Resilient Schools Through Leadership and Community Engagement

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Abstract

At the behest of the State Legislature, the Oregon Seismic Safety Policy Advisory Commission completed *The Oregon Resilience Plan* in February 2013. This plan outlines the risks and challenges facing Oregonians from the next Cascadia Subduction Zone mega-earthquake. The Plan provides very sobering predictions about the impacts from this earthquake, including durations for restoring the critical service lifelines of electricity, water, and highways ranging from months to a year or more in the Willamette Valley. *The Oregon Resilience Plan* is a call to action for all Oregonians, especially for those in public service.

Schools are different from most public facilities. Not only do they shelter thousands of our children, they are distributed in neighborhoods and walkable from homes nearby. With enlightened forward planning, they could be significant resources in helping their communities recover in the aftermath of the earthquake. To respond to *The Oregon Resilience Plan*, Beaverton School District has determined to build its seven new schools to exceed building code requirements in certain critical aspects to better support the community as resource centers and emergency shelters. These new schools will be safe, be available as a community emergency shelter within 72 hours, and be ready to re-open for education within 30 days following a significant earthquake.

Operating within a compressed timeframe and constrained budgets, the District launched a groundbreaking effort to engage community stakeholders and translate the concepts and recommendations of *The Oregon Resilience Plan* into design criteria for its first two schools. We hope that sharing our work with other school districts and design professionals will provide a beginning framework for creating a new standard for resilient school buildings.

Introduction

Hurricane Katrina in 2005, the Great East Japan Magnitude 9.0 Earthquake and Tsunami in 2011, and Hurricane Sandy in 2012 have illustrated the importance of improving the ability of our Nation's communities to prepare for, respond to, and recover from disasters. The implementation of risk reduction measures and pre-disaster planning will help communities recover more quickly and with less continuing vulnerability following a disaster (adapted from OSSPAC, 2013). Due to the unique opportunity presented by the construction of a new high school and a new middle school, the Beaverton School District (BSD) in the State of Oregon has chosen to complete a disaster resilience planning project, with the goal of identifying measures it can implement while these new schools are being designed and constructed that will lead to improved disaster resilience.

Beaverton School District

The BSD is located in Northwest Oregon, directly west of the City of Portland, and east of the City of Hillsboro (see Figure 1). It resides within Washington County, located at the northern end of the Willamette Valley. The District overlaps with the unincorporated Bethany area, the City of Beaverton, and a small portion of the City of Tigard. It is the third largest school district in Oregon, and has 33 elementary schools, 8 middle schools, 5 high schools, and 5 options schools, with an enrollment close to 40,000 students. The population within the school district is estimated to be around 265,000. Much of the population works for Nike, Intel, Genentech, and other numerous high-tech companies.

The District's enrollment has been growing steadily over the past several decades. According to District facilities planning information, four of the five comprehensive high schools are near or over 100% capacity. There are a number of elementary schools near or over capacity. Enrollment projections by Portland State University Population Center and the District have estimated that 5,400 additional students will enroll in Beaverton schools by 2025.

To address repairs, provide new capacity, modernize and renovate all facilities, improve safety and replace outdated learning technology, and equipment over a projected eight-year period, the Beaverton School District staff developed a $680 million school bond program and published it at the end of 2013, after approval from the Board. The bond program includes construction of a total of seven schools. Three new schools (a high school, a middle school, and an elementary school) will be dedicated to provide more capacity and relieve overcrowding. These new schools would provide capacity for an additional 4,000 students and reduce the use of portable classrooms. Also, the District plans to replace four outdated schools and construct new schools with improved learning environments and additional capacity. The bond program was presented and approved by District voters in the May 2014 election.

The District's planning and construction philosophy consists of: (1) making schools safe and secure, (2) promoting efficiency and sustainability features to ensure long term operational savings through focusing on life-cycle costs vs. first-cost of construction, and (3) integrating well with and enhancing the communities they reside in and providing opportunities for community partnerships. Because of the proactive efforts of local design professionals to implement *The Oregon Resilience Plan*, the District added consideration of incorporating community resilience features.

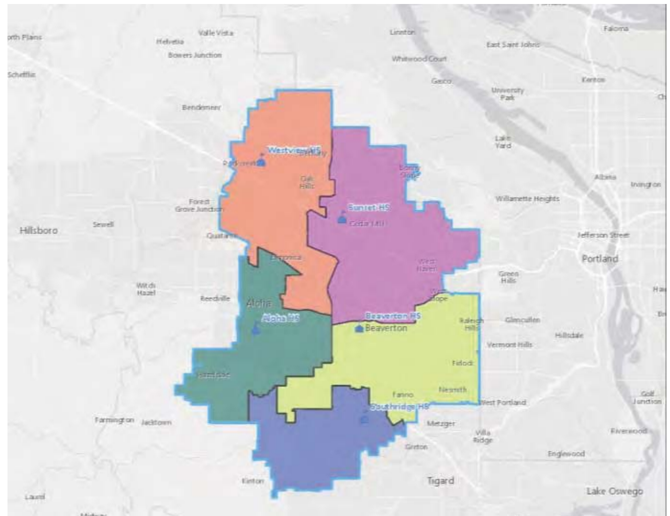
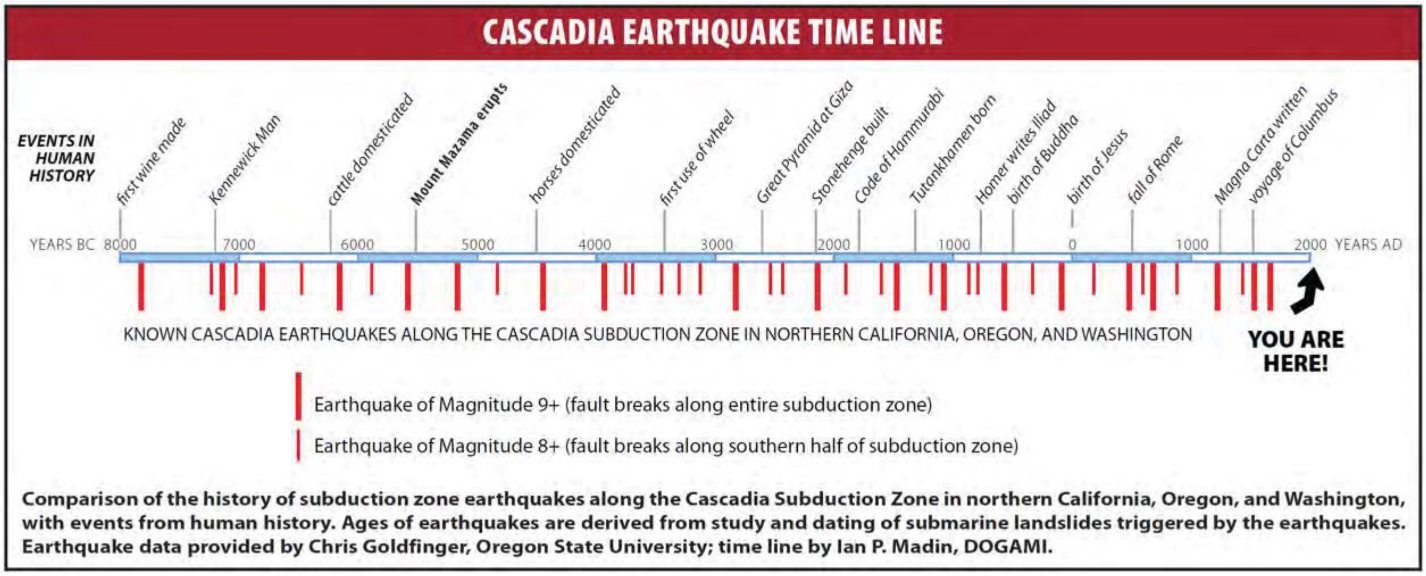


Figure 1 Beaverton School District Boundary

Oregon Seismic Hazard

On a regional scale, the Beaverton School District facilities lie at the northern end of the Willamette Valley, a north-south trending topographic feature separating the Coast Range to the west from the Cascade Mountains to the east. The valley lies approximately 100 miles inland from the surface expression of the Cascadia Subduction Zone. The Cascadia Subduction Zone (CSZ) is an active plate boundary along which the remnants of the Farallon Plate (the Gorda, Juan de Fuca, and Explorer plates) are being subducted beneath the western edge of the North American Continent. The CSZ resembles the subduction zone off the coast of Northern Japan, the source of the deadly 2011 Great East Japan Magnitude 9.0 Earthquake and Tsunami. Strong shaking from a CSZ event will likely last from 3 to 5 minutes, much longer than the 30-second strong shaking duration of a typical California earthquake.

Seismologists' understanding of the CSZ has steadily increased over the past 25 years. Research by the Oregon Department of Geology and Mineral Industries (DOGAMI), Oregon State University, and others has provided evidence of the timeline for historical CSZ events. The timeline of these 41 earthquakes over the past 10,000 years is provided in Figure 2, showing that past events have occurred at highly variable intervals, and can range in size and area of influence. Ruptures can be short, extending only along the Northern California and Southern Oregon Coast, or full, covering the entire length of the subduction zone from Northern California to British Columbia.



Comparison of the history of subduction zone earthquakes along the Cascadia Subduction Zone in northern California, Oregon, and Washington, with events from human history. Ages of earthquakes are derived from study and dating of submarine landslides triggered by the earthquakes. Earthquake data provided by Chris Goldfinger, Oregon State University; time line by Ian P. Madin, DOGAMI.

Figure 2 Cascadia Earthquake Timeline (DOGAMI, 2010)

Major events along the CSZ range from Magnitude 8 to Magnitude 9+. Based on recent research, there is about a 37% chance in the next 50 years of a Magnitude 8+ earthquake originating on the southern portion of the CSZ, and up to a 15% change in the next 50 years of a great earthquake affecting the entire Pacific Northwest. The scenario involving rupture of the northern Oregon portion of the CSZ would significantly impact BSD facilities and the neighboring communities.

The Oregon Resilience Plan

Communities rely on their built environment to support their social and economic institutions that meet the basic needs of individuals, households, and the community at large. The built environment includes buildings that support housings, schools, hospitals, grocery stores, etc. and infrastructure systems that provide transportation, energy, water, wastewater treatment, communication, and information systems. These infrastructure systems are also all dependent upon one another.

With much of the as-built environment constructed prior to the scientific community's understanding of the likelihood of a CSZ earthquake, some forward-thinking public entities and private utilities have begun to take voluntary steps to assess seismic vulnerabilities of their systems to the Cascadia event and have conducted limited rehabilitation. However, these systems were assessed and/or rehabilitated by their public operators and private owners without coordination and without understanding of their dependencies on other systems, let alone the consequence of their systems' failure on the overall pace of community recovery. These efforts have improved safety, but have done little to improve community resilience (i.e., improve the ability to recover rapidly).

To better understand the concept of community resilience, there has been growing interest in breaking down the "silo" mentality and taking a holistic look at comprehensive steps to mitigate the risk of the CSZ earthquake to our economy and to our businesses, homes, and communities. After the 2011 Great East Japan Earthquake and Tsunami, the Oregon State Legislature directed Oregon Seismic Safety Policy Advisory Commission (OSSPAC) to develop a holistic, comprehensive 50-year resilience plan to prepare the state to withstand and recover from a CSZ earthquake and tsunami, with the expectation that the resulting plan would improve Oregon's resilience to other earthquakes and natural hazards.

OSSPAC identified existing earthquake resilience planning from San Francisco, California by the San Francisco Planning and Urban Research Association (SPUR, 2009) as a good model to follow. SPUR developed a method that: (1) defines performance metrics for buildings and lifeline infrastructure based on what a community needs in the context of response and recovery stages, and (2) helps the community identify where the resilience gaps are. The SPUR method focuses on the speed of infrastructure recovery, which is critical for Oregon's economy as 50-60% of our state work forces are employed by small businesses which do not have sufficient financial resources to survive lengthy business disruption.

To apply the SPUR method at a state level, OSSPAC divided the state into four zones – Tsunami, Coastal, I-5/Valley, and Central/Eastern, to reflect the different levels of risk from the CSZ scenario and natural geographic boundaries defined by the Coastal Range and the Cascade Mountains. In addition, this zone-based planning will allow emergency managers to

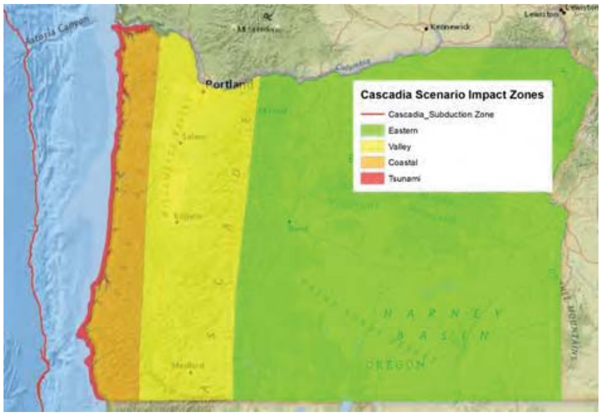


Figure 3 Cascadia Impact Zones (OSSPAC, 2013)

implement statewide response and recovery activities effectively and efficiently (see Figure 3).

OSSPAC assembled eight task groups, to review the likely impacts of a magnitude 9.0 CSZ earthquake and tsunami, and estimate the time required to restore functions to the group's particular sector of the community if the earthquake were to strike under present conditions. These task groups also defined acceptable timeframes to restore functions after a future Cascadia earthquake to fulfill expected resilient performance, and recommend changes to the practice and policies that will allow Oregon to reach the desired resilience targets over the next 50 years (OSSPAC, 2013). These task groups were (1) CSZ scenario, (2) business and workforce continuity, (3) coastal communities, (4) critical and essential buildings, (5) transportation, (6) energy, (7) information and communication, and (8) water and wastewater.

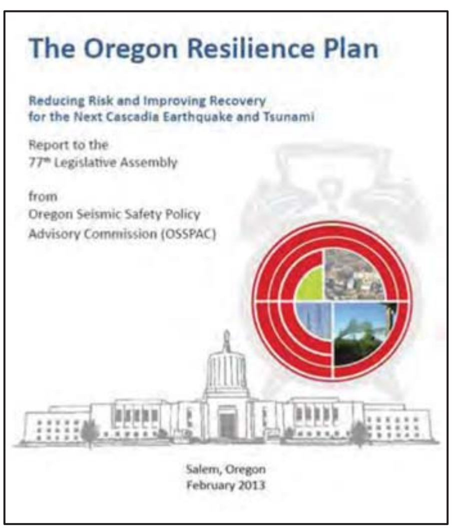


Figure 4 Cover Page of the Oregon Resilience Plan

After fourteen months of extensive planning, coordination, and meetings, OSSPAC delivered the report titled *The Oregon Resilience Plan: Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami* (see Figure 4 for the cover page of the report) to the Oregon's 77th Legislative Assembly on February 28th, 2013. *The Oregon Resilience Plan* (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 buildings and infrastructure systems, new incentives to engage the private sector, and policy changes that reflect current understanding of the Cascadia threat.

The business and workforce continuity task group estimated generally a period of two weeks to be the longest disruption of essential services (i.e., utilities, communications, etc.) that a business can withstand. Service disruptions lasting for one month or longer can be enough to force a business to close, relocate, or leave the state entirely. *The Oregon Resilience Plan* identified major gaps in the resilience capacity of critical services to the community. Within the Valley region, and the area of the BSD, the ORP found estimated recovery time for critical functions, as indicated in Table 1.

Additionally, the ORP identified the current estimated recovery times for critical building types, and compared that to the resilience restoration target (as shown in Table 2). The ORP established a goal of opening emergency shelters within 72 hours and re-opening schools within 30 days following the CSZ event. The plan estimates that Oregon's existing schools and emergency shelters may take up to 18 months to reopen in the Valley region. Such time differences illustrate the current resilience gaps that require investment in resilient buildings and infrastructure systems, and public policy enhancements over the next 50 years.

Table 1 Estimated Recovery for Critical Functions (OSSPAC, 2013)

Critical Service	Zone	Estimated Average Recovery Time
Electricity	Valley	1 to 3 months
Drinking Water	Valley	6 months to 1 year
Sewer	Valley	1 to 3+ years
Top Priority Highways	Valley	6 to 12 months

Table 2 Resilience Gap (OSSPAC, 2013)

Critical Building Category	Zone	Estimated Average Recovery Time	Resilience Target
Healthcare Facilities	Valley	18 months	Immediate
Police and Fire Stations	Valley	2 to 4 months	Immediate
Emergency Sheltering	Valley	18 months	72 hours
K-8	Valley	18 months	30 days
High Schools	Valley	18 months	30 days
Housing	Valley	3 days	72 hours

Since the release of the ORP, several state agencies and utility providers have started comprehensive seismic vulnerability assessments. Tualatin Valley Water District (TVWD), a major water provider in the Beaverton School District has started a $1 Billion Willamette Water Supply Project to address potential seismic vulnerabilities of its water source by bringing a redundant water source into its system. TVWD has also determined that it will be important to have water available at critical facilities and community distribution centers/points (at 20~30% capacity level) within 3 to 7 days.

The Oregon Resilience Plan Recommendations for Schools

Schools are different from most public facilities. Not only do they shelter thousands of our children, they are distributed in neighborhoods. If we plan, they can play a significant role as shelters and resource centers in the response and recovery phases after a major disaster event. As an elementary school is likely within walking distance for the community it is serving, they are well positioned to be community distribution centers or points for water and emergency relief supplies, and could be a hub for day-to-day community needs, such as information transfer, assistance with obtaining needed resources, or charging cell phones. Middle schools and high schools typically have larger facilities with gymnasiums, locker rooms, kitchen, cafeteria, athletic fields, etc. that make them ideally suited for use as emergency shelters. If an elementary school has a larger gymnasium and cafeteria space, they may also be considered for use as an emergency shelter.

The re-opening of schools is an important milestone after a major disaster, and symbolically marks the transition from the response to recovery phase. In accordance with the ORP, schools need to be safe, and should be re-opened preferably within 30 days to ensure that the workforce can go back to work and children can return to a normal routine. Re-opening within 30 days implies that only very minor structural damage is acceptable. If these schools are relatively undamaged after an earthquake, then they potentially can be used as emergency shelters for residents of the local community, with the 72-hour timeline. To achieve this functional level of school performance, the school buildings need to be “safe and usable” immediately after the event and served by the infrastructure system they depend on (including transportation, energy, water, wastewater, communication and information systems).

There is an opportunity to improve the capability of schools to serve as post-disaster centers during the design process for new facilities, or when scheduled for rehabilitation. With deliberate planning in the short-term and long-term, solutions can be found to build or retrofit schools to higher seismic design standards, and establish service backbones (consisting of key supply, treatment, transmission, distribution, and collection elements that, over the 50-year timeframe, have been upgraded, retrofitted or replaced to withstand a CSZ earthquake) to supply the school functioning as a resource center and emergency shelter with necessary services.

Opportunities, Challenges, and Considerations

Resilience Opportunity

In May 2014, two facility administrators of BSD learned about the ORP findings at the annual conference of the Professional Engineers of Oregon. Knowing that voters within the Beaverton School District might approve the $680 million bond program within a month or so, the facility administrators expressed strong interest in incorporating relevant recommendations of the ORP into their new school design and construction. Shortly after the bond program was approved, the facility administrators decided to engage the district’s other top executive leaders for facilities with an overview presentation of the finding and recommendations of *The Oregon Resilience Plan*.

The District’s facilities leadership very quickly came to a consensus and felt that, in addition to addressing their operational needs, the District had a special opportunity – perhaps even a responsibility to respond to *The Oregon Resilience Plan* and the challenge of a Cascadia Subduction Zone earthquake. Stepping up to this challenge, the District determined that they should build all of these seven new schools to exceed building code requirements in certain critical aspects in order to better support the community during an emergency. The District’s vision, determination, strong leadership, and support were critically important to help form a strong partnership between the District and its project managers, the design teams, and the resilience planning consultants (i.e., primary authors of this paper) and ensured the resilient design features would be implemented despite the schedule and budget constraints (discussed below).

Project Schedule and Budget Challenges

The District's bond program set a very tight project delivery schedule for the first two projects, a new high school at South Cooper Mountain and the new middle school at Timberland Development. In order to meet its fast-tracked project delivery schedule, the District had to move ahead with schematic design of the high school and middle school, while engaging its resilience planning consultants to explore means of implementing ORP recommendations for the design and construction of the two new schools. Furthermore, the middle school will be used as a swing space for three elementary schools and an interest-based option school in succession over the next four years following its completion, while each one of the schools is demolished and rebuilt on the existing property. The site work was scheduled to start right after the completion of Schematic Design phase of the Middle School. Therefore, any major change to the building configuration could negatively impact the project schedule for the middle school.

In addition, the original construction budget for all the schools were set based on standard code-level design and construction. Without knowing if there would be a financial partner to pay for some of the resilience features, it was necessary for the District to understand the additional design and construction cost associated with potential resilience features to be added as soon as possible. The District and the resilience planning consultants used this cost information to balance shelter needs, resilience features/options, and associated cost to maximize its available resource. Everything considered, there were a little over three months available for the resilience planning consultants to establish/finalize resilience design features so that the design team could reflect the associated cost in the Schematic Design budget estimate and implement them in the Design Development Phase of the two new schools. The BSD also decided to implement the findings and recommendations from these first two schools to all seven schools that were part of the approved bond program.

Resilience Planning Consideration #1

The typical community planning and infrastructure design process involves professionals working in relative isolation from other disciplines. Rarely are emergency managers involved in the infrastructure planning and design process, but are simply left to pick up the pieces in the aftermath of a disaster. The "silo" mentality has resulted in a disconnect between community planning, public works, and emergency planning. We need to integrate our emergency response planning into community planning and public works planning. Taking a holistic look will facilitate cooperation and promote taking comprehensive steps to mitigate the Cascadia earthquake risk to our economy and to our businesses, homes, and communities.

Resilience Planning Consideration #2

In Japan, schools are pre-designated as shelters and built to the highest seismic safety levels to shelter students, staff, and displaced community members after a major earthquake. In the United States, the approach is typically more ad-hoc. Local communities are responsible for providing emergency shelters and look to the American Red Cross (ARC) or other agencies for support in selection and staffing of shelters. If schools are deemed safe for re-occupation, and are not in session during a disaster or emergency situation, the schools may be used by the ARC as community emergency shelters. If schools are in session or are needed to shelter students and staff, sometimes the school district will determine that a portion of the school (such as the gymnasium) can be made available to the ARC to shelter community members. This system has worked for smaller disasters, but given the general low levels of seismic safety in Oregon's existing schools and other buildings, it will be problematic in the event of a Cascadia earthquake.

Beaverton School District Vision for Resilient Schools

The Beaverton School District vision has been to explore how to prepare the District and the surrounding communities for the eventual Cascadia earthquake. BSD recognizes the importance of school buildings to post-earthquake response and recovery, with schools typically functioning as emergency shelters after a disaster. Using the ORP as a guide, the BSD envisions constructing these two schools as a groundbreaking demonstration project to explore how schools can practically be used as shelters in the immediate aftermath of a Cascadia earthquake, and be able to be re-opened in a timely manner to aid recovery efforts, all within the budget constraints. In line with the ORP, BSD has set the goal of having schools function as an emergency shelter within 72 hours, and resuming education within 30 days.

BSD also recognizes that resilience efforts need to be both realistic and flexible. It would not be realistic to expect the school to immediately be a completely self-sufficient emergency shelter were the Cascadia earthquake to happen tomorrow. Many of the requirements for an emergency shelter are dependent upon continued lifeline support and service to the shelter. Not all desired infrastructure systems (water storage tank, wastewater storage tank, dual-fuel kitchen equipment, etc.) can be practically available at each BSD facility operating as an emergency shelter. Flexibility in the school design is important to have an adaptable building layout that can accommodate future resilience improvements, as resources become available. BSD also wanted to integrate these resilience goals into its existing sustainability goals of reduced energy consumption, natural ventilation, and natural daylighting.

Resilience Planning Approach

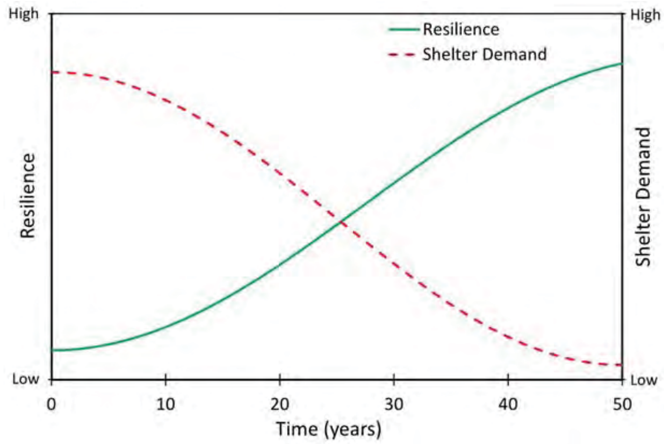
A resilience planning approach looks not just at the individual needs of a building or infrastructure system, but looks at dependencies that underlie these needs. Being able to use a building following an earthquake depends not just on the building performance being structurally adequate, but also the various systems in the building need to survive and be usable. But even this is not sufficient for the building to be usable. A community still needs to be able to travel to and from the site, as well as provide water, eliminate waste, and provide power and telecommunications. This means that it is necessary to look outside to the utility providers to understand how they provide these services to the site/building. The impacts of the damage to roads, bridges, fuel distribution, and other infrastructure systems also need to be taken into account.

The tendency in resilience studies is to take a "silo" mentality, assessing a singular infrastructure system and its performance, rather than assessing the inter-dependencies between systems. This resilience study for BSD needed to take into consideration all systems and their inter-dependencies.

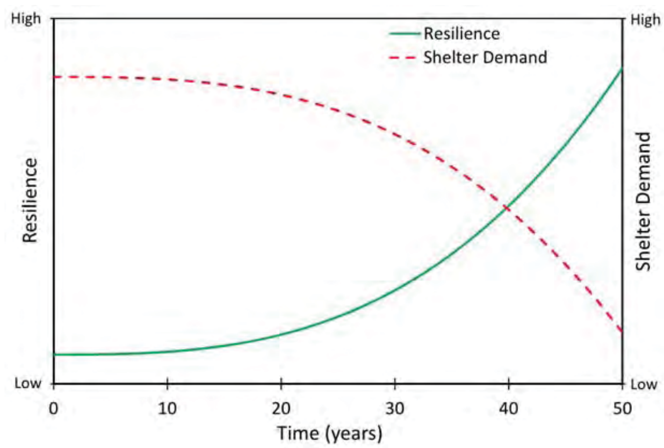
Knowledge of the Cascadia earthquake risk is relatively recent, compared to the era of construction for most infrastructure systems. As a result, most of the infrastructure supporting BSD was not designed with the CSZ earthquake in mind. This results in high vulnerabilities and low resilience levels throughout the Valley region. *The Oregon Resilience Plan* estimates that a significant portion of the population will have a need for emergency sheltering. With a steady 50-year time frame of resiliency investment, the demand for emergency shelters would be significantly reduced. BSD envisions these two schools as small but significant steps toward supporting the sheltering demands the ORP estimates in the as-built environment. Hopefully it will set a precedent for others.

Figure 5(a) qualitatively shows how the resilience level may be expected to gradually increase over time, with shelter demand gradually decreasing over time with a steady investment in resilience improvements (although the exact resilience and shelter demand versus time relationships cannot be accurately predicted). The intersection point of these two curves represents the point in time where shelter capacity can accommodate shelter demand after a major disaster. If resilience investment is delayed, Figure 5(b) qualitatively shows how the intersection point can be pushed further out into the future. Comparing these two shows a potentially significant difference in the timing to achieve resilience goals between immediate and delayed investment in resilience.

Due to the expected variability in community resilience and shelter demands over the next 50 years, this resilience planning effort for BSD has considered short-, intermediate-, and long-



(a) Steady Resilience Investment



(b) Delayed Resilience Investment

Figure 5 Resilience and Shelter Demand versus Time

term strategies for emergency shelter needs. In the short-term, the planning assumes that the school building will be safe to use as a shelter, but utility services and other necessities will need to be provided by emergency management agencies. In the long-term, after the 50-year resilience targets are achieved, the school building will be safe to use as a shelter and utility services are expected to be quickly restored to the shelter. This approach is intended to strike a balance between current and future emergency shelter needs of the community, and the limited economic resources available to invest in resilience improvements.

This resilience planning process has involved four key steps:

1. Working with BSD to confirm that the ORP performance goals and functional recovery timeline for schools is appropriate for them.
2. Coordinating with the county and surrounding cities to determine desirable emergency shelter needs.

3. Working with BSD to explore funding opportunities to cover the financial gap between a standard school design and the needs for a community emergency shelter.
4. Coordinating with the infrastructure systems to understand their resilience plan and how it ties to the school function as a shelter, and assist BSD to develop short and long term strategies.

Achieving BSD's resilience vision will require a community partnership among the county, cities, and infrastructure system providers to meet the needs for school buildings to be effectively used as resource centers and emergency shelters and to be quickly returned to normal operation as schools.

Community Engagement

Internal Engagement

The District's facilities executive leaders and the resilience planning team felt that, in order to ensure the design teams would seamlessly integrate resilience features into the design process that had already started, it was important to first engage internal stakeholders of the two new schools and make sure they understood and appreciated the District's vision in the context of ORP findings. Shortly after the resilience planning consultants were retained by the school district, the District's facilities leaders set up two meetings to introduce the ORP findings, the District's vision for resilient schools, the resilience consultants and their role and responsibilities to the District's project managers and the design teams of both schools. Through these successful meetings, the District's project teams were completely empowered and excited about the opportunity of being one of the earliest adopters to implement the ORP recommendations. At the same time, the resilience consultants were able to gain a better understanding of the project progress and project constraints of the two new schools. This helped forge a strong partnership between the District's project teams and the resilience planning consultants.

External Engagement

To discuss what would be necessary to achieve the goals of utilizing the new high school and new middle school as emergency shelters and to generally improve the disaster resilience of Beaverton schools, we felt that it would be critical to have a workshop, convened by the school district, and attended by external stakeholders. By bringing together all these players to the table, a common understanding could be established for the project between all parties, opening lines of communication that otherwise could not be established in a "silo" mentality to resilience planning.

A number of stakeholders were identified that are essential for creating a resilient school that can be used as a shelter. The stakeholders who will be directly involved in the operation of the shelters and relief efforts include:

1. Washington County Emergency Management Cooperative
2. City of Beaverton Emergency Management
3. American Red Cross
4. Tualatin Valley Fire & Rescue
5. Oregon Office of Emergency Management

The stakeholders providing utilities include:

6. City of Beaverton Water Division
7. Tualatin Valley Water District
8. Clean Water Services
9. Portland General Electric
10. NW Natural

Other stakeholders include:

11. Portland Metro Regional Solutions
12. Federal Emergency Management Agency
13. Legislative representatives within the District

We reached out to all of the stakeholders, first with emails, often followed by a face-to-face meeting, explaining the District's vision and goals and how each stakeholder could participate, contribute and make a difference together. This external community engagement process was time consuming, but necessary to get all parties on the same page, making the workshop more collaborative and productive. Through engaging external stakeholders, we were able to define the needs of the shelters, understand operation of the shelters in the post-disaster environment, and address utilities service needs for school buildings so that they can be effectively used as emergency shelters.

Resilience Workshop

After more than one and half months of outreach, planning, and coordination, a resilience workshop was held, with 33 attendees representing all internal and external key stakeholders, as described above. Through this workshop, the stakeholders were able to:

1. Learn current practice for emergency shelters, including capacity, duration, and level of human services.
2. Understand the needs of emergency shelters.
3. Formulate an integrated approach for building community resilience into school design.
4. Identify potential financial and technical partners to help cover the funding required for the resilience features.

Understanding Current Emergency Shelter Practice

Emergency shelters and the distribution of supplies and services are the responsibility of local government (i.e., Washington County and Cities of Beaverton and Tigard). They are supported in this mission by the American Red Cross (ARC), the Oregon Office of Emergency Management, and the Federal Emergency Management Agency. The current approach used by the ARC is to have a list of facilities pre-identified that may potentially be utilized as emergency shelters after a disaster. Buildings that are on the list have not necessarily been structurally evaluated to determine their expected performance after an earthquake, or any other disaster. The ARC relies on post-disaster building assessments to identify buildings from the list that are safe and suitable for use as shelters. When there is a lack of utility services, the ARC provides temporary workarounds so that the buildings can function as an emergency shelter.

The current process for selection of shelters, performed by the ARC, is an ad-hoc approach following a specific set of criteria. The criteria include:

1. Determination of whether the shelter is for the general population or for those with special needs.
2. Determination of number of occupants based on 40 square feet per person for sleeping capacity.
3. Determination of restroom capacity (1 fixture per 20 people for toilets and shower heads), including ADA accessibility.
4. Availability of spaces for health and mental health services.
5. Availability of spaces for children's activities, play and health needs.

When considering a school, the ARC needs to know what the business continuity plans are for resumption of education, and whether students will be staying at the school immediately following a disaster. The use of schools as shelters is voluntary and depends on the willingness of a school district to enter into an agreement with the ARC. The ARC does not envision using a school as a shelter until at least three days following a Cascadia earthquake, as it will take time to mobilize for shelter operations. In this context, the BSD wanted their schools to be available and selected after the post-disaster inspection process.

Defining Emergency Shelter Requirements

To serve as a shelter, a building needs to meet certain requirements established by the shelter provider. The essential requirement is that the building be safe and usable. One approach that may be used to provide a high probability that the building will be safe to occupy after a large earthquake, is to design the building as an essential facility (Risk Category IV) per the requirements of the currently adopted Oregon Structural Specialty Code (OSSC, 2014). Schools are currently required to meet Risk Category III seismic design standards. The school buildings are intended to achieve the life safety performance objective (i.e., ensuring building occupants will not suffer life-threating injuries), and will likely be damaged and may not be usable without potentially lengthy and costly repair. While making the full building meet Risk Category IV is preferred, one option is to only upgrade common spaces to meet this standard, and count on using only these areas for shelter use. This option would only be possible if the facility was divided into multiple buildings separated by seismic joints that permit relative movement between the individual buildings.

It is also important that non-structural components (building façade, partition walls, ceiling systems, storage cabinets, mechanical equipment, electrical equipment, plumbing equipment, etc.) be adequately braced or anchored. Components that are required for use of the school as an emergency shelter should satisfy Risk Category IV requirements. Equipment that is expected to be operational after an earthquake (emergency generator, automatic transfer switch, ventilation fans, etc.) should satisfy the special certification requirements of the current edition of ASCE 7 referenced by the OSSC.

Achieving a safe and usable performance level in these buildings requires identifying appropriate performance-based design criteria along with a proper design, detailed peer review and plan check during design, and comprehensive inspection during construction. The need for this multi-faceted process is illustrated in every major earthquake when it is observed that excessive damage is caused by a deficiency in one or more of these areas.

The ARC indicated that once the question of a having a safe and usable building is addressed, the minimum shelter requirements are very basic:

1. Thermal Comfort: A wide temperature range is acceptable.
2. Natural Ventilation: Being able to bring in fresh air is important.
3. Lighting: They can make do with natural lighting during the daytime and battery lanterns and flashlights if necessary in the evenings.

Other desirable shelter features include:

4. Emergency Power: A source of electricity for lighting, powering medical devices and recharging personal electronic devices.

5. Water Supply: A source of water for drinking and personal hygiene.
6. Wastewater: An operating wastewater system or holding tank if building restroom and shower facilities are being utilized.

Formulating an Integrated Approach

Based on the understanding of current emergency shelter practice and requirements, we formulated an integrated approach to address the two aspects: (1) design and construct the building such that it will experience little damage and people feel safe to use it, and (2) deliberately coordinate with service providers so that measures can be taken prior to an event to best support functionality requirements of the emergency shelter identified in the previous section.

In order to strike a balance between current and future emergency shelter needs of the community, increase of community resilience over time, and the limited economic resources currently available to invest in resilience improvements, we have decided to categorize support for human services into three areas: brought-in (by emergency service providers), design flexibility (so that the buildings remain adaptable to future available resource and technology change), and hard construction. Hard construction recommendations were incorporated into the design process for final implementation.

To expedite the shelter classification process, BSD considered pursuing a shelter pre-designation agreement with local governments and the ARC. This offers advantages for all parties, providing local emergency service agencies and the ARC with more certainty in planning for shelter needs following a disaster. Pre-designating schools as shelters also provides an impetus for infrastructure system providers to designate the schools as priority service areas following the disaster. If feasible, schools can be connected to the backbone systems that providers are planning in response to the threat of a Cascadia event, reducing the time the schools will be without service. It is the community that benefits the most, since they can count on a dedicated shelter for times of emergency.

Resilience Features – High School

The design of the High School at South Cooper Mountain includes 330,000 square feet in a three-story structure with a partial basement (see Figure 6). With an enrollment capacity of 2,200, the high school has Main Gym, Auxiliary Gym, Aerobics/Dance Room, Commons, Kitchen, 50 classrooms, and many offices. The overall building construction was approximately $98 million. The resilience planning for the high school occurred alongside the design effort. The objective of the resilience planning was to identify resilience measures that could be seamlessly integrated into the design of the building, without notably impacting the cost, schedule, or design of the structure. Through the collaborative resilience planning amongst all stakeholders, a number of resilience features were identified (SEFT, 2015).

Figure 6 High School Rendering

The site layout lends itself to resilient functionality in a post-earthquake environment. Site layout and access to the campus allows for resilience features without major impacts to the site plan (see Figure 7). Those resilience features include the following:

1. The site can provide services for on-site distribution of supplies and services for the initial 30 days and beyond, with minimal impact to school operation.
2. Two surface parking and circulation routes allow for flexibility in allowing one-way traffic for vehicles to enter the campus and obtain supplies and services.
3. The site has an area for portable classrooms. Routing electrical, water, and wastewater services to these portables would come at little cost and provide additional flexibility for relief operations.

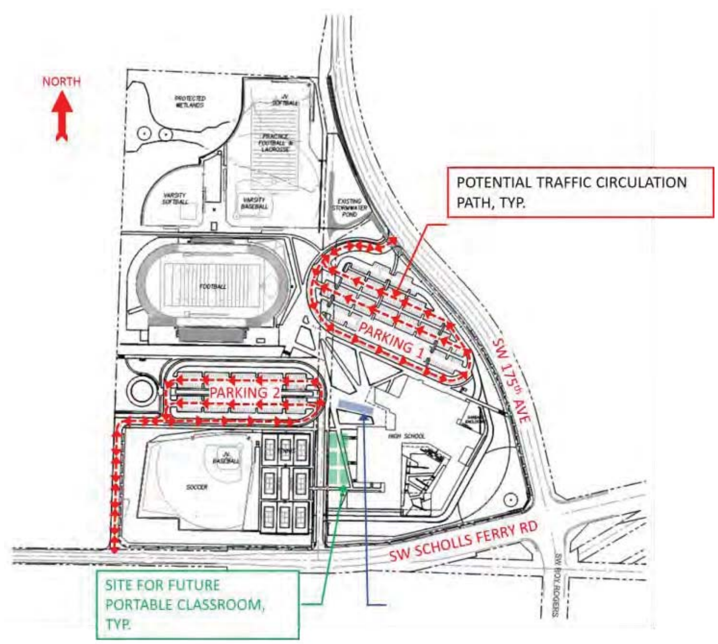


Figure 7 High School Site Layout

4. The site has parking areas and fields available for portable shelters and distribution of supplies as needed during the first 30 days (and for any extended shelter needs once the school has reopened).
5. The site has adequate play areas for children.

The District decided to fully utilize all the open spaces (such as Main Gym, Auxiliary Gym, and Commons) and large classrooms for shelter use. The approximate shelter sleeping capacity is estimated to be 860. In addition, a covered area has been pre-designated for pets. To meet ARC requirement of having a safe and usable building, design of the building allows for the following:

6. Design of the building as an essential facility (i.e. Risk Category IV) promotes a high probability that the building will be safe to occupy after a large earthquake (ASCE, 2010).
7. Design of nonstructural components required for operation as an emergency shelter to Risk Category IV and special certification requirements (ASCE, 2010 and OSSC, 2014).

As stated previously, the shelter requirements set minimum standards for heating, ventilation and cooling of the shelter. To accommodate sheltering in the High School, the following resilience features were recommended:

8. Current Oregon Energy Standards for insulation and windows mean that heat generated by people, lights and equipment will likely keep the space temperature at acceptable levels, assuming occupants will be dressed in jackets or wrapped in blankets.
9. Natural ventilation from doors and windows will provide ventilation and cooling during hot weather, to keep indoor temperature at or below the outside temperature. These were already part of BSD's sustainability design standards.
10. Exhaust fans will provide natural ventilation to common areas during hot weather, and will have to be added to the emergency power circuit.

Emergency power is a basic code requirement, but code only establishes a minimal level of service that provides power for egress lighting and for the operation of elevators (as required) for egress purposes. This power only needs to be provided for a short time frame. While emergency power is not a requirement for using the building as a shelter, there are a number of potential resilience features that would increase the school's usefulness as a shelter.

11. Provide the largest sized generator that the budget will allow.
12. Provide accommodations for hooking up additional emergency power generators.
13. Have exhaust fans, common-lighting, and hot plates in the kitchen be part of an emergency power circuit.
14. Provide for on-site use of PV power array with inverter.
15. Provide seismic bracing of electrical system components intended for emergency shelter use to satisfy Risk Category IV seismic bracing requirements, and satisfy special certification requirements for equipment expected to be operational after an earthquake.

The functionality of the school as a shelter is largely dependent upon the availability of utility services to the site. Resilience features include both short-term and long-term objectives, for both BSD and the utility providers to consider. Those resilience features are as follows:

16. Water service should be on the backbone system to receive water within 24 hours once the system is upgraded to its resilience goals.
17. Water piping installed by BSD between the utility main and school building should be specifically designed to consider seismic resilience.
18. BSD has selected to provide stub-outs at the building exterior for water supply via a portable water tank and pump. This supplies water until the backbone system is established.
19. Water supply is intended to supply key building areas, including the kitchen, locker rooms and showers, drinking fountains in common spaces, and restrooms serving the common spaces.
20. Provide seismic bracing of plumbing system components intended for emergency shelter use to satisfy Risk Category IV bracing requirements.
21. Wastewater service should be on the backbone system to provide services within 1-2 weeks once the system is upgraded to its resilience goals.
22. Wastewater piping installed by BSD between the utility main and school building should be specifically designed to consider seismic resilience.
23. Provide a seismic shutoff valve at the meter to reduce the potential fire hazard associated with natural gas leaks after an earthquake.
24. Have emergency management agencies coordinate a portable communication system that can be used on the school campus. Examples include cell on wheels (COWs) or cell on light trucks (COLTs).

Due to budget and design schedule limitations, not all the resilience features that were discussed as part of this project could be incorporated into the design, construction, and operation of the High School at South Cooper Mountain. The resilience features that have been adopted are summarized in Table 3. The intent behind these selected options was to build-in as much flexibility as possible in order to facilitate future resilience upgrades as funding becomes available. These selected resilience features will continue to be refined as the design evolves. The overall cost premium associated with these selected features is less than 1% of the building construction cost.

As additional funding becomes available or the cost of certain technology (PV inverters, battery storage, etc.) decreases, it may be possible to provide additional resilience features that will make using the school as an emergency shelter easier or enable additional services to be provided by the shelter.

In this project, it has been assumed that the post-disaster availability of certain infrastructure services (i.e., water, wastewater, liquid fuel for generator, etc.) will improve over time as Oregon undertakes a concerted effort to invest in resilience.

Table 3 Resilience Features at High School (SEFT, 2015)

Resilience Feature	Cost Estimate
Design building structure's lateral-force-resisting system for seismic Risk Category IV	$500,000
Provide 500 kW emergency generator with 96-hour run time fuel storage. Emergency generator, switch gear, ventilation fans, and other equipment that is expected to be operational after an earthquake should satisfy the special certification requirements of ASCE 7-10, which is referenced by the OSSC.	$330,000
Provide electrical service to power lighting and ventilation fans in common areas and gymnasium on emergency power; does not provide heated or conditioned air.	$8,000
Provide stub-outs at building exterior to allow use of portable water tank and associated pump to supply water to key building areas: kitchen, locker rooms & showers, drinking fountains in commons spaces and restrooms serving the dining commons.	$15,000
Provide two electrical outlets in kitchen on emergency power to allow hot plates for water boiling, etc.	$5,000
Provide natural gas seismic shutoff valve at meter.	---
Provide hardened water service line from BWD water line to building.	TBD
Provide hardened sanitary sewer service line from CWS sewer line to building	TBD
Provide seismic bracing / anchorage design of nonstructural components based on Risk Category III requirements except that those components required for use of the school as emergency shelter satisfy Risk Category IV requirements.	---
Approximate Total	**$900,000**

Resilience Features – Middle School

The design of the Middle School at the Timberland Development includes 165,000 square feet in a two-story structure. With an enrollment capacity of 1,100, the middle school has Main Gym, Auxiliary Gym, Multi-Purpose Room, Choir Room, Band Room, Commons, Kitchen, 40 classrooms, and many offices. The approximate shelter sleeping capacity is estimated to be 725. The overall building construction cost was approximately $43 million. The findings for the Middle School proved to be very similar to that of the High School. See Table 4 for a list of resilience features proposed for the Middle School. These selected resilience features will continue to be refined as the design evolves. The overall cost premium associated with these selected features is slightly over 1.5% of the building construction cost.

Table 4 Resilience Features at Middle School (SEFT, 2015)

Resilience Feature	Cost Estimate
Design building structure's lateral-force-resisting system for seismic Risk Category IV	$310,000
Provide 450 kW emergency generator with 96-hour run time fuel storage. Equipment that is expected to be operational after an earthquake should satisfy the special certification requirements of ASCE 7-10, which is referenced by the OSSC.	$400,000
Provide electrical service to power lighting and ventilation fans in common areas and gymnasium on emergency power; heating provided for certain areas, does not provide conditioned air.	---
Provide quick connect stub-outs at building exterior to allow use of portable water tank and associated pump to supply water to key building areas.	$20,000
Provide two electrical outlets in kitchen on emergency power to allow hot plates for water boiling, etc.	$5,000
Provide natural gas seismic shutoff valve.	---
Provide hardened water service line from TVWD water line to building.	TBD
Provide hardened sanitary sewer service line from CWS sewer line to building	TBD
Provide seismic bracing of nonstructural components based on Risk Category III requirements except that those components required for use of the school as emergency shelter satisfy Risk Category IV requirements.	---
Approximate Total	**$750,000**

Recommendations

The lessons learned from the resilience planning process for the High School at South Cooper Mountain and the Middle School at Timberland Development demonstrate that the availability and effectiveness of BSD school sites to serve as shelters can be achieved at an affordable price. The reasoning and logic behind the adoption of resilient design features should be tailored to each school, though the overarching concepts are, in general, directly applicable to the design and construction of other new schools and seismic retrofit of existing schools.

For the next new BSD schools, we recommend that the District carry out this style of site-specific planning that includes a stakeholder workshop during the scoping and siting phase of the projects. This will alert the design teams during the team selection phase of the District's intentions and desire to implement the most efficient solutions. Design team selection criteria should include consideration of the design team's resilience experience, desire to embrace resilient design, knowledge of overlaps between resilience and sustainable design, and the ability to implement fresh and improved resilient solutions.

For existing schools undergoing seismic rehabilitation and infrastructure modernization, we recommend a similar site-specific study and workshop that includes in the program a seismic retrofit to an appropriate performance level using the performance-based design and quality assurance features defined in ASCE 41-13: *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2013). We would recommend evaluating and retrofitting middle and high school buildings (and elementary schools, as appropriate) that may be added to the emergency shelter inventory to achieve the Immediate Occupancy performance objective for a BSE-1N level earthquake and the Life-Safety performance objective for a BSE-2N level earthquake. This is essentially equivalent to designing the retrofit to be consistent with the expected structural performance of new schools designed as Risk Category IV buildings (emergency shelters) per the Oregon Structural Specialty Code (OSSC, 2014).

Conclusions

Resilient design features implemented by the Beaverton School District for the new High School at South Cooper Mountain and the new Middle School at Timberland Development will result in safer schools that will be more easily used as shelters following a Cascadia earthquake (or any other disaster). These resilient design features, along with other proposed concepts, can be used as the basis for improved resilient design in other new school construction or renovations.

The proposed resilient design features bore out to add a 1% to slightly over 1.5% cost to the overall project budget, and substantially improve the sheltering capacity and functionality in post-earthquake response.

Bridging the resilience gap between where the State of Oregon is currently (based on *The Oregon Resilience Plan*) and where the state needs to be to be resilient will take continued resilience investment in infrastructure and active advocacy by design professionals. The Beaverton School District is an excellent example of integrating resilience into new design, in a prime example of a building that would likely be considered for emergency shelter.

Acknowledgements

We would first like to acknowledge the Beaverton School District for their courageous response to *The Oregon Resilience Plan* and the challenge of a Cascadia Subduction Zone earthquake. We have appreciated the participation and contributions by the design teams (led by Boora Architects for the new High School at South Cooper Mountain and Mahlum Architects for the new Middle School at Timberland Development) and the Beaverton School District project management teams for both schools (Richard L. Steinbrugge, David Etchart, Leslie Imes, Patrick O'Harrow, Scott Johnson, and Ryan Hendricks). The goal of making the high school and the middle school resilient was introduced to them after the start of the design process. Their participation and feedback allowed us to incorporate resilient design features that will make a difference.

As part of this project, the Beaverton School District convened a resilience workshop to bring together the various stakeholders to discuss what would be necessary to achieve the goals of utilizing the new high school and new middle school as emergency shelters and to generally improve the disaster resilience of Beaverton schools. We would like to thank the workshop participants and the organizations they represent for their time and participation in this groundbreaking resilience planning effort. Lastly, we would like to thank State Representative Tobias Read and the Assistant County Administrator for Washington County, Don Bohn for their overwhelming support of this project and the goal of improving the resilience of Beaverton Schools.

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