II. CONFERENCE PAPERS

EARTHQUAKE HAZARDS IN BRITISH COLUMBIA AND WASHINGTON

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ABSTRACT

British Columbia and Washington are both in earthquake country. Thousands of earthquakes are recorded each year by seismograph networks in the United States and Canada. A number of historic earthquakes have shaken the region hard enough to cause widespread damage and alarm. Many Indian legends attempt to explain this terrifying shaking. One such legend involves the spread of a disease called "Earthquake Foot." People infected with Earthquake Foot cause an earthquake whenever they stumble. Geological and geophysical information collected with modern instruments and analyzed by scientists in Canada and the United States provides more data from which to develop an explanation of why the earth shakes in this region. Recent studies conclude that a "Great" earthquake (similar in size to the largest earthquakes recorded) must be considered a possibility in the Pacific Northwest.

Investigation of the causes and the impact of earthquakes on the physical and built environment have led to efforts to find ways to reduce that impact. Both the United States and British Columbia have developed school earthquake safety and education programs to provide greater protection for a particularly vulnerable population and to disseminate general earthquake preparedness information to the larger community through the schools.

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INTRODUCTION

The Pacific Northwest is well-known for snowclad mountains, white-water rivers, and thick rain forests. Some of the hazards of such an environment - avalanches, drowning, and fires - are obvious and the precautions necessary to deal with them well understood. The hazard from earthquakes is less well recognized, yet damage and loss of life during a large earthquake are certain. A 1975 study by the U.S. Geological Survey of six counties in the Puget Sound area (U.S. Geological Survey, 1975) projects as many as 2,200 deaths and 8,700 injuries in the next magnitude 7.5 earthquake. An earthquake much larger than the one used to make the 1975 estimates is now considered a possibility in the Pacific Northwest (Atwater, 1987).

By understanding the causes and effects of earthquakes in Washington and British Columbia, appropriate actions can be taken to reduce loss of life and property. Earthquakes, like the rain, will always be a part of the region's environment. However, these forces need not level our cities or generate mass confusion and economic disaster. Our homes, schools, and businesses can be made safer places to be during future earthquakes. Earthquake resistant design can improve the ability of buildings to survive strong ground shaking. Individuals can be trained to immediately seek protection and provide emergency care and assistance when the shaking stops. And communities can plan for recovery to accelerate a return to social and economic stability. These efforts require an informed and prepared population.

WHAT CAUSES EARTHQUAKES?

An earthquake is the shaking of the ground produced by an abrupt shift of rock along a fracture in the earth, called a fault. Within seconds, an earthquake may release energy that has taken hundreds or even thousands of years to accumulate. Plate tectonics is a starting point for understanding the forces in the earth that cause earthquakes.

Plates are thick slabs of rock that make up the outermost 100 kilometers or so of the earth. Earthquakes occur only in the outer, brittle portions of these plates, where temperatures in the rock are relatively low. Temperature differences deep within the earth cause very slow movements of interior rock, called convection. Convection results in the movement of the overlying plates. This movement can deform the brittle portions of the plates. If the deformation exceeds the strength of the rocks comprising these brittle zones, the rocks can either break suddenly, releasing the stored elastic energy as an earthquake or change shape slowly and gradually release the energy without an earthquake.

Ninety percent of the world's earthquakes occur along the boundaries between plates. These boundaries are called spreading, convergent, or transform, depending on whether the plates move, respectively, away from, toward, or horizontally past one another. Subduction occurs where one plate converges toward another plate, moves beneath it, and plunges as much as several hundred kilometers into the earth's interior. Each of these boundaries are present in the Pacific Northwest (Fig. 1): 1) the Juan de Fuca Ridge and the Gorda Ridge are spreading boundaries that separate the northwestward moving Pacific Plate from the northeastward moving

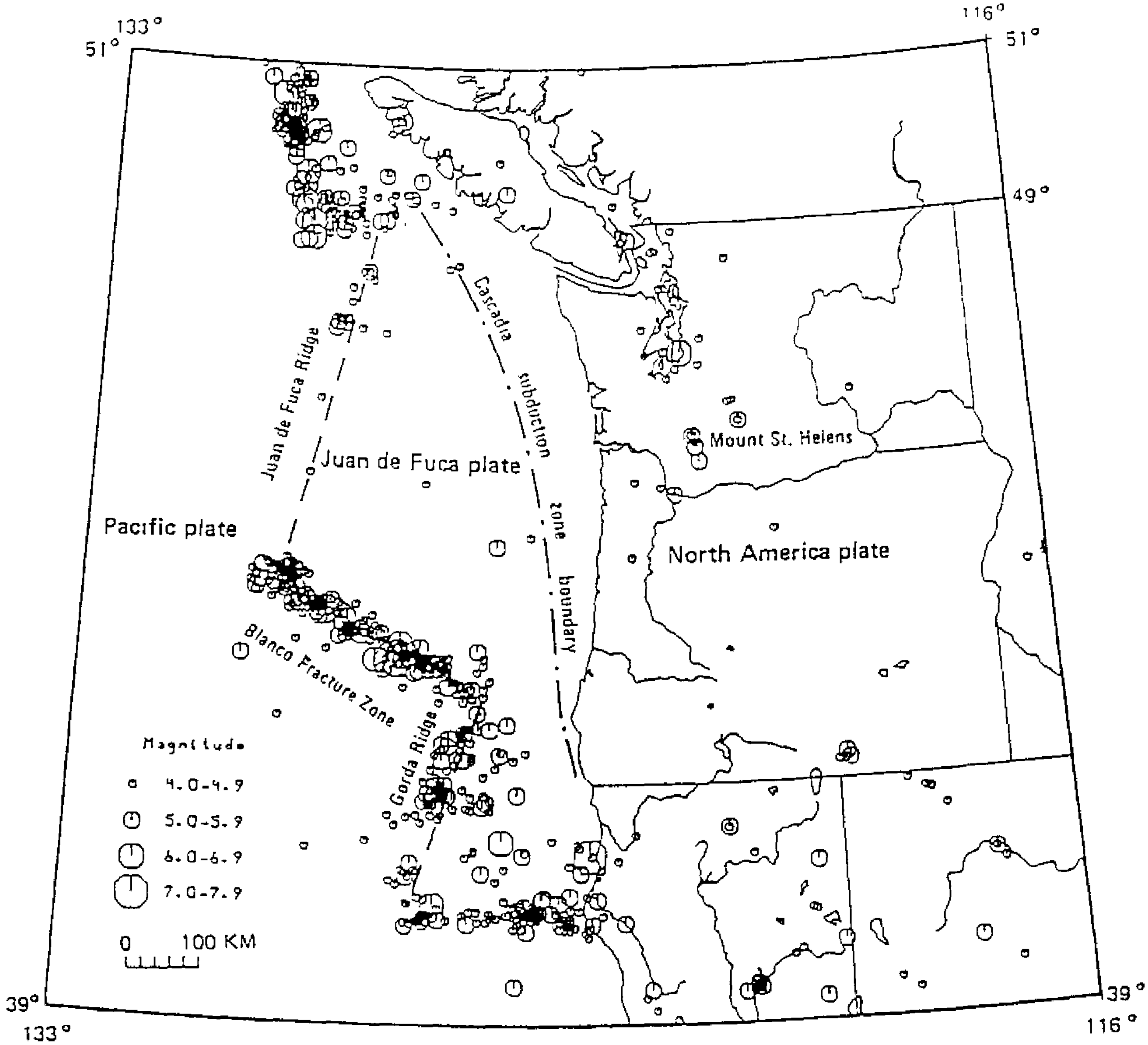

Figure 1. Epicenters of earthquakes in the Pacific Northwest since 1960. Only the largest earthquakes near Mount St. Helens are indicated. Note the position of the Cascadia subduction zone relative to Washington's coast and that epicentral locations mark plate boundaries. (Data from the National Oceanic and Atomospheric Administration and the University of Washington. Figure from Noson and others, 1988).

Juan de Fuca Plate; 2) coastal British Columbia, Washington, and Oregon are in the Cascadia Subduction Zone where the Juan de Fuca Plate converges with the North America Plate; and 3) transform boundaries exist along the Blanco Fracture Zone where the Pacific Plate moves laterally past the Juan de Fuca Plate and along the Queen Charlotte Fault where the Pacific Plate moves laterally past the North America Plate.

Earthquake activity varies according to the type of plate boundary:

The Juan de Fuca Ridge is an area of high temperature and weak rocks that yield readily to the pushes and pulls from inside the earth. This is an area with relatively few earthquakes of small size where the rocks break before large amounts of energy can accumulate.

The Queen Charlotte Transform boundary, like the San Andreas Fault in California builds up tremendous energy in the rocks as the massive North America and Pacific Plates grind by each other. The rate of earthquake activity and the size of earthquakes are greater along transform boundaries than at spreading boundaries. The 1906 San Francisco earthquake (magnitude 8.3) and the 1949 Queen Charlotte earthquake (magnitude 8.1) are examples of notable earthquakes along transform boundaries. Since a transform fault juxtaposes two plates, movement shifts features like streams, fences, and buildings built across the boundary. Earthquakes are concentrated in a narrow zone in width and depth along the boundary.

The convergent boundary between the Juan de Fuca Plate and the North America Plate shows more complicated geologic and geophysical features than the ridge or transform boundaries (Noson et al., 1988). Three source zones have been identified for earthquakes in this area: within the upper part of the North America Plate, inside the descending Juan de Fuca plate, and between the North America and Juan de Fuca Plates. Source Zone 1: The upper North America Plate earthquakes occur most densely within the Puget Sound - Georgia Strait region. However, historically, the largest shallow earthquakes have occurred in the Washington Cascades and on Vancouver Island. Source Zone 2: The best documented and most damaging historic earthquakes have occurred deep beneath Puget Sound and Georgia Strait inside the descending Juan de Fuca Plate. Source Zone 3: No earthquakes have been recorded between the Juan de Fuca Plate and the overlying North America Plate. However, subduction zones in other parts of the world with similar characteristics have had large, historic subduction zone or "Great" earthquakes with magnitudes of 8 and larger.

Geologic evidence from along the British Columbia, Washington, and Oregon coast is compatible with the occurrence of eight "Great" earthquakes during the past 5,000 years. The largest and most devastating earthquakes in the world, called subduction earthquakes, occur between converging plates.

Although the movement of plates can explain most earthquake activity, local rock movements may be caused by other forces. Readjustments of the earth following the melting of massive glaciers, the movement of magma in volcanic areas, and filling reservoirs with water have been known to generate earthquakes.

EARTHQUAKE HAZARDS IN THE PACIFIC NORTHWEST

Geological and geophysical studies carried out by scientists in Canada and the United States have provided the general framework within which to understand where, how often and how big earthquakes will be in the Pacific Northwest. More studies will be needed to better define the spatial and temporal distribution of earthquakes in this region. Will large, deep earthquakes within the descending Juan de Fuca Plate continue to be concentrated within the Puget Sound - Georgia Strait region or will they occur beneath Oregon as well? What is the largest shallow earthquake that is likely to occur? Answers to these questions require continued scientific attention.

Earthquakes produce two major types of hazards: primary and secondary. The primary hazards are ground shaking, surface faulting, and sudden elevation changes. Ground shaking is the most damaging primary hazard even in areas with many active surface faults like California. Surface faulting causes extreme damage, but that damage is very localized where as ground shaking causes damage over a very large area.

Major active surface faults have not been identified in the Pacific Northwest. Sudden elevation changes occur during very large subduction earthquakes. Following the 1964 Alaska earthquake with a moment magnitude[1] of 9.2 (Davies, 1986) and surface wave magnitude 8.4, the land was raised up to 33 feet and subsided about 6 feet over a broad area. Geologists have studied evidence of sudden elevation changes in Canada and the United States that may have been caused by subduction earthquakes in the Pacific Northwest.

Secondary hazards are additional dangers initiated by the ground shaking, faulting and sudden elevation changes. Ground failures, damaging water waves, fires, chemical spills, and dam ruptures are examples of secondary hazards. In order to identify the extent of secondary hazards, research needs to identify areas susceptible to ground failures and water waves and inventory the buildings, people and objects that will be affected.

WHAT HAPPENS DURING A MAJOR EARTHQUAKE?

Earthquake ground shaking produces a number of effects that are relatively consistent regardless of the region involved. The following summarizes what can be expected to occur:

Disrupted communication - either direct physical damage to communication systems or overloaded circuits;

[1]The 1964 Alaska earthquake has a Richter magnitude of 8.4 and a moment magnitude of 9.2. The Richter magnitude scale is inappropriate for magnitudes greater than about 8 because the Richter scale was designed for a particular instrument (Wood-Anderson) at a specific distance (100 km) in California. As a result, the moment magnitude was developed which uses measurements of lower frequency waves than the Wood-Anderson is designed to record in the magnitude calculation. Comparisons of Great earthquakes (magnitudes greater than about 8) for which moment magnitudes have been computed show a better correlation to other indicators of size.

Disrupted transportation - either direct physical damage to roads, freeways, and bridges or severe congestion;

Broken utility lines - gas, electricity, and water systems may be damaged in any of a number of places within the generation and/or distribution systems hampering lifesaving efforts and delaying recovery;

Structural damage - unreinforced masonry buildings and tilt-up construction have performed poorly in past earthquakes;

Non-structural damage - shattered glass, broken light fixtures, fallen ceiling panels, displaced equipment and furniture pose serious hazards to building occupants and effect the usefulness of the building following an earthquake;

Social and economic impact - businesses without a disaster contingency plan frequently fail after an earthquake; inventory may be destroyed, vital records ruined, loan payments not made; and personnel may suffer emotional "aftershocks."

IMPACT OF EARTHQUAKES ON SCHOOLS IN THE PACIFIC NORTHWEST

School earthquake damage has occurred to many school buildings throughout the Pacific Northwest. Only limited parts of this data base, however, have been collected. The most complete study of school earthquake damage followed the 1949 Olympia earthquake (Edwards, 1950). Thirty schools in Washington normally housing 10,000 students were closed. Ten schools were permanently closed and had to be replaced. School buildings suffered a disproportionate amount of damage. Two students were killed by falling bricks while attempting to exit during ground shaking. Most Washington schools were closed for Spring break or fatalities would probably have been much higher.

SCHOOL EARTHQUAKE SAFETY AND EDUCATION PROGRAMS

The United States Federal Emergency Management Agency (FEMA) field tested the *Guidebook for Developing a School Earthquake Safety Program*, FEMA-88, (MacCabe, 1985) in Washington in 1983. The School Earthquake Safety and Education Project (SESEP) located at the University of Washington was funded by FEMA to assist in field testing the guidebook and reviewing earthquake education materials developed by the California Envirnomental Volunteers. SESEP formed an advisory committee that included representatives from education, psychology, sociology, emergency management, seismology, Red Cross, and engineering to review materials and procedures developed by SESEP.

Five pilot schools were chosen in the Seattle Public School District based upon the combined interest of the Principal and Staff at each participating school. These schools formed earthquake safety committees that used the guidebook to develop a school earthquake safety program. SESEP supplemented the staff safety training with hands-on student learning centers on the causes and effects of earthquakes. An assembly on Washington earthquakes was presented prior to the learning centers. Evaluation of student learning (Brattesani & Noson, 1985) showed significant increase in student certainty about proper safety actions and increased factual knowledge about Pacific Northwest earthquakes. Data suggests that anxiety decreased somewhat.

Focused interviews were held with school safety committees to determine the factors involved in motivation and program participation (Brattesani, 1985). Interview results indicated that the primary impetus for being active on the earthquake safety committee was knowledge that the participant's school was among those at high risk of being damaged during an earthquake. Other factors included leadership, other program involvement, district support and funding, and having clearly stated program objectives listed in order of priority. These findings stress the need to clearly communicate the level of risk at a particular site to the staff and administration.

To reach a broader audience, SESEP presented teacher workshops on school earthquake safety that included an overview of regional earthquake hazards, impact of earthquakes on schools and the elements of a school earthquake safety program as outlined in FEMA 88. Participants from Victoria and Vancouver, British Columbia attended SESEP workshops. Subsequently, SESEP workshops were held in those cities. Information and sources on school earthquake safety were shared with the Canadians. British Columbia, with permission of FEMA, included information from FEMA 88 in materials produced for distribution by the Ministry of Education in the Province of British Columbia.

Interaction between the United States and British Columbia continues to occur concerning school earthquake safety efforts. Information has been shared on techniques for reducing nonstructural earthquake hazards in schools and hospitals, and on developing a regionally tailored earthquake education curriculum.

RECENT EVALUATION OF EARTHQUAKE RISK

Scientific studies over the past decade both in Canada and the United States indicate that a greater than magnitude 8, subduction earthquake must be accepted as a possibility within the Cascadia Subduction Zone. An earthquake of that type and size was not part of previous regional risk assessments. Past earthquakes like the Olympia 1949 already established the Puget Sound region as an area of major expected earthquake damage and thus of high earthquake risk. The addition of the possibility of a "Great" earthquake along the coast would dramatically extend the area included as high risk and pose new hazards to life and property. These changes in the risk assessment for the Pacific Northwest resulted in the region being included in the development of a United States Federal Catastrophic Earthquake Response Plan. The Province of British Columbia has similarly been involved in developing a national earthquake response plan to address the need for national assistance following a catastrophic earthquake that exceeds the ability of state and provincial emergency management to meet the demand for emergency services.

SUMMARY

The Pacific Northwest is an area of noteworthy earthquake hazards. Joint scientific studies have delineated the extent of the hazard based on historical and geological records. The population and infrastructure exposed to earthquake hazards has increased dramatically over the past several decades as settlement and development continue to grow. Earthquake education is necessary to create an informed populace capable of understanding what hazards are present and what steps to take to reduce the loss of life and property.

Schools serve a population that suffers relatively greater physical and emotional harm in damaging earthquakes. Studies in Japan (Miyang, 1988) following devastating earthquakes show more fatalities to children than to adults. Emotional damage is also greater among children than adults. School earthquake safety and education programs help increase the physical and emotional preparedness of our children as well as provide compelling lessons in science, social studies, and language arts.

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