid” with the parking structure serving as an energy plant providing electricity via solar panels, generators, and batteries. Within one hour after the earthquake, the buildings will operate 24 hours a day, seven days a week (24/7) with existing occupants removed and replaced with high priority state government users from the Executive Branch, and possibly the Legislative and Judicial Branches. In post-disaster operational mode, the normal building tenants will be temporarily displaced in order to convert the building into workspace for those State agencies that have a critical role in providing continuity of government.

The purpose of ORB 1&2 differs from the state Emergency Coordination Center (ECC) in that the ECC supports Oregon communities with response and short-term recovery. In contrast, ORB 1&2’s purpose is to ensure continuity of government operations and the State’s long term recovery and rebuilding. ORB 1&2 can be integrated into the recovery and rebuilding phases of the Triple 3 Resilience Target, a proposed resilience timeframe for lifeline infrastructure systems to address the response and recovery from a Cascadia earthquake [2]. The Triple 3 Resilience Target proposes that during the response phase, emergency services are to be restored within three days, where peoples’ survival needs along with basic safety and security needs must be met. Within three weeks during the recovery phase, pre-disaster service levels are to be restored to fully address peoples’ needs including safety and security, social and economic stability, health and well-being. Swift recovery and visible progress must be made to prevent the loss of social networks and community relationships. Swift recovery and visible progress must be made to prevent the loss of social networks and community relationships. All new and reconstructed infrastructure must be raised to higher standards of resilience against future hazards, and to promote peoples’ growth and achievement. Response, recovery, and rebuilding must account for individual and community needs to survive and thrive after a Cascadia disaster [2].

**Feasibility Study on ORB 1&2 Performance Objectives**

In 2016, DAS contracted with SEFT Consulting Group to conduct a study to determine the performance requirements, suitability and relative cost of a resilient office building on the site of the Yellow Lot and Red Lot parking areas that could operate immediately after a Cascadia earthquake (Figure 1). SEFT led a team consisting of a structural engineer, mechanical engineer and a general contractor focused on both post-disaster performance and streamlining costs.

The basis for the proposed office building (ORB 1) and parking structure (ORB 2) was a 2008 feasibility study conducted by Hennebery Eddy Architects. Consistent with typical design practice, the conventional office building considered in the Hennebery Eddy Architects study was based on a building that designed to minimize serious injury to building occupants and bystanders during a major earthquake (Life Safety performance objective). There is, however, no expectation that such a code-minimum-designed building would be occupiable after a major earthquake. This standard code-minimum design approach is inadequate when viewed from a continuity of operations and a disaster resilience perspective.
In order to achieve resilient design goals, a building must be able to meet the functional needs of the users in a post-disaster operational mode. This means that the building structure must be safe and usable post-disaster, including the effects of any aftershocks. Also, this involves providing adequate thermal temperature regulation, lighting, and electrical power by alternative strategies than those used in normal operational mode. Designing a building to be sustainable—particularly using a passive or high-performance/low-energy design approach—is beneficial for both normal and post-disaster operational modes. For instance, use of “daylighting” not only reduces day-to-day energy demands, but also provides an added benefit of reducing energy demands in post-disaster operational mode, when the building is expected to operate virtually self-sufficient, or “off-the-grid”. However, there are two exceptions to this: first, the building may still rely on regular resupply of diesel fuel for the emergency generator every 96 hours if the photovoltaic (PV) system is not functioning and critical building functions are being powered by the generator alone; and, second, it is anticipated that building occupants will rely on external portable resources to provide telecommunications infrastructure (cell on wheels [COW] or cell on light truck [COLT]). Table 1 compares each ORB 1&2 operational performance objective with a typical office building at a life safety performance objective that meets state building code requirements.
Table 1. ORB 1&2 Building Performance Objective Summary

<table>
<thead>
<tr>
<th>Building Performance Objective</th>
<th>Overall Damage</th>
<th>Structural Performance Objective</th>
<th>Nonstructural Performance Objective</th>
<th>Special Seismic Certification of Equipment</th>
<th>Backup Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Very Light</td>
<td>Immediate Occupancy</td>
<td>Operational</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Immediate Occupancy</td>
<td>Light</td>
<td>Immediate Occupancy</td>
<td>Position Retention</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Life Safety&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Moderate</td>
<td>Life Safety</td>
<td>Position Retention</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Collapse Prevention</td>
<td>Severe</td>
<td>Collapse Prevention</td>
<td>Not Considered</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

1 ORB 1&2 performance goal
2 Typical code-minimum office building performance

Oregon Resilience Building 1 (ORB 1)

The Oregon Resilience Building 1 will be five stories with a total area of 288,000 sq ft. Office space will be provided for approximately 1,100 employees from one or more state agencies, with roughly 800 people expected during typical operation due to diversity in schedules.

The building will have an additional 57,000 sq ft of basement space to house mechanical equipment and for storage, totaling approximately 345,000 sq ft. A central courtyard will provide landscaped park-like space for building occupants, and potentially the general public during normal operation (9am-5pm, five days per week), the office building will operate like any conventional office building, though it will use highly efficient, sustainable systems that allow easy transition for continuity-of-government use by state agencies in the event of a major disaster. In post-disaster operational mode, the number of employees in the building at any one time may increase to approximately 1,600. ORB 1 will incorporate several low-energy design features and backup utilities to maintain operation “off the-grid”, including a solar array covering 60% of the roof area, battery storage and an emergency generator. It will also incorporate a seismically resistant base isolation system, an independent waste water system, hook-up connections for emergency mobile communication units as well as access to water from an existing ground water well. Table 2 summarizes the performance expectations during a normal mode of operation and a post-disaster mode of operation of structural, nonstructural, HVAC, energy, water, wastewater and telecommunications systems.
<table>
<thead>
<tr>
<th>System</th>
<th>Performance Expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Mode</td>
</tr>
<tr>
<td>Structural</td>
<td>-Not applicable</td>
</tr>
<tr>
<td>Nonstructural</td>
<td>-Not applicable</td>
</tr>
<tr>
<td>HVAC</td>
<td>-Temperature range, 70-75°F -Ventilation air with heat recovery -Passive natural ventilation -Supplemental heating and cooling with air-source heat pump</td>
</tr>
<tr>
<td>Energy</td>
<td>-Solar array on ORB 1 building and ORB 2 parking structure with battery storage (net-zero energy) -Commercial electric utility backup</td>
</tr>
<tr>
<td>Water</td>
<td>-Municipal potable water supply -Municipal fire water supply -Hot water available</td>
</tr>
<tr>
<td>Wastewater</td>
<td>-Onsite constructed wetlands -Effluent to municipal wastewater system</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>-Typical provider</td>
</tr>
</tbody>
</table>

To reduce its electrical energy consumption under normal operation, ORB 1 will utilize passive heating and cooling strategies, plus control elements like daylighting. Grid demand will be further reduced by onsite solar panels and battery storage. For the electrical system, the key difference between normal and post-disaster operational modes will be the reduction of electrical loads to only the most critical services. To achieve this load shedding, the building distribution system will be structured into three distinct branches—normal, critical and life safety:

- Normal branch will serve all non-critical loads present during normal operation;
- Critical branch will operate alongside the normal branch during normal operation with no perceivable difference between the loads served by the normal and critical branches.

During a post-disaster period, the critical branch will remain operational while the normal
branch will be disconnected. The critical branch will support: 50% of interior lighting, 33% of general purpose plug loads, and less than 5% of mechanical loads to supply ventilation fans. Specialty equipment will be limited to a reduced number of coffee makers and printers (no more than 3 of each); and

- Life safety branch will include only egress lighting and fire pump equipment (if needed).

A local micro-grid with full redundancy will be created with both ORB 1 and 2 using a diesel generator, a 96-hour fuel storage tank, two rooftop solar arrays, and a battery system. A controls system will optimize when and how much each system will be used. Preference would be given to the renewable sources of solar and battery to minimize the use of diesel fuel in the event that it cannot be replenished every 96 hours. If fuel can be regularly replenished and there are no maintenance issues, the building will be able to run in critical mode indefinitely. If fuel became unavailable, it is anticipated that ORB 1’s batteries and solar array could fully support the critical loads of the building without the generator for all but 40 days per year. In post-disaster operational mode, occupants should expect these conditions:

- A broad range of thermal comfort (wear sweaters if cold or light clothing if hot);
- Occupants may be asked to open and close windows for ventilation when outside temperatures are appropriate (may be uncomfortable to some);
- Potable water to be supplied from onsite wells with reverse osmosis filtering;
- No hot water will be provided;
- Lighting levels will be reduced to conserve power;
- Limited outlets will be supplied with backup power, others will not have power;
- Using laptop computers without external monitors;
- Sharing plugs for charging of battery operated devices;
- Limited copiers/office equipment, less than one per floor will be operational;
- Limited coffee stations, less than one per floor will be operational;
- Limited use of elevator to conserve power;
- Limited telecommunications bandwidth; and
- Occupants will use on-site emergency supplies stored in the basement.

The ORB 1 energy features, and the associated initial construction cost difference compared to conventional construction, are minimal. This does not include the operational savings that will result from reduced energy usage and lower mechanical system maintenance costs for the high-performance/low-energy features. Energy cost savings from the HVAC system alone could equal approximately $155,000 per year given 2016 energy costs of $0.08/kWh.

ORB 1 will be designed to be operational after a design-level earthquake (an event with an approximate 500-year return period). To achieve this operational building performance will require the following:

- Structural and nonstructural components of the building must be properly designed;
- Mechanical and electrical equipment required post-disaster must be seismically certified to handle the anticipated level of earthquake shaking; and
- The design must consider backup utilities for those potentially damaged and/or unavailable after the earthquake (electricity, water, wastewater, etc.).
Oregon Resilience Building 2 (ORB 2)

ORB 2, located in the Salem Capitol Mall on the Red Lot (Figure 1), will be designed as a 6-story, approximately 1,577 stall parking garage with a combined energy plant that will provide power to ORB 1 in both normal and post-disaster modes, with the latter functioning “off-the-grid”. ORB 2 will also feature the following:

- Solar Array (60% of roof area), batteries, generator, and 96 hours of fuel
- Well water supply for ORB 1 after disaster
- Designed to mitigate flood risk and other natural hazards

The parking garage will be designed for immediate occupancy structural performance for the expected earthquake hazard level (Table 3). The rooftop solar array and emergency generator located on the second level and their associated components will be designed for operational nonstructural performance for the expected earthquake hazard level. Designing to these high performance levels will help ensure that the generator and solar array can provide power to operate the ORB 1 in disaster mode for a relatively minor cost premium. The nonstructural performance objective for other nonstructural components is Position Retention performance (similar to a typical design). Any ground level retail space will not be provided with backup utilities and will likely not be functional after a major earthquake.

<table>
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<td></td>
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<td>-Not applicable</td>
</tr>
<tr>
<td>Nonstructural</td>
<td>-Not applicable</td>
</tr>
</tbody>
</table>
| Energy       | -Solar array supplies electricity to ORB 1 office building and the grid  
-Emergency generator undergoes routine testing under load | -Solar array supplies electricity to ORB 1 office building  
-Emergency generator supplies electricity to supplement solar array and battery storage |

Each parking level has a plan area of approximately 93,150 square feet. The proposed parking garage would incorporate spiral entrance and exit ramps. The main parking structure will use steel buckling restrained-braced frames as the lateral force resisting system and the ramps will use circular concrete shear walls that form the center core of the ramps. The historical performance of conventional parking garages in past earthquakes has been less than reliable. Use of the spiral ramps and flat parking levels will help to ensure that the structural performance of the parking structure does not impact the functionality of the rooftop solar array or emergency generator located on the second level.
ORB 1&2 Benefits to Oregonians

Government expenditures need to be transparent, cost-effective and benefit the public. ORB 1&2 are being designed to maximize flexibility for all users while maintaining characteristics needed to achieve seismic safety and resilience. ORB 1 will provide much needed office space, and allow for maximum flexibility to repurpose tenant space to support organizational changes. The energy efficient design will reduce operations and maintenance costs during its life cycle. In its normal use mode, ORB 1 will implement sustainability/net-zero concepts to advance energy savings for current and future use. In its disaster mode, ORB 1&2 will provide State of Oregon’s continuity of government after an expected magnitude 9 Cascadia earthquake by “operating immediately” within one hour of an initial event and with each subsequent aftershock.

The ORB 1&2, which will set a new standard for resilient design. They will be certified with a Platinum Rating under the U.S. Resiliency Council Building (USRCB) Rating System. A Platinum Rating is current best practice for the highest level design performance for life safety, the lowest cost of building damage repair, and the quickest recovery times. The system includes evaluation of the building’s structure, its mechanical, electrical and plumbing systems, and architectural elements such as cladding, windows, partitions, and ceilings. In addition, the Buildings will be designed to meet or exceed the Leadership for Energy and Environmental Design (LEED) ratings system for Gold certification, and strive to meet LEED v. 4.0 Platinum certification. Incorporating the array of resilience elements into the ORB 1&2 design is estimated to be within 2 percent of conventional building costs.

These buildings will serve as a demonstration and education facility on resilient design. They will highlight Oregon’s resilience identity and partnership prowess. For example, ORB 1 may include eight large rooms that could be used for legislative hearings or other large group meetings, to assist in the recovery work with state government, business and community partners, as well as the Federal government. Furthermore, they will demonstrate Oregon’s technology innovations and expertise, such as a robust emergency power system and mass timber technological innovations.

Conclusion: Next Steps

DAS is currently in the design and planning stage for ORB 1&2. When constructed, ORB 1&2 will be “operable”—that is, self-sufficient and able to function immediately after Cascadia earthquake disaster. ORB 1&2 are designed to exceed minimum building code requirements, and able to function independently, or “off the grid”. ORB 1 will incorporate a special seismic design called “base isolation”, which act as shock absorbers to tolerate strong and prolonged earthquake shaking. It will have separate water and waste water systems, and connections for emergency mobile communication units. ORB 2 will support ORB 1 by providing electricity via solar panels, generators, and batteries as well as water from an existing ground water well when these utility services are down.

These two high performance buildings will allow the State of Oregon to have uninterrupted continuity-of-government operations that will promote post-disaster recovery activities that currently would not be possible. The resilient design, including the estimated costs of ORB 1&2, will serve as resilience educational tools for Oregon communities as well as to
Based on a 2016 feasibility study by SEFT Consulting Group, the estimated cost of ORB 1&2, compared with a 2008 feasibility study for a comparable Class A conventional state office building and parking garage, are within 2 percent of each other.

Mike Harryman, Oregon’s State Resilience Officer and part of the Governor’s Office, concurs that it is difficult and costly to retrofit older buildings to an operational performance objective. He states “building ORB 1 and 2 is the most significant way to advance resilience in state government in preparation for future disasters.” Harryman further emphasizes that “ORB 1 and 2 are the ‘golden ticket’, not just for continuity of government, but also to serve as a model for private sector and local government projects.”

Acknowledgements

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