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Earthquakes: Risk, Monitoring, Notification, and Research

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Earthquakes: Risk, Monitoring, Notification, and Research

Summary

Close to 75 million people in 39 states face some risk from earthquakes. Seismic hazards are greatest in the western United States, particularly California, Alaska, Washington, Oregon, and Hawaii. The Rocky Mountain region, a portion of the central United States known as the New Madrid Seismic Zone, and portions of the eastern seaboard, particularly South Carolina, also have a relatively high earthquake hazard. Compared to citizens of other countries, relatively few Americans have died as a result of earthquakes over the past 100 years, but the country faces the possibility of large economic losses from earthquake-damaged buildings and infrastructure. Until Hurricane Katrina in 2005, the 1994 Northridge (CA) earthquake was the costliest natural catastrophe to strike the United States; some damage estimates were $26 billion (in today's dollars). Estimates of total loss from a hypothetical earthquake of magnitude more than 7.0 range as high as $500 billion for the Los Angeles area.

Given the potentially huge costs associated with a severe earthquake, an ongoing issue for Congress is whether the federally supported programs aimed at reducing U.S. vulnerability to earthquakes are an appropriate response to the earthquake hazard. Under the National Earthquake Hazards Reduction Program (NEHRP), four federal agencies have responsibility for long-term earthquake risk reduction: the U.S. Geological Survey (USGS), the National Science Foundation (NSF), the Federal Emergency Management Agency (FEMA), and the National Institute of Standards and Technology (NIST). They variously assess U.S. earthquake hazards, send notifications of seismic events, develop measures to reduce earthquake hazards, and conduct research to help reduce overall U.S. vulnerability to earthquakes.

Congress established NEHRP in 1977, and its early focus was on research that would lead to an improved understanding of why earthquakes occur and to an ability to predict them accurately. Congress most recently reauthorized NEHRP in 2004 (P.L. 108-360), and designated NIST as the lead agency, to create better synergy among the agencies and improve the program. Understanding has improved about why and where earthquakes occur; however, reliably predicting the precise date and time an earthquake will occur is not yet possible. Research may eventually lead to an ability to predict earthquakes, but the focus of NEHRP now has shifted towards improving the nation's ability to prepare for earthquakes and to minimize losses when an earthquake occurs.

Under NEHRP, the USGS has responsibility for conducting targeted research to improve the basic scientific understanding of earthquake processes. USGS research has produced, for example, a relatively new product called ShakeMap. ShakeMap provides a near real-time map of ground motion and shaking intensity and portrays the extent of damage following an earthquake. NSF supports more fundamental research — it distributes research grants and coordinates programs — that leads to a better understanding of crustal processes that cause earthquakes around the globe. NSF recently initiated a major project called EarthScope to study the structure and evolution of the North American Continent.

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The 1994 Northridge (CA) earthquake caused as much as $26 billion in damage, according to one estimate, and was one of the costliest natural disasters to strike the United States. The U.S. Federal Emergency Management Administration (FEMA) has estimated that earthquakes cost the United States, on an annualized basis, over $4 billion per year. Some damage estimates of a single, large earthquake striking the Los Angeles area range as high as $500 billion.

Under the National Earthquake Hazards Reduction Program (NEHRP), the federal government supports efforts to assess and monitor earthquake hazards and risk in the United States. Four federal agencies, responsible for long-term earthquake risk reduction, coordinate their activities under NEHRP: the U.S. Geological Survey (USGS), the National Science Foundation (NSF), FEMA, and the National Institute of Standards and Technology (NIST). Congress reauthorized NEHRP in 2004 (P.L. 108-360).

Given the potentially huge costs associated with a large, damaging earthquake in the United States, an ongoing issue for Congress is whether the federally supported earthquake programs are appropriate for the earthquake risk. This report describes estimates of earthquake hazards and risk in the United States, the current federal programs that support earthquake monitoring and that provide notification after a seismic event, and the programs that support mitigation and research aimed at reducing U.S. vulnerability to earthquakes.

Earthquake Hazards and Risk

All 50 states are vulnerable to earthquake hazards, although risks vary greatly across the country. Seismic hazards are greatest in the western United States, particularly California, Alaska, Washington, Oregon, and Hawaii (see **Figure 1**). Alaska is the most earthquake-prone state, experiencing a magnitude 7 earthquake[1]

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[1] Magnitude is a number that characterizes the relative size of an earthquake. Earthquake magnitude is often reported using the *Richter* scale (magnitudes in this report are generally consistent with the Richter scale). Richter magnitude is calculated from the strongest seismic wave recorded from the earthquake, and is based on a logarithmic (base 10) scale: for each whole number increase in the Richter scale, the ground motion increases by ten times. The amount of energy released per whole number increase, however, goes up by a factor of 32. The *moment magnitude* scale is another expression of earthquake size, or energy released during an earthquake, that roughly corresponds to the Richter magnitude and is used by most seismologists because it more accurately describes the size of very large earthquakes. *Intensity* is a measure of how much shaking occurred at a site based on observations and amount of damage. Intensity is usually reported on the Modified Mercalli

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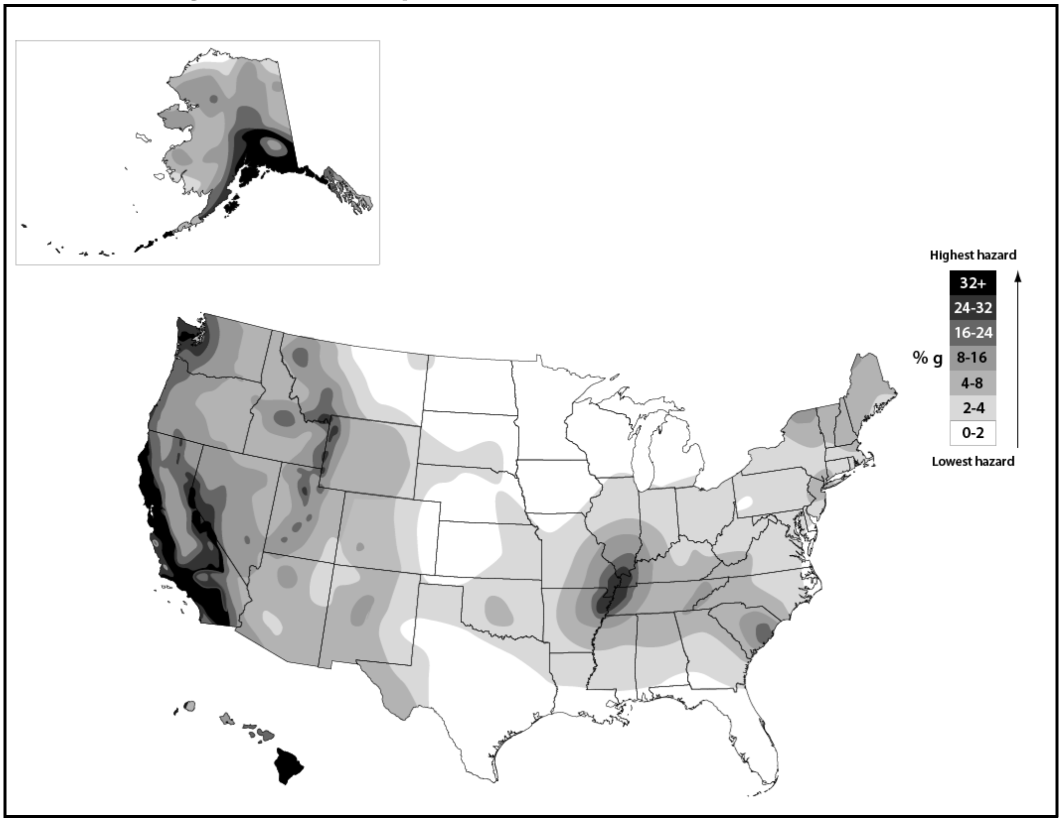
almost every year and a magnitude 8 earthquake every 14 years on average. California has more citizens at risk than any other state because of the state's frequent seismic activity combined with its high population.

Figure 1. Earthquake Hazard in the United States



Source: USGS, "Conterminous States Probabilistic Maps & Data" (modified by CRS), at [http://earthquake.usgs.gov/research/hazmaps/products_data/images/nshm_us02.gif]. **Note**: The hazard levels indicate the potential ground motion — expressed as a percentage of the acceleration due to gravity (g) — with up to a 1 in 10 chance of being exceeded over a 50-year period.

Figure 1 also shows relatively high earthquake hazard in the Rocky Mountain region, portions of the eastern seaboard — particularly South Carolina — and a part of the central United States known as the New Madrid Seismic Zone (discussed below). Other portions of the eastern and northeastern United States are also vulnerable to moderate seismic hazard. According to the USGS, 75 million people in 39 states are subject to significant risk. During the period 1975-1995, only four states did not experience detectable earthquakes: Florida, Iowa, North Dakota, and Wisconsin.

Precisely when an earthquake will occur cannot be reliably predicted yet; however, good information exists on where earthquakes are likely to occur and how severe the earthquake magnitude and resulting ground shaking are likely to be. The

[1] (...continued)
Intensity Scale as a roman numeral ranging from I (not felt) to XII (total destruction).

map in **Figure 1** depicts the potential shaking hazard from future earthquakes. It is based on the frequency at which earthquakes occur in different areas and how far the strong shaking extends from the source of the earthquake.

Shaking-hazards maps, such as the one in **Figure 1**, are often combined with other data, such as the strength of existing buildings, to estimate possible damage in an area following an earthquake. The combination of seismic risk, population, and vulnerable infrastructure can help improve the understanding of which urban areas across the United States face risks from earthquake hazards that may not be immediately obvious from the probability maps of shaking hazards alone. The USGS has identified 26 urban areas that face a significant seismic risk from the combination of population and severity of shaking. **Table 1** lists those areas at risk.

Table 1. 26 Urban Areas Facing Significant Seismic Risk
(alphabetically by state for cities with at least 300,000 people)

State	City	State	City
Alaska	Anchorage	Nevada	Las Vegas
California	Fresno	Nevada	Reno
California	Los Angeles	New Mexico	Albuquerque
California	Sacramento	New York	New York
California	Salinas	Oregon	Eugene-Springfield
California	San Diego	Oregon	Portland
California	San Francisco-Oakland	Puerto Rico	San Juan
California	Santa Barbara	South Carolina	Charleston
California	Stockton-Lodi	Tennessee	Chattanooga-Knoxville
Idaho	Boise	Tennessee	Memphis
Indiana	Evansville	Utah	Provo-Orem
Massachusetts	Boston	Utah	Salt Lake City
Missouri	St. Louis	Washington	Seattle

Sources: USGS Fact Sheet 2006-3016 (March 2006); USGS Circular 1188, Table 3.
Note: These areas are identified using a population-based risk factor based on 1999 population data. (William Leith, ANSS Coordinater, USGS, Reston, VA, telephone conversation, Nov. 15, 2006).

The USGS estimates that several million earthquakes occur worldwide each year, but the majority have very small magnitudes or occur in remote areas, and are not detectable. More earthquakes are detected each year as more seismometers[2] are installed in the world, but the number of large earthquakes (magnitude greater than 6.0) has remained relatively constant. Between 2000 and 2006, the National Earthquake Information Center (NEIC) reported as few as 2,261 and as many as 3,683 earthquakes each year in the United States, ranging in magnitude from less than 2.0 to greater than 7.0. **Figure 2** shows the number of earthquakes plotted against magnitude over the 2000-2006 time span in the United States.

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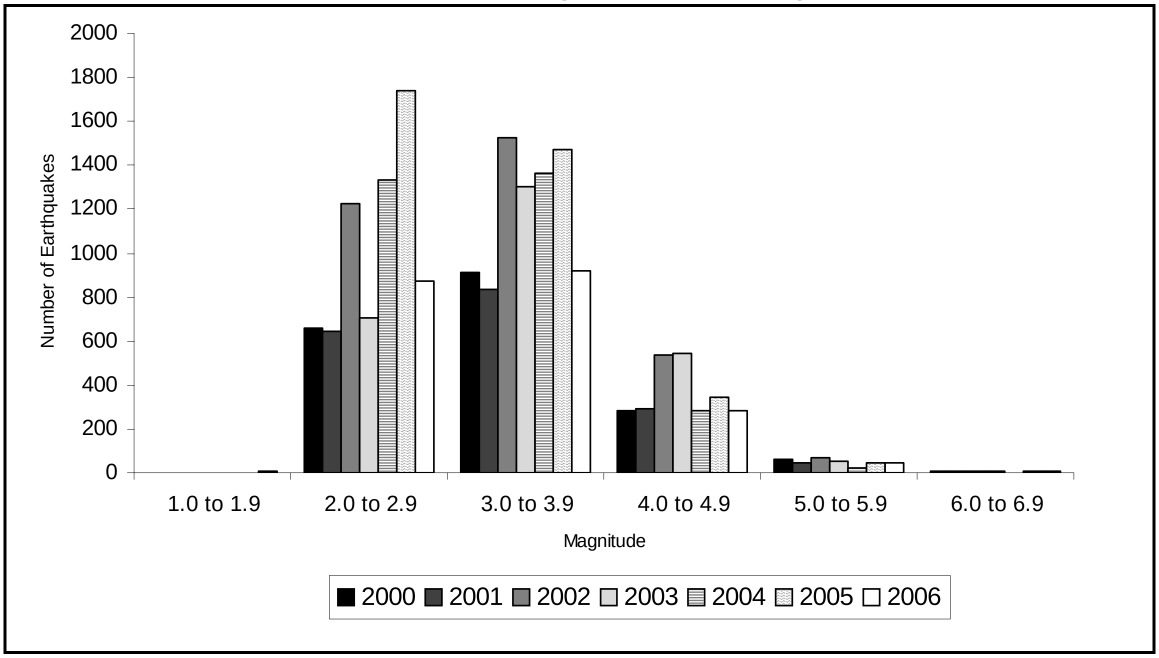
[2] *Seismometers* are instruments that measure and record the size and force of seismic waves, essentially sound waves radiated from the earthquake as it ruptures. Seismometers generally consist of a mass attached to a fixed base. During an earthquake, the base moves and the mass does not, and the relative motion is commonly transformed into an electrical voltage that is recorded. A *seismograph* usually refers to the *seismometer* and the recording device, but the two terms are often used interchangeably.

Figure 2. Histogram Showing the Number of Earthquakes from 2000-2006 Plotted Against Their Magnitude



Source: USGS, "Earthquake Facts and Statistics," at [http://neic.usgs.gov/neis/eqlists/eqstats.html]; data as of Nov. 6, 2006.

As **Figure 2** shows, about 97% of earthquakes detected each year by the NEIC are smaller than magnitude 5.0; only 45 earthquakes exceeded magnitude 6.0 for the five-year period (less than 0.2% of the total earthquakes detected) for an average of six earthquakes per year of at least 6.0 magnitude.

Although infrequent, large earthquakes cause the most damage and are responsible for the most earthquake-related deaths in the United States and around the world. Over the past 100 years, relatively few Americans have died as a result of earthquakes, compared to citizens in other countries. The great San Francisco earthquake of 1906 claimed an estimated 3,000 lives, as a result of both the earthquake and subsequent fires. Since 1970, three major earthquakes in the United States were responsible for 188 of the 212 total earthquake-related fatalities (see **Table 2**).

Since 2000, only two deaths directly caused by earthquakes have occurred in the United States, both associated with falling debris in Paso Robles (CA) during the December 22, 2003, San Simeon earthquake of magnitude 6.5. In contrast, earthquakes are directly or indirectly responsible for more than 430,000 fatalities in other countries since 2000. More than half of those estimated deaths resulted from the December 2004 Indonesian earthquake of magnitude 9.1 and the resulting tsunami.

Table 2. Earthquakes Responsible for Most United States Fatalities Since 1970

Date	Location	Magnitude	Deaths
February 9, 1971	San Fernando Valley, CA	6.6	65
October 18, 1989	Loma Prieta, CA	6.9	63
January 17, 1994	Northridge, CA	6.7	60

Source: USGS Earthquakes Hazards Program.
Note: Other sources report different numbers of fatalities associated with the Northridge earthquake.

The 1994 Northridge earthquake was the nation's most damaging earthquake in the past 100 years, preceded five years earlier by the second most costly earthquake — Loma Prieta. **Table 3** shows the 10 costliest U.S. earthquakes according to one estimate of insured and uninsured losses. Comparing losses between different earthquakes, and between earthquakes and other disasters such as hurricanes, can be difficult because of the different ways losses are calculated. Calculations may include a combination of insured losses, uninsured losses, and estimates of lost economic activity. For example, insured losses — mainly property — from Hurricane Katrina in 2005 may be $41 billion, according to one estimate.[3] Including damage to uninsured property would add to the sum of total property damage. Including interrupted economic activity in the calculation could bring the total loss for Hurricane Katrina to $100 billion, according to another estimate.[4]

The United States faces potentially large total losses due to earthquake-caused damage to buildings and infrastructure, and potential lost economic activity. As urban development continues in earthquake-prone regions in the United States, concerns are increasing about the exposure of the built environment, including utilities and transportation systems, to potential earthquake damage.[5] One estimate of loss from a severe earthquake in the Los Angeles area is over $500 billion. An even higher estimate — approximately $900 billion — includes damage to the heavily populated central New Jersey-Philadelphia corridor if a 6.5 magnitude earthquake occurred along a fault lying between New York City and Philadelphia.[6]

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[3] Insurance Information Institute, [http://www.iii.org/media/facts/statsbyissue/hurricanes/].

[4] Risk Management Solutions (RMS), Newark, CA, press release (Sept. 2, 2005), at [http://www.rms.com/NewsPress/PR_090205_HUKatrina.asp].

[5] FEMA Publication 366, *HAZUS 99 Estimated Annualized Earthquake Losses for the United States* (Feb. 2001). Hereafter referred to as FEMA 366.

[6] A. M. Best Company Inc., *2006 Annual Earthquake Study: $100 Billion of Insured Loss in 40 Seconds* (Oldwick, NJ: A.M. Best Company, 2006), p. 12. The A. M. Best report includes estimates from catastrophe-modeling companies of predicted damage from hypothetical earthquakes in Los Angeles, the Midwest, the Northeast, and Japan. The report cites an estimate by one such company, Risk Management Solutions, that a hypothetical 7.4
(continued...)

Table 3. The 10 Most Damaging Earthquakes in the United States

Year	Location	Magnitude	2005 constant $
1994	Northridge, CA	6.7	$26 billion
1989	Loma Prieta, CA	6.9	$11 billion
1964	Anchorage, AK	9.2	$3.1 billion
1971	San Fernando, CA	6.5	$2.7 billion
2001	Nisqually, WA	6.8	$2.5 billion
1987	Whittier Narrows, CA	5.9	$615 million
1933	Long Beach, CA	6.3	$600 million
1953	Kern County, CA	7.5	$440 million
1992	Landers, CA	7.6	$130 million
1992	Cape Mendocino, CA	7.1	$92 million

Source: Insurance Information Institute, at [http://www.iii.org/media/facts/statsbyissue/earthquakes/].
Note: Includes insured and uninsured losses.

Some studies and techniques combine seismic risk with the value of the building inventory[7] in cities, counties, or regions across the country to provide estimations of economic losses from earthquakes. One report calculates that the annualized loss from earthquakes nationwide is $4.4 billion per year, with California, Oregon, and Washington accounting for $3.7 billion (84%) of the U.S. total estimated loss each year.[8] **Table 4** shows cities with estimated annualized U.S. earthquake losses over $10 million.

A single large earthquake can cause far more damage than the average annual estimate (see **Table 3**.) However, annualized estimates help provide comparisons of infrequent, high impact events like damaging earthquakes, with more frequently occurring hazards like floods, hurricanes, or other types of severe weather.

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[6] (...continued)
magnitude event along the Newport-Inglewood Fault near Los Angeles would cause $549 billion in total property damage. A hypothetical 6.5 magnitude earthquake along a fault between Philadelphia and New York City would produce $901 billion in total loss, according to an RMS estimate.

[7] Building inventory refers to four main inventory groups: (1) general building stock, (2) essential and high potential loss facilities, (3) transportation systems, and (4) utility systems (FEMA 366).

[8] FEMA 366.

Table 4. U.S. Cities With Estimated Annualized Earthquake Losses More Than $10 Million
(in millions)

Rank	Metro area	AEL	Rank	Metro area	AEL
1	Los Angeles, CA	$1,069	21	Bakersfield, CA	$31
2	Riverside, CA	$357	22	Tacoma, WA	$28
3	Oakland, CA	$349	23	Las Vegas, NV	$28
4	San Francisco, CA	$346	24	Anchorage, AK	$25
5	San Jose, CA	$243	25	Boston, MA	$23
6	Orange, CA	$214	26	Hilo, HI	$20
7	Seattle, WA	$128	27	Stockton, CA	$19
8	San Diego, CA	$128	28	Reno, NV	$18
9	Portland, OR	$98	29	Memphis, TN	$17
10	Ventura, CA	$89	30	Philadelphia, PA	$17
11	New York, NY	$56	31	San Luis Obispo, CA	$16
12	Vellejo, CA	$53	32	Salem, OR	$15
13	Santa Rosa, CA	$51	33	Fresno, CA	$14
14	Salt Lake City, UT	$40	34	Charleston, SC	$13
15	Sacramento, CA	$39	35	Albuquerque, NM	$13
16	St. Louis, MO	$34	36	Newark, NJ	$12
17	Eureka, CA	$34	37	Honolulu, HI	$12
18	Salinas, CA	$33	38	Atlanta, GA	$11
19	Santa Barbara, CA	$33	39	Modesto, CA	$11
20	Santa Cruz, CA	$33	40	Redding, CA	$10

Source: FEMA Publication 366, *HAZUS 99 Estimated Annualized Earthquake Losses for the United States* (Feb. 2001). Annualized earthquake losses (AEL) calculated in 2001.

Estimating earthquake damage is not an exact science and depends on many factors. Primarily, these are the probability of ground motion occurring in a particular area (see **Figure 1**), and the consequences of that ground motion, which are largely a function of building construction type and quality, and of the level of ground motion and shaking during the actual event. Some researchers have questioned whether the probability of ground motion estimates for regions of the country that experience infrequent earthquakes, such as the New Madrid Seismic

Zone, are too high.[9] These researchers bring into question whether the benefits of building structures to conform with the earthquake probability estimates merit the costs, in light of the uncertainty in making those probability estimates.[10]

The New Madrid Seismic Zone in the central United States is vulnerable to large but infrequent earthquakes. A series of large (magnitude greater than 7.0) earthquakes struck the Mississippi Valley over the winter of 1811-1812, centered close to the town of New Madrid, MO. Some of the tremors were felt as far away as Charleston, SC, and Washington, DC. The mechanism for the earthquakes in the New Madrid zone is poorly understood,[11] and no earthquakes of comparable magnitude have occurred in the area since these events. Such factors contribute to the difficulty of making a reasonable damage estimate for a low-frequency, high-impact event in the region based on the probability of an earthquake of similar magnitude occurring. This uncertainty has implications for policy decisions to ameliorate risk, such as setting building codes, and for designing and building structures to withstand a level of shaking commensurate with the risk. Developers of building codes tend to err on the side of caution.

Table 4 also shows annualized earthquake losses for the cities of New York, Boston, and Newark, where no destructive earthquakes have struck for generations.[12] Those cities represent areas of relatively low seismic hazard, but have high populations and dense infrastructure, which produces a significant risk according to some estimates.[13] In the absence of any significant or damaging earthquakes for those cities in recent memory, however, the actual risk is difficult to grasp intuitively.

Monitoring

Congress authorized the USGS to monitor seismic activity in the United States in the 1990 reauthorization of the National Earthquake Hazards Reduction Act (P.L. 101-614). The USGS operates two nationwide networks of seismographic stations: the Advanced National Seismic System (ANSS) and the National Strong-Motion Project (NSMP). Globally, the USGS and the Incorporated Research Institutions for Seismology (IRIS) operate 140 seismic stations of the Global Seismic Network

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[9] Andrew Newman, Seth Stein, John Weber, Joseph Engeln, Ailin Mao, and Timothy Dixon, "Slow Deformation and Lower Seismic Hazard in the New Madrid Seismic Zone," *Science*, v. 284 (April 23, 1999), pp. 619-621.

[10] Seth Stein, Joseph Tomasello, and Andrew Newman, "Should Memphis Build for California's Earthquakes?", *Eos*, v. 84, no. 19, (May 13, 2003), pp. 177, 184-185.

[11] In contrast to California, where earthquakes occur on the active margin of the North American tectonic plate, the New Madrid seismic zone is not on a plate boundary but may be related to old faults in the interior of the plate, marking a zone of tectonic weakness.

[12] The largest earthquakes in New York, New Jersey, and Massachusetts were, respectively, 1944 Massena, NY, magnitude 5.8, felt from Canada south to Maryland; 1783 New Jersey, magnitude 5.3, felt from New Hampshire to Pennsylvania; 1755 Cape Ann and Boston, MA, intensity of VIII on the Modified Mercalli Scale, felt from Nova Scotia to Chesapeake Bay (USGS Earthquake Hazards Program).

[13] FEMA 366 and USGS Circular 1188, Table 3.

(GSN) in more than 80 countries. The GSN provides worldwide coverage of earthquakes, including reporting and research, and also monitors nuclear explosions.

Advanced National Seismic System (ANSS). "The mission of ANSS is to provide accurate and timely data and information products for seismic events, including their effects on buildings and structures, employing modern monitoring methods and technologies."[14] If fully implemented, ANSS would encompass more than 7,000 earthquake sensor systems covering parts of the nation vulnerable to earthquake hazards. Currently, the system includes 696 stations that comprise its backbone stations, dense urban networks, and existing regional networks.[15] Approximately 6,000 of the planned stations will be installed in 26 high-risk urban areas to monitor strong ground shaking and how buildings and other structures respond. Currently, five high-risk urban areas have instruments deployed in sufficient density to generate the data to produce near real-time maps, called ShakeMaps,[16] which can be used in emergency response during and after an earthquake.

Approximately 1,000 new instruments will replace aging and obsolete stations in the networks that now monitor the nation's most seismically active regions. The current regional networks contain a mix of modern, digital, broadband, and high-resolution instruments that can provide real-time data together with older instruments that may require manual downloading of data. Universities in the region typically operate the regional networks and will continue to do so as ANSS is implemented.

Lastly, approximately 100 instruments comprise the existing "backbone" of ANSS, with a roughly uniform distribution across the United States, including Alaska and Hawaii. These instruments provide a broad and uniform minimum threshold of coverage across the country. The backbone network consists of USGS-deployed instruments and other instruments that serve both ANSS and the EarthScope project (described below, under "Research — Understanding Earthquakes").

In 2004, Congress passed the National Earthquake Hazards Reduction Program Reauthorization Act of 2004 (P.L. 108-360), which authorized $30 million for ANSS in FY2005 and $36 million per year through FY2009. Congress first authorized the program with P.L. 106-503 at a level of $38 million for FY2002 and $44 million FY2003. Total expenditures for ANSS from FY2002 to FY2006 are slightly more than $28 million, or approximately 15% of authorized levels. Overall, ANSS is about 10% completed.

National Strong-Motion Project (NSMP). The USGS operates the NSMP to record seismic data from damaging earthquakes in the United States on the ground

[14] USGS Earthquake Hazards Program, at [http://earthquake.usgs.gov/research/monitoring/anss/].

[15] William Leith, USGS, telephone conversation Oct. 30, 2006.

[16] ShakeMap is a product of the USGS Earthquake Hazards Program in conjunction with regional seismic network operators, and is discussed in more detail below.

and in buildings and other structures in densely urbanized areas. The program currently has 900 strong-motion[17] instruments in 701 permanent stations across the United States and in the Caribbean. The NSMP has three components: data acquisition, data management, and research. The near real-time measurements collected by the NSMP are used by other government agencies for emergency response and real-time warnings. If fully implemented, the ANSS program would deploy about 3,000 strong-motion instruments, and the NSMP program would operate those strong-motion instruments located in buildings and other structures. Many of the NSMP instruments currently deployed are older designs and are being upgraded with modern seismometers.

Global Seismic Network (GSN). The GSN is a system of broadband digital seismographs arrayed around the globe and designed to collect high-quality data that are readily accessible to users worldwide, typically via computer modems. Currently, 140 stations in 80 countries have been installed and the system is nearly complete, although the spacing and location of stations has not fully met the original goal of uniform spacing of approximately 2,000 kilometers. The system is currently providing data to the United States and other countries and institutions for earthquake reporting and research, and for monitoring nuclear explosions to assess compliance with the Comprehensive Test Ban Treaty. The Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Tsunami Relief, 2005 (P.L. 109-13) provided more than $8 million to the USGS to help make the GSN capable of real-time communications.[18]

The Incorporated Research Institutions for Seismology (IRIS)[19] coordinates the GSN and manages and makes available the large amounts of data that are generated from the network. The actual network of seismographs is organized into two main components, each managed separately. The USGS operates two-thirds of the stations from its Albuquerque Seismological Laboratory, and the University of California-San Diego manages the other third via its Project IDA (International Deployment of Accelerometers). Other universities and affiliated agencies and institutions operate a small number of additional stations. IRIS, with funding from the NSF, supports all of the stations not funded through the USGS appropriations.

Detection, Notification, and Warning

Unlike other natural hazards, such as hurricanes, where predicting the location and timing of landfall is becoming increasingly accurate, the scientific understanding of earthquakes does not yet allow for precise advance warnings to vulnerable populations. Instead, notification and warning typically involves communicating the

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[17] Strong motion seismometers, or accelerometers, are special sensors that measure the acceleration of the ground during large (>6.0 magnitude) earthquakes.

[18] See also CRS Report RL32739, *Tsunamis: Monitoring, Detection, and Early Warning Systems,* by Wayne A. Morrissey.

[19] IRIS is a university research consortium, primarily funded by NSF, that collects and distributes seismographic data.

location and magnitude of an earthquake as soon as possible after the event to emergency response providers and others who need the information.

Short-term probabilistic earthquake forecasts are being made available now that give, for example, a 24-hour probability of strong earthquake shaking for a particular region, such as California. These forecasts are not predictions, and are currently intended to increase public awareness of the seismic hazard, improve emergency response, and increase scientific understanding of the short-term hazard.[20] In the California example, a time-dependent map is created and updated every hour by a system that considers all earthquakes, large and small, detected by the California Integrated Seismic Network[21] and that calculates a probability that each earthquake will be followed by an aftershock[22] that can cause strong shaking. The probabilities are calculated from known behavior of aftershocks and the possible shaking pattern based on historical data.

When a destructive earthquake occurs in the United States or in other countries, the first reports of its location, or epicenter,[23] and magnitude often originate from the National Earthquake Information Center in Golden, CO, or from one of the regional seismic networks that are part of ANSS. Other organizations, such as universities, consortia, and individual seismologists may also contribute information about the earthquake after the event. Products, such as ShakeMap, are assembled as rapidly as possible to assist in emergency response and damage estimation following a destructive earthquake.

National Earthquake Information Center (NEIC). The NEIC, part of the USGS, is currently located in Golden, CO. Originally established as part of the National Ocean Survey (Department of Commerce) in 1966, the NEIC was made part of the USGS in 1973 and moved to Golden from Boulder (CO) in 1974. With data gathered from the networks described above and from other sources, the NEIC determines the location and size of all destructive earthquakes that occur worldwide and disseminates the information to the appropriate national or international agencies, government public information channels, news media, scientists and scientific groups, and the general public.

The NEIC has long-standing agreements with key emergency response groups, federal, state, and local authorities, and other key organizations in earthquake-prone

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[20] USGS Open-File Report 2004-1390, and California 24-hour Aftershock Forecast Map, at [http://pasadena.wr.usgs.gov/step/].

[21] The California Integrated Seismic Network is the California region of ANSS; see [http://www.cisn.org/].

[22] Earthquakes typically occur in clusters, in which the earthquake with the largest magnitude is called the main shock, events before the main shock are called foreshocks, and those after are called aftershocks. See also [http://pasadena.wr.usgs.gov/step/aftershocks.html].

[23] The *epicenter* of an earthquake is the point on the earth's surface directly above the hypocenter. The *hypocenter* is the location beneath the earth's surface where the fault rupture begins.

regions who receive automated alerts — typically location and magnitude of an earthquake — within a few minutes of an event in the United States. The NEIC sends these preliminary alerts by email and pager immediately after an earthquake is detected and its magnitude and epicenter are automatically determined by computer.[24] This initial determination is then checked by around-the-clock staff who confirm and update the magnitude and location data.[25] After the confirmation, a second set of notifications and confirmations are triggered to key recipients by email, pager, fax, and telephone.

For earthquakes outside the United States, the NEIC notifies the State Department Operations Center, and often sends alerts directly to staff at American embassies and consulates in the affected countries, to the International Red Cross, the U.N. Department of Humanitarian Affairs, and other recipients who have made arrangements to receive alerts.

With the advent of the USGS Earthquake Notification Service (ENS), notifications of earthquakes detected by the ANSS/NEIC are provided free to interested parties in a customizable format. Users of the service can specify the regions of interest, establish notification thresholds of earthquake magnitude, designate whether they wish to receive notification of aftershocks, and even set different magnitude thresholds for daytime or nighttime to trigger a notification.

ShakeMap. Traditionally, the information commonly available following a destructive earthquake has been epicenter and magnitude, as in the data provided by the NEIC described above. Those two parameters by themselves, however, do not always indicate the intensity of shaking and extent of damage following a major earthquake. Recently, the USGS developed a product called ShakeMap that provides a near real-time map of ground motion and shaking intensity following a major earthquake in areas of the United States where the ShakeMap system is in place. Currently, ShakeMaps are available for northern California, southern California, the Pacific Northwest, Nevada, Utah, and Alaska.[26]

With improvements to the regional seismographic networks in the areas where ShakeMap is available, new real-time data telemetry from the instruments deployed in the region, and advances in digital communication and computation, ShakeMaps are now triggered automatically and made available within minutes of the event via the Web. In addition, better maps are now available because of recent improvements in understanding the relationship between the ground motions recorded during the earthquake and the intensity of resulting damage. The maps produced portray the extent of damaging shaking and can be used by emergency response and for estimating loss following a major earthquake. If databases containing inventories of

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[24] Stuart Simkin, NEIC, Golden, CO, telephone conversation, Nov. 4, 2006.

[25] In early 2006, the NEIC implemented an around-the-clock operation center and seismic event processing center in response to the Indonesian earthquake and resulting tsunami of December 2004. Funding to implement 24/7 operations was provided by P.L. 109-13.

[26] See [http://earthquake.usgs.gov/eqcenter/shakemap/].

buildings and lifelines are available, they can be combined with shaking intensity data to produce maps of estimated damage.

The ShakeMaps have limitations, especially during the first few minutes following an earthquake before more data arrive from distributed sources. Because they are generated automatically, the initial maps are preliminary, and may not have been checked by human oversight when first made available. They are considered a work in progress, but are deemed to be very promising, especially as more modern seismic instruments are added to the regional networks under ANSS and the computational and telecommunication ability improves.

National Earthquake Hazards Reduction Program (NEHRP)

In 1977 Congress passed the Earthquake Hazards Reduction Act (P.L. 95-124) establishing NEHRP as a long-term earthquake risk reduction program for the United States. The program initially focused on research, led by USGS and NSF, toward understanding and ultimately predicting earthquakes. Earthquake prediction has proved to be intractable thus far and the NEHRP program shifted its focus to minimizing losses from earthquakes after they occur. FEMA was created in 1979 and President Carter designated it as the lead agency for NEHRP. In 1980, Congress reauthorized the Earthquake Hazards Reduction Act (P.L. 96-472), defining FEMA as the lead agency and authorizing additional funding for earthquake hazard preparedness and mitigation to FEMA and the National Bureau of Standards (now NIST).

Mitigation. In 1990, Congress reauthorized NEHRP (P.L. 101-614) and made substantive changes, to decrease the emphasis on earthquake prediction, clarify the role of FEMA, clarify and expand the program objectives, and require federal agencies to adopt seismic safety standards for new and existing federal buildings. In 2004, Congress reauthorized NEHRP through FY2009 (P.L. 108-360) and shifted primary responsibility for planning and coordinating NEHRP from FEMA to NIST. It also established a new interagency coordinating committee and a new advisory committee, both focused on earthquake hazards reduction.

The current program activities are focused on four broad areas:

- developing effective measures to reduce earthquake hazards;
- promoting the adoption of earthquake hazards reduction measures by federal, state, and local governments, national building standards and model building code organizations, engineers, architects, building owners, and others who play a role in planning and constructing buildings, bridges, structures, and critical infrastructure or lifelines;[27]
- improving the basic understanding of earthquakes and their effects on people and infrastructure, through interdisciplinary research involving engineering, natural sciences, and social, economic, and decision sciences; and

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[27] *Lifelines* are essential utility and transportation systems.

- developing and maintaining ANSS, the George R. Brown Jr. Network for Earthquake Engineering Simulation (NEES),[28] and the GSN.

The House Science Committee report on the bill noted that NEHRP has produced a wealth of useful information since 1977, but it also stated that the program's potential has been limited by the inability of the NEHRP agencies to create synergy through coordinated efforts.[29] The committee felt that restructuring the program with NIST as the lead agency, directing funding towards appropriate priorities, and implementing it as a true interagency program would lead to improvement.

Under the reauthorization, the Director of NIST chairs the Interagency Coordinating Committee, which is composed of the directors of FEMA, USGS, NSF, the Office of Science and Technology Policy, and the Office of Management and Budget. The Interagency Coordinating Committee is charged with overseeing the planning, management, and coordination of the program. Primary responsibilities for the NEHRP agencies break down as follows:

- NIST supports the development of performance-based seismic engineering tools and works with other groups to promote the commercial application of the tools through building codes, standards, and construction practices.
- FEMA assists other agencies and private-sector groups to prepare and disseminate building codes and practices for structures and lifelines, and aid development of performance-based codes for buildings and other structures.
- USGS conducts research and other activities to characterize and assess earthquake risks, and (1) operates a forum, using the NEIC, for the international exchange of earthquake information, (2) works with other NEHRP agencies to coordinate activities with earthquake reduction efforts in other countries, and (3) maintains seismic hazard maps in support of building codes for structures and lifelines, and other maps needed for performance-based design approaches.
- NSF supports research to improve safety and performance of buildings, structures, and lifelines using the large-scale experimental and computational facilities of NEES and other institutions engaged in research and implementation of NEHRP.

Table 5 shows authorization of appropriations for NEHRP. The funding authorization for ANSS and NEES are broken out separately in P.L. 108-360 and are shown in **Table 6**.

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[28] NEES is an NSF-funded project that consists of 15 experimental facilities and an IT infrastructure with a goal of mitigating earthquake damage by the use of improved materials, designs, construction techniques, and monitoring tools.

[29] U.S. House, Committee on Science, *National Earthquake Hazards Reduction Program Reauthorization Act of 2003*, H.Rept. 108-246 (Aug. 14, 2003), p. 13.

Table 5. Authorization Levels for NEHRP by Agency

($ millions)

	FY2005	FY2006	FY2007	FY2008	FY2009
NIST	10.00	11.00	12.1o	13.31	14.64
FEMA	21.00	21.63	22.28	22.95	23.64
USGS	47.00	48.41	49.86	51.36	52.90
NSF	38.00	39.14	40.31	41.52	42.77
Total	*116.00*	*120.18*	*124.55*	*129.14*	*133.95*

Table 6. Authorization Levels for ANSS and NEES

($ millions)

	FY2005	FY2006	FY2007	FY2008	FY2009
ANSS	30.00	36.00	36.00	36.00	36.00
NEES	20.00	20.40	20.87	21.39	21.93
Total	*50.00*	*56.40*	*56.87*	*57.39*	*57.93*

HAZUS-MH. FEMA, under contract with the National Institute of Building Sciences,[30] developed a methodology and software program called the Hazards U.S. Multi-Hazard (HAZUS-MH).[31] The program allows a user to estimate losses from damaging earthquakes, hurricane winds, and floods before a disaster occurs. The pre-disaster estimates could provide a basis for developing mitigation plans and policies, preparing for emergencies, and planning response and recovery. HAZUS-MH combines existing scientific knowledge about earthquakes (for example, ShakeMaps, described above), engineering information that includes data on how structures respond to shaking, and geographic information system (GIS) software to produce maps and display hazards data including economic loss estimates. The loss estimates produced by HAZUS-MH include the following:

- physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure;
- economic loss, including lost jobs, business interruptions, repair and reconstruction costs; and

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[30] The National Institute of Building Sciences (NIBS) is a non-profit non-governmental organization established by Congress in the Housing and Community Development Act of 1974 (PL 99-383). NIBS is funded through dues from its membership, private sector contributions, and contracts with federal and state agencies. The mission of NIBS is to improve the building regulatory environment, facilitate introducing new products and technologies into the building process, and disseminate technical and regulatory information. See [http://www.nibs.org/].

[31] See [http://www.fema.gov/plan/prevent/hazus/].

- social impacts, including estimates of shelter requirements, displaced households, and the number of people exposed to the disaster.

In addition to furnishing information as part of earthquake mitigation efforts, HAZUS-MH can also be used to support real-time emergency response activities by state and federal agencies after a disaster. Twenty-seven HAZUS-MH user groups[32] — cooperative ventures among private, public, and academic organizations that use the HAZUS-MH software — have formed across the United States to help foster better-informed risk management for earthquakes and other natural hazards. HAZUS-MH software was first released to the public in 1997 and the first user group, the Bay Area HAZUS-MH User Group, was formed the same year.

Research — Understanding Earthquakes

U.S. Geological Survey. Under NEHRP, the USGS has responsibility for conducting targeted research into improving the basic scientific understanding of earthquake processes. The current earthquake research program at the USGS covers six broad categories:[33]

- *Borehole geophysics and rock mechanics*: studies to understand heat flow, stress, fluid pressure, and the mechanical behavior of fault-zone materials at seismogenic[34] depths to yield improved models of the earthquake cycle.
- *Crustal deformation*: studies of the distortion or deformation of the earth's surface near active faults as a result of the motion of tectonic plates.
- *Earthquake geology and paleoseismology*: studies of the history, effects, and mechanics of earthquakes.
- *Earthquake hazards*: studies of where, why, when, and how earthquakes occur.
- *Regional and whole-earth structure*: studies using seismic waves from earthquakes and man-made sources to determine the structure of the planet ranging from the local scale, to the whole crust, mantle, and even the earth's core.
- *Strong-motion seismology, site response, and ground motion*: studies of large-amplitude ground motions and the response of engineered structures to those motions using accelerometers.

National Science Foundation. NSF supports fundamental research into understanding the earth's dynamic crust. Through its Earth Sciences Division[35] (part of the Geosciences Directorate), NSF distributes research grants and coordinates programs investigating the crustal processes that lead to earthquakes around the

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[32] See [http://www.hazus.org/].

[33] See [http://earthquake.usgs.gov/research/].

[34] Seismogenic means capable of generating earthquakes.

[35] See [http://www.nsf.gov/div/index.jsp?div=EAR].

globe. Recently, NSF initiated a Major Research Equipment and Facilities Construction (MREFC) project called EarthScope.[36] EarthScope is deploying instruments across the United States to study the structure and evolution of the North American Continent, and to investigate the physical processes that cause earthquakes and volcanic eruptions. EarthScope, a five-year, $200 million project, began in 2003, is funded by NSF, and is conducted in partnership with the USGS and NASA.

EarthScope instruments will form a framework for broad, integrated studies of the four-dimensional (three spatial dimensions, plus time) structure of North America. The project is divided into three main programs:

- *The San Andreas Fault Observatory at Depth (SAFOD)*: a deep borehole observatory drilled through the San Andreas fault zone close to the hypocenter of the 1966 Parkfield, CA, magnitude 6 earthquake.
- *The Plate Boundary Observatory (PBO)*: a system of GPS arrays and strainmeters[37] that measure the active boundary zone between the Pacific and North American tectonic plates in the western United States.
- *USArray*: four hundred transportable seismometers that will be deployed systematically across the United States on a uniform grid to provide a complete image of North America from continuous seismic measurements.

Through its Engineering Directorate, NSF funds NEES,[38] a project intended to operate until 2014, aimed at understanding the effects of earthquakes on structures and materials. To achieve the program's goal, the facilities conduct experiments and computer simulations of how buildings, bridges, utilities, coastal regions, and materials behave during an earthquake. **Table 6** (above) shows authorization levels for NEES through 2009.

Additional Reading

Aspects of the federal role in the aftermath of a damaging earthquake or other natural catastrophes — the response and recovery phase — are covered in the following CRS reports.

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[36] See [http://www.earthscope.org/].

[37] A strainmeter is a tool used by seismologists to measure the motion of one point relative to another.

[38] A non-profit NEES consortium (NEESinc.) has operated the facilities for the 10-year operating lifespan at the following institutions: Cornell University; Lehigh University; Oregon State University; Renssalaer Polytechnical Institute; University of Buffalo-State University of New York; University of California-Berkeley; University of California-Davis; University of California-Los Angeles; University of California-San Diego; University of California-Santa Barbara; University of Colorado-Boulder; University of Illinois at Urbana-Champaign; University of Minnesota; University of Nevada-Reno; University of Texas at Austin. See [http://www.nees.org/].

CRS Report RL33330, *Community Development Block Grant Funds in Disaster Relief and Recovery*, by Eugene Boyd.

CRS Report RL32847, *Tsunamis and Earthquakes: Is Federal Disaster Insurance in Our Future?,* by Rawle O. King.

CRS Report RL33060, *Tax Deductions for Catastrophic Risk Insurance Reserves: Explanation and Economic Risk Analysi*s, by David L. Brumbaugh and Rawle O. King.

CRS Report RS22268, *Repairing and Reconstructing Disaster-Damaged Roads and Bridges: The Role of Federal-Aid Highway Assistance*, by Robert S. Kirk.

CRS Report RS22248, *Federal Disaster and Emergency Assistance for Water Infrastructure Facilities and Supplies*, by Claudia Copeland, Mary Tiemann, and Nicole T. Carter.

CRS Report RL33206, *Vulnerability of Concentrated Critical Infrastructure: Background and Policy Options*, by Paul W. Parfomak.

CRS Report RS22273, *Emergency Contracting Authoritie*s, by John R. Luckey.