WASHINGTON STATE DEPT OF
NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

WASHINGTON STATE SCHOOL SEISMIC SAFETY PROJECT

PHASE 1
2017–2019

FINAL REPORT

Contents

Executive Summary

Using a capital budget appropriation of $1,200,000, this study aims to assess the seismic safety of 222 permanent, public, K–12 school buildings in Washington State. This assessment is based on local geology and the engineering and construction of the buildings.

The results of the seismic screening evaluations indicate that Washington State has many older school buildings that are vulnerable to earthquakes. Older unreinforced masonry buildings and non-ductile concrete buildings are especially at risk. Buildings constructed prior to 1975, when the statewide building code was adopted, are particularly vulnerable.

The Earthquake Performance Assessment Tool (EPAT), developed by Earthquake Engineering Research Institute, was utilized to estimate damage and building performance. The EPAT results estimate that the median building is expected to be 43 percent damaged in a design-level earthquake. EPAT also estimates that the majority of buildings in this study are expected to receive a "Red—Unsafe" post-earthquake building safety placard following a design-level earthquake, meaning that they will be unsafe to occupy. In addition, EPAT estimates that approximately one-fourth of buildings studied will not be repairable following a design-level earthquake, and may require demolition.

Many of the schools with the highest estimate of damage following a design-level earthquake are located in areas of highest earthquake hazard.

The results of the seismic upgrade cost estimates (concept-level design studies) indicate that the cost to seismically upgrade a vulnerable structure is less or much less than the damage costs the building would incur in an earthquake. For less vulnerable structures, especially structures in low seismicity areas, however, it may not be financially worth conducting seismic upgrades.

Based on the limited number of buildings (15) where seismic upgrade cost estimates were performed, there is about a 60 percent cost increase between upgrading to Immediate Occupancy (IO) and Life Safety (LS) seismic performance standards. The average seismic structural upgrade cost for the IO concept-level design is $69 per square foot. The average seismic structural upgrade cost for the LS concept-level design is $42 per square foot.

Seismic upgrade estimated construction costs ranged from $63,000 per building to $5,010,000 per building. This illustrates the wide range in costs and the need for individual assessments of each building.

The State of Washington has adopted the 2015 International Existing Building Code as its building standard for existing buildings. Per this building code, a school district is under no obligation to upgrade its school buildings to suggested upgrade recommendations unless there is a change in use or occupancy, an addition, or an alteration made to the existing structure that would trigger such upgrades.

The results presented here are therefore for statewide informational purposes only. The goal is that this information can help districts, schools, parents, state legislature, OSPI, and the public better understand the current level of seismic risk at Washington school campuses. Public schools will need financial support to make the necessary changes highlighted here.

Introduction

This study aims to assess the seismic safety of 222 permanent, public, K–12 school buildings in Washington State. This assessment is based on local geology and the engineering and construction of the buildings. DNR geologists assessed site-specific geology to determine the National Earthquake Hazard Reduction Program (NEHRP) site class category at each school campus. Structural engineers performed American Society of Civil Engineers (ASCE) 41-17 Tier 1 seismic screening evaluations, Federal Emergency Management Agency (FEMA) 154 Rapid Visual Screenings (RVS), and Earthquake Performance Assessment Tool (EPAT) assessments on 222 individual school buildings and five fire stations located within one mile of a school. Following the completion of the seismic screening evaluations, 15 of the 222 school buildings were selected to receive more detailed concept-level seismic upgrade designs and seismic upgrade cost estimates.

This statewide study constitutes a major step taken by Washington State to improve the understanding of seismic risks to public school buildings. These school buildings are important to local communities, as they house hundreds or even thousands of students and staff on a typical day. Many of these buildings are also historic structures, and they are often culturally or societally important. Additionally, parents are legally required to have their children attend school, making it mandatory for children to spend time in these buildings. In urban and rural communities alike, public schools not only educate the next generation of Washington residents but also serve as gathering spaces for communities to come together over interscholastic athletics, meetings, and other events. Without seismically upgrading buildings, earthquakes can be not only devastating and economically damaging, but they can have a significant social impact as well.

There are also negative economic impacts associated with loss of life, injuries, and the prolonged closure of damaged schools. Prolonged closures can lead to increased costs for school districts, and can require parents to find childcare or alternative educational activities for their children. Economic setbacks due to earthquakes (or other natural disasters) can also cause long-term disinvestments that can permanently change the character of a community. It is our hope that the results of this study can spawn future investment in resilience planning, recommendations for policy changes, and ultimately funding to seismically upgrade all Washington schools to improve their seismic safety.

Earthquakes in Washington

The beautiful mountains, plains, and waterways that are the backdrop for Washington schools are the result of complicated geologic processes that have been active for millions of years. Off the coast of western Washington, the Juan de Fuca tectonic plate is being pushed underneath the North American plate in a process known as subduction. This geologic action is in part responsible for Washington’s tall mountains and volcanoes. This terrain directly affect Washington’s climate, which causes heavy snowfall in the mountains and creates the bountiful agricultural region in central and eastern Washington. Washington’s complex plate tectonics have the additional effect of making the State one of the highest seismic risk regions in the United States.

When built-up stress from the subduction process is released, it causes the crust of the Earth to vibrate and move—an earthquake. Washington State can experience three major types of tectonic earthquakes (Fig. 1). In the past thousand years or so, Washington State has experienced deep intraplate earthquakes (such as the 2001 Nisqually Earthquake), earthquakes occurring on shallow surface faults (~930 Seattle Fault Earthquake), and subduction zone earthquakes (1700 Cascadia). Major earthquakes in western Washington in 1946, 1949, 1965, and 2001 killed 15 people and caused billions of dollars’ worth of property damage (Walsh and others, 2011). In eastern Washington, earthquakes near Chelan in 1872 and near Walla Walla in 1936 also caused significant damage (Walsh and others, 2011). The presence of all three earthquake sources and the relatively high likelihood of having another earthquake in the future, in addition to the high population density in areas where these earthquake hazards exist, increases the seismic risk for our state.

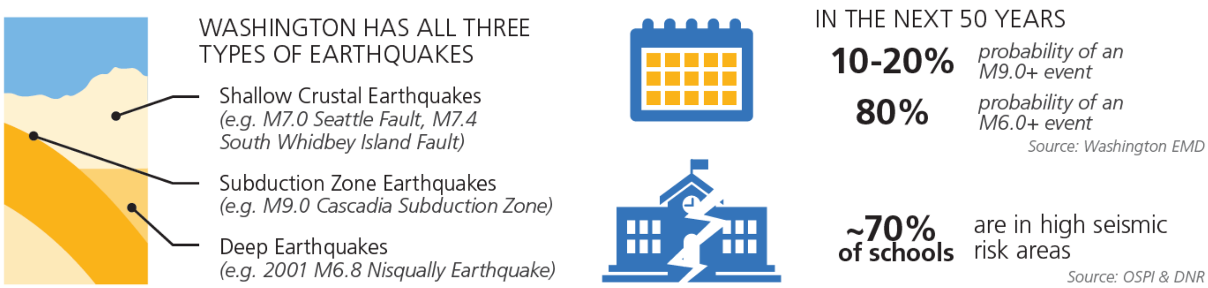


Figure 1. Washington State school seismic safety facts.

Funding and Scope

The directive put forth in the Washington State 2017–2019 capital budget appropriation (henceforth called Phase 1) was an appropriate first step in improving the seismic safety of Washington State schools. The Washington State legislature has elected to continue funding this project in the 2019–2021 biennium at a level of $2,200,000 from the capital budget (Phase 2). This continued funding is important for progressing our understanding of seismic risk in Washington schools. However, it will take much more funding to accomplish this goal than has been allocated to date. Estimated costs to seismically upgrade schools statewide are described in the "Extrapolation" section of this report.

DNR, OSPI, EMD, and the State Board of Education, along with help from the United States Geological Survey (USGS), and the University of Washington Civil Engineering Department, developed a committee—the School Seismic Safety Steering Committee (SSSSC) to determine how to accomplish as much as possible with limited time and funding allotted in the 2017–2019 biennium. The SSSSC hired Reid Middleton Inc., an engineering firm with experience in the design of K–12 schools and statewide resources, to conduct the structural engineering assessments and seismic upgrade design concepts and cost estimates for Phase 1 of this project.

Based on estimated costs to seismically assess school buildings from earlier studies (Washington State School Seismic Safety Pilot Project, 2011), the SSSSC determined that the allocated funding allowed for assessment of 222 individual school buildings on 94 campuses, five fire stations within one mile of a school, and seismic upgrade design concepts and cost estimates for 15 of these school buildings. The project objective was to evaluate a representative sample of school buildings across the State. The results from the geologic and seismic evaluations and costs to upgrade can then be extrapolated to similar school buildings throughout Washington State to determine what it may cost to complete these seismic assessments statewide. Appendices B and C provide the results of the seismic screening evaluations.

Due to limited funding in Phase 1, the 222 school buildings being seismically evaluated in this study comprise a very small sample size of the State's 4,444 individual permanent school buildings. Only 15 of the 222 school buildings studied received concept-level seismic upgrade design and cost estimates.

Consequently, the accuracy of the extrapolations, resulting conclusions, and cost estimates provided in this report will be limited. It is also worth noting that there are another 4,000+ portable facilities not considered in this assessment that are also vulnerable to seismic hazards.

This final Phase 1 report goes over the progress made to date, major findings, estimated costs for assessing and upgrading Washington schools, next steps for continuing this project in the upcoming biennium, and recommendations to the legislature to continue this effort to make Washington State schools safer during earthquakes. The appendices provide more detailed information, frequently asked questions (Appendix D) and links to reports that go over the methods and findings of the geologic and engineering assessments for each school.

"Across Washington State, about 386,000 students—or one in every three enrolled—live in earthquake prone areas and attend schools built before seismic construction standards were adopted statewide. In addition, about 31,000 students in Washington attend schools that are in tsunami inundation zones" (Doughton and Gilbert, 2016).

Building Codes and Seismic Design in Washington

Seismic hazard maps and building codes are continually being updated. New findings shed light on earthquake hazards and active faults. New construction materials are developed, replacing older structures such as Unreinforced Masonry (URM) buildings. Figure 2 is a timeline of major earthquakes and fault discoveries, as well as changes in building codes and earthquake safety policy. Figure 3 shows major damage to Puyallup High School Following the 1949 Olympia earthquake.

As scientists learn more about earthquakes, ground shaking, and active faults, seismic hazard maps continue to evolve. In turn, the building codes adapt to these new findings. As a result, buildings that were constructed to code in one year/decade may become out-of-date or non-compliant with the current building codes. Additionally, engineers continue to learn from earthquakes and other events around the world and change building designs based on new revelations in design standards and as new materials are developed. This is best illustrated in the use of URM buildings early on in school construction (circa 1900–1960); once these were understood to be vulnerable, new URM buildings stopped being constructed, yet these older buildings are still used today.

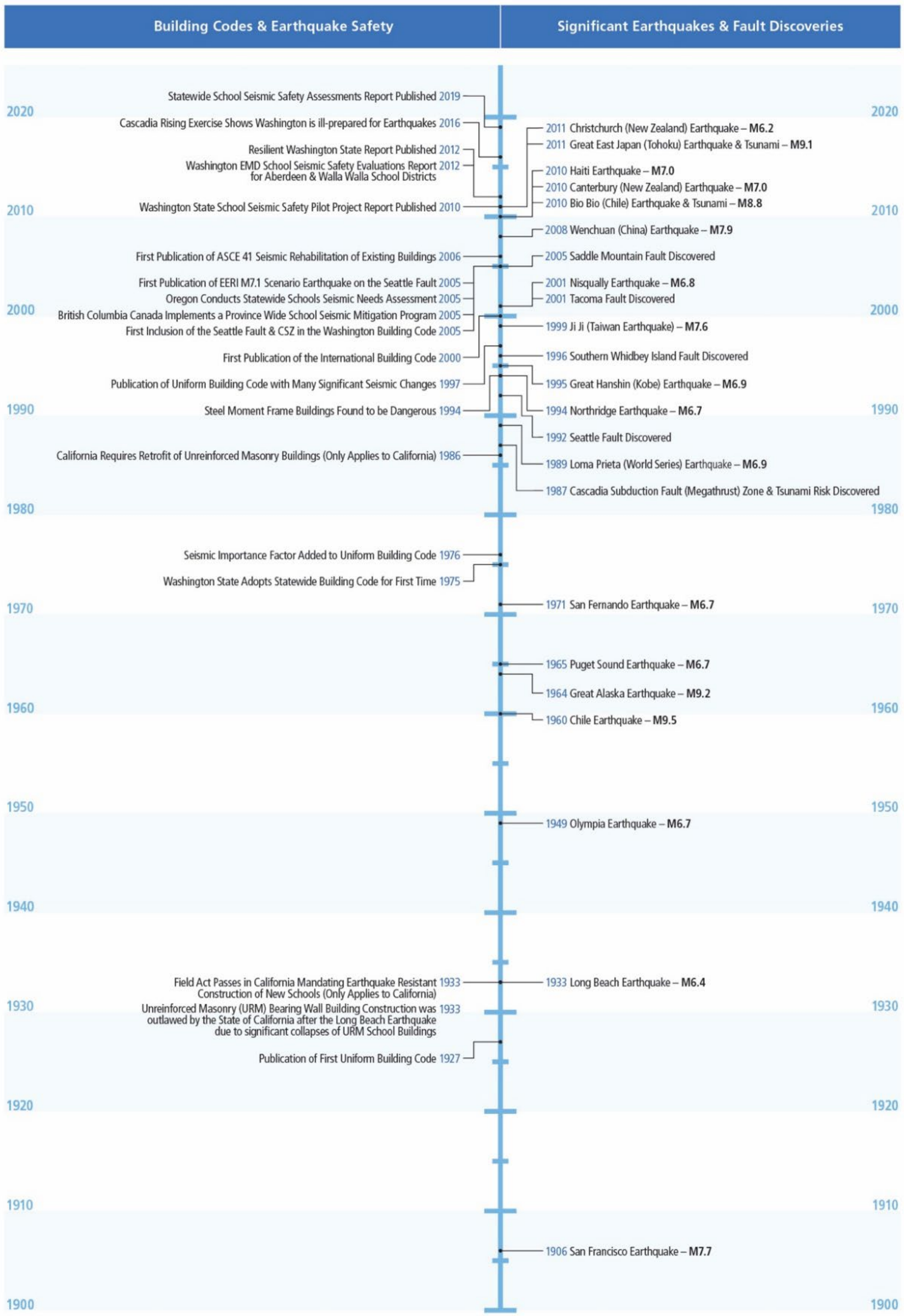


Figure 2. Timeline of significant changes in building codes and earthquake safety policies. Major earthquakes and fault discoveries since 1900 are shown on the right.

Figure 3. Photograph from the Seattle Times showing damage to Puyallup High School during the 1949 Olympia earthquake.

Closing Earthquake-Damaged Schools: *"From the standpoint of children and families, after an impact is a particularly bad time for schools to be closed. Damaged homes and neighborhoods are dangerous and depressing places. Children are often left with no safe place to play when yards, playgrounds, and recreational programs are lost, no one to play with when playmates and friends are forced to relocate and parents are too busy dealing with survival and rebuilding issues to have much time for them.*

The closing of a local school is highly disruptive to social networks and, if it becomes permanent, can rob a neighborhood of its identity and cohesion. One of the most dramatic effects that can occur to a severely impacted community is when a school is closed for a long time, maybe even permanently, due to regional depopulation after homes are destroyed.

Getting schools reopened quickly has been found to be an important step toward rebuilding the community as a whole. An understudied area is the long-term effect of major disasters on the education and development of children. The shock of being uprooted and moved to a new school, even temporarily, can be very difficult for children. The effects can be particularly traumatic if they occur at a critical developmental time, such as the senior year with its preparation for college and graduation festivities."

Human Links to Coastal Disasters, H. John Heinz III Center for Science, Economics and the Environment, Washington, DC, 2002.

Project Activities

222 school buildings (Fig. 4) received a preliminary seismic screening evaluation, which includes:

a) An on-site assessment, under the supervision of a licensed geologist, of the seismic site class of the soils per National Earthquake Reduction Program (NEHRP) provisions at the facilities to determine the level of earthquake shaking expected at the site.
b) Preliminary seismic screenings (based on available information without going to the site) using FEMA 154 Rapid Visual Screening (RVS) for Seismic Hazards and the Washington State Earthquake Performance Assessment Tool (EPAT).
c) A more detailed on-site seismic screening investigation using ASCE 41-17 to screen the building for potential seismic hazards. Field investigations were performed by licensed structural engineers using standardized building code seismic screening and calculation methods and structural plans (where available). The structural engineers evaluated building type, age, configuration, condition, and related structural (building structure and framing) and nonstructural (architectural features and finishes, building envelope, mechanical, electrical and plumbing systems) features to determine conformance or non-conformance with the seismic hazards and expected level of seismic performance.
d) Creation of a seismic screening report documenting the findings from each school building. These reports were distributed to each school district to facilitate further seismic improvement work. Links to the reports can be found in Appendix E.
e) Input of this seismic screening information into the OPSI ICOS database.

15 of those school buildings received a seismic upgrade concept-level design, which includes the preliminary seismic screening evaluation plus the following:

f) Additional seismic screening and structural calculations to determine a cost-effective approach to seismically upgrade the school building.
g) Design of concept-level seismic upgrades and a review of architectural impacts of the proposed seismic upgrades to life-safety performance levels for school buildings and immediate occupancy performance levels for assembly occupancy school buildings (gymnasiums) and fire stations.
h) Preparation of preliminary concept-level design seismic upgrade cost estimates.
i) Preparation of a concept-level seismic upgrade design report for each facility, to be utilized to document the results and communicate the upgrade designs to each school district and fire district.
j) Input of this concept-level seismic upgrade design approach and costs to the OSPI ICOS database.

The engineering seismic upgrade concept-level designs provide: (1) more detailed information about the structural and nonstructural seismic deficiencies of a building; (2) design solutions for how to mitigate these seismic deficiencies; and (3) estimated construction costs to improve the seismic performance of the buildings to meet current building code levels. This information can be extrapolated to the statewide school buildings database to better understand the scope of seismic risk for Washington state schools and related costs to improve school seismic safety.

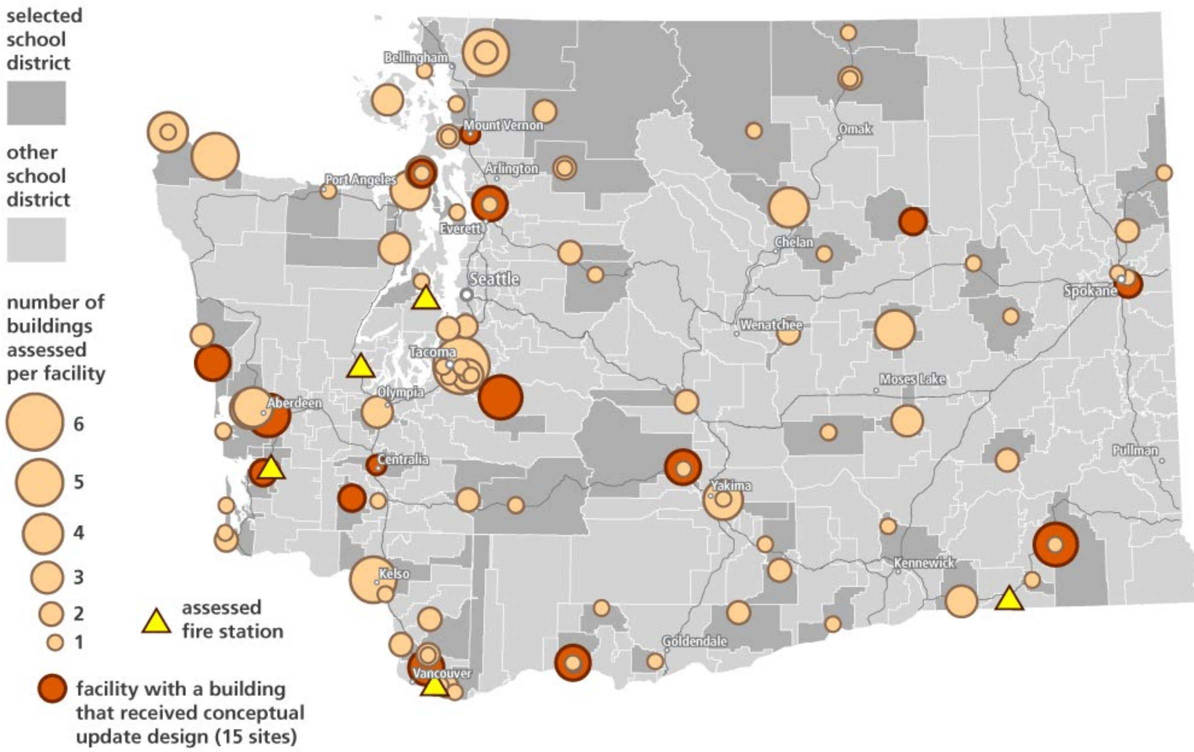


Figure 4. Map showing the location of the 222 school buildings and five fire stations assessed for this project. The map highlights the 15 schools receiving conceptual update designs. See Appendix B for a complete list of schools.

Phase 1 School Building Selection

School buildings were selected based on the seismic hazard, year built, construction type, geographic location, and student capacity. A complete list of selected school buildings can be found in Appendix B and the schools are shown on Figure 4.

a. Seismic Hazard: **We selected schools in high, medium, and low seismic hazard areas (based on contours of peak ground acceleration (PGA) from the 2014 USGS National Seismic Hazard map long-term model, a value known as PGA 2% in 50 years), with a greater emphasis on higher hazard areas and mapped tsunami inundation zones (Fig. 5). We prioritized campuses that were proximal to active faults.** Characteristics of the local, site-specific geology or soil type can amplify ground motion. As seismic waves pass from rock to soil, they slow down but get bigger. What that means is that a soft, loose soil may shake more intensely than hard rock at the same distance from the same earthquake. This is why it is important to understand the geology and soil type at each school, so that engineers can predict how much shaking to anticipate from the maximum considered earthquake and make sure to design the building, or seismic upgrade to withstand that shaking.

b. Building Type: **We selected schools representing all building types (wood frame, concrete, steel, masonry, and unreinforced masonry, among others)(Fig. 6). Building type was collected from the ICOS database and later refined by Reid Middleton, Inc.**

Only educational facilities and permanent structures were assessed in this study; portables and auxiliary buildings such as greenhouses and bus depots were excluded.

c. Year Built*:* **Building age is one of the most easily determined and significant factors to quickly determine the seismic vulnerability of a structure. As we learn more about different faults, the understanding of the seismic hazard for the state continues to evolve. Earthquakes and the damage that they cause also provide relevant lessons for building officials and design professionals, resulting in more stringent seismic codes over time. For this study, we selected a relatively uniform sample of different school buildings built in different decades to try to better understand the effects of more detailed seismic hazard information and more stringent seismic codes on school buildings.**
A large majority of permanent public K–12 school buildings in Washington were constructed prior to 2005, which means they do not incorporate expected shaking from a Cascadia subduction zone or Seattle Fault earthquake into their building design. At the time that they were designed, school buildings built in accordance with building codes (the current one being the 2015 International Building Code (IBC) adopted in Washington on July 1, 2016) are designed to provide life-safety seismic performance for occupants in the building. This means that the buildings are designed to protect the occupants while maintaining safe egress (exits), but these buildings are not necessarily going to be usable after the earthquake (immediate occupancy). Furthermore, most buildings designed using the 1997 Uniform Building Code (or later building code versions) are considered "benchmark" buildings in accordance with ASCE 41. Benchmark buildings are defined by ASCE 41 as buildings that were constructed to a building code with "modern" seismic provisions. Benchmark years vary for different buildings depending on their construction material type and structural system type. This is because, over the last 90 years of building code development and improvement (the building code is updated every three years), damaging earthquakes have uncovered very specific unsafe or unreliable seismic performance issues with certain types of buildings and their configurations. Because the State of Washington first adopted a statewide building code in 1975, that year can become a simplified statewide seismic study benchmark year or dividing line between buildings constructed with archaic building materials and less seismically reliable structural systems, and more modern and seismically reliable buildings. Therefore, buildings constructed before 1975 were the general focus of this study as these buildings are more likely at a higher seismic risk than buildings constructed after 1975.

d. Geography: **School buildings were selected from a wide geographic region across the state to provide representation of schools in rural and urban districts (Fig. 4). School districts in large metropolitan areas such as Seattle and Bellevue were not part of this initial study to ensure that a statewide sample provided a broad representation of state school districts and because some of these larger, more well-funded, urban school districts have implemented seismic improvements programs on many of their older school buildings. Future phases of this project may evaluate schools in these larger districts.**

e. Capacity and Enrollment: **We looked at buildings of varying capacity (building size) and schools with all levels of enrollment, with an emphasis on school buildings with larger enrollments.**

f. Grade: **Only public K–12 school buildings that are used as education facilities are included in this initial study.**

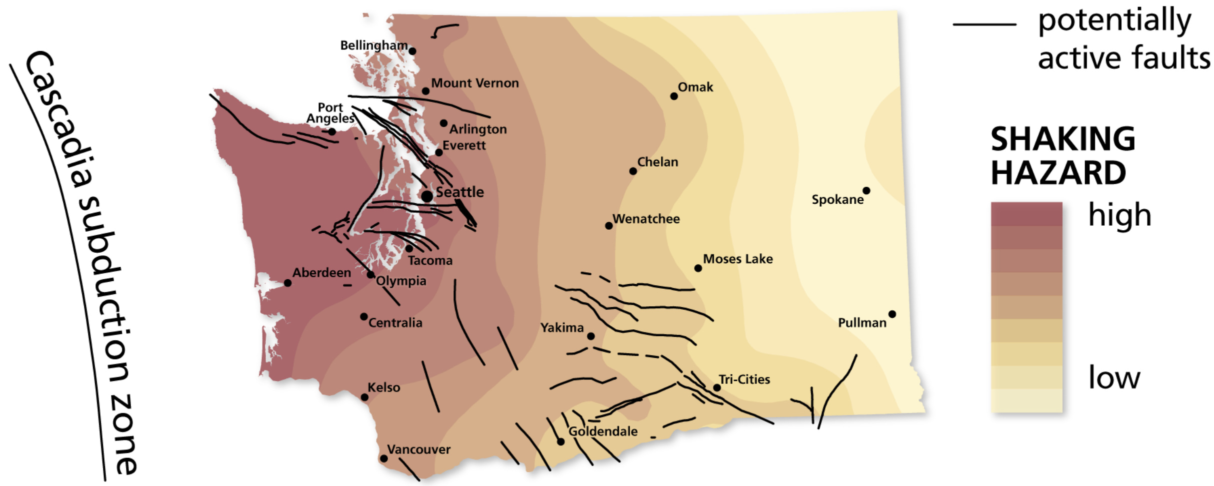


Figure 5. Map of the seismic hazard in Washington State, expressed as contours of peak ground acceleration (anticipated ground shaking, or acceleration in bedrock) as a fraction of standard gravity. These values are from the USGS two percent probability of exceedance in 50 years map of peak ground acceleration, which is a proxy for shaking hazard (Peterson and others, 2015). Warmer colors indicate higher hazard areas. Major active faults are shown as black lines.

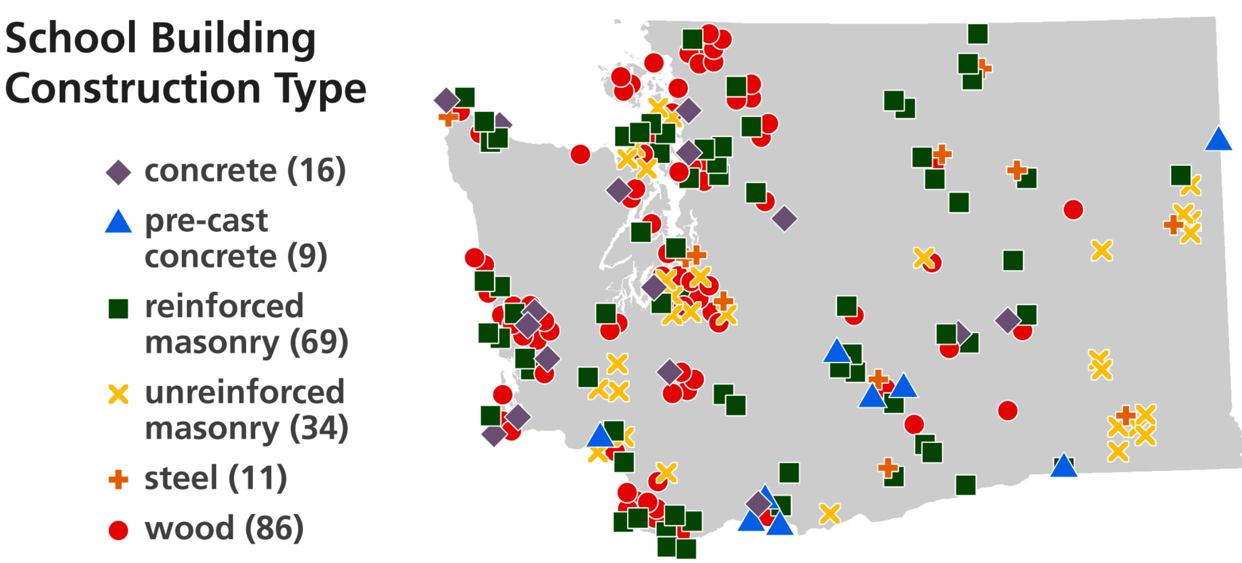


Figure 6. Map of Washington showing the locations of the school buildings assessed in this study, symbolized by construction type.

Selection of 15 School Buildings for More Comprehensive Analysis

A small representative sample of 15 school buildings was selected to receive a more comprehensive seismic evaluation, called a “seismic upgrade concept-level design”, which also includes an estimated cost to upgrade (Appendix B shows the school buildings that were selected and the design objectives). The focus was on schools that are in high seismic risk areas, and a few that are in moderate to lower risk areas so that we could determine the difference in cost to seismically upgrade school buildings across the state. Additionally, we focused on main school buildings and gymnasiums because large public facilities, such as gyms, can be used as community emergency shelters. We also selected school buildings of varying age, type, and construction materials.

Selection of Five Fire Stations

Only five fire stations (shown in Fig. 4 and listed in Appendix B) received a field investigation and a seismic screening evaluation. These five fire stations were selected from a wide geographic region from around the state and are within a mile of a public school building. A link to the fire station reports can be found in Appendix C. Details of the fire station assessments are not part of this study and will be summarized in the next phase.

Geologic Site Class Assessments

Site class is an approximation of how much the soils at a site will amplify ground motion relative to hard rock during an earthquake (Fig. 7). Using the empirical observations of Bordchert (1994), the National Building Safety Council (BSSC, 1997; 2004) developed the site class parameter to categorize the potential for amplification of seismic waves by the local soils.

Site class is an integral parameter for determining the Seismic Design Category (SDC) of a structure. The SDC is a categorization scheme that dictates the seismic risk that buildings must be designed to meet. Site class is also incorporated into all the major U.S. and international building codes, including the American Society of Civil Engineers 7-05 (ASCE, 2017b), the International Building Code (IBC, 2015), and the International Residential Code (IRC, 2015).

At each site, WGS geologists and geophysicists measured the time-averaged shear wave velocity in the upper 100 ft (30 m) of ground (a value known as Vs30)(BSSC, 2004; 2015). This measurement was used to determine the site class at each location. The results were entered into OSPI's ICOS statewide database and the individual screening reports distributed to each school and district. The relationship between Vs30 and site class is defined by the National Earthquake Hazard Reduction Program (NEHRP) provisions (FEMA, 2003; 2015) and is shown in Table 1. Softer soils have a lower Vs30 (site classes E and D) and will amplify ground shaking more than harder soils or rock, which have a higher Vs30 (site classes A–C). A site class of A, B, or C is therefore expected to result in a more economical structural design requirement than a site class of D (BSSC, 2010). Without a measured site class, the NEHRP provisions require that a building be designed assuming a site class of D. This assumption may increase building costs in seismically active areas.

Table 1. NEHRP site class categories. Softer soils typically increase shaking amplification.

NEHRP Site Class	Description	Vs30 measurement (m/s)
A	Hard rock	>1,500
B	Rock	760–1,500
C	Soft rock/ very dense soil	360–760

D	Stiff soil	180–360
E	Soft soil	<180
F	Soils requiring more detailed site-specific study	-

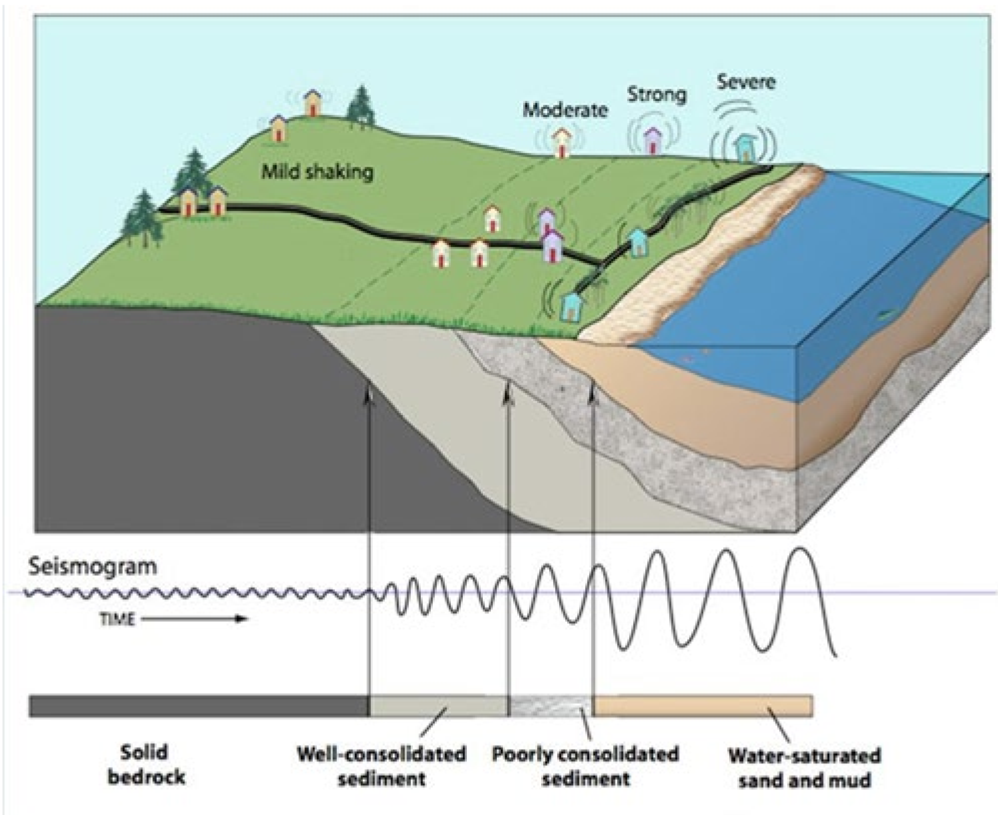


Figure 7. Schematic figure illustrating how seismic waves travel through different rock and soil types. The type of rock or soil beneath a structure greatly affects how a building responds to earthquake shaking. Geologists measure the time it takes sound waves to travel through the ground at each school campus to determine the rock/soil type and correlate it to a site class value. This value is then incorporated into the engineering assessment. https://slideplayer.com/slide/6132863/

Because measuring site class requires either a geophysical survey or boreholes, it can be prohibitively expensive. As a result, state and federal agencies and researchers have developed regional site class maps based on Vs30 proxies. These site class maps are based on topography (Wald and Allen, 2007; Allen and Wald, 2009), geology (Wills and Clahan, 2006; Palmer and others, 2004), or a combination of the two (Thompson and others, 2014). However, site class maps must assume lateral and vertical changes in geology. These assumptions can significantly over- or under-estimate site class in areas of complex geology. Site class maps therefore provide a good approximation for routine building design, but are not intended to replace site-specific testing needed for the design of essential facilities.

In the state of Washington, Palmer and others (2004) utilized surficial geologic mapping and a limited number of Vs30 measurements to construct a reconnaissance-level site class map for the state based on 1:100,000 scale geologic mapping. The SSSP site class assessments improve on this previous predictive mapping by conducting on-site geophysical assessments and using updated 1:24,000-scale geologic mapping where available.

At each school campus, a team of WGS geology personnel conducted a seismic survey using a linear array of geophones (instruments for detecting seismic waves). Based on the results of the survey, WGS geologists determined Vs30 at each site. After an evaluation for complex 3D geologic conditions that could affect site class laterally across a campus (lateral heterogeneity), site class was assigned to the school structures.

Of the total 94 school campuses assessed, 29 have measured site classes that differ from those predicted by the statewide site class map (Palmer and others, 2004). Of those that differed, 19 sites had a measured site class that went from a predicted D or ranged D–E site class to a C or B site class, which would have resulted in an overestimation of soil amplification. At two sites, the predicted site class was B and the measured D, a drastic change that would significantly under-estimate site amplification. Therefore, although the site class map is a good reconnaissance tool, without site-specific measurements, many sites would have been under- or over-designed, significantly affecting cost of upgrade or not engineering the building to the proper standard.

Engineering Evaluations and Upgrade Costs

A team of structural engineers led by Reid Middleton Inc. conducted seismic screening evaluations at 222 school buildings (Fig. 8). The engineers employed the methods described in ASCE 41-17 *Seismic Evaluation and Upgrade of Existing Buildings.* This is a national standard document published by the ASCE for the seismic evaluation of existing buildings. In addition to conducting the ASCE 41 Tier 1 seismic screening evaluations, the Washington State School Earthquake Performance Assessment Tool (EPAT, Developed by Earthquake Engineering Research Institute) was completed for each school building. Finally, FEMA 154 Rapid Visual Screening (RVS) scores were developed for each building. RVS is a preliminary screening tool used to rank buildings based on their seismic risk. EPAT and FEMA 154 utilize less detailed information compared to ASCE 41. EPAT and RVS results are available for download in Appendix E.

Washington State Earthquake Performance Assessment Tool (EPAT)

The Washington State School Earthquake Performance Assessment Tool (EPAT) is a very basic spreadsheet tool developed for the State of Washington by the Earthquake Engineering Research Institute (EERI). The spreadsheet uses FEMA Hazus fragility curves to calculate expected earthquake performance of schools based on basic school seismic screening characteristics. Hazus is a natural hazards loss estimation tool initially developed by FEMA in the 1990s. Hazus uses basic building information, construction type fragility functions, and expected ground shaking intensity to estimate the probable losses of buildings from a earthquake. These results are displayed as a percentage of the building elements that are expected to be damaged in this earthquake. The EPAT spreadsheet only returns performance values for the building’s structural systems, but nonstructural systems are likely to also sustain significant damage in a large earthquake.

Rapid Visual Screening (RVS) of Buildings for Potential Seismic Hazards

The standardized tool for performing rapid visual screening of buildings for seismic hazards is the *FEMA 154: Rapid Visual Screening (RVS) of Buildings for Potential Seismic Hazards standard*. Based on extensive data and research on the seismic performance of buildings in previous earthquakes, these standards provide seismic screening criteria specific to each common building archetype, the structural system, configuration, and characteristics of the specific facility, and the seismic hazard at each facility site.

This tool uses a scoring system to quantify the potential seismic vulnerability of a structure. A base score is identified based on the modeled ground shaking. Other important factors are the building's lateral-force-resisting system (for example, wood or concrete shear walls, steel braced or moment frames, and masonry shear walls). This initial score is then reduced based on the geological hazards (site class, landslide, and liquefaction hazards) and inherent vulnerabilities in the building's configuration (such as vertical and horizontal irregularities). The building score is also adjusted based on the construction year relative to benchmark years in which seismic design code requirements changed significantly.

Figure 8. Structural Engineer inspects a school building using the ASCE 41-17 Tier 1 checklist.

The ASCE 41-17 Seismic Standard

ASCE 41 *Seismic Evaluation and Retrofit of Existing Buildings* is a national standard document published by the American Society of Civil Engineers for the seismic evaluation of existing buildings. ASCE 41 chapter 17 provides criteria and a multi-tiered process by which existing school buildings can be seismically screened, evaluated, and designed to be upgraded to attain a wide range of different performance levels when subjected to earthquakes of varying severity. The ASCE 41-17 standard describes performance levels for structural components and nonstructural components of a structure. The structural and nonstructural performance levels are aggregated for each building for a combined building performance level. This is the seismic screening standard that was used as the basis for this project. The individual reports for each school building contain the entire structural and nonstructural

ASCE 41-17 checklists where building components are rated as compliant, noncompliant, not applicable, or unknown with respect to the specific components compliance with the current building code.

Seismic Hazard Levels

Every earthquake is different. An earthquake's intensity and energy magnitude depend on fault type, fault movement, depth to epicenter, and geology of the subsurface. The precise location, intensity, and start time of an earthquake cannot be predicted before an event occurs. However, earthquake hazards for certain geographic areas are relatively well understood based on historical patterns of earthquakes from the geologic record, measured earthquake ground motions, understanding of plate tectonics, and seismological studies.

Geologists, seismologists, and geotechnical engineers have categorized the seismic hazard for particular locations using models based on the probability of a certain magnitude earthquake occurring in a given time period. ASCE 41-17 specifies four different Seismic Hazard Levels at which to seismically screen, evaluate, and (or) upgrade school buildings and other structures. For voluntary seismic evaluations and voluntary seismic upgrades, the owner of a school and the structural engineer can decide the seismic hazard level at which it is appropriate to evaluate or upgrade a structure.

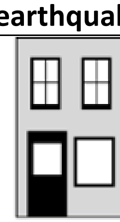
All the school buildings were evaluated as Risk Category III structures as defined by the Washington State Building Code. Generally, schools with more than 250 occupants are classified as Risk Category III and schools with less than 250 occupants are classified as Risk Category II. While it is possible that some school buildings may technically be classified as Risk Category II based on their current occupancy (number of occupants), we elected to evaluate all structures as Risk Category III to keep the risk categories consistent for the relatively small sample size.

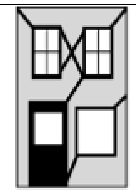
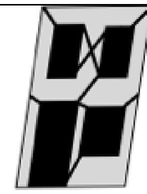
School Building Performance Levels and Seismic Upgrade Options

A target building performance level must be selected for the seismic design of an upgrade of a school building. The terminology used for target building performance levels is intended to represent goals for design, but not necessarily predict building performance during an earthquake.

The ASCE 41-17 standard identifies the following Structural Performance Levels in a design-level earthquake: Immediate Occupancy (IO), Life Safety (LS), Limited Safety (LTD-S), and Collapse Prevention (CP)(Table 2). The nonstructural Performance Levels identified in the standard are: Operational (OP), Position Retention (PR), and Life Safety (LS).

Table 2. Structural performance level definitions following ASCE 41-17 and FEMA P-424.

Structural Performance Level	Description of building state following a design-level earthquake	Schematic diagram of building following earthquake
Immediate Occupancy (IO)	Buildings are expected to sustain minimal damage to their structural elements and only minor damage to their nonstructural components. While it is safe to re-occupy a building designed for this performance level immediately following a major earthquake, nonstructural systems may not function due to power outage or damage to fragile equipment.	

Life Safety (LS) and Limited Life Safety (LTD-S)	Buildings may experience extensive damage to structural and nonstructural components. Repairs may be required before re-occupancy, though in some cases extensive restoration or reconstruction may not be cost effective. The risk of casualties at this target performance level is low.	
Collapse Prevention (CP)	Although buildings that meet this building performance level may pose a significant hazard to life safety resulting from failure of nonstructural components, significant loss of life may be avoided by preventing collapse of the entire building. However, many buildings designed to meet this performance level may be complete economic losses.	

WHAT IS A DESIGN-LEVEL EARTHQUAKE?

A "design-level earthquake" is a theoretical earthquake event, here defined as being two-thirds of the magnitude of the maximum considered earthquake (MCE). The MCE is a risk-adjusted probabilistic event with a return period of 2,475 years. While not exact, the magnitude of the design-level earthquake event is similar to the magnitude of an earthquake event with a 475-year return period for many locations on the west coast of the United States. Earth scientists expect the average return period of a Cascadia subduction zone (CSZ) earthquake to be approximately 500 years. It is possible that a CSZ earthquake could be approximately the magnitude of the design-level earthquake for many parts of Washington State, depending on the particular earthquake characteristics. Engineers and building officials predict the earthquake resilience of a new building by selecting a design-level earthquake. The design-level earthquake is mandated by the building code to represent the most likely source of earthquake shaking hazard for the region where the building is located (for example, nearby mapped active faults). It is used in the design of buildings to ensure that the building behaves in a predictable way if that design-level earthquake event should occur.

School Seismic Performance, Safety, Reliability, and Construction Cost

The seismic performance, safety, and reliability of a school building must be weighed against the relative importance and construction costs associated with that facility. It may be impractical for the average building to be seismically designed or upgraded to experience no damage following a major earthquake. However, steps can be taken to mitigate seismic hazards for new and existing structures.

Some facilities have more community importance or pose special risks to a community following an earthquake (for example, hospitals, fire stations, schools, or even facilities housing highly toxic substances). It is reasonable that important facilities be designed or upgraded to a higher performance standard than the average structure. The relative importance of a facility must be weighed against the relative construction costs associated with facility construction. There are two types of construction costs associated with seismic hazards: the cost of initial construction or seismic upgrade construction and the costs to repair or replace a facility following an earthquake.

The better a structure performs during an earthquake, the faster a structure can be returned to service and the less the repair costs will be for a structure following an earthquake. Many older masonry public school buildings in central Mexico were closed for as long as a year due to significant damage from the 2017 Central Mexico Earthquake. The school building shown in Figure 9 is one such example. Expected building damage during a seismic event can be directly linked to:

- Repair/Replacement Costs—Cost of restoring the facility to pre-earthquake condition.
- Public Safety—Number of critical injuries and casualties to building occupants.
- Downtime—Length of time taken to make repairs to return a structure back to service.

Figure 9. Structural earthquake damage to a primary school in central Mexico from the 2017 M7.1 Central Mexico Earthquake (Photo by Reid Middleton, Inc.).

School Seismic Performance of Nonstructural Components

For much of the 20th century, little attention was given to designing nonstructural components and their anchorage for forces induced by earthquakes, yet these nonstructural systems can pose a safety risk to building occupants (Fig. 10). Nonstructural components of buildings are architectural features, finishes, building envelop and cladding systems, and the various building systems such as mechanical, electrical, plumbing, heating, cooling. These components are essentially everything but the building's structural systems and framing.

Figure 10. Nonstructural earthquake damage to a high school in Anchorage, Alaska, from the 2018 M7.0 Anchorage Earthquake (Photo by Reid Middleton, Inc.).

In addition to the life safety hazards posed by nonstructural components, the cost to repair nonstructural components following an earthquake can be high and significantly delay the reopening of a school. In many cases, the cost to repair or replace nonstructural components can be higher than the cost of repairing structural components following an earthquake.

Finally, the use of the structure and required level of building performance needs to be taken into consideration. For example, essential facilities that are expected to have minimal structural damage following an earthquake must have nonstructural components that are designed to match the seismic performance level of the facility.

Concept-Level Seismic Upgrade Designs

Following the Tier 1 seismic evaluations, fifteen school buildings were selected from those included in the study to receive more detailed concept-level seismic upgrade designs. The fifteen buildings were selected to include a range of construction types, building uses, and building ages. Whether drawings were available for the building was also considered. The primary intent of the concept-level seismic upgrades was to develop seismic upgrade options (ways in which the building could be modified to meet modern code and selected design criteria) and to obtain cost estimates for each upgrade concept. Cost estimates were developed by a professional cost estimator.

While many buildings possess similarities, such as shear walls or parapets, and there are similarities between the different seismic upgrades (such as similar ways to brace parapets for different buildings), each seismic upgrade approach is unique. Many of the seismic upgrades include similar items, such as wall strengthening, connection strengthening, out-of-plane wall strengthening, and diaphragm upgrades, but the extent and arrangement of these upgrade features can vary significantly from building to building.

The seismic deficiencies identified in the ASCE 41 Tier 1 seismic screening evaluations informed the concept-level seismic upgrade designs. Licensed structural engineers used best judgment to develop the concept-level upgrades, based on observations, experience, and the seismic screening results.

Concept-level seismic upgrade designs were developed for either the Immediate Occupancy (IO) or Life Safety (LS) structural performance levels. Five of the buildings were selected for development of concept-level upgrades for the IO level, and ten buildings were selected for development of concept-level upgrades for the LS level. All of the IO performance level buildings are gymnasium structures, with the intention of developing cost estimates for both an enhanced level of safety and approximate costs if gymnasiums were seismically upgraded to provide emergency shelter capabilities. Low and high cost range variances (-20% to +50% of the average cost) were developed and are also presented in the results section for each of the 15 buildings.

Results

High-Level Findings

- Washington State has many older school buildings built prior to the adoption of modern seismic safety codes. Older and more vulnerable construction types are more susceptible to earthquake damage and have a greater percentage of seismically noncompliant structural and non-structural components.
- Unreinforced masonry buildings constructed before the 1940s and non-ductile concrete buildings (without seismic upgrades) constructed before the mid-1970s located in high seismic hazard areas are especially vulnerable to collapse during earthquakes. The risks of these buildings should be mitigated as soon as practical.
- Older school buildings built prior to 1975 and constructed out of reinforced masonry and wood frame materials are vulnerable to collapse.
- Geologic site class measurements showed that 29 campuses have a measured site-specific site class that differs from the predicted site class based on reconnaissance-scale mapping. This helps to inform detailed engineering plans and affects building costs.
- Conducting comprehensive seismic assessments provides districts with actionable information on the condition of their schools and an approximate cost to seismically upgrade their highest-risk buildings.
- Based on the limited number of buildings (15) where seismic upgrade cost estimates were performed, there is about a 60 percent increase difference between upgrading to Immediate Occupancy (IO) and Life Safety (LS) seismic performance standards. The average seismic structural upgrade cost for the IO concept-level design is $69 per square foot. The average seismic structural upgrade cost for the LS concept-level design is $42 per square foot.
- The concept-level seismic upgrade design results indicate that for many buildings, the cost to seismically upgrade the structure is less or much less than the damage costs the building would incur in an earthquake. For less vulnerable structures, especially structures in low seismicity areas, however, it may not be financially worth implementing seismic upgrades.

- Seismically upgrading a vulnerable structure will generally make the building stronger, stiffer, safer, and more resilient and therefore decrease the damage costs the building will incur in an earthquake.

Details of Major Findings

The results of the seismic screening evaluations indicate that Washington State has many older school buildings that are vulnerable to earthquakes. Older unreinforced masonry buildings (URM) and non-ductile concrete buildings are especially at risk. The average date of construction of the buildings included in the study is 1963, which was well prior to the adoption of modern earthquake-resistant building codes. These older buildings should receive top priority for further study. For buildings constructed prior to 1950, almost half of the seismic screening checklist items are identified as non-compliant. This means that there are significant numbers of seismic safety issues in these older public school buildings. The ASCE seismic screening checklists questions are designed to uncover the seismic safety flaws and weaknesses of a school building, in the form of evaluation statements describing building characteristics that are essential if the failures observed in past earthquakes are to be avoided. Compliant statements identify acceptable conditions and non-compliant statements identify conditions in need of further investigation.

For buildings constructed between 1950 and 1990, approximately 30 percent of seismic evaluation checklist items are identified as non-compliant, again signifying additional seismic safety issues in these relatively newer buildings. Post-benchmark buildings (generally constructed after 1975) possess far fewer non-compliant seismic items compared to older buildings. It is important to note that, due to the existence of building finishes, features, and other elements, many of the buildings evaluated were not able to have all of their seismic screening elements positively verified. This means that the estimated numbers of non-compliant seismic screening features is likely to increase as these buildings are examined with more rigorous ASCE 41-17 Tier 2 and Tier 3 seismic evaluation procedures.

The EPAT data show that the median building is expected to be 43 percent damaged in a design-level earthquake. EPAT also estimates that the majority of buildings in this study are expected to receive a "Red—Unsafe" post-earthquake building safety placard following a design-level earthquake, meaning that they will be unsafe to occupy. In addition, the EPAT data show that approximately one-fourth of buildings studied will not be repairable following a design-level earthquake, and will require demolition.

FEMA 154 Rapid Visual Screening (RVS) of Buildings for Seismic Hazards were also completed for each of the 222 school buildings. The median calculated RVS building score is 1.3; a score of less than 2.0 generally indicates that a building may have an elevated earthquake risk and further evaluation is recommended. The EPAT and RVS results show general agreement with the ASCE 41 seismic screening results. These results indicate that Washington State has many school buildings with elevated seismic risk that should be further evaluated and ultimately seismically upgraded.

URM and non-ductile concrete buildings are especially vulnerable to earthquakes. Many of these school buildings in high seismic hazard areas possess damage estimate ratios in the range of 70 to 80 percent. As expected, the URM school buildings in lower seismic hazard areas (parts of eastern Washington, for example) were estimated to have lower damage estimate ratios of around 10 to 30 percent. URM buildings that display relatively low damage estimate ratios are generally not located in "high" seismic areas as defined by ASCE 41 (Eastern Washington, for example). Approximately half of the unreinforced masonry school buildings included in the study are located east of the Cascade Mountain Range. Many of the schools with the highest estimate of damage following a design-level earthquake are located in areas of highest earthquake hazard.

The results of the concept-level design studies indicate that the cost to seismically upgrade a vulnerable structure is less or much less than the damage costs the building would incur from an earthquake. For less vulnerable structures, especially structures in low seismicity areas, however, it may not be financially worth conducting seismic upgrades.

The Earthquake Performance Assessment Tool (EPAT) worksheets, the FEMA 154 Rapid Visual Screening (RVS) system, and ASCE 41 Tier 1 seismic screening evaluation results show that many buildings have items that are identified as structural and nonstructural seismic vulnerabilities. The engineering screenings also helped identify potential vulnerabilities based on construction methods and building codes that were in use during the time of construction

In general, older buildings are known to possess more seismic vulnerabilities than newer buildings. Older buildings were generally designed for lower levels of seismic force and with less interconnectedness than new buildings.

Prior to the first Uniform Building Code in 1927, no seismic considerations were used in the design of buildings. Starting in 1975, the State of Washington adopted a statewide building code for the first time. The adoption of a statewide standard made construction requirements more uniform across the state. This standard, in addition to significant improvements in building codes through the 1970s, 1980s, and 1990s, led to school buildings that are significantly more resilient to earthquakes compared to older school buildings. The results of the SSSP confirm that URM buildings and non-ductile concrete buildings possess the highest percentages of noncompliant seismic screening evaluation items, re-emphasizing the need for this statewide study.

Seismic Upgrade Costs Compared to Expected Damage Costs

Life safety, injury prevention, repair costs, and repair time are the most important metrics when considering whether a seismic upgrade is worthwhile. The preliminary construction cost estimates developed in this study can be compared against expected damage costs at various earthquake levels, as estimated by EPAT. Conservatively, a lower-bound building replacement value of $250 per square foot was assumed (OSPI data from 2012-18 shows that school construction costs ranged from $257 to $426 per square foot) based on basic information provided by OSPI. For future work, it may be prudent to conduct detailed building replacement value estimates in order to produce cost results that can be more accurately extrapolated to the statewide public-school building inventory.

Table 3 below shows the ratio of median estimated building earthquake damage costs divided by the building’s median estimated total seismic upgrade costs, shown as the “cost ratio” in the table. The cost ratio is displayed for the design-level earthquake. A cost ratio greater than 1.0 indicates that the expected damage in an earthquake event exceeds the total seismic upgrade costs.

For the design-level earthquake, the results indicate the average cost ratio is 4.90. Two of the buildings have cost ratios less than 1.0, and thirteen buildings have cost ratios greater than 1.0. These results indicate that for many buildings the cost to seismically upgrade the structure is less or much less than the damage costs the building would incur in an earthquake.

Table 3. Building seismic upgrade costs compared to expected damage costs.

School District, School Building	FEMA Building Type	Year of Construction	Design Earthquake Cost Ratio[1]
Battle Ground, Prairie HS Building 600	Reinforced Masonry	1979	2.59
Boistfort, Boistfort Elementary Gym	Reinforced Masonry	1963	2.62
Carbonado, Carbonado Historical School 19, Gym	Wood Framed	1936	0.89
Centralia, Edison Elementary, Main Bldg	URM	1918	1.95
Cosmopolis, Cosmopolis Elementary, Main Bldg	Wood Framed	1960	1.45
Coupeville, Coupeville High School Gym	Reinforced Masonry	1981	2.60
Dayton, Dayton High School Gym	Steel Light Frame	1965	10+
Grand Coulee Dam, Lake Roosevelt K-12 CTE Bldg	Steel Light Frame	1955	10+
Marysville, Totem Middle School Main Bldg	Reinforced Masonry	1966	2.12
Mount Vernon, Lincoln Elementary Main Bldg	Concrete Shear Wall	1938	1.51
Naches Valley, Naches Valley HS Main Bldg	Reinforced Masonry	1979	3.34
North Beach, Pacific Beach Elementary Gym	Reinforced Masonry	1956	1.25
South Bend, South Bend Jr/Sr HS Koplitz Field House	Reinforced Masonry	1953	2.44

Spokane, Adams Elementary School Main Building	Unreinforced Masonry	1910	0.63
White Salmon Valley, Columbia HS Gym	Tilt-Up Concrete Shear Wall	1970	2.66

1. *Cost ratio is the ratio of median estimated building earthquake damage costs divided by the building's median estimated total seismic upgrade costs.*

Washington State EPAT Summary Findings

Table 4 below shows the EPAT median, average, maximum, and minimum results for all 222 buildings included in the study. The information displayed in the table is based on each building's existing configuration and estimations of loss, life safety risk level, and post-earthquake tagging as expected for the design earthquake. An EPAT "scoresheet" for each school building is included in the final engineering report and can be downloaded from the links in Appendix E.

Table 4. Washington State schools EPAT summary results for school buildings.

Calculated Value	Median	Average	Max	Min
Building damage estimate ratio (Proportion of building that is damaged)	43%	45%	95%	5%
Probability building is not repairable	22%	35%	82%	9%
Life safety risk level	Moderate	-	Very High	Very Low
Most likely post-earthquake tagging	Red*	-	Red*	Green*

**Red = Unsafe to Occupy, Yellow = Restricted Building Access, Green = No Restrictions on Building Access*

The primary value calculated for each building from the EPAT spreadsheet is the amount of damage each existing building is expected to sustain in a design-level earthquake. This value is displayed as a percentage of the building elements that are expected to be damaged. The EPAT spreadsheet only returns performance values for the building's structural systems, but nonstructural systems are likely to also sustain significant damage in a large earthquake.

The EPAT summary results in Table 4 show that the median building is expected to have approximately half of its building elements damaged. It is expected that almost a quarter of the buildings included in the study will not be repairable, meaning these buildings will likely need to be demolished. The most likely post-earthquake tagging identified by EPAT is “Red,” meaning the majority of school buildings included in the study are expected to not be safe to occupy following the design-level earthquake.

Building damage estimate ratios are loosely correlated to building type and seismic hazard as shown in Figure 11, which depicts building damage estimate ratios against building construction or seismic upgrade date. The figure also includes different symbols for the building lateral system’s primary construction material type. As illustrated in the figure, the dominant school construction type prior to the 1940s was unreinforced masonry. Prior to the 1940s, there were also some schools constructed of wood and concrete. Starting in the 1950s, many of the school buildings were constructed of reinforced masonry, wood, concrete, and steel. During the 1950s and after, the most prominent building construction types were wood and reinforced masonry.

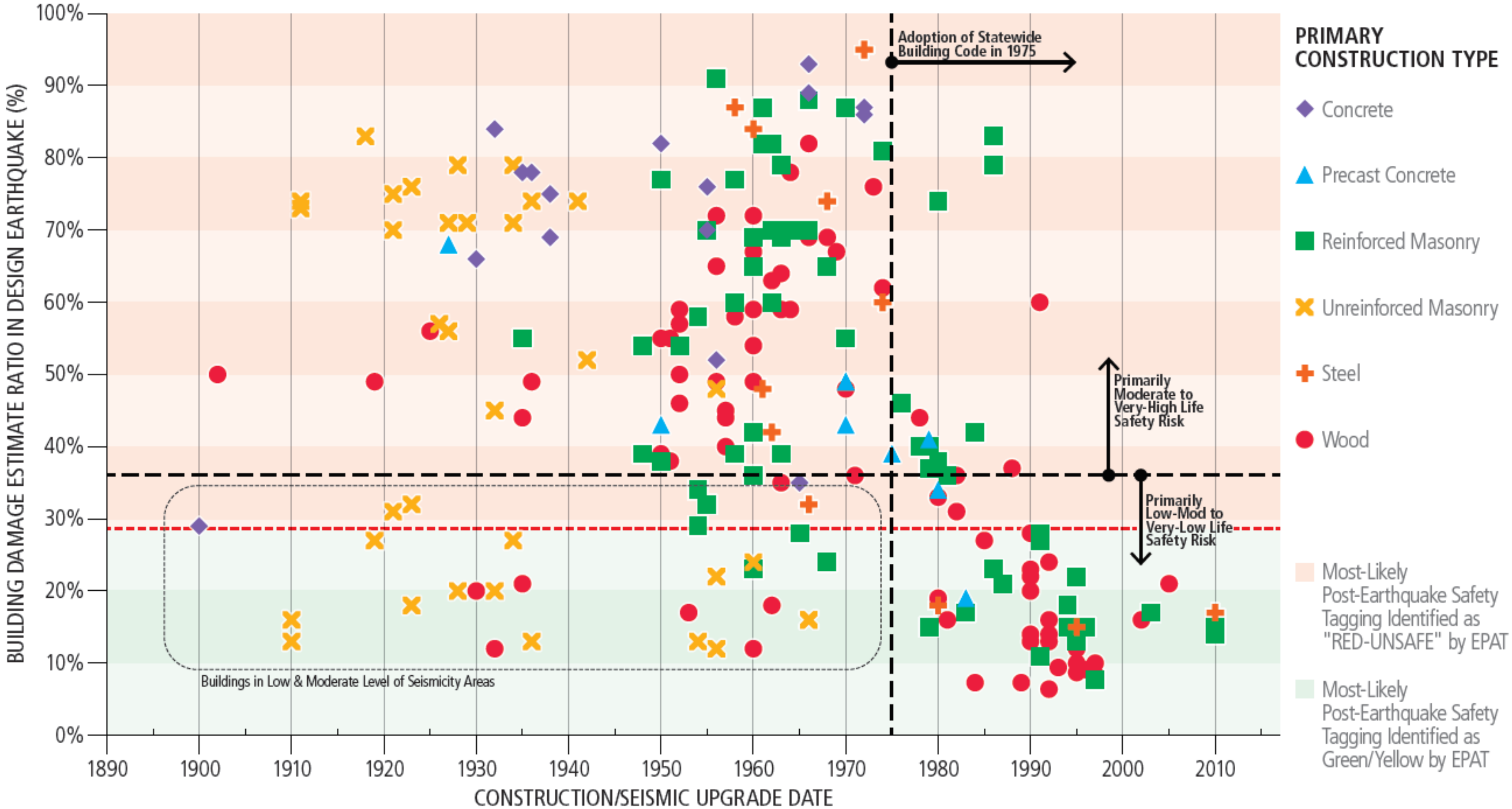


Figure 11. EPAT building damage estimate ratio in ASCE 7/41 design-level earthquake categorized by primary construction type.

Unreinforced masonry buildings and non-ductile concrete buildings are especially vulnerable to earthquakes due to their weight and brittle nature, and these buildings have well-known seismic risks in high seismic hazard areas. As seen in Figure 11, many of these school buildings possess damage estimate ratios in the range of 70 to 80 percent. However, the figure also shows that many unreinforced masonry school buildings display damage estimate ratios of between 10 and 30 percent. Figure 11 also shows that school buildings built after 1975 have precipitously decreasing damage estimate ratios, with school buildings constructed in the 1990s and the 2000s generally possessing the lowest damage estimate ratios of all the 222 school buildings evaluated.

For the most part, unreinforced masonry buildings that display relatively low damage estimate ratios are not located in "high" seismic hazard areas as defined by ASCE 41 (such as parts of eastern Washington). Approximately half of the unreinforced masonry school buildings included in the study are located east of the Cascade Mountain Range (Fig. 6). As expected, Figure 12 shows that many of the schools with the highest estimate of damage following a design-level earthquake are located in areas of highest earthquake hazard.

One significant factor in earthquake performance is the building code standard to which a building was originally designed. The EPAT spreadsheet separates Washington State into zones where the design standards at the time of construction were different. Historically, western Washington and more specifically, the Puget Sound region, has had the strictest seismic code requirements. Buildings in the Puget Sound region were also designed for the highest level of earthquake shaking due to the high seismicity of the region. Buildings in the rest of Washington State were historically designed to lower seismic forces and detailing (toughness) standards.

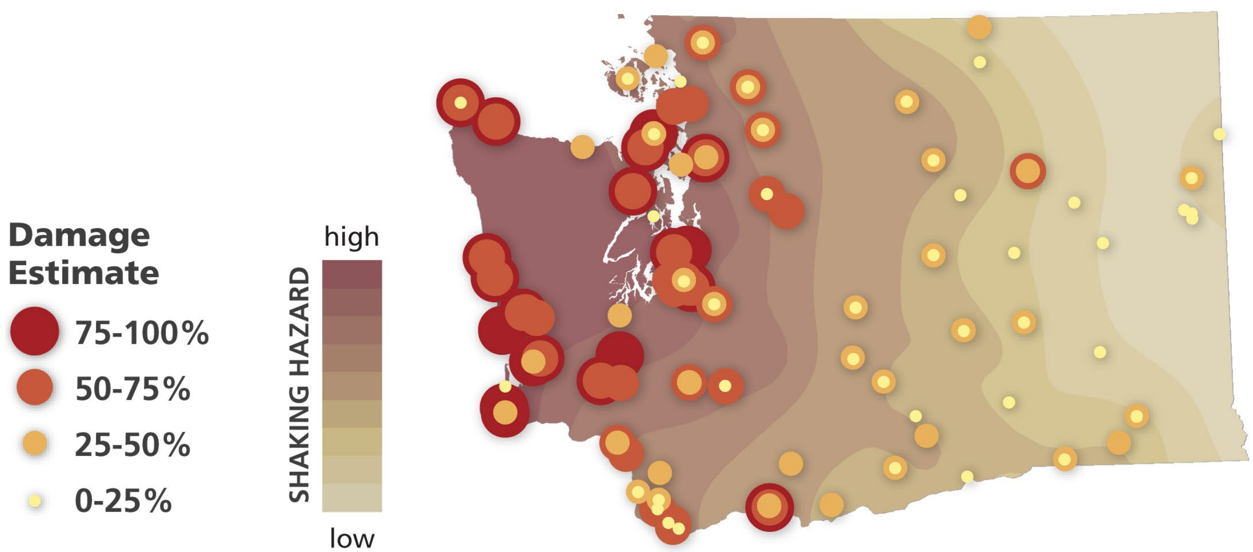


Figure 12. Map of Washington showing school buildings assessed in Phase 1 symbolized by percent damage estimate as calculated using the EPAT tool. The basemap illustrates the peak ground acceleration for a 2% in 50-year earthquake, from the USGS seismic hazard map (Petersen and others, 2014). This is a rough proxy for the estimated shaking hazard for the State.

EPAT Results for Most-Likely Post-Earthquake Tagging

Post-earthquake safety evaluations of buildings tagging is governed in the United States by building officials' adoption of the ATC-20 *Procedures for Post-Earthquake Safety Evaluation of Buildings* guideline. This document separates post-earthquake safety tagging into three post-earthquake building safety categories. Buildings can be tagged as Red Placard—UNSAFE, Yellow Placard—RESTRICTED USE, or Green Placard—INSPECTED. The Red Placard indicates that a building is unsafe to occupy. A Yellow Placard indicates that access is restricted and hazards exist, but limited access may be allowed under certain circumstances. A Green Placard indicates there are no restrictions on post-earthquake occupancy.

The EPAT tool estimates the post-earthquake safety evaluation tagging of a building and also includes the possibility for buildings to be identified as Yellow/Red or Green/Yellow, presumably as damage states that lie midway between the RESTRICTED USE and UNSAFE placards and the INSPECTED and RESTRICTED USE placards. While these are not defined in the ATC-20 post-earthquake safety evaluation guidelines, these designations mean that there is a likelihood that a building may be tagged as either yellow or red, or green or yellow, respectively.

Figure 13 shows the EPAT building damage estimate ratios for the school buildings, categorized by the EPAT most likely estimated post-earthquake tagging. **Based on the simplified EPAT analysis worksheets, for the majority of buildings in the study (139 out of 222) the most-likely post-earthquake tagging is expected to be Red - UNSAFE (for the ASCE 7/41 design-level earthquake).**

EPAT Worksheet Results for Life Safety Risk Level

Figure 14 shows the EPAT school building damage estimate ratios for the buildings, categorized by the EPAT-estimated life-safety risk level. The life-safety risk level reflects the relative risk for loss of life in the ASCE 7 design-level earthquake. **Based on the simplified EPAT analysis worksheets, and as seen in the figure, almost half of the buildings in the study (95 of 222) pose a "high" or "very high" risk for life safety in the design-level earthquake.**

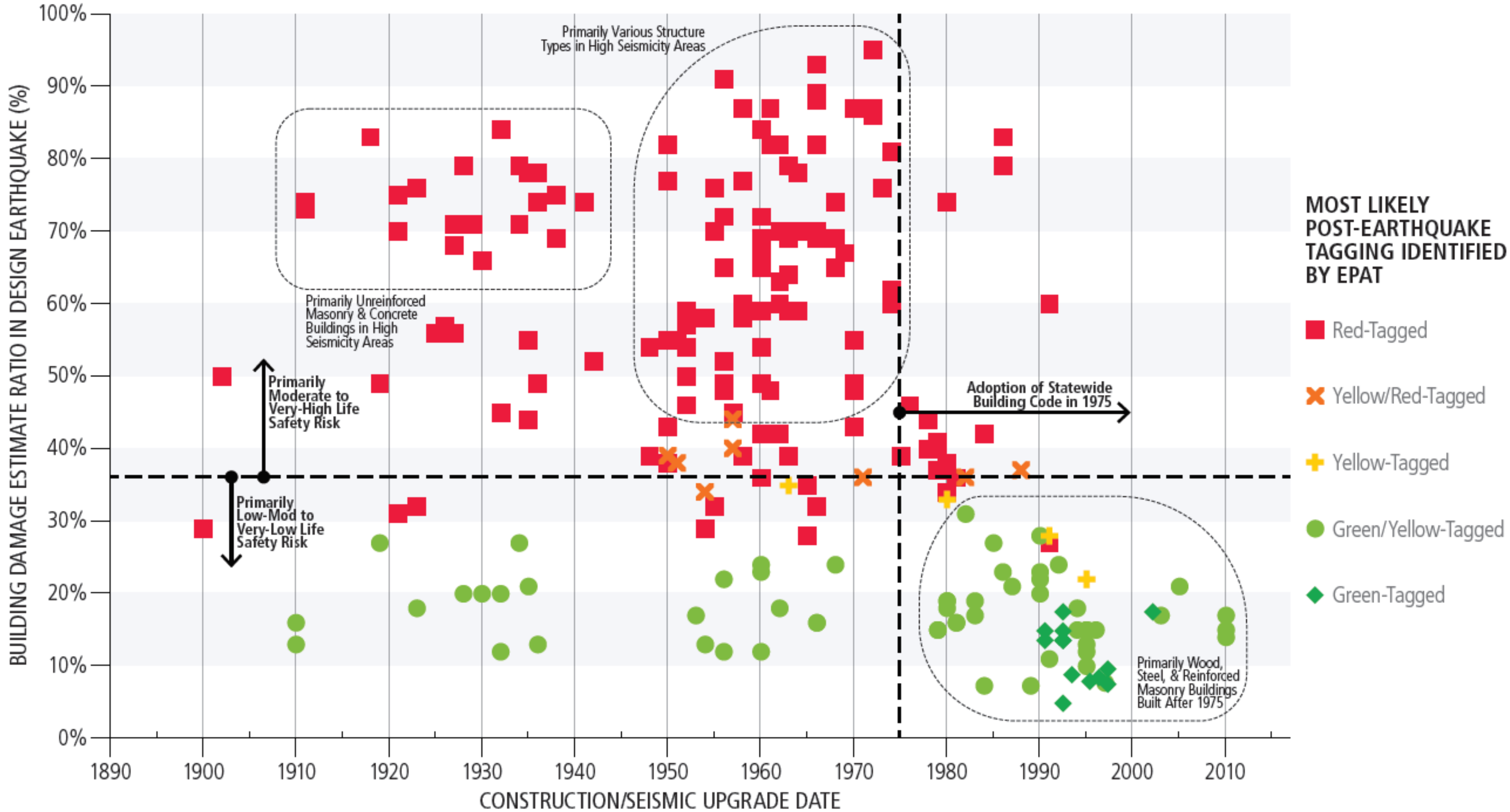


Figure 13. EPAT estimated most likely post-earthquake ATC-20 tagging after ASCE 7/41 design level earthquake.

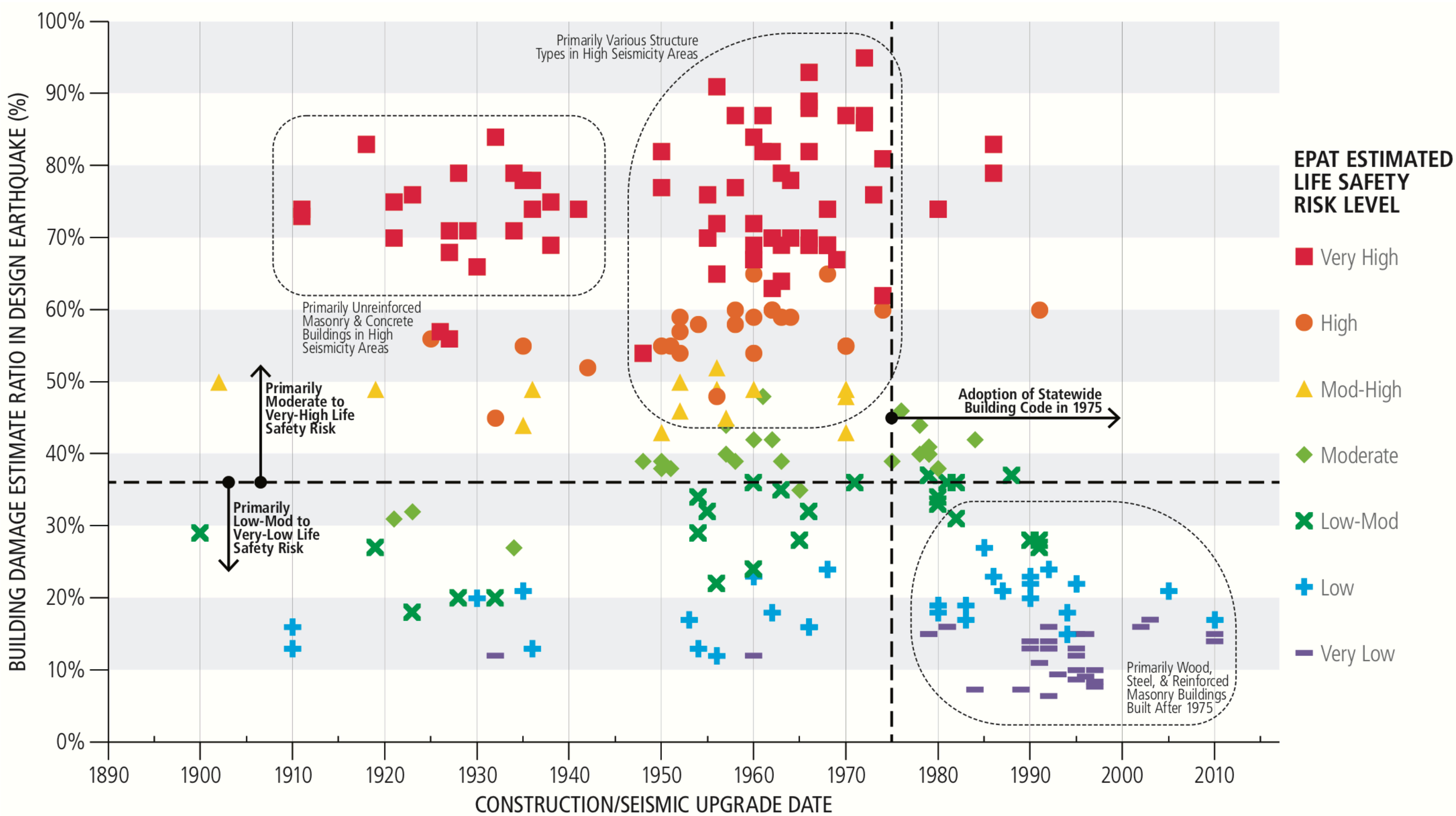


Figure 14. EPAT estimated life-safety risk level vs. building age in ASCE 7/41 design level earthquake.

EPAT Economic Analysis and Estimates

A detailed economic analysis was not included in the scope of this project. However, EPAT provides an initial estimate of how much of a building is expected to be damaged during a design-level earthquake in relation to its replacement value. This information can be used to determine the direct financial costs to the building stock due to earthquake events.

In order to conduct an economic analysis of the school buildings, it is important to know the replacement value of the buildings. OSPI provided our structural engineering consultant, Reid Middleton, with a list of construction costs for new school buildings and renovations of school buildings from 2012 through 2017. The construction costs of new buildings varied depending on contract method, among other factors. In addition, buildings constructed in 2017 were, on average, more expensive than buildings constructed in 2012. In general, construction costs varied from a low of \$256 to \$324/ft^2 in 2012 to \$373 to \$426 per square foot in 2017.

Given the recent rapid escalation of construction costs since the financial crisis of 2008–12, and the desire to use a conservative school construction cost that is more in line with longer-term costs, we used a replacement cost of \$250 per square foot for existing school buildings. While this value is on the low end of the information provided by OSPI, it was selected assuming that existing buildings may not have as expensive or complicated finishes as some of the newest school buildings. We also did not want to dramatically overestimate the value of the existing buildings due to scarcity in the construction environment in recent years. However, an extensive replacement value study was not conducted, and this value was arbitrarily selected based on the information provided by OSPI.

The 222 buildings included in the statewide study have a combined square footage of approximately 6,027,000 square feet. Using the assumed replacement cost of \$250 per square foot, the 222 buildings have a replacement cost estimated at \$1.5 billion. The EPAT spreadsheet estimates the direct damage costs to all 222 study buildings for the design-level earthquake to be \$642 million.

It is important to note that the direct damage costs above only account for the direct damage to the physical building infrastructure. These costs do not account for costs associated with loss of life or business interruption costs associated with the school buildings being closed and inoperable for an extended period of time. These other costs can be substantial. If school buildings are closed for three to six months or longer, school districts must find alternative locations for student instruction. If schools are entirely closed for long periods of time, parents must find alternative activities or child care for their children when they would normally be in school. The long-term closure of school buildings could have profound effects on the economy and well-being of school-aged children beyond the direct damage costs listed above.

ASCE 41 Tier 1 Seismic Screening Findings

ASCE 41 Tier 1 seismic screening evaluations were conducted on the 222 school buildings included in the study. This section describes the findings and trends associated with these seismic screening evaluations.

For about 35 percent of the buildings studied, original record construction drawings and other building construction and configuration information were not available for review, so the engineering data-gathering was limited to visual observations by the project team of licensed structural engineers. Where building component seismic adequacy was unknown due to lack of available information, the unknown conditions were indicated on the ASCE 41-17 Tier 1 seismic screening checklists. The findings are as follows:

1. The average and median year of construction of the 222 buildings is 1963.
2. The average and median occupied space area is 27,359 square feet, and 18,940 square feet, respectively.
3. Figure 15 below illustrates the distribution of building material types represented in this study.

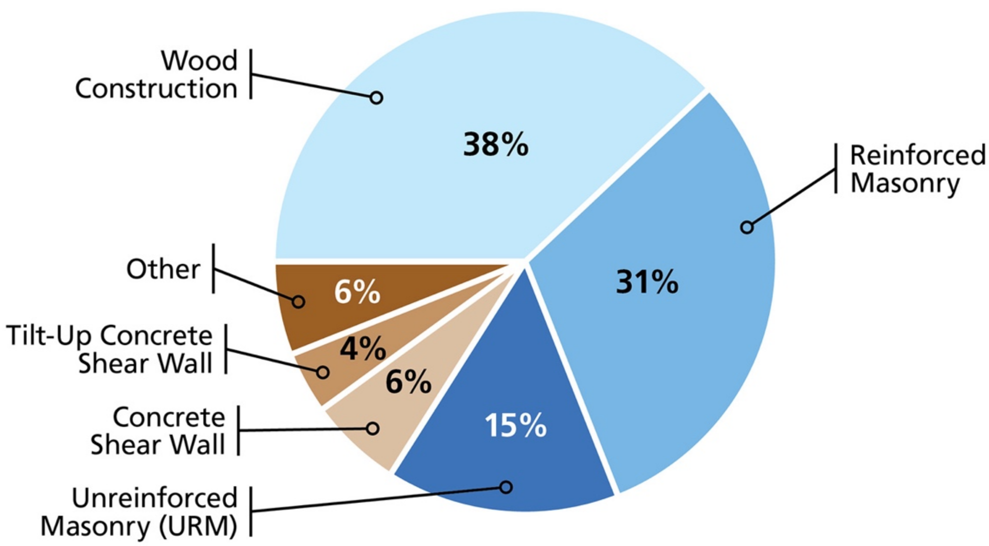


Figure 15. Distribution of Building Material Types of 222 School Buildings Studied.

As expected, most of the ASCE 41 Tier 1 Screening Evaluation noncompliant features were related to building elements that were likely not strong enough or not adequately interconnected to reliably resist seismic loads and (or) are from older construction methods, such as URMs (Fig. 16). Additionally, many of the buildings utilize archaic building materials that do not possess adequate toughness (ductility) or reliable load path for earthquake loads. These seismic weaknesses are typically found in walls, roofs, and floors and are particularly non-compliant where these structural elements are weakly interconnected. These weak structural elements or weak connections are typically not strong or tough enough to reliably transfer (or resist) earthquake loads to the foundations.

ASCE 41 Tier 1 Seismic Screening Analyses

The results of the ASCE 41 Tier 1 evaluations were analyzed for trends that may indicate characteristic hazards and similarities and differences between buildings of different vintages and with different features. Figure 16 shows the percent of items classified as either noncompliant or unknown. Older buildings have a higher percentage of seismically noncompliant or unknown items. This relationship is to be expected as these buildings were built to older versions of building codes, or in some cases no building code at all. One URM building possesses a noncompliant or unknown percentage of about 90 percent. **There is no building within the statewide sample of 222 school buildings that has zero noncompliant or unknown seismic screening evaluation items.**

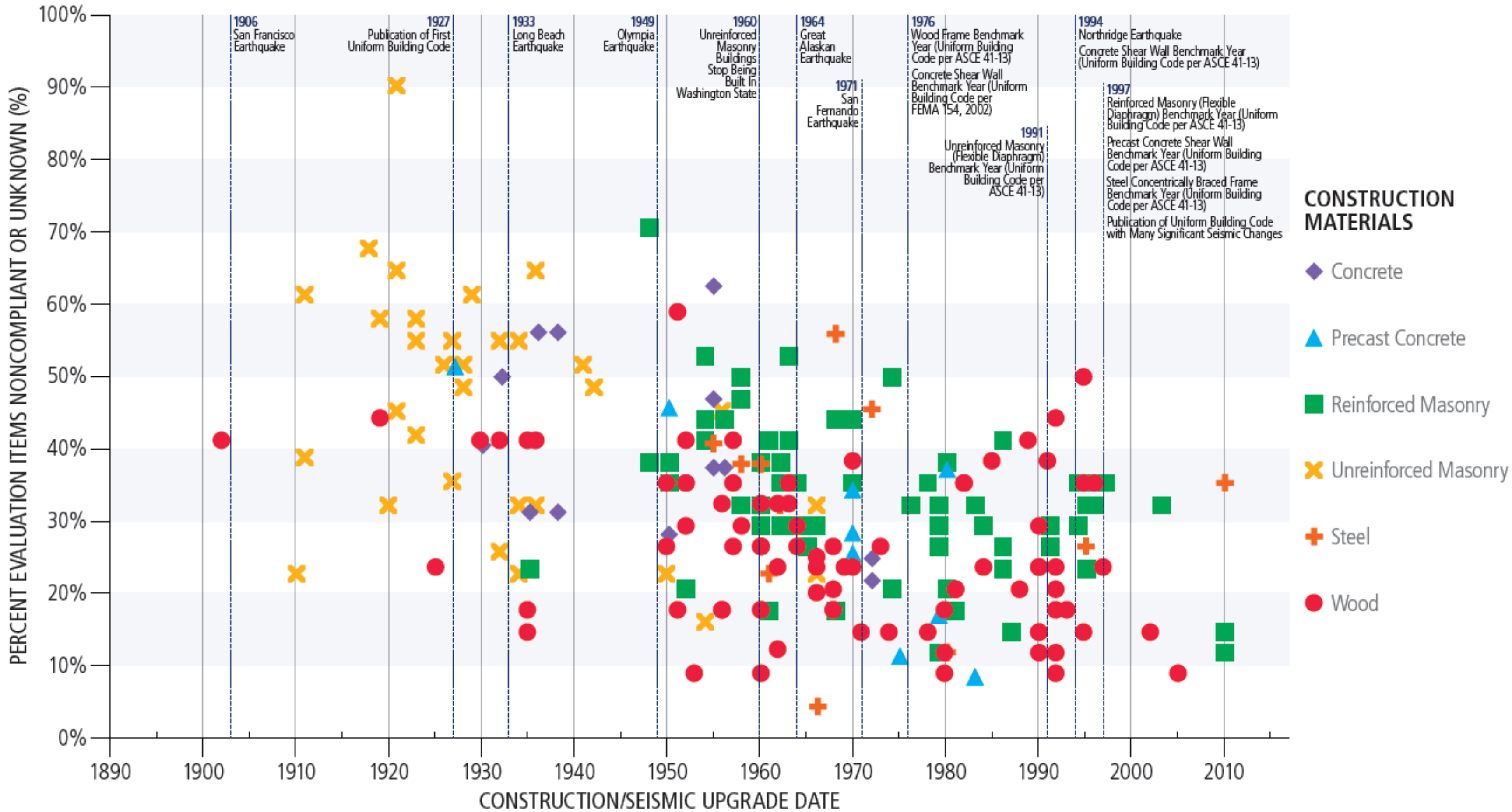


Figure 16. Noncompliant or unknown evaluated building components versus construction date (or last major renovation date) for the 222 school buildings assessed in Phase 1, symbolized by construction type. Chart illustrates major changes in building codes in Washington State.

Costs to Seismically Upgrade Schools

Seismic upgrade construction costs were studied for each of the 15 school buildings that received more detailed concept-level seismic upgrade design recommendations as part of this study. The input for these preliminary probable construction costs are based partly on sketches prepared by experienced structural engineers. These preliminary concept-level design sketches depict a design concept, or possibility for upgrade components for each of the 15 school buildings that could be implemented to improve the seismic safety of that specific school building. Figure 17 provides one example of such a design for the first floor of Lincoln Elementary School, Mount Vernon, WA.

It is important to emphasize that the estimated costs developed for these buildings are preliminary in nature as they are based on the results of the Tier 1 seismic screening checklists and engineering design judgement and have not been substantiated by more typical detailed structural analyses. **Consequently, the costs presented here are very preliminary in nature and are used to make some very generalized costs ranges statewide.**

For these estimated costs, the current year (2019) construction cost of the probable scope of work was developed. Then a -20 percent (low) to +50 percent (high) range variance was used to develop the construction cost estimate ranges. The -20 percent to +50 percent range variance guidance is based on recommended practices given the limited level of design.

These preliminary estimates of construction costs include labor, materials, equipment, and general contractor conditions (mobilization), overhead, and profit. Project costs not included in the construction cost estimate are building permits, design fees, change order contingencies, escalation, materials testing/inspection, project planning and design schedule delay contingencies, and owner's overall project contingency. Additional owner's project costs would likely include owner's general overhead costs, including project management, financing/bond costs, administration/contract/accounting costs, review of plans, value engineering studies, equipment, fixtures, furnishings and technology, and relocation of the school staff and students during construction. These additional costs are not included in this preliminary concept-level design construction cost estimate.

Other costs excluded from the construction costs are site work, construction of replacement facilities, and mitigation of seismic risks for existing facilities and building code changes that occur over time after this report. **Future planning budgets should not be set on the basis of the preliminary construction cost estimates presented in this report.** For budget planning purposes, it is highly recommended that a seismic upgrade budget be determined after the owner defines the scope of work and obtains the services of a professional architect/engineer-led design team.

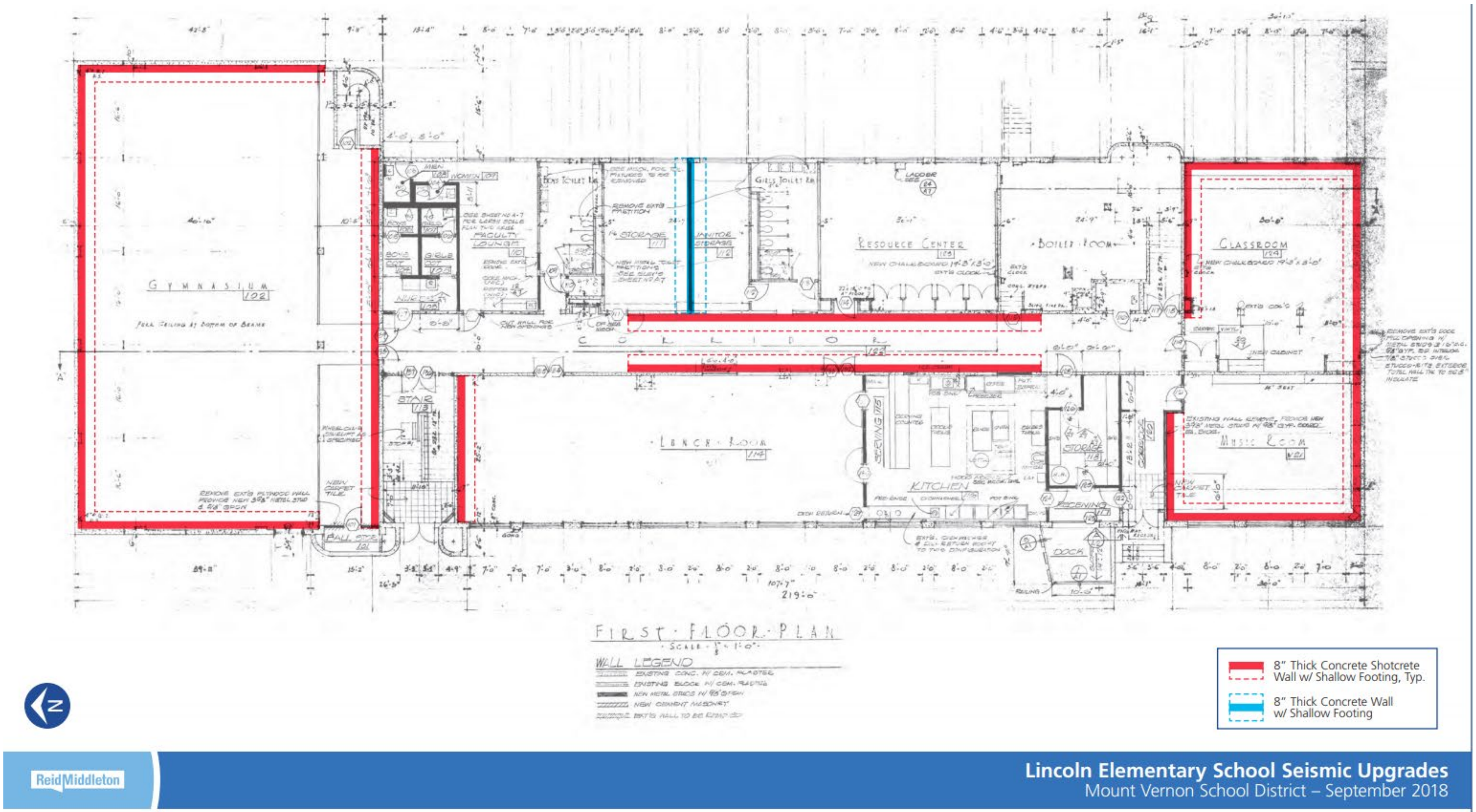


Figure 17. Example of a seismic upgrade design plan for part of the first floor of Lincoln Elementary School, Mount Vernon, WA.

Because seismic upgrade costs are highly dependent on the building type, material, location, configuration, age, and quality among many other factors, the estimated seismic upgrade costs have been aggregated by material type. Table 5 below lists the total structural and nonstructural seismic upgrade estimated cost ranges for each of the 15 subject buildings and their corresponding averages. The cost ranges are presented as cost per square foot (SF) of building area so these estimated cost ranges can be extrapolated to other similar building types and sizes.

Seismic structural upgrade costs vary from a low of $0.55 per square foot to a high of $122 per square foot. The average seismic structural upgrade cost for the IO concept-level upgrades is $69 per square foot. The average seismic structural upgrade cost for the LS concept upgrades is $42 per square foot. There is significant variation in seismic structural upgrade costs, dependent upon what structural deficiencies a building possesses and the extent of the required structural upgrades for each specific building.

Nonstructural component seismic upgrade cost estimates were also prepared for the 15 school buildings in this study. These costs are only for the seismic upgrade of building nonstructural components such as suspended ceiling systems, fire protection equipment, and mechanical systems. Nonstructural component seismic upgrade costs vary from a low of $0.35 per square foot to a high of $71 per square foot. The average nonstructural component seismic upgrade cost is $27 per square foot. There is significant variation in nonstructural component seismic upgrade cost, dependent upon what seismic deficiencies a building possesses and the extent of the required seismic upgrades.

Table 5 lists combined structural and nonstructural component seismic upgrade costs, or total combined costs for these 15 buildings. Average total seismic upgrade costs vary from a low of $2.30 per square foot to a high of $182 per square foot. The average total seismic upgrade cost is $75 per square foot. There is also a significant variation in total seismic upgrade costs that are dependent upon what deficiencies a building possesses and the extent of the required seismic upgrades. For complete concept-level seismic upgrade design reports and costs developed for each of these school buildings and for the ASCE 41 Tier 1 screenings, please download the individual school reports found in Appendix E.

Table 5. Total structural and nonstructural seismic upgrade cost estimates (grouped by building type).

School District, School Building, Bldg. Type	Original Date of Construction	ASCE 41 Level of Seismicity / Site Class	Performance Objective	Bldg. Gross Area (SF)	Total Upgrade Cost Range $/SF (Total)			Median Total, $/SF (Total)
Battle Ground, Prairie HS Building 600, **Reinforced Masonry**	1979	High / D	Life Safety	10,725	$45 ($488K)	-	$85 ($915K)	$57 ($610K)
Boistfort, Boistfort Elementary Gym, **Reinforced Masonry**	1963	High / D	Life Safety	14,530	$60 ($910K)	-	$113 ($1.71M)	$75 ($1.14M)
Coupeville, Coupeville High School Gym, **Reinforced Masonry**	1981	High / D	Life Safety	10,000	$22 ($216K)	-	$40 ($404K)	$27 ($269K)

Marysville, Totem Middle School Main Bldg, **Reinforced Masonry**	1966	High / D	Life Safety	22,384	$66 ($1.45M)	-	$123 ($2.72M)	$82 ($1.81M)
Naches Valley, Naches Valley HS Main Bldg,**Reinforced Masonry**	1979	High / D	Life Safety	85,173	$22 ($1.07M)	-	$42 ($2.01M)	$29 ($1.34M)
North Beach, Pacific Beach Elementary Gym, **Reinforced Masonry**	1956	High / D	Life Safety	10,049	$145 ($1.46M)	-	$273 ($2.74M)	$182 ($1.83)
South Bend, South Bend Jr/Sr HS Koplitz Field House, **Reinforced Masonry**	1950	High / E	Life Safety	16,254	$63 ($1.03M)	-	$119 ($1.93M)	$79 ($1.29M)
Reinforced Masonry Averages	**1968**			***24,159*** [2]	***$60***	-	***$114***	***$76***
Carbonado, Carbonado Historical School 19, Gym, **Wood Framed**	1936	High / C	Life Safety	5,700	$110 ($593K)	-	$206 ($1.11M)	$137 ($740K)
Cosmopolis, Cosmopolis Elementary, Main Bldg, **Wood Framed**	1960	High / D	Life Safety	30,460	$100 ($3.03M)	-	$187 ($5.69M)	$124 ($3.8M)
Wood Framed Averages	**1948**			***18,080*** [2]	***$105***	-	***$197***	***$131***
Centralia, Edison Elementary, Main Bldg, **Unreinforced Masonry**	1918	High / C	Life Safety	31,520	$86 ($2.70M)	-	$160 ($5.05M)	$107 ($3.37M)
Spokane, Adams Elementary School Main Building, **Unreinforced Masonry**	1910	Low / C	Life Safety	27,300	$42 ($1.14M)	-	$78 ($2.14M)	$52 ($1.43M)
Unreinforced Masonry Averages	**1914**			***29,410*** [2]	***$64***	-	***$119***	***$80***
Dayton, Dayton High School Gym, **Steel Light Frame**	1966	Low / B	Life Safety	27,152	$2 ($50K)	-	$3.50 ($95K)	$2.30 ($63K)

Grand Coulee Dam, Lake Roosevelt K-12 CTE Bldg, **Steel Light Frame**	1955	High / D	Life Safety	46,336	$3.10 ($142K)	-	$5.70 ($266K)	$3.80 ($177K)
Steel Light Frame Averages	**1960**			***36,744*** [2]	***$3*** [1]	-	***$5*** [1]	***$3***[1]
Mount Vernon, Lincoln Elementary Main Bldg, **Concrete Shear Wall**	1938	High / C	Life Safety	40,002	$101 ($4.01M)	-	$188 ($7.52M)	$125 ($5.01M)
White Salmon Valley, Columbia HS Gym, **Precast Concrete Shear Wall**	1970	High / C	Life Safety	33,246	$37 ($464K)	-	$70 ($869K)	$47 ($580K)
Precast Concrete and Concrete Shear Wall Averages	**1954**			**36,624** [2]	***$69***	-	***$129***	***$86***
OVERALL AVERAGES	**1955**			***27,389*** [2]	***$60***	-	***$113***	***$75***

1 The S3 buildings estimated are Pre-Engineered Metal Buildings (PEMB) in regions with lower design seismic accelerations and may not be representative of PEMB in high-seismic hazard regions. Therefore, this cost/square foot should not be extrapolated to other steel buildings statewide.

2 The average areas are being used by the study team to correlate the data gathered to the rest of the school buildings evaluated in this project.

These estimated seismic upgrade cost ranges and their corresponding variability are also illustrated in the following figures (Figs. 18, 19, and 20).

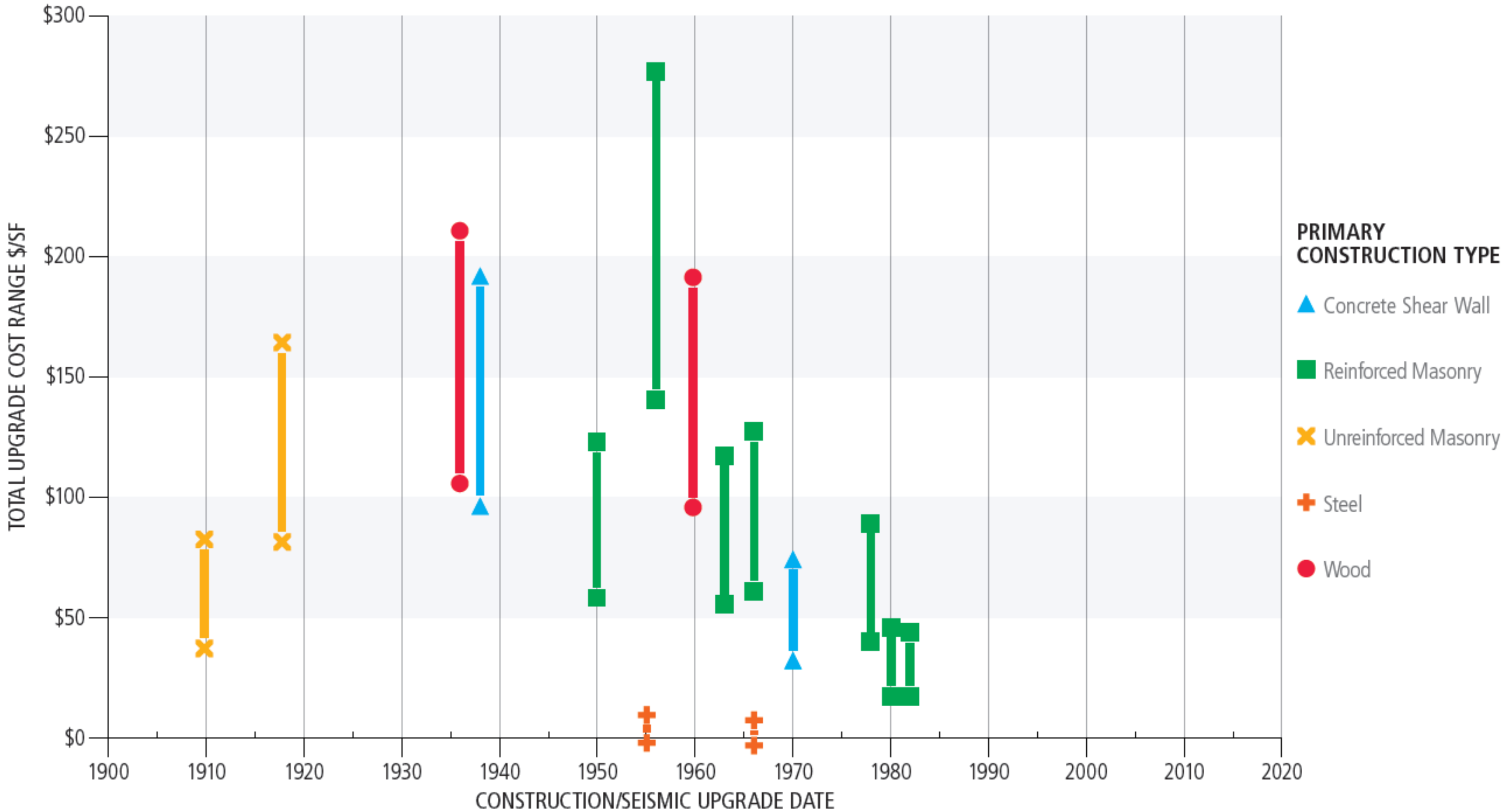


Figure 18. Total seismic upgrade (structural and nonstructural) cost ranges by age and building construction type.

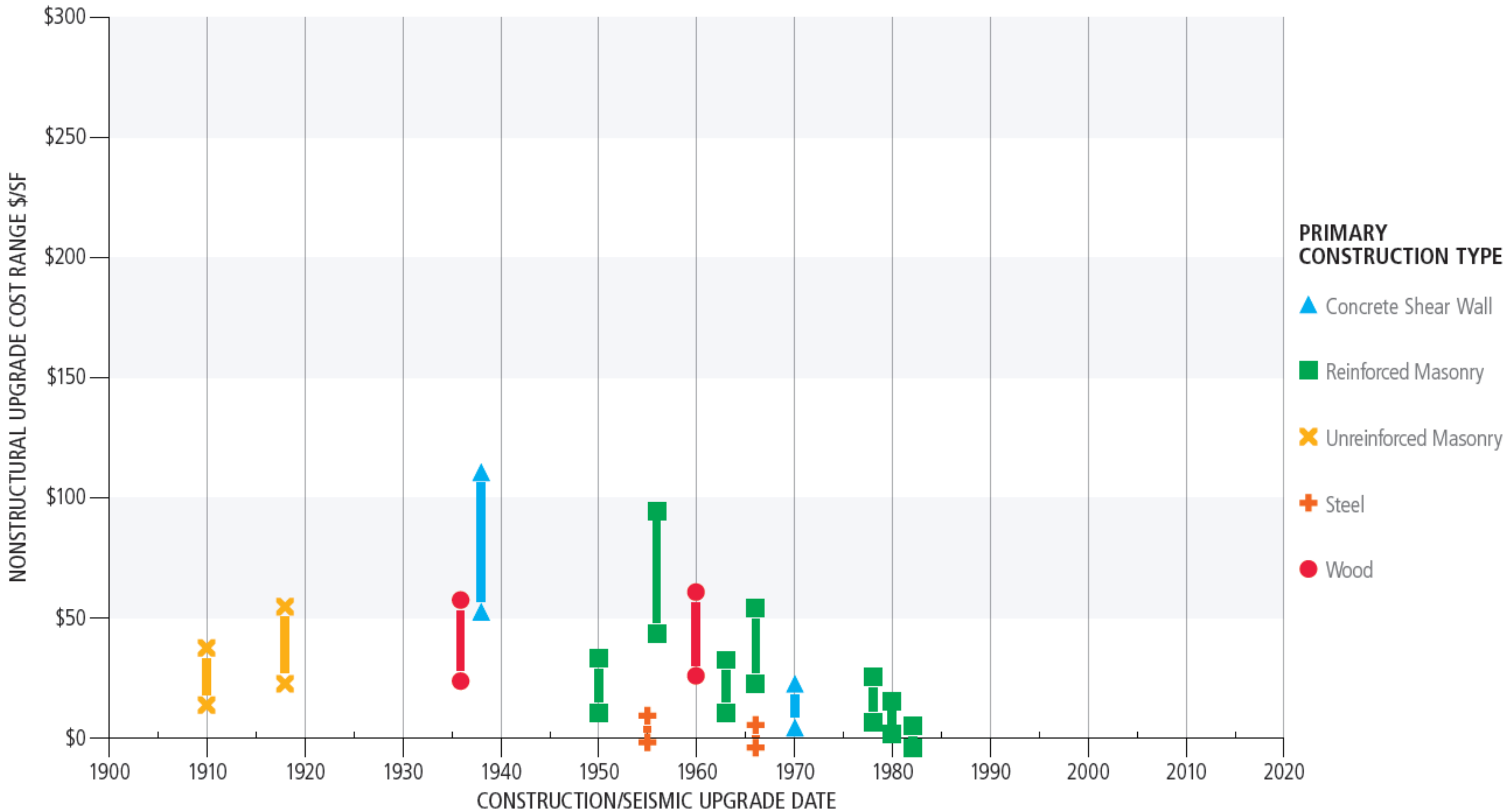


Figure 19. Nonstructural seismic upgrade cost ranges by age and building construction type.

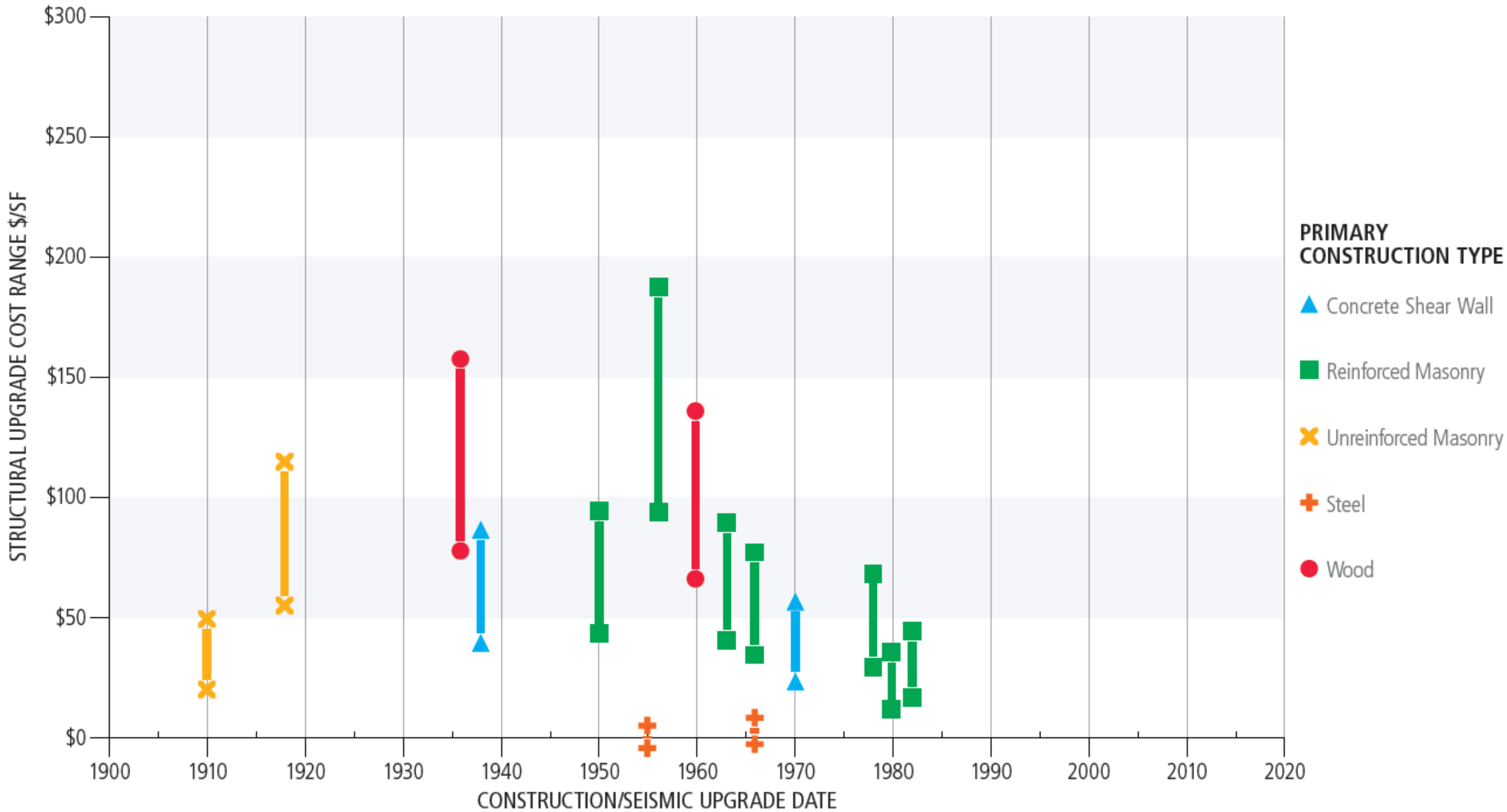


Figure 20. Structural seismic upgrade cost ranges by age and building construction type.

Extrapolation for State

Here we present some rudimentary extrapolations for statewide seismic assessment needs and upgrade costs for all permanent school buildings in the State. However, it is important to note that this study represents a very small sample of older school buildings that does not necessarily reflect the greater population of Washington State school facilities. The map below (Fig. 21) illustrates how few school buildings were assessed in relation to how many schools there are. Figure 22 shows the distribution of all permanent school buildings categorized by decade of construction (or last major modernization) and highlights the population of schools that were assessed in this initial Phase 1 study.

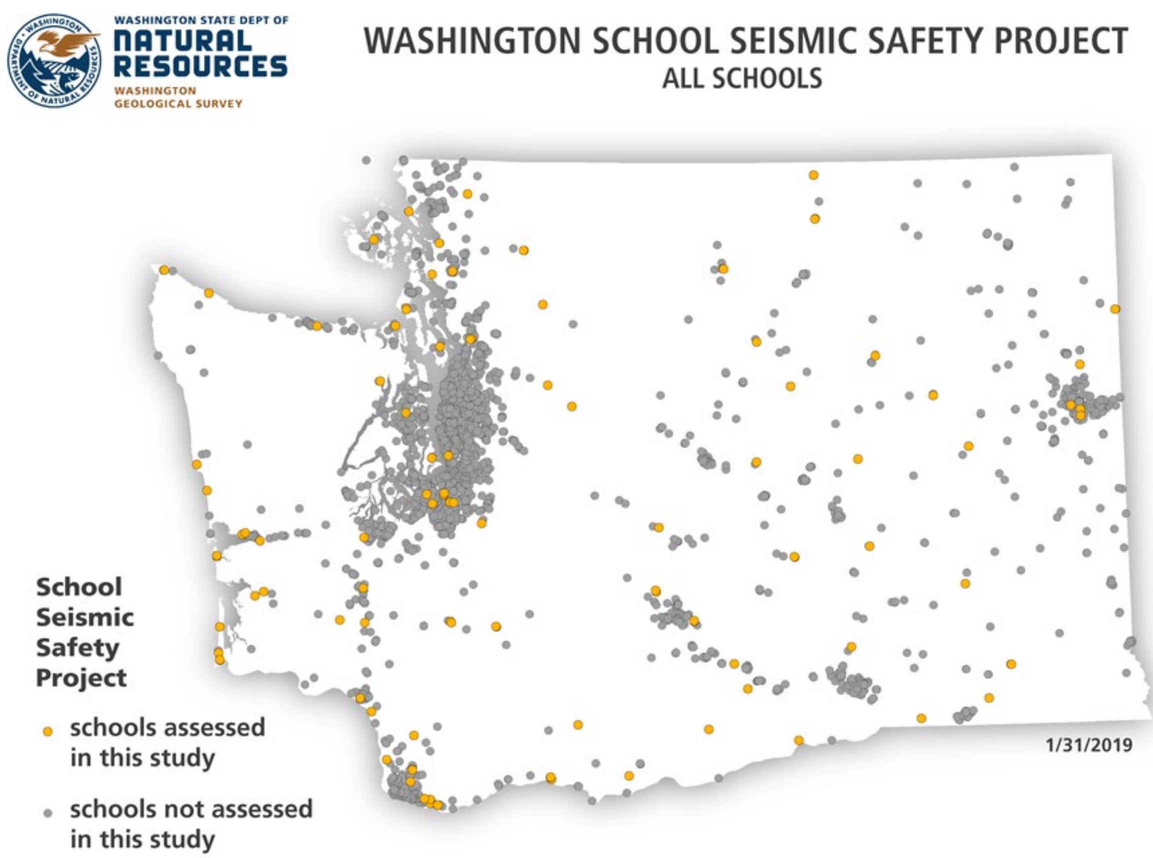


Figure 21. Map of Washington State showing permanent public K–12 school buildings.

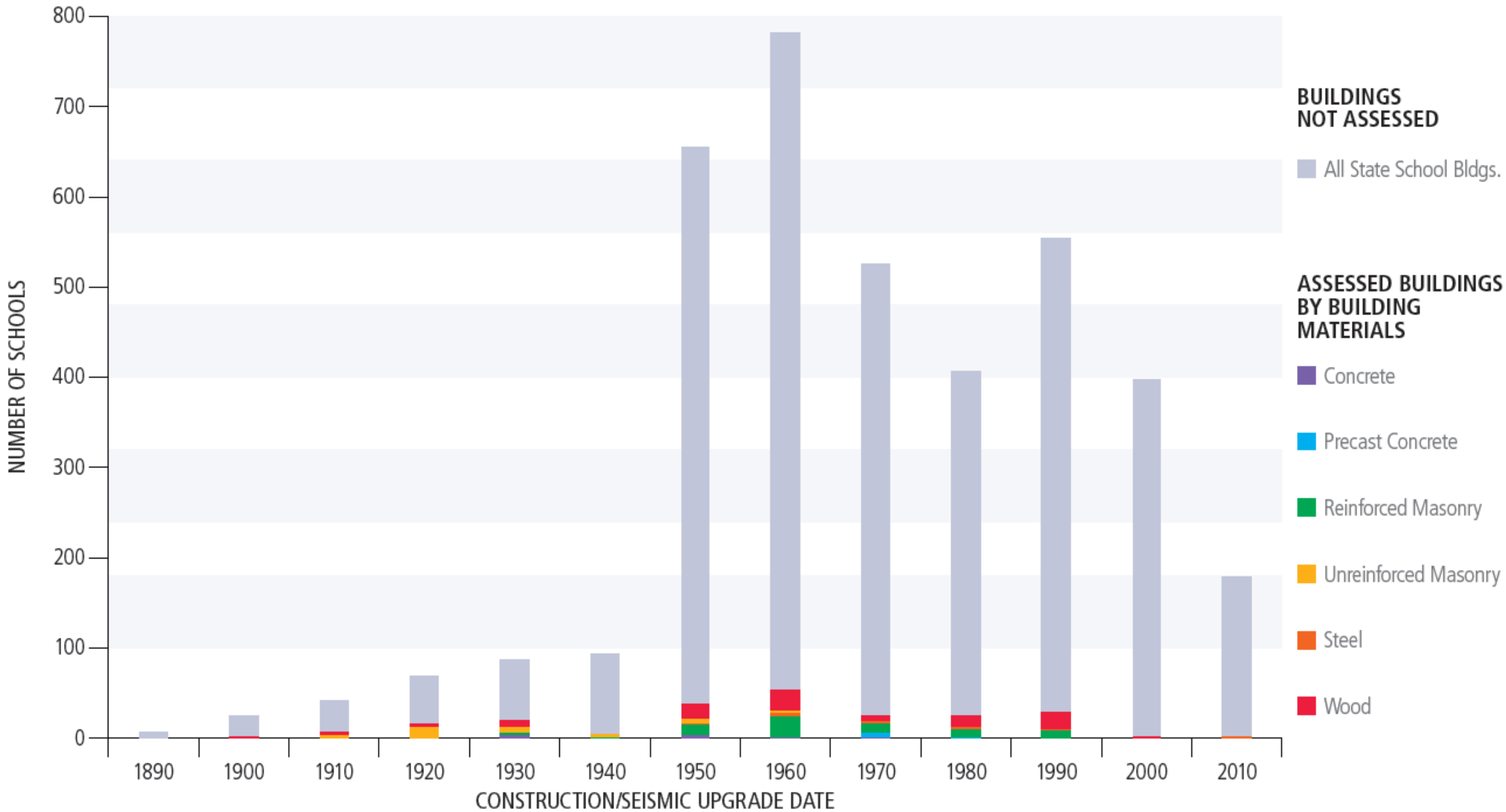


Figure 22. Histogram of the number of permanent, public K–12 Washington schools (gray) categorized by decade built or the date there was a last major seismic upgrade based on the ICOS database. Schools assessed in Phase 1 are colored by construction type (such as wood and concrete).

Cost Extrapolation

The concept upgrade cost estimates developed as part of this study indicate that there is significant variability in building seismic upgrade costs depending on level of seismicity, building construction type, building age, and other building-specific characteristics. Also, the seismic upgrade costs developed as part of the study were developed for both structural and nonstructural components assuming that no other construction work is occurring at the same time.

The results of this study indicate that the average school building in Washington State covers 27,358 square feet. The average concept upgrade costs identified in this study for structural life safety upgrades are \$34–\$63 per square foot. For the average Washington State school building, these costs equate to typical structural upgrade costs of \$0.93–\$1.72 million per building. The range of average concept upgrade costs identified in this study for nonstructural life safety upgrades are \$20–\$37 per square foot. For the average Washington State school building, these costs equate to typical nonstructural upgrade costs of \$0.55–\$1.01 million per building. If you combine the averages for structural and nonstructural seismic upgrades, the average cost to seismically upgrade is ~\$1.48–\$2.73 million per building, with a low of \$63,000 and a high of over \$5 million.

It is often most economical to mitigate structural and nonstructural seismic hazards when a building is already undergoing mechanical, electrical, plumbing, or architectural upgrades or modernizations. If seismic upgrades are conducted at the same time as the renovation of other building elements, the costs associated with seismic upgrades can be substantially reduced. This is because typically the removal and replacement of ceilings, partition walls, finishes, or mechanical and plumbing equipment are a substantial component of seismic upgrade costs. If this equipment is already being renovated or modernized it can lead to substantial cost savings. In addition, some nonstructural seismic improvements can be easily mitigated by school districts at little cost (such as bracing of cabinets/bookshelves, moving heavy contents to the bottom of shelving, or adding seismic strapping or bracing to water tanks and overhead elements).

Other states have developed building seismic upgrade programs (Appendix G) that allocate annual funding to be used on improving seismic safety. It is likely that spending on seismic upgrades of Washington State school buildings will result in a positive return on investment. It is recommended that future studies conduct detailed evaluations of the economic costs of earthquakes and relative benefits of seismic upgrades to the school system. Similar economic analyses conducted by other states have shown significant economic benefits associated with the seismic upgrade of certain buildings.

Communicating Results to Schools and the Public

Communicating the project results to state agencies and the legislature is just one part of the communication plan for the SSSP. The other element of this plan is to send each of the seismic screening reports, the geologic site class assessment reports, and links to download the statewide comprehensive reports to each of the 75 school district superintendents and principals who graciously provided information on their schools and access for our team of geologists and structural engineers. Much of this information can be very useful to the school districts as they maintain and improve their school buildings and facilities.

Our project team has been regularly corresponding with the school districts that have been involved in this initial study and has acted as a seismic safety advocate for each of the school districts. The work and results of this study are being communicated up to the legislature and out to the school districts simultaneously to help prompt a greater awareness of seismic safety needs for our public schools.

Several school districts have already utilized some of our seismic screening report information to help inform their capital planning and modernization strategies.

The preliminary report, this final report, and the results of the detailed geologic and engineering assessments were shared with the Governor, State legislature, school district superintendents, local points of contact at the individual school buildings (such as facility managers and principals), and with OSPI. Additionally, all of these reports are available on the WGS website (see Appendix E). The results of the geologic and engineering assessments were uploaded into the OSPI ICOS database. When the preliminary report was sent to school districts there was a link to a survey where staff could provide feedback and questions they had about this project. The responses were collated and are addressed in the frequently asked questions section (FAQs) in Appendix D. We encourage schools, districts, and interested parties to reach out with questions regarding these reports. Ideally, the results of these studies will be used in school safety planning, prioritizing buildings for modernization, and requesting funding to complete seismic upgrades.

Next Steps

In Washington State, seismic risk and upgrades need to be balanced with other risks, many of which are competing for the same limited financial resources. School districts are balancing these risks on a daily basis. For example, a school district may have to make a decision between spending its limited resources on performing a seismic upgrade, or purchasing and installing a new boiler that provides heating all winter, or providing additional school security that helps keep kids safe from a potential unwanted intruder, or to upgrade a fire sprinkler system that helps prevent a fire. These are just a sample of the everyday needs competing for funding to seismically improve older school buildings.

The recommendations from this report can be integrated into other upgrades to school buildings. Using a phased approach may help improve project delivery efficiency and lower potential construction costs. A major advantage of completing seismic upgrades at the same time as other modernization projects is to avoid duplicating costs. Construction can also occur incrementally in order to correspond with planned capital improvements or other safety projects. For example, seismic upgrade of a roof may be delayed until the building requires reroofing. These are common approaches used by school districts and other public agencies trying to take advantage of modernization projects to also perform seismic upgrades.

Solving large and complex statewide seismic safety concerns with thousands of our aging public school buildings that need local school district funding support is going to take 21st century problem solving skills that rely on data to guide and inform the best approaches. This is a problem that may require a decade or two of action, policy creation, refinement, and funding to successfully complete. The solution will require significant leadership and long-term strategic thinking and execution to accomplish. Large complex problems require a significant amount of patience, fortitude, and guiding principles within our elected and public officials to secure the requisite public support and funding necessary to start a movement toward seismically safer public schools.

With these considerations in mind, the following are a series of next steps that can be taken in subsequent phases of work to better define the extent of the problem and the range of solutions for seismically safer schools. We expect that the recommendations will evolve as we continue to complete assessments and learn more about the state of Washington schools. One thing is certain, we must do more.

1. Further seismically screen, retrofit, or upgrade vulnerable schools in higher risk areas to refine the understanding of policy and funding needs. This will help initiate long-term programs to make public schools safer. Consider prioritizing school building screening evaluations and improvements with the following features in descending order of priority:
    a. Seek immediate funding for seismic improvements or abatement for the buildings with the greatest known seismic risks such as Unreinforced Masonry (URM) Bearing Wall Buildings and Non-ductile Concrete Buildings in high seismic hazard areas.
    b. Perform additional seismic screening evaluations and risk-based prioritization of reinforced masonry, wood framed, and concrete shear wall school buildings in the highest seismic and (or) tsunami risk areas.
    c. Prioritize school buildings with the highest student populations to ensure the greatest good for the most people.
    d. Generally prioritize seismic screening and upgrades of the oldest pre-benchmark buildings first. This can be subdivided into building materials, ages (pre-benchmark), and student population size.
    e. Consider prioritizing schools in high seismic hazard areas where school bond levies have been recently successful. This could be an indicator of better public awareness and support of public school facility needs.
2. Perform an engineering and economic study to determine cost benefit ratio thresholds for seismically upgrading older public school buildings.
3. Develop a statewide public school seismic safety outreach and advocacy program to help smaller school districts in rural or economically disadvantaged, yet high seismic and tsunami risk areas.
4. Study legislative policies and statewide funding levels in CA, OR, UT, and BC Canada to determine which laws and policies and how much funding were beneficial and effective to those communities for improving school seismic safety.
5. Complete a survey and inventory of all WA school districts to see where seismic upgrades have been completed and enter this information into ICOS. Especially survey the larger urban (more well-funded) school districts such as Seattle Public Schools, Bellevue SD, Edmonds SD, and Bellingham Public Schools among others.
6. Assess high risk schools for seismic and tsunami hazards considering upgrades to immediate occupancy standards for gymnasiums and potential shelter facilities.

Recommendations for Legislature

We are thankful to the State for continuing to fund these assessments in the 2019–2021 biennium. We recommend that the results of Phases 1 and 2 continue to drive future funding and help to prioritize assessments. These assessments are the most useful when there is an opportunity for schools and districts to apply for dedicated funding to actually complete the seismic upgrades. Seismically upgrading buildings can save lives, reduce economic loss, and help communities to recover following the next earthquake.

1. We recommend that the State prioritize resilience and safety and create a School Seismic Upgrade Assistance Grant Program that school districts can apply to for funding for seismic upgrades based on the results of the seismic screening evaluations. OSPI proposes to include this in their 2021–2023 legislative request:

School Seismic Upgrade Assistance Grant Program

The proposed pilot program will provide funding assistance to school districts to upgrade school facilities that have been identified as a high safety risk from the prioritized seismic need assessment conducted by the Department of Natural Resources Washington Geological Survey. Grant funds provided can be used along with school construction assistance program grant funding to complete needed seismic upgrades.

Enhance Study & Survey Funding: In order for school districts to apply for State Funding Assistance for Construction, districts are required to develop a Study and Survey. The study and survey is an overall analysis of the school districts' facilities, educational programs and plans, student population projections, capital finance and operating capabilities, and identification of needs for new construction, modernization or replacement of facilities.

OSPI will be asking for increased funding of the Study and Survey process to allow districts to collect building information utilizing RVS and ASCE methodologies and reporting into the OSPI inventory system.

2. Redefine the State's school modernization policies in the Washington Administrative Code to specifically include school seismic safety improvements to be a required part of school modernization funding and construction programs.
3. Establish school seismic safety improvement criteria and make those criteria a part of school modernization and capital improvements funding.
4. Consider allocating one percent of existing school modernization funding for systematic and targeted seismic evaluation and upgrades construction for the most vulnerable buildings in the State's highest seismic and tsunami risk areas.

Recommendations for OSPI

Recommendations for increasing seismic resilience are added here to the six phases of OSPI's School Construction Assistance Program (SCAP) funding program.

1. **Preliminary Planning:** District(s) conduct a Study & Survey and begins project application. In the Study and Survey phase the district must conduct an ASCE 41-17 engineering assessment by a licensed structural engineer for schools built prior to 1975 in their district. The results of this survey must be entered into ICOS. If seismic renovations have been made, districts must report this information to OSPI to be captured in the ICOS database. Information on the building design and cost should be included in engineering documents to OSPI.

2. **Financing School Construction:** District raises local funds for construction.

3. **Predesign Analysis:** District develops Educational Specifications and selects a site and consultant team.

4. **Preparing for Construction:** District works with consultants to develop the facility design, goes out to bid, and awards the construction contract (Design/Bid/Build).

5. **Construction:** Project team builds the facility.

6. **Occupancy:** District is responsible for maintenance and operations.

School Safety Planning

We recommend incorporating the results of these studies into the school districts' required comprehensive district and school safety planning and PDM plan. The goal of the PDM plan is to "proactively facilitate and support statewide resources and programs that assist school districts in making K–12 schools in Washington State more disaster-resistant and disaster-resilient." OSPI received funding from FEMA to develop the Washington State K–12 School Facilities Hazard Mitigation Program, which allows districts to not only understand all hazards that affect each school site across the State, but provides additional building information to help determine the risk posed by each hazard. The funding was also used to develop mitigation plans that can be annexed into a larger county plan and approved through FEMA, allowing districts access to possible federal funding. OSPI is helping districts to incorporate information developed through the hazard assessment process into the schools' overall safety plan and continuity of operations plan (COOP).

Washington State School Seismic Pre Disaster Mitigation (PDM) Plan:
http://www.k12.wa.us/SchFacilities/PDM/pubdocs/PDM_Plan.pdf

Recommendations for Future Studies

This study is the first statewide seismic assessment of Washington State schools. Given the social, communal, and financial importance of publicly-owned schools within Washington State, it is essential that seismic assessment efforts be continued.

Investing in seismically resilient schools now will help protect our students when the next earthquake happens. The overall cost to seismically upgrade the state's most vulnerable buildings is no doubt staggering. However, the cost and time to rebuild a multitude of school buildings at the same time, following a Cascadia-type earthquake event, affecting nearly 750,000 public-school students, could be an overwhelming obstacle in Washington State's post-disaster recovery.

The following recommendations can be performed in subsequent phases of work to better define the extent of the statewide problem and to provide a range of solutions for seismically safer schools throughout Washington State. We expect that statewide seismic safety policy recommendations and associated funding needs will evolve as we continue to learn more about the seismic risks public school buildings face in Washington State.

1. Continue to seismically screen, retrofit, or upgrade vulnerable public school buildings in higher risk areas to refine the understanding of risk, and policy and funding needs. This will help initiate long-term programs to make public schools more resilient. Consider prioritizing school building screening evaluations and improvements with the following features in descending order of priority:

    a. Seek immediate funding for seismic improvements or abatement for the buildings with the greatest known seismic risks such as Unreinforced Masonry (URM) bearing wall buildings and non-ductile concrete buildings in high seismic hazard areas.

    b. Perform additional seismic screening evaluations and risk-based prioritization of older reinforced masonry, wood framed, and concrete shear wall school buildings in the highest seismic and tsunami hazard areas.

c. Prioritize seismic screening and upgrades of the oldest pre-benchmark buildings first. This can be subdivided into building materials and ages.

d. Consider prioritizing schools in high seismic hazard areas where school bond levies have been recently successful. This could be an indicator of better public awareness and support of public school facility needs.

2. Complete a survey and seismic safety improvements inventory of all Washington State school districts to see where seismic upgrades to public school buildings have already been completed and enter this information into the OSPI ICOS database. Start by surveying the larger urban (more well-funded) school districts such as Seattle Public Schools, Bellevue School District, Edmonds School District, and Bellingham Public Schools, among many others.

3. Perform an engineering and economic study to determine cost-benefit ratio thresholds for seismically upgrading older public school buildings of various construction types and vintages. This work could include an earthquake scenario-based use of FEMA P-58—Seismic Performance Assessment of Buildings to evaluate select case study school buildings, helping characterize expected losses. FEMA P-58 is a tool similar to FEMA Hazus Loss Estimation Tool that allows for building loss estimation due to earthquakes but is more detailed and expected to be more accurate than Hazus. Unlike other building evaluation tools, FEMA P-58 allows users to properly account for uncertainty in building performance. The use of FEMA P-58 may allow the State of Washington to much better understand expected financial losses due to earthquakes.

4. For schools in mapped tsunami inundation zones, design seismic upgrades to incorporate vertical evacuation options. For large earthquakes near the coast and within Puget Sound, earthquakes and tsunamis are coupled and the seismic upgrade design needs to reflect these hazards.

5. Develop a statewide public school seismic safety outreach and advocacy program to help smaller school districts in rural or economically disadvantaged communities located within high seismic and tsunami hazard areas.

6. Study legislative policies and statewide funding levels in our region (CA, OR, UT, and BC Canada) to determine the effectiveness of public school seismic safety programs, policies, and laws and how much statewide public funding were beneficial to those communities for improving seismic safety of their public school buildings. Work with state legislature and the building code council to implement effective policies.

7. Study the costs and benefits of higher-than-life-safety seismic performance objectives, such as Immediate Occupancy for assembly-occupancy public school buildings in high seismic and tsunami hazard areas. These facilities may be used as disaster shelters within the public school communities that they serve.

8. Update earthquake seismic scenario catalogs to incorporate updated information on new faults, liquefaction, updated census data, updated hazard maps and other relevant information. Use these maps and the loss estimation tools to help prioritize school assessments.

Solving large and complex statewide seismic safety concerns with thousands of aging public school buildings that need local school district funding support is going to take 21st century problem solving skills. We will need to rely on data to guide and inform the best approaches and most efficient solutions. This statewide study is the first step towards obtaining the data and generating the information and knowledge required to better understand the extent and scope of the problem. This is a problem that may require a decade or more of action, policy creation, refinement, and funding to successfully complete. The solution will require significant leadership, long-term strategic thinking, public support, and funding necessary to start a statewide movement toward seismically safer older public school buildings.

Acknowledgments

We would like to extend our sincere gratitude to all the school employees and facility managers who provided access to their school campuses and facilitated all our information requests. This project would not have been as successful without the participation of these dedicated and committed personnel. We would also like to thank the Washington State Legislature and the Governor for funding this project and supporting the seismic assessment of schools. Continued funding and prioritization of these efforts will help to keep Washington's children and teachers safe from earthquakes.

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Appendices

A. 2017–2019 Capital budget directive (Sec. 3062)
B. Complete list of schools assessed with links to download reports
C. List of fire stations within one-mile radius of schools assessed, with links to download reports
D. Frequently Asked Questions (FAQ)
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Appendix A: 2017–2019 Capital Budget Directive

FOR THE DEPARTMENT OF NATURAL RESOURCES

Public School Seismic Safety Assessment (91000091)

The appropriation in this section is subject to the following conditions and limitations:

(1) The department, in consultation with the office of emergency management, the office of the superintendent of public instruction, and the state board of education, shall develop a prioritized seismic risk assessment that includes seismic safety surveys of public facilities that are subject to high seismic risk as a consequence of high earthquake hazard and soils that amplify that hazard. The seismic safety surveys must be conducted for the following types of public facilities in the following order:

(a) A minimum of twenty-five public school facilities that have a capacity of two hundred fifty or more persons and are routinely used for ((~~student activities by~~)) the instruction of students in kindergarten through twelfth grade ((~~public schools~~)). The survey must be a representative sample of urban and rural school districts located in different geographical areas of the state; ((~~and~~))

(b) Public school facilities with capacity of fewer than two hundred fifty persons; and

(c) Fire stations located within a one-mile radius of a facility described in ((~~subsection (1)~~))(a) of this subsection.

(2) The department must coordinate survey efforts made under subsection (1)(a) and (b) of this section whenever possible.

(3) The initial phase of the prioritized seismic needs assessment of the facilities specified in subsection((~~s~~)) (1)(a) and (b) shall include, but is not limited to, the following:

(a) An on-site assessment, under the supervision of licensed geologists, of the seismic site class of the soils at the facilities;

(b) An on-site inspection of the facility buildings, including structural systems using structural plans where available, condition, maintenance, and nonstructural seismic hazards following standardized methods by licensed structural engineers;

(c) An estimate of costs to retrofit facilities specified in subsection (1)(a) of this section to life safety standards as defined by the American society of civil engineers; and

(d) An estimate of costs to retrofit facilities specified in subsection (1)(b) of this section to immediate occupancy standards as defined by the American society of civil engineers.

((~~(3)~~)) (4) The department ((~~shall develop geographic information system databases of survey data and~~)) must collect and submit survey data to the superintendent of public instruction in a format compatible with the inventory and condition of schools database. The department must enter into an agreement with the superintendent of public instruction to make any necessary modifications to the inventory and condition of schools database to receive and report the survey data.

(5) The department must share that data with the governor((~~, the superintendent of public instruction,~~)) and the appropriate legislative committees.

((~~(4)~~)) (6) The department and the office of the superintendent of public instruction must provide technical assistance to the school facilities sampled to incorporate survey information into their school safety plans.

(7) A preliminary report on the progress of the statewide seismic needs assessment specified in this section shall be submitted to the ((~~office of financial management and the~~)) appropriate committees of the legislature by October 1, 2018. The final report and statewide seismic needs assessment shall be submitted to the office of financial management and the appropriate committees of the legislature by June 30, 2019.

Appropriation:

State Building Construction Account—State.	$1,200,000
Prior Biennia (Expenditures).	$0
Future Biennia (Projected Costs).	$0
TOTAL.	$1,200,000

Appendix B: Complete List of Schools Assessed in Phase 1

Click on each district name to download the seismic screening report for that district.

District Name	Facility Name	Enrollment	Building Name	Year Built	Concept Upgrade Performance Objective
Battle Ground	Maple Grove K-8	484	Gym	1990	
			Main Building	1990	
	Prairie High School	1,577	400 Building	1995	
			500 Building	1979	
			600 Building	1979	life safety
	River Homelink	966	Main Building	1980	
Bickleton	Bickleton Elementary and High School	87	Bldg B—Vocational/Transportation	1961	
			Main Building	2010	
Boistfort	Boistfort Elementary	99	Gymnasium Building	1963	immediate occupancy
			Main Building	1936	
Burlington-Edison	Edison Elementary School	449	Original Building	1995	
Camas	Lacamas Heights Elementary School	353	100 Pod	1962	
			Multipurpose	1962	
	Liberty Middle School	763	Main Building	1958	
			Music Building	1970	
	Skyridge Middle School	936	Main Building	1995	

Cape Flattery	Clallam Bay High and Elementary School	115	Big Gym	1962	
			Elementary Building	1962	
			Elementary Gym	1980	
			High School Building	1972	
			Shop and Art Building	1980	
	Neah Bay Elementary School	166	Elementary School	1961	
	Neah Bay Junior/ Senior High School	185	High School Classroom Building	1976	
			High School Gym	1972	
			High School Shop Building	1972	
Carbonado	Carbonado Historical School 19	179	1st and 2nd Grade and Special Education Building	1968	
			A—Main Building	1929	
			B—Community Gym	1936	immediate occupancy
			Computer Lab and Library	1989	
Centerville	Centerville Elementary School	82	Main Building	1919	
Central Kitsap	Ridgetop Junior High School	438	Main Building	1986	
	Silver Ridge Elementary School	412	Main Building	1990	
Centralia	Edison Elementary School	345	Main Building	1918	life safety
Concrete	Concrete High School	271	Main Building	1951	
			Tech Building	1952	

	Concrete K-6 School	254	Gym	1981	
			Main Building	1981	
Cosmopolis	Cosmopolis Elementary School	164	Auditorium Building	1960	
			Gymnasium Building	1969	
			Main Building	1960	life safety
			Multipurpose Building	1960	
Coupeville	Coupeville Elementary School	413	Cedar Pod	1979	
			Main	1974	
			Multipurpose	1979	
	Coupeville High School	321	Annex	1978	
			Gymnasium	1981	life safety
	Coupeville Middle School	222	Middle and High School Building	1992	
Creston	Creston Junior Senior High School	57	Creston K-12 School Building	1953	
Darrington	Darrington Elementary School	311	Main Elementary School	1990	
	Darrington Senior High School	134	High School	1935	
			Woodshop	1960	
Dayton	Dayton High School	139	Ag Shop	1954	
			Gymnasium	1966	immediate occupancy
			High School Building	1923	

			Wood Shop	1966	
	Dayton K-8 School	245	Elementary and Middle School Building	1966	
Dixie	Dixie Elementary School	30	Main Building	1921	

East Valley (Yakima)	East Valley Central Middle School	686	6th Grade Building	1980	
			7th–8th Grade Building	2010	
			Computer Lab Building	1996	
			Gymnasium Building	1950	
	East Valley Elementary School	550	Main Building	1996	
Evaline	Evaline Elementary School	50	Main Building	1926	
Ferndale	Beach Elementary	30	Main Building	1919	
Fife	Fife High School	837	Building IV 400 Library	1950	
			Building IX 900 Science	1970	
			Building V 500 Main	1950	
			Building VI 600 Gyms	1956	
			Building VII 700 Cafeteria	1963	
			Building VIII 800 Shop	1963	
Glenwood	Glenwood High School	30	Main Building	1981	
	Lake Roosevelt K-12	750	CTE Building	1955	life safety

Grand Coulee Dam		750	Wood Shop	1974
Green Mountain	Green Mountain School	158	Gymnasium	1950
			Main Building	1932
Harrington	Harrington Elementary & High School	87	Main Building	1936
Highline	Woodside Site (Choice Academy)	27	Annex	1960
			Main Building	1958
Hoquiam	Hoquiam High School	491	A—Administration	1966
			B—Science	1966
			E—Library	1966
			H—Gymnasium	1966
	Lincoln Elementary School	317	Administrative and Library Building	1968
			East Wing	1968
			Multipurpose Building	1968
			West Wing	1968
Index	Index Elementary School	44	Enclosed Covered Play	1997
			Main Building	1954
Kelso	Carrolls Elementary School	148	Main Building	1948
La Conner	La Conner High School	219	High School Auditorium	1921
			High School Main Building	1974

	La Conner Middle School (form. Elem.)	133	Old Auditorium/Cafeteria Building	1921	
Longview	R. A. Long High School	928	Gym	1927	
			Main Building	1927	
			RA Long Annex	1963	
			Science Wing	1935	
			Shop Building	1942	
Mabton	Mabton Jr/Sr High School	387	Greenhouse	1900	
			Main Building	1950	
			Shop/Ag Building	1900	
Mansfield	Mansfield Elem and High School	106	Main Building	1983	
Marysville	Liberty Elementary School	520	Main Building	1951	
	Marysville Middle School	800	Building B	1960	
			Building C—Shop Classrooms	1960	
			Main Building	1960	
	Totem Middle School	556	Cafeteria Gym Building	1958	
			Main Building	1966	life safety
			School House Cafe	1955	
			Science Building	1962	
Methow Valley	Liberty Bell Junior Senior High School	259	Main Building	1994	

	Methow Valley Elementary School	341	Main Building	1963	
Morton	Morton Elementary School	176	Gymnasium	1985	
			Main Building	1930	
	Morton Junior Senior High School	152	Gymnasium	1957	
			Main Building	1957	
			Shop	1957	
Mount Baker	Mount Baker Junior High School	256	200 Building—JHS	1992	
			Pro-Rate Portion of Commons—Building 100	1990	
		579	300 North	1980	
			300 South	1980	
			700 Building	1992	
			800 Building (Former Deming Elem.)	1970	
			Field House	1968	
Mount Vernon	Lincoln Elementary School	373	Main Building	1938	life safety
Naches Valley	Naches Valley High School	453	Gym Building		
			Main Building	1979	life safety
			Vocational Building	1979	
	Naches Valley Intermediate School	184	Main Building	1952	
	Naches Valley Middle School	407	Main Building	1994	

Newport	Newport High School	354	Main Building	1983	
North Beach	Pacific Beach Elementary School	150	Gym/Lunchroom	1956	immediate occupancy
			Main Building	1956	
			Quad Building	1970	
Ocean Beach	Ilwaco (Hilltop) Middle School	316	Auditorium	1936	
			Main Building	1932	
	Ilwaco High School	286	Ilwaco High School	1971	
			Stadium Complex	1976	
	Long Beach Elementary School	243	Main Building	1964	
	Ocean Park Elementary School	166	Main Building	2005	
Ocosta	Ocosta Elementary School	320	Primary Addition	1986	
	Ocosta Junior Senior High School	285	Junior Senior High	1986	
Oroville	Oroville Elementary School	323	Main Building	1954	
Palisades	Palisades Elementary School	32	Grange Hall	1930	
			Main Building	1923	
Pasco	Edwin Markham Elementary School	371	Main Building	1962	
Pateros	Pateros K-12 School	138	Main Building	1948	
			Metal Shop	1962	
			Music Building	1958	

			Wood Shop	1995
Paterson	Paterson Elementary School	145	Main Building	1968
Port Angeles	Roosevelt Elementary School	502	Main Building	1978
Port Townsend	Port Townsend High School	366	Gym	1941
			Main Building	1934
			Math Science Annex	1928
			Stuart Building	1952
Puyallup	Maplewood Elementary School	434	Main Building	1934
	Puyallup High School	1,752	Gymnasium and Swimming Pool Building	1958
			Library Science Building	1962
			Main Building	1927
	Spinning Elementary School	318	East and West Classroom Wings	
			Main Building	1890
Quilcene	Quilcene High And Elementary School	206	Elementary	1952
			High School	1935
			Middle School	1964
Raymond	Raymond Elementary School	325	Raymond elementary	1955
	Raymond Junior Senior High School	251	Main Building	1925
Ridgefield	Union Ridge Elementary School	777	Main Building	1952

Riverside	Chattaroy Elementary School	289	35 Wing Building	1934	
			Main Building	1987	
Royal	Red Rock Elementary School	596	Main Building	1992	
	Royal High School	492	A—Gymnasium	1965	
			B—Main Building	1965	
	Royal Middle School	248	Main Building	1991	
Shaw Island	Shaw Island School	16	Admin/RR Building	1952	
			Intermediate Classroom Building	1992	
			Primary Classroom Building	1902	
Skykomish	Skykomish High School	16	Main Building	1938	
South Bend	South Bend Jr/Sr High School	225	Koplitz Field House	1950	immediate occupancy
			Vocational Building	1954	
South Whidbey	South Whidbey Elementary School	510	Main Building	1988	
Spokane	Adams Elementary School	334	Gym and Cafeteria	1950	
			Main Building	1910	life safety
	Audubon Elementary School	427	Main Building	1980	
	Libby Center	278	Main Building	1928	
Sunnyside	Outlook Elementary School	646	Outlook Elementary Main Building	1932	
Tacoma	Fern Hill Elementary School	324	Main Building	1911	

	Oakland High School	203	Main Building	1911
Taholah	Taholah School	187	Covered Court	1991
			Main Building	1973
Thorp	Thorp Elementary and Junior Senior High School	124	Brick Building	1930
			Thorp Elem/Jr/Sr High School	1991
Tonasket	Tonasket Elementary School	593	Greenhouse	1995
			Tonasket Elementary	1995
	Tonasket Middle-High School	569	High School/Middle School	1995
Touchet	Touchet Elementary and High School	226	CTE Building	1960
			Elementary - Main Building	1960
			Secondary Facility	1975
Tumwater	Black Lake Elementary School	504	Building A	1982
			Building B	1982
			Building C	1984
Vashon Island	Vashon Island High School	596	Building D—Gymnasium	1961
			Building F—Votech	1934
			Building K—Annex	1957
Warden	Warden K-12	326	Cafeteria	1900
			Gymnasium	1900
			Middle School/High School	1998

Washougal	Hathaway Elementary School	422	Main Building	1935	
Washtucna	Washtucna Elementary High School	46	Ag Shop/ Music Room	1956	
			Main Building	1956	
White Pass	White Pass Elementary School	231	Main Building	1964	
	White Pass Junior Senior High School	227	Main Building	2010	
White Salmon Valley	Columbia High School	387	C Court—Gym	1970	life safety
			Library	1970	
			Metal /Wood Shop	1970	
	Hulan L. Whitson Elementary School	427	Main Building	1956	
	Wayne M. Henkle Middle School	195	Middle School	1960	
Wilson Creek	Wilson Creek K-12	92	Business Building/Home Ec.	1984	
			Gym/Commons	1997	
			Main—Gym & Classrooms	1932	
			Vo-Ag / Science Building	1989	

Appendix C: List of fire stations within a one-mile radius of a school building assessed in Phase 1

Click on each fire station name to download the seismic screening report for that station.

Fire Station Name	Address	Town
Fire Station No. 2	2201 16th St.	Everett
Fire Station	212 Commercial St.	Raymond
Fire Station	311 Israel Rd. SW	Tumwater
Fire Station No. 9	17408 SE 15th St.	Vancouver
County Fire District No. 4	2251 S Howard St.	Walla Walla

Appendix D: Frequently Asked Questions

The geologic and engineering results of the school seismic safety assessments are provided in this report to shed some light on the state of some of Washington's school buildings and to provide the state legislature, districts, principals, and OSPI with information on which types of buildings are the most vulnerable. We do realize however that this may not get at some of the questions that come up for you after reading this report. After we submitted the preliminary report to legislators and school district personnel in October 2018, we solicited feedback on remaining questions. Below are answers to some of the most frequently asked questions.

- **QUESTION:** How can I get my school signed up to be a part of these statewide school seismic safety assessments?
  ANSWER: DNR is working with OSPI to select schools based on the results of this Phase 1 report as well as the directive put forth in the 2019–2021 capital budget allotment. We expect to have a finalized list of schools for Phase 2 by the end of August 2019. If your school is in the process of planning a major remodel or would like to have this information as soon as possible for planning purposes (or for some other reason) please reach out to Corina Forson (corina.forson@dnr.wa.gov) or Scott Black (Scott.Black@k12.wa.us) to let us know your plans and that you would like your school to receive seismic upgrades. We will see if it is possible to include your school in this next phase.

- **QUESTION:** How can the information from this report be used to get funding for building upgrade/replacement?
  ANSWER: It is our hope that the information from this report will continue to drive funding from the state legislature for seismic assessments and dedicated funding for seismic upgrades in the future. Additionally, we hope that by having engineering reports that identify specific seismic screening issues, schools and districts will be able to use that information to help garner funds locally, from FEMA, OSPI, and/or other grants. There are some things that schools may be able to accomplish without additional funding, such as addressing the nonstructural items, and some other tasks that could be incorporated relatively easily into future planned modernization projects.

- **QUESTION:** What does it mean if a building doesn't meet current seismic safety standards? What can be done to upgrade them?
  ANSWER: Many older school buildings, and older buildings in general, inherently do not meet current seismic safety standards because they were constructed long before our improved modern seismic building codes and the improved statewide seismic hazard. Currently, older school buildings are not required to be seismically upgraded to modern seismic code standards unless they undergo a modernization project involving a substantial repair, alteration, change of occupancy, addition, or building relocation that could, individually or taken together, trigger a set of project-specific seismic upgrade requirements to be determined in consultation with the local Building Official. Guidance for this determination is provided by the most current edition of the International Building Code and International Existing Buildings Code, as adopted and amended by the State of Washington.

  However, many building owners and school districts, once they become more aware of the seismic vulnerability of their buildings, take steps to better understand their seismic risk and implement strategies to improve their risk by seismically upgrading their buildings, repurposing them to different, less risky uses, or by replacing them. This is a very common approach for most school districts and other public owners of large inventories of older public buildings. We believe that the knowledge gained from this statewide school seismic safety assessment project is valuable to not only the elected officials and policymakers, but also to the school districts and the public that use these facilities.

- **QUESTION:** Is my school (my child's school, the school I teach at, and so on) safe? If the answer is no, what are my options?
  ANSWER: That is a difficult question to answer in general and each school's situation varies. The individual school seismic screening reports provided in this study highlight structural (building components) and nonstructural (interior components, such as bookshelves) seismic deficiencies identified at each of the buildings assessed as well as information on the geologic site class and other geologic hazards at the campus. The reports for each school are full of information and can be overwhelming to read. If you have questions about the individual school building seismic screening reports, please contact us and we will work with you to understand them. Washington is the second most at-risk state for earthquake hazards (following California). Many of our schools are constructed prior to modern seismic codes and within seismically hazardous areas, therefore many school buildings will require some level of improvement to make them more resilient to earthquakes. If you are concerned about the seismic risk at your school, contact your school district and OSPI to determine whether there are already plans in place for your school.

  There is currently no Washington State program dedicated to ongoing robust funding statewide for design and construction of seismic upgrades of K-12 facilities. Currently, in Washington State there are two primary mechanisms for funding school district capital improvements, which may or may not include seismic upgrades:

  (1) The main mechanism is via individual school district capital levies or bonds. The State can and does in many cases provide assistance through the School Construction Assistance Program (SCAP) for major capital projects—involving seismic upgrades—funded by district levies or bonds.

  (2) The other mechanism is a combination of individual State grant programs that vary with each biennial capital budget, which in some cases can be used to fund certain urgently needed upgrades.

  The funding shortfalls for seismic upgrade projects vary from district to district. In many cases, districts have difficulty passing bonds and levies. In some cases, those that can pass capital levies and bonds are not eligible for OSPI's SCAP matching funds (http://www.k12.wa.us/SchFacilities/Programs/SchoolConstructionProjects.aspx), which can limit their options. In other cases, district access to individual non-SCAP grant funds is limited, if only because the non-SCAP grant programs are typically not robust in terms of overall funds allocated to them on an annual basis. Finding funding solutions to make schools resilient is complicated and we hope that by better understanding the technical building-specific seismic issues, and having data to support it will help drive further legislative funding. You can contact your representative to discuss additional funding options for school seismic safety improvements.

- **QUESTION:** How will you address the fact that schools that do not meet current code will need to continue to operate? (There are no other, better schools.)
  ANSWER: While the results of this study indicate significant earthquake risks for Washington schools, it is important to point out that upgrading school buildings to current seismic code is a voluntary activity from a building (seismic) code standpoint. The State of Washington has adopted the 2015 International Existing Building Code as its building standard for existing buildings. Per this building code, a school district is under no obligation to upgrade its school

buildings with suggested upgrade recommendations unless there is a change in use or occupancy, addition, or an alteration made to the existing structure that would trigger such upgrade.

This study's main objective is to investigate the current levels of seismic safety, document the facts, determine needs, and inform and educate school districts, schools, parents, state legislature, OSPI, and the public to help them better understand the current level of seismic risks of a statewide sample of school buildings. Public schools need financial support to make the necessary changes highlighted here.

- **QUESTION:** What kind of talking points will you have to share with school districts so that we can communicate with our constituents?
  ANSWER: The Executive Summary section of this report contains the high-level findings and information for this project and can help to answer questions. Additionally, we hope that the responses to these FAQs can serve as talking points in addition to the information provided in the cover letters for each district's school building assessments. If you require more information, we would be happy to provide it to you upon request.

- **QUESTION:** How will you make the issue understandable and acceptable to parents and students?
  ANSWER: The intent of the report to legislature was to make the projects and the overall results understandable for the public. The detailed engineering reports are technical, but each district's reports have a cover letter that goes over the project and buildings assessed. If you have specific questions about the engineering reports we can help to field those questions.

- **QUESTION:** Seismic risk varies across the state, how do you address this?
  ANSWER: For the selection of school buildings and determining seismic risk areas, we use the United States Geological Survey (USGS) Seismic Hazard maps (https://earthquake.usgs.gov/static/lfs/nshm/conterminous/2014/2014pga2pct.pdf).

  The engineering surveys flag non-compliant building components using the "design-level earthquake" which is a theoretical earthquake that engineers and building officials select to either design a new building to resist, or check an existing building to predict, its resilience to earthquake shaking. The design-level earthquake is mandated by the building code to represent the earthquake shaking hazards for the region where the building is located. It is used in the design of buildings to ensure that the building behaves in a predictable way if that design-level earthquake event should occur.

  Seismic hazard does vary across the state and is continuing to evolve as new faults are discovered or identified as active. The entire state is at risk for damage following an earthquake, not just the west side. One of the largest earthquakes in Washington history happened on the eastern side of the cascades near Entiat in 1872. It is important to look at all schools across the state and to understand the local geology and the seismic hazard. That is why geologists went to each campus to determine the site class.

- **QUESTION:** What are less costly steps school districts can make until they can afford a complete upgrade?
  ANSWER: Some of the nonstructural components (bracing bookshelves, for example) are very high-return items that can be done with little effort and cost. These nonstructural components are included in the seismic screening reports for each school building. Additionally, schools and districts can take a phased approach and focus on portions of buildings at a time. If there are

other modernization projects planned, consider adding some of the seismic upgrades into those plans. For example, if a school needs a new roof, it would be a great time to consider seismically upgrading the structural components of the building in that area during that project.

- **QUESTION:** What were the people who visited my school doing on the playing field?
  ANSWER: The geologists that visited your school campus were collecting geophysical data to determine the soil type beneath the school campus. The local geology and soil type play an important factor in amplifying shaking during an earthquake. The site class information is incorporated into the seismic engineering assessments.

- **QUESTION:** What are the next steps for the School Seismic Safety Study?
  ANSWER: The next step is to continue assessing schools with the funding allocated in the 2019-2021 biennium. Additionally, OSPI and DNR will continue to ask for state funding to continue assessments and ultimately try to fund seismic upgrades. It is our hope that we can work together with the state legislature to implement (or change) policies to require seismic upgrades where necessary and to fund them accordingly.

- **QUESTION:** Does this study recommend policy changes and funding plans to help these efforts?
  ANSWER: This report provides seismic screening information on a statewide selection of school buildings, recommendations for legislature, and examples of policies and programs from nearby states and territories. There is no money currently designated to making seismic improvements to schools in Washington State. There is also no current funding for a school district to evaluate all of its schools so that prioritization of this effort is possible. This project begins this effort, but at the current rate it could take decades to complete the required seismic screening assessments, let alone to complete the necessary seismic upgrades. Please refer to the "Recommendations for Legislature" section in this report for more details.

- **QUESTION:** The report will expose to the public a problem that could cause fear without a solution regarding long-term capital funding or support. Why are you using the approach you selected?

  ANSWER: Solving large and complex statewide seismic safety concerns with thousands of our aging public-school buildings that need local school district funding support is going to take 21st century problem-solving skills that rely on data to guide and inform the best approaches. Age of construction alone is not enough to predict and plan for the cost of seismic upgrades. For those types of decisions, we need specific data that is well-documented and understood by the elected officials, the public that they serve, and the school districts.

  This is also a problem that may require a decade or two of action, policy creation, refinement, and funding to successfully complete. The solution will require significant leadership and long-term strategic thinking and execution to secure the requisite public support and funding necessary to start a movement toward seismically safer public schools.

  The entire focus of this project is on school seismic safety. It is our intention as licensed geologists and engineers to utilize this information to not only help educate our governor and legislature on the clear and present needs of new statewide policies and funding for school seismic safety improvements, but to also use the data collected to help inform school districts and the public that they serve of the seismic risks within their facilities. We expect that the school districts that graciously participated in this first-ever statewide school seismic safety assessment project would want to know about the specific seismic risks that we learned about while assessing their older school buildings, so that strategies could be developed over time to reduce these risks.

Appendix E: Links to Related Reports

- Washington Geological Survey School Seismic Safety Project website—Contains overview information about this project and a map where you can download the seismic screening reports for each district.

https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/earthquakes-and-faults/school-seismic-safety

- Preliminary Progress Report submitted in September, 2018

https://fortress.wa.gov/dnr/geologydata/download/School_Seismic_Safety_progress_report_dnr_ospi.pdf?wydd7r

- Washington School Seismic Safety Project site class assessment report

http://www.dnr.wa.gov/publications/ger_ofr2019-01_school_seismic_site_class_report.pdf

- WA Schools Seismic Assessments Engineering Summary Report Vol 1—Contains summary of engineering methods, findings, summaries, and recommendations.

https://fortress.wa.gov/dnr/geologydata/school_seismic_safety/SSSP_2019_Engineering_Vol1_Engineering_Report.pdf

- WA Schools Seismic Assessments EPAT RVS Vol 2—Contains RVS and EPAT summaries for all schools assessed in Phase 1.

https://fortress.wa.gov/dnr/geologydata/school_seismic_safety/SSSP_2019_Engineering_Vol2_EPAT_RVS_Report.pdf

- WA Schools Seismic Assessments ASCE Tier 1 Reports Vol 3—Contains all ASCE 41 Tier 1 Seismic Screening Reports.

https://fortress.wa.gov/dnr/geologydata/school_seismic_safety/SSSP_2019_Engineering_Vol3_ASCE_41-17_Tier_1_Report.pdf

- WA Schools Seismic Assessments Conceptual Upgrade Reports Vol 4—Contains reports for 15 school buildings for the concept level seismic upgrade designs and estimated costs to upgrade.

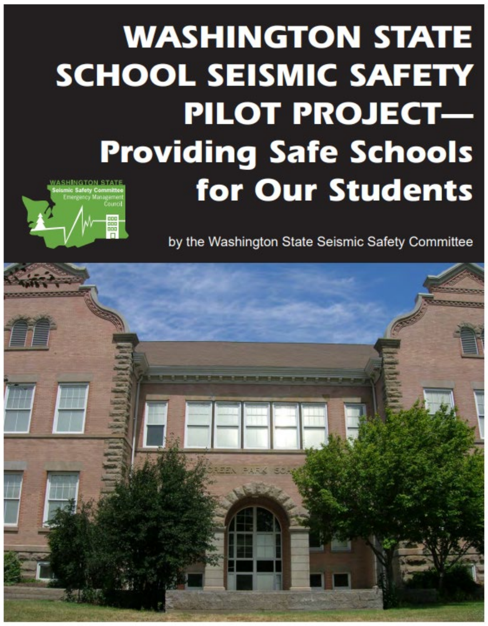
https://fortress.wa.gov/dnr/geologydata/school_seismic_safety/SSSP_2019_Engineering_Vol4_Seismic_Upgrade_Concept_Level_Design_Report.pdf

- Project Summary Poster

https://fortress.wa.gov/dnr/geologydata/school_seismic_safety/SSSP_2019_Poster_DNR_version.pdf

Appendix F: Other Select School Seismic Safety Assessments in Washington

This project is the first state-funded effort to assess school seismic safety at a statewide level. There have been other pilot projects and locally driven efforts that are not captured in this report. A select few of these efforts are highlighted below.



Washington State School Seismic Safety Pilot Project

The purpose of this pilot project was to help determine an appropriate method of assessing the earthquake performance of school buildings. The pilot project focused on two school districts. The selection process considered four criteria: 1) demonstrated earthquake hazard; 2) matching the sizes of districts from eastern and western Washington; 3) manageable number of schools; and 4) cooperation of the district. Ultimately the pilot project selected the Aberdeen and Walla Walla school districts. Each has between five and 10 schools, significant earthquake hazard, moderate to high liquefaction susceptibility, and a willingness to participate in the project. The project used a similar approach as the one employed in this study, using geologic and engineering site assessments and estimating damage probabilities. In the pilot project, the investigators elected to use Hazus (a FEMA loss estimation software). The project found that, as expected, school buildings designed under older building code standards are more likely to sustain significant damage in what are now considered more likely levels of earthquake hazard. This is more the case in the Aberdeen School District, where the greatest threat is from the Cascadia subduction zone. Ground motions from a Cascadia event were not considered at all in building codes before the 1991 Uniform Building Code, and not explicitly until the 2003 International Building Code. In contrast, ground shaking levels in building codes for Walla Walla have not changed as significantly.

The results of this project were instrumental in developing Phase 1 of this project. It is our hope that as we continue into Phase 2 and beyond we can use these results to select schools that are at high risk and potentially conduct concept-level upgrade designs for them.

Case Study of the Seattle School District

Many school districts have made it a goal to seismically upgrade their facilities by leveraging community interest and funding. One such example is the Seattle School District. In a document provided to WGS, the District wrote:

> “The safety of our students and staff is our top priority. Earthquake safety/seismic improvement projects have been completed at Seattle Public Schools’ buildings to meet applicable city codes at the time of construction. The 2001 Nisqually Earthquake, with a magnitude 6.8 on the seismic scale, did not cause structural damage to any of our school buildings, as determined by the City of Seattle building inspectors. None of our school buildings had to be closed for repairs. Seattle Public Schools will continue to

> implement earthquake safety improvements/seismic upgrades to all of our school buildings on a predictable schedule, based on the most recent engineering studies that prioritize the need for seismic improvements. Our mission is to ensure a safe teaching and learning environment for students and staff. Seattle Public Schools Building Excellence (BEX) and Buildings, Technology and Academics (BTA) capital levies, approved by Seattle voters, received funding for earthquake safety improvement/seismic upgrades for our school buildings."

To this end the district has seismically upgraded, or has plans to upgrade all of their school facilities. This is a great example of how districts can phase seismic upgrades and continue to prioritize these efforts.

SEATTLE PUBLIC SCHOOLS

Seattle Public Schools' Earthquake Safety/Seismic Improvements Completed/To Be Completed – update September 2018

The safety of our students and staff is our top priority. Earthquake Safety/Seismic improvements projects have been completed at Seattle Public Schools' buildings to meet applicable city codes at the time of construction.

The 2001 Nisqually Earthquake, with a magnitude 6.8 on the seismic scale, did not cause structural damage to any of our school buildings, as determined by the City of Seattle building inspectors. None of our school buildings had to be closed for repairs.

Seattle Public Schools will continue to implement earthquake safety improvements/seismic retrofits to all of our school buildings on a predictable schedule, based on the most recent engineering studies that prioritize the need for seismic improvements. Our mission is to ensure a safe teaching and learning environment for students and staff. Seattle Public Schools Building Excellence (BEX) and Buildings, Technology and Academics (BTA) capital levies, approved by Seattle voters, received funding for earthquake safety improvement/seismic retrofits for our school buildings.

School Building	**Year of Most Recent Seismic Retrofit (A number of school buildings will receive additional earthquake safety/seismic retrofits in the near future)**
Adams, John	2017
Adams, Jane	2016

Aki Kurose	1994
Alki	1991 (new replacement building to open 2025)
Arbor Heights	2016
Bagley, Daniel	2015
Ballard	1999
Beacon Hill Int’l	2005 (additional scheduled for 2019)
Blaine, Catharine	1992 (additional scheduled for 2019)
Boren, Louisa	2013
Broadview-Thomson	2001 (additional scheduled for 2019, 2020)
Bryant	2001
Cascadia	2017
Cedar Park	2015
Cleveland	2005
Coe, Frantz	2003
Columbia	2011
Concord	2000
Cooper, Frank B.(Pathfinder)	2000
Day, B.F.	2017

Dearborn Park	2018
Decatur, Stephen	2017
Denny, David T. Int’l	2011
Dunlap	2000
Eckstein, Nathan	2018
Emerson	2001
Fairmount Park	2014
Franklin	2015
Garfield, James A.	2006
Gatewood	2017
Gatzert, Bailey	2008
Genesee Hill	2016
Graham Hill	2003 (additional scheduled for 2020)
Green Lake	2001
Greenwood	2002
Hamilton Int’l	2010
Hawthorne	2011
Hay, John	2013
Highland Park	1999

Hughes, E.C.	2018
Ingraham, Edward S.	2018 (additional scheduled for 2019)
John Stanford Center	2001
Kimball, Captain George W.	2015
Lafayette	2005 (additional scheduled for 2019-2020)
Latona (John Stanford Int'l)	2000
Laurelhurst	2003 (additional scheduled for 2019)
Lawton	2008
Leschi	2018
Lincoln	2019
Lowell	2018
Loyal Heights	2018
Madison, James	2004
Madrona	2002
Magnolia	2019 (renovated and opening 2019)
Mann, Horace	2015
Maple	2005 (additional scheduled for 2019)
Marshall, John	2014
Marshall, Thurgood	2008

Martin Luther King, Jr.	2006
McClure, Worth	2003
McDonald, F.A. Int'l	2012
McGilvra, John J.	2015
Meany. Edmond S.	2017
Mercer, Asa	1989 (roof/walls fully seismically reinforced)
Minor, T.T.	2016
Monroe, James (Salmon Bay K-8)	2017
Montlake	2006
Muir, John	2015
Nathan Hale	2012
North Beach	2008 (additional scheduled for 2019-2020)
North Queen Anne	2014
Northgate	1992
Olympic Hills	2017
Olympic View	2018
Pinehurst (Hazel Wolf K-8)	2016
Queen Anne ES (Old Hay)	2011 (new addition/re-opening 2019)
Queen Anne Gymnasium	1995

Rainier Beach	2003
Rainier View	2001
Robert Eagle Staff	2017
Rogers, John	2007
Roosevelt	2004
Roxhill	2002 (additional scheduled for 2021)
Sacajawea	2015
Sand Point	2001 (additional scheduled for 2019)
Sanislo, Captain Stephen E	1998
Schmitz Park	2001
Sealth (Chief Sealth)	2010
Seward (home to TOPS)	1999
South Lake HS	2004
South Shore	2009
Stevens, Isaac S.	2001
Thornton Creek	2016
Van Asselt Elem. (AAA)	2001
Van Asselt (Old Van Asselt)	2013
View Ridge	2010 (additional scheduled for 2019)

Viewlands	2011
Washington	1979 (additional scheduled for 2020)
Webster	2020
Wedgwood	1999 (additional scheduled for 2020)
West Seattle Elementary	2007
West Seattle High School	2002
West Woodland	1991 (roof/walls fully seismically reinforced)
Whitman, Marcus	1995 (additional scheduled for 2020)
Whittier	1999
Whitworth (Orca K-8)	2012 (additional scheduled for 2019)
Wing Luke	2004 (new replacement building opens 2020)

More information on Seattle School District Public School Seismic Safety can be found on their website: https://www.seattleschools.org/departments/capital_projects_and_planning/facilities_master_plan/facilities_condition_assessment_report/seismic_report

Appendix G: School Seismic Safety Policies in the Pacific Northwest

This section covers select existing seismic safety policies in the Pacific Northwest. There are summary tables from the Washington State Gap Analysis Report (Miles and Gouran, 2010) for Washington, Oregon, and California. The aim of this section is to provide context for what other states do that we could borrow from and to highlight how few seismic policies Washington has and how other states (California in particular) have adopted strict policies for schools and earthquakes.

Existing Seismic Policies in WA

Table G1. Table from Washington State Gap Analysis Report (2010) showing Washington State seismic policies. Those policies that are earthquake-specific are colored in blue.

Policy Description	Policy Subject	Policy Type	Earthquake-pecific? Y/N
Growth Management Act: RCW 36.70A	Land use	Legislation	N
Earthquake Construction Standards: RCW 70.86	Buildings	Legislation	Y
State Building Code Act: RCW 19.27	Buildings	Legislation	N
Emergency Management Council: RCW 38.52.040	Advisory	Legislation	N
Bridge Seismic upgrade Program: Transportation Partnership Act of 2005	Infrastructure	Legislation	Y
Geologic Survey, landslide and tsunami hazards: RCW 43.92.025	Science, mapping	Legislation	N
Critical Areas-Geologically Hazardous Areas: WAC 365-190-120	Land use	Legislation	N

Links to Select Washington School Seismic Projects

https://www.wsspc.org/public-policy/legislation/Washington/

Information about California School Seismic Projects and Policies:

Table G2. Table from Washington State Gap Analysis Report (2010) showing California seismic policies. Those policies that are earthquake-specific are colored in blue, and policies that are school- and earthquake-specific are colored green.

Policy Description	Policy Subject	Policy Type	Earthquake-specific? Y/N
Field Act (Education Code-§17281, et seq.)	Schools	Legislation	Y
Riley Act	Buildings	Legislation	Y
Garrison Act	Schools	Legislation	Y
Strong Motion Instrument Act (Public Resources Code§2700-2709.1)	Monitoring	Legislation	Y
Seismic Safety General Plan Element (Government Code § 65302)	Local Mandate: planning	Legislation	Y
Alquist-Priolo Earthquake Fault Zoning Act (Public Resources Code §2621-2630	Mapping	Legislation	Y

Alfred E. Alquist Hospital Facilities Seismic Safety Act (Health andSafety Code§129675)	Hospitals	Legislation	Y
Seismic Safety Commission Act (Business and Professions Code §1014)	Advisory	Legislation	Y
Earthquake Hazard Reduction Program (Senate Bill 1279)	Advisory	Legislation	Y
Alquist Hospital Facilities Seismic Safety Act of 1983 (Health and Safety Code §§130000-130070)	Hospitals	Legislation	Y
California Earthquake Hazards Reduction Act of 1986 (Government Code §8870, et seq.)	Advisory	Legislation	Y
Un-reinforced Masonry Building Law (Government Code §§ 8875-8875.10)	Buildings	Legislation	Y
Essential Services Building Seismic Safety Act (Health and Safety Code §16000	Buildings	Legislation	Y
Katz Act (Education Code §§35295-35297)	Schools	Legislation	Y
Bridge Seismic upgrade Program (Senate Bill 2104)	Infrastructure	Legislation	Y
Earthquake Safety and Public Buildings Rehabilitation Bond Act of 1990 (Prop 122 & Government Code §§ 8878.50-8878.52)	Funding	Legislation	Y
Seismic Hazards Mapping Act (Public Resources Code §§ 2690- 2699.6)	Mapping	Legislation	Y
Health & Safety Code § 1226.5	Hospitals	Legislation	Y
Health and Safety Code §§ 19210-19214	Buildings	Legislation	Y
Executive Order D-86-90	Infrastructure	Order	Y
California Earthquake Authority (Insurance Code §§ 10089.5- 10089.54)	Insurance	Legislation	Y
Education Code§17317	Schools	Legislation	Y
Government Code §8587.7	Schools	Legislation	Y
Health and Safety Code §§19180-83 & §§19200-05	Buildings	Legislation	Y
Streets & Highways Code §188.4	Buildings	Legislation	Y
Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act of 2006 (Proposition 1B, Government Code §8879.23(i))	Funding	Legislation	Y
CA Emergency Services Act (Government Code §8550)	Local Mandate	Legislation	N
Disaster Recovery Reconstruction Act (Government Code §8877.1)	Recovery	Legislation	N
Economic Disaster Act of 1984 (Government Code §8695)	Recovery	Legislation	N
Natural Disaster Assistance Act (Government Code §8680)	Recovery	Legislation	N
Natural Hazards Disclosure Act (Civil Code §1102)	Awareness	Legislation	N
Planning and Zoning Law (Government Code §65000)	Land Use	Legislation	N

Links to select California School Seismic Projects

- Western States Seismic Policy Council-California: https://www.wsspc.org/public-policy/legislation/california/
- Seismic Safety Inventory of California Public Schools: https://www.documents.dgs.ca.gov/dsa/pubs/FinalAB300Report.pdf
- Assembly Bill 300, school seismic safety assessment: http://www.leginfo.ca.gov/pub/99-00/bill/asm/ab_0251-0300/ab_300_bill_19991010_chaptered.html
- Presentation on the Field Act: https://www.shakeout.org/2008/schools/080410kickoff/4_Thorman.pdf
- California Seismic Safety Commission. The Field Act and its Relative Effectiveness in Reducing Earthquake Damage in California Public Schools: https://ssc.ca.gov/forms_pubs/cssc_09-02_the_field_act_report_appendices.pdf
- California School seismic mitigation funding: https://www.dgs.ca.gov/OPSC/Services/Page-Content/Office-of-Public-School-Construction-Services-List-Folder/Obtain-Seismic-Mitigation-Funding
- "No Room For Johnny" 1992 Little Hoover Commission Report on the Field Act and recommendations for updating and funding: https://lhc.ca.gov/sites/lhc.ca.gov/files/Reports/117/Report117.pdf

Information about Oregon School Seismic Projects and Policies:

Table G3. Table from Washington State Gap Analysis Report (2010) showing Oregon seismic policies. Those policies that are earthquake-specific are colored in blue, and policies that are school and earthquake-specific are colored green.

Policy Description	Policy Subject	Policy Type	Earthquake Specific? Y/N
Oregon Revised Statutes 401.025-.335 (Emergency Management and Services)	Emergency Management	Legislation	N
Oregon Revised Statutes 516	Agency Structure	Legislation	Y
Oregon Revised Statutes 336.071	Preparedness ; Awareness	Legislation	Y
Oregon Revised Statutes 455.448	Buildings; Recovery	Legislation	Y
Oregon Revised Statutes Chapter 455 (Building Code)	Buildings	Legislation	Y
Oregon Revised Statutes 401.337 Oregon Seismic Safety Policy Advisory Commission	Advisory	Legislation	Y
Oregon Senate Bill 96 (1991) Seismic Hazard Investigation	Mapping; Awareness	Legislation	Y
Oregon Senate Bill 1057 (1995)	Advisory	Legislation	Y
Oregon House Bill 3144 (1999)	Buildings; Infrastructure	Legislation	N
Oregon Senate Bill 13 (2001) Seismic Event Preparation	Preparednes; Awareness	Legislation	Y
Oregon Senate Bill 14 (2001) Seismic Surveys for School Buildings	Schools	Legislation	Y

Oregon Senate Bill 15 (2001)Seismic Surveys for Hospital Buildings	Hospitals	Legislation	Y
Oregon Senate Bill 2 (2005) Statewide seismic needs assessment for schools and emergency facilities	Schools	Legislation	Y
Oregon Senate Bill 3 (2005) Seismic earthquake rehabilitation grant program	Buildings; Funding	Legislation	Y
Oregon Senate Bill 4&5 State bond authorization	Funding	Legislation	Y
Oregon Revises Statutes 197-Oregon Land Use Planning Act	Land Use	Legislation	N
Oregon Administrative Rule 345-022-0020-Energy Facility Siting Council	Infrastructure	Legislation	Y
Executive Order 08-20	Agency Structure	Order	N

Links to Select Oregon School Seismic Projects

- Oregon Seismic Rehabilitation Grant Program (SRGP): The SRGP is a State of Oregon competitive grant program that provides funding for the seismic rehabilitation of critical public buildings, particularly public schools and emergency services and facilities: http://www.orinfrastructure.org/Infrastructure-Programs/Seismic-Rehab/
- Statewide Seismic Needs Assessment: https://www.oregongeology.org/pubs/ofr/O-07-02/OFR-O-07-02-SNAA-onscreen.pdf
- Implementation of 2005 Senate Bill 2 Relating to Public Safety, Seismic Safety and Seismic Rehabilitation of Public Buildings: http://library.state.or.us/repository/2007/200705230932523/index.pdf
- Western States Seismic Policy Council- Oregon: https://www.wsspc.org/public-policy/legislation/oregon/

Information about Alaska School Seismic Projects and Policies:

Links to Select Alaska School Seismic Projects

- Western States Seismic Policy Council—Alaska: https://www.wsspc.org/public-policy/legislation/alaska/
- Alaska Seismic Hazards Safety Commission: http://seismic.alaska.gov/
- Summary of Alaska School Rapid Visual Screening Project: http://seismic.alaska.gov/download/ashsc_meetings_minutes/Stevens_Hazard_Commission_Handout_FINAL.pdf
- http://seismic.alaska.gov/download/ashsc_meetings_minutes/ASHSC_2012_annual_report.pdf

Information about British Columbia School Seismic Projects and Policies:

Links to Select British Columbia School Seismic Projects

- Seismic Design and Rehabilitation Criteria: https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/technical-circulars/1992/t2-92.pdf
- Engineers and Geoscientists British Columbia School Seismic Upgrade Program: https://www.egbc.ca/Practice-Resources/School-Seismic-Upgrade-Program

- School Seismic in British Columbia: a grassroots success: https://www.crhnet.ca/sites/default/files/library/Monk.pdf
- Structural Engineering Guidelines for the Performance-based Seismic Assessment and upgrade of Low-rise British Columbia School Blocks: https://www.egbc.ca/getmedia/1f46d33a-eb24-4879-8624-807de0ebdcc4/SPIR-Guidelines-3-0-July-2018.pdf.aspx