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Risk assessment and risk management in Oregon

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Abstract

This paper presents the first statewide quantitative seismic risk assessment. Oregon is especially vulnerable to earthquake hazards because of its proximity to the Cascadia subduction zone and its many older buildings. Expected ground motions, building damage, and social and economic losses were estimated for (1) a magnitude 8.5 Cascadia subduction zone earthquake off the coast of Oregon, and (2) statewide probabilistic ground motions for a 10% probability of exceedance in 50 years, which is the basis of the seismic design levels in the building code. The analyses were conducted using geographic information system (GIS) based HAZUS97 software. The local soil conditions were modeled using a statewide 1997 Uniform Building Code soil map based on shear wave velocities. Ground motion maps for peak ground acceleration, peak ground velocity and spectral responses were developed. Expected losses for the magnitude 8.5 earthquake show about 35,000 buildings severely damaged, about 12 billion dollars ($US) of building damage, and over 7,700 casualties. Expected losses from the "design level" earthquake study are over 80,000 buildings severely damaged, over $30 billion of building damage, and over 24,600 casualties. Risk management strategies that help stimulate and prioritize mitigation activities are reviewed.

Introduction

This paper presents the first statewide quantitative seismic risk assessment, which was conducted using HAZUS97 software. Oregon is especially vulnerable to earthquake hazards because its convergent plate tectonic boundary can generate a magnitude 8 or larger earthquake. The study was conducted to better understand future damage and public safety issues. Results for (1) a magnitude 8.5 (M8.5) Cascadia subduction zone earthquake off the coast of Oregon, and (2) statewide probabilistic ground motions for a 10% probability of exceedance in 50 years (or 500-yr return interval), which is the basis of the building code "design level" are provided. The paper also reviews risk management strategies.

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Expected ground motions, building damage, and social and economic losses were estimated. Surface ground motion maps for peak ground acceleration, peak ground velocity and spectral responses for 0.3 and 1.0 second periods were developed. The estimates of expected building damage and social and economic losses generated are low because the computer model did not include damage from unreinforced masonry buildings. Also, the model did not include tsunami inundation damage generated from the Cascadia Subduction Zone earthquake. Even so, casualties of over 7,700 were projected for a M8.5 Cascadia event. In addition, there were about 35,000 buildings severely damaged and $12 billion dollars in damage. Expected losses for the "design level" earthquake study are more than 24,600 casualties, over $30 billion of building damage, and over 80,000 buildings severely damaged. Loss projections for displaced families, unusable schools, bridges and other facilities were also included.

Most of the damage costs are located in western Oregon, where the expected ground motions and population density are higher than in eastern Oregon. Results from this study can be used to help increase public awareness of earthquake hazards and risk and stimulate earthquake risk management activities, such as the development of recovery and reconstruction plans.

Earthquake hazards

Oregon has numerous potential earthquake sources that can produce strong ground shaking and thereby damage to communities. The Cascadia subduction zone fault, which lies just offshore, can produce a M8.5 or perhaps even larger earthquake (Yamaguchi and others, 1997). Inland faults, such as the Mount Angel fault that triggered the M5.6 Scott Mills ("Spring Break") earthquake in 1993 and the West Klamath Lake fault zone that, during the same year, triggered the two Klamath Falls main shocks of magnitudes 5.9 and 6.0, are examples of crustal earthquake sources. About 30 and 10 million dollars in damage were inflicted by the Scotts Mills and Klamath Falls earthquakes, respectively. Inland faults can produce magnitude 6.5 earthquakes or larger.

Risk management strategies

As a result of growing awareness of earthquake hazards in Oregon, steps are being taken to better understand and prepare for the threat of strong ground shaking. For example, more stringent building code requirements have been adopted. In 1993, the Seismic Zone designation for western Oregon was raised from 2B to 3 in the Uniform Building Code (UBC); in 1998, portions of the southern and central Oregon coast were raised to UBC zone 4. Currently, Zone 4 is being considered for the north coast area and Zone 3 for the area just east of the Cascade Range.

The present risk assessment study is another such example. This work may help further the state's risk reduction efforts, by helping to formulate or support state legislation that improves the state's building inventory database, or provide tax credits for purchasing earthquake insurance or seismic strengthening of structures. On the local level, it may help instigate or substantiate the seismic evaluation or strengthening of older school buildings in a local school district. Although loss estimations have inherent uncertainties and limitations, the results provide important information for both regional and local risk management strategies.

Still, the earthquake risk increases everyday as the population increases and as vulnerable buildings age. In fact, the vast majority of older buildings that were built under less stringent building code requirements represent a threat in case of a significant earthquake. For Oregonians, the most significant benchmark year is 1993 when the Zone 2B to 3 code upgrade was enacted. Because this benchmark year is so recent, even entire cities are at risk of severe damage.

Some businesses and local governments have voluntarily strengthened their facilities for better performance. However, the vast majority of the built environment is marked with deficiencies and will respond with a reactive stance rather than take proactive preventative actions. Perhaps progress is slow due to the limited understanding of the risk and perceived need. After all, earthquakes are episodic and infrequent. Whatever the cause, the risk reduction effort has been meager compared to what is necessary to ensure public safety. We know that improving facilities, such as lifelines and unreinforced masonry structures, can be costly. Whatever the case may be, earthquake knowledge and disclosure of risk can help provide necessary information so that informed risk reduction decisions can be made.

Risk management is a complex process because it requires an integrated assessment of the community's hazard environment (e.g. the seismogenic, geologic, and geotechnical data) and the community's built environment (e.g. the buildings and lifeline systems). When these information are combined with knowledge of the policy environment, the community is able to identify and take the appropriate steps to become more earthquake resistant (Hays and others, 1998).

Risk management encompasses the process of deciding what to do when the risk assessments indicate substantial future losses. Choices and actions include avoidance, mitigation, preparedness, response, and recovery and are designed to: 1) stop increasing the risk to future elements, 2) start decreasing the risk to existing elements already at risk, and 3) continue planning ways to respond to and recover from the inevitable damaging earthquakes (Hays and others, 1998).

The starting point is information on a community's hazard and built environments, which must be integrated for a useful risk analysis. Hazard mapping, such as ground shaking and ground failure, provides information invaluable for risk assessment.

How to develop an adequate degree of earthquake resistance and public safety is subjective. To determine an acceptable level of risk and means of implementing policies, a bridge between the technical information and the policy making body is needed. The social, economic and political aspects of policies need to be understood and weighted in the decision making processes. Appropriate public policies can incorporate recognition and incentives that help reduce risk. They may facilitate cost effective, long term mitigation efforts.

Balancing the public safety benefits with limited funds can be more effective with a better understanding of the economics at stake, such as, the possible damage and losses. With these estimated losses, planners and policy makers have useful information to guide public policy issues and to reduce future loss of life and property. Various interest groups can reduce the possible impact in specific areas by targeting information in the predicted damage and loss estimates.

Mitigation measures implemented have included 1) land use planning and management, 2) engineering codes, standards and practices, 3) emergency response, recovery, and reconstruction planning, and 4) insurance.

Lifelines systems can be very complex in that they cover large geographic areas and will often experience differing amounts of ground shaking during the same earthquake. Providing reliable systems and components that will perform their functions during and after earthquakes and will protect property and human activity is a monumental task. Again, for most lifelines, it may be necessary to determine an acceptable amount of risk and aim to achieve a specific level of performance.

Method for risk assessment

The risk assessment estimates for future earthquake ground shaking were obtained using HAZUS97 software produced by the Federal Emergency Management Agency (National Institute of Building Sciences, 1997; Risk Management Solutions, 1997). HAZUS operates through a geographic information system (GIS) to display earthquake hazard information, inventory data, and estimated losses in the form of both maps and tables. Further details on the analytical methods used in HAZUS can be found in Risk Management Solutions (1997) and Whitman and others (1997).

The method involves either modeling an earthquake source along with attenuation relationships or modeling ground motions. Damage is determined based on fragility curves, which indicate the probable degree of damage. Last, losses are quantified on the basis of the inventory database.

The study region is the state of Oregon, with a population of just over 3 million people. HAZUS97 evaluates the study region by census tracts. Oregon has

a total of 727 census tracts. HAZUS97 includes numerous databases from a variety of sources, including information on geography, demographics, economics, buildings, and lifelines. Demographics and residential buildings are obtained from the 1990 data of the United States Census Bureau. Nonresidential data, such as commercial and industrial structures, are obtained from 1995 reports by Dunn and Bradstreet. HAZUS97 estimates a total building exposure (i.e., replacement value, not market value) of about $160 billion for the state.

The soil map includes six soil categories defined in the 1997 Uniform Building Code (UBC) (Wang and others, 1998). UBC soil types were estimated on the basis of published digital regional geologic and agricultural soil maps, previously mapped material properties, and shear-wave velocities measured on the unit or similar units. In order to conduct the HAZUS97 analyses, soil profile type S_F (soil requiring site-specific evaluation) has been reclassified into type S_E (soft soil). Also, the soil map is modified within HAZUS97 to a census tract basis for analyses of most buildings.

Except for the soil data, this study has relied on the HAZUS97 default databases. Therefore, the results provide relative, not absolute, estimates of losses. Statistical uses, for example at the county level, are appropriate.

Two earthquake case studies were evaluated: (1) a (deterministic) M8.5 Cascadia subduction zone earthquake and (2) 500-yr return interval probabilistic bedrock ground motions (or 10% probability of exceedance in 50 years).

<u>M8.5 Cascadia earthquake</u>: The M8.5 earthquake is produced by a rupture along the Cascadia margin that lies generally parallel to Oregon's coastline. The M8.5 model assumes reverse motion, a rupture length of 480 km and a hypocentral depth of 10 km. After the PGA is calculated, deterministic ground motions, including spectral responses, are calculated. Those values are then amplified by factors based on local soil conditions as determined by the soil map described earlier. The ground motions in the general building damage analyses are computed at the centroid of a census tract.

Output ground motions for PGA, peak ground velocity (PGV), and spectral acceleration (S_A), spectral velocity (S_V), and spectral displacement (S_D) at periods of 0.3 and 1.0 seconds are provided on a census track basis. Ground motions for PGA range from 0.44 g towards the west to 0 g in the east; PGV range from 31.43 in/sec to 0.48 in/sec; S_A at 0.3 sec from 1.01 g to 0.01 g; S_A at 1.0 sec from 0.85 g to 0.01 g; S_v at 0.3 sec from 18.59 in/sec to 0.35 in/sec; S_v at 1.0 sec from 51.86 in/sec to 0.79 in/sec; S_D at 0.3 sec from 0.89 in to 0.01 in; and S_D at 1.0 sec from 8.25 in to 0.12 in. The maps include soil influence and thus represent motions at the ground surface.

500-yr return interval ground motions (or 10% in 50 yrs): The ground motions modeled are taken from the U.S. Geological Survey earthquake ground motion hazard map with a 10-percent probability of exceedance in 50 years, which is the basis of the ground motion design levels in the building code. This map represents single median ground motions for the region over the next 475-year period, commonly referred to as the "500-year" return interval.

The probabilistic approach incorporates all fault sources capable of generating earthquake ground shaking and includes earthquake wave propagation from the sources to include all areas of Oregon. Thus, for each given site, the ground motion levels for all the earthquake locations and magnitudes in the vicinity are represented.

Output ground motions for PGA range from 0.45 g to 0.05 g in the east; PGV range from 33.74 inches per second (in/sec) to 1.43 in/sec; S_A at 0.3 sec from 1.03 g to 0.10 g; S_A at 1.0 sec from 0.91 g to 0.03 g; S_v at 0.3 sec from 18.95 in/sec to 1.99 in/sec; S_v at 1.0 sec from 55.50 in/sec to 2.36 in/sec; S_D at 0.3 sec from 0.91 in to 0.09 in; and S_D at 1.0 sec from 8.84 in to 0.37 in. The maps include soil influence and thus represent motions at the ground surface.

Results of risk assessment

Table 1 summarizes the statewide results from the M8.5 Cascadia earthquake ("M8.5") and the 500-yr return interval ground motion model ("500-yr"). Additional information on this study, such as the analyses, summary tables on a county basis, ground motion maps, can be found in Wang and Clark (1999) and Wang (1998).

Table 1. Statewide Summary of Projected Losses

	M8.5 event	500-yr
Injuries	7,700	24,100
Deaths	100	500
Displaced households	17,300	47,400
Short-term shelter needs	12,400	32,700
Economic losses for buildings	$12 billion	$32 billion
Operational the day after the quake:		
Essential facilities	65 %	NA
Schools	66 %	NA
Bridges	85 %	NA
Economic losses to:		
Highways	$370 million	$1.3 billion
Airports	$120 million	$320 million
Communication systems:		
Economic losses	$100 million	$210 million
Operating the day of the quake	71 %	NA
No. of buildings damaged		
Green-tagged (inspected, no restrictions)	885,000	769,000
Yellow-tagged (limited entry, need permission to enter)	55,000	129,000
Red-tagged (unsafe, cannot be used)	37,000	79,000
Percentage of buildings in damage categories		
None	51 %	24 %
Slight	11 %	13 %
Moderate	13 %	19 %
Extensive	9 %	18 %
Complete	5 %	16 %

The figures in Table 1 have a high degree of uncertainty and should be used only for general planning purposes. Because the 500 year model includes many earthquakes, the number of facilities operational the "day after" cannot be calculated.

Social losses: Deaths and injuries are estimated at 7,700 and 24,600 for the M8.5 and 500-yr, respectively. These values are divided into four severity levels: Severity 1 is described as "Injuries requiring only basic medical aid but no hospitalization"; severity 2 is described as "Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status"; severity 3 is described as "Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are a result of structural collapse and subsequent collapse or impairment of the occupants." Severity 4 is described as "Instantaneously killed or mortally injured."

For the M8.5, about 6,300 are estimated at severity 1; 1,200 at severity 2; 200 at severity 3, and 100 at severity 4. For the 500-yr, about 19,700 are estimated at severity 1; 3,800 at severity 2; 600 at severity 3; and 500 at severity 4. The displaced households are estimated at 17,300 and 47,400 for the M8.5 and 500-yr, respectively. The short-term shelter needs are estimated at 12,400 and 32,700 for the M8.5 and 500-yr, respectively.

Building damage: Building damage by count by occupancy class was estimated. For the M8.5, the building damage by count of buildings is estimated at 717,000, 130,000, 75,000, 35,000, and 19,000 for the five damage states None, Slight, Moderate, Extensive, and Complete, respectively. From these damage state results, about 885,000 buildings are estimated to be green-tagged (i.e., the building has been inspected, and there are no restriction on use or occupancy), 55,000 are estimated to be yellow-tagged (i.e., off limits to unauthorized personnel), and 37,000 are estimated to be red-tagged (i.e., unsafe, not to be entered or occupied).

For the 500-yr, the building damage by count of buildings is estimated at 425,000, 253,000, 182,000, 75,000, and 41,000 for the five damage states. From these results, about 769,000 buildings are estimated to be green-tagged, 129,000 are estimated to be yellow-tagged, and 79,000 are estimated to be red-tagged.

Building damage by percent by occupancy class was estimated. For the M8.5, building damage by general occupancy is estimated at 51, 11, 13, 9, and 5 percent for the five damage states. For the 500-yr, building damage by general occupancy is estimated at 24, 13, 19, 18, and 16 percent for damage.

The total direct economic losses to buildings are estimated at $11.8 and $31.6 billion for the M8.5 and 500-yr, respectively. These losses include both capital stock losses and income losses. For the M8.5, capital stock losses are $2.03 billion for structural damage, $4.31 billion for nonstructural damage, $0.95 billion for contents, and $0.03 billion for inventory damage. Income losses are $1.21 billion for relocation, $1.35 billion for capital-related loss, $1.20 billion for wages, and $0.73 billion for rental income. For the 500-yr, capital stock losses are $5.05 billion for structural damage, $12.22 billion for nonstructural damage, $2.76 billion for contents, and $0.06 billion for inventory damage. Income losses are $3.04 billion for relocation, $3.76 billion for capital-related loss, $2.94 billion for wages, and $1.80 billion for rental income.

Essential facilities, transportation and communication: In HAZUS97, police stations, fire stations, and emergency operation centers are considered to be essential facilities. The functionality of emergency facilities and schools is estimated for the day following the earthquake. For the M8.5, functionality of 65 percent for emergency facilities and 66 percent for schools is estimated.

Transportation include highway, railway, light rail, bus, port, ferry, and airport systems. Selected results are provided for highways, including major and urban roadways and bridges; airports, which consists of control towers, runaways, terminal buildings, parking structures, fuel facilities, and maintenance and hangar facilities; and bridges.

For the M8.5, the direct economic loss is estimated at $0.37 billion for highways and $0.12 billion for airports. For the 500-yr, the direct economic loss is estimated at $1.26 billion for highways and $0.32 billion for airports. For the M8.5, the highway bridge damage is estimated at 67, 21, 9, 1, and 7 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. The estimated functionality on the day of the earthquake is 72 percent. For the 500-yr, the highway bridge damage is estimated at 31, 32, 26, 4, and 6 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

Utility systems include potable water, wastewater, oil, natural gas, electric power, and communication systems. For the M8.5, the estimated functionality for communication systems, which consist of broadcasting stations, is 71 percent.

Conclusions and discussion

The preliminary results from this study suggest that there is a serious risk in Oregon from both a M8.5 Cascadia event and 500-yr probabilistic ground motions. Studies of the M8.5 event indicate expected losses of about 35,000 buildings severely damaged, about 12 billion dollars of building damage, and over 7,700 casualties. Expected losses from the 500-yr probabilistic ground motion study are over 80,000 buildings severely damaged, over $30 billion of building damage, and over 24,600 casualties. The 500-yr study produces considerably higher losses because the modeled hazards span the entire state (i.e., offshore subduction zone and local inland earthquakes).

Significant limitations are that the default inventory database and analytical tools are incomplete. Thus, the estimated losses are necessarily in error. For example, although there are numerous unreinforced masonry structures (URMs) in Oregon, the currently available default building database does not include any URMs. Thus, the reported damage and loss estimates seriously under-represents the actual threat. In studies that incorporate URMs in the inventory, the death and injuries toll is likely to increase significantly due to catastrophic failures of URMs. Another example is that this risk analysis does not include damage and losses from tsunami inundation, which would flood low lying coastal areas after a Cascadia subduction zone earthquake.

Based on conservatively low back-of-the envelope calculations, an additional 5,000 fatalities would be incurred from the effects of damaged URMs and tsunami inundation. The URM estimates were achieved assuming that there are: 1,000,000 buildings in Oregon; 1 percent or 10,000 are URMs; there is 1 person in each building; the building experiences 0.1g and is severely damaged; 1 in 5 persons die, which equals 2,000 fatalities. The conservatively low tsunami estimates were determined assuming that for most of larger communities along the coast, 10 percent lie within the tsunami inundation zone; exceptions include Seaside (100%), Rockaway Beach (100%), Warrenton (30%), and Walport (20%); 1 in 5 persons die, which equals over 3300 fatalities. These numbers can greatly increase due to the transient tourist population.

The classic example of the catastrophic soil structure interaction occurred in the 1957 and 1985 Mexico City distant subduction zone earthquakes. Due to resonance of the seismic waves and structures, severe damage and collapse of some 400 mid-rise (5 to 14 stories) buildings (Hays and others, 1998) occurred. In addition, some 10,000 fatalities were suffered. Based on past experiences of damaging subduction zone earthquakes, the performance of longer period structures such as mid-rise buildings and some lifelines are of great concern in the next Cascadia event.

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