UNITED STATES
DEPARMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Proceedings of Conference XLVIII

3RD ANNUAL WORKSHOP ON "EARTHQUAKE HAZARDS IN THE PUGET SOUND, PORTLAND AREA"

March 28-30, 1989
Portland, Oregon

SPONSORED BY

Oregon Department of Geology and Mineral Industries
Oregon Department of Emergency Management Division
Washington Department of Natural Resources
Washington Department of Community Development
Federal Emergency Management Agency
United States Geological Survey

EDITOR
Walter W. Hays
U.S. Geological Survey
Reston, Virginia 22092

Open-File Report 89-465

Compiled By
Linda Huey

Reston, Virginia
1989

TABLE OF CONTENTS

PREFACE i

EXECUTIVE SUMMARY ii
Josh Logan and Steve Palmer

PROGRAM FOR WORKSHOP iii

SECTION I: GEOSCIENCES INFORMATION 1

Rationale and Outline of a Program for Earthquake Hazards Assessment in the Pacific Northwest
Kaye M. Shedlock and Craig S. Weaver 2

Potential Subduction, Probable Intraplate, and Known Crustal Earthquake Source Areas in the Cascadia Subduction Zone
Craig S. Weaver and Kaye M. Shedlock 11

Current Assessment of Earthquake Hazard in Oregon
Robert S. Yeats 27

Seismicity of Puget Sound and Southern Britich Columbia
R.S. Crosson 31

Megathrust and Upper-Plate Paleoseismicity of the Southern Cascadia Margin
Curt D. Peterson 33

Geodetic Deformation of the Southern Casadia Margin
Paul Vincent 35

Coastal Terraces and Subduction Earthquakes
Donald O. West 36

Cascadia Subduction Zone: Structure, Tectonics, and Fluid Process of the Accretionary Wedge and Adjacent Abyssal Plain
LaVerne D. Kulm 38

Engineering Characterization of Strong Ground Motions with Applications to the Pacific Northwest
Walter Silva, Robert Darragh, and Ivan Wong 40

Attenuation Relationships for Evaluation of Seismic Hazards From Large Subduction Zone Earthquakes
R.R. Youngs and K.J. Coppersmith 42

Strong Ground Motion Attenuation in the Puget Sound-Portland Region
Paul Somerville 50

Estimates of Strong Ground Motions in the Seattle-Portland Region from Hypothesized Magnitude 8 Cascadia Subduction Earthquakes
Paul Somerville, Brian Cohee, and Mrinal Sen 52

The Standard Penetration Versus Depth Relations of Quaternary Glacial and Nonglacial Deposits in the Greater Seattle Area, Washington: Implications for Liquefaction Susceptibility Studies
J.C. Yount, G.S. Vick, and G. McCoy 62

Considerations for Deterministic Ground Motion Maping in the Portland-Puget Sound Region
John C. Tinsley 63

Using Earthquake Intensities to Determine Ground Responses in the Puget Sound Region
Anthony Qamar and Tom Bodle 68

Distribution of Potentially Responsive Quaternary Deposits in Portland
Ian Madin 73

Liquefaction Hazards in the Pacific Northwest
W. Paul Grant 82

Liquefaction Hazard Mapping for the Seattle Urban Region Utilizing LSI
T. Leslie Youd 84

Landslides in Washington and Oregon -- An Overview
Robert L. Schuster and Alan F. Chleborad 86

Characteristics of Slope Failures Induced by the April 13, 1949, and April 29, 1965, Puget Sound Area, Washington, Earthquakes
Alan F. Chleborad and Robert L. Schuster 106

The Tsunami Threat in the Pacific Northwest Under Today's Land Use Conditions
Jane Preuss 114

SECTION II: FUNDAMENTAL INFORMATION TO ENHANCE PROFESSIONAL SKILLS 123

What is an Earthquake and How is it Measured?
Anthony Qamar 124

Earthquake Occurrence and Hazards in Washington and Oregon
Ruth S. Ludwin 128

Fundamentals of Earthquake Effects on Land and Water
Stephen P. Palmer 141

Fundamentals of Earthquake Effects on Buildings and Lifelines
Roger W. McGarrigle 146

Concepts on Loss Estimation Used by Insurance Companies
Karl V. Steinbrugge 151

SECTION III: USING EARTH SCIENCE INFORMATION TO REDUCE POTENTIAL LOSSES 154

Knowledge Utilization
Walter W. Hays 155

Reducing Earthquake Losses
Martha Blair-Taylor 184

Summary of Earthquake Hazard Information Needed by Nontechnical Users
William J. Kockelman 188

Reducing Earthquake Hazards in Oregon and Washington: An Introduction to the Five Components Necessary for Effective Hazard Reduction
William J. Kockelman 190

Oregon's Building Regulation System
Walter M. Friday 213

Disaster Risk Analysis and Business Resumption Plan by a Washington State Governmental Agency
Judy H. Burton 215

Senate Bill 603 217

Senate Bill 604 219

Senate Bill 955 220

Senate Bill 956 222

Reacting to Earthquake Hazard Information--State Level
Carole Martens 224

Earthquake Mitigation: The Washington School Safety Program
Carole Martens 226

Mothers For H.E.L.P.
Bev Carter 230

Earthquake Risk Reduction Policies and Practices within the Puget Sound/Portland Area
Peter J. May 231

Post-Disaster Emergency Response Issues in Urban Settings
Patricia A. Bolton 247

The December 7, 1988, Spitak (SSR) Earthquake
Walter W. Hays 254

The International Decade for Natural Disaster Reduction (IDNDR)--AN Opportunity for the Pacific Northwest
Walter W. Hays 260

APPENDICES

A. Draft Work Plan: Regional Earthquake Hazards Assessment in the Pacific Northwest 1A

B. Glossary of Technical Terms 1B

C. List of Publications 1C

D. List of Participants 1D

PREFACE

COOPERATIVE EFFORT TO ASSESS EARTHQUAKE HAZARD AND TO FOSTER THE IMPLEMENTATION OF LOSS-REDUCTION MEASURES IN THE PUGET SOUND-PORTLAND AREA

Since 1985, the Federal Emergency Management Agency (FEMA) and the United States Geological Survey (USGS) have cooperated in fostering a partnership with State and local government, academia, the private sector, and other Federal Agencies to develop a long-term program to mitigate the earthquake hazard in the Puget Sound-Portland area. To date, the program has emphasized building a comprehensive knowledge base and developing an infrastructure of practitioners and professionals who can use it to meet their needs and to foster the implementation of loss-reduction measures.

Annual workshops, like the one held in Portland on March 28-30, 1989, are an important strategy of the National Earthquake Hazards Reduction Program. This workshop, the subject of this report, brought together more than 200 researchers, practitioners, and participants interested in earthquake hazards reduction. They shared in the workshop:

- Scientific and technical information produced by geologists, geophysicists, seismologists, and engineers in ongoing research programs (see Section II of the proceedings).

- Fundamental information that professionals having limited technical backgrounds in earth science or engineering, lay persons, and other professionals can use in various applications to reduce potential losses from earthquakes (see Section II of the proceedings).

- Practical information forming the basis for loss-reduction measures (see Section III of the proceedings).

The workshop was successful and the goals envisioned for it by the steering committee were achieved. The steering committee consisted of the following people who worked together to forge a cooperative partnership between State and local government, academia, the private sector, and the Federal Government:

- <u>Oregon</u>

  George Priest, Department of Geology and Mineral Industries
  Myra Lee, Emergency Management Division
  Ian Madin, Department of Geology and Mineral Industries

- Washington

  Ray Lasmanis, Department of Natural Resources
  Kate Heinback, Department of Community Development
  Chuck Steele, Federal Emergency Management Agency, Region X
  Linda Nosen, Federal Emergency Management Agency, Region X

- Federal Government

  Brian Cowan, Federal Emergency Management Agency
  Albert Roger, U.S. Geological Survey

Many individuals contributed substantially to the success of the workshop and their efforts are acknowledged with appreciation. Carla Kitzmiller, Linda Huey, and Peggy Randalow, U.S. Geological Survey, deserve a special note of appreciation for the efficient way they performed important staff and administrative functions from the beginning of the workshop process to the end product represented by this document.

The accomplishments being made in the Puget Sound-Portland area are an example of what can be done in a cooperative partnership.

Walter W. Hays
U.S. Geological Suvey

1989 Earthquake Workshop

By Josh Logan and Steve Palmer

The third annual "Puget Sound/Portland Area Workshop on Earthquake Hazards and Risks" was presented March 28-30 in Portland, OR. The purpose of the meeting, which was funded by the National Earthquake Hazards Reduction Program (NEHRP), was to increase public awareness of earthquake hazards in the Pacific Northwest and to provide a forum for earthquake research and mitigation activities, giving technical and non-technical professionals an opportunity to interact. Representatives from such diverse fields as geology, seismology, engineering, planning, emergency management, politics, insurance, and fire and police protection participated. The Washington Department of Natural Resources' Division of Geology and Earth Resources (DGER) co-sponsored the event with the Washington Department of Community Development, the Oregon Department of Geology and Mineral Industries (DOGAMI), the Oregon Department of Emergency Management, the Federal Emergency Management Agency (FEMA), and the U.S. Geological Survey (USGS). Ian Madin from DOGAMI chaired the workshop planning committee.

This year's workshop consisted of two days of meetings followed by a day-long field trip to Netarts Bay. In one of the welcoming talks, Walt Hays, deputy for research applications in the Office of Earthquakes, Volcanoes, and Engineering of the USGS, summarized the progress of the NEHRP since its inception and outlined future directions for the program. He stressed the need to accelerate progress in research, development of professional practices, and implementation of mitigation measures. He described the enormity of tasks, such as gaining better knowledge of seismogenic zones; retrofitting existing buildings; eliminating unsafe school buildings; improving siting, design, and construction techniques; improving professional skills; increasing the state of earthquake preparedness; and producing more "champions" of earthquake hazard mitigation.

Two concurrent sessions were held on the workshop's first day, a geosciences session and a professional skill enhancement session. The purposes of the professional skill enhancement session were to explain the basic technical issues regarding earthquakes in the Pacific Northwest and to present methods of using technical information to reduce or respond to earthquake hazards. Talks presented during the morning part of this session reviewed the causes and effects of earthquakes. Tony Qamar and Ruth Ludwin of the University of Washington, and Linda Noson, FEMA, discussed the fundamentals of earthquakes, and answered such questions as "What is an earthquake, and how are they measured?" and "Where will earthquakes occur in the Pacific Northwest?". Steve Palmer, DGER, reviewed the impacts of earthquakes on the land and water, including liquefaction and ground settlement, seismically induced landslides, tsunamis, and seiches. Numerous examples from major earthquakes in Alaska, Japan, Los Angeles, Chile, and the Puget Sound area documented the results of these seismically induced processes. Roger McGarrigle, president of the Structural Engineers Association of Oregon, discussed the effects of earthquakes on buildings, and he graphically demonstrated both poor and good earthquake design using Portland-area buildings as examples. Karl V. Steinbrugge, a consulting engineer from California, discussed the difficulty of assessing the monetary impact of future earthquakes and how this uncertainty influences earthquake insurance underwriters.

The afternoon portion of the professional enhancement session discussed earthquake preparedness and response and the application of earth science information to city and regional planning. Martha Blair-Tyler of William Spangle and Associates summarized earthquake hazard mitigation measures with regard to regional and urban planning. William J. Kockelman, USGS, discussed translating earthquake hazard information for non-technical users who may then influence their peers, supervisors, clients, or constituents. Myra Lee of the Oregon Emergency Management Division and Kate Heimbach of the Washington Department of Community Development moderated a panel discussion concerned with the reaction to earthquake hazards at the state level. Panel members included Walt Friday, Oregon Building Codes Agency; Judy Burton, Washington Department of Labor and Industries; Scott Boettcher, Intern for Washington Representative Dick Nelson; and Carol Martens, Washington Division of Emergency Management. Martha Blair-Tyler and Paula Gori, USGS, moderated a later panel discussion on the use of earthquake hazard information at the local level. Panel members included Paul Kostenaik, Boeing Company Puget Sound Seismic Review Group; Bill Elliot, Portland Water Department; and Bev Carter, Mothers for HELP (Help Everyone Learn Preparedness). Mothers for HELP is a non-profit organization established to educate and organize communities to be self-reliant for the period following a major disaster but before normal services are re-established.

The professional enhancement session concluded with a talk by Jim Tingey of the Utah Division of Comprehensive Emergency Management on the lessons learned in the implementation component of the Utah Regional Earthquake Hazards Assessment Program.

The geosciences session featured technical reviews of earthquake sources and site effects in the Pacific Northwest. Kaye Shedlock, chief of the Branch of Geologic Risk Assessment, USGS, outlined some of the more prominent earthquake-related issues in the Pacific Northwest, including seismological evidence of crustal, interplate, and intraplate earthquakes. She noted that a lack of seismicity along the boundary between the Juan de Fuca and North American plates is particularly disturbing to scientists in light of the geological evidence for "jerky" subsidence that is found in coastal marshes of Oregon and Washington. The evidence leads many scientists to conclude that there is a strong possibility for great earthquakes to occur in western Washington and Oregon.

Craig Weaver, USGS, described the seismicity of western Oregon and Washington and suggested the possibility that earthquakes similar to the 1949 and 1965 events could occur in Oregon.

Bob Crosson, University of Washington, discussed the seismicity of Puget Sound and southern British Columbia, showing through tomographic displays the inferred shape of the subducting Juan de Fuca plate and depths of some of the larger earthquakes identified in the region.

It was generally agreed that stress orientations vary with depth and that the resulting earthquakes have different causes. Major stress axes in the shallow crust are oriented north-south, whereas interplate stresses are oriented northeast-southwest, and intraplate stresses are tensional and down to the east. A talk presented by Paul Vincent, University of Oregon, provided geodetic evidence for north-south oriented stresses in the shallow crust.

Late Cenozoic deformation in northwestern Oregon was the topic of the talk by Bob Yeats, Oregon State University. He described an unnamed subsurface clay of probable Late Cenozoic age that is exposed in the Willamette trough and that may be offset by faulting. He concludes that further study needs to be done in that area. Other geological evidence for paleoseismicity was presented by Curt Peterson and Vern Kulm, Oregon State University, and by Don West, Golder Associates. Peterson discussed the geologically young coastal stratigraphic sequences of the Oregon coast, citing episodic, rapid subsidence of marsh deposits as evidence for great subduction zone earthquakes. Kulm compared geologic features in the marine portion of the Cascadia subduction zone with seismogenic subduction zones in other parts of the world. Evidence of periodic, large-scale deformation, massive sediment slumping, and fluid venting that are typical of other seismogenic subduction zones has also been found off the Washington-Oregon coast, suggesting that our currently aseismic subduction zone may be capable of generating great earthquakes. West compared coastal terraces of Oregon and Washington to those in other parts of the world. These comparisons suggest either that repeated great magnitude earthquakes have not occurred off the Oregon coast during the late Holocene, that the recurrence intervals for great events are longer than previously thought, that smaller magnitude thrust events are possible, or that the tectonic mechanism for our subduction zone is unique.

The geologic evidence presentations were followed by discussions of strong ground motions that could be expected from earthquakes in the Pacific Northwest. Emphasis was placed on megathrust ground motions, and models were presented by the speakers that predicted the strength and duration of the shaking to be expected in the region from various postulated events. Speakers included Ivan Wong and Paul Somerville, Woodward-Clyde Consultants; Bob Youngs, Geomatrix Consultants; and C. B. Crouse, Dames and Moore.

Efforts to determine actual ground response through field investigations and mapping were described by Ken King and John Tinsley, USGS. Tony Qamar, University of Washington, discussed historical earthquake intensity mapping near Seattle.

Paul Grant, Shannon and Wilson, Inc., described liquefaction associated with past Puget Sound events and stressed that the longer duration of ground shaking expected from a subduction zone earthquake could result in considerably more damage than inflicted by historical earthquakes. Robert Schuster, USGS, pointed out the existence of many large landslides located in Washington and suggested that some may have been seismically induced. Jane Preuss, Urban Regional Research, discussed the results of a tsunami case study done in Grays Harbor in which a methodology for defining characteristics of coastal risks and determining the geographic area of vulnerability was developed.

A poster session was held on the evening of March 28 to develop these topics more fully and provide the opportunity for discussion.

Future research, mitigation, and policy directions and needs were addressed during the second day. The need to hone and enhance our earthquake hazard policies was profoundly emphasized by Walt Hays, USGS, in a presentation on the Armenian earthquake. As tragic as the Armenian event was, the impact of a great earthquake in a heavily populated area in the United States could be even more devastating: not only would great loss of lives and property occur, but extreme repercussions on the national and world economy might also result, according to James Lett, Unigard Insurance. Hays, USGS, went on to suggest that such impacts could be reduced if mitigation and research efforts were enhanced. He further believes that an opportunity exists for such enhancement in the International Decade for Natural Disaster Reduction, which will begin next year, and he proposed that our efforts be directed toward increasing the number of "champions" for the earthquake hazard reduction cause. By doing so, we can make greater inroads into reduction of impacts from catastrophic events such as great earthquakes.

Political science professor Peter May, University of Washington, compared earthquake reduction policies of Washington and Oregon, and he provided useful insight into how these policies are perceived, derived, and implemented. John Beaulieu, DOGAMI, described his agency's experiences in attempting to secure funding and legislation for earthquake hazard mitigation. Lessons learned in response to major earthquakes in densely populated areas was the topic of a talk by Patricia Bolton, Battelle Research Institute.

John Nance, author of "On Shaky Ground", spoke at the luncheon. He emphasized the importance of bringing earthquake information to a broad audience and applauded the efforts represented by this workshop in that regard.

The field trip, led by Mark Darienzo, allowed all participants to observe first hand the field evidence interpreted to suggest past occurrences of great earthquakes (magnitude 8 or greater) along the Oregon coast. A guide for the field trip is available in the September/October 1988 issue of *Oregon Geology*, published by the Oregon Department of Geology and Mineral Industries.

Robert L. Logan and Stephen P. Palmer, Geologists, Washington State Department of Natural Resources, Olympia, Washington

(p vii follows)

THIRD ANNUAL PUGET SOUND/PORTLAND AREA WORKSHOP ON EARTHQUAKE HAZARDS AND RISK

March 28-30, 1989
Portland Marriott Inn, Portland, Oregon

SPONSORS: Oregon Department of Geology and Mineral Industries
Oregon Department of Emergency Management Division
Washington Department of Natural Resources
Washington Department of Community Development
Federal Emergency Management Agency
United States Geological Survey

PROGRAM

After introductory remarks, participants will be offered two parallel sessions. The first will be a technical session for geoscientists to present and discuss short papers. The second session will be a nontechnical tutorial for participants with little or no geoscience background.

OVERALL WORKSHOP FACILITATOR: Walter Hays, U.S. Geological Survey

PLENARY SESSION

8:00 a.m. Opening remarks by:
--Donald Hull, Oregon Department of Geology & Mineral Industries
--Myra Lee, Oregon Department of Emergency Management
--Kate Heinback, Washington Department of Community Development
--Ray Lasmanis, Washington Department of Natural Resources
--Chuck Steele, Federal Emergency Management Agency
--Rob Wesson, U.S. Geological Survey

Welcome:
--Dick Bogle, Portland City Commissioner

Vignette on knowledge utilization
--Walter Hays, U.S. Geological Survey

Goals of the workshop
--Ian Madin, Oregon Department of Geology and Mineral Industries

9:00 Participants will form into two groups: Group I - Geosciences Session and Group II - Professional Skill Enhancement Session

AGENDA FOR GROUP I: GEOSCIENCES SESSION

Talks will be presented in 20-minute time slots; 10 minutes for the presentation, 10 minutes for discussion.

Objective: A broad objective of this session is to gain additional understanding of the statement contained in "Washington State Earthquake Hazard," Information Circular 85 published by the Washington State Department of Natural Resources.

"The maximum probable earthquake in Washington would be a subduction earthquake having a magnitude exceeding 8 and an epicenter near the coast. . . . Some scientists believe that such earthquakes have occurred every 300 to 1,000 years. Other large earthquakes in the region can be expected to have magnitudes of at least 6.5 to 7.5 and depths greater than 40 km. Return times for magnitude 6 earthquakes in the Puget Sound area are estimated at 10 years; magnitude 6.5 earthquakes at 35 years; and magnitude 7.0 earthquakes at 110 years."

OVERALL SESSION FACILITATOR AND MODERATOR FOR THE MORNING--Ian Madin, Oregon Department of Geology & Mineral Industries

9:10 Important scientific issues in the Pacific Northwest
--Kaye Shedlock, U.S. Geological Survey

Seismicity of northwestern Oregon and southwestern Washington
--C. S. Weaver, U.S. Geological Survey

Late Cenozoic deformation in northwestern Oregon
--R. S. Yeats, Oregon State University

Seismicity of the Puget Sound and Southern British Columbia
--R. S. Crosson, University of Washington

10:30 Break

10:55 Megathrust paleoseismicity
--C. D. Peterson, Oregon State University

Historical deformation of the southern Cascadia Margin
--P. Vincent, University of Oregon

Coastal terraces and subduction earthquakes
--D. O. West, Golder Associates

Cascadia offshore geology
--LaVerne Kulm, Oregon State University

12:15 Lunch on your own/ad hoc discussions

1:15 GEOSCIENCES SESSION (CONTINUED)

MODERATOR: Kaye Shedlock, U.S. Geological Survey

Engineering characterization of strong ground motions with applicatio
the Pacific Northwest
--Ivan Wong, Woodward-Clyde Consultants

Cascadia megathrust ground motions I
--K. J. Coppersmith, Geomatrix Consultants

Cascadia megathrust ground motions II
--C. B. Crouse, Dames and Moore

Cascadia megathrust ground motions III
--Paul Somerville, Woodward Clyde Consultants

2:35 Break

3:00 GEOSCIENCES SESSION (CONTINUED)

MODERATOR: Ray Lasmanis, Washington Department of Natural Resources

Field experiments to assess ground response
--K. W. King, U.S. Geological Survey

Deterministic ground response mapping
--J. C. Tinsley, U.S. Geological Survey

Historical response mapping
--Tony Qamar, University of Washington

Liquefaction hazards in the Pacific Northwest
--Paul Grant, Shannon and Wilson

Landslide hazards in the Pacific Northwest
--Robert L. Schuster, U.S. Geological Survey

The tsunami threat in the Pacific Northwest under today's land use conditions
--Jane Preuss, Urban Regional Research

5:00 Closing discussion

NOTE: CASH BAR/HORS D'OEUVRES 5:00-7:00 P.M.

POSTER SESSION AT 7:00-9:00 P.M. (SEE PAGE 5)

Subjects of local interest or subjects with complex and detailed data will be presented as poster displays to facilitate discussion.

AGENDA FOR GROUP II: PROFESSIONAL SKILL ENHANCEMENT SESSION

Objective: A broad objective of this session is to gain understanding of the statement contained in "Washington State Earthquake Hazards," Information Circular 85 published by Washington State Department of Natural Resources:

"The maximum probable earthquake in Washington would be a subduction earthquake having a magnitude exceeding 8 and an epicenter near the coast. . . . Some scientists believe that such earthquakes have occurred every 300 to 1000 years. Other large earthquakes in the region can be expected to have magnitude of at least 6.5 to 7.5 and depths greater than 40 km. Return times for magnitude 6 earthquakes in the Puget Sound area are estimated at 10 years; magnitude 6.5 earthquakes at 35 years; and magnitude 7.0 earthquakes at 110 years."

A series of presentations which explain the basic technical issues in simple language and use. Case histories will illustrate the basic principles.

<u>OVERALL SESSION FACILITATORS AND MODERATORS FOR THE MORNING</u>--Linda Noson, Federal Emergency Management Agency; Ruth Ludwin, University of Washington; and Tony Qamar, University of Washington

9:15 Fundamentals of earthquakes

- What is an earthquake?
- Where do they occur?
- How are they recorded, located, and measured?
- Types of earthquakes
- Characteristics of Pacific Northwest earthquakes

10:15 Break

10:35 Fundamentals of earthquake impacts: Land and water
--Steve Palmer, Washington Department of Natural Resources

11:05 Fundamentals of earthquake impacts: Buildings and lifelines
--Roger McGarrigle, Structural Engineer, Portland

11:40 Fundamentals of loss estimation for the financial community
--K. V. Steinbrugge, Consulting Engineer
--S. T. Algermissen, U.S. Geological Survey

12:10 Lunch on your own/ad hoc discussions

1:15 USING EARTH SCIENCE INFORMATION TO REDUCE EARTHQUAKE LOSSES

<u>MODERATOR:</u> Chuck Steele, Federal Emergency Management Agency

Summary of earthquake hazard mitigation measures
--Martha Blair-Tyler, William Spangle and Associates

Summary of earthquake hazard information available to users
--William Kockelman, U.S. Geological Survey

2:15 REACTING TO EARTHQUAKE HAZARD INFORMATION--STATE LEVEL

<u>MODERATORS</u>: Myra Lee, Oregon Emergency Management Division and Kate Heinback, Washington Department of Community Development

<u>Panel discussion</u>: Each panel member will briefly state earthquake hazard mitigation or preparedness objective(s) of their group. A handout describing in greater detail the specific actions proposed and completed by their agency will be provided by each panelist. The moderators will then facilitate discussion concerning the status and future of earthquake hazard mitigation/preparedness activities at the State level.

--Walt Friday, Oregon Building Codes Agency
--Judy Burton, Washington Department of Labor and Industries
--John Boettcher, Intern for Washington Representative Dick Nelson, "Legislative Response to State Earthquake Hazards"
--Carol Martens, Washington Division of Emergency Management, "State Agency Earthquake Task Force"

3:15 Break

3:30 USING EARTHQUAKE HAZARD INFORMATION--LOCAL LEVEL

MODERATORS: Martha Blair-Tyler, William Spangle & Associates and Paula Gori, U.S. Geological Survey

Panel discussion: Each panelist will briefly state earthquake hazard mitigation/preparedness objective(s) of their group and provide a handout listing proposed and completed activities. The moderator will facilitate discussion of the status and future of local initiatives in earthquake hazard mitigation and preparedness.

--Paul Kostenaik, Boeing Company Puget Seismic Review Group
--Bill Elliot, Portland Water Department
--Bev Carter, Mothers for H.E.L.P.

4:30 Lessons learned in the implementation component of the Utah Regional Earthquake Hazards Assessment Program
--Jim Tingey, Utah Division of Comprehensive Emergency Management
5:00 Discussion

CASH BAR/HORS D'OEUVRES 5:00 - 7:00 P.M.

POSTER SESSION 7:00-9:00 P.M.

Subjects of local interest or subjects with complex and detailed data will be presented as poster displays to facilitate discussion.

POSTER SESSION

Knowledge utilization and networking
--Paula Gori, Bill Kockelman, and Walter Hays, U.S. Geological Survey

Inventory and post-earthquake functionality of fire services in the Puget Sound region
--Charles Scawthorn, EQE Inc.

Liquefaction analysis in the Seattle area
--Les Youd, Brigham Young University

Seattle water system loss modeling
--Don Ballantyne, Kennedy, Jenks, and Chiltco

Liquefaction potential in the Seattle area
--J. C. Yount, U.S. Geological Survey

Clackamas river terrace deformation
--L. Palmer, Portland State University

Distribution of Mazama ash in the Portland basin
--Ken Robbins

Distribution of Quaternary sediments in the Portland area
--Ian Madin, Oregon Department. of Geological and Mineral Industries

Gravity modeling of subsurface structure in the Portland basin
--Ansel Johnson, Portland State University

Liquefaction analysis of the Mt. Tabor reservoir
--Saleem Farouqui, Cornforth Consultants

Structural geology of the Portland basin
--M. Beeson, Portland State University

Orientation of stress in Northwestern Oregon
--Ken Werner, Eric Graven, Tom Berkman, Mike Pucker, Oregon State University

Portland earthquake-response exercise
--Chief Dave Norris, Portland City Fire Bureau

Structural geology of the Southeast Portland basin
--Ken Lite, Oregon Water Resources Department

Shallow seismic reflection in the Puget Sound
--Sam Harding, U.S. Geological Survey

GIS systems in earthquake hazard mitigation
--U.S. Geological Survey

High resolution seismic imaging in the Pacific Northwest
--Ken King, U.S. Geological Survey

Hydrogeology of the Troutdale formation in the Portland basin
--Rod Swanson, U.S. Geological Survey, Water Resources Division, Portland

Seismic upgrading, the Portland Structural Advisory Council
--Mike Haggerty, Portland City Bureau of Buildings

Changes in the 1988 UBC seismic requirements for Oregon
--Walt Friday, Oregon Building Codes Division

Portland water system seismic evaluation
--Bill Elliot, Portland Water Bureau

Earthquake insurance in Oregon and Washington
--Maryann Macina and Lisa Hargis, Western Insurance Information Service

Rehabilitation of the Salt Lake City/County buildings
--Steve Weissberg

WEDNESDAY, MARCH 29

The morning session will provide brief summaries of the state-of-knowledge about earthquake hazards in the Portland and Puget Sound regions.

PLENARY SESSION

THE NEXT STEPS IN THE PACIFIC NORTHWEST REGIONAL EARTHQUAKE HAZARDS ASSESSMENT PROGRAM

MODERATOR: Chuck Steele, Federal Emergency Management Agency

8:00 Scientific studies to define the potential earthquakes threat in the Puget Sound-Portland area
--R. L. Wesson

International Decade for Natural Disaster Reduction--an opportunity for the Pacific Northwest
--Walter W. Hays, U.S. Geological Survey

Intraplate and crustal earthquakes in the Puget Sound and Southern British Columbia
--R. S. Crosson

Intraplate and crustal earthquakes in the Willamette Lowland
--R. S. Yeats

10:00 Break

MODERATOR: Linda Noson, Federal Emergency Management Agency

10:30 Ground motion and attenuation in the Portland/Puget Sound region
--P. Somerville, Woodward Clyde Consultants

10:50 Ground response and ground failure Portland/Puget Sound area
--J. C. Tinsley, U.S. Geological Survey
--Robert L. Schuster, U.S. Geological Survey

11:10 Tsunami hazards in the Pacific Northwest
--J. Preuss, Urban Regional Research

11:30 Discussion

12:00 Luncheon Speaker
--John Nance, Author of "On Shaky Ground"

MITIGATION/POLICY

FACILITATOR: Kate Heinback, Washington Department of Community Development

1:45 Identification of existing earthquake hazard policies
--Peter May, University of Washington

2:05 Response to changing earthquake hazard at the Trojan nuclear power plant
--Harry Moomey, Oregon Department of Energy

2:25 To Be Announced

2:45 Break

MODERATOR: George Priest, Oregon Department of Geology and Mineral Resources

3:10 "Insurance perspectives on earthquake hazards"
--James Lett, Unigard Insurance

3:30 Response to major earthquakes in densely populated areas: Lessons Learned
--Patricia Bolton, Batelle Research Institute

3:50 The Armenia earthquake of December 7, 1988
--Walter Hays, U.S. Geological Survey

MODERATORS: Ray Lasmanis, Washington Department of Natural Resources and Donald Hull, Oregon Department of Geology and Mineral Resources

4:10 "On Shaky Ground," (Note: We have asked him to discuss what he has learned since writing "On Shaky Ground" and heard at this meeting.)
--John Nance, Author of "On Shaky Ground"

4:30 Closing remarks
--Ian Madin, Oregon Department of Mineral and Geological Industries
--Linda Noson, Federal Emergency Management Agency
--Chuck Steele, Federal Emergency Management Agency
--Walter Hays, U.S. Geological Survey

THURSDAY, MARCH 30--FIELD TRIP

LEADER: Mark Darienzo

Field trip to Netarts Bay, Oregon, to view evidence for Holocene and Pleistocene subsidence events. Departs Portland Marriott at 8:00 a.m. and returns at 5:00 p.m.

SECTION I: GEOSCIENCES INFORMATION

This section of the report contains 21 contributions that provide the latest scientific information on various aspects of the earthquake hazards in the Puget Sound-Portland area. This state-of-the-art information supplements and extends two documents:

1) U.S. Geological Survey Open-File Report 88-541, Proceedings of the 2nd Annual Workshop on "Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas."

2) Washington State Department of Natural Resources Information Circular B5, "Washington State Earthquake Hazard."

Rationale and Outline of a Program for Earthquake Hazards Assessment in the Pacific Northwest

Kaye M. Shedlock[1]
US Geological Survey
MS 966 Box 25046
Denver Federal Center
Denver, Colorado 80225

and

Craig S. Weaver
US Geological Survey
at Geophysics Program AK-50
University of Washington
Seattle, Washington

Overview

Geologic hazards often occur as multiple processes: an initial hazard (for example, an earthquake) may trigger secondary hazards (landslides and/or tsunamis). Common sources may also trigger multiple hazards: heavy precipitation may cause flooding in lower elevations and debris or mud flows in higher elevations. Yet geologic hazard studies and mitigation programs are commonly divided into studies of individual hazards. The need for a more coordinated approach to hazards study and mitigation in the Pacific Northwest has become increasingly clear to scientists working on various aspects of earthquake related problems.

Generally the area of interest in this NEHRP program relates directly to the subduction zone system and geological provinces adjacent to the Cascade Range, including all of California north of Cape Mendocino, Oregon from the Cascade Range west to the coast, Washington from the Pasco basin and adjacent parts of the Columbia Plateau west to the coast, and southwestern British Columbia. (Figure 1). The Pacific Northwest is the only location in the United States where crustal and lithospheric evolution can be traced from an active mid-ocean ridge to a stable continental platform in a distance of only 1200 km (Figure 1). Some investigators, (e.g., *Heaton and Hartzell*, 1986) have suggested that an earthquake as large as magnitude 9 (similar to the 1960 Chilean or 1964 Alaskan events) could occur along the coasts of northern California, Oregon, Washington, and southern British Columbia.

Within this large geographic area, most regional-scale NEHRP studies will relate primarily to sources and potential for earthquakes, whereas detailed studies of hazards,

[1] This chapter represents a distillation of ideas and suggestions put forth in a series of meetings attended by the authors and T. Algermissen, R. Bucknam, T. Heaton, M. Lisowski, R. Madole, P. Muffler, G. Priest, G. Rogers, R. Schuster, D. Stanley, R. Tabor, R. Updike, and T. Walsh.

shaking effects, and the like will be confined largely to the urban areas of Puget Sound, the Pasco basin, the Willamette Lowland, and immediate coastal areas. We need to include British Columbia in the study area because the subduction zone continues northward to about central Vancouver Island. In addition, we believe that stronger interactions need to occur between the USGS and the Geological Survey of Canada (GSC).

Recognizing the societal implications if the Pacific Northwest is proven to be subject to great earthquakes, we have attempted to outline a broad-scale earthquake hazards program that will encourage major advances in our understanding of the entire subduction margin and forearc region, and will coordinate hazards studies within the active volcanic arc and the adjacent portions of the Columbia Plateau. By the end of the program cycle envisioned here, we anticipate that scientists from the USGS, other government agencies, and universities will have collected and analyzed the key data that are currently missing in our effort to assess the potential hazards associated with the subduction interface.

Because of the complex geologic setting of the Pacific Northwest (see *Weaver and Shedlock*, this volume), scientific objectives central to providing the tectonic framework necessary for a rational assessment of earthquake hazards must be broadly stated. The central objective of the proposed program is to attempt to answer these questions:

- **Can the Cascadia subduction zone produce great thrust-zone earthquakes?**
- **What are the expected distribution, source characteristics, and effects of shallow, crustal earthquakes in the Pacific Northwest?**
- **What is (are?) the principal seismic hazard(s) in the Pacific Northwest?**

EARTHQUAKE RELATED HAZARDS IN THE PACIFIC NORTHWEST

Earthquakes

There are three distinct sources of earthquakes associated with the subduction zone in the Pacific Northwest: 1) crustal earthquakes that occur within the overriding North American plate, 2) intraplate earthquakes that occur within the subducting Juan de Fuca and Gorda plates, and 3) interplate earthquakes that occur at the interface between the Juan de Fuca (and Gorda) plate and the North American plate (subduction or thrust events). There are common questions for each particular source region. How large might such earthquakes be, where might they occur, how often do they occur, and what are the expected ground responses from each source type? Beyond these common questions, there is a wide range of questions appropriate for each source type. Most of these questions have yet to be addressed in any systematic way by the USGS.

Crustal Earthquakes

The outstanding questions regarding crustal events center on the 2 types of crustal events: shallow ($<$ 20 km deep) and deep ($>$ 20 km deep). The largest historic earthquake in the Pacific Northwest is the 1872 North Cascades event of estimated magnitude 7.4 (*Malone and Bor*, 1979). The existence of this event, which was most likely crustal, raises the issue of the extent of Oregon and Washington over which such large crustal events may occur. What is the largest size and type of crustal event possible in the urban centers of Puget Sound and the Willamette Valley, and in the Pasco basin of eastern Washington? The data available to date suggest that in the Puget Sound basin crustal earthquakes are of smaller magnitude than in either southwestern Washington or southeastern Washington (*Ludwin, et al.*, 1989). Hazards assessments in southwestern Washington have now incorporated the St. Helens zone (SHZ), a 100+ km long zone of moderate magnitude earthquakes that strikes north-northwest through Mount St. Helens. Work by the USGS, the Army Corps of Engineers, and the State of Oregon Department of Geology and Mineral Industries has concluded that an earthquake of magnitude 6.2-6.8 could occur along the SHZ. Should these estimates be adopted elsewhere, particularly in Portland which has a history of magnitude 5+ events and at the edge of the Pasco basin where an event of magnitude 6.25 occurred in 1937?

The 1872 earthquake is the largest known event in Oregon or Washington, and has a magnitude estimated from the felt area of 7.4 (*Malone and Bor*, 1979). A study by Kienle and others (1978) suggested that the Ribbon Cliffs rockslide, a prominent feature along the Columbia River north of Wenatchee that has been thought to have been activated by the 1872 earthquake, may have a longer history of activity. Given the nature of the morphology and the materials involved, the slide is most likely earthquake induced (R.L. Schuster, personal communication, 1989). If multiple earthquakes have occurred over the past 1000 or so years, then the effects of a recurrence of an 1872 event on critical facilities in eastern Washington needs careful scrutiny.

Intraplate Earthquakes

The source characteristics of intraplate earthquakes in the Pacific Northwest are fairly well known, but the spatial distribution of these events is uncertain. Most of the large intraplate earthquakes (M > 6) have been located in the southern Puget Sound basin, leading to hypotheses that these events may not occur elsewhere. However, these events are generally believed to be caused by gravitational forces within the subducting plates. Because the plate is thought to be continuous everywhere between the trench and the volcanic arc, these events could occur anywhere that the intraplate stresses reach some critical level. The major unresolved issue with intraplate earthquakes is whether they can occur beneath the southern and central Oregon Coast Range.

Interplate earthquakes

In contrast to the crustal and intraplate earthquakes, which have been instrumentally or historically recorded, the occurrence of interplate events must be inferred from the geologic record. Ongoing work in marshes along the Oregon and Washington coasts has shown that the marsh stratigraphy includes alternating layers of buried peat and intertidal mud (*Atwater*, 1987). The sharp contacts between peat and overlying intertidal muds have been interpreted as evidence for rapid subsidence of the tidal marshes in response to a large subduction earthquake. The marsh stratigraphy thus offers field evidence of episodes of subsidence, supporting comparative studies that have noted that the Cascadia subduction zone has a number of similarities with other subduction zones around the world that have experienced frequent thrust zone activity. In addition, the marsh studies may supply evidence of a locally generated tsunami coincident with a large earthquake.

The dichotomy in the Oregon and Washington is that, despite the existence of a subduction zone, there are no contemporary thrust earthquakes on the shallow dipping interface. This observation sparks debate about whether the thrust interface can be absolutely quiet at some point in the subduction earthquake cycle. Related to this question are questions concerning the length of the potentially locked zone and the width of the zone.

Ground Failure

An important element in the evaluation of the seismic hazard in the Pacific Northwest is an understanding of earthquake-induced landslide and liquefaction activity for 3 periods: 1) prehistoric time, 2) historic time, and 3) the future.

Study of historic (1872 and later) earthquake-induced landslide and liquefaction activity will enable us to better understand the characteristics of these processes in the Pacific Northwest. Data obtained in this part of the study will be useful in field identification of prehistoric earthquake-induced landslides and liquefaction and in predicting the hazards from these processes in future earthquakes. The identification of historic liquefaction is not easy, however, since, unlike the Mississippi embayment, sand boils and fissures caused by historic earthquakes are not evident on aerial photography.

Identification of areas susceptible to future earthquake-induced landsliding and liquefaction will be based on the above prehistoric and historic studies as well as on the determination of the importance of related parameters, such as geology, hydrology, and topography. An understanding of the stratigraphic controls on liquefaction in one area can be applied to evaluating the potential for seismically induced liquefaction in other areas.

Volcanoes

One of our fundamental concerns is that because of the current segregation of volcano hazard studies from those of earthquakes or ground failures, as an agency we are not asking enough of the right questions with regard to the relation between processes typically studied by the Volcano Program and processes studied in other programs. As an example, one of the most disastrous natural hazards scenarios that one might imagine in Washington involves the repeat of the Osceola debris flow of about 5700 years ago. Originating high on the slopes of Mount Rainier, this debris flow covered ≈ 27 mi^2 of the flood plain of the White River, nearly reaching Puget Sound at Tacoma (*Crandall*, 1971). Despite the fact that the source was a volcano, it is possible that it may not have been of volcanic origin (R.L. Schuster, personal communication, 1989). Since 1948 Mount Rainier has generated tens of minor, non-volcanic debris flows: in 1988 a debris flow down the west side of the volcano buried the "west-side" road in Mount Rainier National Park (J.E. Costa, personal communincation, 1988).

This example raises several questions that cross existing program and Division boundaries. First, what are the triggers of this and other episodes of ground failure? Second, where else can such failures occur? Third, does the potential hazard from such a landslide justify expenditures for developing a hazard warning system? Fourth, are changes in glacial areas and runoff being adequately monitored to provide possible forewarning of englacial drainage changes that may be associated with the conditions of mass instability on Mount Rainier?

The relation between volcanoes and earthquakes remains highly problematical. Of particular concern is whether either a moderate magnitude crustal earthquake (M_L 5+) or a subduction zone earthquake would trigger volcanic eruptions. Are the dates for previous eruptions known well enough to examine this scenario?

FRAMEWORK FOR NEHRP STUDIES

There are 6 necessary components of this program (outlined below in order of perceived necessity), designed to address, in varying degrees, the spatial characteristics, expected magnitudes, recurrence intervals, ambient strain, source characteristics, site response, and attenuation associated with the 3 types of earthquakes known to occur in subduction zones like the Pacific Northwest. Coordination among the Earthquake Hazards, Landslide Hazards, Volcano Hazards, Geothermal, Deep Continental Crustal Studies, and Sedimentary Basins Programs is desirable and one of the few possible ways to squeeze more science for limited dollars. A mechanism must be designed to allow the internal program to help influence the direction and type of science supported by the external program.

Necessary Program Elements

Geodetic monitoring - A Global Positioning System (GPS) network must be deployed along the entire Juan de Fuca – North American plate boundary. Deformation data being collected across the Strait of Juan de Fuca suggest that east-northeast compression is occurring across the region. As GPS becomes more readily available, this technology can be employed in an expansion of the current deformation studies in Washington, Oregon, and northern California.

Seismic monitoring - The current seismic networks must be expanded to cover the entire Juan de Fuca - North American plate boundary. Currently, northern California and most of Oregon are inadequately covered. The complete network should utilize the real-time, digital telemetry and storage systems being designed by the US National Seismic Network (USNSN) and complement the exisiting Pacific Northwest short-period network. The purpose of this monitoring is simple: A much better description of potential earthquake sources is needed in the Pacific Northwest. This description by necessity will recognize the the three different source zones. Seismic monitoring will determine if the Juan de Fuca plate beneath central and southern Oregon is truly aseismic. The data recorded by the expanded network, combined with the additional broad-band data collected by the USNSN, will provide the data base necessary for sophisticated structural modeling of the Juan de Fuca-North American plate interaction.

Quaternary geology - All of the ongoing studies of Quaternary geology (geologic mapping, stratigraphy, paleoseismicity, landslide and liquefaction susceptibility, etc.) need to be continued and even expanded appropriately to meet the needs of the NEHRP. The observations and interpretations of coastal marsh zone stratigraphy need to be rigorously tested and debated. Are the Willamette trough and the Puget Sound basin recent features? When did they form and how did the tectonic framework change to allow their formation? Are the mid and upper crustal rocks in the Puget Sound basin highly deformed, with thrust faults having as much as 10 km of offset?

Strong ground motion - A free-field strong ground motion network must be deployed in the populated regions of the Pacific Northwest. The data from this network should be supplemented with building monitoring using a portable network. An updated catalog of all strong ground motion monitoring sites in the Pacific Northwest should be prepared.

Modeling - Geophysical and engineering modeling studies (seismic sources, attenuation, expected ground motion, etc.) must be expanded. Experiments of opportunity, particularly with the Deep Continental Studies program, to study attenuation should be encouraged.

Tectonic framework - The tectonics of the Pacific Northwest subduction zone must be as well understood as possible. Despite comparisons between the Cascadia subduction zone and other zones around the world and geological evidence of movement during Holocene time along the Washington and Oregon coasts (Atwater, 1987), the lack of seismicity on the thrust interface between the Juan de Fuca and the North American plates makes the analysis of the potential for great thrust earthquakes equivocal. In the absence of earthquake activity on the thrust interface, other data that will allow the definition of the active processes occurring in the subduction zone are needed for a complete assessment of the hazards facing this region. These processes, whether they be tectonic underplating in the thrust interface zone, splay faulting in the coastal margins, active magmatism, or the interaction of backarc extension in the Basin and Range with the subduction tectonics of the forearc region, need to be understood to allow earthquake hazards of the Cascadia subduction zone to be placed in the proper plate tectonic framework. Central to these data is an understanding of the long-term effects of convergent margin tectonics on the crust of North America and on the interface between the two plates. In particular, bedrock mapping, at a 1:250,000 scale, of critical areas (Bellingham and Vancouver, WA, Oregon, and northern California) must be completed. Tectonic syntheses of seismic, geodetic, geologic, gravity, etc., data must be undertaken; these studies should include Geographical Information Systems (GIS) approaches. A regional GIS data base must be established.

Communication and Implementation

Major components of the NEHRP effort in the Pacific Northwest must be the communication of the scientific results to the engineering and planning communities and greater cooperation between the states and the scientific community. The State Geological surveys of Washington, Oregon, and California, in partnership with the USGS and universities, should be the key agencies in a coordinated effort to present scientific results in a manner that are understandable and usable to the appropriate users. This effort should include the following components:

- The USGS and the GSC should co-sponsor at least 1 meeting on geologic hazards in the Pacific Northwest that focuses on current science and issues in the area and provides a forum for thorough comparison with other subduction zones. Members of the State Geologic Surveys should be present as advisors. A meeting in 1992 is suggested.

- A new mechanism for transferring research results to state and local communities must be devised. The current mechanism in the Pacific Northwest is a series of workshops that attempt to reach a mixed audience (ranging from scientists to local planners). Better segregation of disciplines should be tried so that the audience is well-defined and so that the material presented is suited to the audience. Contacts between the USGS and primary endusers should be expanded via professional engineering groups and similar organizations. The State Geological Surveys should take a more active role in coordinating the transfer of information, hosting smaller meetings of the necessary scientists, facilitators, and appropriate audiences.
- The states of Washington, Oregon, and California should contribute to all aspects of the program at state level through salary support for researchers and support for university and state agency research projects.

References

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

Crandall, D.R., Postglacial lahars from Mount Rainier Volcano, Washington, *USGS Professional Paper 677*, 75 pp., 1971.

Heaton, T.H., and S.H. Hartzell, Source characteristics of hypothetical subduction earthquakes in the northwestern United States, *Bull. Seismo. Soc. Am., 76*, 675–703, 1986.

Kienle, C.F., S.M. Farooqui, R.J. Strazer, and M.L. Hamill, Investigation of the Ribbon Cliff landslide, Entiat, Washington, Shannon and Wilson technical report, 19 pp., Seattle, WA, 1978.

Ludwin, R.S., C.S. Weaver, and R.S. Crosson, Seismicity of Washington and Oregon, in E.R. Engdahl, ed., *Neotectonics of North America*, Geol. Soc. Amer., Boulder, CO, (in press), 1989.

Malone, S.D., and S. Bor, Attenuation patterns in the Pacific Northwest based on intensity data and the location of the 1872 North Cascades earthquake, *Bull. Seism. Soc. Am., 69*, 531–546, 1979.

Weaver, C.S., and K.M. Shedlock, Potential subduction, probable intraplate, and known crustal earthquake source areas in the Cascadia subduction zone, *US Geological Survey Open-File Rep., 89-xxx*, this volume.

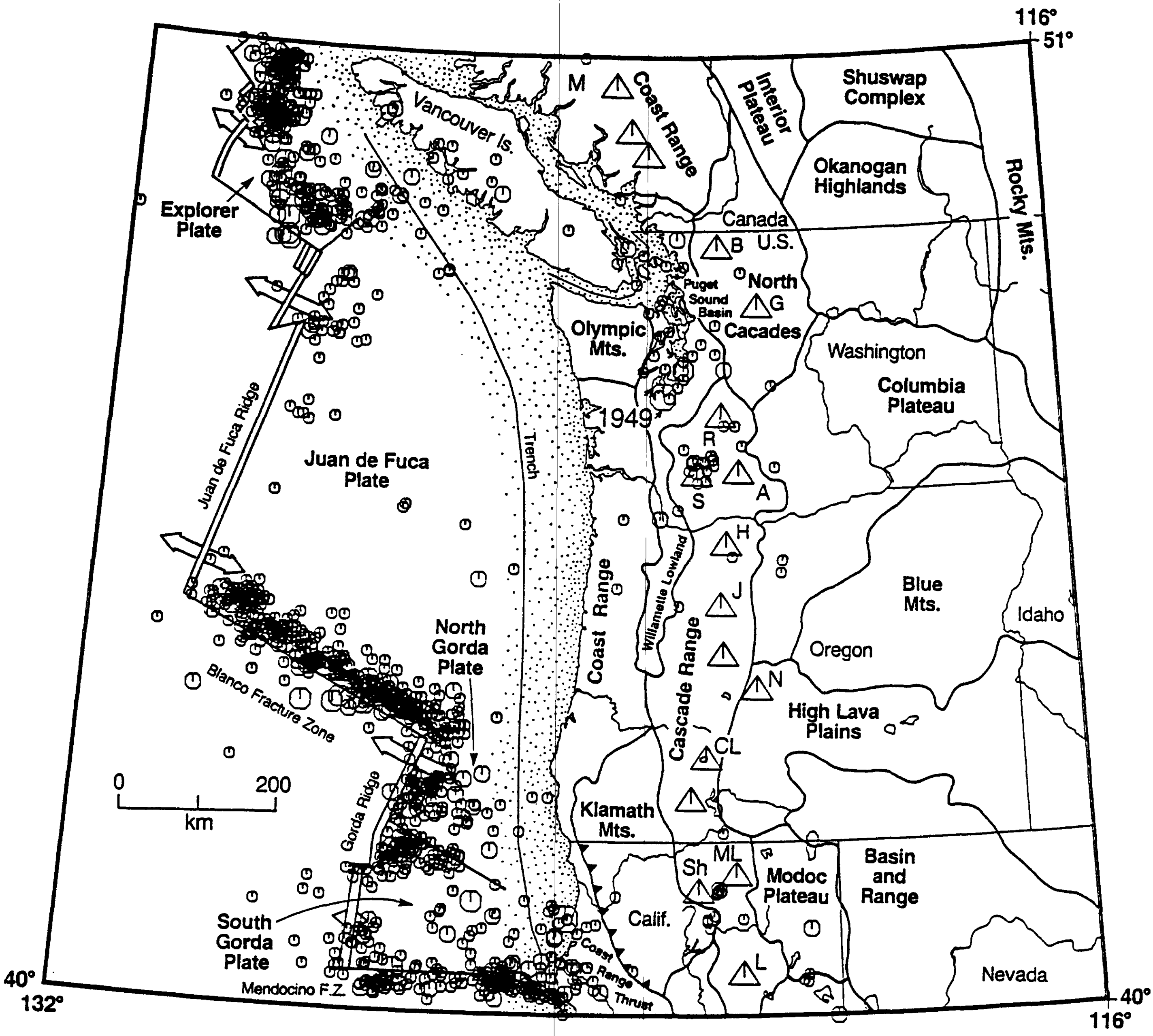


Fig. 1. Location map for the Pacific northwest subduction zone region. Open triangles mark active volcanoes of the Cascade Range. Octagons mark earthquakes of magnitude 4 or larger listed in the NOAA catalog through 1985. Figure is taken from Ludwin and others, 1989.

POTENTIAL SUBDUCTION, PROBABLE INTRAPLATE, AND KNOWN CRUSTAL EARTHQUAKE SOURCE AREAS IN THE CASCADIA SUBDUCTION ZONE

Craig S. Weaver
U.S. Geological Survey
at Geophysics Program AK-50
University of Washington
Seattle, Washington 98195

and

Kaye M. Shedlock
U.S. Geological Survey
Denver Federal Center
Denver, Colorado 80225

INTRODUCTION

The tectonic setting of western Oregon and Washington is dominated by the subduction of the offshore Juan de Fuca plate system beneath the continental North American plate. These two plates are converging, in a relative direction that is approximately northeast, at the rate of between 3-4 cm/yr [Riddihough, 1984]. The zone of convergence between the Juan de Fuca and North American plates is known as the Cascadia subduction zone and includes the area from the trench offshore to the Cascade volcanic arc (Figure 1). In subduction zone environments there are three distinct earthquake types that occur in separate source regions: 1) interface or subduction zone events occur at the long, sloping zone of contact between the two plates (spatially this region of contact in Figure 1 is from the trench landward to about the Coast Range), 2) crustal earthquakes occur within crust of the overriding North American plate, and 3) intraplate earthquakes occur within the subducting Juan de Fuca plate. Knowledge of the earthquake source regions, a prediction of expected fault motions and the forces responsible for generating the earthquakes within the distinct source regions are fundamental to estimating the earthquake hazards of the Pacific Northwest.

Of the three source types, crustal earthquakes in the North American plate and events within the subducting plate (we will refer to these as intraplate events) have formed the basis of earthquake hazard analysis for the Pacific Northwest [e.g., Algermissen, 1988]. The historical record, thought to be complete since the 1870's at the magnitude 6 and greater level for Washington and Oregon [Ludwin et al., 1989], includes two events that almost certainly were crustal (the 1872 in the North Cascades and 1937 events in southeastern Washington) and six earthquakes that are either considered or known to have been within the subducting plate (1873, 1909, 1939, 1946, 1949, and 1965). The 1873 earthquake was located near the Oregon-California border at the coast, whereas all of the other deep events were within the Puget Sound basin. One of the enigmas of the Cascadia subduction zone is that in Oregon and Washington there are no recorded earthquakes that have occurred on the interface. In most subduction zones it is this interface that produces the great (magnitude 8+) thrust events like the earthquake that struck Alaska in 1964. Recently, efforts have been taken to incorporate at least the possibility of great thrust zone earthquakes into the regional hazard analysis [Algermissen, 1988].

This paper focuses on the extent of the three source regions for the Cascadia subduction zone. In drawing the source regions we have relied on recent compilations of earthquake catalogs for Oregon and Washington, studies of regional seismotectonics, investigations of coastal marsh stratigraphy and determinations of the plate geometry.

It is clear that intraplate earthquakes, the most frequently observed of the large magnitude events (6+) in the historical record of Oregon and Washington, are understood well enough that the source region expected to produce events in the future can be specified with great confidence. Despite uncertainty surrounding the details of how and when great subduction zone thrust events may occur on the interface, there is clearly a growing acceptance of the past occurrence of these events. As the general forces that produce these events are understood from comparative studies with other subduction zones, it is possible to illustrate the possible source regions fairly accurately. Finally, because the causes of the large magnitude crustal events in the historical record remain obscure, the extent of western Washington and Oregon which may be subject to large magnitude crustal earthquakes remains uncertain. As noted elsewhere in this volume [Shedlock and Weaver, this volume], narrowing the uncertainty surrounding the occurrence of great subduction zone events and determining whether the urban centers in Puget Sound and the Willamette Valley are subject to magnitude 7, shallow (<20 km) events will require significant investments in new experiments, technology, modeling, and research time.

REVIEW OF PLATE GEOMETRY

All three earthquake sources depend, to some extent, on the geometry of the subducting plate, and this geometry is usually inferred from the locations of Benioff zone earthquakes that occur within the subducting plate. But in the Pacific Northwest the geometry of the subducting Juan de Fuca plate has been difficult to resolve because of the limited number of Benioff zone earthquakes and the limited volume over which these events have been located [Weaver and Baker, 1988]. The most active portion of the Benioff zone is beneath the Puget Sound basin of northwestern Washington, where several large magnitude earthquakes, including the 1949 south Puget Sound (M_s=7.1) and the 1965 Seattle (m_b=6.5) earthquakes have occurred (Figure 1). These large events were within the subducting Juan de Fuca plate and form the basis of most earthquake hazard assessments within the region. Beneath northwestern Washington the plate geometry is expected to be complex, as the strike of the offshore subduction zone changes from nearly north-south along the Oregon coast to northwest along the Vancouver Island coast (Figure 1). The plate geometry beneath Washington must accommodate this change in strike and the associated lateral shortening when the subducting plate encounters the convex face of the continental plate.

The installation of additional seismographic stations since 1980 both along the coast and in southwestern Washington and northwestern Oregon has allowed for better detection and location of earthquakes within the Juan de Fuca plate beneath North America. The distribution of earthquakes deeper than 20 km located since 1980 is shown in Figure 2 along with focal mechanisms for the 1949 (M_s=7.1), 1965 (m_b=6.5) and 1976 (m_b=5.1) earthquakes. Despite the improvement in the seismic network, the majority of earthquakes have continued to be concentrated beneath northwestern Washington. However, since 1980, some earthquakes have been located at depths greater than 30 km beneath southwestern Washington and the northern Oregon Coast Range, including an event in 1981 near the central Oregon coast (Figure 2).

Plotting the earthquake hypocenters in cross section allows the change in the geometry of the Juan de Fuca plate to be mapped across the region. To show the relation between the intraplate events within the Juan de Fuca plate and the crustal earthquakes in the overlying plate in northwestern Washington and northern Oregon, we have replotted the deeper events from Figure 2 and added the events shallower than 20 km (Figure 3). The Juan de Fuca plate arches upward beneath southern and central Puget Sound [Crosson and Owens, 1987; Weaver and Baker, 1988], complicating plotting of seismic cross sections. To avoid the problem of projecting earthquakes across the arch to an inappropriate spatial position on a single cross section, we have plotted two example cross sections of seismicity (Figure 4) on either side of the arch. Cross sections drawn in western Washington show two populations of earthquakes: the shallow distribution is within the crust of North America; the second population is distinct from the shallow events, and these events have been interpreted as being within the subducting plate [Crosson, 1983; Taber and Smith, 1985]. In southwestern Washington these deep events form a thin distribtion that dips east-southeast from near coast to the western edge of the Cascade Range (Figure 4a). The hypocentral depths increase from about 25-30 km near the coast to about 70 km beneath the western Cascade Range, and the plate dip increases from about 10^o near the coast to about $20\text{-}25^o$ near the location of the 1949 earthquake (Figure 4a). Thus, beneath southwestern Washington the Juan de Fuca plate dips to the east-southeast, approximately parallel to the orientation of line A-A' in Figure 3. This direction of plate dip is in contrast to the northeast direction of plate dip beneath northwestern Washington (Figure 4b); the change in dip direction occurs near the location of the 1965 earthquake shown in Figure 3.

This change in the distribution of earthquake hypocenters reflects an upward arching of the Juan de Fuca plate beneath Puget Sound compared with the depth of the plate beneath southwestern Washington (Figure 5). As noted by Weaver and Baker [1988], the average dip of the Juan de Fuca plate between the trench and a depth of 60 km increases both north and south of the arch beneath Puget Sound. One consequence of this geometry is that the contact area between the Juan de Fuca and North American plates is probably greatest beneath northwestern Washington.

PROBABLE SOURCE REGION FOR INTRAPLATE EARTHQUAKES

The plate geometry (summarized in Figure 5) allows the occurrence of the large earthquakes in the historical record (e.g., 1949, 1965) to be related directly to the plate configuration [Weaver and Baker, 1988]. The T-axis from the focal mechanism calculated by Baker and Langston [1987] for the 1949 south Puget Sound earthquake (M_S=7.1) is oriented to the east-southeast, and the 20^o plunge of the T-axis was shown by Weaver and Baker [1988] to be in good agreement with the plate dip angle determined from the earthquake hypocenters (Figure 4a). Therefore, Weaver and Baker [1988] concluded that the 1949 earthquake resulted at least in part from down-dip tensional forces within the subducting Juan de Fuca plate, an interpretation consistent with observations for many earthquakes in this depth range in other subduction zones [Isacks and Molnar, 1971]. Rogers [1983a] reached a similar conclusion concerning the forces responsible for the 1965 south Seattle earthquake and the 1976 Pender Island earthquake (m_b=5.1). Both events were at a depth of about 60 km and focal mechanisms calculated for both earthquakes were normal faulting with the T axes striking northeast and plunging down-dip [Rogers, 1983a].

Based on the agreement between the dip of the Juan de Fuca plate as inferred from earthquake hypocenters determined from the modern seismographic network and the dip of the T-axes calculated for the larger magnitude historical earthquakes, we believe that we can confidently predict the intraplate earthquake source region for the entire plate (Figure 6). We expect that future large magnitude (~7) interplate events will occur within the Juan de Fuca plate (and the Gorda plate beneath southernmost Oregon and northern California) in the depth range of the 1949 and 1965 events. Although the depths of these events are considered to be well-known, we have chosen to bracket our source region at a shallower depth. An examination of the University of Washington seismic catalog for the years 1970 through 1989 shows that all of the intraplate earthquakes greater than magnitude 4 are below 45 km and that none have been located deeper than the 1976 event. Therefore, we have used the depth range of 45 to 60 km for our estimate of the probable source region for intraplate events (Figure 6).

We emphasize that this probable source region represents the likely areal extent within which an event may occur; the actual dimensions of the fault area associated with an earthquake of approximate magnitude 7 would be expected to be similar to the 40 km long-fault estimated for the 1949 south Puget Sound earthquake [Baker and Langston, 1988]. The querried area in southern Oregon represents the region of unknown plate geometry where no intraplate earthquakes have been located either because any events that did occur were not large enough to be detected by the existing seismic network or no events have occurred. We note that the expansion of the existing seismic network, as proposed by Shedlock and Weaver [this volume], would greatly help to resolve this long-standing question concerning whether this portion of the Juan de Fuca plate is currently truly aseismic. Even with few earthquakes an expanded network would provide needed teleseismic and regional earthquake data that could be used to investigate the structure of the Juan de Fuca plate within the querried area. In northern California Benioff zone earthquakes again allow the plate depth to be estimated from the trench eastward to the western edge of the Cascade Range [see Cockerham, 1984; Walter, 1987], so we have shown the probable source area here between the same depth limits as in Washington and northern Oregon.

POSSIBLE SOURCE REGIONS FOR SUBDUCTION ZONE EVENTS

At nearly all convergent margins around the world, large magnitude (8+) earthquakes are known to occur: Cascadia is unusual in that there is no known large earthquake in the historical record. However, recent studies including subduction zone characteristics [Heaton and Kanamori, 1984; Heaton and Hartzell, 1986], crustal strain accumulation in Washington [Savage et al., 1981], crustal earthquakes in southwestern Washington [Weaver and Smith, 1983], and the stratigraphy of coastal marshs along the Washington and Oregon coasts [Atwater, 1987; Grant, 1989] have all either concluded directly or inferred that the Cascadia subduction zone should be regarded as capable of generating great interface events.

There are two points to consider in drawing possible source regions. The first is the possible magnitude of the event (for large earthquakes magnitude is calculated using the "seismic moment of the event" thus we refer to the moment magnitude). As the moment magnitude is critically dependent on the area of the zone that breaks, in order to show examples of possible source areas we must estimate rupture lengths (parallel to the strike of the trench) and widths. A minimum length for these estimates is provided by Heaton and Kanamori [1984]. On the basis of an analysis of plate age and convergence rate used in a regression against the observed magnitude of interface events in other subduction zones, they suggested that in Cascadia an event of about moment magnitude 8.3 would be expected given the plate age and convergence rate measured there; such an earthquake might be expected to rupture a length on the order of 150-200 km along the subduction zone. After comparing a number of additional plate parameters such as offshore bathimetry and gravity and the historical rate of moderate (magnitude 5.7+) earthquakes, Heaton and Hartzell [1986] suggested that the entire length of the Cascadia zone (1100 km), from Cape Mendocino to central Vancouver Island might rupture in one great event with a moment magnitude greater than 9.

The second point in estimating source areas concerns the width of the rupture perpendicular to the coast. Here, there are two competing models. In the first model, the rupture extends from the trench downdip along the interface to a depth of between 30-40 km. Because of the plate geometry, this width varies along the subduction zone. The width is a maximum beneath northwestern Washington (~200 km), and narrows to less than 100 km beneath central Oregon and areas further south (Figure 5). In the second model, in areas like Cascadia that have a very high rate of sedimentation offshore, Byrne et al. [1988] have argued that as these sediments are subducted they allow very poor coupling from the trench landward possibly as far as the coast. With this model, the potential source area capable of generating subduction zone interface earthquakes in Cascadia is greatly reduced, consisting approximately of the area from about the coast inland to where the subducting plate begins to subduct steeply eastward, perhaps at an approximate depth of 50-60 km [Byrne et al., 1988]. Because of the plate geometry, south of the arch beneath Puget Sound this area is particularly small (Figure 5).

In drawing examples of possible source areas, we have illustrated the case where the zone is filled by two events (Figure 7); Heaton and Hartzell [1986] discuss several other possible ways that the entire zone might rupture. With respect to the width, we believe it s difficult to explain the pattern of sudden, jerky subsidence recorded in the coastal marsh stratigraphy that has now been widely observed in Oregon and Washington, without the rupture area extending offshore. We emphasize that our choice of two earthquakes to fill the Cascadia subduction zone is for illustration only. However, we note that if our preference for the trench-40 km depth fault width can be substantiated through experimental and model work, the more westward extent of the eastern limit of this source region compared to the suggestion of Byrne et al. [1988] may have implications for hazards assessments in the urban areas. The greatly expanded strain studies suggested by Shedlock and Weaver [this volume] would help address which of these two source area possibilities is correct. Indeed, the great areas involved in any potential interface earthquake (Figure 7) clearly mandates plate-scale investigations of the processes of earthquake generation.

KNOWN SOURCE REGIONS OF LARGE CRUSTAL EARTHQUAKES

There are few known large magnitude (7+) crustal earthquakes in the North American plate in the Pacific Northwest. During this century two events of magnitude 7 or greater have occurred in central Vancouver Island (in 1918 and 1946), and one event occurred within the North Cascades of Washington in 1872. With respect to the Vancouver Island events, they were probably related to the stress regime generated by the interaction of the Explorer plate (at the northern end of the Juan de Fuca plate) with the North American plate [Rogers, 1983b]. The cause of the 1872 event remains problematical as it occurred in an area with very little contemporary seismicity and little geological evidence of any post-Miocene tectonism.

The existence of these large crustal events does raise the question of whether they might occur within the urban areas of western Washington and Oregon. Unfortunately, the sparsity of known Quaternary faulting [Gower et al., 1985] and the current seismicity distribution does little to answer this question. Part of the problem in the Puget Sound basin is that the crustal earthquakes do not fall along simple, linear fault zones, but appear to be distributed throughout the crust (Figures 3, 4b). Zollweg and Johnson [submitted] have recently interpreted a sequence of earthquakes on the western margin of the North Cascades as evidence of a southerly dipping fault zone, the first such zone identified in northwestern Washington. Nevertheless, it remains impossible to infer either the possibility of or argue conclusively against a future magnitude 7+ shallow crustal earthquake in Puget Sound.

In contrast to the earthquake distribution in the Puget Sound basin, in southwestern Washington, much of the earthquake activity occurs along the St. Helens zone (SHZ), a right-lateral strike-slip zone that defined for over 100 km [Ludwin et al., 1989; Weaver and Smith, 1983]. Two earthquakes greater than magnitude 5 have occurred on the SHZ since 1960. Mount St. Helens directly overlies the zone where a small (few kilometers) right-stepping offset occurs [Weaver et al., 1987]. Several studies have assumed that the complications beneath Mount St. Helens effectively prohibit the entire 100 km length from rupturing in a single earthquake [Weaver and Smith, 1983; Grant and Weaver, in press]. Grant and Weaver [in press] compared possible source areas along the SHZ north of Mount St. Helens with observations of both fault area and magnitudes calculated from earthquakes on other strike-slip fault zones. As a result of this comparison, Grant and Weaver concluded that an earthquake in the magnitude range of 6.2-6.8 was the expected maximum magnitude event for the SHZ north of Mount St. Helens.

Our final plot of crustal earthquake source areas (Figure 8) shows only the regions where these events have occurred plus the SHZ and the northern end of the San Andreas system in California. The large area shaded in the North Cascades illustrates the uncertainty in the epicenter [Malone and Bor, 1979]. From the point-of-view of hazards assessment the expected maximum magnitude event has been considered probable over the entire region [Algermissen, 1988]. The map does emphasize the advantage of both accurate location and an understanding of the seismotectonics responsible for crustal earthquakes, in that along the SHZ it is possible to place a large event on a specific structure, as opposed to having to consider it equally likely that the event may occur throughout a given area. We emphasize that this final map represents a very incomplete assessment of the source regions of large crustal events. Considerable regional geology, local Quaternary studies, and regional-scale strain networks, as discussed by Shedlock and Weaver [this volume], will be required to narrow the uncertainty of source regions for large crustal earthquakes.

SUMMARY

In the convergent margin setting of the Cascadia subduction zone, three distinct earthquake sources are possible: 1) earthquakes at the interface between the Juan de Fuca and North American plate, 2), earthquakes within the crust of the overlying North American plate, and 3) earthquakes within the subducting Juan de Fuca plate. For each source type we have estimated the region over which we expect an earthquake of that type to occur. The probable source region for intraplate earthquakes within the Juan de Fuca plate is the best known, as we are able to combine the historical data from the 1949 and 1965 earthquakes with the modern instrumental record. The latter data have been used to infer the geometry of the Juan de Fuca plate whereas the former have been used to deduce that the large magnitude earthquakes occur at least in part in response to down-dip tensional forces within the subducting plate. We estimate that the entire subduction zone, at depths between 45 and 60 km, is capable of producing these events.

Despite many unresolved issues surrounding great subduction zone interface earthquakes, as these events occur on the shallow interface, the source area is at least limited to those areas of the plate above 60 km depth. In illustrating one of many possible combinations of sources along the zone, we have chosen to limit the source area above 40 km depth. Regardless of the maximum source depth, these earthquakes represent a major threat to the population of the Pacific Northwest that has not been fully integrated into current hazard assessments, and a program to accomplish this integration will necessarily have to consider the large scale of these earthquakes. Finally, the possibility of large crustal earthquakes in the urban areas remains very poorly studied in the Pacific Northwest. Major new initiatives will be required to determine whether the urban centers in western Washington and Oregeon must contend with the problems posed by this source type.

REFERENCES

Algermissen, S. T., Estimation of ground shaking in the Pacific Northwest, *U.S. Geol. Survey Open-File Rep. 88-541,* W. W. Hays, Ed., 43-51. 1988.

Atwater, B. F., Evidence for great Holocene earthquakes along the outer coast of Washington State, *Science, 236,* 942-944, 1987.

Baker, E. G., and C. A. Langston, Source parameters of the 1949 magnitude 7.1 south Puget Sound, Washington, earthquake as determined from long-period body waves and strong ground motion, *Bull. Seis. Soc. Amer., 77,* 1530-1577, 1987.

Byrne, D. E., D. M. Davis, and L. R. Sykes, Loci and maximum size of thrust earthquakes and the mechanics of the shallow region of subduction zones, *Tectonics, 7,* 833-857, 1988.

Crosson, R. S., Review of seismicity in the Puget Sound region from 1970 through 1978, *U. S. Geol. Surv. Open-File Rept. 83-19,* 6-10, 1983.

Crosson, R. S., and T. J. Owens, Slab geometry of the Cascadia subduction zone beneath Washington from earthquake hypocenters and teleseismic converted waves, *Geophys. Res. Lett., 14,* 824-827, 1987.

Gower, H. D., J. C. Yount, and R. S. Crosson, Seismotectonic map of the Puget Sound region, Washington, *U. S. Geol. Surv. Miscell. Invest. Ser., Map I-1613,* scale 1:250,000, 1985.

Grant, W. C., More evidence from tidal-marsh stratigraphy for multiple late Holocene subduction earthquakes along the northern Oregon coast, (abstract), *Abstracts with Programs 1989, Cordilleran and Rocky Mountain Sections Annual Meeting, Geol. Soc. Amer., 21,* 86, 1989.

Grant, W. C., and C. S. Weaver, Seismicity of the Spirit Lake area: Estimates of possible earthquake magnitudes for engineering design, in Schuster, R. L., and W. Meyer, eds., *U. S. Geol. Survey Prof. Paper xxxx,* in press.

Heaton, T. H., and S. H. Hartzell, Source characteristics of hypothetical subduction earthquakes in the northwestern United States, *Bull. Seis. Soc. Amer., 76,* 675-703, 1986.

Heaton, T. H., and H. Kanamori, Seismic potential associated with subduction in the northwestern United States, *Bull. Seism. Soc. Amer., 74,* 933-941, 1984.

Isacks, B.L., and P. Molnar, Distribution of stresses in the descending lithosphere from a global survey of focal mechanism solutions of mantle earthquakes, *Rev. Geophys., 9,* 103-174, 1971.

Ludwin, R. S., C. S. Weaver and R. S. Crosson, Seismicity of Washington and Oregon, in E. R. Engdahl, ed., *Neotectonics of North America,* Geol. Soc. Amer., Boulder, Co., (in press), 1989.

Malone, S. D., and S. Bor, Attenuation patterns in the Pacific Northwest based on intensity data and the location of the 1872 North Cascades earthquake, *Bull. Seism. Soc. Amer., 69,* 531-546, 1979.

Riddihough, R. P., Recent movements of the Juan de Fuca plate system, *J. Geophys. Res., 89,* 6980-6994, 1984.

Rogers, G. C., Some comments on the seismicity of the Northern Puget Sound- Southern Vancouver Island region, in *U. S. Geol. Survey Open-File Rep. 83-19,* J. C. Yount and R. S. Crosson, Editors, 19-39, 1983a.

Rogers, G. C., Seismotectonics of British Columbia, PhD. Thesis, University of British Columbia, Vancouver, 247 pp., 1983b.

Savage, J. C., M. Lisowski and W. H. Prescott, Geodetic strain measurements in Washington, *J. Geophys. Res., 86,* 4929-4940, 1981.

Shedlock, K. M., and C. S. Weaver, Rationale and outline of a program for earthquake hazards assessment in the Pacific Northwest, *U. S. Geol. Survey Open-File Rep. 89-xxx,* this volume.

Taber, J. J., and S. W. Smith, Seismicity and focal mechanisms associated with the subduction of the Juan de Fuca plate beneath the Olympic Peninsula,

Washington, *Bull. Seismol. Soc. Amer., 75,* 237-249, 1985.
Walter, S. R., Intermediate-depth focus earthquakes associated with Gorda plate subduction in northern California, *Bull. Seis. Soc. Amer., 76,* 583-588, 1986.
Weaver, C. S., and Baker, G. E., Geometry of the Juan de Fuca plate beneath Washington and northern Oregon from seismicity, *Bull. Seism. Soc. Amer.78,* 264-275, 1988.
Weaver, C. S., W. C. Grant, and J. E. Shemeta, Local crustal extension at Mount St. Helens, Washington, *J. Geophys. Res., 92,* 10,170-10,178, 1987.
Weaver, C. S., and S. W. Smith, Regional tectonic and earthquake hazards implications of a crustal fault zone in southwestern Washington, *J. Geophys. Res., 88,* 10,371-10,383, 1983.
Zollweg, J. E., and P. A. Johnson, The Darrington seismic zone in northwestern Washington, *Bull. Seis. Soc. Amer.,* (submitted 04 April 89).

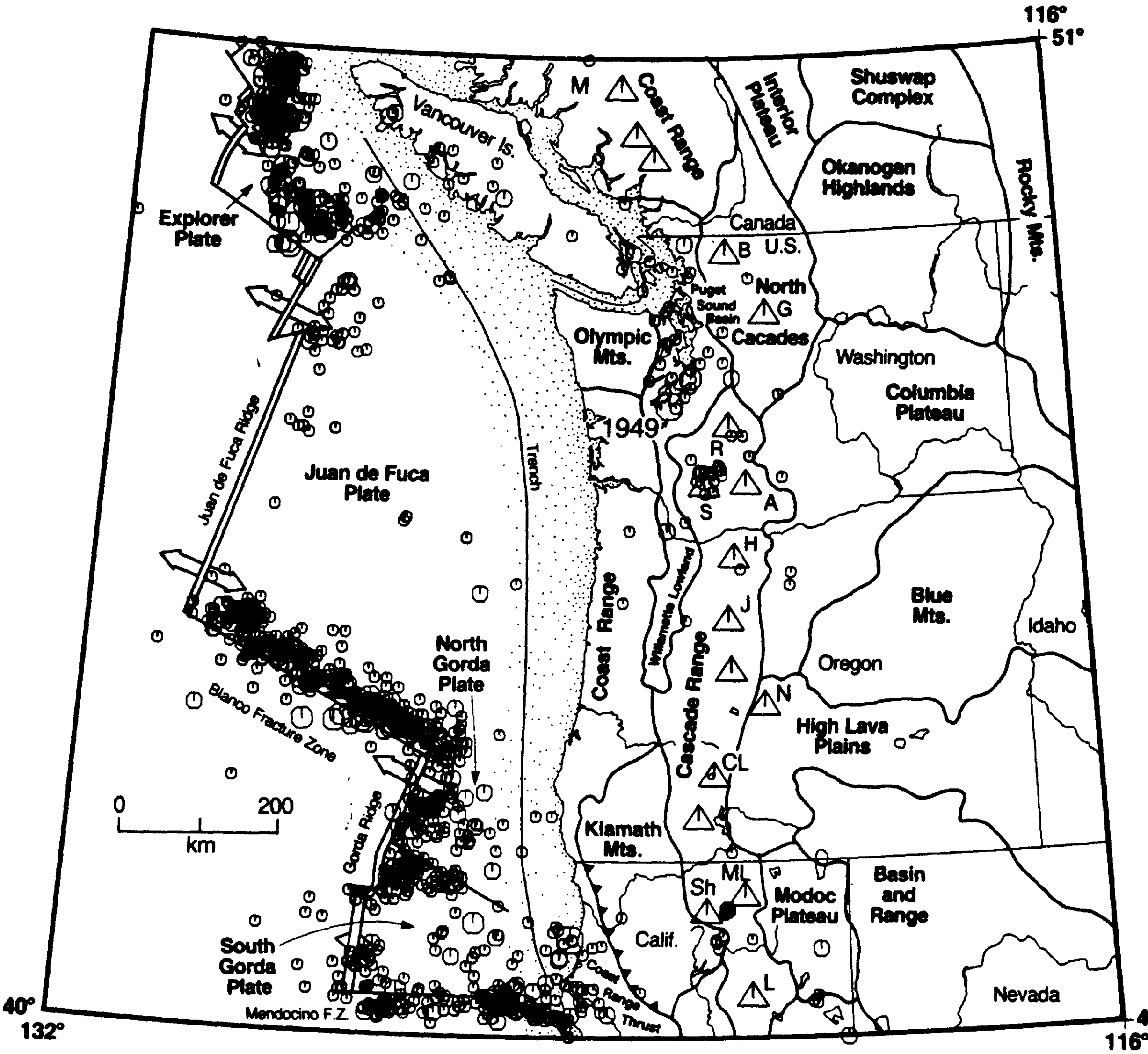


Figure 1. Map showing plate boundaries and physi-tectonic provinces of the Pacific Northwest region. Earthquakes shown are magnitude 4 or larger events listed in the NOAA catalog through 1985. The 1949 south Puget Sound earthquake, the largest instrumentally recorded event in Washington or Oregon, is also shown. Open triangles are Quaternary stratovolcanoes, abbreviated as follows: M, Meagher Mountain; B, Mount Baker; G, Glacier Peak; R, Mount Rainier; S, Mount St. Helens; A, Mount Adams; H, Mount Hood; J, Mount Jefferson; N, Newberry Volcano; ML, Medicine Lake Volcano; Sh, Mount Shasta; L, Lassen Peak. [Figure from Ludwin et al., in press]

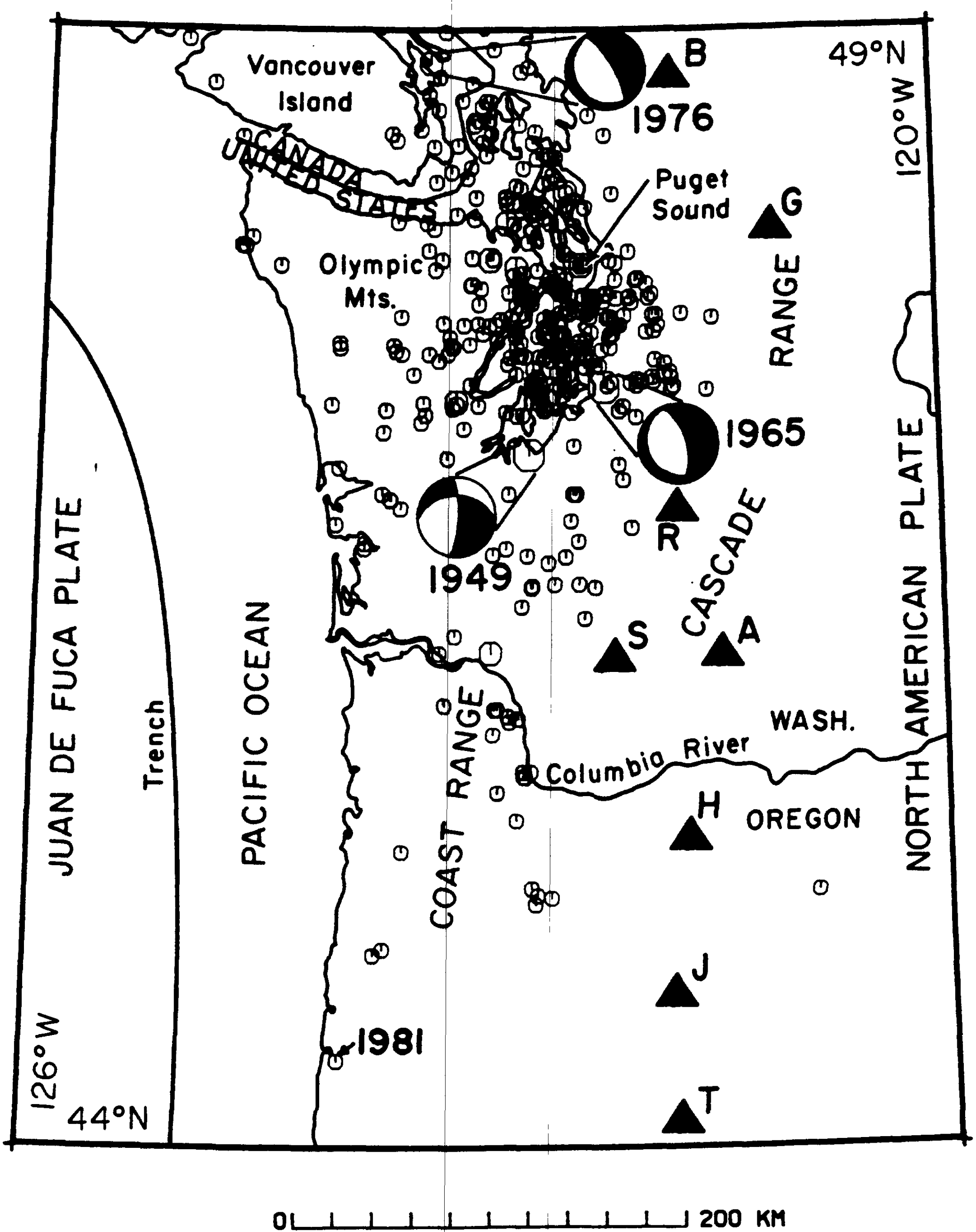


Figure 2. Distribution of earthquakes greater than 20 km depth in western Washington and northwestern Oregon. The earthquakes are from the period 1 January 1980 to 31 August 1986; the 1949, 1965 and 1976 earthquakes discussed in the text have been added. Earthquake magnitudes indicated by size of symbol, with the smallest symbols representing magnitudes between 1.5 and 3.4, event magnitudes between 3.5 and 5.4 by medium symbols, and magnitudes 5.5 to 7.4 by large symbols. Focal mechanisms for the three events have compressional quadrants darkened, dilatational quadrants white. Sources for the mechanisms are given in the text. Darkened triangles are Quaternary Cascade stratovolcanoes, abbreviated as follows: B, Mount Baker; G, Glacier Peak; R, Mount Rainier; S, Mount St. Helens; A, Mount Adams; H, Mount Hood; J, Mount Jefferson; T, Three Sisters. [Figure from Weaver and Baker, 1988]

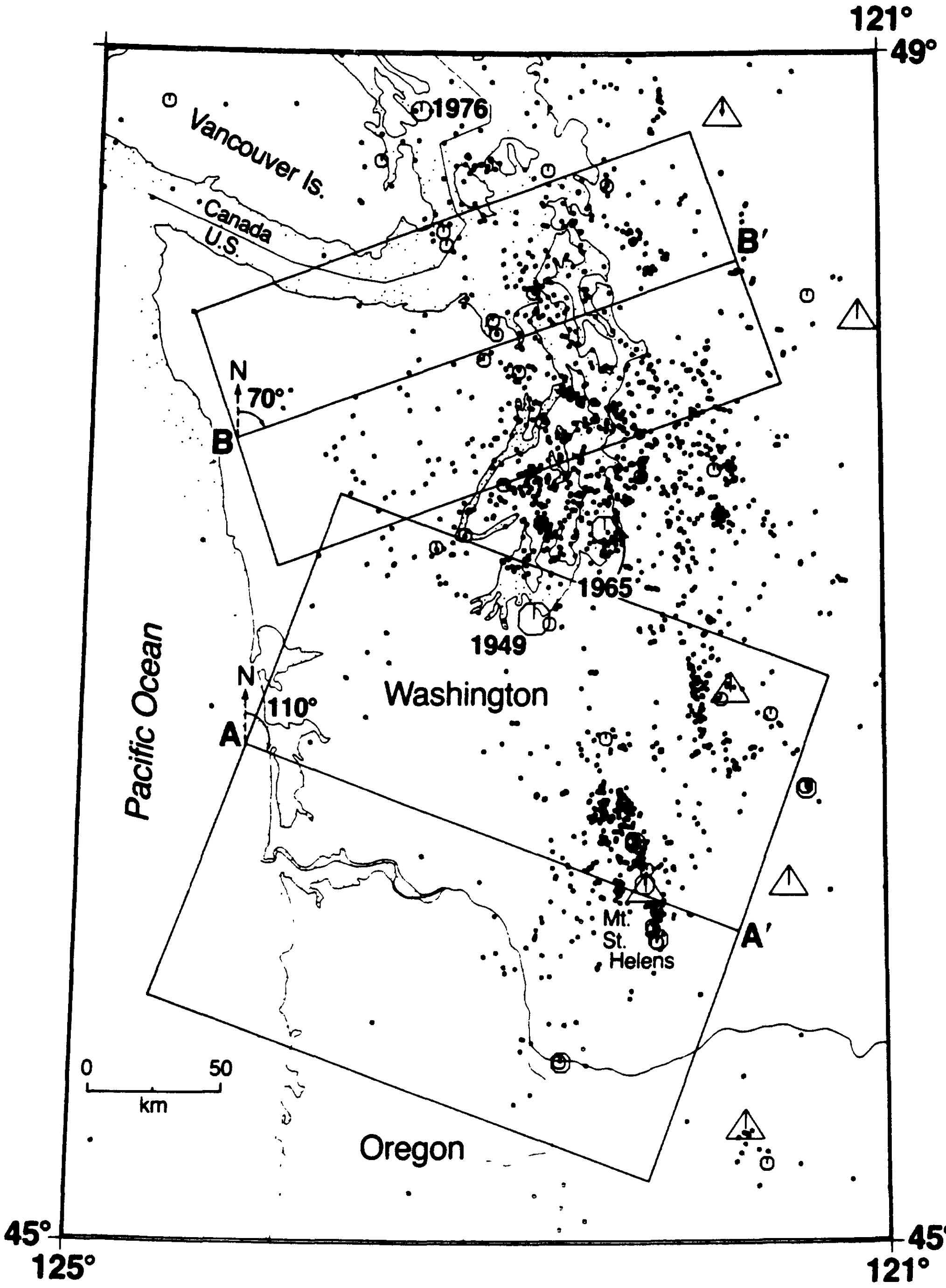


Figure 3. Areas plotted in cross section in Figure 4. All events within each rectangle have been projected onto vertical planes oriented along lines A-A' and B-B'. Well-located crustal earthquakes, above 20 km depth, have been plotted along with the events from Figure 2. Earthquakes are scaled by magnitude, with events smaller than magnitude 4 plotted as the smallest symbols. Events larger than magnitude 4 are plotted in four increasingly larger sizes: 4.0 to 4.9; 5.0-5.9, 6.0-6.9 (only 1965 event), and greater than magnitude 7 (one event in 1949). [Figure from Ludwin et al., in press]

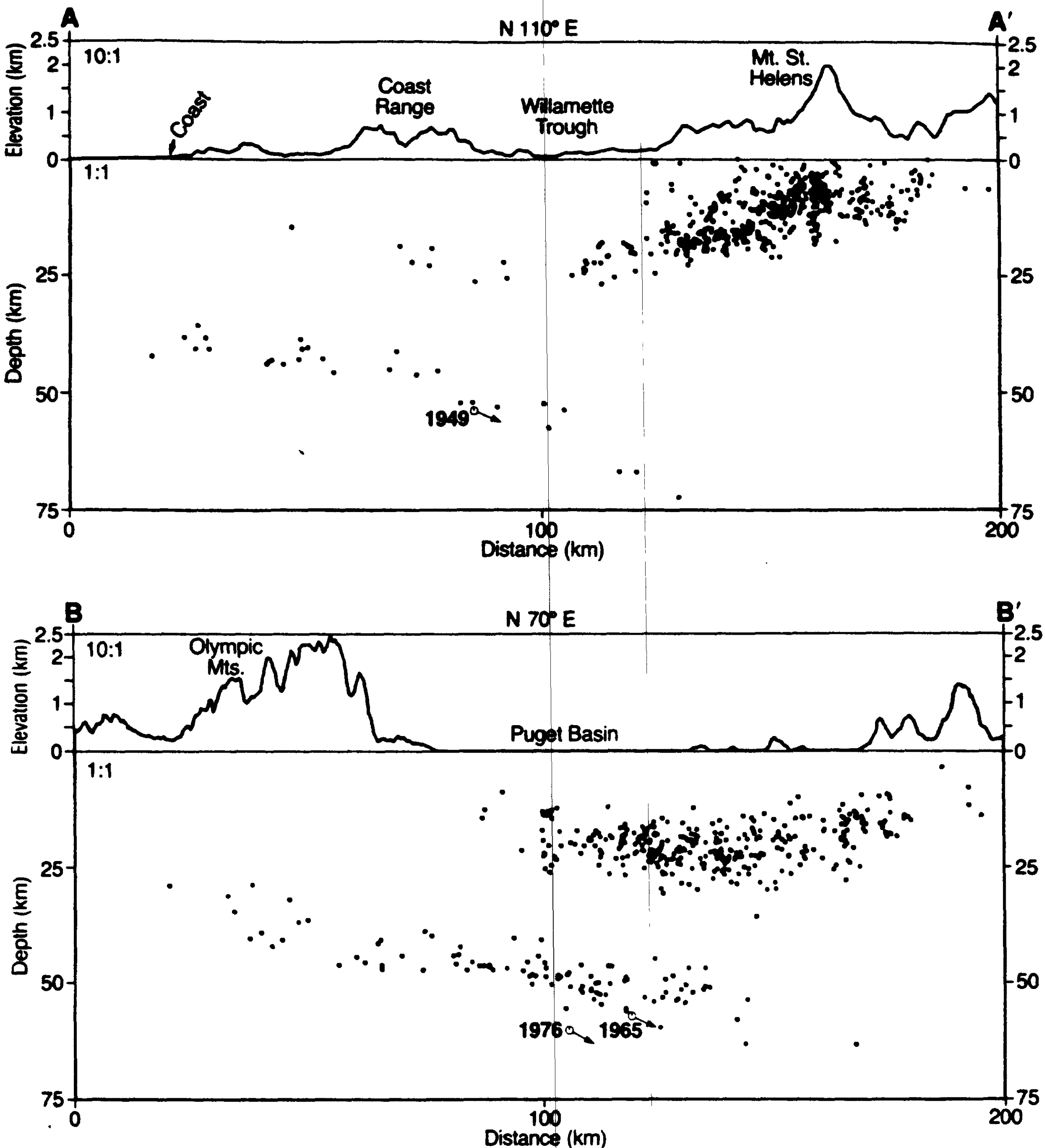


Figure 4. Cross section plots. The orientation of each plane and the area of the projected hypocenters are given in Figure 3. Earthquakes are all plotted with one symbol size, except for the 1949, 1965, and 1976 events discussed in text. Arrows for these events indicate the dip of the T-axes, sources are in the text. Each section is 200 km wide and there is no vertical exaggeration; topography along the lines shown on Figure 3 is plotted at a 10:1 vertical exaggeration. [Figure from Ludwin et al., in press]

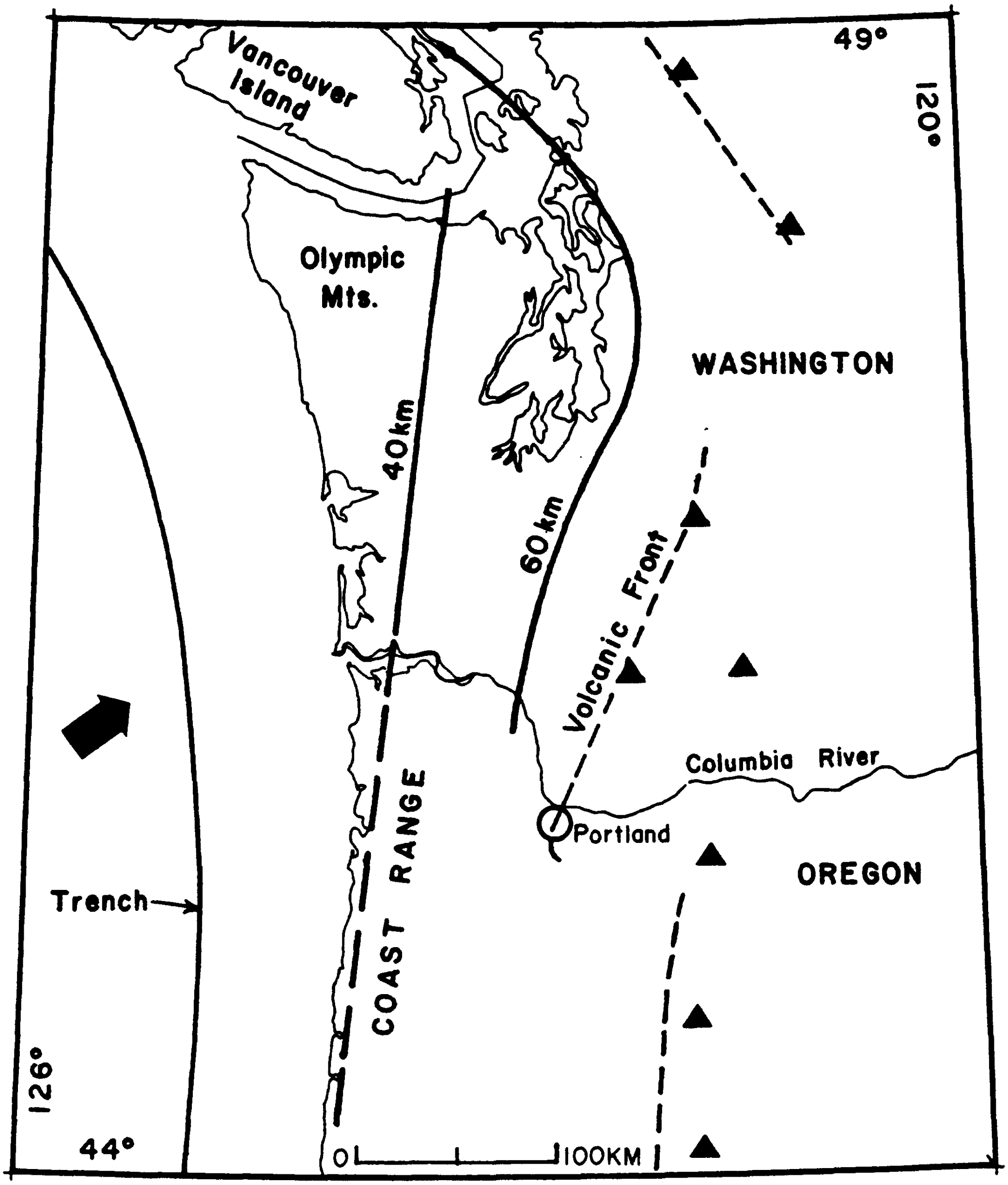


Figure 5. Summary of plate geometry beneath Washington and northern Oregon. The 40 and 60 km depth contours are taken from the westward extent of the 30-40 km and westward extent of the 50-60 km distributions plotted by Weaver and Baker [1988]. Bold arrow offshore shows the direction of convergence between the Juan de Fuca and North American plates. [Figure from Weaver and Baker, 1988]

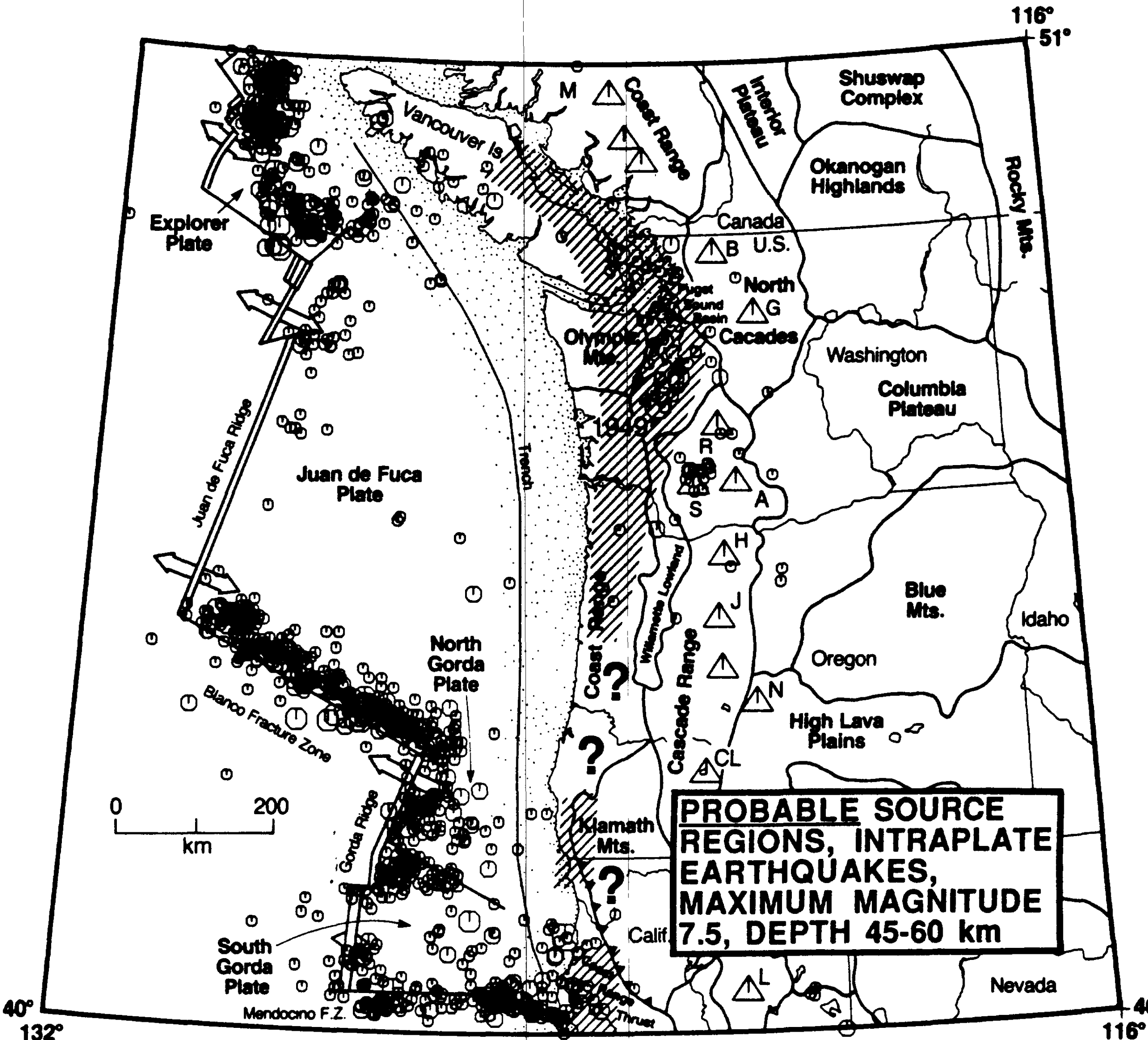


Figure 6. Schematic of the probable source region for intraplate, down-dip tensional earthquakes. Large magnitude earthquakes (~7-7.5) are expected anywhere within the shaded region. Question marks indicate areas where there are no earthquakes located within the Juan de Fuca plate and the plate geometry is uncertain.

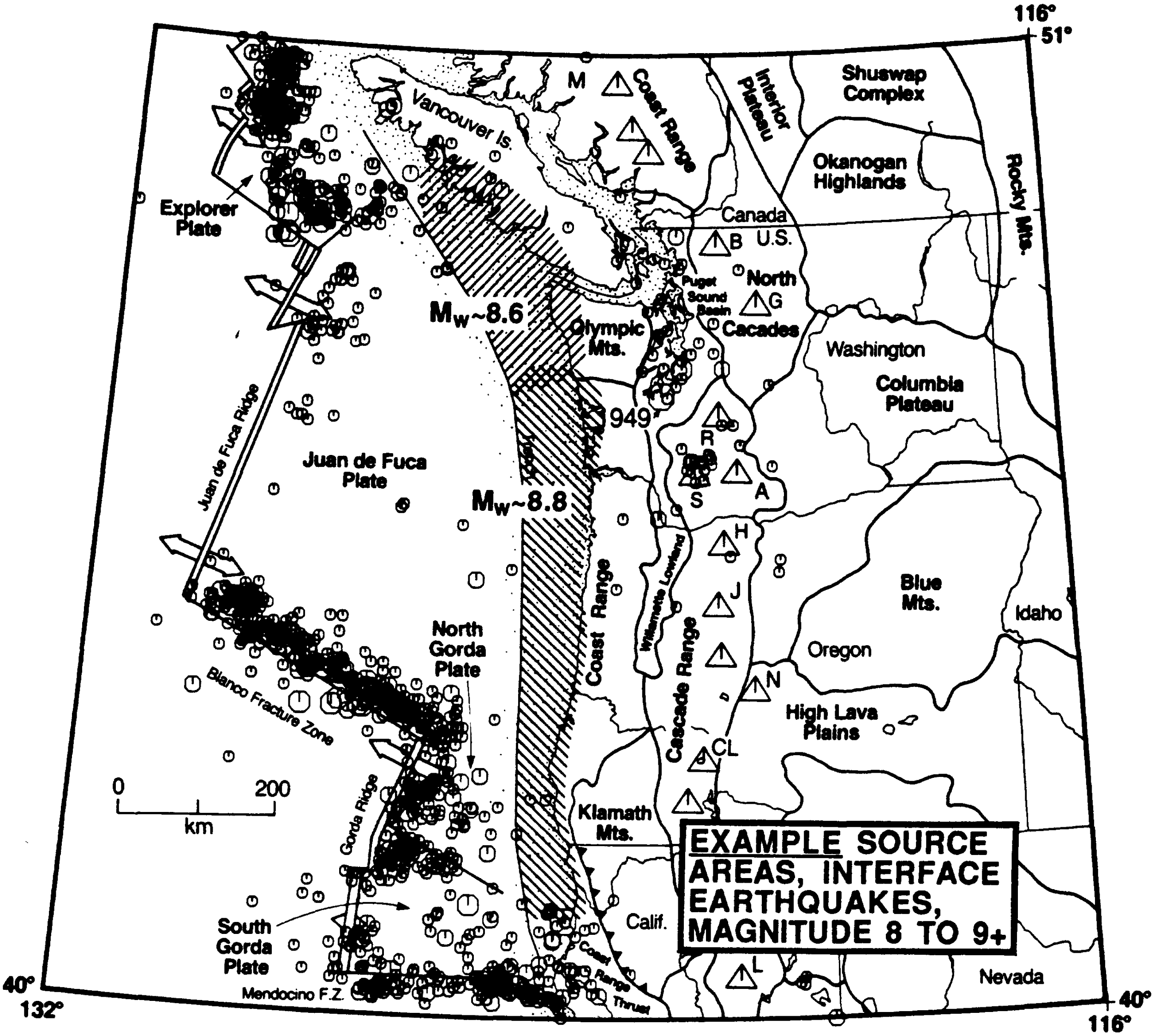


Figure 7. Example of source areas for two interplate earthquakes on the shallow dipping interface. Approximate magnitude of the northern event is 8.6 and of the southern event 8.8. Other combinations are possible--see text for discussion.

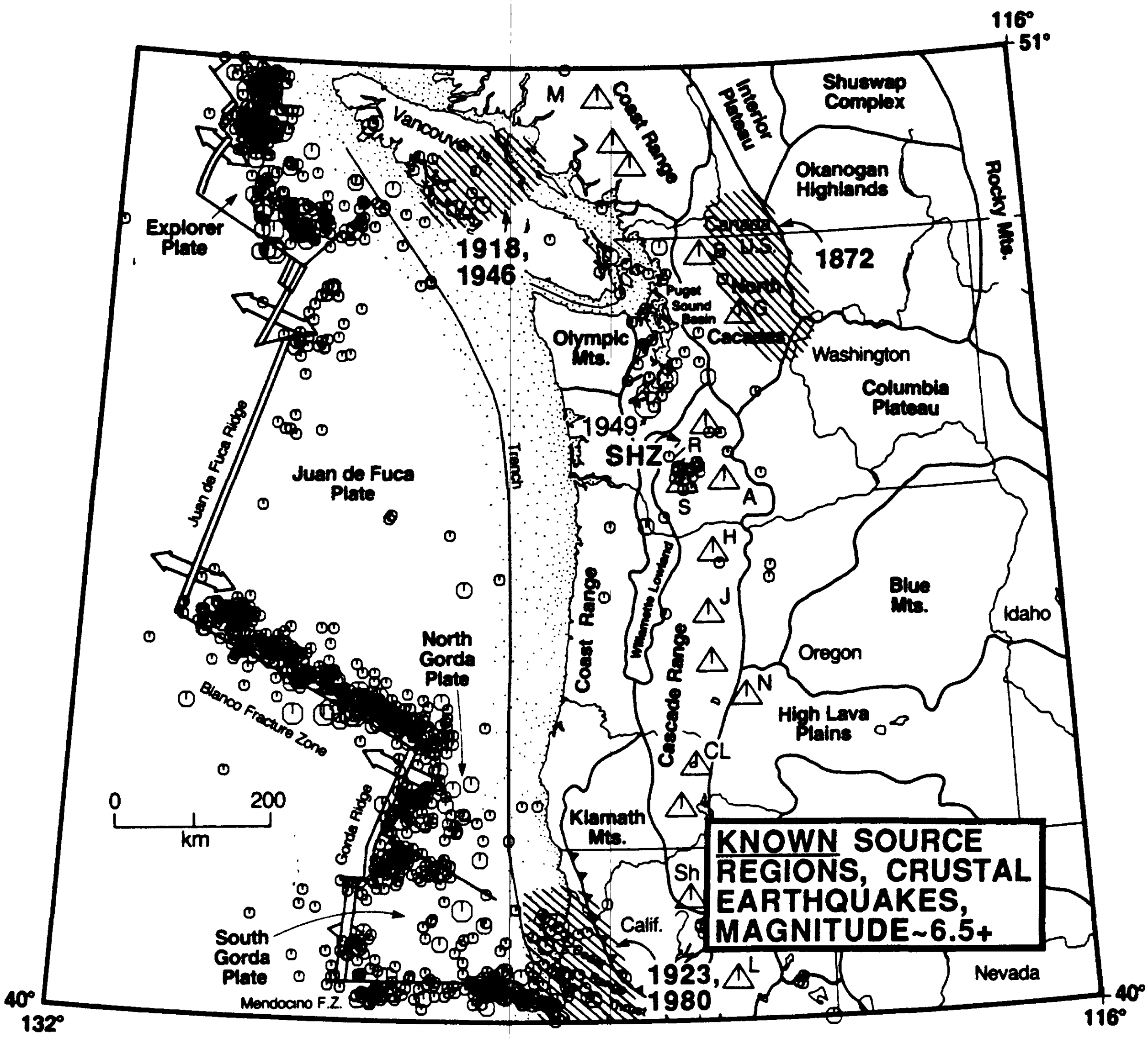


Figure 8. Known source areas for historical crustal earthquakes greater than magnitude ~6.5; dates give the year of events greater than magnitude 7. The hatched area north of Mount St. Helens represent the segment of the SHZ where Grant and Weaver [in press] have suggested a maximum magnitude earthquake in the range of 6.2-6.8.

CURRENT ASSESSMENT OF EARTHQUAKE HAZARD IN OREGON

Robert S. Yeats
Department of Geology, Oregon State University
Corvallis, OR 97331

Five years ago, very few people were concerned about major earthquakes in the State of Oregon. Historical damaging earthquakes had been recorded in the adjacent states of Washington, Idaho, Nevada, and California, but not Oregon. This lack of concern is expressed today in seismic zoning maps, which put the State of Oregon in a lower seismic risk category than adjacent states.

Today, the earth-science community appears to have reached a consensus that Oregon has been struck by large earthquakes in the past, and, therefore, that Oregon is likely to be subjected to large earthquakes in the future. There is no agreement among earth scientists on whether Oregon will be subjected to a magnitude 9 or only a magnitude 7 earthquake. Nor is there compelling evidence for past large earthquakes directly beneath the heavily populated Willamette Valley. But the evidence found in marshes in estuaries on the Oregon coast is compelling enough for reevaluation of seismic zoning maps and of the seismic safety of critical facilities such as power plants, hospitals, and dams.

In evaluating earthquake hazards, it is not enough to show that crustal deformation has taken place in the recent past, because such deformation could take place slowly and smoothly, unaccompanied by earthquakes. It is necessary to show that deformation occurred in sudden jerks, as it does during an earthquake.

In Oregon and Washington, scientists have now shown that coastal marshes and coniferous forests have repeatedly undergone sudden subsidence that killed the marshes and forests by inundating them with sea water. Sand commonly found overlying the marshland sediments shows strong evidence of having been deposited by a seismic sea wave, or tsunami. Sand of this kind has been reported from the Salmon River and Alsea Bay, Oregon and from Willapa Bay, Washington.

Many attempts have been made to account for the buried marshes by non-seismic processes, notably gigantic 500-year storms or a slow rise in sea level. Sea level change in the last 5000 years does not appear to be large enough to account for the marshland burials. Marshes on the East Coast and Gulf Coast of the United States have been subjected to great storms in the past, notably hurricanes, but these marshes do not show evidence of rapid burial. However, marshes around the Gulf of Alaska and in southern Chile do show evidence of rapid burial, including burial after the 1960 Chile earthquake (magnitude 9.5) and the 1964 Alaska earthquake (magnitude 9.2). We cannot completely exclude the possibility that the marshes could have been mantled with sand by a gigantic Pacific storm occurring during a time of temporary sea-level rise in the last few thousand years. But this explanation has very little support among scientists because it is unlikely that a great storm and a temporary sea level rise would have coincided 7 or 8 times in the last 5000 years.

The only note of caution about correlating marsh subsidence with earthquakes is the absence of evidence of strong shaking of marsh deposits, which would be expected during a great earthquake.

The most recent great coastal subsidence event occurred 300-400 years ago, as dated by carbon-14, and is known to have inundated many marshes and forests from Grays Harbor in Washington to Alsea Bay in Oregon. Carbon-14 dates from partially submerged archeological sites are consistent with submergence during the most recent event as well as an earlier event 3100 years ago. However, carbon-14 dates do not permit us to say whether a given subsidence event occurred in one earthquake or several over a period of 50 years. We could calculate the magnitude of an earthquake rupturing the subduction zone from Grays Harbor to Alsea Bay, but this would be considered as a maximum possible event. Tree-ring dating could increase the time resolution, but only where the subsidence events are recorded by killed trees in lowland forests.

These probable subduction zone earthquakes have occurred on average every 500-600 years, but there is so much variation in recurrence interval over the past 4000 years that the average recurrence interval has little value in predicting the next earthquake.

Sediment cores from the abyssal sea floor at the foot of the continental slope west of Oregon provide evidence of strong shaking, perhaps related to the abrupt coastal subsidence. Sediments deposited on the continental shelf by major rivers, particularly the Columbia River, were apparently destabilized and sent down the continental slope as a high-density, sediment-charged flow analogous to a snow avalanche, but much larger. The most likely triggering mechanism was a giant earthquake. The cores also recovered deposits of ash from the Mt. Mazama eruption that formed Crater Lake about 7600 calendar years ago. Based on the number of turbidity-current deposits on top of the Mt. Mazama ash, the average interval between successive turbidity-current deposits is about 500-600 years, with the most recent deposit about 300 years ago. These estimates resemble those for marshland subsidence events, adding support for the origin of both by great earthquakes.

Accurate repeated leveling surveys of Oregon highways provide evidence for deformation in the last 100 years. This releveling study is in its early stages, because the highways were last releveled in 1987, and the data are only partially analyzed. However, there is clear evidence of eastward tilting of the Coast Range toward the Willamette Valley, northward tilting of the coast between southern Oregon and Newport, and southward tilting of the coast between Astoria and Tillamook. We cannot say whether this deformation represents elastic strain accumulation prior to a future earthquake, or whether this deformation has nothing to do with earthquakes. This is a profitable line of investigation, however, and future studies may lead to more definitive evidence from geodetic evidence of this kind.

Studies in the Willamette Valley have not yet produced evidence that the Portland Hills fault, Gales Creek fault, Corvallis fault, and other faults in the Valley are active and capable of producing earthquakes. In addition to these faults, there are broad folds in the Tualatin Valley and Portland basin. The faults are not long and throughgoing as they are in California, but instead are relatively short, offset at right angles by other faults. The faults and folds are consistent with the observed stress field of western

Oregon, which is characterized by the maxiumum compressive stress oriented north-south. These faults and folds clearly deform the Columbia River basalt, deposited 16.5 to 12 million years ago. Most of these structures also deform semiconsolidated sediments that overlie the Columbia River basalt, but these sediments are poorly dated. If these sediments are as young as a few hundred thousand years, then these faults would be shown to be capable of generating future earthquakes. Investigations to answer these questions are underway.

The only clear evidence for recent crustal earthquakes comes from the South Slough of Coos Bay, where marshes show evidence of at least 8 burial events in the last 5000 years. South Slough is in the axis of a syncline, or down-fold, and the buried marshes show that this syncline formed by a series of earthquakes, possibly on a deeply-buried fault that nowhere reaches the surface. Coos Bay is at the eastern margin of a zone of active faults and folds that extends north-northwestward offshore, parallel to the foot of the continental slope and not parallel to the coastline, which extends northward. These faults and folds respond to the northeastward subduction of the Juan de Fuca plate beneath Oregon and are not in accord with the north-south principal compressive stresses measured elsewhere in western Oregon. Thus we cannot apply the evidence for earthquakes at Coos Bay directly to the Willamette Valley, which is much farther inland from the trench.

Western Oregon has very few instrumentally-recorded earthquakes, and most of these are in the Portland area, part of a zone that extends northward into Washington. Part of the reason for so few earthquakes is that Oregon has very few seismographs to record small earthquakes, as compared with adjacent states. For this reason, small earthquakes that could be recorded in Washington or California are not recorded in Oregon. However, the lack of larger earthquakes, magnitude greater than 2.5, is not an artifact of poor instrumentation. The Washington network has recorded many earthquakes in the North American crust and many more in the deep oceanic slab that is now being subducted, but none on the interface between the two plates, the place where subduction-zone earthquakes would occur. The absence of earthquakes could be explained by very smooth, frictionless subduction, or by subduction having stopped entirely. Neither explanation is likely. The most logical explanation is that the subduction zone is completely locked, building up strain for a future earthquake. Most of the San Andreas fault that ruptured in great earthquakes in 1857 and 1906 is seismically quiet, like the Willamette Valley. The Coos Bay region, with the only clear evidence for recent crustal earthquakes, is also seismically quiet. Even so, the complete absence of instrumentally-recorded earthquakes on the subduction zone interface is difficult to explain.

The lack of historical earthquakes should not be taken as evidence for low seismic hazard because Oregon's recorded history spans less than 200 years, not a sufficient time to be significant in earthquake hazard evaluation. The submergence of archeological sites indicates that earthquakes affected Native American communities prior to the establishment of a culture that kept written records. The Armenian earthquake of December, 1988 occurred in an area that had not had a major earthquake in 700 years, based on historical records. A large portion of that part of the San Andreas fault of California that ruptured in great earthquakes in 1857 and 1906 is now as seismically quiet as the Willamette Valley. The southern San Andreas fault has not had a major earthquake in several hundred years, and a long-range prediction experiment is now underway in that region.

In conclusion, the marsh evidence is convincing enough to issue a public warning about earthquake hazard in Oregon. We cannot say how large a subduction zone earthquake could be, nor can we forecast when the next one might occur. We also have not been able to assess the earthquake hazard posed by local earthquake sources beneath the Willamette Valley. We are on the steep part of the learning curve, and there are many challenges ahead of us.

SEISMICITY OF PUGET SOUND AND SOUTHERN BRITISH COLUMBIA

By
R.S. Crosson
University of Washington
Seattle, Washington

Nearly two decades of seismic network operation in the Pacific Northwest have greatly increased our understanding of small earthquake activity and structure of this region. The earthquake pattern is governed to a large degree by the interaction of the North American, Juan de Fuca, and Pacific plates. On the scale of plate dimensions, the subduction zone contact between the Juan de Fuca and North American plates from Vancouver Island to northern California (Cascadia subduction zone) is remarkably seismically quiet. Unlike most subduction zones, we have not yet identified any earthquakes that represent the slip between these two plates along the subduction zone. On a more local scale, however, the Puget Sound and Mt. St. Helens regions of western Washington are relatively active and have provided much new information on seismicity and structure.

Seismicity in western Washington falls into two distinct zones. One is a Wadati-Benioff zone of subcrustal activity, lying within the subducted Juan de Fuca slab, and extending to depths of 70-80 km. The second is a shallow continental crustal zone extending from the surface to about 30 km depth. The two zones are distinguished by spatial separation, differences in clustering behavior of earthquakes, differences in *b* values, and differences in focal mechanisms. *b* values for the two zones are 0.57 (slab) and 1.00 (crustal) based on a 17 year sample of data. The largest Puget Sound region earthquakes such as the 1949 Olympia event have all apparently occurred within the subcrustal zone. Conventional recurrence statistics for the subcrustal (Wadati-Benioff or "slab") earthquakes extrapolate to a 170 year mean recurrence period for magnitude 7.4 earthquakes; however, a saturation of the recurrence curve is observed for this sequence somewhat above magnitude 5. This saturation may reduce our confidence in extrapolation of the recurrence curve. Analysis of crustal earthquakes, excluding the Mt. St. Helens, Elk Lake, and Goat Rocks sequences, suggests a 170 year mean recurrence interval for a magnitude 6.1 earthquake. These estimates are derived for restricted regions of high seismicity within the Puget Sound basin, roughly a 40,000 km^2 region.

Temporal variations of seismicity are observed. For example, a drop in both the number and apparent rate of energy release for the intra-slab earthquakes is observed beginning about 1985. However such variations may be within the normal statistical fluctuation. Extensive focal mechanism studies have revealed that the crustal earthquakes occur in response to regional North-South compression. The stress indicated by slab earthquakes appears to be much more complex. The shape of the subducting Juan de Fuca slab has been estimated primarily from a combination of seismicity and teleseismic waveform analysis. The slab appears to be arched beneath Puget Sound and this structure may govern the stress complexity as well as the localities where earthquakes occur within the slab. Recently we have been able to use earthquake observations from the Washington network to analyze the structure of the crust in the Puget Sound and Mt. St. Helens regions. These results are beginning to provide insight into the distribution of accreted terranes in the continental margin region. There is evidence that the Eocene Crescent terrane extends at depth westward beneath southern Puget Sound, and that the irregular concentration of these rocks in the southern Puget basin coincides with a region of low crustal seismicity.

It is remarkable that we have observed no plate interface earthquakes along the Cascadia subduction zone, even though there is evidence that subduction is continuing at a rate of up to 3-4 cm/yr. Thus, unlike many subduction zones, there is no direct seismic basis upon which to estimate the subduction earthquake hazard if it exists. Such estimates must come from geological observations (paleoseismic studies). Either the plate is entirely locked (even though subducting at varying rates along the trench), or it is slipping continuously and apparently aseismically. This hazard is difficult to quantify at present. We can, however, begin to quantify the intra-plate earthquake hazard based on direct observations. Both historical and recent observational data point to a clear hazard from intra-slab earthquakes, estimated to be up to magnitude 7.4, beneath Puget Sound, and possibly beneath the San Juan Islands and Straits of Georgia region. Crustal earthquakes of intermediate depth (20-40 km) in excess of magnitude 7 are a known hazard in central Vancouver Island. The widely dispersed and seemingly isolated pattern of occurrence of intermediate and large crustal earthquakes in Washington, British Columbia, and northwest Oregon generally does not correlate with present patterns of small earthquake occurrence, indicating that we must learn much more about the details of crustal structure and regional tectonic stress to adequately understand the hazard from these earthquakes.

MEGATHRUST AND UPPER-PLATE PALEOSEISMICITY OF THE SOUTHERN CASCADIA MARGIN

By
Curt D. Peterson
College of Oceanography
Oregon State University
Corvallis, OR 97331-5503

Summary: Coastal stratigraphic sequences from northern, central and southern Oregon record multiple episodes of supratidal marsh burial by intertidal bay muds within the last several thousand years. Detailed field and laboratory studies of sediment composition and stratigraphic sequences in the southern Cascadia bays demonstrate that the marsh burial events are forced by tectonic subsidence and not by extreme climatic or oceanographic conditions. Sharp, non-erosional burial contacts, together with abrupt changes in micro-fossil assemblages and frequent occurrences of tsunami deposits all demonstrate that most subsidence events represent coseismic strain release along this convergent margin. By comparison, interseismic periods are generally characterized by vertical accretion (deposition) and by gradual tectonic uplift (strain accumulation). Differences in the spatial and temporal distributions of paleoseismic events between 43° and 45° N correlate with local and regional tectonic structures, implying segmentation of the southern Cascadia subduction zone. Finally, modern marsh evidence of terminated uplift or possible subsidence might indicate a late stage of the current strain cycle. However, systematic marsh field studies are needed to discriminate between interplate and upperplate seismicity, to constrain rupture zone lengths, and to establish the current stage of the most recent strain cycle in the southern Cascadia margin. These studies should be based on (1) common elevation datum, (2) adjacent basin sampling strategies (3) longer records of coseismic tectonic cycles and (4) integrations with studies of modern strain accumulation and structure maps of Pleistocene terrace-shelf deformation.

Tectonic vs. Climatic/Oceanographic Forcing: End-member marsh systems formed in a coastal lagoon (Netarts Bay, 45.4°), in a transitional fluvial-tidal estuary (Alsea Bay, 44.4°) and in a structural fold-axis basin (South Slough, 43.3°) were studied for evidence of river flood, storm surge and tectonic processes of marsh burial (Curt Peterson and Mark Darienzo, OSU). Tectonic subsidence was isolated as the only mechanism capable of producing the marsh burial sequences which are clearly recorded in each of the end-member marsh systems. Furthermore, persistent (>100 yr) reversals of tidal elevation indicators, including organic:inorganic content, eolian:tidal sediment supply, and fresh:marine diatoms, independently confirm vertical tectonic displacements. Radiocarbon dating of buried peats establishes that 6-9 subsidence events occurred in each basin during the last 3,500-5,000 years, resulting in average recurrence intervals of about 500 years for the different margin sites. Similar events of marsh burial have also been observed in the Nehalem, Salmon, Nestucca and Siletz Bays of northern Oregon (Wendy Grant and Alan Nelson, USGS; Mark Darienzo and Curt Peterson, OSU). Sharp non-erosional burial contacts associated with reversals in the sediment source and in the fresh -to- marine microfossil assemblages are observed across most burial horizons, demonstrating the predominance of abrupt tectonic subsidence.

Coseismic Subsidence: Anomalous sand layers (1-20 cm thick) directly overlie buried marsh horizons in Netarts, Salmon, Siletz, and Alsea Bays of central and northern Oregon. The sediment capping layers lack bioturbation or internal cross-stratification, and were rapidly deposited out of turbulent suspension. Thin sand sheets in Netarts Bay are laterally extensive (>1 km), but in Alsea Bay they are found to thin upriver. Neither distribution pattern can be produced by river flooding or storm surge processes. Heavy mineral analysis of anomalous beach sand in sediment capping layers from the upper reaches of Alsea Bay confirm the upchannel transport of suspended sand over distances of > 1.5 km by landward directed, marine surges. The anomalous sand layers in central and northern Oregon marsh systems are exclusively associated with tectonic subsidence events (burial horizons), and must represent deposits of locally generated tsunamis, as similarly reported for Washington (Brian Atwater, USGS, Mary Reinhart, UW). The nearly one-to-one correlation of tsunami deposits with the marsh burial events in northern and central Oregon provides compelling evidence for coseismic tectonic subsidence in the southern Cascadia margin during late Holocene time. The landward attenuation of tsunami surges in constricted channels accounts for the lack of these diagnostic deposits in some distal marsh sequences that show other evidence of abrupt burial by tectonic subsidence.

Interseismic Strain Accumulation: Interseismic periods recorded in coastal marsh sequences are characterized by decreasing depositional rates associated with the transition from intertidal to supratidal elevation. Post subsidence changes in tidal elevation are produced by both vertical accretion and gradual tectonic uplift associated with vertical strain accumulation. For example, measured burial sequences in Netarts Bay account for <50% of the estimated section depths based on successive 1-1.5 m vertical displacements during the last 4 subsidence events (Mark Darienzo and Curt Peterson, OSU). Section shortening can not be attributed to compaction as constant values of sediment bulk density are observed downcore. In addition, the most recent mud burial horizon in Netarts Bay has been uplifted 0.5-1 m above its initial depositional level (<0.2 m MTL) during the last 300-400 years, yielding a relative tectonic uplift rate > 2 mm/yr. The tectonic cycles of interseismic uplift and coseismic subsidence are consistent with the observed accumulation and release of vertical tectonic strain landward of coastal hingelines in active subduction zones of other convergent margins (George Plafker, USGS). The neotectonic cycles recorded in the northern and central Oregon tidal-basins provide evidence of active subduction tectonics along this historically aseismic margin. The similarity of tectonic cycles (coseismic subsidence and interseismic uplift) in the several adjacent tidal basins (>30 km spacing) of the northern Oregon margin argue against the influence of local faulting/folding in the forcing of observed coseismic subsidence events. However, additional studies of adjacent marsh systems (10-50 km spacings) are needed to confirm these conclusions.

Subduction vs. Upperplate Paleoseismicity: Recent burial events from several northern Oregon and southern Washington bays show significant age overlaps centered on 300-400, 1,600-1,800 and 3,000-3,200 RCYBP, indicating the potential for age synchroneity over 200-300 km length scales (Brian Atwater and Wendy Grant USGS, Curt Peterson and Mark Darienzo, OSU). Due to inherent dating limitations of paleoseismic events it is not possible to prove absolute event synchroneity between these basins. However, the strengths of paleoseismic studies lie in the constraints that they impose on estimates of maximum rupture lengths and/or boundaries of margin segmentation. For example, a dramatic change occurs in the spatial continuity and stratigraphic signature of coastal subsidence events along the southern Cascadia margin. In contrast to the broadly correlated subsidence events in tidal basins of northern Oregon, the sequences of episodic marsh burial in the South Slough basin (southern Oregon) are limited to a narrow syncline axis (Curt Peterson and Mark Darienzo, OSU; Alan Nelson, USGS). Successive burial sequences are conspicuously absent from adjacent fold limbs and anticline axes mapped adjacent to the South Slough syncline. In addition, no tsunami deposits are observed in the burial sequences of the South Slough marshes. Similar (spatially restricted) subsidence events are recorded in marsh sequences adjacent to an active thrust fault in Humboldt Bay, northernmost California (Gary Carver, HSU). Coseismic subsidence events observed in coastal fold/fault belts of southern Oregon and northernmost California are spatially correlated with mapped deformation structures of the upperplate, and are apparently unrelated to subduction paleoseismic events of the northern Oregon and/or Washington margins. The position(s) of the apparent neotectonic boundary(s) between the southern Oregon and northern Oregon margin segments are presently not known.

Stage of the Present Strain Cycle: The majority of prehistoric tectonic cycles recorded along the northern Oregon margin reflect alternating events of coseismic subsidence with long periods (>100 years) of interseismic uplift. It is generally not known how long interseismic uplift has continued after coseismic subsidence in prehistoric tectonic cycles of this margin. However, it is apparent that the modern marsh dynamics (widespread erosional scarps) along the northern Oregon margin reflect the termination of interseismic uplift or possibly the beginning of aseismic subsidence (Curt Peterson and Mark Darienzo, OSU). At least one aseismic subsidence event is recorded in the Netarts marsh stratigraphy (3,200 RCYBP) and this event was followed by the longest aseismic period (1,000 yr) during late Holocene time. Significantly, undefined periods of aseismic subsidence (landward of coastal hingelines) are reported to have proceeded large subduction zone earthquakes from the south Chile and southeast Alaska margins (George Plafker, USGS). The question arises as to whether the present termination of interseismic uplift along the northern Oregon margin represents (1) the initiation of a long aseismic period or (2) the last stage of interseismic strain accumulation leading to coseismic strain release. Studies of longer records of coseismic and aseismic tectonic cycles from the southern Cascadia margin are required to address this question.

GEODETIC DEFORMATION OF THE SOUTHERN CASCADIA MARGIN

by

Paul Vincent
University of Oregon
Eugene, Oregon

SUMMARY:

Vertical and horizontal geodetic deformation of western Oregon is currently being analyzed at the University of Oregon. Vertical deformation (determined from repeated leveling surveys) along the coast of Oregon shows a down-to-the-north tilt from Crescent City, California to Tillamook, Oregon and a down-to-the-south tilt from Tillamook to Astoria. This suggests some form of discontinuity of the megathrust somewhere (at depth) near Tillamook. Smaller-scale warping signals are also seen in the vertical data that may indicate localized strain or the presence of faults. Horizontal/strain deformation (determined from repeated triangulation and/or G.P.S. surveys)in western Oregon is also currently being analyzed. The precision of the historical triangulation data is sufficient to estimate horizontal strain rates and directions of maximum compression for western Oregon. A G.P.S. resurvey of the Columbia River triangulaion network will take place during July of 1989 (in cooperation with the U.S.G.S. Crustal Strain Project, Menlo Park) and is expected to yeild a reliable strain measurement for that region.

PRESENTAION OUTLINE:

Vertical Deformation:
- -previous work (E-W) by Reilinger and Adams
- -N-S deformation
  - -Crescent City to Reedsport — $3\text{-}6\times10^{-8}$ rad/yr
  - -Reedsport to Newport
  - -Newport to Tillamook — (1930-1941)
  - -Tillamook to Astoria

  - -Coquille to Newport
  - -Tillamook to Astoria — (1930-1987)

Horizontal/Strain Deformation:
- -previous work
- -triangulation surveys in Oregon

G.P.S. Data/Survey:

COASTAL TERRACES AND SUBDUCTION EARTHQUAKES

By

Donald O. West
Golder Associates Inc.
Oakland, California

The occurrence of great magnitude (M_w 8.0+) thrust earthquakes along the shallow interface of subduction zones is often accompanied by significant coseismic and permanent vertical deformation of the coastline of the overriding plate. Coseismic deformation is typically characterized by parallel, linear zones of uplift and subsidence that are arcward of the trench. Uplift occurs closest to the trench with subsidence more distant, such that a coastline may experience uplift or subsidence based on its proximity to the trench.

The geologic characteristics of the vertical coastline deformation associated with interface thrust events can be used to evaluate the paleoseismicity of a subduction zone and therefore also provide information about the nature of future seismicity. This may be useful in evaluating the nature of potential Cascadia subduction-zone seismicity because the Cascadia zone has been notably aseismic, with respect to great magnitude shallow thrust events, for at least the past 200 years.

Based on an examination of the nature and characteristics of coseismic coastline deformation from 14 earthquakes along 9 subduction zones world-wide, as well as long-term vertical deformation, the following may be summarized:

* The length of the zone of coseismic deformation increases with earthquake magnitude; events greater than M_w 8.5 generally affect more than 400 km of coastline.

* The maximum coseismic uplift of the coastline is commonly greater than 2 m (may be up to 6 m); maximum coseismic coastline subsidence is generally at least 0.5 m (may be up to 2 m).

* Coseismic uplift of the coastline generally occurs exclusively within about 110-120 km of the trench; coseismic subsidence is at greater distances (to 275 km from the trench).

* Multiple uplifted Holocene marine features (wave-cut platforms, terraces, strandlines) are common to 30 m elevation in the zone of coseismic uplift and are evidence of past thrust events.

* Multiple uplifted Pleistocene high-sea-level-stand terraces are common to 400 m elevation at distances of 40-180 km from the trench, and resultant average rates of uplift are from 0.2-4.0 mm/yr (commonly >0.5 mm/yr).

* Geologically-derived recurrence intervals for great earthquakes indicate they have return periods of 300-2000 years

while the historic records suggest the periods may be shorter (50-500 yrs).

The coastline of Oregon and Washington contains a sequence of at least five uplifted, Pleistocene, high-sea-level-stand marine terraces with ages from 42 to 220 ka. The most preserved and continuous of these terraces is the 82 ka Whiskey Run. It varies from about 5 to 50 m elevation (20 m ave.) for about 600 km of the coastline from just north of Cape Blanco to La Push. The coastline is located from 60-140 km from the buried Cascadia subduction-zone trench. Uplift rates derived from the Whiskey Run terrace are low (0.2-0.6 mm/yr; 0.4 mm/yr ave.) and uniform along the 600 km of coastline. No uplifted marine features younger than 42 ka have been observed along the coastline; broad modern wave-cut platforms occur directly below the Pleistocene terraces whether the coastline is close to the trench (as in Oregon) or distant (as in Washington).

Given the characteristics of coseismic and long-term vertical coastline deformation observed along other subduction zones and given that great thrust events have been postulated for the Cascadia subduction zone with recurrence intervals ranging from about 400 to over 1000 years, the effects of uplift should be particularly evident along the Oregon coast at distances up to 110-120 km from the trench. However, the characteristics of the coastline of Oregon, as well as Washington, differ from other subduction zones in that:

* There are no known uplifted Holocene marine features that would indicate repeated great magnitude earthquakes.

* Broad, modern wave-cut platforms are ubiquitous, indicating vertical stability during the late Holocene (past 1-6 ka).

* The amount and rate of late Quaternary uplift is low, and uniform along the 600 km of coastline.

These different characteristics suggest that repeated great magnitude earthquakes have not occurred along the Cascadia subduction zone (at least off Oregon) during the late Holocene. Alternatively, if the plate interface has generated great earthquakes, the differences may be explained by longer recurrence intervals for great events, smaller magnitude thrust events, or a tectonic mechanism that does not result in coseismic uplift of the coastline where expected.

Additional Reading:

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

West, D.O. and McCrumb, D.R., 1988, Coastline uplift in Oregon and Washington and the nature of Cascadia subduction-zone tectonics: Geology, v. 16, p. 169-172.

CASCADIA SUBDUCTION ZONE : STRUCTURE, TECTONICS , AND FLUID PROCESSES OF THE ACCRETIONARY WEDGE AND ADJACENT ABYSSAL PLAIN

By
LaVerne D. Kulm
College of Oceanography
Oregon State University
Corvallis, OR 97331-5503

Recent studies document periodic, large scale deformation, massive sediment slumping and fluid venting in the accretionary wedges of seismogenic subduction zones of the world (e.g., Boulegue et al., 1987; Moore et al., 1988). The marine portion of the Cascadia subduction zone (i.e., abyssal plain and accretionary wedge) off Oregon and Washington displays many of the active structural-tectonic elements and tectonic-induced sedimentation patterns and fluid venting processes (Kulm et al., 1986) that characterize these seismogenic zones with similar plate tectonic settings. We now have the opportunity to utilize these deformational and fluid processes to evaluate the earthquake potential of the Cascadia subduction zone.

Studies in progress (L.D. Kulm) outline numerous faults and mud volcanos on the abyssal plain, 1-15 km seaward of the initial deformation front, using SeaBeam bathymetry, high resolution SeaMARC-IA side scan sonar, seismic reflection records and the submersible ALVIN. Some faults offset by a few meters the youngest Holocene sediments and some are expressed as fault-bend anticlines with landward vergence. The mud volcanos lie from 2 to 7 km seaward of the initial deformation front on the abyssal plain, rise from 75 to 250 m above the seafloor, and contain highly dewatered mudstones. They imply that the rapidly deposited submarine fan/abyssal plain deposits are overpressured. A fault, oriented approximately perpendicular to the convergence direction, usually cuts the abyssal plain, crossing the volcanos and intersecting the deformation front.

Two main types of structural styles, seaward vergence (thrust faults dipping toward the continent) and landward vergence (thrust faults dipping toward the oceanic plate) of sedimentary sequences, are recognized along the lower continental slope off Oregon and Washington (Silver, 1972; Barnard, 1978; Snavely, 1987). These structures are characterized by an underthrust and an overthrust structural framework, respectively. In both cases the clastic terrigenous sediments of the subducting Juan de Fuca plate (Cascadia Basin) are being offscraped to form an accretionary wedge on the lower continental slope (Kulm and Fowler, 1974). In several areas faults clearly offset and folds involve the most recently deposited sediments associated with deformation fronts of different ages and the overlying basins. Internal basinal faults may surface on the seafloor and are several kilometers long with approximately 3 to 7 meters of vertical offset. In other areas the basin deposits exhibit migrating depocenters (i.e., in a landward or seaward direction) but no major internal faults. Although large thrust earthquakes apparently do not nucleate within the unconsolidated or semi-consolidated sediments of the accretionary wedge (Byrne et al., 1988), they must propagate updip into this zone from the seismic front, which is situated in the vicinity of the more consolidated material of the backstop (i.e., Eocene volcanics in the case of Oregon-Washington) and located behind the accretionary wedge on the middle to outer shelf.

Additional studies in progress (L.D. Kulm) show that both small and large scale sediment slumps are very prominent along the 800-1200 m-high initial deformation front. Large re-entrants in the SeaBeam bathymetry (several kilometers across) and associated slump scars with debris piles at their base in the side scan sonar records indicate large-scale catastrophic slumps off Oregon. These sediment mass wasting patterns may result from strong ground motion generated from seismic activity in the Cascadia subduction zone. The spatial distribution of the large-scale sediment slumps should identify the possible rupture zone patterns associated with large earthquakes off Oregon and Washington.

Active venting of pore fluids was recently documented in the accretionary wedges and on mud volcanos on the adjacent abyssal plain in several different subduction zones of the world (e.g., Oregon, Japan, Nankai, Kuril, Barbados, Peru). The pore fluids and gases are derived from the tectonic-induced dewatering of the accreted and subducted abyssal sediments caused by the compressive stresses. Numerous expulsion zones are mapped off Oregon by the occurrence of chemosynthetic animal communities of live clams and tube worms, authigenic carbonate deposits and chimneys, anomalous concentrations of methane, helium, carbon dioxide and other gases (Kulm et al., 1986; Ritger et al., 1987). The first measured total water flow rate, 188 liters/m^2/day, in a subduction zone vent was obtained off Oregon (Carson and Suess, 1989). Fluids and gases are advected upward through the accretionary complex and mud volcanos to produce these seafloor manifestations. The chemical/isotopic composition, temperature and fluid flux of venting pore fluids from the Cascadia convergence zone have the potential to decipher the fluid sources, nature of fluid communication, and deformational history between the subducting sediments of the Juan de Fuca plate and the accreted sediments of the North American plate. The scientific community needs to formulate working hypotheses that relate the hydrogeology of the world's convergence zones to their seismic characteristics and earthquake potential so that field experiments can be conducted to test the hypotheses. The marine portion of the Cascadia subduction zone is a prime candidate for long-term monitoring experiments.

Two structural/tectonic end-member models may be used to test the seismic versus aseismic nature of the Cascadia subduction zone. If the convergence zone is extinct or locked for long periods of time (e.g., 10^3 to 10^6 years) the basin sediments of the accretionary complex would be draped over the static complex with no faults propagating through the Holocene basin deposits. Fluid expulsion would probably cease within the complex. If the convergence zone is active, it will display continuing deformation with faults propagating upward into the Holocene deposits. Active fluid expulsion and large scale sediment slumps also would characterize this complex.

Barnard, W.D., 1978, The Washington continental slope: Quaternary tectonics and sedimentation: Marine Geology, v. 27, p. 79-114.

Boulegue, J., Iiyama, J.T., Charlou, J.-L., and Jedwab, J., 1987, Nankai Trough, Japan Trench and Kuril Trench: geochemistry of fluids sampled by submersible "Nautile", Earth and Planetary Science Letters, v. 83, p. 363-375.

Byrne, D.E., Davis, D.M., and Sykes, L.R., 1988, Loci and maximum size of thrust earthquakes and the mechanisms of the shallow region of subduction zones, Tectonics, v. 7, p. 833-857.

Carson, B., and Suess E., 1989, Fluid flow and mass flux determinations at vent sites on the Cascadia margin accretionary prism, submitted to Jour. Geophy. Res., Special Issue on The Role of Fluids in Sediment Accretion, Deformation, Diagenesis, and Metamorphism at Subduction Zones.

Kulm, L.D., and Fowler, G.A., 1974, Oregon continental margin structure and stratigraphy: a test of the imbricate thrust model: *in* The Geology of Continental Margins, eds. C.A. Burk and C.L. Drake: New York, Springer-Verlag, p. 261-284.

Kulm, L.D., Suess, E., Moore, J.C., Carson, B., Lewis, B.T., Ritger, S., Kadko, D., Thornburg, T., Embley, R., Rugh, W., Massoth, G.J., Langseth, M., Cochrane, G.R., and Scamman, R.L., 1986, Oregon subduction zone: Venting, fauna and carbonates: Science, v. 231, p. 561-566.

Moore, J.C. et al., 1988, Tectonics and hydrogeology of the northern Barbados Ridge: Results form Ocean Drilling Project Leg 110: Geological Society of America Bulletin, 100, 1578-1593.

Ritger, S., Carson, B., and Suess, E., 1987, Methane-derived authigenic carbonates formed by subduction-induced pore water expulsion along the Oregon/Washington margin, Geological Society of America Bulletin, 98, p. 147-156.

Silver, E.A., 1972, Pleistocene tectonic accretion of the continental slope off Washington: Marine Geology, v. 13, p. 239-249.

Snavely, P.D., Jr., 1987, Tertiary geologic framework, neotectonics, and petroleum potential of the Oregon-Washington continental margin, *in* Scholl, D.W., Grantz, A., and Vedder, J.G., eds., Geology and resource potential of the continental margin of western North America and adjacent Ocean Basins--Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 6, p. 305-335.

ENGINEERING CHARACTERIZATION OF STRONG GROUND MOTIONS WITH APPLICATIONS TO THE PACIFIC NORTHWEST

By

Walter Silva, Robert Darragh, and Ivan Wong
Woodward-Clyde Consultants
500 - 12th Street
Oakland, California 94607

An essential element in the seismic design of engineered structures is a quantitative estimate of the characteristics of strong ground motion. Of particular importance is a specification of the peak levels of ground motion, as well as spectral content, as characterized by response spectra or power spectral density. The spectral content is reasonably well defined for shallow earthquakes occurring in western North America with approximate moment magnitude (M) 6-1/2. However, recent observations of strong ground motions in different tectonic regimes have revealed significant differences in the spectral content of earthquakes recorded at rock sites. Ground motions recorded in stable tectonic regimes typical of eastern North America may have significantly higher frequency content and larger peak values than corresponding motions typical of active regimes like western North America (Boore and Atkinson, 1987; WCC, 1988; WCC, 1989).

A relatively new ground motion model which is extremely simple in concept, called the Band-Limited-White-Noise (BLWN) model combined with random vibration theory (RVT) has been remarkably successful in predicting peak values as well as spectral ordinates in different tectonic regimes (Hanks and McGuire, 1981; Boore, 1983; Boore and Atkinson, 1987). A recent study by Woodward-Clyde Consultants (WCC) has employed the BLWN-RVT methodology in an analysis of rock motions based upon a world-wide data set of earthquakes ranging from M 1.5 to 8.1 (WCC, 1989). This study has shown that the controlling factors in the specification of strong ground motion for engineering design are moment magnitude and the rock properties directly beneath the site extending to depths of approximately several hundred meters to 2 km. Specifically, the near-surface attenuation modeled through the parameter kappa, exerts a predominate effect upon spectral composition for frequencies beyond 5 to 10 Hz. Below that frequency range, moment magnitude through corner frequency controls spectral shapes in the BLWN-RVT ground motion model.

Of particular interest to seismic hazard in the Pacific Northwest, is the possibility of a large Cascadia subduction zone earthquake (M > 8) occurring beneath western Washington and Oregon. While the source processes of such earthquakes may in detail, be different from intraplate and non-subduction interplate events, our analyses suggest that the simple BLWN model accurately predicts the spectral content of such events for engineering design. Four earthquakes including the 1985 M 8.1 Michoacan mainshock which occurred in the subduction zone along the coast of western Mexico and were recorded by the Guerrero strong motion network have been modeled quite well for periods of 0.03 to 4 sec and at distances to the rupture surface as close as 16 km (WCC, 1989). Thus for both interplate

RESULTS OF NUMERICAL MODELING STUDY

The numerical simulations of ground motion for large subduction zone thrust earthquakes were obtained by the superposition of the motions from a large number of subevents propagated to the site using ray theory. The radiation from each subevent was obtained from a dynamic simulation of faulting based on numerical solutions to propagating crack problems. The model was tested by simulating ground motions from the 1983 Coalinga, California earthquake sequence and from the 1985 Valparaiso, Chile and Michoacan, Mexico M_w 8 earthquakes (Day and Stevens, 1987). Figure 3 compares response spectra for the recorded and simulated ground motions for the Chile and Mexico earthquakes. The main conclusions drawn from the numerical modeling study are:

- Numerical modeling can adequately simulate near-field earthquake strong ground motions in the frequency range of 0.2 to 10 Hz from large subduction zone earthquakes.

- The rate of increase in ground motion amplitude with magnitude for events > M_w 8 is less than that observed empirically for events of magnitude ≤ M_w 8 and is similar to that predicted by theoretical relationships based on non-self-similar source spectra (e.g. Heaton and Hartzell, 1988).

ATTENUATION RELATIONSHIPS

The results of the empirical and numerical analyses were combined to develop ground motion attenuation relationships for rock and soil sites. The relationships for peak acceleration on rock are:

$$\ln(a_{max}) = 19.16 + 1.045M_w - 4.738\ln[R + 205.5\exp(0.0968M_w)] + 0.54Z_t \quad \text{for } M_w \le 8$$
$$\ln(a_{max}) = 19.16 + 1.045M_w - 4.738\ln[R + 154.7\exp(0.1323M_w)] + 0.54Z_t \quad \text{for } M_w > 8$$

and the relationships for peak acceleration on soil are:

$$\ln(a_{max}) = 18.75 + 1.045M_w - 4.565\ln[R + 162.5\exp(0.1309M_w)] + 0.54Z_t \quad \text{for } M_w \le 8$$
$$\ln(a_{max}) = 18.75 + 1.045M_w - 4.565\ln[R + 154.1\exp(0.1375M_w)] + 0.54Z_t \quad \text{for } M_w > 8$$

where R is closest distance to the rupture surface in km and a_{max} is in g's. The term Z_t takes on the value 0 for interface events and 1 for intraslab events. The standard error of $\ln(a_{max})$ for both rock and soil sites is given by the expression

$$\sigma = 1.55 - 0.125M_w \text{ for } M_w \le 8, \qquad \sigma = 0.55 \text{ for } M_w > 8$$

Attenuation relationships were also developed for spectral velocity on rock sites applicable in the distance range of 20 to 150 km. Median spectral velocities, S_v, are estimated by multiplying the median peak accelerations obtained from the above relationships by values of the ratio S_v/a_{max} given by the following equations.

for T = 0.1 sec $\ln(S_v/a_{max}) = 3.431$
for T = 0.2 sec $\ln(S_v/a_{max}) = 4.278 - 0.0026(10 - M_w)^3$
for T = 0.3 sec $\ln(S_v/a_{max}) = 4.652 - 0.0044(10 - M_w)^3$
for T = 0.5 sec $\ln(S_v/a_{max}) = 5.076 - 0.0101(10 - M_w)^3$
for T = 1.0 sec $\ln(S_v/a_{max}) = 5.140 - 0.0145(10 - M_w)^3$
for T = 2.0 sec $\ln(S_v/a_{max}) = 4.960 - 0.0189(10 - M_w)^3$

The comparison shown in Figure 4 indicates the above relationships give similar estimates of near-field ground motion to those developed by Heaton and Hartzell (1986). Examination of these relationships indicates near-field (20 to 30 km source-to-site distances) high frequency ground motions from great subduction zone thrust earthquakes are not expected to have greatly different amplitudes than may result from large shallow crustal earthquakes at similar distances.

PUGET SOUND GROUND MOTIONS

The above relationships were used to estimate ground motions in the Puget Sound region resulting from postulated subduction zone earthquakes. Figure 5 presents a schematic east-west cross section through western Washington. Shown are the locations of observed intraslab seismicity and the postulated seismogenic plate interface. Figure 6 compares the estimated 5%-damped response spectra for large intraslab and interface earthquakes. The distances from these zones to Seattle are approximately 50 and 70 km, respectively. The comparison shown in Figure 6 indicate that ground motions in the Puget Sound region resulting from large intraslab earthquakes, such as those that occurred in 1949 and 1965, may be comparable to those resulting from postulated $M_w \geq 8$ events occurring on the North America-Juan de Fuca plate interface to the west.

REFERENCES

Coppersmith, K.J., and R.R. Youngs, Seismic hazard analysis using expert opinion: an example from the Pacific Northwest: in GSA Memoir on Neotectonics in Earthquake Evaluation, E. Krinitsky, ed., (in press).

Day, S.M, and J.L. Stevens, 1987, Simulation of ground motion from the 1985 Michoacan, Mexico earthquake (abs.): Eos, v. 68, p. 1354.

Heaton, T.H., and S.H. Hartzell, 1986, Estimation of strong ground motions from hypothetical earthquakes on the Cascadia subduction zone, Pacific Northwest: U.S. Geological Survey Open-File Report 86-328, 69 p.

Heaton, T.H., and S.H. Hartzell, 1988, Failure of self-similarity for large ($M_w > 8\frac{1}{4}$) earthquakes: Bulletin of the Seismological Society of America, v. 78, p. 478-488.

Youngs, R.R., S.M. Day, and J.L. Stevens, 1988, Near-field ground motions on rock for large subduction zone earthquakes: Proceeding of Earthquake Engineering Soil Dynamics II, ASCE, Park City Utah, June 27-30, p. 445-462.

and intraplate earthquakes, the controlling factor in ground motions for engineering design at rock sites again appears to be the rock characteristics directly beneath the site, specifically the density, shear-wave velocity and the quality factor Q or attenuation.

An additional advantage of the BLWN-RVT methodology is the ability to easily incorporate non-linear soil response directly into the ground motion analyses using RVT and the plane-wave propagators of Silva (1976) in an equivalent-linear formulation. This is an important consideration in seismic hazard evaluations in the Pacific Northwest because of the widespread existence of alluvial deposits beneath many of the cities in Washington and Oregon.

In this study, we have applied the BLWN-RVT methodology to generate response spectra to compare with recordings of the 1949 M 7.1 Olympia and 1965 M 6.5 Seattle-Tacoma earthquakes as recorded by the strong motion instruments located in the Highway Test Office in Olympia and the Federal Office Building in Seattle. Both earthquakes occurred within the subducting Juan de Fuca plate. Incorporating site-specific shear-wave velocity and density data on the subsurface geology beneath these two sites and the source parameters of the two earthquakes, we have been able to match quite well the average response spectral shape computed from the actual strong ground motion recordings. Based on the BLWN-RVT approach, predicted time histories and response spectra for a postulated M 8 Cascadia earthquake have also been generated for the Olympia site.

REFERENCES

Boore, D. M., 1983, Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra, Bulletin of the Seismological Society of America, v. 73, p. 1865-1984.

Boore, D. M. and Atkinson, G. M., 1987, Prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America, Bulletin of the Seismological Society of America, v. 77, p. 440-467.

Hanks, T. C. and McGuire, R. K., 1981, The character of high-frequency strong ground motion, Bulletin of the Seismological Society of America, v. 71, p. 2071-2095.

Silva, W. J., 1976, Body waves in a layered anelastic solid, Bulletin of the Seismological Society of America, v. 66, p. 1539-1554.

Woodward-Clyde Consultants, 1988, Estimated ground motions for a New Madrid event, prepared for Waterways Experiment Station, Corps of Engineers (unpublished report).

Woodward-Clyde Consultants, 1989, Engineering characterization of strong ground motion recorded at rock sites, prepared for Electric Power Research Institute (unpublished report).

ATTENUATION RELATIONSHIPS FOR EVALUATION OF SEISMIC HAZARDS FROM LARGE SUBDUCTION ZONE EARTHQUAKES

by
R.R. Youngs and K.J. Coppersmith
Geomatrix Consultants
San Francisco, California

The evaluation of seismic hazards in western Washington and Oregon from potential earthquakes occurring on the Cascadia subduction zone requires the ability to estimate ground motions in the near-field (<50 km) of large (perhaps > M_w 8) subduction zone earthquakes. Published attenuation relationships for subduction zone earthquake ground motions are based on data recorded at distances greater than 50 km from $M_w \leq 8$ events. This paper summarizes the work done to develop ground motion attenuation relationships appropriate for estimating peak acceleration on rock and soil sites and spectral velocities on rock sites in the near-field of large subduction zone earthquakes (the studies are presented in more detail in Youngs et al., 1988). The attenuation relationships were developed by combining the results of regression analysis of recorded ground motion data and numerical simulations of accelerograms for large earthquakes. The empirical data consist of the available strong motion recordings, including those from the 1985 events in Chile and Mexico. The empirical attenuation relationships were extended to events larger than M_w 8 using numerically simulated near-field ground motions for events of magnitude $M_w \geq 8$. The simulations were calibrated using near-field strong motion recordings obtained from the 1985 events in Chile and Mexico.

The results of the analysis were expressed in the form of attenuation relationships for peak acceleration and 5%-damped spectral velocity applicable to events in the magnitude range of M_w 5 to 9½ and for source-to-site distances of 20 to 500 km. The attenuation relationships were used as part of an large probabilistic seismic hazard analysis conducted for the Satsop Nuclear Power Plant in western Washington (Coppersmith and Youngs, in press).

RESULTS OF EMPIRICAL DATA ANALYSIS

Figures 1 and 2 compare the attenuation relationships developed from regression analysis with the empirical strong motion data for rock and soil sites, respectively. The main conclusions drawn from the statistical analysis of the empirical data are:

- Peak accelerations on soil sites are expected to be larger than on rock sites
- Ground motions from intraslab earthquakes (occurring within the subducting slab) are significantly larger than those from interface earthquakes (occurring between the subducting and overriding plates).
- The dispersion of individual peak values about the attenuation relationship is magnitude-dependent.

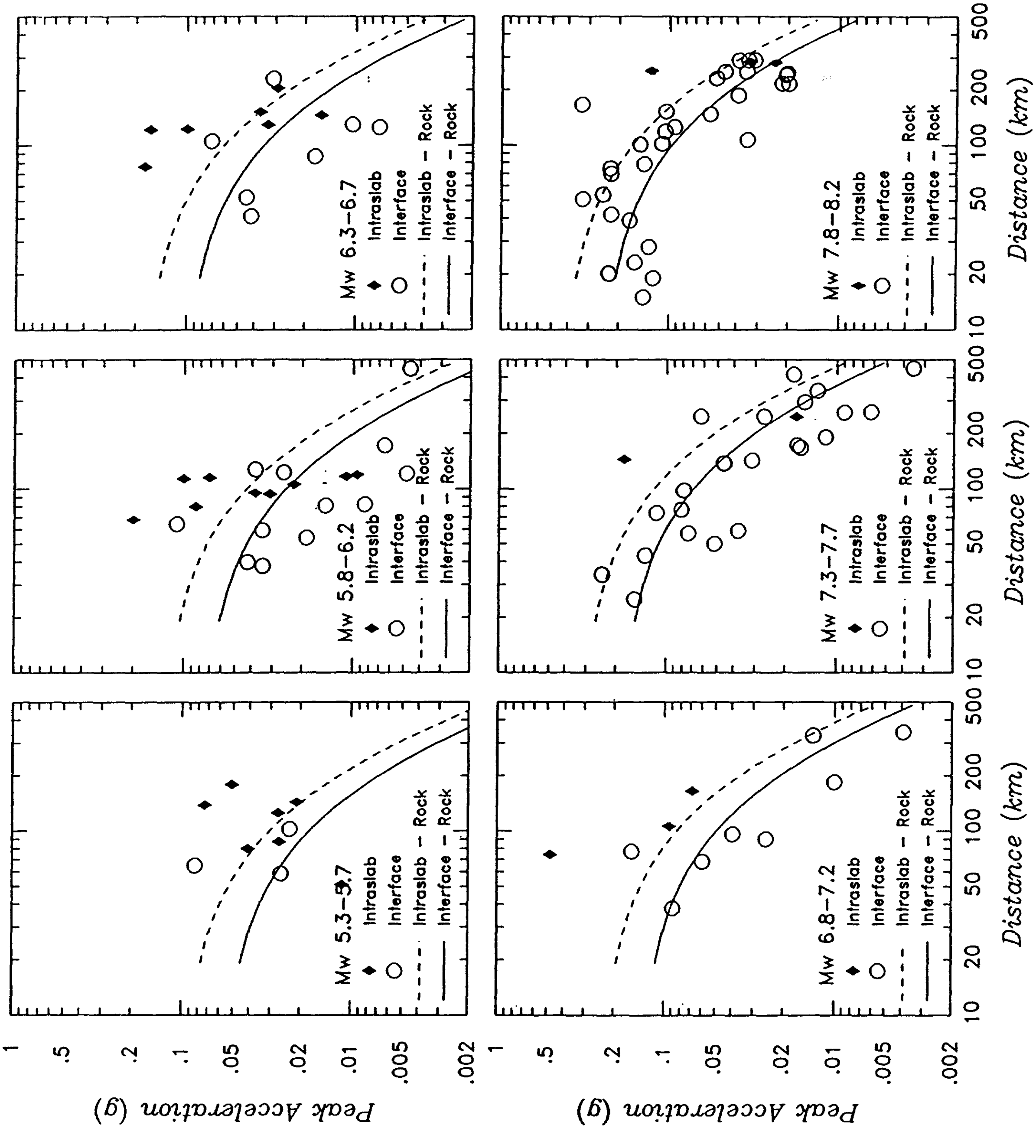


Figure 1. Median attenuation relationship for peak acceleration on rock compared with recorded data.

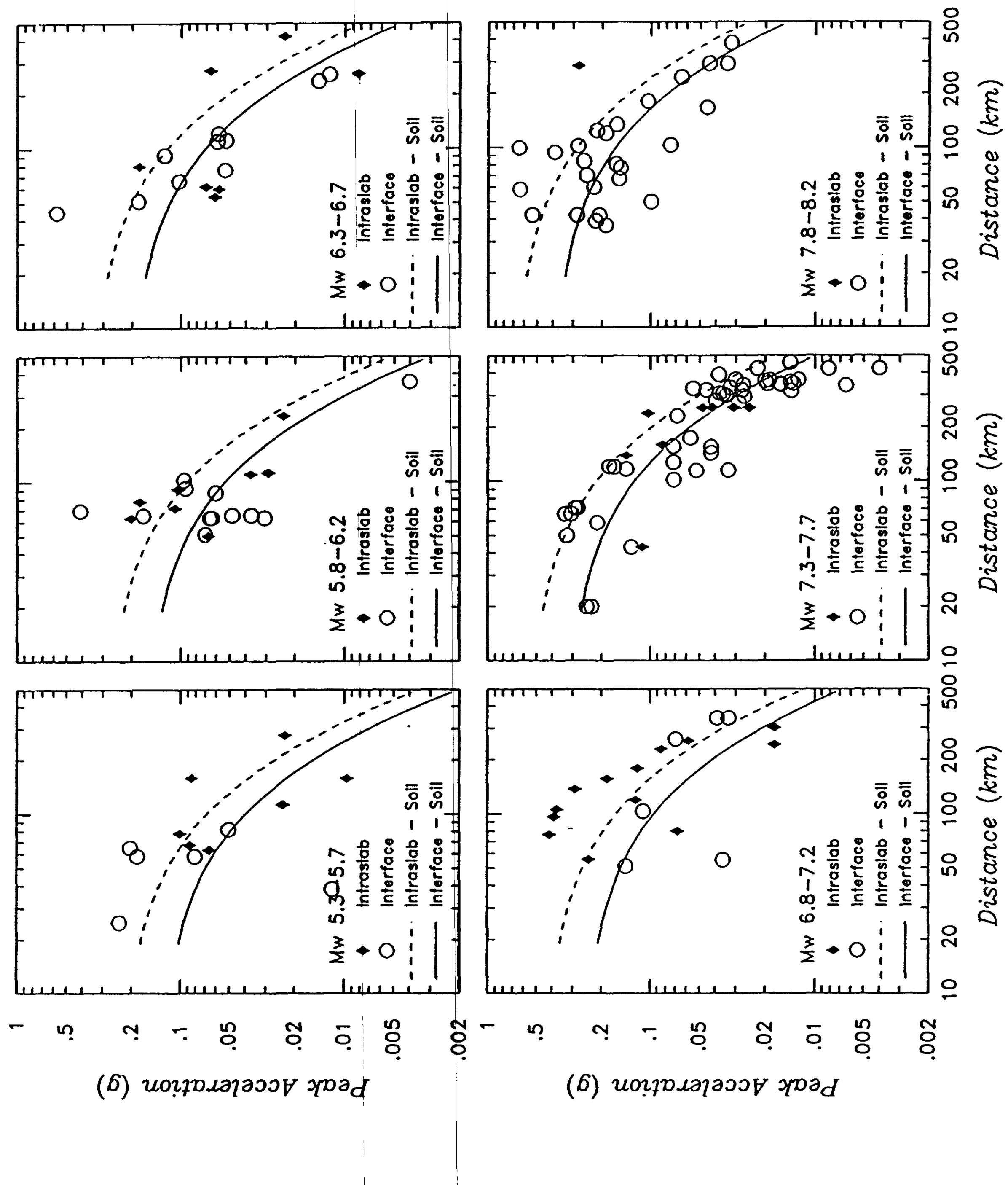


Figure 2. Median attenuation relationship for peak acceleration on firm soil compared with recorded data.

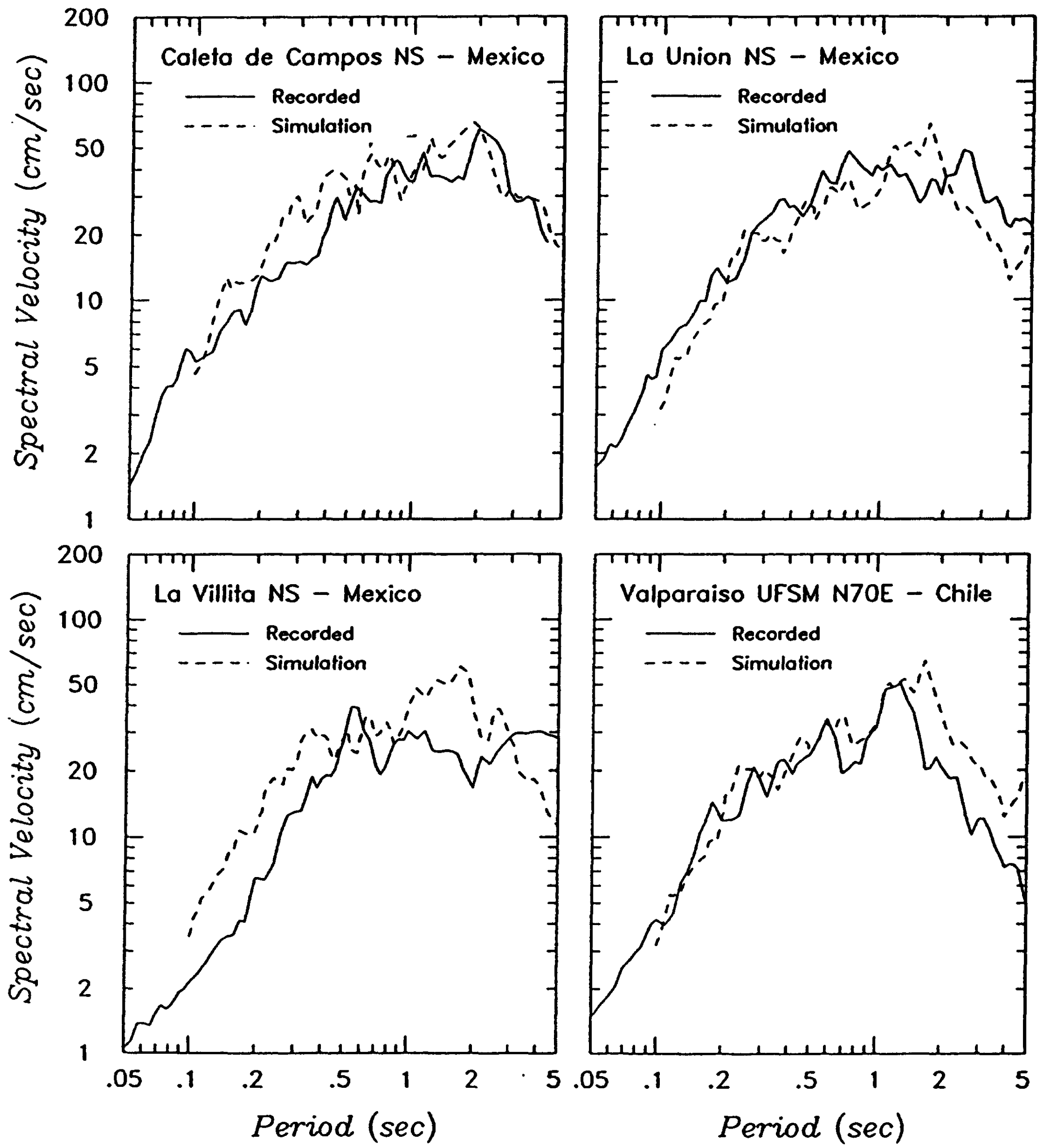


Figure 3. Comparison of 5%-damped response spectra for simulated and recorded motions for the 1985 M_W 8 Mexico and Chile earthquakes.

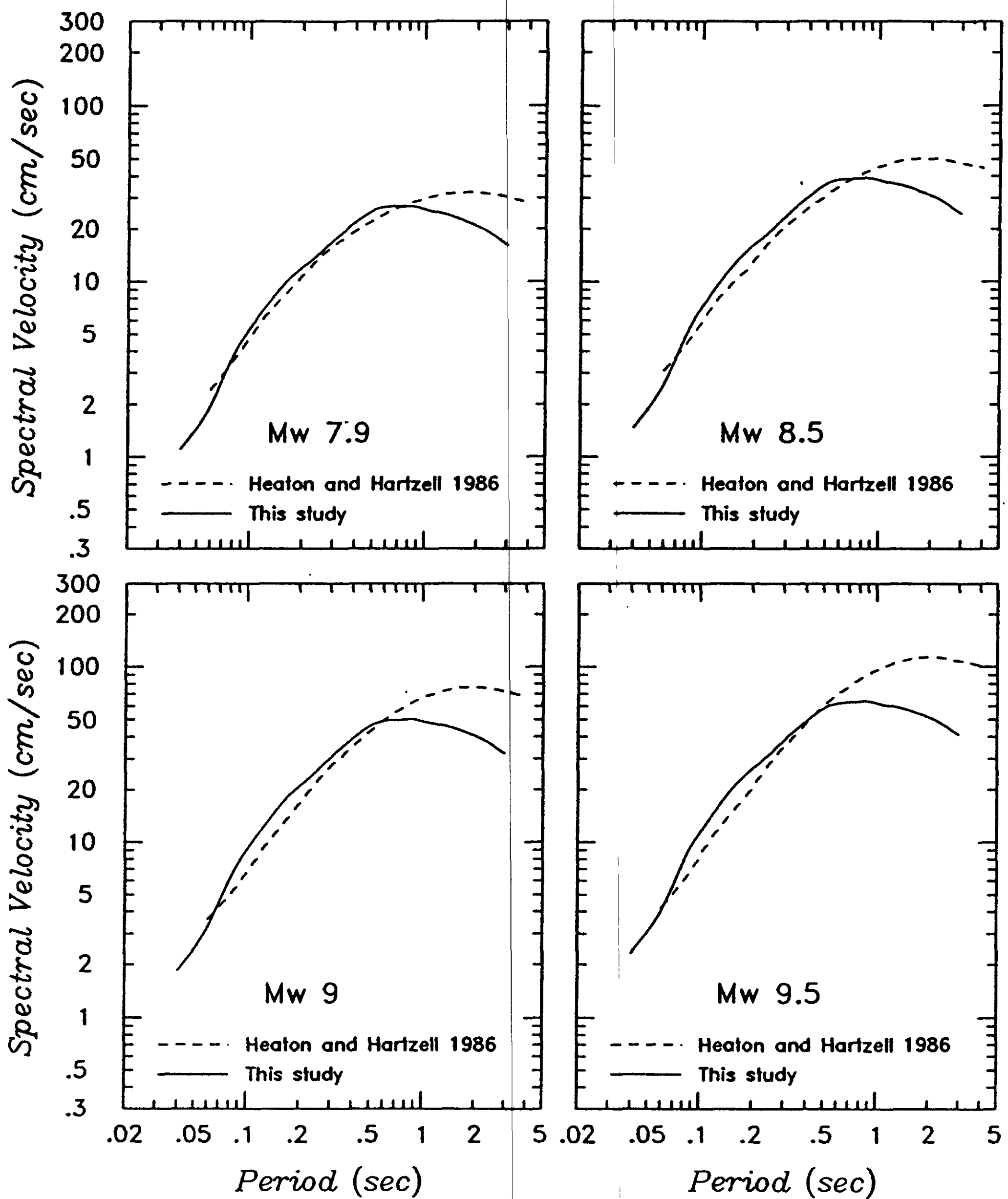


Figure 4. Comparison of 5%-damped response spectra predicted by the relationships given in this paper with response spectra developed by Heaton and Hartzell (1986).

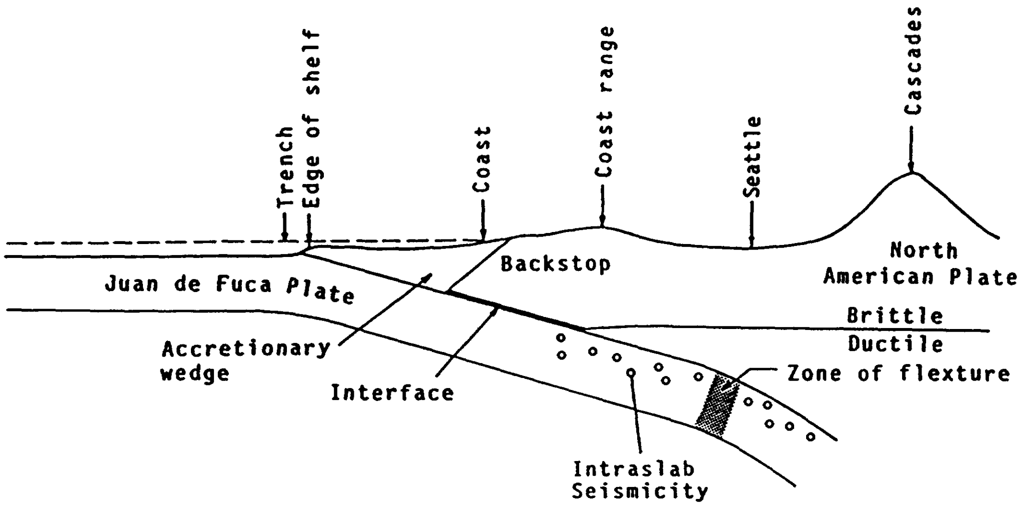


Figure 5. Schematic east-west cross section of Cascadia subduction zone through Puget Sound.

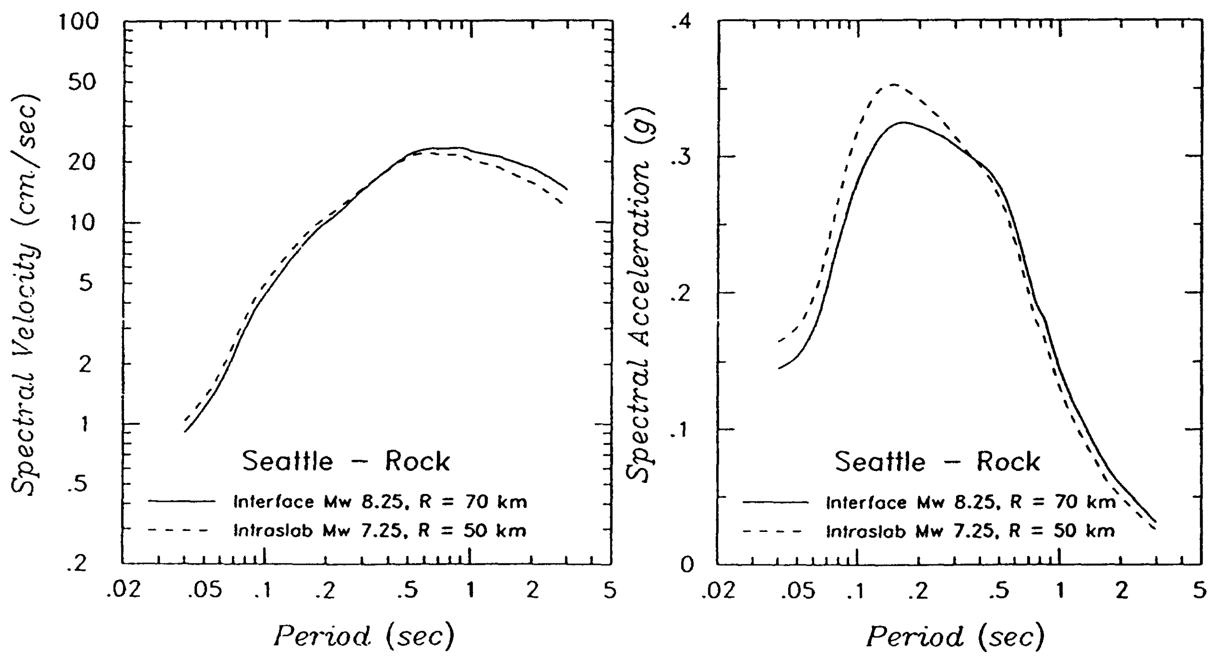


Figure 6. Comparison of median 5%-damped response spectra for rock site in Seattle from large interface and intraslab earthquakes.

STRONG GROUND MOTION ATTENUATION IN THE PUGET SOUND-PORTLAND REGION

Paul Somerville
Woodward-Clyde Consultants
566 El Dorado Street, Pasadena, California 91101. (818) 449-7650

We are currently performing studies of strong ground motion attenuation in the Puget Sound-Portland region for the United States Geological Survey. The program of studies is planned to address three different categories of potential earthquake sources: the subduction earthquakes on the plate interface, Benioff zone earthquakes within the subducting Juan de Fuca plate (such as the 1949 Olympia and 1965 Seattle earthquakes), and earthquakes within the crust of the overriding North American plate. For each category of earthquake, the program will provide attenuation relations for peak acceleration and response spectral ordinates, and representative acceleration time histories.

SUBDUCTION EARTHQUAKES ON THE CASCADIA PLATE INTERFACE

The interface between the Juan de Fuca and North American plates underlies the coastal regions of Oregon, Washington, and Vancouver Island. In contrast with other subduction zones, which typically generate great earthquakes (magnitude 8 1/4 and larger) with recurrence intervals of several tens to hundreds of years, the Cascadia subduction zone is not known to have generated any earthquakes during historical time. Consequently, we must use strong motion recordings from other subduction zones, together with ground motion simulation methods, in order to estimate the ground motion characteristics of potential subduction earthquakes in the Pacific Northwest.

The occurrence of the magnitude 8 earthquakes off Michoacan, Mexico and Valparaiso, Chile in 1985 provided valuable sets of strong motion recordings for use in the estimation of ground motions of Cascadia subduction earthquakes. These accelerograms have been used by several researchers both in the development of empirical attenuation relations, and in the validation of ground motion simulation methods that have then been applied to Cascadia. Strong reflections from the base of the subducting crust are required to explain the gradual rate of ground motion attenuation of subduction earthquakes. At the workshop, acceleration time histories, response spectra and attenuation relations for the Puget Sound-Portland region derived from ground motion simulations of Cascadia subduction earthquakes will be presented and compared with the results of other investigators.

Several important conclusions can be drawn from the results of these recent studies. First, there is generally good agreement in the ground motion estimates obtained by different researchers; this is presumably because they are all using the recently augmented strong motion data base either directly or to validate simulation methods. Second, the largest source of variability in the strong motion data base, and of uncertainty in the estimation of ground motion characteristics in Cascadia, is due to local site conditions. A strong motion recording on rock above the Valparaiso earthquake is quite similar to rock recordings above the Michoacan event, but several times smaller in amplitude over a broad range of frequencies than recordings of the Valparaiso earthquake at nearby soil sites. Third, there presently exists more uncertainty in the estimation of long-period motions (periods longer than 1 sec) than for short-period motions.

These results have the following implications for the estimation of ground motions of subduction earthquakes in Cascadia. Assuming that the source characteristics of potential Cascadia subduction events are comparable to those of the 1985 Michoacan and Valparaiso events, we are now able to make quite accurate estimates of rock site ground motion characteristics of magnitude 8 subduction earthquakes in Cascadia, especially at the shorter periods (less than 1 second). However, site-specific information on subsurface seismic velocities and soil characteristics may be required in order to obtain accurate estimates of ground motion characteristics on specific soil sites. This is of special importance in the Puget Sound and Portland regions, because of the presence of variable thicknesses of glacial and alluvial deposits in these regions. This highlights the importance of obtaining and using information on shallow seismic velocities in the estimation of strong ground motions.

It has already been noted that the estimation of ground motion characteristics at longer periods (longer than 1 second) is also subject to a significant degree of uncertainty. This is due to the greater variability at longer periods in the recorded ground motion data, which reflects the influence of deep seismic velocity structure, especially that of sedimentary basins, in controlling the amplitudes of seismic surface waves. The basin effects that are represented in the strong motion data base of earthquakes from other subduction zones may not be representative of the basin effects that control long-period ground motions in the Puget Sound and Portland regions. In this case, ground motion simulations that use basin models specific to the Puget Sound and Portland regions may be required in order to obtain accurate estimates of long-period ground motions.

BENIOFF ZONE EARTHQUAKES WITHIN THE SUBDUCTED SLAB

Historically, the largest earthquakes in the Puget Sound region have occurred not on the subduction interface, but within the subducted Juan de Fuca plate. The two largest of these Benioff zone events have been the magnitude 7.1 Olympia earthquake of 1949, and the magnitude 6.5 Seattle earthquake of 1965, which both caused extensive damage. There is the potential for the occurrence of similar earthquakes beneath the Portland region. The strong motion recordings of the 1949 and 1965 events, together with recordings of Benioff zone events in other subduction zones, provide a substantial basis for the estimation of strong motions from this category of earthquakes. Ground motion simulation techniques are currently being used in conjunction with the recorded strong motion data to develop attenuation relations specific to Benioff zone earthquakes in the Puget Sound-Portland region.

CRUSTAL EARTHQUAKES IN THE OVERRIDING NORTH AMERICAN PLATE

In the Puget Sound-Portland region, the crust of the North American plate, which is overriding the subducting Juan de Fuca plate, is characterized by numerous small earthquakes. However, no large earthquakes are known to have occurred in the crust during historical time (although a magnitude 7.3 crustal earthquake occurred on Vancouver Island in 1946). Consequently, we do not have strong motion recordings in the Puget Sound and Portland regions from earthquakes in this source zone. However, weak motion recordings obtained on earthquake monitoring networks can be used, together with strong motion simulation techniques, to estimate the ground motion characteristics of large crustal earthquakes. The basin structure of the Puget Sound and Portland regions is expected to have an important influence on strong motion characteristics of crustal earthquakes, especially at periods longer than 1 second.

ESTIMATES OF STRONG GROUND MOTIONS IN THE SEATTLE-PORTLAND REGION FROM HYPOTHESIZED MAGNITUDE 8 CASCADIA SUBDUCTION EARTHQUAKES

by

Paul Somerville, Brian Cohee and Mrinal Sen
Woodward-Clyde Consultants
566 El Dorado Street, Suite 100
Pasadena, CA 91101

INTRODUCTION

This summary report describes estimates of strong ground motions for hypothetical M_w=8.0 subduction zone thrust earthquakes in the Puget Sound - Portland region using a semi-empirical computational method. The use of strong motion simulation procedures is motivated by the complete absence of subduction earthquakes on the Cascadia subduction zone during historical time (and the consequent absence of strong motion recordings of such events). We compare our ground motion estimates with those derived empirically from global data bases of strong motion recordings of subduction earthquakes, and with the strong motions recorded in the Puget Sound region during the 1949 Olympia and 1965 Seattle Benioff zone earthquakes.

The simulation procedure (Wald and others, 1988), illustrated schematically in Figure 1, assumes that the rupture surface may be represented by a grid of fault elements. Green's functions are computed with generalized ray theory in an appropriate two-dimensional velocity structure for each element-receiver propagation path. Scattering, attenuation structure, and off-path propagation are not deterministically modelled, but are contained in the individual fault element "source functions" which are constructed from corrected accelerograms from M_w~6.9 Michoacan, Mexico and Valparaiso, Chile aftershocks. The "source functions" also contain information about the recording site, allowing different site conditions to be empirically included in the simulation procedure. Spatial variations in slip on the fault (asperities) are introduced by weighting the fault elements, and the synthetic accelerogram is generated by lagging and summing element contributions as rupture moves across the fault plane.

VALIDATION AGAINST THE 1985 MICHOACAN AND VALPARAISO EARTHQUAKES

We have validated the procedure for large subduction zone earthquakes by modeling acceleration time histories and response spectra from the 1985 Michoacan (M_w=8.1) and Valparaiso (M_w=8.0) mainshocks. For the 1985 Michoacan, Mexico earthquake, Mendoza and Hartzell (1989) obtained a fault strike of 300° and dip of 14° with a hypocentral depth of 17 km based on teleseismic modeling studies. The 150 km by 140 km fault model of the mainshock is divided into fault elements as shown in Figure 2a. The numbers inside the fault elements are values of slip derived from the slip model of Mendoza and Hartzell (1989). With the hypocenter fixed at a depth of 17 km, this fault plane spans a depth range of 6 to 40 km. The seismic moment of 1.4 x 10^{28} dyne-cm from Mendoza and Hartzell (1989) is used for the mainshock. The strong motion displacements above the rupture surface of the Michoacan earthquake indicate a slip duration (rise time) of ten seconds. This slip duration was simulated by sequentially adding the empirical source function, whose rise time was estimated to be 1.7 seconds, six times. A comparison of recorded and simulated accelerograms at Caleta de Campos is shown in Figure 4a. The simulations show close agreement in peak acceleration, overall duration of strong motion, and frequency content. Figure 5a shows a comparison of recorded and simulated response spectra at 5% critical damping for the five closest coastal rock stations (Caleta de Campos, La Villita, La Union, Zihuatenejo, and Poponoa).

For the 1985 Valparaiso, Chile earthquake, Houston (1987) used a fault dip 25^0, strike of 10^0 and a slip of 96^0, and a seismic moment of 1.0 x 10^{28} dyne-cm. The fault area was chosen to be 210 X 75 km^2 on the basis of that study and the aftershock distribution pattern obtained by Choy and Dewey (1988). The mainshock fault area was divided into 7 elements along strike and 3 elements down-dip, as shown in Figure 3a. Rise times of six and three seconds respectively were used for the mainshock and the subevent. The distribution of slip on the fault was based on the moment release model of Houston (1987).

Figure 5 shows that the recorded strong ground motions of the Valparaiso earthquake on rock sites (panel b) were significantly smaller than those recorded on soil sites (panel c), but comparable to rock site motions from the Michoacan earthquake (panel a). Recorded and simulated response spectra at the rock site Valparaiso U.F.S.M. are shown in Figure 5b; this simulation used the Valparaiso U.F.S.M. recording of the March 3 aftershock. Recorded and simulated response spectra averaged over the five closest soil sites (stations SAF, LLA, VINA, VALU, and LLO) are shown in Figure 5c; these simulations used the Vina del Mar recording of the same aftershock. The large difference between rock and soil motions is apparent from a comparison of Figures 5b and 5c. A comparison of the recorded and simulated acceleration time histories at Llollelo, on soil, is shown in Figure 4b.

GROUND MOTION ESTIMATES FOR THE SEATTLE - PORTLAND REGION

The validation studies described above demonstrate that our simulation procedure provides estimates of strong ground motions of magnitude 8 subduction earthquakes whose peak acceleration, duration, and response spectra are in good agreement with recorded data. We now proceed to use this simulation procedure to estimate strong ground motions in the Seattle - Portland region from magnitude 8 subduction earthquakes on the Cascadia plate interface. Figure 6a shows fault models appropriate for the western Washington and Oregon areas respectively, which differ in fault dip (11°, 21°), length (150 km, 120 km), and downdip width (120 km, 75 km). For each model, three-component acceleration time series were computed for a grid of stations, and the dependence of ground motion on uncertainties in source parameters was quantified.

The sensitivity of ground motions to slip distribution on the fault was investigated using three generalized asperity models in which 60% of total moment was released in the shallow, middle and deep third of the fault respectively. Figure 7 shows an example of estimated horizontal peak acceleration for the three depth distributions of slip at each receiver location for the western Washington fault model. Peak accelerations for all sites along a line equidistant from the fault were averaged to produce a single value, and plotted against distance in Figure 8. When distance is defined as the closest distance to the fault plane, there is significant variability in peak horizontal accelerations for the three slip distribution models. However, when distance is defined from receiver to nearest asperity, the decay of peak acceleration with distance has relatively little scatter. This shows that uncertainty in slip distribution of the fault gives rise to a large degree of uncertainty in the expected ground motions. In contrast, the ground motions are not very sensitive to fault dip. Our simulations for soil and rock sites follow the behavior observed in Chile and Mexico for different site conditions: motions on soil sites are larger and more variable (particularly at periods greater than 1 sec) than motions recorded on rock sites.

Comparison With Other Ground Motion Estimates: The results of this study agree well with peak accelerations and response spectra predicted in the Pacific Northwest by other investigators using empirical strong motion data from other circum-Pacific subduction zones. Figure 9 shows empirically-based response spectral estimates by Heaton and Hartzell (1986) and Crouse and others (1988) for soil site ground motions in Seattle from a magnitude 8 earthquake, compared with two simulated response spectra. The first simulated response spectrum assumes the slip distribution of the 1985 Michoacan earthquake, which has slip concentrated at relatively shallow depths. The second is the average of the three slip models decribed above. The simulated response spectra are in generally good agreement with the empirically derived ones.

Comparison With Ground Motions Recorded During The 1949 And 1965 Events: For periods less than 1 sec, the estimated response spectral values in the Seattle - Portland region for a M_w=8.0 subduction earthquake are not much larger than those recorded during the 1949 magnitude 7.1 Olympia and 1965 magnitude 6.5 Seattle earthquakes that occurred in the Benioff zone, as shown in Figure 10. However, the duration of strong motion is expected to be significantly longer (60 sec vs. 10-20 sec), and the motions at periods less than 1 sec are expected to be significantly larger. In particular, large long period motions may be generated by waves that become trapped when they enter the deep sedimentary sequences of the Puget Trough and the Portland Basin.

REFERENCES

Cohee, B.P. and P.G. Somerville (1989). Simulated strong ground motions for hypothetical M_w = 8 earthquakes on the Cascadia plate interface, *Seismological Research Letters*, 60, p. 16; and manuscript in preparation.

Choy, G. L. and J. W. Dewey (1988). Rupture process of an extended earthquake sequence: teleseismic analysis of the Chilean earthquake of 3 March 1985, *J. Geophys. Res.*, 93, 1103-1118.

Crouse, C. B., Y. K. Vyas and B. A. Schell (1988). Ground motions from subduction zone earthquakes, *Bull. Seism. Soc. Am.* 78, 1-25.

Heaton, T. H. and S. H. Hartzell (1986). Estimation of strong ground motions from hypothetical earthquakes on the Cascadia subduction zone, Pacific Northwest, U. S. Geological Survey Open File Report 86-328.

Houston, H. (1987). Source Characteristics of Large Earthquakes at Short Periods, Ph.D. Thesis, California Institute of Technology, 129 pp.

Mendoza, C. and S. H. Hartzell (1989). Slip distribution of the 19 September 1985 Michoacan, Mexico earthquake: near-source and teleseismic constraints, *Bull. Seism. Soc. Am.* 79, in press.

Somerville, P.G., M.K. Sen and B.P. Cohee (1989). Simulation of strong ground motions recorded during the 1985 Michoacan, Mexico and Valparaiso, Chile subduction earthquakes, *Seismological Research Letters*, 60, p. 16; and manuscript in preparation.

Wald, D.J., L.J. Burdick and P.G. Somerville (1988). Simulation of acceleration time histories close to large earthquakes. *Earthquake Engineering and Soil Dynamics II - Recent Advances in Ground Motion Evaluation*, Geotechnical Special Publication 20, J. Lawrence Von Thun, ed., 430-444.

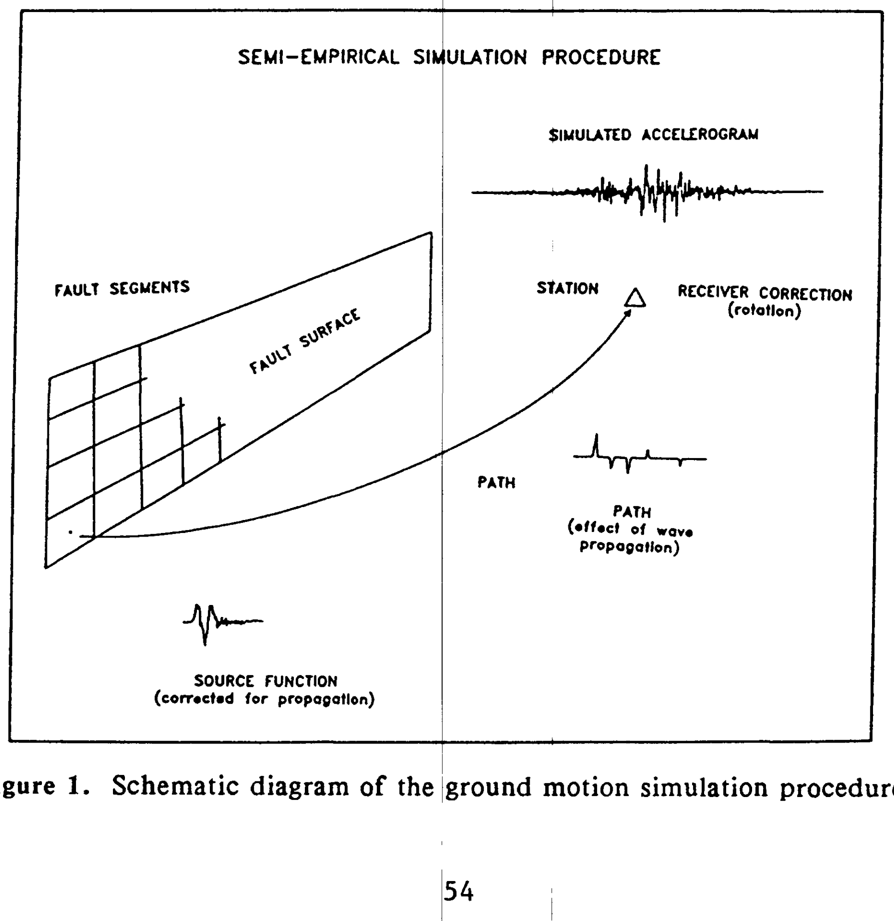


Figure 1. Schematic diagram of the ground motion simulation procedure.

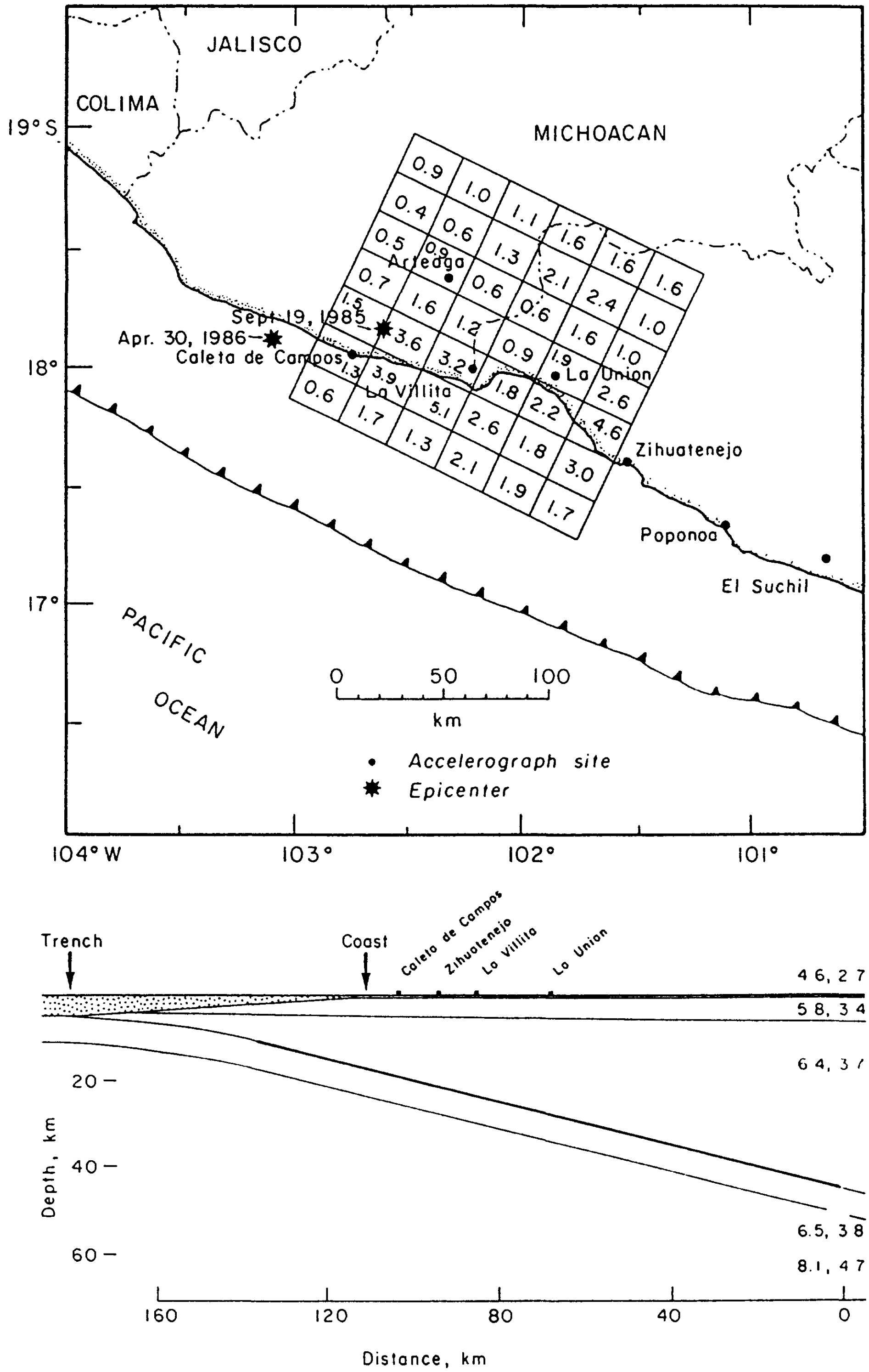


Figure 2. Source and station geometry for the 1985 Michoacan, Mexico earthquake: a) map view; numbers in fault elements represent slip in meters; b) vertical section.

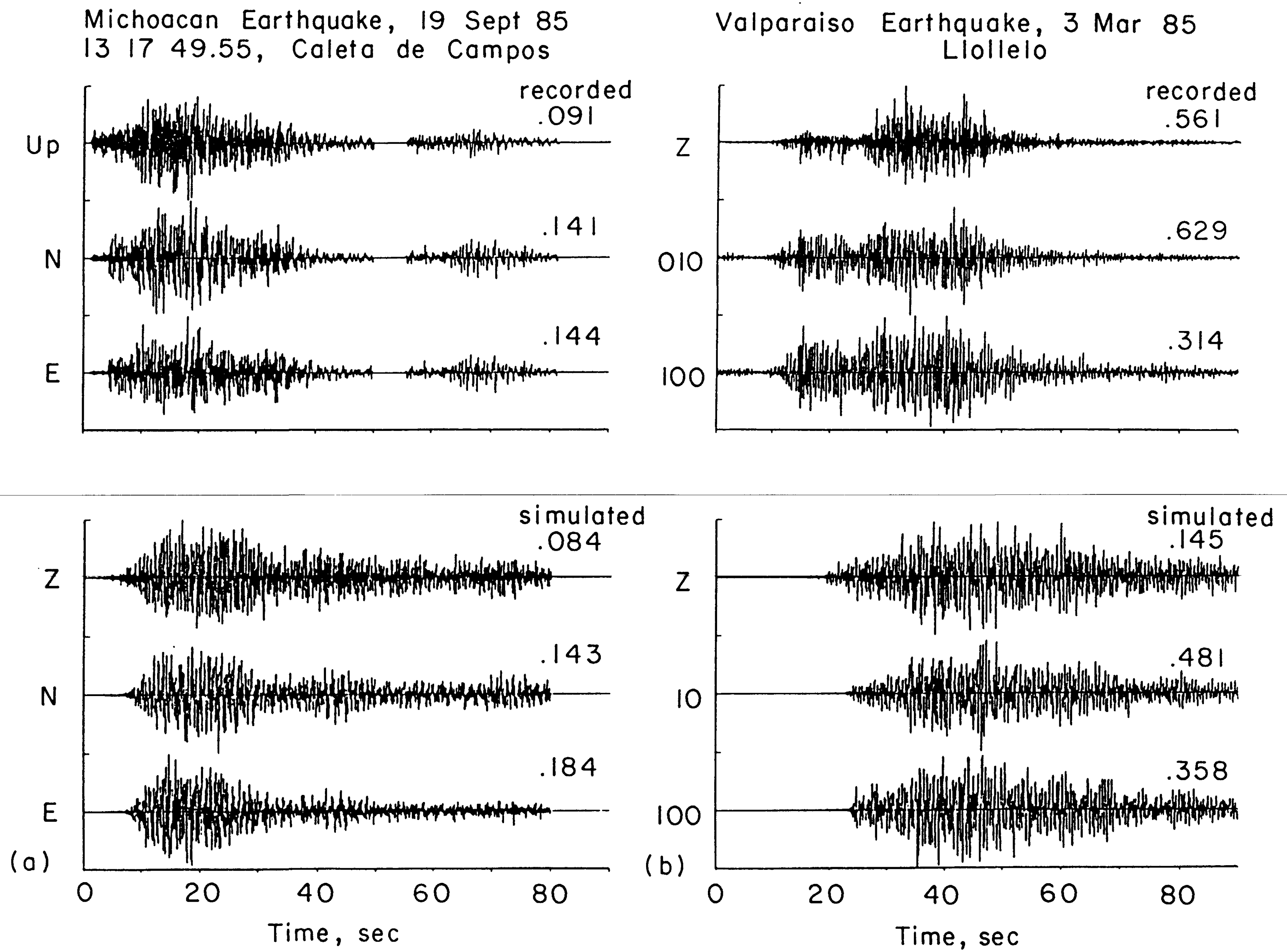


Figure 3. Comparison of recorded and simulated time histories: a) Caleta de Campos recording (rock site) of the 1985 Michoacan earthquake; b) Llollelo recording (soil site) of the 1985 Valparaiso earthquake.

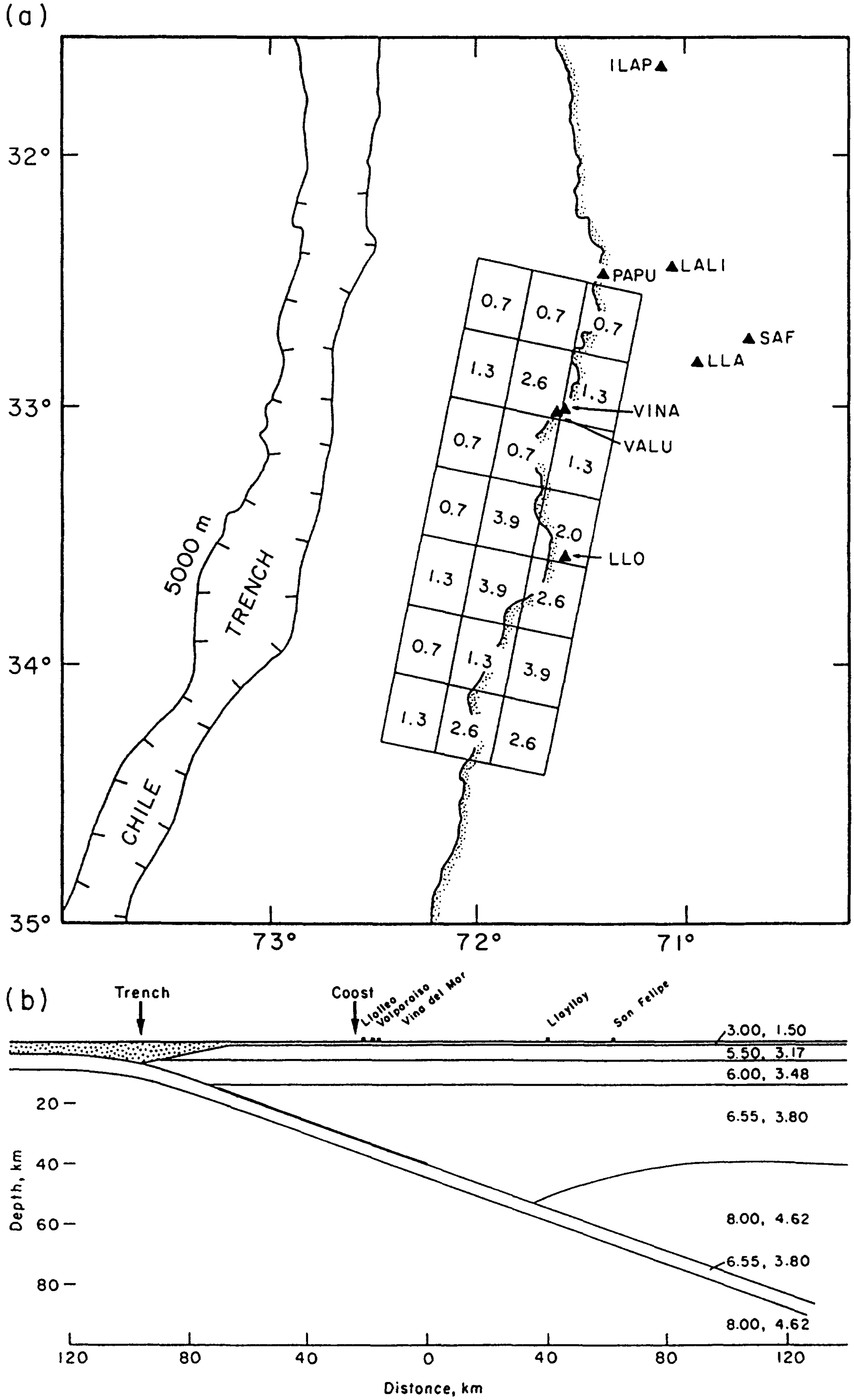


Figure 4. Source and station geometry for the 1985 Valparaiso, Chile earthquake: a) map view; numbers in fault elements represent slip in meters; b) vertical section.

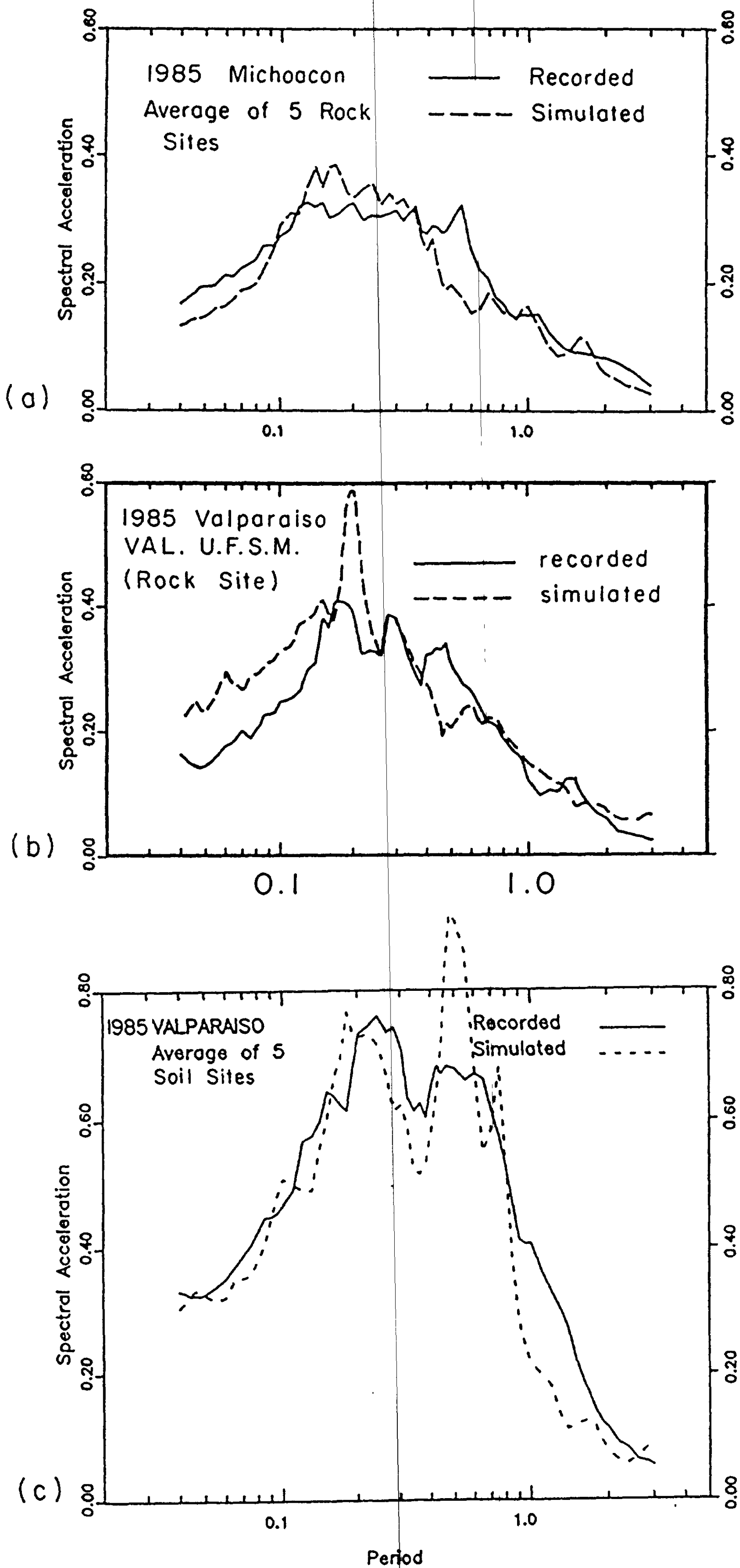


Figure 5. Comparison of recorded and simulated response spectra at 5% damping for: a) the Caleta de Campos recording of the Michoacan earthquake; b) the Valparaiso U. F. S. M. recording of the Valparaiso earthquake; and c) the Llollelo recording of the Valparaiso earthquake.

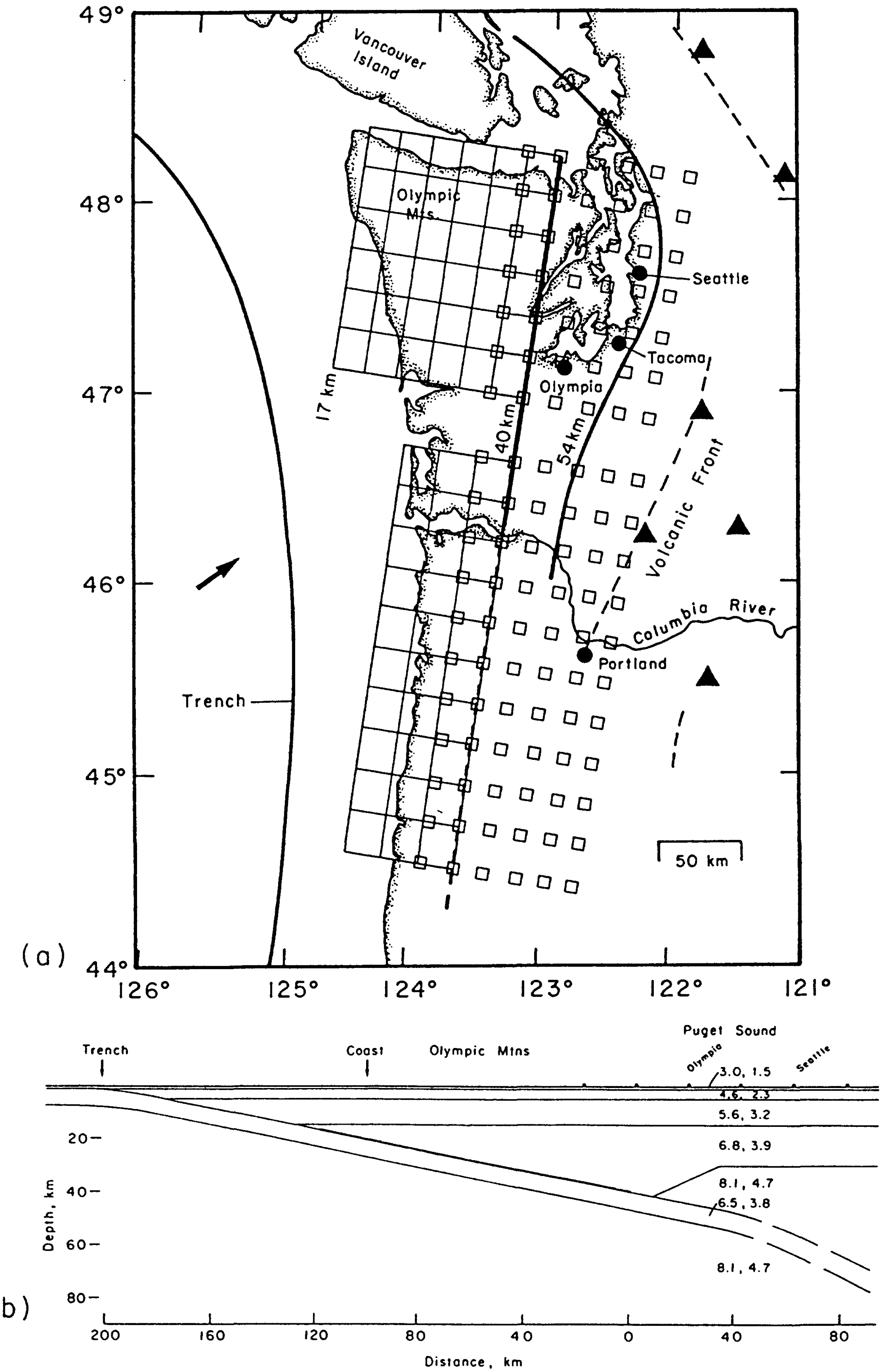


Figure 6. Source and station geometry for two hypothetical magnitude 8 subduction earthquakes in the Pacific Northwest: a) map view, showing source zones in western Washington and Oregon; b) vertical section through the western Washington zone.

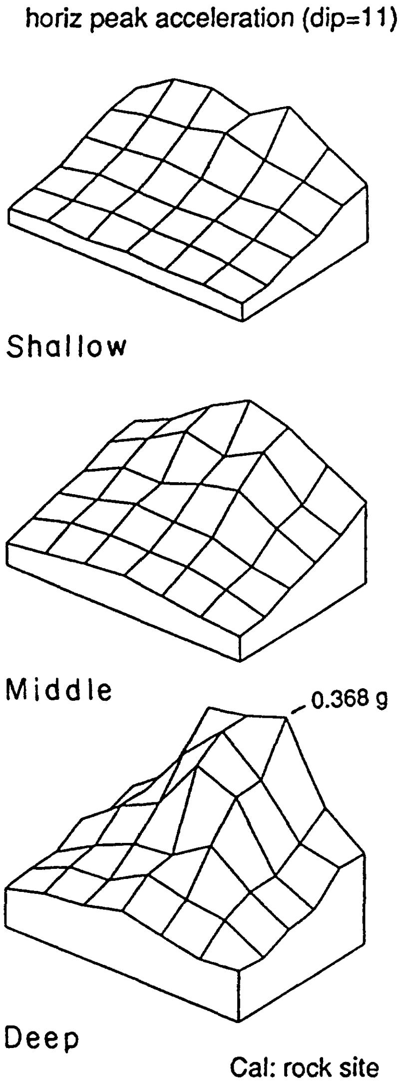


Figure 7. Average horizontal peak acceleration on soil on the grid of station locations for the western Washington earthquake source model for three depth distributions of slip: shallow, middle, and deep. The near corner is the northeasternmost station, and all peak accelerations are plotted on a common scale.

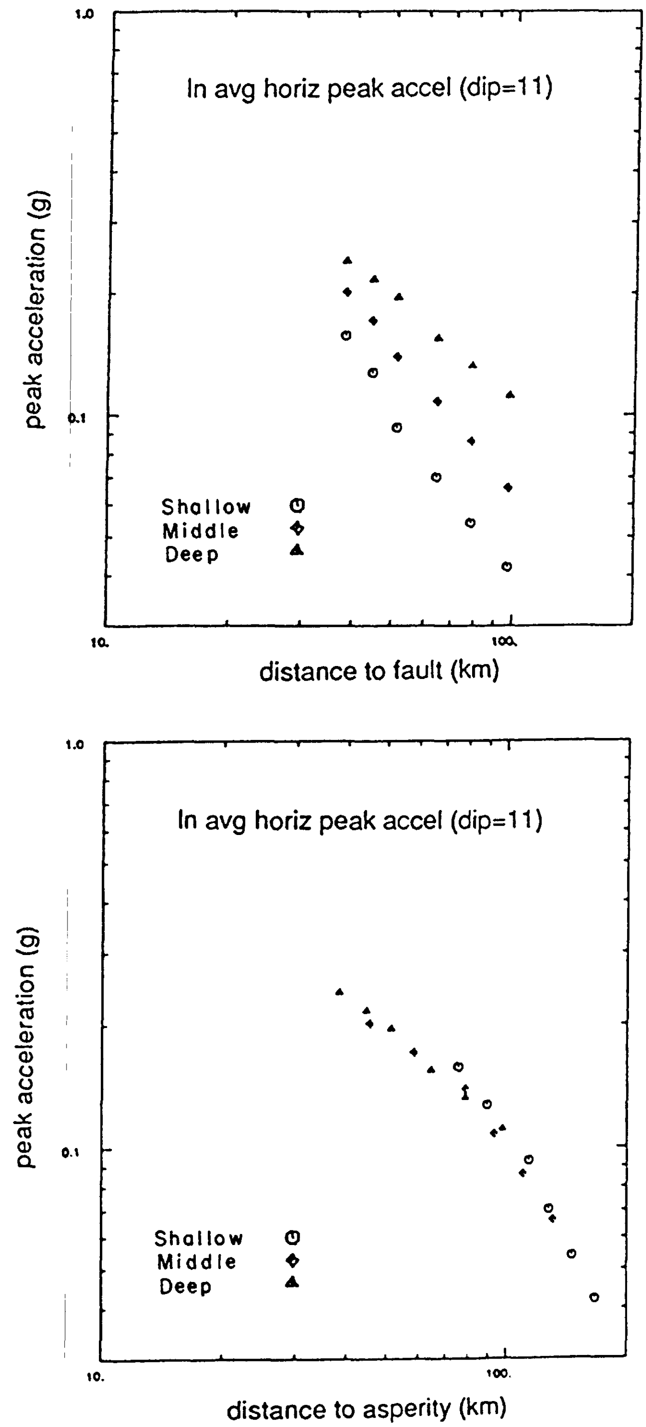


Figure 8. Average horizontal peak acceleration on soil vs. a): closest distance to the fault; and b) distance to nearest asperity for the western Washington earthquake source model for three depth distributions of slip.

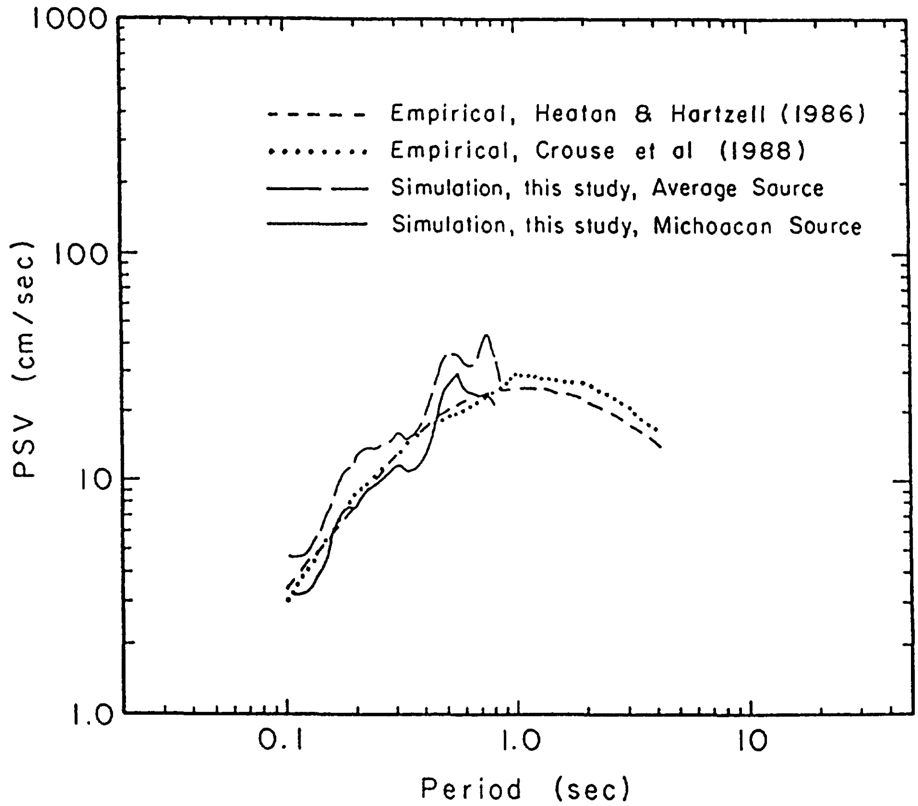


Figure 9. Comparison of simulated horizontal response spectra on soil in Seattle for two slip models of a magnitude 8 subduction earthquake with two estimates derived from global sets of recorded data.

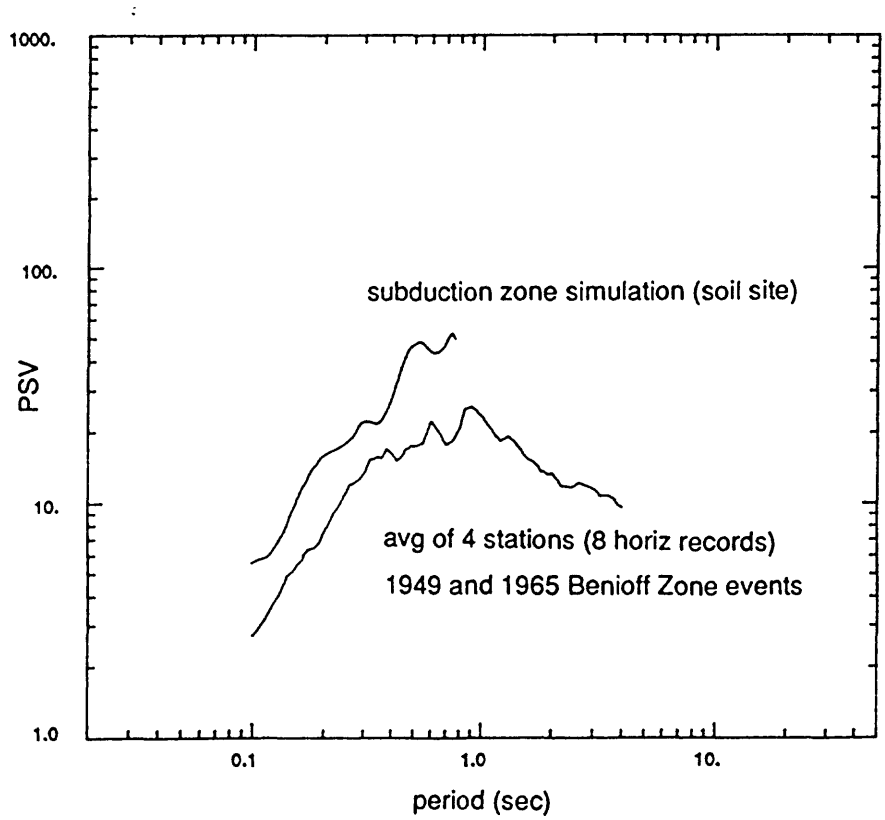


Figure 10. Comparison of simulated horizontal response spectra on soil for the Seattle - Olympia region for a magnitude 8 subduction earthquake with the average of eight horizontal components recorded in Seattle and Olympia from the 1949 and 1965 Benioff zone earthquakes.

THE STANDARD PENETRATION VERSUS DEPTH RELATIONS OF QUATERNARY GLACIAL AND NONGLACIAL DEPOSITS IN THE GREATER SEATTLE AREA, WASHINGTON: IMPLICATIONS FOR LIQUEFACTION SUSCEPTIBILITY STUDIES

By
J C. Yount, G. S. Vick, and G. McCoy
U.S. Geological Survey
Menlo Park, California

The greater Seattle area is underlain by a lithologically complex sequence of glacial and nonglacial gravels, sands, and muds of Quaternary age that show a wide range of physical properties. In this study, we explore the usefulness of one particular property, standard penetration, as an indicator of near-surface liquefaction potential for the water-saturated unconsolidated sediments in the Seattle area. Following Youd and others (1975), we examine the depth relations of standard penetration data for individual, mappable geologic units and compare the slopes of plots of standard penetration values, in blows per foot, versus depth for various lithologic and stratigraphic units in order to determine a relative ranking of liquefaction potential for the various units considered.

The standard penetration data is derived from approximately 150 boreholes in the Seattle South and Duwamish Head 7 1/2 ' quadrangles, and, except where noted, is confined to measurements made with a 2-inch outside diameter, split-spoon sampler dropped 30 inches with a 140 pound weight. Mappable geologic units are grouped into the following stratigraphic scheme: artificial fill (including circa 1900 hydraulic fill), Holocene alluvium, Vashon recessional outwash deposits, Vashon till, Vashon advance outwash deposits, pre-Vashon nonglacial deposits, and pre-Vashon glacial deposits. The units are further subdivided into dominantly muddy (silt and clay) and dominantly sandy sediment types. Plots of standard penetration, measured in blows per foot, versus depth for samples within 45 feet of the ground surface were prepared for each stratigraphic category, with muddy units plotted separate from sandy units.

The resulting plots show a great deal of variability through the studied depth range for any given stratigraphic class. The Vashon glacial deposits including tills and associated outwash show considerable variability as is typical of standard penetration data derived from gravelly sediments. In general, plots for fill and alluvium display less variability than do the plots for the glacial sediments, reflecting the more homogeneous nature of those sediments. Using the slope of the standard penetration-depth plot as a measure of a unit's sensitivity yields a crude three-fold classification, with muddy alluvium (.21) and muddy fill (.10) being most sensitive, muddy recessional (.45) and advance (.57) outwash, sandy alluvium (.61), and older glacial deposits (.49) making up an intermediate category, and sandy recessional (1.1) and advance (1.7) outwash, Vashon till (2.1), and pre-Vashon nonglacial mud (1.3) and sand (2.0) comprising the most stable category. Interestingly, the olot for sandy fill displays relatively steep slope (.94), perhaps reflecting improved techniques for emplacing fill in the recent past.

CONSIDERATIONS FOR DETERMINISTIC GROUND MOTION MAPPING IN THE PORTLAND-PUGET SOUND REGION

John C. Tinsley
Branch of Western Regional Geology

INTRODUCTION

The character of ground shaking at a point on the earth's surface is influenced by several factors. These include the size of the earthquake, the distance to the zone of seismic energy release, the manner in which the seismic energy is released, and the geologic conditions within the earth's mantle and crust. The latter is of interest here. Earthquake studies worldwide have demonstrated that geologic conditions at or near a site are known to exert a strong influence on the nature of ground shaking; noteworthy examples include the 1906 San Francisco earthquake, the 1933 Long Beach earthquake, the 1967 Caracas, Venezuela, earthquake, the 1985 Chilean earthquake, and the 1985 Michoacan earthquake that damaged parts of Mexico City. Mitigation of earthquake shaking damage will require identification of areas underlain by deposits which are especially susceptible to increased levels of ground motion compared to nearby areas. To do less is to invite an increased incidence of unpleasant surprises in the event of an earthquake.

The purpose of this deterministic study of geologic and geophysical factors influencing ground response in the Portland-Puget Sound region is to characterize how subsurface geology controls site-dependent aspects of ground response; that is, to appraise the degree to which earthquake-generated ground shaking might be rendered more severe or less severe compared to some reference site. If continued, this research would extend to the Puget Sound and Portland areas a methodology employed to characterize relative ground shaking in the San Francisco Bay region and the Los Angeles region of California, and the Wasatch region of Utah. The researchers in turn would be able to appraise the effects of a glacial history (Puget Sound area) and a mega-flood history (Portland basin area) on the seismic wave-propagation characteristics of earth materials. Regional aspects of both basin settings have yet to be analyzed using regional approaches that depend on a 3-dimensional appraisal of basin sediments.

METHODOLOGY

The empirical technique uses the methodology developed by Rogers and others (1985) whereby several geotechnical and geologic factors that are generally available from existing records of geotechnical studies and that are known to correlate with site response are used to predict how site conditions will influence ground motion during an earthquake. Sites are classified into site types or clusters according to their common geologic attributes and geotechnical factors, and a mean ground shaking factor which depends on the site's cluster type is assigned to the site in terms of 2 or 3 separate period bands, corresponding to period bands of interest for engineering purposes that range typically from 0.1-10 seconds.

The classification scheme developed for Los Angeles has been applied in a preliminary fashion for the Portland area (see poster session by Ian Madin and John Tinsley, this workshop). The maps are intended to guide future experiments to validate the technique for the Portland area, a basin that is quite shallow compared to the structurally deep basins of Los Angeles and the Wasatch area. Validation of the technique for the Portland and for the Seattle-Olympia areas will be accomplished by comparing recorded ground motions with predictions. By combining and comparing the cluster results at selected sites throughout the cities with maps showing the thickness and characteristics of geologic map units, maps of the ground-shaking response on different types of alluvium, glacial progradational and recessional deposits, estuarine and post-glacial alluvial deposits and Missoula Flood deposits can be ascertained. Provided the distribution of key properties is known in the subsurface across a region, maps showing the response relative to rock can be drawn for the period bands of interest on a regional basis.

The factors essential to the success of the Rogers and others' (1985) approach are several. The site types used in the San Francisco Bay region, the Los Angeles region, and the Wasatch region are not all-inclusive. Additional site types must be described, and additional ground motion data will have to be collected and new correlation techniques and collections of new site properties will have to be undertaken, tailored especially for the conditions in the Portland and Puget Sound areas. The latter will involve collection of uphole/downhole shear-wave velocity profiles at selected sites in the Portland and Puget Sound areas. Development of an understanding as to what factors control similar response at geologically different sites as well as different site response at geologically similar sites requires careful geologic and geophysical studies if reliable results are to obtain. The alluvial fan deposits of the San Francisco and Los Angeles regions and the pluvial lacustrine deposits of the Wasatch region differ markedly from the massive Missoula Flood deposits of the Portland area and the commonly overconsolidated glacial till deposits and outwash of the Puget Lowland. These studies in the Wasatch area have established for the first time that ultra-severe soil conditions that meet or exceed the criteria for category S-4 as specified by SEAOC (greater than 40 ft thickness of deposits having a shear-wave velocity of 500 ft/sec (150 m/sec) or less), resulting in design engineers having to employ increased lateral force coefficients in their designs for significant structures.

Whether or not a map is drawn, statistically significant suites of geologic parameters coupled to expected levels of ground shaking relative to rock would be of interest. An interested party could take a set of data known from explorations on their property and use the chart/matrix to decide in general terms the degree of site response likely to occur at that site.

CONCLUSIONS--PORTLAND AREA

A. The Portland Basin is relatively shallow compared with the Wasatch area, Utah and the Los Angeles area, California. The relatively thin sedimentary section near Portland is expected to show measurable site-dependent effects chiefly corresponding to the short period band (0.2-0.5 seconds) and perhaps at the short end of the intermediate period (0.5-3.0 seconds) as defined in the Los Angeles study. The long period response (3.0-10.0 seconds) in the Portland basin is expected to show little variation across the region and to have relatively minimal impact.

B. Variations in thickness and clast size among Missoula flood deposits are expected to be important factors controlling shear wave velocity and, thus, in evaluating site response in the Portland area.

C. The bedrock surface (Columbia River Basalts, for the Portland Basin) apparently slopes northeastwardly from surface exposures west of and beneath parts of the City of Portland to depths exceeding 1200 ft subsurface. Deployments of seismometers can take full advantage of this relatively simple structure; the significance of the thickening wedge of overburden could be determined reasonably well, with respect to azimuthal effects.

D. Shear-wave velocity data are lacking for the Portland area. In Portland, void ratios of sediments are rather high (generally greater than 1.0) and, thus, are not expected to correlate with shear-wave velocity; in Los Angeles, void ratio was reasonably well-correlated with shear-wave velocity, especially for Holocene and late Pleistocene alluvial deposits. Down-hole measurements of Vs will be needed to characterize the basin sediments; many of these can be made in existing, cased holes, usually production or observation water wells, saving considerable time and expense compared to the cost of drilling and casing holes for such studies.

E. Drilling is costly and money is scarce. Arrangements to conduct shear-wave profiling in properly-logged, existing boreholes is likely to prove to be an effective cost-cutting measure. Some drilling is likely to be required, as accessible boreholes may not be properly located.

CONCLUSIONS--PUGET SOUND REGION

A. The Puget Sound area has a complex Quaternary history in which a succession of glacial advances and retreats have strongly modified conditions in the subsurface. Conditions change rapidly laterally, and every effort must be made to appraise the degree to which deposits exposed at the surface extend to subsurface depths of interest for seismic hazards evaluations.

B. Initial geological explorations in the Olympia area (six sites) indicate that some areas show an excellent correlation between conditions at the surface and conditions at depths of as much as 500 ft subsurface. Preliminary reflection studies (Kenneth W. King, Golden, Colorado) indicate the sections investigated to date are relatively deep without many reflectors above 200-300 feet subsurface, a relation that is consistent with the exploratory drilling performed to date. A suite of 60 ground motion recordings were made in the Olympia-Lacey area, including 30 sites that reported damage and were assigned a Modified Mercalli Intensity damage level following the 1965 earthquake. This array of recordings, when interpreted as spectral ratios relative to bedrock in the period band 0.2-0.4 seconds closely mimics the pattern of Modified Mercalli Intensities (correlation exceeds 90%) [Ken King, personal communication, 1989].

C. Seattle is underlain by a significantly deeper basin than Portland; the site clusters developed for Los Angeles will have an inherently greater degree of applicability to the Puget Lowland than is likely to be the case in Portland. However, the rapid lateral changes in subsurface materials known to characterize parts of the Puget Lowland will make drawing maps a relatively difficult exercise, unless a good correspondence can be shown to exist between surficial materials, subsurface conditions, and site response.

D. In the West Seattle area, intensity maps by Algermissen and others showing the intensity effects of the 1965 earthquake expressed as percentages of chimneys damaged show some impressive variations. We have only drilled two holes to date in the West Seattle area, and have not got enough information to begin to evaluate the role of site-dependent effects in terms of the geology of the subsurface.

E. Shear-wave velocity data are lacking for the Puget Lowland and additional studies are needed to characterize the deposits for seismic zonation purposes.

F. Post-glacial deposits in the down-town Seattle area are likely to exhibit significant site effects, on the basis of preliminary work by Yount and by others.

REFERENCES CITED

Rogers, A. M., Tinsley, J. C. and Borcherdt, R. D., 1985, Predicting relative ground response in Ziony, J. I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth science perspective: U. S. Geological Survey Professional Paper 1360, p. 159-167.

Using Earthquake Intensities to Determine Ground Response in the Puget Sound Region

Anthony Qamar and Tom Bodle
Geophysics Program AK-50, University of Washington
Seattle, WA 98195

Introduction

We have begun a study of the variation of strong ground-motion during earthquakes in the Puget Sound-to-Portland region of Washington and Oregon using intensity data from past earthquakes. Our goal is to find earthquake intensity patterns that show consistency from earthquake to earthquake. We hope to discover geologic factors responsible for the observed patterns that can be used to predict intensity patterns for large earthquakes in the future. Similar methods have been used by Evernden (1975) and Evernden and Thompson (1985) to predict earthquake damage in California.

The attempts to find geologic factors that would account for the variation in chimney damage in West Seattle during the Seattle/Tacoma earthquake of 1965 are well known. Mullineaux found no obvious correlation with surface geology, and Langston and Lee (1983) suggested that deeper geologic structures might have been responsible. Yount (1983) proposed that areas in Seattle underlain by alluvium, fill, or the water saturated Esperance sand unit did show strong shaking effects, but only if bedrock was near the sensitive unit.

Method

So far, we have focused on the analysis of intensity data for the 1981 Elk Lake Washington earthquake, a shallow, magnitude 5.5 earthquake that occurred 130 km south of Seattle on February 14, 1981. We have digitized the locations of 3,378 earthquake sites in Washington and Oregon where we have felt reports that were obtained by Linda Noson immediately after the earthquake. The Puget Sound region, between 47° and 48°N and 122° and 123°W, is the area where we have the greatest concentration of felt reports (2651); See Figure 1.

The intensities reported for the 1981 earthquake are not as large as those reported for the 60 km deep, magnitude 7.1 and 6.5 Puget Sound earthquakes of 1949 and 1965. They fall mostly in the range III (*felt quite noticeably by persons indoors; vibration similar to the passing of a truck*) to V (*felt by nearly everyone; some dishes and windows broken; unstable objects overturned*) on the Modified Mercalli scale. However, the 1981 earthquake is valuable, from a statistical point of view, because of the large number of felt reports available, especially in the Seattle region. Although there is considerable variance in the apparent intensities reported for the 1981 earthquake, there are some patterns that emerge. In Figure 1, the data are smoothed to emphasize patterns with long spatial wavelengths. The region shown lies 75 to 175 km north of the epicenter and a regional gradient (one tenth unit per ten kilometers) has been removed from the estimated values of Modified Mercalli intensity to approximate the normal decrease of intensity with distance.

As seen in Figure 1, a prominent north-northwest trending ''ridge'' of relatively high intensity values extends from Tacoma to the northern Kitsap peninsula on the western side of the Puget Sound. On the other hand, relatively low values of intensity are seen in north Seattle and the southwest portion of the region that includes Olympia and the southern Kitsap peninsula. These patterns are not obviously correlated with gross structural features such as the distribution of glacial sediments whose thickness ranges from 0 to 1 km in this area.

The broad regional pattern of observed intensities does not seem to result from random variability of the intensity values assigned at each site. At the top right of Figure 1 is an example of the pattern obtained from randomizing the data. That is, the 2651 observed intensity values were randomly assigned to the actual sites before the data were smoothed and contoured. The randomized map does not produce an intensity pattern with amplitudes nearly as high as those seen in the observed data shown at top center. This can be seen also in the two profiles shown in Figure 1 at bottom right.

Shorter wavelength intensity patterns can be seen in Figure 2 which shows a relatively large number of high intensities east of Lake Washington. The location of these observations of high intensity is intriguing because it correlates with the area of relatively strong shaking reported during the recent earthquakes east of Lake Washington in January, 1989. In contrast, North Seattle showed a large number of low intensity values during the 1981 Elk Lake earthquake. A pattern of high intensity in West Seattle, noted during the 1965 earthquake, is not evident in the 1981 intensity data. Unfortunately, there are few data in 1981 along the river delta of the Duwamish river, an industrial area of Seattle that reported considerable damage in 1965. This is due to the fact that most of our data are taken from letters written by people in residential areas.

Table 1 summarizes the variation of intensity in the Seattle region (47.42° - 47.75°N., 122.17° - 122.46°W) as a function of surface geology during the 1981 Elk Lake earthquake. The geology has been lumped into three categories: *bedrock* (sediments of Tertiary age), *glacial sediments* (old clays, sands, gravels, and tills of Quaternary age), and *post glacial sediments* (young sands, gravels, alluvium, and fill that are recent or only a few thousand years old). The number of observations at bedrock sites is too small to draw firm conclusions. However, there is a tendency for sites on young, post glacial sediments to show stronger intensities than sites on older sediments. A χ^2 test on a contingency table using the intensity observations on glacial and post glacial sediments shows that the the probablility that the values are due to chance alone is less than p=0.001.

Table 1
Modified Mercalli Intensity versus Geology in Seattle for the Elk Lake earthquake of February 14, 1981

Geology at Site	Number of Observations at each Modified Mercalli Intensity I	II	III	IV	V	VI
Post Glacial Seds.	11	2	55	87	6	0
Glacial Seds.	120	16	563	387	29	4
Bedrock	2	0	7	8	0	0

References and Additional Background Reading

Evernden, J. F., 1975. Seismic intensities, size of earthquakes and related parameters, Bull. Seism. Soc. Am., 65, 1287-1313.

Evernden, J. F. and J. M. Thomson, 1985. Predicting seismic intensities, in "Evaluating earthquake hazards in the Los Angeles region", U.S. Geological Survey Professional Paper 1360, 151-220.

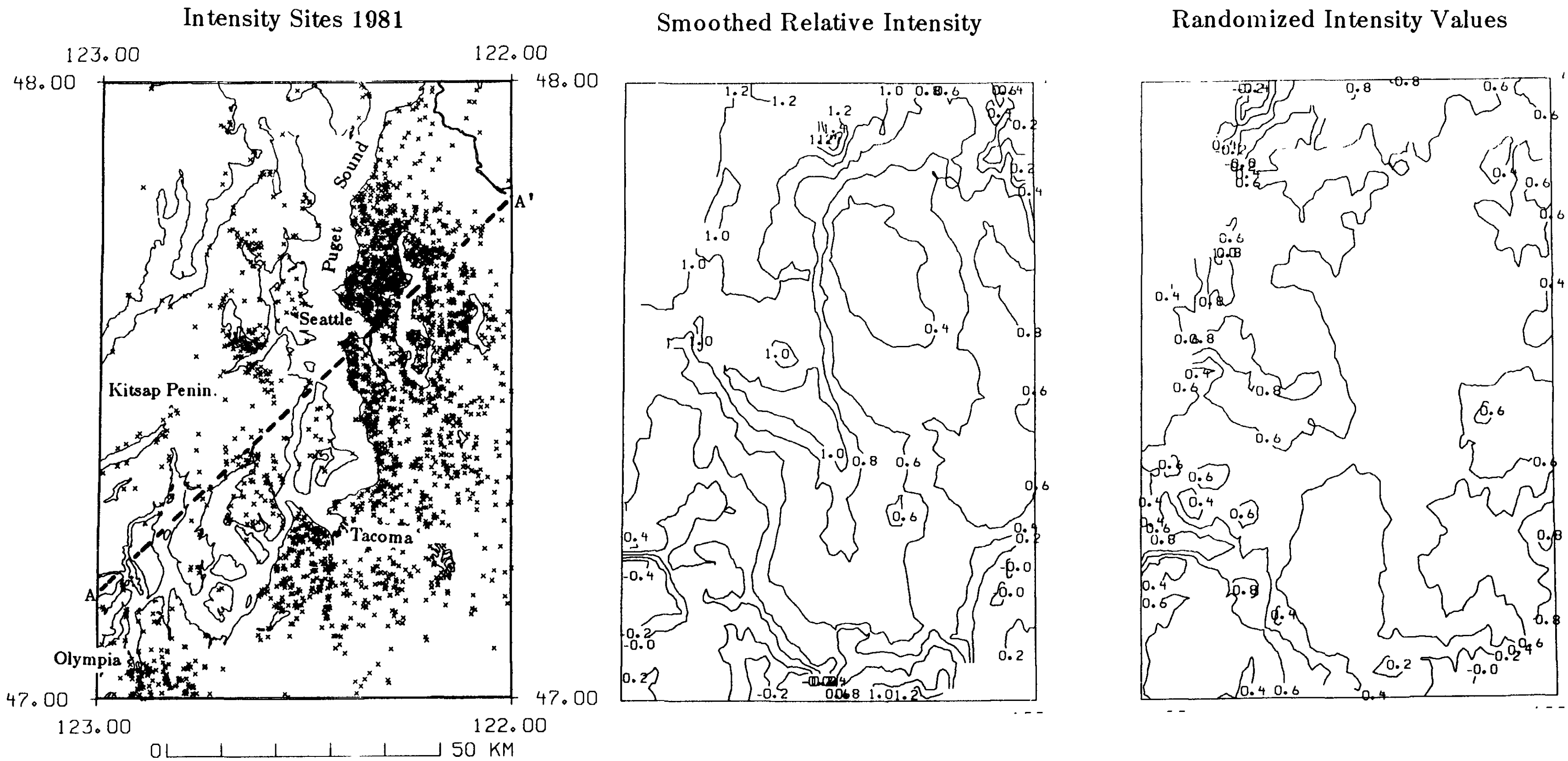
Hays, Walter W., 1980. Procedures for estimating earthquake ground motions, U.S. Geological Survey Professional Paper 1114, 1-77.

Ihnen, S. M. and D. M. Hadley, 1986. Prediction of strong ground motion in the Puget Sound region: the 1965 Seattle earthquake, Bull. Seism. Soc. Am., 76, 905-922.

Langston, C. A. and J. J. Lee, 1983. Effect of structure geometry on strong ground motions: the Duwamish River Valley, Seattle, Washington, Bull. Seism. Soc. Am., 73, 1851-1864.

Mullineaux, D. R., M. G. Bonilla, and J. Schlocker, 1967. Relation of building damage to geology in Seattle, Washington, during the April 1965 earthquake, U.S. Geological Survey Professional Paper 575-D. D183-D191

Yount, J. C., 1983. Geologic units that likely control seismic ground shaking in the greater Seattle area, Proceedings of Workshop XIV: Earthquake hazards of the Puget Sound Region, Washington, U.S. Geological Survey Open File Report: OF 83-19, 268-279.



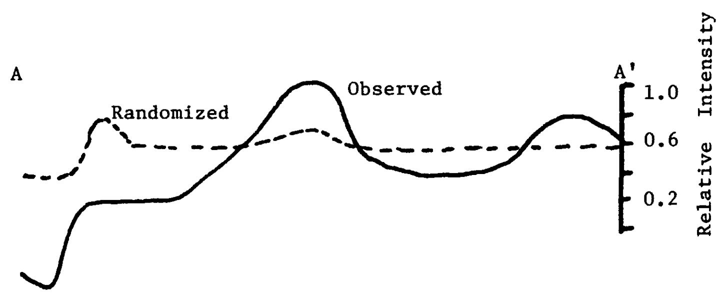


Figure 1. Observations of Modified Mercalli Intensity for the 1981 Elk Lake earthquake in the Puget Sound region. Top left: Sites where earthquake intensity reports were obtained. Top center: Smoothed relative intensity. Relative intensity is observed intensity minus (5.15 - 0.0098*dist) where dist is in km. Value contoured is average intensity within 10 km of each point. The earthquake epicenter is 75 km to the south at 46.35 °N, 122.24 °W. The focal depth was 7 km. Top right: Same as top center except that the observed intensity values were assigned randomly to the sites. Bottom right: Profiles along AA' (shown on map at top left) of the observed values shown on map at top center and the randomized values shown at top right.

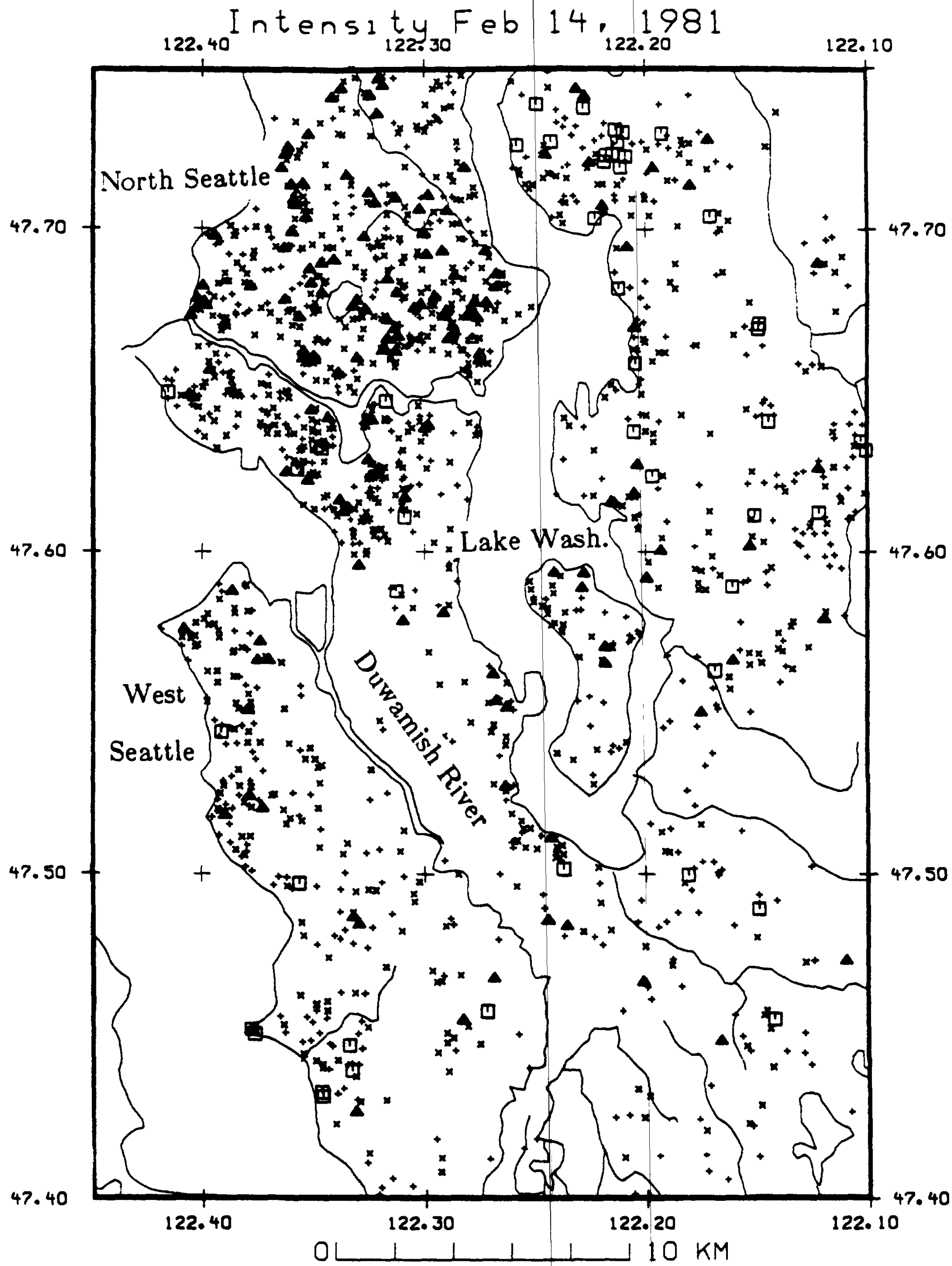


Figure 2. Observations of intensities for the 1981 Elk Lake earthquake for a portion of Figure 1 (Seattle). Intensities I or II are indicated by large triangles, III by a small cross, IV by a small plus-symbol and V or VI by a large square.

DISTRIBUTION OF POTENTIALLY RESPONSIVE QUATERNARY DEPOSITS IN PORTLAND

Ian Madin
Oregon Department of Geology and Mineral Industries
Room 910, 1400 SW 5th Ave.
Portland OR, 97201

The distribution of Quaternary sediments has been mapped in the central portion of the City of Portland (Portland, Mt. Tabor, Gladstone and Lake Oswego 7 1/2 minute sheets) using available surface information and analysis of several thousand water, engineering and highway borehole logs. Preliminary versions of these four maps are presented here, and depict the Quaternary and bedrock geologic units, mapped and inferred faults and borehole data points.

The mapping has delineated four major potentially responsive Quaternary units. The first two, Qff and Qal, are sufficiently consistent in thickness to allow isopach maps to be drawn. The isopachs reflect the total thickness of QAL and Qff, and hence cross the contacts between these two units. The other two units, Qaf and Qph, have inconsistent thicknesses and have not been isopached, but their characteristics are well known from borehole and outcrop data in local areas.

The oldest unit, Qff, consists of crudely to complexly layered medium sand to silt deposited by one or more phases of catastrophic glacial outburst floods from late Pleistocene Lake Missoula. These sediments are of latest Pleistocene age and are poorly consolidated, with an average void ratio (void ratio **e**, is defined as e=GS/GD-1 where GS is the average density of the components of the sediment, and GD is the measured dry density the sediment) of 0.85. Qff sediments occur along both sides of the Willamette River in downtown Portland, where they are as much as 120 ft thick. Relatively thin deposits also occur as a strip along the south bank of the Columbia River, and as discontinuous patches in the Clackamas-Lake Oswego areas. In addition, a widespread dense, uniform sand unit which underlies Qal on the floodplain along the south bank of the Columbia River may be Qff. This unit is known only from boreholes, but its relative density, homogeneity and lack of organic materials strongly suggest that it is an outburst flood deposit.

The youngest responsive unit that has been isopached is Qal, alluvial sand, silt and clay deposited in the channels of the modern Columbia and Willamette rivers. These sediments consist of medium to fine sand, silt, clay and locally abundant organic material. Limited gravel deposits in this unit form bars (Ross Island), or occur at the bottom of the section. The early Holocene post-outburst-flood channels of the Columbia and Willamette rivers have been filled with Qal to an elevation of approximately 35 ft; about the maximum level of historic floods. Significant thicknesses (> 90 ft) of poorly consolidated and saturated Qal underlie the Guild Lake and Mocks Bottom areas of downtown Portland, and most of the floodplain along the south bank of the Columbia. The Qal sediments are very poorly consolidated, with an average void ratio of 1.17.

Qaf, artificial fill, is widespread in developed areas along the banks of the Columbia and Willamette rivers. The most common material is dredged river sand, though older fills contain significant thicknesses of rubble, wood and sawdust. In most floodplain areas sand fill thicknesses are 5-15 ft, but greater thicknesses, up to 60 ft, occur in areas of pre-development lakes, sloughs or gullies.

Qph, Portland Hills Silt, is widely distributed above an elevation of 300 ft in most of the Portland area. This loessal silt is probably of late Pleistocene to Holocene age, and it's absence below 300 ft elevation probably reflects the effects of outburst floods. The thickness of the loessal silt is quite variable, but is generally greatest on ridgecrests and least in valleys. A thickness of 20-40 ft is commonly seen in engineering boreholes and up to 100 ft of silt is suggested by some water well logs. Qph may locally have a strong influence on earthquake ground shaking, because of it's low density and consequent high impedance contrast relative to the basalt that commonly underlies it.

Analysis of borehole data in this study, and surface mapping by M.H. Beeson and T.L. Tolan have delineated numerous mappable faults and inferred faults. The faults have been depicted on the maps in two patterns, one of which indicates faults mapped from surface and/or subsurface information, the other indicates faults that are only inferred from subsurface data. Although all the faults are drawn crossing Quaternary materials, none has yet been shown to cut the upper Pleistocene Missoula flood deposits. Many of the faults do cut Upper Pliocene-Lower Pleistocene rocks (QTb, QTg). Radiometric dating of these units is currently planned, and may supply new information on the age and rate of faulting.

Map Units

Qaf Fill. Dredged sand fill 5-20' thick is common in developed areas on the Columbia and Willamette River floodplains and is not mapped. Mapped fill occurs only in areas where pre-development channels, sloughs and lakes existed along the Willamette River. Older fills locally contain significant amounts of construction and sawmill debris.

Qal Alluvium. Predominantly sand and silt with lesser amounts of clay, gravel and organic material. Qal is restricted to the channels and floodplains of the major rivers and to local deposits adjacent to minor tributaries.

Qfch Qff Qfc Catastrophic Flood Deposits. Boulders, gravel, sand and silt deposited by one or more catastrophic outburst floods from glacial Lake Missoula. The flood sediments are divided into three facies listed below:

Qfch Channel facies. Complexly layered gravel, sand and silt deposited in major floodways. Topographic iregularities on the post-flood surface of Qfch deposits are commonly filled with local alluvial or bog deposits.

Qff Fine-grained facies. Medium sand to silt, in poorly defined beds 1 to 3 ft thick, locally with complex layering and channeling.

Qfc Coarse-grained facies. Coarse sand, pebbles, cobbles and boulders up to GfT in diameter. Large-scale foreset crossbedding is common in much of the deposit, locally bedding is crude or absent.

Qph Portland Hills Silt. Silt and clayey silt of probable loessal origin. Portland Hills silt up to 40 ft thick commonly mantles ridges and slopes in the Portland Hills above 300 ft in elevation. The silt has only been mapped on the Lake Oswego sheet, where it is not differentiated from older sediments (Beeson and others, 1989). On the other sheets the distribution of the silt is highly irregular and it has not been mapped.

QTg Outlook gravels. Moderately indurated interbedded conglomerate, sandstone, and claystone with local volcanic debris flows. The sand in this unit commonly contains significant quarzo-feldspathic material from the upper reaches of the Columbia River, but the gravels are predominantly andesitic and basaltic material derived from the adjacent Cascade Range. The unit is locally interbedded with lava flows of the Boring Lava.

Qtb Boring Lavas. Basalt and basaltic andesite flows erupted from local vents. Near vent complexes are up to 600' thick and include considerable pyroclastic material. Away from the vents, layers of lava 20-100 ft thick cover significant areas and are interbedded with or fill canyons in the Outlook Gravels.

Tt Troutdale Gravels. Moderately to well indurated conglomerate interbedded with quarzo-feldspatihic and hyalocastic sands and sandstone. The gravel clasts are predominantly Columbia River Basalt Group with significant amounts of quarzite and other metamorphic rocks derived from the upper reaches of the Columbia River. The hyaloclastic sands are commonly composed of Boring-type basaltic material (Swanson, 1986).

Tsr Sandy River Mudstone. Moderately to poorly indurated interbedded siltstone, claystone, sandstone and mudstone. The sandstone and siltstones layers are predominantly quarzo-feldspathic and micaceous, and plant fossils and organic debris are common. The Sandy River Mudstone is interbedded with Boring lavas near the top of the section at Carver.

Tcr Columbia River Basalt Group. Subaerial Tholeiitic flood basalts erupted from vents in eastern Oregon and Washington. The basalt is undifferentiated on this map, but eight flow units have been mapped on the Lake Oswego sheet by Beeson and others (1989).

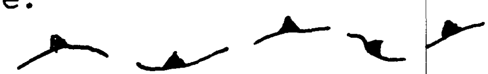
Twh Basalt of Waverly Heights. Subaerial basalt flows and associated sediments of Eocene age (sediments are not exposed) which unconformably underlie the Columbia River Basalt Group (Beeson and others, 1989). The thickness of this unit is unknown, but is probably great.

MAP SYMBOLS

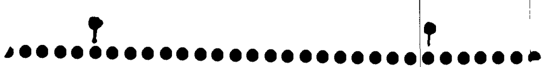
Contact, located or inferred.

Fault, mapped with surface, subsurface or geophysical data. Ball and tick on downthrown side

Thrust Fault, mapped with surface or subsurface data, teeth on upper plate.

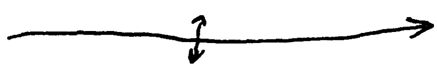


Fault, inferred from surface or subsurface data.

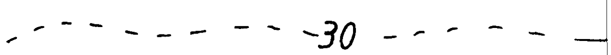


Recorded subsurface data.

Fold Axis



Isopach on Qal and Qff, 30' interval.

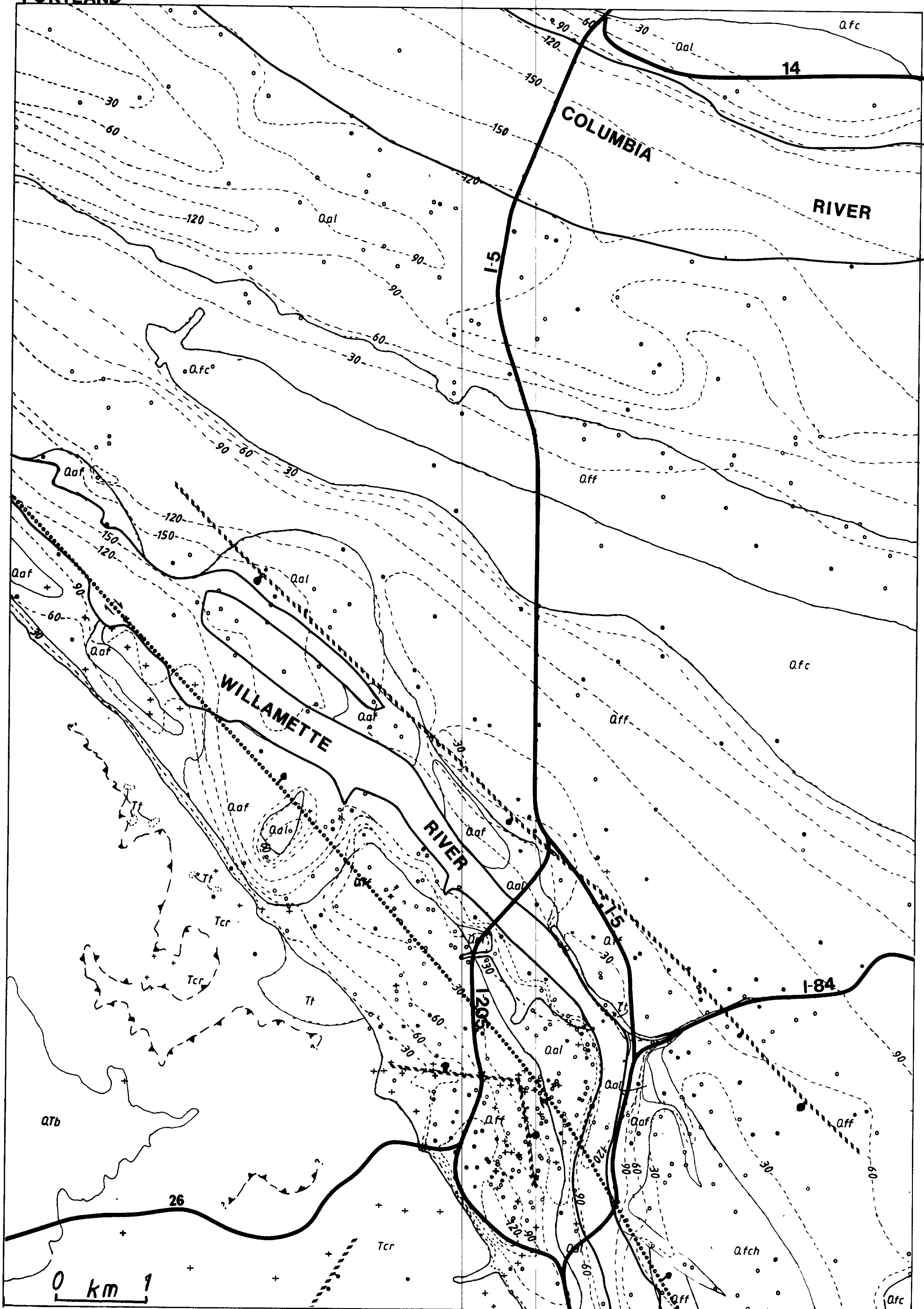


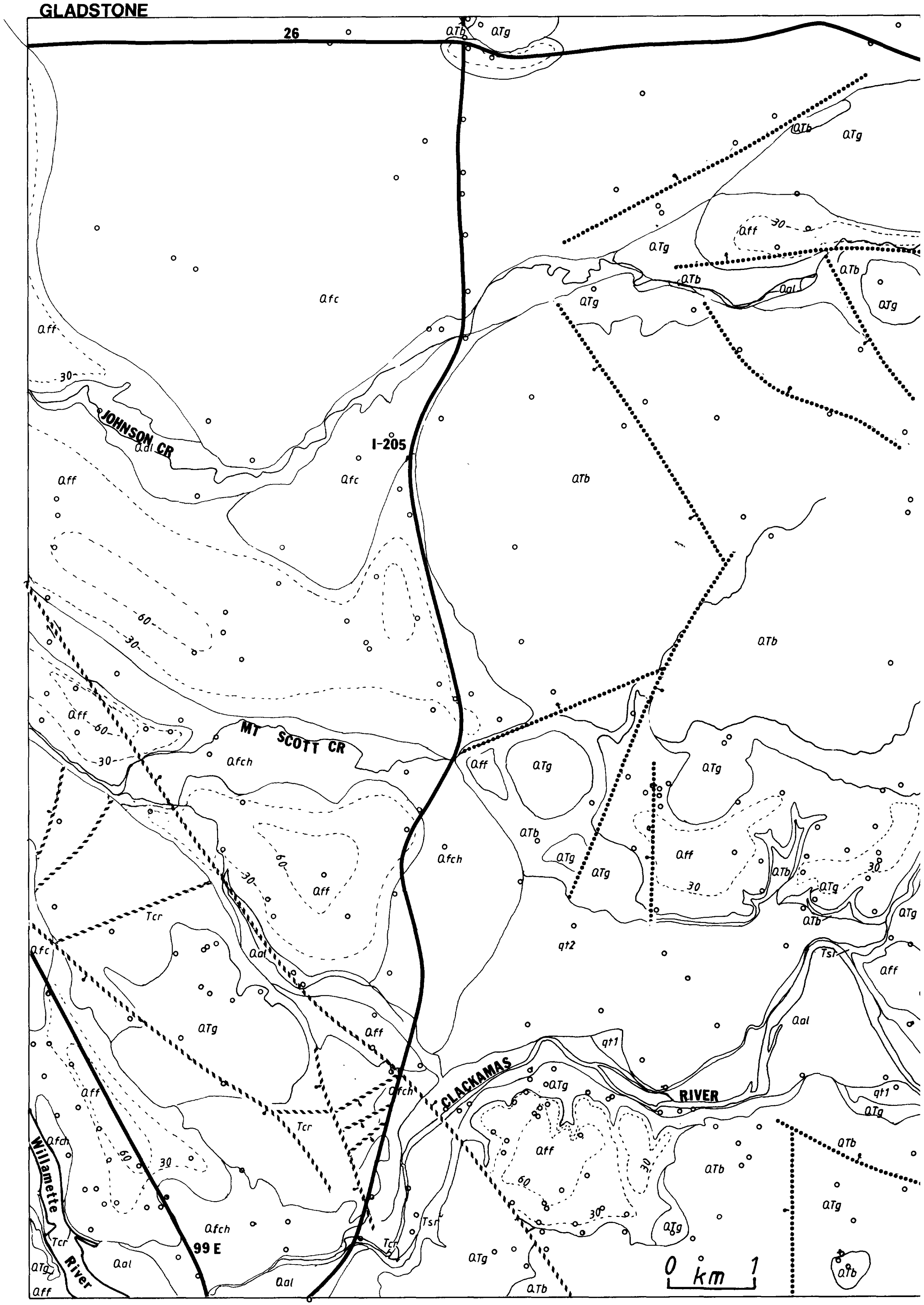
REFERENCES

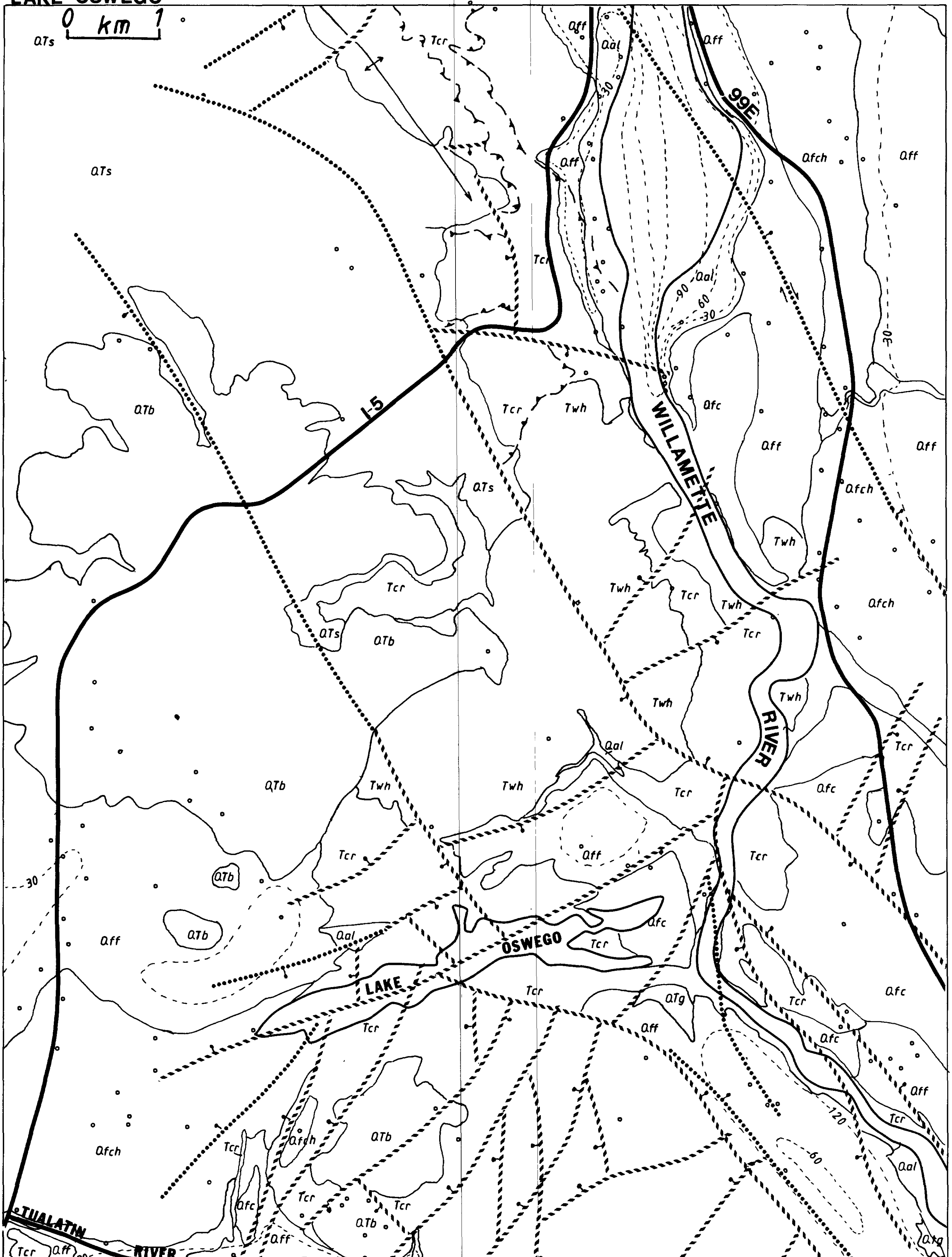
Beeson, M.H., Tolan, T.L. and Madin, I.P. 1989. Geologic Map of the Lake Oswego Quadrangle, Clackamas, Multnomah and Washington Counties, Oregon. Oregon Department of Geology and Mineral Industries GMS 59.

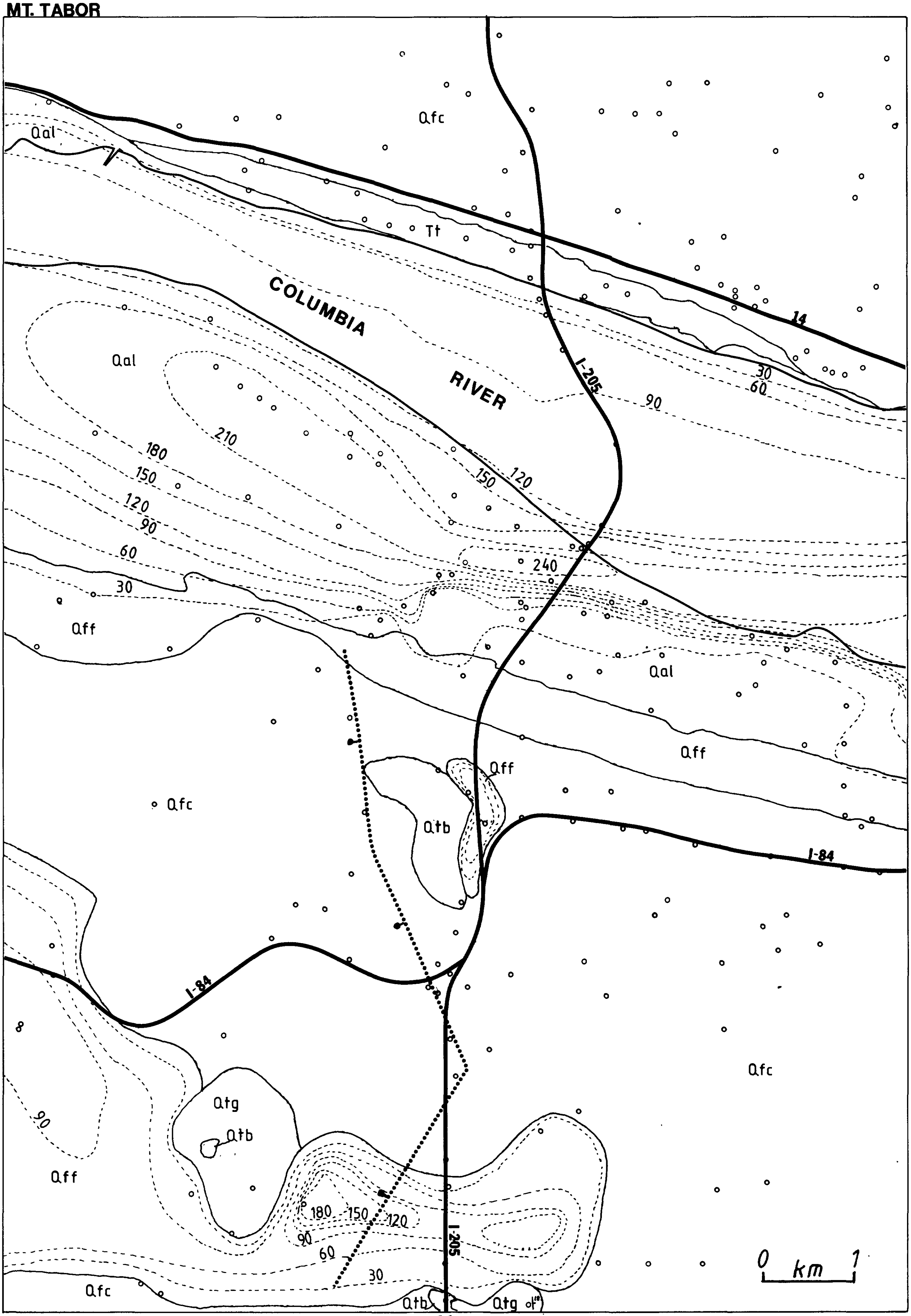
Swanson, R.D., 1986. A Stratigraphic-Geochemical Study of the Troutdale Formation and Sandy River Mudstone in the Portland Basin and Columbia Gorge. Portland State University, MS Thesis, Portland, OR. 103 pp.

PORTLAND


COLUMBIA
RIVER
WILLAMETTE
RIVER
14
I-5
I-205
I-84
26
Qfc
Qal
Qff
Qaf
Qfch
Tcr
Tt
QTb
0 km 1


GLADSTONE
26
I-205
JOHNSON CR
MT SCOTT CR
CLACKAMAS
RIVER
Willamette
River
99 E
0 km 1
Qfc
Qff
Qfch
Qal
QTb
QTg
Tcr
Tsr
Tsl
qt1
qt2
30
60


0 km 1
QTs
QTb
Tcr
Twh
Qal
Qff
Qfc
Qfch
QTg
I-5
99E
WILLAMETTE
RIVER
LAKE
OSWEGO
TUALATIN
RIVER
30
60
90
120


Qfc
Qal
Tt
COLUMBIA
RIVER
14
I-205
30
60
90
210
180
150
120
90
60
30
240
Qal
Qff
Qff
Qff
Qfc
Qtb
I-84
I-84
Qfc
Qtg
Qtb
Qff
180
150
120
90
60
30
I-205
Qfc
Qtb
Qtg
0 km 1

LIQUEFACTION HAZARDS IN THE PACIFIC NORTHWEST

by
W. Paul Grant
Shannon & Wilson, Inc.
Seattle, Washington

Major damage and property losses have occurred during earthquakes as a result of liquefaction or liquefaction-related effects. Liquefaction is a phenomenon in which a loose deposit of sand existing below the water table loses its internal shear strength when subjected to severe earthquake ground motions. Other liquefaction-related effects would include lateral spreading which is characterized by horizontal ground movements which typically occur as a result of liquefaction within an underlying sand layer.

There are three major factors which control the occurrence of liquefaction: 1) earthquake severity, 2) high groundwater table, and 3) liquifiable soils. All three of the above factors must be simultaneously present for liquefaction to occur. The actual hazard of the occurence of liquefaction, as expressed in terms of potential casualties or property loss, is dependent not only upon the above three factors, but also upon the extent of development in potentially liquefiable areas.

Locations that are most susceptible to the development of liquefaction are low-lying areas adjacent to waterways that are underlain by recent alluvial deposits. These deposits are typically composed of loose, fine sands which exist below the water table and, consequently, are the most susceptible to liquefaction during a strong earthquake.

The areas which are typically the most susceptible to liquefaction damage are typically located in areas of significant development. These low-lying areas were either first developed as cities were established in the Northwest, or these low-lying areas are currently used today for industrial purposes involving commerce along the waterways. Thus, there is a significant proportion of development in the Pacific Northwest that is susceptible to damage from the occurrence of liquefaction.

Earthquakes in the Pacific Northwest, including the 1949 and 1965 Puget Sound earthquakes, have resulted in liquefaction damage. Total damage estimates from these earthquakes have been estimated at 25 million and 12.5 million respectively, at the time of occurrence of these events. Based upon a review of damage records from these earthquakes, it is estimated that liquefaction may have been involved in at least 25% of this total damage.

Liquefaction potential in the future in the Pacific Northwest is highly dependent upon the source of seismic activity. It is anticipated that typically-recognized sources of seismic activity, including subcrustal earthquakes in the Puget Sound region or shallow earthquakes in the Portland region, could result in liquefaction losses that are significantly higher than damage that has occurred during prior historic events. Furthermore, the potential occurrence of a

Cascadia subduction zone earthquake in the Pacific Northwest could greatly increase liquefaction losses several fold as a result of the potentially higher level of ground motions and anticipated longer duration associated with this type of event.

Future studies in the region to evaluate the potential hazard from liquefaction should concentrate on three major areas. First, the earthquake potential from a subduction zone earthquake should be clarified, including the potential size of the events and the recurrence intervals of events. This postulated information should be correlated to geological evidence of past earthquakes in the area. Secondly, potential liquefaction should be delineated through hazard maps. Liquefaction maps are currently being developed for the Puget Sound region. Finally, uncertainties involved in the methods of liquefaction analysis must be considered when evaluating potential liquefaction effects.

References

Atwater, B.F, 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: Science, Vol. 336, pp. 942-944.

Heaton, T.H., and Kanamori, H., 1984, Seismic potential associated with subduction in the northwestern United States: Seismological Society of America, Vol. 74, No. 3, pp. 933-941.

Hopper, M.G., 1981, A study of liquefaction and other types of earthquake-induced ground failures in the Puget Sound, Washington Region: M.S. thesis, Virginia Polytechnic Institute and State University.

Keefer, D.K., 1983, Landslides, soil liquefaction, and related ground failures in the Puget Sound earthquakes: Proceedings of Workshop XIV, Earthquake Hazards of the Puget Sound Region, Washington, U.S. Geological Survey Open-file Report 83-19.

Seed, H.B., and Idriss, I.M., 1981, Evaluation of liquefaction potential of sand deposits based upon observations of performance in previous earthquakes: Proceedings, Session on In Situ Testing to evaluate liquefaction susceptibility, ASCE National Convention, St. Louis, Missouri, October 26-30, preprint Vol. 81-544.

Shannon & Wilson, Inc., and Agbabian Associates (SW-AA), 1978, Geotechnical and strong motion earthquake data from U.S. accelerograph stations, Vol. 4: Report to the U.S. Nuclear Regulatory Commission.

U.S. Geological Survey, 1975, A study of earthquake losses in the Puget Sound Washington area: U.S. Geological Survey Open-file Report 75-375.

LIQUEFACTION HAZARD MAPPING FOR THE SEATTLE URBAN REGION UTILIZING LSI

By

T. Leslie Youd
Brigham Young University
Provo, Utah 84602

INTRODUCTION

Liquefaction is a major cause of damage during many large earthquakes. More precisely, ground displacement generated by liquefaction is the actual cause of most of this damage. For example, more than half the total damage inflicted by the 1964 Alaska earthquake was attributable to ground failure displacements, most of which were triggered by liquefaction. Port and harbor facilities, transportation routes, bridges, and buildings were particularly affected (Youd, 1978). Similar damage, although not generally as extensive, has occurred during many other past earthquakes. Because of recent population growth and urban development in many seismic regions, such as the Seattle and Portland urban regions, future damage as a consequence of liquefaction and ground displacement is likely to be even more costly.

Parts of the Seattle and Portland urban regions are underlain by natural or man-made deposits that could be vulnerable to liquefaction and ground failure. These deposits include late Pleistocene and Holocene sandy sediments and artificial fills in areas with high ground water levels (within a few meters of ground surface). Deposits of these types have been particularly vulnerable to liquefaction and ground displacement during past earthquakes.

Liquefaction hazard assessments in other areas in the past have used maps of liquefaction susceptibility or liquefaction potential as the key element in evaluating liquefaction hazards. While useful for mapping areas susceptible to liquefaction, that is areas where high pore-water pressures might be generated during severe earthquake shaking, these maps are not sufficient for hazard evaluation. This deficiency is because they do not provide information on the severity or damage potential of ground effects that might occur as a consequence of liquefaction. As noted above, damage is primarily a function of ground displacement. To evaluate ground-displacement potential, factors beyond those considered in standard liquefaction susceptibility evaluations must be considered such as ground slope and thickness and extent of liquefiable layer.

This project will develop techniques for compiling ground displacement potential maps and field test the techniques in the Seattle Urban area. The mapping will make use of a parameter termed liquefaction severity index (LSI). LSI is an estimate of maximum probable ground displacement that would occur within a given exposure time assuming that all localities are underlain by sediment that is susceptible to liquefaction and lateral-spread ground failure (Youd and Perkins, 1987). Thus, LSI is an estimate of maximum ground displacement that is likely to occur in areas underlain by highly susceptible sediment.

Clearly, in regions such as Puget Sound the susceptibility of sediments to liquefaction and ground displacement varies with many factors such as geologic origin of sediments, depth to the water table, ground slope, etc. For this study, we will develop procedures for combining maps of liquefaction susceptibility, LSI, quaternary geology, topography, etc., and assessments of local stratigraphic and geotechnical conditions to compile derivative maps of potential for liquefaction-induced ground deformation or liquefaction hazard. We will field test this new technique in the Seattle South and North quadrangles where Shannon and Wilson, Inc. are compiling standard liquefaction potential maps.

The first task is to develop relationships between ground displacement and various ground conditions. We will evaluate empirical correlations between these factors, such as those recently proposed by Hamada and others (1986) in Japan. They studied ground displacements during the 1964 Niigata and 1983 Nihonkai-Chubu earthquakes. We have already found that those proposed relationships do not predict displacements measured at various sites of past liquefaction in the U.S. Differences in sediment characteristics such as grain-size and a wider range of earthquake magnitudes seem to be two reasons for the lack of predictive capability of U.S. displacements by the Japanese relations. We will attempt to develop improved relationships that take these factors into account. We will also evaluate the use of analytical procedures, such as application of the Newmark procedure at liquefaction sites, to develop predictive criteria.

The second task is to develop and field test procedures for using the relationships developed in Task 1 for liquefaction hazard mapping. We will use maps of liquefaction potential, topography, geology, etc., plus compilations of bore-hole logs and other geotechnical data for the Seattle North and South quadrangles in a pilot study to develop a methodology for mapping ground-displacement hazard. We will then compile maps for those two quadrangles to demonstrate the procedure and as a basis for dialogue with professional colleagues and potential users of this information to assure that the developed methods are sound and useful. Part of this dialogue will occur at future Puget Sound/Portland Area Workshops on Earthquake Hazards.

The final task will be preparation of journal papers and reports to publicize and disseminate the results of this study. If this study is successful, additional proposals will be prepared to extent this work to broader segments of the Seattle and Portland urban regions.

REFERENCES

Hamada, M., Yasuda, Y., Isoyama, R., and Emoto, K., 1986, Study on liquefaction induced permanent ground displacements: monograph, Assoc. for the Development of Earthquake Prediciton, Tokyo, Japan, 87 p.

Youd, T. L., 1978, Major cause of earthquake damage is ground failure: Civil Engineering, v. 48, no. 4, p. 47-51.

Youd, T. L., and Perkins, D. M., 1987, Mapping of liquefaction severity index: Journal of Geotechnical Engineering, ASCE, vol. 113, no. 11, p. 1374-1392.

LANDSLIDES IN WASHINGTON AND OREGON -- AN OVERVIEW

by

Robert L. Schuster and Alan F. Chleborad
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

Studies of the distribution of landslides within the conterminous United States have indicated that the States of Washington and Oregon are particularly susceptible to landslide activity (Wiggins and others, 1978; Radbruch-Hall and others, 1982; Committee on Ground Failure Hazards, 1985). However, even though landslides in the Pacific Northwest have received considerable attention beginning with the early work of Russell (1893, 1898, 1900) in Washington in the late 19th century, a definitive study of the character and distribution of landslides in this area has yet to be attempted. This paper is a small step in that direction.

Because climate, physiography, and geology vary so dramatically within Washington and Oregon, these States exhibit a wide variety of gravitational mass movements ranging from rock falls, rock slides, and rock avalanches in mountainous areas to soil slips, slides, and spreads along stream banks in broad valleys. This paper will briefly review the causes of landslides in Washington and Oregon, and then will discuss the types and characteristics of landslides that are most common in the individual physiographic subdivisions of the area. Terminology used here is based on the mass-movement classification by Varnes (1978). For simplicity, the term "landslide" will be used as the general term that includes all gravitational mass movements even though some of these processes are not truly "slides."

The States of Washington and Oregon can be divided into the following physiographic subdivisions (fig. 1): Coast Ranges, Puget-Willamette Lowland, Cascade-Klamath Ranges, Columbia Basin, Northern Rocky Mountains, Blue Mountains, Basin and Range Area, and Harney-Owyhee Broken Lands (Hammond, 1965). In general, the Coast Ranges, the Puget-Willamette Lowland, the Cascade-Klamath Mountains, the Northern Rocky Mountains, and the Blue Mountains are subject to moist winter-spring climates with heavy snowfall at higher elevations; their annual precipitations range from about 24 to more than 130 inches (fig. 2). The Columbia Basin, the Basin and Range Area, and the Harney-Owyhee Broken Lands are generally semi-arid.

CAUSES OF LANDSLIDING

Landslides occur when the forces of gravity on earth materials comprising slopes exceed the shearing resistance of these materials to downslope movement. Long-term conditions affecting slope stability are:

(1) steepness of slope -- Commonly, the steeper the slope, the more prone it is to gravitational failure;

(2) physical properties of slope materials -- Unconsolidated, soft materials will fail more readily than consolidated or indurated materials;

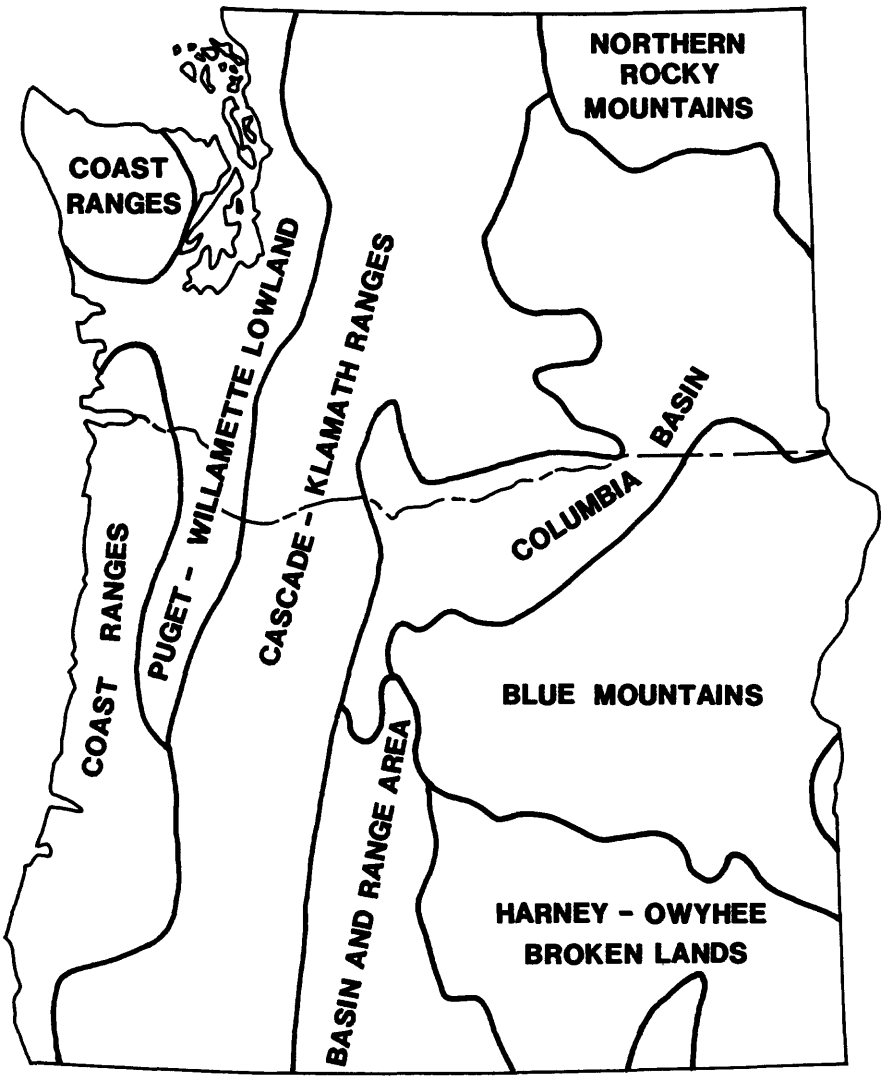


Figure 1. Physical subdivisions of Washington and Oregon (modified from Hammond, 1965).

Figure 2. Contour map showing mean annual precipitation (in inches) in Washington and Oregon for the period 1931-1960 (modified from U.S. Geological Survey, 1970)

(3) moisture content of earth materials -- For most earth materials, high moisture contents/pore pressures result in lower shear strengths, thus increasing the probability of slope failure;

(4) weathering of slope materials -- Physical and chemical weathering processes often reduce the shear strength of slope materials;

(5) structure of earth materials -- Geologic units that dip downslope are more prone to failure than are horizontal units or those that dip back into the slope;

(6) vegetation -- Although its weight may slightly increase the gravitational driving force contributing to slope failure, the overall effect of vegetation (mainly trees) on a hillside is to increase slope stability by decreasing the moisture content of slope materials and by physically strengthening slope materials by root action;

(7) long-term slope erosion -- Steepening of slopes by coastal or stream erosion will reduce slope stability.

Landsliding on slopes that have become susceptible to failure due to critical combinations of the above long-term conditions can be initiated by the following triggering processes, all of which are active in Washington and Oregon:

(1) precipitation -- As shown in figure 2, precipitation is particularly high in western Washington and Oregon, exceeding 100 in. annually in some parts of the Coast and Cascade Ranges;

(2) seismic shaking -- Noson and others (1988) noted that 14 earthquakes caused landsliding in the State of Washington between 1872 and 1980. As shown in figure 3, the probability of damaging seismic activity is particularly great in western Washington and Oregon;

(3) volcanic activity -- The Cascade Mountains include a dozen volcanic peaks, some of which have the capability of erupting and causing landslide activity;

(4) erosion -- In addition to being a long-term factor in the reduction of slope stability, toe erosion can be an immediate triggering factor. The most common scenarios involve toe erosion caused by storm-related wave action along steep coastal shorelines and river erosion of steep banks during floods;

(5) human activities, such as irrigation of crops, filling and/or drawdown of reservoirs, construction of highways and railways, logging operations, mining, and ground shaking from large-scale explosions or vibrations of heavy machinery -- Logging operations have been particularly damaging to the forested lands of western Washington and Oregon, and reservoirs and irrigation have caused slope-failure problems in the eastern parts of these States.

LANDSLIDE ACTIVITY BY PHYSIOGRAPHIC SUBDIVISIONS

Coast Ranges

The Coast Ranges of Washington and Oregon (fig. 1) consist mainly of Upper Mesozoic and Tertiary sedimentary rocks, but intrusive and metamorphic rocks and some volcanics also are present. Most rocks have been folded, faulted, and, in some cases, intensely sheared. The topography is mountainous with steep slopes. The Coast Ranges are subject to heavy precipitation, in some places exceeding 100 in./yr (fig. 2). The combination of soft rocks, steep slopes, heavy precipitation, severe wave erosion of steep coastal

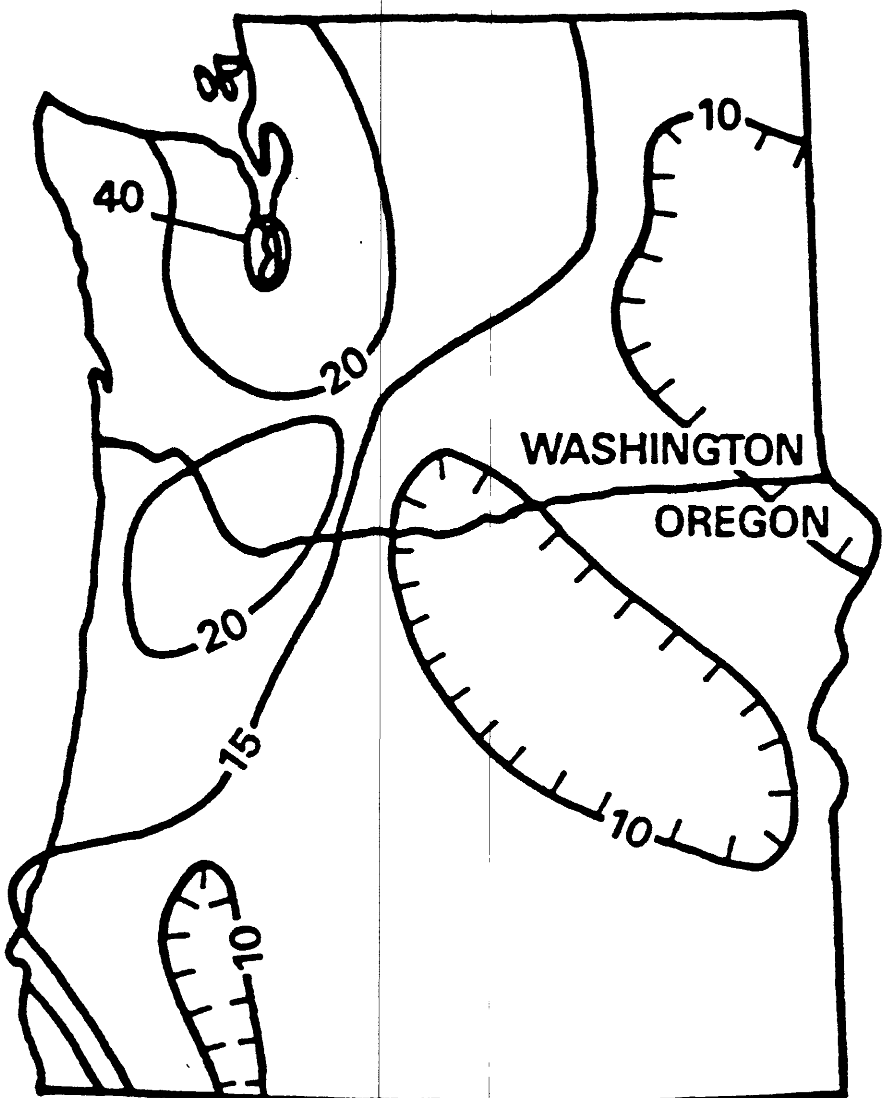


Figure 3. Contour map showing seismic ground-shaking hazard in Washington and Oregon in terms of peak horizontal bedrock acceleration and a 250-yr exposure time. The values of acceleration have a 90-percent probability of non-exceedance (modified from Algermissen and others, 1982).

bluffs, extensive human activities (particularly logging and associated road building), and possible seismic shaking makes the Coast Ranges, in general, a very landslide-prone area. Factors relating to landsliding in specific areas within the Coast Ranges subdivision are as follows:

(1) Olympic Mountains -- The rocks forming the high mountain core of the Olympic Mountains, which comprise the northern part of the Coast Ranges in northwestern Washington, are mostly lower Tertiary interbedded sandstone, slate, and phyllite. Except on the western slopes of the Olympics, this core is surrounded by pillow basalts, volcaniclastic rocks, and diabase of Eocene age. On their geologic map of the Olympic peninsula, Tabor and Cady (1978) recorded only a few major landslides, mainly in the north-central part of the peninsula. In addition, Tabor (1971) observed sackungen (deep-seated gravitational creep along ridge tops) in the heart of the Olympic Range. Because development and logging are not permitted in Olympic National Park, which constitutes the core area of the peninsula, little landslide activity has been noted there. However, Heusser (1957) observed historic landslide deposits in the heart of Olympic National Park near Mount Olympus; he feels that debris flows and earth slides near Mount Olympus that occurred during the 1940's or early 1950's may have been earthquake-induced. The authors have noted numerous small landslides in logged areas outside the Park and along the coastal bluffs in the extreme northwestern part of the peninsula.

As part of a study to assist forest managers in identification of potential sediment sources, Fiksdal and Brunengo (1981) have described mass wasting in the Clearwater River drainage of the southwestern Olympic peninsula. The geology of the area consists primarily of complexly folded, faulted, and sheared marine sandstones and siltstones. Being outside Olympic National Park, the drainage area of the Clearwater River has been intensely logged.

(2) Willapa Hills -- The Willapa Hills, which form the Coast Range of southwestern Washington, have not been glaciated; so most of the area has been exposed to weathering for more than 10 million years. Very thick weathering profiles have developed except where landsliding or erosion has removed the soil. Three basic factors result in the great instability of this area: (1) easily weathered, soft tuffaceous marine sediments; (2) inherently unstable contacts between sedimentary and volcanic rocks, and (3) deep soils (Fiksdal and Brunengo, 1980). The rocks of the Willapa Hills are all of Tertiary age; major rock types include submarine and subaerial basalt flows, pillow basalts, breccias, and marine and non-marine sandstones and siltstones. Landslides are common in residual soils in logged-off areas. In the Grays River basin, interbedded lavas, pyroclastics, siltstones, and sandstones of the Upper Eocene Goble Volcanics are exceedingly susceptible to slope failure; almost the entire Goble Volcanics terrain consists of obvious slump/earthflow topography (Fiksdal and Brunengo, 1981). In general, the most landslide-prone geologic unit in the Willapa Hills is the Miocene Astoria Formation, a siltstone/sandstone unit, which is locally argillaceous. This formation has been particularly troublesome on steep slopes that have been subjected to logging and road building.

(3) Oregon Coast Range -- The Astoria Formation has also been involved in considerable landslide activity in the city of Astoria, Oregon, at the mouth of the Columbia River. Dole (1954) noted that the Astoria Formation in Astoria is composed mostly of a bentonitic clay shale, which is extremely prone to slope failure when wet. In 1950, 23 houses were destroyed in Astoria by landsliding; in 1954 another 27 were destroyed or damaged. In both cases, failure followed heavy rainfall.

The high bluffs of the Oregon coastline have been particularly subject to landsliding due to coastal erosion. Tertiary marine sediments, mainly micaceous and tuffaceous sandstones, siltstones, mudstones, and shales, dominate the rocks that have been subject to erosion (North and Byrne, 1965). Particularly landslide-prone along the northern Oregon coast are cliffs formed of mudstones of the Astoria Formation. Several large landslides have occurred in the Astoria Formation in Ecola State Park on the coast about 20 mi south of the mouth of the Columbia River; the best-known slide occurred in 1961 when a 1/2-mi-long mass moved into the the ocean at a rate of as much as 3 ft/day (Schlicker and others, 1961). Another outstanding example of landsliding due to coastal erosion has occurred in the vicinity of Newport, where wave undercutting of coastal terraces in this century has triggered large areas of landsliding (North and Byrne, 1965; Beaulieu, 1976). Many similar slides and slumps, plus debris falls and rock falls, occur commonly along much of the Oregon coastline.

Inland from the coast line, the Oregon Coast Range attains elevations of as much as 3,000-4,000 ft. Valleys in the Oregon Coast Range are characteristically steep-walled due to rapid erosion during and since the Pleistocene. The Range includes Mesozoic and Tertiary sedimentary and volcanic rocks that are very susceptible to landsliding. The central part of the southern one-half of the Range is underlain by Tertiary turbidite sandstone beds as much as 12 ft thick with thin interbeds of mudstone and siltstone (Swanson and Lienkaemper, 1985); these beds are particularly landslide-prone. Evidence of large (approximately 1 acre or larger in area) slope movements, especially large slumps and block glides along bedding surfaces, is widespread. For example, J. D. Graham of the U.S. Army Corps of Engineers has noted that large slope movements comprise 5-10 percent of a 40-mi^2 area of the Umpqua River basin (Swanson and Lienkaemper, 1985). Large, rapidly moving landslides have been reported in the central and southern Oregon Coast Range during the past 15 years, most notably the 40-acre Drift Creek slide. This 1975 reactivation of an ancient landslide in gently dipping sandstones and siltstones is the largest landslide in recent Oregon Coast Range history.

Puget-Willamette Lowland

The Puget Lowland of western Washington is, in general, a relatively flat glacial plain interrupted by river valleys and complex bays and inlets of Puget Sound. It is underlain by thick sediments related to Pleistocene glaciation; relatively little bedrock is exposed at the surface. Where these sediments have been eroded to form steep slopes, particularly along the coastal bluffs of Puget Sound, they are susceptible to slope failure. The best-known examples of slope failure occur in coastal and river bluffs of Vashon Drift, in which the Esperance Sand member overlies the Lawton Clay, a fine-grained pro-glacial lacustrine deposit (Tubbs and Dunne, 1977). Ground water carried through the sand at the surface of this clay aquiclude often causes slope failures, mainly slumps and debris avalanches (Thorsen, 1987). Such failures are common after prolonged heavy rainfall, and have been triggered by historic seismic activity. An outstanding example of an earthquake-triggered landslide involving glacial drift, and possibly liquefaction of sediments within the drift, was the 650,000-yd^3 Tacoma Narrows debris avalanche, which is thought to have been triggered by the 1949 Olympia earthquake (Chleborad and Schuster, this volume). A particularly hazardous combination might occur in these Vashon Drift bluffs if a major earthquake were to strike the Puget Lowland soon after a period of prolonged precipitation. Landslides also are common in the Puget Lowland in Eocene sedimentary rocks at the south end of Puget Sound (Radbruch-Hall and others, 1982).

The southern part of the Puget-Willamette Lowland consists of alluvial valleys along the Cowlitz, Columbia, and Willamette Rivers. Of particular interest are large-scale, generally slowly moving slope failures that have occurred within the developed area of the City of Portland, Oregon, where the Willamette River valley merges with a range of hills to the west. The West Hills area of Portland has large areas covered by ancient landslide terrain which formed about 12,000-15,000 B.P., when most of Portland was inundated by a deep lake (Cornforth Consultants, Inc., 1989). The first significant modern reactivation of these old landslides occurred in 1894 in Pleistocene clays/silts overlying basalt in what is now Washington Park in west Portland (Clarke, 1904; Landslide Technology, 1986). This 3.5-million-yd^3 reactivation was probably initiated by construction of a city water reservoir. In recent years, local slope failures have occurred frequently at other sites in these clay/silt-covered hills in west Portland (Cornforth Consultants, Inc., 1989)..

Cascade and Klamath Ranges

The Cascade Range has both rugged topography, with elevations ranging from only a few hundred feet above sea level to 14,400 ft at the summit of Mount Rainier, and heavy precipitation (more than 100 in/yr in the northern Cascades). The Range, which forms the "backbone" of Washington and Oregon, is primarily volcanic, and is characterized along its length by large, recently active volcanoes. Rock slides, debris avalanches, and debris flows have accompanied volcanic eruptions; in addition, due to heavy precipitation, the steep slopes of the volcanoes are subjected to debris flows, rock falls, and rock and snow avalanches.

Volcanoes are susceptible to large and catastrophic landslides (particularly debris avalanches) because: (1) they have high relief and steep slopes; (2) their basic structure commonly consists of outward-dipping layers of relatively competent volcanic rock alternating with unconsolidated deposits that may become zones of failure, (3) they commonly include rocks weakened by hydrothermal alteration; and (4) they may be locally saturated (Schuster and Crandell, 1984). The largest of such catastrophic failures to have been noted in the Pacific Northwest is the 5,700-yr-old Osceola debris flow, which flowed from Mount Rainier down the White River to bury at least 27 mi^2 of the Puget Lowland east of Tacoma, Washington (Crandell, 1971). This 60-mi-long lahar (volcanic debris flow) with an estimated volume of 2×10^9 yd^3 (0.36 mi^3)

probably began as a rock slide/avalanche from the northeast side of the cone of Mount Rainier (Crandell, 1963). The Electron debris flow was a similar, but smaller, feature that descended the Puyallup River from Mount Rainier about 600 yrs ago (Crandell, 1971). This 40-mi-long lahar underlies about 14 mi^2 of the Puyallup River valley. Rockfalls and rock/debris avalanches also have occurred on Mount Rainier within historic time, the best-known being the 1963 rockfall/avalanche event on Little Tahoma Peak on the east side of the volcano; rock debris descended as much as 6,200 ft in elevation in traveling about 4 mi down the Emmons Glacier (Crandell and Fahnestock, 1965).

The largest known landslide to originate on a Pacific Northwest volcano was the 0.67-mi^3 rock slide-debris avalanche that occurred on Mount St. Helens in southwestern Washington in conjunction with the 1980 eruption of that volcano (Voight and others, 1983). The enormous, hot debris avalanche, which is the world's largest historic landslide, swept 15 mi down the North Fork Toutle River. Due to the presence of large amounts of water from melted glaciers and snow, the avalanche then remobilized to form large debris flows/mudflows that traversed the avalanche and continued downstream for 60 mi beyond its toe, modifying a total of more than 75 mi of river channel, including the main Toutle River and sections of the Cowlitz and Columbia Rivers.

Smaller landslides have originated on Mount Baker, in northern Washington, and Mount Hood, in northern Oregon, in recent years. Avalanches of snow, firn, and hydrothermally altered rock and mud were released from Mount Baker six times between 1958 and 1975; these debris avalanches traveled distances of 1.2 to 1.6 mi down the east slope of the volcano (Frank and others, 1975). Debris flows/mudflows have been common occurrences on the slopes of Mount Hood (Crandell, 1980), some old ones extending as far as the eastern part of the metropolitan area of Portland, a distance of some 45 mi (Trimble, 1963). In 1980, the Polallie Creek debris flow on the lower slopes of Mount Hood briefly dammed the East Fork of the Hood River (Gallino and Pierson, 1985).

Factors relating to landslide activity in specific areas of the Cascade-Klamath Ranges are as follows:

(1) Northern Cascade Range of Washington -- In addition to the Mount Baker and Glacier Peak volcanoes, the North Cascades in northern Washington are composed of Paleozoic metamorphic rocks (gneisses, phyllites, and schists); Paleozoic and Mesozoic marine conglomerates, sandstones, shales, and submarine volcanic materials; Tertiary continental sandstones and shales; and volcanic and plutonic rocks of a variety of ages and compositions (Fiksdal and Brunengo, 1981). Many of these geologic materials are subject to landsliding, particularly because the North Cascades have been lifted to high elevations in the last few million years, and, as a result, glaciers and rivers have cut deeply into the range, producing high relief and steep slopes susceptible to slope failure.

Fiksdal and Brunengo (1980) have noted patterns to the distribution of landslides in the north Cascades. Many of the large landslides (primarily rockslides and slumps) are in the Paleozoic Chuckanut sandstone and shale, most commonly where bedding dips downslope. Some of these landslides are probably early post-glacial in age (about 10,000 yrs old); others, such as the rock slump on Big Slump Mountain, appear to be only hundreds of years old (Fiksdal and Brunengo, 1981). Some of these old slides are stable; others have reactivated within historic time. Large slumps also have occurred in older carbonate rocks, phyllites, and schists, and in glacial-marginal or proglacial lake terraces (Fiksdal and Brunengo, 1980). A few large slides are located in granitic rocks and young pyroclastic deposits.

Debris flows and debris torrents have been fairly common on steep slopes of Chuckanut sandstone along the west slope of the North Cascades. G. W. Thorsen (personal communication, Consultant, Port Townsend, Washington) has noted the occurrence of several hundred debris flows/torrents in January 1983 on both logged and unlogged slopes in steep gullies in the Chuckanut sandstone in Whatcom County.

(2) Central Cascade Range of Washington -- South of the Skykomish River, the central part of the Cascade Range of the State of Washington is composed mainly of rocks that are younger and less deformed than those to the north (Fiksdal and Brunengo, 1981). The result is a region that generally has less extreme relief than the North Cascades. In addition, most of the region is made up of Tertiary and Quaternary volcanic rocks, which have been intruded by plutons of various sizes; these rocks are not as susceptible to slope failure as the sedimentary rocks to the north. Mesozoic and Tertiary sediments are found in this region, but they cover smaller areas than the volcanics. In addition, the central Cascades of Washington were not as intensely glaciated as the North Cascades. The result is that slope failures are not as large or as numerous as in the North Cascades. However, rockfalls and rock/debris avalanches are not uncommon on steep slopes, debris flows/torrents occur occasionally, and there have been a few major prehistoric slumps, particularly in the Green River basin (Fiksdal and Brunengo, 1981).

The 13-million-m^3 Ribbon Cliff rock slide, along the western shore of the Columbia River near the town of Entiat at the eastern edge of the Cascade Range, may be the key to an important part of the seismic history of the Pacific Northwest (Kienle and others, 1978). On December 14, 1872, a major earthquake was felt in an area extending from Eugene, Oregon, on the south, to central British Columbia on the north, and as far as east as Bozeman, Montana. This quake has received considerable study, but, because of a paucity of reliable contemporary accounts, there is a lack of agreement on its epicentral location and intensity. Based on contemporary accounts, Coombs and others (1977) concluded that the Ribbon Cliff slide was triggered by the 1872 quake. Based largely on the evidence presented by this slide, they assigned a MM intensity of VIII to the 1872 quake and established its epicenter in an area north of Lake Chelan, Washington, not far north of the slide. However, Kienle and others (1978), by dating trees and stumps on the Ribbon Cliff slide debris, concluded that no significant amount of movement of the slide debris has occurred in the past 215 yrs, and thus have inferred that the Ribbon Cliff slide was not triggered by the 1872 earthquake. This controversy leaves the intensity and epicentral location of the important 1872 quake very much in doubt.

(3) <u>Southern Cascade Range of Washington</u> -- The rocks of the southern Cascades (Mount Rainier to the Columbia River) of Washington State generally consist of a layered sequence of Tertiary volcanics, mainly andesite and basalt flows and volcaniclastics (Fiksdal and Brunengo, 1981). In general, volcanic rocks having a substantial proportion of volcaniclastics are the most unstable.

A common factor in slope instability in this region is interbedding of dense, hard andesites and basalts with softer volcaniclastics, which often have weathered to weak clay-rich layers (Fiksdal and Brunengo, 1981). Where these interbedded strong and weak layers dip downslope, failure is likely to occur. For example, this combination of alternating beds has resulted in major landsliding along the north shore of the Columbia River Gorge in southern Washington. More than 50 mi^2 of landslide deposits have been mapped in the Gorge, nearly all on the Washington side of the river (Palmer, 1977). The best-known of these landslides is the 12-14 mi^2 Bonneville landslide area, which forms the north abutment of Bonneville Dam. The main movement of this slide occurred slightly more than 700 yr B.P. (Lawrence and Lawrence, 1958).

Debris avalanches, flows, and torrents occur throughout the Cascade Range in southern Washington wherever there are steep slopes. Concentrations of debris failures have occurred in both sedimentary and volcanic rocks south and west of Mount Rainier, in young pyroclastic deposits east of Mount St. Helens, and elsewhere in granitic rocks, volcaniclastics, sedimentary rocks, andesites, and basalts (Fiksdal and Brunengo, 1980). Unconsolidated sediments also are subject to slumping in this region. For example, glacial, glacial margin, outwash, and alluvial terrace deposits in stream valleys radiating from Mount Rainier commonly fail as small slumps, leaving terrace scarps (Fiksdal and Brunengo, 1980).

(4) <u>Cascade Range of Oregon</u> -- In general, the Cascade Mountains of Oregon, chiefly volcanic in origin and Cenozoic in age, have two major geologic subdivisions: the western Cascades and the high (eastern) Cascades. The western Cascades are older (Late Eocene to Late Miocene in age), and consist of deformed, partially altered lava flows and pyroclastic rocks. The high Cascades consist mainly of undeformed, unaltered andesites and basalts, ranging in age from Pliocene to Holocene (Peck and others, 1964; Pyles and others, 1987). Because of these differences in alteration and structure, landslide activity is much more prevalent in the western Cascades than in the high Cascades.

On the Oregon side of the Columbia River Gorge, the same combination of generally southward-dipping, hard volcanic strata interbedded with clay-rich volcaniclastics exists as on the north side of the river. However, because the rocks dip into the southern valley wall, landsliding is on a much smaller scale than it is on the north side of the river. Although the total area of the slides on the south side is only about 0.8 mi^2, they have received considerable attention because they have been active recently and have posed coninuing problems to a transcontinental railroad and an interstate highway (I-84) (Palmer, 1977). The Fountain landslide, which is located along I-84 3 mi east of Cascade Locks, Oregon, has moved periodically for more than 30 yrs, causing considerable distress to the highway (D'Agnese, 1986).

The western Cascades of Oregon are generally composed of Tertiary lava flows and volcaniclastic and intrusive rocks, having in many areas undergone extensive weathering to form clay-rich soils (Peck and others, 1964; Swanson and Swanston, 1977). The western Cascades are dominated by the Oligocene and Lower Miocene Little Butte Volcanic Series, consisting of lava flows, altered ash flows, and laharic and epiclastic materials. The overlying lavas and ash flows of the Upper Miocene Sardine Formation are less altered. The most unstable areas of the western Cascades are located in terrain of the Little Butte Series and the Sardine Formation. For example, in the U.S. Forest Service's H. J. Andrews Experimental Forest in the central western Oregon Cascades, more than 25 percent of the area underlain by volcaniclastic rock is mantled by active or currently inactive earthflows (Swanson and James, 1975). Less than 1 percent of younger basalt and andesite rocks have been subjected to landslide activity.

An example of a large landslide in the western Cascades is the Lookout Creek earthflow in the H. J. Andrews Experimental Forest, about 45 mi east of Eugene (Pyles and others, 1987). This reactivated earthflow, which is part of a 1.5-mi^2 area of complex landslide topography, has been active for the past 80 yrs. Movement of this landslide varies with the amount of precipitation; annual movement for the years 1976-83 ranged from 0 to 8 in./yr, with the year of no movement corresponding to a year of low precipitation; the 8 in./yr movement occurred during a year in which precipitation was 102 in.

(5) Klamath Range-- The Klamath Mountains of southwestern Oregon, bounded by the Coast Range on the west and the Cascade Range on the east, are made up of a variety of rocks that include Paleozoic and Mesozoic sedimentary rocks, serpentinite, and granitic and metamorphic rocks (Radbruch-Hall, and others, 1982). Many of these rocks are jointed, foliated, and faulted. Topography is steep, and precipitation is heavy (fig. 2). As a result, landslides, particularly large-scale earthflows, debris slides, slumps, amd soil creep, are common, especially in highly sheared serpentinite.

Earthflows have disrupted 10-30 percent of the terrain in southwestern Oregon (Swanston and others, 1988). In the Klamath Mountains, these complex landslides, which commonly begin as slumps, individually range in area from less than 2.5 acres to slightly less than a square mile. There is strong evidence that logging operations have contributed to the activity of some of these earthflows.

Columbia Basin

The Columbia Basin subdivision (fig. 1) of south-central Washington and north-central Oregon is made up primarily of Tertiary volcanic rocks (Columbia River Basalt), except for minor areas of alluvial or lacustrine sediments which floor valleys crossing the basin. The climate is arid to semiarid, with an average annual rainfall generally not exceeding 16 in. (fig. 2.). The relatively flat surfaces of the basalt flows are not prone to landsliding. However, where the Columbia River and its tributaries have deeply incised the relatively flat Columbia River Basalt surface, steep cliffs are susceptible to failure, particularly where the basalt is interbedded with relatively weak volcanic tuffs or fine-grained sedimentary rocks; both such interbeds commonly have high clay contents. Rock slides of basalt with failure surfaces along these interbeds are common along both sides of the Columbia River upstream from the Columbia River Gorge to Lake Roosevelt, the impoundment behind Grand Coulee Dam (examples in: Shannon & Wilson, Inc., 1974; Hays and Schuster, 1987). Most of these basalt slides are large rock-block slides related to late Pleistocene flooding and erosion of the Columbia River valley and other erosional troughs (coulees) that trend generally northeast-southwest across the Columbia Basin. However, some are modern reactivations or first-time movements that have been caused by construction along valley walls. Such was the case in the 1960's when major highways and railroads on both sides of the Columbia River upstream from The Dalles, Oregon, had to be moved up the valley wall due to construction of John Day Dam and filling of its reservoir. These activities resulted in numerous slope failures along interbeds in the Columbia River Basalt (Anderson and Schuster, 1970).

An outstanding example of a prehistoric complex landslide in Columbia River Basalt due to the presence of weak interbeds and to late Pleistocene cataclysmic flooding is the Corfu landslide in the Saddle Mountains of central Washington. This large, complex rock slide (estimated volume: 0.22 mi^3) has a width of nearly 4 mi and a length of about 1 to 1 1/2 mi (Lewis, 1985). The present landslide configuration formed as a result of multiple episodic mass movements from 13,000-7,000 B.P.

Irrigation-induced landslides are a major problem in Pliocene fluvial-lacustrine sediments overlying Columbia River Basalt along the Columbia River north of Pasco, south-central Washington (Hays and Schuster, 1987; Schuster and others, 1987). These sediments, which range from conglomerates to fine-grained siltstones and shales, form the White Bluffs along the east bank of the Columbia River adjacent to the Hanford Site of the U.S. Department of Energy. The bluffs have been oversteepened by the river, but were relatively stable until irrigation water from Grand Coulee Dam was applied to new croplands immediately east of the river beginning in the period 1954-1963. Since then, the irrigated area has been subjected to about 60 in. of irrigation water annually, eight times the average annual precipitation (Brown, 1970). Waste water from irrigation has caused about 50 individual active landslides (some are reactivations of much older landslides) over the 30-mi length of the White Bluffs. The two largest landslide groups, the Savage Island and Locke Island landslides, which began as earth slides in soft siltstones and shales and degenerated into major earthflows, have active volumes of more than 13 million yd^3 each; one of the Locke Island slides has moved out into the Columbia River more than 150 yds.

Another example of irrigation-induced landsliding in the Columbia Basin is a creeping 0.4-mi^2 landslide in clay-rich alluvial-volcanic sediments along the south side of the Columbia River valley at The Dalles, Oregon (Beaulieu, 1985). Beginning in the 1970's, this landslide, which probably was triggered primarily by irrigation of fruit orchards upslope from the slide, damaged a school, streets, sidewalks, water and sewer lines, and homes.

Northern Rocky Mountains

The Northern Rocky Mountains subdivision (fig. 1), which makes up most of northern Idaho and western Montana, extends into northeastern Washington as an area of north-south-trending valleys between mountain ranges (elevations to above 7,000 ft). This subdivision generally is subject to semiarid to subhumid climate, with mean average precipitation locally exceeding 30 in. (fig. 2). The probability of landslide-triggering earthquake activity is low (fig. 3). The principal valley in this area is that of the Columbia River, which trends north-south for about 100 mi after it crosses the Canadian border into Washington, and then turns to the west to flow east-west along the southern boundary of the Northern Rocky Mountains subdivision. In the eastern part of the subdivision, the rocks are primarily Paleozoic and Mesozoic limestone, marble, quartzite, schist, and gneiss (Weaver, 1920). The western part, north of the east-west-flowing Columbia River, is composed mainly of granitic rocks of the Colville batholith (Pardee, 1918).

In general, bedrock in the Northern Rocky Mountains of the State of Washington has not been a source of significant historic landslide problems. However, landslides have been a major problem in fine-grained terrace materials of glaciofluvial and glaciolacustrine origin in the valley of the Columbia River and its tributaries. There is evidence of many large prehistoric landslides in these materials (Jones and others, 1961). In addition, the shores of Franklin D. Roosevelt Lake, the Grand Coulee Dam impoundment of the Columbia River, have been subject to hundreds of reservoir-induced landslides since filling of the reservoir in the early 1940's. These slides occurred, and are still occurring, in unconsolidated glaciofluvial sediments that constitute much of the rim of the reservoir. Jones and others (1961) studied some 500 individual landslides that took place between 1941 and 1953; these slope failures were primarily earth slumps, earth spreads, earthflows, and debris flows. Schuster (1979) noted an increase in slide activity from 1969 to 1975 due to drawdown of the reservoir during construction of the Third Powerplant at Grand Coulee Dam. Although some individual landslides in these Pleistocene deposits have been large and the total volume of modern slope movement probably is about 50-100 million yd^3, damages due to the slides have not been catastrophic and no deaths have occurred. This lack of catastrophe can be attributed to the following: (1) individual slides in these Pleistocene soils have not been large enough, nor have they attained sufficient velocities, to produce large and far-reaching surges in the reservoir; (2) the area around the reservoir rim is only lightly populated; and (3) since the inception of the Grand Coulee project, the U.S. Bureau of Reclamation has recognized the potential for landsliding and has employed mitigative measures, including restrictions on development in areas with landslide potential (Schuster, 1979).

Blue Mountains

The Blue Mountains subdivision of northeastern Oregon is bordered on the north and west by the Columbia Basin, on the east by the Northern Rocky Mountains in Idaho, and on the south by the Harney-Owyhee Broken Lands (fig. 1). Its climate varies from subhumid to semiarid; annual precipitation at higher elevations exceeds 30 in./yr, much of which is snow. The probability of landslide-triggering earthquake activity is low (fig. 3). The Blue Mountains have been arched upward and faulted since Miocene time; subsequent rapid erosion has cut steep gorges that are separated by sharp ridges or tablelands. The area is underlain primarily by Tertiary sedimentary and volcanic rocks, with some Mesozoic sedimentary rocks (Radbruch-Hall and others, 1982). In the western Blue Mountains, landslide incidence is high in the interbedded tuffs, rhyolite flows, and tuffaceous sedimentary rocks of the Tertiary John Day Formation.

There also has been considerable prehistoric landslide activity in Tertiary basalts along the Snake River and its tributaries in the Hell's Canyon area in the eastern part of the Blue Mountains. During the early 1980's, reactivation of part of a huge prehistoric landslide in Tertiary basalts occurred at the confluence of the Powder River with the Snake River. This probably was a result of the greater-than-normal precipitation in the area from 1982-84. This period of abnormally high precipitation also triggered the Hole-in-the-Wall Gulch landslide in 1984 in Tertiary basalts along the Powder River about 10 miles upstream from its mouth. The 8-million-yd^3 Hole-in-the-Wall Gulch rock/debris slide destroyed Oregon State Highway 86 and dammed the Powder River, impounding a 237-acre-ft lake, which is still in existence (Geist and Schuster, 1986).

Basin and Range Area

The Basin and Range Area (fig. 1) is located mainly in Nevada, California, Arizona, Utah, and New Mexico; however, a small percentage of the area extends into south-central Oregon. The Basin and Range Area, as a whole, is characterized geologically by tilted fault blocks, the crests of which form linear ranges separated by deep structural basins that generally are filled with poorly consolidated sediments (Radbruch-Hall and others, 1982). The climate in the Basin and Range Area of Oregon is semiarid to arid; annual rainfall generally is less than 8 in./yr (fig. 2). Much of the precipitation occurs as cloudbursts of high intensity and short duration, so that runoff is heavy and infiltration is minimal. The probability of landslide-triggering earthquake activity is low (fig. 3). Precipitation conditions favor the formation of debris flows, rather than slumps or slides, as the current types of landsliding in the Basin and Range Area (Radbruch-Hall and others, 1982). However, there is evidence of prehistoric slump/slide activity along the edges of fault-bounded basins in the Basin and Range Area; these slumps and slides generally date back to the Pleistocene.

Harney-Owyhee Broken Lands

The Harney-Owyhee Broken Lands are similar to the Basin and Range Area in structure and climate, except that fault-block topography is less common in the Broken Lands than in the Basin and Range. The probability of landslide-triggering seismic activity is low (fig. 3). The rocks in the Broken Lands are predominantly volcanic, and landsliding is minor (Radbruch-Hall and others, 1982). As in the Columbia Basin, but on a lesser scale, landslides occur where sedimentary rocks are overlain or interbedded with basalt. They occasionally occur along steep fault scarps, or along bluffs of tuffaceous Pliocene volcanic rocks.

REFERENCES

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., Bender, B. L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p., 6 plates.

Anderson, R. A., Jr., and Schuster, R. L., 1970, Stability of slopes in clay shales interbedded with Columbia River Basalt: Proceedings, 8th Annual Symposium on Engineering Geology and Soils Engineering, Pocatello, Idaho, p. 273-284.

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

Beaulieu, J. D., 1985, Geologic landslides in and near the community of The Dalles, Oregon: Oregon Geology, v. 47, no. 9, p .103-106, 108.

Brown, R. E., 1970, Some effects of irrigation in the Pasco Basin, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 2, no. 5, p. 326-327.

Chleborad, A. F., and Schuster, R. L., this volume, Characteristics of slope failures induced by the April 13, 1949, and April 29, 1965, Puget Sound area, Washington, earthquakes: 8 p.

Clarke, D. D., 1904, A phenomenal land slide: American Society of Civil Engineers Transactions, v. 53, paper no. 984, p. 322-412.

Committee on Ground Failure Hazards, 1985, Reducing losses from landsliding in the United States: National Research Council, Washington, D. C., National Academy Press, 41 p.

Coombs, H. A., Milne, W. G., Nuttli, O. W., and Slemmons, D. B., 1977, Report of the Review Panel on the December 14, 1872, earthquake, in WPPSS [Washington Public Power Supply System] Nuclear Projects No. 1 and 4, Preliminary safety analysis report: Docket nos. 50-460 and 50-513, Subappendix 2R A, Amendment 23.

Cornforth Consultants, Inc., 1989, Geotechnical considerations of the surface alignment, Westside Light Rail Project, Portland, Oregon: Report to Tri-County Metropolitan Transportation District of Oregon, Portland.

Crandell, D. R. 1963, Paradise debris flow at Mount Rainier, Washington, in Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 475-B, p. B135-B139.

Crandell, D. R., 1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geological Survey Professional Paper 677, 75 p.

Crandell, D. R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S. Geological Survey Bulletin 1492, p. 81.

Crandell, D. R., and Fahnestock, R. K., 1965, Rockfalls and avalanches from Little Tahoma Peak on Mount Rainier, Washington: U.S. Geological Survey Bulletin 1221-A, 30 p.

D'Agnese, S. L., 1986, The engineering geology of the Fountain landslide, Hood River County, Oregon: M.S. thesis, Department of Geology, Portland State University, 174 p.

Dole, H. M., 1954, The Astoria landslides: Ore Bin, Oregon Department of Geology and Mineral Industries, Portland, v. 16, no. 1, p. 1-2.

Fiksdal, A. J., and Brunengo, M. J., 1980, Forest slope stability project, phase I: Report prepared by State of Washington Department of Natural Resources, Division of Geology and Earth Resources, for Washington State Department of Ecology, Olympia, DOE 80-2a, 18 p.

Fiksdal, A. J., and Brunengo, M. J., 1981, Forest slope stability project, phase II: Report prepared by State of Washington Department of Natural Resources, Division of Geology and Earth Resources, for Washington State Department of Ecology, Olympia, WDOE 81-14, 62 p.

Frank, David; Post, Austin; and Friedman, J. D., 1975, Recent geothermally induced debris avalanches on Boulder Glacier, Mount Baker, Washington: U.S. Geological Survey, Journal of Research, v. 3, no. 1, p. 77-87.

Gallino, G. L., and Pierson, T. C., 1985, Polallie Creek debris flow and subsequent dam-break flood of 1980, East Fork Hood River Basin, Oregon: U.S. Geological Survey Water Supply Paper 2273, 22 p.

Geist, J. M., and Schuster, R. L., 1986, Hole-in-the-Wall Gulch landslide, Baker County, Oregon: Proceedings of the 22nd Symposium on Engineering Geology and Soils Engineering, Boise, Idaho, p. 227-244.

Hammond, E. H., 1965 [1970], Physical subdivisions [of the United States], in The National Atlas of the United States of America: U.S. Geological Survey, Washington, D.C., p. 61, scale 1:17,000,000.

Hays, W. H., and Schuster, R. L., 1987, Maps showing ground-failure hazards in the Columbia River valley between Richland and Priest Rapids Dam, south-central Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1699, scale 1:100,000.

Heusser, C. J., 1957, Variations of Blue, Hoh, and White Glaciers during recent centuries: Arctic, v. 10, p. 139-150.

Jones, F. O.; Embody, D. R.; and Peterson, W. L., 1961, Landslides along the Columbia River valley, northeastern Washington: U.S. Geological Survey Professional Paper 367, 98 p.

Kienle, C. F., Jr.; Farooqi, S. M.; Strazer, R. J.; and Hamill, M. L., 1978, Investigation of the Ribbon Cliff landslide, Entiat, Washington: Shannon & Wilson, Inc., Geotechnical Consultants, Portland, Oregon, 19 p. plus appendixes.

Landslide Technology, 1986, Washington Park geotechnical study: Report to City of Portland Bureau of Water Works, Portland, Oregon, 62 p. plus 30 figs.

Lawrence, D. B., and Lawrence, G., 1958, Bridge of the Gods legend -- its origin, history and dating: Mazama, Portland, v. 40, no. 13, p. 33-41.

Lewis, S. W., 1985, The Corfu landslide: a large-scale prehistoric compound-complex slide in south-central Washington: M.S. thesis, University of Arizona, 48 p. plus appendix.

North, W. B., and Byrne, J. V., 1965, Coastal landslides of northern Oregon: Ore Bin, Oregon Department of Geology and Mineral Resources, Portland, v. 27, no. 11, p. 217-241.

Noson, L. L.; Qamar, Anthony; and Thorsen, G. W., 1988, Washington State earthquake hazards: Washington Division of Geology and Earth Resources Information Circular 85, 77 p.

Palmer, Leonard, 1977, Large landslides of the Columbia River Gorge, Oregon and Washington: Geological Society of America Reviews in Engineering Geology, v. 3, p. 69-83.

Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation: U. S. Geological Survey Bulletin 677, 186 p.

Peck, D. L.; Griggs, A. B.; Schlicker, H. G.; Wells, F. G.; and Dole, H. M., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Pyles, M. R.; Mills, Keith; and Saunders, George, 1987, Mechanics and stability of the Lookout Creek earth flow: Bulletin of the Association of Engineering Geologists, v. 24, no. 2, p. 267-280.

Radbruch-Hall, D. H.; Colton, R. B.; Davies, W. E.; Lucchitta, Ivo; Skipp, B. A.; and Varnes, D. J., 1982, Landslide overview map of the conterminous United States: U.S. Geological Survey Professional Paper 1183, 25 p. plus map, scale 1:7,500,000.

Russell, I. C., 1893, A geological reconnaissance in central Washington: U.S. Geological Survey Bulletin 108, 108 p.

Russell, I. C., 1898, Topographic features due to landslides: Popular Science Monthly, v. 53, p. 480-489.

Russell, I. C., 1900, A preliminary paper on the geology of the Cascade Mountains in northern Washington: 20th Annual Report of the U.S. Geological Survey to the Secretary of the Interior, 1898-99, Part 2, General Geology and Paleontology, p. 83-210.

Schlicker, H. G.; Corcoran, R. E.; and Bowen, R. G., 1961, Geology of the Ecola State Park landslide area, Oregon: Ore Bin, Oregon Department of Geology and Mineral Industries, Portland, v. 23, no. 9, p. 85-90.

Schuster, R. L., 1979, Reservoir-induced landslides: Bulletin of the International Association of Engineering Geology, no. 20, p. 8-15.

Schuster, R. L., Chleborad, A. F., and Hays, W. H., 1987, Irrigation-induced landslides in fluvial-lacustrine sediments, south-central Washington State: 5th International Conference and Field Workshop on Landslides, Proceedings, Christchurch, August, p. 147-156.

Schuster, R. L., and Crandell, D. R., 1984, Catastrophic debris avalanches from volcanoes: 4th International Symposium on Landslides, Toronto, Proceedings, v. 1, p. 567-572.

Shannon & Wilson, Inc., 1974, Geotechnical studies for preliminary evaluation of a proposed nuclear power plant site at West Roosevelt, Washington: Report to Pacific Power & Light Company, Portland, Oregon, 113 p. plus figs. and appendixes.

Swanson, F. J., and James, M. E., 1975, Geology and geomorphology of the H. J. Andrews Experimental Forest, western Cascades, Oregon: U.S. Department Agriculture Forest Service Research Paper PNW-83, 15 p.

Swanson, F. J., and Lienkaemper, G. W., 1985, Geologic zoning of slope movements in western Oregon, U.S.A.: 4th International Conference and Field Workshop on Landslides, Proceedings, Tokyo, p. 41-45.

Swanson, F. J., and Swanston, D. N., 1977, Complex mass-movement terrains in the western Cascade Range, Oregon: Geological Society of America Reviews in Engineering Geology, v. 3, p. 113-124.

Swanston, D. N.; Lienkaemper, G. W.; Mersereau, R. C.; and Levno, A. B., 1988, Timber harvest and progressive deformation of slopes in southwestern Oregon: Bulletin of the Association of Engineering Geologists, v. 25, no. 3, p. 371-381.

Tabor, R. W., 1971, Origin of ridge-top depressions by large-scale creep in the Olympic Mountains, Washington: Geological Society of America Bulletin, v. 82, p. 1811-1822.

Tabor, R. W., and Cady, W. M., 1978, Geologic map of the Olympic Peninsula, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-994, scale 1:125,000.

Thorsen, G. W., 1987, Soil bluffs + rain = slide hazards: Washington Geologic Newsletter, Washington Division of Geology and Earth Resources, Olympia, v. 15, no. 3, p. 3-11.

Trimble, D. E., 1963, Geology of Portland, Oregon, and adjacent areas: U.S. Geological Survey Bulletin 1119, 119 p.

Tubbs, D. W. and Dunne, Thomas, 1977, Geologic hazards in Seattle: field guide for the Geological Society of America Annual Meeting, Seattle, 37 p.

U.S. Geological Survey, 1970, Mean annual precipitation [map], in The National Atlas of the United States of America: Washington, D.C., p. 97, scale 1:17,000,000.

Varnes, D. J., 1978, Slope movement types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides -- analysis and control: Transportation Research Board Special Report 176, National Academy of Sciences, Washington, D.C., p. 11-33.

Voight, B.; Janda, R. J.; Glicken, H.; and Douglass, P. M., 1983, Nature and mechanics of the Mount St. Helens rockslide-avalanche of 18 May 1980: Geotechnique, v. 33, no. 3, p. 243-273.

Weaver, C. E., 1920, The mineral resources of Stevens County: Washington Geological Survey Bulletin 20, 350 p.

Wiggins, J. H.; Slosson, J. E.; and Krohn, J. P., 1978, National hazards -- earthquake, landslide, expansive soil loss models: J. H. Wiggins Company Technical Report, Redondo Beach, Calif., 162 p.

CHARACTERISTICS OF SLOPE FAILURES INDUCED BY THE APRIL 13, 1949, AND APRIL 29, 1965, PUGET SOUND AREA, WASHINGTON, EARTHQUAKES

By
Alan F. Chleborad and Robert L. Schuster
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

Ground failures generated by historic earthquakes have caused major loss of life and severe property damage in many areas of the world. Much of this loss has resulted, either directly or indirectly, from slope failures (landslides) induced by earthquakes. Most slope failures triggered by seismic activity are relatively small and are not catastrophic; however, even they can result in significant losses, especially if they are numerous and occur in heavily populated areas where they can damage residential and industrial structures and disrupt lifelines, such as transportation, water, sewer, power, fuel, and communication facilities. Occasionally, earthquakes trigger large landslides that are truly devastating, resulting in enormous losses. Examples of major catastrophes related to earthquake-induced landslides are cited or described in detail in numerous reports (e.g., Close and McCormick, 1922; Plafker and others, 1971; Jaroff, 1977; Keefer, 1984; Crespo and others, 1987; Schuster and Chleborad, 1988; Li, in press).

Landslides triggered by historic earthquakes in western Washington have not resulted in catastrophic losses, although significant damage to lifelines and residential and industrial property by relatively small slope failures occurred as a result of the major earthquakes in the Puget Sound area in 1949 and 1965 (Hopper, 1981; Keefer, 1983; Grant, 1986). The rockslide/debris avalanche triggered by the M_s=5 earthquake associated with the 1980 eruption of Mount St. Helens destroyed public and private buildings and roads and bridges along the valley of the North Fork Toutle River (Schuster, 1983). Obviously, losses from a landslide that large (2.8 km^3) would have been much greater had it occurred in a setting of higher population density and greater development.

The potential for loss of life and severe property damage related to earthquake-induced landsliding and other forms of ground failure is a concern because of the recently acknowledged possibility of a future great earthquake in the Pacific Northwest (Heaton and Kanamori, 1984; Atwater, 1988). In addition, increased population density and land development throughout the Puget Sound area can be expected to result in greater losses in the future as increasing numbers of people and newly developed property are exposed to the landslide hazard.

Fourteen earthquakes, between 1872 and 1980, have caused landslides in the State of Washington (Noson and others, 1988). During that period, the greatest number of recorded earthquake-induced slope failures occurred as a result of the M_b=7.1 Olympia earthquake of April 13, 1949, and the M_b=6.5 Seattle-Tacoma earthquake of April 29, 1965. Previous studies by Hopper (1961) and Keefer (1983), describe the nature and extent of landslides and other ground failures related to the 1949 and 1965 events; their studies were based on published and unpublished data, including extensive data from written responses to University of Washington intensity-survey questionnaires by local people in the damage areas. A discussion of the types and distribution of ground failure that have occurred due to historic earthquakes in western Washington and a review of plans for additional studies was presented by the authors in a previous report (Schuster and Chleborad, 1988).

The purpose of this report is to present preliminary results of studies undertaken to better define the distribution and characteristics of earthquake-induced slope failures related to the April 13, 1949, and April 29, 1965, earthquakes. This information is intended to help develop an understanding of the probable location and nature of future earthquake-induced slope failures needed for earthquake hazard reduction and effective land-use planning on a regional scale.

CURRENT STUDY

In an effort to verify and refine reported data and to expand the data base, a study was undertaken consisting of: (1) review of published information (newspaper and technical journal articles, and governmental agency accounts), (2) interviews with residents and local officials having information on ground failures related to the 1949 and 1965 earthquakes, and (3) field study of earthquake-induced slope-failure sites.

RESULTS OF THE STUDY

Results of the present study indicate that at least 50 slope failures were triggered by the 1949 earthquake and at least 55 by the 1965 event. The current estimates are more than double those presented in a previous study based on a review of published accounts (Keefer, 1983), indicating considerable under-reporting at the times of the earthquakes. Undoubtedly, the current estimates also understate the actual number of slope failures. As pointed out by Keefer (1983), reporting of ground failures is relatively complete in populated areas, but is less thorough in sparsely inhabited areas. Consequently, the data of the present study probably are heavily weighted toward occurences in populated areas. Nevertheless, it is believed the considerable addition to the data set provides a clearer picture of landslide activity related to the 1949 and 1965 events.

The slope failures reported for the 1949 and 1965 earthquakes occurred mostly in the Puget Sound lowland area with outlying occurrences in parts of the Cascades Range and in far northwestern Oregon. Figure 1 shows the areas (~5000 mi^2 and ~2500 mi^2, respectively) within which all but a few of the reported 1949 and 1965 earthquake-induced slope failures occurred. Although various types of slope movement were generated by the quakes, most were minor soil slides (slope failure nomenclature from Varnes, 1978) with several inches to several feet of displacement. Nearly all of the rock falls and rock slides that were reported occurred in mountainous areas of the Cascade Range adjacent to the Puget Sound lowland and along parts of the Columbia River Valley to the south. The largest reported landslide (~65 x 10^4 yds^3) occurred on the eastern shore of the Tacoma Narrows 3 days after the 1949 earthquake that is considered to have triggered it.

Some characteristics of the the 50 reported slope failures triggered by the April 13, 1949, earthquake are shown in Table 1; similar data on landslides induced by the April 29, 1965, earthquake are presented in Table 2. As shown in Tables 1 and 2, most of the 1949 and 1965 slope failures were determined to have been slumps (or other slides of undetermined type) in artificial fill, glacial drift, or surficial debris derived from glacial drift. Most of these slides occurred on slopes between 15^0 and 45^0 and had

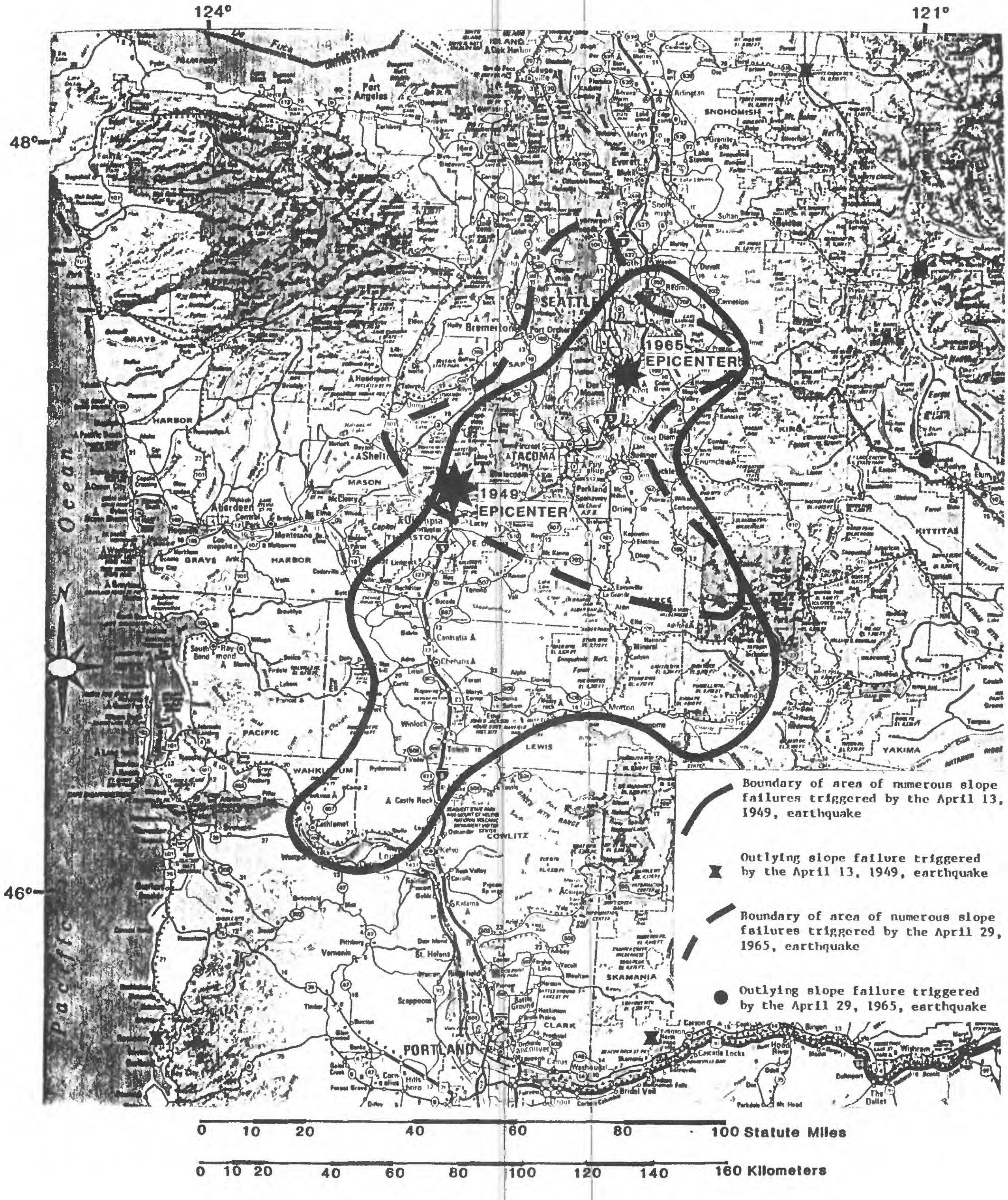


Figure 1. Areas within which numerous slope failures were reported for the April 13, 1949, earthquake and the April 29, 1965, earthquake.

Table 1. Characteristics of April 13, 1949, earthquake-induced slope failures

Slope failure type	Total number	Estimated volumes: total number per category	Average slope angle: total number per category	Geologic material: total number per category
Slump	27	$<2 \times 10^3$ yds^3: 16 $>2 \times 10^3$ yds^3: 8 Undetermined: 3 Largest vol: 25 $\times 10^3$ yds^3	0-15^0: 3 15-30^0: 10 30-45^0: 6 45-90^0: 1 Undetermined: 7	Artificial fill: 14 Glacial drift and(or) surficial debris derived from glacial drift: 9 Holocene alluvium: 2 Holocene beach deposit (sand): 1 undetermined: 1
Rock fall or rock slide	12	$<2 \times 10^3$ yds^3: 6 Undetermined: 6 Largest vol: 2.0 $\times 10^3$ yds^3	45-90^0: 12	Volcanic rock: 8 Sedimentary rock (nonglacial-continental): 2 Metamorphic rock: 1 undetermined: 1
Slide (type undetermined)	6	$<2 \times 10^3$ yds^3: 2 $>2 \times 10^3$ yds^3: 1 Undetermined: 3 Largest vol: 5.0 $\times 10^3$ yds^3	30-45^0: 2 Undetermined: 4	Glacial drift and(or) surficial debris derived from glacial drift: 4 Undetermined: 2
Lateral spread and(or) slump	3	$<2 \times 10^3$ yds^3: 1 $>2 \times 10^3$ yds^3: 1 Undetermined: 1 Largest vol: 3.0 $\times 10^3$ yds^3	Undetermined: 3	Artificial fill underlain by alluvium, deltaic deposits, or tidal-flat mud: 3
Debris avalanche	1	Volume: 65 $\times 10^4$ yds^3	Avg. slope: 32^0	Glacial drift (sand and gravel on a clay base)
Block slide	1	Volume: 14 $\times 10^3$ yds^3	Avg. slope: 13^0	Deposits of mass wasting derived from glacial drift

Table 2. Characteristics of April 29, 1965, earthquake-induced slope failures

Slope failure type	Total number	Estimated volumes: total number per category	Average slope angle: total number per category	Geologic material: total number per category
Slump	23	$<2 \times 10^3$ yds^3: 16 $>2 \times 10^3$ yds^3: 4 Undetermined: 3 Largest volume: 12×10^3 yds^3	0–15^0: 2 15–30^0: 8 30–45^0: 10 Undetermined: 3	Artificial fill: 13 Glacial drift and(or) surficial debris derived from glacial drift: 8 Holocene landslide deposit: 2
Slide (type undetermined)	17	$<2 \times 10^3$ yds^3: 7 Undetermined: 10 Largest volume: 2×10^3 yds^3	30–45^0: 7 Undetermined: 10	Glacial drift and(or) surficial debris derived from glacial drift: 7 Artificial fill: 4 Holocene landslide deposit: 1 undetermined: 5
Debris, earth, or mud flow	5	$<2 \times 10^3$ yds^3: 2 $>2 \times 10^3$ yds^3: 3 Largest vol: 5×10^3 yds^3	15–30^0: 3 30–45^0: 2	Artificial fill: 3 Glacial drift and(or) surficial debris derived from glacial drift: 2
Rock fall or rock slide	4	$<2 \times 10^3$ yds^3: 2 Undetermined: 2	45–90^0: 2 Undetermined: 2	Volcanic rock: 1 Metamorphic rock: 1 undetermined: 2
Lateral spread or slump	4	$<2 \times 10^3$ yds^3: 2 $>2 \times 10^3$ yds^3: 1 Undetermined: 1	0–5^0: 4	Artificial fill underlain by alluvium, deltaic deposits, or tidal-flat mud: 4
Block slide	1	Volume: 14×10^3 yds^3	Avg. slope: 15^0	Deposits of mass wasting derived from glacial drift
Debris fall	1	Volume: $<2 \times 10^3$ yds^3	Avg. slope: 90^0	Glacial drift (sand and gravel)

volumes of less than 2 x 10^3 yds^3. Several of the 1965 slides were apparent reactivations of slope failures that showed movement during the 1949 earthquake. Most of the few rock falls and(or) rock slides that occurred were in volcanic rock and all occurred on slopes greater than 45 degrees. Several debris, earth, or mud flows were generated by the 1965 earthquake, but none of these types of slope failures were identified among the landslides reported for the 1949 quake. Comparison of the volume of the 1949 Tacoma Narrows landslide (~65 x 10^4 yds^3) with other reported slope failures (all less than 25 x 10^3 yds^3) underscores its anomalous size.

A significant number of the reported slope failures occurred in an environment thought to be conducive to liquefaction failures, as suggested by the presence of sediment types susceptible to liquefaction, high water tables, and in some cases the occurrence of sand boils in the immediate vicinity. Included among these are some slides and(or) lateral spreads located along the shores of rivers, lakes, and other bodies of water that typically involve recent alluvium, artificial fill, lacustrine sediments, tidal flat muds, or deltaic deposits. Also, liquefaction may have been involved in the failure of some slopes on hillsides underlain by glacial drift. For example, in the case of the Tacoma Narrows landslide, the slope may have been weakened by liquefaction of sediments within the hillside at the time of the 1949 earthquake, 3 days prior to the failure, as suggested by a newspaper report (Vogel, 1949) of white sand boiling up through a deep crack a short distance from the cliff's edge.

The Esperance Sand member of the Vashon drift is widespread and near the surface in many parts of the Seattle-Tacoma area. The contact zone of the Esperance Sand with underlying impermeable materials has been identified as a zone of particular landslide hazard in the Seattle area because of the effect of the contact on ground-water movement and because of its association with landslides that occur during wet periods (Tubbs, 1974). According to Tubbs (1974), ground water moves down through the sand to the impermeable contact and then moves laterally to the hillside resulting in saturation of the zone of contact and surficial slope materials. In most wells that extend through the Esperance Sand in the Seattle area, it is found that the zone a few meters above the underlying Lawton Clay member of the Vashon drift is water-saturated and shows a low penetration resistance that is usually less than five blows per foot (Yount, 1983). It has been suggested by Yount (1983) that the water-saturated condition within the zone may be a contributing factor to intensified seismic ground shaking. The reported low penetration resistance and saturated condition of the zone also suggests that sediment within the zone may be susceptible to liquefaction and that liquefaction may have played an important role in past earthquake-induced slope failures involving the zone of contact of Esperance Sand with underlying impermeable materials.

REFERENCES

Atwater, Brian, 1988, Probable local precedent for earthquakes of magnitude 8 or 9 in the Pacific Northwest, _in_ Hays, W.W., Ed., Proceedings of Conference 42, Olympia, Washington, April, Workshop on Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas: U.S. Geological Survey Open-File Report 88-541, p. 62-68.

Close, Upton, and McCormick, Elsie, 1922, Where the mountains walked: National Geographic Magazine, v. 41, no. 5, p. 445-464.

Crespo, E., Nyman, K. J., and O'Rourke, T. D., 1987, 1987 Ecuador earthquakes of March 5, 1987: Earthquake Engineering Research Institute Special Earthquake Report, 4 p.

Grant, P. W., 1986, The potential for ground failures in the Puget Sound area, in Kitzmiller, Karla, Proceedings of Conference XXXIII, A Workshop on Earthquake Hazards in the Puget Sound Washington Area, October 29-31, 1985, Seattle, Washington: U.S. Geological Survey Open-File Report 86-253, p. 134-138.

Heaton, T. H., and Kanamori, H. 1984, Seismic potential associated with subduction in the Northwestern United States: Bulletin of the Seismological Society of America, Vol. 74, No. 3, pp. 933-941

Hopper, M. G., 1981, A study of liquefaction and other types of earthquake-induced ground failures in the Puget Sound, Washington, region: M.S. thesis, Virginia Polytechnic and State University, Blacksburg, 131 p.

Jaroff, Leon, 1977, Forecasting the earth's convulsions, in Nature/science annual, 1977 edition: Time/Life Books, New York, p. 21-33.

Keefer, D. K., 1983, Landslides, soil liquefaction, and related ground failures in Puget Sound Earthquakes, in Jacobsen, Muriel, compiler, Proceedings of Workshop XIV, Earthquake Hazards of the Puget Sound Region, Washington, 13-15 October 1980, Lake Wilderness, Washington: U.S. Geological Survey Open-File Report 83-19, p. 280-299.

Keefer, D. K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406-412.

Noson, L. L., Qamar, Anthony, and Thorsen, G. W., 1988, Washington State earthquake hazards: Washington Division of Geology and Earth Resources, Information Circular 85, 77 p.

Li, T., in press, Landslides: extent and economic significance in China, in Brabb, E.E., and Harrod, B.L., Landslides: extent and economic significance: Proceedings of 28th International Geological Congress, Symposium on Landslides, Washington, D.C., 17 July 1989, p. 231-247.

Plafker, George, Ericksen, G.E., and Fernandez Concha, Jaime, 1971, Geological aspects of the May 31, 1970, Peru earthquake: Seismological Society of America Bulletin, v. 61, no. 3, p. 543-578.

Schuster, R.L., 1983, Engineering aspects of the 1980 Mount St. Helens eruptions: Bulletin of the Association of Engineering Geologists, v. 20, no. 2, p. 125-143.

Schuster, R.L., and Chleborad, A.F., 1988, Earthquake-induced ground failure in western Washington, in Hays, W.W., ed., Proceedings of Conference 42, Olympia, Washington, April, Workshop on Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas: U.S. Geological Survey Open-File Report 88-541, p. 100-109.

Tubbs, D.W., 1974, Landslides in Seattle: Washington Division of Geology and Earth Resources, Information Circular No. 52, 15p.

Varnes, D. J., 1978, Slope movement types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides -- analysis and control: Transportation Research Board Special Report 176, National Academy of Sciences, Washington, D.C., p. 12-33.

Vogel, Elmer, 1949, Cliff topples into Sound, Vast slide laid to quake, Slide stirs tidal wave: Tacoma News Tribune, Tacoma, Washington, April 18, p. 1, 2.

Yount, J.C., 1983, Geologic units that likely control seismic ground shaking in the greater Seattle area, in Jacobsen, Muriel, compiler, Proceedings of Workshop XIV, Earthquake Hazards of the Puget Sound Region, Washington, 13-15 October 1980, Lake Wilderness, Washington: U.S. Geological Survey Open-File Report 83-19, p.268-273.

THE TSUNAMI THREAT IN THE PACIFIC NORTHWEST UNDER TODAY'S LAND USE CONDITIONS

by
Jane Preuss
Urban Regional Research
Seattle Washington

Gerry Hebenstreit
Science Applications International Corporation
McLean, Virginia

PROJECT OBJECTIVE

The underlying significance of this project lies in this goal of a threat inventory which treats the earthquake/tsunami event not as the sole threat but as the initiator of a suite of interrelated hazards. It is only by such an approach that detailed loss estimates and mitigation efforts can be conducted with a relatively high level of accuracy and effectiveness.

BACKGROUND

Thrust-type earthquakes occurring offshore always have the potential for generating destructive local tsunamis. Such waves could produce widespread damage on the outer coasts of Washington, Oregon, and California (as well as British Columbia). It would also be possible for such waves to propagate along the Strait of Juan de Fuca and into the Puget Sound-Georgia Strait Region. In addition, major earthquakes occurring under the Strait of Juan de Fuca-Puget Sound-Georgia Strait would move sufficiently large volumes of water, whether through upthrust of the sea floor, subsidence or earthquake-induced slumping to generate tsunamis within the complex.

Evidence presented in recent investigations (Bourgeois, Reinhardt 1987; Atwater 1987; Heaton & Hartzell 1985) indicates that the outer coasts of the Cascadia subduction zone are vulnerable to tsunami activity. Atwater (1987) reported evidence for at least six subsidence episodes in the last 7,000 years. In all cases, vegetated coastal lowlands were buried by intertidal mud. In three of the episodes, patterns of sand sheets lying atop the buried lowlands could be explained by inundation due to tsunamis and the resulting shoreward transport of sand. Other research (Reinhardt & Bourgeois 1987; Atwater, Hull & Bevis 1987) cites additional evidence for subsidence and possible tsunami-related flooding in the past thousand years. Geologically, it appears clear that tsunamis have accompanied great subduction zone earthquakes in the Puget Sound Region.

In the Cascadia south zone, as with other areas examined, the extreme wave height values are found along the coast within the source region. Dominant wave energy distributions are confined to the immediate source area; i.e., the most extreme wave heights are found along the coastal zones within the source uplift zone. It was also found that the elevations tend to taper off (although not uniformly) to the north and south of the immediate area of the uplift (Hebenstreit 1988). See Figure 1.

These studies, by themselves, cannot provide estimates of the current tsunami threat. In order to understand the modern implications of this susceptibility, it is critical to correlate the tsunami threat *per se* with current land use characteristics. Simply calculating flooding patterns leaves the threat picture incomplete.

This project, conducted jointly by SAIC and Urban Regional Research, develops a methodology for defining characteristics of coastal risks and for projecting the geographic area of vulnerability. A case study methodology is being used which focuses on Grays Harbor, Washington. The case study area also corresponds to the location of sand lenses discovered on the outer Washington coast (at Willapa Bay and Grays Harbor) by Atwater, Bourgeois and Reinhardt. Data from Reinhardt indicates that in prehistoric events large stands of trees were able to retard the waves' runup. Today, not only are the prehistoric trees for the most part gone, but the urban uses often increase the hazard. For example, industrial uses will significantly compound both the physical and economic effects of any coastal disturbance. Thus, this current series of studies is significant in that it examines the threat in its modern context.

This study is unique in that it integrates the physical threat - inundation, strong currents, and a potential for ground subsidence with the land use characteristics of the threatened area to assess potential hazards due to floating debris, fire, contamination from hazardous substances, etc. In essence, it treats tsunami threat as a system rather than a single physical process. Once the threat is formulated it becomes possible to estimate loss patterns and management.

METHODOLOGY

Three key risk based variables and the tools used for analysis were:

- Definition of coastal area subject to water incursion
  A fine scale numerical model of wave and water behavior calculates runup, wave amplitude and velocity forces (during runup and drawdown) in Grays Harbor. The coastal areas subject to high water were defined by these calculations. Subsequently, structures subject to high wave forces are identified.

- Definition of areas subject to subsidence
  Flooding is to a significant degree dependent upon elevation. Thus, a critical variable in projecting inundation and risk is a determination of the areas prone to subsidence. These areas can reasonably be expected to be soft and highly saturated such as the alluvium in virtually the entire urbanized Hoquiam/Aberdeen areas (Walsh, et al 1987). Figure 2 shows land use in the Hoquiam/port area. A corresponding three dimensional map prepared using the Surfer program from Golden Graphics is shown in Figure 3.

- Definition of air contamination patterns from hazardous materials
  EPA requires mandatory filing of hazardous materials stored in an amount exceeding a specified threshold level. Contamination plumes have been mapped using the Cameo air dispersion model developed by NOAA. Spill conditions were simulated with chlorine and ammonia as representative chemicals using EPA threshold levels under ambient temperature and prevailing wind directions during both summer and winter conditions for selected sites which had reported storage of

such chemicals. Figures 4a and 4b illustrate the extent of potential airborne contamination in Hoquiam from a release at the ITT Rayonier Plant under two alternative assumptions. Note that the threatened areas are primarily residential and that the Fire Department is potentially within the contamination zone. Figures 4a and 4b are for the same parcels as are shown in Figure 3.

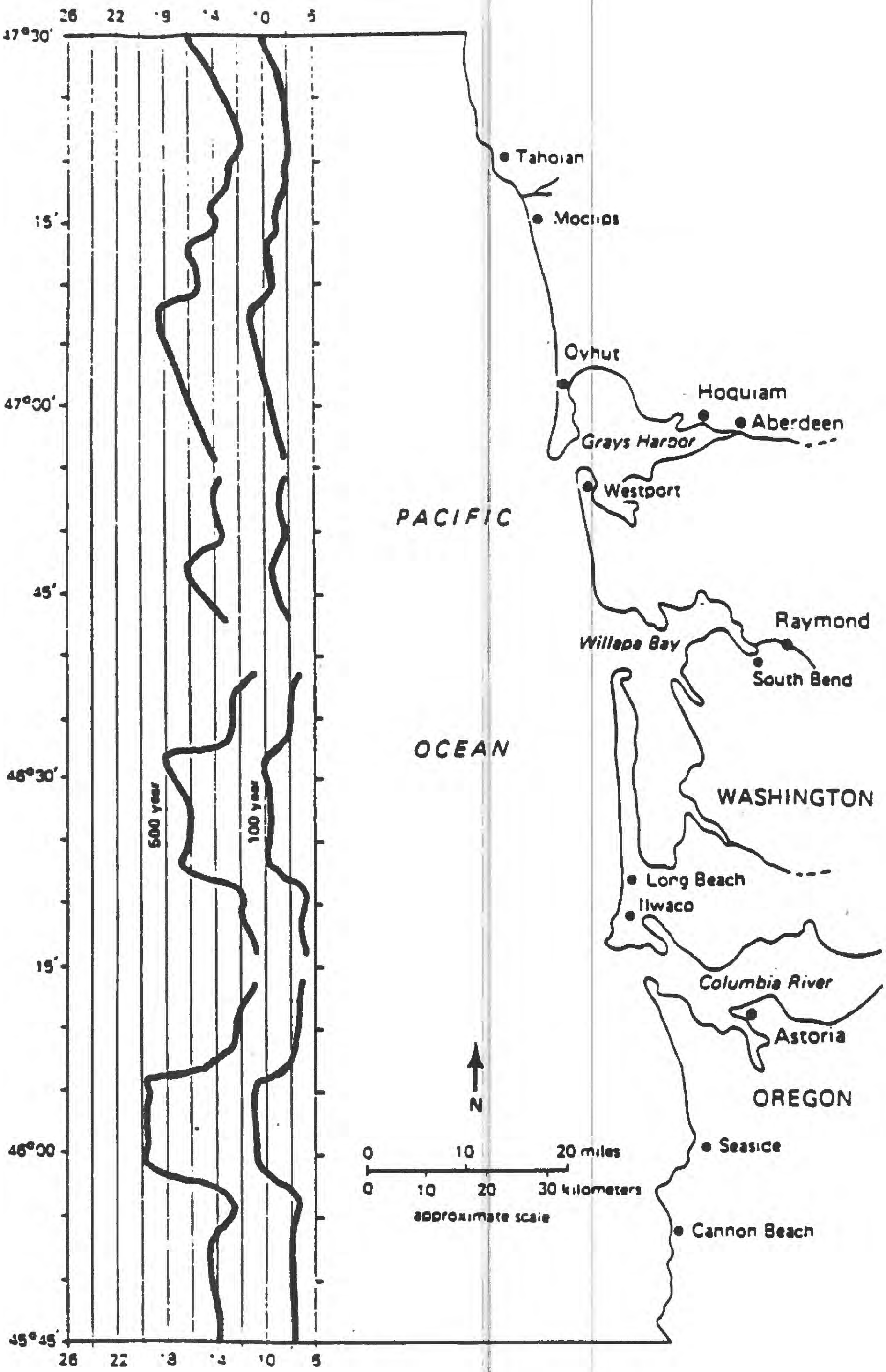
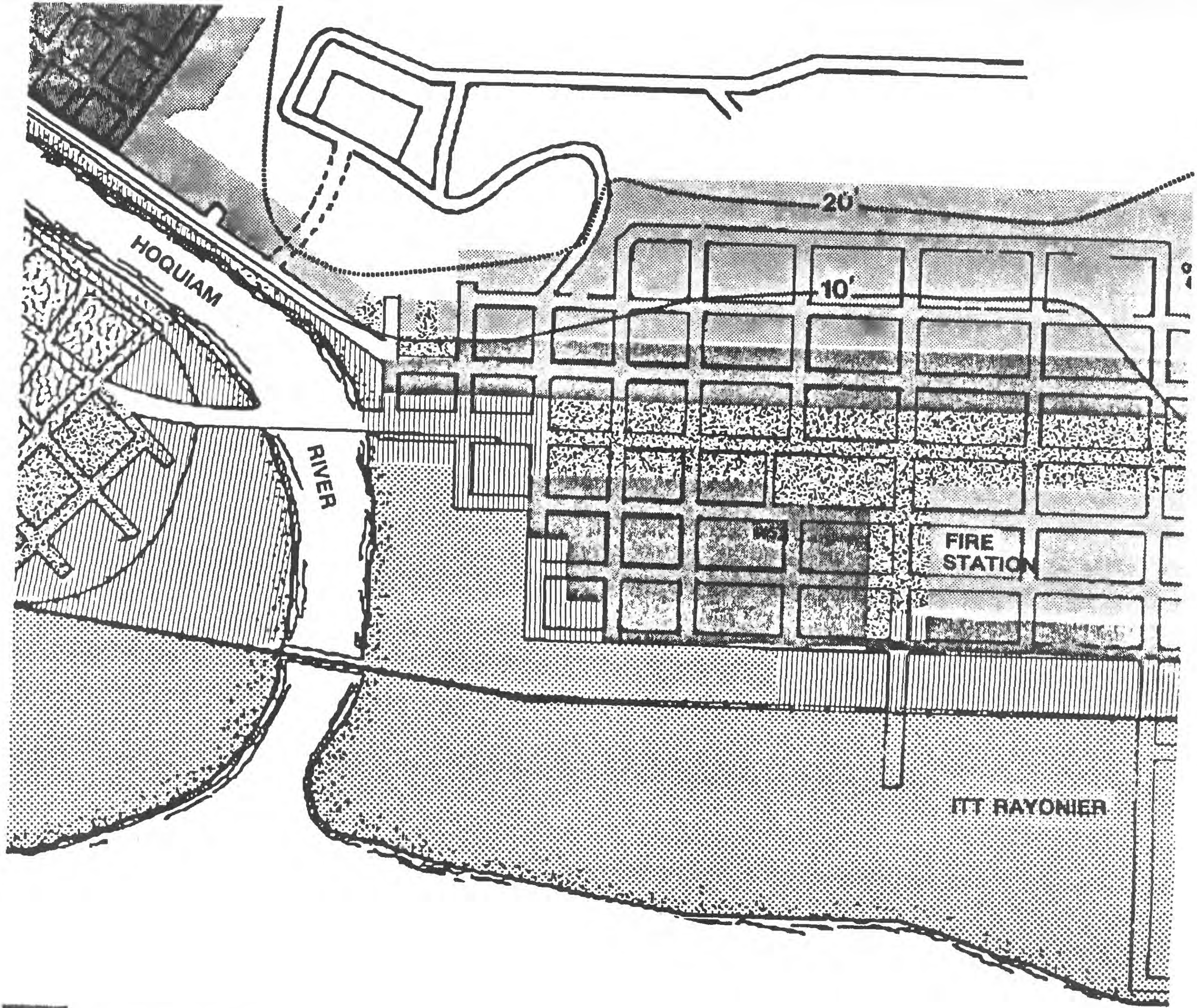


Figure 1 100 and 500 year Tsunami elevations in feet above mean sea level.



Mixed Residential

Medium Density Residential

Central Commercial

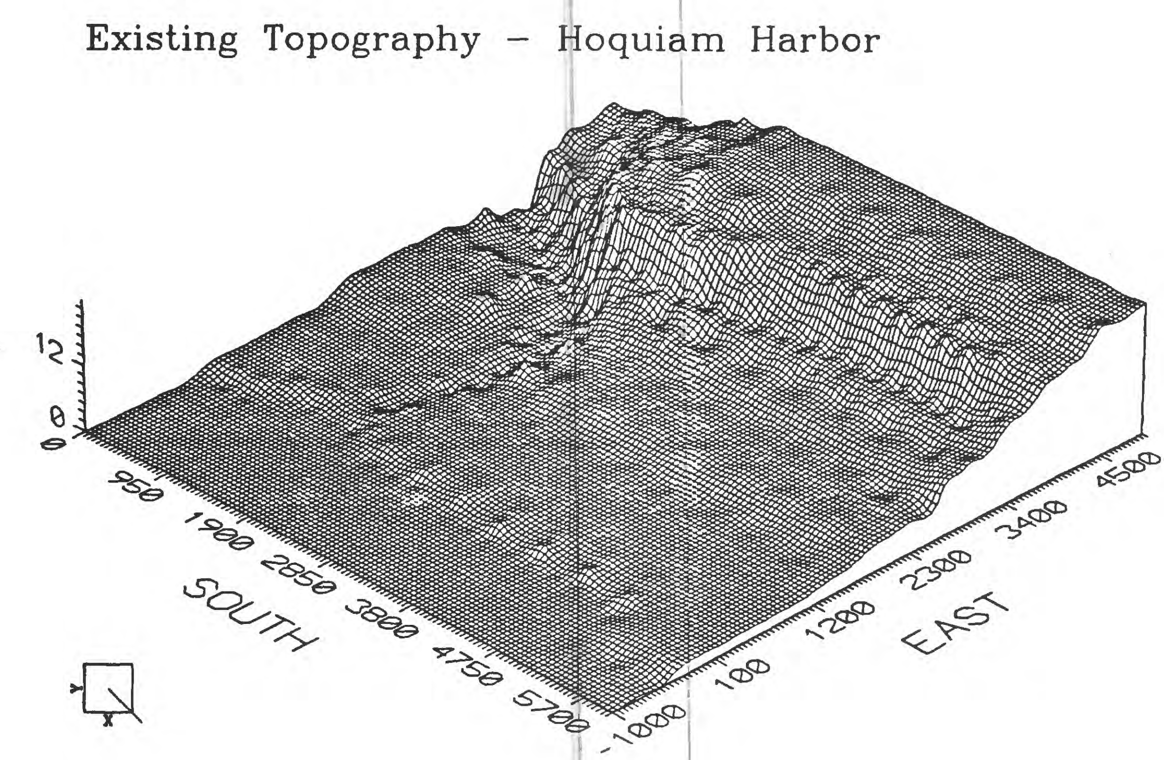
Commercial/Industrial

General Commercial

Heavy Industrial

Soil Conditions: Alluvium

Figure 2: Land Use for selected portion of Hoquium.



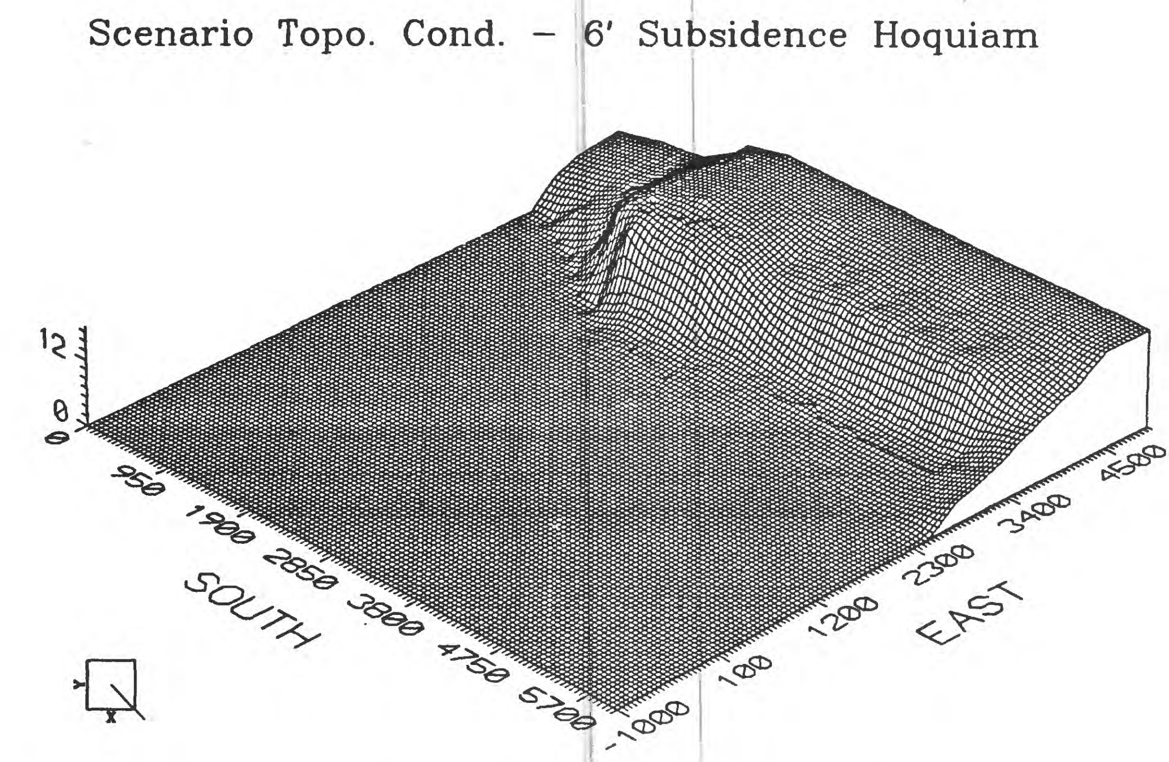


Figure 3: Topography parcels of land shown in Figure 2

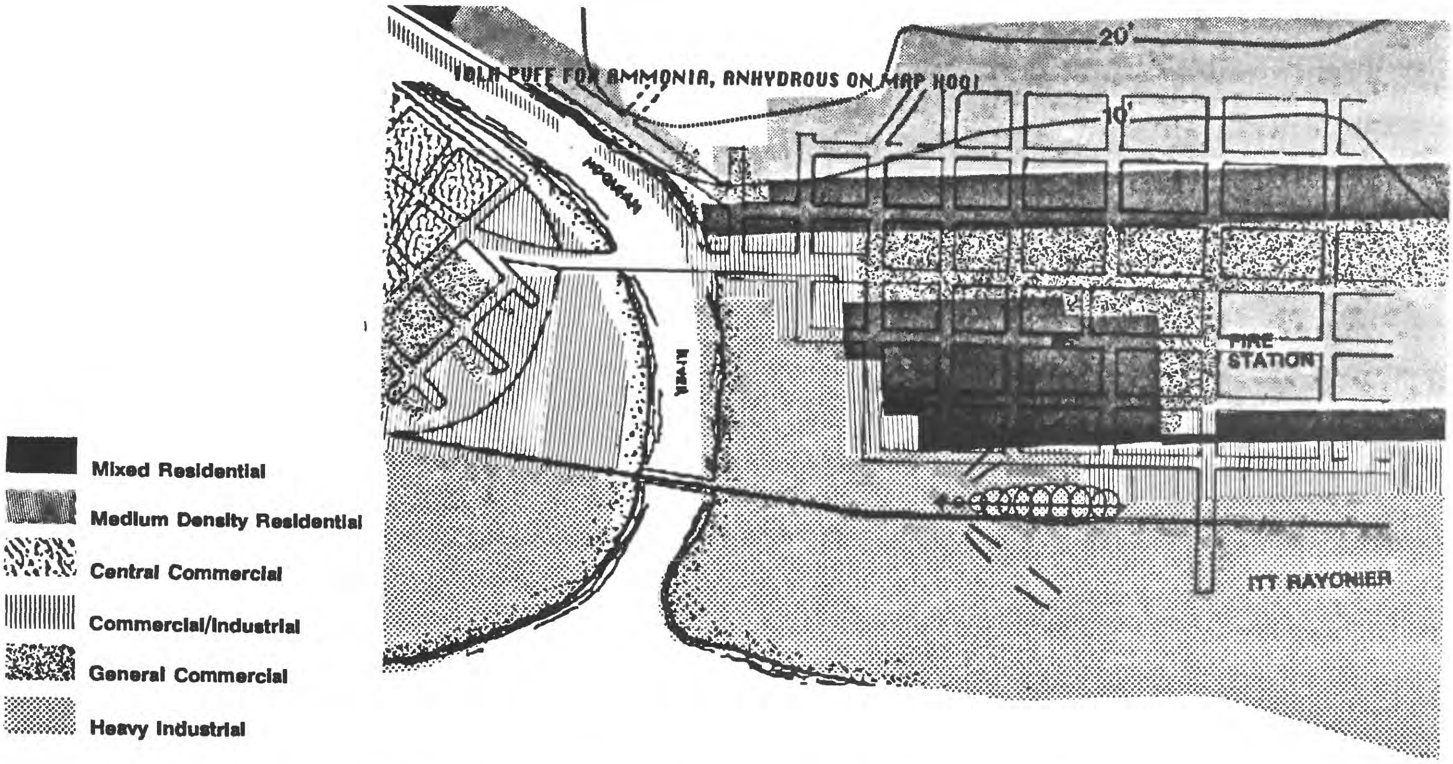


Figure 4a Air Contamination under IDLH (immediately dangerous to life and health) conditions for Chlorine

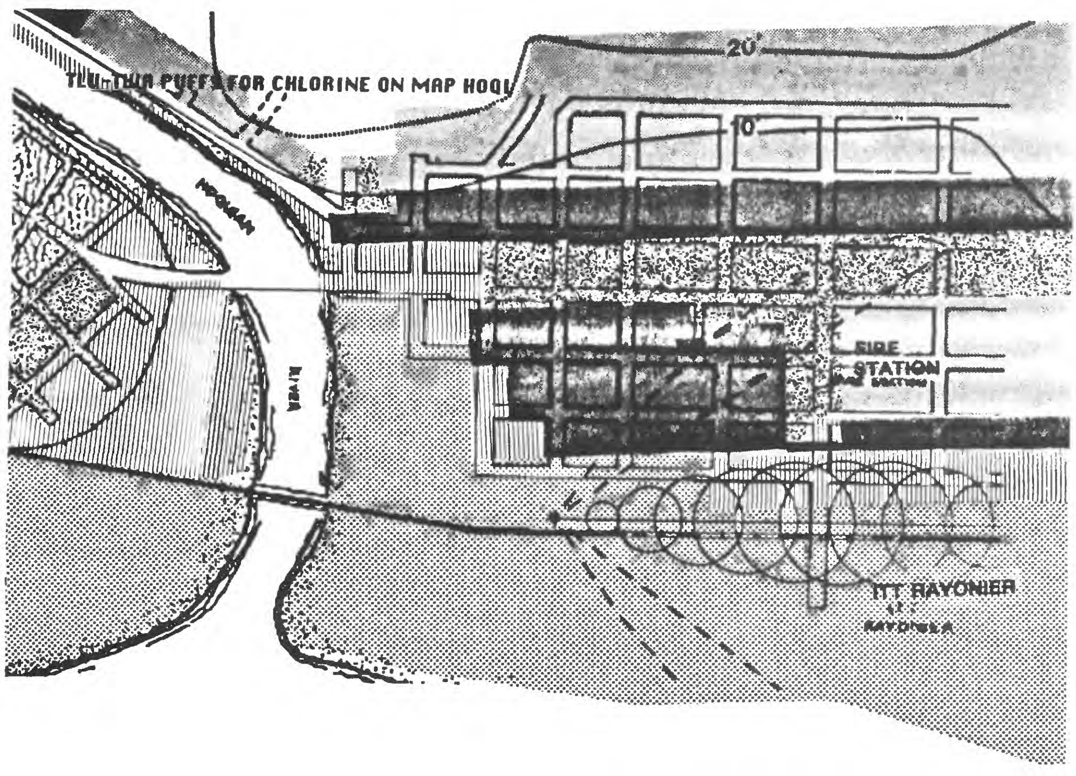


Figure 4b Air Contamination under TLV-TWA (threshold limit value-time weighted average) for Chlorine

SECTION II: FUNDAMENTAL INFORMATION TO ENHANCE PROFESSIONAL SKILLS

This section of the report contains 5 contributions that provide fundamental information of the non-technical professional end user of earth science and engineering information. These end users seek to apply information describing:

- Where earthquakes have occurred in the past,
- their frequency,
- their probability of occurrence, and
- their potential impacts.

in various kinds of application that

- save lives and prevent injuries,
- reduce property damage and economic losses, and
- reduce social and economic disruption.

These applications must be economically and politically feasible in order to be adopted. Understanding of the basic data.

What is an Earthquake and How is it Measured?

By
Anthony Qamar
Geophysics Program AK-50, University of Washington
Seattle, WA 98195

Introduction

The existence of volcanoes and earthquakes is the most obvious indication that the inside of the earth is in motion. These motions are small but are measurable, even at the earth's surface. For example, we now know that most of North America sits on a thick slab or **plate** that moves to the southeast relative to the **Pacific plate** at a rate of about two inches per year. When this motion is jerky, it creates an earthquake.

Most of the world's earthquakes occur at or near the boundaries of these plates. In the Northwest, the geologically young Juan de Fuca plate is moving away from the Pacific plate and toward North America. As the Juan de Fuca plate butts up against North America it dives beneath British Columbia, Washington, and Oregon. As in other parts of the world where the convergence of plates occurs, this situation could potentially lead to a great **subduction earthquake**, caused by the sudden slip of a portion of the Juan de Fuca plate beneath North America.

The stresses that develop from the convergence of these two plates are believed to cause most of the shallow and deep earthquakes that we experience in the Northwest.

What is an earthquake?

When rock is stressed, it may suddenly slip along a weak zone or **fault** (Figure 1). If the slip occurs over a large area we experience an earthquake of large **magnitude**; slip over a small area produces a small earthquake. If the fault ruptures the surface, we may observe displacements of the ground of less than a millimeter in a small earthquake or greater than tens of meters in a great earthquake. In the Northwest, many earthquakes occur at relatively great depths (up to 100 km below the earth's surface), and the faults that cause these earthquakes do not reach the earth's surface where they can be recognized. But even if we are far from the fault, we can feel motion of the ground because different types of waves (eg P, S, and surface waves) travel rapidly through the earth, away from the fault, at speeds of 3 to 8 kilometers per second. The ground shaking at a site produced by these **seismic waves** causes most of the damage during earthquakes. The shaking of the rock is analogous to the quivering of a a block of jello that is disturbed. Any structure built on the ground will shake too, and, even if the ground stopped moving, the building would continue to oscillate for a time.

Let us review some terms used by seismologists that are important in understanding earthquake hazards. An additional discussion can be found in Noson and others (1988).

A fault is the surface which ruptures at the time of an earthquake. Over thousands or millions of years, the rock may periodically rupture in the same **fault zone**, but each earthquake may fracture a different portion of the fault. Very tiny earthquakes may rupture only a small area of the fault, perhaps a few meters by a few meters. A great earthquake might rupture an area as large as 30 kilometers by 800 kilometers, but it is important to realize that this whole area does not rupture at the same time. The point at which the rupture begins is called the **focus** of the earthquake, and a point on the earth's surface, directly above the focus, is the **epicenter** (Figure 1). Seismic (or vibrational) waves are produced at the point where rupture is occurring. During a great earthquake, it may take several minutes for the rupture to propagate from one end of the fault to the other. A long rupture-time tends to increase the **duration** of the shaking, and this can accentuate damage. That is, a structure that might be able to withstand a few cycles of strong ground motion might ultimately fail if shaking were prolonged.

A **seismograph** is used to make a permanent record of the ground shaking at a particular spot; the record is called a **seismogram.** Figure 2 illustrates some quantities that can be measured on a seismogram.

Seismometers can be designed to be sensitive to **vertical ground motion** or **horizontal ground motion.** In most cases, the horizontal motion causes the most damage because many buildings, particularly older ones, have not been designed to withstand horizontal motions of their foundations. The **amplitude** (or amount) of the motion is almost always greater close to the fault. The **period** of the motion (period = 1/**frequency**), the time between successive oscillations of the ground, is important because buildings that vibrate naturally with a certain period of oscillation will be most affected by ground motions having the same period. A match of the natural oscillation period of a building and the the period of the ground motion is called **resonance** and it causes greater damage. Earthquake waves generally produce motions with a wide range of frequencies, although the high frequency motions diminish rapidly with distance from the fault.

Seismographs designed to record 'on-scale', even during large ground motions are called **strong motion** instruments and are often designed to record ground acceleration directly (although some record velocity or displacement). Such instruments are called **accelerometers** and in recent years they have provided engineers with important recordings of strong ground motions near earthquake faults. Vertical and horizontal accelerations exceeding 1 g (980 cm/sec^2) have been recorded. In the Northwest, few accelerometers exist and only a few accelerograms have been obtained during large earthquakes.

From seismograms, seismologists may determine the **magnitude** of an earthquake (Kanamori, 1978) which is a measure of the degree of shaking at a standardized distance from a fault. It is a logarithmic scale in which each increase of one magnitude unit corresponds to ground motion ten times greater. There are several ways to estimate magnitude that are based on measurements like the amplitudes of P waves and surface waves or the duration of shaking, and all give similar numbers. One may hear terms like 'body wave', 'surface wave', 'local', 'Richter', 'coda' and or 'duration' magnitude, and, more recently, 'moment magnitude'. In Washington state we traditionally calculate coda-magnitude of local and regional earthquakes based on duration of the seismic signal (Crosson, 1972), although for large earthquakes we also determine 'local' magnitude from wave amplitudes recorded on Wood Anderson seismographs.

The degree of shaking and damage at a site is given by a quantity called **intensity** and is estimated using the **Modified Mercalli** scale. The Seattle/Tacoma earthquake of 1965 had a magnitude of 6.5 but the **intensity** varied at different sites. In Seattle and Tacoma, near the epicenter, damage varied from moderate to considerable. Many chimneys collapsed or were damaged. The intensity there was VII to VIII. In Portland, the shaking was less intense, but it was felt by nearly everyone. Some objects overturned and some windows broke. The intensity was about V. Intensity I to IV effects occurred as far away as British Columbia, Montana, and southern Oregon.

One reason shaking intensity can depend strongly on local geology is that a process analogous to resonance between a shaking building and the moving ground also occurs by interference of waves reflecting back and forth between layers of rock. For example, If a structure is built on a thick layer of sediments overlying bedrock, certain frequencies of ground motion will be amplified at the surface. The resonant frequencies depend on the thickness and degree of compaction of the sediments. Decreasing the thickness or increasing the compaction will cause resonance at a higher frequency. In 1985, amplification of ground motion at relatively low frequency caused severe damage to tall buildings built on sediments in Mexico City.

References

Crosson, R. S., 1972, Small earthquakes, structure, and tectonics of the Puget Sound region : Seismological Society of America Bulletin, 62, 1133-1171.

Kanamori, H., 1978, Quantification of earthquakes: Nature, v. 271, 411-414.

Noson, L. N., Qamar, A., and Thorson, G. W., 1988, Washington state earthquake hazards: Washington Division of Geology and Earth Resources Information Circular 85, 77 pages.

Steinbrugge, K. V., 1982, Earthquakes, volcanoes and tsunamis: Skandia America Group, 392 pages.

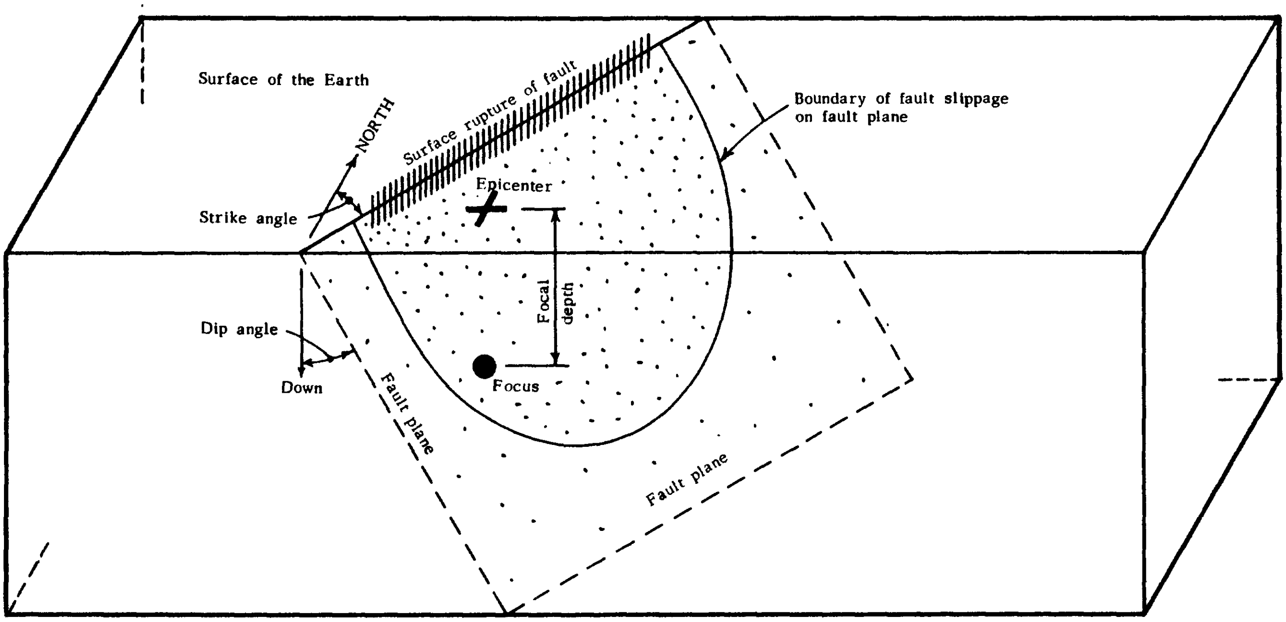


Figure 1. A fault. The fault plane is stippled. During a particular earthquake only a portion of the fault may rupture (closely spaced stippled pattern). The focus is the point on the fault plane where the rupture initially begins. The epicenter is a point on the earth's surface directly over the focus and does not necessarily lie along the surface rupture of a fault. From Steinbrugge (1982).

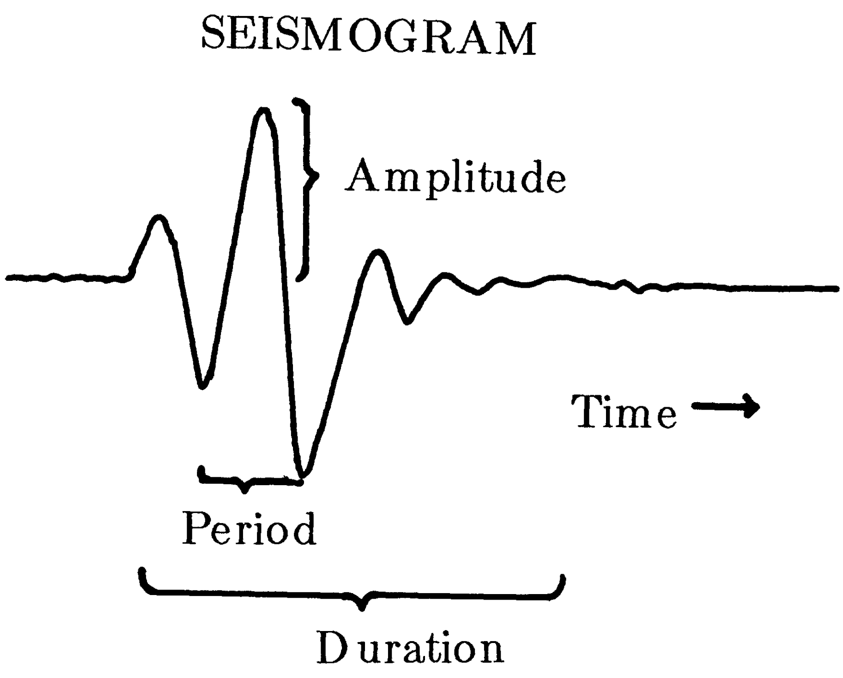


Figure 2. A seismogram shown schematically.

Earthquake Occurrence and Hazards in Washington and Oregon

Ruth S. Ludwin
Geophysics Program AK-50
University of Washington
Seattle, WA 98195
(206) 543-4292

Introduction

Washington and Oregon lie on a boundary of plate convergence and have features typical of convergent boundaries in other parts of the world. Fig. 1 shows a map view of the general plate configuration along with regional seismicity (magnitudes greater than 4.) from the NOAA catalog through 1985 (Ludwin, et al., 1989). Major offshore plate boundaries (transform zones and spreading ridges) are shown, and major geologic provinces onshore. Offshore Washington and Oregon, along the 400 km length of the Juan de Fuca Ridge, molten rock wells up. As the Juan de Fuca plate moves east at a rate of 4-4.5 cm/yr, in a N50°E direction relative to the North American Plate (Riddihough; 1977, 1984), and meets the the North American plate along the "trench" (Fig. 1), it is pushed beneath the North American continent.

Known Pacific Northwest earthquakes with magnitudes greater than 4.0 only weakly reflect the convergence framework. Most of the earthquakes are located offshore, at the transform plate boundaries such as the Blanco fracture zone. Although there is moderate activity near the Gorda and Explorer ridges, the major ridge in the region, the Juan de Fuca, is seismically quiet. Likewise, the subduction zone where the Juan de Fuca plate is subducted beneath the North American plate, and the continental margin of Washington and Oregon, is seismically quiet compared to the offshore transform faults. Very few earthquakes occur between Portland, Oregon and Crescent City, California; either historically or more recently. The sparse distribution of earthquakes onshore in Washington and Oregon contrasts markedly with the distribution of seismicity reported in most active subduction zones where numerous earthquakes occur at the interface between the two plates, within the subducting plate, and within the overriding plate (Uyeda and Kanamori, 1979).

Fig. 2 (from McCrumb et al., 1989) is a cartoon cross section of the interaction of the Juan de Fuca and North American plates. The Cascade volcanic arc which stretches from northern California to southern British Columbia results from melting of the subducted plate at which lies at depths of about 100 km beneath the volcanic arc. Two types of seismicity are observed in western Washington and northwestern Oregon;
1) crustal "shallow" (0-35 km) earthquakes in the North American Plate.
2) a dipping zone of deeper (35-80 km) earthquakes within the subducted plate beneath western Washington and northwestern Oregon. Some of the largest earthquakes in the Pacific Northwest since the mid-1800's have occurred within the deep zone (Rogers, 1983). As the Juan de Fuca Plate descends beneath the North American plate, the material around it is at higher pressure and temperature, causing changes in the density and rigidity of the subducting plate. At about 50 km depth, the subducting plate begins to bend more steeply, and earthquake focal mechanisms suggest that it is under tension.

The proposed "great" earthquake that is causing a lot of recent concern is one that we have never yet observed on the Cascadia subduction zone. It would be a "thrust" type earthquake, where the interface between the North American plate and the Juan de Fuca plate would break, and several meters of the Juan de Fuca plate would be thrust underneath the North American plate. These thrust earthquakes, like the 1964 Alaskan earthquake and 1960 Chilean earthquakes, are typically associated with active subduction zones. For the entire Cascadia subduction zone, in the 200-year historical record no earthquake has occurred along the boundary between the converging Juan de Fuca and North American plates that could be interpreted as a large, thrust-faulting event. The only evidence of such earthquakes along the Cascadia subduction zone is in the geological record (Atwater, 1987).

Seismicity

Fig. 3 shows a map view of instrumentally located seismicity in western Washington and north-western Oregon, and Fig. 4 shows two cross sections of seismicity in Washington. In the cross sections, seismicity is seen to be divided into two zones of activity, crustal earthquakes shallower than 30 km, and earthquakes within the subducting Juan de Fuca slab at depths greater than 30 km (Taber and Smith, 1985). The structure of the Juan de Fuca plate has been interpreted to include an upward arch of the plate (Crosson and Owens, 1987; Weaver and Baker, 1988). The arch structure represents a change in the direction of plate dip, with the plate dipping to the northeast beneath the northern Puget Sound basin and dipping east-southeast beneath southern Puget Sound and southwestern Washington. Comparing the cross sections, differences can be seen both in the dip of the earthquake distribution within the subducting slab, and within the crustal earthquake distribution. As the slab is forced beneath the North American plate, its angle of descent may not be the same everywhere along its length. In fact, the slab appears to dip less steeply, in the vicinity of Puget Sound (Crosson and Owens, 1987). The concentration of seismicity, both shallow and deep, in the Puget Basin suggests that some localized process, probably related to the shape of the subducting plate, has a considerable influence on the shallow as well as the deep seismicity. Comparing crustal seismicity in the two cross sections, considerable differences can be seen between the Puget Sound basin, and southwestern Washington.

The possibility of a great subduction earthquake

The interface between the Juan de Fuca and North American plates, where the two plates are in contact, lies sandwiched between the two volumes of earthquakes shown in Fig. 4.. The inferred megathrust lies to the west, near the coast, where the two volumes zones would meet if they were extended. Heaton and Kanamori (1984) and Heaton and Hartzell (1987) have argued, on the basis of a general comparison of the Cascadia subduction zone to other subduction zones worldwide, that great (magnitude 8+) thrust-type earthquakes could occur on the megathrust. No thrust earthquakes on the Juan de Fuca/North America plate interface have yet been identified, but historical records extend back only 200 years (Heaton and Snavely, 1985), and the recurrence interval for such earthquakes could be very long (500-1,000 yrs or more) (Atwater, 1987). Heaton and Kanamori (1984) base their argument on the observation that subduction earthquake size is related to slab age and convergence rate. The largest earthquakes occur in subduction zones where young material is being subducted at a high rate of convergence (8-12 cm/yr). Although the Juan de Fuca plate is composed of extremely young material (10-15 Ma), it has a low convergence rate (4-4.5cm/yr; Riddihough, 1977 and 1984) and is one of the youngest and most slowly converging subduction zones worldwide. While the Juan de Fuca plate is small compared to other plates, if the megathrust were to break along its entire length from southern Oregon to mid-Vancouver Island over a width of 100 km, an earthquake of magnitude 9.0 or larger could be generated (Heaton and Hartzell, 1987).

Searches for geologic evidence of great earthquakes along the west coast from Vancouver Island to northern California have been conducted by several investigators (Atwater, 1987; Hull, 1987; Reinhart and Bourgeois, 1987; Darienzo and Peterson, 1987; Grant and McLaren, 1987; Nelson, 1987). Major subduction earthquakes are normally accompanied by vertical deformation. This deformation consists of belts of uplift and subsidence parallel to the trench (Plafker, 1969; Plafker and Savage, 1970; Thatcher, 1984). Evidence interpreted as due to subsidence has been found along the coast of Washington (Atwater, 1987), where well vegetated fresh-water lowland horizons are found in the intertidal zone, resulting in vegetation kill and subtidal peat horizons. Sand deposits interpreted as tsunami generated overlie some of these horizons. In some locations, eight or more peat horizons can be found: several may correlate between localities near the mouth of the Columbia River and Grays Harbor, Washington, a distance of 100 km. These observations and the plate comparative studies have focused attention on the possibility that large subduction earthquakes may have occurred off the coast of the Pacific Northwest (Heaton and Kanamori, 1984; Heaton and Hartzell, 1987; Atwater, 1987).

Largest known earthquakes in Washington and Oregon

Fig. 5 shows all events estimated to be greater than magnitude 6 (based on felt areas) from 1870 to the present. The earliest earthquake data available are felt reports published in newspapers, which began publication less than 150 years ago. Locations for the older earthquakes are estimated from reported maximum ground shaking, and magnitudes are estimated from the areas where the earthquakes were felt. These older earthquakes, aside from the few well located ones, are useful mainly for estimating recurrence intervals and approximate locations of larger earthquakes. Around 1900, seismometers began to be installed, and in 1970, a multi-station telemetered seismograph network was installed capable of detecting and precisely locating earthquakes in Washington for magnitudes less than 4.0 (Crosson, 1974; Malone, 1979). Throughout the 1970's, this network was expanded and modified to increase sensitivity to small earthquakes and to provide better coverage of northwestern Washington, eastern Washington, and a portion of northeastern Oregon. Large areas of southwest Washington and northern Oregon were instrumented further after the 1980 eruption of Mount St. Helens.

Earthquakes estimated from felt areas as magnitude 6 or larger (Fig. 5), are largely restricted to northwestern Washington. The best studied are the earthquakes of 1949 and 1965 (Thorsen, 1986) which occurred in the southern Puget Sound basin (Figs. 3, 4, 5); The 1949 (M_S=7.1) and 1965 (m_b=6.5) earthquakes caused significant damage in the Puget Sound region (Algermissen and Harding, 1965; Nuttli, 1952) and had instrumentally determined hypocentral depths of 54 km and 60 km respectively (Baker and Langston, 1987; Algermissen and Harding, 1965). Eight people were killed in the 1949 event (Ulrich, 1949) and six died in the 1965 earthquake (Steinbrugge and Cloud, 1965). No aftershocks were felt or recorded after the 1949 earthquake; instrumentation available at the time would have detected events larger than magnitude 4.5. Similarly, following the 1965 earthquake, no aftershocks were felt, or recorded on available instrumentation.

Estimates of Maximum Possible Earthquake Magnitudes

Subcrustal Earthquake The subcrustal zone beneath the Puget Sound basin may be capable of generating an earthquake somewhat greater than the 1949 magnitude 7.1 event. In subduction zones worldwide, similar tensional earthquakes within the subducting plate have magnitudes as large as 8.0 (Astiz et al., 1988). However, the Juan de Fuca plate is somewhat thinner than most subducting slabs, and an earthquake of magnitude 7.5 is usually considered to be a conservative feasible event.

Crustal Earthquake In the crust, determination of the maximum credible earthquake is difficult, since heavy vegetation and glacial deposists conceal most geologic evidence of faulting, and seismic activity has not been correlated with mapped surface faults. Because much of the crustal seismicity occurs at depths of 10-20 km, faults may not extend to the surface. The largest known earthquake in Washington or Oregon was the 1872 magnitude 7.3 North Cascades earthquake (Malone and Bor, 1979). Although neither the depth nor the location is well established, this is believed to have been a crustal earthquake. Although the tectonic forces driving the 1872 earthquake are not understood, because of its existence estimates of maximum magnitude in the crust are placed at about 7.5.

In southwestern Washington, the St. Helens Seismic Zone (SHZ), with a length of more than 90 km (Fig. 3), was revealed in 1981 by an extensive aftershock sequence following a magnitude 5.5 earthquake. A maximum magnitude of 7.0 has been suggested for the SHZ (Weaver and Smith, 1983). Other such crustal fracture zones may revealed in the future, either by seismic activity, or through geological and geophysical studies.

Great Subduction Earthquake Plate tectonic features of the Pacific Northwest suggest that there is a possibility of a great thrust earthquake. Estimates of probable magnitudes (Heaton and Hartzell, 1987) range from magnitude 8, if half or less of the subduction interface ruptures, to magnitude 9 or greater if the entire subduction interface from mid-Vancouver Island to northern California ruptured in a single earthquake.

Estimates of Recurrence Intervals

Estimates of earthquake recurrence intervals are based on observations of earthquake occurrence. If a long enough history exists, an average interval between large, damaging earthquakes can be estimated, although the observed intervals between such earthquakes may vary widely. The main problem with this technique is that there is no accurate or consistent method of determining magnitudes of earthquakes which lack instrumental records. Another method of estimating recurrence intervals is to use the rate of occurrence of small earthquakes to estimate the recurrence time of large earthquakes. An assumption is made that for each magnitude 3 earthquake, there are approximately 10 magnitude 2 earthquakes, for each magnitude 4 earthquake there are approximately 10 magnitude 3 earthquakes, etc. Based on the frequency of smaller earthquakes, say in the magnitude 1 to 4 range, an estimate of the frequency of larger earthquakes can be made by extrapolation. Such an extrapolation presumes that the frequency-magnitude relation determined from small earthquakes remains valid for all magnitudes, which may not be true. Rasmussen et al. combined these two techniques (1974), by estimating magnitudes for historic earthquakes on the basis of intensities (felt reports), and including them in the frequency-magnitude relation. For the entire Puget Sound basin, including both crustal and subcrustal earthquakes, they estimate a recurrence interval of 10 years for a magnitude 6 earthquake, 35 years for a magnitude 6.5 earthquake, and 110 years for a magnitude 7.

Recurrence intervals for possible great subduction earthquakes cannot be predicted by the methods above, since there is neither a historic record of such events, nor any instrumental record of smaller subduction-style earthquakes. Recurrence intervals can only be estimated from the geologic record, which may be incomplete. Atwater (1987), suggests that intertidal mud deposits overlying killed fresh-water vegetation layers may be evidence of six great subduction earthquakes in the past 7000 years.

Estimates of Ground Shaking

In an earthquake, shaking at a particular site can be characterized by the frequency content, duration, and amplitude of ground motion at that site. These factors are determined by the rupture size, the time history of the rupture, the stress state of the source area during rupture, the distance of the site from the source, and the attenuation characteristics of the earth. Damage to structures at the site depends not only on the shaking but also on quantities intrinsic to the structures, such as their frequency responses, and abilities to resist lateral loading and torsional forces. Minor damage incurred in previous earthquakes may predipose a structure to significant damage in later earthquakes or aftershocks. A measure of shaking during past earthquakes, based on felt reports and damage, is the Modified Mercalli Intensity scale, which rates felt intensities from I through XII, with structural damage occurring at intensity VII and above. Figure 6 shows Modified Mercalli intensity maps for 5 earthquakes widely felt in Washington and Oregon. Also included is a map on the same scale which shows the intensity distribution during the great Alaskan subduction earthquake of 1964 (Cloud and Scott, 1969), to indicate the scope of strong shaking that results from a great subduction type earthquake.

Conclusions

Observations of the distribution of seismicity in the Pacific Northwest indicate the pattern of seismicity varies considerable in time, making interpretation of earthquake hazards difficult. The historical record, although brief (150 years), suggests that observations of small earthquakes may not be adequate to identify seismic hazards, since two of the largest earthquakes in the region (1872 and 1873) apparently occurred in areas which are currently seismically quiet. The severity of seismic hazard can only be roughly estimated in this region, since the catalog of known earthquakes provides limited only limited assistance. No great subduction earthquake is in the historic record, and the interval between such earthquakes may be a thousand years or more.

REFERENCES

Algermissen, S. T.; Harding, S. T.; Steinbrugge. L. V; and Cloud, W. K.,1965, *The Puget Sound, Washington Earthquake of April 29, 1965* : U.S. Department of Commerce, Coast and Geodetic Survey, 51 p.

Astiz, L, T. Lay, and H. Kanamori, 1988, Large intermediate depth earthquakes and the subduction process: *Physics of the Earth and Planetary Interiors,* Vol. 53, pp. 80-166.

Atwater, B. F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: *Science,* Vol. 236, pp. 942-944.

Baker, G. E. and Langston, C. A., 1987, Source Parameters of the 1949 Magnitude 7.1 South Puget Sound, Washington, Earthquake as Determined From Long-Period Body Waves and Strong Ground Motions: *Bulletin of the Seismological Society of America,* Vol. 77, No. 5, pp. 1,530-1,557.

Cloud, W.K., and N.H. Scott, 1969, Distribution of Intensity, Prince William Sound Earthquake of 1964, *in* The Prince William Sound, Alaska, earthquake of 1964 and aftershocks, U.S. Dept. of Commerce, Vol. 2, parts B and C, pp. 5-48.

Crosson, RS., 1974, *Compilation of earthquake hypocenters in western Washington, July, 1970 to December 1972* : Washington Division of Geology and Earth Resources, Information Circular 53, Olympia Washington, 26 p.

Crosson R.S., T.J. Owens, 1987, Slab geometry of the Cascadia subduction zone beneath Washington from earthquake hypocenters and teleseismic converted waves, *Geophysical Research Letters,* Vol. 14, pp. 824-827.

Darienzo, M. and Peterson, C., 1987 [abstract], Episodic tectonic subsidence recorded in Late-Holocene salt-marshes, northwest Oregon: *EOS (Transactions of the American Geophysical Union),* Vol. 68, No. 44, p. 1,469.

Grant W.C. and D.D. McLaren, 1987 [abstract], Evidence for Holocene subduction earthquakes along the northern Oregon coast, *EOS (Transactions of the American Geophysical Union),* Vol. 68, No. 44, p. 1,239.

Heaton, T. H. and Kanamori, H., 1984, Seismic potential associated with subduction in the northwestern United States: *Bulletin of the Seismological Society of America,* Vol. 74, No. 3, pp. 933-941.

Heaton, T. H. and Snavely, P. D., Jr., 1985, Possible tsunami along the northwestern coast of the United States inferred from Indian traditions: *Bulletin of the Seismological Society of America* Vol. 75, No. 5, pp. 1,455-1,460.

Heaton, T. H. and Hartzell, S. H., 1987, Earthquake hazards on the Cascadia subduction zone: *Science,* Vol. 236, pp. 162-168.

Hull A.G., 1987 [abstract], Buried lowland soils from Willapa Bay, southwest Washington: Further evidence for recurrence of large earthquakes during the last 5000 years, *EOS (Transactions of the American Geophysical Union),* Vol. 68, No. 44, p. 1,468.

Ludwin, R. S., C.S. Weaver, R.S. Crosson, 1989 (in revision), Seismicity and Tectonics of the Pacific Northwest, in: Slemmons, D.B., E.R. Engdahl, D. Shwartz, and M. Zoback editors, Decade of North American Geology associated volume GSMV-1;

Malone, S.D. and S.S. Bor, 1979, Attenuation Patterns in the Pacific Northwest based on intensity data and the location of the 1872 north Cascades earthquake, *Bulletin of the Seismological Society of America,* Vol. 69, No. 2, pp. 531-546.

Malone, S.D., 1979, *Earthquake Monitoring in Eastern Washington, Annual Technical Report 1978* : Report prepared for U.S. Department of Energy and Washington Public Power Supply System, Richland, WA, 12 p.

McCrumb, D.R, R.W. Galster, R.S. Crosson, R.S. Ludwin, D.O. West, W.E. Hancock, and Lawrence V. Mann, 1989 (in press), Tectonics, Seismicity, and Engineering Seismology in Washington, in Association of Engineering Geologists, Washington State Centennial Volume

Nelson A.R., 1987 [abstract], Apparent gradual rise in relative sea level on the south-central Oregon coast during the late Holocene: Implications for the great Cascadia earthquake hypothesis, *EOS (Transactions of the American Geophysical Union),* Vol. 68, No. 44, p. 1,240.

Noson, L. L.; Qamar, A. I.; and Thorsen, G. W., 1988, *Washington State Earthquake Hazards* : Washington Division of Geology and Earth Resources Information Circular 85, Olympia, WA, 77p.

Nuttli, O.W., 1952, The western Washington earthquake of April 13, 1949, *Bulletin of the Seismological Society of America,* Vol. 42, No. 1, p. 21-28.

Plafker, G., 1969, *Tectonics of the March 27, 1964 Alaska Earthquake,* U.S. Geological Survey Professional Paper 543-I, p. I1-I17.

Plafker, G. and Savage, J. C., 1970, Mechanism of the Chilean earthquakes of May 21 and 22, 1960: *Geological Society of America Bulletin,* Vol. 81, No. 4, pp. 1,001-1.030.

Rasmussen, N.H., R.C. Millard, and S.W. Smith, 1974, Earthquake Hazard Evaluation of the Puget Sound Region, Washington, University of Washington, 99 p.

Reinhart, M. A. and Bourgeois, J., 1987 [abstract], Distribution of anomalous sand at Willapa Bay, Washington - Evidence for large-scale landward-directed processes, *EOS (Transactions of the American Geophysical Union),* Vol. 68, No. 44, p. 1,469.

Riddihough, R. P., 1977, A model for recent plate interactions off Canada's West Coast:

Canadian Journal of Earth Science, Vol. 14, pp. 384-396.

Riddihough, R. P., 1984, Recent Movements of the Juan de Fuca Plate System: *Journal of Geophysical Research,* Vol. 83, No. B8, pp. 6,980-6,994.

Rogers, G. C., and H.S. Hasegawa, 1978, A second look at the British Columbia earthquake of June 23, 1946, *Bulletin of the Seismological Society of America,* Vol. 68, No. 3, pp. 653-675.

Rogers, G. C., 1983, *Seismotectonics of British Columbia* [Ph.D. thesis]: University of British Columbia, Vancouver, BC, Canada, 247 p.

Stein, R.S., and R.C. Bucknam, 1985, The Basin and Range reviewed from Borah Peak, Idaho, *Earthquake Information Bulletin,* Vol. 17, No. 3, pp. 98-105.

Steinbrugge, K.V., and W.K. Cloud, 1965, Preliminary engineering report *in* The Puget Sound Washington earthquake of April 29, 1965, U.S. Dept. of Commerce, 51 p. (Reproduced in Thorsen, 1986).

Taber, J. J. and Smith, S. W., 1985, Seismicity and focal mechanisms associated with the subduction of the Juan de Fuca plate beneath the Olympic Peninsula, Washington: *Bulletin of the Seismological Society of America,* Vol. 75, No. 1, pp. 237-249.

Thatcher, W., 1984, The earthquake deformation cycle at the Nankai Trough, southwest Japan, *Journal of Geophysical Research,* Vol. 89, No. B5, pp. 3,087-3101.

Thorsen, G. W., 1986, *The Puget Lowland Earthquakes of 1949 and 1965* : Washington Division of Geology and Earth Resources Information Circular 81, Olympia, WA, 113 p.

Ulrich, F. P., 1949, Reporting the Northwest earthquake from the scientific point of view: *Building Standard Monthly, Vol. 18, No. 6, pp. 8-16.*

Uyeda, S., and H. Kanamori, 1979, Back-arc opening and the mode of subduction, *Journal of Geophysical Research,* Vol. 84, p. 1,049-1,061.

Weaver, C. S. and Smith, S. W., 1983, Regional tectonic and earthquake hazard implications of a crustal fault zone in southwestern Washington: *Journal of Geophysical Research,* Vol. 88, No. B12, pp. 10,371-10,383.

Weaver, C.S. and G.E. Baker, 1988, Geometry of the Juan de Fuca plate beneath Washington and northern Oregon from seismicity, *Bulletin of the Seismological Society of America,* Vol. 78, pp. 264-275.

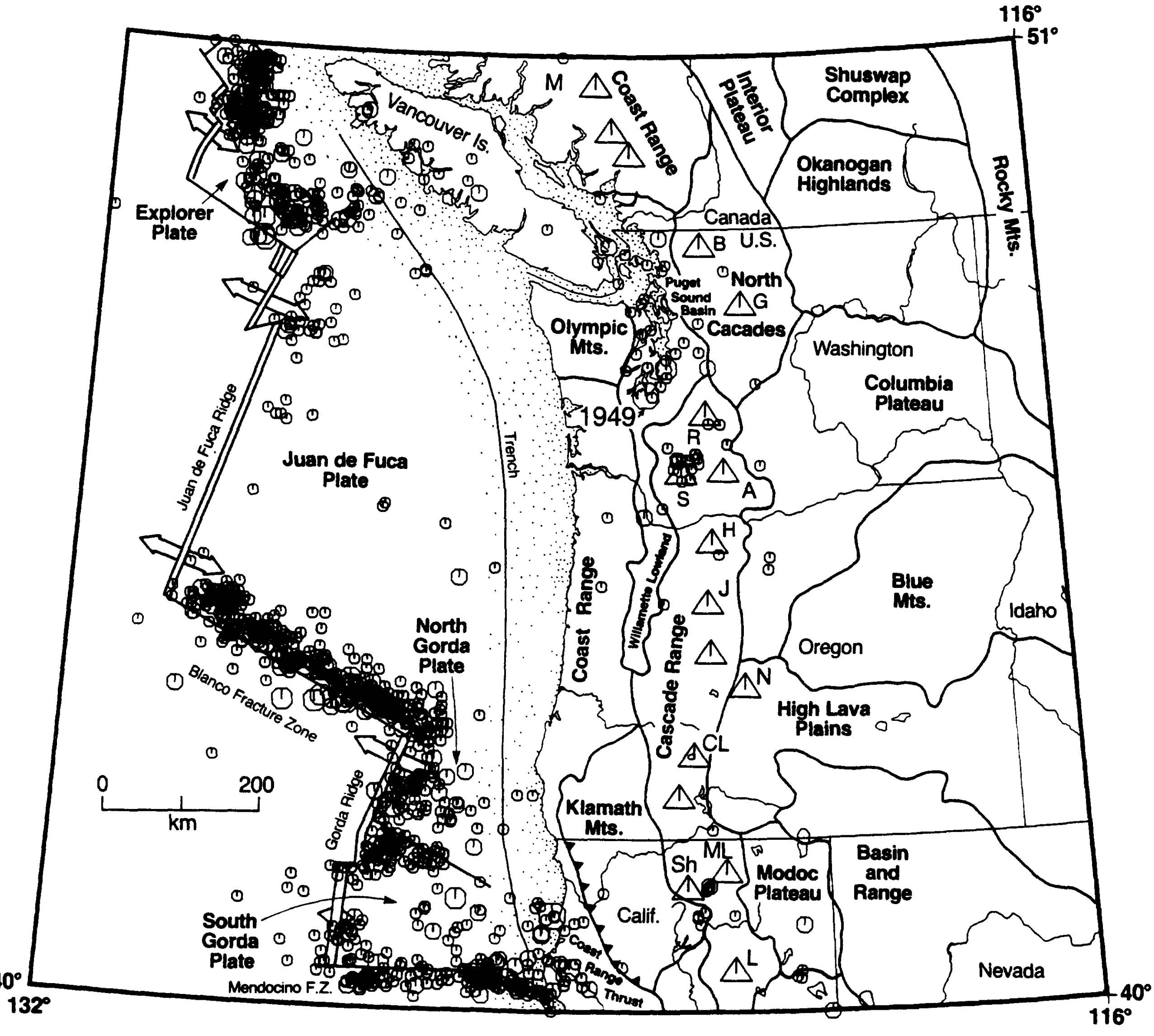


Figure 1. Plate Boundaries offshore Washington and Oregon, and physio-tectonic provinces of Washington and Oregon Earthquakes shown are magnitude 4 or larger events listed in the NOAA catalog through 1985. This catalog is fairly complete at this magnitude range since 1963, before that date the data is not complete. The 1949 Olympia earthquake (not included in the NOAA catalog) is also shown. Volcanos are indicated by triangles. [From Ludwin et. al, 1989.]

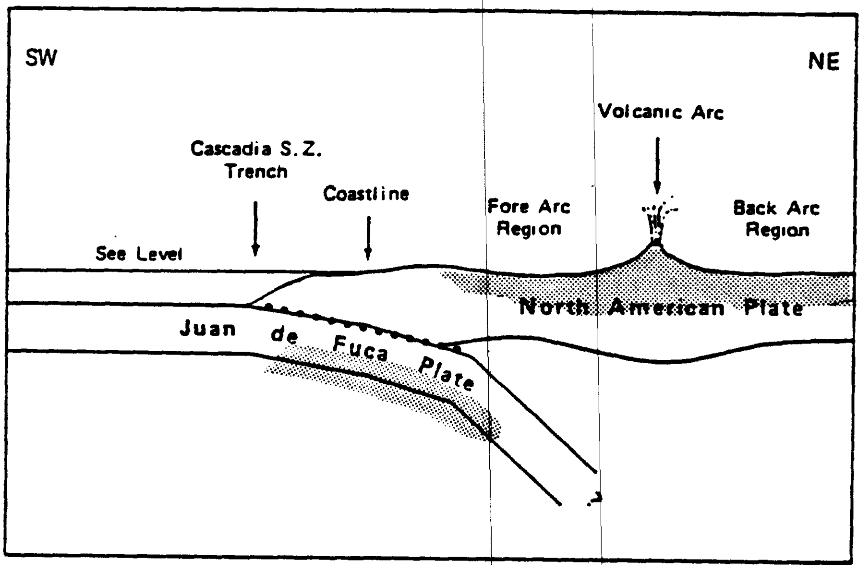


Figure 2. Schematic cross section (not to scale) showing relationship between Juan de Fuca and North American plates. Known crustal and subcrustal (within the subducting slab), seismogenic volumes are indicated by shaded areas, while the subduction interface, currently aseismic, is shown by a series of dots. Solid lines at the base of the North American and JDF plates indicate the position of the Moho. [Adapted from McCrumb et. al, 1989.]

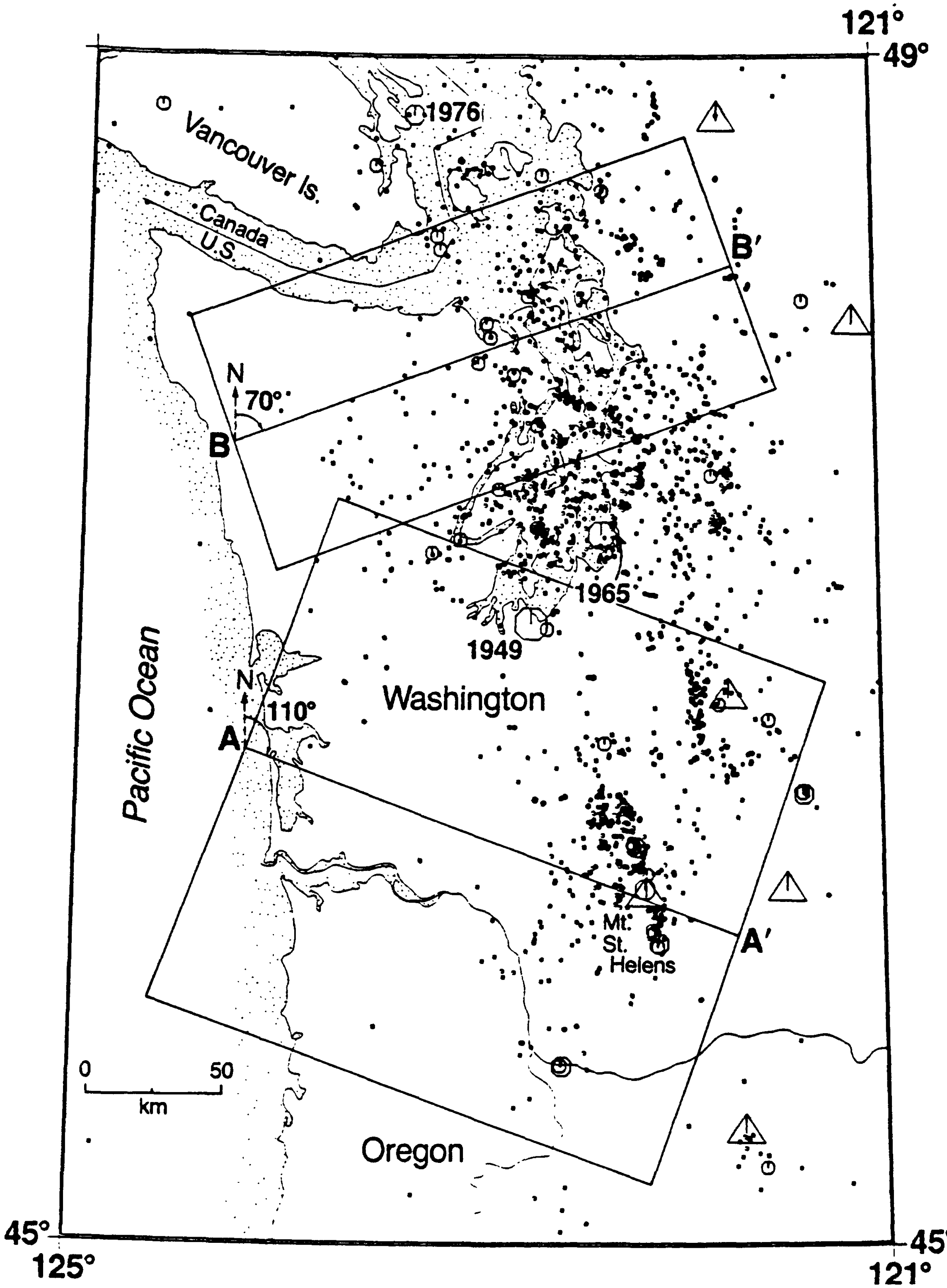


Figure 3. Detailed map of epicenters in western Washington. All events smaller than 4.0 have the same symbol size. For events magnitude 4.0 or larger, symbols are scaled proportionally to earthquake size (four symbol sizes, representing magnitude ranges 4.-4.9, 5.-5.9, 6.-6.9, and 7.-7.9.). All events since 1970 located by the WRSN with magnitudes larger than 2.5 are included. Earlier earthquakes larger than magnitude 4.0 which also have adequate instrumental locations are included. These include the 1949 and 1965 Puget Lowland Earthquakes, the 1962 Portland Earthquake, the Warner Valley Sequence of 1968 in southern Oregon, and the Swift Reservoir earthquakes south of Mt. St. Helens in 1960 and 1961. These earthquakes are supplemented by the addition of epicenters of best-located earthquakes regardless of magnitude since 1970. Each event since 1970 met the following criteria; at least 5 stations and 8 phases read, azimuthal gap smaller than 100°, nearest station no farther than 40 km, WRSN quality factors "B" or higher, and events with problem depths excluded. Earthquakes at Mt. St. Helens were omitted except for unusual earthquakes deeper than 3 km in April and May, 1980. Aftershocks of the 1981 Elk Lake earthquake (M_L 5.5) smaller than magnitude 3 were also excluded. (From Ludwin et al., 1989)

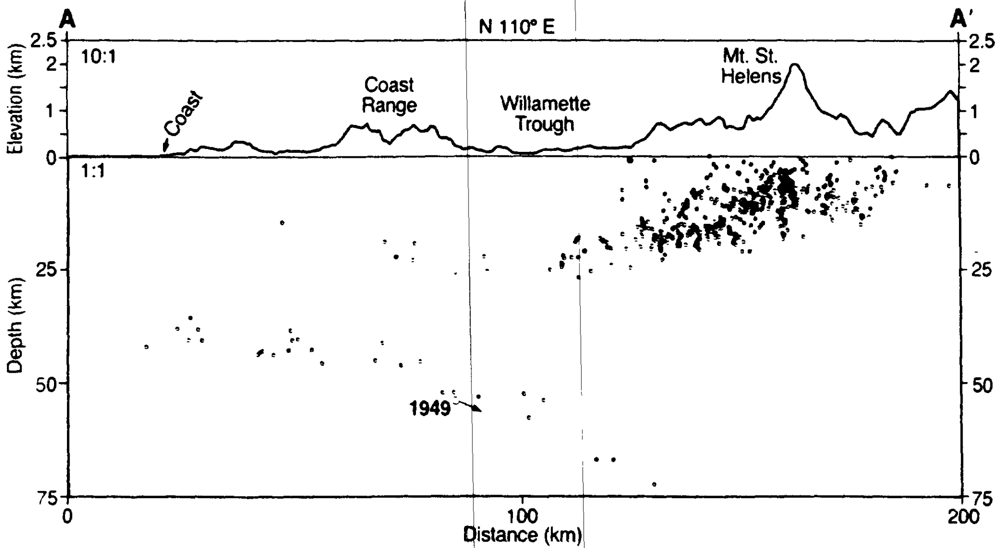
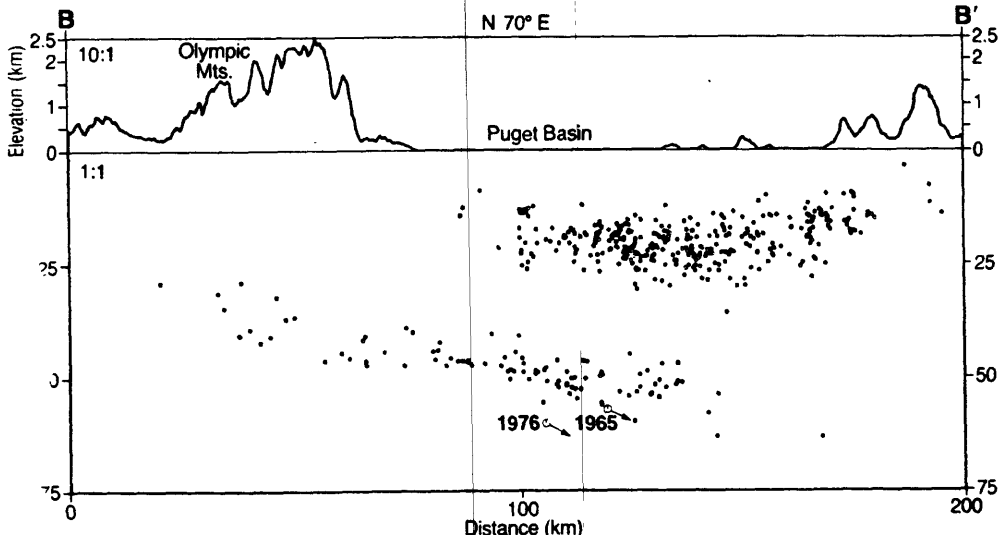


Figure 4. a) Southwestern Washington cross section A-A' (Figure 3) 10:1 vertical exaggeration of topography; no vertical exaggeration of subsurface. Best-located (criteria in Figure 3) earthquake hypocenters since 1970, projected onto a vertical plane striking N 110° E, are shown by a single symbol size. The hypocenter of the damaging 1949 Olympia earthquake is within this distribution, and is plotted as a larger symbol with a vector representing the extensional axis from its focal mechanism (Baker and Langston, 1987) shown. The profile of Mt. St. Helens shown is prior to the May 18, 1980 explosion which lowered the summit by .4 km. (From Ludwin et al., 1989)



b) Northwestern Washington cross section B-B' (Figure 3); 10:1 vertical exaggeration of topography; no vertical exaggeration of subsurface. Best-located (criteria in Figure 3) earthquake hypocenters since 1970, projected onto a vertical plane striking N 70° E, are shown by a single symbol size. The 1965 and 1976 earthquakes are shown as larger symbols with vectors representing extensional axes from focal mechanisms. These earthquakes were located to the south and north, respectively, of the cross section area (see Figure 3). (From Ludwin et al., 1989)

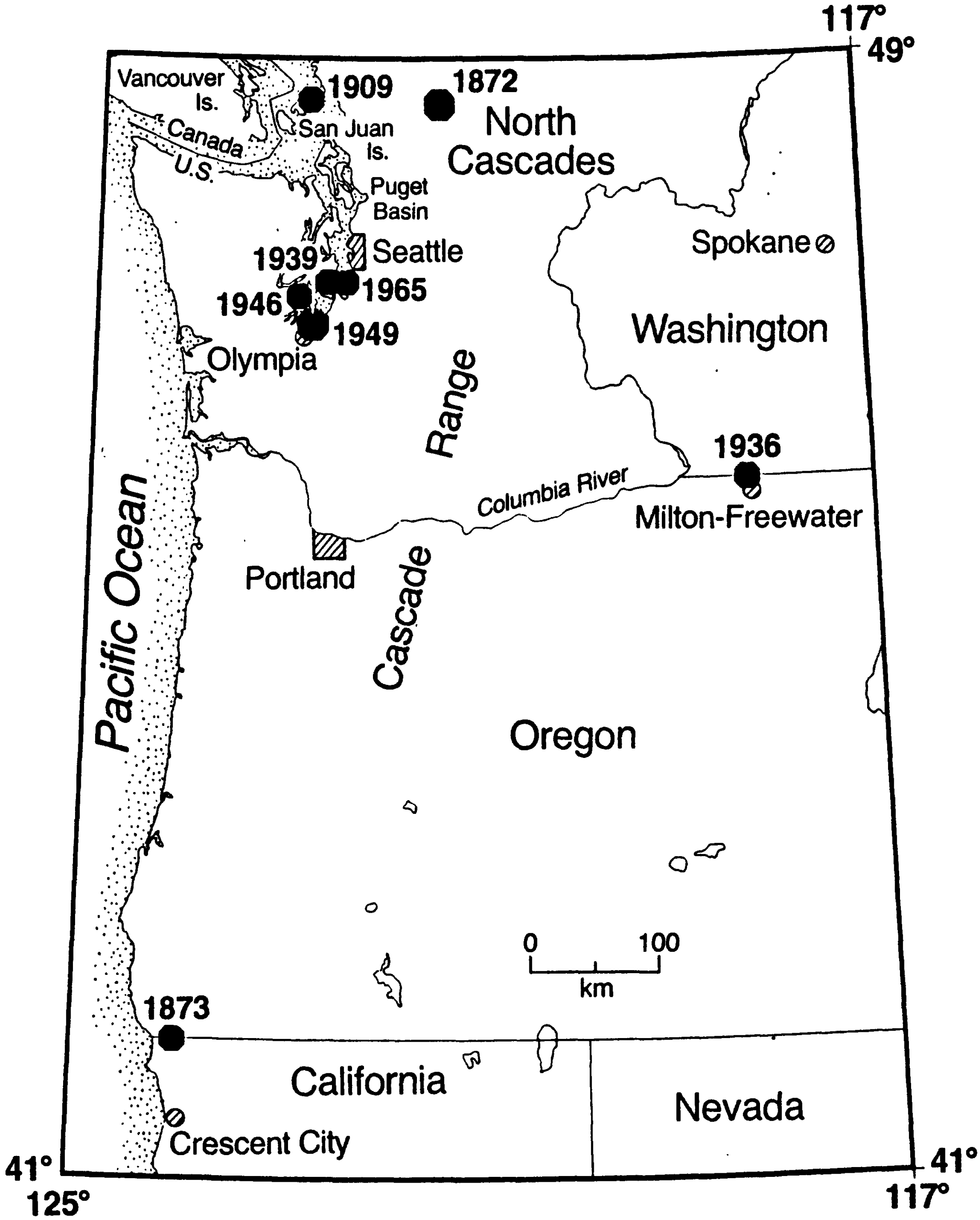


Figure 5. Largest known earthquakes in the Pacific Northwest, magnitudes estimated from felt areas to be larger than 6. [From Ludwin, et al., 1989.]

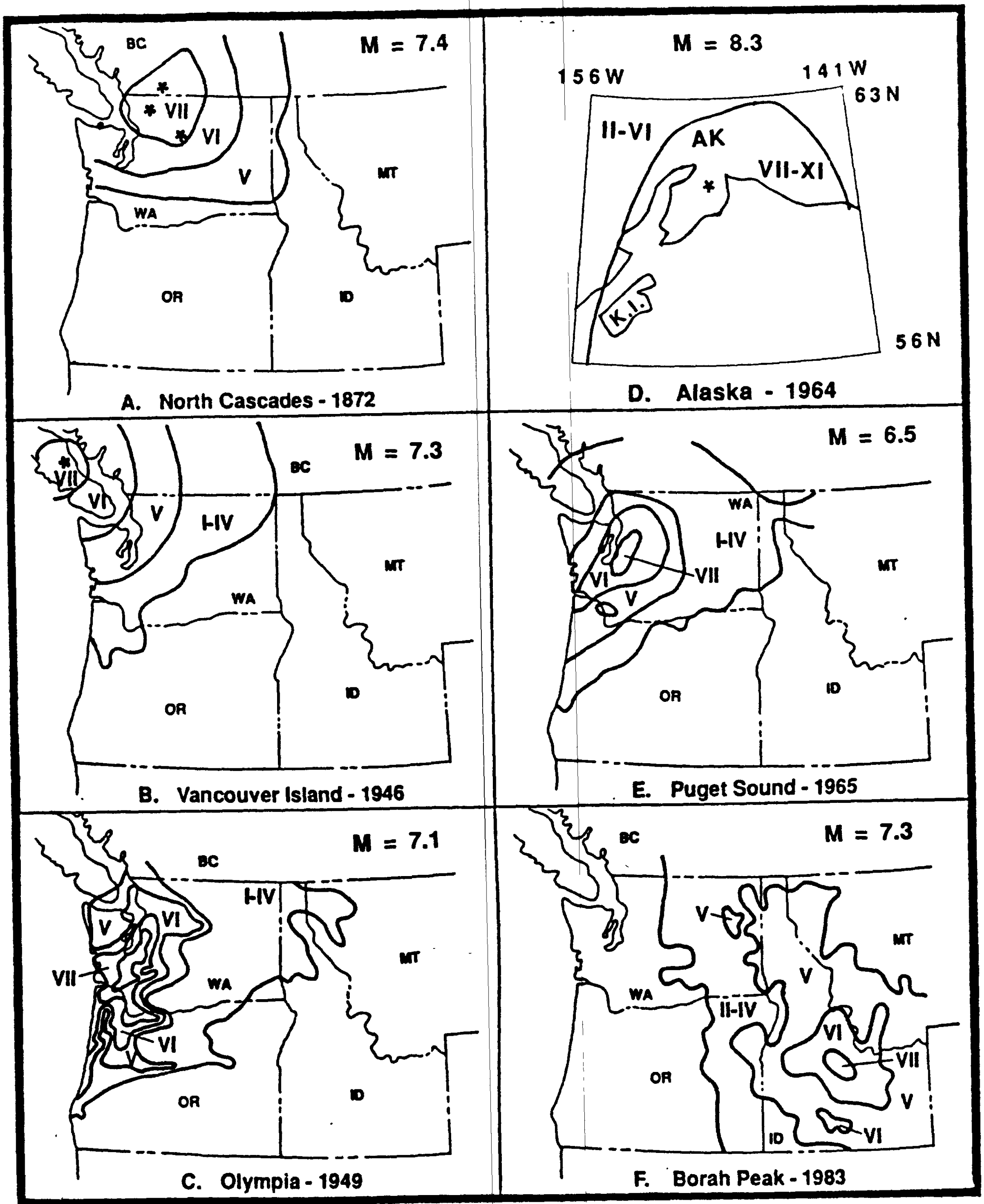


Figure 6. [Adapted from McCrumb, et al. 1989] Isoseismal maps of the Pacific Northwest for five major historic earthquakes that have been widely felt in Washington, plus an isoseismal map on approximately the same scale for the great Alaskan subduction earthquake of 1964. Note the tremendously larger area of intensity VII or greater shaking for the 1964 earthquake compared with the others. A. North Cascades earthquake of December 1872 (after Malone and Bor, 1979). Limit of felt area (intensity bound I-IV) not shown. B. Vancouver Island Earthquake of June 23, 1946 (after Rogers and Hasegawa, 1978). C. Olympia Earthquake of April 13, 1949 (after Ulrich, 1949). Shaded area is intensity VIII. D. Prince William Sound, Alaska Earthquake of March 27, 1964 (after Cloud and Scott, 1969) (Kodiak Island is labeled K.I.). E. Puget Sound Earthquake of April 29, 1965 (after Algermissen, et al., 1965). F. Borah Peak Earthquake of October 28, 1983 (after Stein and Bucknam, 1985)

Fundamentals of Earthquake Effects on Land and Water

Stephen P. Palmer
Washington State Department of Natural Resources
Division of Geology and Earth Resources
Olympia, Washington

INTRODUCTION

Earthquakes can cause tremendous damage through their effects on land and water. Landslides, liquefaction-induced ground failure, and tsunamis are major causes of the destruction and casualties resulting from large earthquakes. This paper reviews some of the physical processes that occur on the Earth's surface during an earthquake.

EFFECTS ON THE LAND SURFACE

The strong ground motion of a large earthquake can cause catastrophic failure of hillslopes, building foundations, roadbeds, and manmade embankments such as earthfill dams. Ground subsidence, liquefaction, and landslides are three categories of land surface failures that may occur as a result of earthquake shaking.

Ground Settlement and Tectonic Subsidence

A sandy soil is composed of variously sized grains of sand, rock fragments, and clay. Grain-to-grain contact provides physical support in a granular soil mass. Recently deposited sandy soils, such as those on a beach or in a river valley, may be loosely packed (unconsolidated) and have large void spaces among grains. Ground shaking can cause the grains to become more densely packed (fig. 1). This denser packing results in vertical shortening (compaction) of the soil layer, a process termed ground settlement. Ground settlement can occur in dry to water-saturated soils. Differential amounts of ground settlement can result in failure of building foundations and disruption of roadbeds and pipelines.

Tectonic subsidence is the lowering of large areas of land surface with respect to sea level due to the relaxation of elastic strain during an earthquake. Tectonic subsidence commonly occurs during thrust earthquakes associated with the subduction of converging lithospheric plates. Subsidence and consequent flooding of low-lying coastal areas can result in significant economic losses.

Figure 2 shows the effects of both ground settlement and tectonic subsidence resulting from the 1964 Alaska earthquake. During this earthquake the ground surface dropped 4.5 ft with respect to sea level. Tectonic subsidence accounted for 2 ft of this drop, and 2.5 ft of ground settlement developed in the alluvium overlying the bedrock.

Liquefaction

Liquefaction is a process in which a water-saturated granular soil layer loses strength during vibratory shaking. The soil mass can then be subject to large lateral deformation, resulting in the disruption of building foundations, buried pipelines, and roadbeds. Large ground accelerations and a long duration of shaking during an earthquake increase the liquefaction susceptibility of a given soil layer. Soils with a large clay content are usually not subject to liquefaction.

Below the ground-water table, the void spaces among grains of a sandy soil are filled with water. The weight of the overlying soil is supported both by grain-to-grain contact and by the pressure of water in the pore spaces

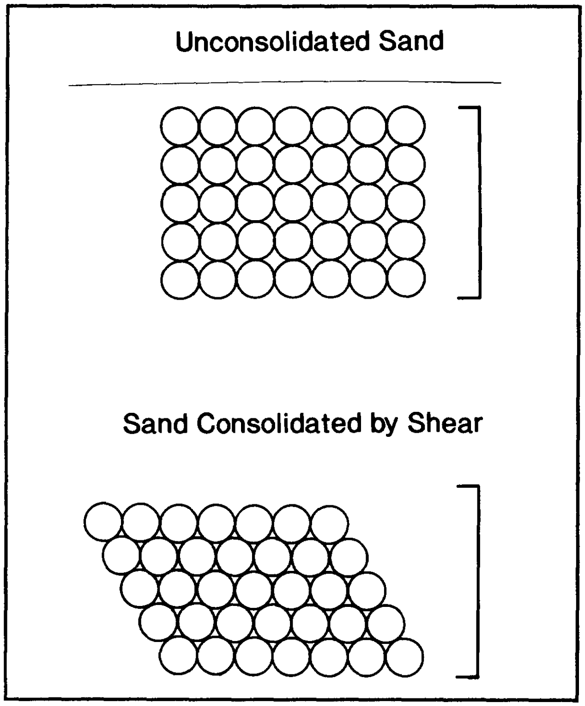


Figure 1. The grains of an unconsolidated sand are loosely packed, creating large void spaces among grains. When the unconsolidated sand is shaken during an earthquake, shear stresses cause the sand grains to be rearranged into a tighter packing. This consolidation leads to vertical shortening of the soil layer, which is termed ground settlement.

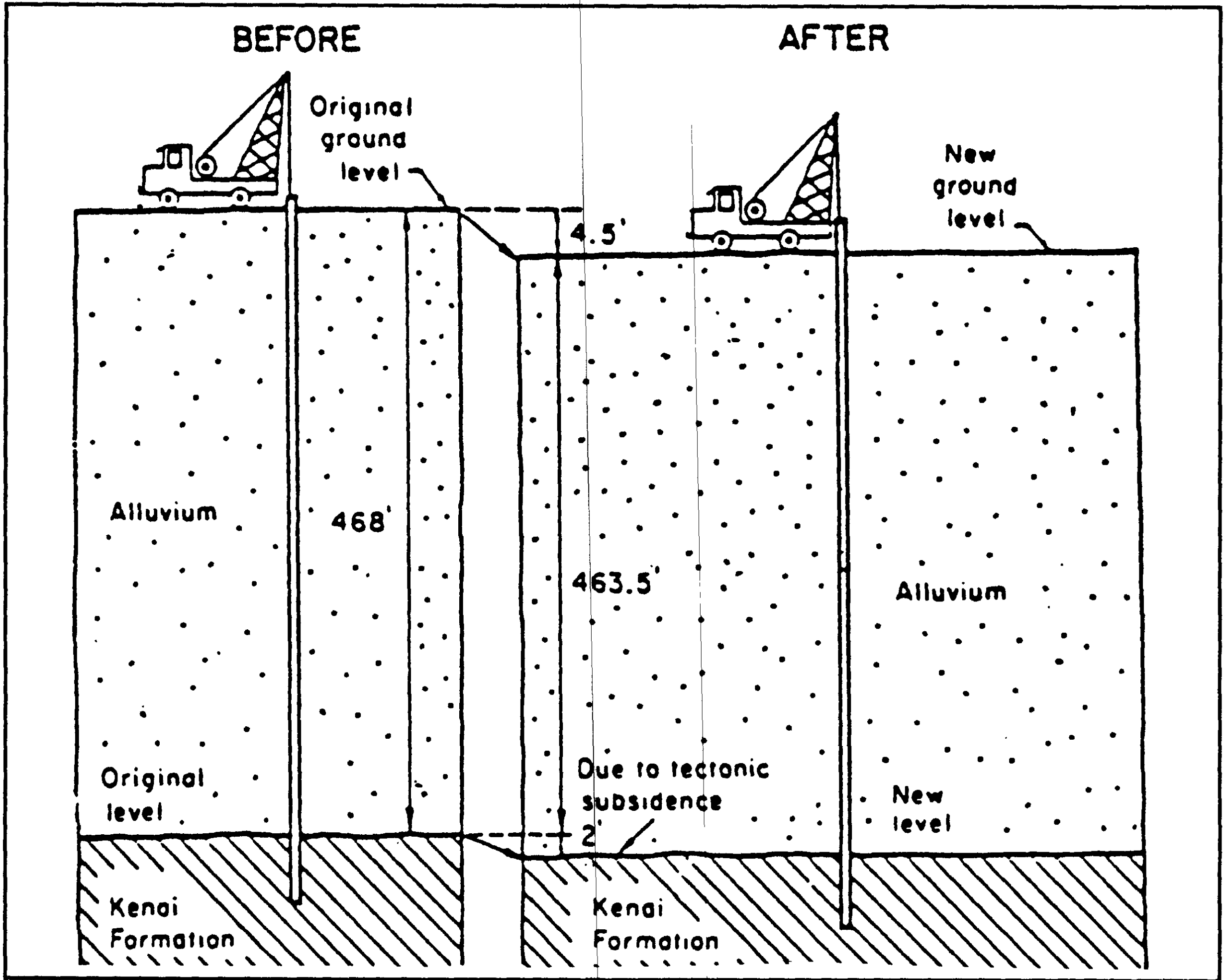


Figure 2. Both ground settlement and tectonic subsidence during the 1964 Alaska earthquake led to a 4.5 ft-drop of the land surface with respect to sea level. After the earthquake, the top of a water well casing rose 2.5 ft due to compaction and settlement of the alluvium, and the land surface had dropped another 2 ft due to tectonic subsidence. Adapted from Grantz and others, 1964.

(fig. 3a). Figure 3b shows the mechanical analog of a buried water-saturated soil layer. The two springs represent the separate support provided by grain-to-grain contact and by pore-water pressure. Vibratory shaking disrupts the grain-to-grain contact, causing a decrease in the support provided by grain contact. In the mechanical

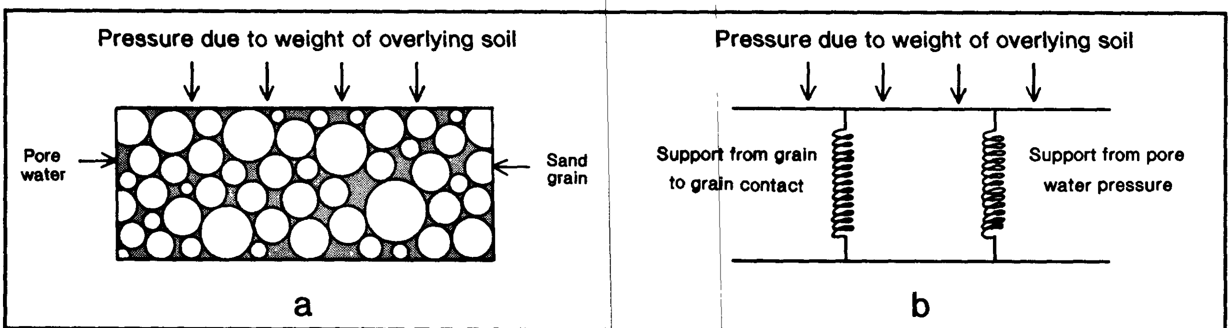


Figure 3a. In a saturated granular soil, the weight of the overlying soil is supported by the framework of the sand grains (grain-to-grain contact) and the pressure of the water filling the pore spaces. **3b.** In the mechanical analog of this situation, the support provided by grain-to-grain contact and by pore-water pressure are represented by two compressed springs bearing the weight of the overlying soil.

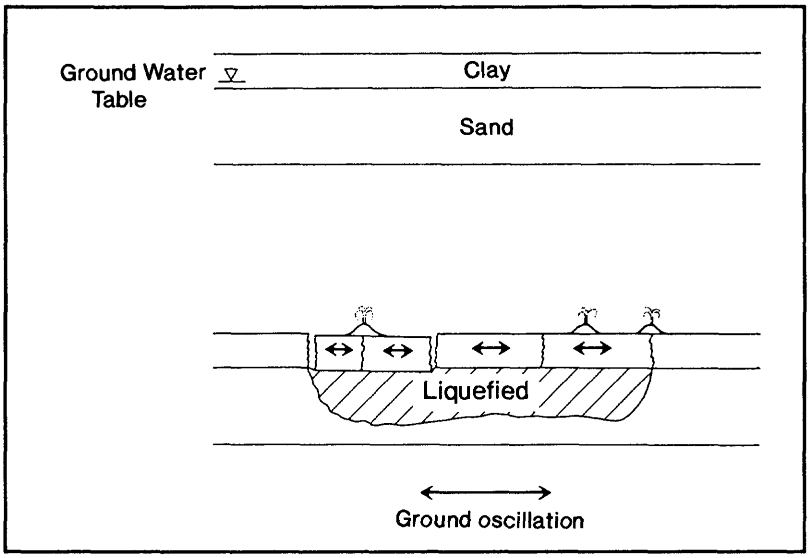


Figure 4. A saturated sand layer underlying a impermeable clay layer may become liquefied by earthquake shaking. A liquefied zone within this sand layer may decouple from the surrounding firm soil and cause the overlying clay to break apart along fissures. Sand boils occur where the liquefied sand, driven by high pore-water pressure, breaks through a weak point in the overlying clay layer and erupts as a slurry of sand and water. The small conical mound built by this slurry eruption resembles a volcano. Adapted from Youd, 1984.

analog, the spring representing grain-to-grain contact loses its resistance to the overlying load. To maintain equilibrium, the spring representing pore-water pressure must increase its resistance to the load; thus, the pore-water pressure must increase as the grain-to-grain support diminishes. During extreme shaking the pore-water pressure may have to bear nearly all of the weight of the overlying soil; at this point the soil is liquefied.

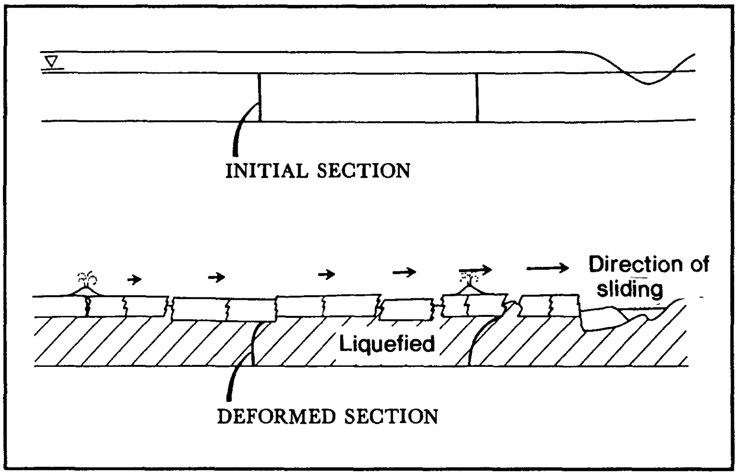
A liquefied soil may be subjected to extreme lateral deformation because water cannot resist horizontal forces. Thus, building foundations seated in a liquefied soil layer can lose bearing strength, resulting in structural damage. Likewise, the soil mass can flow down very shallow slopes, disrupting buried pipelines and underground utilities. Ground settlement is also a common consequence of liquefaction.

Several phenomena associated with liquefaction are described below.

Fissures and sand boils, diagrammatically shown in figure 4, are commonly observed during large earthquakes. During an earthquake, coherent blocks overlying a liquefied soil layer become detached and independently oscillate, opening and closing inter-block fissures. Sand boils are indicators of elevated pore-water pressures in the liquefied stratum. A sand-water slurry, driven by increased pore-water pressure in the liquefied zone, penetrates a weak point in the overlying soil layer (e.g., along a portion of a fissure) and erupts as a spout, leaving a conical deposit of sand and silt around the vent. Many fissures and sand boils were observed after the 1949 and 1965 Puget Sound earthquakes (Hopper, 1981; Thorsen, 1986).

Lateral spreading occurs when blocks overlying a liquefied stratum slide down shallow (0.5° - 3°) slopes toward a free face such as an incised river channel or manmade cut (fig. 5). Lateral spreading can disrupt building foundations and rupture sewer and water pipelines as well as other buried utility conduits. More than 250 bridges were damaged due to lateral spreading of floodplain deposits toward river channels during the 1964 Alaska earthquake (National Resource Council, 1985). Damage to water and gas pipelines resulted from the 1949 and 1965 Puget Sound earthquakes, and lateral

Figure 5. Lateral spreading occurs where a liquefied layer and the overlying soil mass move down a shallow (between 0.5° and 3°) slope toward a free face such as a river channel or manmade cut. The lateral movement can damage building foundations and disrupt underground utilities. Adapted from Youd, 1984.



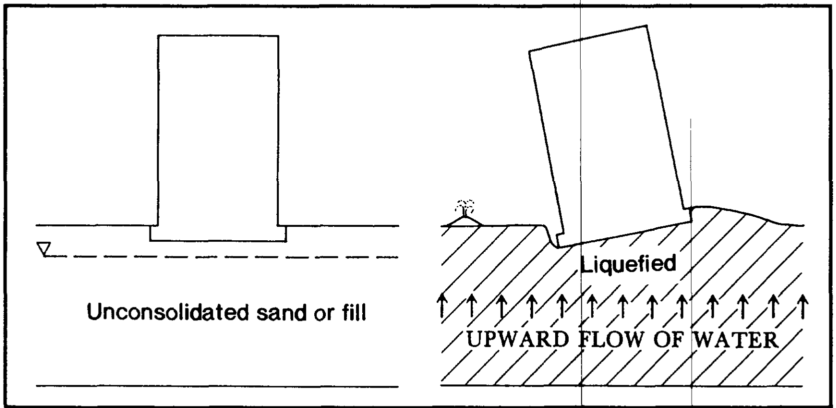


Figure 6. A surface layer of unconsolidated sand or fill that has a shallow ground-water table can liquefy during an earthquake. Foundations seated in the liquefied sand will not bear the building load, causing the structure to tip from vertical. Adapted from Youd, 1984.

spreading during the 1965 event damaged roads in Olympia.

Loss of bearing strength occurs where the foundation or support of a structure is situated in a soil that liquefies during an earthquake (fig. 6). The liquefied soil cannot support the structural load, and the resulting soil deformation can lead to severe settlement and damage of the structure. Loss of bearing strength during the 1964 Niigata, Japan, earthquake resulted in tipping of four-story apartment buildings to as much as 60° from vertical. Liquefaction-induced ground settlement and loss of bearing strength resulted in structural damage to buildings and piers during the 1949 and 1965 Puget Sound earthquakes.

Landslides

The mass movement of soil and rock down a slope is termed a **landslide.** Figure 7 shows some generalized features of a landslide. A soil layer resting on a hillside is subjected to a downslope gravitational force. Heavy rainfall may saturate this soil layer, increasing its weight. This increased weight can overcome the internal friction of the soil which resists the downslope force. The soil fails along a curved surface and slides downslope, as shown in the figure. The steep headwall scarp represents the upslope termination of the failure surface. The toe of the landslide is typically composed of disrupted soil that has flowed downslope.

Landslides are a common phenomenon, but they may be triggered by the intense shaking occurring during a large earthquake. Numerous landslides were caused by the 1949 and 1965 Puget Sound earthquakes; the most notable of these slides happened near the Tacoma Narrows three days after the 1949 event (Keefer, 1983). The port areas of Seward and Valdez were destroyed by submarine landslides during the 1964 Alaska earthquake (Grantz and others, 1964).

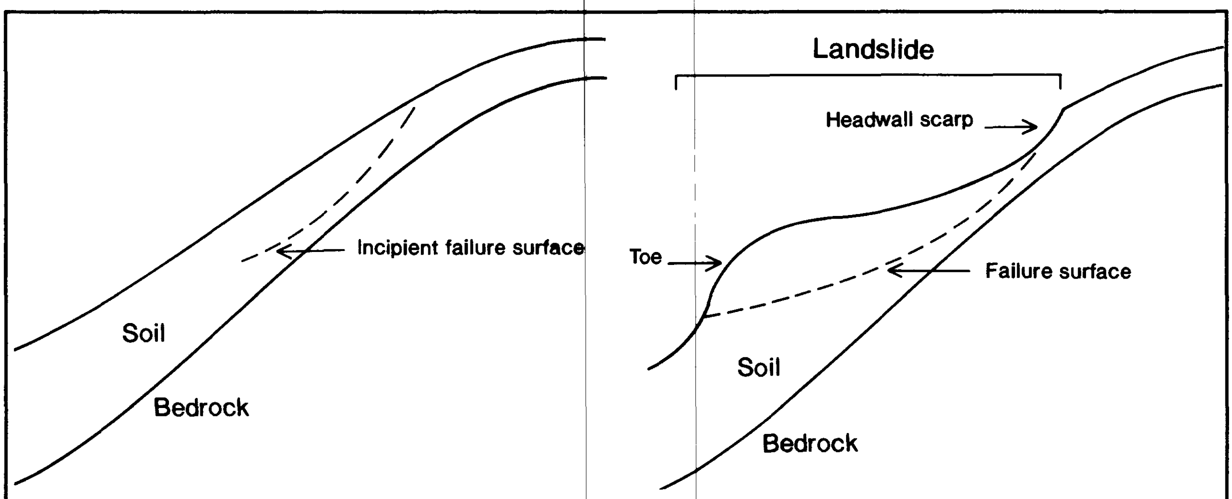


Figure 7. Landslides typically occur on steep slopes where a soil layer overlies bedrock. The downhill weight of the soil layer is supported by the material strength of the soil. A rainstorm will increase the weight of the soil, and the increased downhill load may exceed the soil strength. When the soil strength is exceeded, the soil slips along a curved failure surface creating a landslide. The uphill extension of the failure surface is a steep headwall scarp. Reworked slide mass soil will flow downhill, causing a bulbous thickening of the soil layer at the toe of the slide. Shaking during an earthquake may contribute to the downhill load and may also reduce the soil strength resulting in failure of the soil mass and landsliding.

EFFECTS ON WATER

Tsunamis are large-amplitude, low-frequency water waves that travel in open water. Tsunamis are generated when the seafloor suddenly subsides or is uplifted during a large earthquake. The waves may travel thousands of miles across the ocean, causing destruction wherever they come ashore. Tsunamis may be amplified by shoaling, funnelling in open bays and estuaries, and refraction around islands and points. Also, large sea waves generated by submarine landslides can inundate nearby coastal communities, as happened during the 1964 Alaska earthquake.

The tsunami and landslide-caused water waves following the 1964 Alaska earthquake resulted in 103 fatalities in Alaska. A family of four was drowned on the Oregon coast, and in Crescent City, California, 12 deaths were caused by a tsunami that had travelled approximately 1,000 mi across the open ocean. On the Washington coast three homes and two highway bridges were destroyed by this tsunami, but there was no loss of life (Noson and others, 1988).

A seiche is a water wave generated in a closed body of water, such as a lake or reservoir, in response to earthquake shaking or tilting of the lake bed. A seiche can cause damage along shorelines and may overtop dams, as occurred during the Hebgen Lake, Montana, earthquake of 1959 (Stermitz, 1964). A seiche created by the 1964 Alaska earthquake caused minor damage to small craft on Lake Union in Seattle.

DISCUSSION

Past experience has demonstrated that ground settlement, soil liquefaction, and landslides may be caused by the strong shaking of a large earthquake. These ground failures can result in damage to structures and foundations, disruption of pipelines and buried utilities, collapse of roadbeds, and loss of life. Earthquake-generated tsunamis likewise can cause major destruction and casualties in coastal areas.

Property damage and loss of critical lifelines can be minimized by proper seismic hazard evaluation and engineering practice. As one of several hazard reduction projects, the Division of Geology and Earth Resources has started to identify and map potentially liquefiable soil units in the Puget Sound region.

REFERENCES CITED

Grantz, Arthur; Plafker, George; Kachadoorian, Reuben, 1964, Alaska's Good Friday earthquake, March 27, 1964–A preliminary geologic evaluation: U.S. Geological Survey Circular 491, 35 p.

Hopper, M. G., 1981, A study of liquefaction and other types of earthquake-induced ground failures in the Puget Sound, Washington, region: Virginia Polytechnic Institute and State University Master of Science thesis, 131 p.

Keefer, D. K., 1983, Landslides, soil liquefaction, and related ground failures in Puget Sound earthquakes. *In* Yount, J. C.; Crosson, R. S., editors, 1983, Proceedings of Conference XIV, Earthquake hazards of the Puget Sound region, Washington: U.S. Geological Survey Open-File Report 83-19, p. 280-299.

National Research Council Committee on Earthquake Engineering, 1985, Liquefaction of soils during earthquakes: National Academy Press, 240 p.

Noson, L. L.; Qamar, Anthony; Thorsen, G. W., 1988, Washington State earthquake hazards: Washington Division of Geology and Earth Resources Information Circular 85, 77 p.

Stermitz, Frank, 1964, Effects of the Hebgen Lake earthquake on surface water. *In* The Hebgen Lake, Montana earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435, 242 p., 5 pl.

Thorsen, G. W., compiler, 1986, The Puget Lowland earthquakes of 1949 and 1965–Reproductions of selected articles describing damage: Washington Division of Geology and Earth Resources Information Circular 81, 113 p.

Youd, T. L., 1984, Geologic effects–Liquefaction and associated ground failure. *In* Proceedings of the geologic and hydrologic hazards training program: U.S. Geological Survey Open-File Report 84-760, p. 210-232.

FUNDAMENTALS OF EARTHQUAKE IMPACTS
on
BUILDINGS and LIFELINES

By

Roger W. McGarrigle, P.E., President
Structural Engineers Association of Oregon
Portland, Oregon

PREFACE - Earthquakes (EQs) cause some very dramatic movements to surrounding portions of the Earth. While these movements can be impressive to observers, their impact may become incredibly more dramatic and damaging when buildings, dams, pipelines, fuel storage tanks, and other types of structures, are present.

Structures, because of their concentration of mass, tend to resist the EQ movements induced by the ground that supports them. However, since they are attached to the ground (usually), the base of the structure is forced to move with the ground. These two factors are the basic reasons why structures tend to self destruct in a significant earthquake.

We design structures to resist EQs as follows;

Minor EQs,	no damage	< 5.5
Moderate EQs,	no structural damage	5.5 - 6.5
Severe EQs,	no structural collapse	> 6.5

That philosophy sounds reasonable enough but, the results are sometimes totally unacceptable. What happens ? Here are a few of the issues that can adversely effect EQ impact on a structure.

- A- Deep, soft sites & flexible structures
- B- Interesting structural configurations
- C- Giving credit for distance from known EQs.
- D- Soft structures on soft sites & stiff ones on stiff sites.
- E- Assuming that we know all about EQs.
- F- Low amount of reserve strength.
- G- Existing inadequate structures
- H- Designs by unproven engineers & architects
- I- Unknown seismology

CAUTION - Society should be aware that engineers have concluded that new structures are to be designed to resist only "moderate" earthquakes without structural damage, and that many existing older structures are expected to partially, or totally, collapse during just a moderate EQ, because they were not constructed to resist EQ ground shaking.

LIFELINES - The effects of EQs are devastating to lifelines, those functions that are critical to living in dense population areas. These include water distribution systems, electrical power systems, hospital services, transportation systems, harbors, sewers, natural gas systems, telephones, and other common utilities and functions that we have come to rely on for our everyday lives.

EARTHQUAKE RISKS - New structures and lifeline systems are usually being designed based on the known, or understood, EQ risks associated with the area. However, EQ risk in an area, appears to be based on the EQ history of an area and not on it's geologic EQ potential. The problem with using history as a basis of risk is that recorded history in the Northwest, doesn't go back very far, relative to earthquakes. Since there were no large structures around to amplify EQ damage, a severe EQ could have been less significant, to the Indians present 200 years ago, than a major wind storm.

The need to identify EQ risk was illustrated by the Borah Peak event (M7.3) of 1983, in central Idaho. It was larger than the 1949 Olympia event and was larger than all but four events in the US, in recorded time. It happened in an area that was zoned as having the same risk as Portland. Fortunately, it happened in an area that was not heavily populated, or there would have been much more destruction and many more deaths. It seems clear that with each new EQ we verify that we don't know as much about EQ's as some believe.

WHERE ARE THE RISKS - Most one and two story wood frame residential structures will perform very well. Some of the factors that, in my opinion, affect performance of residences and structures in general are;

GOOD	POOR
Gently sloping sites	Hillsides
Small % of wall openings	Large % of wall openings
Reinforced foundations	Unreinforced foundations
Lots of anchor bolts	Few, or no, anchor bolts
Plywood wall sheathing	Gypsum & paper wall sheathing
Many interior walls	Large enclosed open spaces
Nailed wood siding	Masonry veneers
Away from a floodway	In a floodway
Firm soils or rock	Soft or wet soils
Regular configuration	Overhanging rooms, etc.

BIG RISKS - The big risks come from structures that can affect large numbers of people. These include schools, dams, hospitals, nuclear reactors, office buildings, water systems, shopping centers, sewer systems, theaters, petroleum transportation systems, prisons, electrical systems, fire fighting facilities, bridges and tunnels, etc.

Some structures have been designed with an "Importance Factor" to address the higher risks associated with the loss of one structure relative to another. However, the codes seem to change in this regard, from time to time.

EARTHQUAKE IMPACT ON STRUCTURES - Structures fail after repeated shaking, and repeated over-stress of critical components. One structure may fail after one or two shakes, while another may withstand ten or twenty such movements, depending on the toughness of the design and on other factors. EQ loads are such that the first major movement does not usually cause rupture of structural elements. Large EQs will shake a structure 20 times, while smaller ones may only give one or two strong shakes.

Each EQ is unique and so are most structures. EQs are characterized by their MAGNITUDE (the energy release), ACCELERATIONS (usually the peak acceleration of the ground motions as measured at some location), PERIOD (the amount of time in seconds between peaks of acceleration), DISPLACEMENT (the amount of movement) and DURATION (the amount of time that the significant vibrations continue).

A structure will respond to one EQ different than it will to another however, there are certain generalizations that can be made. For example, short stiff structures will react more dramatically to short period EQs than to ones with long periods. The reverse is true for tall flexible structures.

The pattern of EQ vibrations will change, sometimes dramatically, as the vibrations radiate away from the rupture zone. Short period vibrations are more pronounced near the center, with longer period vibrations occasionally persisting at greater distances from the EQ center.

This can mean that for a given structure and EQ, the location of the structure relative to the EQ center will determine the degree of impact. Being farther away from the center of an EQ may not always be such a good thing. However, the impact of an EQ is generally lessened as you are farther away from it's center.

The most important factors of EQ vibrations, from a structural point of view, are the magnitudes of PERIOD, ACCELERATION, DISPLACEMENT, and DURATION. These combined factors generally reflect the way that the EQ ENERGY is delivered.

The higher the accelerations of the ground shaking, the higher the forces that the structure must resist. However, the significance of these accelerations will depend on the period of these vibrations, if the EQ vibration period matches the natural period of the structure, the vibrations will impart maximum shaking to the structure. This condition is refereed to as "RESONANCE".

The larger the displacements, the greater the risk of one structure pounding against a neighboring one. Displacement refers to the change in position at one point in time relative to that at another time. For the most part, we are talking about horizontal movement. The top of a building will be displaced relative to the base, as a result of EQ loading. Also, one floor will move relative to the ones above and below it. In design we place limits on displacement.

The longer the duration of shaking, the more likely that material fatigue will result in structural failure. Significant EQ vibrations may last for as long as 3 or 4 minutes in a very large event and for just 3 or 4 seconds in a small one. Three minutes of vibrations with a period of about 1 second could mean nearly 200 impacts to a structure.

THE FORCE - F = MA (Force = Mass times Acceleration) is the basic relationship associated with the action of an EQ on a structure. The force required to accelerate a mass is equal to the product of the mass times the acceleration. This force must be resisted by the structure in order for the structure to move with the ground, instead of breaking-up and collapsing.

The highest levels of force in a structure occur at the base, where the entire mass of the structure is being dragged along with the movements of the ground while the mass tries to remain at rest, at the beginning of the EQ. Once the mass gets moving in one direction, then the ground motion changes direction and tries to change the momentum that has been built up by the moving mass.

Stiff structures, such as the Pyramids, tend to experience the full force of an EQ, while flexible structures, like willow trees, tend to only experience a portion of the F = MA force. This means that stiff structures must be stronger than flexible ones, and they usually are.

However, flexible structures may not be acceptable due to the amplification of ground movements in their upper levels. Flexible structures can become like a whip, causing injury and damage by throwing contents around inside, and throwing elements to the ground outside. The movements at the top of a tall structure will be more dramatic than at the base.

FOUNDATIONS - Occasionally the site under a structure will not provide the required support. Footings may become overloaded and punch deeper into the soil, causing the structure to lean. Piling supporting a structure may become overloaded and break, or they may be lifted out of the soil, and allow the structure to lean. These foundations are being forced into the ground on one side of the structure, and are being lifted out on the other side, then when the movement changes direction, the loads on the foundations reverse.

Sandy soils that are saturated (loaded with water) will begin to act like a liquid under the weight of a structure, when subjected to EQ vibrations. These sandy soils will loose their ability to support structures of any size. This concept is refereed to as LIQUEFACTION.

COST - Structures can be designed to resist EQ forces, and the cost of such EQ resistant construction will range from zero to generally less than 2% above the construction cost for a structure that is designed to resist wind loads. The problem is that just 2% of a 50 million dollar building is 1 million dollars and no developer can be expected to ignore an expenditure like that, if it may not be necessary.

There is a serious question about the size of EQ that should be designed for, in any location. This is not just a local question. Structures, buildings and lifelines, can be designed and constructed "economically" to perform according to an acceptable "philosophy". However, society must decide that such design is essential, and must be willing and able to pay the price before an EQ, rather than after one.

Hopefully, many new structures will be constructed and many years will pass, before a large EQ hits in our area. These new structures should be designed to resist large EQs, unless we can be certain that they will not happen in our area. And, existing structures should be reinforced to resist the same EQ's.

CONCEPTS ON LOSS ESTIMATION USED BY INSURANCE COMPANIES

by
Karl V. Steinbrugge
Structural Engineer
El Cerrito, California

For economic reasons, most major property insurance companies have been placing increased reliance on the identification of earthquake construction characteristics of buildings from sources other than structural engineers. Costs involving the examination of construction drawings plus field inspections, which must be included in the insurance premiums, do not allow this for all but high value structures. Relying on the "law of large numbers", there is a growing tendency to use simple construction types or other parameters identifiable by non-specialists. This reliance is especially true for dwellings and small businesses.

Underway for a long time is a second trend whereby all field information is processed directly by computer.

The uses of this information can be two-fold: (1) Ratemaking which requires additional knowledge on earthquake recurrence intervals, and (2) Company solvency after an earthquake. It is the latter of these which is addressed in this presentation. Also, the discussion is limited to direct damage, and not to workers compensation, ensuing fire, liability, and the like -- several of which may equal or exceed direct damage losses.

State regulators and insurance companies have preferred a conservative approach to solvency estimates, and practices of the California Department of Insurance may be used as a guide for simplistic "Probable Maximum Loss" (PML) estimates. This presentation is restricted to the solvency viewpoint.

A major goal in the development of loss estimation concepts is that all data and methodology is to be reproducible by others, meaning that judgmental inputs are to be continually reduced as data improve. Microzonation maps present great difficulties in this regard when quantifying them for monetary loss purposes.

There are problems which lead to incorrectly or inappropriately classified buildings in today's insurance practice. For example, the field person must recognize that "reinforced" brick walls essentially exist only in post-1933 construction in the Los Angeles area as one consequence of the 1933 Long Beach earthquake; other visual characteristics can assist in this determination. A similar situation exists in the Pacific Northwest for reinforced hollow concrete block walls (cinder block). These are examples of types of earthquake construction characteristics which, if properly recorded by the non-professional, allow appropriate computer programs to develop better PMLs. The trend is toward obtaining these kinds of identifiable characteristics, including field identifiable regional construction practices by age, mapped microzoned soil characteristics which are computer related to building location, and fault locations in computer data bases.

Best computational methodology involves:

1. Placing the geographic coordinates of known active faults into a computer file.

2. Determining the maximum magnitude and average focal depth to be expected for each fault in the context of the definition of PML and each fault's geologic characteristics.

3. Determining the probable rupture length for the maximum PML magnitude. Considerable world-wide data exist, and judgment is required to select those best suited for the study region.

4. Establishing attenuation algorithms which relate damage by class of building construction to distance from the earthquake fault rupture (seismic energy source). These attenuation algorithms can be based on the attenuation curves from strong motion records. For subclasses with high-rise buildings, the so called "long period effects" can be crudely approximated as a function of number of stories if better data are not available.

   Serious differences of opinion exist regarding the coefficients to be used for attenuation. We are having increasing difficulty in using modern intensity data since observers are not consistent in their intensity evaluation of earthquake resistive construction which is now becoming increasingly common in new construction in most western states -- or they may not have the engineering background to judge the "intensity" for these modern buildings. When possible, it is preferred to use actual monetary loss experience rather than intensity information since, as the loss data bases grow, the importance of erratic judgmental intensity will decrease.

5. From surficial geologic microregional maps, establishing numerical damage relationships between locations in these zones and damage to buildings by class of construction. Most present microzonation maps use subjective terms such as "slight", "moderate", etc. for increases in damage; the professionals needs some clairvoyance when interpreting these for monetary loss to earthquake resistive construction.

Loss estimation methodologies for the Pacific Northwest have a weak foundation for many consultants since there is little published consensus on the parameters necessary for model earthquakes to be used for loss estimation.

 (page 154 follows)

SECTION III: USING EARTH SCIENCE INFORMATION TO REDUCE POTENTIAL LOSSES

This section of the report contains 21 contributions that provide guidance on the use of earth science information to reduce potential losses. This state-of-the-art information supplements and extends two documents:

1) U.S. Geological Survey Open-File Report 88-13A, "A Review of Research Applications in the National Earthquake Hazards Reduction Program", and

2) U.S. Geological Survey Open-File Report 88-13B, "Applications of Knowledge Produced in the National Earthquake Hazards Reduction Program: 1977-1987."

These two reports represent the products of a unique cooperative endeavor undertaken in 1987-1988 by the four principal agencies of the NEHRP: Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and the United States Geological Survey (USGS).

Special attention should be given tot he last four papers which describe opportunities associated with:

- Earthquake risk policies and practices within the Puget Sound-Portland Area.
- Post-disaster emergency response issues.
- The December 7, 1988, Spitak (SSR) earthquake.
- The International Decade.

KNOWLEDGE UTILIZATION*

By
Walter W. Hays
U.S. Geological Survey
Reston, VA 22092

2.1 Critical Factors

Study of the sixty case histories (see U.S. Geological Survey Open-File Report 88-13A) showed that applications of knowledge to protect lives and property from earthquakes is a complex dynamic process requiring people, funding, and time. For simplicity and ease of comparison, the case histories describing applications were evaluated in terms of:

- Enlightenment (uses of knowledge to increase understanding, awareness, concern, and commitment). (Note: The program of an earthquake education center epitomizes enlightenment uses.)

- Decisionmaking (uses of knowledge to build a basis for decisionmaking concerning legislation, building codes, regulations, earthquake insurance, investment, development, and comprehensive planning). (Note: The activities of a seismic safety organization typify decisionmaking uses.)

- Practice (uses of information to change, modify, and improve the state-of-practice in siting, design, construction, land-use, preparedness, mitigation, and emergency management). (Note: A program of retrofit of unreinforced masonry buildings is an example of practice uses.)

These three categories of knowledge utilization were described by Yin and Moore in 1985 when they evaluated knowledge utilization models

These case histories and other past experiences in the nation showed that applications happen as a consequence of twelve factors which strongly influence the research applications process. These factors, which happen in combination with each other, are necessary but not sufficient by themselves to guarantee success (i.e., implementation of an action to mitigate or reduce the earthquake hazard). However, their absence guarantees failure. The factors are described individually in the following section and are illustrated in Figures 1-12. They are:

---

* Reprinted from U.S. Geological Survey Open File Report 88-13-B

- o People to provide leadership in the research applications process efficiently,
- o Funding to create programs that forge a partnership between reseachers and architectures.
- o Time to reach the implementation period.
- o A knowledge base.
- o A perceived need for action.
- o Internal advisors and advocates.
- o External champions.
- o Credible products.
- o Useful products
- o Balanced technical, societal, and political considerations.
- o Windows of opportunity.
- o Collaboration of researchers and practitioners.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

THE CALIFORNIA SEISMIC SAFETY COMMISSION (CSSC)--THE FORERUNNER OF SEISMIC SAFETY ORGANIZATIONS IN THE NATION

(From: Lambright, 1988; Scott, 1988; Jones, 1988; Olson, 1988; Lindbergh, 1988; and Whitehead, 1988)

The February 9, 1971, San Fernando earthquake, which caused $500 million in direct losses, provided a window of opportunity which eventually led to the formation of the California Seismic Safety Commission in 1975. Senator Alfred Alquist played a major role in its birth and eventual institutional role as a symbol of seismic safety, a catalyst for action, and an incubator of applications to reduce potential losses. Since 1975, CSSC has served as an "enabling institution," playing a major role in the legislative process and the establishment of the Southern California Earthquake Preparedness Project (SCEPP) and the Bay Area Regional Earthquake Preparedness Project (BAREPP).

Although the causative factors, funding, histories, and missions differ, the CSSC has influenced the creation of seismic safety organizations throughout the nation: Utah in 1977; Nevada and Montana in 1978; South Carolina in 1981; Kentucky in 1982; the Central United States in 1984; New England, New York, and Puerto Rico in 1985 and Washington in 1986. The organizations in Utah, Nevada, Montana, and Washington were short lived; Puerto Rico's is still evolving. All have made an important impact on research applications in their region of the nation.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

2.2 People (see Figures 1, 2, 3, and 7)

People are the essential ingredient in the process leading to applications because they provide leadership for the programs that comprise the six elements of the research applications process. As researchers, they produce the knowledge base and products, and as practitioners, they apply it. They interact within and between their individual networks. They evaluate and make the required adjustments to improve preparedness and mitigation programs.

2.3 Funding (see Figure 3)

Adequate funding to sustain the programs is essential. The case histories show that although funding is necessary, it is not a sufficient condition for guaranteeing applications of knowledge. The critical issues are:

- Funding that is adequate to support a critical mass of researchers and practitioners working together on a program, and

- Continuity of funding over a period of 5 to 10 years or more to complete the integration period.

2.4 Time (see Figure 11)

The case histories showed clearly that most states of the nation are still in the integration period which may sometimes last a decade or more. Researchers accept this fact, because they work on a long timeline, but practitioners do not understand or accept it. Therefore, the critical issue is:

- **Can the time required for applications of knowledge for mitigation of the earthquake hazard be shortened? If so, what is the best way?**

  The answer is to produce many more champions of earthquake hazard mitigation and to give them a reason to collaborate.

2.5 Knowledge Base (see Figures 1 and 2)

Building a sound knowledge base that practitioners can use should be the goal of the researchers. Experience shows that practitioners can attain adequate understanding of the physical, social, and economic makeup of the region/urban system for successful applications to be realized. Such an understanding of these complex parameters, their central tendency and variability, and their sensitivity to extrapolation, comes only from collaboration between the researchers and practitioners in the development, translation, and use of the knowledge base.

All preparedness and mitigation measures require a knowledge base that can be used to answer basic questions such as the following:

Questions Addressed by the Researchers

- o Where have earthquakes happened in the past? Where are they occurring now?
- o How frequently do they occur?
- o How big have they been? How big can they be?
- o What kind of physical, social, and economic effects have they caused? What are the worst effects they could cause in a given exposure time (e.g., 50 years--the useful life of an ordinary building).
- o How have soils, buildings, and lifeline systems performed under earthquake loadings?

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

THE SOUTHERN CALIFORNIA EARTHQUAKE PREPAREDNESS PROJECT (SCEPP)

(From: Goltz and Flores, 1988)

The Southern California Earthquake Preparedness Project (SCEEP) demonstrates many elements common to successful research applications. SCEPP was initiated in response to a perceived need by the state and Federal governments in the late 1970's to prepare for a major earthquake in southern California. Four unrelated events: a) the "Palmdale Bulge," b) the prediction of a moderate earthquake by a scientist at the California Institute of Technology, c) the eruption of Mount St. Helen's in 1980, and d) the request made after the eruption by the National Security Council to examine the possibility of a major earthquake in

California led to the formation of SCEPP in 1980. SCEPP was institutionalized in 1986 by the California State Legislature.

SCEPP has had both internal and external supporters in its infancy and throughout its lifetime, enabling it to endure changes in state and Federal administration, changes in funding, and changes in perceived level of earthquake potential. Very early in the process, SCEPP developed partnerships with local governments and businesses, the potential users of its products and information. In conjunction with selected businesses, cities, and counties, SCEPP developed prototype planning products capable of being transferred to other organizations. Conferences with other businesses, cities, and counties are held periodically to "transfer" the prototype products and experiences.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

- o How have people behaved before, during, and after a damaging earthquake? How are they likely to behave in the future?
- o What earthquake preparedness and mitigation measures are available for application? Which measures are most effective from the technical-societal-political perspectives? What actions are required?

Questions Addressed by the Practitioners

- o Will the loss reduction measures save lives and prevent injuries?
- o Will the measure reduce property damage and economic losses?
- o Will the measure reduce social and economic disruption?
- o Is the measure in line with community values?
- o Is the measure feasible and can it stimulate actions by others?
- o Is the measure affordable?

2.6 A Perceived Need For Action (see Figures 4, 5, and 8)

Knowledge alone makes no contribution to the reduction of earthquake losses if the knowledge is unknown, misunderstood, inappropriate, unintelligible, misdirected, or ignored by knowledge users. The reality is that full use of the knowledge base produced in the NEHRP has not yet been made--probably for all of the above reasons--even though all regions of the nation have advanced their capacity to mitigate the earthquake hazard.

Both researchers and pratitioners (e.g., earth scientists, social scientists, architects, engineers, planners, emergency management specialists) have played a major role in calling attention to the need for dealing with the earthquake hazard in their region or community. Increased awareness of the hazard and professional skill enhancement have served to clarify the need and to equip professionals for action.

Programs to increase awareness and to enhance professional skills were created, enacted, and institutionalized during the first decade of the NEHRP. Examples include:

- The California Seismic Safety Commission (Lambright, 1988; Scott, 1988)
- The Southern California Earthquake Preparedness Project (SCEPP) (Goltz and Flores, 1988)
- The Bay Area Regional Earthquake Preparedness Project (BAREPP) (Eisner, 1988)
- The Utah Earthquake Hazards Program (Sprinkel, 1988, Tingey, 1988)
- The Central United States Earthquake Consortium (CUSEC) (Jones, 1988)
- Western States Seismic Policy Council (Truby, 1988)
- South Carolina Seismic Safety Consortium (Olson, 1988)
- New England Earthquake Project
- Continuing Education Committee of Earthquake Engineering Research Institute
- The California Earthquake Education Project (Thier, 1988) (Note: this project is totally supported with state funds.)
- Public Information and Awareness Programs in the Puget Sound, Washington, area (Martens, 1988).
- Charleston Earthquake Education Center (Bagwell, 1988)
- Outreach programs of the Tennessee Center for Earthquake Research and Information (Metzger, 1988)

2.7 Internal Advisors and Advocates (see Figures 2, 8, and 9)

Internal advisors and advocates are very important in fostering applications of knowledge to mitigate the earthquake hazard in their community or region. These are men and women who may or may not have a scientific or technical background, but who are aware of and understand the reality of the earthquake threat to their community and who are willing to be personally involved in the solution. Because of their knowledge, understanding, commitment, and position of responsibility in the organizations they represent, they usually find themselves in a position to advise and influence the heads of their organizations with respect to seismic safety and to recommend policy. Often, they may be charged with evaluating and recommending loss reduction measures that are appropriate for the need and are balanced in terms of internal and external societal and political considerations. These special people play a major role in influencing policymaking and action taking (Thiel, 1988). The case histories contain many examples showing how internal advisors and advocates have contributed to the research applications process.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

A PARTNERSHIP IN UTAH TO ASSESS EARTHQUAKE HAZARDS AND RISK AND TO FOSTER IMPLEMENTATION OF LOSS-REDUCTION MEASURES

(From Sprinkel, 1988; Tingey, 1988; Barnes, 1988; and Reaveley, 1988)

Researchers and practitioners met in 1983 to formulate an integrated five-year research and implementation program in the ten county area adjacent to the Wasatch fault where approximately 90 percent of the populace live. The principal partners were the Utah Geological and Mineralogical Survey (UGMS), Utah Division of Comprehensive Emergency Management (CEM), FEMA, and USGS. Universities and the private sector participated through grants. The singular accomplishments in the first 5-years included: a) annual workshops to enhance collaboration between knowledge producers and knowledge users, b) production, dissemination, communication, and evaluation of an improved knowledge base, c) institutionalization of a county geologist's program, d) production of an award winning video, "Not if--But When," for use in training and awareness programs in Utah, and e) improved emergency response plans.

Because of the five-year study, Utah is now taking steps to deal with an estimated loss of $3 to 5 billion in a magnitude 7.0-7.5 earthquake on the Wasatch Front. The solution must deal with the large percentage of unreinforced masonry buildings in the state.

A similar partnership was created for an analogous five-year study in the Puget Sound, Washington--Portland, Oregon area in 1985.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

2.8 Champions (see Figure 3)

The term "champion" is used for the men and women who tirelessly promote earthquake hazard mitigation. They may have widely different backgrounds. For example, they may be engineers (e.g., the late Professor Nathan Newmark, University of Illinois), earth scientists (e.g., the late Professor Otto Nutli, St. Louis University), emergency management specialists (e.g., the late Erie Jones, Executive Director of the Central United States Earthquake Consortium) public officials (e.g., the late Robert Rigney, San Bernardino County), or volunteers (e.g., Corrine Whitehead, League of Women voters). These individuals have such a strong commitment to earthquake hazard mitigation that they are able to influence public officials, policymakers, researchers, and practitioners to join with them in fostering and implementing mitigation measures. Their influence, which benefits the entire nation, comes from intrinsic motivation.

The case histories identified some of the current champions who have promoted earthquake hazard mitigation during the first decade of the NEHRP. Many of these individuals are new in their role as champions; they only emerged during the past 10 years. Clearly, many more champions are needed during the second decade of the NEHRP because:

- **the key to earthquake hazard mitigation throughout the nation is the production of champions who will collaborate with other champions to reach the goal of earthquake hazard mitigation in their communities.**

2.9 Credible Products (see figures 2 and 4)

Credibility of the products (data, reports, maps, loss estimation models, computer models, model building codes, etc.) produced by researchers and disseminated to practitioners for applications is essential. Credibility is an intangible quantity that will be "high" (good) or "low" (not good) as a function of factors such as: 1) the reputation of the researcher(s) in the research community, 2) whether they are local or "foreign," 3) the organization supporting the researcher, 4) the organization sponsoring the research, and 5) the peer-review and/or consensus development process that was used to institutionalize the results.

A period of time ranging from a few years to a decade or more is required in most cases to develop a "high" level of credibility; credibility can be lost much faster than it is attained. Examples of the importance of "high" credibility include:

- The Parkfield, California earthquake prediction--credible because of the extensive reviews by the National Earthquake Prediction Evaluation Council (NEPEC), the California Earthquake Prediction Review Council, and the institutional reputation of the USGS (Goltz, 1988).

- The reports, "A Study of Earthquake Losses in Hawaii," and "Earthquake Vulnerability of Honolulu and Vicinity"--credible because of the high professional stature of the principal local consultants: Dr. A. S. Furumoto, Walter Lum, N. Norby Nielsen, and James Yamamoto (from Hawaii), and the external consultants Karl Steinbrugge and Henry Lagorio (from California) (Gransback, 1988).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

ROLES OF THE ARCHITECT, ENGINEER, AND URBAN PLANNER
(From: Mader, 1988, and Barnes, 1988)

The seismic performance of a city's buildings and lifeline systems depends on the architect, engineer, and urban planner. The architect deals with the individual building--its concept, configuration, and planning. The architect and engineer share the responsibility for seismic design, especially when conformance to the seismic design provisions of a building code is required. The urban planner is concerned with buildings in groups that form a street, a community, or a city. Architecture, engineering, and urban planning are complimentary.

Urban planning involves the preparation of plans for future growth and change in urban areas, open spaces, and the implementation of these plans to address topics such as: land use, open space, transportation, hazardous areas, and emergency evacuation routes. Implementation requires zoning and subdivision, regulations, and building codes. One example of the planning process in California is the seismic safety element, a requirement introduced in California in the early 1970's.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

- Tsunami hazard maps for Alaska--credible because of the reputation of the researcher, the sponsoring agency (NSF) the quality of the work, and the recent memory of the physical effects of the 1964 Prince William Sound, Alaska earthquake (Pruess, 1988).

- Seismic design provisions for building codes--credible because of the ongoing work by the model code bodies to develop a consensus (Corley, 1988, Arnold, 1988).

- Guidelines for design of low-rise buildings subjected to lateral forces--credible because of the activities of the Council of low-rise Buildings that was created with support from the National Science Foundation to meet a perceived need (Gupta, 1988).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

SEISMIC SAFETY LEGISLATION

(From: Tobin (1988), Fowler (1988), and Meek (1988))

A combination of many factors is responsible for seismic safety legislation throughout the nation. Research results must be credible, but they often are oversimplified or exaggerated and are but one element in the process; often they are not the most important element. Unlike the objective and measured process of scientific research which produces carefully written and qualified reports that are peer reviewed and published in journals, the legislative process lives with unique rules, last-minute deadlines, competing interests and political philosophies, and compromise. From this process, seismic safety policy is born in legislatures throughout the nation.

In many cases, major seismic safety legislation is enacted after a damaging earthquake. Even foreign events can serve as a catalyst in the legislative process.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

2.10 Useful Products (see figures 2 and 4)

In order for applications of knowledge that mitigate the earthquake hazard to happen, the research products must be both credible and useful (i.e., user friendly). It is entirely possible for a product (e.g., a ground-shaking hazard map) to be credible but not useful. Useless products usually result when:

- The practitioners in the community were not involved in the research-applications process until after the research was completed and the results were disseminated (i.e., the practitioners did not have a stake in energizing the process).

- The product is scientifically correct, but socially unacceptable and/or politically naive.

- The product, although scientifically correct, has not been translated for use by nonspecialists to answer the key questions:

  Where, how bad, when, and the probability of occurrence.

The case histories illustrate many examples of useful products. They include:

- A ground-shaking hazard map (produced by USGS) for a scenario earthquake in the Mississippi Valley region. The map was used in a six-city loss study (sponsored by FEMA) and in hazard awareness and "Train the Trainer" programs (conducted by CUSEC) (Jones, 1988).

- The "lessons" learned from earthquakes (sponsored by NSF) and earthquake loss studies in northern and southern California (prepared by USGS and sponsored by the predecessor organizations of FEMA) by the University of California system to evaluate the need for strengthening of existing buildings (McClure, 1988).

- Research on unreinforced masonry buildings (sponsored by NSF) to devise and enact a plan to repair and strengthen existing buildings in the Los Angeles area (Kariotis, 1988; Asakura, 1988).

- Social science research (sponsored by NSF) to evaluate and improve response and recovery planning in St. Louis, Missouri (Gillespie, 1988).

- Research on structural systems (sponsored by NSF) by a practicing architectural engineering consulting firm to foster earthquake damage and loss control (Scholl, 1988).

- Computer programs for probabilistic hazard analysis and dynamic structural analysis (from projects sponsored by NSF) by an engineering consulting firm to plan and implement seismic strengthening of the Palo Alto Civic Center (Sharpe, 1988).

- Technology for retrofitting existing hazardous buildings (sponsored by NSF) and comprehensive technical program planning (sponsored by FEMA) by university researchers to devise a research agenda and a strategy for evaluating and strengthening existing buildings in the Eastern United States (Soong and White, 1988).

- Experience and reputation gained from studies sponsored by NSF to evaluate the effectiveness of land-use planning measures in Provo, Utah, and Bellingham, Washington (Bolton, 1988).

- Information on regional earthquake hazards (from projects sponsored by NSF and USGS) to improve earthquake preparedness (sponsored by FEMA) in San Juan and other urban areas in Puerto Rico (Molinelli, 1988).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

WINDOWS OF OPPORTUNITY PROVIDED BY A DAMAGING EARTHQUAKE

(From: Tierney, 1988; Jennings, 1988; Singh, 1988; Bartholomew and others, 1988; Holt, 1988; Fratto, 1988; Meet, 1988; and Santiago, 1988)

A damaging earthquake, almost independent of where it occurs, makes the earthquake threat more salient to officials of state and local government and the financial community throughout the nation. The event reinforces awareness and concern by showing how destructive and disruptive even a moderate-magnitude (magnitudes of 5.5 and greater) can be to a community. With few exceptions, the event serves as a catalyst for action by knowledge producers and knowledge users. Media coverage can stimulate a public call for action, especially if deaths, injuries, homelessness, and joblessness are high. The legislative process is usually enhanced by a damaging event, as are new initiatives for research and loss reduction.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

- Loss estimates (prepared by the USGS under the sponsorship of the predecessor organization of FEMA) by FEMA to improve earthquake preparedness in the Puget Sound, Washington, area (Buck, 1988).

2.11 Balanced Technical, Societal, and Political Considerations (see figures 2 and 11).

For earthquake hazard mitigation to be realized, the societal and political considerations must be balanced along with the technical. Dr. John Wiggins introduced the concept of balanced risk in the early 1970's in conjunction with an assessment of the seismic hazard to existing buildings in Long Beach, California (Wiggins, 1988). Many others (e.g., Selkregg and Pruess, 1988) have verified the concept.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

A LESSON LEARNED IN ALASKA
(From: Selkregg and Pruess, 1988)

"In order to achieve effective implementation, any plan for seismic risk mitigation should reflect the shared responsibility among all levels of government. . . . better communication must be established among these partners and between government decisionmakers and the public."

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

However, one well known fact should be reiterated:

- **A damaging earthquake changes the rules of the game for a short period of time. Applications that were lagging before the earthquake because of the "pocketbook issue" or the "legal liability issue" can be achieved after the earthquake because of a new factor, the window of opportunity.**

2.12 Windows of Opportunity (see figures 2 and 11).

In most cases, the legislative process requiring implementation of loss-reduction measures can be accelerated by the occurrence of a damaging earthquake. Even events outside the United States (e.g., the 1985 Mexico and 1988 Soviet Armenia earthquakes) create opportunities. After the earthquake, a window of opportunity is opened for a short period of time (typically a few months to a few years). Regions where public and private apathy exists because earthquakes are perceived as infrequent, low-saliency problems can use the tragedy as an opportunity to call for relevant action to impact and improve awareness, decisionmaking, and practice. The organizations that are prepared can achieve notable successes in: legislation, adoption of the seismic provisions of building codes, funding for emergency response, funding for research and equipment, funding for retrofit programs, et cetera Every damaging earthquake is important, some more than others. Examples of how a window of opportunity was seized to accelerate the applications process in the NEHRP include:

- o The 1976 Tangshan, China, earthquake, which was a contributing factor to the enactment of the NEHRP Act in 1977.
- o The February 8, 1971, San Fernando earthquake (Jennings, 1988; Lambright, 1988) which caused all seismic design criteria to be reevaluated.
- o The 1985 Coalinga, California, earthquake (Tierney, 1988)
- o The 1979 Imperial Valley, California, earthquake (Singh, 1988)
- o The 1983 Borah Peak, Idaho, earthquake (Meek, 1988)
- o The August 18, 1959, Hebgen Lake, Montana, earthquake (Bartholomew and others, 1988)
- o The 1886 Charleston, South Carolina, earthquake (Lindbergh 1988, and Elton 1987).
- o The October 11, 1918, Mayaguez, Puerto Rico, earthquake and the September 19, 1985, Mexico earthquake (Santiago, 1988; Molinelli, 1988).
- o The October 10, 1980, El Asnam, Algeria, earthquake (Thiel, 1988).

The legislative process is usually but not always enhanced when the window of opportunity is opened. Examples include:

- o California (Tierney, 1988; Tobin, 1988; Mader, 1988; and Palm, 1988).
- o Washington (Fowler, 1988).
- o Idaho (Meek, 1988).

However, one should remember that a window of opportunity does not stay open very long and that some of the accomplishments may be rescinded later when the window closes.

2.13 Collaboration of Researchers and Practitioners (see figures 9 and 12)

Collaboration is the complex process researchers and practitioners use to pass information to each other to work together to make applications happen. The collaborative process requires an interrelated network of people, events, ideas, and communication methods.

The case histories showed that long term collaboration of champions of earthquake hazard mitigation is the single most important factor for success. From the beginning (the research) to the end (the applications of the research), collaboration of researchers and practitioners is essential for earthquake hazard mitigation. Opportunities to gain support for and to accelerate the research cannot be seized unless there is a high degree of collaboration between researchers (e.g., scientists, engineers, architects, planners, social scientists). The same is true in gaining support for applications; there must also be a high degree of collaboration between the practitioners. The case histories showed clearly that:

- o The key to successful applications of knowledge is not only a function of collaboration within the networks, but also between the networks. (i.e., Tobin, 1988; Goltz, 1988; Whitehead, 1988; Sprinkel, 1988; Tingey, 1988; Andrews, 1988; and Pruess, 1988).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

MYTHS OF COMMUNICATION
(From: Hays, 1978)

Gilbert White noted five myths in communication in the 1978 workshop on "Communicating Earthquake Hazards Information," sponsored by USGS. People everywhere make mistakes by assuming that:

- o *There is a general public or "the public."*
- o *Mailing a report constitutes communication.*
- o *Scientific consensus is the equivalent of overall consensus.*
- o *There is a consistency between what people say and what they do.*
- o *There is a general relationship between the provision of scientific information and what is done with the information.*

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Collaboration of researchers and practitioners is complex and very difficult to achieve quickly. Explanations for the inherent difficulty include:

o People having different educational backgrounds and experiences have difficulty collaborating. They naturally have different perspectives (Szanton, 1981) which affect their willingness and ability to collaborate effectively as well as their levels of trust.

o Communication--communication--and more communication is the key for narrowing the differences between researchers and practitioners and for creating trust between people and synergism between programs.

o Collaboration is not an act; rather, it is a dynamic process that must be done consistently over a long period of time.

The case histories contain many examples of the importance of communication to collaboration (e.g., Thiel 1988; and Gillespie, 1988).

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

ENHANCING UTILIZATION
(From: Thiel, 1988)

"Publication of the results of research and dependence on the users to find and interpret it (or the "toss it through the transom" approach) is not a particularly effective method of getting information to those who that need it. Research suggests that the most effective approaches are those that focus on the involvement of the nonresearcher, particularly internal advisors/advocates and external champions who are viewed within their community as leaders, in workshops, prototype studies, priority setting exercises, advisory groups, and any other approach that exposes them to the problem."

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

EXPERIENCE IN ST. LOUIS, MISSOURI
(From Gillespie, 1988)

"The emergency management practice community in St. Louis . . . claimed: 1) results are too "scientific" or vague for practitioners, 2) little dissemination of research findings, 3) resistance on the part of the practitioners to the dissemination of research results, for political or personal reasons, 4) frustration, and hence resistance, on the part of practitioners who perceived that scarce resources are being used on research

rather than practice, 5) research is only for the self-gratification of the research community, and 6) emergency management and training programs often do not use research results. Each of these problems could be reduced if there were more contact and communication between researchers and practitioners."

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

2.14 Summary of the Research Applications Process (see Figures 1-12)

The nation has an urgent need for: 1) a comprehensive body of fundamental knowledge on earthquake hazards and risk and 2) many more champions who will collaborate in the applications of the knowledge to mitigate the earthquake hazard. The process of creating this body of knowledge and publishing the results is well advanced; however, the process of translating, communicating, and applying the knowledge in the form of enlightenment uses, decisionmaking uses, and practice uses by "partnerships" throughout the nation is not as well advanced and much work remains to be done. Applications of knowledge lag behind the production of knowledge in a region when there is an imbalance between or the absence of some or all of the following factors:

- o People to provide the leadership, perform the collaboration, and forge the partnerships in the dynamic long term research application process.
- o Funding to create and sustain programs having a critical mass of researchers and practitioners working as partners to create, disseminate, translate, communicate, and apply knowledge and evaluate the results.
- o Timeliness as well as time--independence of programs.
- o A sound knowledge base.
- o A perceived need for action.
- o Internal advisors and advocates.
- o External champions of earthquake hazard mitigation.
- o Credible products.
- o Useful products.
- o Balanced technical-societal-political considerations.
- o Windows of opportunity.
- o Collaboration of researcher and practitioner champions.

The next section will describe some of the accomplishments of the NEHRP.

THE RESEARCH APPLICATIONS PROCESS

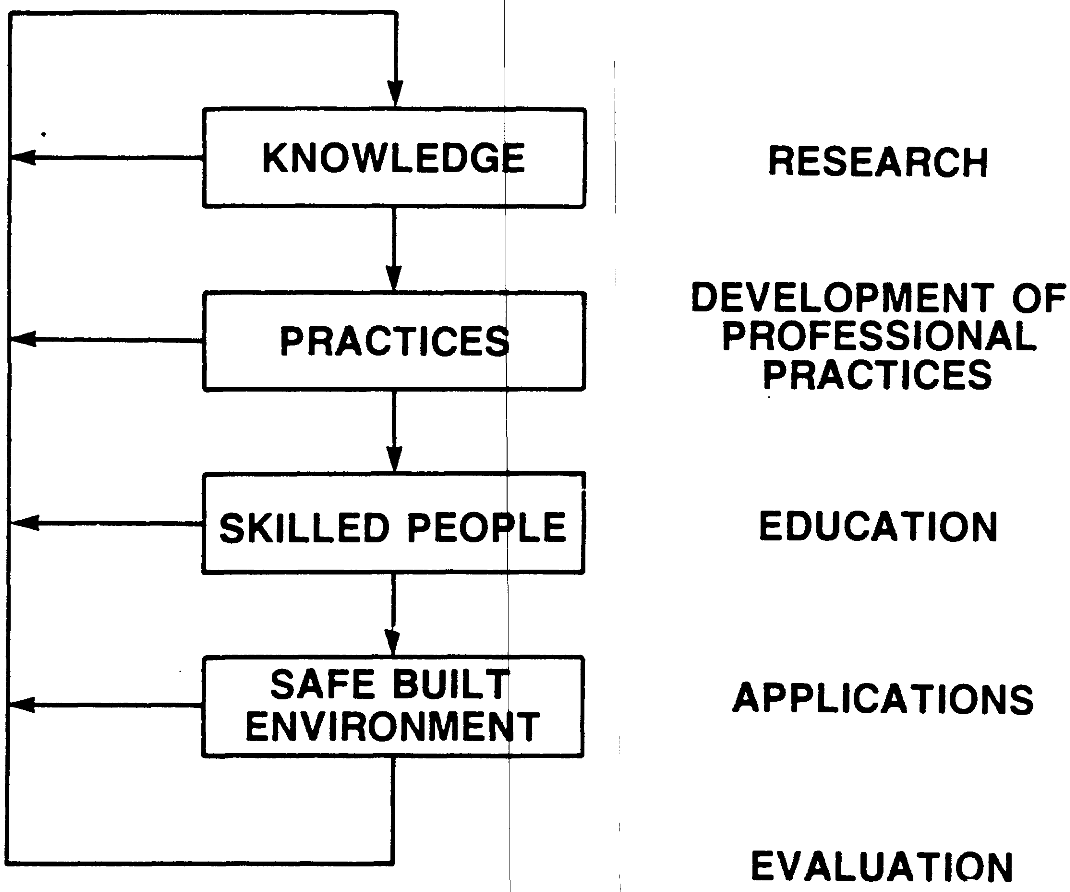


Figure 1:--Schematic illustration of research applications process (from Richard Wright, NIST).

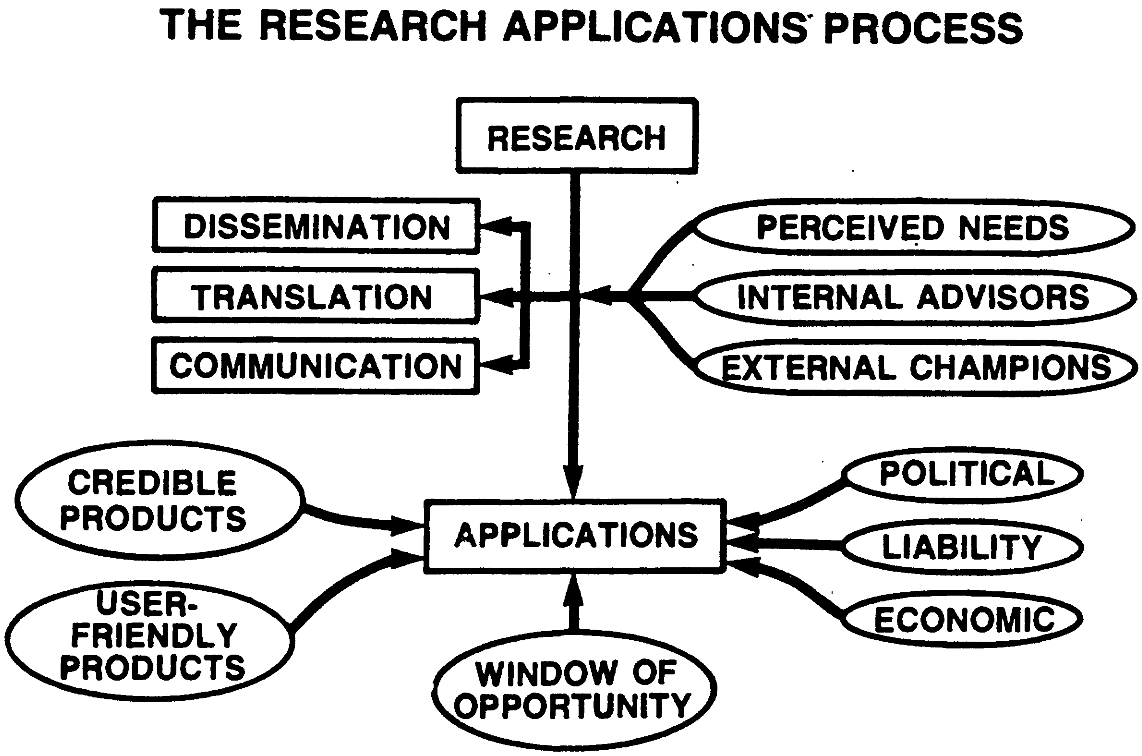


Figure 2:--Schematic illustration of factors contributing to the success of the research applications process. The two most significant factors that lead to success in the long term are activities that: a) produce champions of earthquake hazard mitigation and b) give them a goal or cause to work for in collaboration with other champions.

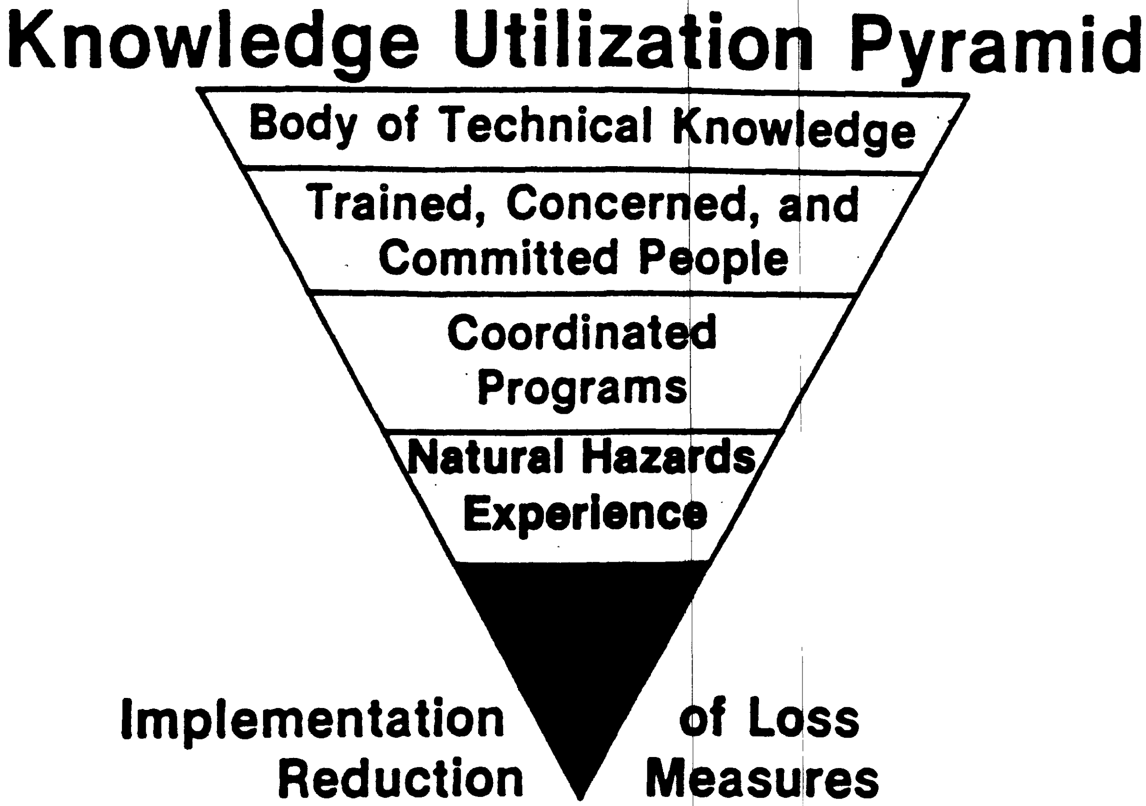


Figure 3.--Schematic illustration of the knowledge utilization pyramid. The gamble throughout the nation is whether implementation of loss-reduction measures will happen before the damaging earthquake strikes.

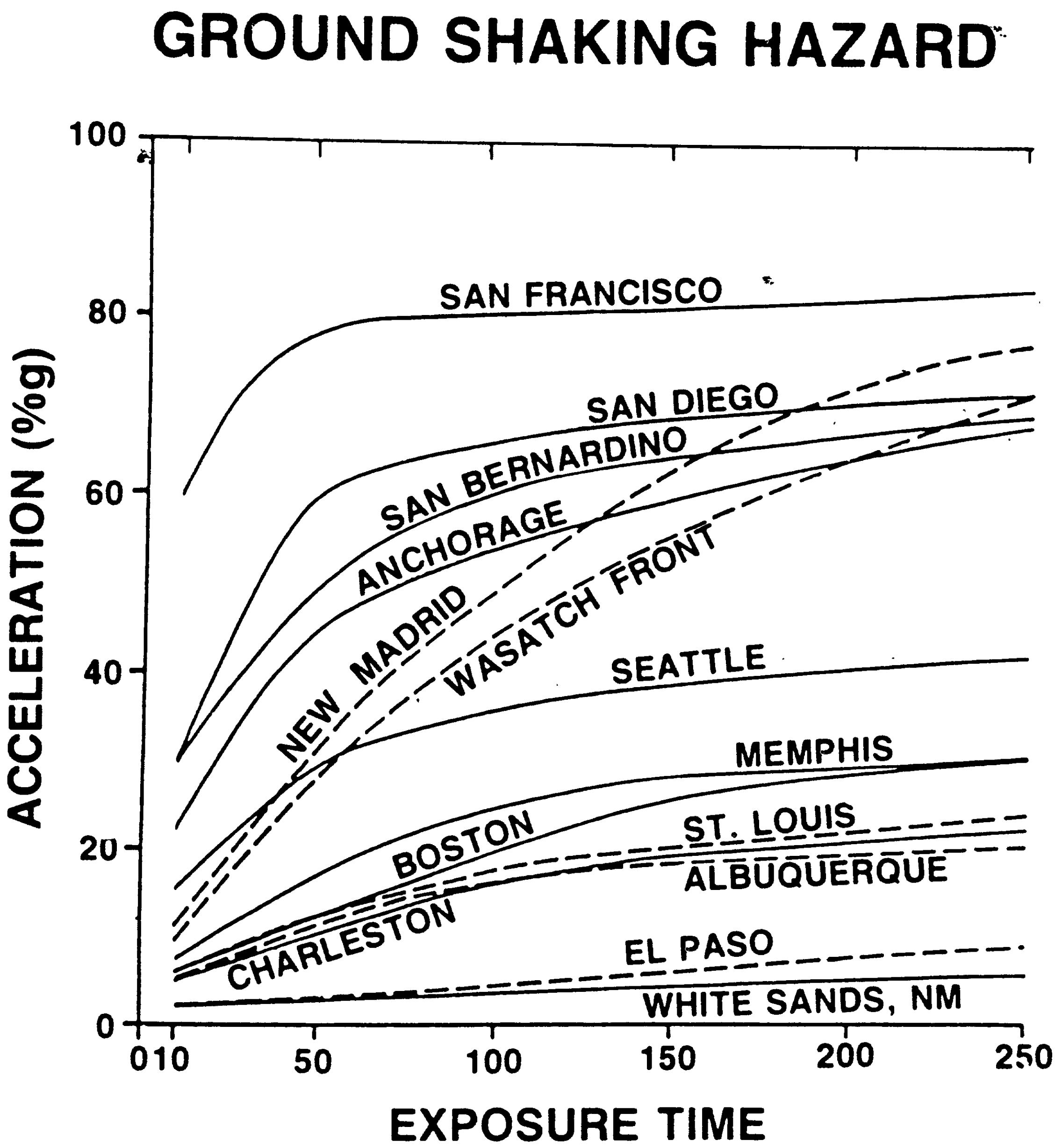


Figure 4.--Graph showing a comparison of the ground shaking hazard in the conterminous United states. Preparation of the maps from which these hazard curves were derived required the collaboration of several hundred researchers and practitioners over a period of 15 years. (Source: S. T. Algermissen, and others, 1982, U.S. Geological Survey Open-File Report 82-1033).

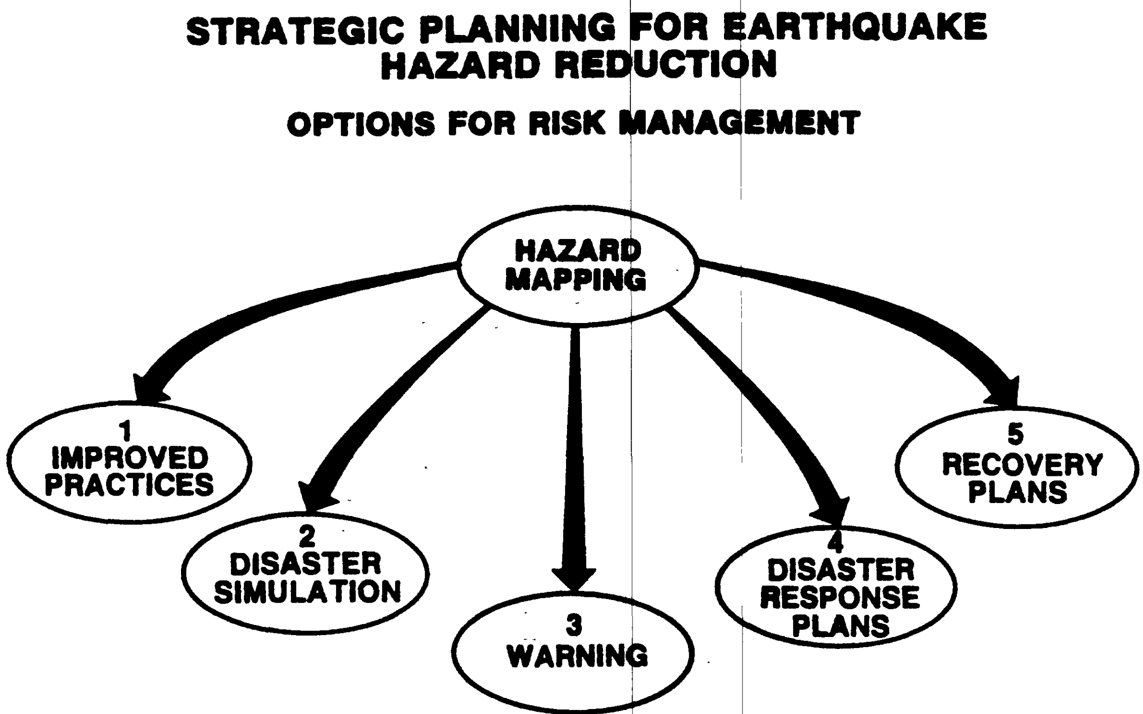


Figure 5.--Practitioners use maps of the ground-shaking hazard, an essential first step in many applications of knowledge, to devise the earthquake hazard mitigation measures.

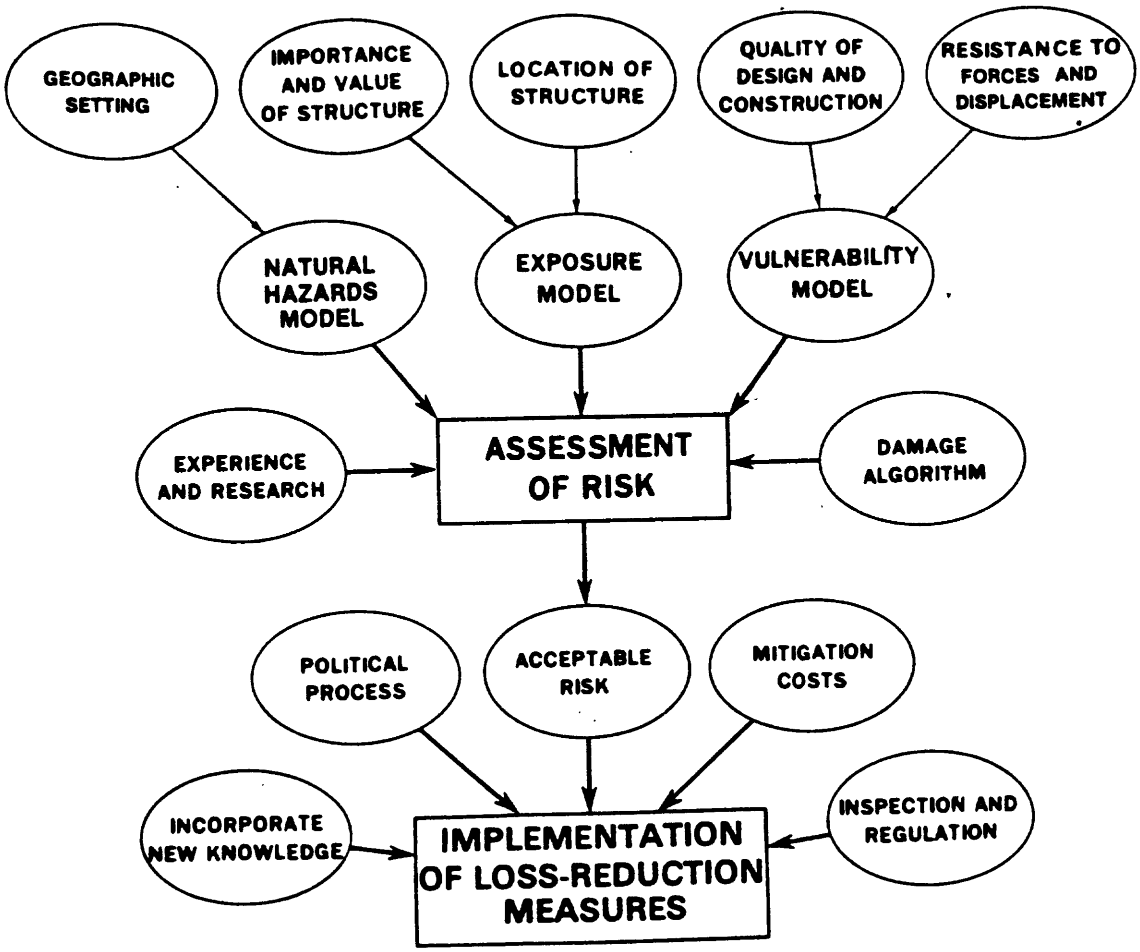


Figure 6.--Schematic illustration of important topics that researchers and practitioners must deal with in order to foster earthquake hazard mitigation (after Petak and Atkisson, 1983).

Differences in the perspective of scientists-engineers and decisionmakers (from Szanton, 1981).

ATTRIBUTES	PERSPECTIVES	
	SCIENTIST/ENGINEER	DECISIONMAKER
1. Ultimate objective	Respect of peers	Approval of electorate
2. Time horizon	Long	Short
3. Focus	Internal logic of the problem	External logic of the problem
4. Mode of thought	Inductive, generic	Deductive, particular
5. Most valued outcome	Original insight	Reliable solution
6. Mode of expression	Abstruse, qualified	Simple, absolute
7. Preferred form of conclusion	Multiple possibilities with uncertainties emphasized	One "best" solution with uncertainties submerged.

Szanton, Peter, 1981, Not Well Advised: Russell Sage Foundation and Ford Foundation, 81 p.

Figure 7.--Differences in the perspectives of researchers (typified by scientists and engineers) and practitioners (typified by "decisionmakers") (after Szanton, 1981).

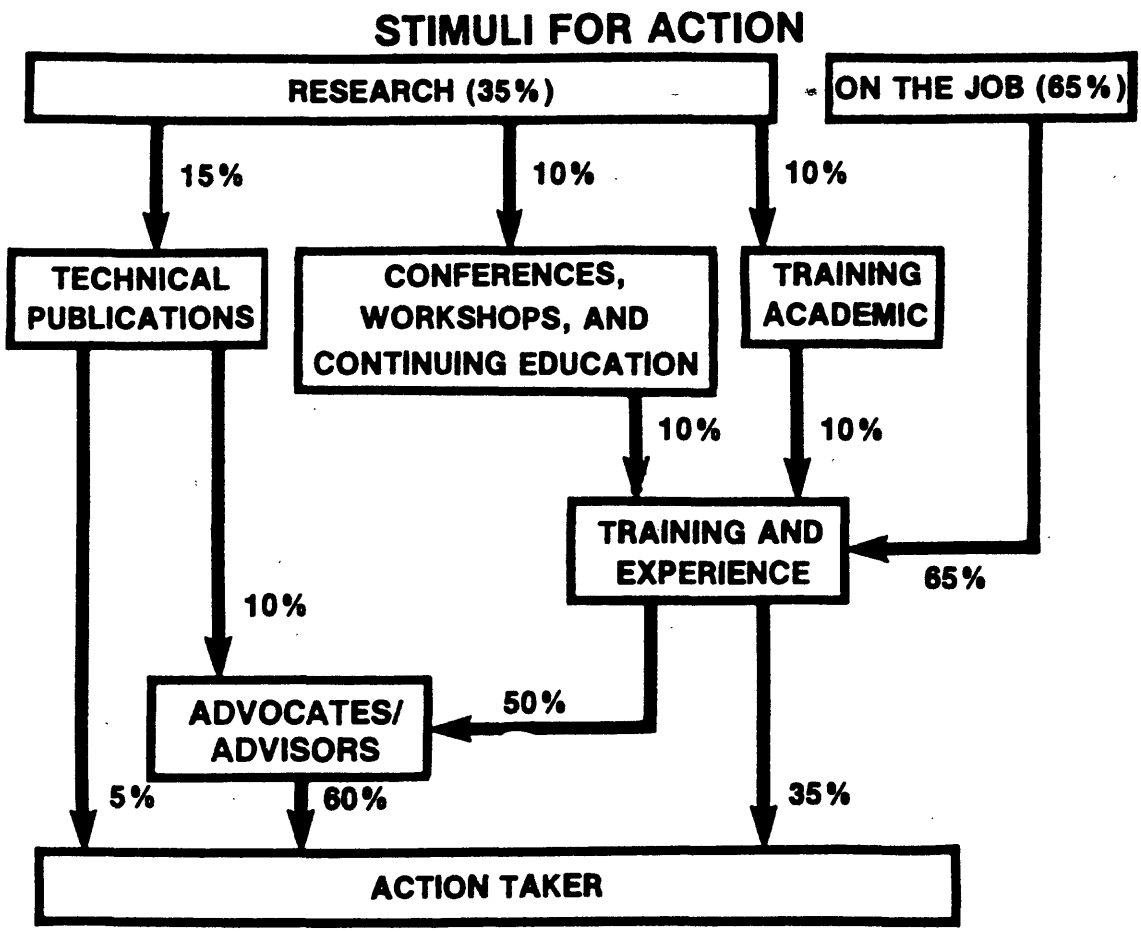


Figure 8.--Schematic illustration showing the relative importance of various external influences on an action taker. The influence of on-the-job training, workshops, experience, and advocates/advisors is very high; whereas, that of mailing publications is very low (from Thiel, 1988).

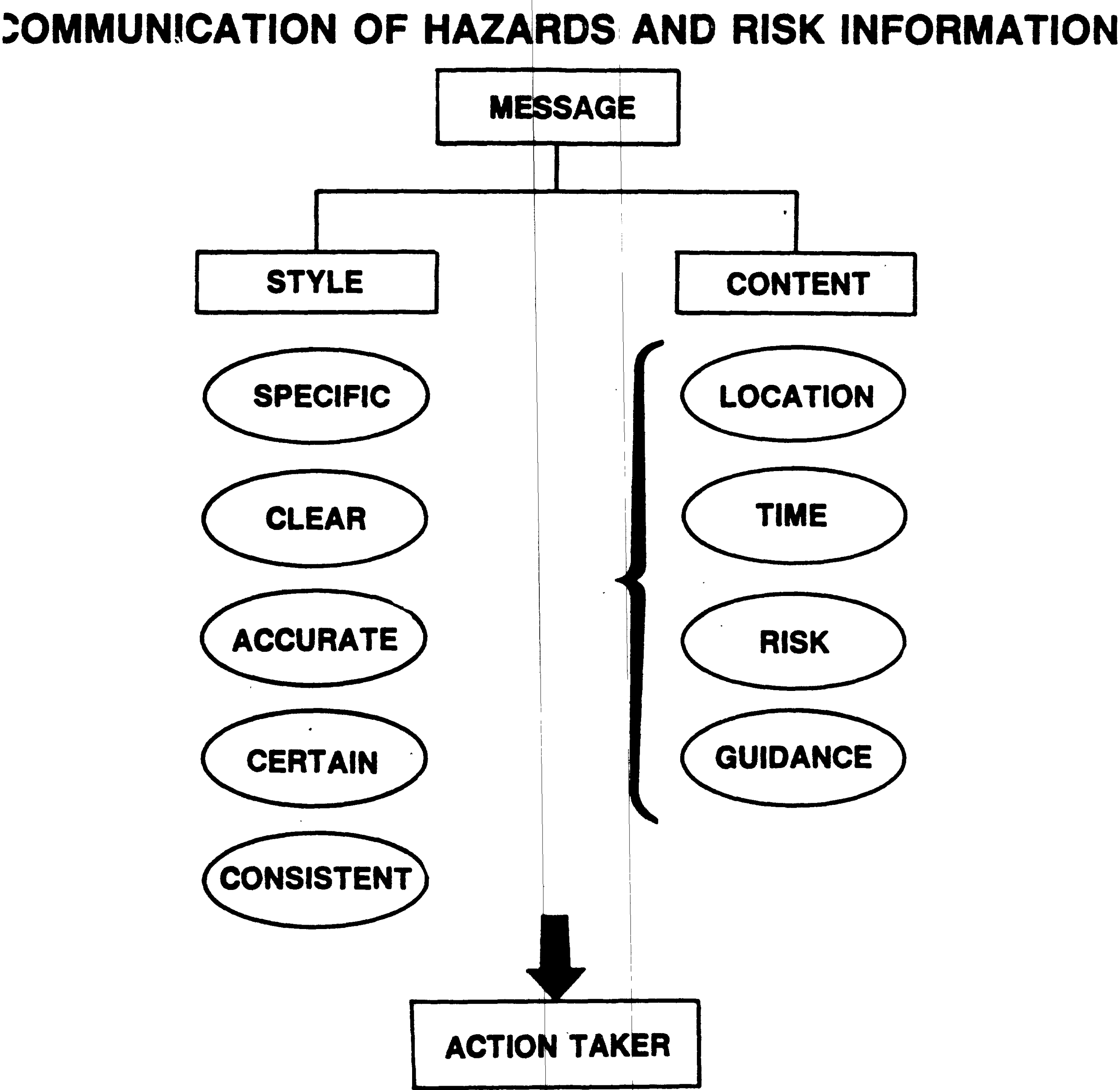


Figure 9.--Schematic illustration showing the essential characteristics of well designed message to communicate earthquake hazards and risk information (after Mileti, 1987).

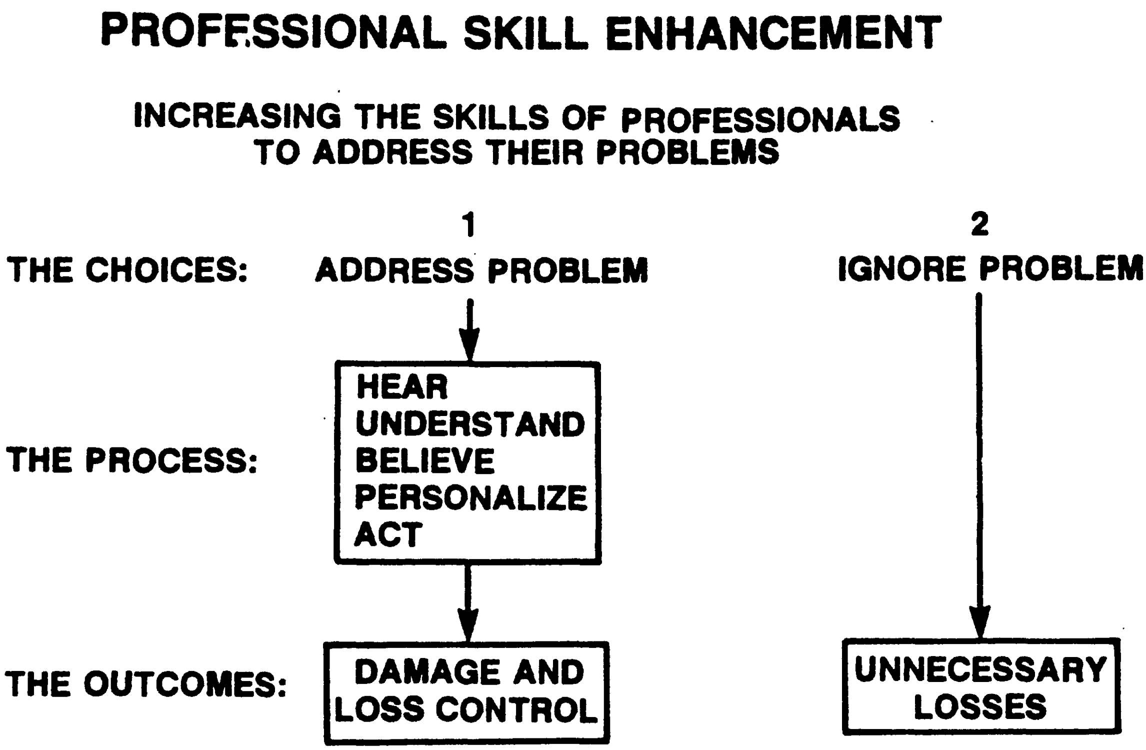


Figure 10.--Schematic illustration showing the basic process of professional skill enhancement.

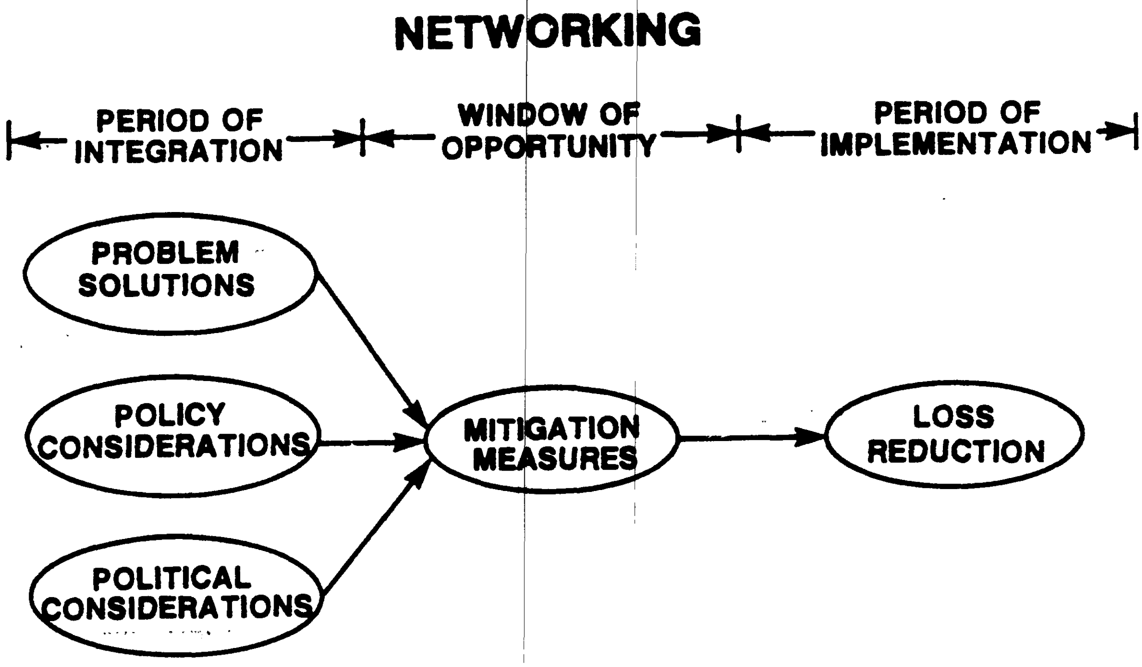


Figure 11.--Schematic illustration of the time-dependent flow of actions in the research applications process of the NEHRP. The first decade of the NEHRP has been characterized mainly as a period of integration in all states except California.

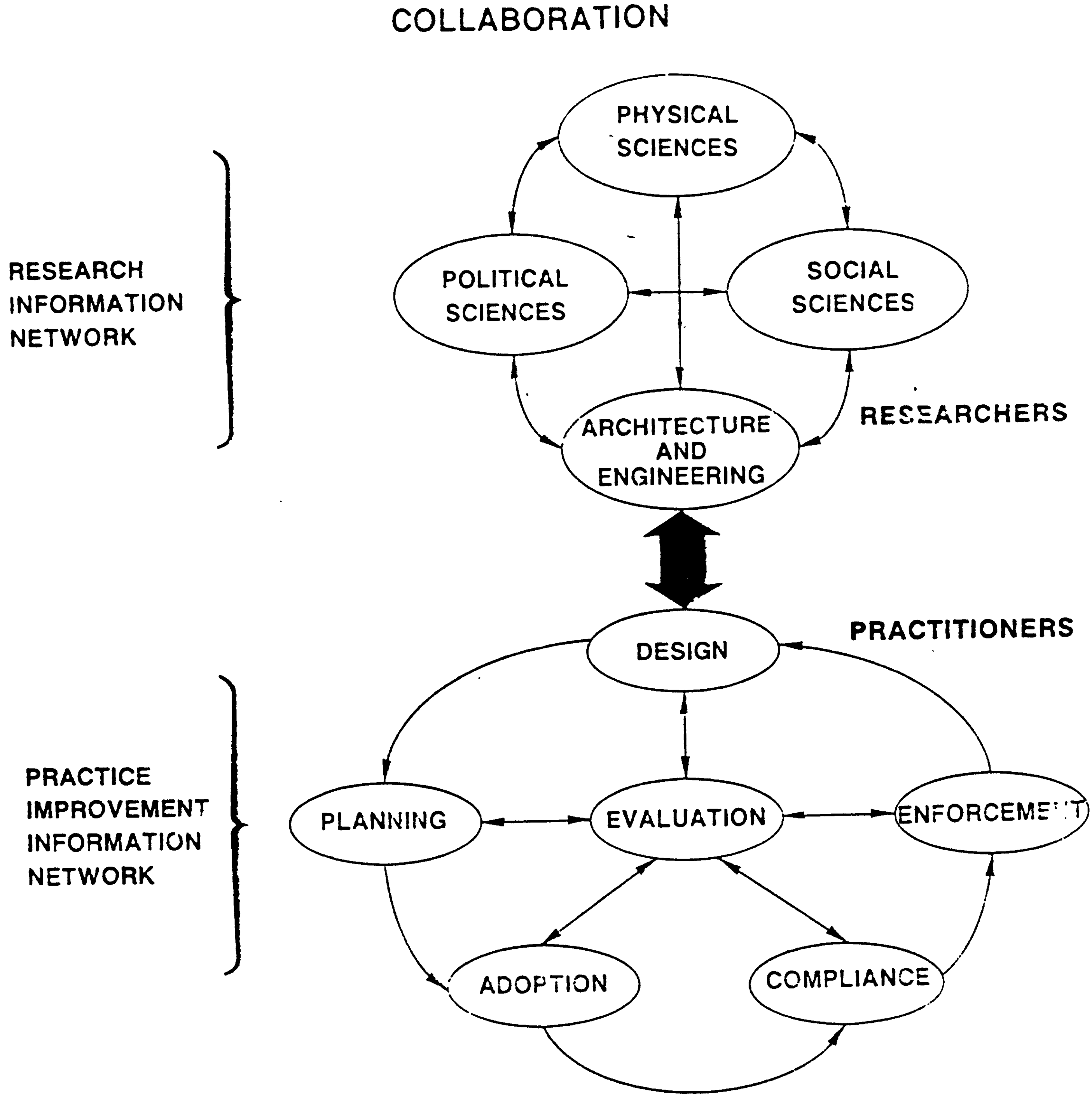


Figure 12.--Schematic illustration of collaboration between researchers and practitioners. In the first decade of the NEHRP, many researchers and practitioners exhibited a disdain for collaboration and limited ability to collaborate effectively. The key factor leading to earthquake hazard mitigation seems to be activities that: a) produce champions of earthquake hazard mitigation in each network, and b) give them a reason for collaboration. One deficiency of the research program is that very little research was performed to aid emergency medical response and disaster response operations.

REDUCING EARTHQUAKE LOSSES

Martha Blair-Tyler
William Spangle and Associates, Inc.
Portola Valley, California

When someone mentions earthquake hazard mitigation, I suspect most people immediately think of expensive programs to retrofit hazardous buildings, or perhaps to prohibit building on active faults. These are very important, but there are many other ways to reduce the impacts of earthquakes and some very effective ones are quite simple and inexpensive. Many actions require very little information beyond the fact that the area is seismically active. Detailed geologic information is not necessary to apply appropriate building code standards to new construction, to foster programs to reduce nonstructural earthquake damage or to ascertain the survivability of many public buildings and critical facilities. Some emergency response planning and public education efforts can also go forward with little interpretation of basic geologic and seismic data for the region.

However, the kind of information that USGS is helping to provide in the Puget Sound region will allow local governments to consider a broader range of mitigation options--particularly those that affect the use and development of land. When one can differentiate areas on the basis of hazard potential, then one can decide how to use or reuse specific areas to reduce exposure to loss in an earthquake. Important buildings can be designed and constructed to withstand the ground shaking expected at their particular sites. Hazard mitigation can become integrated into the normal development control process.

INTEGRATING EARTHQUAKE HAZARD REDUCTION

Integration of hazard reduction into normal government operations seems to come about gradually. Initially the actions are extraordinary, but with time they evolve into routine procedures that are simply seen as the way things are done in a community. These steps seem to be involved:

1. Locate Hazardous Areas. It is particularly important to identify potential for ground failures of various kinds (eg. faulting, landsliding, liquefaction). Designing and building structures to withstand the effects of ground failure is difficult and expensive. Areas prone to ground failure often can be used for recreation, open space, parking, agriculture or some suitable low intensity activity which meets a community need and avoids excessive exposure of buildings and people to earthquake losses.

2. Identify Hazardous Buildings and Facilities. Buildings can be hazardous because of construction and/or structural design deficiencies. Unreinforced masonry buildings are a primary example, however many other kinds of buildings, such as buildings with tilt-up walls, soft stories, and nonductile concrete frames, can also be dangerous in earthquakes. Buildings can also be hazardous because they are located on sites subject to ground failure or unusually intense ground shaking. It is particularly important to identify any hazardous construction or hazardous site conditions of buildings essential to emergency response or whose failure would have dire consequences.

3. Assess Risk. Risk is exposure of people and property to the hazards. Risk is typically expressed as the number of deaths, injuries and amount of property damage that is expected in a given earthquake. A community needs to know what facilities are particularly vulnerable and what the consequences of failure would be, what areas of the community are most hazardous and what populations are most at risk. The information does not have to be quantified, but should be specific enough to set priorities for action.

4. Identify Mitigation Options. Explore the options for reducing risks that are effective, and politically and fiscally feasible. In general the options will include measures to strengthen or remove existing hazardous structures, to regulate the location, design and construction of new development and to prepare for emergency response and post earthquake recovery. Going hand and hand with all the possible measures is the strong need for efforts to educate the public and maintain a good level of awareness of earthquake hazards.

5. Develop Support and Adopt Options. Usually, a "champion" is needed to persist through the hard work of building political support for adoption of loss reduction measures. The champion keeps the issue of earthquake safety before staff and public legislative bodies and is prepared to suggest options for action when the chances come--whether as the result of day to day education efforts or a damaging earthquake that catches the attention of decisionmakers.

6. Train Staff and Decisionmakers. Training and education is an ongoing necessity to be sure that staff members and elected officials understand the hazards and how to administer the adopted measures. Through training, the earthquake loss reduction measures become integrated as part of normal governmental operations. This is the step where the action shifts from the "champion" to the "team".

AN EXAMPLE OF EARTHQUAKE HAZARD MITIGATION

Hayward is a city of about 100,000 people on the east side of San Francisco Bay. The Hayward fault, capable of producing a magnitude 7.5 earthquake, runs through the center of downtown. Using the steps listed above as a guide, the key actions taken by Hayward to deal with its seismic hazards are described below:

1. Locate Hazardous Areas. In 1972, the city commissioned a study of its earthquake hazards in order to prepare the seismic safety element of the general plan as required by a California state law adopted after the 1971 San Fernando earthquake. The study identified the potential for severe ground shaking citywide, tectonic creep and ground rupture along the Hayward fault, landslides in the eastern hills, and liquefaction along the Bay shoreline. The report included a map of the Hayward fault at a scale of 1 inch = 1,000 feet and identified the area including the fault traces and 50 feet on either side as a fault corridor with a high risk of ground rupture.

2. Identify Hazardous Buildings and Facilities. None of the buildings in the fault corridor were adequately designed and constructed to withstand ground rupture. Also, the study estimated that 50 percent of the buildings in the central business district were inadequately constructed to withstand anticipated ground shaking. Finally, existing buildings within the fault corridor included the city hall, the police station, a fire station and a major hospital.

3. Assess Risk. It is apparent from the actions that followed the release of the study that local officials in Hayward considered the potential losses from fault rupture in the Hayward fault corridor as the most serious seismic risk. The other hazards were noted, but initial action centered on this very difficult problem area.

4. Identify Mitigation Options. The earthquake study recommended amending the city's zoning, grading and subdivision ordinances and building code to reduce earthquake hazards in new construction, adopting a zoning combining district covering the fault corridor to regulate building in the corridor, and requiring soils engineering and geological engineering reports for all proposed major buildings outside the fault corridor.

5. Develop Support and Adopt Options. A subcommittee of the Planning Commission worked with staff and consultants to produce the Hayward Earthquake Study and provide the leadership to carry the recommendations to the Planning Commission and City Council. The zoning combining district as recommended in the earthquake study was under consideration by the planning commission when California enacted the Alquist-Priolo Special Studies Zones Act in 1972. The city moved to implement the provisions of the state law which dealt with the question of new construction within the fault corridor. Then in 1975, to address the problem of existing hazardous buildings as well as the general deterioration of the central business district, the city adopted a redevelopment plan. Additional geologic studies, including trenching were commissioned to provide more detailed information for redevelopment planning. To reduce risk, much of the fault corridor is planned for streets and parking. A new civic center complex, including public and private buildings, was proposed at a new location to the east of the fault corridor. The plan was supported primarily to revitalize the central business district. Earthquake hazard reduction was embedded in some of the plan's provisions, but was not the primary motivation.

6. Train Staff and Decisionmakers. Adoption of the ordinance and a redevelopment plan did not guarantee risk reduction. The process is a long one that takes continual effort. In Hayward, the city hall and the police station have been moved to the new civic center complex. One hospital wing which was found through trenching to overlie a fault trace, was removed. The rest of the hospital remains in use in the fault zone. The community is still debating the future of the old city hall which is showing increasing signs of damage from fault creep. Preservationists wish to restore it as a cultural center; the growing cadre of citizens who are conversant with the nature of fault hazards favor tearing it down. Earthquake hazards are now a normal part of the debate on land use and development proposals for the central business district in Hayward.

SOURCES OF INFORMATION

1. California at Risk--Steps to Earthquake Safety for Local Government, California Seismic Safety Commission, 1988. This is a supplement to the California state plan for action to reduce earthquake losses. The guide describes 30 actions to reduce earthquake hazards in existing development, new development, emergency planning and response, and recovery. It also includes actions related to public information, education and research and an earthquake safety self-evaluation checklist for local governments.

2. Putting Seismic Safety Policies to WorK, Bay Area Regional Earthquake Preparedness Project, 1988. This guidebook to help local governments implement seismic safety elements of general plans describes ten seismic safety issues (hazardous buildings, critical facilities, high occupancy buildings, hazardous materials, nonstructural hazards, rebuilding, fault rupture, ground failure, ground shaking, flood hazards) and the steps for addressing each. Thumbnail sketches of successful approaches of local governments in California to deal with each issue are included.

3. Geology and Planning, The Portola Valley Experience, William Spangle and Associates, Inc., 1988. This case study of the evolution of the Portola Valley program to use geologic information in land use decisions is a good example of integration of loss reduction measures into ongoing local government operations.

SUMMARY OF EARTHQUAKE HAZARD INFORMATION NEEDED BY NONTECHNICAL USERS

by

William J. Kockelman
U.S. Geological Survey
Menlo Park, California

The objective of translating hazard information for nontechnical users is to: make them aware that a hazard exists which may affect them or their interests; provide them with information that they can easily present to their superiors, clients, or constituents; and provide them with materials that can be directly used in a hazard reduction technique.

Much has been said about the need for and objectives of translation. No clear concise definition or criterion has been offered, nor can it be found in the literature except by inference or by an analysis of what is actually used. However, various researchers, translators, and users of earthquake hazard information are specific about what is needed by nontechnical users.

My experience with reducing potential natural hazards indicates that hazard information successfully used by nontechnical users has the following three elements in one form or another:

1. Likelihood of the occurrence of an event that will cause human casualties, property damage, or socioeconomic disruption.

2. Location of the effects of the event on the ground.

3. Estimated severity of the effects on the ground, structure, or equipment.

These elements are needed because usually engineers, planners, and decision-makers will not be concerned with a potential hazard if its likelihood is rare, its location is unknown, or its severity is slight; neither will lenders, politicians, or citizens.

1. Likelihood of Occurrence

This element can be conveyed for a selected size and location of a damaging earthquake by the use of various concepts -- probability, return period, frequency of occurrence, or estimated, average, or composite recurrence interval. Sometimes a specific event is chosen -- design earthquake, hypothetical earthquake, characteristic earthquake, or postulated earthquake.

In some cases, an engineering parameter is used for a specific ground failure: "the probability that the critical acceleration would be exceeded in 100 years" for liquefaction or for landslides. In others, a map showing probabilistic bedrock peak horizontal ground acceleration that has a 90-percent probability (or likelihood) of not being exceeded in a 50-year period.

No matter what term is used, it must convey a likelihood of occurrence that is important to the user. This likelihood varies widely, depending upon the use or the user.

2. Location and Extent

Once users are convinced of the likelihood of the occurrence of a damaging event, they want to know if their interests might be affected. This information is conveyed by showing the location and extent of ground effects or geologic materials susceptible to failure. These are usually shown on a planimetric map having sufficient geographic reference information to orient the user to the location and extent of the hazard. Geographic information, such as streams, highways, railroads, and place names is very helpful. Some maps show streets; others show property boundaries.

3. Estimated Severity

After the users recognize the likelihood of an event which may affect their interests, their next question is: how severe will be its effects? In other words, is the hazard something that should be avoided, designed for, or should preparations be made to respond during, and recover and reconstruct after damaging events.

Severity of anticipated effects is best expressed by use of measurable engineering parameters for the various hazards, for example:

- vertical and horizontal displacements for surface fault ruptures.
- peak acceleration, peak velocity, peak displacement, frequency, and duration for ground shaking.
- velocity and volume for landslides.
- extensional or vertical displacement for liquefaction.
- vertical displacement for tectonic subsidence.
- runup height for tsunamis.

Modified Mercalli or Rossi-Forel intensity scales of observed or estimated damage can also be used to show severity.

Format

These three elements -- likelihood, location, and severity -- have been combined into various formats, some easy for the nontechnical user, and others requiring additional information, or an experienced user to appreciate, adapt, and use in a reduction technique. Sometimes all of the elements are placed on a single map; at other times, information in the text or volume must be combined, or outside supplemental information must be obtained.

Many times, one of the elements (likelihood of occurrence) is one of public knowledge or experience. Sometimes the elements are available or combined for only a demonstration area. When adequate research information is available for other areas, additional translation work can be done; otherwise new research must be undertaken to cover the user's area of jurisdiction or interest.

REDUCING EARTHQUAKE HAZARDS IN OREGON AND WASHINGTON:

AN INTRODUCTION TO THE FIVE COMPONENTS

NECESSARY FOR EFFECTIVE HAZARD REDUCTION

by

William J. Kockelman
U.S. Geological Survey
Menlo Park, California

INTRODUCTION AND PURPOSE

Effective comprehensive programs having earthquake-hazard reduction as a goal need five components, each a prerequisite for its successor:

1. Conducting scientific and engineering studies of the physical processes of earthquake phenomena -- source, location, size, likelihood of occurrence, triggering mechanism, path, ground response, structure response, and equipment response.

2. Translating the results of such studies into reports and onto maps at an appropriate scale so that the nature and extent of the hazards and their effects are understood by nontechnical users.

3. Transferring this translated information to those who will or are required to use it, and assisting and encouraging them in its use through educational, advisory, and review services.

4. Selecting and using appropriate hazard reduction techniques -- legislation, regulations, design criteria, education, incentives, public plans, and corporate policies.

5. Evaluating the effectiveness of the hazard reduction techniques after they have been in use for a period of time and revising them if necessary. Evaluation and revision of the entire program as well as the other components -- studies, translation, and transfer -- may also be undertaken.

These five components (Figure 1) encompass a broad range of activities which are often described or divided differently. Examples include: 48 resolutions by the United Nations Educational, Scientific, and Cultural Organization (1976), six general topics and 37 issues by the U.S. Office of Science and Technology Policy (1978), 48 detailed initiatives recommended by the California Seismic Safety Commission (1986), and five tasks needed to implement the Pacific Northwest work plan (Kockelman and others, 1988, p. 22-25).

Sometimes one or more of the components are emphasized depending upon the originating agency's assignment, for example, geologic or seismologic research (Wallace, 1974); the topics and disciplines of the advisory groups, for example, reduction techniques (California Joint Committee on

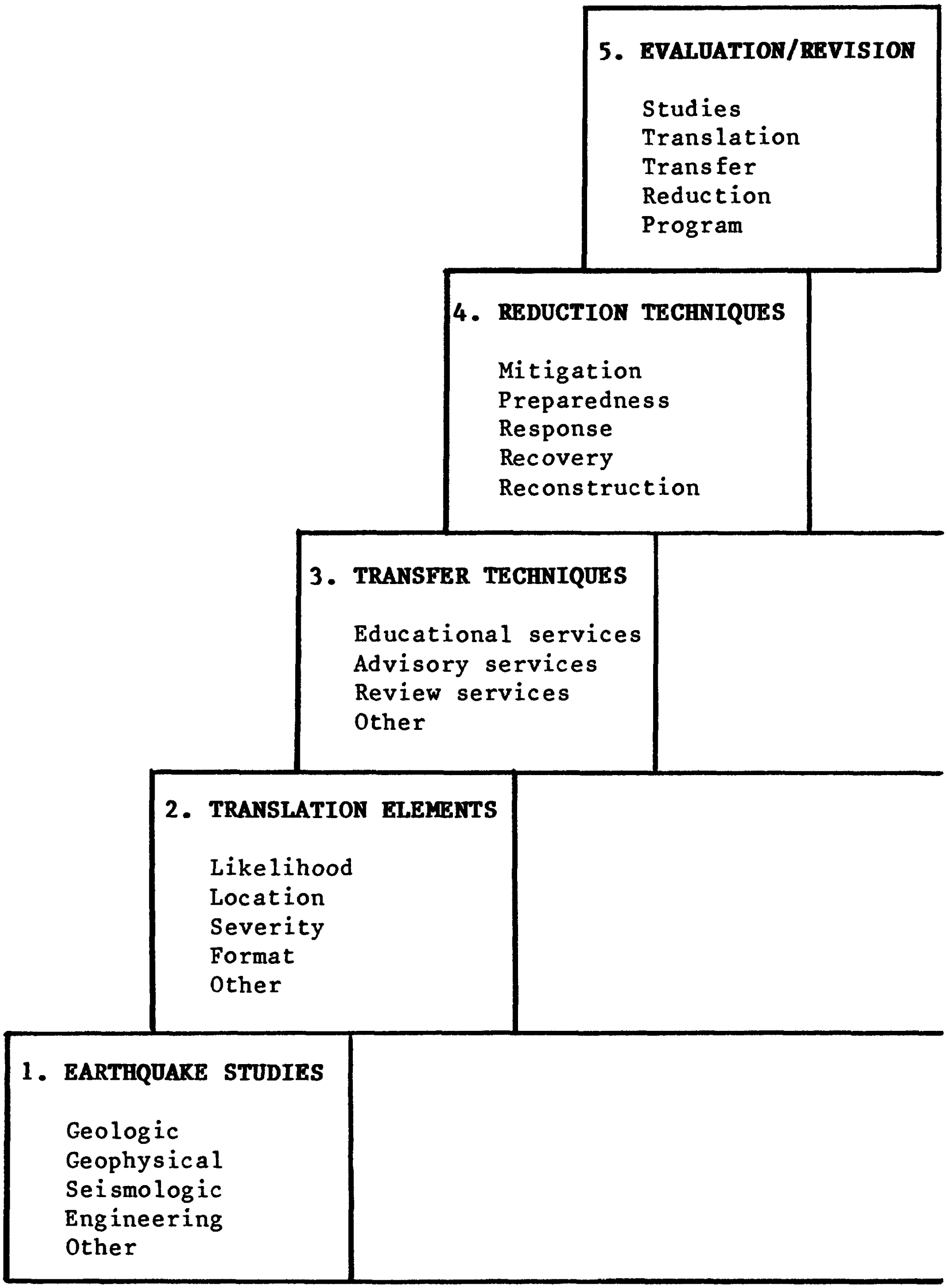


Figure 1. -- Five components needed for an effective comprehensive earthquake-hazard reduction program depicted as steps or building blocks, each a a prerequisite for its successor.

Seismic Safety, 1974) or the review of a national earthquake hazard reduction program in effect for many years by the NEHRP Expert Review Committee (1987).

The purpose of this paper is to introduce the five components and the crucial connection between scientific and engineering studies and their effective use for hazard reduction by nontechnical uses in Oregon and Washington.

1. SCIENTIFIC AND ENGINEERING STUDIES

A prerequisite for an effective earthquake-hazard reduction program is the production by researchers of adequate and reliable scientific and engineering information about potential earthquake hazards -- surface fault rupture, ground shaking, landsliding, liquefaction, seiches, tsunamis, subsidence, and their effects. Actual hazards occur when land uses, or structures, or equipment are located, constructed, or operated in such a way that people may be harmed, their property damaged, or their socioeconomic systems interrupted.

Numerous geologic, geophysical, seismologic, and engineering studies are necessary to assess potential earthquake hazards in Oregon and Washington. These studies are concerned with the physical process of earthquakes -- source, location, size, likelihood of occurrence, triggering mechanism, path, and severity of effects on sites, structures, or equipment. These studies can be divided in several ways. To give the nontechnical reader an overview, some of the studies are shown in List 1.

A description of many of these studies can be obtained from perusing various scientific and technical reports and texts, such as: Richter (1958), Wallace (1974), Borcherdt (1975), Applied Technology Council (1978), Hays (1980), Ziony (1985), Power and others (1986), Evernden and Thomson (1988), and Schwartz (1988).

Most of these studies are complex, interconnected, have limitations because of lack of data, and require special technical skills. For example, the uncertainties that affect ground response generally are identified and listed by Hays (1980, Table 23, p. 67); five levels of the reliability of the data used to calculate the probability of large earthquakes are given for each fault segment by a working group on California earthquake probability (Agnew and others, 1988).

Many of these studies were envisioned and are described in the "Regional Earthquake Hazards Assessments" draft work plan for the Pacific Northwest. This plan is reproduced in a workshop proceedings edited by Hays (1988b, p. 12-33).

Such studies are vital, because in the words of a former U.S. Geological Survey director, Walter C. Mendenhall: "There can be no applied science unless there is science to apply."

It has been my experience that it is not prudent for planners to develop land-use regulations, engineers to design structures, and lenders

List 1

Examples of scientific and engineering studies necessary to assess earthquake hazards 1/

Types of Studies 2/	Knowledge Derived
Geologic	
Detailed geologic mapping Lithologic investigations Stratigraphy Borehole sampling Trenching Paleontology Scarp analysis Stream offsets Geomorphologic studies Structural geology	Fault slip rates, physical properties, fault length, fault age, fault geometry, bedrock strength, zones of deformation, amplification of ground motion, lateral and vertical offsets, earthquake recurrence intervals, earthquake sources, depth to ground water, fault location, bedrock types, deformation patterns, plate tectonics context, driving forces, and other knowledge concerning surface rupture, ground shaking, landsliding, liquefaction, seiches, tsunamis, and subsidence.
Geophysical/Geochemical	
Geodetic leveling and trilateration Field monitoring: Stress and strain Tilt and creep Electrical changes Radon/helium emissions Water chemistry changes Water-well levels Electromagnetic soundings Gravity, electrical, and magnetic studies Seismic refraction and reflection profiling Radiometric dating	Precursor detection, ongoing deformation, fault zone properties, recurrence intervals, shear wave velocity, stress accumulation, crustal anatomy, crustal properties, wave attenuation, crustal velocity model, ground-motion characteristics, deformation patterns, buried faults or structure locations, and three-dimensional crustal geometry.

1/ These studies are just some of the ones necessary to assess earthquake "hazards;" many other types of studies are necessary to evaluate "vulnerable" structures, "secondary" hazards (fires, floods, and toxin spills), people "exposed," and socioeconomic activities at "risk."

2/ The term "studies" is loosely used here to include experiments, measurements, investigations, observations, models, techniques, analyses, mapping, monitoring, or testing. Many of the seismologic studies are a special type of geophysical research.

List 1 (continued)

Examples of scientific and engineering studies necessary to assess earthquake hazards

Type of Studies	Knowledge Derived
Seismologic	
Historical seismicity Earthquake monitoring Strong ground-motion monitoring networks Ground response Seismic wave propagation Segmentation analyses Wave propagation Rupture process	Asperity locations, velocity, severity of shaking, acceleration, displacement, seismic gaps, source zones, fault mechanism, rupture direction, seismic direction, recurrence interval, epicenters, epicentral intensity, fault type, fault length, fault width, maximum probable magnitude, seismic hazard zones, rupture characteristics, seismic moment, stress drop, local amplification, duration of shaking, focal mechanism and depth, and response spectrum.
Engineering	
Structural mechanics Engineering characteristics Risk analysis Monitoring of structures Damage inventories Soil-structure interaction Structural vulnerability Soil mechanics Rock mechanics Soil/rock acoustic impedance Standard penetration tests	Seismic risk maps, structural performance, hysteretic behavior, strength of materials, stiffness degradation, structural strength, structural reliability, design criteria, material properties, response spectra, seismic intensities, nonlinear behavior, inelasticity, ductility, damping, energy absorption, bearing capacity, soil properties, amplification levels, shear wave velocity, shear modulus, failure limits, load limits, ultimate load limits, and foundation design.

Note: Robert Brown, geologist, Robert Simpson, geophysicist, Allan Lindh, seismologist, and Mehmet Celebi, structural engineer, U.S. Geological Survey, provided critical comments and valuable suggestions that have refined and improved this list. However, because of its abbreviated form, the author remains responsible for its omissions and any errors.

and public works directors to adopt policies reducing earthquake hazards without adequate and reliable scientific and engineering assessments.

2. TRANSLATION FOR NONTECHNICAL USERS

The objective of translating hazard information for nontechnical users is to: make them aware that a hazard exists which may affect them or their interests; provide them with information that they can easily present to their superiors, clients, or constituents; and provide them with materials that can be directly used in a reduction technique. Examples of potential users (many nontechnical) are shown in List 2.

Much has been said about the need for and objectives of translation. No clear concise definition or criterion has been offered, nor can it be found in the literature except by inference or by an analysis of what is actually used. My experience with reducing potential natural hazards indicates that hazard information successfully used by nontechnical users has the following three elements in one form or another:

- Likelihood of the occurrence of an event that will cause casualties, damage, or disruption.
- Location of the effects of the event on the ground.
- Estimated severity of the effects on the ground, structure, or equipment.

These elements are needed because usually engineers, planners, and decisionmakers will not be concerned with a potential hazard if its likelihood is rare, its location is unknown, or its severity is slight; neither will lenders, politicians, or citizens.

Likelihood of Occurrence

This element can be conveyed for a selected size and location of damaging earthquake by the use of various concepts -- probability, return period, frequency of occurrence, or estimated, average, or composite recurrence interval. Sometimes a specific event is chosen -- design earthquake, hypothetical earthquake, characteristic earthquake, or postulated earthquake.

In some cases, an engineering parameter is used for a specific ground failure: "the probability that the critical acceleration would be exceeded in 100 years" for liquefaction or for landslides. Others use a map showing probabilistic bedrock peak horizontal ground acceleration that has a 90-percent probability (or likelihood) of not being exceeded in a 50-year period.

No matter what term is used, it must convey a likelihood of occurrence that is important to the user. This likelihood varies widely, depending upon the use or user, for example:

Insuring agent	Premium period (1 yr)

List 2

Examples of potential users of earthquake-hazard information in the Pacific Northwest

City, county, and multicounty government users

Local building, engineering, zoning, and safety departments
City and county offices of emergency services or management
County tax assessors
Mayors and city council members
Multicounty planning, development, and preparedness agencies
Municipal engineers, planners, and administrators
Planning and zoning officials, commissions and departments
Police, fire, and sheriff's departments
School districts

State government users

Fire Marshall
Building Codes Agency
Department of Information Systems
Department of Geology and Mineral Industries
Department of Ecology (Dam Safety Section)
Department of Energy
Department of Natural Resources (Division of Geology and Earth Resources)
Department of Land Conservation and Development
Department of Transportation
Division of Emergency Management
Department of Water Resources
Legislature
Museum of Science and Industry
National Guard
Office of the Governor
Office of Risk Management
Public Utility Commission

Private, corporate, and quasi-public users

Civic, religious, and voluntary groups
Concerned citizens
Communication companies, construction companies, and utility districts
Consulting planners, geologists, architects, and engineers
Extractive, manufacturing, and processing industries
Financial and insuring institutions
Landowners, developers, and real-estate salespersons
News media
Professional and scientific societies (including geologic, engineering, architecture, and planning societies)
University departments (including geology, geophysics, civil engineering, structural engineering, architecture, urban and regional planning, oceanography, and environmental departments)

Elected official	Term of office (2-6 yr)
Lending officer	Amortization schedule (10-30 yr)
Bridge designer	Structure's life (50-100 yr)
Waste manager	Hazard's life (1,000-10,000 yr)
Pyramid builder	Next world (10,000-10,000,000 yr)

Location and Extent

Once users are convinced of the likelihood of the occurrence of a damaging event, they want to know if their interests might be affected. This information is conveyed by showing the location and extent of ground effects or geologic materials susceptible to failure. These are usually shown on a planimetric map having sufficient geographic reference information to orient the user to the location and extent of the hazard. Geographic information such as streams, highways, railroads, and place names is very helpful. Most earthquake hazard maps are a compromise between detail, scale, reliability, difficulty and cost of preparation and the purpose for which they were designed. There are no "best" scales, only more convenient ones.

Estimated Severity

After the users recognize the likelihood of an event which may affect their interests, their next question is: how severe will be its effects? In other words, is the hazard something that should be avoided, designed for, or should preparations be made to respond during, and recover, repair, and reconstruct after damaging events.

Severity of anticipated effects is best expressed by use of measurable engineering parameters for the various hazards, for example:

- vertical and horizontal displacements for surface fault ruptures.
- peak acceleration, peak velocity, peak displacement, frequency, and duration for ground shaking.
- velocity and volume for landslides.
- extensional or vertical displacement for liquefaction.
- vertical displacement for tectonic subsidence.
- run-up height for tsunamis.

Modified Mercalli or Rossi-Forel intensity scales of observed or estimated damage are also used to show severity.

3. TRANSFER TO NONTECHNICAL USERS

The objective of transferring hazard information to nontechnical users is to assist in and encourage its use to reduce losses for future earthquakes. Translated hazard information is a prerequisite for transfer to nontechnical users.

Various terms are used to convey "transfer" of information to users, namely, disseminate, communicate, circulate, promulgate, and distribute. Often these terms are interpreted conservatively, for example, merely issuing a press release on hazards or distributing research information to potential users. This level of activity usually fails to result in effective hazard reduction techniques and may even fail to make users aware of the hazard.

No clear concise definition of, or criteria for, "transfer" has been offered, or can be found in the literature except by inference or by analysis of what actually works for those who have developed and adopted reduction techniques. Therefore, I suggest that we use "transfer" to mean the delivery of a translated product in a usable format at a scale appropriate to its use by a specific person or group "interested" in, or responsible for, hazard reduction. To delivery of a product, we must add assistance and encouragement in its use.

Such delivery, assistance, and encouragement can be accomplished through specific transfer techniques which may be categorized into educational, advisory, and review services (List 3).

Educational services range from merely announcing the availability of earthquake-hazard information, through the publishing and distributing of newsletters and brochures, to sponsoring, conducting, or participating in seminars and workshops for potential users.

Advisory services range from explaining or interpreting earthquake-hazard reports and maps, through publishing guidebooks and assisting in the design of regulations based upon the information, to giving expert testimony and depositions concerning the information.

Review services include review and comment on policies, procedures, studies, plans, statutes, ordinances, or other regulations, that are based upon, cite, interpret, or apply earthquake-hazard information.

The educational and advisory services should not supplant existing programs or activities of educational institutions, or replace services of private consulting firms or state and local organizations, instead they should supplement them!

Multiple ways of imparting information should be encouraged. A single exposure to new information, especially if the information is complex or differs from a user's previous knowledge, is often insufficient. Repeated exposure in different formats and through different conduits is needed. This strategy is particularly successful when new information is provided by persons who are customarily looked to for guidance, such as members of the same professional group. The most effective transfer techniques should be selected jointly (if possible) by the translator, transfer agent, and user.

Transfer Agents

For the purpose of this paper, the term "transfer agents" is defined as those who deliver translated research information to potential users and assist and encourage them in selecting and adopting appropriate hazard reduction techniques. Examples of potential transfer agents of earthquake-hazard information in Oregon and Washington are given in List 4. Many of

List 3

Examples of hazard information transfer techniques

Educational services

Providing serial and other types of publications reporting on hazard research underway and reduction techniques in process.

Assisting and cooperating with universities, their extension division, and other schools in the preparation of course outlines, detailed lectures, casebooks, and audio or visual materials.

Contacting speakers and participating as lecturers in state and community educational programs related to the use of hazard information.

Sponsoring, conducting, and participating in topical and areal seminars, conferences, workshops, short courses, technology utilization sessions, cluster meetings, innovative transfer meetings, training symposia, and other discussions with user groups.

Releasing information needed to address critical hazards early through oral briefings, newsletters, seminars, map-type "interpretive inventories," open-file reports, reports of cooperative agencies, and "official use only" materials.

Sponsoring or cosponsoring conferences or workshops for planners, engineers, and decisionmakers at which the results of hazard studies are displayed and reported on to users.

Providing speakers to government, civic, corporate, conservation, church, and citizen groups, and participating in radio and television programs to explain or report on hazard-reduction programs and techniques.

Preparing and exhibiting displays that present hazard information and illustrate their use for hazard reduction.

Attending and participating in meetings with local, district, and state agencies and their governing bodies for the purpose of presenting hazard information.

Guiding field trips to disaster areas, damaged structures, and potentially hazardous sites.

Preparing and distributing brochures, TV spots, films, kits, and other visual materials to the news media and other users.

Operating public inquiries offices, information sales offices, and information clearinghouses.

Reporting on the adoption and enforcement of hazard reduction techniques.

Advisory services

Preparing annotated and indexed bibliographies of hazard information and providing lists of pertinent reference material to various users.

List 3 (continued)

Examples of hazard information transfer techniques

Assisting local, state, and federal agencies in designing policies, procedures, ordinances, statutes, and regulations that are based on, cite, or make other use of hazard information.
Assisting in recruiting, interviewing, and selecting planners, engineers, and scientists by government agencies for which education and training in hazard information collection, interpretation, and use are criteria.
Providing explanations of hazard information and reduction techniques during public hearings.
Providing expert testimony and depositions concerning hazard research information and its use in reduction techniques.
Assisting in the presentation and adoption of plans and plan-implementation devices that are based upon hazard information.
Assisting in the incorporation of hazard information into local, state, and federal studies and plans.
Preparing brief fact sheets or transmittal letters about hazard products explaining their impact on, value to, and most appropriate use by local, state, and federal planning and development agencies.
Assisting users in the creation, organization, staffing, and formation of local, state, and federal planning and plan-implementation programs so as to ensure the proper and timely use of hazard information.
Preparing and distributing appropriate guidelines and guidebooks relating to natural hazards processes, mapping, and reduction techniques.
Preparing model state safety legislation, regulations, and development policies.
Preparing model local safety policies, safety plan criteria, and hazard reduction techniques.
Advising on and providing examples of the methods or criteria for hazard identification, vulnerability assessments, and risk management.

Review services

Reviewing proposed programs designed for collecting and interpreting hazard information.
Reviewing local, state, and federal policies, administrative procedures, and legislative analyses that relate to assessing and reducing hazards.
Reviewing studies and plans that are based on, cite, or otherwise use hazard information.
Reviewing proposed legislation, regulations, policies, and procedures that incorporate or cite hazard information.

List 4

Examples of potential transfer agents in the Pacific Northwest

American Planning Association
American Society of Civil Engineers
American Society of Public Administrators
Association of Engineering Geologists
Associations of counties

Church groups, church organizations, and church leaders
City engineers, planners, and emergency managers
Civic and voluntary groups
Consultants (engineers, planners, geologists, sociologists, and others)
County geologists and extension agents

Educators (university, college, secondary, and elementary)
Geological associations
International Conference of Building Officials
League of Cities and Towns
League of Women Voters

Local building, engineering, zoning, and safety departments
Local seismic safety advisory groups
Media (journalists, commentators, editors, and feature writers)
Museum of Natural History
Neighborhood associations

Oregon Building Codes Agency
Oregon Department of Geology and Mineral Industries
Oregon Geological and Mineral Survey
Public information offices
Researchers, engineers, and planners (local, state, and federal)

Speakers' bureaus (state, local, or project area)
State departments of information services
State divisions of emergency management
Structural Engineer's Association
Thurston Regional Planning Council

U.S. Forest Service
U.S. Geological Survey
U.S. Soil Conservation Service
Washington Department of Community Development
Washington Department of Natural Resources

the users in List 2 will also be transferring such information.

Of course, geologists, seismologists, and other earthquake researchers will be available to provide some of the educational, advisory, and review services, but to rely solely or heavily on these skilled and scarce resources is unreasonable and would divert them from their work of understanding the process, assessing the hazard, and translating their research. The role of professional associations -- planners, engineers, geographers, and geologists -- should be emphasized. The professions can not only contribute to identifying user needs, translating and transferring complex information, and fostering an environment for use, but are principal users themselves.

Examples of successful transfer agents and their transfer programs follow:

- Circuit-rider geologist in the State of Washington (Thorsen, 1981).
- Advisory services unit of the California Division of Mines and Geology (Amimoto, 1980).
- Educational, advisory and review services by the Southeastern Wisconsin Regional Planning Commission (1968, 1987).
- Earth science information dissemination activities of the U.S. Geological Survey (Information Systems Council's Task Force on Long-range Goals for USGS Information Dissemination, 1987).
- Earthquake-hazard reduction activities of the staff, members, and committees of the California Seismic Safety Commission (1986).

4. HAZARD REDUCTION TECHNIQUES

Numerous earthquake-hazard reduction techniques are available in Oregon and Washington to engineers, planners, and decisionmakers, both public and private. These techniques have the following specific objectives: awareness of, avoidance of, accommodation to, or response to, the effect of the earthquake phenomena on people and their land uses, structures, and activities. The general goal of these objectives is to reduce human casualties, property damages, and socioeconomic interruptions.

Many of the reduction techniques are also complex, interconnected, and require special skills -- legal, financial, legislative, design, economic, communicative, educational, political, and engineering. To give the reader an overview, examples of specific reduction techniques are shown in List 5. These techniques can also be divided in other ways, for example:

- Pre-event mitigation techniques, which may take 1 to 20 years.
- Preparedness measures, which may take 1 to 20 weeks.
- Response during and immediately after an event.
- Recovery operations after an event, which may take 1 to 20 weeks.
- Post-event reconstruction activities, which may take 1 to 20 years.

List 5

Examples of specific techniques for reducing earthquake hazards in the Pacific Northwest

Incorporating hazard information into plans and programs
- Community-facilities inventories and plans
- Economic-development evaluations and plans
- Emergency and public-safety plans
- Land-use and transportation inventories and plans
- Redevelopment plans (pre-disaster and post-disaster)
- Utility inventories and plans

Regulating development
- Reviewing annexation, project, and rezoning applications
- Enacting building and grading ordinances
- Requiring engineering, geologic, and seismologic reports
- Requiring investigations in hazard zones
- Enacting subdivision ordinances
- Creating special hazard-reduction zones and regulations

Siting, designing, and constructing safe structures
- Reconstructing after a disaster
- Reconstructing or relocating community facilities and utilities
- Securing building contents and nonstructural components
- Evaluating specific sites for hazards
- Siting and designing critical facilities
- Training design professionals

Discouraging new development in hazardous areas
- Creating financial incentives and disincentives
- Adopting lending policies that reflect risk of loss
- Adopting utility and public-facility service-area policies
- Requiring nonsubsidized insurance related to level of hazard
- Posting public signs that warn of potential hazards
- Clarifying the liability of developers and government officials

Strengthening, converting, or removing unsafe structures
- Condemning and demolishing unsafe structures
- Creating nonconforming land uses
- Repairing unsafe dams or lowering their impoundments
- Retrofitting bridges and overpasses
- Strengthening or anchoring buildings
- Reducing land use intensities or building occupancies

Preparing for and responding to emergencies and disasters
- Estimating damages and losses from an earthquake
- Providing for damage inspection, repair, and recovery
- Conducting emergency or disaster training exercises
- Operating monitoring, warning, and evacuation systems
- Initiating public and corporate education programs
- Preparing emergency response and recovery plans

These estimated time periods vary depending upon the postulated or actual size of the earthquake, its damage, the reduction techniques in place, and the resources available to the states of Oregon and Washington, their communities, their corporations, and their families.

Many of the hazard reduction techniques identified in this report have been discussed and illustrated by Blair and Spangle (1979), Kockelman and Brabb (1979), Brown and Kockelman (1983), Kockelman (1985, 1986), Jochim and others (1988), Mader and Blair-Tyler (1988), Blair-Tyler and Gregory (1988), and the United Nations Office of the Disaster Relief Coordinator (Lohman and others, 1988).

5. EVALUATION AND REVISION

The last component in any comprehensive earthquake-hazard reduction program is evaulating the effectiveness of the reduction techniques and revising them if necessary. See figure 1. Evaluating and revising the entire program as well as the other components -- studies, translation, and transfer -- may also be undertaken.

The evaluation component was included as a task in the national earthquake-hazard reduction program by Wallace (1974), and as recommendations of the California Joint Committee on Seismic Safety (1974) advisory groups. Evaluation has been emphasized in a review of ten cities' efforts to manage floodplains (Burby and others, 1988, p. 9), in the comprehensive tasks of a national landslide ground-failure-hazards reduction program (U.S. Geological Survey, 1982, p. 44), and in the recommendations of the NEHRP Expert Review Committee (1987, p. 81-85).

The effectiveness of each hazard reduction technique varies with the time, place, and persons involved. Therefore, it is prudent to include a continuing systematic evaluation as part of any earthquake-hazard reduction program. An inventory of uses made of the information, reports of interviews with the users, and an analysis of the results and responses will also result in identifying new users, innovative uses, as well as any problems concerning the research information; its translation, transfer, and use. The evaluation will be helpful, even necessary, to those involved in producing, translating, transferring, and using the research information as well as to those funding and managing the program.

Performing the studies and then translating and transferring the research information is expensive and difficult because of the limited number of scientists and geotechnicians -- national, state, local, corporate, and consulting -- particularly when aligned with the needs of communities throughout the United States. The adoption and enforcement of an appropriate hazard reduction technique is time-consuming, and requires many skills -- planning, engineering, legal, and political -- as well as strong and consistent public support.

Scarce financial and staff resources must be committed; necessarily persistent and difficult actions must be taken to enact a law, adopt a policy, or administer a reduction program over a long period of time. To discover later that the hazard reduction technique selected is ineffective, unenforced, or its cost is greatly disproportionate to its benefits is not only disheartening but may subject those involved to criticism and withdrawal of financial support!

Few systematic evaluations have been made of earthquake-hazards reduction techniques. To my knowledge, no rigorous studies of the benefits-to-costs have been conducted; a few intensive evaluations have been made for flood, landslide, and other hazard reduction techniques and programs which may be applicable to earthquakes. Examples of various evaluations shown in List 6 are presented for introductory purposes; discussions of their findings and recommendations are beyond the scope of this paper.

List 6

Examples of Evaluations

Reduction Techniques

- o Planning for urban land use in California by Wyner (1982).
- o Lending, appraising, and insuring policies of the 12 largest home mortgage lenders in California by Marston (1984).
- o Disclosing fault rupture hazards to real estate buyers in Berkeley and Contra Costa County by Palm (1981).
- o School earthquake safety and education project in Seattle and community outreach education centers at Memphis State University and Baptist College in Charleston, South Carolina, by Bolton and Olson (1987b).
- o Strengthening masonry-bearing-wall buildings in the city of Los Angeles after the 1987 Whittier Narrows earthquake by Deppe (1988).
- o Retrofitting highway bridges after the 1986 earthquake in Palm Springs by Mellon (1986).

Translation and Transfer Techniques

- o Disseminating earthquake education material to California public and private schools by Bolton and Olson (1987a).
- o Disseminating earthquake-hazards information to public officials and private sector representatives in Charleston, South Carolina, by Greene and Gori (1982).
- o Using earth-science information in cities, counties, and selected regional agencies in the San Francisco Bay region by Kockelman (1975, 1976, 1979), Kockelman and Brabb (1979), and Perkins (1986).
- o Translating and transferring information in the U.S. Geological Survey by O'Kelley and others (1982).
- o Awareness and reduction of earthquake hazards in Puget Sound by Perkins and Moy (1988, p. 9-19).
- o County Hazards Geologist Program by Christenson (1988).

Program Evaluations

- o Community seismic safety programs before, during, and after the 1983 Coalinga, California, earthquake by Tierney (1985).
- o Use of earthquake-hazard information for enlightenment, decisionmaking, and practice in California, Washington, Utah, South Carolina, Massachusetts, Idaho, Puerto Rico, Kentucky, Alaska, Missouri, U.S. Virgin Islands, and the eastern, western, and central United States by Hays (1988a).
- o National Earthquake Hazards Reduction Program in the United States by the NEHRP Expert Review Committee (1987).
- o Effectiveness of the geology and planning program in Portola Valley, California, by Mader and others (1988, p. 55-61).
- o Land use and reconstruction planning after the 1971 San Fernando, 1964 Alaska, and 1969 Santa Rosa earthquakes by Mader and others (1980).
- o Structure design and behavior investigation after over 200 earthquakes by members of the Earthquake Engineering Research Institute (Scholl, 1986).

List 6 (continued)

Examples of Evaluations

Reduction Techniques for Other Hazards

- Disclosing hurricane-flood-hazards information to prospective home buyers in Florida by Cross (1985).
- Subsidizing flood insurance for property owners and their lenders by Miller (1977), Burby and French (1981, p. 294), and Kusler (1982, p. 36, footnote 55).
- Notice, watch, and warning system for a potential 1978 Pillar Mountain landslide in Kodiak by Saarinen and McPherson (1981).
- Warnings for the 1980 Mount St. Helens volcano eruption by Saarinen and Sell (1985).
- Planning and engineering response and recovery to 1982 debris flows at Love Creek (Santa Cruz County) and Inverness (Marin County) by Blair and others (1985).

REFERENCES

Agnew, D.C., Allen, C.R., Cluff, L.S., Dieterich, J.H., Ellsworth, W.L., Keeney, R.L., Lindh, A.G., Nishenko, S.P., Schwartz, D.P., Sieh, K.E., Thatcher, W.R., and Wesson, R.L., 1988, Probabilities of large earthquakes occurring in California on the San Andreas fault: U.S. Geological Survey Open-File Report 88-398, 62 p.

Amimoto, Perry Y., 1980, Advisory services: California Division of Mines and Geology, California Geology, May 1980, p. 99 and 100.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings -- A cooperative effort with the design professions, building code interests, and the research community: Washington, D.C., U.S. Government Printing Office, Publication ATC 3-06, 505 p., 2 plates.

Blair, M.L., and Spangle, W.E., 1979, Seismic safety and land-use planning -- Selected examples from the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 941-B, 82 p.

Blair, M.L., Vlasic, T.C., Cotton, W.R., and Fowler, William, 1985, When the ground fails -- Planning and engineering response to debris flows: Boulder, University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior, Monograph 40, 117 p.

Blair-Tyler, M.L., and Gregory, P.A., 1988, Putting seismic safety policies to work: Portola Valley, Calif., William Spangle and Associates, Inc., 40 p.

Bolton, P.A., and Olson, Jon, 1987a, An assessment of dissemination activities of the California earthquake education project: Seattle, Battelle Human Affairs Research Centers Contract no. SSC-6009, 43 p.

-----1987b, Final report on the evaluation of three earthquake education projects: Seattle, Battelle Human Affairs Research Centers, BHARC 800-88-027, 153 p.

Borcherdt, R.D., ed., 1975, Studies for seismic zonation of the San Francisco Bay region -- Basis for reduction of earthquake hazards, San Francisco Bay region, California: U.S. Geological Survey Professional Paper 941-A, 102 p.

Brown, R.D., Jr., and Kockelman, W.J., 1983, Geologic principles for prudent land use -- A decisionmaker's guide for the San Francisco Bay region: U.S. Geological Survey Professional Paper 946, 97 p.

Burby, R.J., Bollens, S.A., Holloway, J.M., Kaiser, E.J., Mullan, David, Sheaffer, J.R., 1988, Cities under water -- A comparative evaluation of ten cities' efforts to manage floodplain land use: Boulder, University of Colorado, Program on Environment and Behavior, Monograph 47, 250 p.

Burby, R.J., and French, S.P., 1981, Coping with floods -- The land use management paradox: Journal of the American Planning Association, v. 47, no. 3, p. 289-300.

California Joint Committee on Seismic Safety, 1974, Meeting the earthquake challenge -- Final report to the legislature: California Division of Mines and Geology Special Publ. 45, 223 p.

California Seismic Safety Commission, 1986, California at risk -- Reducing earthquake hazards, 1987 to 1992: Sacramento, California Seismic Safety Commission, 92 p.

Christenson, G.E., 1988, Final technical report -- Wasatch Front county hazards geologist program: Salt Lake City, Utah Geological and Mineral Survey, USGS Grant no. 14-08-0001-G991, 14 p.

Cross, J.A., 1985, Flood hazard information disclosure by realtors: Boulder, University of Colorado, Institute of Behavior Sciences, Natural Hazard Research, Working Paper 52, 44 p.

Deppe, Karl, 1988, The Whittier Narrows, California earthquake of October 1, 1987 -- Evaluation of strengthened and unstrengthened unreinforced masonry in Los Angeles City: El Cerrito, Earthquake Engineering Research Institute, Earthquake Spectra, v. 4, no. 1, p. 157-180.

Evernden, J.F., and Thomson, J.M., 1988, Predictive model for important ground motion parameters associated with large and great earthquakes: U.S. Geological Survey Bulletin 1838, 27 p.

Greene, M.R., and Gori, P.L., 1982, Earthquake hazards information dissemination -- A study of Charleston, South Carolina: U.S. Geological Survey Open-File Report 82-233, 57 p.

Hays, W.W., 1980, Procedures for estimating earthquake ground motions: U.S. Geological Survey Professional Paper 1114, 77 p.

-----, ed., 1988a, A review of earthquake research applications in the National Earthquake Hazards Reduction Program: 1977-1987 -- Proceedings of Conference XLI: U.S. Geological Survey Open-File Report 88-13-A, 597 p.

-----, ed., 1988b, Workshop on "Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas," Proceedings of Conference XLII, Olympia, Wash., April 12-15, 1988: U.S. Geological Survey Open-File Report 88-541, 347 p.

Information Systems Council's Task Force on Long-Range Goals for USGS's Information Dissemination, 1987, Review of current and developing U.S. Geological Survey earth-science information dissemination activities (summary version): Reston, Va., U.S. Geological Survey, update of May 1985 report, 6 p.

Jochim, C.L., Rogers, W.P., Truby, J.O., Wold, R.L., Jr., Weber, George, and Brown, S.P., 1988, Colorado landslide hazard mitigation plan: Denver, Colorado Geological Survey, Bulletin 48, 149 p.

Kockelman, W.J., 1975, Use of U.S. Geological Survey earth-science products by city planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 75-276, 110 p.

-----1976, Use of U.S. Geological Survey earth-science products by county planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 76-547, 185 p.

-----1979, Use of U.S. Geological Survey earth-science products by selected regional agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 79-221, 173 p.

-----1985, Using earth-science information for earthquake-hazard reduction, in Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 443-469.

-----1986, Some techniques for reducing landslide hazards: College Station, Texas, Association of Engineering Geologists Bulletin, v. 23, no. 1, p. 29-52.

Kockelman, W.J., Gori, P.L., and Hays, W.W., 1988, Summary and background of the workshop, in Hays, W.W., ed., Workshop on "Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas," Conference XLII Proceedings, April 12-15, 1988, U.S. Geological Survey Open-File Report 88-541, p. 1-33.

Kockelman, W.J., and Brabb, E.E., 1979, Examples of seismic zonation in the San Francisco Bay region, in Brabb, E.E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 73-84.

Kusler, J.A., 1982, Regulation of flood hazard areas to reduce flood losses: Washington, D.C, U.S. Government Printing Office, U.S. Water Resources Council, v. 3, 357 p.

Lohman, Ernst, Vrolijks, Luc, and Roos, Jaap, 1988, Disaster Mitigation --A manual for planners, policymakers, and communities, final draft: Geneva, United Nations Office of the Disaster Relief Coordinator, 489 p.

Mader, G.G., and Blair-Tyler, M.L., 1988, California at risk -- Steps to earthquake safety for local government: Sacramento, Calif., California Seismic Safety Commission Report no. SSC-88-01, 55 p.

Mader, G.G., Spangle, W.E., Blair, M.L., Meehan, R.L., Bilodeau, S.W., Degenkolb, H.J., Duggar, G.S., and Williams, Norman, Jr., 1980, Land use planning after earthquakes: Portola Valley, Calif., William Spangle and Associates Inc., 158 p.

Mader, G.G., Vlasic, T.C., and Gregory, P.A., 1988, Geology and planning -- The Portola Valley experience: Portola Valley, Calif., William Spangle and Assoc., Inc., 67 p., 2 app.

Marston, S.A., 1984, A political economy approach to hazards -- A case study of California lenders and the earthquake threat: Boulder, University of Colorado Institute of Behavioral Science, Natural Hazards Research Working Paper 49, 31 p.

Mellon, Steve, 1986, Highway bridge damage -- Palm Springs earthquake July 8, 1986 -- Seismic report, post-earthquake investigation team (intra-agency document): Sacramento, California Department of Transportation, Office of Structures Design, 40 p.

Miller, H.C., 1977, Coastal flood hazards and the national flood insurance program: Washington, D.C., Federal Emergency Management Agency FIA-9/March 1981, 50 p.

NEHRP Expert Review Committee, 1987, The National Earthquake Hazards Reduction Program -- Commentary and recommendations of the expert review committee: Washington, D.C., Federal Emergency Management Agency, 85 p.

O'Kelley, J.T., Jr., Fleisig, Susan, Shapiro, Carl, Kugel, T.L., DuBose, Lorraine, Gordon, Leonard, and Pittman, Russell, 1982, Program evaluation of USGS information translation and transference activities (unpublished report): Reston, U.S. Geological Survey, 90 p.

Palm, Risa, 1981, Real estate agents and special studies zones disclosure -- The response of California home buyers to earthquake hazards information: Boulder, University of Colorado, Institute of Behavioral Science Program on Technology, Environment, and Man, Monograph 32, 147 p.

Perkins, J.B., 1986, Results of a survey of local governments -- Use of earthquake information: Oakland, Calif., Association of Bay Area Governments, 14 p.

Perkins, J.B., and Moy, Kenneth, 1988, Liability of local governments for earthquake hazards and losses -- Background research reports: Oakland, Calif., Association of Bay Area Governments, 3 reports, 295 p.

Power, M.S., Chang, C.-Y., Idriss, I.M., and Kennedy, R.P., 1986, Engineering characterization of ground motion -- Task II, Summary Report: Washington, D.C., U.S. Nuclear Regulatory Commission, NUREG/CR-3805, v. 5, 131 p., 1 app.

Richter, C.F., 1958, Elementary seismology: San Francisco and London, W.H. Freeman and Company, 768 p.

Saarinen, T.F., and McPherson, H.J., 1981, Notices, watches and warnings -- An appraisal of the U.S.G.S's warning system with a case study from Kodiak, Alaska: Boulder, University of Colorado, Institute of Behavioral Science, Natural Hazard Research Working Paper 42, 88 p.

Saarinen, T.F., and Sell, J.L., 1985, Warning and response to the Mount St. Helens eruption: Albany, State University of New York Press, 240 p.

Scholl, R.E., mgr., 1986, Reducing earthquake hazards -- Lessons learned from earthquakes: El Cerrito, Calif., Earthquake Engineering Research Institute, 208 p.

Schwartz, D.P., 1988, Geologic characterization of seismic sources -- Moving into the 1990s: Park City, Utah, (reprint) Earthquake Engineering and Soil Dynamics II Proceedings, GT Division/ASCE, 42 p.

Southeastern Wisconsin Regional Planning Commission, 1968, Project completion report, urban planning grant project no. Wis. P-53 -- Educational, advisory, and review service programs: Waukesha, Wisconsin, South-eastern Wisconsin Regional Planning Commission, 32 p.

-----1987, Twenty-five years of regional planning in southeastern Wisconsin -- 1960-1985: Waukesha, Wisconsin, Southeastern Wisconsin Regional Planning Commission, 49 p.

Thorsen, G.W., 1981, The circuit rider geologist: Final report, U.S. Geological Survey Agreement No. 7020-086-79, Project no. 9-7020-26001, 29 p.

Tierney, K.J., 1985, Report on the Coalinga earthquake of May 2, 1983: Sacramento, California Seismic Safety Commission, Report no. SSC-85-01, 90 p.

United Nations Educational, Scientific, and Cultural Organization, 1976, Intergovernmental conference on the assessment and mitigation of earth-quake risk: Paris, United Nations Educational, Scientific, and Cultural Organization, Final report, 50 p.

U.S. Geological Survey, 1982, Goals and tasks of the landslide part of a ground-failure hazards reduction program: U.S. Geological Survey Circular 880, 48 p.

U.S. Office of Science and Technology Policy, 1978, Earthquake hazards reduction -- Issues for an implementation plan: Washington, D.C., Working Group on Earthquake Hazards Reduction, Office of Science and Technology, Executive Office of the President, 231 p.

Wallace, R.E., 1974, Goals, strategy, and tasks of the earthquake hazard reduction program: U.S. Geological Survey Circular 701, 27 p.

Wyner, A.J., 1982, Urban land use planning for seismic safety in California, <u>in</u> Third International Earthquake Microzonation Conference Proceedings, Seattle, June 28-July 1, 1982, v. II, p. 681-695.

Ziony, J.I., ed., 1985, Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, 505 p.

Oregon's Building Regulation System

State of Oregon
Building Codes Agency Salem, Oregon

Walter M. Friday, P.E.

- Oregon has a relatively sophisticated code enforcement system for new and remodeled buildings.

- State-wide building code. The State Building Code is composed of Specialty Codes:
  - Plumbing
  - Electrical
  - Mechanical
  - Elevator
  - Boiler and Pressure Vessel; and
  - Structural Specialty Codes.
- Codes are adopted by Administrative Rule.
- Nationally recognized model codes areused.
- Statute provides for State amendments to these model codes.
- No local government may adopt requirements either more or less restrictive than the Specialty Codes (for systems regulated by the Specialty Codes).

State-wide requirements have been in effect for 15 years to make new buildings earthquake resistant.

The Oregon Structural Specialty Code = Uniform Building Code + Oregon amendments.

Passed Oregon seismic related amendments:
- Lesser reinforcing standard for small masonry buildings.
- Seismic Risk Map up-graded to make all of Oregon in Seismic Risk Zone 2.

In final stages of adopting of the 1988 Edition of the Uniform Building Code.

The 1988 UBC seismic section has been:
- Completely revised and strengthened
- More detailed.
- State-of-the-art
- Incorporates much of NEHRP's seismic building provisions
- Seismic Risk Map is revised.

In the 1989 UBC all of Oregon is in Seismic Risk Zone 2B, with exception of a small area in the south/central Oregon, along the California line which is now in Seismic Risk Zone 3. The amendment allowing the lesser reinforcing standard for masonry buildings has been deleted. Now pure model code.

Other facets of the Oregon system which enhance seismic safety.

All building officials, plan examiners, and inspectors are required to be certified.

Certification requirements include:
- education
- experience
- passage of a test, and
- continuing education. Education funds are gathered via a 1% surcharge on the permit fees on all permits issued in Oregon.

Direct application of codes are primarily by local governments. Under the Structural Specialty Code, 95 % of the population is under city or county government's jurisdiction. The state applies the code over about 1/3 of the land area, but this area only contains 5% of the population. Electrical and plumbing programs have different mixes.

The Building Codes Agency is concerned about the potential for subduction zone earthquakes. Will consider:
- Amendment though the model code process
- Wish to avoid state amendments.

We need a clear statement from the scientific community of the increased risk. We need advice on the characteristics of such quakes:
- Ground motion
- Frequency of such quakes

Oregon Building Codes Agency has no authority to retroactively apply corrective regulations to existing buildings.

We will be watching the development of the Northwest study and stand ready to assist in revising regulations to address the changing perceived risk.

DISASTER RISK ANALYSIS AND BUSINESS RESUMPTION PLAN BY A WASHINGTON STATE GOVERNMENTAL AGENCY

BY
JUDY H. BURTON
DEPARTMENT OF LABOR AND INDUSTRIES
OLYMPIA, WASHINGTON

March 28, 1989

INTRODUCTION

The Washington Department of Labor and Industries is a diverse agency with approximately 2,000 employees, based mostly in Olympia with 17 field offices throughout the state. It has complex and varied functions: collects approximately $1 million premiums daily from employers, claims administration, pays approximately $1 million daily in time-loss payments for industrial injury/health claims, vocational rehabilitation, underwriting, investment and reserve management of approximately $3.5 billion, medical bill processing in addition to other functions of a full-service insurance company.

The Department also serves as a regulatory agency to protect workers throughout the state, enforces employment laws, oversees the apprenticeship programs, protects the public from unsafe commercial, residential and industrial construction and administers the State crime victims' compensation program.

BRIEF HISTORY OF DISASTER AWARENESS

Over the past decade, the Department has given some consideration to emergency planning. On a division level, two unrelated reciprocal agreements exist with other agencies to maintain a minimal level of operation in the event of a disaster. These documents resulted from a 1983 fire loss of another state building; the agreements have not been updated. A paper file inventory was completed by one division in 1983 with written instructions on preservation of paper files and microfilm. No reference was made for prioritization of services, disaster contingency plans, electronic transfer of data, or backup of data.

The Department's current top management is sensitive to the need for disaster preparedness and has taken steps to analyze its resources to adequately plan for a possible disaster. To further protect our employees in event of emergency a BUilding Emergency Plan is currently being developed.

PRESENT AGENCY DISASTER RISK ANALYSIS

Among the Department's most valuable resources are its records and data. The continued sophistication and reliance upon electronic communication and telecommunications increases the potential damage in the event of disruption to these services. With this in mind, an agency-wide sample review of business vulnerability in event of disaster was recently completed. The results heightened the concern and attention of top management. That survey revealed a distinct vulnerability to disaster of any nature in several critical business, insurance and regulatory areas of the agency.

The Information Services Division (data processing) is currently surveying the agency's numerous computer applications on a unit by unit basis to determine the importance of each automated application to complete the work. An in-house designed survey was used though soft-ware risk analysis packages were considered. The survey shall reveal the organization's automated vulnerabilities by division, building, program or function area and computer application information. The survey allows management to prioritize their own automated applications and acknowledge existance and vulnerability of this resource.

In addition, telephone companies, the agency's electrical power provider and several other state agencies who provide L&I computer support service were analyzed as to disaster prepardness.

THE FUTURE FOR LABOR AND INDUSTRIES DISASTER RISK ANALYSIS AND BUSINESS RESUMPTION PLAN

The lack of adequate backup and contingency planning by primary outside agencys providing L&I service only strengthens the need for continual risk assessment and development of a Business Resumption Plan.

A through analysis of the entire agency and field offices is anticipated. The results of that survey will likely portray the need for mitigative measures to be taken in event of disaster. Appropriate, cost effective and continually updated disaster contingency plans should then be formed as a result of the study.

Senate Bill 603

Sponsored by Senators SPRINGER, BRADBURY, CEASE, COHEN, J. HILL, KERANS, McCOY, Representatives DWYER, EDMUNSON, GERSHON, KEISLING, McTEAGUE, RIJKEN, SOWA, STEIN (at the request of Forelaws on Board Foundation)

SUMMARY

The following summary is not prepared by the sponsors of the measure and is not a part of the body thereof subject to consideration by the Legislative Assembly. It is an editor's brief statement of the essential features of the measure **as introduced.**

Requires Energy Facility Siting Council to adopt safety standards for nuclear power plants to withstand major earthquakes. Requires council to perform independent geologic investigation and engineering analysis before adopting safety standards. Requires owner of operating nuclear power plant to pay costs of investigation and analysis. Appropriates moneys collected to council for such investigations and analyses.

A BILL FOR AN ACT

Relating to nuclear energy; creating new provisions; amending ORS 469.500; and appropriating money.

Be It Enacted by the People of the State of Oregon:

SECTION 1. ORS 469.500 is amended to read:

469.500. (1) The council shall adopt safety standards promulgated as rules for the operation of all thermal power plants and nuclear installations. Such standards shall include but need not be limited to:

(a) Emission standards at the lowest practicable limits, taking into account the state of technology and the economics of improvements in relation to the benefits to public health and safety;

(b) All necessary safety devices and procedures; [*and*]

(c) The accumulation, storage, disposal and transportation of wastes including nuclear wastes; **and** [.]

(d) The ability of nuclear power plants to withstand a major earthquake without harm to the public and comply with seismic protection requirements of the United States Nuclear Regulatory Commission. Before adopting the standard, the council shall commission an independent geologic investigation and engineering analysis to identify and evaluate all geologic faults underneath and in the vicinity of each nuclear power plant, the potential magnitude of subduction zone earthquakes and their effect on each nuclear power plant and the adequacy of each nuclear power plant's design to withstand a major earthquake.

(2) The council shall establish programs for monitoring the environmental and ecological effects of the construction and operation of thermal power plants and nuclear installations to assure continued compliance with the terms and conditions of the certificate and the safety standards adopted under subsection (1) of this section.

(3) The director shall perform the testing and sampling necessary for the monitoring program or require the operator of the plant to perform the necessary testing or sampling pursuant to standards established by the council. The council and director shall have access to operating logs, records and reprints of the certificate holder, including those required by federal agencies.

(4) The monitoring program may be conducted in cooperation with any federally operated pro-

NOTE: Matter in **bold face** in an amended section is new; matter [*italic and bracketed*] is existing law to be omitted.

gram if the information available therefrom is acceptable to the council, but no federal program shall be substituted totally for monitoring supervised by the director.

(5) The monitoring program shall include monitoring of the transportation process for all radioactive material removed from any nuclear-fueled thermal power plant or nuclear installation.

SECTION 2. Section 3 of this Act is added to and made a part of ORS 469.300 to 469.570.

SECTION 3. In addition to any fee required by law, each owner of an operating nuclear power plant within this state shall pay an assessment in an amount determined by the Energy Facility Siting Council to be necessary to pay for the cost of the investigation and analysis required under ORS 469.500 (1)(d). Moneys collected under this section are continuously appropriated to the council for conducting or commissioning such investigations and analyses.

Senate Bill 604

Sponsored by Senators SPRINGER, CEASE, COHEN, J. HILL, KERANS, McCOY, ROBERTS, Representatives BAUMAN, CALHOON, DWYER, EDMUNSON, FORD, GERSHON, KEISLING, KOTULSKI, McTEAGUE, RIJKEN, SOWA, STEIN (at the request of Forelaws on Board Foundation)

SUMMARY

The following summary is not prepared by the sponsors of the measure and is not a part of the body thereof subject to consideration by the Legislative Assembly. It is an editor's brief statement of the essential features of the measure **as introduced.**

Requires Energy Facility Siting Council to adopt by rule emergency evacuation plan for area within 50-mile radius of nuclear power plant. Establishes elements required in evacuation plan. Requires council to include maximum consumer involvement in rulemaking.

A BILL FOR AN ACT

Relating to nuclear energy; amending ORS 469.533.

Be It Enacted by the People of the State of Oregon:

SECTION 1. ORS 469.533 is amended to read:

469.533. (1) Notwithstanding ORS chapter 401, the [*Department of Energy*] **Energy Facility Siting Council** in cooperation with the Health Division and the Emergency Management Division shall establish rules for the protection of health and procedures for the evacuation of people and communities who would be affected by radiation in the event of an accident or a catastrophe in the operation of a nuclear power plant or nuclear installation.

(2) The emergency plan for a nuclear power plant adopted by the council under subsection (1) of this section shall include:

(a) Provisions for notifying, at least once a year, the public within a 50-mile radius of the nuclear power plant about response to potential emergencies at the plant. The notice shall include but need not be limited to:

(A) Information about the kinds of accidents, including the worst case scenario, that could occur at the nuclear power plant;

(B) Directions about how to receive emergency directions about protective actions that should be taken in the event of an accident; and

(C) Procedures to be followed in event of a need to evacuate all or part of the population within the 50-mile radius of the nuclear plant.

(b) Provisions for a technical assessment of the emergency situation.

(c) Procedures for announcing necessary protective actions.

(d) Provisions for annual training exercises to test the effectiveness of all emergency procedures.

(3) The rules required under subsection (1) of this section shall be completed with maximum public involvement and shall be adopted initially within six months after the effective date of this 1989 Act. Thereafter, the council shall review the rules biannually.

NOTE: Matter in **bold face** in an amended section is new; matter [*italic and bracketed*] is existing law to be omitted.

Senate Bill 955

Sponsored by Senators McCOY, BRADBURY, CEASE, COHEN, FAWBUSH, J. HILL, KERANS, SPRINGER, Representatives BAUMAN, CALHOON, DWYER, EDMUNSON, FORD, HUGO, KEISLING, MANNIX, McTEAGUE, SOWA, STEIN, WHITTY (at the request of Forelaws on Board Foundation)

SUMMARY

The following summary is not prepared by the sponsors of the measure and is not a part of the body thereof subject to consideration by the Legislative Assembly. It is an editor's brief statement of the essential features of the measure **as introduced.**

Requires State Department of Geology and Mineral Industries to study and assess potential for earthquake and related hazards in Oregon. Defines "geologic hazard."

A BILL FOR AN ACT

Relating to earthquakes; amending ORS 516.010 and 516.030.

Be It Enacted by the People of the State of Oregon:

SECTION 1. ORS 516.010 is amended to read:

516.010. As used in this chapter:

(1) "Mine" includes all mineral-bearing properties of whatever kind and character, whether underground, quarry, pit, well, spring or other source from which any mineral substance is obtained.

(2) "Mineral" includes any and all mineral products, metallic and nonmetallic, solid, liquid or gaseous, and mineral waters of all kinds.

(3) "Mineral industries" includes all enterprises engaged in developing and exploiting the natural substances of the earth.

(4) "Geologic hazard" means a geologic condition that is a potential danger to life and property which includes but is not limited to earthquake shaking, landslide, flooding, erosion, expansive soil, fault displacement, volcanic eruption and subsidence.

[*(4)*] **(5)** "Geology" means the study of the earth, and in particular the study of the origin, history and topographic form of rocks, ores and minerals, either under the ground or upon the surface, and their alteration by surface agencies, such as wind, water, ice and other agencies, and the economics of their use.

SECTION 2. ORS 516.030 is amended to read:

516.030. The department shall:

(1) Initiate and conduct studies and surveys of the geological and mineral resources of the state and their commercial utility; and conduct as a continuing project a geological survey of Oregon, either as a department undertaking or jointly with federal or other agencies.

(2) Initiate, carry out or administer studies and programs that will, in cooperation with federal, state and local government agencies, reduce the loss of life and property by mitigating geological hazards. These studies and programs shall include but not be limited to:

(a) State-wide hazard assessment and emergency response, including identification and mapping of geologic hazards, estimation of their potential consequences and likelihood of occurrence and monitoring and assessment of potentially hazardous geologic activity;

(b) Studies of paleoseismicity including but not limited to providing evidence of whether prehistoric subduction zone earthquakes have occurred in Oregon;

NOTE: Matter in **bold face** in an amended section is new; matter [*italic and bracketed*] is existing law to be omitted.

(c) A state seismic network through the strategic placement of instrumentation to monitor earthquake activity as it occurs;

(d) A state geodetic network through the monitoring and periodic survey of markers in order to detect modern deformation of the earth's crust and the subsequent buildup of stress; and

(e) Development and application of hazard reduction mitigation methods, including identifying state research needs, facilitating needed research and expediting the application of new research results to public policy.

[*(2)*] **(3)** Consider and study kindred scientific and economic questions in the field of geology and mining that are deemed of value to the people of Oregon.

[*(3)*] **(4)** Cooperate with federal or other agencies for the performance of work in Oregon deemed of value to the state and of advantage to its people, under rules, terms and conditions to be arranged between the governing board of the department and such agencies. But in no case shall the cost to the department be in excess of the amount appropriated therefor, and the results of any joint undertakings shall be made available without restrictions to this department.

(5) Serve as a bureau of information and advisory services concerning geologic hazards, including maintenance of a library, a public education program and a geologic database; review of functions; expert advice to federal, state and local government agencies; and operation of a clearinghouse for post-event earth science investigations.

[*(4)*] **(6)** Serve as a bureau of information concerning Oregon mineral resources, mineral industries and geology; by means from time to time selected by the board, conduct a mineral survey of the state, and catalog each and every mineral occurrence and deposit, metallic and nonmetallic, together with its location, production, method of working, name of owner or agent, and other detailed information capable of being tabulated and published in composite form for the use, guidance and benefit of the mineral industry of the state and of the people in general and deemed necessary in compiling mineral statistics of the state.

[*(5)*] **(7)** Collect specimens and samples and develop a museum for their deposition and public exhibitions; collect photographs, models and drawings of appliances in the mines, mills and metallurgical plants of Oregon, and store them in such manner as to be readily viewed or used by the people of the state.

[*(6)*] **(8)** Collect a library of literature describing the geology and mineral deposits, metallic and nonmetallic, of Oregon.

[*(7)*] **(9)** Make qualitative examinations of rocks, mineral samples and specimens.

[*(8)*] **(10)** Study minerals and ores, additional uses for the state's minerals, and explore the possibilities for using improved treatment, processes and mining methods.

Senate Bill 956

Sponsored by Senators McCOY, CEASE, J. HILL, SPRINGER, Representatives BAUMAN, DWYER, EDMUNSON, HUGO, KEISLING, MANNIX, McTEAGUE, SOWA, STEIN (at the request of Forelaws on Board Foundation)

SUMMARY

The following summary is not prepared by the sponsors of the measure and is not a part of the body thereof subject to consideration by the Legislative Assembly. It is an editor's brief statement of the essential features of the measure **as introduced.**

Creates Seismic Safety Commission to address earthquake hazards by mitigation, preparedness, response coordination and recovery. Prescribes membership, duties and powers.

A BILL FOR AN ACT

Relating to earthquakes.

Be It Enacted by the People of the State of Oregon:

SECTION 1. (1) The Legislative Assembly finds and declares that there is a pressing need to strengthen earthquake safety in Oregon by improving public policy, especially that related to reducing hazards and mitigating the effects of potentially damaging earthquakes. This need is not being addressed by any existing state government organization.

(2) It is not the purpose of this Act to transfer any authorities and responsibilities now vested by law in state and local agencies.

SECTION 2. (1) There is created a Seismic Safety Commission, which shall report annually to the Governor, the Legislative Assembly, the State Department of Geology and Mineral Industries, the Emergency Management Division, the Building Codes Agency, the Energy Facility Siting Council and the Department of Land Conservation and Development.

(2) The commission shall consist of nine members as follows:

(a) The State Geologist or the State Geologist's designee, the Administrator of the Emergency Management Division or the administrator's designee and the Administrator of the Building Codes Agency or the administrator's designee;

(b) One seismologist from the state university educational system, active in earthquake-related research, and one engineer appointed by the Governor; and

(c) Four members of the Legislative Assembly, including two members of the House of Representatives appointed by the Speaker of the House of Representatives and two members of the Senate appointed by the President of the Senate. The two members appointed from each house shall be representatives of the two major political parties.

(3)(a) The term of office for each member of the Seismic Safety Commission shall be four years. The commission may elect its own chair, vice-chair and other officers. All business shall be conducted by majority vote and a majority of members shall constitute a quorum.

(b) No appointed member shall serve more than two terms.

(c) A vacancy shall be filled by the appointing authority in the manner provided for the original appointment.

(4) Commission members who are not members of the Legislative Assembly shall be entitled to compensation and expenses as provided in ORS 292.495. Members of the committee who are members of the Legislative Assembly shall be paid compensation and expense reimbursement as provided in

NOTE: Matter in **bold face** in an amended section is new; matter [*italic and bracketed*] is existing law to be omitted.

ORS 171.072, payable from funds appropriated to the Legislative Assembly.

SECTION 3. (1) There is established the Oregon Earthquake Hazards Reduction Act of 1989 pursuant to which this state shall implement new and expanded activities to significantly reduce earthquake threat to its citizens. This program shall be prepared and administered by the Seismic Safety Commission. The program shall specify resources needed to significantly reduce earthquake hazards state wide by January 1, 2000. The achievement of this goal shall be undertaken with the following objectives:

(a) Mitigation to reduce earthquake hazard to acceptable levels through significant reduction in the number of hazardous buildings and the expansion of scientific and engineering studies.

(b) Increase in the level of preparedness state wide through the implementation of programs addressing earthquake prediction, hazardous materials, critical facilities, disaster preparedness plans for all major population centers and education, training and public information.

(c) Response coordination necessary to enhance the state's ability to respond to a major earthquake disaster by giving priority to increased coordination and integration of federal, state and local plans and preparedness activities, improvements in the state-wide communication system, creation or enhancement of a state emergency coordination center or centers and greater automation of emergency management data.

(d) Recovery necessary to develop management systems for major earthquake recovery, the enhancement of resources management and the minimization of high unemployment, multiple business failures, tax base erosion and associated monetary and financial issues critical to the restoration of Oregon's economy and public services.

(2) The program shall consist of a series of five-year programs, and each five-year program shall be revised annually by the Seismic Safety Commission and submitted as a part of its report in section 2 of this Act.

SECTION 4. In the discharge of its responsibilities, the commission may:

(1) Accept grants, contributions and appropriations from public agencies, private foundations or individuals; and

(2) Seek advice from interested individuals and public and professional groups, and appoint nonvoting members to advise the commission.

REACTING TO EARTHQUAKE HAZARD INFORMATION--STATE LEVEL

BY
CAROLE MARTENS
WASHINGTON STATE DIVISION OF EMERGENCY MANAGEMENT
OLYMPIA, WASHINGTON

WASHINGTON STATE EARTHQUAKE PROGRAM ACTIVITIES

During the 1988 year, initial activities were undertaken and priorities established for the Washington State Earthquake Program. The major goal of the program is to improve earthquake safety in Washington State by beginning to develop a long-range earthquake program. Some of the activities during this period were:

- An introductory meeting was held with various state agency representatives. The representatives identified their agency's roles and will be responsible for updating their agency's earthquake plan. Additionally, the representatives will continue to provide earthquake support activity within their own agencies.

- Key members were identified to participate on a statewide citizen advisory committee to provide input and recommendations for Washington State's earthquake program.

- Published an article describing the state program in the Department of Natural Resources, Division of Geology and Earth Sciences, Newsletter.

- Provided resources and technical assistance to the public and private sector through mailings of earthquake information packets, audio-visual materials, presentations, and discussions.

- The Department of Community Development and FEMA co-sponsored a workshop in Seattle on Identification and Mitigation of Earthquake Hazards to Lifeline Systems. As an outgrowth of the workshop, an on-going committee has been formed to develop goals and time-lines for earthquake hazard reduction for lifeline systems.

- Worked with FEMA, local school districts, the Office of the Superintendent of Public Instruction, and a private structural consultant in the development of an illustrated guidebook for the identification and reduction of non-structural earthquake hazards in schools.

- Participated in the annual Western States Seismic Policy Council Conference. Issues common to the 14 member states as they develop and plan earthquake hazard reduction activities were discussed. Special reports referenced Washington and Oregon and their minimal earthquake programs. This emphasis was made because of the two states' vulnerable location on the Rim of the Pacific Plate.

- Developed earthquake information, as required by the state's Legislature. This information includes a "drop and cover" poster and targeted information for administrators and staffs of hospitals and schools.

- Planned activities for the annual Earthquake Awareness Week proclaimed by the Governor to be April 9 - 15, 1989.

CATASTROPHIC EARTHQUAKE PLANNING

The Department of Community Development staff continues to meet with the Federal Emergency Management Agency (FEMA) and other federal and state agencies to plan for catastrophic earthquake activities in Federal Region X. This plan is to reflect coordination of federal support and resources to assist local and state government in responding to a catastrophic earthquake.

A presentation on the federal planning process and possible earthquake scenarios was made to state agency liaisons on November 29, 1988.

The draft scenarios and planning assumptions have recently been sent to local emergency management organizations and state agencies for review and comment. Work with local governments and state agencies on this plan will continue.

EARTHQUAKE MITIGATION: THE WASHINGTON SCHOOL SAFETY PROGRAM

BY
CAROLE MARTENS
WASHINGTON STATE DIVISION OF EMERGENCY MANAGEMENT
OLYMPIA, WASHINGTON

INTRODUCTION

School systems are an especially desirable pathway to meeting the goal of reducing the threat of earthquakes to the citizens of our jurisdictions. This is true for at least three reasons: first, children, along with the elderly, are considered to be among the most vulnerable of all population groups; second, school children are a "dependent population" because they are mandated by state law to be in school and therefore require a higher standard of care; and third, there is a potential for outreach from the schools into all corners of the community.

We who are professionals in science, engineering, or emergency management are primary sources of information and can be instrumental in informing school decision makers about the need for earthquake safety and education programs. Other groups and individuals become informed and can and do make giant strides in raising awareness and providing information and direction.

APPROACH SCHOOL SYSTEMS WITH A PLAN

Especially valuable to busy and overburdened school administrators is concise information to help them:

--<u>Recognize the Hazard</u>. There is greater incentive and urgency for school decision makers to adopt earthquake preparedness programs when information is presented that convinces them the earthquake hazard exists under their enrollment area--be that state-wide, district-wide, or a neighborhood school. It helps dispel the common misconception that "Earthquakes are a California Phenomenon."

--<u>Conceptualize the Risk.</u> An understanding is needed of what to expect in a major earthquake and in the hours immediately following if major damage to structures and lifelines has occurred. The risk to school children then will become clear.

--<u>Organize for Action.</u> The action can be as simple as forming a school safety committee to gather information, or practicing and evaluating "drop and cover" drills. It can be as extensive as mobilizing the community to become involved. The key point is success brings additional success, so it is important to do something that is accomplishable with the available time and talent and move forward from the current success.

SCHOOL EARTHQUAKE PROGRAM RESOURCES

Following are some examples of materials that are available and have been used successfully:

Bus Drivers Video and Lesson Plans
Grades K-3 and 4-6 Original Stories and Curricula
FEMA "Guidebook" and WA ST Users' Guide
British Columbia, Canada, School Earthquake Preparedness Guide
Yogi Bear Comic Books and Video

The following materials are in the development stage--and are soon to be available:

Identification of Nonstructural Hazards in the Schools
"Drop and Cover" Poster and School Checklist

SUPPORT FOR SCHOOL EARTHQUAKE PROGRAMS

In a sampling of opinion among various members of the school community, it was found that most people thought support for earthquake preparedness in the schools should come from the top: the legislature should require and fund school earthquake programs; the state superintendent should provide funding, guidelines, and resources; and that districts should seek state help in order to support their building-level programs. One response indicated that support should come from the community level.

SUMMARY

Effort put into initiating school earthquake preparedness programs is well worthwhile. Through the schools is an important and effective way to reach many people and at the same time reduce the vulnerability of a highly vulnerable population--school children--to the effects of future earthquakes.

Methods used to encourage school programs might include helping school decision makers:

1. Recognize the earthquake hazard.
2. Conceptualize the risk.
3. Organize for action.

Participants in this workshop and many others like us are the primary sources of scientific, technical, and educational information. Our information can help show school decision makers how to plan and implement school earthquake safety and education programs to the benefit of the entire community.

SOURCES OF FURTHER INFORMATION

For further information, please contact:

Washington Division of Emergency Management
4220 East Martin Way, PT-11
Olympia, Washington 98504
Telephone (206) 459-9191

Listed on the following two pages are other sources of information and earthquake-related materials:

SOURCES OF EARTHQUAKE INFORMATION

April, 1989

U.S. GEOLOGICAL SURVEY Telephone: (509) 456-2524
Public Inquiries Office
Room 678, U.S. Courthouse
West 920 Riverside Avenue
Spokane, Washington 99201

Titles: Earthquake Information Bulletin (by subscription)
The Severity of an Earthquake
Earthquakes
Safety and Survival in an Earthquake
The Interior of the Earth

FEDERAL EMERGENCY MANAGEMENT AGENCY Telephone: (206) 481-8800
Region X
Federal Regional Center
130 228th Street S. W.
Bothell, Washington 98021

Titles: Contact FEMA for list of materials available from FEMA.

AMERICAN RED CROSS Contact your local chapter

Titles: Family Disaster Plan and Personal Survival Guide
Safety and Survival in an Earthquake
Employee Earthquake Preparedness for the Workplace and Home
Disaster Preparedness for Disabled & Elderly People
Assisting Disabled & Elderly People in Disasters
Many more

WASHINGTON STATE DIVISION OF EMERGENCY MANAGEMENT Telephone: (206) 459-9191
Department of Community Development
4220 East Martin Way, PT-11
Olympia, Washington 98504

Titles: Family Earthquake Safety Home Hazard Hunt & Drill
27 Things to Help you Survive an Earthquake
Earthquake Safety Checklist
Coping with Children's Reactions to Earthquakes
Preparedness for People with Disabilities
Preparedness in Apartments and Mobile Homes
Preparedness in High Rise Buildings
Washington State Earthquake Hazards
Guidebook for Developing a School Earthquake Safety Program
Washington State School Earthquake Emergency Planning
Safety Tips for Earthquakes; Disaster Driving
Reducing the Risks of Nonstructural Earthquake Damage
Abatement of Seismic Hazards to Lifelines (7 Volumes)
Earthquake Insurance: A public Policy Dilemma

Videos:
On Shaky Ground, 50 min. 1/2" VHS
A documentary on Puget Sound Earthquake risk, impacts and past damages. Overview of preparedness activities here and in California: KOMO-TV.

Shake, Rattle, and Roll, 25 min. 1/2" VHS
Describes home, family, and community preparedness for earthquakes and other disasters, comes with handbook: Lafferty and Associates, Inc.

Earthquake Dont's and Do's, 11 min. 1/2" VHS
Home routine interrupted by a sharp earthquake. Actor John Ritter does everything wrong. Correct procedures are then shown for what to do at school, at the office, and on the street. Ritter knows what to do when a second quake occurs. Produced by LSB Productions.

Earthquake Preparedness: The School Bus Driver, 16 min. 1/2" VHS
Describes the role of the school bus driver in an earthquake during route pick-up or drop-off times. A packet containing bus driver training lesson plans and school district procedures is also available. Can be used as general awareness video. Produced in a cooperative effort by the Seattle School District, et al.

Yogi Bear Earthquake Tips, 5 min. 1/2" VHS
Cartoon character shows children how to prepare for an earthquake at home and at school. A Hanna Barbera Production for the City of L.A.

Rumble Ready, 12.41 min. 1/2" VHS
An original story about "Drop and Cover" for children grades 3-6. Story title is Desk Nest. Produced by University of Washington Health Sciences Center for Educational Resources.

The Earthquake is Coming, 1 hr. 1/2" VHS
Documentary focuses on California. Discussion includes the impact of a major quake on communities, hospitals, economy and defense. Shows school preparedness programs. Produced by PBS "Frontline."

Slide Sets:

When the Unusual Happens, 46 35mm slides & script
An original story called "Habit Rabbit," about a town that wasn't prepared for an earthquake. The school children know what to do and "save the day." Appropriate for grades K-3.
Produced by University of Washington Health Sciences Center for Educational Resources.

Safety and Survival in an Earthquake, 71 35mm slides with audio cassette-34 min., or script available as option. Produced by Am.Red Cross.

Employee Earthquake Preparedness for the Workplace and Home, 137 35mm slides, audio cassette-19 min., or script available as option. Produced by American Red Cross, L.A. Chapter.

Books: On Shaky Ground, An Invitation to Disaster, by Tacoma Author John J. Nance. 419 pp. "What Every American Needs to Know About the Threat of Major Earthquakes, and Why We Are Not Prepared." Published by William Morrow and Company, Inc., New York.

MOTHERS FOR H.E.L.P.

By

Bev Carter
P.O. Box 87
Woodinvlee, WA 98072

Out of concern for their children's safety, as well as the influence of the film, ON SHAKEY GROUND, a documentary on Earthquakes in the Northwest produced by KOMO 4, **MOTHERS FOR H.E.L.P.** (Help Everyone Learn Preparedness), a non-profit organization was established to educate and organize communities to be self-reliant in the event that professional services are unavailable within **72-hours** after a major disaster.

The group has volunteered their time, funds, and services to teach an emergency community plan with neighbor helping neighbor using the **Singal Ribbon Concept** as the foundation for rendering help. After a community is educated to a self-reliant attitude, they can then be better prepared to render assistance to the local fire departments in aiding rescue and first-aid procedures.

The group of five Mothers has established a unified community plan which authorities seem to have a need and interest. Establishing local fire stations or designated schools or churches as a central emergency location, with the necessary supplies to meet the demands of emergency victims is one of the first goals of the group. Their second goal is to educate the public to the Signal Ribbon Concept to help save lives. A good school emergency program with first-aid kits, certified first-aid school personnel, stored water and an evacuation plan are foremost on their list of concerns.

After expenditures, donations would go to establish supplies in portable storage facilities outside each **COMMUNITY COMMAND CENTER.**

The greatest hurtle for the group has been first, apathy in city and local governments; secondly the necessary funding; media backing, and public ignorance. (If the populace were educated to what is ahead, they would then be able to prepare and could eliminate some destruction to property and life.)

The greatest asset has been the continued endorsement and support from those professionals like Linda Noson, FEMA, local fire and school authorities. Because of their independence, they have had the freedom to move quickly and efficiently on issues. Consequently, time has been focused where it has been most effective:

PREPARING THE PUBLIC!

Earthquake Risk Reduction Policies and Practices within the Puget Sound/Portland Areas

Peter J. May
Associate Professor of Political
Science and Public Affairs
Political Science DO-30
University of Washington
Seattle, WA 98195
(206) 543-9842

Overview

This presentation is based on an on-going study of risk reduction policies and practices at the local level within the Puget Sound and Portland areas. The findings from this research will help guide actions that can be taken during the implementation phases of the USGS assessment process.

Research to Date

The first nine months of this research project have been devoted to data collection concerning land use and building practices in relevant cities, counties, and special districts. Six counties in Oregon and 13 counties in Washington have been selected within which to study risk reduction practices among relevant local jurisdictions: (a) Puget Sound -- Island, Jefferson, King, Kitsap, Mason, Pierce, Skagit, Snohomish, Thurston, Whatcom; (b) Southeast WA -- Clark, Cowlitz, Greys Harbor; (c) Oregon -- Clackamas, Marion, Multnomah, Polk, Washington, Yamhill.

This expands somewhat the USGS delineated area in order to include a greater portion of the Willamette valley and seismic active areas in Southeast Washington. These 19 counties encompass 97 incorporated cities, 22 port districts, and some 182 related major public and private utility districts (water & sewer, gas, electric). Within these geographic areas there is a population of some 4.7 million people and commercial building permits for 1987 were valued at $1.5 billion. Interviews have been conducted in the 19 counties, 43 major cities over 10,000 population, and selected port and utility districts.

Findings to Date

Although the interview results have yet to be fully analyzed, several themes stand out from preliminary analyses of interviews with 170 officials in the 19 counties and 43 cities over 10,000 population in the area under study. In particular, the interviews evidence:

-Generally low levels of policy-level official perception of the risks posed by major seismic events, particularly in Oregon. Policy makers perceive the risks of significant damage, injuries, or loss of life from a major earthquake (M_L 6.5-7.5) in the next 20 to 30 years to be lower than the same risks posed (in increasing order of perceived risk) by landslides, flooding, or chemical spills. The perception of risk posed by moderate seismic events (M_L 5.5-6.5) is somewhat greater than a major landslide, but still less than major flood or chemical spill/hazardous material incident.

-None of the building officials had "building inventories," but our interviews were able to provide an overview of the building stock based on the building official's general knowledge of the jurisdiction. Among Washington cities over 10,000 population, unreinforced masonry buildings are very common in 40 percent of the cities, tilt-up concrete slab buildings built before the mid-1970s are prevalent in 22 percent of the cities, and reinforced concrete frame buildings built before the 1960's were prevalent in 25 percent of the cities. The corresponding figures for Oregon cities over 10,000 population are 15 percent having URM buildings as very common, 25 percent with tilt-ups built before the 1970s and 13 percent with reinforced concrete frame buildings built before the 1960s.

-Building officials seemed to be relatively aware of the potential damages that could result from moderate to major earthquakes (defined as above). Building officials ranked the expected damage to buildings and related injuries and deaths, if an event occurred, to be the greatest for a major earthquake followed in order by a moderate earthquake, major flood, and major landslide (not asked about chemical spills). This perception appears to be meaningful as it corresponds with differences among cities in the nature of the building stock. Building officials' sense of damage potential is moderately correlated with the prevalence of unreinforced masonry buildings ($r=.41$) and the prevalence of tilt up buildings built before the mid-1970s ($r=.46$). It is only weakly correlated ($r=.14$) with the prevalence of reinforced concrete frame buildings built before the 1960s.

-Major differences between Oregon and Washington in state-level policy mandates and roles. Both Oregon and Washington have state-level mandates for building regulation in referencing the UBC. There are important differences, however, in that Oregon has a lower seismic zone designation, Oregon has a stronger state role in regulating building, and Oregon puts more limits on local discretion in amending the UBC. Oregon has a much stronger state-level mandate for land use planning that incorporates a mandate for attention to natural hazards (Goal 7 of the 1973 Oregon Land Use Act). Washington's mandate for consideration of natural hazards in land use decisions comes less directly through the Washington State Environmental Protection Act of 1973 which provides a local option to regulate sensitive areas.

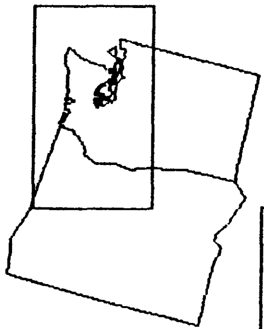
-Little variation within each of the two states among local *policies* with respect to land use and building regulation. State building code (referencing UBC) and land use provisions dominate the framing of local policies, within which there are relatively minor variations in local adoption. Relatively few "innovations" exist in regulations or policies concerning seismic hazards in this region of the country.

-Some 80 percent of the Washington jurisdictions over 10,000 population and 60 percent of the Oregon jurisdictions over 10,000 population had building codes prior to the state-level mandates of the mid 1970s. Typically, the codes were adopted by larger cities in the late 1950s or early 1960s in referencing the then current UBC provisions. Counties tended to follow later in adopting building codes. There appears to be limited local "regulatory capacity" to deal with seismic provisions in that only 20 percent of the larger cities have structural engineers on staff (most rely on ICBO or outside consultants), and primary enforcement of code provisions takes place through plan review and inspection.

-Considerable variation in local *practices* in the way in which policies are carried out and in exercising building official discretionary actions. This variation is in part explained by "sophistication" of building and land use departments, but also is dependent upon the general development and building climate of a jurisdiction. These differences are most evident for the treatment of renovations of existing buildings.

-Heavy dependence in port districts and utilities upon "engineering practice" in addressing seismic hazards. Utilities vary in the extent to which they rely upon in-house staff, but in any instance ports and utilities are subject to building practices that are often not defined by codes. Engineering practices, in these instances, are heavily dependent upon knowledge of relevant guidelines (e.g., guidelines for water tanks, pipelines) and assumptions about design earthquakes.

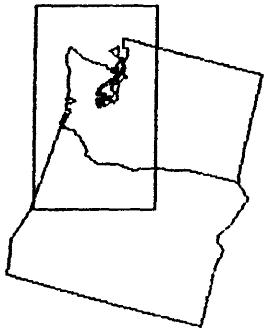
The broad implications of these themes are to draw attention in two directions: (1) to the way in which state mandates help shape local policies and practices, and (2) to the way in which professional practices affect earthquake risk reduction.



Research Agenda

- Characterize Sense of Risk
- Identify Local Policies and Practices
- Provide Context for Future Implementation

P. May

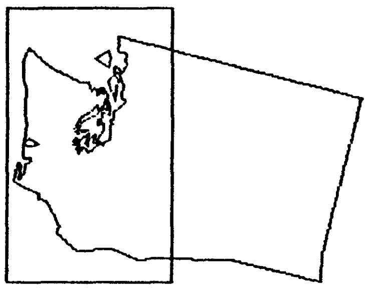


Facts About The Setting

Area Under Study Includes

- Many Local Jurisdictions
  - 97 Incorporated Cities
  - 22 Port Districts
  - 200+ Major Special Districts
- 1987 Population of 4.7 Million
- 1987 Commercial Building Permit Value of $1.5 Billion

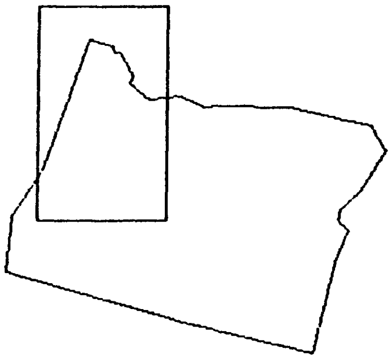
P. May



Washington Jurisdictions
Under Study

- 1987 Population 3.3 million
- Commercial Building $1.5 billion 1987
- 13 Counties Under Study
  - P. Sound -- Island, Jefferson, King, Kitsap, Mason, Pierce, Skagit, Snohomish, Thurston, Whatcom S.E./Other -- Clark, Cowlitz, Grays Harbor
- 27 Major Cities Under Study
  - Bellingham, Bellevue, Everett, Olympia, Seattle, Tacoma, Vancouver

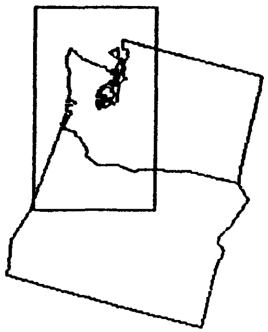
P. May



Oregon Jurisdictions
Under Study

- 1987 Population 1.4 million
- Commercial building $.2 billion 1987
- 6 Counties under study
  - Clackamas, Marion, Multnomah, Polk, Washington, Yamhill
- 16 Major cities, including:
  - Beaverton, Gresham, Portland, Salem

P. May



EARTHQUAKE RISK PERCEPTIONS

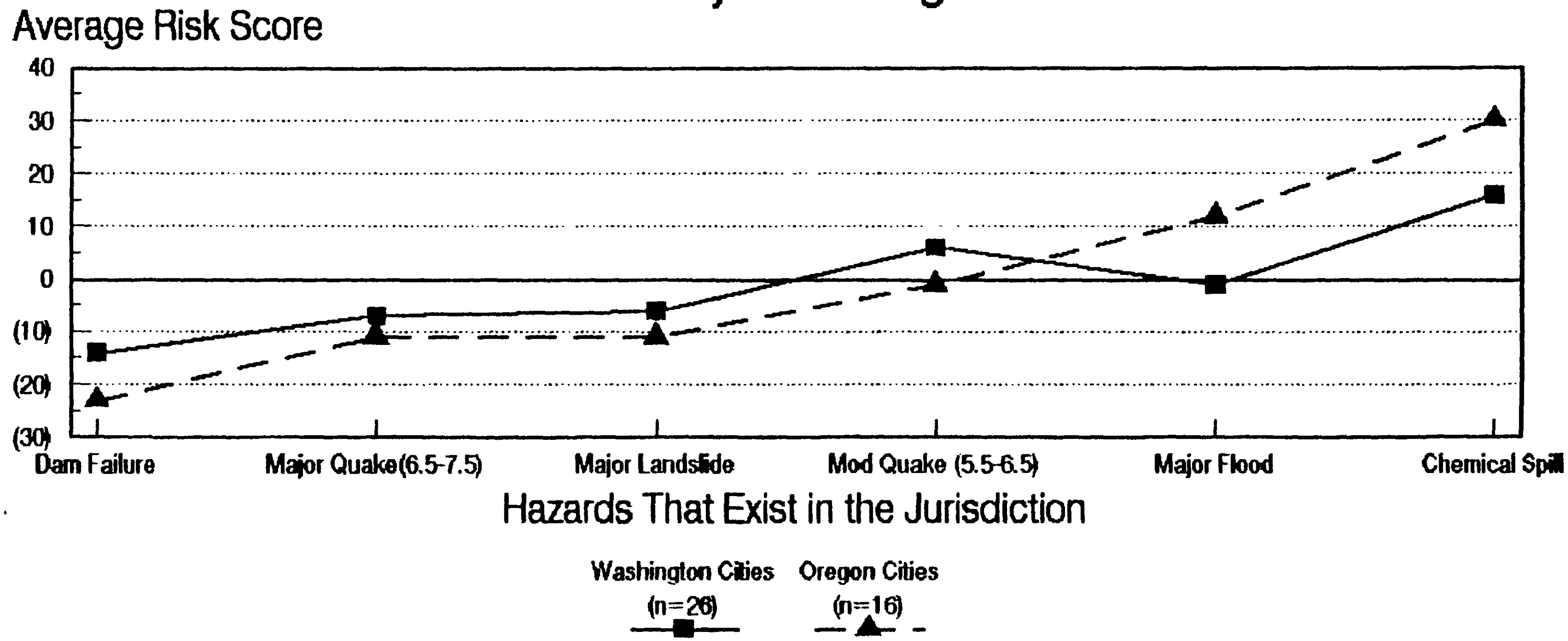
Overview -- Policymaker Perceptions

- Lower Perception than Some Other Risks
  - Policymakers think about other hazards
  - Policymakers discount probability of major quake
- Some Correspondence with Objective Risk
  - Oregon perception lower than Washington
- Building Officials Provide Different Sense
  - Awareness corresponds to existing bldgs
  - Low correspondence with policy officials

P. May

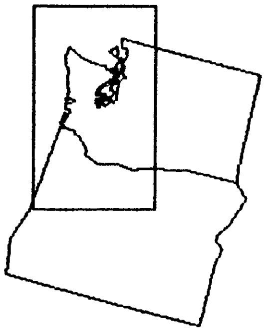
Officials' Risk Perceptions
(Cities Over 10,000 Population)

Policy Makers Rate Major Quakes As Lower Probability of Damage than Other Hazards



Scores are scaled to be deviations from means given relative risk, excludes DK and NR

P. May



Potentially Hazardous Buildings

Existing Buildings As Potential Hazard

Building Official Perception of Damage

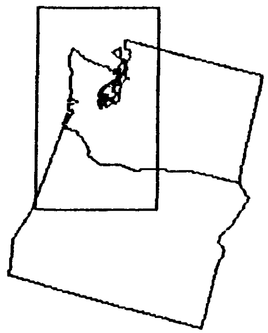
Cities Reporting Hazard
(some or very common)

	WA Cities (n=26)	OR Cities (n=16)	Correlation with Damage Rating
Unreinforced Masonry	40 %	15 %	0.41
Tilt Up before 1970s	22 %	25 %	0.46
Reinf C-Frame 1960s	25 %	13 %	0.14

Table for cities over 10,000 pop; some missing

Damage Rating is for Quake R6.5-7.5

P. May

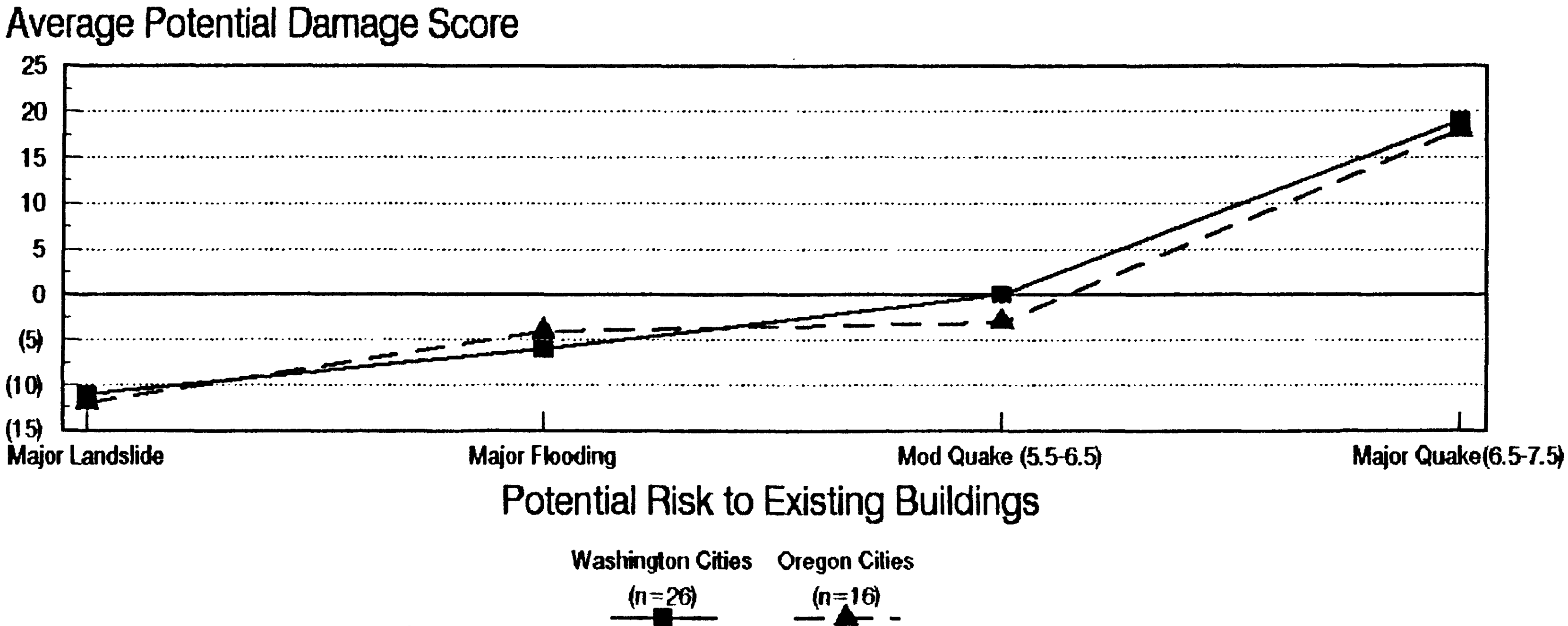


Building Officials' Projection Of Damages

(Cities Over 10,000 Population)

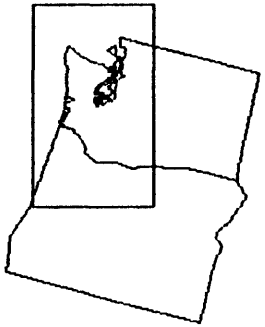
Noteworthy Damages Are Expected

(assuming events occur)



Scores are scaled to be deviations from means of potential damage, excludes DK and NR

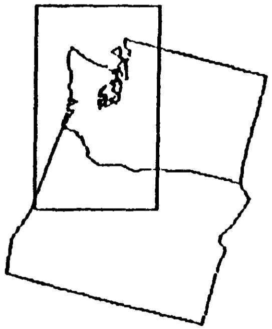
P. May



Building Regulation
State Policy

- State-Level Policy Mandates Exist
  - WA & OR 1974 Legislation -- UBC
  - State-level building code agencies
- Important Differences -- OR & WA
  - UBC Seismic Zone Designation/Provisions
  - ORE different enforcement mechanisms
  - ORE more limits on local discretion
- Results in Local Policy Differences

P. May



Building Regulation

Local Policy & Practice

(Cities over 10,000 population)

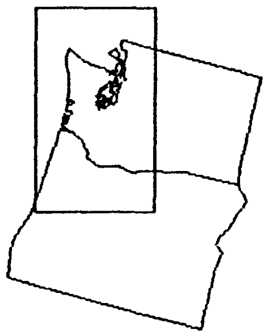
- Seismic Codes Prior to State Legislation
  - 80% WA cities, 60% ORE cities
  - Mostly adopted late 1950s or early 1960s
  - Counties tended to follow later
- Limited Local Regulatory Capacity
  - 20% cities have struct eng on staff
  - Enforce through plan review & inspection
- Variation in Practice for Existing Bldgs
  - Levels of review, triggers for review
  - Parapet ordinances – Tacoma, Seattle

P. May

Land Use
State Policy

- **State-Level Policy Mandates**
  - ORE Land Use Act 1973
    - State-wide standards and mandate
    - Goal 7 addresses natural hazards
  - WA State Environmental Protection Act 1973
    - Local option to regulate sensitive areas
- **Differences Oregon & Washington**
  - ORE stronger state mandate & role
  - ORE establishes land use guidelines

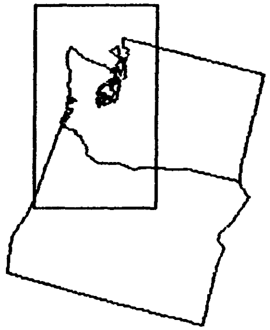
P. May



Land Use - Local Policies
(Major cities and counties)

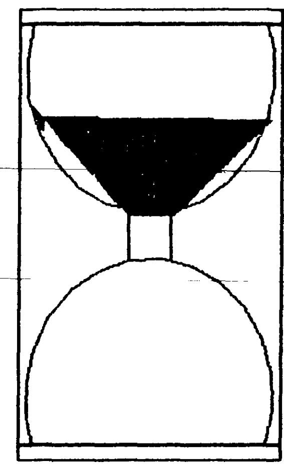
- **Some Attention to Secondary Seismic Hazards**
  - Steep slopes regulated 60% cities
    - Sensitive area ordinances (WA)
    - Drainage and fill ordinances
    - Engineering review for new construction
  - Less Attention to Unstable Soils
    - If at all, through building process
- **Federal Mandates Drive Local Flood Regulation**
  - 90% cities have FEMA flood regs
  - Some attention to tsunami (e.g., Aberdeen)

P. May



Implications
(More to Come)

- **Glass Half-Empty, Half Full**
  - Awareness of building officials generally good
    - But they tend to have little policy influence
  - Newer buildings appear relatively good shape
    - But exising buildings are noteworthy hazard
- **Future Ability to Reduce Risk Depends On**
  - Altering state mandates – bldg codes/zones
  - Influencing professional practices
- **Potential for Local-Level Risk Reduction**
  - Discretion in practice for existing buildings
  - Innovations have & can occur



P. May

POST-DISASTER EMERGENCY RESPONSE ISSUES IN URBAN SETTINGS

By

Patricia A. Bolton
Battelle Human Affairs Research Center
Seattle, Washington

INTRODUCTION

Major disasters in urban settings are characterized by a tremendous increase in the demands placed on local organizations responsible for emergency response, and by convergence of a large number of local and extra-local organizations of various types offering to assist in providing emergency services. Several decades of disaster research on organizational and individual response provide insights into some of the characteristics inherent in disaster settings that affect the ability to meet the demands created by the destruction. Disaster response managers need to be aware of the fact that there are some general lessons from past disasters that can be helpful in anticipating certain kinds of problems. At the same time every disaster is also unique in a variety of ways, meaning that disaster managers also must be able to improvise to meet the totally unanticipated problems. Many of the findings from this research and their implications are summarized in Drabek (1986), Quarantelli (1985) and by the Earthquake Engineering Research Institute (1986).

ORGANIZATIONAL RESPONSE

Following a major disaster there are many kinds of demands that can be met by the community's functional agencies. Examples of these demands following earthquakes are putting out fires, fixing life lines, and clearing debris. However, major disasters also create a wide array of organizational demands due to the greatly increased levels of interaction necessary among the many responding organizations and groups. The organizational demands created by disasters are not necessarily totally new to emergency managers, but the far greater number of the demands and relevant players, and the need for quick resolution often exceed the capability of the response system to meet them effectively. These demands center around changes that can be observed after a disaster in the communication process, the exercise of authority, and the need for well-developed coordination of the ongoing activities (Quarantelli, 1985).

Examples of some of the problems that arise include the following. Not only will there be a need for higher levels of communication within and between organizations involved in the response, but the efforts of the public to provide or receive information can quickly founder the phone system. The information seeking activities of the general public, and also of the media, can be expected to place extra demands on response organization staff. Normal patterns of authority may be strained when new disaster tasks are encountered for which someone must take responsibility, and when emergency groups from outside the local area arrive, or ad hoc groups emerge from the community to assist in the response activities. Few players in the response organization will disagree that coordination is necessary, but there may be disagreement about the definition of coordination which can hamper the achievement of adequate coordination.

One aspect of disasters that is less typical in small-scope emergencies is the emergence of another set of organizations and groups of people volunteering to help with various aspects of the response. Emergency response planners need to view this phenomenon as basically inevitable and natural, and consider the positive gains that can be made by taking these groups into account (Stallings and Quarantelli, 1985). This emergent behavior cannot be eliminated by better planning, but it may be possible to make effective use of it to meet unanticipated demands following disasters.

The organizational demands placed on the response system are inherent in the disaster context and can be expected to occur to a greater or lesser degree, depending on the scale of the disaster and the capabilities of the emergency response managers. Disaster planning can help to reduce communication and coordination problems following disasters, but only if efforts are made to assure that actions in the plan can be implemented when the time comes. Disaster planning that focuses on the production of a written plan probably will be the least effective approach to minimizing organizational problems. Instead, disaster planning needs to be treated as an ongoing process, involving interaction among the relevant organizations, and various training and educational activities. The disaster planning process should result in disaster response managers that view disaster response from the viewpoint of the whole system of relevant organizations rather than just their own, that think about general problems likely to occur and their solutions, rather than about specifics, and that seek ways to achieve appropriateness of responses rather than just speed (Quarantelli, 1985).

Also, it has been observed that disaster response managers carry many misconceptions about how people respond under the extreme stresses associated with experiencing a disaster (Wenger, et al., 1980). Disaster response will be more effective when it takes into account what is known about individual and group response, rather than operating to prevent things that don't occur anyway, or assuming that individuals and groups will accommodate themselves to the preferences of the authorities.

INDIVIDUAL BEHAVIOR

Individuals and families coping with the destruction and disruption of a disaster have been found generally to exhibit the following behaviors: a high degree of reasonable behavior and personal initiative, rather than panic or passive despair; little inclination to see the disaster as an opportunity for anti-social behavior such as looting; an overwhelming emphasis on ascertaining the location and safety of other members of the family before attending to any other activities; a strong preference for remaining near their homes in the disaster area when possible; a tendency to seek assistance from and give assistance to relatives and friends, initially ignoring formal assistance contexts (Mileti, et al., 1975; Drabek, 1986; EERI, 1986). Misconceptions about how individuals react to disasters has lead to an over-emphasis on such things as security activities after disasters, efforts to evacuate people from the area immediately, and a lack of insight into the extent to which the survivors themselves serve as a major response resource.

The generally rational and instrumental behavior observed on the part of individuals caught in disaster situations is an important concept for earthquake response planning. A strong earthquake in an urban setting can lead to widespread disruption, blockage of access routes, and overwhelming demands likely to be placed on response organizations to respond first to the most acute life-threatening problems. In California, efforts have been made to make citizens aware of the fact that many neighborhoods may be left on their own for even as long as three days following a major earthquake. It is assumed that citizens will be able to rise to such an occasion without undue difficulty, especially if they have been made aware of the likelihood of this situation, and guided in preparing for it.

Generally, a spirit of community togetherness and altruism will emerge following a disaster. People help each other, and informal groups emerge to attack problems such as search and rescue, or debris clearance. But this altruism wanes after the early emergency phase, and expectations of assistance and quick solutions to the disruption will increase. Ineffective emergency response can serve to hasten and heighten the eventual expressions of dissatisfaction and frustration on the part of the disaster victims.

EARTHQUAKES AND THE URBAN SETTING

Larger cities in the United States present very complex environments in which to anticipate potential problems. The populations typically are very heterogeneous, and even in very earthquake-prone areas awareness of and reactions to earthquakes may vary across ethnic or socioeconomic groups. Large urban areas are likely to already be facing various social services crises, such as shortages of housing, which are exacerbated by the destruction of residences and facilities. And even in circumstances where only a small proportion of the overall population is directly affected by the damage, there still may be a large absolute number of victims needing services that can create severe short-term problems in relief management.

Earthquakes differ from several other types of natural disaster agents in that they typically come with no warning, compared to many extreme weather-related disaster agents. All mobilization of response activities must come after the destruction has occurred. Also, there is no way to be sure that the first shock will be the only one, or even the strongest one. This creates considerable uncertainty about the safety of moving around in the disaster area, in case of further damage by later tremors. Damage assessments need to be made quickly, but must be done by experts that may be in short supply. People wanting to re-enter their residences to retrieve necessary and valuable items may be at further risk.

Another more fortunate feature is that the consequences of the ground shaking are transferred to humans through the built environment. That is to say, people are not hurt and killed by earthquakes, but rather by what earthquakes do to the buildings where people carry on their daily activities. The damage pattern will typically correspond to some interaction between building type and its location with respect to soil type, so that particularly vulnerable population groups, or neighborhoods can be identified during the planning process. Thus, a very effective approach to reducing loss of life and damage, is to strengthen or eliminate those buildings most vulnerable to earthquake damage. Because of political and economic factors, this can be a time-consuming process. In the meantime, it is important for emergency planners to understand where the greatest damage is likely to occur, and to try to anticipate special problems indicated by the social characteristics of these areas.

An illustration of this is provided for the City of Seattle. Even without knowing much about individual structures, and spending only a few hours compiling data, some general patterns can be suggested. For example, Figure 1 ranks neighborhoods in terms of the proportion of residences over a certain age. Frequently older buildings are among those most damaged, because of less widespread use of building practices that may be required in more recent structures to provide greater resistance to seismic forces. It can be clearly seen that such buildings are not evenly distributed throughout the city. To the extent that these residential structures prove less seismically resistant than others, some parts of town can be expected to have more damage than others. Additional information on topography and soils could refine this further.

Figure 2 specifies the problem in another way, by identifying those census tracts in which there still exist clusters of unreinforced masonry buildings used for residential purposes. These buildings are particularly sensitive to certain kinds of groundshaking, and can suffer extensive damage or collapse even in moderate earthquakes. Areas with many of these buildings should be given special consideration in earthquake response planning. The areas indicated in Figure 2 are those noted by local experts with a special interest in earthquake loss reduction. A somewhat more systematic survey of the city, even a quick visual scan of neighborhoods without entering buildings, perhaps would suggest other similar areas that warrant special concern.

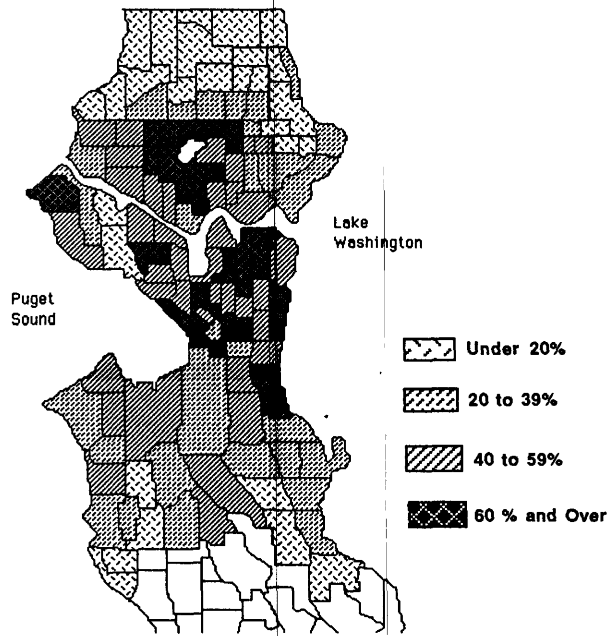


Figure 1. Percent of Housing Structures Built 1939 or Before, by Census Tract, City of Seattle, 1980

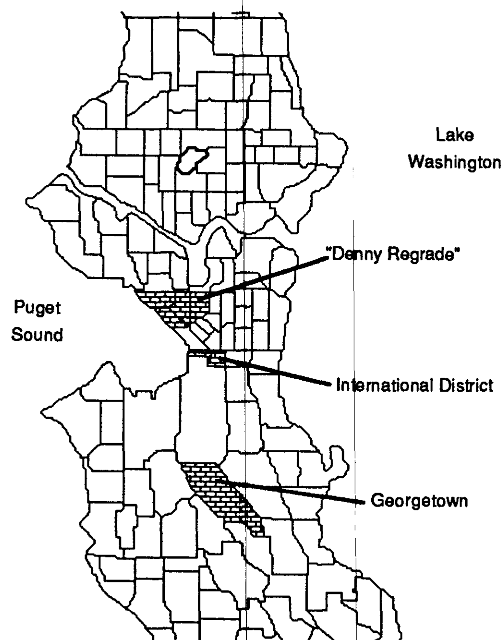


Figure 2. Census Tracts Estimated to Have the Greatest Concentrations of Unreinforced Masonry Residential Units

Figure 3 categorizes census tracts in terms of the proportion of Asian-descent residents. Since this is based on 1980 U.S. census data, it is likely that 1990 census data will show some variation from this pattern. In the meantime, such data can be refined by talking with local agencies. This type of information is especially important if much of this population consists of newly arrived immigrants who may be unfamiliar with English, or with the earthquake hazard. Even in long-established ethnic neighborhoods, the older residents may not be English-speaking. A similar analysis of the distribution of the elderly showed a distinct concentration of elderly in the downtown area, where the elderly represented over 35% of the population in six tracts. The elderly may need special attention due to mobility problems, and replacement housing will be difficult to find since since many will also be in the low income group, and unable to afford most other housing in the city.

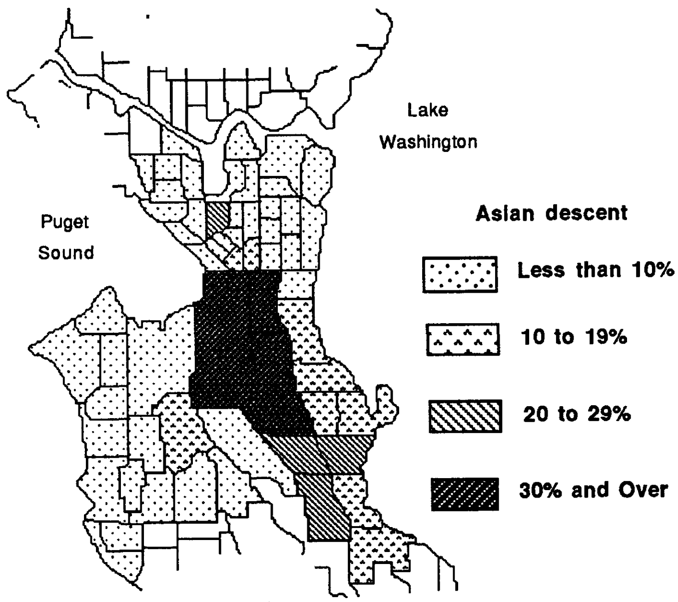


Figure 3. Percent of Residents of Asian Descent, by CensusTract, Central and South Seattle, 1980

Figure 4 summarizes the information by using the two population characteristics of age and ethnicity to describe the areas with the most unreinforced masonry in residential use. This suggests that two neighborhoods with some of the city's least seismically resistant housing---the Denny Regrade and the International District—in 1980, and probably to date, have high concentrations of populations that may require special attention following an earthquake.

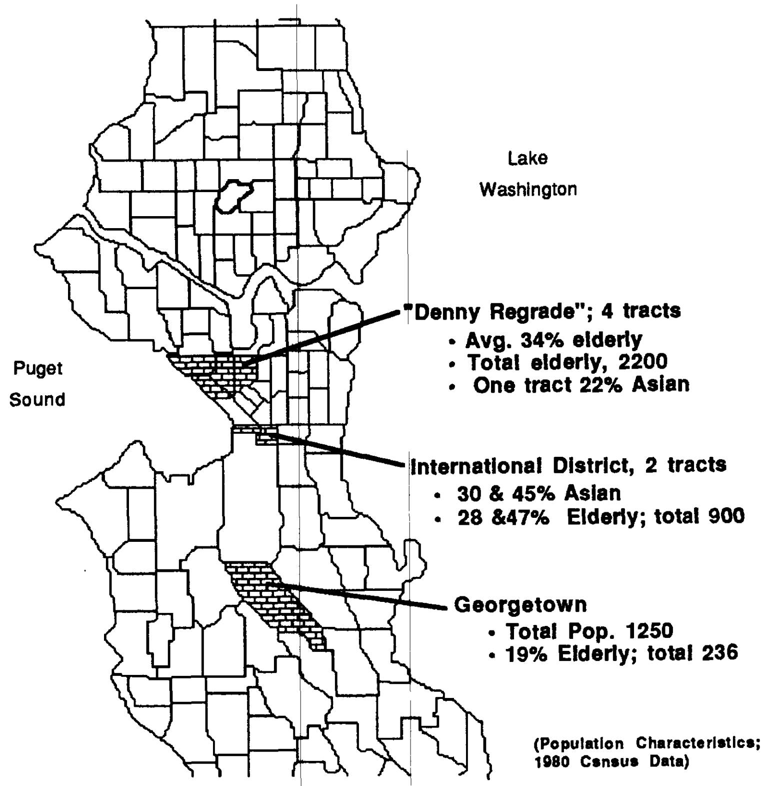


Figure 4. General Characteristics of Areas With Unreinforced Masonry Residential Units

The Whittier Narrows earthquake of 1987 demonstrated that such a situation existed in parts of downtown Los Angeles. Although the number of residential buildings in the City of Los Angeles that were damaged by that earthquake was insignificant in terms of the total size of the city, most of the damaged buildings were of unreinforced masonry construction, and most were apartment buildings. Even one damaged building could displace 50 or 100 families. Further, because of social and economic factors, a large proportion of people living in these buildings were of Hispanic origin and non-English speaking. The emergency relief system found itself faced with special communication and relocation problems. Approximately 10,000 persons eventually registered at Red Cross shelters, most of them fluent only in Spanish. Special efforts had to be made after the earthquake to provide Spanish-language signs about building damage and brochures on assistance sources, and find Spanish-speaking staff and volunteers to work with the affected population in the shelters and relief centers.

In summary, research on emergency response has identified elements of the emergency period that pose challenges to emergency response organizations, and to the coordination of the entire emergency response system following major disasters. Earthquakes, because of their potential for creating wide-spread building damage and disruption in lifelines in densely populated urban areas can create high levels of demands on the emergency response system. However, relationships among variables such as type of building, soil, and groundshaking suggest that it can be helpful to identify as part of the emergency planning process those areas of the city likely to experience the greatest disruption, and to consider the social characteristics of the areas for indicators of special response problems likely to be encountered there.

REFERENCES

Drabek, T.E., 1986. Human Systems Responses to Disaster: An Inventory of Sociological Findings. New York: Springer-Verlag.

Earthquake Engineering Research Institute, 1986, Reducing Earthquake Hazards: Lessons Learned from Earthquakes, Chapter 7. Publication No. 86-02. El Cerrito, California.

Mileti, D.S., T.E. Drabek, and J.E. Haas, 1975. Human Systems in Extreme Environments. Boulder, CO: Institute of Behavioral Science, University of Colorado.

Quarantelli, E.L., 1985, Organizational Behavior in Disasters and Implications for Disaster Planning. Columbus, Ohio: Disaster Research Center, The Ohio State University.

Stallings, R. A., and E.L. Quarantelli, 1985. Emergent Citizen Groups and Emergency Management. Public Administration Review, Vol. 45, pp. 93-100.

Wenger, D.E., T.F. James, and C.E. Faupel, 1980. Disaster Beliefs and Emergency Planning. The Disaster Research Project, Final Report to the National Science Foundation, Grant # EN77-10202. Newark, Delaware: University of Delaware.

THE DECEMBER 7, 1988, SPITAK (SSR) EARTHQUAKE

By
Walter W. Hays
U.S. Geological Survey
Reston, VA 22902

INTRODUCTION

On December 7, 1988, when the magnitude 6.8 earthquake struck Soviet Armenia at 11:41 a.m., leaving an estimated 60,000 dead, 18,000 injured, 510,000 homeless, and reconstruction costs of $16 billion, the world was reminded of what a damaging earthquake can do to a nation, its urban centers, gross national product, and the societal fabric. An earthquake:

- o shows whether preparedness planning and mititgation measures were adequate, or not,
- o tests the siting, design, and construction practices for lifelines, buildings, and critical facilities, and
- o stretches the capacity of the populance to respond to the disaster and to make appropriate modifications in practices during the long recovery period.

IMPORTANT LESSONS

Multidisciplinary studies of the Soviet Armenia earthquake by a U.S. team of experts and previous studies of other earthquakes have taught us many important lessons. Several are singled out:

- o A community that does nothing to prepare for a damaging earthquake sows the seed of disaster, especially if damaging earthquakes have occurred in the past. (Armenia was unprepared for such an earthquake, even though damaging earthquakes have occurred there in the past).
- o The destructiveness of an earthquake depends on its size, proximity to urban centers, and the state-of-preparedness in the urban centers. (Armenia was unprepared, the earthquake was the largest in their history, and villages like Spitak took a "direct hit" in the epicentral region.)
- o The time factor is extremely important. The critical time frames are:
  - -- seconds for duration of ground shaking,
  - -- minutes for the first occurrence of the aftershock sequence and the build up of pore water pressue in liquefiable soils,
  - -- hours to a few days for emergency response and search and rescue activities,
  - -- days to years for predictions and warning and personal preparedness,
  - -- years to decades for community preparedness and recovery programs, and
  - -- decades to centuries for the seismic cycles of various active faults to be completed. (Armenia could have been spared much of the

devastation if: a) the earthquake had occurred 5 minutes later when the school children were outside the schools that were destroyed and on their way home for lunch, b) the level of personal preparedness had been greater, and c) the level of community preparedness had been greater.)

- o Earthquake prediction and warning are of limited value when the societal component is not as well developed as the scientific component. (Soviet authorities had been advised three years ago by scientists of the increased probability of a damaging earthquake in Armenia, but no action was taken.)

- o A primary cause of damage to buildings is underestimation of the amplitude, frequency composition, and duration of the ground shaking. (The earthquake had an epcientral intensity of MSK IX-X; whereas, the design was for intensity VII, i.e., about one-eighth the actual force level.

- o Good quality of construction provides a margin of safty to compensate for uncertainties scientists and engineers face in siting and design. (Quality of construction and detailing were poor in Armenia. Modern buildings designed and constructed in the 1970's failed and became death traps primarily because the floor systems were not constructed and anchored in a way that allowed them to participate with the strucutre in the absorption of energy.)

- o Almost all earthquakes produce "surprises" because we either have not learned everything we need to know about the nature and effects of earthquakes, or we have not done a good job of applying what we do know. A damaging earthquake exposes the flaws in:

  - -- siting and design of structures and lifeline systems,
  - -- construction practices,
  - -- emergency response, and
  - -- personal and community preparedness.

Armenia provided the following "surprises:" a) the harsh realities of the first 24 hours of search and rescue in a winter environment, b) the vulnerability of precast reinforced concrete frame buildings--for which a large inventory still exists in Yerevan (the capital) and in other parts of the Soviet Union, and c) the injury to death ratio, which is typically 3 or 4 to 1, was reversed in the earthquake-creating a major public health problem.

SUMMARY

The Armenia earthquake provided many important lessons that can be adapted to every earthquake-prone part of the United States. On May 23-27, 1989, representatives of the U.S. team that went to Armenia after the December 7 earthquake and other specialists will be meeting in Yerevan to share their insights with representatives of the French and Japanese teams. These insights will be offered to Soviet authorities as recommendations to aid the Soviet's reconstruction program and as proposals for cooperative endeavors to keep a disaster like this one from happening again anywhere in the Soviet Union and other parts of the world.

ARMENIA EARTHQUAKE

BACKGROUND

The magnitude 6.8 Spitak earthquake which struck Soviet Armenia at 11:41 a.m. local time on Wednesday, December 7, 1988, caused the following impacts:

- twenty thousand injured,
- an estimated 60,000 dead, (the exact number may never be known),
- five hundred and ten thousand homeless,
- collapse and heavy damage to buildings and industrial facilities:
  - in Spitak: damage to 100% of the building stock, with at least 12,000 to 15,000 dead.
  - in Leninakan: damage to 80% of the building stock with at least 10,000 to 12,000 dead, and
  - in Kirovakan: damage to 50% of the building stock, with at least 450 dead.
- extensive social disruption, and
- reconstruction costs that are estimated to reach $16 billion or more.

In Armenia, the principal building types were:

- Stone-bearing wall buildings, the traditional construction technique until 1970. These buildings were limited in height to five stories. The masonry walls are thick, lack steel reinforcement, and provide both lateral and vertical support for the hollow core concrete plank floors and roofs which were introduced in the 1950's and 1960's.

- Composite frame and stone wall buildings, mostly 4- and 5-story buildings consisting of exterior stone shear walls and framing system cast within the walls as well as the interior of the building.

- Precast concrete frame-panel buildings, which began in the 1970's and today are the predominant design for residential and industrial structures. In the affected area, the tallest of these buildings was nine stories with one-story penthouses. Floors and roofs are precast hollow-core concrete planks that bear on the walls but have no connections. The buildings have steel reinforcement.

- Precast concrete-panel buildings, a contemporary building type in Armenia which was just beginning to be widely constructed for public and residential use. They ranged in height to nine stories. Floor and roofs are also precast hollow-core concrete planks. They are relatively stiff.

- Concrete lift-slab buildings, which involve either one central core or double cores of cast-in-place concrete shear walls. Floor and roof slabs are cast in grade, lifted into place, and supported by columns. The cores provide lateral stability for the structure. Building performance depends strongly on the quality of the attachments of the slabs of the cores. Only two buildings of this type--one of 10 stories and another of 16 stories--had been erected in Leninakan at the time of the Spitak earthquake. Both buildings were heavily damaged, requiring subsequent demolition.

In the 400 square kilometer epicentral region affected most severely by the Spitak earthquake, the damage statistics for the four principal types of buildings (see Table 1) stone bearing wall, composite frame and stone wall, precast concrete frame-panel, and precast concrete-panel are:

-- 314 buildings collapsed,
-- 641 needed to be demolished,
-- 1,264 needed repairs or strengthening, and
-- only 712 (24%) remained habitable after the earthquake.

The Spitak earthquake produced two contrasts in performance:

-- the performance of precast concrete frame-panel buildings in Leninakan versus their performance in Kirovakan, and

-- the performance of precast concrete frame-panel versus the performance of precast concrete-panel buildings.

In Leninakan, 54% of the precast concrete frame-panel buildings collapsed, 41% will have to be demolished, 5% will need repairing and none escaped damage. In contrast, in Kirovakan, none of the precast concrete frame-panel buildings collapsed or needed to be demolished and 19% escaped damage altogether. The explanation--site amplification in the 1.0 to 2.5 second period band by the deep (200-300 m; 660-1000 ft) lake bed deposits underlying Leninakan; soils in Kirovakan are thinner and stiffer. Also, the buildings in Kirovakan are limited in height to 5 stories.

The damage distribution is give in Table 1. Armenian engineers rated the epicentral intensity as IX t X (MSK scale). They estimated that levels of horizontal peak ground acceleration may have reached 0.50 to 1.0 g in Spitak, possibly with a large vertical component as well because of the thrust fault. The estimated level in Leninakan was about 0.40 g, based on seismoscope records.

Recorded peak ground acceleration values are 0.21 g at Ghoukasian (located 33 km from the epicenter) and 0.06 g at Yerevan, (located 100 km from the epicenter).

In Armenia, most designs were for an intensity (MSK scale) of VII to VIII, with reductions being permitted for volcanic tuff foundation materials.

ISOSEISMAL MAP

In the Soviet Union, a 12-point intensity scale known as MSK-64 is used for seismic zoning and design. The description of each intensity level closely parallels that for the Modified Mercalli Intensity scale. Before the earthquake, Leninakan was specified as zone VIII, and Spitak and Kirovakan were specified as zone VII. The epicentral intensity was IX - X. The correlation of intensity with peak ground acceleration is:

-- intensity VI; 0.025 to 0.05 g
-- intensity VII; 0.05 to 0.10 g
-- intensity VIII; 0.10 to 0.20 g
-- intensity IX; 0.20 to 0.40 g
-- intensity X; 0.40 to 0.80 g

The structures in Leninakan, Spitak, and Kirovakan had been designed for lateral forces approximately equal to 2.5 to 5 percent of their weight.

FAILURE MECHANISMS OF STONE-BEARING-WALL BUILDINGS

Damage to stone-bearing-wall buildings, which were the predominant construction type in Spitak, occurred in a variety of ways:

-- The onset of damage typically occurred at building corners with almost every surviving building showing visible cracks.

-- In some buildings, the walls tilted away from the concrete plank floors, resulting in the collapse of the planks.

-- In some buildings, the end walls collapsed; whereas, in others, the end walls remained upright and the middle collapsed as a consequence of the failure of the precast hollow-core concrete planks to act as an effective floor diaphram, causing the transfer of forces to the masonry walls.

FAILURE MECHANISMS OF PRECAST CONCRETE FRAME-PANEL BUILDINGS

Precast concrete frame-panel buildings in Armenia were typically constructed in long rectangular configurations with columns and beams providing the vertical load carrying system. The floor and roof systems were hollow-core precast concrete plans, without topping slabs or positive connections to the building frame. Perimeter walls and selected interior walls of unreinforced masonry infill, precast fascia panels, and precast-concrete-shear panels were designed to provide lateral stability in the longitudinal direction; whereas, the frames were designed to provide the lateral-load resisting path in the transverse direction.

The most common failure patterns included:

-- Separation at wall, floor, and corner connections.
-- Loss of longitudinal stability due to infill masonry (typically volcanic tuff) falling out of the frames.
-- Damage at corner splices, which consisted of lap welds of reinforcing steel bars extending from the upper and lower column sections. Due to poor quality control in the field, these splices were often eccentric.
-- Loss of containment due to minimal hoop reinforcement.
-- Buckling of columns at reinforcing splices.
-- Failure of frames due to the rigid, heavy, precast infill panels.

REFERENCES

1) The Soviet Armenia Earthquake Disaster: Could a Similar Disaster Happen in the United States? Hearing of March 15, 1989, convened by the Subcommittee on Science, Research and Technology of the Committees on Science, Space and Technology of the U.S. House of Representatives: Witnesses: Frederick Krimgold, Peter Yenev, Loring Wyllie, Eric Noji, Henry Siegleson, Ronald Coleman, Larry Green, Christopher Rojan, Jerome Iffland, Michael Heisler, and Richard Bail.

2) Cluff, Lloyd S., and Tobin, L. Thomas, The December 7, 1988, Earthquake in Armenia Soviet Socialist Republic, Report to the California Seismic Safety Commission, March 1989.

3) Filson, John R., Agbabian, Mihran S., and Noji, Eric R., Postearthquake Investigations of the December 7, 1988, Spitak Earthquake, Proceedings of by the United States International Symposium on the Spitak Earthquake, May 23-26, 1989, Yerevan, Armenia.

THE INTERNATIONAL DECADE FOR NATURAL DISASTER REDUCTION (IDNDR)--AN OPPORTUNITY FOR THE PACIFIC NORTHWEST

By
Walter W. Hays
U.S. Geological Survey
Reston, Virginia

THE DECADE

The United States has been challenged to join with, and indeed to lead, other nations throughout the world in concerted actions to make the 1990's a "decade of disaster reduction." This period has been dedicated to improve and invigorate efforts to reduce the economic and death tolls from natural hazards such as earthquakes, floods, hurricanes and tornadoes, landslides, volcanic eruptions, tsunamis, and wildfires.

THE NEED

The need for reducing the economic toll from natural hazards in the United States is urgent. The United states has a large number of seismogenic zones, active volcanoes, thousands of miles of storm-prone coastline, large and small flood-producing river systems, slopes susceptible to landslides, coasts susceptible to tsunami runup, and wilderness/urban interfaces vulnerable to wildfires. Every year, economic losses average about ten billion dollars, comprised of:

- four billion dollars for floods,
- two billion dollars for landslides,
- two billion dollars for hurricanes and tornadoes,
- six hundred eighty million dollars for earthquakes with several urban areas facing potential losses in the tens of billions of dollars,
- millions for tsunamis, volcanic eruptions, and wildfires.

The economic losses continue to increase as mankind builds and expands communities along the water's edge, on floodplains, in earthquake-prone regions, on unstable slopes, in zones susceptible to volcanic eruptions, and at wilderness interfaces susceptible to wildfires.

WORLD WIDE LOSSES AND SOCIETAL IMPACTS

The United States has been very fortunate to escape the great loss of life and societal impacts experienced recently in other nations:

- At least 60,000 dead and 500,000 homeless in Soviet Armenia from the magnitude 6.9 earthquake of December 7, 1988.

- At least 300,000 to 500,000 dead and 1.3 million homeless in the cyclone and flooding that struck Bangladesh in 1988. Similar impacts were experienced in 1970.

- At least 1,000 dead and 4,000 missing in the Reventador, Equador, landslide of March 1987 which also ruptured the Trans Ecuador oil pipeline.

- At least 22,000 dead and 10,000 homeless from the eruption of Colombia's Nevada del Ruiz volcano in November 1985.
- Sixty-nine dead and 11,000 homeless in Australia's Ash Wednesday wildfire of February 1983.

THE SURVEY'S STRATEGY

The U.S. Geological Survey is working with other Federal agencies and the National Academy of Sciences and others to develop a U.S. program for Natural Disaster Reduction during the Decade. The program's goals, objectives, and strategies, although consistent with other natural hazard reduction programs within the Federal Government, go far beyond any single program. A major part of tge U.S. program, a Natural Hazard Geographic Information System, is already in a mature state of development. It will be made available to Federal and state government agencies, academia, and the private sector in all 50 states and territories as a basic resource for a wide range of loss reduction strategies such as:

- Prevention - controlling the source of the event in a way that changes the physical characteristics of the physical phenomena generated in the event.
- Protection - designing and building new buildings and lifeline systems to standards developed for each natural hazards.
- Hazard mapping - making maps that depict the spatial and temporal variation of natural hazards.
- Alert and warning - providing warnings, forecasts, predictions, and scenarios of impending or potential events.
- Retrofit and repair - strengthening existing structures to withstand expected physical effects.
- Emergency preparedness - improving the state-of-preparednes in urban areas.
- Indemnification - devising financial strategies (e.g., insurance) to spread the risk.
- Response and recovery planning - making plans to respond and to recover from a potential disaster.

BENEFIT/COST

The Decade will lead to concerted actions both in the United States and throughout the world that will prevent needless catastrophies. The institutional framework and capacity to implement loss reduction measures developed during the Decade are expected to last far beyond 2000. Estimates of the benefit of the Decade suggest that the activities of the Decade could save 10,000,000 lives and ten trillion dollars worldwide during the Decade. Given worldwide funding levels on the order of one to 10 billion dollars for the Decade, the benefit to cost ratio ranges from about 100:1 to 1,000:1, without consideration of loss of life and societal impacts.

REGIONAL EARTHQUAKE HAZARDS ASSESSMENTS IN THE PACIFIC NORTHWEST
DRAFT WORK PLAN: FY 87-89

FOREWORD

This draft work plan describes the integrated goals, plans, and activities of the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), Washington State Department of National Resources, Washington Office of Emergency Services and others for the program element, "Regional Earthquake Hazards Assessments: Puget Sound-Portland Area," a part of the Geological Survey's National Earthquake Hazards Reduction Program (NEHRP). The purpose of the work plan is to define research **GUIDELINES** and general **RESPONSIBILITIES** for 3-years, FY 87-89, the first phase of a focused effort on the Pacific Northwest. The program concentrates studies in the Puget Sound, Washington, and in the Portland, Oregon, regions. The work plan will be reviewed each year and revised, as appropriate, to reflect progress, new goals, opportunities for synergism, and more effective use of resources. The following persons participated in the planning meeting held in Bothell, Washington, on December 9-10, 1986, and contributed to the formulation of the work plan:

Walter Hays	U.S. Geological Survey
Albert Rogers	U.S. Geological Survey
Thomas Terich	Washington University
Eugene Hoefrauf	Western Washington University
Lora Murphy	U.S. Department of Community Development
Janice Leonardo	Whatcom County Department of Emergency Services
Lt. William M. Stockham	King County Office of Emergency Management
Richard Buck	Federal Emergency Management Agency
Ayres W. Johnson, Jr.	Evergreen Safety Council
Bill Brown	Federal Emergency Management Agency
Gary Johnson	Federal Emergency Management Agency
William Mayer	Federal Emergency Management Agency
Robert Brelin	Building System Technology
Ray Lasmanis	Washington State Department of Natural Resources (WSDNR)
Anshel G. Johnson	Portland State University
Bruce C. Olson	Consulting Engineer
Peter May	University of Washington
Gerald W. Thorsen	Washington State Department of Natural Resources (WSDNR)
Karl V. Steinbrugge	Structural Engineer
Philip S. Cogan	Federal Emergency Management Agency
Chuck Steele	Federal Emergency Management Agency
Jane Pruess	Urban Regional Research
Robert S. Yeats	Oregon State University
John D. Beaulieu	Oregon Department of Geology and Mineral Industries (DOGAMI)
Patricia Bolton	Batelle Seattle Research Center

HISTORICAL BACKGROUND

The concept of the Regional Earthquake Hazards Assessments program element evolved out of discussions held at Asilomar Conference Center, Pacific Grove, California, in April 1982. At this meeting, 54 participants (27 USGS and 27 non-Survey) in the NEHRP were asked to debate the question "are changes in the

NEHRP, now 5 years old, needed and if so what are they?" From these discussions, the five interrelated program elements constituting the current NEHRP were defined as follows:

1) Regional Monitoring and Earthquake Potential--Perform geologic and seismological analyses of current earthquake activity including the seismic cycle of active faults and estimates of earthquake potential in earthquake-prone regions of the United States (23% of budget).

2) Earthquake Prediction Research--Conduct field, laboratory, and theoretical studies of earthquake phenomena with the goal of reliable prediction of the time, place, and magnitude of damaging earthquakes (44% of budget).

3) Data and Information Services--Provide data on earthquake occurrence to the public, other Federal agencies, State and local governments, emergency response organizations, and the scientific community (12% of budget).

4) Engineering Seismology--Operate a national network of strong-motion instruments, disseminate the basic ground-motion information, and conduct research on the data (9% of budget).

5) Regional Earthquake Hazards Assessments--Compile and synthesize geologic and geophysical data needed for evaluating the earthquake hazards of ground shaking, ground failure, surface fault rupture, and tectonic deformation and for assessing the risk in broad geographic regions containing important urban areas. Foster an environment for implementation, creating partnerships and providing high quality scientific information that can be used by State and local governments to devise, foster, and implement loss-reduction measures (such as building codes, zoning ordinances, personal prepardness, etc.) (12% of budget).

COMPONENTS OF THE REGIONAL EARTHQUAKE HAZARDS ASSESSMENTS PROGRAM ELEMENT

The Regional Earthquake Hazards Assessments program element has five **INTERRELATED** components:

1) Information Systems--The goal is to produce **QUALITY** data along with a comprehensive information system, available to both internal and external users for use in earthquake hazards evaluations, risk assessment, and implementation of loss-reduction measures.

2) Synthesis of Geological and Geophysical Data for Evaluation of Earthquake Hazards--The goal is to produce synthesis reports describing the state-of-knowledge about earthquake hazards (ground shaking, surface faulting, earthquake-induced ground failure, and regional tectonic deformation) in the region and to recommend future research to increase the state of knowledge required for the creation and implementation of loss-reduction measures.

3) Ground Motion Modeling--The goal is to produce deterministic and probabilistic ground-motion models and maps of the ground-shaking hazard with commentaries on their use.

4) Loss Estimation Models--The goal is to devise economical methods for acquiring inventories of structures and lifeline systems in urban areas, to create a standard model and commentary for loss estimation, and to produce loss and casualty estimates for urban areas.

5) Implementation--The goal is to foster the creation and implementation of hazard-reduction measures in urban areas, providing high-quality scientific information that can be used by local government decision-makers as a basis for "calling for change in seismic safety policy."

Research focusing on one or more of the above components is presently being conducted in the following urban areas, ranked according to their respective priority:

1) Puget Sound, WA-Portland, OR	2)Wasatch Front, UT
3) Californial	4)Anchorage, AK
5) Mississippi Valley	6)Puerto Rico
7) Charleston, SC	8)Buffalo-Rochester area, NY

In each region, the research is performed using the resources of the USGS's internal and external programs (the external program is implemented through grants awarded annually following a national solicitation for proposals. The goal is to achieve maximum synergism of State and Federal resources with everyone having a stake in the process. In some cases, suggested task assignments outside the USGS as shown below are uncertain and are dependent on the interests and resources of those organizations.

STRATEGIES FOR CONDUCTING RESEARCH IN THE PUGET SOUND, WASHINGTON-PORTLAND, OREGON, AREA

The strategies for the Puget Sound-Portland area are:

1) Foster Partnerships--USGS and FEMA will seek to foster strong partnerships with the universities, private sector, agencies of local government, and other State and Federal agencies. Existing partnerships will be strengthened. The goal is to obtain a stronger commitment at all levels of state and local governments.

2) Take Advantage of Past Research Studies and Other Activities--Results of past research and vulnerability studies will be utilized to the fullest extent possible. Achievements of the USGS-FEMA sponsored earthquake-hazards workshop of October 1985 will be used as building blocks for future activities. Also, the recommendations of the Washington State Seismic Safety Council, published in 1986, will be addressed to the fullest extent possible.

3) Convene Annual Meetings to Review Progress and Recommend New Research--Beginning in 1988, an annual workshop will be held in the Puget Sound area to review: **WHAT HAS BEEN ACCOMPLISHED** and **WHAT IS STILL NEEDED TO ACCOMPLISH THE GOALS.** Participants from many different disciplines

in the workshop will be asked to address the question "what changes, if any, are needed to accomplish the goals of the program?"

4) Publish Annual Reports and Communicate Findings--Proceedings of the workshops, which will include papers documenting results from all research projects in the Pacific Northwest area will be published as USGS Open-File Reports approximately 3- or 4-months after each meeting. In FY 89, the third year of the program, a USGS Professional Paper will be compiled. The workshops, their products, and the findings in the professional paper will be **COMMUNICATED** to policymakers whose task is to implement hazard-reduction policy.

5) Take Advantage of Earthquakes--Use knowledge gained from past earthquakes in the Puget Sound-Portland area and other areas such as the Mexico earthquake of September 1985 to improve the methodology that is currently used in the assessment of earthquake hazards and risk in the Puget Sound-Portland area. Many scientists consider the 1985 Mexico earthquake as representative of the type of earthquake that can occur in the Puget Sound-Portland area. In addition, other parts of the world have a similar tectonic setting as the Puget Sound-Portland area.

   Earthquakes in all of these areas will be investigated to provide insight into the characteristics of ground-shaking and the physical effects that might occur in a major subduction earthquake in the Puget Sound-Portland area. Because large shallow crustal earthquakes like the 1872 eastern Washington earthquake control the risk (chance of loss) to a large degree, earthquakes having similar characteristics will be investigated in detail.

RESEARCH GOALS, OBJECTIVES, AND TASKS OF THE PROGRAM ELEMENT "REGIONAL EARTHQUAKE HAZARDS ASSESSMENTS: PUGET SOUND-PORTLAND AREA"

INTRODUCTION

The five **INTERRELATED** components comprising the program element "Regional Earthquake Hazards Assessments: Puget Sound-Portland Area" are described below to provide **GUIDELINES** for researchers who are either working now or planning to work in the area. These guidelines will also help to guide the formulation of seismic safety policy in the Puget Sound-Portland area. Each component of the workplan will be reviewed annually and revised as appropriate, to meet the research goals of the program element.

Study Area--In Washington, the primary study area includes King, Kitsap, Mason, Pierce, Snohomish, Thurston, Clark, Cowlitz, Grays Harbor, Island, Skagit, and Whatcom Counties. In Oregon, the main emphasis will be on Marion and Multnomah Counties. The urban areas include: Seattle, Tacoma, Vancouver, Bellingham, and Olympia, Washington, and Portland and Salem, Oregon.

COMPONENT 1: INFORMATION SYSTEMS

Every research study will generate basic data on earthquake hazards which must be organized with existing data. A large but unorganized quantity of data relating to the earthquake hazards in the Puget Sound-Portland area already exists in published maps, reports, and computerized data sets. If these data were organized, the resultant data base would be an extremely valuable resource for a wide variety of user groups, including the participants in the NEHRP. In addition, the data base is expected to grow as research studies mature.

The objectives of this component are: 1) to make quality data readily available to meet the needs of researchers and policymakers, 2) to create asystem that assures that new data will be available in the form most useful to meeting program objectives, 3) to devise a system whereby potential users will have easy access to data in media, scales, and formats that will be most useful to them, and 4) to provide continuing information on objectives and progress of the program element. Accomplishing these objectives will require: 1) inventorying existing data sets, 2) developing data standards for critical data sets, 3) identifying user groups and their needs, 4) developing strategies for data management and data dissemination, and 5) assuring that pertinent hazards data are available to the user community.

Priorities--The first priority is the creation of a directory of hazards information. Second priority is an inventory of existing data sets, perhaps using a standard questionnaire or form. Third priority is to test the capability for data interchange and communications.

Action--The objectives listed above will be accomplished primarily by the Federal and State partners. The task statements include:

1) Inventory of Existing Data--Compile a computerized bibliography of the Puget Sound-Portland geology and geophysics that provides for keyword searches, including terms that are pertinent to the evaluation of earthquake hazards and the assessment of risk. The bibliography will be upgraded to meet the needs of the program element.

   USGS Role--USGS will compile a directory of hazards information to determine what data exist, what form the data are in, and the availability of the data. A determination will be made of each data set as to its adequacy for the needs of the research program.

2) Standardization--To the extent possible, the catalog of Puget Sound-Portland earthquakes (especially the preinstrumental data) will be standardized because it is important, if not crucial, to several of the research studies. The catalogs of the University of Washington Seismograph Network and the USGS (National Earthquake Information Service, Algermissen) are the best starting point. Standards may need to be established for other major data sets, such as computer files of digitized geological data.

   Part of this effort will be the selection of standard base maps and mapping scales for data compilation and publication by all participants in the program. Reproducible base materials must be available for rapid production of greenlines, paper copies, and film composites of maps. In addition, standards for computer storage of point data and line data will have to be established if automated computer mapping is to be realized.

USGS Role--The USGS will implement a new Geographical Information System (GIS) in collaboration with DOGAMI, WSDNR to integrate existing base map data with new geographical data sets developed during the course of Puget Sound-Portland studies.

3) Data Set Management--A complete library of publications, reports, and a hard copy of data sets related to the Puget Sound-Portland area are needed. These could be established as a part of the existing libraries.

   USGS Role--The successful management of computerized data should expedite many research studies. Existing computer resources in Golden, Colorado and other locations will be utilized. The University of Washington Computer Center and the NOAA data center in Boulder are other systems that may have to be accessed. Documented software to access and utilize the major data sets must also be available.

4) Information Transfer--An earthquake information office is needed in the Puget Sound-Portland area. Such an office will be concerned primarily with the dissemination of earth science information (e.g., in a quarterly newsletter) related to the earthquake hazards of ground-shaking, surface rupture, ground failure, and tectonic deformation, as well as earthquake preparedness. The office will provide, to a wide variety of users: historic and current data on Puget Sound-Portland earthquakes, information on current research, and advice on obtaining access to earthquake-related literature and data.

COMPONENT 2: SYNTHESIS OF GEOLOGIC AND GEOPHYSICAL DATA FOR EVALUATION OF EARTHQUAKE HAZARDS

Geologic and geophysical research aimed at a better understanding of the potential for the occurrence of large, damaging earthquakes in the Puget Sound-Portland area have been carried out since the early 1970's. These studies have provided a critical perspective on the level of the potential hazard for the region and have contributed, in large part, to the high priority given to this area in the Regional Earthquake Hazards Assessments program element. The geologic and geophysical data collected in these studies are essential in the evaluation of earthquake hazards and the assessment of risk from earthquakes occurring in the region. However, the results of these studies have been released primarily as discrete scientific papers in research journals or in the "gray" literature of USGS open-file reports and other publications. They have not been synthesized or integrated into a comprehensive evaluation of the potential for the occurrence of damaging earthquakes and the associated hazards of ground-shaking, ground failure, surface fault rupture, and tectonic deformation in the Puget Sound-Portland area.

Priorities--First priority will be given to collecting and synthesizing basic geologic and geophysical data required for evaluation of earthquake hazards. The second priority is to conduct additional research needed to achieve the goals of the program element by closing gaps in knowledge.

Action--Federal, state, and university scientists (identified below) will provide leadership and perform the specified research tasks. Researchers in universities and the private sector (e.g., University of Washington, and others) will participate under the auspices of the USGS's grants program.

1) Collection and Synthesis--Research initiated in prior years will be continued. New research will also be conducted focusing on the collection and synthesis of those data needed for realistic deterministic and probabilistic calculations of hazard and risk for the region. These data collection and synthesis efforts provide: a) a broader understanding of the tectonic settings and rates of tectonic activity and b) definition of specific geologic hazards of special significance to the Puget Sound-Portland area.

   The objective of the above task is to develop synthesis reports and maps on four main topics:

   a) Geologic/tectonic setting of current seismicity of the Puget Sound-Portland area. These activities are related to source zone modeling for probabilistic hazard calculations and the revision of existing neotectonic maps of these regions. This research will seek to improve understanding of the tectonics of this region through reexamination of old fault data, collection of new fault data, and Quaternary mapping. Seismicity, geophysical, and remote sensing data will also be evaluated. (USGS: WHEELER, THENHAUS, ALGERMISSEN). Studies of current seismicity including focal mechanism, state of stress, and relationship between seismicity and faults will be conducted. This work may include reevaluation of some aspects of historical earthquakes (USGS: HOPPER, SPENCE; UW: CROSSON, MALONE; OSU--JOHNSON). For instance, reevaluation of the historic intensities as they relate to source zones will also be conducted (USGS: HOPPER).

   b) Quaternary tectonic activity of the Puget Sound-Portland area. These tasks have two principal elements: 1) to assess the potential for a great subduction zone earthquake; and 2) to assess the potential for shallow or lithospheric earthquakes. Studies related to the assessment of subduction zone earthquakes involve research on subsidence of Washington and Oregon estuarine deposits (USGS: ATWATER, NELSON; STATE SURVEYS; OSU--PETERSON, DARIENZO; UW--BOURGEOIS), coastal uplift/terraces (USGS: PERSONIUS; HUMBOLDT STATE--CARVER, KELSEY, BURKE; DOGAMI, WSDNR), back-tilted Pleistocene beach deposits (DOGAMI, WSDNR), earthquake induced landslides (USGS: MADOLE, SCHUSTER), lake sediment liquefaction or other liquefaction (USGS: MADOLE, OBERMEIER), crustal structure (TELEDYNE: McLAUGHLIN) Studies related to the potential for shallow earthquakes involve research on Quaternary stratigraphy (CASCADE VOLCANO OBSERVATORY; DOGAMI, WSDNR; OSU--YEATS), research on Quaternary deformation in the Seattle-Kitsap Peninsula area primarily from study of coastal marsh deposits (USGS; BUCKNAM, BARNHARD), high-frequency reflection/Minisosie (USGS: HARDING, URBAN, BUCKNAM, BARNHARD; WSDNR: LINGLEY, UNIVERSITIES).

   c) Timing and character of Quaternary ground-failure events: These tasks are directed at producing ground failure inventory maps

(USGS: CHLEBORAD, SCHUSTER, MADOLE; DOGAMI, WSDNR) and susceptibility maps (USGS: CHLEBORAD, SCHUSTER; DOGAMI; WSDNR).

d) Information for use in local and regional hazards reduction activities.

COMPONENT 3: GROUND MOTION MODELING

This component is concerned primarily with the prediction of the effects of source, path, and local geologic site conditions on ground shaking in the Puget Sound-Portland area. Knowledge of the nature and severity of ground motion induced at a site is fundamental to sound earthquake-resistant design. Although the importance of local geologic conditions has been recognized for many years, the quantitative prediction of their influence on ground shaking using either empirical or theoretical models is still evolving. In this component, the application, extension, and validation of relevant research techniques will be continued in the Puget Sound-Portland area.

Priorities--The first priority is to install and maintain strong-motion accelerographs in the Puget Sound-Portland area and to acquire and use the MiniSosie portable reflection system in ground-response research. Ninty-six strong motion accelerographs are currently in place in Washington and Oregon. The second priority is to prepare a synthesis report of the ground shaking data available from prior studies in the Puget Sound-Portland. The third priority is to extend the results of these studies, performing deterministic and probabilistic hazard analysis and utilizing new equipment (MiniSosie, strong motion accelerographs, etc.) to acquire basic data.

Action--The research will be conducted primarily by USGS and non-USGS researchers who may participate through the Survey's external grants and contract program. The tasks are described below:

1) Synthesis Report--A report of the current knowledge of ground motion characterisitics in the Puget Sound-Portland area.

2) Deterministic and Probabilistic Hazard Analysis--Research on deterministic and probabilistic hazard analysis, applied in 1982 on a national scale by Algermissen and others, will be applied in the Puget Sound-Portland areas, and extended by using a variety of probabilistic models of earthquake occurrence (USGS: ALGERMISSEN, PERKINS, THENHAUS, WHEELER, ARNOLD). Maps of the peak acceleration, velocity, and intensity will be prepared for exposure periods of 10, 50, and 250 years. These maps will incorporate the effects of regional attenuation and local geologic conditions. Maps of spectral velocity for selected periods may also be prepared. These analyses, combined with the inventory and vulnerability studies discussed below in the loss estimation component, will form the basis for estimates of economic loss (risk) and casualties.

3) Research on Attenuation and Ground Response--A methodology to zone the ground-shaking hazard will be applied to the Puget Sound-Portland area (USGS: KING, TARR). Site effects at a large number of sites in the Seattle-Portland regions will be measured using local earthquake

data. Uphole/downhole shear-wave velocity measurements will also be collected at select sites (USGS: KING, TINSLEY). Sites will be classified into site types or clusters according to significant geotechnical factors for three period bands (0.05 to 10 seconds). By combining and comparing the cluster results at selected sites throughout the city with mapped near-surface geology and geotechnical data (USGS; TINSLEY, KING, BUCHANAN-BANKS; UW: QAMAR), maps of the ground-shaking response relative to rock can be constructed for each of the three period bands on a regional basis. These results will also be used to construct intensity maps for scenario earthquakes.

Several approaches will be taken in the study of attenuation. Attenuation and source functions are likely to differ for each of the major source types, i.e., subduction zone events, i.e., events within the subduction plate and shallow events. Regional seismic-wave attenuation functions for the Puget Sound-Portland area will be derived using data from other subduction zone earthquakes, including data for the 1985 Chile and Mexico earthquakes (USGS: ALGERMISSEN, CAMPBELL). These two earthquakes provide a unique data sample of close-in data from major subduction zone earthquakes. Using small shallow and deep earthquakes, a Q-model will be derived that will serve as data for stochastic modeling of earthquake ground motions from the various source types (USGS: LANGER, JOYNER, CAMPBELL, HARMSEN). Deterministic modeling of subduction-zone earthquakes will also be conducted (EARTH TECH. CORP.: CROUSE; WOODWARD-CLYDE: SOMMERVILLE). Intensity attenuation for historical Pacific Northwest earthquakes will be evaluated (USGS; HOPPER, ALGERMISSEN; UNIVERSITIES).

4) Zoning Research--Beginning in FY 87, research with high-frequency techniques (e.g., MiniSosie) will be initiated to determine subsurface conditions within the study area that are known to exhibit high ground response (USGS: KING, TARR). For example, in the Los Angeles study near-surface velocity contrasts in the depth range of 10-20 meters were found to cause the highest levels of ground response for buildings that are in the two- to five-story class. Buildings having more than five stories were also found to be at greatest risk when located at sites where the depth to basement rock is the greatest. Because reflection techniques may provide the only means to define the important subsurface factors controlling site response in some urban areas, experiments will be conducted in Seattle and Portland at sites where measured site response can be correlated with reflection data.

COMPONENT 4: LOSS ESTIMATION MODELS

This component has three parts: 1) definition of the scenario earthquake(s), 2) inventory, and 3) ground-motion-damage matrices or algorithms.

In this component all available hazards data will be used in the development of economic loss (risk) and casualty estimates. Estimates of probable losses and casualties in an earthquake are important results. Loss estimates provide a scientific basis for land-use planning, an economic basis for the implementation of suitable building codes, and form the framework for disaster mitigation, preparedness, and relief programs. A considerable amount of research on loss estimation (seismic risk) has already been done in the Puget Sound-Portland area by USGS and its consultants. A deterministic earthquake loss study was completed in 1976 (Hopper, et al 1976) to provide planning guidance for earthquake preparedness and mitigation.

Priorities--The first priority is to update the existing building inventory in the Puget Sound-Portland area (especially considering high-rise buildings) and to create an inventory for lifeline systems. The second priority is to establish building inventories and lifeline system inventories in other parts of the study area, seeking to achieve uniformity with other inventories. The third priority is to reassess the vulnerability relationships for the Puget Sound-Portland area.

Action--Both USGS internal research and grants studies will contribute to this effort. The tasks are described below:

1) Loss Estimation, Seattle area; other urban areas--The primary emphasis will be placed on research concerning earthquake loss (risk) studies is the Seattle metropolitan areas (USGS: LEYENDECKER, ALGERMISSEN, HIGHLAND, ARNOLD, HOPPER, POWERS; OLSEN CONSULTING: ENGLEKIRK AND HART: HART; KENNEDY/JENKS/CHILTO: BALLANTYNE; TELESIS: THIEL). The data requirements are: 1) update the existing building inventory in Seattle, 2) develop an inventory of buildings in other parts of the study area, 3) reassess vulnerability relationships for the Puget Sound-Portland area utilizing new data from the 1983 Coalinga, California, earthquake and data obtained from additional review and analysis of the 1971 San Fernando, California, earthquake, and 4) develop additional data on the distribution and vulnerability of lifeline systems in the Seattle area. Develop scenario intensity maps for several possible major earthquakes. These maps will incorporate regional attenuation functions and site response effects (USGS; HOPPER).

   Deterministic loss and casualty estimates will be made for magnitude (M_s) 6.5 and 7.5 earthquakes (and possibly for a major subduction zone event having various locations in the Puget Sound-Portland area. Probabilistic loss and casualty estimates will be computed for exposure times of interest of 10, 50, and 250 years at the 90 percent probability level. Both deterministic and probabilistic loss estimates will be based on appropriate ground-motion hazard maps which, where possible, will include site response (see above discussion of ground-motion modeling). The loss estimates will also include, where possible, losses associated with the geologic effects of earthquakes such as liquefaction. Total economic losses will be estimated and, in addition, losses by class of construction and the vulnerability. In general, the classes of construction used will be based principally on their framing system. Casualty estimation will require additional data on building occupancy.

2) Loss Estimation, Other Parts of the Study Area--To the extent possible, the same data identified in task 1 above will be acquired in other parts of Washington and Oregon and used to perform loss estimates.

COMPONENT 5: IMPLEMENTATION

The goal of this component is effective use of scientific information to reduce loss of life and damage to property caused by earthquake hazards as well as by other geologic and hydrologic hazards. Successful achievement of the goal requires **COMMUNICATION** of **TRANSLATED SCIENTIFIC INFORMATION** to **RESPONSIBLE OFFICIALS** and **INTERESTED PARTIES** seeking to **REDUCE HAZARDS** by use of one or more **REDUCTION TECHNIQUES**. These aspects of the problem and its solution will be discussed below, providing a framework for an integrated work plan involving all concerned parties and guidelines for proposals to the USGS's external grants and contracts program.

Priorities--The first priority is to determine the needs of users in the Puget Sound-Portland area for earthquake hazards information. The second priority is to produce translated (i.e., interpreted information derived from basic scientific data) scientific information that meets the needs of these user groups. The third priority is to foster an environment for implementation of research results by local governments, utilizing workshops, training classes, questionnaires and other procedures to communicate the scientific information.

Action--Leadership for the implementation components will be provided by FEMA and USGS. FEMA, Region X, will take a major role in the implementation process. One objective of this component is to make it easy for local government, engineers, architects, planners, emergency preparedness planners, and emergency responders to use the technical information generated in this and prior programs (UW: MAY). A key strategy is to build on past successful activities such as the Southern California Earthquake Preparedness Project which has produced some 20 publications on various aspects of implementation. Partnerships between the research community (USGS, DOGAMI, WSDNR, universities, and the private sector) and those who will ultimately use the information to implement loss-reduction measures are necessary for success, and the strongest possible effort will be made to achieve these partnerships within the initial three years.

1) Scientific Information--Many prior studies have already produced considerable high-quality information in the Puget Sound-Portland area. Adoption and generalization of scientific information is a prerequisite to its transfer to a user and its use in a loss-reduction measure or technique. While a great deal of scientific information can be used directly by engineers or other scientists, some information must be translated to enhance its understanding and effective use by nonscientists. Such translated information includes: fault-rupture locations with forecasts of earthquake recurrence intervals and the anticipated surface displacement, coastal flooding from tsunamis, seiches and/or subsidence, liquefaction with levels of susceptibility, areas of landslide hazard with levels of susceptibility, areas of inundation caused by hypothetical dam failures, and areas of building failures caused by ground shaking. SOME TRANSLATION ACTIVITIES WILL TAKE PLACE USING GIS TECHNIQUES (USGS; TARR). The following actions are likely to improve use of scientific information by nonscientists:

    -- Identify and catalog existing earthquake hazards maps and reports.

- -- Identify the hazards maps and reports needed for loss hazard-reduction measures.
- -- Estimate cost and determine responsibility, funding, and delivery of the information that can be provided.
- -- Assure that new information is prepared in detail and at the scales needed by the users (see Table 1).
- -- Make special efforts to present the information in a format and language suitable for use by engineers, planners, policy recommenders, and decisionmakers.
- -- Assure that information (including discoveries, advances, and innovative uses) is released promptly through appropriate communicators and communication techniques (see Tables 2 and 3).

2) <u>Communication</u>--This task is also a continuation of past activities. Communication of scientific information consists of both its transfer and its effective use for hazard reduction. Examples of communicators and communication techniques are listed in Tables 2 and 3. The following actions are likely to improve effective use of the technical information:

- -- Design the communications program after an assessment of potential users' needs and capabilities.
- -- Select the most effective educational, advisory, and review services (Table 2) appropriate to the targeted users.
- -- Design the communications program so that information can be effectively disseminated (including use of the scientists and investigators to help communicate).

3) <u>Determine Users' Needs</u>--The past work on geologic hazards has succeeded to some extent in determining the needs for earthquake hazards information in Washington. Use of scientific information by nonscientists requires a considerable effort on the part of both the producers and the users to communicate with each other, and although a variety of users exist, effective use depends upon the users' interests, capabilities, and experience in hazard reduction. Examples of users are listed in Table 1. The following actions will ensure effective transfer of the information to potential users:

- -- Identify and target users (Table 1) who have urgent needs and who could be expected to use the hazards information most effectively.
- -- Consult with those users about their needs and priorities and prioritize the hazards information needed.
- -- Monitor and analyze the enactment of local, State, and Federal hazard-reduction laws or regulations and the issues that affect users in order to anticipate and respond to their needs.

-- Encourage users--both public and private--to develop an in-house capability to obtain and apply the information (including risk assessment).

-- Orient or train users in order to enable them to understand and to use the information effectively.

4) Reduction Techniques--This task must also build on past activities. Many opportunities are available for reducing geologic and hydrologic hazards. Examples of hazard-reduction techniques are listed in Table 4. The following actions will increase the likelihood of an effective reduction of hazards:

-- Identify the most effective reduction techniques that are either being used by the users or are available to them.

-- Review existing State programs or laws that could incorporate such reduction techniques and recommend changes or new programs and laws.

-- Devise and test innovative reduction techniques.

5) Evaluation--Continuing systematic evaluation will be a part of this program and is a key to any successful State-local earthquake hazards reduction program. An inventory of uses made of the scientific information, interviews with users, and an analysis of the inventory and responses will result in identifying new users, and any obstacles to communication of the information or its effective use. The following actions will make evaluation easier and enhance implementation:

-- Inventory uses of hazards information (Table 4) to identify and document the type and number of uses of each hazards map or report.

-- Analyze uses of the hazards information and any problems identified and suggest improvement to the format or content of information or the communication techniques.

-- Identify problems with and suggest improvements to reduction techniques by the monitoring of land-use decisions.

-- Interview users of information (Table 1) to evaluate the adequacy of the information and the communication techniques and to identify obstacles to their effectiveness.

Proposed-Selection Criteria--Numerous combinations of scientific information, communication techniques, users, and reduction techniques exist. Consideration of the following factors will be helpful in the selection of proposals for grants in support of the above implementation tasks:

-- User is an applicant.

- -- Experienced communicator is an applicant.
- -- A high probability exists for successful transfer and effective use of the information.
- -- A communicator is in place and communication technique are in operation.
- -- Translated scientific information is immediately available to the user.
- -- Minimum time is required for translation and transfer of the information.
- -- A large number of people or numerous critical facilities are at risk in the targeted area.
- -- Rapidly urbanizing areas are located in the targeted area.
- -- An opportunity exists for innovative or prototypical communication or reduction techniques.
- -- Sponsor, convene, and coordinate at least one workshop each year designed to foster an environment for implementation of loss-reduction measures at the State and local level.
- -- Evaluate proposals and fund selected projects that will enhance implementation.
- -- Enlist Federal partners.

<u>Suggested Roles for State Agencies</u>--Initially, the role of the State Agencies will be to:

- -- Advise the USGS on the selection of projects that will enhance implementation.
- -- Serve as a technical advisor and reviewer of funded implementation projects.
- -- Enlist partners in states of Washington and Oregon.

Table 1

Some Potential Users of Geologic and Hydrologic Information for Earthquake-Hazard Reduction in the Puget Sound-Portland Area.

City, County, and Area-wide Government Users

City building, engineering, zoning, and safety departments
County building, engineering, zoning, and safety departments
Mayors and city council members
Multicounty planning, development, and preparedness agencies
Municipal engineers, planners, and administrators
City and county offices of emergency services
Planning and zoning officials, commissions and departments
Police, fire, and sheriff's departments
Public works departments
County tax assessors
School districts

State Government Users

Department of Community and Economic Development (Community Services Office, Economic and Industrial Development)
Department of Business Regulation (Contracts Division, Real Estate Division)
Department of Financial Institutions
Department of Health (Environmental Health, Health Care Financing)
Department of Natural Resources
Department of Transportation
Division of Comprehensive Emergency Management
DOGAMI
Division of Water Resources
Division of Water Rights
Facilities Construction and Management
Geological and Mineral Survey
Governor's Office
Legislative Fiscal Analyst
Legislative Research and General Counsel
National Guard
Planning and Budget Office
Public Service Commission
Science Advisor
State Tax Commission
WSDNR

Federal Government Users

Army Corps of Engineers
Bureau of Land Management
Bureau of Reclamation
Congress and Congressional staffs
Department of Agriculture
Department of Energy
Department of Housing and Urban Development
Department of Interior
Department of Transportation
Environmental Protection Agency
Farmers Home Administration
Federal Emergency Management Agency
Federal Housing Administration
Federal Insurance Administration
Federal Power Commission
Forest Service
General Services Administration
Geological Survey
National Bureau of Standards
National Oceanic and Atmospheric Administration
National Park Service
National Science Foundation
Nuclear Regulatory Commission
Small Business Administration
Soil Conservation Service

Other National Users

Applied Technology Council
American Association of State Highway and Transportation Officials
American Public Works Association
American Red Cross
Association of Engineering Geologists
Association of State Geologists
Council of State Governments
Earthquake Engineering Research Institute
International Conference of Building Officials
National Academy of Sciences
National Association of Counties
National Association of Insurance Commissioners
National Governors' Association
National Institute of Building Sciences
Natural Hazards Research and Applications Center
National League of Cities
Professional and scientific societies (including geologic, engineering, architecture, and planning societies)
United States Conference of Mayors

Private, Corporate, and Quasi-public Users

Civic and voluntary groups
Concerned citizens
Construction companies
Consulting planners, geologists, architects, and engineers
Extractive, manufacturing, and processing industries
Financial and insuring institutions
Landowners, developers, and real-estate persons
News media
Real-estate salespersons
Utility companies
University departments (including geology, geography, civil engineering, architecture, urban and regional planning, and environmental departments).

Table 2

Typical Communication Techniques

Educational services

Assisting and cooperating with universities and their extension divisions in the preparation of course outlines, detailed lectures, casebooks, and display materials.
Contacting speakers and participating as lecturers in regional and community educational programs related to the application of hazard information.
Sponsoring, conducting and participating in topical and areal seminars, conferences, workshops, short courses, technology utilization sessions, cluster meetings, innovative transfer meetings, training symposia, and other discussions with user groups, e.g. 1983 Utah Governor's Conference on Geologic Hazards, UGMS Circular 74.
Releasing information needed to address critical hazards early through oral briefings, newsletters, seminars, map-type "interpretive inventories," open-file reports, reports of cooperating agencies, and "official use only" materials.
Sponsoring or cosponsoring conferences or workshops for planners and decisionmakers at which the results of hazard studies are displayed and reported on to users, e.g. scheduled USGS workshop, August 1984.
Providing speakers to government, civic, corporate, conservation, and citizen groups, and participating in radio and television programs to explain or report on hazard-reduction programs and products.
Assisting and cooperating with regional and community groups whose intention it is to incorporate hazard information into school curricula.
Preparing and exhibiting displays that present hazard information and illustrate their use in hazard reduction.
Attending and participating in meetings with local, district, and State agencies and their governing bodies for the purpose of presenting hazard information.
Guiding field trips to potentially hazardous sites.
Preparing and distributing brochures, TV spots, films, and other visual materials to the news media.

Advisory services

Preparing annotated and indexed bibliographies of hazard information and providing lists of pertinent reference material to various users.
Assisting local, State, and Federal agencies in designing policies, procedures, ordinances, statutes, and regulations that cite or make other use of hazard information.
Assisting in recruiting, interviewing, and selecting planners, engineers, and scientists by government agencies for which education and training in hazard information collection, interpretation, and application are criteria, e.g. pending proposal to fund county geologists.
Assisting local, State, and Federal agencies in the design of their hazard information collection and interpretation programs and in their work specifications.
Providing expert testimony and depositions concerning hazard research information and its use in reduction techniques.

Assisting in the presentation and adoption of plans and plan-implementation devices that are based upon hazard information.

Assisting in the incorporation of hazard information into local, State, and Federal studies and plans.

Preparing brief fact sheets or transmittal letters about hazard products explaining their impact on, value to, and most appropriate use to local, State, and Federal planning and decisionmaking.

Assisting users in the creation, organization, staffing, and formation of local, State, and Federal planning and planning-implementation programs so as to assure the proper and timely use of hazard information.

Preparing and distributing appropriate user guides relating to earth hazard processes, mapping, and hazard-reduction techniques, e.g. UGMS fliers.

Preparing model State safety legislation, regulations, and development policies.

Preparing model local safety policies, plan criteria, and plan-implementation devices.

Review services

Review of proposed programs for collecting and interpreting hazard information.

Review of local, State, and Federal policies, administrative procedures, and legislative analyses that have a direct effect on hazard information.

Review studies and plans based on hazard information.

Table 3

Representative Communicators of Hazard Information

American Institute of Architects/Research Corporation
American Institute of Certified Planners
American Institute of Professional Geologists
American Society of Public Administrators
American Society of Civil Engineers
Association of Engineering Geologists
Children's Museum
Church groups, church organizations, and church-sponsored events
Circuit riders (regional or project area)
City Management Association
Civic and voluntary groups
Community planning assistance programs
Council of State Governments
County extension agents
Educators (university, college, high school, and elementary school levels)
Governor's Advisory Council on Local Governments
Hazard-information clearinghouse (national, regional, or project area)
Hazard researchers, interpreters, and mappers
International Conference of Building Officials, Utah Chapter
Journalists, commentators, and editors, and their professional associates
Local seismic safety advisory groups
Mountain Lands Association of Governments
Museum of Natural History
National Council of State Legislators
National Governor's Conference
Neighborhood associations
Public information offices (Federal and State)
Researchers, engineers, and planners
Speakers bureaus (regional or project area)
Society of American Foresters, Wasatch Front Chapter
Urban and Regional Information Systems Association
United States Conference of Mayors
U.S. Bureau of Land Management
U.S. Forest Service
U.S. Geological Survey
U.S. Soil Conservation Service
Western Governor's Policy Office

Table 4

Some Opportunities for Using Geologic and Hydrologic Information to Reduce Earthquake Hazards in the Puget Sound-Portland Area, Washington

Preparing development studies and plans

Circulation of transportation studies or plans
Community facility and utility inventories or plans
Environmental impact assessments and reports
Land-use and open-space inventories or plans
Land subdivision lot layouts
Multihazards inventories, risk analyses, and response capabilities
Natural-hazards reduction plans
Redevelopment plans (pre- and post-earthquake)
Seismic safety and public safety plans
Site-specific investigations and hazard evaluations

Discouraging new or removing existing unsafe development

Capital-improvements expenditures
Costs of insurance
Disclosing hazards to real-estate buyers
Financial incentives and disincentives
Governor's executive orders
Policies of private lenders
Non-conforming use provisions in zoning ordinances
Posted warnings of potential hazards
Public acquisition of hazardous areas
Public facility and utility service policies
Public information and education
Recording the hazard on public records
Removing unsafe structures
Special assessments or tax credits
Strengthening or retrofitting of unsafe structures

Regulating development/construction

Building ordinances
Design and construction regulations
Grading regulations
Hazard-zone investigations
Land-use zoning districts and regulations
Special hazard-reduction ordinances
Subdivision ordinances
Critical facilities, siting, design, and construction
Public-facility or utility reconstruction or relocation
Reconstruction after earthquakes
Repair of dams

Preparing for and responding to disasters

Anticipating damage to critical facilities
Damage inspection, repair, and recovery procedures
Dam and reservoir supervision
Disaster training exercises
Earthquake-prediction response plans
Earthquake-preparedness plans
Emergency response plans
Monitoring and warning systems
Relocating occupants of exceptionally hazardous buildings

GLOSSARY

Accelerogram. The record from an accelerometer showing acceleration as a function of time. The peak acceleration is the largest value of acceleration on the accelerogram.

Acceptable Risk. A probability of occurrences of social or economic consequences due to earthquakes that is sufficiently low (for example in comparison to other natural or manmade risks) as to be judged by authorities to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions.

Active fault. A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. This active state exists independently of the geologists' ability to recognize it. Geologists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geologically recent displacement inferred from #opography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behavior of faults to assure identification of all active faults by such characteristics. Selection of the criteria used to identify active faults for a particular purpose must be influenced by the consequences of fault movement on the engineering structures involved.

Attenuation. A decrease in seismic signal strength with distance which depends on geometrical spreading and the physical characteristics of the transmitting medium that cause absorption and scattering.

Attenuation law. A description of the average behavior of one or more characteristics of earthquake ground motion as a function of distance from the source of energy.

b-value. A parameter indicating the relative frequency of earthquakes of different sizes derived from historical seismicity data.

Capable fault. A capable fault is a fault whose geological history is taken into account in evaluating the fault's potential for causing vibratory ground motion and/or surface faulting.

Design earthquake. A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology and used for the earthquake-resistant design of a structure.

Design spectra. Spectra used in earthquake-resistant design which correlate with design earthquake ground motion values. A design spectrum is typically a broad band specturm having broad frequency content. The design spectrum can be either site-independent or site-dependent. The site-dependent spectrum tends to be less broad band as it depends at least in part on local site conditions.

Design time history. One of a family of time histories used in earthquake-resistant design which produces a response spectrum enveloping the smooth design spectrum, for a selected value of damping.

Duration. A description of the length of time during which ground motion at a site exhibits certain characteristics such as being equal to or exceeding a specified level of acceleration such as 0.05g.

Earthquake hazards. Natural events accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation which may cause damage and loss of life during a specified exposure time. See earthquake risk.

Earthquake risk. The probability that social or economic consequences of earthquakes, expressed in dollars or casualties, will equal or exceed specified values at a site during a specified exposure time.

Earthquake waves. Elastic waves (P, S, Love, Rayleigh) propagating in the Earth, set in motion by faulting of a portion of the Earth.

Effective peak acceleration. The value of peak ground acceleration considered to be of engineering significance. It can be used to scale design spectra and is often determined by filterng the ground-motion record to remove the very high frequencies that may have little or no influence upon structural response.

Epicenter. The point on the Earth's surface vertically above the point where the first fault rupture and the first earthquake motion occur.

Exceedence probability. The probability (for example, 10 percent) over some exposure time that an earthquake will generate a level of ground shaking greater than some specified level.

Exposure time. The period of time (for example, 50 years) that a structure or facility is exposed to earthquake hazards. The exposure time is sometimes related to the design lifetime of the structure and is used in seismic risk calculations.

Fault. A fracture or fracture zone in the Earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. See Active and Capable faults.

Focal depth. The vertical distance between the earthquake hypocenter and the Earth's surface.

Ground motion. A general term including all aspects of motion; for example, particle acceleration, velocity, or displacement; stress and strain; duration; and spectral content generated by an earthquake, a nuclear explosion, or another energy source.

Intensity. A numerical index describing the effects of an earthquake on the Earth's surface, on man, and on structures built by him. The scale in common use in the United States today is the Modified Mercalli scale of 1931 with intensity values indicated by Roman numerals from I to XII. The narrative descriptions of each intensity value are summarized below.

I. Not felt--or, except rarely under specially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds and animals reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds and animals reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body of striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink or clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practially all, outdoors by many or most; outdoors direction estimated. Awakened many or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes and glassware to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors and shutters abruptly. Pendulum clocks stopped, started or ran fast, or slow. Move small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees and bushes shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees and bushes shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knickknacks, books, pictures. Overturned furniture in many instances. Move furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows and furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches and trunks broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse, racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls, cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changes level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipelines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures, remained standing. Destroyed large well-built bridges by the wrecking of supporting piers or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipelines buried in each completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

Liquefaction. The primary factors used to judge the potential for liquefaction, the tranformation of unconsolidated materials into a fluid mass, are: grain size, soil density, soil structure, age of soil deposit, and depth to ground water. Fine sands tend to be more susceptible to liquefaction than silts and gravel. Behavior of soil deposits during historic earthquakes in many parts of the world show that, in general, liquefaction susceptibility of sandy soils decreases with increasing age of the soil deposit and increasing depth to ground water. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil, distorting its granular structure and causing some of the void spaces to collapse. The pressure of the pore water between and around the grains increases until it equals or exceeds the confining pressure. At this point, the water moves upward and may emerge at the surface. The liquefied soil then behaves like a fluid for a short time rather than as a soild.

Magnitude. A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. Professor C. F. Richter devised the logarithmic scale for local magnitude (M_L) in 1935. Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicenter of an earthquake. Several other magnitude scales in addition to M_L are in use; for example, body-wave magnitude (m_b) and surface-wave magnitude (M_S), which utilize body waves and surface waves, and local magnitude (M_L). The scale is theoretically open ended, but the largest known earthquakes have had M_S magnitudes near 8.9.

Region. A geographical area, surrounding and including the construction site, which is sufficiently large to contain all the geologic features related to the evaluation of earthquake hazards at the site.

Response spectrum. The peak response of a series of simple harmonic oscillators having different natural periods when subjected mathematically to a particular earthquake ground motion. The response spectrum may be plotted as a curve on tripartite logarithmic graph paper showing the variations of the peak spectral acceleration, displacement, and velocity of the oscillators as a function of vibration period and damping.

Return period. For ground shaking, return period denotes the average period of time or recurrence interval between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be exceeded once in 475 years.

Risk. See earthquake risk.

Rock. Any solid naturally occurring, hard, consolidated material, located either at the surface or underlying soil. Rocks have a shear-wave velocity of at least 2,500 ft/sec (765 m/s) at small (0.0001 percent) levels of strain.

Seismic Microzoning. The division of a region into geographic areas having a similar relative response to a particular earthquake hazard (for example, ground shaking, surface fault rupture, etc.). Microzoning requires an integrated study of: 1) the frequency of earthquake occurrence in the region, 2) the source parameters and mechanics of faulting for historical and recent earthquakes affecting the region, 3) the filtering characteristics of the crust and mantle along the regional paths along which the seismic waves travel, and 4) the filtering characteristics of the near-surface column of rock and soil.

Seismic zone. A generally large area within which seismic design requirements for structures are uniform.

Seismotectonic province. A geographic area characterized by similarity of geological structure and earthquake characteristics. The tectonic processes causing earthquakes are believed to be similar in a given seismotectonic province.

Source. The source of energy release causing an earthquake. The source is characterized by one or more variables, for example, magnitude, stress drop, seismic moment. Regions can be divided into areas having spatially homogeneous source characteristics.

Strong motion. Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes or in earthquake-resistant design of structures.

CONFERENCES TO DATE

Conference I	Abnormal Animal Behavior Prior to Earthquakes, I Not Open-Filed
Conference II	Experimental Studies of Rock Friction with Application to Earthquake Prediction Not Open-Filed
Conference III	Fault Mechanics and Its Relation to Earthquake Prediction Open-File No. 78-380
Conference IV	Use of Volunteers in the Earthquake Hazards Reduction Program Open-File No. 78-336
Conference V	Communicating Earthquake Hazard Reduction Information Open-File No. 78-933
Conference VI	Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps Open-File No. 78-943
Conference VII	Stress and Strain Measurements Related to Earthquake Prediction Open-File No. 79-370
Conference VIII	Analysis of Actual Fault Zones in Bedrock Open-File No. 79-1239
Conference IX	Magnitude of Deviatoric Stresses in the Earth's Crust and Upper Mantle Open-File No. 80-625
Conference X	Earthquake Hazards Along the#Wasatch and Sierra-Nevada Frontal Fault Zones Open-File No. 80-801
Conference XI	Abnormal Animal Behavior Prior to Earthquakes, II Open-File No. 80-453
Conference XII	Earthquake Prediction Information Open-File No. 80-843
Conference XIII	Evaluation of Regional Seismic Hazards and Risk Open-File No. 81-437
Conference XIV	Earthquake Hazards of the Puget Sound Region, Washington Open-File No. 82-19
Conference XV	A Workshop on "Preparing for and Responding to a Damaging Earthquake in the Eastern United States" Open-File No. 82-220
Conference XVI	The Dynamic Characteristics of Faulting Inferred from Recording of Strong Ground Motion Open-File No. 82-591
Conference XVII	Hydraulic Fracturing Stress Measurements Open-File No. 82-1075
Conference XVIII	A Workshop on "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area Open-File No. 83-157
Conference XIX	Active Tectonic and Magmatic Processes Beneath Long Valley Open-File No. 84-939
Conference XX	A Workshop on "The 1886 Charleston, South Carolina, Earthquake and its Implications for Today" Open-File No. 83-843

Conference XXI — A Workshop on"Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeastern United States"
  Open File No. 83-844

Conference XXII — A Workshop on "Site-Specific Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design"
  Open-File No. 83-845

Conference XXIII — A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States"
  Open-File No. 83-846

Conference XXIV — A Workshop on "Geologic Hazards in Puerto Rico"
  Open-File No. 84-761

Conference XXV — A Workshop on "Earthquake Hazards in the Virgin Islands Region"
  Open-File No. 84-762

Conference XXVI — A Workshop on "Evaluation of the Regionald and Urban Earthquake Hazards in Utah"
  Open-File No. 84-763

Conference XXVII — Mechanics of the May 2, 1983 Coalinga Earthquake
  Open-File No. 85-44

Conference XXVIII — A Workshop on "The Borah Peak, Idaho, Earthquake"
  Open-File No. 85-290

Conference XXIX — A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States"
  Open-File No. 85-386

Conference XXX — A Workshop on "Reducing Potential Losses From Earthquake Hazards in Puerto Rico
  Open File No. 85-731

Conference XXXI — A Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Alaska"
  Open File No. 86-79

Conference XXXII — A Conference on "Future Directions in Evaluating Earthquake Hazards of Southern California"
  Open-File No. 86-401

Conference XXXIII — A Workshop on "Earthquake Hazards in the Puget Sound, Washington Area"
  Open-File No. 86-253

Conference XXXIV — A Workshop on "Probabilistic Earthquake-Hazards Assessments,"
  Open-File 86-185

Conference XXXV — A Workshop on "Earth Science Considerations for Earthquake Hazards Reduction in the Central United States," Open-File Report No. 86-425

Conference XXXVI — A Workshop on "Assessment of Geologic Hazards and Risk in Puerto Rico"
  Open-File 87-007

Conference XXXVII — A Workshop on "Earthquake Hazards Along the Wasatch, Utah
  Open File 87-154 ,

Conference XXXVIII — A Workshop on "Physical & Observational Basis for Intermediate Term Earthquake Prediction
  Open-File 87-154

Conference XXXIX	Directions in Paleoseismology Open File 87-673
Conference XL	A Workshop on "The U.S. Geological Survey's Role in Hazards Warnings" Open-File Report 87-269
Conference XLI	A Review of the Earthquake Research Applications in the National Earthquake Hazard Reduction Program: 1977-1987 Open-File 88-13-A
Conference XLII	A Workshop on "Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas" Open-File Report 88-541
Conference XLIII	A Workshop on "Earthquake Risk: Information Needs of the Insurance Industry" Open-File Report 88-669
Conference XLIV	Geological, Geophysical, and Tectonic Settings of the Cascade Range Open-File Report 89-178
Conference XLV	Workshop on "Fault Segmentation and Controls of Rupture Initiation and Terminations" Open-File Report 89-315
Conference XLVI	Seventh US-Japan Seminar on Earthquake Prediction Open File Report 89-[in press]
Conference XLVII	Workshop on "USGS's New Generation of Probabilistic Ground Motion Maps and Their Applications to Building Codes" Open-File Report 89-364
Conference XLVIII	3rd Annual Workshop on "Earthquake Hazards In the Puget Sound, Portland Area" Open File Report 89-465

For information on ordering the above publications, please contact:

U.S. Geological Survey
Books and Open-File Reports Service Section
Building 41, Box 25425
Federal Center
Denver, Colorado 80225

THIRD ANNUAL PUGET SOUND/PORTLAND AREA WORKSHOP ON EARTHQUKAE HAZARD AND RISK

March 28-30, 1989
Portland Marriott Inn, Portland, Oregon

Mr. Norman A. Abbott, AICP
Planning Director, City of Portland
1120 SW Fifth Avenue, Room 1002
Portland, Oregon 97204
503/796-7700

Mr. Ronald L. Angle
AT&T
4430 Rosewood Drive, Suite 3189
P.O. Box 9083
Pleasanton, California 94566
415/224-1499

Col. Alfred B. Aus, Sr.
FEMA IMA - OREGON
State of Oregon Emergency Management Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Mr. Alfred A. Aya Jr.
Cannon Beach RFPD
P.O. Box 121
Cannon Beach, Oregon 97110
503/436-2343

Ms. Tammy L. Baier
Western Washington University
2901 Bill McDonald Parkway #322
Bellingham, Washington 98225
206/671-2353

Mr. Donald Ballantyne
Kennedy/Jenks/Chilton
33301 9th Avenue S., Suite 100
Federal Way, Washington 98003
206/874-0555

Ms. Clarissa H. Beatty
2958 S.W. Dosch Road
Portland, Oregon 97201

Mr. John Beaulieu
Department of Geology and Mineral Industries
Room 910 1400 S.W. 5th
Portland, Oregon 97034
503/229-5580

Mr. Paul T. Beeson
Portland State University
4400 SE West Road
Milwaukie, Oregon 97267
503/659-8617

Dr. Marvin Beeson
Portland State University
Box 751
Portland, Oregon 97207
503/464-3024

Mr. Jim Bela
3412 SE 160th Avenue
Portland, Oregon 97236

Mr. John Bethel
King County B.A.L.D
3600 136th Pl. SE
Bellevue, Washington 98006

Mr. Alex Bittenbinder
Neut Inc.
3600 15th Avenue, W. # 301
Ses, Washington 98119
206/285-2281

Ms. Martha Blair-Tyler
William Spangle & Associates, Inc.
3240 Alpine Road
Portola Valley, California 94025
415/854-6001

Mr. Scott Boettcher
Intern to Washington Rep. Dick Nelson
House of Representatives
307 House Office Building
Olympia, Washington 98504
206/789-7938

The Honorable Dick Bogle
Portland City Commission
1220 SW Fifth Avenue, Room 404
Portland, Oregon 97204
503/248-4682

Dr. Patricia Bolton
Battelle Seattle Research Center
4000 NE 41st Street
Seattle, Washington 98105
206/525-3130

Mr. Tom Bottenberg
City of Portland
Room 400, 1120 SW 5th
Portland, Oregon 97204
503/796-7125

Mr. Steve Bottheim
King County B.A.L.D.
3600 136th Pl. SE
Bellevue, Washington 98006

Mr. Robert B. Brier
NW REACT
12900 SW 9th Street #321
Beaverton, Oregon 97005
503/636-1846

Mr. Clyde V. Brummell
President
Oregon State Homeowner's Association
8435 S.E. 17th Avenue
Portland, Oregon 97202
503/233-4841

Ms. Jane Buchanan-Banks
Geologist, CVO
5400 MacArthur Boulevard
Vancouver, Washington 98661
206/696-7966

Ms. Judy H. Burton
Department of Labor and Industries
MS 281-2
Olympia, Washington 98504
206/586-8882

Mr. Ted E. Bushnell
Portland General Electric
Nuclear Safety and Regulation Dept.
121 SW Salmon
Portland, Oregon 97204
503/464-8298

Mr. Michael Carrigan
Forelaws on Board
2217 NW Johnson
Portland, Oregon 97210
503/223-1785

Mr. Clayton C. Carter
Fireman's Fund Insurance Companies
101 S.W. Main, Suite #710
Portland, Oregon 97204

Ms. Bev Carter
Mothers for H.E.L.P.
P.O. Box 787
Woodinville, Washington 98072
206/821-2614

Mayor Larry D. Cole
City of Beaverton
P.O. Box 4755
Beaverton, Oregon 97076
503/526-2481

Mr. Tarno Coleman, P.E.
Oregon Building Code Agency
15335 Edgewater Street, N.W.
Salem, Oregon 97310
503/378-8319

Ms. Hallie Cook
Volunteer Work
300 N.W. 95th Circle
Vancouver, Washington 98665
206/573-7159

Dr. Kevin J. Coppersmith
Geomatrix Consultants
One Market Plaza, Spear Tower
Stan Francisco, CA 94105
415/954-9557

Ms. Kelly Jo Craigmiles
Exercise Assistance Officer
Oregon Emergency Management Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Dr. Robert S. Crosson
University of Washington
Geophysics Program AK-50
Seattle, Washington 98195
206/593-6505

Dr. C. B. Crouse
Dames and Moore
500 Market Place Tower
2025 1st Avenue
Seattle, Washington 98121
206/728-0744

Mr. Reagan Crowell
Benton County Emergency Services
180 NW 5th Street
Corvallis, Oregon 97330
503/757-6864

Mr. Mark Darienzo
College of Oceanography
Oregon State University
Corvallis, Oregon 97331
503/754-2296

Mr. Tom Davis
Multonmah County Emergency Management
12240 NE Glisan Street
Portland, Oregon 97230
503/255-3600 x. 207

Mr. Tom DeJardin
Metropolitan Service District
2000 S.W. 1st
Portland, Oregon 97201
503/221-1646

Mr. Edwin T. Dean
KPFF Consulting Engineering
421 SW 6th Avenue, Suite 911
Portland, Oregon 97204
503/227-3251

Dr. Gordon M. Denby
Geo Engineers, Inc.
2405 - 140th Avenue N.E., Suite 105
Bellevue, Washington 98005
206/746-5200

Mr. Edward Dobrick
Consulting Geologist
5925 160th Ct. N.E.
Redmond, Washington 98502
206/881-7735

Mr. Lansing G. Dusek
Portland General Electric
Nuclear Safety and Regulation Dept.
121 SW Salmon
Portland, Oregon 97204
503/ 464-8298

Mr. Stan Eccles
Federal Emergency Management Agency
1940 Yale Avenue, E
Seattle, Washington, 98102
206/487-4750 FTS 323-0831

Mr. William M. Elliott
Portland Water Bureau
1120 S.W. 5th Avenue
Portland, Oregon 97204-1926
503/796-7486

Mr. Saleem Farouqui
Cornforth Consultants, Inc.
7440 SW Hunziker Road, Suite C
Tigard, Oregon 97223
503/684-3201

Mr. Cy Field
Lewis and Clark Law School
9537 SW 4th
Portland, Oregon 97219
503/245-0787

Mr. Allen Fiksdal
State of Washington - EFSEC
Mail Stop: PY-11
Olympia, Washington 98504
206/459-6490

Mr. Robert Filson
Green River Community College
11501 S.E. 322 Pl.
Auburn, Washington 98002
206/833-8426

Mr. Dennis Fisher
U.S. Bank
111 S.W. 5th
Portland, Oregon 97030
503/275-6720

Ms. Cherilyn Foglio
American Red Cross -- Disaster Services
P.O. Box 3200 - 3131 N. Vancouver Avenue
Portland, Oregon 97208
503/284-1234

Dr. Ducan Foley
Pacific Lutheran University
Department of Earth Sciences
Tacoma, Washington 98447
206/535-7568

Mr. Hugh Fowler
Department of Community Development
Division of Emergency Management
4420 E. Martin Way
Olympia, Washington 98504

Mr. William S. Freeman
City of Portland
1120 SW 5th Avenue
Portland, Oregon 97204
503/796-7537

Mr. Walter M. Friday
Oregon Building Code Agency
401 Labor and Industries Building
Salem, Oregon 97310
503/373-7902

Mr. Robert W. Fryer
12070 SW Camden LN
Beaverton, Oregon 97005
503/644-8786

Mr. Richard W. Galster
Consulting Engineering Geologist
18233 13th Avenue, N.W.
Seattle, Washington 98177
206/542-2596

Ms. Paula L. Gori
U.S. Geological Survey
905 National Center
Reston, Virginia 22092
703/648-6707

Ms. Sherry Grandy
City Beaverton Emergency Management
4755 SW Griffith
Beaverton, Oregon 97076
503/526-2536

Mr. Paul Grant
Shannon & Wilson
1105 N. 38th Street
Seattle, Washington 98103
206/632-8020

Mr. Erik P. Graven
Oregon State University
Department of Geology
Oregon State University
Corvalis, Oregon 97331-5506

Mr. Jim Griffiths
U.S. Army Corps of Engineers, Portland District
P.O. Box 2946
Portland, Oregon 97208
503/326-6460

Mr. Michael R. Hagerty, P.E.
City of Portland
Bureau of Buildings
1120 SW 5th Avenue, 930
Portland, Oregon 97204
503/796-7538

Mr. Harry T. Halverson
2220 Bublin Drive, N.W.
Olympia, Washington 98502
206/866-8818

Ms. Molly L. Hamill
NGS
2505 NE 42nd Avenue
Portland, Oregon 97213-1201
503/249-1093

Ms. Laurel Harrington
Seattle Water Dept.
710 Second Ave.
Seattle, Washington 98104
206/684-5901

Mr. John H. Hart
Portland Bureau of Fire, Rescue and Emergency Services
Portland Office of Emergency Management
55 S.E. Ash
Portland, Oregon 97204
503/248-2683

Ms. Susan Hartford
Oregon Water Resources Department
3850 Portland Road NE
Salem, Oregon 97310
503/378-8456

Mr. Fred F. Hawkins
U.S. Bureau of Reclamation
D-3611 P.O. Box 25007 DFC
Denver, Colorado 80225-0007
303/236-4195

Dr. Walter W. Hays
U.S. Geological Survey
905 National Center
Reston, Virginia 22092
703/648-6712

Mr. Charles W. Hedel
CH2M Hill
2020 SW Fourth Avenue, 2nd Floor
Portland, Oregon 97201
503/224-9190

Ms. Kate Heinback
Emergency Management Division
State of Oregon
Capital Building
Salem, Oregon 97310

Ms. Lorie S. Hoffman, P.E.
Bonneville Power Administration
P.O. Box 3651
Portland, Oregon 97208
503/230-5573

Mr. Jack M. Hogan
Washington State Department of
Transportation
3558 NE 166th Street
Seattle, Washington 98155
206/753-7088

Mr. Hugh Holte
Wasco County Emergency Services
c/o 707 East 18th
The Dalles, Oregon 97058
503/296-6424

Dr. Donald A. Hull
Oregon Department of Geology & Mineral
Industries
910 State Office Building
Portland, Oregon 97201
503/229-5580

Mr. Gene Humphreys
University of Oregon
Department of Geology
Eugene, Oregon 97403
503/683-2522

Mr. Jack Irvin
North Pacific Insurance Company
1675 S.W. Marlow Avenue
Portland, Oregon 97225
503/643-7661

Mr. Robert Johnen
Federal Emergency Regulatory Agency
1120 SW 5th Avenue
Suite 1340
Portland, Oregon 97204

Dr. Ansel G. Johnson
Geology Department
Portland State University
Portland, Oregon 97202
503/464-3022

Mr. Samer M. Jomad
Wayne State University
5050 Anthony Payne Drive
Detroit, Michigan 84202
313/577-3789

Mr. Mark Jones
Federal Energy Regulatory Commission
1120 S.W. %th Avenue, Suite 1340
Portland, Oregon 97204
503/326-5844

Ms. Chris Joninentz-Trisler
University of Washington Geophysics
University of Washington geophysics
Program, AK-50
Seattle, Washington 98136
206/543-7010

Mr. Pat Jorgenson
U.S. Geological Survey
MS 144, 345 Middlefield Road
Menlo Park, California 94303
415/329-4000

Mr. Jerry Kagan
Terra Technology Corp.
3860 148th Avenue, N.E.
Redmond, WA 98052
206/883-7300

Mr. Ron Kelm
Department of General Services
Risk Management Division
1225 Ferry Street, S.E.
Salem, Oregon 97306
503/378-5467

Ms. Mary Kennedy
OHSU
3181 SW Sam Jackson Park Road
Portland, Oregon 97201
503/279-5690

Mr. James B. Kennedy
Oregon Department of
Land Conservation and Development
1175 Court Street
Salem, Oregon 97310
503/378-2332

Ms. Abby Kershaw
Local/Administrative Programs Manager
State of Oregon Emergency Management
Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Mr. Rick Kienle
NGS
2505 NE 42nd Avenue
Portland, Oregon 97213-1201
503/249-1093

Mr. Kenneth King
U.S. Geological Survey
Box 25046, MS 966
Denver Federal Center
Denver, Colorado 80225
303/236-1591

Mr. Berni Kleutsch
Oregon Highway Division, Region 2, Geology
2960 State Street, Room 202
Salem, Oregon 97310
503/373-7801

Mr. Paul E. Kluvers
Cooper Consultants, Inc.
11675 SW 66th Avenue
Portland, Oregon 97215
503/639-4914

Mr. William J. Kockelman
U.S. Geological Survey
345 Middlefield Road, MS 922
Menlo Park, California 94025
415/329-5158 FTS 459-5128

Mr. Dave Korwin
Mt. Hood Community College
26000 SE Stark
Gresham, Oregon 97030
503/667-7441

Mr. Paul W. Kostenick
Boeing Company
4500 144th Avenue, S.E.
Bellevue, Washington 96006
206/641-5960

Mr. Barry Krieg
Oregon Health Sciences University
3181 SW Sam Jackson Park Road
Portland, Oregon 97230
503/279-8707

Dr. V. D. Kulm
Oregon State University
College of Oceanography
Oc Admin Building 104
Corvallis, Oregon 97331
503/754-2296

Mr. Raymond Lasmanis
Geology and Earth Resources Division
Department of Natural Resources
Olympia, Washington 98504
206/459-6372

Ms. Myra Thompson Lee
Administrator
Oregon Emergency Management Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Mr. David Leibbrandt
Murray, Smith & Associates, Inc.
121 SW Salmon, Suite 1110
Portland, Oregon 97204
503/225-9010

Mr. Tony Leon
AT&T
4430 Rosewood Drive, Room 5240
Pleasanton, California 94566
415/224-4425

Mr. L. R. Lepp
Associated Earth Sciences, Inc.
911 5th Avenue
Kirkland, Washington 98033
206/827-7701

Mr. Brad Lewis
Fireman's Fund Insurance
2121 4th Avenue, Suite 1100
Seattle, Washington 98121
206/728-5276

Mr. Jack Linderman
City Police
313 Court Street
The Dalles, Oregon 97058
503/296-2233

Mr. Ken Lite
Oregon Water Resources Department
38350 Portland Road N.E.
Salem, Oregon 97310
6503/378-8456

Mr. Dan Loomis
Federal Programs Manager
State of Oregon Emergency Management Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Mr. David W. Lord
Federal Energy Regulatory Commission
1120 SW 5th Avenue, Suite 1340
Portland, Oregon 97204
503/326-5842

Mr. Steve M. Lowell
Washington State Department of Transportation
P.O. Box 167
Olympia, Washington 98504
206/753-4660

Ms. Ruth Ludwin
Geophysics AK 50
University of Washington
Seattle, Washington
206/545-7563

Mr. Ian Madin
Oregon Department of Geology and Mineral Industries
Room 910 1400 S.W. 5th
Portland, Oregon 97034
503/229-5580

Mr. Richard Malin
Portland State University
P.O. Box 751
Portland, Oregon 97207
503/464-3022

Ms. Penny Malmquist
Multonmah County Emergency Management
12440 NE Glisan Street
Portland, Oregon 97230
255/3699 x 207

Mr. Marcia Malstrom
Oregon State Highway Division
1576 Alaha Ct. S.
Salem, Oregon 97302
503/362-6223

Mr. Jeff Manle
Fireman's Fund Insurance
2121 4th Avenue, Suite 1100
Seattle, Washington 98121
206/728-5276

Ms. Connie J. Manson
Washington Division of Geology and Mineral Research
Box 12
Olympia, Washington 98504
206/459-6373

Mr. Lloyd K. Marbet
Co-director
Forelaws on Board Foundation
19142 S. Baker Ferry Road
Boring, Oregon 97009
503/637-3549

Mr. Cliff Marks
City of Seattle
Office for Long-Range Planning
600 Fourth Avenue, Room 200
Municipal Building
Seattle, Washington 98104
206/648-8056

Ms. Casey Marley
Clackamas County Emergency Managmeent
2200 S. Kaen Road
Oregon City, Oregon 97045
503/655-8378

Ms. Carole Martens
Washington State Division of Emergency Management
4220 E. Martin Way
Olympia, Washington 98504
206/459-9191

Ms. Shirley Mattingly
City of Los Angeles
200 N Main Street, Room 300
Los Angeles, California 90012
213/485-6400

Mr. Peter May
University of Washington
Political Science Division
Seattle, Washington 98195
206/543-9842

Mr. James A. Mazza
Oregon Emergency Management Division
43 Capitol Building
Salem, Oregon 97302
503/378-4104

Mr. C. A. McCune
Commercial Building Owner
P.O. Box 845
Port Townsend, Washington 98368
206/385-6167

Mr. William D. McFarland
U.S. Geological Survey, Water Resources Division
847 NE 19th Street, Suite 300
Portland, Oregon 97232
503/231-2013
FTS 429-2013

Mr. Jeff McFarland
Forelaws on Board Foundation
3878 Meadowlawn, S.E.
Salem, Oregon 97301
503/364-8975

Mr. Roger McGarrigle, P.E.
Structural Engineers Association of Oregon
3933 S.W. Valley
Portland, Oregon 97201
503/222-4453

Mr. Jerry Menard
313 Eugene street
Hood River, Oregon 97031
503/386-5755

Mr. Mike Mendenhall
Building Code Agency
1535 N.W. Edgewater
Salem, Oregon 97310
503/378-8319

Mr. Roy G. Metzgar
Snohomish Co.
P.O. Box 1107
Everett, Washington 98206

Ms. Sarah Michaels
Natural Hazards Center
Campus Box 482
University of Colorado
Boulder, Colorado 98195
303/492-6818

Mr. Mike Michaelson
Jackson County Sheriff's Department
10 South Oakdale
Medford, Oregon 97501
503/776-7691

Dr. Hugh H. Mills
Portland State University
Geology Department
Portland, Oregon 97207-0751
503/464-3022

Dr. Rick Minor
Heritage Research Associates
1997 Garden Avenue
Eugene, Oregon 97403
503/485-0454

Mr. Michael Mitchell
Lane Community College
4000 E. 30th Avenue
Eugene, Oregon 97405
503/474-4501

Ms. Carol S. Mladinich
U.S. Geological/National Mapping Division
P.O. Box 25046, MS 516
Denver, Colordo 80225
303/236-5838

Mr. Terry Montgomery
DHUBB Group of Insurance Companies
720 Olive Way
Seattle, Washington 98101
206/624-2100

Mr. Harry Moomey
ODOE, Trojan Resident
635 Marion Street, NE
Salem, Oregon 97310
503/556-0005

Mr. William E. Moor
The Boeing Company
P.O. Box 3707, MS 1E-73
Seattle, Washington 98124
206/393-2831

Mr. Cliff Moore
Josephine Co. Sheriff's Office
Courthouse
Grant Pass, Oregon 97526
503/474-5118

Mr. Gary E. Munson
Risk Management Division
Department of General Services
State of Oregon
1225 Ferry Street, S.E.
Salem, Oregon 97310
503/378-5519

Mr. Joseph Murray
Planner
State of Oregon Emergency Management Division
43 State Capitol
Salem, Oregon 97310
503/378-4124

Dr. John Nabelek
Oregon State University
College of Oceanography
Corvallis, Oregon 97331
503/754-2757

Mr. John Nance
4512 87th Avenue, West
Tacoma, Washington 98466
206/565-2900

Ms. Sharon No
Seattle City Light
1015 3rd Avenue, Room 300
Seattle, Washington 98104-1198

Chief David Norris
Division Chief
Portland Fire Bureau
55 SW Ash Street
Portland, Oregon 97204
503/248-2680

Ms. Linda Lawrence Noson
Federal Emergency Management Agency
  Region X
130 228th Avenue S.
Seattle, Washington 98021-9796
206/487-4694

Mr. Bruce C. Olsen
Consulting Engineer
1411 Fourth Ave., #1420
Seattle, Washington 98101-2216
206/624-7045

Mr. Gustavo A. Ordonez
Washington State Department of Ecology,
Dam Safety Section
Mail Stop PV-11
Olympia, Washington 98504
206/459-6751

Dr. Elaine Padovani
U.S. Geological Survey
905 National Center
Reston, Virgina 22092
703/648-6722

Dr. Leonard Palmer
Portland State University
P.O. Box 751
Portland, Oregon 97707
503/464-3022

Mr. Sue Patterson
American Red Cross -- Disaster Services
P.O. Box 3200, 3131 N. Vancouver Avenue
Portland, Oregon 97208
503/284-1234

Ms. Sheila Paulsen
Chubb Group of Insurance Cos.
1500 First Avenue, Suite 1000
Portland, Oregon 97217
503/221-4240

Mr. Paul F. Pedone
Soil Conservation Service
1220 SW 3rd Room 1640
Portland, Oregon 97204
503/336-2746

Mr. William J. Perkins
Shannon and Wilson, Inc.
406 N. 34th Street, Suite 100
Seattle, Washington 98103
503/632-8020

Mr. Gary Peterson
L.R. Squiek Associates
4255 Oakridge Road
Lake Oswego, Oregon 97035
503/635-4419

Mr. John L. Peterson
City of Seattle
400 Municipal Building
Seattle, Washington 98104
206/648-8473

Dr. Curt D. Peterson
College of Oceanography
Oregon State University
Corvallis, Oregon 97331
503/754-2759

Mr. John Poe
Fireman's Fund Insurance
2121 4th Avenue, Suite 1100
Seattle, Washington 98121
206/728-5276

Ms. Cathy J. Poe
Unigard Insurance Company
600 108th NE, Suite 340
Bellevue, Washington 98004
206/641-4321

Mr. Thomas A. Popowski
Oregon State University
Department of Geology
Corvallis, Oregon 97331-5506
503/754-2484

Ms. Jane Preuss
Urban Regional Research
1809 7th Avenue, Suite 1000
Seattle, Washington 98101
206/624-1669

Dr. George R. Priest
Oregon Department of Geoscience
University of Washington
Seattle, Washington 98115
206/459-6327

Mr. Bert Pschunder
GeoEngineers, Inc.
2405 - 140th Avenue N.E., Suite 105
Bellevue, Washington 98005
206/746-5200

Mr. Ed Pyne
NGS
2505 NE 42nd Avenue
Portland, Oregon 97213-1201
503/249-1093

Dr. Anthony Qamar
University of Washington
Geophysics AK-50
Seattle, Washington 98195
206-545-7563

Ms. Marion J. Ramsaur
U.S. West Communications
Room 910, 1600 7th Avenue
Seattle, Washington 98191
206/345-6528

Mr. William L. Reagan
ORVOAD-EMO
C&S Disaster Response Consultants
1635 George Ct. NW
Salem, Oregon 97304
503/362-1234

Mr. Phil Rice
Oregon Department of Education
700 Pringle Parkway, SE
Salem, Oregon 97310
206/378-8142

Mr. Paul Vincent
University of Oregon
Department of Geology
Eugene, Oregon 97403

Captain Leon Riggs
Marvin County Emergency Services
P.O. Box 710
Salem, Oregon 97308
503/588-5110

Mr. K. C. Robbins
K. C. Robbins - Geotechnical Consultant
3203 S.W. Newby Terr
Portland, Oregon 97201
503-246-4384

Mr. Robert Rose
Bellevue Public Schools
12037 N.E. 5th
Bellevue, Washington 98005
206/455-6121

Ms. Cory Samia
Oregon Museum of Science and Industry
4015 SW Canyon Road
Portland, Oregon 97221
503/222-2828

Mr. William Satoris
Federal Emergency Management Agency
Federal Regional Center
Bothell, Washington 98021-9726
206/487-4760

Dr. Robert L. Schuster
U.S. Geological Survey
Box 25046, MS 966
Denver Federal Center
Denver, Colorado 80225
303/236-1633

Mr. David Scofield
Corps of Engineers, Portland District
P.O. Box 2946
Portland, Oregon 97208
503/326-6310

Mr. William E. Scott
Cascade Volcano Observatory
U.S. Geological Survey
5400 MacArthur Boulevard
Vancouver, Washington 98661
206/696-7909 FTS 422-7909

Mr. Paul D. See
Independent Consultant
300 Surf Pines Road
Seaside, Oregon 97138
503/738-5869

Mr. Thomas L. Servatius
U.S. Geological Survey
Earth Science Information Center
Room 678, U.S. Court House
Spokane, Washington 99201
509/456-2524 FTS 439-2524

Dr. Kaye Shedlock
U.S. Geological Survey
Box 25046, MS 966
Denver Federal Center
Denver, Colorado 80225
303/236-1585

Mr. Trevor D. Smith
Portland State University
Dept. of Civil Engineering
P.O. Box 751
Portland, Oregon 97201
503/464-4282

Mr. Paul Somerville
Woodward-Clyde Consultants
566 El Dorado Street
Pasadena, California 91101
818/449-7650

Mr. Steve Starkey
Oregon Department of Transportation
ODOT Building, Room 329
Salem, Oregon 97310
503/378-655

Mr. Charles E. Stearns
Soil Conservation Service
511 SW Broadway, Room 248
Portland, Oregon 97209
503/326-2854

Mr. Chuck Steele
Federal Emergency Management Agency
Federal Regional Center
Bothell, Washington 98021
206/487-4682

Dr. Karl V. Steinbrugge
Consulting Structural Engineer
6851 Cutting Boulevard
El Cerrito, California 94530
415/233-1060

Mr. Tom Stephens
ISO Commercial Risk Services Inc.
3000 Executive Parkway, Suite 510
San Ramon, California 94583
415/830-8778

Mr. Thomas J. Sternburgh
Umatilla County Emergency Management
Court House
Pendleton, Oregon 97801
503/276-7111 x 250

Ms. Judith L. Stiles
Emergency Program Manager
Portland Office of Emergency Management
2960 SE 103
Portland, Oregon 97266
503/248-5580

Mr. Richard Stoddard
Washington State Department of Transportation
Research Office, KF01
Olympia, Washington 98504
206/586-1886

Mr. Eric Sutter
KPFF Consulting Engineers
421 SW 6th
Portland, Oregon 97204
503/227-3251

Dr. Donald A. Swanson
U.S. Geological Survey
5400 MacArthur Boulevard
Vancouver, Washington 98661

Mr. Rodney D. Swanson
USGS Water Resources Division
847 NE 19th Street, Suite 300
Portland, Oregon 97232
503/231-2014 FTS/429-2014

Mr. T. Kenneth Tang
SEAW - EERI
87 Wau Street
Seattle, Washington 98109
206/728-7088

Mr. John Testa
Supervisor, Information Center
Snohomish County Public Utility District No. 1
P.O. Box 1107
Everett, Washington 98206
206/258-8675

Mr. Michael Thomas
St. Paul Insurance Company
825 Multnomah
Portland, Oregon 97232
503/238-6240

Dr. Jim Thompson (James B.)
GeoEngineers, Inc.
2405 - 140th Avenue N.E., Suite 105
Bellevue, Washington 98005
206/746-5200

Mr. Gerald W. Thorsen
Consulting Geologist
1926 Lincoln
Port Townsend, Washington 98368
206/385-6002

Mr. Jim Tingey
Utah Division of Comprehensive Emergency Management
1543 Sunnyside Avenue
Salt Lake City, Utah 84108
801/533-5371

Dr. John Tinsley
U.S. Geological Survey
345 Middlefield Road, MS 975
Menlo Park, California 94025
415/853-4928 (FTS) 459-8300

Dr. John O. Truby
Colorado Division of Disaster Emergency Services
Camp George West
Golden, Colorado 80401

Ms. Joy Tumbaga
Multonmah County Emergency Management
12440 NE Glisan Street
Portland, Oregon 97230
255/3699 x 207

Mr. Donald Turner
Oregon State Highway Division
9002 SE McLoughlin Boulevard
Milwaukie, Oregon 97222
503/652-3080

Dr. Randy Updike
U.S. Geological Survey
905 National Center
Reston, Virgina 22092
703/648-6708

Ms. Marcia Van Orman
Water Bureau
1100 SW 5th Avenue, 6th Floor
Portland, Oregon 97204

Dr. Richard B. Waitt
USGS
4500 MacArthur Boulevard
Vancouver, Washington 98661
206/696-7538 (FTS) 422-7538

Dr. Craig S. Weaver
U.S. Geological Survey
Branch of Seismology
Geophysics Program AK-50
University of Washington
Seattle, Washington 98195
FTS 399-0627

Dr. Stephen Weissberg, P.E.
Director of Marketing
2855 Telegraph Avenue, Suite 410
Berkeley, CA 94705
415/843-7233

Mr. Kenneth S. Werner
Oregon State University
Department of Geology
Corvallis, Oregon 97331-5506
503/754-2484

Dr. Robert L. Wesson
Chief, Office of Earthquakes, Volcanoes, and Engineering
U.S. Geological Survey
905 National Center
Reston, Virginia 22092
703/648-6714

Mr. Donald O. West
Golder Associates
333 Hegenberger Road, Suite 203
Oakland, California 94561
415-635-6143

Mr. Robert West
2960 State Street
Salem, Oregon 97310

Dr. Gerald Wieczorek
U.S. Geological Survey
905 National Center
Reston, Virgina 22092
703/648-6713

Ms. Cynthia Wilhite
Portland General Electric
121 SW Salmon
Portland, Oregon 97304
503/464-8565

Mr. Larry Wilkerson
B.P. Administration, E F P.O. Box 321
Portland, Oregon 97208
FTS 429-4607

Mr. F. Otis Winchester
Wasco County Tire District #1
P.O. Box 801
The Dalles, Oregon 97058
503/296-9445

Ms. Bonnie Witek
CH2M Hill
777-108th Avenue NE
Bellevue, Washington 98004
503/453-5000

Mr. Max Wjhitaker
4200 Victor Point Road
Silverton, Oregon 97381

Mr. John Wohlhaupter
P.O. Box 742
Port Townsend, Washington 98368
206/385-3622

Mr. Ivan G. Wong
Woodward-Clyde Consultants
500 12th Street, Suite 100
Oakland, California 94607
415/874-3014

Dr. Robert S. Yeats
Oregon State University
Department of Geology
Corvallis, Oregon 97331-5506
503/754-2484

Mr. Van York
Municipality of Metropolitan Seattle
821 Second Avenue, M/S 65
Seattle, Washington 98104
206/684-1305

Dr. Les Youd
Brigham Young University
Department of Civil Engineering
Provo, Utah 94602
801/378-6327

Mr. Robert Youngs
Geomatrix Consultants
1 Market Place
Spear St. Tower, Suite 717
San Francisco, California 94105
415/957-9557

Mr. Jim Yount
U.S. Geological Survey
c/o Nevada Bureau of Mines and Geology
University of Nevada
Reno, Nevada 89557-0088
703/784-6966

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989— 262 - 139 /05816