Seismic Screening of Public Facilities in Oregon's Western Counties

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Abstract: The objective of this study was to use rapid visual screening (RVS) methods to identify potential seismic hazards for Oregon's public facilities, including schools, hospitals, fire stations, police stations, and emergency response centers. There were 1,075 buildings screened in nine western Oregon counties. This study is part of a larger effort under the 2005 Oregon Senate Bill 2 to assess the seismic needs and upgrade public facilities in Oregon. RVS methodology generally followed FEMA 154 *Rapid Visual Screening of Buildings for Potential Hazards: A Handbook*. This method identifies structural type and building characteristics that may indicate poor performance under the maximum considered earthquake (MCE). Each building is given a final score related to the probability of collapse under the MCE. Screening was conducted by four individuals over three months. Quality assurance (QA) testing on nine buildings examined consistency between screeners. QA results showed final scores varied between screeners depending on building size, structure type, and architectural cladding. FEMA 154 was developed using California buildings. Differences between Oregon and California construction and the use of FEMA 154 in Oregon are discussed in this paper, reviewing the Uniform Building Code (UBC) and Oregon Structural Specialty Code (OSSC) amendments. The study provided two important conclusions. First, the average final score for buildings screened fell below the FEMA 154 cut-off score of 2.0 Second, the OSSC had an exception to the UBC that allowed the construction of unreinforced masonry buildings two stories or less in height. With this context, screening results can help in assigning priorities for further analysis and seismic retrofits.

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CE Database subject headings: Buildings, nonresidential; Earthquakes; Seismic analysis; Oregon.

Background

In the 1980s, scientists began thinking the Pacific northwest was at risk from a large earthquake, from a zone off the coast of northern California, Oregon, and Washington (Yeats 2004), where the Juan de Fuca plate is being subducted under the North American plate. The Cascadia subduction zone (CSZ) was compared to zones in southern Chile, southwestern Japan, and Columbia, where the subducting plates' age and rate of subduction are similar. Unlike the CSZ, a recent, written record exists of large moment magnitude (M_w) 8 to 9.5 earthquakes occurring at these other zones. Geophysicists concluded that similar magnitude earthquakes could also occur along the CSZ (Heaton and Hartzell 1987). In addition, Atwater (1987) observed repetitive soil layering in coastal estuaries of Washington. This layering is consistent with that found in Alaska and Chile, and is cited as evidence of coastal subsidence due to past subduction zone earthquakes. More recently, evidence of coastal subsidence due to earthquakes has been found in estuaries from Vancouver Island to Northern California (Yeats 2004). Moreover, a record of past CSZ earthquakes has been established by turbidites (avalanche deposits of dense sediment) in cores from channels in the Cascadia Basin. The record shows an accumulation of 13 turbidites overlying a layer of ash from the eruption of Mt. Mazama, that geologists believe occurred 7,700 years ago, giving the CSZ an approximate average recurrence interval of 600 years (Adams 1990). Evidence of the most recent Cascadia earthquake was found by reviewing Japanese harbor records describing a large tsunami around midnight Jan. 27, 1700. Given a tsunami travel time of 10 h from Cascadia to Japan, the earthquake origin time was 9 p.m. (local time) on Jan. 26, 1700 (Satake et al. 1996). Based on the height and damage of this tsunami, the estimated earthquake is M_w=9.0. This evidence indicates a M_w 8 to M_w 9 earthquake could occur at the CSZ.

More recently, three crustal earthquakes occurred in Oregon within the North American plate. On Mar. 25, 1993, a M_w 5.6 earthquake occurred along the Mt. Angel Fault southwest of Woodburn. Damage from this earthquake was estimated at over $28 million. On Sept. 20, 1993, two earthquakes occurred along the Klamath Falls Fault, M_w 5.9 and M_w 6.0, killing two people and causing $7.5 million in damage. The largest magnitude for crustal earthquakes in Oregon is expected to be greater than M_w 7 but less than M_w 8 (Yeats 2004). There have also been several earthquakes within the descending Juan de Fuca plate in Washington and California. The largest earthquakes within the Juan de Fuca plate are estimated to be greater than M_w 7 but less than M_w 8 (Yeats 2004). In summary, Oregon is at risk from three types of earthquakes: (1) at the interface between the Juan de Fuca and North American plate; (2) within the North American plate; and (3) within the subducting Juan de Fuca plate.

With Oregon's earthquake hazard better defined, studies were

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conducted to predict losses to life and property damage, building codes were improved, and existing buildings began to be retrofitted. Wang and Clark (1999) conducted a statewide study modeling an 8.5 magnitude CSZ earthquake. Predictions included almost 8,000 injuries with 66% of facilities essential to the postearthquake response left operational the day after the earthquake, and 66% of schools left operational.

With Oregon at risk from a large earthquake, the 1994 Uniform Building Code (ICBO 1994) responded by increasing seismic design levels. Unfortunately, Oregon has a large number of buildings built before seismic design requirements were implemented or increased.

In 2001, Oregon Revised Statue (ORS) 455.400 mandated that public schools, fire, police, and hospitals meet life safety standards for a major earthquake (Oregon State Legislature Website 2007). In addition, in Aug. 2005, the Oregon Legislature passed Senate Bill 2 (SB2) to appropriate funds to conduct a seismic needs assessment (Oregon Legislature Committee 2005). Oregon 2005 Senate Bills 3, 4, and 5 (SB3, SB4, SB5) then provided $1.2 billion to improve seismic safety to these facilities (DOGAMI 2006). SB2 was a first step in evaluating Oregon's public facilities for improved seismic safety, and initiated this study to prioritize buildings (SB3) for seismic retrofits to be completed with SB4 and SB5. Developing this inventory had to be completed at low cost in three months, and required teams from the State of Oregon Department of Geology and Mineral Industries (DOGAMI), Oregon State University, Portland State University, and the University of Oregon screening simultaneously.

Table 1. FEMA 154 Building Types

Symbol	Building description	High seismicity basic score
W1	Light wood frame smaller than or equal to 465 m^2 (5,000 ft^2)	4.4
W2	Light wood frame larger than 465 m^2 (5,000 ft^2)	3.8
S1	Steel moment resisting frame buildings	2.8
S2	Braced steel frame buildings	3.0
S3	Light metal buildings	3.2
S4	Steel frame buildings with cast-in-place concrete shear walls	2.8
S5	Steel frame buildings with unreinforced masonry infill walls	2.0
C1	Concrete moment-resisting frame buildings	2.5
C2	Concrete shear-wall buildings	2.8
C3	Concrete frame buildings with unreinforced masonry infill walls	1.6
PC1	Tilt-up buildings	2.6
PC2	Precast concrete frame buildings	2.4
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms	2.8
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms	2.8
URM	Unreinforced masonry bearing-wall buildings	1.8

Screening Process

Introduction to the Screening Process

Seismic screening in this project was based on FEMA 154 *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (ATC 2002a), and identifies building characteristics that could influence damage in an earthquake. These include the building lateral force resisting system (LFRS), construction date, building height, falling hazards, pounding, vertical irregularities, and plan irregularities. In addition to the above data, the screeners collected GPS coordinates, site address, building name(s), estimated construction date, building use, evidence of poor condition, and photos of the building. Data were then entered into a field tablet computer on site or recorded on standard forms and entered into the computer later.

Table 1 shows the 15 types of LFRS in FEMA 154. Correctly identifying the LFRS can be challenging as the structural system may be covered by architectural cladding, be located inside the building where the screener may not have access, or the building may be comprised of several different types of LFRS. Fig. 1 shows a school gym constructed of wood, masonry, and light metal. Buildings with more than one possible structure type were ranked as primary, secondary, and tertiary structural types based on the confidence assigned by the screener.

To substantially improve confidence in identifying the LFRS, one would need to review structural plans. Previous studies on Oregon community colleges (Miller, unpublished data, 2005) showed that 30% of the buildings could not be classified accurately for structural type without reviewing plans. This would also help identify the dominant structural type when several types are present. For example, if a building is entirely of wood with the exception of a masonry wall that encases a mechanical room, W1 or W2 would be taken as the dominant structure type and used to calculate the final score. In this study, if masonry was found in a wood building, the final score was calculated for both types and the controlling lowest score reported. Making determinations for dominant structure type should only be done where it is clear from a thorough review of drawings. The dominant structural type depends on the lateral load path and structural element rigidity. Thus, for more complex buildings, further analysis should be completed using documents such as ASCE 31 (ASCE 2003) or FEMA 356 (ASCE 2000).

The final score (S) is equal to the basic structural hazard score (BSH) plus the score modifiers (SMs), as shown in Eq. (1)

$$S = \mathrm{BSH} \pm \mathrm{SMs} \tag{1}$$

The basic structural hazard score is related to the probability of collapse for a building type given the maximum considered earthquake (MCE) by Eq. (2)

Fig. 1. Building with W2, RM2, and S3 structure types; RM2 is the controlling structure type

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Fig. 2. Reentrant corners as plan irregularities, moderate severity

$$\mathrm{BSH} = -\log_{10}[P(\text{collapse given MCE})] \quad (2)$$

BSHs are developed from HAZUS fragility and capacity curves (ATC 2002b). MCE has a 2,475 yr recurrence interval or 2% probability of being exceeded in 50 yrs. The BSH is then modified by SMs to give a final score for a specific building. SMs are based on building characteristics that affect seismic performance, and involve either recalculating a BSH with the characteristic or are based on judgment. For example, the SM for high rise buildings is based on a recalculated BSH for a taller building, while the SM values for vertical irregularity are assigned so if that were the only SM, the final score would be below the cut-off score of 2.0. Thus, the final score is loosely related to the probability of collapse and a lower score indicates a higher hazard.

Using rapid visual screening (RVS) to evaluate a large inventory of buildings is a cost effective means to assess the seismic hazards. Prioritization can be accomplished and buildings with higher seismic hazards (lower final scores) addressed first. However, a building with a high hazard needs to be more fully evaluated, using methods such as ASCE 31 (ASCE 2003), to determine which aspects need to be upgraded, if any.

Classifying the Irregularities

Guidelines for further classifying the plan and vertical irregularities in FEMA 154 were developed based in part on the International Building Code (ICC 2000) to help screeners be consistent. For example, the building in Fig. 2 would be appropriately classified as having a plan irregularity: reentrant corner, moderate severity. Moderate severity was identified because both horizontal projections are greater than 15% of the total length in that direction. Irregularities were classified as low, moderate, or high severity. Irregularities with moderate and high severity were used to calculate the final scores. Low severity irregularities would not affect the final score. To help identify and document the plan irregularities, screeners used satellite images in addition to walking around the building perimeter. These images also helped document and label the different buildings on the site. Sites that had several buildings with different structural types or dates of construction had those identified and screened separately.

Buildings Screened

Buildings screened in western Oregon consisted of fire and police stations, hospitals, and schools with occupancy of 200 or greater. In addition, all schools along the coast were viewed as a potential high risk, and screened. Enough schools were screened in each county so that 90% of all students were included. Buildings were not screened if constructed after 1994 or previously seismically studied or retrofitted. Oregon State University's Department of Civil, Construction, and Environmental Engineering, funded by DOGAMI through Senate Bill 2, screened nine counties and 1,075 buildings in 10 weeks. Buildings varied in age from pre-1900 to the 2000s. The largest percentage was constructed in the 1970s and 1960s with 25% and 20% from these decades, respectively.

Results

The average final score for the public buildings screened was 1.7, with a maximum score of 6.8, minimum score of −1.7, and a standard deviation of 1.61. A total of 670 buildings scored below the FEMA 154 cut-off score of 2.0, thus, recommending further evaluation. Final score was calculated for all identified structure types. Of these scores, the lowest was used in the results summary. Score modifiers for precode were used for all buildings built before 1941, except 1974 for tilt-up buildings (PC1) as recommended by FEMA 154. Postbenchmark dates were included in final scores based on Oregon building code history. Precode score modifiers discount the score when a building was constructed before the adoption and enforcement of seismic codes. Postbenchmark score modifiers increase the final score when significant code improvements have been made. Unfortunately, postbenchmark years outlined in FEMA 154 do not include the Oregon Structural Specialty Code. The final score was calculated with both the FEMA-154 postbenchmark year SM based on the UBC and an Oregon postbenchmark year SM.

The Oregon Structural Specialty Code had an exception that allowed construction of one- and two-story unreinforced/partially reinforced masonry and concrete shear wall type buildings until 1990. In most cases to confirm if the building is actually reinforced or unreinforced, testing or structural plan review would have to be completed. However, neither of these was accomplished in this study, thus, all concrete buildings were assumed reinforced and masonry buildings built after 1950 were assumed reinforced. These buildings may lack detailing such as minimum reinforcement, so the postbenchmark score modifier was not applied to RM2, S4, and C2 buildings if built before 1990 and two stories or less in height. RM1 and RM2 buildings may actually be unreinforced, so the final score was calculated an additional time as a URM structure type and both scores were reported.

Table 2 illustrates how the scores were calculated. Final scores were reported for both the controlling field identified structure type and for URM. The OSU team did not collect soil data. Since

Table 2. Example Score Calculations for RM2 Structure Type Identified in the Field and If URM

Structure type	Basic score	Midrise (4–7 stories)	High-rise (>7 stories)	Vertical irregularities	Plan irregularities	Precode	OSSC postbenchmark	Soil D	Soil E	Final score
RM2	2.8	0	0	0	−0.5	0	0	−0.6	0	1.7
URM	1.8	0	0	0	−0.5	0	0	−0.6	0	0.3

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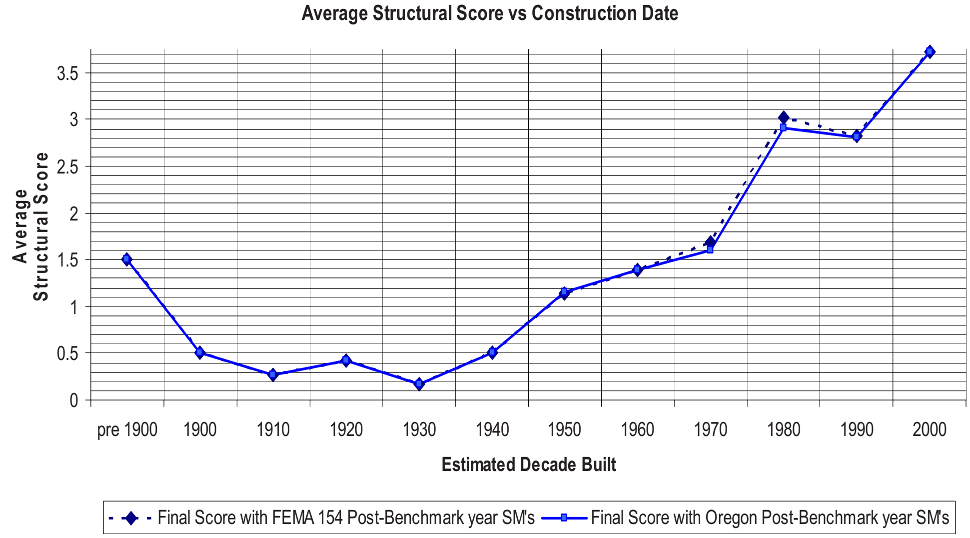

Fig. 3. Average final score versus estimated construction date (decade)

soil conditions were not known, the following was assumed in accordance with FEMA 154: type D or stiff soil for buildings two stories or less, and type E or soft soil for buildings taller than two stories. The seismicity hazard was high for this region. Note that the official RVS scores for 2005 Oregon Senate Bill 2 are calculated by DOGAMI and include other considerations such as local soil types, and will vary from those in this paper.

Fig. 3 shows average final scores for each decade, using both score modifiers from FEMA 154 and based on Oregon postbenchmark years. Buildings built before 1900 had an average final score of 1.5. However, only three buildings were constructed before 1900, including two fire stations and one school. One of the fire stations is constructed from wood and the other is from light metal; both structure types have high basic structural scores combined with a low number of irregularities, resulting in high final scores and a high average final score for the time period. The average final scores increase during the 1950s because buildings built after 1941 did not receive the precode SM, which discounts the score. The scores began to further increase in the 1970s because Oregon postbenchmark year score modifiers apply in 1976 through 1997 depending on the structural type.

Fig. 4 shows ranked average final scores for each facility type. Fire stations scored highest with an average score of 1.9. A higher score for fire stations is due to a large number of these facilities being wood or light metal buildings with few or no irregularities. K–12 schools scored the lowest, with an average final score of 0.94. K–12 schools consist of a large number of older, complex buildings with a wide range of structural types. Emergency response centers also scored low with an average final score of 1.0. These buildings have a range of structural types, the most common being C1 and RM1, combined with irregularities resulting in a low average score. Police stations and community colleges scored slightly better with average final scores of 1.35 and 1.41, respectively.

Discussion and Recommendations

Oregon Specific RVS Procedure

The RVS procedure in FEMA 154 was developed considering California building practices that differ from those in Oregon. For example, a one story, hollow concrete masonry building built in 1976 in California would be designed for a total base shear of 15.1% of the building seismic weight. The same building in Oregon would have been designed for 5.7% of the building seismic weight, or 63% less than the California building. This same building would also have been required to be reinforced masonry in

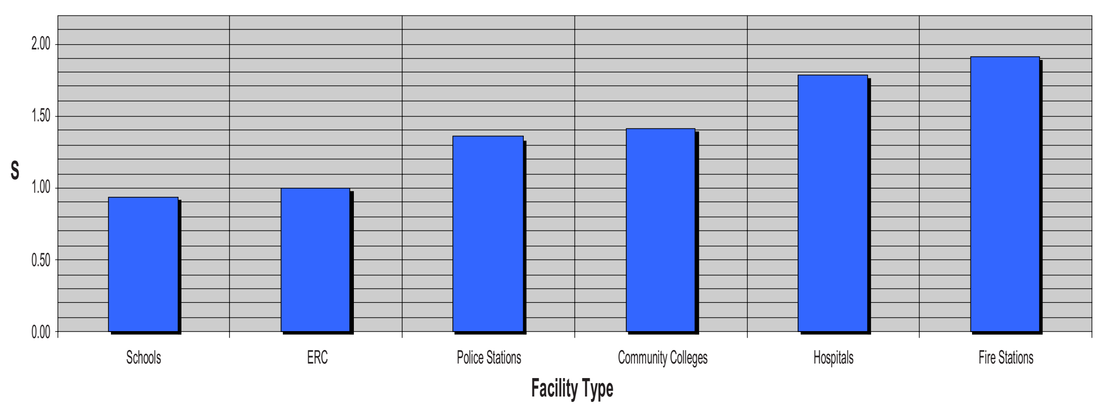

Fig. 4. Average final score (S) based on facility type

California and allowed to be unreinforced masonry in Oregon. These differences would have an obvious impact on the probability of collapse given the MCE. These differences need to be considered when using RVS to estimate seismic hazard for Oregon buildings.

To develop an Oregon specific RVS procedure, a thorough Oregon building code review was conducted to establish modified building code cut-off (precode) dates and modified postbenchmark dates when significant seismic improvements were made to the Oregon building code. The appropriate score modifiers from FEMA 154 were then applied to buildings constructed before the modified precode years and to buildings constructed after the modified postbenchmark years. This helps reflect improved detailing such as connections or minimum reinforcement; however, this would not address the issue of buildings designed for a lower earthquake force. Buildings built in lower seismic zones still have the LFRS system designed for wind loads. However, ductility requirements would be deficient. With all of Oregon formerly designated a low seismicity zone and now designated as either high or moderate, it is imperative that the ductility of the structure be captured. An attempt to establish the postbenchmark years for Oregon has been completed and included below.

Oregon Building Code History

The state of Oregon released the first state-wide building code, the Oregon Structural Specialty Code (OSSC), in 1974. This first edition of the OSSC was an amended version of the 1973 Uniform Building Code (Oregon Building Codes Division 2005). Prior to 1974, counties and cities adopted the Uniform Building Code (UBC) at their own discretion (DOGAMI, personal communication, 2006). The state continued to adopt and amend the latest edition of the UBC until 2000 when the state adopted the International Building Code (ICC 2000). It is important to note that the OSSC was published sequentially after the UBC, often with a delay of between one and two years. This resulted in delayed enforcement of the latest UBC; a list of the UBC adoption dates can be found at Oregon Building Codes Division (2005). Amendments to the UBC typically increased the seismic zone for Oregon. Another significant amendment to the UBC is an exception (until 1990 OSSC) that allowed unreinforced and partially reinforced concrete and masonry buildings to be constructed in seismic zones one and two if the structures are two stories or less in height. Seismic zone 2 was the highest seismic zone in Oregon until release of the 1990 OSSC.

The Uniform Building Code was first published by the Pacific Coast Building Officials (1927), later the International Conference of Building Officials (ICBO). Seismic design requirements were included in the Appendix as “suggested.” Seismic design was elastic and based on the building location and weight. This method of seismic design remained until 1956 (Pacific Coast Building Officials 1956). The 1956 UBC included the effects of the building period as well as benefits from inelastic deformation with a *K*-factor based on structure type. In 1959, the Structural Engineers Association of California (SEAOC) published the first edition of the recommended lateral force requirements and commentary (Seismology Committee 1976), also referred to as the “SEAOC Blue Book.” The Blue Book was adopted into the main part of the UBC in 1961. The next large improvements to the UBC occurred in 1976, shortly after the 1967 earthquake in Caracas, Venezuela, and the 1971 earthquake in San Fernando, California (Olshansky 1998). As mentioned in the Results section, the 1976 UBC (ICBO 1976) included the addition of seismic zone 4; improved provisions for attaching a building diaphragm to the LFRS; the addition of the S and I factors, which account for site/soil conditions and occupancy importance of essential facilities; dynamic analysis required for irregular shapes or unusual framing systems; and several other important considerations

Possible Postbenchmark Years for Oregon

Light Wood-Frame (W1 and W2)

These are usually low rise buildings constructed with wood stud walls covered with wood sheathing to create bracing panels. Larger buildings can also be from timbers in post and beam or truss structures. The FEMA 154 UBC postbenchmark year for W1 and W2 buildings is 1976. The 1976 UBC had several improvements related to the addition of seismic zone 4. All of the following improvements for wood structures are seismic zone independent: more stringent diaphragm connection requirements that eliminate connections that rely on cross-grain bending and cross-grain tension; and requirements for diaphragms that resist forces from concrete or masonry, eliminating connections that rely on toenails or nails subject to tension. Thus, the 1976 UBC is used to establish the postbenchmark year for light wood-framed (W1 and W2) buildings constructed in Oregon.

Braced Steel Frames (S2)

Braced steel frame structures are typically characterized by steel frames with diagonal members axially loaded under earthquake loading. The FEMA 154 UBC postbenchmark year for braced steel frames is 1988. There are several improvements in the 1988 UBC, mostly seismic zone specific requirements. For all braced frames, except eccentrically braced frames, in seismic zones 3 and 4, the braces must meet slenderness requirements. In addition, in seismic zones 3 and 4, these buildings must meet a horizontal load distribution requirement. The total horizontal force component of either the tension braces or compression braces must not be greater than 70% of the total horizontal force on the bracing line. For buildings taller than two stories, *K*-braces are not allowed in seismic zones 3 and 4. There are several detailing requirements for eccentrically braced frames, especially concerning the required “link beam,” and none of the requirements are seismic zone specific. Thus, if the screener can confirm that the frames are eccentrically braced, it is recommended that the postbenchmark year for braced frames be taken as 1990, the year the OSSC adopted the 1988 UBC. Since braced frames that were not constructed to seismic zone 3 requirements do not meet the above requirements, they should not receive the postbenchmark SM. Braced frames constructed in zone 3 should receive the postbenchmark year SM.

Steel Frame Buildings with Cast-in-Place Shear Walls (S4)

These buildings consist of a grid of steel columns and beams with concrete shear walls. Steel connections are typically designed for shear only and concrete shear walls resist the majority of the lateral load. Common problems include wall bending failures due to insufficient steel lap lengths, cracking around wall openings, and wall failures at construction joints (ATC 2002a). The FEMA 154 UBC postbenchmark year for this type of building is 1976. The 1976 UBC added seismic zone 4 and increased the minimum lap length for class A, B, C, and D lap splices. The 1976 Oregon Structural Specialty Code has an exception allowing for the construction of unreinforced and partially reinforced concrete buildings two stories or less in seismic zones 1 and 2. This exception

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was eliminated in the 1990 Oregon Structural Specialty Code (Oregon Building Codes Division 1990). These buildings may lack detailing such as minimum reinforcement, so the postbenchmark score modifier should not be applied to S4 buildings if built before 1990 and two stories or less in height. The postbenchmark year for these buildings should be 1990. However, if taller than two stories, the postbenchmark year should be taken as 1976.

Concrete Moment-Resisting Frame Buildings (C1)

These buildings are characterized by concrete beams and columns that resist vertical gravity loads and lateral earthquake loads. Successful performance is linked to the ductility of the frame (ATC 2002a). FEMA 154 UBC postbenchmark year is 1976. As mentioned above in the Oregon Building Code History section, there were several improvements made in the 1976 UBC. The improvements to the 1976 UBC that affect C1 buildings are all seismic zone independent. Thus, 1976 is used for the postbenchmark year for C1 buildings in Oregon.

Concrete Shear Wall Buildings (C2)

These buildings are typically characterized by perimeter concrete bearing walls, and may also incorporate beams and columns to provide a larger open area. Earthquake forces are primarily resisted by the concrete walls (ATC 2002a). This type of structure suffers from problems similar to S4 type structures. The FEMA 154 UBC postbenchmark year is 1976. As mentioned in the Oregon Building Code History section, there were several improvements in the 1976 UBC, however, all the improvements that affect C2 buildings are seismic zone independent. The 1976 Oregon Structural Specialty Code has an exception that allows the construction of unreinforced and partially reinforced concrete buildings that are two stories or less in seismic zones 1 and 2. This exception was eliminated in the 1990 Oregon Structural Specialty Code (Oregon Building Codes Division 1990). These buildings may lack detailing such as minimum reinforcement, so the postbenchmark score modifier should not be applied to C2 buildings if built before 1990 and two stories or less in height. The postbenchmark year for these buildings should be 1990. However, if taller than two stories, the postbenchmark year should be taken as 1976.

Tilt-Up Concrete Structures (PC1)

These buildings are characterized by concrete perimeter walls that are cast on site on the ground or at a location possibly closer to the concrete batch plant. Walls are then tilted up to a vertical position. A roof is then constructed, often out of wood or light metal. These buildings are very common for light industrial buildings and can be identified by vertical joints at a regular spacing. A common deficiency is poor connections between the walls and the diaphragm. FEMA 154 (ATC 2002a) comments that poor anchorage between diaphragms and walls has been corrected for buildings since 1973, yet gives the postbenchmark year for PC1 buildings as 1997 for the Uniform Building Code. The 1997 UBC adds a requirement of a minimum of two connections for each wall. For buildings three stories or more, the 1997 UBC also increases connection requirements. Reinforcement cover requirements have also been changed to increase cover by one-quarter inch for most bars. Code improvements mentioned above are independent of the seismic zone. The OSSC adopted the 1997 UBC in 1998, at which time the major increase in seismic zone for the state had already taken place. The state was either seismic zone 2, 3, or 4, thus, the 1998 OSSC should capture the necessary strength and ductility requirements. It is recommended that the postbenchmark year for PC1 buildings in Oregon be taken as 1998.

Reinforced Masonry with Flexible Diaphragms (RM1)

These buildings typically consist of concrete masonry units with grouted cells or two wythes of brick masonry separated by reinforced concrete. Roofs and floors are constructed of wood or light gauge steel. Stiffnesses of floors and roofs are typically much less than the walls, and are, thus, referred to as flexible diaphragms. The UBC classifies a flexible diaphragm as a diaphragm with maximum lateral deformation greater than two times the average story drift. Typical seismic deficiencies for RM1 buildings are due to a lack of reinforcement and insufficient connections between diaphragms and walls. The FEMA 154 UBC postbenchmark date is 1997. The 1997 UBC increased the requirements for anchoring the diaphragm to reinforced masonry walls and added requirements for out-of-plane wall anchorage to flexible diaphragms. These additions to the code were limited to seismic zones 3 and 4. The 1998 OSSC adopted the 1997 UBC and made it effective on October 1, 1998. It identifies the western counties of Oregon as seismic zone 3 with some coastal areas as seismic zone 4. It is recommended that the postbenchmark year for Oregon RM1 buildings in seismic zones 3 and 4 be taken as 1998. Masonry buildings two stories or less built before 1990 may be unreinforced masonry (see discussion on Oregon building code history). Walls should be confirmed to be reinforced or not by reviewing structural plans or by nondestructive testing. If the walls are unreinforced, the structure type should be taken as URM.

Reinforced Masonry with Rigid Diaphragms (RM2)

These are similar to RM1 buildings and are usually characterized by hollow concrete masonry units with grouted reinforced or two wythes of brick masonry separated by reinforced concrete. The rigid diaphragm is generally concrete, or a composite of concrete and steel. The FEMA 154 UBC postbenchmark year for these buildings is 1976. The 1976 Oregon Structural Specialty Code has an exception that allows the construction of unreinforced and partially reinforced concrete buildings that are two stories or less in seismic zones 1 and 2. This exception was eliminated in the 1990 Oregon Structural Specialty Code (Oregon Building Codes Division 1990). These buildings may lack detailing such as minimum reinforcement, so the postbenchmark score modifier should not be applied to RM2 buildings if built before 1990 and two stories or less in height. The postbenchmark year should be 1990. One should also confirm whether the walls are reinforced or not by reviewing structural plans or by nondestructive testing. If walls are unreinforced, the structure type should be URM. However, if taller than two stories, the structure type should be RM2 and the postbenchmark year taken as 1976.

Irregularities and Building Performance

For buildings with the same structure type, FEMA 154 discounts the basic hazard score the same for each type of plan irregularity. Each different vertical irregularity is also treated the same. This study added the criteria that plan and vertical irregularities must be of moderate or high severity, but additional criteria could be considered, accounting for whether different irregularities equally affect the building's performance. For example, consider two buildings both having reentrant corners. Building 1 has a "T-

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shape," while building 2 has an "L-shape." Both buildings have plan irregularities, but further analysis would be needed to determine which would perform better.

Next, consider two buildings with vertical irregularities. The first has a soft story and the second has a single elevation step. Seismic performance of both buildings would be affected by the vertical irregularities. A soft story often results in a concentration of ductility demand or damage to that story (Chopra 2007). In the MCE, the building with the soft story may be at risk of collapse, while the single elevation step may result only in localized damage and not affect the probability of collapse.

There are other concerns with comparing buildings with different irregularities. One concern is the severity, and whether the same SM should be used for low, moderate, and high severity. Another is the total number of irregularities, and if a building with one plan irregularity should get the same SM as a building with multiple plan irregularities. Some of these differences could be incorporated into RVS by increasing the detail of the SMs. For example, separate SMs could be developed for a vertical step and a soft story. Other irregularities would need a more detailed analysis as outlined in ASCE-31 (ASCE 2000) to determine their effect. It is beyond the scope of this paper to quantify the differences between irregularities. However, it is recommended that screeners and policy/decision makers be cognitive of these differences when prioritizing buildings based on RVS results.

Prioritizing the Buildings for Seismic Retrofits

The final score can be used to help prioritize the buildings for seismic retrofits. Priority can simply be given to buildings with lower scores. However, this neglects several important issues discussed below.

Building Occupancy

The FEMA 154 screening method does not consider the building occupancy in the score calculation, but only the potential for collapse given the MCE. For example, a reinforced masonry fire station in rural Oregon that houses two fire trucks and an ambulance but no fire department personnel would be scored the same way as a reinforced masonry hospital. Comparison between the two final scores would account for differences in irregularities, building height, soil type (assumed D or E in this report), and whether constructed before the adoption of seismic codes (pre-code year) or after significant improvements to the code (post-benchmark), but not the different occupancies. Building occupancy should be considered when prioritizing the buildings for seismic retrofitting. One approach would be to compare final scores for buildings with similar occupancies and then begin prioritization.

Future Use and Construction Plans

Seismically retrofitting a building can be a costly investment. The owner (state, municipality) should be committed to the building. If planning to construct a new building within the next few years and abandoning the current building, then retrofitting may not be a good investment. If planning critical maintenance or remodeling the existing building, then incorporating a seismic retrofit may be wise. For example, if a new roof is being constructed on the building, then combining the new roof with strengthened connections to the walls is often cost effective.

Facility Use and Its Effect on the Community

The public facilities screened are very important to their communities. Schools have large occupancies of teachers and children, which make up the future of the community. Hospitals house a large number of patients, as well as doctors, nurses, medical equipment, and provide emergency medical treatment critical to citizens after an earthquake. A single hospital may also serve several towns and a large rural area. These facilities are often operated by private companies and may not be as dependent on public funding for upgrades. Fire stations house important emergency equipment. Occupied fire stations also house firemen and paramedics who are critical to the postearthquake response effort. Fire stations also work in combination with each other in order to provide an adequate response. Thus, a large population may not be served by a single station. Police respond to a wide range of emergencies as well as maintain public order, however, all police stations may or may not be occupied 100% of the time. When prioritizing the buildings for seismic retrofitting, the facility use should be considered as well as the size of the population it serves. A building serving a larger population would be given a higher priority.

Collapse Prevention versus Life Safety

Upgrading an existing building to the collapse prevention performance level still leaves occupants at significant risk of loss of life or injury, as the building would be at the verge of partial or total collapse, and it would not be safe to reoccupy the building. However, this would prevent a total collapse that seriously endangers every occupant of the building. Upgrading to life safety performance level would reduce the risk of life threatening injuries, and the building would not be at risk of immediate collapse (ASCE 2000). Ideally all these public buildings should be upgraded to at least a life safety performance level. Buildings that house sensitive equipment and are used in the postearthquake response effort, such as hospitals, should be upgraded even further to an operational state after the MCE. Some buildings, such as schools, have already been retrofitted to a collapse prevention level. Unfortunately, funds will be exhausted long before all the needed upgrades can be made. The decision to upgrade to either life safety or collapse prevention should be well considered before action is taken.

Community Financial Need

This study was conducted in several counties that have a range of economic need. Some communities have already demonstrated the financial ability to complete seismic retrofits and they should be encouraged to continue doing so. Other communities may find it more difficult financially or impossible to complete seismic retrofits. In order for Oregon to have the largest possible number of public facilities that meet collapse prevention or life safety requirements, the community financial need should also be considered. It is recommended that additional criteria be implemented in prioritizing the buildings to include the communities' financial need. One option would be to have increased retrofit funding based on average income level or tax base. Thus, all communities would qualify for bonds to perform the retrofits; however, communities with a lower tax base or income level would also qualify for additional funds, thus, increasing the total number of facilities retrofitted.

Results from the Quality Assurance Testing

Quality assurance (QA) testing was completed on nine buildings. The purpose was to evaluate consistency between the RVS teams.

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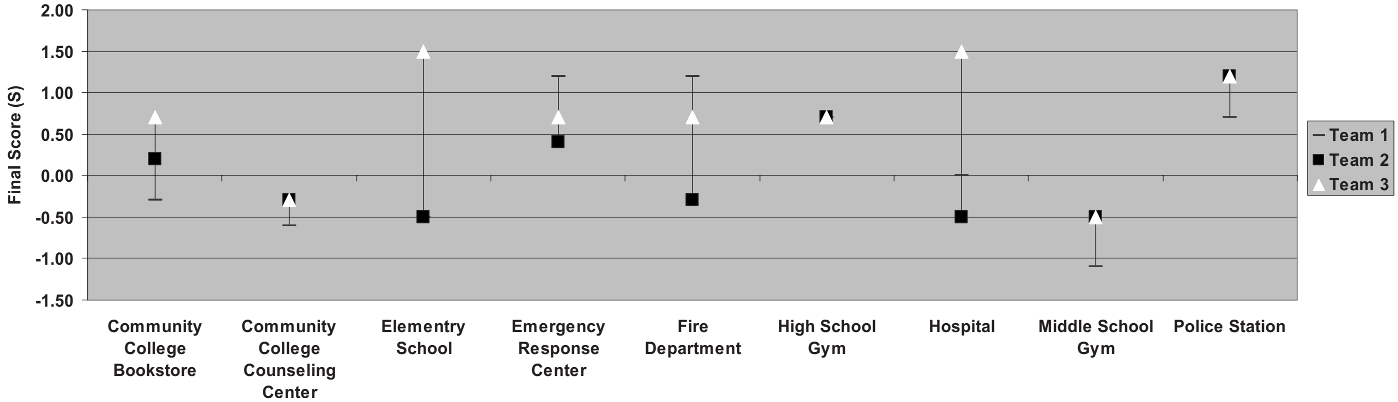

Fig. 5. Final score comparison from quality assurance testing

Each team screened these buildings separately. The test sites consisted of two community college buildings, a state police station, a high school gym, a middle school gym, an elementary school, a hospital, an emergency response center, and a fire station. Final structural scores varied as shown in Fig. 5.

Quality assurance testing revealed that screeners identified the largest number of possible structure types for three of the four buildings that where covered by an architectural façade. However, this did not always result in less consistent final scores. Screeners agreed on plan irregularities for four of the nine buildings and agreed on vertical irregularities for five of those. They may have had trouble identifying some irregularities because the view was obstructed, making identification difficult. It is recommended that similar quality assurance testing be conducted on more buildings with a known structural system so both accuracy and consistency can be evaluated.

Conclusions

Rapid visual screening was conducted in western Oregon on 1,075 public buildings, including hospitals, schools, police stations, fire stations, community colleges, and emergency response centers. The conclusions follow:

1. Average final scores for the facilities varied from 0.94 for schools to 1.91 for fire stations. A large number of the fire stations were smaller wood or light steel buildings with few irregularities. A large number of the schools were older buildings with several irregularities.
2. QA results indicated that final scores varied between screening teams. Score variations were due to teams identifying different structure types and irregularities. Screeners identified a larger number of possible structure types for buildings that were covered by an architectural façade, but this did not necessarily result in a wider range of controlling final scores for these buildings. In addition, screeners had an easier time identifying irregularities that were larger or more evident. Similar testing should be conducted on buildings with known structure types (from reviewing structural plans) to also measure accuracy.
3. A review of Oregon's building code revealed that UBC post-benchmark years from FEMA 154 should be adjusted to account for timing of implementation and different code requirements in Oregon. The Oregon Structural Specialty code adopted the UBC with amendments. One of these amendments allowed the construction of unreinforced masonry and concrete buildings if the height is two stories or less. Consequently, Oregon could have a large number of unreinforced masonry buildings.
4. Screening results can be used to help prioritize the facilities for seismic retrofitting. In addition to the final scores, the building occupancy, role in the postearthquake relief effort, community financial need, and effect on the community should be considered. Before the buildings are retrofitted, a detailed structural evaluation should be conducted by a registered engineer.

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