The expected financial losses due to building damage caused by severe earthquakes in Oregon

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INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI) has estimated the direct financial losses from buildings damaged by severe earthquakes in Oregon over the next 55 years. The analysis shows that, over that period, the average annual loss would be $108.6 million. This conclusion is based on a county-level study of building stocks, construction outlooks, and earthquake recurrence rates.

A severe earthquake is defined here simply as one that causes ground shaking of 0.3 times the acceleration of gravity (0.3 *g*) or more. Three types of earthquakes can produce such violent motion: subduction-zone interface, subduction-zone intraplate, and large crustal earthquakes.

The subduction-zone interface earthquakes that affect Oregon occur along the margins where the continental and oceanic plates meet. This zone is found deep below the ocean floor off the Oregon coast. Subduction-zone earthquakes in Oregon are powerful yet infrequent events. They are often characterized by long periods of shaking that occur over extensive areas. A subduction-zone interface earthquake off the northern Oregon coast could produce shaking of 0.3 *g* as far away as the Portland metropolitan area.

Subduction-zone intraplate earthquakes occur as the downgoing, or subducted, oceanic plate breaks beneath North America. The memorable and fatal earthquakes occurring in the Puget Sound region in 1949 and 1965 were of this type.

Crustal earthquakes are more common. They are more localized events, but they can also be quite destructive near their source. Crustal earthquakes are caused by sudden movements between different sections of bedrock. These movements occur along faults that are typically near the surface. Ground shaking of 0.3 *g* or more is not uncommon in crustal earthquakes of magnitude 6 or 7 (Geomatrix, 1995).

RECURRENCE RATE

How often are there earthquakes that cause 0.3 *g* of ground shaking or more? The power and frequency of crustal earthquakes largely depends on local geological conditions. For subduction zone earthquakes, distance from the epicenter is a crucial factor in determining how much ground shaking occurs in an area.

By examining the geologic record, it is possible to estimate the historical frequency of earthquakes in different parts of the state. For this analysis, estimates of the frequencies of large crustal and the subduction-zone earthquakes were used. These estimates were derived from the seismic design mapping project of the Oregon Department of Transportation (Geomatrix, 1995). The frequencies of earthquake occurrence were used to calculate how often these seismic events resulted in ground shaking of 0.3 *g* or more. This was done for the main population center of each county. As a necessary simplification, it is assumed that the frequency of 0.3 *g* ground shaking is the same in all parts of a given county. The results are shown on Table 1.

The probabilities on Table 1 are expressed in recurrence rates. For instance, for Benton County, the recurrence rate is calculated for Corvallis. It is the main population center for the county. In Corvallis, seismic events that cause at least 0.3 *g* of ground shaking happen about once every 1,750 years. The chance that such an event will occur in any one year is 1:1,750, or a little less than 0.06 percent. This probability is applied to all parts of Benton County.

BUILDING STOCK DATA AND DAMAGE RATES

The building stock is the total square footage of buildings in place. To compute the expected future losses from seismic events, a forecast of the building stock of every county was needed. With the exception of the Census of Housing, building stock data are not collected. The construction statistics firm of F.W. Dodge, however, estimates the building stock of each county as part of its regular program of monitoring construction contracts and permits. This is the most reliable source of building stock data.

F.W. Dodge provided 1995 county building stock estimates for 15 categories of structures. These included categories such as retail buildings, schools, and offices. The 1995 data were used as a base for the building stock forecast.

In connection with a study of aggregate demand, DOGAMI built construction forecasting models for each county (Whelan, 1995). The models forecast the number of square feet for over a dozen categories of buildings on an annual basis through the year 2050.

The forecasts were consolidated into categories common to both F.W. Dodge and the county aggregate models. This yielded a projection of additions to the building stock for different types of structures. It was then assumed that a certain percentage of buildings are removed each year from the building stock. Removals happen because of demolition, abandonment, and obsolescence. A removal rate of 0.0111

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Table 1. *The probability of a seismic event causing at least 0.3 g of ground shaking in a county*

County	Population center	Recurrence rate (years)
Baker	Baker City	4,250
Benton	Corvallis	1,750
Clackamas	Portland area	1,250
Clatsop	Astoria	500
Columbia	St. Helens	1,250
Coos	Coos Bay	350
Crook	Prineville	7,250
Curry	Gold Beach	125
Deschutes	Bend	4,500
Douglas	Roseburg	1,500
Gilliam	Condon	5,000
Grant	John Day	7,500
Harney	Burns	25,000
Hood River	Hood River	3,125
Jackson	Medford	1,250
Jefferson	Madras	7,250
Josephine	Grants Pass	1,000
Klamath	Klamath Falls	1,500
Lake	Lakeview	1,500
Lane	Eugene	1,750
Lincoln	Newport	300
Linn	Albany	1,750
Malheur	Ontario	3,500
Marion	Salem	1,500
Morrow	Boardman	5,000
Multnomah	Portland	1,250
Polk	Dallas	1,075
Sherman	Moro	5,000
Tillamook	Tillamook	400
Umatilla	Pendelton	5,000
Union	La Grande	4,250
Wallowa	Enterprise	4,250
Wasco	The Dalles	5,000
Washington	Portland area	1,250
Wheeler	Mitchell	25,000
Yamhill	McMinnville	825

was used for school buildings. A rate of 0.0167 was used for all other nonresidential buildings. For housing, a slightly different approach was used.

Housing data for this analysis came directly from the aggregate models. The total square footage of single and multifamily housing in 1995 came from F.W. Dodge. For manufactured homes, which are not reported in construction statistics, an estimate was made for the total square footage in 1995 by multiplying the number of units by 1,300. The forecasts of additions and removals are part of the aggregate models, and these were used in the forecasts of building stocks.

The square footage of buildings by type was converted into dollar values. The interest here is in the replacement cost of structures. In other words, if a retail building is destroyed in an earthquake, how much would it cost to rebuild it? The concern here is not the market or assessed value, but rather replacement cost.

Construction cost estimates were made with data used in the development of the aggregate models. F.W. Dodge provided construction cost and square footage statistics for 1978 to 1993. These figures exclude the costs of land and of some of the site improvements. They are a fair representation of what it would cost to rebuild a structure after an earthquake. DOGAMI used the F.W. Dodge data to calculate costs per square foot for each major building category. For manufactured homes, which F.W. Dodge does not report, it was assumed that replacement costs equal 60 percent of the replacement cost of single-family site-built houses.

Construction costs tend to be higher in the three counties that make up the Portland metropolitan area. For all building types, construction costs per square foot in Clackamas, Multnomah, and Washington Counties were 4.3 percent higher than the 1978–1992 state average. One reason for this is the prevalence of high-rise multifamily housing in and around Portland. High-rise units historically cost 29 percent more per square foot to build than low-rise units. Approximately 87 percent of the high-rise multifamily construction done in Oregon from 1978 to 1992 took place in the three Portland area counties. Those counties accounted for only 51 percent of the total square footage of building construction during that period. For the other 33 counties in Oregon, average construction costs were 4.6 percent less than the state average.

Construction costs were converted into 1996 dollars, using an index of building costs (Kiley and Moselle, 1993). The average 1996 cost per square foot was calculated for the 1978–1993 period for each building type. The replacement value of the building stock was then estimated by multiplying the square footage for each year in the forecast by the 1996 cost per square foot.

The value for the whole state for 1996 was estimated at $144.3 billion. The forecast shows the value of the building stock rising as the state's population and income level grows. In 2050, the building stock reaches a value of $275.6 billion (1996 dollars). This is equivalent to a 1.2-percent compound annual growth rate over the forecast period.

Damage rates in the analysis are measured as a percentage of the replacement value of buildings. These damage rates, shown in Table 2, come from a preliminary analysis for Multnomah County in the case where buildings are subjected to an approximately 0.3-*g* seismic event (for purposes of this paper, from here on simply referred to as "0.3-*g* event"). Direct losses to buildings equal 15.43 percent of the replacement value of the building stock. Related losses, which include building contents, lost wages, and business interruptions, are 44.55 percent of the building stock's value. Seismic events resulting in weaker ground shaking

Table 2. *Direct economic losses due to building damage from 0.3-g seismic events expressed as a percentage of building replacement value*

Type of loss	Percent of value
Damage to buildings:	
Building support structure	3.83
Other building features	11.60
Total building damage	15.43
Losses related to building damage:	
Building contents	10.47
Inventory losses	0.25
Relocation costs	5.95
Lost wages and business income	27.46
Rental income loss	1.42
Total losses related to building damage	45.55
Total direct economic loss	60.98

would obviously result in lower losses; likewise, stronger ground shaking would cause higher losses.

EXPECTED VALUE OF LOSSES

The expected value of losses due to buildings damaged in 0.3-*g* seismic events equals $75.4 million in 1996. It rises over time as the building stock increases. The expected value of losses in 2050 is forecast at $143.8 million (in 1996 dollars). The average expected value for the 55-year period is $108.6 million.

Expected value is a probability-weighted estimate. It measures the average annual loss due to 0.3-*g* earthquakes. That average combines the zero loss years when no destructive earthquakes occur with the infrequent, yet catastrophic losses from years when large earthquakes hit. For example, if an earthquake would cause $100 million in losses, but has a probability of occurring only once every 50 years, the expected value of losses would be $100 million divided by 50 years or $2 million a year.

The expected values of losses were calculated for each county. These are shown in Table 3. The losses are higher in urbanized and coastal counties and lower in eastern Oregon counties. The actual loss in a year will range from zero to several hundred or thousand times the expected value.

The expected value was calculated for each year for each county. The value of the building stock was multiplied by the damage rates shown on Table 2. The result was then divided by the recurrence rate shown on Table 1.

WHAT DOES THIS ALL MEAN?

We noted that if we factor in all our expectations about the frequency, destructiveness, and locations of 0.3-*g* earthquakes and combine them with a forecast for Oregon's building stock, we find that losses from damaged buildings will average $108.6 million a year. At first blush, that may seem like a manageable loss. Is it, then, really worth spending much money to mitigate building damage from potential earthquakes? It depends, in part, on the remaining life of a building.

Table 3. *Expected value of losses due to building damage from 0.3-g seismic events for the period 1996–2050 (in millions of 1996 dollars per year)*

County	Average expected value of losses (millions of $)
Baker	125
Benton	1,396
Clackamas	11,421
Clatsop	2,297
Columbia	1,149
Coos	6,021
Crook	82
Curry	7,744
Deschutes	1,080
Douglas	1,952
Gilliam	35
Grant	30
Harney	8
Hood River	207
Jackson	4,921
Jefferson	88
Josephine	2,426
Klamath	1,363
Lake	145
Lane	6,756
Lincoln	5,784
Linn	2,053
Malheur	245
Marion	6,542
Morrow	59
Multnomah	21,532
Polk	1,750
Sherman	17
Tillamook	2,538
Umatilla	386
Union	170
Wallowa	58
Wasco	163
Washington	14,484
Wheeler	4
Yamhill	3,534
State total	108,565

The expected value of losses is an annual figure. However, most of the work done to a building and its contents to make them more resistant to earthquake damage will last for the lifetime of the structure. The cost of these efforts must be measured against the losses we expect for the life of the building.

A typical building today has a remaining life of about 55 years. The expected value of losses for the next 55 years in Oregon totals $5,971.2 million. About $1,510.7 million of that amount will be damage to the buildings themselves.

The remaining $4,460.5 million will come from lost incomes, building contents, and other items.

From our analysis, we estimate that in any given year losses equal 0.0522 percent of the value of buildings in the state. A building with a remaining life of 55 years can expect a loss of 2.87 percent of its current value. If an earthquake mitigation plan could reduce expected losses by 50 percent, then one might expect a building owner to be willing to pay up to 1.44 percent of the building's value for mitigation work.

For the purposes of this paper we used an example that is oversimplified. One should consider the characteristics of buildings and their locations. Also, the data here represent an average for the whole state. Some parts of Oregon are very unlikely to suffer a major earthquake, while others are quite vulnerable. For example, if we consider similar buildings in Burns and Portland, much greater expenditure on mitigation would be justified in Portland because the annual loss would be greater there, since earthquakes occur more frequently than in Burns. We also did not factor in loss of life, insurance tradeoffs, and the time value of money. For example, depending on the value placed on a life, the cost of the earthquakes considered here could increase as much as ten times the value of the damage considered in this study.

Perhaps most importantly, we showed the economic costs of 0.3-*g* earthquakes only. We neglected the losses due to weaker ground shaking events, as well as the potential for far greater loss rates than those used here that comes with ground shaking stronger than 0.3 *g*.

A similar analysis based on 0.2-*g* crustal earthquakes gave us very high loss figures. For some counties, the expected value of losses from 0.2-*g* earthquakes is greater than for 0.3-*g* earthquakes. While these smaller quakes cause far less damage, they occur at a much greater frequency. In some places, the frequency is so high that buildings are more likely to suffer losses from 0.2-*g* events than from 0.3-*g* earthquakes.

Much more work needs to be done so that the expected losses from earthquakes can be fully assessed. This preliminary analysis helps place an order of magnitude to the risks to property and commerce from seismic events. Further research will allow us to consider the full spectrum of seismic events and their impact on different building types. This analysis can also be used to place a financial value on mitigation efforts and earthquake insurance.

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DOGAMI PUBLICATIONS

Released October 8, 1996:

Relative Earthquake Hazard Maps of the Salem East and Salem West Quadrangles, by Yumei Wang and William J. Leonard. Geological Map Series map GMS–105, scale 1:24,000, 4 full-color maps and 10 p. text, $12.

The four maps include three maps showing liquefaction susceptibility, ground motion amplification susceptibility, and landslide susceptibility. The fourth, relative hazard map, combines the results of those three to determine the relative earthquake hazards.

In preparation for the Salem maps, engineering studies were made of the local soil and rock to determine how they would respond to an earthquake, and that information was used to develop the relative hazard maps.

Released November 7, 1996:

Geologic Map of the Steelhead Falls Quadrangle, Deschutes and Jefferson Counties, Oregon, by Mark L. Ferns, Donald A. Stensland, and Gary A. Smith. Geological Map Series map GMS–101. Scale 1:24,000, full-color map and 13 p. text, $7.

The Steelhead Falls quadrangle covers an area of about 53 square miles in northern Deschutes and southern Jefferson Counties, where the Crooked and Deschutes Rivers have carved 800-foot-deep canyons into a volcanic basin that is 6 million years old.

The full-color map and 10-page text provide information on the geologic history and resources of this highly scenic part of central Oregon. The map gives both technical and nontechnical people information on how the geology influences groundwater and surface water flow.

Released November 12, 1996:

Earthquake Hazard Maps for Oregon, by Ian P. Madin and Matthew A. Mabey. Geological Map Series map GMS–100. Four full-color maps on one sheet, $8.

GMS–100 provides the most up-to-date and complete information on earthquake hazards in Oregon currently available. It allows users to compare hazards in one part of the state to another and to evaluate the likelihood of damaging earthquake shaking at a particular locale.

The new map was based on data from a report *Seismic Design Mapping, State of Oregon*, prepared by Geomatrix Consultants, Inc., for the Oregon Department of Transportation, and on a 1993 UO dissertation, *Active Faults and Earthquake Ground Motions in Oregon* by Silvio K. Pezzopane.

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