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2001

LIFE IN THE SUBDUCTION ZONE:
THE RECENT NISQUALLY QUAKE AND FEDERAL
EFFORTS TO REDUCE EARTHQUAKE HAZARDS

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH
COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

MARCH 21, 2001

Serial No. 107–2

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NATALIE PALMER *Staff Assistant*

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LIFE IN THE SUBDUCTION ZONE: THE RECENT NISQUALLY QUAKE AND THE FEDERAL EFFORTS TO REDUCE EARTHQUAKE HAZARDS

WEDNESDAY, MARCH 21, 2001

House of Representatives,
Subcommittee on Research,
Committee on Science,
Washington, DC.

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The Subcommittee met, pursuant to call, at 2:05 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Nick Smith [Chairman of the Subcommittee] presiding.

Committee on Science
Subcommittee on Research
U.S. House of Representatives

Washington, DC 20515

Hearing on

Life in the Subduction Zone: The Recent Nisqually Quake and Federal Efforts to Reduce Earthquake Hazards

Wednesday, March 21, 2001

Witness List

Dr. John Filson
Coordinator of Earthquake Programs,
U.S. Geological Survey

Dr. Priscilla Nelson
Director, Division of Civil and Mechanical Systems,
National Science Foundation

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

Dr. M. Meghan Miller
Professor of Geological Sciences,
Central Washington University

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Chairman **SMITH.** The Subcommittee on Research will come to order. First, let me welcome you to this hearing of the House Science Subcommittee on Research. Today marks the first hearing of our newly named Subcommittee on Research. For the last several years, it was Basic Research. I hope we will be very productive this session. We certainly were in the last 2 years. I look forward to working with our distinguished Ranking Member, the gentlewoman from Texas, Eddie Bernice Johnson, and certainly Tim Johnson from Illinois, the Vice Chairman of this subcommittee.

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I look forward to all the Subcommittee members' input and participation in what I anticipate will be an active Subcommittee agenda this session, including a National Science Foundation reauthorization bill, a hard look at education research, and other issues that may arise during the course of the year in which we have a significant role to play.

I would like to mention that I think already one issue of concern for me is the unbalanced Federal research portfolio that we are considering. This Subcommittee will continue to emphasize the important role of the National Science Foundation and its role in basic and fundamental research. To continue to fund it at a —what I consider a disproportionately low level when compared to other Federal research agencies, such as NIH, that politically is easy to excite additional funding, I think we have got to be very careful that we don't overlook some of the basic research that has truly added to the knowledge of NIH to proceed in several of their areas.

The basic research NSF funds is not just interesting, but it forms the foundation for much additional research, as it takes places in all areas of government, including NIH. It often leads to economically important breakthroughs and it can even help save lives. Our hearing today, Life in the Subduction Zone: The Recent Quake and certainly Federal Efforts to Reduce Earthquake Hazards, will highlight this last point, because research aimed at better understanding how and why earthquakes happen is really the first step in being able to mitigate the damage they cause, both physical and human damage.

At a little before 11 on the morning of February 28, a large earthquake shook the Seattle, Washington area, injuring 410 individuals, and could cost an estimated $2 billion worth of damage. The quake, which measured a magnitude of 6.8 on the Richter scale was centered about 11 miles northeast of Olympia, damaged structures and caused ground failures throughout the Puget Sound region.

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At first glance, it seems fortunate that there were relatively few serious injuries and fairly limited damage considering the strength of the quake. After all, when a magnitude 6.7 quake struck the Northridge, California area in January of '94, it killed 60 and caused over $40 billion in damage.

A closer look reveals that in this quake the Seattle/Olympia area was maybe, in a way, somewhat fortunate. The hypocenter of the quake, that is, the point in the earth at which the energy from the quake was released, was an estimated 30-plus miles beneath the surface, blunting considerably the ground motion associated with a quake of that size. And while it may have been a magnitude 6.8 quake, it didn't feel like one in Seattle and the damage is still being analyzed.

Perhaps, the question should be, given the smaller apparent size of the earthquake in the Seattle area, how was it able to cause so much damage? And how will determining the answer to that question help us to alleviate the damage caused by future quakes in other parts of the country and certainly, as we look at El Salvador and other areas, in the rest of the world? The USGS, the U.S. Geological Survey, indicated that 39 states are subject to serious earthquake risk and 79 million people that live in these 39 states in urban and nonurban areas stand the risk of earthquake.

The Federal Emergency Management Agency estimates annual losses due to earthquakes in the United States at 4.4 billion. Internationally, earthquakes have been incredibly costly already this year. In India, a recent quake killed 18,000 people and recent quakes in El Salvador have left thousands dead and displaced almost a million people. Clearly there is much at stake.

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The National Earthquake Hazard Reduction Program was established by Congress in 1977 to address this risk we face from earthquakes. This Subcommittee was instrumental in reauthorizing NEHRP for 2001 through 2003 with the passage of the Earthquake Hazards Reduction Authorization Act of '99, and it was signed by the President last year.

A little bit about NEHRP. Since its inception, NEHRP has focused on earthquake research, as well as hazards mitigation in general. NEHRP activities in research and mitigation are executed by four separate Federal agencies, FEMA, USGS, the National Science Foundation, and the National Institute of Standards and Technology. Congress authorized a total of $464.7 million for Fiscal Year 2001 and through 2003 for these programs.

In today's hearing, we will hear how some of these programs had an impact before, during, and after the earthquake that have—has happened this year and how the lessons learned from the quake could help mitigate the effects of future quakes. In particular, I am interested to learn about some of the new technologies, including the more sensitive ground-based equipment and satellite-based sensors for monitoring fault movements, as well as efforts to provide real-time warnings or more accurate predictions of earthquakes.

The USGS recently—one of your colleagues stated that he thought, in the future, with the advent of technology, it would be—it is plausible that we will be able to predict earthquakes as well as we do the weather. And not to lead that as an out, but potential—we have that potential. And, of course, even gaining a few seconds of advanced notice time would allow us technologically to cut off some switches that might control some of the gas movement in those areas if—which would have a tremendous potential savings.

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You know, Seattle may have dodged the bullet with recent—with its recent quake, but we need to be well-equipped and well-prepared for the next shot, wherever it may occur. And I want to thank our Panel of witnesses for appearing before us today, and I look forward to your testimony. The Chair now recognizes the Ranking Member of this Committee, Eddie Bernie Johnson, for this Subcommittee. And usually, only the Chair and Ranking Member give statements, but you can recognize, certainly, other members, if you would like to, in this occasion with Dr. Palmer.

[The prepared opening statement of Mr. Smith follows:]

OPENING STATEMENT OF NICK SMITH

Welcome to this hearing of the House Science Subcommittee on Research. Today marks the first hearing of our newly-named Research subcommittee and the start of what I hope will be a very productive session. I look forward to working with our distinguished Ranking Member, the gentlewoman from Texas, Eddie Bernice Johnson, and the other members—new and old—of our subcommittee. I look forward to your input and participation in what I anticipate will be an active subcommittee agenda this session, including a National Science Foundation reauthorization, a hard look at education research, and other issues that may arise during the course of the year in which we have a role to play.

Already one issue of concern for me is our unbalanced federal research portfolio. This Subcommittee will continue to emphasize the important role NSF plays in funding fundamental research. To continue to fund it at a disproportionately low level when compared to other federal research agencies like the National Institutes of Health will hurt long-term productivity and our standard of living. The basic research NSF funds is not just interesting, but it forms the foundation for much additional research at places like NIH. It often leads to economically-important breakthroughs, and it can even help save lives. Our hearing today, *Life in the Subduction Zone: The Recent Nisqually Quake and Federal Efforts to Reduce Earthquake Hazards,* will highlight this last point, because research aimed at better understanding how and why earthquakes happen is the first step in being able to mitigate the damage they cause.

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At a little before lIon the morning of February 28th, a large earthquake shook the Seattle, Washington, area, injuring 410 people and causing over $2 billion in damages. The quake, which measured magnitude 6.8 on the Richter scale and was centered about 11 miles northeast of Olympia, damaged structures and caused ground failures throughout the Puget Sound region. At first glance, it seems fortunate that there were relatively few serious injuries and fairly limited damage considering the strength of the quake. After all, when a magnitude 6.7 quake struck the Northridge, California area in January, 1994, it killed 60 and caused over $40 billion in damage. But a closer look reveals that, in this quake, the Seattle/Olympia area caught a break. The hypocenter of the quake—that is, the point in the earth at which the energy from the quake was released—was over 30 miles beneath the surface, blunting considerably the ground motion associated with a quake of that size. While it may have been a magnitude 6.8 quake at the hypocenter, it didn't feel like one in Seattle.

So perhaps the question should be, given the smaller apparent size of the earthquake in the Seattle area, how was it able to cause so much damage? And how will determining the answer to that question help us to alleviate the damage caused by future quakes in other parts of the country, or the rest of the world? The US Geological Survey indicates that 39 states are subject to serious earthquake risk, and 75 million people live in urban areas with moderate to high earthquake risk. The Federal Emergency Management Agency estimates annualized losses due to earthquakes in the U.S. at $4.4 billion. Internationally, earthquakes have been incredibly costly already this year. In India, a recent quake killed over 18,000 people and recent quakes in El Salvador have left thousands dead and displaced nearly a million. Clearly there is much at stake.

The National Earthquake Hazards Reduction Program (NEHRP) was established by Congress in 1977 to address this risk we face from earthquakes. This subcommittee was instrumental in reauthorizing NEHRP for FY 2001–2003 with the passage of the Earthquake Hazards Reduction Authorization Act of 1999, signed by the President last year. Since its inception, NEHRP has focused on earthquake research as well as hazards mitigation. NEHRP activities in research and mitigation are executed by four separate federal agencies: FEMA, USGS, the National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST). Congress authorized a total of $464.7 million for FY 2001–2003 for NEHRP programs.

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In today's hearing we will hear how some of these programs had an impact before, during, and after the Nisqually earthquake, and how the lessons learned from the quake could help mitigate the effects of future quakes. In particular, I'm interested to learn about some of the new technologies—including more sensitive ground-based equipment and satellite-based sensors for monitoring fault movements—as well as efforts to provide real-time warnings or more accurate predictions of earthquakes.

Seattle may have dodged a bullet with this recent quake. But we need to be well-equipped and well-prepared for the next shot, wherever it may occur. I want to thank our panel of witnesses for appearing before us today, and I look forward to your testimony.

Ms. **JOHNSON.** Thank you very much, Mr. Chairman. I am pleased to have the opportunity to work with you again this term on areas of which we both have great interest, and to have the opportunity to hear from the witnesses about the details of the Nisqually earthquake and Federal efforts aimed at reducing earthquake hazards. But more than that, I am looking forward to hearing about what we are doing right and how we can focus our future efforts so that we can do even a better job.

The science of ground motion is complex and research is essential to our ultimate understanding of this natural phenomenon. I understand that the focus of today's hearing is on the recent earthquake and our Federal earthquake research programs. I have visited one of the labs in California. However, I am also—I would like to hear about where this research has been supplemented—has supplemented mitigation efforts, disaster response, and preparedness. It is my hope that our witnesses will speak to these issues, as well as to the science behind the earthquakes.

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I think we can all agree that the key to the successful reduction of loss of life and property lies in both information and implementation. I want to thank you, Mr. Chairman, and I would like to yield my remaining time to Mr. Baird, a Democrat from Washington, and someone for which the Nisqually earthquake was particularly significant. Mr. Baird.

[The opening prepared statement of Ms. Johnson follows:]

OPENING STATEMENT OF THE HONORABLE EDDIE BERNICE JOHNSON

Mr. Chairman, I am pleased to have the opportunity to hear from witnesses about the details of the

Nisqually Earthquake and Federal efforts aimed at reducing earthquake hazards. But more than that, I'm looking forward to hearing about what we're doing right, and how we can focus our future efforts so that we can do even better.

The science of ground motion is complex, and research is essential to our ultimate understanding of this natural phenomenon. I understand that the focus of today's hearing is on the recent earthquake and our federal earthquake research programs. However, I'd also like to hear about where this research has supplemented mitigation efforts, disaster response, and preparedness. It is my hope that our witnesses will speak to those issues as well as to the science behind earthquakes.

I think we can all agree that the key to the successful reduction of loss of life and property lies in both information and implementation.

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Thank you, Mr. Chairman, and with that I'd like to yield my remaining time to Mr. Baird, Democrat from Washington, and someone for which the Nisqually earthquake was particularly significant.

Mr. **BAIRD.** I would like to thank the Committee Chair and Ranking Member Johnson. As members of this Committee know, the epicenter of this quake was located just 11 miles outside of one of the largest population centers in my district, Olympia, Washington. Less than 24 hours after the quake hit, I, along with other members of our Washington delegation and the FEMA Director, Joe Albaugh, we were on the ground in Olympia and Seattle to evaluate the quake and see firsthand the effects. And I want to take a moment here to compliment the Administration, and particularly Joe Albaugh and Lacy Suiter, who did just such a tremendous job of responding quickly, as did the Small Business Administration and FEMA, in general.

I want to let you know that in Olympia, Washington, and throughout the Seattle and southern part of our state, businessmen and women were forced to close their businesses, some possibly forever. I met with workers who would be out of their jobs for weeks, some possibly for months. We visited bridges, critical bridges, that were damaged to such an extent you couldn't use them. And these are critical access bridges—one in particular, the Fourth Avenue bridge in Olympia that connects the west side of the town to the center of the town, connects hospitals, schools, etcetera, and it is a crisis situation to have that bridge out.

But when I tell the Committee that I am concerned about the devastation, it is devastation I have seen firsthand and it extensively affects the lives of our people.

We have learned that the earthquake mitigation measures implemented in our area were extremely effective. And by mitigation measures, I mean both the infrastructure hardening and also the emergency service personnel preparation. But we still have much to learn and we need to use this opportunity to listen to the recommendations from experts in the field. I believe it is appropriate for us to look at this Nisqually earthquake as a quiz, but not the final exam. We are in an area of geological hazards. And, as the Chairman, I think, aptly put it, we were, in some ways, relatively lucky. Had this been the same magnitude quake closer to the surface, the damage and loss of life might have been much greater. So, hence, our need for further preparation is also greater.

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I think we have an opportunity to learn from last month's earthquake and to prepare structurally, financially, and scientifically for the next quake right now. I also want to take this opportunity again to thank the FEMA, the Federal Emergency Management Agency, and Small Business Administration for their quick work and to commend all the local fire, safety, and state personnel who responded so quickly.

I would further want to reiterate the Chairman's concerns about funding availability for critical agencies. In the Pacific Northwest, we have such agencies and scientists who dedicate their lives to trying to study and reduce these hazards and it would be I don't think wise to reduce their funding when we have seen that that funding and the preparation spent today can prepare us to save money in the long term.

I would like to also welcome some special guests from our state. And, if I may, I would begin with Steven Palmer, who is here—Dr. Steve Palmer, who is here today from our district. Dr. Palmer received his undergraduate degree in Geology and his MS and Ph.D. degrees in Engineering Science form the University of California at Berkeley. He is currently employed with the Washington State Department of Natural Resources and did a superb job, I might add, on the ground studying this issue. During his time at the Department he has been a principal investigator on a number of projects involved with the evaluation of regional earthquake hazards in the Puget Sound region. And most recently, he completed detailed mapping of the liquefaction ground failure hazards along the I–5 corridor between Seattle and Olympia, and those maps provided immensely important and helpful.

Dr. Palmer is not the only Washington resident here today. We also have Dr. Meghan Miller of Central Washington University. Dr. Meghan—or Dr. Miller will focus her testimony today on the experience using the GPS geodesy system to measure earthquake formation—or deformation and to assist in predicting future earthquakes. Welcome to the hearing, Drs. Palmer and Miller. I look forward to your testimony and I thank, again, the Chair and Ranking Member for convening this hearing.

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[The prepared statement of Mr. Baird follows:]

PREPARED STATEMENT OF THE HONORABLE BRIAN BAIRD

I'd like to thank the Subcommittee Chair, Congressman Nick Smith and the Ranking Member, Congresswoman Eddie Bernice Johnson for convening this hearing today and for allowing me the opportunity to speak to this important issue.

As the Members of the Committee know I the epicenter of this quake was located just 11 miles outside one of the largest population centers in my District—Olympia, Washington. Less than 24 hours after the quake hit, I, along with other members of the Washington delegation and FEMA director, Joe Allbaugh, was on the ground in Olympia and Seattle to evaluate the effects of the quake and to see the damage first-hand.

I want to let you know that I met with homeowners that didn't have a home they could live in anymore. I talked with businessmen and women whose businesses would be closed—some forever. I worked alongside worried city officials to make sure that damaged roads and bridges didn't prevent ambulances or fire trucks from getting where they need to go in time to save life or property. So when I tell the committee that I am concerned with the devastation produced by these natural disasters and am interested in how we can reduce quake damage in the futurel please know that thousands of my constituents are just as concerned and just as interested.

We have learned that the earthquake mitigation measures implemented in our area were extremely effective, however, we still have much to learn and we should use this opportunity to listen to recommendations from experts in the field. I believe that we should look at the Nisqually quake as a quiz and use it to prepare for the test.

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As urban centers built along fault lines become more and more populated, the potential for disastrous and costly damage from earthquakes has increased. This is true even in technologically ad,vanced countries that have implemented seismic zoning policies to mitigate the harm from quakes. The earthquakes that hit San Francisco in 1989, Northridge in 1994, and Kobe, Japan in 1995 illustrate this point. In a sense, the Nisqually case is unusual because, despite the power of the quake, it produced only $2 billion in damage and only minor injuries. Compare this to the earthquake in Kobe, which resulted in nearly 5,500 deaths, 35,000 injuries, and $147 billion in direct damage, and I think its clear that things could have been much worse.

I believe that we have an opportunity to learn from last month's earthquake, and to prepare structurally, financially and scientifically for the next quake right now. The best way to do that is to examine this experience with an eye to learning what we did well, what didn't work so well and how we can do better with the next quake—which will come—so that we have even less damage and disruption.

I would also like to briefly take this opportunity to thank everyone at the Federal Emergency Management Agency and the Small Business Administration for their quick response to our emergency and the thorough assistance they have provided the citizens of Washington State.

I again applaud the Committee for organizing this hearing and would like to introduce two witnesses that experienced the quake first hand.

First I would like to welcome Dr. Steve Palmer who is here today from my district. Dr. Palmer received his undergraduate degree in Geology, and MS and Ph.D. degrees in Engineering Science from the University of California, Berkeley. He is currently employed by the Washington State Department of Natural Resources, Geology and Earth Resources Division in Olympia. During his time at the Department he has been a principal investigator on a number of projects involved with evaluation of regional earthquake hazards in the Puget Sound. Most recently he has completed detailed mapping of liquefaction ground failure hazards along the I–5 corridor between Seattle and Olympia.

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I note that Dr. Palmer isn't the only Washingtonian here today—we also have Dr. Meghan Miller of Central Washington. Dr. Miller will focus her testimony on her experience in using Global Postion Sattelite geodesy system to measure earth deformation and to assist in predicting and detecting future earthquakes. Welcome to the hearing, Doctors Palmer and Miller, and I look forward to hearing your testimony as well as that of the rest of the panel. Thank you for yielding me time Ms. Johnson and thank you Mr. Chairman.

Chairman **SMITH.** Representative Baird, thank you. At this time, I would like to finish introducing our panelists. And our first panelist is Dr. John Filson, who is the Coordinator of Earthquake Programs at the U. S. Geological Survey. He joined USGS in 1978 and since then has traveled the world studying earthquakes and their aftermath. He is the past President of the Seismological Society of America and a Fellow at the American Association for the Advancement of Science.

Our second panelist, Dr. Priscilla Nelson, is Director of the Civil and Mechanical Systems Division of the Directorate for Engineering of the National Science Foundation. She has a national and international reputation in geological and rock engineering and a particular application of underground construction. She has more than 15 years of teaching experience and more than 120 technical and scientific publications to her credit.

And, of course, Dr. Stephen Palmer, whom Representative Baird introduced quite eloquently. And our final panelist, Meghan Miller, who had also accolades from you, Representative Baird. We welcome you all to our Panel and look forward to your testimony. And with that, Mr. Filson, if you would proceed.

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STATEMENT OF DR. JOHN R. FILSON, COORDINATOR OF EARTHQUAKE PROGRAMS, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. **FILSON.** Mr. Chairman, and distinguished members of this Subcommittee, thank you for the opportunity to testify on behalf of the Geological Survey regarding the recent earthquake in the Pacific Northwest. I provided you hard copies of my visual materials, and I believe they will also be projected on the screen in the rear.

The Geological Survey carries out the applied earth science element of the National Earthquake Hazards Reduction Program under the leadership of FEMA. Basically we do three things. Earthquake monitoring and notification through the operation of networks of seismic instrumentation and associated data centers, and earthquake hazards assessments; how hard is the ground expected to shake where? And we do research on earthquake effects and processes.

The cause of the recent earthquake is related to the plate tectonics of the region shown in Figure 1 of my testimony. In the Pacific Northwest, the Juan de Fuca plate forms 500 miles offshore and moves northeast at about 1.5 inches per year. As it moves northeast, it collides with the North American plate. It is overridden by it and then sinks into the mantle. This process results in enormous strain or the bending of rock. The strain is not released continuously, but is stored and released suddenly when the rock breaks in earthquake. This process gives rise to three types of earthquakes.

Type 1 earthquakes are very large earthquakes that break the fault boundary between the two plates. These could be as large as magnitude 9. Type 2 earthquakes occur at depth within the Juan de Fuca plate as it bends and sinks within the mantle. The recent Nisqually earthquake was one of this type. Type 3 earthquakes occur at shallow depths within the North American plate. These are due to the release of strains built up in the general plate convergence process.

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As part of our National Earthquake Hazards Program, we have done a national assessment of the ground shaking of the entire country. Figure 2 is a portion of this map for the Pacific Northwest. In general, the warmer colors here represent higher anticipated ground shaking.

The earthquake of 28 February had a magnitude 6.8 and was located 33 miles deep. It was a Type 2 event caused by the bending of the sinking Juan de Fuca plate, as shown in Figure 3.

Figure 4 of my testimony shows the actual shaking levels experienced during this earthquake. Again, the warmer colors indicate strong shaking. Although the earthquake was widely felt, the potential damage was light and moderate. As you did, Mr. Chairman, in Figure 5, we can compare the shaking—this shaking pattern with that of the magnitude 6.7 Northridge earthquake near Los Angeles. The Northridge earthquake was relatively shallow with the fault break coming up within about two miles of the surface. The strong shaking was not diminished due to dispersion and attenuation, but hit the surface and the structures thereon. A schematic diagram of this effect is shown in Figure 6. As you noted, Mr. Chairman, the Northridge earthquake killed 60 persons and resulted in about $40 billion worth of damage.

The levels of ground shaking experienced in the Nisqually earthquake did not exceed those predicted by our national assessment shown in Figure 2. Shaking levels on the national assessment are for one uniform rock type and do not take into account the variation of shaking levels caused by various local rock conditions. By previously placing numerous instruments in the Seattle area, we were able to record the variation of ground shaking in the area due to local geologic side effects. Preliminary results are shown in Figure 6. In general, areas of soft alluvium and artificial fill experienced higher degrees of ground shaking. We are still in the process of analyzing this data.

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The USGS began work on earthquake problems of the Pacific Northwest more than 20 years ago. We have worked with the University of Washington to establish and operate a regional seismograph network. Last year we installed 20 new seismic stations in this network under the Advanced National Seismic System Initiative, and they all worked during this earthquake.

In delivering science, we helped form the Cascadia Regional Earthquake Workgroup or CREW, a coalition of private and public interests dedicated to reducing earthquake effects in the area.

Over the past 5 years, we have worked closely with the City of Seattle in identifying earthquake and landslide hazards and identifying measures to lessen their impacts.

What did we learn from this earthquake? Public awareness apparently paid off. Although the earthquake was widely and strongly felt, there was no general panic. There was little structural damage due to the depth of the earthquake and possibly due to retrofitting or strengthening of buildings. Most of the losses appear to be in nonstructural damage and in economic losses due to business interruption.

Thank you, Mr. Chairman. I will be happy to answer any questions that you might have.

[The prepared statement of Mr. Filson follows:]

PREPARED STATEMENT OF JOHN R. FILSON

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1. INTRODUCTION

Mr. Chairman and distinguished members of the Subcommittee, thank you for this opportunity to present testimony on behalf of the U.S. Geological Survey (USGS) regarding the recent earthquake near Olympia, Washington.

The USGS Earthquake Hazards Program is the applied Earth sciences element of the National Earthquake Hazards Reduction Program (NEHRP), led by the Federal Emergency Management Agency (FEMA). We carry out three roles: (1) earthquake monitoring and notification through the support national and regional networks of seismic instruments, (2) earthquake hazards assessments at the national and regional scales, and (3) research on earthquake processes, theory, and effects.

We have been working in the Pacific Northwest for over 20 years. With our partners at the University of Washington and elsewhere, we have made significant strides in our understanding of earthquake causes and earthquake hazards in the region. We have promoted, supported, and implemented improvements in earthquake monitoring and notification. And most important of all, we have worked tirelessly with government agencies at all levels and with private and industrial interests to educate anyone who would listen on the nature of the earthquake threat and to advise them on how to prepare to meet that threat.

The recent earthquake is referred to as the Nisqually earthquake, due to the location of the epicenter near the mouth of the Nisqually River. My testimony will focus on the geological cause of this earthquake, its seismological and geological effects, the lessons the USGS has learned and expects to learn from it, and our continuing work on addressing earthquake hazards in the Pacific Northwest. Every earthquake that causes damage in an urban area provides the USGS and others with opportunities to evaluate our past assessments of the earthquake hazard, to test the effectiveness of earthquake preparedness measures, and to strengthen and adapt these measures to lessen the impact of future events.

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We welcome advice and direction from this Subcommittee as we address these opportunities.

2. WHAT CAUSES EARTHQUAKES IN THE PACIFIC NORTHWEST?

Tectonic Setting. The term "tectonics" describes the broad, active geology of a region. Most of the tectonic activity of the Earth is related to the movement of large sections of the Earth's crust, called plates. There are a dozen or so plates that drift slowly with respect to each other and to the deeper mantle of the Earth. The rate of drift varies but can be a few inches per year. Most of the Earth's volcano and earthquake activity can be tied to sub-ocean ridges where plates form, or to continental masses and margins where plates collide or grind past each other. The size of these tectonic plates can vary widely. The North American plate stretches some 5,000 miles from the mid-Atlantic ridge to the San Andreas fault in California, whereas the Juan de Fuca plate is bounded by our Pacific Northwest coastline and an ocean ridge less than 500 miles offshore. The Juan de Fuca plate is being pushed away from the sub-ocean ridge of the same name toward the coast at a rate of about 1.5 inches per year.

The tectonic setting of the Pacific Northwest is complex due to the convergence of the Juan de Fuca plate and the North American plate, as shown in Figure 1. In this plate convergence, the Juan de Fuca plate, as it drifts to the northeast, is being overridden by the North American plate. This plate convergence is commonly called the Cascadia subduction zone. The boundary or contact between the two plates is the Cascadia subduction zone fault. As the Juan de Fuca plate is overridden, it slowly sinks into the Earth's mantle.

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Although the buildup of strain along the Cascadia subduction zone fault and internally within the two plates is a continuous process, the release of this strain is not. The rock near the plate boundary and within the plates is slowly bent over years and centuries, until the accumulated strain is suddenly released in earthquakes as the rock breaks or fails.

Types of Earthquakes. This process of strain buildup and release gives rise to three types of earthquakes in the region:

Type 1. Very large earthquakes that occur on the Cascadia subduction zone fault, the contact between the two plates,

Type 2. Deep earthquakes, such as the Nisqually earthquake, occur internally within the Juan de Fuca plate as it bends and deforms while sinking into the mantle, and

Type 3. Shallow earthquakes that occur in the North American plate, as it is internally deformed due to strain caused by overriding the Juan de Fuca plate in the convergence process.

Very large Type 1 earthquakes are the most infrequent and largest that can affect the region. This is the same kind of earthquake that struck Alaska in 1964, when the shallow fault boundary between the Pacific and North American plates "broke" for some 500 miles, releasing a tremendous buildup of strain energy and causing an earthquake of magnitude 9.2. Seismologists estimate that the Cascadia subduction zone could rupture over a distance of 360 miles, causing an earthquake of magnitude 9.0. Although, in such an event, the rupture at the Earth's surface would be offshore; it would have widespread impact throughout western Oregon and Washington. Such a large-scale earthquake could also generate a devastating tsunami. The last earthquake of Type 1 occurred in 1700, based on evidence of shoreline deformation in western Washington and historical records from Japan of a large tsunami hitting Hokkaido.

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Type 2 earthquakes occur 30–40 miles deep and are caused by deformation and rock changes within the Juan de Fuca plate as it sinks, or subsides, under the continent. The recent Nisqually earthquake was of this type. These earthquakes are more frequent than Type 1 events. A previous earthquake of the same type occurred in 1949 with a magnitude of 7.1. Because these earthquakes occur at depth, the strong shaking at the source of the earthquake is weakened somewhat before it reaches the surface, which results in diminished impact compared to an earthquake of similar size at shallow depth.

Type 3 earthquakes occur along shallow faults distributed in the crust throughout the Pacific Northwest region west of the Cascade Mountains. These earthquakes can reach the magnitude 7.5 range; however, earthquakes of this type at that size are infrequent. Nevertheless, these can be the most dangerous earthquakes in the region because they can occur at shallow depths near urban centers where the strong shaking can have an immediate impact on concentrations of population and development.

Pacific Northwest Earthquake Hazard Assessment. As part of a nationwide earthquake hazard assessment, the USGS has produced an analytical model (or map), that shows the expected levels of ground shaking for all geographic regions for various time (or exposure) periods. Figure 2 shows a portion of this map for the Puget Sound region. The contour lines represent horizontal ground shaking, as a percentage of gravitational acceleration, which we expect, with a 98% confidence level, will not be exceeded over a 50-year period. (A building subject to a horizontal acceleration equal to 50% of gravity ["0.5g"] will be subject to a horizontal shaking force equal to 50% of its weight.) Other versions of this map with different confidence limits and exposure periods are available.

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The warmer colors on this map indicate stronger expected shaking. The higher shaking levels near the coast reflect a model scenario in which there is a large earthquake of Type 1. The oblong, east west contours near Seattle are due to the Seattle fault, a potential source of shallow earthquakes of Type 3. The broad areas with smooth contours showing moderate expected shaking from Olympia to the Canadian border are due mainly to deep earthquakes of Type 2.

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These maps are the most important product of our USGS Earthquake Hazards Program. Practically everything we do—earthquake and geodetic monitoring, geologic mapping, and detailed studies of earthquake fault history and behavior—goes into these maps. Engineers and architects use this information to take into account expected earthquake shaking in the design of buildings and structures. Most importantly, FEMA has adopted these maps in their seismic design guidelines, through which they have also become the exclusive earthquake hazard basis of building codes published by the International Code Council. These codes are used to design structures throughout the United States.

3. THE FEBRUARY 28, 2001, NISQUALLY EARTHQUAKE—GEOLOGICAL AND SEISMOLOGICAL EFFECTS

Earthquake source. The Nisqually earthquake was a Type 2 event, 33 miles deep in the top portion of the sinking Juan de Fuca plate. The earthquake occurred at 10:54 am local time (PST) and had a magnitude of 6.8. The epicenter, or point on the surface of the Earth directly above the earthquake source, is near the "Nisqually delta," a prominent feature in South Puget Sound at the mouth of the Nisqually River. Analysis of seismic data from the earthquake indicates that it was caused by slippage on a normal fault striking in a north-south direction. Normal, or gravity, faults are caused by tension, or "pull apart," forces. In this case, the tension may have been caused by the bending of the upper portion of the Juan de Fuca plate as it sinks into the mantle. Figure 3 shows a cross section of the seismicity beneath Puget Sound and the location of the Nisqually earthquake. The location and faulting pattern of the recent earthquake are almost identical to an earthquake of magnitude 7.1 that occurred in 1949.

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Ground shaking. The Nisqually earthquake was widely felt, as far south as Salem, Oregon, and as far east as Spokane. Figure 4 is a map of ground shaking caused by the earthquake, with the warmer colors showing a higher level of shaking. In this map the yellow colors represent shaking capable of causing light to moderate damage, with peak accelerations within the 0.1g to 0.3g range.

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It is interesting to compare the shaking pattern of the Nisqually earthquake with that of the Northridge earthquake, which occurred in the Los Angeles area in 1994. The Northridge earthquake had a magnitude of 6.7, killed 60 people, and resulted in approximately $40 billion in losses. Figure 5 shows the shaking patterns for the two events on maps of the same scale.

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It is clear that the intensity of shaking for the Northridge event was much more severe than that experienced recently near Seattle. The reason for this is that the Northridge event was relatively shallow—the buried fault that broke came within 2 miles of the Earth's surface. Strong seismic shaking decreases rapidly with distance from the fault that is the source of the shaking. This effect is shown in the sketch in Figure 6. Because the Nisqually earthquake was 33 miles deep, every location on the surface was at least 33 miles from the source and outside of the range of severe shaking. In the Northridge case much of the eastern portion of the densely populated San Fernando Valley was within 30 miles of the earthquake source.

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The shaking map for the Nisqually earthquake shown in Figures 4 and 5 was prepared several days after the earthquake. The capability to produce such maps within ten minutes of an earthquake has been developed by the USGS for southern and northern California and was in the process of being implemented in the Puget Sound region when the Nisqually earthquake occurred. The capability to produce such maps within 10 minutes in all seismic regions is a goal of the Advanced National Seismic System (ANSS).

The development of these "shakemaps" is a major advance of the USGS Earthquake Hazards Program. The availability of these maps within 10 minutes of an earthquake is very valuable to emergency response officials and others for whom a quick determination of the scale of the problem and of the severity and distribution of ground shaking is important. This information can be used in the life-saving dispatch of emergency equipment to where it is needed most, in the assessment of damage to infrastructure elements, and in the restoration of infrastructure services.

Last year, 20 new ANSS seismometers were installed in the Seattle area—too few to produce a rapid, accurate shakemap for the Nisqually earthquake. However, the data from these modern seismometers enabled scientists to quickly determine that the ground shaking was not likely to cause heavy damage. These 20 new instruments nearly doubled the number of permanent seismic stations in the area capable of recording strong ground shaking in a digital format and sending the data in real-time to regional and national data centers. All of these instruments functioned well during the earthquake and provided valuable, quantitative data on the amplitude, frequency content (shaking cycles per second), and duration for shaking at given sites, and the variation of these parameters from site to site.

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All measured levels of shaking were lower than those shown in the USGS hazard assessment for the Pacific Northwest (Figure 2), which we estimate with 98% confidence will not be exceeded in any 50-year period. It is important to note that the estimated levels on Figure 2 are for one uniform geologic layer throughout the entire region. Local geologic structures and soil conditions can amplify and extend the duration of seismic shaking. The data collected in the recent earthquake can now be used to estimate and map the expected ground shaking in the region in much finer detail than shown in Figure 2. The results of this "microzonation" can be used in the future design and construction of buildings and structures at specific sites in the region. Figure 7 shows the relative amplitudes of shaking recorded on sites of various soil conditions within the City of Seattle. In general, soft alluvium soils and areas of artificial fill were subject to greater shaking.

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Ground failures. In addition to direct damage to structures caused by seismic shaking, earthquake shaking can also trigger landslides, lateral spreading of weak soils, and liquefaction, a process in which soils lose bearing strength and begin to flow like liquids. The hillsides of the Puget Sound region are susceptible to landslides during or following intense rainfall, even without an earthquake acting as a triggering mechanism. Although ground failures were observed at sites over a wide area, the number and impact of the failures was not severe. The distribution of these sites is shown in Figure 8. Coastal Washington is experiencing a serious drought, with below-normal rainfall since November 2000. If the earthquake had occurred after a series of intense storms, or even after a normally wet winter, the damage from landsliding and other ground failures may have been much greater.

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Aftershocks. There have been only four recorded aftershocks from the Nisqually earthquake, all were below magnitude 3.4. Earthquakes of this size near the surface are usually followed by aftershock sequences that may cause additional damage and most certainly cause general unrest in the population. These aftershocks decrease in frequency and magnitude with time. Generally speaking, deeper earthquakes have fewer aftershocks than earthquakes of the same magnitude near the surface. The 1949 earthquake in this region generated only a few aftershocks.

4. USGS EARTHQUAKE HAZARDS PROGRAM IN THE PACIFIC NORTHWEST

Under the aegis of the National Earthquake Hazards Reduction Program (NEHRP), the USGS has been supporting earthquake monitoring and hazards assessment work in the Pacific Northwest for over 20 years. We have eight personnel at a field office at the University of Washington in Seattle; other personnel from Menlo Park, California, and Golden, Colorado, are fully committed to working in the Seattle area. In addition, we work closely with local governments and private interests in translating the results of our scientific studies into terms that can be understood and acted upon by those responsible for public safety, industrial and economic development, and maintaining the critical infrastructure in the wake of an earthquake.

Important examples of our work in the region are:

Earthquake monitoring. The USGS provides annual support for the operation and maintenance of the Pacific Northwest Seismic Network by the University of Washington. We have provided additional recent support for the expansion and modernization of this network through the Advanced National Seismic Network (ANSS). Twenty new stations were installed last year in or near urban areas, and an additional 20 stations are being installed this year. All 20 instruments installed last year provided data from the recent earthquake. Shakemaps, such as those described earlier in this testimony, will be available quickly after the next earthquake through ANSS implementation in this region.

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Evidence for a large subduction zone earthquake (Type 1). A USGS scientist working out of the University of Washington for the past 15 years has uncovered evidence for large earthquakes (magnitude 9) occurring on an offshore fault that will impact the entire Pacific Northwest region. This evidence is in the form of buried marsh and forest soils and tsunami deposits in southern coastal Washington, which provide a geologic history of past large earthquakes and foretell the future possibility of future events of this size.

Evidence for shallow faults near urban areas (Type 3). For over 5 years the USGS, along with researchers from the University of Washington and elsewhere, has conducted extensive geological and geophysical studies of the structure of the shallow crust on the Puget Sound region. These studies have identified several shallow faults that appear capable of producing earthquakes that could cause considerable damage. For example, the Seattle fault, which runs (from west to east) under Bainbridge Island and Mercer Island and just south of downtown Seattle, was discovered by advanced geophysical techniques and recently confirmed through LIDAR observations.

Ground-Motion Studies. The USGS and other collaborators are conducting extensive studies of the geologic and soil conditions in the Puget Sound area that may amplify and extend the duration of seismic shaking. These studies include detailed geologic mapping and use of portable arrays of seismic instruments to record natural and manmade seismic events.

CREW. Along with the Federal Emergency Management Agency (FEMA), the USGS helped form the Cascadia Regional Earthquake Work Group (CREW), a coalition of private and public representatives working to reduce the impact of earthquakes in the Pacific Northwest. Private interests represented include Hewlett-Packard, Boeing Corporation, Bank of America, and Intel.

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City of Seattle. During the past 5 years, the USGS has been working with the City of Seattle in providing information on earthquake and landslide hazards. As recently as November 2000, the USGS sponsored a workshop in Seattle that brought together the "user community" so that we could convey the results of our efforts and receive guidance on future work. Approximately 250 representatives of local government and private industry, including Mayor Schell of Seattle, attended this workshop.

5. LESSONS LEARNED.

Although it is still too early to know all that we may learn from the data collected in the earthquake, we shall permit ourselves a few general observations:

Although the earthquake event itself was startling and frightening to those who experienced it, it was not unexpected. Information had been made available to government officials and the general population on the earthquake hazard in the region. There was no widespread panic.

Seismic retrofitting of older buildings was a significant factor in reducing structural damage; however, it is too early to quantify this impression.

Seismic instrumentation in urban areas provided valuable data on the amplification, the shaking cycles per second, and the duration of ground shaking at specific sites throughout the region. However, the 40 modern, digital seismic instruments capable of recording strong shaking and sending data continuously to the regional data center are completely inadequate. Additional stations of this type will be needed to adequately cover the region. Instruments are also needed in buildings and structures to record their response to strong shaking.

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Much more work is needed to locate and understand the characteristics of shallow, crustal faults capable of producing damaging earthquakes (Type 3). Seismic and geomagnetic surveys are needed to locate these faults underground; high-resolution topographic surveys (LIDAR) are needed to locate the surface expressions of these faults.

More work is needed in the major urban areas in estimating the response of surface rock, soils, and artificial fill to earthquake shaking. Work in Seattle is ongoing. Work has not begun in Tacoma, Olympia, and other cities of the region.

From the USGS perspective, the fact that we had a small staff of qualified and dedicated personnel stationed in the area has greatly increased the effectiveness with which we can deliver our messages and products related to earthquake hazards and provide the support and information that the community needs.

World Wide Web sites at the USGS National Earthquake Information Center and the University of Washington Pacific Northwest Seismic Network (supported by the USGS) were overwhelmed in the hours after the earthquake. Up to 1,000 hits per second were experienced. The USGS needs to increase the capacity of the electronic "pipelines" to these sites and of the web servers at these sites.

The use of partnerships, such as CREW, between FEMA, the USGS, State and local governments, and the private sector are very effective, in fact essential, in earthquake preparedness.

The partnerships and cooperative research efforts we have formed with the scientists at the University of Washington and with other Federal, State, and local agencies in the region served us all well in response to this earthquake. We look forward to continuing our work with these institutions and agencies.

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The national earthquake monitoring and assessment program of the USGS, which—working in cooperation with others—maintains long-term data on earthquake occurrence, develops hazards assessments, produces maps of shaking intensity, and is continually investigating and implementing new knowledge and technology, is a tremendous asset to the Nation in ensuring that society has the information that science can provide and is needed to address the earthquake threat.

Mr. Chairman, this concludes my remarks. I shall be happy to respond to any questions.

[The information referred to follows:]

BIOGRAPHY FOR JOHN R. FILSON

Since July 1997 Dr. John Filson has served as Coordinator of the Earthquake Hazards, Urban Hazards, Geomagnetism, and Global Seismology Programs of the U. S. Geological Survey (USGS).

Dr. Filson was born in St. Joseph, Missouri, and attended schools there and in Kansas City. He received a Bachelor of Science degree in Geology from Rice University in 1960. From 1960–1963 he served in the United States Marine Corps. He entered graduate school in geophysics in 1963 at the University of California at Berkeley from which he received a Master of Science degree in 1965 and a Doctor of Philosophy degree in 1968.

He joined the U.S. Geological Survey in 1978 and from 1980–1988 served as the Chief of the Office of Earthquakes, Volcanoes, and Engineering. In December 1988 he led a team of United States scientists and engineers to Armenia, USSR, to study the cause and effects of a devastating earthquake in that region. From 1991–1994 he was Chief of the USGS Branch of Earthquake and Geomagnetic Information, and from November 1994–April 1995 he served as Acting Chief Geologist of the USGS.

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From April 1995–April 1997, he served as a member of the Arms Control Intelligence Staff under the Director of Central Intelligence, working as a technical officer on the negotiation of the Comprehensive Test Ban Treaty.

He has received the Meritorious and Distinguished Service Awards of the Department of the Interior, the Presidential Meritorious Service Award, and the Outstanding Public Service Award of the Federal Emergency Management Agency. He is a past president of the Seismological Society of America and a Fellow of the American Association for the Advancement of Science.

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Chairman **SMITH.** Thank you, Dr. Filson. Dr. Nelson.

STATEMENT OF DR. PRISCILLA P. NELSON, DIRECTOR, DIVISION OF CIVIL AND MECHANICAL SYSTEMS, DIRECTORATE FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION

Ms. **NELSON.** Mr. Chairman, and distinguished members of the Subcommittee, I appreciate the opportunity to be here today to discuss the programs at National Science Foundation and I will focus my comments here to information pertinent to the questions posed by the Committee.

NSF has long supported both individual investigators and NSF consortia and research centers for reconnaissance activities and post-earthquake research. This slide indicates the locations of five consortia that were involved in response following Nisqually.

IRIS, the Incorporated Research Institutions for Seismology consortia, provides seismographic research facilities to monitor earthquakes worldwide. IRIS operates the Global Seismographic Network, the GSN, in partnership with the USGS and data from GSN stations are made available in near real time over the Internet through the IRIS data management center located in Seattle. IRIS also maintains portable seismic systems to capture aftershocks. And this array was deployed to Nisqually after the event.

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The Southern California Earthquake Center, or SCEC, at the University of Southern California, maintains an active web site that was a significant source of information following the Nisqually quake.

There are three Earthquake Engineering Research Centers or EERC's and each of them sent engineers to participate directly in information-gathering after the Nisqually quake. These include the Pacific Earthquake Engineering Research Center at Berkeley, which focuses on performance-based design; the Mid-America Center at Illinois, which focuses on critical facilities; and the MCEER Center, which is at the State University of New York at Buffalo, which emphasizes advanced technologies. For Nisqually, the most active was the PEER Center, which includes the University of Washington as a consortia member.

Actual earthquake events provide a wealth of knowledge relative to earthquake hazard mitigation. Areas struck by such events represent full-scale laboratories from which vital lessons about earthquake impacts can be learned. For nearly 30 years, mainly through the NSF-supported Learning From Earthquakes Program at the Earthquake Engineering Research Institute, or EERI, NSF has supported post-disaster information and investigations that involved teams of researchers working onsite to collect perishable information.

Leadership for the Nisqually reconnaissance efforts was established by a coordination group headed by faculty from the University of Washington. And this group set tasking for reconnaissance efforts with direct involvement of researchers from the PEER Center and the other organizations indicated here.

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Teams were also formed for particular focus responsibilities, including personnel from the other EERCs. The coordination group held several public briefings at the University of Washington campus, at which information from the reconnaissance teams was presented, discussed in breakout sessions, and plans were laid for the following day. These meetings were well-attended by researchers, the public, and media, and continued for several days after the event.

In addition, there was close coordination established with several state agencies and city departments, and members of local area practice were out in force, coordinated also with the University-led team. Activities also included international teams that were onsite.

FEMA, overall, has been supplying support for GIS data entry and management, and USGS has supplied Internet expertise that allowed a coordinated web site to be brought on line very quickly as an informational clearing house. The support from FEMA and USGS will continue for several weeks.

The Nisqually teams have produced preliminary reports and will soon be developed into a final report by EERI. Based on the conclusions from the reconnaissance, the most significant damage occurred at sites with weak soils and sites were construction was with unreinforced masonry. Additional observations certainly include that nonstructural damage was the major impact, that other than unreinforced buildings, masonry buildings on poor soils, there was little structural damage.

The effect of local soil conditions and amplifications was very strong and widely observed around the area. Lifelines apparently performed well, but there will still be data coming in on lifeline performance for some time. And regarding critical facilities, there was damage at both area airports in the Seattle area and hospitals were not overly stressed, and were mostly affected by nonstructural damage.

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Although full consideration of the research opportunities would take some time after the Nisqually earthquake, there certainly are a couple of areas where research opportunities can easily be highlighted. This event represents a unique opportunity to include a database that deals both with indirect and direct losses which permit unambiguous efforts to separate structural damage from nonstructural damage, which is something that has been very difficult to do in the earthquakes that have been done recently. I think there has been structural retrofit and soil improvement, which will be able to be evaluated for performance in this particular event. And for social science research, I think the implications of a noncatastrophic event on the public response and policy will be something of great interest to the researchers.

And, finally, I think Performance-Based Earthquake Engineering, which is a major area of current concern in the United States, will be carried forward very strongly by the research opportunities possible out of this event. And, in this case, what happens is the buildings are evaluated not just for collapse, but also for pre-collapse performance so you can understand exactly what level of performance you want for what dollar invested in the design. Thank you.

[The prepared statement of Ms. Nelson follows:]

PREPARED STATEMENT OF DR. PRISCILLA P. NELSON

INTRODUCTION

Mr. Chairman and distinguished members of the Subcommittee:

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I appreciate the opportunity to be here today with the Subcommittee to discuss the programs at NSF that support the development of new science and engineering knowledge, and that enable U.S. researchers to acquire information following extreme events including the recent Nisqually earthquake. Among other functions, NSF is involved in enabling knowledge creation and the education of future professionals, activities which make possible effective earthquake hazard mitigation in the nation.

NSF is privileged to serve as one of the principal agencies in the National Earthquake Hazards Reduction Program (NEHRP), and many NSF activities are carried out with close coordination and collaboration with our NEHRP sister agencies: Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST) and the United States Geological Survey (USGS). Our participation in NEHRP is consistent with our policy of integrating NSF's activities with those of other agencies when it will facilitate the achievement of national goals, which in the case of NEHRP involves the goals of reducing deaths, injuries and property damage and other economic losses caused by earthquakes. We are confident that NEHRP—in collaboration with other Federal agencies, local and state governments, and private sector organizations throughout the country - will continue to take crucial steps toward meeting this challenge in the years to come.

I will initially put the role of NSF in perspective by saying a few words about the broader NSF mission. Then I will discuss the specific focus of NSF-supported reconnaissance activities following the Nisqually earthquake.

THE NSF MISSION

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In recent years, we have seen an acceleration in the rate of change in society and the world at large. In this era of rapid change, in which science and technology play an increasingly central role, NSF has remained steadfast in pursuit of its mission. That mission is to support science and engineering research and education for the advancement of the nation's well being, and NSF accomplishes this mission by investments in people, ideas and tools that build the nation's research and education infrastructure.

At NSF, we believe that federally funded research should have economic and social benefits for society, as well as represent excellence in science and engineering. We also see the necessity for and benefits from integrating research and education, which can most effectively be done at academic institutions.

NSF makes its investments in science and engineering with the recognition that there is a need to maintain excellence across the frontiers of scientific and engineering disciplines. In order to significantly enhance the return on such investments, we actively seek partnerships with other Federal agencies as well as other entities.

Finally, NSF places significant emphasis on the diffusion of knowledge and technological innovations that are relevant to such national goals as education, environmental sustainability, creation of a robust information technology infrastructure, and the development of reliable and safe civil infrastructure systems. This requires an appreciation of a broad range of research and educational contexts, including the recognition that research centers, consortia, and individual investigator projects all contribute to the advancement of needed scientific and engineering knowledge.

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ROLE OF NSF IN NEHRP

NSF supports research and educational activities in many disciplines, and this is reflected in the role we fulfill under NEHRP. Our role complements the responsibilities assigned to our principal partners in the program: FEMA, NIST and USGS. NSF is involved in continuing strategic planning with the other NEHRP agencies in order to further interagency coordination and integration. NSF is also a frequent collaborator with the other NEHRP agencies. This collaboration includes co-funding research, educational and outreach activities.

NEHRP authorization legislation calls for NSF to support studies in the earth sciences, earthquake engineering, and the social sciences. Since an integrated body of knowledge is needed to understand earthquake problems and to develop effective solutions for dealing with them, such as innovative building designs and control technologies, NSF encourages cross-disciplinary research. The NSF-supported earthquake centers, which I will discuss later, provide one of the most useful institutional arrangements for conducting complex holistic research.

NSF'S EARTHQUAKE-RELATED RESEARCH AND EDUCATIONAL ACTIVITIES

Earthquake-related research and educational activities are supported at NSF in the Computer and Information Science and Engineering, Education and Human Resources, Engineering, Geosciences, and Social, Behavioral and Economic Sciences Directorates. The research areas include seismology and fault processes, earthquake engineering and social science research related to earthquake hazard mitigation, preparedness and post-earthquake recovery. Significant progress continues to be made in these programs in understanding plate tectonics and earthquake processes, geotechnical and structural engineering, tsunamis. and the social and economic aspects of earthquake hazard mitigation.

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NSF supports numerous individual investigator and small group projects, two university consortia, and four earthquake centers that advance NEHRP goals. Other NEHRP-related NSF activities include programs involving earthquake research facilities, post-earthquake investigations, international cooperation, and information dissemination.

Incorporated Research Institutes in Seismology (IRIS)

NSF supports the Incorporated Research Institutes in Seismology (IRIS) consortium in order to provide the seismographic facilities necessary to monitor earthquakes worldwide, study the tectonic structure of active seismic zones, and provide emergency seismographic response to aftershock zones of major earthquakes.

IRIS' Global Seismographic Network (GSN), operated in partnership with the U.S. Geological Survey, is the primary means of locating, in near-real time, seismic events around the world to provide emergency and policy planners information with which decisions on responses can be made. The GSN is nearly complete on land with over 136 stations worldwide, most of which are accessed in near-real time, and all of which are available over the Internet through the IRIS Data Management Center. The Data Management Center now stores over 10 terabytes of data and is growing at a rate of 3 terabytes per year. Tests are now being conducted on the deep ocean floor to determine the best technology with which to instrument the vast oceanic areas of the Earth.

IRIS maintains a ready array of advanced, portable seismic systems for rapid deployment in the aftershock region of major earthquakes, and this array was deployed to the Nisqually earthquake region. A separate dedicated portable array is also used to map the tectonic structure of active seismic regions. With knowledge of the tectonic structure, scientists can better understand the geometry of potential earthquake rupture zones and compute their associated destructive strong motions, especially close to the earthquake source.

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Global Positioning System (GPS)

The Global Positioning System (GPS) was initially developed by the Department of Defense in order to provide position accuracies of a few meters. However, the differential use of GPS with two or more receiving systems can achieve sub-centimeter accuracy and this fact has revolutionized the science of earthquake tectonics. The distortion of the earth's surface is an essential measure of the potential for earthquakes in a given region. This distortion can be monitored with GPS and other space-based positioning systems. NSF supports facilities that use GPS to monitor crustal distortion in both campaign and fixed-network modes.

The University Navstar Consortium (UNAVCO), supported by NSF in partnership with NASA, was formed to support scientific campaigns that monitor crustal distortion in active tectonic areas. UNAVCO provides instrumentation, training and logistics support to individual scientists who have been funded to study specific tectonic areas throughout the world.

The Southern California Integrated GPS Network (SCIGN) is the most ambitious U.S. GPS fixed-network to date and is under construction with support of NSF in partnership with NASA, the USGS, and the Keck Foundation. SCIGN, now almost one-half complete, will consist of 250 fixed GPS stations in southern California. It will be linked with less dense networks in Nevada, northern California, and the Pacific Northwest. The SCIGN data is available on the Internet in near-real time, and has already provided significant new discoveries and constraints on our ideas of the tectonics of the San Andreas Fault plate-boundary zone.

Research Centers

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NSF established the Southern California Earthquake Center (SCEC) in 1991 as a Science and Technology Center for the purpose of promoting and integrating science related to earthquake hazard estimation and reduction in the southern California region. The USGS is a partner in SCEC, which also receives support from, the State of California, the City of Los Angeles, County of Los Angeles, industry and private foundations. Such broad funding is an example of how NEHRP agencies leverage funds and indicates that SCEC truly is seen as an activity that cuts across the concerns of the NEHRP program. SCEC is a consortium of institutions and is administered through the University of Southern California. It continues to contribute significantly to a new understanding of the earthquake hazard in southern California by combining insights from seismicity, new geodetic technology, new geologic discoveries, and local site conditions in an innovative framework of earthquake hazard evaluation. Recent examples of SCEC findings include a) the discovery that magnitude 7 earthquakes have occurred on at least one local thrust fault in the Los Angeles metropolitan region, b) a determination that one major thrust fault discovered beneath the region is currently inactive, and c) a suggestion that north-south strain across the Los Angeles region may be partially accommodated by east-west crustal extension. SCEC advances are being effectively communicated to professionals, students and the public through a very active education and outreach program.

NSF funded three new earthquake engineering research centers (EERCs) in October 1997. Representing a new generation of such institutions, these recently funded EERCs build on the experience of the first such center that was funded by NSF in 1986, the National Center for Earthquake Engineering Research (NCEER).

Each EERC is a consortium of 7 to 18 academic institutions involved in multidisciplinary team research, educational and outreach activities. With its administrative headquarters at the University of California at Berkeley, the Pacific Earthquake Engineering Research Center (PEER) focuses on earthquake problems in areas west of the Rocky Mountains and emphasizes performance-based design in its research and educational programs. The Mid-America Earthquake Center (MAE) is headquartered at the University of Illinois at Champaign-Urbana and focuses on hazards in the Central and Eastern U.S. and emphasizes research related to critical building and transportation facilities. The Multi-disciplinary Center for Earthquake Engineering Research (MCEER), which is the successor to NCEER, has its headquarters at the

State University of New York at Buffalo and emphasizes research related to advanced technologies for soils, structures, and lifelines that are applicable to earthquake problems throughout the U.S.

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The EERCs are combining research across the disciplines of the earth sciences, architecture, earthquake engineering, and the social sciences. And in order to meet the need for future professionals and assure continuing U.S. leadership in the field, they are educating hundreds of undergraduate and graduate students in the latest analytical, computational and experimental techniques. Additionally, even though it is early in their tenure, the EERCs have established major partnerships with industry, state government agencies, the other NEHRPO agencies and other federal agencies (e.g., FHWA), and foreign research organizations, which should also help advance earthquake hazard reduction in the Nation in the years ahead.

The three EERCs have developed significant collaborative efforts in their research and educational programs, and coordinate their seismic hazard research with SCEC.

POST-EARTHQUAKE INVESTIGATIONS

Actual earthquake events provide a wealth of knowledge relevant to earthquake hazard mitigation. Areas struck by such events represent natural full-scale laboratories, offering unusual opportunities to learn vital lessons about earthquake impacts on the natural and built environment and to test models and techniques derived from analytical, computational and experimental studies. For this reason, NSF continues to support post-disaster investigations, often in conjunction with the Earthquake Engineering Research Institute (EERI), the Earthquake Engineering Research Centers, and faculty at local universities and colleges. The post-earthquake investigations involve quick-response teams of researchers visiting impacted sites to collect perishable information that remains available only up to the time that full-scale community restoration and reconstruction commence. The events investigated with NSF support in the recent past include the 1999 earthquakes in Turkey and Taiwan, the January 2001 earthquake in India, and the Nisqually earthquake south of Seattle on February 28, 2001.

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Nisqually reconnaissance efforts have included many activities and involved many organizations, including:

Earthquake Engineering Research Institute (EERI) through the NSF-funded "Learning from Earthquakes" (LFE) project

The University of Washington

Washington State University

NSF Earthquake Engineering Research Centers (EERCs)

PEER (Pacific Earthquake Engineering Research) Center

MAE (Mid America Earthquake) Center

MCEER (Multidisciplinary Center for Earthquake Engineering Research)

Southern California Earthquake Center

University of California, San Diego

Utah State University

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Central Washington University

University of Arizona

CUREE (Consortium of Universities for Research in Earthquake Engineering)

The City of Seattle

The City of Tacoma

Washington State Department of Natural Resources

Washington State Department of Transportation

United States Geological Survey

FEMA

The main coordination was established by a local team chartered by EERI under the LFE project and headed by faculty from the University of Washington. This team established main tasking for reconnaissance efforts by self-assignment with direct involvement of researchers from the University of Washington, PEER and several of the organizations listed above. Other teams were formed for particular focus responsibilities, including personnel from the MAE and MCEER EERCs. The local team arranged for public briefings on the University of Washington campus March 1, 2, and 3. These were well attended by researchers, the public, and the media. FEMA supplied support for GIS data entry and management, and the USGS gave access to strong motion earthquake equipment and supplied Internet expertise to bring a coordinated web site on line as soon as possible. This web site came on line as an information clearinghouse very shortly after the Nisqually event [*http://maximus.ce.washington.edu/peera1/*]. The support from FEMA and USGS will continue for several weeks more as reconnaissance activities wind down.

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The reconnaissance activity following Nisqually has greatly benefited from the participation of university-based engineers experienced in observation through reconnaissance activities for previous recent earthquakes—primarily funded through NSF and the Learning from Earthquakes grant to EERI. In addition, members of local area engineering practice were out in force, and coordinated with the university-led reconnaissance teams but had the prime focus of completing work for clients. International reconnaissance teams from New Zealand (the Building Research Association) and Japan (Tokyo Institute of Technology) have also been on site and contribute to the data repository.

The Nisqually reconnaissance teams have produced preliminary reports, and these will be developed into a comprehensive assessment by the Earthquake Engineering Research Institute through its "Learning from Earthquakes" project, which is funded by NSF. The focus of this assessment will be on the geotechnical aspects of the event, including soil characteristics and strong ground motion features; structural aspects, including damage to various types of structures and focusing on the preponderance of nonstructural damage; the performance of lifelines, including electric, water and telecommunications systems; and socioeconomic aspects, including business interruptions and emergency response. A preliminary report is available on the Web.

Based on the observations from the reconnaissance, preliminary conclusions include:

Nonstructural damage was the major impact affecting costs and occupancy.

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Other than unreinforced masonry buildings on poor soil, few buildings sustained significant damage.

Local soil conditions and amplifications of ground motions were important in causing variations in performance—including soil liquefaction, lateral spreading, and landslides.

Lifelines apparently performed well, but final information on pipeline breaks will be slow to come in.

Regarding critical facilities—

airports: there was damage at SeaTac Airport (e.g., the control tower) and at King County (Boeing) airfield (building and runway damage)

hospitals: most experienced nonstructural damage which will be costly nonetheless, but there were relatively few injuries, so the health services were not stressed by the Nisqually event.

Although full consideration of research opportunities that follow from the Nisqually earthquake will require additional time, some focus areas of importance have already been identified:

Nisqually presents a unique opportunity to assemble a database on direct and indirect losses—which will permit unambiguous evaluation of economic impact of nonstructural damage, disruption to the business of government, and business interruptions. In the case of Nisqually, these losses can be determined separated from the costs of severe structural impacts. This will be of great benefit for calibration of loss estimation models.

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Recent investments in structural retrofit, soil improvement, and application of new technology in the Seattle area can be evaluated to provide input for performance and repair cost models.

Social science research is needed to evaluate the implications of a non-catastrophic event for the public, and to study changes in decision making and in risk perception caused by the Nisqually quake.

For engineering, recent focus is on new methodologies for design, most importantly involving the concept of Performance Based Earthquake Engineering (PBEE). In PBEE, analytical and experimental models are used to develop relationships between measures of earthquake shaking and resulting damage. These relationships, like the fragility curve shown here, are used to explicitly define costs and risks.

In the past, engineering research has focused on catastrophic collapse of structures, and recent highly damaging quakes have provided field observations that can be used to validate these models for structural failure.

In Performance Based Engineering, however, engineers seek information on how to design for performance levels other than catastrophic failure and complete loss of functionality. This means fully defining the fragility curve. This approach allows explicit definition of costs and risks for any level of performance. The Nisqually quake will provide access to exactly this kind of knowledge needed in PBEE design.

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EARTHQUAKE RESEARCH

NSF funds earthquake-related research projects conducted at colleges and universities in nearly every state. These projects are carried out by faculty in geosciences, engineering, socio-economics and other areas. Many of these projects are interdisciplinary and integrate contributions from several principal investigators. Projects are often completed with participation on undergraduate and graduate students, and also with involvement of K–12 teachers as a recently added program at NSF. The integration of research and education is inherent in earthquake research funding at NSF.

As indicated by this testimony, earthquakes are a global hazard. For this reason, many countries find collaborative research and the sharing of information essential in meeting this challenge; the U.S. is no exception. Similar to the other NEHRP agencies, NSF has a long history of cooperating with other countries —such as China, India, Italy, Japan, Mexico, Taiwan and Turkey—facing similar seismic risks. Let me briefly mention some recent developments with regards to NSF's efforts to enable U.S. earthquake researchers to collaborate with their counterparts.

In 1993, the US/Japan Common Agenda for Cooperation in Global Perspective was established to facilitate cooperation in addressing pressing global problems, including natural hazards. In 1998, a new joint earthquake research program, called the US/Japan Cooperative Research in Urban Earthquake Disaster

Mitigation, emerged out of this broad agreement. Under this five-year program, NSF provides funding for U. S. researchers, while collaborating Japanese researchers are being supported principally by the Japanese Ministry of Education, Science, Sports and Culture.

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NSF has made thirty awards under the program thus far, and current set of projects includes highly innovative and multidisciplinary research topics, each with a significant educational component. Subject areas include, for example, studies of the effects of near-field ground motions, earthquake resistant design for lifelines and foundations, performance-based design, perceptions of earthquake impacts and loss-reduction preferences of citizens, and disaster mitigation for urban transportation systems. These projects involve significant interaction between U.S. and Japanese researchers and are enabling researchers from both countries to accomplish goals that they could not accomplish separately.

As another example, following the earthquakes in Turkey and Taiwan in 1999, NSF established a research program to support exploratory research that would lead to collaborations between U.S. researchers and their counterparts in Turkey and Taiwan. Many of these collaborations were established well before the destructive earthquakes. Workshops in both countries will be held during the summer, 2001, and research opportunities will be identified. NSF will work with counterpart agencies in Turkey and Taiwan to establish a research program similar in operation to that developed for the collaborations with Japan. In a similar fashion, NSF will be open to proposals for collaborative research between U.S. and international colleagues following the Nisqually quake.

RESEARCH FACILITIES

NSF has long recognized that its mission to advance science and engineering in the U.S. includes providing the academic community with requisite resources for developing world-class research facilities and equipment. And NEHRP legislation has reinforced our own expectations regarding this important role for NSF. Let me provide some examples of our efforts to ensure that U.S. researchers have the required facilities to conduct cutting-edge research well into the next century.

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George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)

Congress has authorized funding for the George E. Brown, Jr. Network for Earthquake Engineering Simulation for a five-year construction period from October 1, 1999 through September 30, 2004, for a total of $81.9 million. This project is the result of a planning process called for in the 1997 NEHRP reauthorization legislation, from which NSF, in collaboration with the other NEHRP partners, developed a comprehensive plan for modernizing and integrating experimental earthquake engineering research facilities in the U.S. The goal of NEES is to provide a national, networked collaboratory of geographically distributed, shared use next-generation experimental research equipment sites, with teleobservation and teleoperation capabilities.

I am happy to report progress in the construction of NEES. Eleven equipment awards have been made in the first phase of construction. These awards include funding for two shake table sites, two centrifuge sites, a tsunami wave basin, four large-scale laboratory testing sites, and two mobile laboratories for field experimentation and monitoring, including post-earthquake damage evaluation. This equipment portfolio provides unique, new and advanced research capabilities for the nation's earthquake engineering research community.

Construction of the NEES network has also started, with a scoping study award made to the NEESgrid team at the University of Illinois at Urbana-Champaign. The NEES program will leverage public and private investments in the $100 billion-a-year information technology industry by using existing software and making effective use of the high-speed networking infrastructure that is one of NSF's most successful investments. We believe that this utilization of advanced IT will enable the earthquake engineering research field to move from a reliance on physical testing to integrated model-based simulation. This will be a major transition for earthquake engineering research and lead to results that rapidly help advance performance-based design concepts for earthquake engineering and hazard reduction in the nation.

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In addition to providing access for telepresence at the NEES equipment sites, the network will use cutting-edge tools to link high performance computational and data storage facilities, including a curated repository for experimental and analytical earthquake engineering and related data. The network will also provide distributed physical and numerical simulation capabilities and resources for visualization of experimental and computed data. In addition to the NEES equipment sites, the network will provide connectivity to other major earthquake engineering equipment sites that bring unique experimental capabilities to NEES, both in the United States and abroad.

The collaboratory, including experimentation sites networked together through the high performance Internet, is on schedule and on budget for completion by the end of FY2004.

NEES will also serve as a major educational tool. By being Internet-based, the collaboratory will be accessible by researchers, students, professional engineers, owners of public and private works, and the general public. For example, teachers and students at all levels throughout the U.S. will be able to access the network for data, information, and course material as well as to participate in various experiments. Involvement with NEES will also enable students to sharpen skills in utilizing modern information technology tools and resources. Such learning opportunities could be made available for pre-college students, as well as college students, ushering in an unprecedented appreciation for earthquake problems and a new age for earthquake engineering education.

NEES, then, promises to lead to a new age in earthquake engineering research and education. It will be well worth our Nation's investment. We look forward to keeping the Subcommittee informed about its development.

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Mr. Chairman, this completes my remarks. I will be happy to answer any questions that the Subcommittee might have about NSF's activities.

[The information referred to follows:]

WEB SITES

FEBRUARY 28, 2001 NISQUALLY EARTHQUAKE INFORMATION CLEARINGHOUSE at the University of Washington
http://maximus.ce.washington.edu/nisqaully/

DRAFT REPORT FROM PEER, U. CALIFORNIA BERKELEY, WASHINGTON STATE, ET AL.
http://peer.berkeley.edu/nisqaully/geotech/

REPORT FROM U. CALIFORNIA SAN DIEGO/PEER/CUREE
http://www.structures.ucsd.edu/UCSD%20Reconnaissance%20Report.htm

UNIVERSITY OF WASHINGTON SEISMOLOGY & EARTHQUAKE INFORMATION
http://www.geophys.washington.edu/SEIS/

CALIFORNIA EARTHQUAKE CLEARINGHOUSE
http://www.eeri.org/Clearinghouse/Clearinghouse.html

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SHANNON AND WILSON
http://www.shannonwilson.com/index2.html

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
http://www.wsdot.wa.gov/

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
http://www.eeri.org/

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER
http://peer.berkeley.edu/

MAE (Mid America Earthquake) Center
http://mae.ce.uiuc.edu

MCEER (Multidisciplinary Center for Earthquake Engineering Research)
http://mceer.buffalo.edu

SCEC (Southern California Earthquake Center)
http://www.scec.org

INSTITUTIONS FOR RESEARCH IN SEISMOLOGY
http://www.iris.washington.edu/NEWS/news20010228110948.htm

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UC BERKELEY SEISMOLOGICAL LABORATORY
http://www.seismo.berkeley.edu/seismo/egw/egw—01.02.28.html

USGS EARTHQUAKE HAZARDS PROGRAM
http://earthquake.usgs.gov/

FEMA DAMAGE HOTLINE
http://www.metrokc.gov/exec/news/2001/030201fema.htm

NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION
http://www.eng.nsf.gov/nees

SEATTLE TIMES
http://seattletimes.nwsource.com/photogallery/quake/

THE OLYMPIAN
http://news.theolympian.com/eggallery/

[The information referred to follows:]

BIOGRAPHY FOR DR. PRISCILLA NELSON

Dr. Priscilla Nelson is Director of the Civil and Mechanical Systems (CMS) Division in the Directorate for Engineering at the National Science Foundation (NSF). She has been at NSF since 1994, and previously served as Program Director for the Geotechnical Engineering program, and as Program Manager for the NEES (Network for Earthquake Engineering Simulation) project which represents an $82 million federal investment in earthquake experimentation equipment to be completed between FY2000 and FY2004.

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Dr. Nelson was formerly Professor of Civil Engineering at the University of Texas at Austin. Her undergraduate degree is from the University of Rochester in Geological Sciences, and she has received three earned advanced degrees including Master's degrees in both Geology (Indiana University) and Structural Engineering (University of Oklahoma). In 1983, she received her Ph.D. from Cornell University in Geotechnical Engineering. Dr. Nelson has a national and international reputation in geological and rock engineering, and the particular application of underground construction. She has more than 15 years of teaching experience and more than 120 technical and scientific publications to her credit.

Dr. Nelson is Past-President of the Geo-lnstitute of the American Society of Civil Engineers, and a lifetime member and first President of the American Rock Mechanics Association. Among many professional affiliations, she is an active member of the American Underground-Construction Association, the Association of Engineering Geologists, and the International Tunnelling Association. She has served as a member of several National Research Council boards and committees.

[The information referred to follows:]

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Chairman **SMITH.** Thank you, Dr. Nelson. Dr. Palmer. Well, see, is your mike on, Dr. Palmer?

STATEMENT OF DR. STEPHEN PALMER, Ph.D., WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES, GEOLOGY AND EARTH RESOURCES DIVISION

Mr. **PALMER.** I would like to thank the Chairman and distinguished members of the House Subcommittee on Research for allowing me the opportunity to present some of the early findings for the Nisqually earthquake.

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One thing that I don't think that has pointed out is that the Nisqually earthquake was very near the location of the 1949 Olympia earthquake, a magnitude 7.1 deep event. Consequently, a lot of the effects seen in the Nisqually earthquake were replaying of events that were observed in 1949.

As has been said, structural damage was mainly concentrated in unreinforced masonry buildings on soft soil conditions in downtown Olympia and Seattle. I think that we were lucky to not have had causalities associated with this earthquake, as you can see by the condition of the van in this photograph.

Both the State Capitol and the Governor's Mansion are both unoccupied at this time because of earthquake damage. A number of other buildings on the State Capitol campus were damaged. They are used right now, but they are actually in some state of disrepair.

Ground failures were fairly moderate throughout the Puget Sound, the most intense in the Olympia area, nearest the earthquake. Liquefaction failures, such as this lateral spread on Deshutes Parkway, occurred in areas that were fairly well known. Deshutes Parkway was a major emergency route for Olympia police and fire and ambulances.

As with all liquefaction events you get the expulsion of sand to the ground surface in the form of sand blows. This photo has a little City of Olympia logo so you know where it happened.

The failure at Sunset Lake is just south of Olympia in a residential community. Here liquefaction damaged the roadway. The landslide on Highway 101 cut both northbound lanes. It was shown on Newsweek and erroneously attributed to being in eastern Washington. All of these ground failures were within about a 10 square mile area.

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What I wanted to show the members of this committee, in particular, was the fruits of some of the NEHRP funding in previous years. I have personally been a principal investigator on a number of efforts to map liquefaction hazards in the Puget Sound region. We put this information out in terms of maps, such as this one, where areas of red have the highest liquefaction hazard; areas of orange have a moderate hazard; yellow a low hazard; and green are essentially, no hazard. The purple triangles you can see on this figure show sites of liquefaction in the Nisqually event. There is very good correspondence, if you will, between the hazardous map areas shown on the map and the actual failures caused by this event.

Now, this is a similar map that covers the area from Seattle to Tacoma. Again, the same color scheme applies—the oranges or reds are high hazards. There was a lot of liquefaction in the Port of Seattle, a hydraulic fill area known to have this response in 1949. However, there had been a lot of good geotechnical engineering practiced in the last few decades in new construction projects which minimized damage to port facilities.

Boeing Field's liquefaction was in an area mapped as a very high hazard. It was a filled area of the Duwamish River. The big surprise is that there was almost no liquefaction in the Puyallup Valley. We will probably never be able to completely understand this lack of liquefaction because we have very little measured ground motions in that area. This figure is the Shake Map that was shown by Dr. Filson. In this map, the red triangles are measured ground motion stations. There are practically none in Olympia, and none in the Puyallup Valley. They are mainly concentrated in the Seattle area. One of the important reasons to continue to support ANSS is because that program will provide more regional coverage of important ground shaking information.

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In conclusions, this wasn't the big one. I think you have heard that before. As usual, there were surprises. I think one of the largest was the damage to the control tower at Sea-Tac Airport. There was measured ground motions of .18g at Sea-Tac. Structural design in the Puget Sound for the last 20 or so years has been to a .3g level. So although that structure was not loaded to anywhere near the design levels by this earthquake, it was put out of service mainly through nonstructural damage.

Earthquakes capable of causing more damage are possible. A shallow crustal event on one of the potentially active faults in the Puget Sound region would be much more similar to Northridge in terms of damage. Investigation of crustal faults is a crucial issue.

I would like to think that the type of hazard mapping that I have been involved in can provide useful information, both before and after an earthquake. I know that the maps that I have published have been used by building officials to require special foundation studies in areas of poor soils. Private businesses have, in fact, used these maps in making decisions about situating future expansion—in one particular case, a business that uses hazardous chemicals. And, finally, we are hoping that others, like emergency managers and underground utility operators, could use these maps to assess the potential for liquefaction ground movement. Besides all the other problems at Deshutes Parkway, it also ruptured a new fiber optic cable.

So I thank the Chairman and members of the Committee.

[The prepared statement of Mr. Palmer follows:]

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PREPARED STATEMENT OF STEPHEN P. PALMER, PH.D.

INTRODUCTION

I thank the Chairman and Members of the House Subcommittee on Basic Research for allowing me the opportunity to present some of the early findings regarding the Nisqually earthquake of February 28, 2001. The Nisqually earthquake had a reported magnitude of 6.8, making it comparable, in terms of seismic energy release, to the Northridge and Kobe earthquakes. Damage from the Nisqually earthquake was moderate because the release of energy occurred at a considerable depth (30 miles) beneath the earth's surface. The Northridge and Kobe earthquakes occurred on shallow faults where the seismic energy was released within a mile or two below ground surface.

An interesting aspect to the Nisqually earthquake is that its location is very close (within a few miles) of the magnitude 7.1 Olympia earthquake that occurred in 1949. This older earthquake was likewise a deep event, and many of the effects of the 1949 event were replayed on February 28th, 2001. Consequently, many of the effects of the Nisqually earthquake were well understood and predictable prior to the event; however, as with any earthquake, there were some surprises.

DAMAGE TO STRUCTURES

The Nisqually earthquake caused only heavy building damage in selected areas within the Puget Sound region. Severe structural damage primarily occurred in older unreinforced masonry buildings and bridges located in areas where soil conditions aggravated the strength of ground shaking. The most significant damage occurred in portions of the cities of Olympia and Seattle, where many older buildings showed severely cracking to masonry, and some suffered partial collapse of walls or parapets. A few older bridges in these two areas were also severely damaged, and in some cases will require replacement. Some of the most costly damage occurred on the State Capitol campus in Olympia. Here, several State buildings suffered varying levels of damage, and the Legislative Building and Governor's Mansion remain unoccupied because of safety concerns. Similar damage to older buildings likewise occurred in other smaller cities and towns throughout the region. None of this damage was a surprise, and was quite predictable based on past performance during the 1949 earthquake.

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Damage to buildings and bridges was quickly assessed by local building officials and public works engineers. State highway bridges were reviewed by Washington State Department of Transportations engineers through the implementation of their agency's emergency response plan. Severely damaged buildings and bridges were inspected and tagged within a few hours after the earthquake, and re-inspection of most structures was completed within two or three days. Documentation of the damage to buildings and bridges resulting from the Nisqually earthquake will be published by the end of March as Earthquake Engineering Research Institute (EERI) preliminary post-earthquake report.

GROUND FAILURES

Ground failures resulting from the Nisqually earthquake, including liquefaction and landsliding, were of moderate intensity. Liquefaction occurred in areas well-understood to be vulnerable to this phenomenon. The following two maps (Figures 1 and 2) indicate the relative liquefaction hazard (high, moderate, low) in a large portion of the Puget Sound region between Seattle and Olympia. As the principal investigator for many of the hazard mapping shown in these two figures, I feel that some discussion of these maps would be useful to the Sub-Committee. Much of the funding that supported the development of these maps was provided by the National Earthquake Hazard Reduction Program through the external grant program administered by the U.S. Geological Survey.

The purpose of these liquefaction hazard maps is to provide a variety of organizations within both the private and public sector with a relative assessment of this hazard. For example, building officials use these maps to determine areas where thorough geotechnical investigations must be required to support the design of proposed buildings and developments. Private businesses can (and have) used these maps to determine where to situate future expansion, and to ascertain the vulnerability of their existing operations. Earthquake insurance underwriters use these maps to evaluate portfolio risk and exposure. Finally, emergency managers and underground utility operators (sewer and water districts, natural gas distributors, fiber-optic cable providers, etc.) can use these maps to assess areas where liquefaction-related ground movement could disrupt their pipeline or telecommunication networks.

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Areas where liquefaction was documented during the Nisqually earthquake are indicated on the liquefaction hazard map of the Olympia area (Figure 2). A thorough reconnaissance of liquefaction sites in the Olympia area was performed by staff geologists at the Department of Natural Resources. Liquefaction occurred only in some areas having a moderate hazard, but most liquefaction occurred in high hazard areas. In many cases liquefaction was observed at sites where this phenomenon was reported during the 1949 earthquake. The most severe damage in the Olympia area resulting from liquefaction was to the Deshutes Parkway along Capitol Lake and to a private road within a mobile home park at Sunset Lake. The north end of the runway at Boeing Field was severely damaged by liquefaction, closing the airport to landing. This portions of the airfield is underlain by the filled-in channel of the Duwamish River, and was designated as a very high hazard area (see Figure 1). Liquefaction in the port area of Seattle (a very high hazard area) was widespread, but damage was limited because of the application of sound geotechnical engineering to new construction projects completed in the last few decades.

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Damage from landslides was limited, with only a few residences affected by this type of ground failure. The most significant landslides affecting residences were at Salmon Beach in Tacoma and in Maple Valley, southeast of Seattle. A small number of State highways were temporarily closed by landslides, but emergency repairs restored traffic along these roadways within a day or two. An earthquake-triggered landslide destroyed the northbound lanes of State Route 101 near Olympia, and temporary lanes were constructed in the median and opened to traffic the next day.

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Local emergency management and building officials quickly responded to those ground failures that represented a threat to life and safety. Documentation of ground failures has been accomplished through a coordinated effort of private-sector geotechnical engineering consultants, staff of the University of Washington Civil Engineering and Geology Departments, and geologists from the Washington Department of Natural Resources and the U.S. Geological Survey. The EERI preliminary post-earthquake report will provides documentation of ground failures and geotechnical considerations related to the Nisqually earthquake. This report will also includes sections discussing seismology and ground motion, lifelines, and socio-economic consequences of the Nisqually earthquake.

SOME SURPRISES

As with any earthquake, some things happened during the Nisqually earthquake that were not expected.

One of the most significant incidents resulting from the earthquake was the partial closure of SeaTac Airport because of severe non-structural damage to terminals and the main control tower. Measured ground shaking at the airport indicated a peak ground acceleration (PGA) of 0.18 g. Current structural design codes in western Washington use a seismic loading coefficient roughly equivalent to a PGA of 0.30 g. Evaluation of current non-structural design and retrofit requirements for such critical facilities would seem warranted based on this experience.

From a seismological perspective, there were surprisingly low levels of ground shaking measured in the Tacoma area. Interestingly, the city of Tacoma was reported to have suffered less severe damage to buildings during the 1949 earthquake than either Seattle or Olympia. However, our current understanding of the distribution of ground shaking during the Nisqually earthquake is severely limited by the scarcity of ground motion instrumentation in the Puget Sound region. Figure 9 is the SHAKEMAP intensity map produced by the Pacific Northwest Seismological Network (PNSN) at the University of Washington for the Nisqually earthquake. The sites where strong ground shaking was actually measured by the PNSN are shown by red triangles on this map. The overall pattern of the ground shaking depicted on the SHAKEMAP is estimated using a very rough seismological model.

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The distribution of strong ground motion instruments shown in Figure 9 represents the initial implementation of the Advanced National Seismic System (ANSS) program by the PNSN. There were no PNSN strong motion measurements in the Olympia area, and only two free-field (non-structure) measurements were recorded by the U.S. Geological Survey Strong-Motion Program. However, Olympia was the most severely damaged urban area during the Nisqually earthquake. This event clearly shows the importance of maintaining the ANSS program, and insuring that PNSN receives the support necessary to install all of the additional instruments specified in the ANSS plan. This support must include both funding for the hardware that makes and transmits the measurements, and the staff that must install and maintain this instrumentation.

Another surprise was the lack of liquefaction in the Puyallup Valley southeast of Tacoma during the Nisqually event. Numerous occurrences of liquefaction were observed in the Puyallup Valley during the 1949 earthquake. However, careful field checking by at least four different teams of geotechnical engineers and geologists have found no evidence of liquefaction between the port area of Tacoma (where there were limited instances of liquefaction) and Sumner, a town at the upriver end of the valley (see Figure 1). One explanation for this inconsistent behavior could be that the ground shaking throughout the Puyallup Valley was unaccountably light, similar to the measured ground motions nearby in Tacoma. However, there were no strong motion recorders operating in the Puyallup Valley at the time of the earthquake, and it will be impossible either support or rule-out this explanation. It is also possible that the very dry winter has resulted in less saturated soil and deeper ground water levels in the Puyallup Valley, which would also inhibit liquefaction.

The other ground failure surprise was the lack of intense landslide activity associated with the earthquake. There were a number of State highways temporarily closed by landslides, and a few houses damaged. However, there were very few saturated debris flows, and little evidence of instability along the marine bluffs of the Puget Sound. There is little doubt that the lack of landslides associated with the Nisqually earthquake was tempered by the unusually dry conditions preceding the event.

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CONCLUSIONS

The Nisqually earthquake was a moderate earthquake where damage patterns were quite predictable based on the experience of the 1949 Olympia earthquake. The actual levels of measured ground shaking showed that almost all of the Puget Sound region experienced PGA values less than 0.20 g, and much of the region experienced less than 0.10 g. For more than 20 years the earthquake ground motion design coefficient for new structures constructed in the Puget Sound region has been equivalent to a PGA of 0.30 g. Consequently, no site with measured ground motions experienced design level shaking during the Nisqually earthquake. Only downtown Olympia (PGA of 0.24 g) and Boeing Field (PGA of 0.27 g) experience ground motions near the structural design level.

From the perspective of ground failures, it is clear that the most severe liquefaction occurred in areas of predictably susceptible soils that experienced significant ground shaking, such as the in the Olympia area and at Boeing Field. However, liquefaction was less common in other susceptible deposits at comparable distances from the earthquake (like the Puyallup Valley). It is clear that these areas did not experience shaking sufficient to cause liquefaction. However, lack of ground motion instrumentation in the Puyallup Valley and at many other sites in the Puget Sound region will limit our understanding ground failures associated with this earthquake.

The Nisqually earthquake demonstrated that earthquakes centered on shallow crustal faults in the Puget Sound region have the greatest potential for causing ground motions that exceed code levels. Investigations performed during the 1990's have indicated that the Seattle fault is active, and capable of producing earthquakes with magnitudes similar to or even greater than the Nisqually earthquake. A Seattle fault earthquake of comparable magnitude would result in very strong ground motions, such as those experienced during the Northridge and Kobe earthquakes. Preliminary investigations indicate that there are other possible major fault systems within the Puget Sound region, and it is necessary that the hazard posed by these potentially active faults be thoroughly assessed. The planned extension of the Seismic Hazard Investigation of the Puget Sound (SHIPS) experiment will provide data that will help in accurately locating potentially active faults in the southern Puget Sound region, and map the crustal structure within the source area of the Nisqually earthquake.

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Finally, this earthquake provided a ground-truth demonstration of the earthquake community's ability to provide detailed maps that identify areas at risk to liquefaction. This demonstration could be considered one of the recent successes of the NEHRP program. It suggests that hazard maps identifying areas subject to amplified ground shaking and earthquake-induced landsliding could also be useful to a wide variety of end-users.

The most important lesson to be learned from the Nisqually earthquake was that is was a wake-up call for accelerating earthquake hazard mitigation in the Puget Sound region, and in the many other at-risk areas throughout the United States. For the Puget Sound region, this earthquake demonstrated that most modern buildings will remain serviceable at ground motion levels roughly one-half to two-thirds of the current design standard. It also demonstrated that some ground failures, particularly those related to liquefaction, can result in serious damage at conditions approaching design level ground shaking. The implication is that there could have been more significant damage if the ground shaking had been stronger, or lasted much longer, during the February 28th earthquake.

[The information referred to follows:]

BIOGRAPHY FOR STEPHEN P. PALMER

Dr. Steve Palmer received his A.B. degree in Geology, and M.S. and Ph.D. degrees in Engineering Science from the University of California, Berkeley, and has been employed by the Washington State Department of Natural Resources, Geology and Earth Resources Division, since 1989. During his employment with the Department he has been a principal investigator on a number of projects involved with evaluation of regional earthquake hazards in the Puget Sound region of Washington. Most recently he has completed detailed mapping of liquefaction ground failure hazards from Seattle to Olympia along the Interstate 5 corridor. The recent Nisqually earthquake has provided a "ground" truth of the assessments presented on these hazard maps. He has also acted as an advisor to state and local government agencies in their response to the Aldercrest-Banyon and Carlyon Beach landslides. He has made numerous presentations about Washington's earthquake and landslide hazards to the State Legislature, local government officials and agency staff, business groups, engineering societies, and the public at large.

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[The information referred to follows:]

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Chairman **SMITH.** Thank you, Dr. Palmer. Dr. Miller.

STATEMENT OF DR. M. MEGHAN MILLER, PROFESSOR OF GEOLOGICAL SCIENCES, CENTRAL WASHINGTON UNIVERSITY

Ms. **MILLER.** Thank you for the opportunity to be here. I would like to make three points today—one about earthquakes, one about where we have—how we have built science and technology in the last decade, and the third one will be, where we are poised to go from here.

As you have heard from the other members of the Committee, this is one of three types of earthquakes that we expect in the Pacific Northwest. It occurs in the down-going oceanic slab and that is why it occurred at such depth. The other two types that we expect are in the overriding North America plate, and then at the very large fault that forms the boundary between the two plates, which are shown in red and orange on this figure. And both of those sources would be significantly shallower. Next slide, please.

The subduction zone, which is the interface between the two plates is quite wide in Washington, and, therefore, is capable of generating quite a large seismic energy release—next slide, please—and would be accompanied by a tsunami because the actual displacements would happen in the submarine realm and the devastation of the earthquake would be accompanied by a large tsunami. Next slide, please.

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We have had the opportunity to study how much strain is accumulating across these faults in the Pacific Northwest through a project that is funded by the National Science Foundation. GPS geodesy is one example of a powerful new technology that can help us map the likely distribution, size, and frequency of the shallow earthquakes, because we can actually map—we can monitor the motion of sites across faults and their deformation.

GPS geodesy is very much in a discovery mode. It has been with us for a decade now. And when we set out to solve problems, we are constantly surprised at the wealth of what we know and the detail of what we are able to resolve. It is a very exciting area to be involved in right now. We—what we do is determine positions to millimeter level and then map the changes in those positions through time. So if, for example, you had two sites on opposite sites of the Seattle fault, you could actually map their convergence through time, though the fault itself is locked, the strain is being loaded from afar and during an earthquake would be recovered episodically or catastrophically.

NASA and NSF have taken leadership roles in developing this technology for the earth sciences applications that I will be talking about today. It has become a widespread tool in the national scientific community. It is a critical piece of our national research effort during the last decade. NASA is recognized for leading the technology development for the international coordination of a global array and providing the critical global data products that make it possible for us to do this. NSF has systematically funded equipment and research to disseminate this new technology to a broad, investigator community. Next slide, please. Next slide. Sorry.

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So this is the Pacific Northwest Array—Geodetic Array that we have installed. And you can see the vectors actually show the annual velocity of each of these stations with respect to a stable North America. Next slide, please. We have determined these velocities since 1997. If we take out the effects of the subduction zone and look at the deformation that is accumulating on crustal faults, you can see that western Washington is moving forward—is moving northward rapidly relative to Vancouver Island, which is not moving detectably with respect to North America. That 5 or so millimeters a year that accumulates is what will ultimately be released in crustal earthquakes. Next slide, please.

This is just another way of looking at it. If you look at the leftover northward velocity, on the left are stations in Oregon and southern Washington—they are impinging on Vancouver Island which has effectively a zero velocity. Next slide, please.

Okay. Yeah. This one is—using this network, we were able to determine—because we had the permanent—or the continuous GPS infrastructure in place, we were able to determine how much deformation occurred during the Nisqually earthquake. And it is not showing up particularly well here, but it actually maps the co-seismic deformation that occurred during that earthquake. Next slide, please.

In response to the Nisqually earthquake, we have received support from NSF to densify our observations in the Puget Sound region with a three-fold scientific objective. One is that there is evidence from recent earthquakes in Alaska and El Salvador that deep earthquakes, such as the Nisqually, triggered subsequent crustal seismicity. We will be poised to measure those events and understand them if similar events are triggered from the Nisqually event.

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There are issues that get at how much strain is released by earthquakes and how much is released through aseismic mechanisms, and that is another thing we are looking at. But the real value of this network, in terms of seismic hazard assessment, is that we will be able to set limits on the budget of deformation that is happening on the individual faults that cut through the Puget Sound area, such as the Seattle fault. And that, in turn, allows us to map the likely distribution, size, and frequency of the shallow earthquakes. Next slide, please.

Okay. NSF and NASA have partnered with the USGS and other sponsors, including some private concerns, to establish a test network in southern California of 200 sites, much denser than the one I have shown here. The Japanese have taken advantage of our collective resources and our investment in the GPS system and in the scientific background to doing this kind of work to establish a very dense network in their small country. Taiwan hopes to shortly follow and has invited an American panel to serve in an advisory role.

We are poised to realize the benefits of our investment through Earthscope, which is a proposal that has come forward from the scientific community and has been supported by NSF, NASA, the USGS, and DOE, and has the approval of the National Science Board. It now waits a Congressional appropriation.

The Earthscope is a multi-instrument array. One of the components would be GPS geodesy, as I have described to you. That would be widespread through the United States. I will detail that in just a little bit. The other components would be a much more detailed seismic array. San Andreas Observatory at Depth, which is an opportunity to actually study the guts of an active fault boundary by drilling through it and an InSAR component, which is a satellite-based component that NASA is the champion of.

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The U.S. scientific community is well-poised to take the lead in this research area. This community is well-trained. It is gifted. It is energetic. Sometimes you can't stop them from talking. And it is a community characterized by intellectual creativity. We are practiced in interdisciplinary studies of this kind. We are experienced in developing, managing, and integrating complex databases. This community has a strong ethic of publicly available data, an open review process, and translating research into benefits to society.

And, lastly, America's plate boundary is really the best place globally to do this research for scientific reasons. Tectonically, it is a very varied plate boundary. We have two different kinds of subduction zones. We have the San Andreas Fault. We have extension in the continental interior. It is also America's plate boundary and so it has the dual benefit of the scientific rationale and being a place—being a plate boundary on which we dwell and on which our citizens live and experience exposure to earthquake hazards. So I would urge you to make Earthscope a centerpiece of our national research agenda. Thank you.

[The prepared statement of Ms. Miller follows:]

The February 28, 2001 Nisqually earthquake:

GPS Geodesy and quantifying seismic hazard.

Testimony prepared for:
Subcommittee on Research, The Committee on Science
United States House of Representatives

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Hearing: March 21, 2001. 2:00 PM to 4:00 PM, Rayburn House Office building

Topic: *Life in the Subduction Zone: The Recent Nisqually Earthquake and Federal Efforts to Reduce Earthquake Hazards*

M. Meghan Miller, Ph.D., Professor of Geological Sciences, Central Washington University, Ellensburg, WA 98926–7417; 509/963–2825; 509/963–1109 (fax); *meghan@geology.cwu.edu* *http://www.geodesy.cwu.edu/*

Tectonic setting of the Nisqually Earthquake:

The February 28, 2001, Mw = 6.8 Nisqually earthquake broke within the subducting Juan de Fuca slab, the oceanic plate that is being thrust under the western edge of North America. GPS geodesy can measure Earth deformation at the millimeter level. The Nisqually earthquake was the first in the Pacific Northwest to be detected with GPS geodesy.

There are three types of earthquakes that pose seismic risk in the Pacific Northwest: those, like the Nisqually, that break the down going oceanic plate, those along shallow faults within the North America plate, and the potentially much larger but also less frequent ruptures along the subduction zone fault that separates the two plates. Each of these types has expected characteristic seismic hazard. The deep earthquakes, common during the last century, are strong and widely felt but on the whole less damaging at a particular magnitude because of their depth. Forecasting size and frequency of such earthquakes are perhaps the most difficult using current methods. The potential size and frequency distributions of shallow earthquakes can be much better known as geodetic constraints improve, in studies that are currently underway and planned. Finally, the subduction zone fault poses special hazard, despite its largely offshore location, because the likely magnitude is greater than 8 and may well be close to 9, exceeding even the 1906 San Francisco earthquake and would be comparable in size to the Great 1964 Alaska earthquake. Such earthquakes also generate large tsunamis.

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1) *How significant were the effects of the Nisqually earthquake on the Puget Sound region? How are these effects assessed?*

The Nisqually earthquake was widely felt. Two of the major geologic effects of the earthquake were widespread landslides and liquefaction. The USGS led a major scientific effort that involved members of the academic scientific community to map and assess the damage resulting from these processes. Urban development on unconsolidated materials such as landfill are particularly, vulnerable to liquefaction. Developments on unstable hill slopes are most susceptible to landslides.

The co-seismic deformation (the change in the position of the ground after the earthquake fault has slipped) that accompanied this earthquake was also significant, and was the first to be observed using continuous GPS geodesy in the Pacific Northwest. These observations give us constraints on the physics of earthquakes and the parameters, such as rigidity, that control how the earth responds to earthquakes. These in turn have implications for seismic risk assessment and planning.

2) *To what extent did buildings and land behave differently than expected in this earthquake? To what extent should codes, earthquake preparations and the research agenda be altered as a result?*

The Pacific Northwest is recognized as an area where the engineering community has taken seriously the sometimes abstract determinations of the scientific community, and has systematically worked to strengthen seismic zoning in the urban corridor from Seattle, Washington, to Portland, Oregon. Nevertheless, as the body of scientific information continues to grow, this collaboration continues to be important, especially as urban growth places increased pressure on remaining hill slope properties that may not be suitable for development from the standpoint of seismic risk and periods of intense rainfall.

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The co-seismic geodetic deformation that we observed in this earthquake was somewhat smaller than we expected from seismic parameters. This pattern has emerged from several recent earthquakes such as large earthquakes in the California desert during the 1990s. This growing database leads us to reassess our working models for earthquake physics.

The national research agenda needs to be strengthened in this area. All the elements from basic research to risk mitigation are the targets of ongoing efforts by the scientific and engineering communities. As new advances in geodesy (such as GPS and strain meters) and seismology become available, responsive federal support is needed to implement state of the art research programs.

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3) *What is the current depth of our understanding about earthquakes in the Pacific Northwest and elsewhere, and where should we focus future research efforts.*

The last decade has been a period of great vitality in Pacific Northwest active tectonics research. New technology and new geologic approaches have rapidly advanced our understanding, yet a tremendous amount of work remains to be done in order to quantify the regional seismic hazard.

Several factors concentrate Pacific Northwest seismic hazard in the Puget Sound and Olympic Peninsula region. Seismicity along deep faults such as the Nisqually earthquake fault, and along shallow faults in the Puget Lowlands, is regionally concentrated in this area. This is a result of arching of the slab underneath western Washington, where it is breaking up in response to this arching. Earthquakes on the shallower faults result from a concentration of north-south shortening as the Oregon-southern Washington coastal block drives into Vancouver Island and is absorbed through earthquake faulting. Finally the locked or seismogenic part of the subduction zone fault is very wide under western Washington, implying greater energy release in that area during infrequent but great earthquakes.

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Advancing Seismic Risk Assessment and Hazards Planning in Puget Sound:

GPS geodesy demonstrates that the coastal region from central Oregon to central Washington is a coherent block that is driving into a rigid backstop, Vancouver Island. Approximately 5 mm (about one quarter of an inch) of shortening occurs each year across the Olympic Mountains and Puget Sound. This background deformation will ultimately be released through earthquakes and related processes. The deformation is similar in magnitude to the annual shortening across the Los Angeles Basin. The Seattle fault, oriented east-west under West Seattle, is the strongest among several candidates for carrying much of this deformation and could rupture in an earthquake at least as large as magnitude 7.5, or in more numerous smaller events. Because of its proximity to urban corridor, such events could rival or exceed the Northridge earthquake for damage and casualties.

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Seattle ought not to be lulled into a false sense of security, having sustained so little damage in the Mw 6.8 Nisqually earthquake. The depth of this earthquake greatly reduced the amplitude of shaking experienced in the metropolitan region. A shallow event of that size, or larger, which is expected on the shallow faults, would not be so kind to the older buildings and perhaps modern structures throughout the urban area.

Denser distribution of continuous GPS stations in the Puget Lowlands will characterize which faults pose seismic hazard. The GPS-determined parameters have a direct impact on seismic zoning and building code development: How much strain is accumulating? Where it is accumulating? Which faults are being loaded with seismic deformation? How wide are the down-dip rupture patches on shallow faults? These findings will constrain the likely size, location, and frequency of earthquakes on active faults in Puget Sound. Because the Seattle, Tacoma Narrows, Southern Whidbey Island and other similar faults are shallow (likely seismic sources at 10–15 km depth), they pose much graver seismic risk than the fault ruptured in the Nisqually earthquake.

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Mitigation strategies, community preparedness, and response planning depend on the accuracy of fault parameter determinations. GPS geodesy is a new technology that is rapidly advancing our ability to set scientific constraints on these parameters.

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GPS geodesy and the Nisqually earthquake:

Central Washington University received NSF support to densify the PANGA continuous GPS network in the Puget Lowlands in order to address critical questions regarding the Nisqually earthquake and future Pacific Northwest earthquakes. Partners in this effort include the Southern California Earthquake Center, the U.S. Geological Survey, and UNAVCO (the University NAVSTAR Consortium).

1. How is the budget of north-south shortening (5 mm) that accumulates each year between coastal central Washington and Vancouver Island relieved? The budget is comparable in size to that across the Los Angeles Basin. Should we expect a flurry of earthquakes on the Seattle, Tacoma Narrows or Whidbey Island fault, like those in the last 15 years in Los Angeles which followed a long period of dormancy?

2. Is the series of deep earthquakes recorded in 1939, 1946 and 1949 a typical sequence? Are we entering another period of such events, beginning with the 1999 Grays Harbor and the 2001 Nisqually earthquakes, to be followed by some near-term future event(s)?

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3. Do earthquakes relieve all of the strain in the Puget Lowlands or do other processes play a role?

4. Can these deep earthquakes and trigger earthquakes on shallow faults, as suggested by recent patterns of earthquakes in southern Alaska and El Salvador? The December 1999 Kodiak earthquake is similar to the Nisqually earthquake in that both ruptured the slab although the style of faulting is different. The January 2001 El Salvador event is probably more similar to the Seattle event, but with about 3 times the energy release. That earthquake was also followed by a complex aftershock sequence that included faulting in the upper plate. It is clear from the Kodiak and El Salvador examples that these slab events can be followed by aftershocks or triggered events in the upper plate. This may be explained by static stress changes, or by patterns of deformation that are temporarily perturbed after such a large earthquake.

Nisqually earthquake response deployment:

We have undertaken an immediate deployment of seven continuous GPS stations in the Puget Lowlands in order to quantify the distribution of slip on active faults in the metropolitan region. We currently have four teams in the field finding suitable sites for installation, negotiating permits, and making the installations. These seven stations will add to the more widely spaced existing network of 40 stations, which spans the region from northern California to the international border, and from the coast as far east as Idaho and Nevada.

PANGA (the Pacific Northwest Geodetic Array)

The Pacific Northwest Geodetic Array (PANGA) is an international consortium of institutions committed to using continuous GPS geodesy to further understanding of Earth deformation in the Pacific Northwest, including seismic hazard assessment. Central Washington University coordinates PANGA. Institutions that participate in funded PANGA projects include Central Washington University, the Geological Survey of Canada, the U.S. Geological Survey, University of Washington, University of Oregon, Oregon State University, and University of Alaska. Many other academic institutions and government agencies participate in annual PANGA Investigator Community Meetings. Data analysis is performed at the PANGA Data Analysis Facility in the Geodesy Laboratory at Central Washington University, an NSF facility.

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The core projects that have established PANGA and supported the PANGA Data Analysis Facility at Central Washington University since 1997 have been funded by the National Science Foundation, through the Earth Sciences Research programs. Supplementary funding has come from the U.S. Geological Survey—National Earthquake Hazards Research Program (External Research), the National Aeronautics and Space Administration, and private gifts from Sun Microsystems.

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Translating Scientific Results into Benefits to Society:

An essential element of long-term earthquake hazard mitigation is the establishment and refinement of hazard maps. The data from these GPS stations will be used as input to probabilistic seismic hazard analysis to refine future versions of these hazard maps. By better defining areas most susceptible to strong shaking, future land use planning can take this into account, thereby improving seismic risk mitigation in this rapidly developing urban and suburban region. Furthermore, data from the PANGA network will rapidly provide earthquake information that will be useful to emergency responders, helping them to target and prioritize their response efforts.

Precise location data provided by GPS is of much broader utility than PANGA's scientific goals. This network of GPS base stations will be widely used by federal, state, county, city and private parties for routine surveying applications. These uses support damage reparations, landslide and liquefaction mapping, road repair, life line and damage mapping and reparation, GIS applications for urban and seismic planning including HAZUS, road reparations and hill slope stability planning, and other geotechnical needs directly related to mitigation.

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The Future: Earthscope

The existing PANGA network, as well as its in-progress enhancement following the Nisqually earthquake, forms a critical first step towards understanding the processes that cause earthquakes in the Pacific Northwest. The nascent GPS technology promises enormous results if implemented more broadly. Each time the scientific community has attempted to learn something about how the Earth deforms using GPS as a tool, we discover far more than we set out to measure and we must reformulate the questions in light of results that exceed our expectations. The Earth is a complex and intriguing laboratory, sometimes messy, but always rewarding. GPS is an unprecedented tool for characterizing the Earth's dynamics.

The scientific community is poised to expand these observations in a manner that will support a systematic accounting of seismic hazard in many vulnerable states: through the Earthscope initiative. This initiative from the scientific community has NSF's National Science Board approval and is awaiting congressional support. It is a multi-agency collaboration between the NSF, USGS, NASA, and DOE.

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PANGA is one of a few continuous GPS networks in the western United States. The scientific community has recognized the potential synergy of combining GPS observations throughout the country, with concentrated "clusters" of geodetic instrumentation in areas that are known to experience many earthquakes. This planned Earthscope network, termed the Plate Boundary Observatory or PBO, has three levels of deployment: (1) a sparse network of GPS stations that covers the stable continental interior and provides key constraint for understanding the deforming regions, (2) a backbone of GPS stations through all the areas from the Rocky Mountain westward at 200 km spacing to provide even, systematic characterization of the active mountain building regions, and (3) clusters that focus on areas where deformation is caused by either earthquake faulting or volcanic activity occur. The Pacific Northwest has been targeted for such clusters that will constrain earthquake faulting and volcano deformation.

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The PBO is one of several components of Earthscope. It provides a perspective that is unique among the elements of Earthscope, setting seismological and other observations within the context of how the Earth deforms through time. Together the elements of Earthscope provide a state of the art characterization of the actively deforming continent on which we live.

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International Aspects and Global Uniqueness of Earthscope

Earthscope has two international components: (1) partnerships with Canada and Mexico and (2) similar initiatives in Japan and Taiwan. The scientific community is committed to developing international partnerships with Canada and Mexico that would complete the picture of the deforming continent beyond our national boundaries.

Japan has implemented a similar project of 1000 GPS sites within their small country. The U.S. has provided scientific expertise to this project. In the wake of the 1999 Chi-Chi earthquake, Taiwan is planning to implement a PBO modeled after the U.S. plan, and is seeking the experience and expertise of our scientific community to support this effort.

The U.S. scientific community is poised to implement the Earthscope initiative that would provide urgently needed observations on a global scale. The investigator community is very strong, and practiced in interdisciplinary studies. Furthermore, we dwell on a varied active plate boundary that includes microcosms of each of Earth's major tectonic environments: subduction zones of two important types in Cascadia and Alaska, a the textbook example of a transform boundary in the San Andreas fault, and rifting by extension in the Great Basin of Nevada, Utah, and adjacent states. No similar projects boast this wealth of tectonic environments.

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Summary

Because of dramatic growth in our understanding of seismicity in the Pacific Northwest over the last decade or more, scientists were not surprised by the February 28, 2001, Mw = 6.8 Nisqually earthquake. Continued integration of scientific results into urban planning and risk mitigation requires enhanced support for the new technologies that can help scientists map the likely locations, size and frequency of future earthquakes on shallower faults, which pose much more serious risk to life and property.

Recent technological advances include the use of GPS to study how the planet Earth's tectonic plates deform in real time. With NSF, NASA, USGS, and Sun Microsystems support, the Pacific Northwest Geodetic Array (PANGA) has piloted applications of this technology in the Pacific Northwest. PANGA has responded to the Nisqually earthquake by initiating installation of seven new stations in the Puget Lowlands region. This has been undertaken with NSF support and in partnership with the geodetic investigator community including the Southern California Earthquake Center, UNAVCO, and the U.S. Geological Survey.

The scientific community is poised to dramatically extend our knowledge base by implementing these technologies at an unprecedented scale in the planned projects that make up Earthscope, which has been approved by the National Science Board. Through Earthscope, the scientific community will provide meaningful constraints for urban planning and emergency response measures, in addition to advancing our basic research in the areas of earthquake physics, the physics of deforming volcanoes, and the forces that drive plate tectonics and mountain building within the continents.

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Recommendation:

Federal funding of earthquake sciences needs to be strengthened to support the growth of technology such as GPS geodesy. This includes Earthscope, which has been approved by the National Science Board, funding to earthquake response agencies, and basic research initiatives implemented through the research programs of the NSF.

[The information referred to follows:]

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Chairman **SMITH.** Thank you, Dr. Miller. Dr. Miller, following up on—each member will now have 5 minutes to ask questions, and then, if we want a second round, we will do a second round. Following up a little bit, Dr. Miller, on your comparison with the El Salvador quake with Nisqually, both occurred fairly deep within the subduction zone.

Ms. **MILLER.** Uh-huh.

Chairman **SMITH.** I am wondering—and, of course, the aftershock in El Salvador, 1 month later, was devastating. What is the relationship? What is—is there a likelihood of a devastating aftershock? And how well do we understand what happened in El Salvador in terms of the serious aftershock a month later? And we will start with you, Dr. Miller, and then any other comments from the panelists.

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Ms. **MILLER.** Well, I don't think this is a well-understood process, and that is one of the rationales for monitoring it closely. The—certainly after the 1949 earthquake in Olympia, there was not a similar crustal events, but we have two events within the last year that show a relationship between a deep seismicity and a shallow seismicity. If you had asked any geologist 15 years ago about the causality of one earthquake triggering another, there would have been a high level of skepticism. We have a growing database that shows us how the deformation that happens after the earthquake can actually change the configuration of static stress in the crust and lead to a subsequent earthquake.

Chairman **SMITH.** And so you are—anybody's analysis of the possibility of an after quake in the Puget Sound area—is that still a possibility at this late a date?

Ms. **MILLER.** It is certainly a possibility.

Chairman **SMITH.** Other comments on El Salvador. Dr. Filson.

Mr. **FILSON.** It is certainly a possibility, but, as Dr. Miller said, there wasn't an earthquake of this type following the 1949 earthquake. I would also point out that the earth—the first earthquake in El Salvador had numerous aftershocks—very rich aftershock sequence, as we say. Both the 1949 deep earthquake near Olympia and the recent earthquake have had a dearth of aftershocks. So far, I think, about four aftershocks have been recorded from the February 28 earthquake. So anything is likely, but there seem to be different animals when comparing the Seattle area to El Salvador.

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Chairman **SMITH.** Are we having more earthquakes now than historically, or do we just read more about them? What is the frequency of quakes?

Mr. **PALMER.** I can probably speak to that because I looked into this fairly extensively about 10 years ago. The problem, first of all, is that our long-term historic record is based on modified Mercalli intensity measurements, the actual damage that is attributed to the earthquake, rather than measured magnitudes.

In 1939 and 1945, '46, Washington State experienced three magnitude 6 earthquakes, similar in size to the Satsup earthquake that occurred in 1999. There was also 1949 magnitude 7.1 event and the 1965 magnitude 6.5. In all, in that 25-or-so-year time period, there were approximately 17 earthquakes in the Puget Sound region that produced intensity VI or greater Mercalli intensity, which is indicated by minor damage to buildings, or, as you go up on the Mercalli scale, greater damage.

We did not have a Mercalli VI earthquake in the Puget Sound region from 1965 until 1990.

Chairman **SMITH.** Let me ask what I think is one of our challenges, and that is, our ability to predict earthquakes, such as we predict hurricanes. What is the bottleneck? What kind of technology do you advise that we look at? Is it something that is realistic to pursue? And part of that question also is what is happening to the effort for the underwater monitors—quake monitors that we have started putting off the coast of—the West Coast? Starting with whoever wants to start.

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Mr. **FILSON.** Mr. Chairman, for several years, beginning in 1980 and for about 15 years, we had what we call an earthquake prediction element of our program. But we finally backed away from that. In fact, we did predict an earthquake that never occurred. The problem is, we don't understand the physics of the phenomena. The problem is that the earthquake weather takes place at depth where we can't see it coming like a hurricane. We don't know the physical conditions or the material rock conditions at these depths.

So I think rather than start off on a earthquake prediction effort, there should be an effort to understand the physics of earthquakes, to drill to depths in the San Andreas Fault, say, where we can make samples of the temperatures, the pressures, the rock conditions, to make surface measurements, as Dr. Miller has indicated, to try and understand how these phenomena work, how they are loaded, how the earth responds to strain. And then once we have that understanding, then move into earthquake prediction.

Chairman **SMITH.** Any follow-up from the other witnesses on that question of how—where we put our limited resources. If we are going to spend money, where do we spend it?

Ms. **MILLER.** Because earthquakes don't have the same kinds of precursory behavior as some other earth phenomenon like volcanic eruptions, it has been more elusive as a target for prediction of specific events. But we do have the technologies available to us to do better mapping of where the hazards are concentrated and what the likely frequency distribution, and/or size distribution on particular faults could be.

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Chairman **SMITH.** Dr. Nelson.

Ms. **NELSON.** The second part of your question is interesting because it raises the issue of how can we be prepared for an event when it does happen. And I think that we are coming much more clearly to terms with how to be prepared and what it means to be prepared, both in terms of the engineering and the social science aspects. And every one of these events that happens is something that we study exhaustively to learn more about each of those aspects.

But I think that the decade of the future is going to be a decade where we sense more and more and more about our environment, both the built environment, the constructed environment, and the natural environment. And as we learn more, because we are deploying sensors, we will understand more. And the predictability of impacts, whether we can actually predict the event—the predictability of impacts and the minimization of the impacts is something we are going to be able to get better and better at without a doubt.

Chairman **SMITH.** Representative Baird.

Mr. **BAIRD.** Thank you, Mr. Chairman. And thanks to all the panelists for very informative testimony. This is a topic that we could obviously spend—you have spent your dissertations on and degrees on—that we could spend a lot more time. But let me ask about the investment we make in research and mitigation efforts as—in relation to the cost savings, and I will open this up to any of you who wants to address it. But do we have a sense of the kind of cost benefit ratio we get for our research or mitigation dollar as a reduction in loss of property, infrastructure, or human life? Dr. Nelson.

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Ms. **NELSON.** I will be happy to take a first stab, but I am sure others will respond as well. This event, and all events, are studied very closely to understand the impact of mitigation, which can include structural mitigation, and it can also include new technologies used for soil improvement, in addition to better mapping and better understanding of where the hazards are. And the more we know about the performance, the better able we are to understand the cost impacts and where to put the investments.

But there is another change going on in engineering aspects, and that has to do with really understanding the performance of a building or a structure or any facility for a low energy earthquake, both smaller events and larger events. And much of engineering perspectives has been focused on the very—the large events that cause collapse. And that has been the strategy that is used for code and standards-based development in engineering.

What is happening now is people are saying, well, we wish to know something about our risks for investments in mitigation that will permit another level of performance, maybe a performance that is defined by life safety rather than absolute collapse, or one that is for critical facilities where you want immediate occupancy. In order to do that, we need to know an awful lot more about the structures than we did before. So an event like Nisqually, even though it did not cause widespread structural damage, is very interesting for what it didn't cause, as well as for what it did cause, both in the soil and in the structures.

And just let me mention one thing I wasn't able to mention in my oral testimony, and that is the project NEES, the Network for Earthquake Engineering Simulation, which Congress authorized for 5 years and which is well underway to being completed. NEES is going to be an Internet-connected network of international facilities and facilities that are invested in by NSF in United States locations. And it is going to include mobile laboratories, which could actually have deployed—although we are not ready, because we are just starting—could have deployed mobile shakers, mobile testing devices, to Seattle, to Olympia, that would actually have been able to evaluate onsite the damage that had occurred to structures. And this is something that relates into the social science aspects, because if you can understand more quickly what is reoccupiable, what is damaged, and what constitutes a real repair, you regain the public's trust and the sense of recovery occurs much sooner. So this sense of being able to deploy and understand how to repair is very important.

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Mr. **BAIRD.** Thank you for that explanation. It sounds like what—to summarize, it sounds like we are making some progress in understanding the behavior of earthquakes and human structures in response, but we still have a ways to go before we have specific data pertaining to how to harden and how we make the cost benefit decisions.

Related to that, to some extent, I know that a great issue that came up had to do with liquefaction. What do we know about whether or not we should discourage building in liquefiable areas or are there ways to build in these areas that we aren't so likely to sustain damage? Or can we actually prepare the ground in some fashion to reduce the liquefaction?

Mr. **PALMER.** The answer to your question is that we can reliably predict areas that will liquefy. Ground truthing from this earthquake demonstrates the renewability of the liquefaction mapping in the Puget Sound region. I point out that in most of the areas, the shaking was actually less than my lowest bound on analysis to produce these maps. So this was not really a comprehensive test of these maps except in the Olympia area and the Port of Seattle, and at the Boeing Field.

The issue is what do you do about building in these areas? There are certainly a lot of engineering mitigations that can be done. In the Port of Seattle a lot of the recent construction was concerned with mitigating the liquefaction hazards. The money was put out because of the importance, economically, to the port and its customers.

In other areas that are at a high level of hazard to liquefaction, is that engineering mitigation being performed? I would have to raise some skepticism that it necessarily is. We will find out when we really have a major earthquake.

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One thing that I think is important to note is that the failure on Deshutes Parkway occurred in 1965 as well. It is likely that the only money that will come from the Federal Government to compensate for this damage will only focus on repairing the road surface itself and not to deal with the problem of mitigating the liquefiable soils. The difference between that is probably $5 million to repave the road and tens of million dollars to do soil improvement necessary to mitigate liquefaction.

Mr. **BAIRD.** Thank you.

Chairman **SMITH.** The Vice Chairman of our Subcommittee, Tim Johnson.

Mr. **JOHNSON.** Thank you, Mr. Chairman. Obviously, today's testimony and focus has been on recent earthquake that is so current in our mind. I live in central Illinois and our part of the country has been subject, over more than a century, to threat of and the actuality of earthquakes. My question, I guess, would be, to any of the Panel, as to what research—what studies are being done that would impact, either identically or similarly or differently, on the central and eastern part of the United States, vis-á-vis what research is going on in your specific areas? Yes, sir.

Mr. **FILSON.** In response to your question, we have a small contingent of USGS personnel stationed in Memphis, Tennessee, and their responsibility is to do work on the earthquake hazards assessment in the central United States. We also support the operation of seismic networks at the University of St. Louis and at University of Memphis to monitor the seismicity throughout the region.

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We also have done extensive geologic studies looking for liquefaction features that have occurred in the past, as indicators of past earthquakes. And we have produced a national hazard assessment map, a portion of which I showed earlier, that is being developed and incorporated into the model building codes for the area. So the problems are a little different or more difficult in the central United States, because the earthquakes are more infrequent and the faults aren't as obvious, but a considerable amount of effort has gone into addressing these issues.

Mr. **JOHNSON.** In light of that—yes, ma'am.

Ms. **NELSON.** Well, I was just going to say that there is an awful lot of work going on at MCEER and at the MAE Center, at the University of Illinois, both of them dealing with the technologies and information about this rare event that occurs in the middle part of the United States. I think the issue about paleoliquefaction, being able to understand fossil evidence of liquefiable materials—a key element there is to tie into the current liquefactions that we observe under current earthquakes and to understand how to extrapolate from that observation to an understanding of what would happen under a rare event.

But I think there are a couple of other things that are going on with the University of Illinois as the focus. One is total system vulnerability, which really focuses in on the transportation system, which is so important to the middle part of the United States, and the vulnerability aspects of that.

And I think the other thing is that in the middle part of the United States there haven't been so many events that have stressed the infrastructure. And a lot of the infrastructure is older inventory. It has been there for a long time. Sometimes it has been deteriorating through normal corrosion processes or just long-term use. And the idea of trying to understand how a building like that or a structure like that would perform under an earthquake, is a different kind of a question than how a new structure would perform somewhere on the east or on the West Coast. So it is under-researched, but it is a different kind of a problem.

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Mr. **JOHNSON.** I appreciate your response. As a matter of fact, within the last week, I represent the University of Illinois——

Ms. **NELSON.** Uh-huh.

Mr. **JOHNSON** [continuing]. And both the President and others from the University have been here and were vitally concerned, as I know you are, with research in our—from our university—the impact not only on the central and eastern part of the United States, but you, as well. And I guess my question was more cosmic.

I guess my second question is this, and I can direct this almost as well. But let me ask anyway. People who live on the West Coast are probably more confronted with the daily potential or reality of earthquakes than we are in the central and the eastern United States. So I guess my question would be two-fold. One is, from your judgment, or anybody's judgment, how adequately schooled, prepared, are people in our part of the world for significant earthquakes and the effects of them. And, number two, how do the—how does the impact, the losses, the potential losses and impact of those earthquakes in our part of the world differ, if at all, from what they do on the West Coast? Yes, sir.

Mr. **FILSON.** It is hard for me to quantify exactly what the level of preparedness is in the central United States compared to the western United States, sir, but I think, relatively speaking, as you said, they are more aware in the western United States. Recently, there was a decision taken by a state building code group in South Carolina, which has had significant earthquakes in the past, to ignore the seismic elements of a building code because of the lack of being confronted with the seismic hazard on a day-by-day basis.

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The other part of your question is interesting, though, that because of the makeup of the earth and the age of the earth, seismic events in the western United States aren't—the impact of them aren't felt as greatly or as widely as a similar-sized seismic event would be in the central United States. The 1811–'12 earthquakes that occurred there supposedly rang chimes in Philadelphia and places like that, very widespread effects. And this, in addition to the untested infrastructure, the widespread nature of the shaking would probably have a very severe impact in the central United States if a large earthquake occurred.

Ms. **NELSON.** I am going to take a little bit of a different tack. I think what is very interesting about Performance-Based Earthquake Engineering is that if we can actually get to the point where we understand the full response of a building under a wide variety of earthquakes, there can be some selectivity about retained risk by all parties involved in any sort of a structure in a way that right now it is very difficult to do.

So the sense of having the public, having an owner, having a policy organization, make a rational cost-based, perhaps, or life-based decision, is one which, if we do the work, we can get there. But we have work to do. And I think a lot of the issues about communication of risks and uncertainties to the public so that they can better able participate in making these decisions—I think, really fundamental research on decision-making before and after an event so we start to understand where are those thresholds for making the investments, is extremely important.

And the issue of economic loss and disruption models is something that we need to document thoroughly so that we can actually figure out where to make those investments in policy and in public safety more effectively. So I think we understand some of the questions that need to be worked on. And while this was a natural system event, an earthquake, it is also an event that impacts upon the people. And we deserve the opportunity to go and learn from them what their recovery is going to be like.

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Chairman **SMITH.** Representative Rivers.

Ms. **RIVERS.** Thank you very much, Mr. Chair. I apologize to the Panel for not hearing your remarks earlier. I was at another Committee meeting. I am very interested, in reading, watching the news, that there doesn't seem to be the kind of damage in the Pacific Northwest that we have seen in other West Coast earthquakes. How does this particular area compare to other West Coast areas, in terms of building codes and preparedness? Was there something different about the quake or was there something different about the way the buildings were constructed? What made the response look so different between the areas?

Mr. **FILSON.** The geologic reason for the reduced damage in this earthquake was that it was buried somewhat deeply within the earth about 30 miles. And earthquakes in the Los Angeles and San Francisco area tend to be closer to the surface, so the buildings on the surface are closer to the source of the shaking and that shaking is not attenuated before it reaches these buildings.

I can't speak to the building codes in the Washington area compared to——

Mr. **PALMER.** This was a deep earthquake——

Ms. **RIVERS.** Uh-huh.

Mr. **PALMER** [continuing]. At 30 miles below the surface that attenuated the ground motions considerably. Nowhere in the Puget Sound did we measure ground motions greater than .27g, "g" being the acceleration of gravity. For the last 20 or more years, structural design in the Puget Sound has used .3g as the design level. So this earthquake, even in the worst soil conditions, did not actually reach the design code.

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Ms. **RIVERS.** When building codes are developed, does the National Government give guidance in that? Does the National Government do research and share that information with municipalities or is each community in each state left to its own devices to decide best how to approach this kind of risk?

Mr. **FILSON.** The National Government, in fact, NEHRP, has sponsored the development of what we call model building codes, and each model building code has a seismic element. The USGS seismic shaking map goes into the model and is a basis for these model building codes. The engineering work that NSF does is also incorporated in these codes. But it is up to the individual jurisdiction, and can vary from state to state, whether to adopt these codes or adopt sections of these codes. So the Federal Government does not enforce adoption of the code. It just sets out a model for incorporation into local codes.

Ms. **RIVERS.** Please.

Ms. **NELSON.** Just to add to both comments, there are very different subsurface geologies in their near-field shallow sense, in terms of the softness of the soil, the general grain size, and where the water table is were quite different, for example, for the Northridge and Nisqually events. So the response was bound to be quite different.

I think that what is happening in engineering is, as we make more and more measurements and observations and deploy more equipment, we start realizing that there are an awful lot of site-specific, very locality-based effects that are very difficult to incorporate in a grand code. And that is one of the reasons that people have been moving toward performance-based earthquake engineering toward wider deployment of instrumentation, so we can actually start to understand that variation, because that variation is what causes the surprises.

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And there can be two ways of surprises. There are some places, I think, in the Seattle area, where liquefaction would have been predicted, but didn't happen, and other places where it did happen and it wasn't predicted. So we still have scientific work to do in some of these basic soil responses, for example.

Ms. **RIVERS.** One of the budget rumors that has been floating around here for a little while, is that the USGS is going to take a budget cut on the next round of numbers, and I have heard up to 22 percent. Would that kind of cut likely impact the kind of work we are talking about here? It is probably an unfair thing to do, but I am going to do it anyway.

Mr. **FILSON.** If such a cut were—of that size were imposed, it would likely impact the work we are trying to do here, but I think these issues are still being discussed within the Administration.

Ms. **RIVERS.** I hope so. All right. Thank you very much.

Chairman **SMITH.** Representative Biggert.

Ms. **BIGGERT.** Thank you, Mr. Chairman. Could you describe the real time seismic warning system and any plans to implement a pilot warning system?

Mr. **FILSON.** Yes. We are under an initiative called the Advanced National Seismic System. We are trying to deploy dense arrays of instruments in urban areas that are subject to the earthquake threat—Los Angeles, San Francisco, Puget Sound, Reno, Salt Lake, St. Louis, Memphis, other places.

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Within this system, the instrumentation will have three capabilities. It will allow for the rapid assessment of earthquake shaking within 10 minutes after an earthquake occurs, the so-called shake map. This capability exists now in southern and northern California. It was just being implemented in the Seattle area when the earthquake occurred. It will also provide the information that the engineering community needs for the rebuilding or the future building of structures, knowing how strongly the ground is expected to shake, and what the characteristics of shaking are.

Also, it has the technical capability, in the right circumstances, of providing a few seconds warning. Once an earthquake has occurred over here, the seismic waves are moving fast, a few seconds warning can be given to the people somewhat removed from the epicenter, that the strong shaking is on the way. Such a system would not have been effective in the recent Nisqually earthquake because you would have needed to have seismometers down at 30 miles in the earth in order to detect that the earthquake occurred.

But in other geometries, in other situations, a strong earthquake on the San Andreas Fault, outside of Los Angeles, it is technically possible to provide a few seconds warning that strong ground shaking is in the way. We are working on the feasibility studies of this rapid warning approach at our office in Pasadena in cooperation with the California Institute of Technology.

Ms. **BIGGERT.** Yes, ma'am.

Ms. **NELSON.** If I can just add one thing? I spoke a little bit before about the Network for Earthquake Engineering Simulation, which will be equipment for testing. But there will also be a network. And this network will serve as the platform for real time and very high-performance computation of response.

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One of the things about just simply telling people that an earthquake is coming is that it doesn't give you the full picture of how the impact and the response has to be planned for. If more information about the earthquake could be entered into an analysis in fairly real time, you would have a much greater knowledge about where the damage would likely occur in a city instead of just knowing that an earthquake is coming. And I think that this sense of what we hope for the network is, that we can interface with the USGS network that will give us the full information about what an event looks like, and also interface with the socioeconomic planners in a city so that there can be a very rapid prediction of what the damage is going to be and where it is going to be for a particular location. So that is the hope.

Ms. **BIGGERT.** Well, I guess that is part of my follow-up question is, what would be some of the implications of giving only a 30-second warning in a large urban area and the social and, really, policy ramifications for doing that?

Mr. **FILSON.** That is a very difficult question. Even if the technology exists, you have to make the social handshake on how to use the technology. And whether it would be useful to give a warning in a building like this, that is the question. In a school, allowing the children to get under their desks, where there is a lot of nonstructural material around, bookcases, TVs, fishbowls, that might land on them, it might be very useful. In a movie theater, or something like that, probably not.

Ms. **BIGGERT.** Right.

Mr. **FILSON.** So there are very strong social questions.

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Ms. **BIGGERT.** Uh-huh.

Mr. **FILSON.** Again, some work is being done in southern California with—through questionnaires and other means to try and address these social questions, what people would do with the information if they had it.

Ms. **BIGGERT. THANK YOU. DR. PALMER.**

Mr. **PALMER.** I would like to relate a summary of a conversation I had with a Department of Transportation bridge engineer. We have a structure in Seattle, the Alaska Way Viaduct, that shares some similarities with the Cypress Way Viaduct that collapsed during the Loma Prieta earthquake. Similarities only in very broad terms, in the sense it is an old structure designed to much lower levels of ground shaking than you would today.

The question came up about a subduction zone earthquake, which would really impact that structure—that is, cause it to potentially collapse, and what you would do about it. If you had 30 or 40 seconds of warning, which is very possible, because that event is 110 or 20 kilometers away from Seattle, you might able be able to devise some way to stop traffic from getting on the viaduct. Of course, I guess you would have to have automatic speed limit signs that would change to 90 or 100 miles an hour to get the people off. But there are some feasible things that might be done with adequate warning. Then you would have to deal with some of the practical issues of liability and things like that.

Ms. **BIGGERT.** I think if that—I am from Illinois and have—had lived in California and was in Illinois and the building started to shake. And I was talking to my geologist's brother-in-law on the phone and said we are having an earthquake and he said it is not possible in Chicago. And I said, well, it is. I am in it. But I think people have changed since then to know that it happens not only on the coast, but here.

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Ms. **NELSON.** I want to bring up one point which is this—this is a subject of research. Exactly how do you communicate this concern, this opportunity——

Ms. **BIGGERT.** Uh-huh.

Ms. **NELSON** [continuing]. To inform someone 15 to 30 seconds ahead of time? What is it that you are going to say? And with information technology becoming widely accessible by anyone, the question becomes, you can't control who gets access to it——

Ms. **BIGGERT.** Uh-huh.

Ms. **NELSON** [continuing]. And what it is that they have access to in many cases. This is really a subject of research and it is difficult to do because it is inherently filled with biases of the way you go about doing it or the response after an earthquake, how fast you get in there, affects the answers that you get from any approach. But it is a real viable subject of research that needs to be addressed.

Ms. **BIGGERT.** Thank you very much. Thank you, Mr. Chairman.

Chairman **SMITH.** The gentleman from Missouri, Mr. Akin.

Mr. **AKIN.** Thank you, Mr. Chairman. I understand there has been some discussion about the quakes on the different coastal regions, but in the Missouri area, we have the New Madrid Fault. And——

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Chairman **SMITH.** I don't think an engineer has asked any questions yet. So——

Mr. **AKIN.** So we got one designated engineer question here. Thank you, Mr. Chairman. I was just curious, first of all, what sort of research has been done relative to New Madrid, if one of you can comment? And then, also, more specifically, in the St. Louis region, how well prepared are we for some type of eventuality in—from the New Madrid fault?

Mr. **FILSON.** We have been investigating the situation in the central United States for about 10 or 15 years. We have a group stationed at Memphis University. We support research at the University of St. Louis and at the University of Memphis and we support the operation of seismographic networks in both areas. We think we know what the level of ground shaking will be if the repeat of the 1811–1812 earthquakes occur, and they have been incorporated in our seismic hazard maps, which are the basis of these model building codes that can be used by local jurisdictions.

As Dr. Nelson pointed out earlier, the infrastructure, the building inventory of many of the eastern cities, is a little bit older and maybe not as seismic-resistant as we find in the western United States.

Ms. **NELSON.** Sure. Certainly, in St. Louis, it is where Washington University is and one of my favorite bridges in the world, the Eads Bridge. There certainly is an awful lot of work that has been done in trying to characterize and understand the seismic risk in major cities. I think St. Louis really brings the focus toward the transportation industry and the system vulnerability for crossing the Mississippi. Personally, I always think they should have built a tunnel because tunnels would generally be better behaved in earthquakes, but that is my bias. I think the research that is going——

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Mr. **AKIN.** That sounds counter-intuitive almost. I mean, I couldn't think——

Ms. **NELSON.** Oh. It is true.

Mr. **AKIN** [continuing]. Of a place I would less like to be in an earthquake than in a tunnel under a river.

Ms. **NELSON.** However, it would be a good decision. But I think the Washington University is a member of the MAE Center, the Mid-America Earthquake Center. And they work very strongly at the University of Illinois to actually address the risks associated with a large event however unlikely it is, where it to occur on the New Madrid Fault system.

And I think the idea of really understanding old building performance, as the structure deteriorates, the likelihood of really significant damage increases under smaller events. So I mean, you reach a point where the investment becomes something that people will think about. But the quantification of that, so you can look at the cost benefits, is something that really needs quite a bit of work, because it also involves a retained risk by the owner of a building or by the state agency that is——

Mr. **AKIN.** I hear you saying that old buildings are——

Ms. **NELSON.** Uh-huh.

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Mr. **AKIN** [continuing]. Going to be just that. I would think even particularly old masonry buildings——

Ms. **NELSON.** Yes.

Mr. **AKIN** [continuing]. Particularly would be the most——

Ms. **NELSON.** Very much.

Mr. **AKIN** [continuing]. Difficult to try and—now, I do know that there are some engineers, in fact, some that I have been in contact with, who are redoing a number of our bridges and some of those structures to make them a little bit more resistant, I gather.

Ms. **NELSON.** You bet. Well, the unreinforced masonry question is significant. And there was quite bit of damage associated with unreinforced masonry in Seattle. So while it was generally a test of the code, some of the aspects of the nonstructural elements, we will be able to learn from Seattle and actually take it to use to Mid-America.

Mr. **AKIN.** Thank you very much.

Mr. **PALMER.** Could I follow up on your question——

Mr. **AKIN.** Certainly.

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Mr. **PALMER** [continuing]. Because this has a relevancy to Representative Johnson's previous question. It has to do with the code requirements. Most of the model codes, now implemented in the 2000 International Building Code, do not deal with foundation design. Foundation design is only mentioned in the code in that special investigations of foundation conditions for liquefaction can be required by local building officials. There are, in fact, no standards beyond that within the code.

I think a significant issued faced in the middle part of the United States, is recognizing that the codes do have to be understood and used by the local building officials to recognize this foundation problem, that is, liquefaction. And that usually maps, such as the one that I showed, provide guidance to these local building officials as to what areas they should really be concentrating on this hazard.

Mr. **AKIN.** Yeah. I—you are using a little technical language on me here, but I think what I hear you saying is the soil conditions are going to vary somewhat, particularly in the case where if we are on a flood plain, that is something that has to be geographically specific and you have to deal with that in the overall plan. Am I paraphrasing correctly or——

Mr. **PALMER.** I think that is correct. And the issue is that there is very little guidance given in the code as to what to do about liquefaction and identifying those areas is one of the educational parts that has to go on to local building officials, as well as local engineers who practice in the region.

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Mr. **AKIN.** Is this—are you referring particularly to certain types of clay soils where if you get a certain amount of shock, it becomes almost a super liquid? Is that what you are getting at?

Mr. **PALMER.** Typically, those are sandy soils.

Mr. **AKIN.** Sandy, not clay.

Mr. **PALMER.** Not clay, but——

Mr. **AKIN.** Okay.

Mr. **PALMER** [continuing]. Sands, usually.

Mr. **AKIN.** Okay.

Mr. **PALMER.** And there are plenty of sandy soils in the flood plain of the Mississippi.

Mr. **AKIN.** Okay. Thank you.

Ms. **NELSON.** And just one follow-up. There is no code that includes lifelines—codes or standards. There is, under development, one that deals with the underground pipelines, for example. But the intimate association of that with the soil, which is inherently variable, has made it difficult to conceive of having a code. But there is code work now underway that may reach the point where there is a standard associated with lifeline engineering.

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Mr. **AKIN.** Thank you very much for answering those questions. Thank you, Mr. Chairman, for letting an engineer in.

Chairman **SMITH.** Thank you, Todd. Dr. Miller, could you maybe describe some of the ways satellite technology are being used or could more effectively be used to monitor seismic activity?

Ms. **MILLER.** I would be happy to.

Chairman **SMITH.** That is not an earthquake alarm. I see somebody looking around.

Ms. **MILLER.** Well, beyond the use of the GPS satellite technology—are you asking specifically——

Chairman **SMITH.** Well, GPS——

Ms. **MILLER.** GPS in particular or——

Chairman **SMITH.** Well, also, any of the——

Ms. **MILLER.** Okay.

Chairman **SMITH.** Our whole satellite effort in the follow-up question, of course, would be NASA's role in looking at post-quake efforts.

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Ms. **MILLER.** Okay. Yes. There are three different elements that come to mind that involve satellite systems. And that would be, of course, the GPS satellites, which were—have been adapted from a use intended to position at a 10-meter accuracy to this very high resolution scientific instrument because of the technology development that NASA has done.

And so, in terms of monitoring after an earthquake, one thing that we would do is look for anomalous signals, that there was strain being released after an earthquake at higher levels than it had been, the background level before an earthquake. We have done this with great success in shallower earthquakes in southern California and in many other places in the world. We will—the jury is out on that category for this particular earthquake.

Another very important satellite system is the proposed InSAR system. We currently have been able to use interferometry from radar, from synthetic aperture radar, to—you can actually difference images taken before and after and earthquake and get a mapped spatial pattern of the deformation that occurs during that earthquake. In the past, this has relied on European and Japanese satellites. We haven't had a U.S. mission that supports this scientific application. And this is a component of Earthscope that would bring NASA very much into the mainstream of what we are trying to do.

It has also been useful, not just from measuring the earthquake-related deformation, but after the earthquake, some of this post-seismic deformation that is time-dependent—we call it transient deformation—we have been able to detect using the InSAR interferometry. And it is a very interesting technique because it gives us a full—you don't have to know where the earthquake was or is going to be before it happens if you have a global data set, and then you can go collect data after the earthquake and immediately start picking up information that is relevant to advancing your understanding of earthquake physics. Those are the two that relate most closely to earthquakes.

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Chairman **SMITH.** Thank you. Representative Baird for a follow-up.

Mr. **BAIRD.** Thank you very much, Mr. Chairman. I am going to open this generally, but I am going to ask Dr. Filson what maybe a somewhat tough question. A good friend of mine used to work for the Volcanic Observatory in—that we have in actually southwest Washington. He shared with me that when he first started working there, there was a tremendously dedicated cadre of scientists who spent probably 70 to 80 hours a week, even though they were paid for 40, because they loved the topic, they loved their work, they appreciated how important it was, they knew it could be lifesaving. But over the last couple of decades, as the sort of antigovernment rhetoric has heated up, as the call for downsizing has led to unpredictability in funding, he had experienced a moral decline among his colleague.

And people report to me in other agencies that it is hard to start a research project, for example, of the sort these folks are involved in, that may expand 10 years knowing that your funding could get cut after 3 before you get the data. Similarly, it is hard to attract top-flight scientists to a profession when they think they are going to get bashed as government employees.

Not trying to put you on the spot, but could you share with us, is this an issue, as we look at uncertain funding, for these critical agencies to provide the background research that help us cope with these situations?

Mr. **FILSON.** Well, it is a difficult question because it involves the personalities of individuals. The Geological Survey did have a reduction in force about 6 years ago, and that obviously was a—damaged morale. But I think these people love their work. They love volcanoes. They love earthquakes. They love trying to understand these natural phenomenon.

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Mr. **BAIRD.** It is a sick job, but somebody has to do it.

Mr. **FILSON.** Yes. And they will spend 60 or 70 hours a week at working. When an earthquake occurred in—near Olympia, we had to keep people from going there because they wanted to get on a plane with all their equipment and we had to wait and get them organized. So I think, at one level, yes, people worry about, you know, will they be able to buy the groceries next year, but, on another level, they are so wrapped up in the scientific challenge of their work. And not only the scientific challenge, but the social challenge of getting the results of the science, having it make a difference, that, I think, in general, we are doing pretty well. Thank you.

Mr. **BAIRD.** I appreciate that. I just—I would just encourage those of who—in elective office, to maybe spend more time honoring and supporting the work and the employees and individuals who do it. It is a fine thing that folks spend 70 or 80 hours because they love the work, but we shouldn't take advantage of them, and certainly we should not disparage them, nor should we starve their research budget when they are doing critical work that helps save us money in the long run.

Chairman, thank you. I am going to have to leave shortly, but I applaud you for hosting this——

Chairman **SMITH.** Two hours. We are going to run it pretty close, Representative Baird. Let me follow up just a little bit on Representative Baird's thought though. Are we doing what we should in terms of encouraging the new generation of scientists and technicians in this area? Should we—as we look at where we go in education and the importance of encouraging these kind of scientific endeavors, are we falling behind in the kind of—in the next generation people that we are developing to do the work that you are doing? Do we have a feel for what is happening in our colleges and universities?

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Ms. **NELSON.** Well, I wish I could speak from more authority. I could speak from experience and recent conversations. Certainly, this issue of attracting people into science, math, and engineering, and actually continuing with the lifelong learning aspects of a growing——

Chairman **SMITH.** Dr. Nelson, could I ask you to do a little research in that effort and——

Ms. **NELSON.** Yes.

Chairman **SMITH** [continuing]. And look quantitatively at the number of people in geology, seismology, geophysics, and maybe other related disciplines, and maybe report back to our Subcommittee in that regard?

Ms. **NELSON.** Certainly.

Chairman **SMITH.** And, Dr. Miller, a comment.

Ms. **MILLER.** We have monitored this to some extent because I come from a program that was very small when I arrived at Central Washington University in 1991, and that has grown significantly in the number of majors. And we have a research program that is ultimately very student-centered and engages students in the kinds of projects that we have been talking about today so that we can infuse that excitement and that knowledge base in the students.

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And I think that there has been a number of projects, like Project Kaleidoscope, which is funded by the National Science Foundation, and many others, that have been very successful at strengthening the paradigm of how we teach science at the higher education level. Geology, itself, is cyclical. It depends a lot on what is happening in the USGS, what is happening in private industry. Our enrollments respond to those issues. But the early '90's were a difficult time. Our program has done very well, though. And so I think that there is a lot of hope out there and there is a lot of good students.

Chairman **SMITH.** Thank you for that response. Representative Biggert, I—you would like a follow-up.

Ms. **BIGGERT.** Thank you. Dr. Miller, you were talking a little bit about going to various sites where there have been earthquakes. And how about internationally? Are we—how significant is the international cooperation in earthquake-related research?

Ms. **MILLER.** There is quite a bit of international cooperation in earthquake-related research and American investigators are often looked to in times of crisis to provide expertise on both the new technologies and what we have learned from these new technologies to areas where there are critical needs. And what comes to mind is Turkey and Taiwan, the Izmit earthquake in Turkey and the Chi-Chi earthquake in Taiwan. And, you know, there are many examples, but I think that is a place we have really been able to play a leadership role.

Ms. **BIGGERT.** So there is not a problem with access to the area or access to data that they might have collected.

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Ms. **MILLER.** Well, there can be sensitivities. In those two cases, the data were jointly collected in Turkey and in Taiwan, it has been a very open situation. The Japanese GPS network has not been as open with sharing their data as the U.S. community has been.

Ms. **BIGGERT.** I had the opportunity—I was down in Colombia after the earthquake there——

Ms. **MILLER.** Uh-huh.

Ms. **BIGGERT** [continuing]. And—on another matter, but we flew over in a helicopter to go look at it and——

Ms. **MILLER.** Yeah.

Ms. **BIGGERT** [continuing]. It was fascinating to see. And then actually went and talked to the people who were living outside of their homes. They didn't want somebody to take over the—where they lived, but they were afraid to go back into their homes. So it was really, you know, very emotional, as far as—for the people that were there. So I guess then do you think that we are doing as much research as other countries or are——

Ms. **MILLER.** Well, I addressed that, to some extent, in my written testimony. I think that in terms of the proposed Earthscope initiative, we are really well-poised to do this. We have invested a tremendous amount, both, you know, the DoD investment and the GPS system itself, for instance, as well as the scientific community, in really exercising a high degree of creativity and resourcefulness in turning these tools to look at issues like the ones we are discussing today.

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And we are poised to implement this on a much grander scale. Japan is already doing it. Taiwan is looking—is planning to do it. And I would hate to see us lose the advantage of what we have invested as a Nation in developing these technologies and the intellectual resources that go along with developing the technologies.

Ms. **BIGGERT.** Thank you. Thank you, Mr. Chairman.

Chairman **SMITH.** Thank you. And I would like to thank the panelists for taking your time and sharing your expertise with us. With your permission, we would like to keep the record open for the submission of additional questions to each of you or all of you. And, additionally, without objection, the record will stay open for any additional comments by members of this Subcommittee. You had a comment, Mr. Baird.

Mr. **BAIRD.** I just want to thank the Chair for convening this meeting and thank all the panelists for their most informative presentation and thank you for your response to this disaster as well. Thank you, Mr. Chairman.

Chairman **SMITH.** And with that, the Subcommittee is adjourned.

[Whereupon, at 3:55 p.m., the Subcommittee was adjourned.]

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APPENDIX 1: Answers to Post-Hearing Questions

POST-HEARING QUESTIONS

POST-HEARING QUESTIONS

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE

SUBCOMMITTEE ON RESEARCH

HEARING ON

Life in the Subduction Zone: The Recent

Nisqually Quake and Federal Efforts

to Reduce Earthquake Hazards

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Post-Hearing Questions Submitted to Dr. John Filson Coordinator of Earthquake Programs, U.S. Geological Survey

Post-hearing questions from Chairman Nick Smith:

1. *What do you see as the most important lessons learned from the Nisqually quake? How will the data collected from this quake help future hazard predictions?*

A**NSWER:** The State of Washington and the City of Seattle had undertaken aggressive programs of earthquake awareness, mitigation, and preparedness. It is difficult to quantify things that did not happen during the earthquake, but it is clear that the mitigation and preparedness efforts paid off in keeping the damages and casualties low According to a post earthquake report published by the Earthquake Engineering Research Institute: "The (seismic) retrofit measures that have been undertaken over the past decade, in both buildings and bridges, undoubtedly reduced the amount of damage and loss of life that would have otherwise occurred." This is an important lesson that should be studied by other States and communities in earthquake prone areas.

The data collected during and after the earthquake will be very valuable in determining how local geologic conditions affect ground shaking and in measuring the effectiveness of various mitigation practices. Twenty new urban seismographs in the Seattle/Tacoma region, installed in 2000, all performed admirably and provide an unprecedented data set of high-fidelity recordings, which can be used by the engineering community to study local site response in this urban area.

2. *How well do we understand the geology of the Puget Sound region? How has our knowledge of the*

geology been improved as a result of data collected from this quake?

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A**NSWER:** The geologic structure of the Puget Sound region is very complex due to its proximity to the convergence zone of the Juan de Fuca and North American plates. The surface geology is complicated by several recent periods of glaciation. To conduct regional assessments of the earthquake hazard, it is important to understand the geologic structure, the location of active faults, earthquake potential, and the large-scale geologic features that may focus seismic waves.

To assess local variations in the earthquake hazard, it is important to understand the surface geology and to determine how these layers amplify or extend the duration of seismic shaking.

We understand the broad framework of the regional geologic structure and the location and characteristics of some of the shallow, active faults that can produce earthquakes. Further studies could determine the exact locations and characteristics of other shallow faults that may be capable of producing damaging earthquakes.

Data from the recent earthquake has helped us understand the effects of surface geology on seismic shaking. The Nisqually earthquake was recorded by more than 90 digital and analog seismometers at distances between 8 and 60 miles from the epicenter. Stations located on soft soils show substantial amplification (i.e., greater ground motion) compared to sites on hard rock. Comparison of soil site recordings of the mainshock and an aftershock indicates nonlinear response at the soft-soil sites, some of which had nearby liquefaction. Nonlinearity means the soil is not responding in a simple manner and is subject to failure (e.g., slumps, liquefaction) or some other type of complex deformation.

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3. *What is our ability to monitor seismic activities in urban settings? Do we have access to the terrain data necessary in order to provide the information that has been developed for the Puget Sound region? Is the urban environment limiting our ability to use traditional techniques to address these questions? Do new research areas or technological approaches need to be developed to address these questions?*

A**NSWER:** Our ability to monitor seismic shaking in urban areas varies and is limited. The USGS installed 80 new instruments were installed in urban areas in FY 2000 and 110 will be installed in FY 2001.

Accurate terrain data has proven useful in the Puget Sound area in locating surface features (scarps) of active faults. Recently a new technique known as light direction and ranging (LIDAR) has become available which employs an airborne laser which can see through the vegetative cover and provide detailed images of surface topography. LIDAR has been used successfully to image the Seattle fault and thereby provide geologists with information on where the fault can be trenched to study past slip and earthquake recurrence.

It is difficult to study geology and conduct geophysical surveys in urban areas due to the development of urban residences, business and manufacturing buildings, and the general infrastructure. Standard geological and geophysical techniques, such as field mapping and seismic reflection surveys using massive shakers and explosions, are impractical to use in urban settings. We are adapting traditional techniques, with some success, for use in the urban areas. One example of our adaptation to the urban environment is the Seismic Hazards Investigations in Puget Sound (SHIPS) project, where we took advantage of the many waterways in Puget Lowland to successfully perform seismic reflection and refraction profiling of the Seattle and Tacoma basins and several known and suspected crustal faults. Another example of our adaptation was the seismic recording of the Kingdome demolition in March 2000 to learn more about the site response on a neighborhood-by-neighborhood basis in Seattle.

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4. *Please describe the Real Time Seismic Warning System and any plans to implement a pilot warning system.*

A**NSWER:** Seismic waves that transmit strong shaking travel about 2 miles per second. The concept of a Real Time Warning System is to determine within a few seconds that a large earthquake has occurred and to immediately transmit a warning of imminent strong ground shaking to populated areas somewhat removed from the earthquake source zone. The basic elements of an early warning system are:

Closely spaced seismic instruments throughout the region where earthquakes are expected,

Rapid communications between these instruments and a data analysis center,

Continuous, automatic analysis of the incoming seismic signals with fast, reliable compute hardware and software capable of determining within a few seconds that a large earthquake has occurred, and

Automatic communication or broadcast capability to issue a warning to areas at some distance from the earthquake source.

As part of Project TriNet in southern California, seismologists at the California Institute of Technology, using data recorded near the earthquake source, are working on the problem of automatically determining within a few seconds that a large earthquake has occurred. Depending on the results of this research, an experimental or pilot system could be in place within two years. Project TriNet is a cooperative between Caltech, the California Division of Mines and Geology, and the USGS to modernize earthquake monitoring and notification in the region. The project has received substantial support from FEMA.

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4a. *What are some of the implication of giving only a 30 second warning in a large urban area? What are some of the other important social and policy ramifications of such a warning system? What kind of research in these areas is being undertaken?*

A**NSWER.** The USGS addressed these issues in a report entitled "A Plan to Implement a Real-time Seismic Hazard Warning System" dated March 27, 1998. This report was required by Public Law 105–47 and was submitted to Congress in the spring of 1998.

As part of Project TriNet, a further study is underway to assess the potential uses of early earthquake warning technologies and how to optimize their effectiveness. Preliminary results from this study are expected within one year.

5. *The USGS produces Seismic Hazard Maps that indicate expected levels of ground shaking over a given period for different regions of the country. How important are these maps in influencing regional building codes? What assumptions go into creating these maps and how are they reviewed prior to release?*

A**NSWER:** The USGS Seismic Hazard Maps are the basis for the seismic designs provisions of the new International Building code (IBC, developed for U.S. use) of the International Code Council. The IBC was published in 2000 and is the first model building code for the entire country. Building codes in the U.S. are, generally speaking, a local responsibility. Development of building codes is an expensive process. Partly because of this, building code adoption in the U.S. has relied on the use of model building codes, of which states or local governments can adopt all or part.

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The Seismic Hazard Maps incorporate most of what we have learned from our research, geological field studies, and earthquake monitoring networks. They are based on the location and earthquake potential of active faults, the location, size and frequency of past earthquakes, the propagation of seismic shaking through the Earth's crust, and other relevant information.

The Seismic Hazard Maps are subject to two levels of review. Regional workshops are held to allow the presentation of new data and information, the evaluation of these results, and the impacts of using them in the revised maps. A national level workshop is held to present a draft of the revised national map and to accept comments, advice, and criticisms. Both workshops draw heavily from the external community, including earthquake researchers, civil engineers, and State and local government representatives.

Post-hearing questions from Ranking Minority Member Eddie Bernice Johnson

1. *Our ultimate goal in seismic monitoring, research and development is to be able to predict with some degree of certainty when a seismic event will occur.*

a. *How do the occurrences of minor earthquakes in a region factor into earthquake prediction in that area?*

b. *How about the presence of slow ground movement, say half an inch per year?*

c. *How well are we able to correlate the events leading up to a seismic event to the actual event?*

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d. *Is this a substantial improvement over our predictive capabilities from 5 or 10 years ago?*

ANSWER: It is true that earthquake prediction is the ultimate goal of earthquake research, just as curing cancer is the ultimate goal of a large body of medical research. Nevertheless, we have a lot to learn about earthquake physics and earthquake occurrence before reliable prediction can be achieved. While we move forward toward the goal of earthquake prediction, we increase our understanding of earthquake causes and effects. This understanding can be used today to reduce the impacts of future earthquakes when and wherever they occur.

Minor earthquakes can generally reduce the state of strain in the crust of the Earth—not enough, however, to avoid future large earthquakes. Some large earthquakes are preceded by foreshocks, but it is difficult to identify a foreshock without the large mainshock having happened. Some research is being done using pattern recognition techniques applied to seismicity distributions in time and space. So far, no unequivocal signs in the patterns of small earthquakes have been found pointing to the time and location of larger earthquakes.

We know that some tectonic plates move relative to each other at rates of up to two inches per year. Much of the relative motion is taken up in bending the rock along the plate boundary; the rock eventually breaks or fails suddenly, causing an earthquake. Obtaining a detailed and comprehensive picture of how the rock is strained throughout a plate boundary region and over an extended time period would provide additional insights into the processes that cause earthquakes.

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To date we have found no reliable earthquake precursor that will allow us to predict the time, place, and magnitude of future earthquakes. This situation is about the same as it was 5 or 10 years ago. During the last ten years we have focused our efforts on understanding and predicting the effects of earthquakes and in providing long-range probabilistic forecasts of earthquake occurrence in seismically active areas. We are thus concentrating our efforts on assessing the seismic hazard and mitigating the effects of earthquakes rather than predicting these phenomena.

2. *What was the status of the mitigation effort in the Olympia/Seattle region prior to the earthquake? What mitigation programs are in place there? How does this compare to other earthquake prone areas, in terms of how disaster proof those regions are and what mitigation programs are in place?*

ANSWER: Local governments in the Seattle region had been advised in recent years of the earthquake hazards and had taken significant steps to mitigate this threat. In fact, the Seattle region may be unique for the effectiveness of the public and private partnerships that have been formed there in recent years to promote earthquake mitigation. The focus of these efforts has been two-fold: 1) mitigating against non-structural damage in public schools, and 2) encouraging home retrofits by homeowners in the Olympia/Seattle area. In our view, these efforts have been very successful in mitigating the earthquake risk. Another important cooperative effort has been the study of the earthquake performance of transportation systems along the I–5 corridor between Tacoma and Seattle. This engineering study has identified the freeway overpasses most at risk during the next big earthquake so that limited public dollars can be targeted towards their retrofit, helping the region recover more rapidly from the next big earthquake in the Puget Sound.

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USGS products actively sought by these local partnerships are maps showing the locations of critical lifelines against a very simple geologic background showing the locations of good versus bad ground. The critical lifelines shown on the map are 150 kilovolt electric lines and substations, major water supply lines, major sewer lines and treatment plants, natural gas and liquid fuel pipelines, interstate and major highways, active rail lines, and airports. These maps highlight areas where stronger shaking and higher levels of damage might be expected during future earthquake and are being used by local governments for earthquake preparedness and mitigation.

3. *How thorough are the current assessments of seismic hazards? What factors contribute to this risk assessment? What factors are unique to urban or inner-city areas? What factors are unique to [sub]urban or extremely secluded areas?*

A**NSWER:** We need to distinguish between earthquake hazard and earthquake risk. Earthquake hazards are the severe ground shaking, ground failures, and other natural phenomena that are caused by an earthquake. Earthquake hazards cannot be lessened through human intervention. Earthquake risk is the potential for casualties and damages to buildings and other structures due to an earthquake. Earthquake risk can be lessened or controlled through human intervention. In general, earthquake risk in urban areas is due to buildings and other structures that have not been constructed or strengthened to withstand the earthquake hazard.

In 1996 the USGS released national seismic hazard assessment maps for the U.S.; these maps are currently being upgraded and a release of the new maps is expected in 2001. These assessment maps incorporate all we know about the location of active geologic faults and the earthquake potential of these faults, historical seismicity, earthquake rates, seismic wave propagation, and attenuation of seismic waves with distance. The challenge is that there is a lot more to be learned about all of these topics. As we continue to monitor earthquakes and undertake geologic field studies, we expect to improve our assessments of the earthquake hazards nationwide.

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A particular area of focus for us going forward is to improve our understanding of the amplification of strong ground motion in sedimentary basins, which is where many of the urban centers in the U.S. are concentrated. The USGS is presently conducting focused studies of the geometry, thickness, and material properties of the sedimentary basins in the San Francisco, Los Angeles, Puget Sound, and Memphis regions in order to learn more about the effects of basin amplification of seismic energy.

In September of 2000, FEMA released the first earthquake risk assessment for the Nation (FEMA #366). This report was based on a characterization of the built environment across the U.S. combined with the USGS seismic hazard assessments. When considered together, the data provide a means of estimating expected annualized dollar loss from earthquakes and how this expected loss is distributed geographically.

4. *There was significantly less damage in this earthquake than the Loma Prieta or Northridge earthquakes. How do building codes in the Washington State compare to those in California? How do they compare to those in other seismically active regions such as the Northeastern U.S.?*

A**NSWER:** Washington and California currently use the same model building code, thus they would have comparable building design standards, differing only according to geographic differences in earthquake hazards.

It is difficult to make a general statement comparing Washington and California building codes to the rest of the country. There is no required national building code; there exists only a national model building code. States can have a required building code based in whole or in part on the national model code. States can allow local modification to the state code.

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The difference in the damage experienced in either the Loma Prieta or Northridge earthquakes versus the Nisqually earthquake is attributable primarily to the depth of the Nisqually event, not to differences in building codes. The Loma Prieta and Northridge events both occurred at relatively shallow depths in the Earth's crust (less that 11 miles) compared to a depth of 30 miles for the Nisqually earthquake. Thus the built environment in the Puget Sound region was at a much greater distance from the seismic source than in California, thereby allowing for greater dissipation of seismic energy and lower overall levels of ground shaking.

5. *What is the process by which research and analysis is translated into building codes? Safety procedures?*

A**NSWER:** The USGS works with FEMA and the Building Seismic Safety Council (BSSC) to translate its Seismic Hazard Maps into Seismic Design Maps for incorporation into the NEHRP Recommended Provisions and, ultimately, into the model building codes for new buildings. These same maps are also incorporated in FEMA documents used in the seismic evaluation and rehabilitation of existing buildings. The scientific Seismic Hazard Maps are developed using broad input and review from the scientific community through regional and national workshops. This allows results of all research to be considered in the maps.

The BSSC was established in 1979 as a Council of the National Institute of Building Sciences. The BSSC deals with the complex regulatory, technical, social, and economic issues involved in developing and promulgating regulatory provisions for earthquake risk mitigation for buildings that are national in scope. The BSSC has a small staff of engineers and other science types; committees of engineering professionals do most of the work.

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The Seismic Design Maps are then considered for incorporation in the NEHRP provisions and similar FEMA guidance documents using consensus procedures. Technical committees review the seismic design maps and endorse or reject proposals for change. Membership on these committees is open and well balanced. Recommendations contained in the NEHRP Provisions are then submitted to the International Code Council for consideration in the revision process of the International Building Code. Provisions from the FEMA rehabilitation documents are submitted for incorporation in nationally recognized building standards.

6. *What are the most common mitigation practices? How do they help secure the structure in the case of an earthquake? How much do they cost, say, for your average homeowner?*

A**NSWER:** Other National Earthquake Hazards Reduction Program (NEHRP) agencies, FEMA, the National Institute of Standards and Technology or the National Science Foundation's Engineering Directorate, are better qualified to address specific questions on mitigation practices and costs. FEMA has funded projects on earthquake resistant rehabilitation and retrofit practices and costs.

The isolation of the base of a building from ground shaking is an effective but expensive solution. Installation of cross (X) bracing in steel structures and shear walls in concrete structures is also common.

Homeowners are advised to bolt the house frame to the foundation and brace studs in the short frame walls that often connect the first floor to the foundation. Securing heavy, non-structural elements, such as water heaters, is very effective and costs little.

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7. *We have come along way in the past twenty plus years. Are there aspects of the original NEHRP program that are now obsolete? Are there other promising areas of research and analysis that are not being funded?*

A**NSWER:** NEHRP requires the cooperation and collaboration of four independent agencies (USGS, NSF, FEMA, and the National Institute of Standards and Technology (NIST)) with four independent lines of funding and authority. The NEHRP agencies work well together, in our view, and have made significant progress, particularly in the area of earthquake hazards assessments and model building code development.

At the request of Congress, the NEHRP agencies recently completed a comprehensive strategic plan, which contains a detailed discussion of priority areas of research and analysis that are not currently being funded.

8. *How closely are our federal agencies, seismological societies, and researchers working with other countries in general—independent of severe seismic events such as those in India and El Salvador?*

A**NSWER:** In general, international exchange of earthquake data, information, and research results is currently working very well. Much of this success can be attributed to the advent of the Internet. When NEHRP began, scientific communications with the Soviet Union and China often took months and had to go through diplomatic channels. Scientific cooperation with Japan and other countries was often extremely formal. Now results and data fly back and forth between countries through e-mail and through the transmittal of documents and images via the Internet.

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9. *In your opinion, what does the cessation of funds dedicated to initial mitigation efforts in places such as Seattle, mean to communities that may not yet be ''disaster resistant''? And I am thinking specifically of the Project Impact program that was killed by the current administration. Please address the hole that is left by the zeroing out of that particular program or similar programs designed to ensure the safety and security of families, businesses and communities by reducing the effects of natural disasters and fostering public and private sector partnerships.*

A**NSWER:** Project Impact is under the jurisdiction of the Federal Emergency Management Agency (FEMA), and it would be more appropriate for them to address questions about that program in particular. Over the past ten years, however, the USGS has significantly increased efforts to cooperate with other Federal, State, and local organizations and the private sector to achieve earthquake mitigation. We have learned that partnerships with community-based groups provide an important means of obtaining feedback from communities, local governments, and grass roots organizations. This dialogue greatly facilitates our ability to perform studies in urban areas involving many jurisdictions. In addition, these programs provide an effective conduit for transmitting USGS research results directly into the community where they can be applied to public outreach and community-based mitigation efforts. Thus, community based programs are effective in fostering dialogue between the research and mitigation communities, in transferring knowledge, and in inspiring communities to take action.

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SUBCOMMITTEE ON RESEARCH

HEARING ON

Life in the Subduction Zone: The Recent

Nisqually Quake and Federal Efforts

to Reduce Earthquake Hazards

Post-Hearing Questions Submitted to Dr. Priscilla P. Nelson, Director, Division of Civil and Mechanical Systems; Directorate for Engineering, National Science Foundation

Questions for the Record from Chairman Nick Smith

Q**UESTION** 1: *What do you see as the most important lessons learned from the Nisqually quake? How will the data collected from this quake help future hazard predictions?*

A**NSWER:** The Nisqually lessons include: (1) economic losses can be significant even if structural damage is generally light, and (2) the, most significant contributors to economic losses from the Nisqually earthquake have been nonstructural damage and interruptions to business and government.

Business interruptions have included traffic congestion (continuing highway closures due to landslides and bridge damage), SeaTac Airport Control Tower damage (continuing flight delays), Boeing Field closure (runway and control tower)(reopened after 16 days), loss of power (widespread impact first 6 hours), and the impacts associated with management of nonstructural damage. While each of these occurrences is documented, it will be difficult to develop a comprehensive documentation of the economic losses. However, data from this earthquake will help with the development of performance-based engineering that can lead to improved management and prediction of economic losses.

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The preponderance of nonstructural and contents damage was not unexpected. Preparedness investments and retrofit of existing buildings mattered, and this underlines the importance of continuing to develop good sources of information for the public, for businesses, and for government and non-government organizations. Despite the known vulnerability of unreinforced masonry buildings and non-ductile reinforced concrete structures, few such structures are being upgraded in regions where earthquakes are less frequent than California. Unless the perception of risk changes in such regions, it is unlikely that most vulnerable structures will be retrofitted. Therefore, improved tools are needed to identify the structures that pose the greatest risk to life safety, so that these structures can be the target of scarce retrofit funds.

Soil and near-surface materials and conditions mattered. The Nisqually earthquake gave testimony to the importance of local soil conditions which had a dramatic influence on the response of surface and subsurface constructed facilities. Data collected following this earthquake can be used to calibrate models of soil amplification and liquefaction, and will contribute to development of performance-based earthquake engineering approaches for structures, subsurface facilities, and lifelines. This new information will help narrow the range of uncertainty in earthquake characteristics, structural response, and site response and will help to refine models of earthquake damage prediction.

The impact of the Nisqually quake on the public will continue to be significant. Following an earthquake, it is important to assess quickly the condition of public and private facilities so that the trust of the public in the reliability of infrastructure service, the functionality of enterprises, and the safety of housing will be recovered. The capture of data on public perceptions of risk and confidence is very important in establishing changing attitudes toward risk and safety following disasters.

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Q**UESTION** 2: *How well do we understand the geology of the Puget Sound region? How has our knowledge of the geology been improved as a result of data collected from this quake?*

A**NSWER:** We have a reasonable understanding of Puget Sound geology on a regional scale. However, for the desired detailed predictions of local damage, much more fine-scale information will be needed to identify specific locations of active faults, and for effective understanding of local site effects on amplification of strong ground motion. Post-earthquake observations have emphasized the importance of site-specific properties and conditions, including both variability in natural geologic materials and in materials at sites that have been modified by construction (including fill areas, locations where soils have been engineered to improve performance, and areas of coastal and port construction where softer soils are more prevalent). It will be important to complete fieldwork needed to interpret subsurface conditions, and to support validation of quantitative models to predict soil behavior.

Q**UESTION** 3: *What is our ability to monitor seismic activities in urban settings? Do we have access to the terrain necessary in order to provide the information that has been developed for the Puget Sound region? Is the urban environment limiting our ability to use traditional techniques to address these questions? Do new research areas or technological approaches need to be developed to address these questions?*

A**NSWER:** The urban environment definitely limits our use of traditional techniques for studying earthquake phenomena in urban environments. Seismic monitoring in urban areas is limited by lack of access, lack of installed equipment, and by cultural noise.

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Lack of access certainly impacts on the monitoring of seismic activity, and new or modified techniques are needed to provide expanded coverage at higher spatial resolution. New seismic sources are needed that have less impact than explosives; new receivers that can be more easily installed; new processing techniques are needed to minimize effects of noise. Research to improve the resolution of tectonic structures and crustal distortion in the region will give us a better understanding of future earthquake and volcanic hazards.

The lack of access to the subsurface is inherent in urban settings, and assumptions of subsurface conditions are necessarily uncertain given the historic intensity of development and construction disturbance and modification of soils at such sites. Research is certainly warranted into remote sensing and acquisition of subsurface information from the surface, and into technologies for nonintrusive and nondestructive testing of the subsurface materials.

Lack of installed equipment will also limit what we can learn from each earthquake event. The number of installed sites in the Puget Sound region is too small to investigate important localization effects, and for moderate quakes such effects are very important to determine the location of vulnerable structures. Modest additions to the existing array of seismic equipment would greatly improve earthquake hazard mitigation, and our ability to monitor seismic activities in urban settings could be increased ten-fold.

There is a missing link in the monitoring process to date. While the deployment of strong motion instruments has increased in Washington State in recent years, realization of the full benefits of that instrumentation requires site characterization studies at each of the strong motion instrument sites so that the ground motion recorded by a particular instrument is interpreted to reflect the geologic conditions that exist beneath and in the vicinity of the instrument. This information is needed for reliable interpretation of data from the Nisqually earthquake, and also for analysis of future earthquakes. Elements of NSF's George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) project will contribute to the collection of the needed information.

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Q**UESTION** 4: *Federal investments in this research area have yielded valuable and practical results, but as always we are limited in the amount of funding we can devote to any one field. How would you characterize the level of funding going into these research areas relative to other fields? Have advances in technology resulted in new opportunities for advancing our understanding of earthquakes and seismic activity? Are we missing those opportunities due to a lack of resources or misplaced priorities? Do you have recommendations on how to restructure our research investments to best exploit new opportunities?*

A**NSWER:** Earthquake risk is little understood as a societal issue and this calls for more intensive understanding of policy approaches to dealing with earthquakes. There is much to be done in terms of responding to the societal need to deal with existing buildings/facilities and earthquake hazards. We owe the public meaningful communications about the needs for retrofit investments, and we need to enable the science and engineering research and professional communities to develop the better understanding of how, what and where to retrofit.

Earthquake casualties (deaths, injuries) and economic losses are caused by the failure and/or poor performance of constructed facilities (buildings, bridges, lifelines, etc.). Reducing casualties and economic losses requires that constructed facilities be designed for improved performance during earthquakes. This requires (a) understanding the ground motion hazard, (b) understanding the manner in which ground motions are modified by local geologic conditions, (c) understanding the performance of structures in response to those modified ground motions, (d) understanding the consequences (physical, social, and economic) of the structural performance, and (e) translating the understanding of structural performance and its consequences into science-based criteria underpinning performance standards for design and construction.

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Clearly, understanding (or even some day, predicting) ground motions does not, in itself, lead to reduced risk. But the amount of funding devoted to research on seismology and ground motions caused by earthquakes has been significantly larger than the funding provided for research on soil and building response, social and behavioral aspects, direct and indirect economic studies, and to develop mitigation strategies. Investments in all areas (a) through (e) is required to develop a balanced throughput from new fundamental knowledge, to new technology, and on to effective implementation.

We may be missing critical opportunities due to a lack of resources. NEHRP investments have seen a steep decline, exceeding 33 percent in constant dollars, since inception of the program in 1977. This has limited the ability of the research and professional communities to act to reduce the. vulnerability of the Nation and the public to loss of life, damage and economic impacts from earthquakes. An expanded experimental research budget would take full advantage of the unique facilities being constructed under the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) project. The NEES project represents a major restructuring of our research investment and will go a long way toward enhancing our understanding of how ground motions are modified by local geologic conditions, and how the performance of structures changes in response to ground motion changes. Research investments in the Geosciences would similarly apply new technical advances to achieve revolutionary improvements in our understanding of earthquake hazards. Additional investments in new seismic instruments in urban areas would enable optimized use of new and existing resources for a degree of collaboration between engineers and seismologists that has not existed before.

Increased investment is also warranted to support technology transfer and implementation, taking the gains in basic knowledge and innovative technologies through problem-focused research and development aimed at removing technical barriers, evaluating advanced technologies, and developing measurement and prediction tools that are needed to underpin performance standards for structures and lifelines. To complete the R&D process, the applied research results need to be implemented through development of usable loss-reduction tools and methods that will improve the practice of seismic risk reduction. Federal investments are needed throughout this process to complete the transfer of fundamental research into valuable and practical results.

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POST-HEARING QUESTIONS

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE

SUBCOMMITTEE ON RESEARCH

HEARING ON

Life in the Subduction Zone: The Recent

Nisqually Quake and Federal Efforts

to Reduce Earthquake Hazards

Post-Hearing Questions Submitted to Dr. Priscilla P. Nelson, Director, Division of Civil and Mechanical Systems; Directorate for Engineering, National Science Foundation

Questions for the Record from Ranking Minority Member Eddie Bernice Johnson

Q**UESTION** 1: *Our ultimate goal in seismic monitoring, research and development is to be able to predict with some degree of certainty when a seismic event will occur. How do the occurrences of minor earthquakes in a region factor into earthquake prediction in that area? How about the presence of slow ground movement, say half an inch per year? How well are we able to correlate the events leading up to a seismic event to the actual event? Is this a substantial improvement over our predictive capabilities from 5 or 10 years ago?*

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A**NSWER:** Prediction is a goal, but it is still elusive. There is valid scientific debate about whether earthquakes will ever be truly predictable on a short-term basis. But without clear demonstration that they are not, we owe it to ourselves and our children to work very hard on this. Prediction on an intermediate to long term basis is being done successfully now through probabilistic hazard analysis. This type of prediction is of more value for engineering purposes because it gives time for retrofit of the built environment.

We are still limited in our ability to establish clear and common events that are identified with direct precursors to large earthquakes. Earthquakes differ from place to place and from one event to another in the same place. Small earthquakes in an area provide the basic understanding of the regional geology and geophysics, as well as understanding of the earthquake process there. Each earthquake is a bit different from each other earthquake, and data from many earthquakes are needed to discern the general patterns. The types of information that we get from small earthquakes include geological structure, earth stresses, and present day deformation and slip.

Even areas with slow ground movement can be subjected to earthquakes of significant size. Measurements of slow ground movement are useful because they provide information on how frequently we can expect to see earthquakes of different sizes in a particular region. If we see movements of half an inch per year, the rate at which energy is being built up on a particular fault can be estimated. That energy can be released suddenly in the form of an earthquake. Deformation is therefore a critical measurement that should be made in all seismically active areas. What measures of slip rates do not tell us, however, is whether the energy will be released in a large number of relatively small earthquakes or in a small number of large earthquakes. Other information, frequently in the form of detailed geologic investigations, is required to help answer that question. The research communities have definitely made substantial improvements compared to 5 or 10 years ago. But the problem is not simple and will take more work to fully understand.

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Efforts at earthquake prediction have not been successful, and the earthquake engineering profession does not rely on advance predictions of earthquakes. What the profession does is attempt to quantify ground motion hazards, i.e., the probabilities of having certain levels of shaking in certain periods of time. These analyses consider, to the extent that they are known, all possible earthquake magnitudes and all possible earthquake locations. These effects are summed, in a manner that accounts for the relative likelihood of each effect, so that the sum includes the contributions of all combinations to ground motion hazards at a particular site.

Q**UESTION** 2: *What was the status of the mitigation effort in the Olympia/Seattle region prior to the earthquake? What mitigation programs are in place there? How does this compare to other earthquake prone areas, in terms of how disaster-proof those regions are and what mitigation programs are in place?*

A**NSWER:** Generally, the Seattle area lags behind California in implementation of mitigation measures, but is ahead of other regions with earthquake risk in the U.S. such as Salt Lake City, Memphis, St. Louis, and Charleston. California, understandably, leads the nation in terms of state investment in seismic safety programs and efforts to advance hazard mitigation. Washington State has an attentive involvement but a much more limited investment in seismic safety programs and advocacy. Relative to the risk, the programs have not been nearly as extensive as have been those in California.

The City of Seattle has been carrying out mitigation of some schools and older buildings over the past 10 years; it has been a Project Impact city since 1997. In general, private and public owners in western Washington are interested in better understanding the risks that they face, but in the public sector, efforts to reduce the risk vary greatly among the jurisdictions. With some exceptions, private owners have invested little in seismic mitigation.

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Regarding lifeline systems, many publicly owned utilities have conducted system vulnerability assessments. In some cases, recommendations from those assessments have been fully implemented, in other cases, only partially implemented. For example, Seattle Public Utilities lip had an aggressive earthquake mitigation program in the early 1990s, but funding over the last few years has been substantially redirected to other capital projects.

NSF-funded research by Dr. Peter May (University of Washington) has addressed the issue of earthquake preparedness and mitigation in the state in comparison to other western states and in particular California. May and his co-workers have found that there is considerable variation among cities and counties in western Washington in earthquake mitigation and preparedness, but that is also the case in California. Some leading jurisdictions have been active in developing retrofit buildings for city facilities, schools, and so on—but many lagging jurisdictions have paid little attention to the issue. So the situation is very mixed, and much more can be done.

Q**UESTION** 3: *How thorough are the current assessments of seismic hazards? What factors contribute to this risk assessment? What factors are unique to urban or innercity areas? What factors are unique to [sub] urban or extremely secluded areas?*

A**NSWER:** Current assessments of seismic hazards are fairly thorough on a regional basis. Risk assessments are based on regional fault studies as well as regional earthquake studies. The 1996 USGS seismic hazards maps represent a national consensus and state-of-the-art assessment at a fairly large scale. However, site specific circumstances can make a huge impact (increase by factors of 2 to 5 or more) on actual ground motions. The primary areas where liquefaction occurred in Seattle were areas where the Duwamish River channel was filled. That information has previously never been documented. There are many suburban areas in the Puget Sound region where there is no liquefaction susceptibility mapping. This is critical to assessing the vulnerability of buried utilities.

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The largest factors contributing to risk and damage in general are the population density and the behavior of constructed facilities, which depends on characteristics of the constructed inventory. Many of these structures were designed under previous codes without seismic consideration, and many have been in use for decades and have deteriorated significantly in use. Factors unique to hazards assessment of urban areas are the large number of people at risk, the intensity of infrastructure system development, difficulty of access, and large variability over small distances in terms of both constructed facility inventory (including time of construction) and subsurface soil conditions. Factors unique to suburban and secluded areas are smaller populations, smaller structures, and generally less information about local conditions. Fewer local hazards assessment studies have been completed in more remote areas. However, from the standpoint of learning about seismic impacts, it is important to enable scientific and engineering access for post-event reconnaissance activities in both urban and remote locations.

For example, the NSF-supported Incorporated Research Institutions for Seismology (IRIS) consortium provides seismographic facilities necessary to monitor earthquakes worldwide, study the tectonic structure of active seismic zones, and provide emergency seismographic response to aftershock zones of major earthquakes. IRIS operates the Global Seismographic Network (GSN) in partnership with the USGS, and data from GSN stations are made available in near-real time over the Internet through the IRIS Data Management Center in Seattle. IRIS also maintains a ready array of portable seismic systems to capture aftershocks, and this array was deployed to the Nisqually earthquake region. A separate dedicated portable array is also used to map the tectonic structure of active seismic regions. With knowledge of the tectonic structure, scientists can better understand the geometry of potential earthquake rupture zones and compute their associated destructive strong motions, especially close to the earthquake source.

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As a second example, NSF supports the Earthquake Engineering Research Institute (EERI), the Earthquake Engineering Research Centers, and faculty at local universities and colleges to conduct post-earthquake investigations. These studies involve quick-response teams of researchers visiting impacted sites to collect perishable information that remains available only up to the time that full-scale community restoration and reconstruction commence.

Congress has authorized funding for the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) for a five-year construction period through FY 2004. This project is the result of a planning process called for in the 1997 National Earthquake Hazards Reduction Program (NEHRP) reauthorization legislation, from which NSF, in collaboration with the other NEHRP partners, developed a comprehensive plan for modernizing and integrating experimental earthquake engineering research facilities in the U.S. The goal of NEES is to provide a national, networked collaboratory of geographically distributed, shared use next generation experimental research equipment sites. The NEES sites will include laboratory facilities and also mobile facilities—such as could be deployed to evaluate damage following an earthquake in the future. The NEES collaboratory, including experimentation sites networked together through the Internet, is on schedule and on budget for completion by the end of FY 2004.

Q**UESTION** 4: *There was significantly less damage in this earthquake than the Loma Prieta or Northridge earthquakes. How do building codes in the Washington State compare to those in California? How do they compare to those in other seismically active regions such as the Northeastern US?*

A**NSWER:** The difference in levels of damage is consistent with the differences in level of shaking. New buildings and bridges generally fared well during the Nisqually earthquake. Structural damage was concentrated in older structures that do not meet current codes and, in any event, the ground motions experienced in the Nisqually earthquake were modest.

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For construction of new buildings, Washington State relies on the same basic building code (Uniform Building Code, 1997 edition) by reference as its "state building code" as does California and several other western states. However, the seismic provisions for those codes are largely framed by engineering experience in California. Force levels are generally lower, but more importantly, seismic detailing requirements are basically the same. In some California cities (Los Angeles, in particular), local officials have added additional requirements of their own. Cities in Washington State have few local seismic provisions.

Bridge design varies more between the states, because the California Department of Transportation has developed its own seismic provisions. East of the Rocky Mountains, the adoption and implementation of seismic design provisions of building codes has been a slower process.

In addition, as is true in many states, the enforcement of the code's seismic provision is a critical issue in how effective the code is in lessening earthquake damage. Enforcement in Washington, as with most states, is conducted at the local level of government. Enforcement is generally good in Washington State and particularly good in some of the larger jurisdictions, but there is variability, particularly as it relates to rehabilitation of older buildings.

Q**UESTION** 5: *What is the process by which research and analysis is translated into building codes? Safety procedures?*

A**NSWER:** In some cases, the translation of research and analysis into building codes is direct. For example, the California Department of Transportation has sponsored the development for its own use of assessment tools, design methodologies and actual guidelines. In general, the translation is less direct. Research sponsored by NSF provides material for those that serve on code committees for a variety of code-development agencies. These agencies usually have a lengthy process that allows owners, producers and engineers to comment on the need and effects of proposed changes. Model building codes are promulgated by private organizations (e.g., the Uniform Building Code by the International Council of Building Officials) through consensus decision making and volunteer committees. The work is completed by civil (including structural and geotechnical) engineers, building officials, and others for whom the influence of research is usually indirect.

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The primary resource document that takes these research results and translates them into language and format usable by the design and construction industry is the NEHRP Recommended Provisions. This document is produced by the FEMA, with support from the Building Seismic Safety Council (BSSC), an arm of the National Institute of Building Sciences (NIBS). The BSSC work includes an extensive multi-year development of relevant guidelines for seismic provisions as they relate to new and more recently, existing buildings. The NEHRP provisions currently form the basis of the seismic provisions of model building codes in the United States.

The two key policy influences on hazard mitigation are the building code and land use requirements. In Washington State codes and land use documents are incorporated into "comprehensive land use planning and critical areas ordinances" as part of the states Growth Management Act of 1991 [that does not apply statewide]. Land use provisions have also only been indirectly influenced through research findings, with lesser attention to them as an important component of hazard mitigation. FEMA has funded a joint project with the American Planning Association to draw attention to these issues.

Q**UESTION** 6: *What are the most common mitigation practices? How do they help secure the structure in the case of an earthquake? How much do they cost, say, for your average homeowner?*

A**NSWER:** Mitigation strategies differ widely according to the building and bridge type.

For owners of existing homes of typical wood construction, the strategies are: establishing a firm attachment of the structure to the foundation walls; adding shear walls to handle the lateral loads that predominate, particularly at the ground level; and attaching appliances, bookshelves and other non-structural elements to the structure. A typical home retrofit might cost in the range of $2,000 to $15,000.

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For new home construction, the most common mitigation practice is to follow the seismic design procedures in the building codes that include securing the structure. For the average new homeowner, including the proper lateral load-carrying capacity in the design and construction of the home might be on the order of 0.5% of the cost of the home.

Q**UESTION** 7: *We have come a long way in the past twenty-plus years. Are there aspects of the original NEHRP program that are now obsolete? Are there other promising areas of research and analysis that are not being funded?*

A**NSWER:** Perhaps the most significant change in the original NEHRP program has been the focus away from prediction and toward increased emphasis on mitigation. Earthquake casualties (deaths, injuries) and economic losses are caused by the failure and/or poor performance of constructed facilities (buildings, bridges, lifelines, etc.). Reducing casualties and economic losses requires that structures be designed for improved performance during earthquakes. This requires an understanding of the source and propagation of earthquake ground motions, and of how ground motions are modified by local geologic conditions. Then it is necessary to understand the performance of structures in response to those modified ground motions, and to understand the consequences (physical, social, and economic) of the structural performance. Resources need to be invested in all these areas of study, and such a thorough knowledge of the response of constructed facilities comprises the backbone of the developing approach of "performance-based earthquake engineering," which is considered to be the future of earthquake engineering.

Currently, the biggest demand is for attention to the need to mitigate against damage to our extremely large inventory of existing buildings and lifelines. To increase public safety and minimize economic losses in future earthquakes, we as a nation will need to selectively upgrade or retrofit older construction. While ultimately the facility owner or user will have to pay for such upgrades, there is an urgent need for governments to increase public awareness of the problem, expand guidelines and standards development efforts; and increase both fundamental and problem-focused research and development on seismic retrofit technologies.

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Performance-based engineering needs to be developed not only to reduce economic losses, but also, to rationally guide investments to reduce loss of life. Current U.S. building codes and standards are intended to address life safety and are based on decades of engineering research and development as well as experience. Unfortunately, these codes and standards are not appropriate if the facility owner or user desires to achieve a higher level of performance—such as immediate occupancy or full operational capacity. To make this possible, the earthquake community has strongly expressed the need for problem-focused research and development to support a new generation of performance-based building codes and standards. Such codes and standards, which would require more intensive and focused engineering research on modeling and analysis of the dynamic behavior and fragility of structures, would provide engineers with the capability to design structures and lifeline systems with predictable and reliable performance in earthquakes.

Failures of infrastructure lifelines during earthquakes can cause post-earthquake fires, hinder emergency and rescue operations, delay the recovery and reconstruction process, and cause adverse environmental impact, in addition to loss of life and economic losses. Although there are nationally accepted codes and standards for buildings and highways, the suite of available codes and standards are less developed for earthquake-resistant design of utility lifelines and other transportation systems. The earthquake community has recognized the need for problem-focused research and development to support the ongoing development and refinement of such standards.

Next-generation technologies promise breakthrough improvements in safety and performance as well as reductions in economic losses and cost-of-repair in major earthquakes. Such technologies include base isolation, energy dissipation, structural control, smart materials, and innovative structural connections and systems. One of the ultimate engineering challenges is the design and construction of intelligent structures that function adaptively, and that are instrumented for safety protection with real-time health condition-monitoring systems. This will require development of enabling technologies in distributed smart sensors, powerful actuators at small scales, and state-of-the-art Information Technology (IT) software systems for data processing and damage identification. It is widely recognized that we must strengthen our support for long-term research and development directed at next-generation technologies for both retrofit and new construction applications.

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The NEHRP program has been under continuous evolution and review since its establishment by Congress in 1977. NEHRP's contributions and leadership since 1977 form the basis for the Nation's building codes and standards and construction practices in earthquake prone regions. NEHRP has partnered with other federal, state, and private sector efforts to encourage community-based mitigation activities in Seattle and elsewhere. More recently, the NEHRP agencies have completed an extensive period of strategic planning that involved stakeholder input throughout the process. This document lays out a plan for research and technology activities that are important to reduce the vulnerability of the Nation to future earthquakes.

Q**UESTION** 8: *How closely are our federal agencies, seismological societies, and researchers working with other countries in general—independent of severe seismic events such as those in India and El Salvador?*

A**NSWER:** Earthquakes are a global hazard, and the U.S. federal agencies, professional societies, and the academic community find collaborative research and the sharing of information essential in meeting this challenge. Similar to the other NEHRP agencies, NSF has interacted most closely with countries that have significant seismological risk, so that NSF has a long history of research cooperation with countries such as China, India, Italy, Japan, Mexico, Taiwan and Turkey—countries that face similar seismic risks. It is appreciated that, while research may be usefully transferred directly between countries, code development is different. Codes are usually developed by each country, and reflect the different technical, social and economic conditions of that country.

NSF has sponsored cooperative research in seismology and earthquake engineering—these involve NSF funding for U.S. researchers and funding from NSF-type agencies in the foreign countries for their researchers, and allow the researchers to work closely on topics that are of interest to both countries. NSF also co-supports international workshops at which leading experts from different countries can gather to discuss cutting edge research and practical implementation issues. These activities are extremely important and are beneficial to all countries. The increased communication they have engendered has allowed U.S. researchers to gain access to data from earthquakes around the world, and to use that data to help reduce losses from future earthquakes in the U.S.

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As an example of research collaboration, the US/Japan Common Agenda for Cooperation in Global Perspective was established in 1993 to facilitate cooperation in addressing pressing global problems, including natural hazards. In 1998, a new earthquake research program was initiated jointly by NSF and the Japanese Ministry of Education, Culture and Sports, called the US/Japan Cooperative Research in Urban Earthquake Disaster Mitigation. Under this five-year program, subject areas have included studies of the effects of near-field ground motions, earthquake-resistant design for lifelines and foundations, performance-based design, perceptions of earthquake impacts and loss-reduction preferences of citizens, disaster mitigation for urban transportation systems, and advanced technologies for hazard reduction. These projects involve significant interaction between U.S. and Japanese researchers and are enabling researchers from both countries to accomplish goals that they could not accomplish separately. Also, FEMA has conducted a number of High-Level Forums with the Japanese that have addressed the issues of risk assessment and loss prevention measures, tsunami hazard and risk reduction, technology transfer, and lessons from large earthquakes around the world.

As another example, following the earthquakes in Turkey and Taiwan in 1999, NSF established a research program to support exploratory research that would lead to collaborations between U.S. researchers and their counterparts in Turkey and Taiwan. Many of these collaborations were established well before the destructive earthquakes. NSF wilt work with counterpart agencies in Turkey and Taiwan to establish a research program similar in operation to that developed for the collaborations with Japan. In a similar fashion, NSF will be open to proposals for collaborative research between U.S. and international colleagues following the Nisqually quake.

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Q**UESTION** 9: *In your opinion, what does the cessation of funds dedicated to initial mitigation efforts in places such as Seattle, mean to communities that may not yet be ''disaster resistant''? And I am thinking of specifically of the Project Impact program that was killed by the current administration. Please address the hole that is left by the zeroing out of that particular program or similar programs designed to ensure the safety and security of families, businesses and communities by reducing the effects of natural disasters and fostering public and private sector partnerships.*

A**NSWER:** Project Impact has been successful in presenting the public with the opportunity to learn about earthquake risk, and in coordinating the efforts of disaster-response managers, in some cases leading to substantial investments by partner agencies in local mapping projects. Perhaps the biggest impact has been the partnerships established between organizations, and face to face meetings that brought diverse sectors together to discuss about the earthquake risk and its impact on the local jurisdiction. As such, Project Impact has demonstrated its effectiveness in mobilizing attention and increasing action, as well as in providing direct seed funding for action.

POST-HEARING QUESTIONS

U.S. HOUSE OF REPRESENTATIVES

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HEARING ON

Life in the Subduction Zone: The Recent

Nisqually Quake and Federal Efforts

to Reduce Earthquake Hazards

Post-Hearing Questions Submitted to Dr. Stephen Palmer, Washington State Department of Natural Resources, Geology and Earth Resources Division

Post-Hearing Questions Submitted by Chairman Nick Smith

1. *What do you see as the most important lessons learned from the Nisqually quake? How will the data collected from this quake help future hazard predictions?*

From the perspective of my own work on producing liquefaction hazard maps to be used in mitigation and emergency response activities, the Nisqually earthquake was an unqualified demonstration of the ability to accurately delineate areas that are subject to liquefaction ground failures. Regardless of statements made during the hearing, there were no areas where liquefaction occurred where a significant hazard had not been shown on pre-existing mapping. As NEHRP has provided most of the funding used in producing these liquefaction hazard maps, much of the credit for this success is due this program.

Another critical lesson learned from the Nisqually earthquake were that even an event that causes only moderate levels of ground shaking can result in severe non-structural damage (e.g., tipped over computers and file cabinets, broken water pipes, falling ceiling tiles, damaged sales inventory, etc.). This damage then caused significant economic losses to businesses.

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Because the Nisqually earthquake was nearly a repeat of the 1949 Olympia event, the comparison of damage from these two quakes is particularly informative. The damage to unreinforced masonry buildings during these two events was strikingly similar; in fact, so similar that it is possible to compare photographs of the same buildings damaged during these two earthquakes. Liquefaction ground failures that occurred in the 1965 Seattle-Tacoma earthquake (e.g., Deschutes Parkway in Olympia), reoccurred during the Nisqually quake. The lesson learned here is that there has been little focus on retrofitting known past problems, and apparently all of the engineering efforts to mitigate future damage are directed towards new construction.

The most valuable data set presented at this time is the ground shaking measurements made by the Pacific Northwest Seismographic Network (PNSN) and the U.S. Geological Survey Strong Motion Program. Over 60 strong motion measurements were obtained from the Nisqually earthquake; only 2 such measurements were made during the 1949 earthquake, and 3 during the 1965 event. These new data will result in significant insights for predicting ground shaking during future earthquakes.

2. *How well do we understand the geology of the Puget Sound region? How has our knowledge of the geology improved as a result of the data collected from this quake?*

Much remains to be learned about the geology of the Puget Sound region and its effect on earthquake effects, particularly with regard to amplified ground shaking. Although geological mapping of surface exposures is readily available in most areas, there are only a few areas (Seattle, Olympia) where the mapping includes data on the distribution of the geological units at depth. This "third dimension" of geological mapping is crucial to understanding amplification of ground shaking in the shallow crust and unconsolidated soil layer. The Nisqually earthquake will provide some understanding of the effect of this "third dimension" on the ground shaking at the roughly 60 measurement sites. However, a detailed geologic model will be needed to extrapolate beyond these measured sites and to evaluate adverse site conditions throughout the region.

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3. *What is our ability to monitor seismic activities in urban settings? Do we have access to the terrain necessary in order to provide the information that has been developed for the Puget Sound region? Is the urban environment limiting our ability to use traditional techniques to address these questions? Do new research area or technological approaches need to be developed to address these questions?*

The ability to measure ground shaking in the Puget Sound regions is limited only by a lack of resources and funding, rather than by inadequacies in the technology. The full implementation of the Advanced National Seismic System (ANSS), which is part of NEHRP, will provide the coverage necessary to go beyond our current limitations in understanding earthquake ground motions both in the Puget Sound region, and nationwide. Implementation of Global Positioning Satellite technologies for measuring crustal strain *has* provided crucial information in assessing strain accumulation on the Cascadia Subduction zone. Expansion of the spatial distribution of permanent GPS sites *may* provide valuable information for assessing the activity of crustal faults, such as the Seattle fault; however, the practical results of this research are as yet unproven.

4. *How does our understanding of liquefaction and other causes of ground failure inform building codes nationwide? Do we incorporate enough of what we know about earthquake hazards into our model building codes?*

Until the issuance of the 1997 Uniform Building Code, there was no consideration of liquefaction conditions in the design of new buildings. Beginning with the 1997 UBC, a local building official has the discretion to require a geotechnical investigation and report if liquefaction is considered a possible factor in foundation design. However, this requirement is discretionary, not mandatory. Furthermore, neither existing nor model building codes provide minimum standards for such a geotechnical investigation and report. In the Puget Sound region, this lack of standards results in a two-fold problem, assuming that the local building official even bothers to require such an investigation. First, the investigation and analysis performed by the foundation engineer may fail to adequately characterize the site or properly perform the engineering analysis. Second, the choice of earthquake parameters, namely magnitude and level of ground shaking, may not be consistent with those used by the structural engineer. In short, the current state of foundation design standards incorporated by either the existing or model building codes is inadequate to address this hazard.

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5. *The USGS produces Seismic Hazard Maps that indicate expected levels of ground shaking over a given period for different regions of the country. How important are these maps in influencing regional building codes? What assumptions go into creating these maps and how are they reviewed prior to release?*

The Seismic Hazard Maps produced by the USGS in 1996 have been incorporated as the design ground motion maps in the 2000 International Building Code. The 2000 IBC will be used in many jurisdictions throughout the United States as the basic structural design code. Consequently, these USGS maps are critically important in their influence on regional building codes. In Washington State, implementation of the 2000 IBC will result in a significant increase in the design ground motions in the Seattle area. For more than 20 years Washington building codes have used a value of 0.30 g (g being the acceleration of gravity) for the design ground motion. The 2000 IBC will require buildings in the Seattle area to use the equivalent of 0.45 g as the design ground motion, mainly due to the contribution of the Seattle Fault to the USGS ground motion maps.

The USGS uses an entirely internal review process in generating these maps, and only provides for external input through sporadic workshops held in the various regions of the country. As an example, the slip rate used by the USGS to model the Seattle fault in the 1996 Seismic Hazard Map was not published in an external, peer-reviewed publication until 1999. For a number of years the justification for the use of this slip rate was unclear, and even at this time this quoted value has a large uncertainty. At the last Pacific Northwest workshop held in April, 2000, the USGS agreed to form a number of working committees that would include both USGS and outside investigators to review the input parameters for the next version of these seismic hazard maps. To date, there has been no action by the USGS on forming these committees. Bluntly, the production of the USGS Seismic Hazard Maps is not a process open to those outside of that agency.

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POST-HEARING QUESTIONS

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE

SUBCOMMITTEE ON RESEARCH

HEARING ON

Life in the Subduction Zone: The Recent

Nisqually Quake and Federal Efforts

to Reduce Earthquake Hazards

Post-Hearing Questions Submitted to Dr. Stephen Palmer, Washington State Department of Natural Resources, Geology and Earth Resources Division

Post-Hearing Questions Submitted by Ranking Minority Member Eddie Bernice Johnson

1. *Our ultimate goal in seismic monitoring, research, and development is to predict with some degree of certainty when a seismic event will occur.*

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a. *How do the occurrences of minor earthquakes in a region factor into earthquake prediction in that area? How about the presence of slow ground movement, say, half an inch a year?*

b. *How well are we able to correlate the events leading up to a seismic event to the actual event?*

c. *Is this a substantial improvement over our predictive capabilities from 5 or 10 years ago?*

Earthquake prediction is the "Holy Grail" of hazard mitigation, and is likely to be as elusive in its finding. Minor earthquakes have provided little or no information useful for short-term prediction of earthquakes. In the Puget Sound region there are hundreds of small earthquakes every year, but there is no indication that the monitoring of these events could have led to a short-term prediction of the Nisqually event. The most potentially useful area of new research into earthquake prediction is the application of Global Positioning Satellite and other spacebased technologies in the measurement of crustal movement and strain. The word "potential" is key, as there is no certainty that application of these techniques will be more useful in short-term prediction of earthquakes than any of their failed predecessors.

I must express my concern over any reliance on "new" technology that claims it may provide short-term prediction of earthquakes. The seismological community has followed this path a number of times in the last 40 years, and in each instance has found itself at a dead-end. If the primary goal of NEHRP is to reduce earthquake losses, then there are many actions which can be taken that rely on proven engineering and scientific approaches, rather than on speculative "new" technologies. A short list of engineering studies that would greatly mitigate future earthquake damage include improved approaches to identifying and retrofitting sub-standard buildings, and development of building codes that include standards for mitigation of adverse foundation conditions (such as liquefaction). Scientific investigations that characterize the hazard from earthquake sources, such as newly discovered faults, and identify and map areas subject to earthquake-induced ground failures or amplified ground shaking, will have a real short-term payoff in reducing earthquake losses. These actions do not rely on "breakthrough" technologies, but do require the funding support provided through NEHRP.

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2. *What was the status of mitigation efforts in the Olympia/Settle region prior to the earthquake? What mitigation programs are in place there? How does this compare to other earthquake prone areas, in terms of how disaster proof those regions are and what mitigation programs are in place?*

A number of regional hazard mitigation organizations have been formed in the last few years. The first of these is the Cascadia Region Earthquake Workgroup (CREW), a not-for-profit corporation of private and public representatives working together to improve the ability of Cascadia Region communities to reduce the effects of earthquake events. CREW has been very active in promoting pre-earthquake preparedness, especially for private businesses, and is presently conducting a region-wide estimate of losses resulting from a magnitude 9.0 Cascadia subduction zone earthquake. Seattle Project Impact is a public-private partnership whose overall goal is to make the community more resistant to the damaging effects of disasters. The Project encourages people to take action before a disaster occurs through initiatives promoting safer homes, schools, businesses, and better earthquake and landslide hazard mapping. Initial funding for Seattle Project

Impact was through a grant from the Federal Emergency Management Agency (FEMA) to the City of Seattle. The Project Impact program has been expanded to include King, Pierce, Kitsap, and Clark Counties, and now includes nearly all of the urban population centers in western Washington.

I have very little knowledge of the state of earthquake preparedness in other parts of the Nation, but I suspect that there are few states where organizations such as CREW or community involvement in Project Impact activities exceeds that of Washington. However, earthquake preparedness and hazard mitigation are long-term efforts, and continuation of these partnerships is critical to the success of earthquake hazard mitigation efforts in the Pacific Northwest. Support from the Federal government, through such innovative programs as Project Impact, is crucial in continuing these community efforts.

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3. *How thorough are the current assessments of seismic hazards? What factors contribute to this risk assessment? What factors are unique to urban or inner-city areas? What factors are unique to urban or extremely secluded areas?*

Again, my knowledge of the state of current seismic hazard assessments is limited to the Pacific Northwest. In the past decade, our understanding of earthquake sources in this part of the Nation has undergone dramatic changes. In the mid-1980's, the hazard was considered to be dominated by deep earthquakes, such as the 1949 Olympia or 2001 Nisqually earthquakes. In the 1990's geologic research has demonstrated that great (magnitude 9) earthquakes occur frequently (every 500 years on average) on the Cascadia subduction zone, and that there are major active crustal faults, such as the Seattle fault, that could severely impact urban centers in the Pacific Northwest. The hazard posed by great earthquakes on the Cascadia subduction zone is reasonably well understood. However, our knowledge of the hazard posed by crustal faults is very limited. First, few of the potential fault structures in Washington have had sufficient study to determine if they are capable of producing earthquakes (Are they active?). Second, for the few active faults that have been identified (e.g., the Seattle and South Whidbey Island faults), the characteristics of the hazard (size and recurrence time of damaging earthquakes) are poorly understood.

Identification and mapping of areas susceptible to earthquake-induced ground failures, such as liquefaction or landsliding, is limited. A series of liquefaction hazard maps, at a scale of 1 inch equals 2000 feet, has been completed along the urban corridor from Seattle to Olympia. Much of the funding to produce this series of maps has been provided through the USGS-NEHRP external grant program. No mapping of earthquake-induced landslide hazards has been completed, and there is only a pilot project currently underway in the city of Seattle. Also, there are no maps showing areas subject to amplified ground shaking, even in the form of a NEHRP soil-type map. The NEHRP soil-type is required to determine design ground motions under current building codes, but this determination is currently made by the project engineer rather than use of a standard reference. Although some assessments of ground failure hazards are done, there is much work left to do.

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4. *There was significantly less damage in this earthquake than the Loma Prieta or Northridge earthquakes. How do building codes in Washington State compare to those in California? How do they compare to those in other seismically active regions such as the Northeastern US?*

Both California and Washington have adopted the Uniform Building Code as the minimum standard statewide for several decades. The difference is that the design ground motions used in the seismically active areas of California are somewhat larger than those used in Washington, mainly because of the perceived higher likelihood strong earthquakes in the coastal area of California. I cannot respond to the issue of building codes in most other parts of the United States.

5. *What is the process by which research and analysis is translated into building codes? Safety procedures?*

In general, NEHRP has developed model building codes every three years or so, and portions of these model codes are incorporated into the Uniform Building Code. Improvements in the NEHRP model codes are based on the results of research and analysis performed from funding by NEHRP as well as other public and private sources.

6. *What are the most common mitigation practices? How do they help secure the structure in case of an earthquake? How much do they cost, say, for your average homeowner?*

Typically residential home retrofit focuses on securing the structural framing to the foundation, strengthening of cripple (half-height) walls, tying brick or stone facAE9ade to the wall sheathing, and insuring that masonry fireplaces and chimneys are in good repair. The most costly damage that can occur to a standard wood-frame house during an earthquake is if the structure slides off of the foundation. This type of failure can result in the total loss of the house, and is usually easy to prevent by bolting or strapping the structural framing to the foundation. A complete retrofit of a residential house usually will cost between $2000 to $10,000, depending on the size of the house and the specifics of the work.

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7. *We have come a long way in the past twenty plus years. Are there aspects of the original NEHRP program that are now obsolete? Are there other promising areas of research and analysis that are not being funded?*

My relevant experience with NEHRP has been with the external funding program administered by the USGS. This program has provided most of the support for my work in mapping liquefaction hazards in the Puget Sound region. This program is currently authorized at a funding level of eight million dollars, the same authorization level as provided in 1978. The current appropriation for the external program is six million dollars. In the mid-1990's appropriation for the external program was zeroed out, so that the savings could be passed along to the USGS internal NEHRP program. The external program funding was restored primarily by the actions of a Senator from Washington State, but the appropriation was set to its current low level.

I believe that no other part of NEHRP has seen decreased funding since its original passage in 1978. However, this external program is the only avenue for State geologic surveys or nonacademic organizations to compete for NEHRP funding. Its my opinion that some very valuable work is performed through the external funding grants. However, participation in this program is declining, mainly as a result of the declining appropriations. Simply put, external grant proposals cannot not be funded at levels adequate to perform the work, so there is little incentive to submit proposals to this program.

8. *How closely are our federal agencies, seismological societies, and researchers working with other countries in general—independent of severe seismic events such as those in India and El Salvador?*

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I have little to no contact with researchers outside of the United States, and no real avenue to make those connections. A State geologic survey can in no way justify expenditures of stateprovided funding to develop international contacts and exchange mutually beneficial data and knowledge. This could be done through the auspices of the external program discussed in the previous question, except that funding support for this program is clearly inadequate to even support domestic projects.

9. *In your opinion, what does the cessation of funds dedicated to the initial mitigation efforts in places such as Seattle, mean to communities that may no yet be "disaster resistant"? And I am thinking specifically of the Project Impact program that was killed by the current administration. Please address the hole that is left by the zeroing out of that particular program or similar programs designed to ensure the safety and security of families, businesses and communities by reducing the effects of natural disasters and fostering public and private sector partnerships.*

In answering Question 2 submitted by the Congresswoman Johnson, I discussed the two major mitigation programs in Washington State that have received FEMA funding. At this time support for these programs is partially provided by local communities and businesses, and at some point in the future Federal support for these programs may become unnecessary. However, there is little likelihood that these programs would have become established without the initial financial support of FEMA. The most recent Project Impact community in Washington state is Clark County, the fastest growing county in the state during the 1990's. This is a county clearly as risk to both earthquake and flood hazards. If funding for Project Impact is terminated, I believe that it is very unlikely that a similar mitigations program could be organized. Federal funding for Project Impact begins a process which can gather momentum, and ideally will reach a point where community and private sector participation will replace the need for Federal support.

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March 21, 2001 Hearing on the Nisqually Earthquake

A series of post-hearing questions were sent to the National Science Foundation from the March 21, 2001 Nisqually (Seattle) earthquake hearing. Due to the nature of questions 2, 3, 4, 5, 6, 7, and 9 from Ranking Minority Member Eddie Bernice Johnson, they were referred to FEMA for response. Among its other responsibilities, FEMA is also the lead agency for the National Earthquake Hazards Reduction Program. FEMA's responses are below.

2) *What was the status of the mitigation effort in the Olympia/Seattle region prior to the earthquake? What mitigation programs are in place there? How does this compare to other earthquake prone areas, in terms of how disaster proof those regions are and what mitigation programs are in place?*

While California may be the most advanced state in the implementation of mitigation measures, Washington is relatively proactive compared to other high-risk areas. With respect to codes, the entire State of Washington mandates the use of the 1997 version of the Uniform Building Codes, which includes earthquake mitigation provisions, this is discussed in more detail in the response to question number four.

In terms of facilitating mitigation, FEMA has been very active in the State of Washington through both the Hazard Mitigation Grant Program (HMGP) and Project Impact.

Through the HMGP, FEMA and the State of Washington have partnered together to implement seismic retrofit projects to reduce the future vulnerability of communities to damages and losses in the aftermath of an earthquake. Through this partnership, FEMA has approved in excess of $2.3 million in HMGP funds for six projects in Washington State between 1994 and 1999. Examples of approved projects include two fire station seismic retrofits, power line conversions, bridge and flood control structure seismic retrofits, and a water storage seismic retrofit.

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The City of Mercer Island was one of the communities to benefit from the availability of HMGP funds. The city received an HMGP grant to retrofit a water storage facility to withstand a moderate to major earthquake. The facility's reservoirs and pump station, which pressurizes all the water through a system of pipes that then delivers it to the upper end of the island, were structurally retrofitted, and non-structural restraints were installed to brace the pump station's automatic generator and other large pieces of equipment. The project was completed in March 2000. Those located close to the reservoirs during the earthquake state that the water in the reservoirs "sloshed for an hour." The water tanks "rode" through the earthquake with minimal to no damage and performed the way the retrofit was designed. Power went out throughout Mercer Island, but the automatic generator came on line and maintained the function of the pumps. Subsequent engineering inspection has determined that there is no threat of collapse of the facility. The timely mitigation project eliminated danger to the homes and structures as well as protecting the water supply. Minimally, the project saved over $9 million in home replacement costs.

Within this region of Washington there are three Project Impact efforts targeted towards reducing the region's vulnerability to earthquakes: the City of Seattle, King and Pierce Counties (a joint county effort), and Kitsap County.

The City of Seattle has the most established disaster resistant effort. The city chose to focus on rehabilitating residential structures and performing non-structural retrofits of city schools and used grant funds to develop ongoing mitigation programs to accomplish each goal.

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The residential structure rehabilitation was chosen based on recent findings that indicate that older, wood-frame residential buildings are subject to failure during ground shaking. This is particularly true for structures built on cripple walls. There are approximately 125,000 residential structures in Seattle that fall into this category. To address this potential problem in a comprehensive manner, the city established the Seattle Project Impact Home Retrofit Program. The program was launched in 1998. To date, the city has distributed 15,000 Home Retrofit application packages and trained 260 contractors and 1600 homeowners. As a result, 300 homes have been retrofitted, and eight surrounding jurisdictions have joined the program.

The City of Seattle has been working on reducing the earthquake risk to their schools for several years and has funded $50 million dollars towards that effort. However, the project did not include non-structural hazards such as overhead water tanks, file cabinets and bookshelves. These nonstructural hazards pose a significant threat to life and continuity in community services and result in economic losses. Thus, city chose to establish an ongoing program that trains maintenance personnel to perform the more complex non-structural retrofits and student volunteers to perform the simpler tasks.

King and Pierce Counties have focused on ensuring, to the extent possible, the availability of major transportation routes by creating hardened land routes and viable modes of transportation following a catastrophic earthquake, identifying priority routes, prioritizing bridge retrofit projects, and formulating plans for controlling traffic flow. The joint county partnership is also working towards increasing the survivability of small businesses and motivating computer users to secure their equipment with earthquake mitigation devices. In addition, King County residents passed a levy in September 2000 that provides for over $250 million to complete seismic retrofits and upgrades to critical facilities. Both counties are also participating in the Seattle Home Retrofit program.

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Kitsap County joined the initiative in 2000. The County began its Project Impact effort by implementing a critical areas ordinance that prohibits development in hazardous or geologically sensitive areas.

3) *How thorough are the current assessments of seismic hazards? What factors contribute to this risk assessment? What factors are unique to urban or inner-city areas? What factors are unique to [sub]urban or extremely secluded areas?*

Probabilistic seismic hazard assessment is a key contribution by the USGS to the NEHRP strategic plan. These assessments reflect the current state of knowledge about the location and frequency of earthquake source zones, as well as the attenuation of strong ground motion with distance. Local programs in the Seattle area have focused on identifying the role soils play in amplifying these ground motions and in collateral hazards such as landslides and liquefaction.

FEMA combines earthquake hazards data from the USGS with state-of-the-art engineering models in our earthquake loss-estimation methodology Hazards U.S. (HAZUS) to provide earthquake risk assessments in terms that are relevant to the policy choices faced by local officials. Seismic risk estimates include economic losses from damage to the general building stock (both structural and nonstructural), as well as contents, inventory, and income related losses. Casualties and shelter needs following significant earthquakes are also estimated in addition to estimates of the loss of functionality of critical facilities such as hospitals and schools. We are investigating the capabilities to address differential social vulnerability to earthquake risk in urban environments as well.

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A recent FEMA publication FEMA 366—*"HAZUS99 Estimated Annualized Earthquake Losses for the United States"* ranked the state of Washington second in the nation in terms of projected annual losses to the general building stock from earthquakes. Metropolitan areas account for the majority of projected losses from earthquakes due to high concentrations of population and building inventory. The cities of Seattle and Tacoma, Washington rank 7th and 22nd in the nation, respectively, in terms of estimated average annual earthquake losses.

4) *There was significantly less damage in this earthquake than the Loma Prieta or Northridge earthquakes. How do building codes in the Washington State compare to those in California? How do they compare to those in other seismically active regions such as the Northeastern US?*

It is important to understand that the main reason there was so little damage in the Nisqually earthquake is the extreme depth of this earthquake. Given that caveat, however, the building code used in Seattle and the State of Washington is the 1997 Uniform Building Code (UBC). This is the same code that forms the basis of the code in California, though this code classifies most of Washington as a lower hazard area than California, i.e., buildings are generally designed to stricter standards in California.

Compared to building codes used in other seismically active regions of the United States, the 1997 UBC is a good standard that provides adequate protection. For example, while the jurisdictions in the Wasatch Front (Salt Lake City, UT area) also use the 1997 UBC, other high-risk areas of the US, such as New Madrid and Charleston, use codes that are neither up to date nor technically adequate. The State of Washington, in general, and the Seattle area, in particular, have done a very good job of keeping their building codes up to date for many years and of properly enforcing these codes at the local level. This is evidenced by the fact that there was little structural damage to modern facilities. In addition, the State of Washington has begun the process of adopting the most recent model building code, the new International Code series.

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5) *What is the process by which research and analysis is translated into building codes? Safety procedures?*

For almost twenty years, FEMA has used the procedure of developing a substantial number of "resource documents" that translate research results into language, interpretations, and formats that design professionals, building inspectors, code officials, building owners, and decision-makers at all levels of government can readily understand and apply in their day-to-day activities. The translation process essentially synthesizes and simplifies research data and other information, and presents it in a format most suitable for these intended audiences. The contents of these documents are then widely disseminated to the intended users by means of seminars, workshops, and similar mechanisms.

One example of such a resource document is the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*, which FEMA has produced and triennially updated since 1985 and which recently was adopted intact for use by both the International Building Code and the International Residential Code. This adoption ensures that research results diffuse into the mainstream of construction practices throughout the United States in a timely fashion. The *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, a first-of-its-kind, performance-based manual originally produced by FEMA in 1997, was updated in 2000 and has been accepted by the Standards Committee of the American Society of Civil Engineers for use in the development of a new standard on how to make existing buildings earthquake resistant. As a national standard reflecting the latest research results, its provisions will be referenced in building codes and construction contracts and, as a result, will establish the accepted practices in regard to the seismic rehabilitation of buildings.

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6) *What are the most common mitigation practices? How do they help secure the structure in the case of an earthquake? How much do they cost, say, for your average homeowner?*

There are many common mitigation practices for building types known to perform poorly in past earthquakes. For unreinforced masonry buildings, it is common to add roof-to-wall ties, to strengthen existing walls with sprayed-on concrete, and to brace parapets. For older concrete buildings, common techniques include adding new shear walls to stiffen the structure and/or using composite wraps to increase strength and ductility of columns and other structural members. Other engineered mitigation measures include the use of base isolation (where isolation devices are installed between the building and its foundation to reduce the amount of energy being transmitted into the building) and energy dissipation (where devices are included within the building's structural framing to dissipate earthquake energy before it can impact on the building).

For single-family wood homes, the most common mitigation techniques are bracing cripple walls with diagonal bracing or plywood, and bolting the structure to its foundation. This is the mitigation technique around which the Seattle Home Retrofit program has been built. Although the Nisqually event resulted in relatively light ground shaking that did not seriously test the performance of the retrofitted structures, it is estimated that this mitigation technique prevented an average of approximately $475 worth of damage to retrofitted structures. For all building types, anchoring non-structural items such as water heaters, shelving, equipment, etc., is a common and good practice. In Seattle, overhead hazards were removed from 43 public schools. Again, while the majority of these schools are located in areas that were subjected to relatively light shaking in the Nisqually earthquake, an economic analysis indicates that this type of mitigation measure resulted in a cost savings of approximately $120,000.

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In terms of cost, a typical residential house can be retrofitted for between $2,000 and $15,000, depending on the configuration and size of the house. It is something that generally can be done by homeowners themselves with only a little bit of help. For example, the average cost of the Seattle home retrofits has been $3,300, many of which were performed by the homeowner.

7) *We have come a long way in the past twenty plus years. Are these aspects of the original NEHRP program that are now obsolete? Are there other promising areas of research and analysis that are not being funded?*

The legislation that originally authorized NEHRP has its genesis from both the 1964 Anchorage and 1971 San Fernando earthquakes. At that time, the general belief was that with sufficient research, we could reach the point where it would be possible to predict when and where earthquakes would strike.

In the over 20 years since that time, it has become clear that earthquake prediction remains an elusive goal. During that same period, however, the NEHRP has made great strides in: identifying and mapping where the earthquake hazard exists and its approximate recurrence intervals; developing design and construction criteria that have resulted in buildings that now are capable of resisting most earthquake ground motions with an acceptable risk to loss of life; and in getting these design and construction criteria adopted into the nation's model building codes.

Where the work of the NEHRP remains greatest is in implementing the Program's products at the state and local level. While the nation's model building codes now contain adequate design requirements, the state and local building codes currently in place are generally still in need of improvement. Of even more concern is the problem of satisfactorily enforcing these codes, which remains an issue for all hazards.

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While research and development will always remain important components of the NEHRP, for this country to be able to effectively implement the NEHRP provisions and its earthquake loss reduction products, NEHRP will need to devote additional attention to the research-to-practice cycle to accelerate the implementation process at the state and local levels.

Another implementation issue relating to building codes is the need to fully develop performance-based building codes. Current building codes are designed to only one performance level, which ensures that building occupants are not killed or seriously injured (referred to as life safety). However, they are not currently designed to provide higher levels of performance, such as to prevent damage to the building or to ensure that the building would be functional immediately after an event. What this means is that even when a building is built to "code," it will likely suffer damage in its design event, possibly to the point that it would not be usable or that repair would not be economically feasible. Obviously, this presents a problem for critical facilities such as hospitals and emergency response centers, where higher performance levels than just life safety would be desirable.

Performance-based codes would allow owners and design professionals to explicitly design structures to suffer less damage in earthquakes. FEMA is currently starting work on the development of such codes, but there are many obstacles. There is a significant amount of problem-focused or applied research that is required to develop the technical bases of this next generation of codes. The National Institute of Standards and Technology (NIST) is the NEHRP agency with responsibility for conducting problem-focused studies and applied research; however, NIST's budget is only two percent of the total NEHRP budget, a level of funding that is insufficient to carry out the needed studies in a timely manner.

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The critical national need is to reduce the costs of disasters through mitigating risks posed by existing buildings and promoting better construction and siting of new buildings. The NEHRP Strategic Plan responds to meeting this need. We believe that multi-State groups could play a more effective role in reducing the effects of natural hazards by more closely following the strategic plan and by supporting States and communities in disaster prevention initiatives.

9) *In your opinion, what does the cessation of funds dedicated to initial mitigation efforts in places such as Seattle, mean to communities that may not yet be "disaster resistant"? And I am thinking of specifically of the Project Impact program that was killed by the current administration. Please address the hole that is left by the zeroing out of that particular program or similar programs designed to ensure the safety and security of families, businesses and communities by reducing the effects of natural disasters and fostering public and private sector partnerships.*

The elimination from the FY 2002 budget of funds for Pre-Disaster Mitigation will not affect the grants committed to existing Project Impact communities. FEMA will provide the seed grants and technical assistance that have been committed to each community.

The principles of Project Impact—preventive actions must be decided at the local level; private sector participation is vital; and long-term efforts and investments in prevention measures are essential—can and should continue to be adopted by communities in an effort to reduce the damage caused by disasters. FEMA recognizes the importance of community-based mitigation whether or not Project Impact exists as a federal initiative.

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The original design of Project Impact was always to encourage community based mitigation efforts. Grounded in this plan is a commitment to find means to sustain the momentum of building a disaster resistant community by institutionalizing mitigation practices into local governance. We encourage communities to continue this momentum by proceeding with planned mitigation projects.

FEMA's goal is to reduce the impact of disasters, and Project Impact is only one of many proactive initiatives FEMA has provided to state and local governments to help them prepare for and reduce damage from disasters. In addition to the Project Impact and the National Earthquake Hazard Reduction Program (NEHRP), FEMA administers mitigation technical assistance programs, the Hazard Mitigation Grant Program (HMGP), the Community Rating System and the Flood Mitigation Assistance Program. FEMA remains committed to reducing the loss of life and destruction of property that results from disasters.

APPENDIX 2: Material for the Record

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DEVELOPING THE NEXT GENERATION OF EARTHQUAKE SCIENTISTS

QUESTION: *Are we doing what we should in terms of encouraging the new generation of scientists and technicians in this area? As Congress looks at education and the importance of encouraging these kinds of scientific endeavors, are we falling behind in terms of the next generation of people that we are developing to do the work that you are doing? Do we have a feel for what is happening in our colleges and universities? Please do a little research in that effort and look quantitatively at the number of people in geology, seismology, geophysics, and maybe other related disciplines and report back to our Subcommittee in that regard.*

ANSWER: The National Science Foundation, through its "Science and Engineering Indicators," reports statistics concerning the academic workforce and degrees awarded annually in fields of science and engineering. This information can be used to assess trends and to establish the numbers of next-generation highly educated scientists and engineers who might deal with a natural disaster such as an earthquake in the United States.

There are several fields of study that are relevant to the needs precipitated by an earthquake disaster: Civil Engineering and Geosciences (especially geophysics/seismology). Knowledge concerning natural disasters is also derived through other fields of social, policy, and economic study that include public administration, public policy, sociology, urban affairs, and economics. The statistics for doctorate awards in these fields of study for the period 1990 through 1999 are summarized in the tables below.

Table 1

Table 2

SOURCE: NSF/SRS, Science and Engineering Doctorate Awards: 1999 (NSF01–314), table 1.

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Table 3

Table 4

SOURCE: NSF/SRS, Science and Engineering Doctorate Awards: 1999 (NSF01–314), table 1.

The annual number of doctorates in the core fields of Civil Engineering and Geosciences has generally been between 1,000 and 1,100 for the past 10 years, dipping to a low of 960 awards in 1999. In the important field of geophysics/seismology, the number of degrees awarded has remained relatively small and stable from 1990 to 1999, hovering around 100 doctorates awarded from U.S. universities each year. In 1999, the 100 degrees in seismology accounted for 22 percent of the total doctorates awarded in all Geoscience fields (453).

In other relevant fields, the annual number of doctorate awards in economics was the largest (912 doctorates in 1999); this was followed by sociology (543). Both of these large fields experienced a decline in doctorate awards since 1996 or 1997. The field of urban affairs, although a much smaller doctoral field, also experienced a large decline in awards since 1996. The fields of public administration and public policy, although small, have maintained relative stability in terms of doctorate awards since 1997. While there have been declines in these other relevant fields of 7 percent from 1997 to 1999, doctorate awards in Geosciences and Civil Engineering have declined 11 percent between 1997 and 1999.

The National Science Foundation data on trends in higher education yields a picture of relatively stable or slightly decreasing numbers for the aggregated fields of Civil Engineering and Geosciences in general; however, we do not adequately track data below the aggregate level. For example, at the aggregate level of Geosciences, including Earth, Atmospheric and Ocean Sciences, enrollment of full-time graduate students peaked at almost 12,000 in the early 1980s. Enrollment has been below 11,000 since 1996 and there are no indications that enrollment will increase in the near future. There is cause for concern then about future generations of Geoscientists and Civil Engineers. While we are doing a lot to encourage students to join the next generation of scientists and engineers, there is room to do more, especially at the K-12 and undergraduate levels. There is a great concern among educators that students are not being given the early introduction to the sciences and engineering that will provoke and maintain their interest. We know that offering challenging and rewarding research experiences retains student interest at the undergraduate level, and NSF has programs and is developing new programs that emphasize the integration of education and hands-on research experiences in Geosciences and Engineering.

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Examples of pertinent NSF programs include:

Research Experiences for Undergraduates (REU), NSF-wide program for supplements to existing awards, *http://www.nsf.gov/home/crssprgm/reu/start.htm*

NSF Graduate Teaching Fellows in K–12 Education (GK–12), NSF-wide *http://www.nsf.gov/home/crssprgm/gkl2/*

Research Experiences for Teachers (RET), developed in NSF's Directorate for Engineering for supplements to existing NSF awards,
http://www.nsf.gov/cgi-bin/getpub?nsf0118

Geoscience Education, developed in NSF's Directorate for Geosciences to fund small proposals that integrate research and education at all educational levels,
http://www.nsf.gov/cgi-bin/getpub?nsf0142

Opportunities for Enhancing Diversity in the Geosciences, developed in NSF's Directorate for Geosciences and designed to provide research funding that increases representation of African-Americans, Hispanics and Native Americans, as well as persons with disabilities, in the Geosciences,
http://www.nsf.gov/cgi-bin/getpub?nsf0l36.

EERCs: The three NSF-funded Earthquake Engineering Research Centers (EERCs)—the MidAmerica Earthquake (MAE) Center, led by the University of Illinois at Urbana-Champaign, the Multidisciplinary Center for Earthquake Engineering Research (MCEER), led by the State University of New York at Buffalo, and the Pacific Earthquake Engineering Research Center (PEER), led by the University of California, Berkeley, have been active in involving undergraduate and graduate students in their research and education programs. Table 3 shows the number of students who participated in EERC research activities during FY 2000.

Table 5

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* Students supported through Research Experiences for Undergraduates (REU) supplements to the EERC award

** Undergraduate students supported directly through the EERC award

With the funding support and guidance of the National Science Foundation, the encouragement of the future generation of engineers and scientists is being achieved through the following activities at the EERCs:

short courses in the earthquake engineering field to interest undergraduate students in earthquake engineering graduate studies (i.e., at PEER);

direct undergraduate and graduate student involvement in EERC funded research projects, often in multidisciplinary teams and with outside practitioners;

formal Research Experiences for Undergraduates (REU) programs;

frequent multi-institutional and multidisciplinary seminars on earthquake engineering topics;

new multidisciplinary earthquake engineering courses and curricula to increase students appreciation of the systems approach to earthquake research and the relevance of research participation to advances made within the discipline; and,

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participation in EERC Student Leadership Councils where students can acquire leadership skills.

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PREPARED STATEMENT OF MARGARET LAWLESS

Acting Executive Associate Director, Mitigation Directorate, Federal Emergency Management Agency

For the Record of the Subcommittee on Research of the Committee on Science
United States House of Representatives

In the aftermath of the February 28, 2001 Nisqually earthquake, the House Science Committee staff requested a briefing on the Federal government's response to the earthquake. Subsequently, a hearing was held that focused on research activities of the National Earthquake Hazards Reduction Program (NEHRP). The Committee members asked a number of probing questions concerning earthquake loss reduction activities which went beyond the realm of research. This written testimony responds to certain points raised during the March 21, 2001 hearing and presents other general information pertinent to comprehensive earthquake loss reduction activities.

Earthquakes represent the largest single potential for casualties and damage from a natural hazard facing this country. They are a national threat, since 45 States and territories have a very high to moderate risk of a damaging earthquake. The earthquake that struck western Washington State on February 28, 2001, measured Richter magnitude 6.8, but produced relatively moderate groundshaking and damage in the $1–2 billion range. Fortunately, the 37-mile depth of the hypocenter diminished what could have been a very damaging event. In the January 1994 Northridge event, a 6.8 magnitude earthquake centered on the fringe of Los Angeles, California, caused an estimated $40 billion in damage. Exactly one year later, the Kobe, Japan earthquake demonstrated the impact of a slightly larger event and caused thousands of casualties and losses approaching $200 billion. It occurred directly under a major metropolitan area that bears a striking resemblance to Oakland, California.

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Recent findings show a significantly increased potential for damaging earthquakes in southern California, and in northern California on the Hayward fault. Studies also show higher potential of earthquakes for the Pacific Northwest and coastal South Carolina. This is in addition to areas of earthquake risk that have already been identified, such as the New Madrid fault zone in the central U.S. and Wasatch front in Utah. The responsibility for reducing our Nation's earthquake hazards is shared by Federal, State, and local governments and the private sector.

NEHRP is the Federal government's coordinated approach to addressing earthquake risks. NEHRP involves the closely coordinated efforts of four Federal agencies—FEMA, the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS). The premise of the Program is that while earthquakes may be inevitable, earthquake disasters are not. NEHRP activities include basic and applied research, technology development and transfer, and training, education and advocacy for seismic risk reduction measures. The NEHRP agencies work collaboratively with each other, and with other Federal and State agencies, private partners, universities, and with regional, voluntary and professional organizations.

Our basic authority is the Earthquake Hazards Reduction Act of 1977, the purpose of which is ". . .to reduce risks of life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards reduction program." The Act's aims include improved understanding, characterization and forecasting of seismic hazards and vulnerabilities; improved model building codes and land use practices; development and improved seismic design and construction techniques; accelerated application of research results; and reduced risk through the use of post-earthquake investigations and education.

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FEMA has two roles within NEHRP. First, we serve as lead agency for the program. This role involves program coordination, both within the Federal government and with external constituencies, the preparation of a consolidated program budget document and a multi-year plan, and periodic reports to the Congress. Second, FEMA works to produce technical guidance and to translate the results of research and technology development into effective earthquake loss reduction measures at State and local levels of government. In this role, we administer a program of grants and technical assistance to States and multi-State consortia designed to increase awareness of the earthquake hazard and to foster plans, actions, and partnerships to reduce seismic vulnerability.

Partnerships have been actively pursued among FEMA headquarters, FEMA regions, State emergency management, State geologists, and multi-State consortia. These partnerships serve to effectively promote the evaluation of earthquake risks and to establish means to reduce those risks. To provide effective techniques to reduce seismic risk to the built environment, we support the development and dissemination of improved seismic design and construction techniques for new buildings and rehabilitation guidelines for existing buildings. This material is made available to Federal, State, local and private sector entities for voluntary use through model building codes, standards organizations, and design professionals. FEMA also supports public education and awareness programs on earthquake loss reduction. Following is a summary of FEMA's key loss reduction activities.

Strategic Plan Development

Mindful of the increasing risks posed by earthquakes, NEHRP initiated a review of the scientific goals and strategies of the Program and a discussion of the opportunities and priorities for the five-year interval 2001–2005. This review and discussion culminated in the development of a new strategic plan. A working group composed of members of the four NEHRP agencies authored the document, and the document was approved by each of the agencies during the fall of 2000. The Strategic Plan was developed and validated with input from two workshops of public and private NEHRP partners and stakeholders. The plan builds upon the complementary missions of the four agencies. FEMA works with States, local governments, and the public to develop tools and improve policies and practices that reduce earthquake losses; NIST enables technology innovation in earthquake engineering by working with industry to remove technical barriers, evaluate advanced technologies, and develop the measurement and prediction tools underpinning performance standards for buildings and lifelines; NSF strives to advance fundamental knowledge in earthquake engineering, earth science processes, and societal preparedness and response to earthquakes; and USGS monitors earthquakes, assesses seismic hazard for the Nation and researches the basic earth science processes controlling earthquake occurrence and effects.

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Shaping the plan are four goals that represent the continuum of activities in the Program, ranging from research and development to application and implementation. These four goals are as follows:

A. *Develop effective practices and policies for earthquake loss-reduction and accelerate their implementation.*

B. *Improve techniques to reduce seismic vulnerability of facilities and systems.*

C. *Improve seismic hazard identification and risk assessment methods and their use.*

D. *Improve the understanding of earthquakes and their effects.*

The goals will be used to guide NEHRP planning and activities for the near future. All NEHRP activities and projects are being developed and prioritized using this Strategic Plan as a guidepost.

The Strategic Plan also lays out a number of challenges and opportunities for the NEHRP program over the next five years, including new technologies, emerging information needs, and resource issues. Chief among these are:

Upgrading seismic networks to allow for real-time notification of earthquake activity and intensity of ground shaking

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On-scale recording of strong motion to facilitate prediction of ground motion and its effects

Simulation and testing of earthquake engineering design parameters

Development of performance-based seismic design methods

Monitoring of active fault zones to constrain the conditions that prevail prior to, during, and after an earthquake

Improving the effectiveness of earthquake risk mitigation efforts through utilization of both existing and new research in the social, behavioral, and economic sciences

FEMA also works with consensus standards; documents that have been developed following a specific and rigorous process that may be adopted by reference in a model building code. FEMA has worked with the American Society of Civil Engineers (ASCE) since the late 1980's to ensure that their standard ASCE–7, *Minimum Design Loads for Buildings and Other Structures* adequately addresses seismic, wind and flood loads. Since the 1995 version, this document has addressed seismic loads and design in a manner that is substantially equivalent to the NEHRP guidelines. ASCE 7–98 is the current version of this standard and ASCE 7–02 is currently under development. The NFPA intends to adopt ASCE 7–02 by reference in its new model building code.

New Construction

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FEMA continues work to improve technical quality in the construction of new buildings and other structures. One of our most important activities in this area has been the continuing development and revision of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* through the Building Seismic Safety Council. Using seismic hazard mapping information from the USGS, and aided by knowledge developed from NSF and NIST, the *NEHRP Recommended Provisions* and the related *Commentary* present criteria for designing and constructing buildings and other structures subject to earthquakes anywhere in the United States.

The *NEHRP Recommended Provisions* has succeeded in meeting its original goal of becoming a resource document widely used by practicing design professionals and building officials. The 1997 *NEHRP Recommended Provisions* formed the basis of the recently released *International Building Code (IBC) and International Residential Code (IRC).* The *2000 Recommended Provisions* will form the basis of the 2003 IBC and 2003 IRC as well as the proposed *National Fire Protection Association (NFPA) 5000 Building Code.* These are the two model building codes that are expected to govern nearly all construction in the United States within the next decade.

The *2000 NEHRP Recommended Provisions* update cycle is nearly complete, and this document will be released by the end of May. Among the major improvements are the development of a simplified design procedure, inclusion of state-of-the-practice material related to anchorage to concrete and masonry, the further introduction of advanced analysis procedures which allow designers to better control damage, and updating of steel design procedures to include information from the recently completed FEMA Steel Buildings Initiative. Many of these improvements will make their way into the national buildings codes over the next several years.

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FEMA views the building code process as the best means to have the nation's local communities adequately protected against natural hazards. Since almost all State and local codes are based on a model building code, FEMA's focus has been to work with the model code process to ensure that these model codes adequately address all natural hazards.

It now appears that this country will shortly have two model building codes: the *International Codes*, promulgated by the International Code Council (ICC); and the *NFPA 5000 Life Safety Code*, which is currently being developed by the National Fire Protection Association (NFPA). FEMA has committed to work with both of these model codes to ensure that they both contain adequate provisions to address all natural hazards.

Existing Buildings

In the built environment of any community, the overwhelming number of buildings that are exposed to earthquake risks consists of buildings that already exist. For this reason, in 1984 FEMA started a program that focused resources toward making existing buildings more resistant to the effects of earthquakes. By now this program has produced a substantial number of widely used manuals, reports, and training and other informational material directed both at technical and non-technical audiences. Following are the most recent achievements.

In September of 1997, we completed the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* and related *Commentary*, the culmination of a 5-year $7.7 million effort performed for FEMA by the Building Seismic Safety Council, which represents a broad spectrum of the engineering and construction industries. For the first time ever in this country, building owners, design professionals, and construction practitioners now had at their disposal nationally applicable performance-based technical criteria covering all building types and building materials. These users were able to choose design approaches consistent with different levels of seismic safety as dictated by location, seismic safety performance objective, building type, occupancy, availability of resources, or other relevant considerations. Combined with new analytical techniques, these criteria yield estimates of the seismic performance of a higher order of reliability than had previously been possible and engineering and construction firms throughout the country are using the Guidelines in their day-to-day activities.

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Another goal of the program is to produce a resource document that would become the basis for a national code on seismic rehabilitation. The development of the *Guidelines* was a necessary first step in this process; in the summer of 1998 we undertook the second step, namely, the development of a document ("a pre-standard") that could become a standard after a consensus review process approved by the American National Standards Institute (ANSI). As such, it could then enter model codes, as well as ordinances and contracts, as a reference. The effort was completed in September 2000 and the *Pre-Standard for Seismic Rehabilitation* was published by FEMA and also made available to the ASCE Standards Committee for their balloting and eventual approval as an ANSI standard. At the same time, FEMA is providing technical assistance to the recently constituted International Existing Building Code (IEBC) committee, which is developing the first comprehensive nationally applicable code for rehabilitation of buildings, with the objective of facilitating the use of the *Pre-Standard for Seismic Rehabilitation* as a basis for the new code.

i The other major program element of the existing buildings program concerns the assessment of existing buildings. We have completed an updated and enlarged handbook for the seismic evaluation of buildings. It builds on an earlier version that had become a *de facto* standard in this field, but also introduces a three-tier analytical approach, reflects advances in technology and lessons learned in earthquakes in the past ten years, is consistent with the *Guidelines* and *Pre-Standard for Seismic Rehabilitation*, and covers higher-than-life-safety rehabilitation levels. This *Pre-Standard* has been published and is being very widely used.

We are also preparing manuals for audiences not heretofore addressed, such as construction craftspersons and inspectors on construction sites, and updating a number of manuals to reflect new information.

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Steel Moment Frame Buildings

We learned a critical lesson from the January 1994 Northridge earthquake: unexpected brittle fractures of the beam-to-column connections occurred in welded steel moment-resisting frame buildings. While no casualties or collapses occurred, a wide range of brittle connection damage has been found in almost 200 buildings, although the number of buildings suffering severe damage was far less. The effect of this damage was a concern that these structures may not be safe and recognition that the codes and design procedures may need to be upgraded. Because of this, FEMA quickly initiated a high priority, coordinated, problem-focused program of research and investigation to develop and validate reliable and cost-effective seismic-resistant design procedures.

The project included assessing current knowledge of steel building performance, conducting topical investigations, developing a series of state-of-the-art reports, conducting a comprehensive testing program, developing an inspection program, assessing the economic, social and political impacts, and writing the final series of documents that will provide design criteria. The guidelines are now complete and available through FEMA. Much of the material that has resulted from this research has already been adopted into the nation's codes and standards, including the 1997 edition of the *NEHRP Recommended Provisions*, the American Institute for Steel Construction industry standard and common practice.

Wood Frame Construction

The seismic performance of wood frame residential structures has always been of concern to FEMA. While each individual house may not represent a significant financial threat, the sheer number of homes that make up this class of structure makes it one of the largest in terms of loss potential. It is for this reason that

FEMA maintains its guidance document *Home Builder's Guide to Seismic Resistant Construction.*

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In the investigation of damage from the Northridge earthquake, one of the more significant observations was the generally poor performance of wood-frame residential structures. Insurance and other loss data from Northridge has shown that roughly three fourths of all losses were to this class of structure. This does not include the cost of temporary housing, an issue that impacts FEMA directly.

I In 1998, FEMA worked with the State of California to fund a $5.2 million Hazard Mitigation Grant Program Award to the California Institute of Technology to study and develop economical methods of improving woodframe building performance in earthquakes. The Caltech-CUREe (California Universities for Research in Earthquake Engineering) project, funded through the Stafford Act Section 404, will involve both industry and academia and will focus on applying results of project research into design materials usable for building codes. We believe that some very useful material will result from this project, and we will work to integrate that material into the *NEHRP Provisions* and into the model codes.

Lifelines

Recognizing the public need to deal with the severe effects of earthquakes on our nation's infrastructure, Congress in Public Law 101–614, the Earthquake Hazards Reduction Act, requires NEHRP to improve the performance of lifelines in earthquakes. FEMA has taken the lead in this area and in August of 1998, together with the American Society of Civil Engineers (ASCE), signed a cooperative agreement to form the American Lifelines Alliance (ALA). ALA's goals are to support projects that develop and assess design and construction guidelines and standards, provide a bridge between researchers and practitioners, support the consensus process with Standards Developing Organizations, and educate regulatory agencies and practitioners.

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During 1999–2000, ALA started its work in earnest and achieved several notable results. The key accomplishments are the development of a strategic plan and operating vision, the development of a number of public and private sector partnerships, and the beginning of three guideline and standards development projects which will be completed this year. ALA will also have complementary role within the *NEHRP Recommended Provisions for Buildings and Other Structures.*

Performance-Based Design

The building codes referenced earlier are all based on a life safety standard, the goal of which is to prevent loss of life by preventing collapse of the building. At this performance level, the building is expected to suffer structural damage, and may not be economical to repair. This design level is clearly not adequate for such structures as hospitals, fire stations, emergency command facilities, and other buildings that the owner would like to have functional immediately after an earthquake. Also, the current building codes provide no explicit method to design with the express goal of limiting damage in mind.

The chief benefit of performance based design is that it would allow building owner and designers to explicitly design buildings to suffer reduced damage in earthquakes, lessening the financial burden on communities, insurance companies, businesses, and taxpayers.

FEMA recently funded the Earthquake Engineering Research Institute (EERI) to develop an Action Plan that could possibly be used to support development of acceptable seismic performance based criteria for both new and existing buildings. Using that plan, FEMA is in the process of funding the first phase of a project that will begin development of performance-based seismic design guidance.

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HAZUS

Any mitigation action must first begin with an accurate assessment of the seismic risk faced by a community or state. To accomplish this, several years ago FEMA began funding the development of HAZUS (Hazards US), a standardized regional loss estimation model. HAZUS is the first nationally applicable methodology that can be used to determine and graphically display losses that could occur as the result of a given earthquake. The software includes modeling capability and an extensive inventory of GIS-located infrastructure. It enables users to determine the degree to which losses could be reduced as a result of mitigation actions. Emergency managers are now using HAZUS as a planning tool to predict the impact of an earthquake in their area. HAZUS can also be used in the immediate aftermath of an earthquake as a means to quickly estimate areas of severe damage. Finally, it offers the prospect of providing both a baseline and future measurement of seismic risk in the context of the Government Performance and Results Act (GPRA).

The HAZUS earthquake module was released to the public, including States, local communities and other Federal agencies in the spring of 1997. FEMA is also currently working to develop loss estimation modules for flood and hurricane hazards that will be incorporated within the next release of HAZUS, thereby expanding it to be a multi-hazard loss estimation tool. This next release of HAZUS is scheduled for December 2002.

Since the initial release of HAZUS in 1997, all of the States and Territories have received training in its use. Copies have been distributed free-of-charge to users representing all levels of government, the private sector, academic institutions and the international community. To promote the use of HAZUS, FEMA provides technical support to a growing number of HAZUS user-groups by participation in workshops, on-site training and technical assistance activities through the FEMA regional offices, earthquake consortia, and local and State agencies and their private partners.

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HAZUS has also been used to provide background for earthquake policy development at the Federal level. For example, Senator Dianne Feinstein used HAZUS-based scenarios to demonstrate the economic consequences of damaging earthquakes in urban areas, and the potential savings that mitigation activities could achieve, in support of the Earthquake Loss Reduction Act of 2001 (S. 424).

FEMA has used HAZUS to conduct an Earthquake Average Annual Loss Study. Released in September 2000, FEMA 366, *HAZUS99 Estimated Annualized Earthquake Losses for the United States,* helps to demonstrate that earthquakes, though they happen less frequently than floods or hurricanes, are at least as costly as these other natural disasters. This study estimates the annualized loss to the general building stock at $4.4 billion per year and uses new measures to compare seismic risk at both the national and local level and to identify high-risk areas throughout the country. Earthquake vulnerability is not equal everywhere in the United States, and the steps taken by each city and region should be commensurate to the level of vulnerability. This type of quantitative and objective information will help decision-makers develop seismic risk management policies at the national level. The study also lays the groundwork to evaluate the benefits of earthquake mitigation strategies on an annualized basis.

State Support

One of the most important actions undertaken by FEMA is its continued support of earthquake risk reduction activities by State and multi-State organizations. The FY 2001 budget includes about $5 million—approximately one-third of FEMA's earthquake program budget total after salaries and expenses—for state grants and technical assistance. Of this amount, $4.4 million is distributed as grants among all 43 participating states and territories identified by the USGS as having a very high to moderate seismic hazard. The remainder is divided between support to multi-state organizations and the provision of ad hoc technical assistance in the form of short-term architectural and engineering support to states and localities. Recent Congressional earmarks for particular multi-state organizations at the expense of similar groups, could disrupt the consistency of State support.

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In Fiscal Year 2000 the State grants were consolidated into the Emergency Management Performance Grant, combining seven non-disaster State grant programs within FEMA. This consolidation has allowed States more flexibility in funding their priorities for multi-hazard initiatives such as hazard identification and risk assessment, mitigation planning, and promoting effective mitigation programs. The ongoing funding allows States to pursue long-term mitigation projects and to form partnerships in developing and implementing these initiatives.

Executive Orders

At the national level, FEMA continues its oversight of implementation of Executive Order 12699 dealing with new buildings that are leased, assisted or regulated by the Federal Government and Executive Order 12941 dealing with existing buildings owned or leased by the Federal Government. Technical guidance for implementing these Orders is provided through the Interagency Committee on Seismic Safety in Construction (ICSSC), which is chaired by and receives technical secretariat support from NIST. The 1999/2000 biennial report on implementation status of both Executive Orders will soon be completed and submitted to this Committee. Concerning new construction, all affected agencies have issued the procedures or regulations required to implement Executive Order 12699.

Other NEHRP Agency Activities

While you have heard from the other NEHRP agencies on their accomplishments, FEMA would like to highlight a few that hold great potential for the future. NSF's selection of the three Earthquake Engineering Research Centers will benefit our state and regional partners by making these technical resources more accessible at the regional level. The new NSF Network for Earthquake Engineering Simulation (NEES) will result in significant improvements to the physical testing infrastructure and establish a network to allow testing and monitoring over the Internet. This will provide new research resources while honoring the September 1995 EERI report, *Assessment of Earthquake Engineering Research and Testing Capabilities in the United States*. The USGS latest seismic hazard maps were used in seismic design maps that are included in three FEMA documents. One of NIST's most valuable contribution is their publication on retrofitting existing steel moment buildings, which was developed in cooperation with our Steel Moment Frame Buildings Project and the industry. These and other NEHRP agency activities demonstrate the growing success of the program, and the impact that we are having across the country.

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