Preparing for earthquakes in Oregon

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This article is a slightly modified version of a paper by Yumei Wang, Geotechnical Engineer and Director of Earthquake Programs of the Oregon Department of Geology and Mineral Industries. The paper will be included in *Engineering and Environmental Geology of Oregon: Case Histories*, an upcoming publication sponsored by the Oregon Section of the Association of Engineering Geologists. The paper is presented here because April is Earthquake Awareness Month—an appropriate time to examine what has been and is being done in the State of Oregon to prepare for earthquakes and to consider what other steps need to be taken to protect Oregonians and their property from earthquakes. *—ed.*

ABSTRACT

This paper traces the changes in the understanding of Oregon's earthquake hazards and provides an overview of how Oregon addresses reducing earthquake risks. The threat of a great Cascadia subduction zone earthquake identified during the last decade and the occurrence of two relatively minor yet damaging "wake-up calls" with the Scotts Mills and Klamath Falls earthquakes of 1993 have underscored the reality of earthquake hazards in Oregon. While periodic earthquake shaking has been reported in Oregon for over the last century and a half, modern earthquake monitoring has been possible only for the past few decades. Most of the earthquake hazard assessment and mitigation efforts made to date have been accomplished within the last decade, and public awareness has risen remarkably during that same period. Major federal, state, and local government agencies and private organizations support earthquake risk reduction and have made significant contributions. Despite the progress, Oregon still remains underprepared. Many structures and lifelines, such as buildings, bridges, and water systems, need to be strengthened, and land use planning needs to be improved.

INTRODUCTION

Some people who used to live in Oregon believed so strongly that earthquakes pose a tremendous threat that they have packed their belongings and moved out of the state. Others have sought refuge from earthquake hazards by moving to Oregon after the 1989 Loma Prieta earthquake in California. These extreme cases illustrate the range of problems that people are having in understanding and responding to earthquake hazards in Oregon.

Earth scientists now believe that all parts of Oregon can be shaken by earthquakes. Oregon lies where two tectonic plates, the North American plate and the Juan de Fuca plate, are colliding, and the Juan de Fuca plate is being forced to dive under the North American plate along a large active fault called the Cascadia subduction zone. Earthquakes can occur within the Juan de Fuca plate (such earthquakes are called intraplate earthquakes), in the overriding North American plate (called crustal earthquakes), or along the Cascadia subduction zone, which is the interface between the two plates (called subduction zone earthquakes). All three possible earthquake types (intraplate, crustal, and subduction zone) (Figure 1) can severely impact the state. Active volcanoes in the Cascade Range present another earthquake source.

Although the number of earthquakes in Oregon's recorded history is limited compared to that of California or Washington, earthquakes have occurred in every Oregon county. Surface expressions of faults capable of producing earthquakes are sparse, but young faults (defined here as active within the Quaternary Period, the last 1.6 million years) have been mapped in almost every county in Oregon (Figure 2). These facts show Oregon's earthquake potential despite its moderate level of seismicity and suggest the existence of a significant seismic threat to the inhabitants.

EARTHQUAKE SOURCES AND THEIR SIGNIFICANCE

The western part of the Pacific Northwest lies in an actively converging plate-tectonic setting. The scenic topography along the coast, throughout the Willamette Valley, and in the Cascades, was essentially created by plate tectonic activity related to the Cascadia subduction zone, the active fault zone separating the Juan de Fuca and North American plates. The Juan de Fuca plate extends from northern California to British Columbia and lies just off Oregon's coastline. This plate is continually being "subducted" or forced under the North American plate (Figure 1). As a result, the highly publicized Cascadia subduction zone "megathrust" earthquake is expected to occur sometime in the future along the boundaries of these plates. Although no significant Cascadia subduction zone earthquake has occurred in historic times, several large-magnitude subduction zone earthquakes are thought to have occurred during the past few thousand years, with the last event about 300 years before the present (Atwater and others, 1995). The maximum magnitude of Cascadia subduction zone earthquakes, for both past and future events, is estimated to be about 8.5–9.0.

Intraplate earthquakes occur within the subducting Juan de Fuca plate at depths of 40–60 km. The maximum magnitude of an intraplate earthquake is estimated to be about 7.5. Although numerous microearthquakes have been identified as intraplate events in Oregon, none has been of significant magnitude. The Puget Sound region in Washington has experienced two significant intraplate events in modern

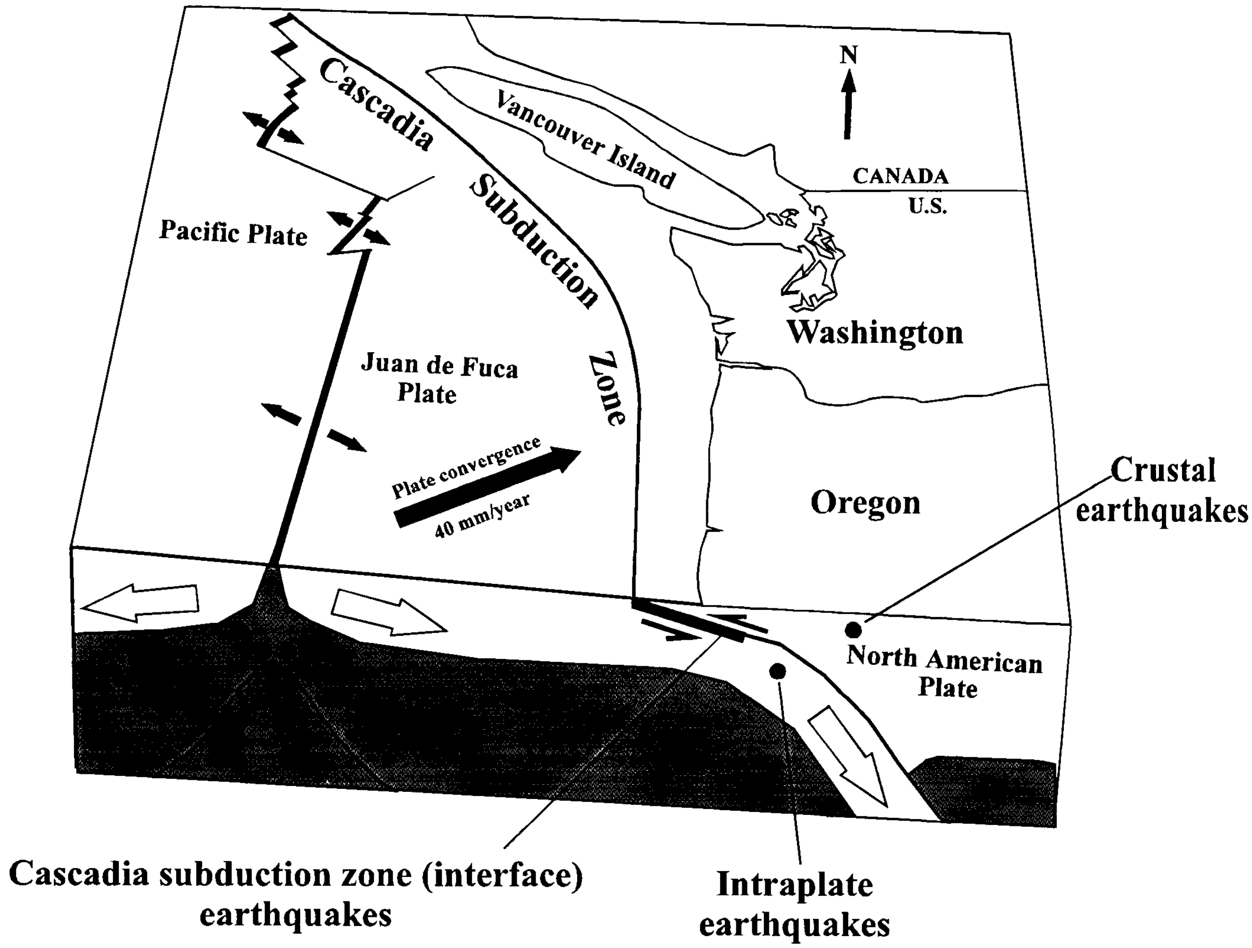

Figure 1. Map and cross section showing the North American plate, the Juan de Fuca plate, the Cascadia subduction zone, and typical locations for the three earthquake types discussed in the text. Figure modified from Anthony Qamar, University of Washington (written communication, 1996).

times, in 1949 and 1965, with magnitudes of 7.1 and 6.5, respectively. Both events caused serious local damage and were felt in Portland and as far away as Montana.

Shallow crustal earthquakes typically occur within the overriding North American plate at depths of 10–25 km. The 1993 M 5.6 Scotts Mills earthquake (Figure 3) centered northeast of Salem was a crustal event, as were the 1993 Klamath Falls earthquakes (M 5.9 and M 6.0). The maximum estimated magnitude of a crustal earthquake ranges from 6.5 to over 7.0. In 1962, a M 5.5 event with a maximum intensity of MM VII (Bott and Wong, 1993) that occurred in the Portland area was felt a distance of 150 mi away (Dehlinger and Berg, 1962; Dehlinger and others, 1963).

Volcanic earthquake sources, such as at the Mount St. Helens seismic zone in Washington and the less active Mount Hood area in Oregon, generally pose a lesser threat than the other types of earthquake sources. Seismic volcanologists limit the maximum magnitude of volcanic earthquakes to about 5¼. Two volcanic earthquakes of M 4.9 and M 5.1 occurred in May 1980 at the time of the Mount St. Helens volcanic eruption (Steve Malone, University of Washington, personal communication, 1996).

A recent statewide seismic study commissioned by the Oregon Department of Transportation (ODOT) includes a map onto which the locations of all known Quaternary-active faults and earthquake epicenters since 1827 were compiled. The report, which also includes probabilistic ground motion maps, provides the most current and comprehensive data available for the state (Geomatrix Consultants, Inc., 1995). This information is being used by ODOT to provide ground motion parameters necessary for design, construction, and earthquake mitigation of the state-owned road system.

A recent study of historic earthquakes in the greater Portland area indicates that several earthquakes larger than M 5 have occurred in the Willamette basin over the last 150 years and gives descriptive accounts of each earthquake (Bott and Wong, 1993).

THE GROWING UNDERSTANDING

Earthquakes were felt in Oregon as early as 1877 (Algermissen, 1983). Human recollections of earthquakes tend to fade quickly, however, and the general sentiment has been that "Oregon is not earthquake country." As early as 1912, geologists recognized and documented the fact that Oregon was seismically active (Smith, 1919). Despite early scientific recognition, the public failed to understand and appreciate the seismic risk for many decades. During the past decade, however, there has been increasing acknowledgment that earthquakes pose a real threat to the state's inhabitants.

In reality, the seismic risk is getting more severe, not because the level of seismicity is increasing, but because the population is increasing. With more people, more buildings, more infrastructure, and more businesses and industries in the state, more is at stake. It is fortunate that the awareness of Oregon's seismic threat has grown from "almost nil by most" to "well recognized by many." Furthermore, awareness of Oregon's vulnerability to earthquakes has even reached the national level, and several significant Portland-based seismic projects that will be discussed later in this paper were federally supported.

The first major earthquake risk studies in the Pacific Northwest, however, were related to siting of nuclear power plants. In 1970, when the siting of the Trojan nuclear power plant near Rainier in Columbia County was under consideration, the realization of the need for considering earthquake risk for the siting of this facility led to an investigation of earthquake potential and risk within the state (see appendix of Oregon Department of Geology and Mineral Industries, 1978).

The question of seismic hazards at Trojan was later revisited. In 1978, the Oregon Department of Geology and Mineral Industries (DOGAMI) conducted an independent geologic hazard review of the site, including earthquake hazards (Oregon Department of Geology and Mineral Industries, 1978). In 1981, following the May 1980 Mount St. Helens volcanic eruption, DOGAMI geologists conducted a seismic and volcanic hazard evaluation of the Trojan site (Beaulieu and Peterson, 1981). The 1981 study indicated that the maximum possible earthquake in the source region was in the range of M 5.2 to M 6.2. This report also described the plate tectonic setting off the coast of Oregon and presented the seismic potential associated with the Cascadia subduction zone as an unresolved question.

The first notable regional seismic study was performed in 1972. It was conducted to assess ground motion characteristics in the federal Bonneville Power Administration service area (Shannon and Wilson, Inc., 1972), which includes Oregon, Washington, Idaho, and western Montana. At that time, the still relatively new theory of plate tectonics, which helped to explain the nature of earthquakes, was gaining broad acceptance. The report's findings alluded to the existence of the Cascadia subduction zone and stated that "it is generally recognized . . . that the Pacific Northwest is not the site of major tectonic thrusting, nor is it as inactive as the central area of a tectonic plate." The study surveyed historic earthquakes and considered an earthquake of "magnitude $m_b = 6.5$ as the likely maximum for Portland and vicinity" (Shannon and Wilson, Inc., 1972).

Among many important studies on the Cascadia subduction zone, the following three played a key role in leading toward the current mainstream understanding that the Cascadia subduction zone is an active subduction zone: First, in 1981, findings from a study on geodetic strain measurements in Washington indicated that, in the vicinity of the Olympic Peninsula, measurable horizontal strain parallel to the direction of plate-convergence had accumulated over a 10-year observation period (Savage and others, 1981). This manifestation of crustal shortening indicated that active convergence was taking place on the Cascadia subduction zone and supported a history of subduction zone earthquakes. Second, in 1984, a study that compared the Cascadia subduction zone with many other subduction zones around the world was published (Heaton and Kanamori, 1984). The authors noted the low level of seismicity associated with the Cascadia subduction zone and provided three possible explanations: "(1) The North American and Juan de Fuca plates are no longer converging; (2) the plates are converging, but slip is accommodated aseismically; or (3) the northwestern United States is a major seismic gap that is locked and presently seismically quiescent but that will fail in great earthquakes in the future." The authors concluded that the plate convergence rate appeared to be 3–4 cm/yr and "that there was sufficient evidence to warrant further study of the possibility of a great subduction zone earthquake in the Pacific Northwest." Finally, a 1987 paper by B.F. Atwater (1987) presented paleoseismic evidence (buried peat soils) for great Holocene earthquakes along the outer coast of Washington. These three studies have fundamentally shaped the way earth scientists currently view the Cascadia subduction zone and its potential impact on Oregon.

In 1987, the Oregon State University Geology Department and DOGAMI hosted a landmark professional gathering at the Oregon Academy of Science in Monmouth, Oregon. For the first time, earth scientists gathered together to discuss the potential of a Cascadia subduction zone earthquake. Later that same year, DOGAMI hosted a "cluster" meeting of regional state surveys with U.S. Geological Survey (USGS) scientists to discuss earthquake hazards in the Pacific Northwest. With the added momentum generated by these scientific enthusiasts, the USGS was convinced that the Portland, Oregon, area was vulnerable to major earthquakes. This led to a Cooperative Agreement between the USGS and DOGAMI that involved collecting earthquake-related geologic data in the greater Portland area and educating the public on earthquake hazards. These initial meetings directed DOGAMI to assist in leading many of the present-day statewide earthquake efforts.

CURRENT STATE OF UNDERSTANDING

Since 1987, voluminous research findings support the fact that the Cascadia subduction zone is active and a threat. These research data are from three primary sources: (1) prehistoric earthquakes, (2) instrument-recorded earthquakes, and (3) geologic records from old earthquakes. More specifically, data on prehistoric earthquakes include Native American legends and Japanese historic documents. Instrument-recorded earthquake data include geophysical and seismicity analyses, geodetic (including global positioning system [GPS]) analyses, and heat-flow analyses. The geologic evidence of old earthquakes (paleoseismic data) comprises the most compelling evidence and includes earthquake-induced landslides (in Washington State), marsh soils buried and forests drowned by coseismic subsidence, tsunami sand deposits, liquefaction features, turbidites, and offshore submarine landslide features possibly related to past Cascadia subduction zone events.

By the early 1990s, the idea of the threat of a Cascadia subduction zone earthquake in the Pacific Northwest was accepted by many in the scientific community; by the mid-1990s, the idea was much more widely accepted. In April 1996, at the Geological Society of American Cordilleran Section conference in Portland, a straw poll of some 150 earth scientists attending a session on Cascadia subduction zone earthquake issues indicated they all believed that the Cascadia subduction zone could experience a M 8 or larger earthquake.

The most pressing unresolved problem that remains for most scientists is not whether a Cascadia subduction zone event will occur but rather how big it can be and how often it will occur. Some scientists believe that M 8 is the upper magnitude limit, while others believe that an event even greater than M 9 is possible. One can assert, based on presumed rupture zone, paleoseismic evidence, and historic Japanese tsunami records, that it is possible for the Cascadia subduction zone to generate an earthquake greater than M 9. One counterargument is that major offshore strike-slip faults, such as the offshore Wecoma fault located west of Siletz Bay in Lincoln County (Goldfinger

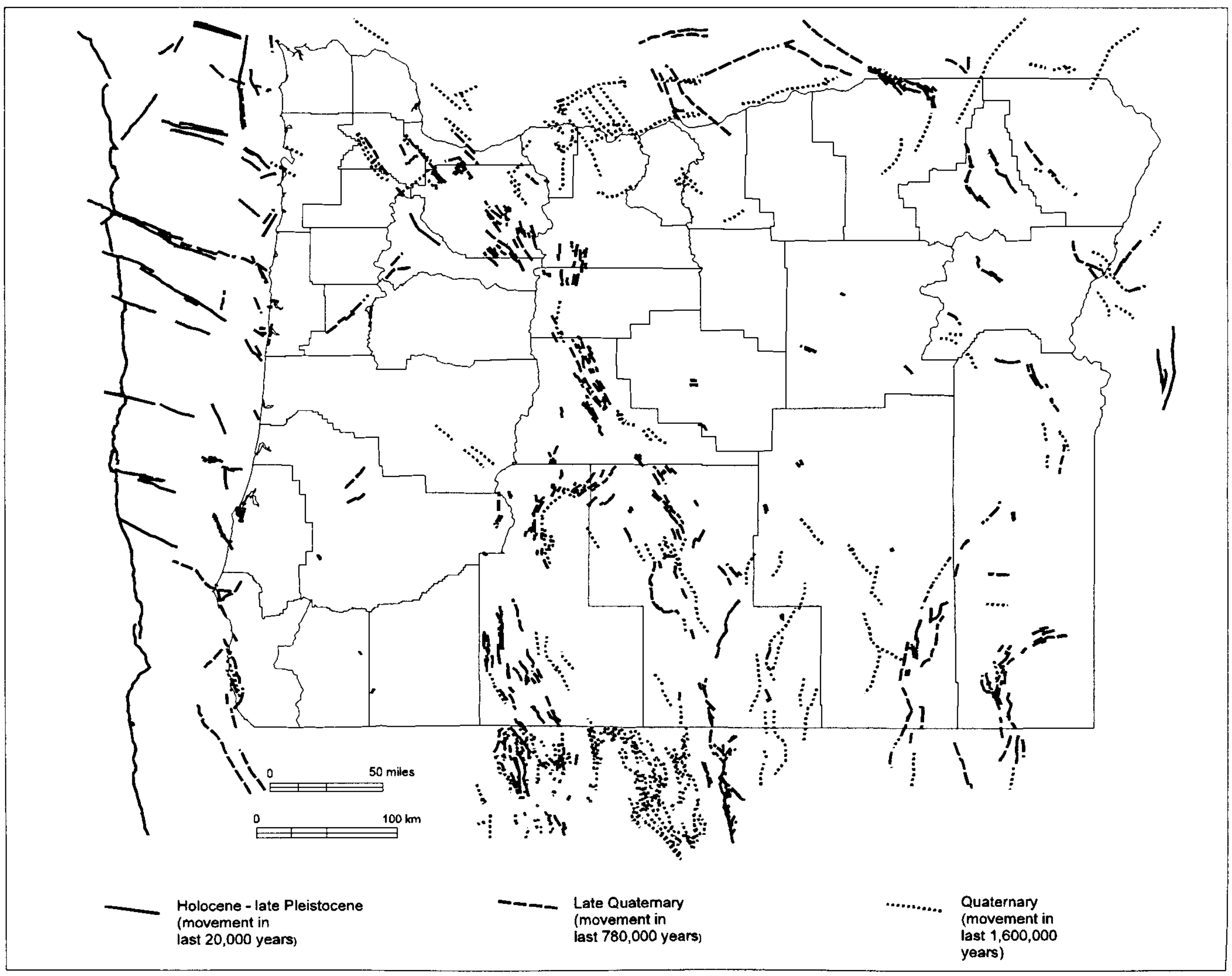

Figure 2. Map showing young faults in Oregon. Map from Geomatrix Consultants, Inc. (1995).

and others, 1992), may divide the Cascadia subduction zone into "segments" and limit the size of the maximum possible earthquake to M 8 or so. Although the possible maximum magnitude question needs to be pursued, clearly, even a M 8 event would be ominously large and would impact a widespread region.

How often do these great subduction zone earthquakes occur? Current thinking limits the range for the average recurrence interval (the time between earthquakes) to between 400 and 600 years (Atwater and others, 1995). The recent Geomatrix Consultants, Inc. (1995) study narrows the estimate of the recurrence interval to 450±150 years. Japanese historic documents describing a tsunami not preceded by a local earthquake suggest that the most recent Cascadia subduction zone event occurred on January 26, 1700 (Satake and others, 1996).

Although these questions of magnitude and frequency of a Cascadia subduction zone earthquake cannot be definitively answered at this time, our understanding of earthquake hazards is at the level where we can say, "There is consensus in the scientific community that in Oregon strong ground shaking from earthquakes is inevitable and poses a significant threat."

NEED FOR ACTION

Giving society a better chance to function in personal and economic safety and with minimal disruption after an earthquake involves a concentrated effort among many people. It is no easy task to convey to the community at large the importance of being well prepared and the necessity of taking concrete steps to get prepared. For instance, many who purchase earthquake insurance do not realize that being insured does not equate with being adequately prepared. Having insurance does not prevent fatalities, strengthen facilities, or stave off damage in any way—being prepared does.

Therefore, the next fundamental steps are to define the "hazards" associated with ground shaking and to identify the "risks" associated with the hazards. "Hazards" are important only when there are "risks," and the level of risk depends not only on the hazards present but also the amount of exposure (population and buildings). Therefore, the higher the hazard and the greater the exposure (such as vulnerable populations or weak buildings), the higher the risk. Risk includes not only fatalities, injuries, and property damage, which are immediate impacts, but also lifeline interruption, business interruption, worker displacement, homelessness, and other effects that can have a serious long-term impact on recovery from an earthquake.

The next steps are to identify ways to reduce these risks, mitigate the unacceptable risks to acceptable levels, and develop policies to reduce risk. The following discussion reviews how reduction of earthquake risks has been addressed through state legislation and organized efforts in Oregon.

STATE LEGISLATION

A broad array of earthquake-related state legislation has been introduced over the last decade, and many laws have been passed to help improve earthquake preparedness in Oregon. Listed below are the more important items of legislation that have been passed and written into the Oregon Revised Statutes (ORS).

In mid-1989, the Oregon legislature expanded the scope of DOGAMI's responsibilities, thereby requiring the agency not only to develop an understanding of hazards, including earthquakes, landslides, tsunamis, and floods, but also to mitigate the loss of life and property these hazards can cause (ORS 516.030[3]).

Following the October 1989 Loma Prieta earthquake, then Governor Goldschmidt created a task force to evaluate Oregon's seismic vulnerability. In response to the task force findings that indicated the general vulnerability of the state, the Governor issued an Executive Order (EO–90–02) to form a eight-member commission. In 1991 legislation, this commission was formally established as the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) (ORS 401.337 to 401.353). OSSPAC's mission is to reduce exposure to earthquake hazards through education, research, mitigation, and response preparation. In 1995, four more members were added to OSSPAC.

Also in 1991, DOGAMI introduced State Senate Bill 96, which involved several seismic issues and became law. It required site-specific seismic hazard investigations for essential facilities, major structures, hazardous facilities, and special-occupancy structures (e.g., schools and hospitals); the filing of the hazard investigation reports with DOGAMI; and a program for the installation of strong-motion accelerographs in or near selected major buildings (ORS 455.447). It also required "duck, cover, and hold" drills to be conducted for grades K–8 in public schools (ORS 336.071).

By 1992, there was substantial support of seismic mitigation by State Legislators and executive leaders. The Oregon Legislative Emergency Board increased DOGAMI's base budget to cover the salary of an earthquake geologist (initially funded by the previously mentioned USGS Cooperative Agreement).

In 1993, the Building Codes Division (BCD) of the Department of Consumer and Business Services adopted a zone change from Seismic Zone 2B to Seismic Zone 3 in western Oregon (Figure 4). This change meant that new buildings were required to meet a higher standard of seismic strength. That same year, the State Senate adopted Senate Joint Memorial (SJM) 12, which asked Congress to retain existing earthquake funding levels and encouraged federal agencies to assist Oregon, California, Alaska, and Washington in earthquake hazard mitigation efforts.

In 1993, Senate Bill 81 designated $4.3 million in lottery funds for reinforcing the poorly constructed State Capitol dome, which was damaged from low levels of shaking during the 1993 Scotts Mills earthquake. The Legislative Administrative Committee oversaw this retrofit work and is pursuing additional seismic strengthening of the remainder of the State Capitol Building.

Most recently, in 1995, 14 earthquake-related bills were introduced into the legislature. Passage of several of them resulted in new or changed Oregon Revised Statutes (ORS). Included among the new statutes were a requirement for tsunami drills and education in schools (ORS 336.071), a requirement that essential and special occupancy structures be built outside the tsunami zone (ORS 455.446), the creation of a Seismic Rehabilitation Task Force to make recommendations to the legislature for the seismic rehabilitation of existing buildings (ORS 455.395[4]), provisions for entering and inspecting earthquake-damaged buildings (ORS 455.448), and provisions for the abatement of unsafe buildings (ORS 455.449).

The Seismic Rehabilitation Task Force was created in 1995 by the legislature and appointed by the Governor in consultation with the State Geologist. This 13-member Task Force convened to examine the safety of buildings that were built under prior building code criteria and to make recommendations to the 1997 Legislature for any seismic rehabilitation that should be required in those existing buildings to protect the public from seismic risk. The identification of existing buildings that require mitigation and the implementation of mitigation measures are highly complex and controversial issues. A report containing the recommendations of the Task Force was submitted to the legislature in September 1996 and developed into 1997 House Bill 2139.

House Bill 2139 proposes a survey over the next six years that will determine the type of construction and degree of safety of each building in the state, except for one- and two-family homes and other exempt structures. House Bill 2139 also proposes that seismic rehabilitation be performed in a three-stage time frame, dating from notification that results from the survey: (1) within 15 years, for unreinforced masonry (URM) buildings with parapets, signs, and other appendages, except for cornices and nonstructural cladding, that may constitute a falling hazard during an earthquake; (2) within 30 years, for the remainder of the URM buildings; and (3) within 70 years, for all other unsafe buildings. The upgrading may be stimulated by tax credits, property tax abatements, and public education.

LEADING ORGANIZATIONS

Experience has shown that public expenditures for mitigation (e.g., risk reduction of loss of life and property) are dramatically less than the costs of reconstruction following a disaster. The potential billions of dollars that will be spent in Oregon on reconstruction and business interruption losses by governments, private insurers, and the public can be minimized by mitigation expenditures to an amount on the order of only millions. The benefit-to-cost ratio is generally estimated to be somewhere between 10:1 and 100:1. More importantly, many needless fatalities can be avoided.

Several organizations have led the effort on reducing earthquake risks. These organizations included DOGAMI, Metro (Metropolitan Portland area regional government), Oregon Seismic Safety Policy Advisory Commission, Building Codes Division, Seismic Rehabilitation Task Force, Oregon Department of Transportation, and Oregon Emergency Management. Their most significant contributions are described below.

Oregon Department of Geology and Mineral Industries

In addition to its other responsibilities, DOGAMI has the legislature's mandate to better understand and mitigate earthquake hazards. Part of the agency's mission is to "reduce the future loss of life and property due to potentially devastating earthquakes." Realizing that the state is currently underprepared to suffer a destructive earthquake, the agency applies its earthquake efforts in three broad areas: (1) earthquake hazard identification, (2) mitigation of earthquake hazards, and (3) increasing earthquake hazard awareness. Although the agency provides technical information, it also encourages policy applications associated with its efforts.

Earthquake hazard identification: Since the year 1987, DOGAMI has incorporated earthquake hazard identification into the agency's scope of work. DOGAMI concluded that hazard identification was best approached by evaluating ground response from source-independent earthquakes, rather than by attempting to determine the locations of all active faults. The agency further concluded that the geology-related hazards that contribute to most of the damage are strong ground shaking (including amplification of peak ground accelerations), landsliding, and liquefaction.

DOGAMI has focused on earthquake hazard identification by developing geology-based earthquake hazard maps that indicate susceptibility to ground shaking amplification of peak ground accelerations, landsliding, and liquefaction susceptibility. Also, a general hazard composite map was produced by combining these three hazards with geographic information system (GIS) tools. Information on expected ground response from these regional maps can be used for a variety of purposes and applications. For example, in the case of new buildings, consideration of the siting of facilities may be based on expected ground response, and the level of the geotechnical investigation, design, and construction may be scaled according to the expected hazards. For existing buildings, the maps can be used to conduct a systematic risk assessment, so that property owners have the information needed to prioritize retrofit of their structures. The maps can also help facilitate prudent regional land use planning and emergency response planning both before and during an earthquake disaster.

Hazard mapping is under way in several urban areas, including the outer reaches of the greater Portland area and the greater Eugene and Springfield area. Mapping has been completed for most of Portland, for Salem, and for the Siletz Bay area in coastal Lincoln County. Continued mapping efforts are projected for Klamath Falls and 24 small-

Figure 3. Damage to Molalla High School, Molalla, Oregon, from the Scotts Mills earthquake of 1993. Bricks from the unreinforced masonry gable over the doorway fell to the steps and sidewalk (left photo) during the earthquake, illustrating the need for seismic rehabilitation. The damage to the steps (right photo) that was revealed when the debris was removed can serve as a vivid reminder of an important rule for response during an earthquake: Do not run out of a building! Rather, "duck, cover, and hold"!

to moderate-sized cities in western Oregon (including communities such as Albany, Corvallis, Newberg, Medford, Coos Bay, and Newport).

The Oregon coast is the focus of substantial risk from Cascadia subduction zone earthquakes and accompanying tsunamis, which have estimated first-wave arrival times of about 5 to 30 minutes after the onset of ground shaking. Regional tsunami-inundation zone maps have been completed for the entire Oregon coast. Also, detailed mapping has been completed for the greater Siletz Bay area; mapping is being conducted in Seaside and Newport; and future mapping in other areas (including Gold Beach and Coos Bay) is in preparation. In addition, large historical markers describing tsunamis have been erected at Seaside, Newport, and Reedsport; tsunami hazard zone and evacuation route signs have been installed in several coastal towns and communities; and informational tsunami brochures and bookmarks have been distributed all along the coast.

Mitigation of earthquake hazards: In 1989, DOGAMI was charged with the additional duties of mitigating earthquake hazards, that is, reducing the loss of life and property from earthquakes. Four main areas are targeted: new buildings, existing buildings, uses of the DOGAMI hazard maps, and earthquake damage and loss studies.

Since 1993, the Building Codes Division has required construction of safer new buildings (discussed below under "Building Codes Division"). For existing buildings, efforts are underway to develop a prioritized strategy for reduction of future losses by identifying steps that can provide for greatly enhanced safety at reasonable and justifiable expense. The goal is to establish policies that will help identify and strengthen vulnerable existing buildings (discussed below in "Seismic Rehabilitation Task Force").

DOGAMI collaborates with Metro on the Portland earthquake hazard mapping project, with DOGAMI developing the maps and Metro focusing on the application of the maps in its jurisdiction over the greater Portland area (see discussion below under "Metro"). DOGAMI's and Metro's efforts can help guide the use of hazard maps in other areas of the state as well as other parts of the country.

Another element of mitigation is conducting damage and loss assessments to estimate the loss of life and property from expected future earthquakes. With this information, strategic retrofit programs can be developed. DOGAMI has been involved in several earthquake damage and loss assessments. In 1993, a hazard map of the Portland 7½-minute quadrangle was accompanied by an earthquake damage and loss estimate for an area of 60 city blocks (Metro/Oregon Department of Geology and Mineral Industries, 1993). Initiated in 1995, a federally funded National Institute of Building Sciences (NIBS) damage and loss study of the greater Portland area is under way. Results are projected to be available to the public in early 1997 (discussed below in "National Institute of Building Sciences"). In 1996, DOGAMI completed an economic impact evaluation from a design earthquake for each county. The study led to the result that over the next 55 years, the estimated average annual loss in Oregon would total over $100 million (Whelan and Mabey, 1996).

The agency encourages local partnerships and cooperation with communities, so that a systematic evaluation of risk can be better understood and mitigation efforts can be prioritized. An additional element is cooperation with local officials, such as land use and emergency planners and building officials, to incorporate the understanding of the mapped hazards and risks into everyday practices, plans, and policies.

Increasing earthquake hazard awareness: Earthquake risk can be reduced by increasing hazard awareness in the public. DOGAMI engages in technology transfer and public education by leading and participating in committees, conferences, workshops, and applied sessions with targeted audiences, including planners and building officials, and by developing and distributing fact sheets and brochures. Some outreach includes disseminating information through media, schools, and universities and supporting continuing education and studies for organizations such as the Oregon Building Officials Association, Oregon Planning Institute, American Society of Safety Engineers, Oregon Occupational Safety and Health Division of the Department of Consumer and Business Services, Oregon League of Women Voters, Northwest Power Pool (lifeline managers), and insurers. DOGAMI also assists with preparedness efforts of the American Red Cross.

Metro

Metro is authorized through its charter to address natural-disaster planning and response coordination in the greater Portland area. The agency's focus to date is on collection and dissemination of seismic risk information and on interaction with federal, state, and local governments, businesses, utilities, and special-interest groups in developing a regional earthquake preparedness program.

Metro was a key player in the Regional Planning Group that created the Regional Emergency Management Workplan, with the stated goal "to determine the emergency management issues and needs of the region and propose methods of coordinating, improving, and maintaining the emergency services system in the region." A geographic information system (GIS) database with regional infrastructure and building inventory is about half completed and has been shared with those who are conducting the National Institute of Building Sciences (NIBS) damage and loss assessment of the greater Portland area.

In early 1994, Metro formed the Metro Advisory Committee for Mitigating Earthquake Damage (MACMED) to support cooperative efforts among community members and to address regional policy issues regarding uses of the DOGAMI earthquake hazard maps. In May 1996, MACMED completed its efforts to tie earthquake hazard maps to land use planning and building practices and issued a report titled "Using Earthquake Hazard Maps for Land Use Planning and Building Permit Application." Metro plans to present the recommendations in the report to the Metro Policy Advisory Committee and Metro Council for future action.

Since 1993, Metro has sponsored several regional conferences that addressed earthquake hazards and emergency response. Metro is involved in several ongoing projects, including the NIBS-funded damage and loss study for the Metro area.

Oregon Seismic Safety Policy Advisory Commission (OSSPAC)

OSSPAC serves to reduce earthquake exposure and advises the legislature and government agencies on earthquake policy issues. OSSPAC includes representatives from the Building Codes Division, DOGAMI, the Department of Human Resources, Department of Land Conservation and Development, Department of Transportation, Oregon Emergency Management, Department of Water Resources, legislature, school districts, structural engineers, city governments, and county governments.

While OSSPAC functions as a forum and is still in developmental stages, it has identified the potential risk from existing buildings and bridges as the greatest earthquake-related risk the state now faces. OSSPAC played a vital role in presenting legislation that upgraded Oregon's building requirements from Zone 2B to Zone 3 for western Oregon. Currently, OSSPAC is evaluating the policy issues surrounding a possible change of seismic zone ratings along the Oregon coast for the Building Codes Division.

Department of Consumer and Business Services, Building Codes Division (BCD)

BCD sets state requirements of the minimum design and construction standards for new buildings. In 1993, BCD upgraded the Oregon Structural Specialty Code (OSSC) seismic zonation rating for western Oregon and Hood River and Klamath Counties from Zone 2B to Zone 3, which requires that new buildings be built to higher seismic standards.

Also since 1993, BCD requires that site-specific seismic hazard investigations be performed for new essential facilities, major structures, hazardous facilities, and special-occupancy structures such as hospitals, schools, and emergency response facilities. BCD is currently evaluating the merits of changing the requirements of coastal Oregon, such as possibly upgrading to a Uniform Building Code Zone 4 rating, and is active on several earthquake committees and continuing education programs.

Oregon Department of Transportation (ODOT)

ODOT has focused on reducing seismic risks by placing an emphasis on strengthening future construction and by developing a priority list for retrofitting existing structures. Starting in 1991, ODOT began seismic retrofit of high-priority bridges, a screening of all state-owned bridges for seismic retrofit prioritization, and installation of a statewide seismic strong-motion instrumentation network. By 1995, ODOT had concluded its seismic hazard mapping project for the state. The agency is continuing its aggressive search for funding alternatives for seismic strengthening of bridges and is moving forward as well on other mitigation efforts.

Department of State Police, Oregon Emergency Management (OEM)

OEM is charged with applying for and administering disaster and other grants related to emergency program management and emergency services for the state. OEM coordinates the activities of all public and private organizations providing emergency services within the state. Most of the coordination efforts are related to planning for and conducting emergency response. OEM coordinates the response to an earthquake, which includes providing inspectors to assess damage. OEM led its first biannual statewide emergency response exercise for a Cascadia subduction zone earthquake scenario (QuakEx) in 1994 and continues scheduling the exercise on a biannual basis, involving many public and private organizations and sponsoring conferences and education focused on mitigation.

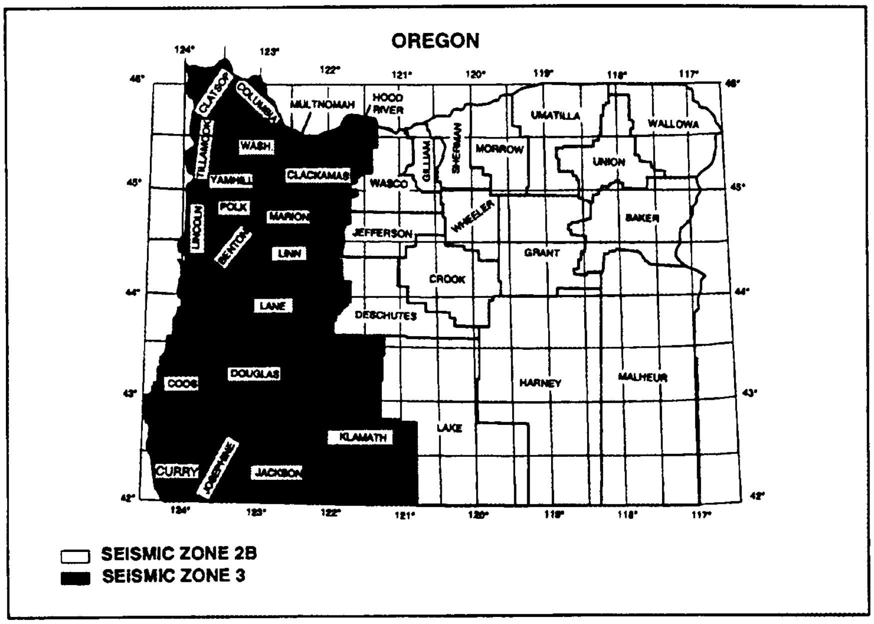

Figure 4. Seismic zone map of Oregon. Prior to the 1993 change of the Oregon Structural Specialty Code, all of Oregon was Seismic Zone 2B.

OTHER GOVERNMENT ORGANIZATIONS

Other organized efforts by agencies on the federal, state, and local government levels, some of which some are partnerships among various governmental agencies and private groups, are listed below. For the purposes of this paper, information about partnership efforts is generally provided under the section of the leading organization.

Federal Emergency Management Administration (FEMA)

FEMA is charged with mitigating the effects of natural disasters and responding to needs that develop after a disaster. FEMA provides disaster relief funds following an emergency and works most closely with OEM (for example, in response to the 1993 Scotts Mills and Klamath Falls earthquakes). FEMA has helped elevate the awareness of Oregon's seismic risk to the national level and has been a strong financial supporter of earthquake mitigation projects in the Portland area, including the Portland area earthquake hazard mapping project.

U.S. Geological Survey (USGS)

The USGS actively engages in earthquake research and also strongly supports research by others by providing funds and professional involvement through a variety of means. Recent USGS research includes paleoseismic investigations along the Columbia River, aeromagnetic surveys of the Portland area and the northern Willamette Valley, recordings of the 1993 Scotts Mills and Klamath Falls earthquake aftershocks by deployment of temporary seismometers, evaluation of landslides induced by the 1993 Klamath Falls earthquake and of slopes in the greater Eugene and Springfield area that are prone to fail in earthquakes, and evaluation of crustal strain related to the Juan de Fuca plate subduction zone through a global positioning system (GPS) network.

In addition, the USGS funds the Pacific Northwest Regional Network, with headquarters at the University of Washington (UW), which provides earthquake recording coverage of much of Oregon. Other parts of Oregon are covered by Boise State University. The USGS, UW, and DOGAMI are currently initiating a system that allows for real-time monitoring of earthquakes. The USGS participates in partnership efforts (FEMA, DOGAMI, and California Division of Mines and Geology) to develop standardized methods of making earthquake hazard maps.

National Earthquake Hazards Reduction Program (NEHRP)

NEHRP was established by act of Congress in 1977 and is charged with providing long-term, nationwide earthquake risk reduction. NEHRP consists of federal agencies-FEMA, USGS, National Science Foundation (NSF), and National Institute of Standards and Technology (NIST) and awards grants on a competitive basis. NEHRP has funded such studies in Oregon as the evaluation of the 1993 Scotts Mills and 1993 Klamath Falls earthquakes, publication of liquefaction maps in the greater Portland area, Portland area basin studies, Portland area probabilistic ground motion studies, and Coos Bay area fault maps.

National Earthquake Loss Reduction Program (NEP)

NEP, which was formed in 1996 to focus on earthquake loss reduction by complementing NEHRP activities, is led by FEMA and involves many agencies in addition to those that make up NEHRP. The stated goals are to provide leadership and coordination for federal earthquake research, improve technology transfer and outreach, improve engineering of the built environment, improve data for construction standards and codes, continue the development of assessment tools for seismic hazards and risks, analyze seismic hazard mitigation incentives, develop understanding of societal impacts and responses to earthquake hazard mitigation, and continue documentation of earthquakes and their effects.

National Institute of Building Sciences (NIBS)

FEMA has sponsored NIBS to develop for NEHRP a risk assessment tool that estimates earthquake losses and that should be available in early 1997. Ultimately, local officials responsible for planning and stimulating mitigation efforts can utilize this methodology to reduce losses and better prepare for emergency responses and recovery following and earthquake. With results thus obtained by a consistent method, NEHRP can better determine the level of resources needed on a nationwide basis and more accurately allocate those resources to appropriate regions.

At this time, three pilot studies to test the developmental software (HAZUS) produced by NIBS are being conducted. The greater Portland area was selected as the western U.S. site.

Cascadia Region Earthquake Workgroup (CREW)

CREW is a private-public coalition formed in 1995 that works to reduce the risk of Cascadia-region earthquake hazards by linking regional mitigation resources and encouraging regional mitigation projects. CREW consists of a broad spectrum of Northwest-based members, including representatives of government, corporate, medical, financial, manufacturing, utility, and transportation groups. CREW plans to develop earthquake scenarios of Cascadia subduction zone and Portland earthquakes to identify areas of high risk.

Western States Seismic Policy Council (WSSPC)

WSSPC is a policy consortium of 18 governmental bodies from 13 western states represented by their emergency managers and State Geologists, whose mission includes the sharing of information among the states for earthquake mitigation purposes.

Oregon Department of Land Conservation and Development (DLCD)

DLCD supports earthquake hazard planning relating to its Comprehensive Plan Goal 7 on natural hazards and encourages prudent land use planning according to the MACMED report recommendations (see "Metro," above). DLCD participates in earthquake efforts together with OSSPAC and MACMED.

Oregon State System of Higher Education

All three of the state's major public universities, University of Oregon, Oregon State University, and Portland State University, are involved with earthquakes and earthquake hazards in some capacity. At these institutions, the federally funded work conducted tends to be oriented towards basic research, whereas the state-funded work typically has more practical application.

Some of this work has included the analysis of the Scotts Mills and Klamath Falls earthquakes, studies of offshore faults and geology, studies of paleoseismic evidence along the coast and the Columbia River, installation and operation of a limited seismic network in cooperation with the Pacific Northwest Regional Network, geologic modeling and geophysical studies for supporting DOGAMI earthquake hazard mapping, and course offerings and seminar lectures on earthquake engineering issues.

Oregon Department of Education

The Department of Education is generally concerned with seismic safety in schools. It supports the required monthly earthquake drills mandated in the Oregon Revised Statutes (ORS 336.072). The Department does not have authorization to mandate seismic safety efforts in schools but can make recommendations to local school districts on such issues. For example, it encourages use of a curriculum produced by FEMA that focuses on mitigating nonstructural hazards in schools and assists schools in obtaining funds for these purposes.

Oregon Department of Administrative Services (DAS)

DAS is responsible for all state government buildings and has taken a leading role in applying the new earthquake awareness to the safety of structures. The new state office building in Portland was built to Zone 3 standards in 1991/1992—before Zone 3 was adopted by BCD. Existing structures, such as the Public Service building and the Public Utility Commission building in Salem, have been rehabilitated for increased seismic resistance.

Oregon Department of Water Resources (DWR)

DWR safeguards many of the existing dams in the state. The agency has recently begun to consider earthquake safety of dams, for instance, as part of the dam relicensing process and has recommended installing seismic instrumentation on dam sites.

Oregon Boards of Geologist Examiners and Engineering Examiners

In late 1996, the Boards jointly adopted guidelines for the preparation of reports on seismic hazard investigations required for new essential facilities, major structures, hazardous facilities, and special-occupancy structures.

Local governments

Implementation of earthquake preparedness policy often takes place at the local government level, in cities, counties, water districts, and on school boards. For example, many decisions regarding planning, building, strengthening of structures, and post-disaster response are made at the local level.

In August 1993, the City of Portland formed the Portland Seismic Task Force to address the City of Portland Dangerous Building Code, which was substantially affected by the 1993 state building code changes. In order to determine which existing Portland buildings need to undergo seismic rehabilitation, the task force initiated a risk study to determine acceptable levels of risk within its jurisdiction. The ultimate goal of the task force is to develop public policies encompassing acceptable seismic practices involving the Portland Dangerous Building code and existing vulnerable structures. The history of the building codes for Portland can be found in Kennedy (1996).

PRIVATE ORGANIZATIONS

Various branches of the professional engineering, earthquake, and earth science communities have been actively involved in Oregon's earthquake issues. The Structural Engineers Association of Oregon (SEAO) has recommended requiring continuing education for structural engineers to better address the increasing level of competence needed to design seismically resistant structures. The Oregon Chapters of the American Society of Civil Engineers (ASCE) and the Association of Engineering Geologists (AEG) have provided input on various proposed earthquake-related items of legislation and have offered numerous lectures on seismic issues. National conferences of ASCE and AEG covering Pacific Northwest earthquake issues are planned in 1997. The Earthquake Engineering Research Institute (EERI) and the Geological Society of America (GSA) have sponsored conferences centered on earthquake issues in the Pacific Northwest.

The growing earthquake awareness and concern over earthquake preparedness and mitigation is reflected in the activities of many more organizations, institutions, media, and individuals. Coverage of earthquake-related issues has increased considerably in the region's public media. Educational facilities have developed instructional programs such as the FEMA-funded "Seismic Sleuths" and "Tremor Troops" teacher workshops presented throughout the Pacific Northwest by the Oregon Museum of Science and Industry. Nonprofit organizations have been active in earthquake awareness activities. For example, the League of Women Voters of Oregon conducted a statewide earthquake hazard and awareness study partially funded by DOGAMI that also raised awareness of earthquake issues at the community level. The American Red Cross focuses on public education, preparedness, and emergency response aimed at families and businesses.

DISCUSSION

The understanding of Oregon's earthquake hazards and the way the state addresses earthquake risks have changed over the years. Periodic earthquake shaking has been felt in Oregon for over a century and a half. The great Cascadia subduction zone earthquake threat was identified in the past decade. The 1993 Scotts Mills and 1993 Klamath Falls "wake-up call" earthquakes confirmed to most people that earthquake hazards are present in Oregon. These recent events have dispelled the notion that Oregon was not earthquake country.

Because earthquakes are low-probability catastrophic events, it is not easy to gain political support and the necessary resources to reduce earthquake risks. However, enough Oregonians have come to realize that the huge costs to society associated with damaging earthquakes can easily exceed the cost of reasonable efforts of preparedness, and attempts are being made to bring the state into a better position before next big earthquake hits.

Progress in identifying hazards and risks, estimating the damage and loss potential, reducing risks, and planning for emergency response has been made mainly in the last decade. In view of the fact that no major earthquakes that would raise public awareness have occurred yet, Oregon has made great strides. Many, in fact, consider Oregon to have created an exemplary framework of proactive steps that may be applied elsewhere in the nation to regions that can benefit from guidance in earthquake preparedness. National and regional awards have been granted to the DOGAMI/Metro hazard-mapping project for the Portland area. The surprising thing about Oregon's remarkable progress is that the earthquake mitigation efforts have been performed in fragments by various organizations without comprehensive oversight, whereas addressing the region as a whole would probably have been more efficient. Perhaps the most noteworthy aspect of the accomplishments is that the professional disciplines, including those within government agencies, have managed to overcome the common communication barriers between each other to the advantage of society and have taken decisive initial steps in the right direction. Still, Oregon remains largely underprepared for a significant earthquake, and much more effort is needed to lower the earthquake risk.

History shows that every earthquake has been a "surprise." The exact timing of an earthquake always contains the element of surprise, because true prediction is not possible at this time, nor does it seem likely to be possible for decades to come. Also, earthquakes are all different in respect to their type, the environment in which they occur, and the built environment they affect. In seismically active regions, the earthquake "surprises" and the associated damages and losses should not really be surprises. For that reason, inhabitants of seismically active regions have the opportunity of being prepared for the next "surprise" earthquake. It is possible to understand reasonable bounds of potential earthquakes and earthquake hazards, to approximate them through earthquake scenarios, and to reduce the risks to a reasonable level to the benefit of current populations and future generations.

Many earthquakes around the world have had disastrous consequences. Preliminary estimates from earthquake damage-and-loss studies of the densely populated greater Portland area indicate that many hundreds of lives could be lost and that property loss could be on the order of tens of billions of dollars in such an event. Quantifying potential losses is one step in getting closer to the difficult question: "How much can we invest prudently in safer living?"

Since 1993, a higher standard for the seismic safety of new buildings and seismic investigations of building sites for certain new structures, such as hospitals, schools, or emergency response facilities, have been mandated in Oregon. To achieve safer conditions for the entire community, however, more than just the safety of its new buildings must be assured. All buildings and the vulnerability of lifelines such as roads and water, waste-water, electricity, gas, and communication systems need to be addressed. Many need seismic strengthening. Realistic measures to prioritize seismic strengthening must be taken quickly and prudent land use measures established promptly. In addition, a higher degree of preparedness needs to be attained at many levels, from emergency response at the government level to disaster preparedness at the personal level.

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Although it is not the author's intention, this paper may be biased with general viewpoints of the Oregon Department of Geology and Mineral Industries due to the fact that much of the background was gathered from the agency's staff and files. Significant earthquake research and mitigation efforts by those not mentioned in this paper can be brought to the author's attention for future clarification.

REFERENCES CITED

Algermissen, S.T., 1983, An introduction to the seismicity of the United States: Berkeley, Calif., Earthquake Engineering Research Institute Monograph, 148 p.

Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: Science, v. 236, p. 942–944.

Atwater, B.F., Nelson, A.R., Clague, J.J., Carver, G.A., Yamaguchi, D.K., Bobrowsky, P.T., Bourgeois, J., Darienzo, M.E., Grant, W.C., Hemphill-Haley, E., Kelsey, H.M., Jacoby, G.C., Nishenko, S.P., Palmer, S.P., Peterson, C.D., and Reinhart, M.A., 1995, Summary of coastal geologic evidence for past great earthquakes at the Cascadia subduction zone: Earthquake Spectra, v. 11, no. 1, p. 1–18.

Beaulieu, J.D., 1976, Geologic hazards in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 38, no. 5, p. 67–83.

Beaulieu, J.D., and Peterson, N.V., 1981, Seismic and volcanic hazard evaluation of the Mount St. Helens area, Washington, relative to the Trojan nuclear site, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–81–9, 80 p.

Bott, J.D.J., and Wong, I.G., 1993, Historical earthquakes in and around Portland, Oregon: Oregon Geology, v. 55, no. 5, p. 116–22.

Dehlinger, P., and Berg, J.W., Jr., 1962, The Portland earthquake of November 5, 1962: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 11, p. 185–188.

Dehlinger, P. Bowen, R.G., Chiburis, E.F., and Westphal, W.H., 1963, Investigations of the earthquake of November 5, 1962, north of Portland: Oregon Department of Geology and Mineral Industries, the Department of Geology and Mineral Industries, Ore Bin, v. 25, no. 4, p. 53–68.

Geomatrix Consultants, Inc., 1995, Seismic design mapping, State of Oregon: Final report to Oregon Department of Transportation, Project no. 2442, var. pag.

Goldfinger, C., Kulm, L., Yeats, R., Mitchell, C., Weldon, R., Peterson, C., Darienzo, M., Grant, W., and Priest, G.R., 1992, Neotectonic map of the Oregon continental margin and adjacent abyssal plain; Oregon Department of Geology and Mineral Industries Open-File Report O–92–4.

Heaton, T.H., and Kanamori, H., 1984, Seismic potential associated with subduction in the northwestern United States: Seismological Society of America Bulletin, v. 74, no. 3, p. 933–941.

Kennedy, R.E., 1996, The development of the Portland, Oregon, Building Code—50 years of evolution, 1945–1995. A comparison of seismic events and structural aspects: Oregon Geology, v. 58, no. 1, p. 10–14.

Metro/Oregon Department of Geology and Mineral Industries, 1993, Earthquake scenario pilot project: Assessment of damage and losses: Oregon Department of Geology and Mineral Industries Open-File Report O–93–6, 19 p., 16-p. appendix.

Oregon Department of Geology and Mineral Industries, 1978, Geologic hazards review, Trojan nuclear power plant site, Columbia County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–78–1, 42 p.

Satake, K., Shemazaki, K., Yoshinobu, T., and Ueda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700, 1996: Nature, v. 379, no. 6562, p. 246–249.

Savage, J.C., Lisowski, M., and Prescott, W.H., 1981, Geodetic strain measurements in Washington: Journal of Geophysical Research, v. 86. no. B6, p. 4929–4940.

Shannon and Wilson, Inc., 1972, Seismic regionalization studies, Bonneville Power Administration service area, Washington, Oregon, Idaho, and western Montana: Portland, Oreg., Report to Agbabian Associates, El Segundo, Calif. (Job no. 0–653); R.W. Couch and R.J. Deacon, investigators, 43 p.

Smith, W.D., 1919, Earthquakes in Oregon: Seimological Society of America Bulletin, v. 9, no. 3, p. 58–71 (Reprint: University of Oregon Publications, v. 1, no. 3).

Whelan, R.M., and Mabey, M.A., 1996, The expected financial losses due to building damage caused by severe earthquakes in Oregon: Oregon Geology, v. 58, no. 6, p. 146–149. □