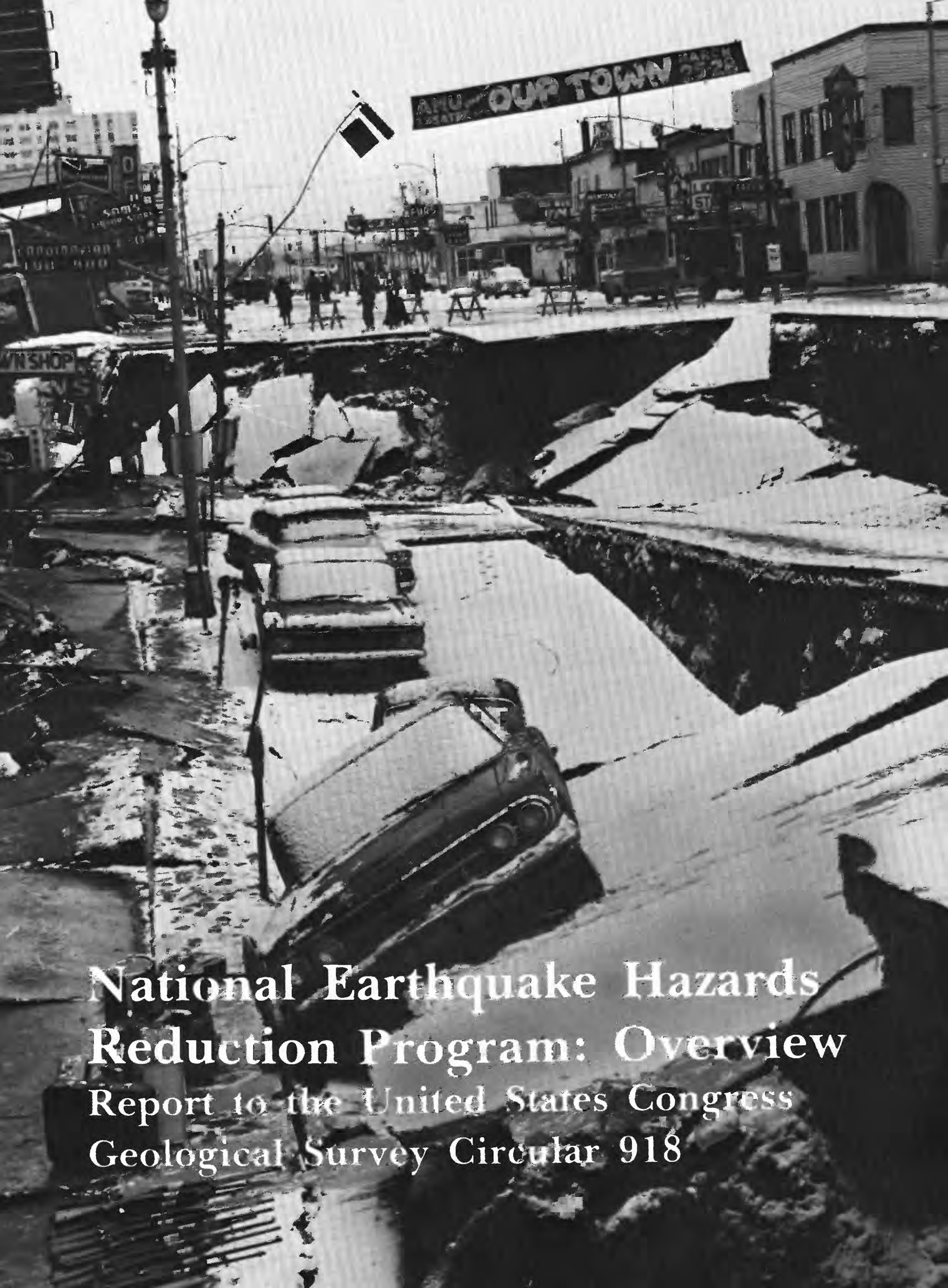

National Earthquake Hazards Reduction Program: Overview

Report to the United States Congress

Geological Survey Circular 918

Damage caused by the Good Friday earthquake, Anchorage, Alaska, March 27, 1964. The north side of Fourth Avenue and a row of cars parked on it subsided about 20 feet when the crown of a large landslide opened beneath the street during the great 1964 Alaskan earthquake. The earthquake caused 131 deaths and more than $1.02 billion in property damage. (Photograph, United Press International.)

National Earthquake Hazards Reduction Program: Report to the United States Congress

Overview

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Geological Survey Circular 918

Prepared by the
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Turnagain Heights landslide, Anchorage, caused by the 1964 Prince William Sound, Alaska, earthquake. (Photograph, Alaska Pictorial Service.)

FOCUS

A catastrophic earthquake poses perhaps the greatest natural hazard faced by the Nation. Dollar losses in that one earthquake alone could total tens of billions of dollars, and fatalities and injuries could be in the tens of thousands. Damaging earthquakes have occurred in almost every region of the United States. Earthquakes in the United States during the 20th century have resulted in at least 1,380 deaths and have caused more than $5 billion in property damage. The significant probability of a large, perhaps great, earthquake in southern California in the next several decades is well known. Less well known is the high potential for large earthquakes in Alaska, the Great Basin and Rocky Mountain interior, Puerto Rico, the Virgin Islands, and the central Mississippi Valley within this century or early in the next.

In 1977, the United States Congress established the National Earthquake Hazards Reduction Program (NEHRP) to provide a comprehensive, integrated national program to reduce losses of life and property resulting from earthquakes. The Congress recognized that losses and disruption to the individual, community, State, and the Nation caused by earthquakes could be substantially reduced through the development and implementation of earthquake hazards reduction measures. The Congress directed the Federal Government to provide a central focus for leading, coordinating, and conducting earthquake research, hazard mitigation, and disaster preparedness.

Although nearly all Federal agencies contribute to the NEHRP, the Federal Emergency Management Agency, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards carry out principal responsibilities for the reduction of losses caused by earthquakes. Our agencies are acutely aware of the Nation's vulnerability to earthquakes and earthquake hazards and of the urgent need to promote public safety and welfare.

The reduction of earthquake hazards rightly occupies a place among our national priorities. Our agencies will work aggressively to ensure the success of the NEHRP.

Louis O. Giuffrida, *Director*
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EARTHQUAKES: A NATIONAL PROBLEM

Tens of potentially damaging earthquakes (magnitude ≥ 5) occur annually in the United States. In 1982 (a typical year), 70 magnitude ≥ 5 earthquakes occurred in the United States. Of these, there were 45 in Alaska, 22 in the contiguous 48 States, and 3 in Hawaii. Great magnitude ≥ 8 earthquakes are more infrequent, occurring in the United States on average about once every 12 years. Although earthquakes in the United States occur most frequently in States west of the Rocky Mountains, all 50 States, Puerto Rico, and the Virgin Islands have some degree of risk.

Earthquakes cause loss from ground shaking, surface faulting, tectonic uplift and subsidence, ground failures, and tsunamis. The economic loss increases typically as the magnitude increases and is most extensive for the infrequent great earthquakes of magnitude 8 and above. In this century, earthquakes in the United States have resulted in at least 1,380 deaths and have caused more than $5 billion in property damage (1979 dollars). Recent assessments prepared by the Federal Emergency Management Agency (FEMA) and the U.S. Geological Survey (USGS) indicate that there is a greater than 50 percent probability that a catastrophic earthquake will occur in the next 30 years in southern California. Dollar losses in that one earthquake likely would total tens of billions of dollars, and fatalities and injuries would be in the tens of thousands. Communities throughout the Nation, however, face the greatest threat of potential loss from moderate and large earthquakes which happen more frequently than great ones.

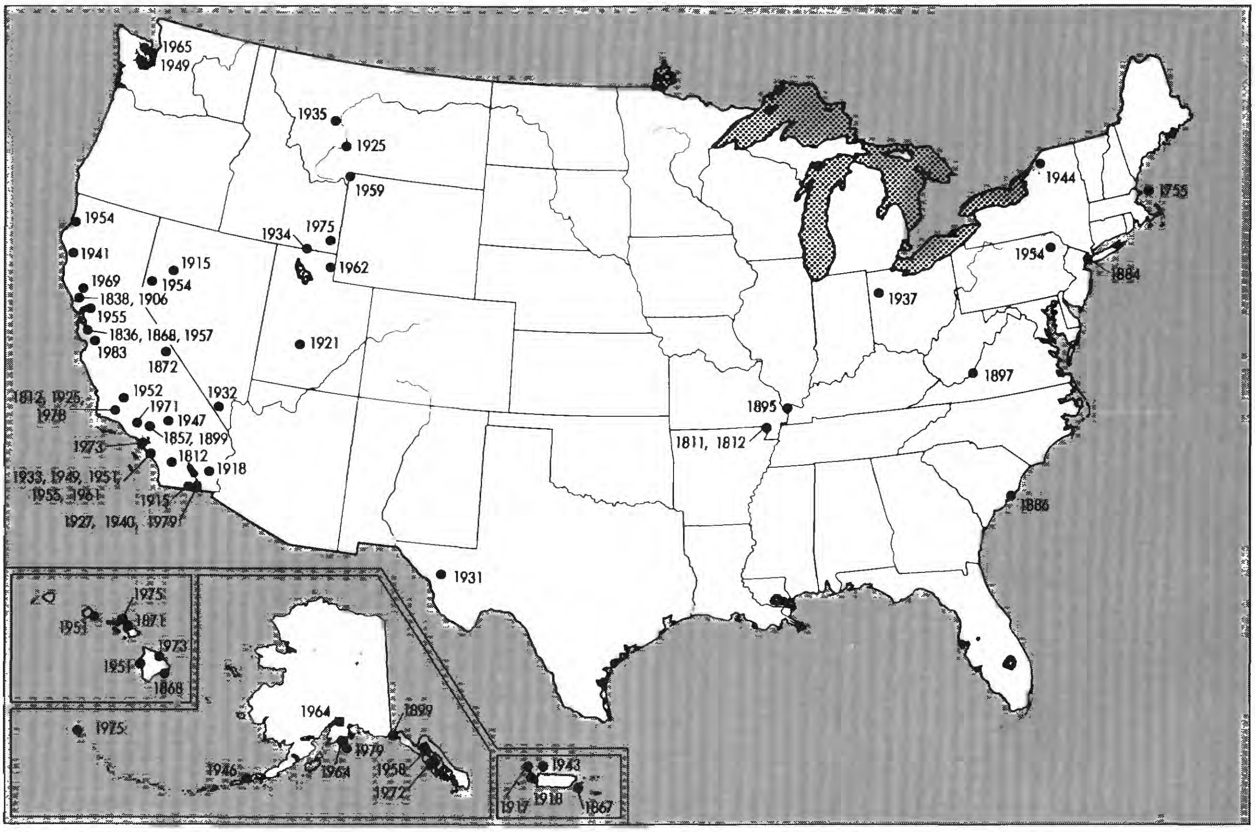
EARTHQUAKES

An earthquake is the sudden motion or trembling of the ground produced by abrupt displacement of rock masses, usually within the upper 10 to 20 miles of the Earth. Most earthquakes (apart from those associated with volcanic processes, landslides, and collapse of caverns) result from the movement of one rock mass past another in response to tectonic forces. Rock is elastic and can, up to a point, accumulate strain where adjacent areas of rock are subjected to forces pushing or pulling them. When the stress exceeds the strength of the rock, the rock breaks along a preexisting or new fracture plane called a fault.

The rupture extends outward along the fault plane from its point of origin, or focus. The epicenter of an earthquake is the point on the Earth's surface that is directly above the focus. The rupture usually does not proceed uniformly; its progress typically is jerky and irregular. Variations in rock properties and overburden pressures can bring the rupture front almost to a stop; then, because of the rearrangement of elastic forces, the rupture suddenly may break free and swiftly move out. The rupture will continue until it reaches the places at which the rock is not sufficiently strained to permit it to propagate further. If the rupture reaches the surface, it produces a visible surface break.

During the rupture, the sides of the fault rub against one another so that considerable energy is expended by frictional forces and in the crushing of rock. The surfaces are heated locally. Earthquake waves are generated at the same time by the rebounding of the adjacent sides of the fault at the rupture surface, as well as by the rubbing and crushing. The seismic energy is emitted from the rupture as seismic waves. The fastest are the primary, or P, waves, which are compression-dilation waves and travel in average crustal rocks at about 3 miles per second. The secondary, or S, waves, which are slower, are shear waves with a speed in the crust of about 2 miles per second. The slowest waves are surface waves, called Rayleigh and Love waves, whose depths of penetration are dependent on their wavelengths. They travel near the surface of the Earth with a speed of less than 2 miles per second.

Three men flee the J.C. Penny department store in downtown Anchorage, Alaska, as the structure's concrete facade falls to the street during the Good Friday earthquake, March 27, 1964. The earthquake caused 131 deaths and more than $1.02 billion in property damage. (Photograph, Wide World.)



Notable historic earthquakes in the United States that have caused damage are shown.

Significant, damaging earthquakes, 1755 to 1983, in the United States, Puerto Rico, and the Virgin Islands.
Damage in millions of dollars (1979 dollars)
[-- do ---ditto]

Date	Location	Damage	Dead	Magnitude					M_o, × 10^{25} dyn cm
				M[1]	M_L[2]	m_b[3]	M_s[4]	M[5]	
Nov. 18, 1755	Cape Ann, Massachusetts								
Dec. 16, 1811	New Madrid, Missouri					7.2	8.6	8.5	210
Jan. 23, 1812	---- do ----					7.1	8.4	7.5	210
Feb. 7, 1812	---- do ----					7.3	8.7	7.5	210
Dec. 8, 1812	San Juan Capistrano, California		40	6.9					
Dec. 21, 1812	Santa Barbara, California			7.1					

Significant, damaging earthquakes, 1755 to 1983, in the United States, Puerto Rico, and the Virgin Islands. Damage in millions of dollars (1979 dollars)—Continued

Date	Location	Damage	Dead	Magnitude					M_o, × 10^{25} dyn cm
				M[1]	M_L[2]	m_b[3]	M_s[4]	M[5]	
June 10, 1836	Hayward, California			6.8					
June 1838	San Francisco, California			7.0					
Apr. 16, 1844	Off Puerto Rico			7¼					
Jan. 9, 1857	Fort Tejon, California						8.3	7.8–7.9	530–900
Nov. 18, 1867	Virgin Islands			7¾–8					
Apr. 2, 1868	Hawaii, Hawaii			7½–7¾					
Oct. 21, 1868	Hayward, California			6.8					
Feb. 19, 1871	Off Molokai, Hawaii			7					
Mar. 26, 1872	Owens Valley, California		27					7.8	500
Aug. 10, 1884	New York City, New York		0						
Aug. 31, 1886	Charleston, South Carolina		60			6.8		6.8	20
Oct. 31, 1895	Charleston, Missouri					6.2			
May 31, 1897	Giles County, Virginia		0						
Sept. 3, 1899	Cape Yakataga, Alaska			8.3					
Sept. 10, 1899	Yakutat Bay, Alaska			8.6					
Dec. 25, 1899	Hemet, California		6	6.6					
Apr. 18, 1906	San Francisco, California	2,000	700		6.8–7		8¼	7.7	350–430
June 22, 1915	El Centro, California	10.6	6						
Oct. 2, 1915	Pleasant Valley, Nevada		0	7¾					
July 26, 1917	Mona Passage, Puerto Rico			7.0					
Apr. 21, 1918	Riverside County, California	1.4	0				6.8		

Significant, damaging earthquakes, 1755 to 1983, in the United States, Puerto Rico, and the Virgin Islands. Damage in millions of dollars (1979 dollars)—Continued

Date	Location	Damage	Dead	Magnitude					M_o, × 10^{25} dyn cm
				M[1]	M_L[2]	m_b[3]	M_s[4]	M[5]	
Oct. 11, 1918	Mona Passage, Puerto Rico	28.6	116				7.5		
Sept. 29, 1921	Elsinore, Utah		0						
Oct. 1, 1921	---- do ----		0						
June 27, 1925	Manhattan, Montana	1.8	0			6¾			
June 29, 1925	Santa Barbara, California	47	13		6.2				
Jan. 1, 1927	Imperial Valley, California	5.4	0		5.8				
Aug. 16, 1931	Mount Livermore, Texas		0	6.4					
Dec. 20, 1932	Cedar Mountain District, Nevada		0	7.3					
Mar. 11, 1933	Long Beach, California	266	115		6.3	6¼		6.2	2
Mar. 12, 1934	Kosmo, Utah		0	6.6					
Oct. 19, 1935	Helena, Montana	19	2				6.2		
Oct. 31, 1935	---- do ----	6	2				6.0		
Mar. 2, 1937	Anna, Ohio		0						
May 19, 1940	Imperial Valley, California	33	9		6.4		6.7	7.0	30
Nov. 14, 1941	Torrance, California	5	0				5.4		
July 28, 1943	Off Puerto Rico			7¾					
Sept. 5, 1944	Massena, New York	8	0				5.6		
Apr. 1, 1946	Unimak Island (Aleutians), Alaska	90	173				7.4		
Apr. 10, 1947	Barstow, California		0				6.4		
Apr. 13, 1949	Olympia, Washington	80	8				7.0		
Nov. 18, 1949	Long Beach Harbor, California	30	0		3.7				

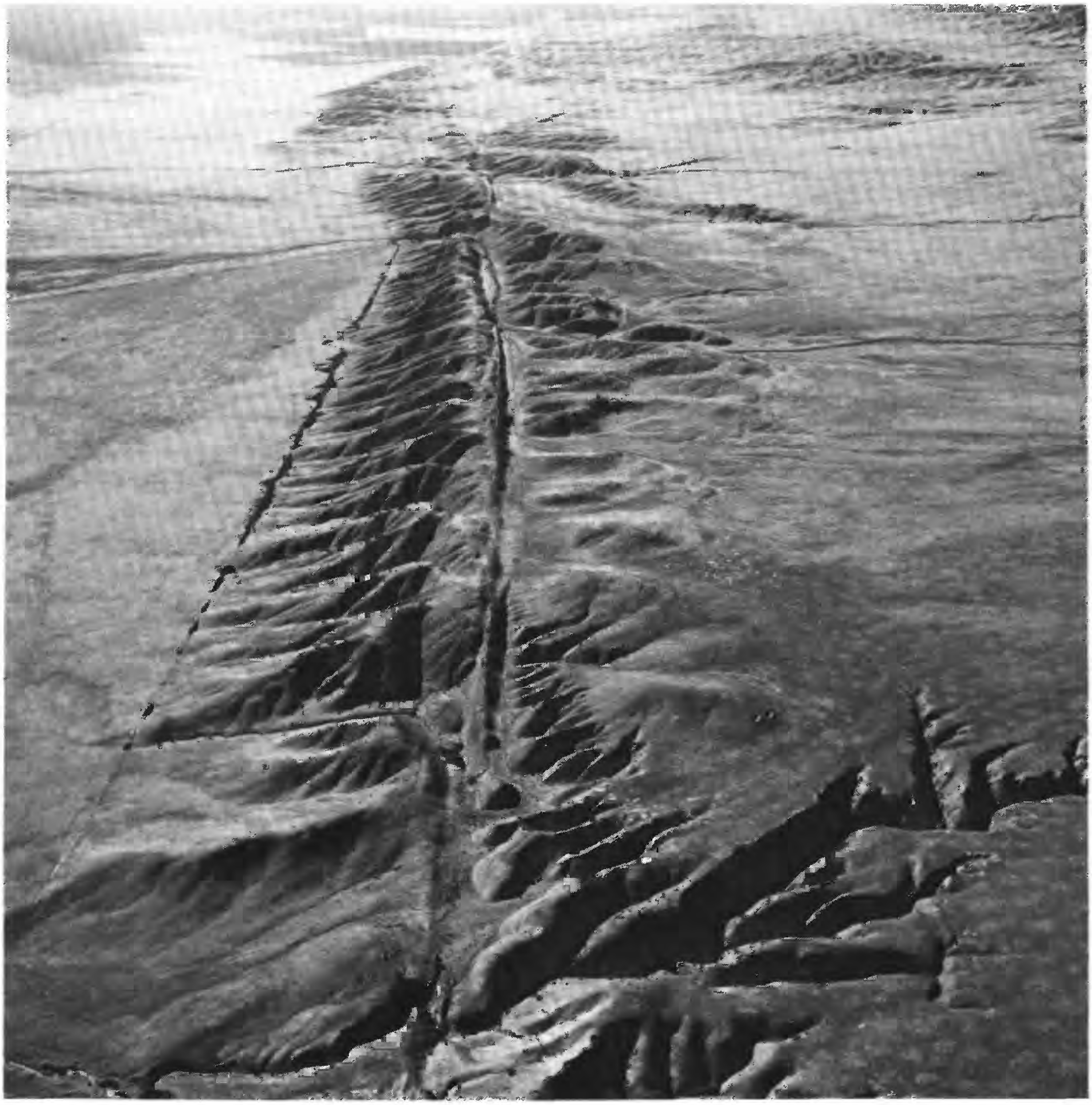
Significant, damaging earthquakes, 1755 to 1983, in the United States, Puerto Rico, and the Virgin Islands. Damage in millions of dollars (1979 dollars)—Continued

Date	Location	Damage	Dead	Magnitude					M_o, $\times 10^{25}$ dyn cm
				M^1	$M_L{}^2$	$m_b{}^3$	$M_s{}^4$	M^5	
Aug. 15, 1951	---- do ----	9	0						
Aug. 21, 1951	Kona, Hawaii		0				6.9		
July 25, 1952	Kern County, California	150	12		7.2		7.7	7.5	200
Aug. 22, 1952	Bakersfield, California	30	2				5.8		
Feb. 21, 1954	Wilkes-Barre, Pennsylvania	3	0						
July 6, 1954	Fallon, Nevada		0				6.8		
Dec. 16, 1954	Dixie Valley, Nevada		0	7.1					
Dec. 21, 1954	Eureka, California	6	1				6.6		
Jan. 25, 1955	Long Beach Harbor, California	8	0						
Oct. 23, 1955	Concord, California	3	1				5.4		
Mar. 9, 1957	Andreanof Islands (Aleutians), Alaska	8	0				8.3	9.1	
Mar. 22, 1957	Daly City, California	3	0				5.3		
July 9, 1958	Lituya Bay, Alaska		5				7.9	8.2	
Aug. 18, 1959	Hebgen Lake, Montana	26	28				7.1		
Apr. 4, 1961	Long Beach Harbor, California	11	0						
Aug. 30, 1962	Cache County, Utah	5	0				5.8		
Mar. 27, 1964	Prince William Sound, Alaska	1,020	131				8.4	9.2	82,000
Apr. 29, 1965	Seattle, Washington	28	7				6.5		
Oct. 1, 1969	Santa Rosa, California	13	0				5.6		
Feb. 9, 1971	San Fernando, California	900	58		6.4		6.6	6.6	10
July 30, 1972	Southeastern Alaska		0	7.6					

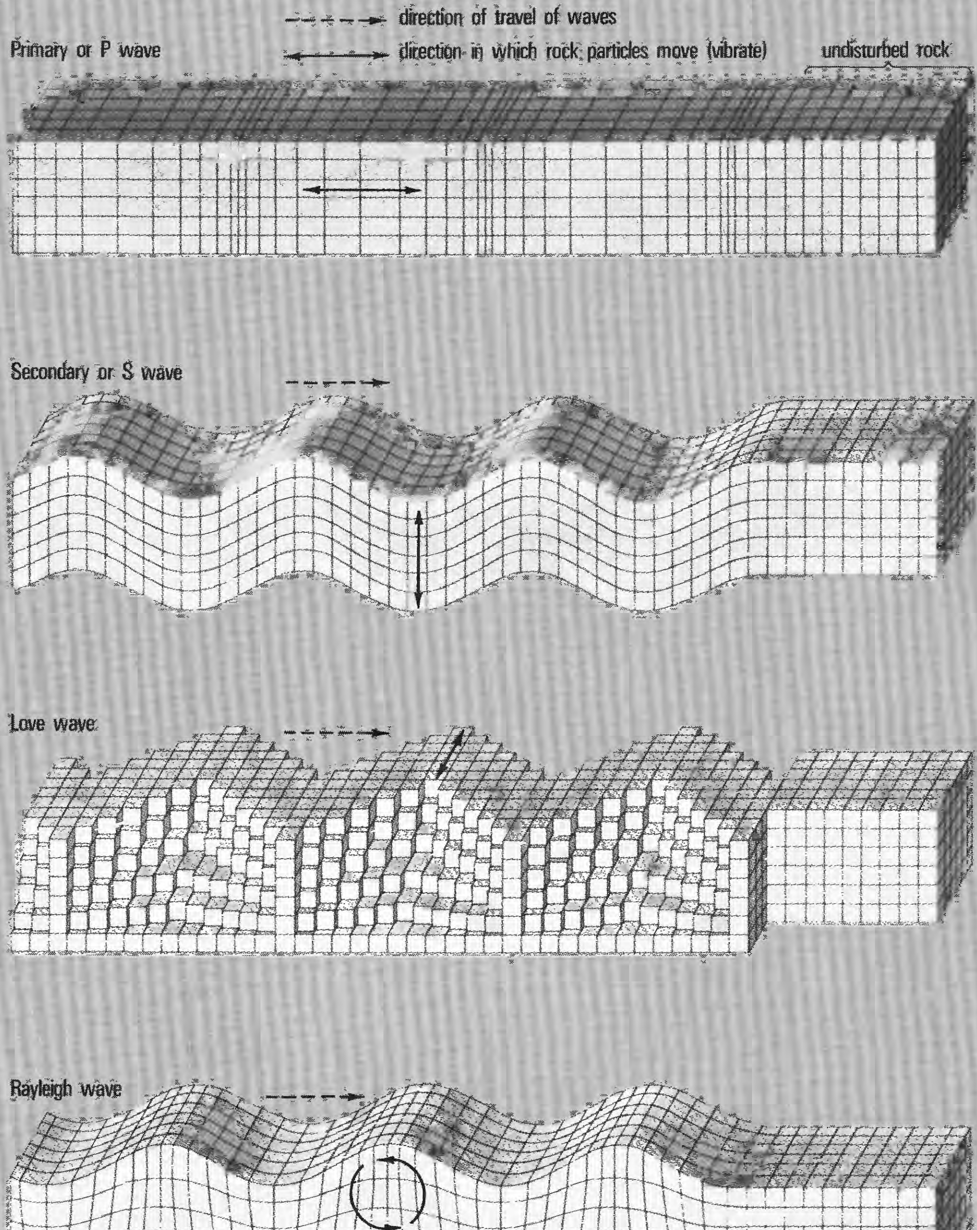
Significant, damaging earthquakes, 1755 to 1983, in the United States, Puerto Rico, and the Virgin Islands. Damage in millions of dollars (1979 dollars)—Continued

Date	Location	Damage	Dead	Magnitude					M_o, $\times 10^{25}$ dyn cm
				M[1]	M_L[2]	m_b[3]	M_s[4]	M[5]	
Feb. 21, 1973	Point Mugu, California	2	0				5.2		
Apr. 26, 1973	Hilo, Hawaii	9	0				6.2		
Feb. 2, 1975	Near Islands, Alaska		0	7.6					
Mar. 28, 1975	Pocatello Valley, Idaho	1	0				6.1		
Nov. 29, 1975	Kalapana, Hawaii	5	2				7.2		
Aug. 13, 1978	Santa Barbara, California	15	0				5.6		
Feb. 28, 1979	St. Elias, Alaska		0	7.1					
Oct. 15, 1979	Imperial Valley, California	21.1	0		6.6			6.5	6
May 2, 1983	Coalinga, California	31	0		6.7	6.2	6.5	6.4	5

[1]Unreferenced magnitude.
[2]Local (Richter) magnitude.
[3]Body-wave magnitude.
[4]Surface-wave magnitude.
[5]Moment magnitude.



This reach of the San Andreas fault, Carrizo Plain, California, has been "locked" since it last ruptured in the great Fort Tejon, California, earthquake (moment magnitude 7.8–7.9) of 1857. Geologic studies of past large slip events suggest that great earthquakes recur on this part of the San Andreas fault about every 140 to 300 years.


direction of travel of waves
direction in which rock particles move (vibrate)
Primary or P wave
undisturbed rock
Secondary or S wave
Love wave
Rayleigh wave

MAGNITUDE

Earthquake magnitude is a measure of the strength of an earthquake, or the strain energy released by it, as calculated from the instrumental record made by the event on a calibrated seismograph. In 1935, seismologist Charles F. Richter first defined local magnitude (M_L), or Richter magnitude, as the logarithm, to the base 10, of the amplitude in micrometers of the maximum amplitude of seismic waves that would be observed on a standard torsion seismograph at a distance of about 60 miles from the epicenter. The seismic waves used for local magnitude have periods ranging approximately from 0.1 to 2 seconds, equivalent to a wavelength of 1,000 feet to 3.8 miles.

Since 1935, more than one half dozen different magnitude scales have been devised to measure earthquake magnitude. Most magnitudes of earthquakes occurring at great distances (more than about 400 miles) from a seismograph station are determined using the logarithm of the amplitude of surface waves or body waves. The surface-wave magnitude scale (M_s) measures the amplitude of surface waves with a period of 20 seconds (a wavelength of about 38 miles), which are often dominant on the seismograms. The body-wave magnitude scale (m_b) measures seismic body waves, primary (P) and secondary (S), which have periods usually from 1 to 10 seconds.

The M_L and m_b magnitude scales "saturate" at magnitudes above approximately 7 and M_s saturates above 8.3. Above these thresholds, the scales continue to yield about the same maximum magnitude calculation even as seismic energy increases. The amplitudes of the short-period waves that are measured to determine magnitude do not continue to increase in size once the earthquake fault rupture length exceeds the wavelength of the short-period waves. The magnitudes of large (magnitude 7–8) and great (magnitude ≥8) earthquakes can be measured with a new magnitude scale, moment magnitude (**M**), which does not saturate with magnitude and is uniformly valid with respect to the Richter magnitude and surface-wave magnitude scales, where M_L is less than 7 and M_s is less than 7.5. Moment magnitude is derived from seismic moment, M_o, the product of the surface area of the fault, the average displacement on the fault plane, and the rigidity of the material of the fault. After certain corrections, M_o can be calculated from measurements of long-period waves (200–300 seconds) that typically accompany great earthquakes.

Earthquake magnitude, when cited without reference to any particular measurement scale, is usually reported as (M).

GROUND SHAKING

The body (P and S) and surface (Rayleigh and Love) seismic waves that propagate outward in all directions from the focus when a fault ruptures cause the ground to vibrate at frequencies ranging from about 0.1 to 30 Hertz. As a generalization, the severity of ground shaking increases as magnitude increases and decreases as distance from the causative fault increases. Buildings vibrate as a consequence of the ground shaking; damage takes place if the building cannot withstand these vibrations. Compressional waves (P waves) and shear waves (S waves) mainly cause high-frequency (greater than 1 Hertz) vibrations, which are more efficient than low-frequency waves in causing low buildings to vibrate. The fast-moving P waves are the first waves to cause vibration of a building. S waves arrive next and cause a structure to vibrate from side to side. They are the most damaging waves because buildings are more susceptible to damage from horizontal motion than from vertical motion. Rayleigh and Love waves, which arrive last, mainly cause low-frequency vibrations, which are more likely than high-frequency waves to cause tall buildings to vibrate. Because amplitudes of low-frequency vibrations decay less rapidly than high-frequency vibrations as distance from the fault increases, tall buildings located at relatively great distances (60 miles) from a fault are sometimes damaged.

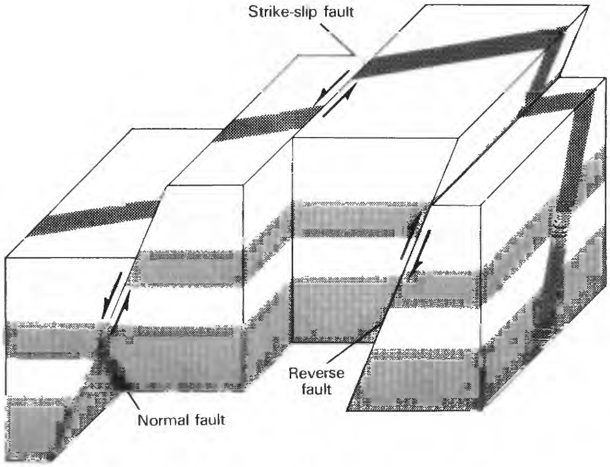
The ways in which seismic waves travel. Primary waves radiating outward from the focus of the earthquake alternately push (compress) and pull (dilate) the material through which they travel. Secondary waves shear the rock sideways at right angles to the direction of travel, producing an up-and-down and side-to-side oscillation like the snapping of a rope. The long waves that travel along the surface are more complex: Love waves whip back and forth horizontally and Rayleigh waves, like an ocean breaker, rotate the rock and soil in an elliptical pattern.

Damage at the Veterans Administration Hospital in Sylmar, California, which resulted from the 1971 San Fernando earthquake, presented a classic picture of inadequate vs. earthquake-resistive building design. The building at right, constructed in 1926 without earthquake-resistive features, collapsed "like smashed orange crates," according to one observer. The building was designed to carry only vertical loads and could not withstand the strong lateral forces it experienced during the severe ground shaking. The structures at left, built after 1933 and designed to resist strong earthquake forces, escaped without any significant structural damage. Forty-five persons died in the collapse of buildings at the hospital. (Photograph, *Los Angeles Times.*)

SURFACE FAULTING

Surface faulting—the offset or tearing of the Earth's surface by differential movement across a fault—is an obvious hazard to structures built across active faults. A variety of structures have been damaged by surface faulting, including houses, apartments, commercial buildings, nursing homes, railroads, highways, tunnels, bridges, canals, storm drains, water wells, and water, gas, and sewer lines. Surface faulting can be particularly severe for structures partially embedded in the ground and for buried pipelines and tunnels. In the Kern County, California, earthquake of July 25, 1952, three railroad tunnels were so badly damaged by faulting that traffic on a major rail linking northern and southern California was stopped for 25 days despite an around-the-clock repair schedule.

Losses from fault displacement, which have ranged from a fraction of an inch to more than 33 feet of differential offset, tend to be relatively low compared to losses from ground shaking. Surface faulting generally affects a long narrow zone, the total area of which is small compared with the total area affected by ground shaking. Most fault displacement is confined to zones ranging from a few inches to several hundred feet in width. Subsidiary branch faults have extended as much as 6 miles from the main fault, and secondary faulting has occurred 19 miles or more from the main fault. The lengths of the ruptures on land have ranged from a few hundred feet up to about 250 miles.



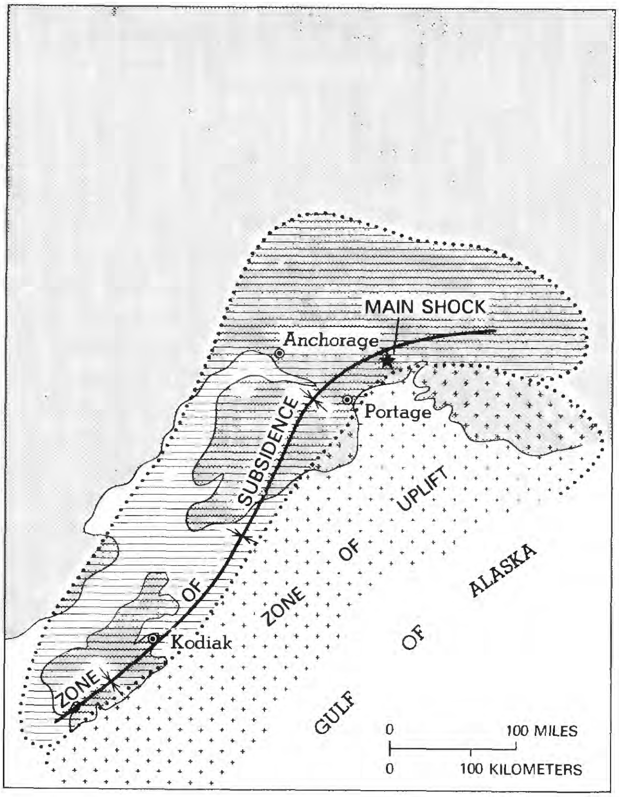
Three main types of surface faulting are dip-slip (normal and reverse), strike-slip, and oblique slip (a combination of strike-slip and dip-slip movement). Actual ruptures are typically complex and may consist of many branching or discontinuous fault breaks.

TECTONIC UPLIFT AND SUBSIDENCE

Tectonic deformation of the Earth's surface usually accompanies surface faulting. The deformation may be local, affecting a narrow zone near a fault break, or it may involve major differential vertical and horizontal movements over broad parts of the Earth's crust.

Surface faulting generally is accompanied by horizontal or vertical distortion of the Earth's surface within a few feet to a few hundred feet from the fault. This local deformation can distort or tilt structures constructed near the fault break. The distortion can result from drag (bending), rebound, or concealed closely spaced fractures. Fences offset by the San Andreas fault in the San Francisco, California, earthquake of 1906, for example, were distorted for distances of 40 to 1,800 feet from the fault. The distortion was greatest at the fault and decreased as distance from the fault increased.

This house was damaged by displacement along a thrust fault during the San Fernando earthquake on February 9, 1971. The house, which sits astride the fault (note humocky fault rupture), has been shortened and racked by compressional movement across the break. The garage, on the left side of the fault, has been carried toward the opposite end of the house, built on the right side of the fault break.



Regional crustal movements during the 1964 Alaskan earthquake were more extensive than any known to have been associated with previous earthquakes. Significant tectonic deformation, involving uplift, subsidence, and horizontal displacements, affected a minimum area of 77,000 square miles. The continental margin of central-southern Alaska was thrust seaward and uplifted, with elastic horizontal extension and subsidence behind. Maximum uplift in the Alaskan earthquake was 37 feet at Montague Island; the maximum measured subsidence was 8 feet.

Regional uplift and subsidence may accompany earthquakes that are caused by large displacements on shallow buried faults, particularly reverse or thrust faults. Regional tectonic deformation constitutes a hazard to shoreline facilities and extensive hydraulic systems where broad-scale changes in land elevation occur relative to water level. Such changes, either uplift or subsidence, can affect many hundreds of square miles of the Earth's surface, damaging harbor facilities, canals, and other structures. In the 1964 Alaska earthquake, piers, docks, breakwaters, highways, railroads, airstrips, houses, and other buildings were tectonically lowered relative to sea level, resulting in permanent or intermittent inundation. Tectonic uplift caused shallowing of harbors and waterways, which restricted their use, but subsidence improved navigation in a few places.

EARTHQUAKE-INDUCED GROUND FAILURES

Landslides, lateral spreads, differential settlements, and ground cracks induced by earthquake ground shaking are a principal cause of damage and casualties. In the 1906 San Francisco, California, earthquake, lateral spreads and ground settlement were responsible for considerable damage in the city, including the breaking of several major water pipelines that, in turn, left the city largely defenseless against the conflagration that followed.

LIQUEFACTION

During strong ground shaking, areas having clay-free sands and silts (typically deposited in the past 10,000 years) and ground water within 30 feet of the surface can temporarily lose strength and behave as viscous fluids. Structures founded on these materials can settle and (or) tip or be ripped apart as the ground spreads laterally or flows. This process, liquefaction, takes place when seismic shear waves pass through the saturated granular soil layer, distort its granular structure, and cause some of the void spaces to collapse. Disruptions to the soil generated by these collapses cause transfer of the ground-shaking load from grain-to-grain contacts to the pore water. This transfer of load increases pressure in the pore water, either causing drainage or, if drainage is restricted, a sudden buildup of pore-water pressures. When pore-water pressures reach a critical level (grain-to-grain stresses approach zero), the granular material suddenly behaves as a liquid rather than as a solid.

Ground shaking can cause lateral movement of large blocks of soil on top of a liquefied subsurface layer. These lateral spreads, which break up in numerous fissures and scarps, generally develop on gentle slopes, most commonly on those between 0.3 and 3 degrees. Horizontal movements on lateral spreads commonly are as much as 10 to 15 feet, but, where slopes are favorable and the

Homes and streets in Portage, Alaska, were flooded when the coastal village tectonically subsided about 6 feet during the 1964 Alaskan earthquake. An additional 2 to 4 feet of subsidence occurred locally because of liquefaction.

duration of ground shaking is long, lateral movement may be as much as 100 to 150 feet. During the 1964 Prince William Sound, Alaska, earthquake, lateral spread failures damaged highways and severely disrupted use of railway grades and bridges, requiring about $50 million in repairs.

Flow failures—consisting of liquefied soil or blocks of intact material riding on a layer of liquefied soil—can form in loose saturated sands or soil on slopes greater than 3 degrees. These flows typically move several tens of feet and, if conditions permit, can travel tens of miles at velocities as great as many tens of miles per hour. Submarine flow failures at Seward,

Water from a main ruptured by ground failure gushes onto Van Ness Avenue in San Francisco the morning of the 1906 earthquake. Smoke rises in the distance from an uncontrolled fire near Hayes Street that will eventually spread eastward into the city's financial district. Ground failures occurred mainly in areas underlain by fill over marsh and bay mud deposits, filled-in ravines, and sand dunes. (Photograph, California Historical Society, San Francisco.)

SEISMIC ENERGY

The energy release associated with an increase of one in magnitude is not tenfold but about thirtyfold. For example, approximately 900 times more energy is released in an earthquake of magnitude 7 than in a magnitude 5 earthquake. About 45,000,000,000,000,000,000,000,000 (4.5×10^{25}) ergs of seismic energy were released in the 1964 Prince William Sound, Alaska, earthquake of magnitude (**M**) 9.2. The seismic energy release nearly equaled the present annual total consumption of energy in the United States.

Whittier, and Valdez during the 1964 Alaskan earthquake carried away docks, warehouses, and adjacent transportation facilities costing about $15 million.

LANDSLIDES

Earthquake shaking can dislodge rock and debris on steep slopes, triggering rock falls, avalanches, and slides. Ground shaking can initiate shallow debris slides on steep slopes and, less commonly, rock slumps and block slides on moderate to steep slopes. Rarely, shaking can reactivate dormant slumps or block slides. Earthquake shaking can also trigger soil avalanches in some weakly cemented fine-grained materials, such as loess, that form steep stable slopes under nonseismic conditions.

Earthquake-induced avalanches can be very destructive. Two catastrophic rockfalls in the Santa Cruz Mountains, for example, triggered by the San Francisco earthquake of April 18, 1906, buried a saw mill and a shingle mill, which killed 10 men.

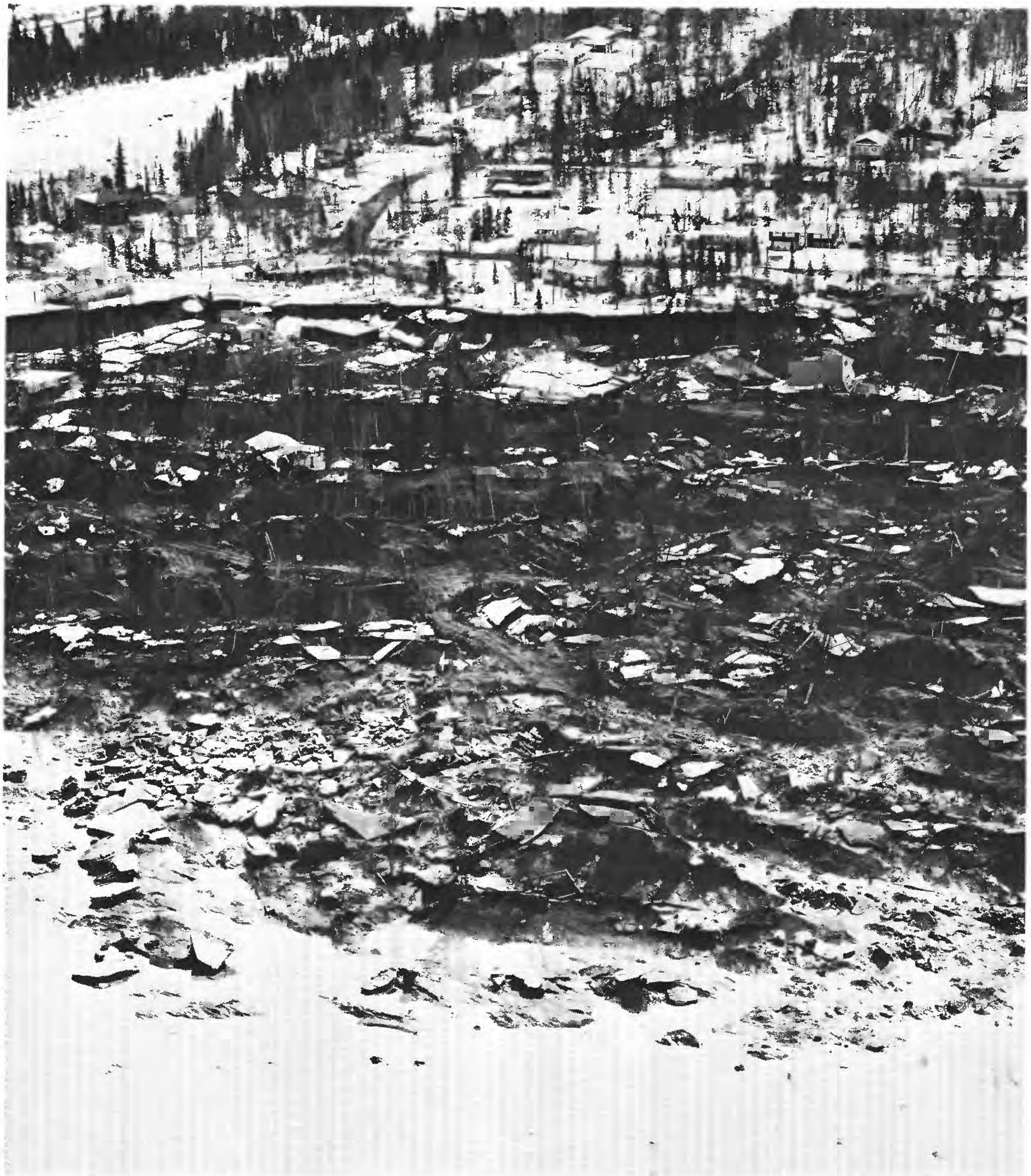
Intense earthquake shaking during the 1959 Hebgen Lake, Montana, earthquake triggered an enormous rock avalanche that blocked Madison Canyon with 37 million cubic yards of broken rock. Impounded by the slide, Madison River formed a lake, which 3 weeks afterward had become nearly 200 feet deep and 6 miles long. The landslide buried 26 people who were camped along the river.

"QUICK" CLAYS

Most clays lose shear strength when disturbed by ground shaking. If the loss of strength is large, or nearly complete, some clays, called "quick" or "sensitive," may fail. Failures of sensitive clays occurred during the 1964 Prince William Sound, Alaska, earthquake. In Anchorage, five major landslides were induced by a combination of loss of strength in sensitive clay layers and liquefaction of sand and silt lenses. The landslides disrupted 250 acres and caused an estimated $50 million in damages.

TSUNAMIS

A tsunami (a Japanese word meaning "harbor wave") is a series of waves of extremely long length and period typically caused by a sudden vertical displacement of a large area of the sea floor during an undersea earthquake. (Although tsunamis are often called tidal waves, they are not caused by the tidal action of the Moon and Sun.) The waves travel outward in all directions from the generating area, traveling at speeds of 300 to 600 miles per hour in the deep and open ocean. The distance between successive crests can be as much as 300 to 400 miles. In deep water, the height of the waves may be no more than 1 to 2 feet and may pass a surface vessel unnoticed. However, upon reaching shallower water around islands or on a continental shelf, the speed of the advancing wave diminishes, its length decreases, and its



Approximately 75 homes in the heavily populated residental section of Turnagain Heights, Anchorage, were destroyed during the 1964 Prince William Sound, Alaska, earthquake when the bluff above Knik Arm collapsed seaward in a complex landslide. A total area of about 130 acres was completely devastated by displacements that broke the ground into countless deranged blocks, which collapsed and tilted at odd angles. The failure zone of the slide passed through the Bootlegger Cove Formation, which contains layers of quick clay and lenses of saturated sand and silt. Severe ground shaking caused strength loss in the clays and liquefaction in the sand and silt lenses. (Photograph, Alaska Picture Service.)

A lone man (left) stands before a wall of water about to engulf him at Hilo, Hawaii, on April 1, 1946. This tsunami, which was generated by a magnitude (M_s) 7.2 earthquake south of Unimak Island in the Aleutian Islands, surged into Hilo Harbor, devastating the city's waterfront. Waves of 20 to 32 feet crashed over the city's breakwater, flooding the downtown area. The S.S. *Brigham Victory*, from which this photograph was taken, survived the tsunami, but 159 people in Hawaii, including the man seen here, were killed. Near the tsunami source, a lighthouse at Scotch Cap on Unimak Island was destroyed by waves that surged to a height of more than 100 feet. (Photograph, University of California, Berkeley, Water Resources Center Archives.)

height increases greatly, owing to the piling up of water. The advancing turbulent wave front of a tsunami may crash inland, sweeping all before it, sometimes beaching boats and ships thousands of feet inland. Successive wave crests, each typically arriving from 10 to 45 minutes later, may continue to pound the coast for several hours. Several days may pass before the sea returns to its normal state.

Most tsunamis are generated in the Pacific. Hawaii and the west coast of the United States have been struck repeatedly by tsunamis generated by earthquakes in South America and the Aleutian-Alaskan region. The 1964 Alaskan earthquake caused a tsunami having waves of more than 20 feet at Crescent City, California, and waves ranging from 10 to 16 feet along parts of the California, Oregon, and Washington coasts. Over $94 million in damage resulted in Alaska, California, Hawaii, Oregon, and Washington from the tsunami; fatalities totaled 122.

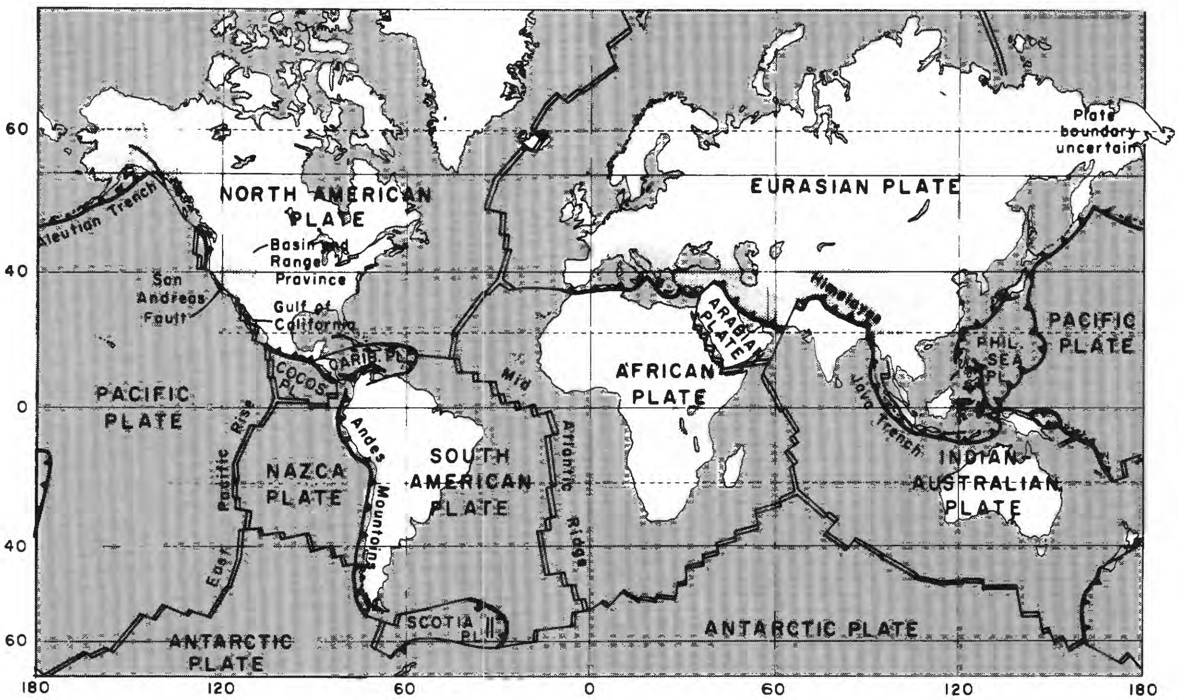
Tsunamis are rare, but not unknown, along the Atlantic coastline. A severe earthquake on November 18, 1929, in the Grand Banks of Newfoundland generated a seismic sea wave that caused considerable damage and loss of life at Placentia Bay, Newfoundland. Small sea waves were recorded along the east coast of the United States as far south as Charleston, South Carolina. In the Caribbean, a large earthquake on November 18, 1867, centered between St. Thomas and St. Croix caused sea waves more than 20 feet high that swept inland in the Virgin Islands and in Puerto Rico. A local tsunami accompanying a magnitude 7.5 earthquake that occurred offshore northwestern Puerto Rico on October 11, 1918, drowned many persons and destroyed numerous dwellings.

WHERE EARTHQUAKES OCCUR

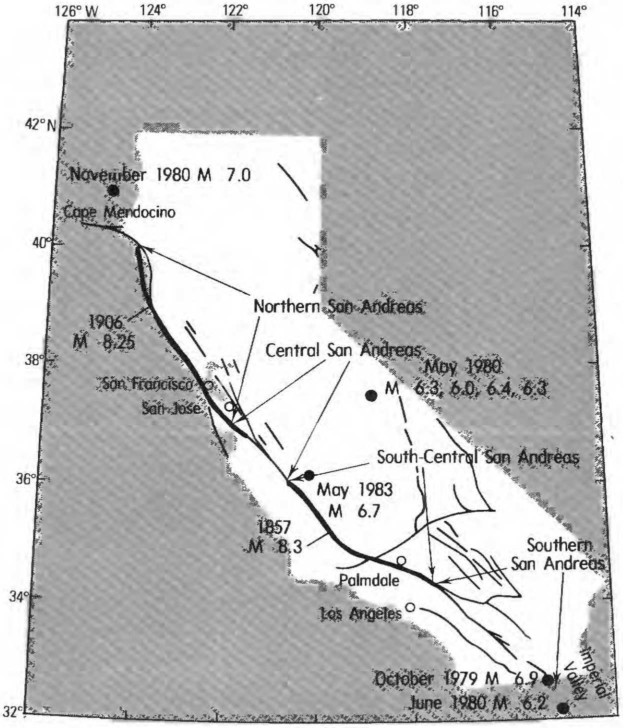
Earthquakes occur in virtually all 50 States, Puerto Rico, and the Virgin Islands. They occur most frequently in California, Alaska, and the Caribbean, in the grid of faults, chains of volcanoes and mountains, and deep oceanic trenches that represent the boundaries between the great crustal plates that form the Earth's lithosphere, or outer shell. Intraplate earthquakes—shocks occurring within the interior of the giant crustal plates—are less common, but they can be equally destructive. Most are located on recently active faults or in rifts that separate secondary crustal blocks.

CALIFORNIA

Analysis of seismic activity along the San Andreas fault has led to the identification of four distinct fault segments: the northern 270 miles of the fault that ruptured in 1906, the central 100-mile-long segment that adjoins the 1906 break to the south, the 220-mile-long south-central segment that last ruptured in a magnitude (M_S) 8.3 earthquake in 1857, and the southernmost 120 miles of the fault that terminates in the birthplace of the fault in the Imperial Valley. Estimates of the mean slip rate on each segment of the fault, when combined with detailed studies of ancient earthquakes preserved in the geologic record, give rather compatible estimates of long-term recurrence. When combined with the historic record of seismicity and measurements of crustal strain,



The Earth's crust and upper mantle are broken into a mosaic of rigid plates that move slowly and continuously over the interior of the Earth, meeting in some areas and separating in others. Velocities of relative motion between adjacent plates range from less than a fraction of an inch to about 5 inches per year. Although these velocities are slow by human standards, they are rapid by geologic ones; a motion of 2 inches per year adds up to 30 miles in only 1 million years. As these plates move, strain accumulates. Eventually, faults along or near plate boundaries slip abruptly, and an earthquake occurs.



Eight magnitude ≥6 earthquakes have occurred in or near California in the past 5 years, compared with only four in the previous 20 years. Segments of the San Andreas fault that ruptured in historic magnitude 8 earthquakes are shown by heavy lines.

On April 18, 1906, the Call Building in San Francisco smolders as fire approaches Market Street. Troops from Fort Mason, carrying rifles with fixed bayonets, patrol a rubble-strewn sidewalk. Left without water following the great earthquake, the city burned for 3 days. The fire consumed much of the city and left 250,000 people homeless. Over 700 lives were lost as a result of the earthquake, and property damage exceeded $500 million in 1906 dollars (similar damage in dollar values for the late 1970's would result in losses greater than $2 billion). (Photograph, University of California, Berkeley, Bancroft Library.)

they give some estimate of today's short-term risk.

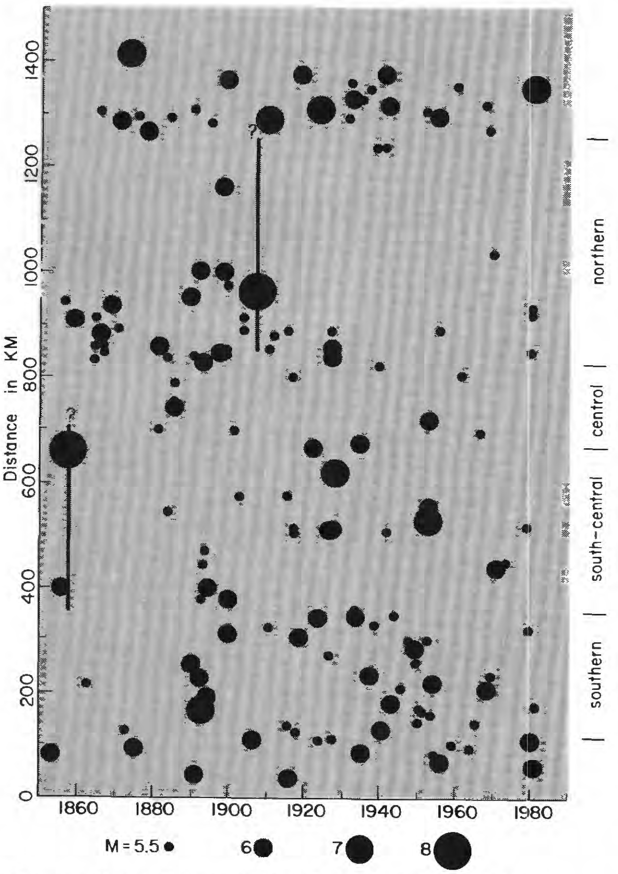
Northern San Andreas Fault

On April 18, 1906, the San Francisco Bay area and northern coastal California were struck by one of the most devastating earthquakes in the history of the United States. The great earthquake, magnitude (M_S) 8¼, ruptured the northernmost 270 miles of the 700-mile-long San Andreas fault. The ground along the fault north of San Francisco moved an average of more than 12 feet; south of the city the displacement was about 6 feet. Buildings were damaged in a 50-mile-wide region extending for more than 350 miles parallel to the fault break. The 1906 earthquake ended nearly a century of seismic activity characterized by the occurrence of about one large earthquake (magnitude 6–7) per decade in northern coastal California. One of these 19th century earthquakes, on the eastern shore of San Francisco Bay on the Hayward fault in 1868, caused such damage that, prior to 1906, it was popularly referred to as "the great earthquake."

Current data suggest that the recurrence of a magnitude 8 earthquake on the northern segment of the San Andreas fault between San Francisco and Cape Mendocino is unlikely within the next several decades. Geologic studies of the long-term slip rate on the northern San Andreas fault suggest that the average return time for a 1906-sized event is roughly 150 years. Contemporary strain data also suggest that approximately another 50 to 100 years will elapse before the crust returns to its pre-1906 strain state, assuming that the current strain rate is maintained throughout the interval. In the 77 years since 1906, not one magnitude ≥6 earthquake has occurred in the San Andreas fault system north of San Jose. Remarkably, in the nearly 50 years following 1906, no magnitude ≥5 earthquakes occurred in the northern San Andreas fault system. However, the return of magnitude 5 events in 1955 and their increasing size (one in 1980 had a magnitude of almost 6) may presage the reappearance of large earthquakes in northern California as stress recovers preparatory to the next great earthquake. A magnitude 6 to 7 earthquake, particularly one on any of the several secondary active faults (for example, the Hayward fault) in the densely populated San Francisco Bay area, could cause losses as serious, or even greater than a 1906-sized earthquake on the northern San Andreas fault.

Central San Andreas Fault

The central segment of the San Andreas fault between San Juan Bautista and Parkfield



Space-time diagram of seismicity of the San Andreas fault system from 1850 to present is shown. The extent of surface faulting in the earthquakes of 1857 and 1906 is indicated by vertical lines. Earthquake activity in south-central California declined for about three decades following the great 1857 earthquake. The decline in earthquake activity in northern California that followed the 1906 earthquake appears to be ending.

appears to have very low potential for producing a major earthquake in the near future. The central segment is uniquely characterized by the occurrence of numerous small-magnitude (<5) earthquakes. This segment is presently moving in rigid block motion, principally by aseismic slip (fault creep). No detectable strain has accumulated in the crust adjacent to the fault since at least the mid-1880's.

South-Central San Andreas Fault

The short-term risk of a damaging earthquake on the south-central San Andreas fault between Parkfield and San Bernardino, which last ruptured in the great Fort Tejon earthquake in 1857, appears significantly greater than it is to the north. Estimates place the annual probability of a magnitude 6 earthquake in the Parkfield area at roughly 5 percent per year; the cumulative probability in 30 years is almost 100 percent. The probability of a magnitude 7.5 to 8 earthquake on the south-central San Andreas fault east of Los Angeles is somewhat less, slightly more than 1 percent per year, or about 40 percent in 30 years. The mean recurrence time for major earthquakes on that portion of the 1857 break has been determined from the record of ancient earthquakes preserved in a marsh at Pallett Creek, near Palmdale, California. The mean frequency of ancient earthquakes there is one event every 140 years. At this site, the 126-year interval since the last event in 1857 is approching the mean time interval between events.

Analysis of variations in long-term earthquake rates also suggests that the probability of a major earthquake is high. Observed changes in earthquake frequency follow the same cyclic pattern as that for the northern San Andreas fault system. In the broad region surrounding the 1857 Fort Tejon earthquake, seismicity has apparenty increased to a level comparable to that observed along the northern segment preceding the 1906 earthquake since the early part of the 20th century. This high level of seismicity is expected to continue up to the repeat of an 1857-sized event.

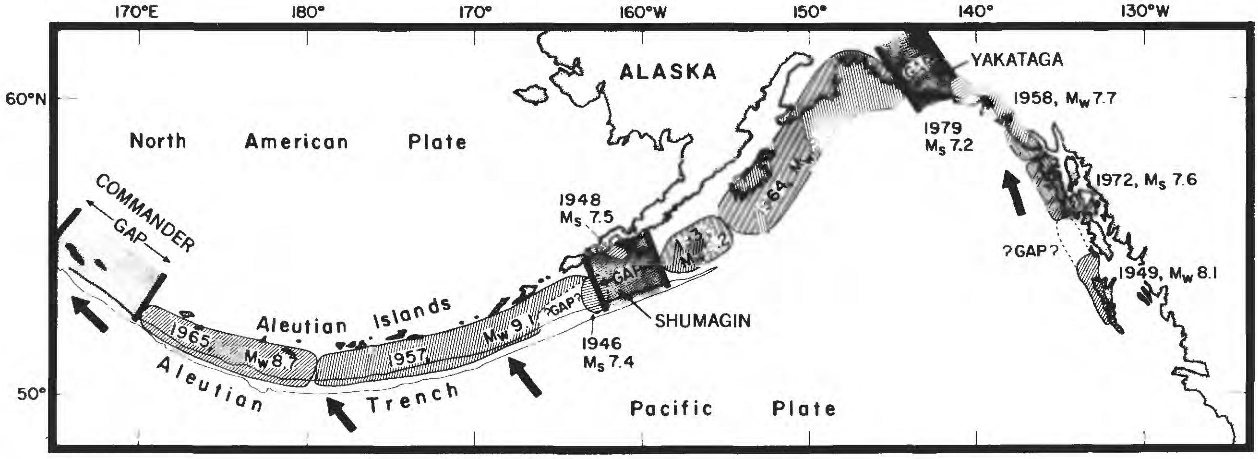
Southern San Andreas Fault

The earthquake potential of the southernmost San Andreas fault is less well defined because

The southern half of California was jolted on February 9, 1971, by a magnitude (M_S) 6.6 earthquake centered in San Fernando. Sixty-four people died, including 44 in the collapse of nonearthquake-resistant buildings at the Veterans Administration Hospital in Sylmar (above). Property losses exceeded $900 million. On the average, at least one earthquake of similar magnitude has occurred in southern California every decade of this century. (Photograph, *Los Angeles Times.*)

no major earthquakes are known from either the historic record or detailed geologic studies. However, the probability here appears high. This portion of the fault, like the northern and south-central segments, is locked at the surface, has elastic strain accumulating across it, and currently produces very few small earthquakes. It is embedded within the most seismically active area in California, one that has

The head of a landslide intersected the Government Hill Grade School, Anchorage, during the great Alaskan earthquake of 1964, carrying part of the building downslope. The slide devastated all but one wing of the school, destroyed two houses, damaged a third, left a fourth perched precariously above a cliff, wrecked a shed in the railroad yards at the foot of the slide, and did extensive damage to railroad equipment and trackage.



Rupture zones of large and great earthquakes in the Aleutians, southern Alaska, and offshore British Columbia from 1938 to 1979 are shown. Heavy arrows denote motion of the Pacific plate with respect to the North American plate. Seismic gaps, where large or great earthquakes may occur in the next several decades, are shaded.

produced magnitude ≥6 earthquakes at a nearly constant rate during the historic period. The features believed to signal a high potential for major earthquakes appear to be present here, as elsewhere on the San Andreas fault.

ALASKA

Southern coastal Alaska and the Aleutian Islands comprise one of the world's most active zones seismically. From 1938 to 1979, nine magnitude ≥7.4 earthquakes have ruptured much of the zone of contact between the North American and Pacific plates from offshore British Columbia to southern Alaska and thence along the Aleutian arc. The rupture zones, magnitudes, and seismic moments of several of these shocks are among the largest known anywhere in the world. The 1964 Prince William Sound, Alaska, earthquake, magnitude (**M**) 9.2, is the second largest earthquake to have occurred in the 20th century; only the May 22, 1960, Chilean earthquake (moment magnitude 9.5) was larger.

Accounts of historic earthquakes and instrumental data both show that almost all the plate boundary along the Alaska–Aleutian arc has ruptured sequentially in a succession of earthquakes since at least 1788; the ruptures have affected limited segments but have left intervening portions undisturbed as seismic gaps. Repeat times of great earthquakes appear to be about 50 to 100 years for several portions of the Alaska–Aleutian arc and to exceed 100 years for much of the rupture zone of the 1964 earthquake.

Three segments of the plate boundary have not broken in past decades. These seismic gaps —Yakataga, Shumagin, and Commander— appear to be regions of unrelieved strain accumulation between the rupture zones of past large earthquakes. The gaps seem likely sites of future large shocks.

Yakataga Seismic Gap

In the past decade, a number of investigators have suggested that the Yakataga area between Icy Bay and Kayak Island might be a seismic gap between the rupture zones of the 1958 Lituya Bay and 1964 Prince William Sound earthquakes. The occurrence of the 1979 magnitude 7.2 St. Elias earthquake on the eastern margin of this quiescent zone between the 1958 and 1964 aftershock zones, together with a recent study of seismicity patterns in this region, raised Federal concern that potentially damaging earthquakes could occur in the area. On May 31, 1979, the USGS issued a Notice of Potential Hazard, warning that one or more major earthquakes having magnitudes near 8 could occur in the Yakataga seismic gap anytime, probably within the next two to four decades.

Intensity

Earthquake intensity is a measure of the effects of an earthquake at a particular place. Intensity is determined from observations of an earthquake's effect on people, structures, and the Earth's surface. The first intensity scale to gain wide use was developed in Europe in 1883 by M. S. DeRossi of Italy and F. G. Forel of Switzerland. The Rossi-Forel Scale grouped earthquake effects into 10 steps of intensity beginning with I for the least noticeable. The Rossi-Forel Scale proved too peculiar to 19th century Europe to be universally applicable. In 1902, Giuseppe Mercalli introduced an improved scale which also had 10 grades of intensity (later increased to 12). A modified and condensed version, the Modified Mercalli Intensity Scale (MM), is used extensively in the United States today.

Modified Mercalli Scale (Abridged)

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to III Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

Shumagin Seismic Gap

The Shumagin gap has not been the site of a great shock since at least 1903, and possibly since 1847. (The earthquake history of the Aleutian Islands is incomplete.) However, at least the eastern one half of the gap broke in 1788 and 1847. Observations of the adjoining zone that ruptured in 1938 suggest that the average repeat time for earthquakes in this portion of the arc is about 50 to 75 years. If this recurrence interval can be applied to the Shumagain gap, it seems likely that one or more large earthquakes (magnitude ≥7) will rupture the gap sometime in the next 15 years. A history of tsunamis from the Shumagain area, including the devastating 1946 tsunami with waves locally reaching heights of more than 100 feet, indicates that a large future earthquake in the Shumagain gap could be expected to generate a sizable tsunami.

Commander Seismic Gap

The Commander gap in the westernmost Aleutians is not known to have been the site of a large earthquake since 1858. However, a large interplate event may have occurred in the gap in 1849. If so, then the region may be one of considerable tsunamic-seismic risk. Because plate movement along the southern side of the Commander Islands is nearly parallel to the boundary and occurs along shallow-dipping thrust faults, the repeat time of large earthquakes in this area may well differ from that farther east.

HAWAII

The Hawaiian Islands have experienced numerous earthquakes. Substantial ground shaking of Modified Mercalli intensity VI or greater has occurred in all principal Hawaiian Islands except Kauai. At least three magnitude ≥7 earthquakes have rocked the islands:

Date	Magnitude	Location
April 2, 1868	7½–7¾	Off southeast Hawaii
Feb. 19, 1871	7	Off Molokai
Nov. 29, 1973	7.2	Kalapana, Hawaii

Most earthquakes in the Hawaii Islands are small (magnitude ≤2) and are associated predominantly with movement of magma at depth (at least on the island of Hawaii). The exact cause of the large-magnitude

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of falling plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage *negligible* in buildings of good design and construction; *slight to moderate* in well built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale.)

VIII. Damage *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)

IX. Damage *considerable* in specially designed structures; well-designed frame structures thrown out of plumb; *great* in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage *total.* Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

earthquakes in the Hawaiian Islands is unclear, but those on or near Hawaii appear to be related to volcanism. The 1975 earthquake, for example, is believed to have been caused either by the forceful intrusion of magma into one of Kilauea Volcano's rift zones or by catastrophic failure of a large slab, several hundred square miles in extent, that apparently broke loose along the north edge of the Hilina fault system as a result of magma-caused swelling of Kilauea's east flank. The 1871 earthquake, which was not located near an active volcano, may have been caused by nonvolcanic tectonism.

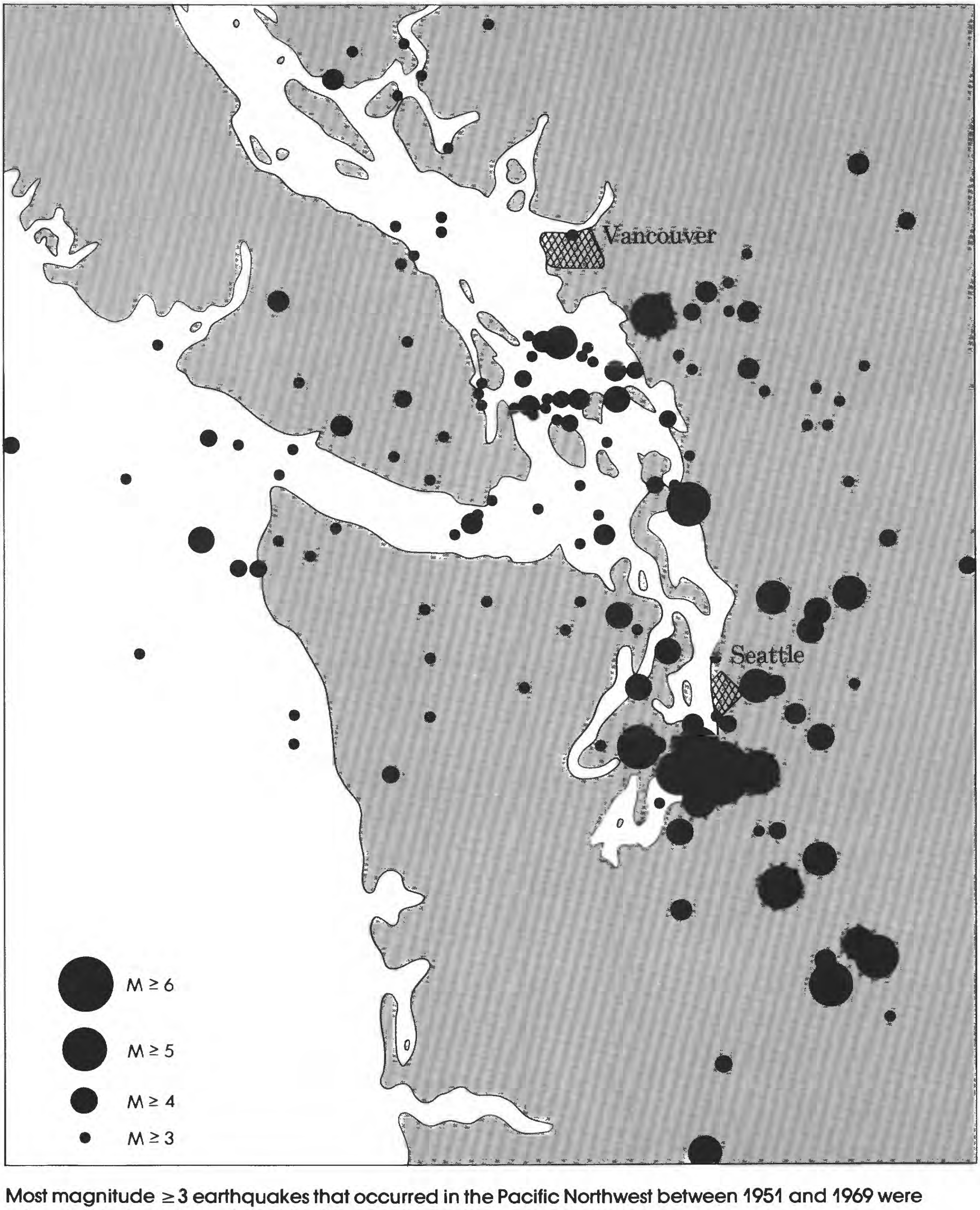
Tsunamis are the most feared geologic hazard in the Hawaiian Islands. Tsunamis have ravaged the Hawaiian coasts repeatedly during historic time and have taken hundreds of lives. Generated primarily by tectonic movements associated with great earthquakes in the circum-Pacific region and, more locally, by large earthquakes in the Hawaiian Archipelago, tsunamis have overswept most of the coastal areas of the islands. The tsunami of April 1, 1946, caused by a large earthquake in the Aleutian Islands, reached heights of up to 55 feet in the Hawaiian Islands. The tsunami of April 2, 1868, which originated just south of Hawaii, is reported to have come in over the tops of trees on the south shore of the island.

PACIFIC NORTHWEST

Most historic earthquake activity in the Pacific Northwest has been concentrated in western Washington, largely in the Puget Sound-southern Georgia Strait area. In the past 135 years, there have been more than 1,000 felt earthquakes; a number of the shocks have been of moderate to large magnitude. In 1877, an earthquake of intensity (MM) VIII (magnitude about 6.5) occurred near the Oregon-Washington border. In 1946, a magnitude 7.3 earthquake, centered in the Georgia Strait, caused heavy damage in the epicentral region. A magnitude (M_S) 7.0 earthquake near Olympia, Washington, in 1949 killed eight persons and caused more than $80 million in property damage (in 1979 dollars). A magnitude (M_S) 6.5 earthquake in 1965 in Seattle, Washington, resulted in seven deaths and $28 million damage (in 1979 dollars). Although destructive, the 1946, 1949, and 1965 shocks occurred relatively deep (30–40 miles below the Earth's surface) and produced less severe ground shaking effects than is typical for their respective magnitudes.

A suitable tectonic explanation for the occurrence of earthquakes in the Pacific Northwest—particularly why most earthquake activity in the region has been localized in the

The largest Hawaiian earthquake in over a century—magnitude (M_S) 7.2—struck southeast Hawaii on the morning of November 29, 1975. The earthquake was preceded by numerous foreshocks and was accompanied, or was followed closely, by a tsunami, massive ground movements, hundreds of aftershocks, and a volcanic eruption. The summit and south flank areas of Kilauea Volcano were severely deformed by vertical and horizontal displacements of several feet forming numerous ground cracks and faults. At Halape (above), ground subsidence of as much as 11.6 feet left a grove of coconut palms standing in water averaging 4 feet deep. Prior to the earthquake, the palms had been 300 to 500 feet landward of the presubsidence shoreline.



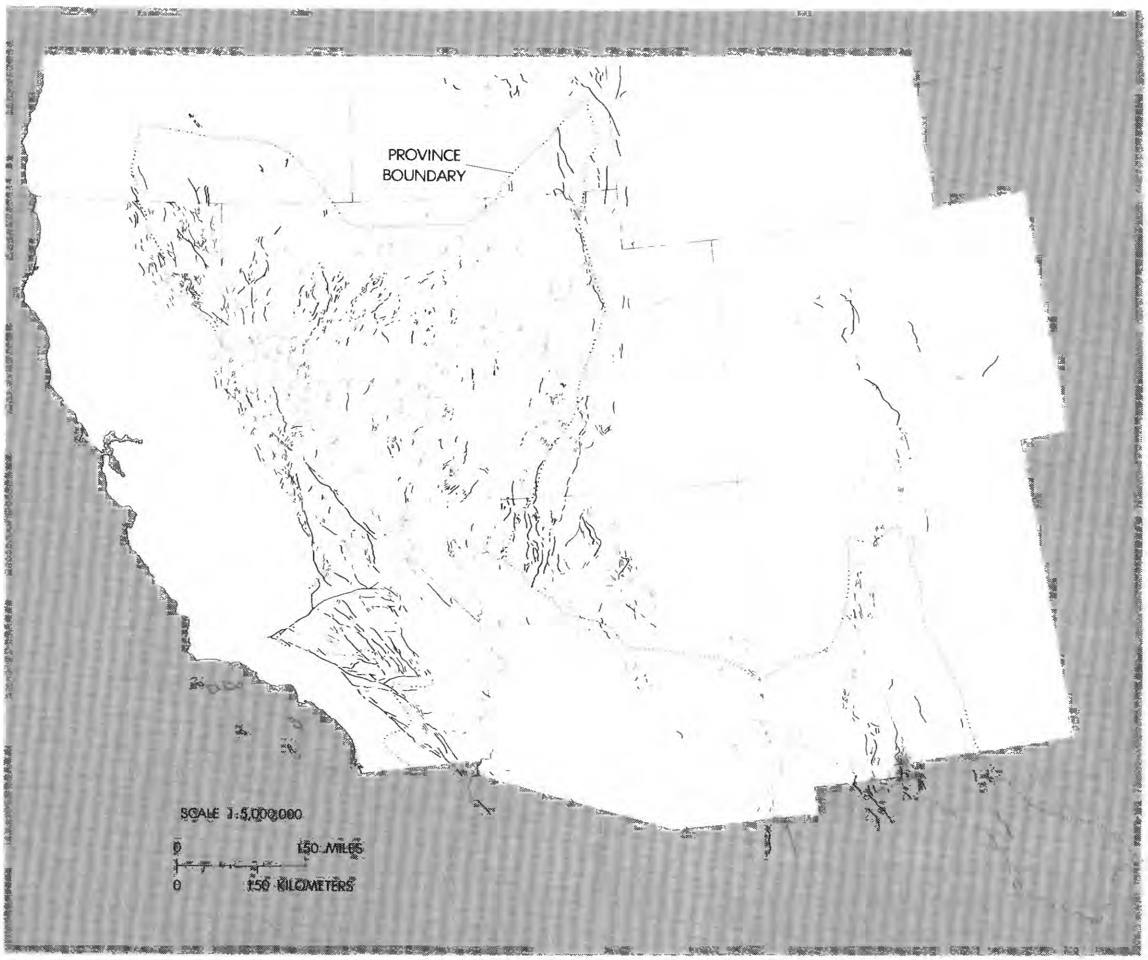
Most magnitude ≥ 3 earthquakes that occurred in the Pacific Northwest between 1951 and 1969 were located in Puget Sound and the Georgia Strait.

Puget Sound-Georgia Strait area—has not yet emerged from the continuing seismic studies of the region. Numerous shallow (less than 20 miles deep), small earthquakes with magnitudes predominantly less than 4 appear to occur randomly beneath Puget Sound and the Georgia Strait. However, the deeper (30–40 miles), large, damaging earthquakes seem associated with the subducted Juan de Fuca plate, a piece of the eastern Pacfic Ocean crust that has underthrust western Washington, Oregon, and northwestern California.

A growing body of data suggests that a magnitude ≥ 8 earthquake could occur in the Pacific Northwest on the subducting Juan de Fuca plate beneath western Washington, Oregon, and northernmost California. This hypothesis is still debated, but acceptance by the general scientific community of the possibility for a magitude 8 earthquake would necessitate the design and construction of structures to withstand substantially greater ground shaking levels than previously believed possible in the Pacific Northwest. The USGS, the National Science Foundation (NSF), and the Nuclear Regulatory Commission (NRC) are supporting seismologic and geologic investigations to assess the likelihood of such a great earthquake.

BASIN AND RANGE PROVINCE AND ROCKY MOUNTAINS

Much of the mountainous western interior of the United States is part of an extensive zone of intraplate deformation that is characterized by normal faulting, diffuse shallow seismicity,



These active and potentially active faults are in the Basin and Range province and adjoining Rocky Mountains.

and episodic moderate to large earthquakes. The zone includes the Basin and Range province, which extends eastward from the Sierra Nevada of California to the Colorado Plateau and the Rio Grande River and adjacent areas of the Rocky Mountains.

Most large (magnitude ≥7) historic seismic events accompanied by surface faulting in the Great Basin have been concentrated along the eastern and western margins of the province and in a north-trending belt approximately 125 miles wide that extends from California through central Nevada. The largest historic events in the magnitude 7 to 8 range occurred in 1872, 1915, 1932, and 1954, and an event in 1952 occurred along the same trend but outside the province to the southwest. Smaller earthquakes (magnitudes 6–7) also accompanied by surface faulting occurred in 1869(?), 1932, 1950, and twice in 1934. The large earthquakes occurred, on the average, about every 22 years. Because nearly 30 years have elapsed since the Dixie Valley, Nevada, earthquake (magnitude 7.1) of 1954, a number of investigators believe that future large earthquakes in the Great Basin likely will rupture faults in the gaps (Stillwater, White Mountain, and Southern Sierra) interrupting the north-trending belt of historic fault breaks.

Numerous other faults in the Basin and Range province show evidence of repeated, geologically recent offsets. Studies of prehistoric fault scarps suggest that a magnitude ≥7 earthquake occurs somewhere in the Great Basin on the average every 240 years. The Wasatch fault zone, near which 85 percent of Utah's population lives, has not ruptured in any earthquake since the settlement of the area in 1847. Geologic studies of the fault zone suggest that the average recurrence interval for moderate-to-large earthquakes in the fault zone is between 50 and 400 years.

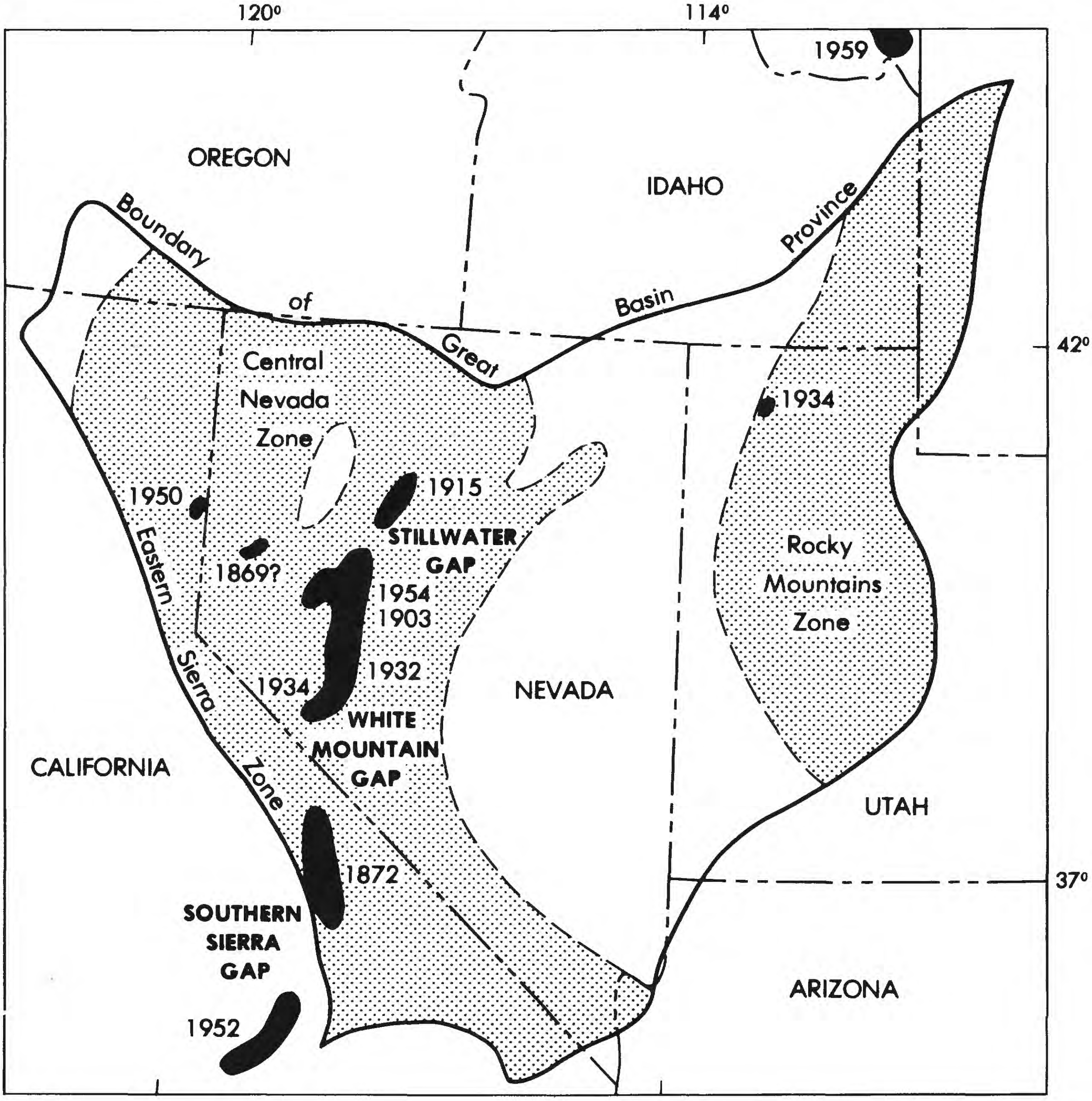
EASTERN UNITED STATES

Earthquake activity in the United States east of the Rocky Mountains is low compared with the West. However, a damaging earthquake occurs somewhere in the Eastern United States on the average about every 25 years. There is a large-to-great earthquake about every 50 to 100 years.

Three great earthquakes, plus 203 damaging aftershocks, occurred near New Madrid, Missouri, in the 3-month interval from December 16, 1811, through March 15, 1812. The earthquakes are estimated to have had magnitudes (M_s) of 8.6, 8.4, and 8.7. The tremors caused extensive disruption of the land over a vast area between the confluence of the Ohio and Mississippi rivers on the north and Memphis, Tennessee, on the south. Only a few persons are known to have died in the then thinly populated area, but other casualties may have occurred among the several hundreds of people who were traveling or transporting goods on the Mississippi River when the shocks struck.

The earthquakes virtually destroyed the town of New Madrid. Most of the structures were tumbled by the first shocks, and the site of the town sank 15 feet. The earthquakes were felt over most the United States east of the Rocky Mountains. Doors and windows rattled in Washington, D.C., at a distance of 750 miles; in Boston, about 1,000 miles away, church bells rang from the shocks. The shocks caused extensive liquefaction in the central Mississippi Valley in a 100-mile-long zone between Marked Tree, Arkansas, and New Madrid, Missouri. Near Blytheville, Arkansas, an area of more than 25 square miles was covered by about 3 feet of extruded sand. The extensive lowlands, or "sunken lands," of northeastern Arkansas, southeastern Missouri, and northwestern Tennessee were created by liquefaction and tectonic deformation of the land surface. Reelfoot Lake in Tennessee was enlarged and deepened by the earthquakes.

About 9:50 p.m. on August 31, 1886, the Southeastern United States was strongly shaken by a large earthquake having an estimated magnitude (m_b) of 6.8 centered near Charleston, South Carolina. The major shock lasted less than 1 minute but resulted in about 60 deaths and extensive damage to the city of Charleston. The area of maximum damage (MM X) of the earthquake was an elliptical area roughly 20 by 30 miles centered near Summerville, South Carolina, about 18 miles northwest of Charleston. The intense ground shaking caused liquefaction of water-saturated, unconsolidated sandy alluvium in the meisozeismal area (area of maximum damage). Numerous fissures, cracks, and sand craterlets (sand boils) were reported. The



SURFACE FAULTING IN THE GREAT BASIN PROVINCE

1915

HISTORIC FAULTING
$3x10^{-3}$ > event > $1x10^{-4}$
year per 1000 KM^2

HOLOCENE FAULTING
(last 12,000 ± years)
$5x10^{-5}$ > event > $5x10^{-6}$
per year per 1000 KM^2

NO LATE QUATERNARY EVENTS
(last $5x10^{-5}$± years)

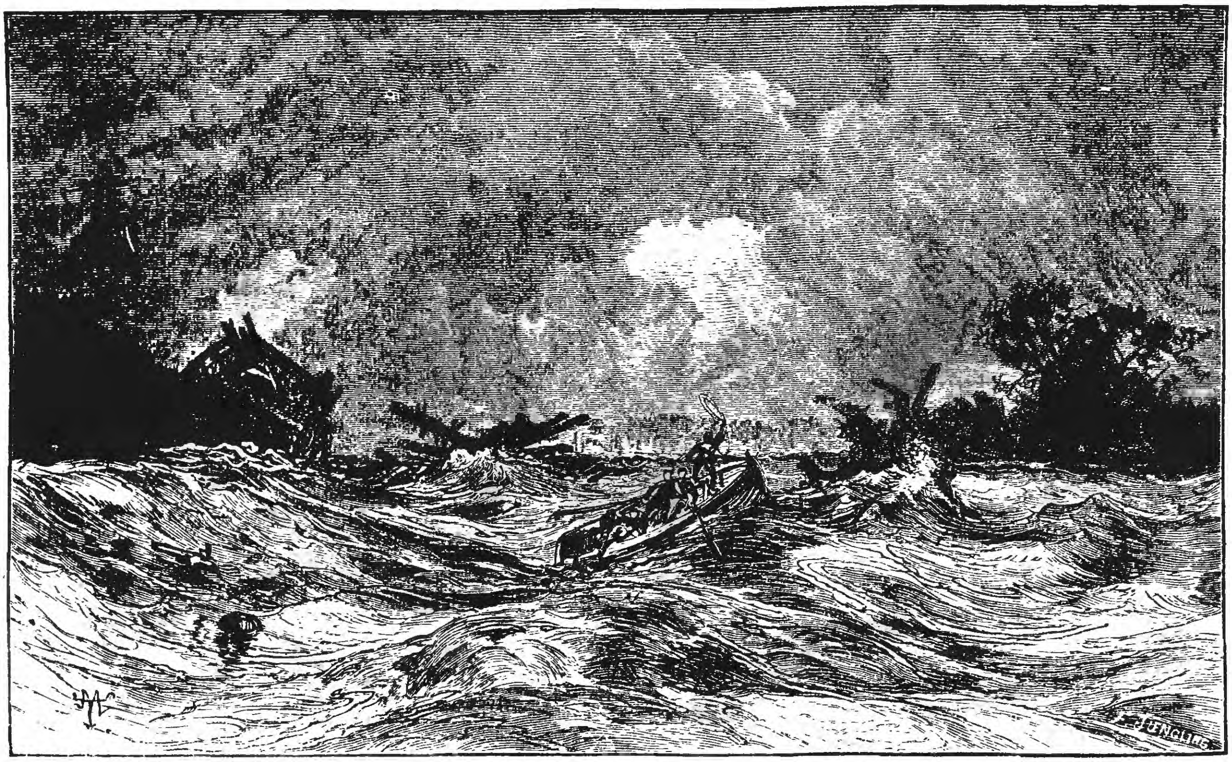
Most historic earthquakes in the Great Basin have occurred in a north-trending belt extending from the Sierra Nevada through central Nevada. Prehistoric large earthquakes (deduced from ancient fault scarps) occurred in adjacent areas (stippled) of the Great Basin with a frequency of about one event every 100,000 years per 400 square miles.

More than 5 to 15 feet of vertical movement occurred on the Dixie Valley fault zone during the magnitude 7.1 earthquake of December 16, 1954.

Charleston, South Carolina, earthquake was felt over the entire United States east of the Mississippi River, producing MM V effects in Chicago—750 miles from the earthquake epicenter.

Damage caused by earthquakes east of the Rocky Mountains has been more widespread than in the West because

- Lower attentuation of seismic waves in the East causes shaking to extend over much larger areas for earthquakes of comparable magnitude,



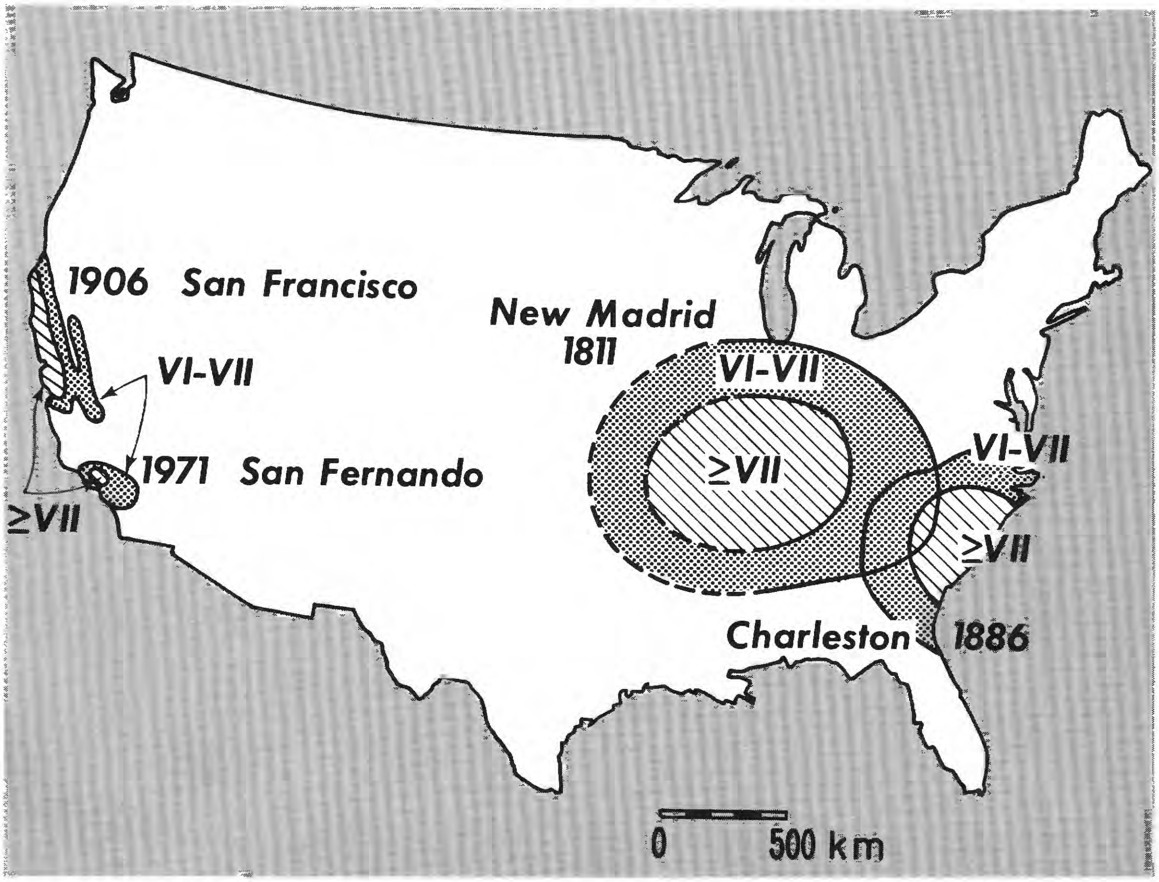
Woodcut of "the great earthquake in the West" (p. 220 in *Our First Century: One Hundred Great and Memorable Events*, 1877). The New Madrid, Missouri, earthquake of 1811 created great waves on the Mississippi River, which overwhelmed many boats and washed others high upon the shore; the return current broke off thousands of trees and carried them out into the river. Rapids and even waterfalls appeared in the river, high banks slid into the river channel, sand bars and points of islands gave way, and whole islands disappeared. (Photograph, State Historical Society of Missouri)

Many buildings in Charleston, South Carolina, sustained serious damage or collapsed during the August 31, 1886, earthquake. The extent of damage varied greatly, ranging from total demolition to the loss of chimney tops and plaster. Property losses in Charleston alone are estimated to have exceeded more than $5 million (1886 dollars).

- Population density is higher in the East, and
- Lower earthquake awareness in the East has led to lower standards of earthquake design and preparedness.

If the New Madrid earthquakes were to recur today, they would likely cause very widespread destruction of property and loss of life from Arkansas to Indiana. According to 1975 census information, the population within the MM VII or greater zone—which corresponds with damage threshold—for the New Madrid sequence is about 12.6 million people. Some estimates suggest that property damage could exceed $50 billion.

The origin of earthquakes in the Eastern United States is not understood fully. At least several of the larger earthquakes in the East evidently were caused by reactivation of ancient fault systems that were formed as early as Precambrian time (more than 600 million years ago). The source of the New Madrid earthquakes appears to be an ancient buried fault zone that is coincident with a zone of recent seismicity. This fault zone lies along the axis of a buried northeast-trending graben in the upper Mississippi embayment probably associated with a rift of late Precambrian or early Paleozoic age. The fault zone is probably the source of at least two of the three largest shocks that took place in 1811 and 1812. In addition, a northeast-trending set of faults was found that offset the youngest strata by about 250 feet. The offset certainly took place during the past 50 million years and may have occurred entirely within the past few thousand years.



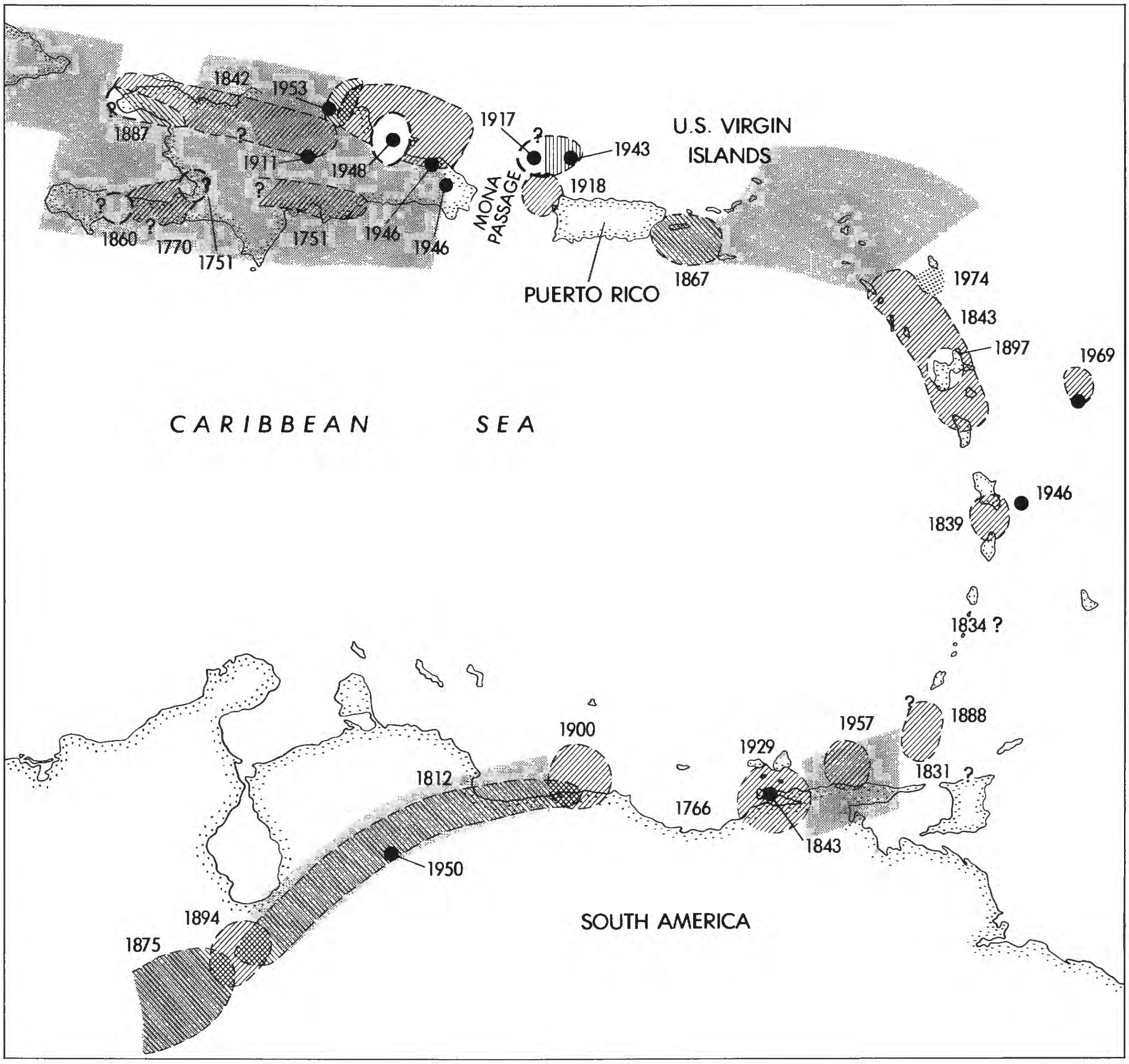
The effects of ground shaking extend over a much larger area in the Eastern United States than in the West. The distributions of intensities (MM VI or greater) of the 1811 New Madrid, Missouri, earthquake (moment magnitude 7.5) and the 1886 Charleston, South Carolina, earthquake (moment magnitude 6.8) each were substantially greater than those of the 1906 San Francisco, California, earthquake (moment magnitude 7.7) and the 1971 San Fernando, California, earthquake (moment magnitude 6.6).

No geologic structure or feature has been identified unequivocally as the source of the 1886 Charleston earthquake. On the basis of geologic and geophysical studies, it seems possible that 1886-like events might occur elsewhere along the eastern seaboard of the United States. The geology of the Charleston area is not unlike other areas in the Coastal Plain from northernmost Florida north to New Jersey.

Magnitude-frequency studies and trench investigations of sand-boil relationships indicate a recurrence interval of 600 to 700 years for large earthquakes in the New Madrid region. Enough strain energy already may have accumulated in the New Madrid fault zone to produce a magnitude 7.6 earthquake. An earthquake of this size would cause damage over an area of 200,000 square miles.

PUERTO RICO AND THE U.S. VIRGIN ISLANDS

The Greater and Lesser Antilles (including Puerto Rico and the Virgin Islands) are part of a seismic zone bordering the Caribbean plate. Large destructive shocks of magnitude near 7¼, such as that in 1844, apparently have originated in the zone to the north of Puerto Rico. The Anegada Passage northeast of the Virgin Islands was the source of a large tsunamic earthquake in 1867 (probably magnitude 7¾–8) that caused property damage in the Virgin Islands and over all Puerto Rico. Large earthquakes were centered in the Mona Passage off western Puerto Rico in 1917 (magnitude 7.0), 1918 (magnitude 7.5) and 1943 (magnitude 7¾). The 1918 shock was one of the most violent earthquakes felt on Puerto Rico and was accompanied by a destructive



Estimated rupture zones of Caribbean shocks since 1800 are shown; three great shocks of the 18th century are included also. Areas with highest seismic potential for events of magnitude ≥ 7 during the next few decades (regions where great earthquakes occurred 100 or more years ago) are shaded.

tsunami. Property damage was estimated at about $28.6 million (1979 dollars), and 116 lives were lost.

The relatively low rate of motion between the Caribbean and the North and South American plates (estimated to be approximately 0.8 inches per year) suggests that earthquake recurrence intervals of at least 100 to 150 years, and probably hundreds of years, may be commonplace for this region. Although great (magnitude ≥ 8) earthquakes are unknown in Puerto Rico and the Virgin Islands, the oblique thrust character of plate motion in this region is similar to that in the Commander Gap in the westernmost Aleutian Islands of Alaska. By analogy, the Puerto Rico-Virgin Islands region may be one of considerable tsunamic-seismic risk.

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A NATIONAL PROGRAM FOR EARTHQUAKE HAZARDS REDUCTION

In recognition of the threat of catastrophic losses of life and property posed by the earthquake hazard in the United States, the Earthquake Hazards Reduction Act of 1977 (Public Law 95–124) and the 1980 amendments to that Act (Public Law 96–472) mandated that a National Earthquake Hazards Reduction Program (NEHRP) be established and maintained. In citing its reasons for enacting that legislation, Congress found and declared the following:

All 50 States are vulnerable to the hazards of earthquakes and at least 39 of them [now known to be 44] *are subject to major or moderate seismic risk. . . . A large portion of the population of the United States lives in areas vulnerable to earthquake hazards. Earthquakes have caused, and can cause in the future enormous loss of life, injury, destruction of property, and economic and social disruption.*

With respect to future earthquakes, such loss, destruction, and disruption can be substantially reduced through the development and implementation of earthquake hazards reduction measures, including (a) improved design and construction methods and practices, (b) land-use controls and redevelopment, (c) prediction techniques and early warning systems, (d) coordinated emergency preparedness plans, and (e) public education and involvement programs.

An expertly staffed and adequately financed earthquake hazards reduction program, based on Federal, State, local, and private research, planning, decision making, and contributions would reduce the risk of such loss, destruction, and disruption in seismic areas by an amount far greater than the cost of such a program.

Part of the grounds of the Alaska Native Service Hospital in Anchorage, Alaska, collapsed in a landslide triggered by the 1964 Good Friday earthquake. The landslide wrecked a fuel-storage tank at the foot of the bluff; fractures extending back from the slide damaged the hospital building. The slide of March 27, 1964, transected the scar of an older landslide, which may date to a prehistoric earthquake.

A well-funded seismological research program in earthquake prediction could provide data adequate for the design of an operational system that could predict accurately the time, place, magnitude, and physical effects of earthquakes in selected areas of the United States.

An operational earthquake prediction system can produce significant social, economic, legal, and political consequences.

There is a scientific basis for hypothesizing that major earthquakes may be moderated, in at least some seismic areas, by application of the findings of earthquake control and seismological research.

The implementation of earthquake hazards reduction measures would, as an added benefit, also reduce the risk of loss, destruction, and disruption from other natural hazards and man-made hazards, including hurricanes, tornadoes, accidents, expansions, landslides, building and structural cave-ins, and fires.

Reduction of loss, destruction, and disruption from earthquakes will depend on the actions of individuals and organizations in the private sector and governmental units at Federal, State, and local levels. The current capability to transfer knowledge and information to these sectors is insufficient. Improved mechanisms are needed to translate existing information and research findings into reasonable and usable specifications, criteria, and practices so that individuals, organizations, and governmental units may make informed decisions and take appropriate actions.

Severe earthquakes are a worldwide problem, and since damaging earthquakes occur infrequently in any one nation, international cooperation is desirable for mutual learning from limited experiences.

An effective Federal program in earthquake hazards reduction will require input from and review by persons outside the Federal Government expert in the sciences of earthquake hazards reduction and in the practical application of earthquake hazards reduction measures.

THE EARTHQUAKE HAZARDS REDUCTION ACT, AS AMENDED

In establishing a national program of earthquake hazards reduction, the Act directs the President to establish and maintain, in accordance with the provisions and policies of the Act, an effective, coordinated Federal program which would achieve the following objectives:

Development of technology and economically feasible design and construction methods and procedures to make new and existing structures, in areas of seismic risk, earthquake resistant, giving priority to the development of such methods and procedures for nuclear power generating plants, dams, hospitals, schools, public utilities, public safety structures, high-occupancy buildings, and other structures which are especially needed in time of disaster.

Implementation in all areas of high or moderate seismic risk of a system (including personnel, technology, and procedures) for predicting damaging earthquakes and for identifying, evaluating, and accurately characterizing seismic hazards.

Development, publication, and promotion, in conjunction with State and local officials and professional organizations, of model codes and other means to coordinate information about seismic risk with land-use policy decisions and building activity.

Development, in areas of seismic risk, of improved understanding of, and capability with respect to, earthquake-related issues, including methods of controlling the risks from earthquakes, planning to prevent such risks, disseminating warnings of earthquakes, organizing emergency services, and planning for reconstruction and redevelopment after an earthquake.

Education of the public, including State and local officials, as to earthquake phenomena, the identification of locations and structures which are especially susceptible to earthquake damage, ways to reduce the adverse consequences of an earthquake, and related matters.

Development of research on (a) ways to increase the use of existing scientific and engineering knowledge to mitigate earthquake hazards; (b) the social, economic, legal, and political consequences of earthquake prediction; and (c) ways to assure the availability of earthquake insurance or some functional substitute.

Development of basic and applied research leading to a better understanding of the control or alteration of seismic phenomena.

As stated in the Act, these objectives, the research elements of the NEHRP shall include the following:

Research into the basic causes and mechanisms of earthquakes;

Development of methods to predict the time, place, and magnitude of future earthquakes;

Development of an understanding of the circumstances in which earthquakes might be artificially induced by the injection of fluids in deep wells, impoundment of reservoirs, or other means;

Evaluation of methods that may lead to the development of a capability to modify or control earthquakes in certain regions;

Development of information and guidelines for zoning land in light of seismic risk in all parts of the United States and preparation of seismic risk analyses useful for emergency planning and community preparedness;

Development of techniques for the delineation and evaluation of the potential effects of *earthquakes, and their application on a regional basis;*

Development of methods for planning, design, construction, rehabilitation, and utilization of man-made works so as to effectively resist the hazards imposed by earthquakes;

Exploration of possible social and economic adjustments that could be made to reduce earthquake vulnerability and to exploit effectively existing and developing earthquake mitigation techniques; and

Studies of foreign experience with all aspects of earthquakes.

Furthermore, Federal preparedness and mitigation activities are to include the following:

Issuance of earthquake predictions;

Development of ways for State, County, local, and regional governmental units to use existing and developing knowledge about the regional and local variations of seismic risk in making their land use decisions;

Development and promulgation of specifications, building standards, design criteria, and construction practices to achieve appropriate earthquake resistance for new and existing structures;

Examination of alternative provisions and requirements for reducing earthquake hazards through Federal and Federally financed construction loans, loan guarantees, and licenses;

Determination of the appropriate role for insurance, loan programs, and public and private relief efforts in moderating the impact of earthquakes;

Dissemination, on a timely basis, of (a) instrument-derived data of interest to other researchers, (b) design and analysis data and procedures of interest to the design professions and to the construction industry, and (c) other information and knowledge of interest to the public to reduce vulnerability to earthquake hazards;

Transmittal to Congress by the Director [of the Federal Emergency Management Agency (FEMA)] *of an interagency coordination plan for earthquake hazard mitigation and response, which plan shall coordinate all of the directorates of the agency; and*

Development and implementation of a preparedness plan for response to earthquake predictions which include (a) a prototype plan to be in place in one major metropolitan area, (b) an action plan to be completed for specific adaptations by the prototype plan to other high-risk metropolitan areas, (c) integration of these prediction response plans with preparedness response plans, (d) coordination of plans with State and local governmental companion efforts, and (e) update of plans as new, relevant information becomes available.

Under the Title III amendment to the Act (Public Law 96–472), FEMA is directed to utilize a multihazard approach in implementing its preparedness and mitigation programs. In carrying out this directive, the Act, as amended, specifically directs FEMA to

Initiate studies designed to define and develop a multihazard research, planning, and implementation process within the agency;

Develop, in cooperation with State and local governments, prototypical multihazard mitigation projects that could be used to evaluate several approaches to the varying hazard mitigation needs and to assess the applicability of these prototypes to other jurisdictions with similar needs;

Investigate and evaluate the effectiveness of a range of incentives for hazard reduction that can be applied at the State and local levels;

Prepare a report on the status of FEMA's emergency information and communications systems; and

Conduct a program of multihazard research, planning, and mitigation in coordination with those studies and evaluations authorized above, as well as other hazard research, planning, and mitigation deemed necessary by the Director.

To ensure the success of the Program in meeting the stated objectives, Congress also stipulated certain managerial and administrative functions and reporting mechanisms. These provisions include establishment of goals, priorities, budgets, and target dates for implementation; provision of qualified and sufficient staffing; development of a Program Plan; provisions for participation in the Program; review and evaluation of the Program; and coordination.

EXECUTIVE ORDER 12381

The functions vested in the President by the Earthquake Hazards Reduction Act of 1977, as amended, were delegated to the Director of FEMA by Executive Order 12381 of September 8, 1982.

PRESIDENTIAL PLAN

In establishing the NEHRP following enactment of Public Law 95-124 in 1977, the Office of Science and Technology Policy (OSTP), on behalf of the President, reviewed the activities and plans of Federal, State, and local governmental units, as well as those of the private sector, for implementing the results of earthquake mitigation research. OSTP also established an independent Working Group on Earthquake Hazards Reduction, with representation by the USGS, the Federal Disaster Assistance Administration [which became part of FEMA when the agency was established in 1979], the NSF, the National Bureau of Standards (NBS), the Veterans Administration (VA), and other agencies and departments to provide assistance in outlining a national program, establishing priorities, and formulating a Federal implementation plan.

Issued as a Presidential Plan to the Executive agencies and sent to the Congress in June 1978, the principles governing the NEHRP are as follows:

The priorities of hazards reduction are to be based on relative risk; that is, the probability of significant loss of life and property, considering the population exposed, the nature and magnitude of the hazards posed by man-made structures to the population, and the likelihood and character of significant earthquakes. Regional differences in the nature and magnitude of the risk and of the perception of the risk require a flexible approach.

While the Federal Government can take a strong, exemplary position with regard to its own facilities and develop guidelines and standards for Federally assisted or licensed critical facilities, the effort to improve local land use and building codes—as a basis for all private construction, including Federally assisted, noncritical construction—must be accomplished by persuasion and encouragement, particularly through working with professional organizations and State and local officials.

Earthquake hazards reduction must not only take into account the direct natural hazards from faulting and vibration, but also the indirect natural hazards from tsunamis, seiches, landslides, floods, soil consolidation, soil failure, and slumping. Damage to works of man by these natural hazards leads to both primary hazards such as structural failure, and secondary hazards such as fire, flood, and the escape of contained toxic or hazardous fuels and materials.

Experience both in the United States and abroad has proved that buildings and other structures can be designed so as to protect life safety during very strong ground shaking from major earthquakes. For some buildings and structures the additional cost of earthquake resistance is quite small; in other cases the costs would be very significant.

Prediction cannot, in the near future, be relied upon as an effective tool to reduce earthquake casualties (for example, to avoid the problem posed by existing hazardous buildings). However, since scientific breakthroughs could come at any time, we *must prepare to cope with different levels of predictive capability.*

Hazards reduction procedures, whenever and wherever possible, need to be incorporated into existing organizations, institutions, legislation, regulations, rules, building codes, relief procedures, and loan requirements, so that they are part of established activities rather than being superimposed as separate and additional. As the local building codes improve through time as a result of persuasion and encouragement, it may be appropriate to increase gradually the seismic provisions in requirements for Federal assistance.

Outside assistance to the local community must be planned for quick identification of needs that cannot be handled locally, and for provision of aid to supplement, rather than to replace local efforts. Our society has a great resilience and recuperative power when called upon to respond to sudden disaster.

Special attention must be given to persons who are particularly vulnerable to earthquake hazards (the poor, the aged, the handicapped, the children) to provide them equal protection and ensure that they do not suffer disproportionately.

To be acceptable in regions characterized by lower, but significant, seismic risk, earthquake hazards mitigation activities should lead to the reduction of risks from hazards other than earthquakes and be coordinated with efforts to protect people and property from other potential hazards and disasters.

International cooperation on earthquake hazards research should be fostered as essential to ensure opportunities for mutual learning. Studies of foreign experience and exchange of information are therefore a fundamental part of this Program.

Continuing evaluation is needed to assess the strengths and weaknesses and the successes and failures of the Program. An annual report to Congress will reflect the progress and evaluate the effectiveness of the Program.

As set forth in the President Plan of 1978, the NEHRP activities of the Federal Government shall consist of the following:

Provision of National Leadership

The lead agency [FEMA] *shall stimulate and coordinate earthquake hazards reduction activities within the Federal Government and throughout the Nation, assisting State and local governments in planning and implementing their own programs.*

The lead agency shall provide leadership in coordinating earthquake hazards reduction activities in the appropriate Federal agencies and in assisting State and local governments in planning and implementing their own programs. In carrying out these responsibilities, the lead agency will consider regional differences in the nature and perception of the earthquake threat and encourage flexible programs embodying earthquake hazards reduction in efforts to mitigate other natural hazards where feasible and appropriate.

The lead agency will have primary responsibility for maintaining an overview of the national program and identify opportunities and needs.

The lead agency will be responsible for the development of guidelines to assist Federal agencies involved in construction in implementing earthquake hazards reduction elements in their ongoing programs. To develop these guidelines for consideration, the lead agency will organize and lead an Interagency Committee on Seismic Safety in Construction (ICSSC), composed of representatives of all Federal agencies significantly engaged in construction, the financing of construction, or related activities.

The lead agency will formulate a detailed work plan for its continuing role, including procedures for monitoring the assignments and responsibilities of the Program and for participation in programmatic review and assistance in budgetary review. The work plan will describe the mechanisms that will be *used to identify additional areas for hazards reduction activity through consultation with other Federal agencies, State and local governments, and private relief groups, including the establishment of advisory groups and interagency committees, and procedures for developing earthquake hazards guidelines for reconstructing damaged communities to make them more resistant to future earthquakes.*

Each year the lead agency will summarize progress toward the goals of the Program in a report submitted to the President for transmittal to the Congress. [Pursuant to Executive Order 12381, issued in 1982, FEMA submits the report directly to the Congress.]

Improvement of Contingency Planning and Emergency Response

The Federal Disaster Assistance Administration [now part of FEMA] *will develop a schedule, covering the areas of high seismic risk throughout the Country, for completion of Federal contingency plans and for assistance to State and local governments in completing their response plans. This schedule will reflect (a) evaluation of the contingency planning completed to date, (b) priorities accorded to the level of seismic hazards and interest of the affected communities, and (c) recognition that contingency plans must be preceded by estimates of potential damage and casualties.*

The Federal Disaster Assistance Administration [now part of FEMA] *will bear a continuing responsibility for overseeing the revision of Federal earthquake contingency plans and for stimulating the revision of State and local contingency plans as new information on earthquake hazards is developed and as the perception of this threat in affected communities increases. (Guided by these plans, State and local governments can assess the potential impact of earthquakes on safety to life and on essential community facilities and can take steps to reduce the loss of life and to ensure the maintenance of vital services.)*

Evaluation of Earthquake Predictions

A fundamental research objective is the development of a reliable capability to predict earthquakes.

Information that, although insufficient at the time for issuing an earthquake prediction, may heighten scientific concern about the imminence of a destructive earthquake must be evaluated and communicated to responsible public officials in much the same way that scientifically credible earthquake predictions will be evaluated and communicated.

USGS, assisted by the National Earthquake Prediction Evaluation Council (composed of scientists inside and outside the government), will have the responsibility for evaluating and communicating earthquake predictions and other information of this type. (The responsibility for warning the people about the imminent danger from a natural hazard and to advise or direct them on how to respond is principally a function of State and local government.)

The National Oceanic and Atmospheric Administration (NOAA) tsunami warning system will be continued and advances in earthquake prediction will be incorporated into this system to improve its overall effectiveness and efficiency.

NSF will continue its program of research to provide background information on the social and economic effects of an earthquake prediction and about how officials can respond so as to minimize both potential losses and possible negative impacts.

Preparation of National Seismic Risk Assessments

Maps, showing the degree of seismic risk and providing information necessary for engineering design of structures, are needed for use in establishing national priorities for hazards reduction activities and model building codes and incorporating *earthquake hazards reduction activities in a wide variety of Federal programs. These maps should show the broad variation of seismic risk and are not intended for local zoning or the evaluation of specific sites.*

High priority will be given to the production of such seismic risk maps under the USGS program.

Maps will be revised as fundamental scientific problems are solved and new information becomes available.

USGS will review, in consultation with the ICSSC, professional organizations, and model code groups, the priorities and types of information to be shown on national seismic risk maps and will revise and update the maps as required.

USGS (which emphasizes the development of new techniques for identifying and evaluating earthquake hazards and the application of existing and development of new techniques for evaluation and regional delineation of earthquake hazards) will implement a priority schedule for completion of regional evaluation and delineation of earthquake hazards by 1984. This schedule will take into consideration the views of State and local governments, hazards evaluation programs of the NRC and other agencies, differences in the nature of the hazards in each region, and the current state of knowledge in each.

Particular attention will be given to the timely publication of hazards information in a form readily understood by nonspecialists.

Agencies and firms planning special or critical facilities appropriately will bear the incremental cost of information required for their detailed analysis of specific sites to comply with the guidelines and requirements of States, local communities, and the Federal Government. Planning new construction to avoid especially hazardous zones, where possible, is an extremely effective mitigation measure. Because the regional information rarely will be sufficiently detailed to be used in making decisions about local construction, local land use planning, or the evaluation of specific sites, State and local governments may find it desirable to build on the Federal program in developing detailed information on which to base their decisions affecting construction and land use.

Management of Federal Lands

The Federal Government must set an example for State and local governments by carefully considering earthquake hazards in managing Federal lands.

In developing Federal lands, decisions about siting and construction of facilities affecting the safety and welfare of the public or providing vital services must reflect consideration of seismic hazards.

The lead agency will work with principal land-management agencies in the Departments of the Interior (DOI), Agriculture, Defense (DOD), and Energy (DOE) as well as others to develop guidelines indicating when and how earthquake hazards should be taken into account.

Improvement of Codes and Construction Standards and Practices

Agencies involved in construction, working through the ICSSC, will develop seismic design standards for Federal building construction.

Following testing and analysis of costs, implementation of the standards will be considered, and an Executive Order will be utilized in the implementation if required.

Standards should reflect regional differences in the earthquake hazards, placing emphasis on providing life safety, and will be built on existing model codes where feasible.

To assist State and local governments, industry, and the public in developing construction standards, criteria, and practices, NBS will work with the Department of Housing and

Urban Development (HUD), other Federal agencies (particularly those performing research), National Institute of Building Sciences, professional organizations, model code groups, and State and local building departments, assisting and cooperating with them in continuing development, evaluation, and improvement of model seismic design provisions suitable for incorporation into local codes and practices.

The provisions must be flexible and consider both costs and benefits, regional variation of seismic hazard, and adaptation to local conditions. (Incorporation of these seismic design provisions into local codes and practices is voluntary.)

NBS has a continuing responsibility for adequately testing the standards and design provisions developed.

Reduction of Hazards for Existing Buildings and Other Facilities

Until such time as the potential to predict, reliably, damaging earthquakes may present an economically attractive alternative to upgrading substandard structures, it is important that hazards be reduced from those structures presenting the greatest risk in terms of occupancy and potential secondary impacts.

Special attention must be given to those structures that provide vital community services or pose unacceptable risks because of high occupancy.

It is essential to reach a realistic and cost/effective solution to the problem of existing buildings that are not seismically resistant. Some hazardous existing buildings may not warrant reinforcement or replacement, while it may be most cost/effective to achieve an increment of improved seismic resistance in others but not require upgrading to meet the criteria for new construction.

The lead agency [working closely with and drawing upon the expertise of the General Services Administration (GSA), DOD, VA, HUD, etc.] will develop a targeted strategy for identifying the Federally owned structures that present unacceptable risks—considering their use, occupancy, vulnerability, and the magnitude of the hazard.

A strategy for an approach to this problem should be outlined and tested and approved by GSA and DOD. When the strategy has been developed adequately for widespread application at reasonable cost, the agencies can request additional funds for implementation.

As structures that present unacceptable risks are identified, each agency will include corrections of seismic deficiencies along with other necessary improvements to maintain a balanced annual construction program within its available resources and consistent with its other systemwide priorities.

Corrective measures must consider other factors than earthquake safety alone and must be undertaken in a reasoned way.

The strategy for identifying hazardous buildings will be coordinated with DOE's Federal Energy Management Program where feasible and appropriate.

GSA, in addition to identifying Federally owned structures that present unacceptable risks, will prepare guidelines for evaluating seismic hazard in leasing of buildings. By applying standards for seismic resistance to prospective leased buildings, the Federal Government will encourage the gradual reduction of hazard from existing privately owned hazardous structures.

Federal assistance to States and local communities in exploring approaches to the problems posed by existing hazardous buildings within their jurisdictions can be provided through existing planning grant programs, with assistance for implementing a reduction in the hazards posed by existing buildings continuing through various existing Federal programs such as HUD's Community Development Block Grant Program.

Ensurance of the Safety of Critical Facilities

Special attention must be given to earthquake resistance of dams, hydraulic structures, nuclear reactors, liquid natural gas plants, and storage facilities for explosive and hazardous materials, lifelines such as transportation routes and facilities, energy transmission facilities, water supply systems, sewage disposal systems, and communications systems.

Federal agencies responsible for dam construction will implement guidelines for safety of Federal dams, which contain provisions regarding earthquake resistance and independent review. Further, the U.S. Army Corps of Engineers, the Bureau of Reclamation, and other agencies involved in dam construction have established requirements to include seismic design considerations—in accordance with the latest state of the art—for new dams and appurtenant structures. In addition to the requirements providing for re-evaluation of existing dams to determine their earthquake resistance in accordance with the latest standards, the Corps of Engineers has begun the inspection of approximately 9000 non-Federal dams that could be the cause of substantial loss of life and property in the event of failure. Among other considerations, the Corps will make an assessment of the potential vulnerability of these dams to seismic events and will recommend additional seismic investigation of these dams where required. Results will be made available to the States to encourage them to initiate effective non-Federal dam safety programs.

Special attention also must be given to facilities that will be vitally needed following a destructive earthquake—hospitals, fire and police stations, communication and administration centers, water and fuel storage facilities, and transportation facilities and other lifelines.

Federal agencies, working through the ICSSC, will develop special guidelines for ensuring the serviceability of these facilities after a destructive earthquake for consideration when new facilities of this type are constructed or financed by the Federal Government.

Reduction of Risks Through Public Information and Participation

All Federal agencies implementing actions or supporting research must communicate with those affected by their actions and the results of their work.

The lead agency will monitor, and stimulate as needed, the flow of information among research workers, planners and designers, construction industry, public officials, and the public. Communications with key groups in society—particularly engineers, architects, planners, and building and emergency preparedness officials—is important. Training programs for these groups would be especially fruitful.

The lead agency will seek to identify areas where communications among these groups can be strengthened and take actions to effect it.

The lead agency must be aware of new research results, the success or failure of various mitigation programs, and the status of all earthquake hazard reduction actions throughout the Nation.

The lead agency must develop mechanisms to allow for participation in and periodic review of its program by appropriate representatives of State and local governments, the public, and professional and research communities. These mechanisms and other procedures for the dissemination of information will be included in the work plan to be prepared by the lead agency.

Expansion of Understanding Through International Cooperation

Lessons should be learned from earthquakes, foreign and domestic. Information on all earthquakes can be of value in mitigating the hazards of future U.S. earthquakes. Through *continued and broadened cooperation and exchange with nations having more advanced research and hazard mitigation programs, much can be learned.*

The Agency for International Development (AID) has a continuing responsibility for providing other nations and peoples with information that may help them to moderate the impacts of earthquakes and to provide and coordinate Federal assistance when destructive earthquakes occur abroad.

The lead agency should identify gaps in present private and public programs dealing with the damage caused by earthquakes and assist in providing a means to fill the gaps.

Because some actions for earthquake hazards reduction could begin immediately and others would have to await research results or the commitment of financial resources, the Executive Office of the President at the same time established the highest priorities for immediate action as follows:

Establishment of a focus—a lead agency—to provide national leadership and to guide and coordinate Federal activities;

Determination of the interest of States for the development of State and local strategies and capabilities for earthquake hazards reduction;

Completion of Federal, State, and local contingency plans for responding to earthquake disasters in the densely populated areas of highest seismic risk;

Development of seismic-resistant design and construction standards for application in Federal construction and encouragement for the adoption of improved seismic provisions in State and local building codes;

Estimation of the hazard posed to life by possible damage to existing Federal facilities from future earthquakes, and

Maintenance of a comprehensive program of research and development for earthquake prediction and hazards mitigation.

Recognizing that the Nation faces substantial loss of life and property should a large earthquake occur and that the NEHRP could not effect a change overnight, Federal agencies were directed to "attempt to identify those risks that are simply unacceptable, eliminate them, and work gradually through time to achieve a National posture in which the Nation is less and less susceptible to the catastrophic losses associated with a major earthquake." Furthermore, it was recognized that several financial problems associated with earthquake hazards and their reduction remained unsolved. Therefore, the lead agency was directed in the Presidential Plan to examine these problems and undertake studies to

Develop means to ensure a viable financial system in the event of a truly catastrophic earthquake. (Preparations currently are made to ensure the viability of the financial system in the face of disasters such as nuclear attack. If a catastrophic earthquake would present different problems, these must be identified and appropriate preparations must be made.);

Understand the impact of an earthquake prediction on financial institutions and private investment. (A credible earthquake prediction made several months or more in advance of the predicted event might lead to severe stresses in the financial and investment systems. The nature of these stresses must be identified so that remedies can be devised in advance.); and

Explore the utilization of financial mechanisms within the public and private sectors, including Federal loan, loan-guarantee, and grant programs, to effect earthquake hazards reduction. (Although significant leverage for mitigation actions exists through these mechanisms, a potential for serious dislocation also exists. Consequently, a cautious, studied approach is required.).

The Department of the Treasury was directed to assist the lead agency in these studies. Assistance also was to be requested from the Federal Reserve Board, Federal Home Loan Bank Board, Federal Deposit Insurance Corporation, Farmers Home Administration, the HUD Office of Housing, and the Small Business Administration (SBA).

The Presidential Plan also noted that "the role of insurance as a means to compensate victims and encourage earthquake mitigation is potentially great." Unfortunately, however, mitigation at the State and local level is the phase of the disaster activities most frequently neglected, and although residential and commercial earthquake insurance was available, it was not widely purchased. Furthermore, "serious questions existed regarding the capacity of the insurance industry alone to absorb the cost of a catastrophic earthquake if such insurance were widely purchased." Therefore, the Federal Insurance Administration (part of HUD at the time of the Plan, now part of FEMA), in cooperation with other appropriate agencies, was directed to undertake a study of earthquake insurance and the appropriate role of insurance in mitigating the impacts of earthquakes.

Federal Roles and Responsibilities

In accordance with the Earthquake Hazards Reduction Act of 1977, as amended, Executive Order 12381, and the Presidential Plan of 1978, specific roles and responsibilities for the NEHRP are being carried out by the individual departments, agencies, and subagencies of the Federal Government in keeping with their areas of concern and operational authorities. Although some changes have occurred in the name or alinement of the Executive agencies since passage of the Act in 1977 and the issuance of the Presidential Plan in 1978, the fundamental roles and responsibilities have remained unchanged in meeting the specific requirements of the Act and ensuring that its basic objectives are met.

Within the NEHRP, the Federal program and responsibility is to

- Provide a central focus for leading and coordinating the national program;
- Conduct research to obtain the information needed for preparedness and mitigation programs at all levels;
- Develop and implement preparedness and mitigation measures to protect lives and property at Federal facilities and on Federal lands and to provide supplementary assistance to State and local response efforts; and
- Assist State and local governments and the private sector in developing effective preparedness and mitigation programs—to include public awareness and education activities, coordination, and mitigation incentives and support mechanisms as appropriate as well as technical and financial assistance in preparedness, response, and mitigation activities.

To ensure the success of the Federal as well as national program, four agencies—FEMA, USGS, NSF, and NBS—are carrying out principal responsibilities in regard to the various program elements, as follows:

Leadership and coordination	FEMA
Research	USGS, NSF, NBS
Mitigation:	
Building standards	FEMA, NBS
Insurance and financial protections and incentives	FEMA
Hazard identification and reduction	USGS
Land use guidance	FEMA
Predictions	USGS
Multihazard coordination and planning	FEMA
Federal mitigation, preparedness, and response	FEMA

Assistance to state and
local governments
and the private
sector -----------FEMA, USGS, NBS
Information
dissemination and
public awareness --FEMA, USGS, NSF, NBS

In a number of areas, all four principal agencies have responsibilities—distinct and yet interdependent within the program element. For example, basic research is provided by several of the principal agencies, each in its own area of expertise and authority. Mitigation measures are a primary responsibility of FEMA in terms of emergency management and State assistance but are also the responsibility of the USGS in terms of hazard delineation and reduction, predictions, and warnings and of the NBS in terms of development of building standards and working with building officials and organizations. Technical and financial assistance are other areas in which several principal agencies share responsibilities, each within its respective program area.

FEDERAL EMERGENCY MANAGEMENT AGENCY

As the lead agency for the NEHRP, FEMA is responsible for program planning, direction, and coordination and for stimulation of actions needed to reduce earthquake hazards within the Federal Government and throughout the Nation. Under its own enabling authorities and in support of the NEHRP, FEMA also is responsible for coordinating Federal emergency management activities (preparedness, response, recovery, and mitigation) for all types of disasters—natural and manmade—and for providing technical and financial assistance to the States and local communities in carrying out their preparedness, response, recovery, and mitigation programs. Included in FEMA's mitigation responsibilities are the evaluation and recommendation of mitigation incentives and mechanisms needed to protect the individual, community, State, region, and Nation against the risk of financial loss and economic disruption associated with a catastrophic earthquake. When a major disaster or emergency is declared by the President, FEMA administers Federal assistance to the State(s), affected local governments, and individual victims and coordinates the disaster relief efforts of other Federal agencies and voluntary organizations.

Responsibilities specified for FEMA as the lead agency by Congress, the Presidential Plan, and Executive Order 12381 include the following:

- Establishing the roles and responsibilities of each appropriate Federal department, agency, and entity with respect to each object and element of the program;
- Establishing goals, priorities, budgets, and target dates for implementation of the program;
- Providing a method for cooperation and coordination with, and assistance (to the extent of available resources) to, interested governmental entities in all States, particularly those containing areas of high or moderate seismic risk;
- Providing for qualified and sufficient staffing for the program and its components;
- Compiling and maintaining a written program plan which will recommend base and incremental budget options for the agencies to carry out the elements and programs specified through at least 1985 and which will be updated annually;
- Recommending appropriate roles for State and local units of government, individuals, and private organizations;
- Developing mechanisms for the participation in and periodic review of the NEHRP by appropriate representatives of State and local governments, the public, and professional and research communities;
- Reviewing and periodically updating the research and implementation plans to assure that they reflect the latest developments and objectives;

- Stimulating and coordinating actions to reduce earthquake hazards within the Federal Government and throughout the Nation;

- Providing leadership to the ICSSC;

- Developing guidelines for the inclusion of earthquake hazards reduction activities in ongoing Federal programs;

- Developing a strategy to identify existing Federal buildings and other structures that pose unacceptable earthquake-related risks;

- Coordinating the development of guidelines for the consideration of seismic risk in the development of Federal lands;

- Identifying gaps in present private and public programs dealing with the damage caused by earthquakes and assisting in filling those gaps;

- Monitoring, and stimulating as needed, the flow of information among research workers, planners and designers, construction industry, public officials, and the public; and

- Preparing and submitting an annual report on the NEHRP to the Congress.

In addition, in regard to the programmatic elements of agency's role and responsibilities, FEMA is directed by Congress and the President to

- Prepare Federal earthquake contingency plans and assist State and local governments in the preparation of their plans;

- Undertake a study of the appropriate role of insurance in mitigating the impacts of earthquakes;

- Assist in the studies of financial problems related to earthquakes;

- Initiate studies designed to define and develop a multihazard research, planning, and implementation process within the agency;

- Develop, in cooperation with State and local governments, prototypical multihazard mitigation projects that could be used to evaluate several approaches to the varying hazard mitigation needs and to assess the applicability of these prototypes to other jurisdictions with similar needs;

- Investigate and evaluate the effectiveness of a range of incentives for hazards reduction that can be applied at the State and local levels;

- Prepare a report on the status of FEMA's emergency information and communications systems;

- Conduct a program of multihazard research, planning, and mitigation in coordination with those studies and evaluations authorized under the Earthquake Hazards Reduction Act of 1977, as amended, as well as other hazards research, planning, and mitigation deemed necessary by the Director; and

- Maintain liaison on earthquake-related matters with regulatory agencies such as the NRC and the Federal Energy Regulatory Commission.

U.S. GEOLOGICAL SURVEY

USGS supports the mitigation activities of the NEHRP through the provision of earth science data and evaluations essential for land use planning, engineering design, and other measures and emergency preparedness. Specific USGS responsibilities are to (1) evaluate the earthquake potential of seismically active areas of the United States, (2) provide assessments of earthquake hazards and risk in urban regions exposed to the earthquake threat, (3) predict damaging earthquakes, (4) provide data and information on earthquake occurrences to the public and scientific community, and (5) provide data and estimates of the level and character of earthquake strong ground motion for earthquake-resistant design and construction.

This base program can be divided into the following five subelements along structural lines within the NEHRP:

Regional Monitoring and Earthquake Potential Studies: Seismological and geological analyses of the current seismic activity, active geologic faults, and earthquake potential of all seismic regions in the United States.

Earthquake Prediction Research: Laboratory and theoretical studies and field experiments in some areas identified in monitoring with the goal of establishing the procedures and knowledge needed in reliable prediction of the time, place, and magnitude of damaging earthquakes.

Regional Earthquake Hazards Assessments: Regional earthquake hazards assessments in urban areas identified as having moderate to high risk, including analyses of potential ground shaking and ground failure on a regional scale and the demonstration of specific hazard-assessment techniques unique to each region. [This does not include block-by-block analyses (microzoning), which are more properly performed at the State and local level.]

Data and Information Services: Networks providing data on earthquake occurrence for use by the public, other Federal agencies, State and local governments, emergency response organizations, and the scientific community.

Engineering Seismology: Analyses of data on strong earthquake ground motion, the results of which are provided to other Federal agencies and the engineering community for development of seismic-resistant designs and construction of buildings, dams, and critical facilities.

The USGS program is designed to fulfill the Congressional directives and Presidential Plan to

- Conduct research on the nature of earthquakes, earthquake prediction, hazards evaluation and delineation, and induced seismicity;
- Evaluate, with the advice of the National Earthquake Prediction Evaluation Council, earthquake predictions;
- Prepare national seismic risk maps;
- Evaluate and delineate earthquake hazards on a regional basis; and
- Provide data and information on earthquake occurrences and hazards.

NATIONAL SCIENCE FOUNDATION

As specified in the Congressional directives and Presidential Plan, the NSF supports fundamental research studies on earthquakes and basic and applied research on earthquake engineering and policy. Through its studies of seismology, gravity, geodesy, magnetism, Earth currents, heat flow, and the behavior of natural materials at high pressure and temperatures, the NSF's Earth Sciences Division improves the understanding of the natural phenomena involved in an earthquake and provides information necessary for the potential prediction of earthquakes and destructive ground motion. The Division of Civil and Environmental Engineering supports research in the fields of earthquake engineering, architecture, urban planning, and societal response to obtain needed information on the nature and effects of destructive ground shaking as well as on practical methods of analysis, design, and planning for safe and economical earthquake countermeasures for both existing and planned structures. Through its Societal Response Program, the NSF supports research on the responses of individuals, organizations, and communities to earthquakes and related hazards, which are critical to emergency response planning and mitigation, particularly in the case of a long-term prediction. Thus, the Societal Response Program provides information on the socioeconomic aspects of hazards mitigation; a data base for hazards preparedness planning; a greater understanding of disaster impacts, responses, and recovery; and a basis for improving the dissemination and utilization of earthquake hazard information by decisionmakers and the public.

NATIONAL BUREAU OF STANDARDS

As the Nation's central physical sciences and engineering measurements laboratory, the NBS conducts research on performance criteria and supporting measurement technology for earthquake-resistant construction. Unique laboratory facilities support studies of the strength and energy absorption characteristics of structural and geotechnical materials and systems. Methods are developed to predict earthquake resistance during design, to assess resistance of existing facilities, and to measure properties of materials and systems.

The NBS provides technical support for the development, testing, and improvement of seismic design and construction provisions. These are incorporated in practices for Federal construction and are used in national standards and the regulations of State and local governments.

As specified in the Congressional directives and Presidential Plan, the NBS assists and cooperates with other Federal agencies, the National Institute of Building Sciences, professional organizations, model building code groups, and State and local building departments. Although the NBS has no role in the promulgation or the enforcement of building standards or codes, the technical support provided for organizations that do develop them is effective in getting research into practice.

OTHER FEDERAL AGENCIES

However, nearly all Federal agencies participate in Federal preparedness, mitigation, and response efforts undertaken within their respective programs. These responsibilities continue undiminished, but include consideration of seismic-related hazards in carrying out those responsibilities. Where deficiencies, overlaps, or gaps in the overall Federal Program are identified over time, steps will be taken to remedy them.

The Presidential Plan of 1978 outlines responsibilities for the various Federal agencies as follows:

Office of Science and Technology Policy

- Review the research program periodically.

Agency for International Development

- Coordinate assistance to other nations stricken by earthquake disaster.
- Coordinate assistance to other nations in developing strategies for mitigating earthquake hazards.

Department of Agriculture

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Work with professional organizations, model code groups, and State and local officials to establish appropriate local seismic requirements to be followed in Federal aid, grant, and loan programs.
- Participate in the development of guidelines for the consideration of seismic risk in the development of Federal lands.
- Assist in the dissemination of information about earthquake hazards reduction activities through existing channels within the agencies of the department.

Department of Commerce

National Oceanic and Atmospheric Administration

- Operate the tsunami warning network and issue tsunami warnings.
- Conduct geodetic surveys through the National Geodetic Survey.
- Provide data to researchers and the public through the Environmental Data Service

[now the National Environmental Satellite, Data and Information Service].

Department of Defense

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Work with the lead agency and other Federal agencies in developing and testing a strategy to identify Federal structures that pose unacceptable seismic risks.
- Initiate corrective action where existing agency facilities pose unacceptable seismic risks.

Corps of Engineers

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Assess potential vulnerability of selected non-Federal dams to earthquakes and develop recommendations for additional seismic investigations as required.
- Participate in the development of guidelines for the consideration of seismic risk in the development of Federal lands.

Department of Energy

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Participate in the development of guidelines for the consideration of seismic risk in the development of Federal lands.

Department of Housing and Urban Development

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Work with Federal research activities, professional organizations, model code groups, and State and local officials and planners to establish appropriate local seismic requirement guidelines to be followed in Federal aid, grant, and loan programs.
- Cooperate with other Federal agencies, State and local governments, and private sector agencies in the conduct of appropriate research to improve building codes and other mitigation measures.

Department of the Interior

- Participate in the development of guidelines for the consideration of seismic risk in the development of Federal lands.

Bureau of Reclamation

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.

Department of Transportation

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.
- Work with the lead agency and other Federal agencies in developing a strategy to identify Federal structures that pose unacceptable seismic risks.
- Initiate corrective action where existing agency facilities pose unacceptable seismic risks.
- Work with professional associations, model code groups, and State and local officials to establish appropriate local seismic requirements to be followed in Federal aid and grant programs.
- Cooperate with other Federal, State, and private agencies in the conduct of appropriate research to provide an adequate technological base for standards for projects, such as bridges and tunnels, not covered by common building codes.

General Services Administration

- Participate in the ICSSC to develop seismic design and construction standards for Federal projects and related guidelines.

- Work with the lead agency and other Federal agencies in developing a strategy to identify Federal structures that pose unacceptable seismic risks.

- Test and improve the strategy for identifying potentially hazardous Federal structures.

- Initiate corrective action where existing agency facilities pose unacceptable seismic risks.

- Develop guidelines for consideration of seismic hazard in the leasing of buildings.

Veterans Administration

- Participate in the ICSSC to develop design and construction standards.

- Work with the lead agency and other Federal agencies in developing a strategy to identify Federal structures that pose unacceptable seismic risks.

The Plan also states that in carrying out the Federal program, the participation, assistance, and cooperation of many other agencies and units of the Federal Government will be needed. These agencies include, but are not limited to, the SBA; the NRC; the Environmental Protection Agency (EPA); the Department of Health, Education and Welfare [now the Departments of Health and Human Services (HHS) and Education]; the National Aeronautics and Space Administration (NASA); and the Department of the Treasury.

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM COMMITTEES

As indicated in the Act and Presidential Plan, the lead agency (FEMA) was to organize and lead an Interagency Committee on Seismic Safety in Construction to assist Federal agencies involved in construction in implementing earthquake hazards reduction elements in their ongoing programs. FEMA also was directed to identify additional areas for hazards reduction activity identified through consultation with appropriate Federal agencies, State and local governments, and private relief organizations. Advisory groups and interagency committees were to be established as required to meet the needs of the program and assist FEMA in its management and evaluation responsibilities.

Currently, the principal committees of or associated directly with the NEHRP are as follows:

Earthquake Policy Review Group

This interagency group of top policy-level officials from the four principal agencies, established by FEMA in January 1983, deals with overall program policy issues. FEMA plans for this group to oversee the necessary program planning, budgeting, and evaluation.

Membership: FEMA (Chair), USGS, NSF, NBS

Interagency Coordination Committee

The Interagency Coordination Committee (ICC) was established by FEMA in 1981 at the program-manager level to ensure the coordination of the activities among all Federal agency participants in the NEHRP and the exchange of information on those activities. The ICC advises FEMA on all earthquake-related matters affecting the NEHRP and refers policy issues to the Review Board for resolution.

Membership: All Federal departments and agencies that conduct programs to prepare for, respond to, recover from, and mitigate the effects of earthquake-related hazards may participate. Each department and agency is represented by a designated midlevel official or that official's designee. The ICC chairman is the FEMA representative.

Ad Hoc Five-Year Plan Review Panel

In fiscal year 1982, Karl V. Steinbrugge was selected to conduct an independent review of the NEHRP Five-Year Plan. In assisting him, he chose a group of 22 experts representing all relevant disciplines and State and local governments to aid him. The group was provided with a draft of the plan, which represents a synthesis of materials provided by Federal agencies conducting earthquake-related activities. Their review and recommendations on the NEHRP goals, direction, and funding were submitted in fiscal year 1983.

ICC Subcommittee on Federal Earthquake Response Planning

This interagency subcommittee was created to assist in the coordination of activities necessary for developing a Federal-level response plan for catastrophic earthquakes.

Membership: Federal departments and agencies that are major sources of disaster assistance under their own statutory authorities or under the authority of Public Law 93–288 (Disaster Relief Act) in a presidentially declared major disaster. The subcommittee's chairman is from FEMA.

Interagency Committee on Seismic Safety in Construction

The ICSSC was established in 1978 to assist the Federal departments and agencies involved in construction to develop earthquake hazards reduction measures and to incorporate them in their ongoing programs. In fiscal year 1983 the ICSSC was revitalized, the 10 subcommittees were reduced to 4 as identified below, and a steering committee was established.

Membership: Policy-level representatives of the Department of Agriculture, Soil Conservation Service (SCS); Department of Commerce, NBS; DOD; Department of Education; Department of Energy (DOE); HHS; HUD; Department of the Interior, USGS; Department of Justice; Department of Labor; Department of State; Department of Transportation, Federal Highway Administration (FHWA); Department of the Treasury; EPA; FEMA; GSA; NASA; NSF; NRC; Postal Service; SBA; Tennessee Valley Authority (TVA); VA. FEMA is responsible for providing leadership to the ICSSC; an NBS representative currently is serving as the chairman. The Steering Committee is comprised of representatives of the Department of Commerce, NBS; DOD; HUD; Department of the Interior, USGS; Department of Transportation, FHW; FEMA; GSA; NSF; VA.

Subcommittee 1: Standards for New and Existing Buildings:

This subcommittee is responsible for recommending earthquake-resistant design and construction standards for new and existing Federal buildings and their appurtenances and nonstructural components. The subcommittee's mission also includes development of a strategy and technique for identifying existing seismically hazardous buildings and developing hazard mitigation techniques and procedures.

Membership: Department of Agriculture, Farmers Home Administration (FHA) and U.S. Forest Service (USFS); Department of Commerce, NBS; Department of Defense, Army and Navy; HHS; HUD; Department of State; Department of Transportation; Federal Aviation Administration (FAA); GSA; NSF; Postal Service; VA. Subcommittee 1 is chaired by the NBS.

Subcommittee 2: Lifelines:

The mission of this subcommittee is to identify existing guidelines or standards for earthquake-resistant design, construction and retrofit of energy, transportation, water, and telecommunication systems; to recommend Federal adoption of such standards when found adequate; and to encourage development of new standards where there are significant omissions. The subcommittee will study techniques for evaluating the seismic vulnerability of existing lifelines and for improving their resistance to seismic effects and ease of repair. The subcommittee will consider strategies that will permit identification of those lifeline facilities important in the emergency, immediate recovery, and long-term economic recovery periods and will provide guidance for appropriate levels of seismic protection for each type. In addition, the subcommittee will establish liaison with existing professional and industrial groups active in the seismic design of lifeline facilities and make an assessment of the state of the art.

Membership: Department of Argiculture, FHA and Rural Electrification Administration (REA); Department of Commerce, NBS; Department of Defense, Navy; HUD; Department of Transportation, FHWA; GSA; NSF; TVA; VA; several consultants from the private sector. Subcommittee 2 is chaired by the FHW.

Subcommittee 3: Evaluation of Site Hazards:
The mission of this subcommittee is to establish guidelines, procedures, and criteria for site selection and the evaluation of seismic risk and seismically induced geologic hazards to federally funded, assisted, and regulated construction sites. Hazards that will be considered include seismicity, ground shaking, surface faulting and other tectonic deformation, liquefaction, landslides, and tsunamis.

Membership: Department of Agriculture, SCS; Department of Commerce, NBS and NOAA; Department of Defense, Army and Navy; HUD; Department of the Interior, USGS; Department of Labor; GSA; NSF; NRC; VA. Subcommittee 3 is chaired by the USGS.

Subcommittee 4: Seismic Practices for Federal Domestic Assistance, Leasing, and Regulatory Programs:
The subcommittee's mission is to develop strategies for implementation of appropriate standards for earthquake-resistant design and construction of structures and facilities involving Federal domestic assistance (aid, grant, loan, and mortgage insurance), leasing, and regulatory programs. The subcommittee will deal primarily with policy matters related to application of mandatory standards or guidelines for Federal domestic assistance, leasing, and regulatory programs, with consideration of State and local codes. Recommendations will be formulated for the implementation of mandatory standards and guidelines and for required regulatory procedures which can be adopted by individual agencies. Specific requirements and exceptions to the mandatory standards and guidelines will be developed for Federal assistance and leasing programs. Proper coordination will be maintained among all related regulatory organizations and other Federal, State, and local agencies involved in construction under Federal domestic assistance, leasing, and regulatory programs to assure resolution of conflicts prior to adoption of mandatory seismic standards. A procedure will be developed for the periodic review of mandatory standards and guidelines for the purpose of revising and updating the standards and guidelines and for adopting future applicable standards and guidelines.

Membership: Department of Agriculture, FHA and REA; Department of Commerce, NBS; HHS; HUD; Department of State; EPA; FEMA; GSA; NSF; Postal Service; SBA; VA. Subcommittee 4 is chaired by HUD.

Emergency Mobilization Preparedness Board

President Reagan established the Emergency Mobilization Preparedness Board (EMPB) on December 17, 1981, to ensure that the Nation would be capable of responding effectively to major peacetime and wartime emergencies. The EMPB consists of the representatives of 23 key Federal departments, agencies and Executive Offices. Chaired by the Assistant to the President for National Security Affairs, the EMPB is empowered to develop overall policy and a plan of action that will improve the Nation's preparedness capabilities. The EMPB has the authority to resolve mobilization preparedness issues within the framework of current administration policy. Any issue which cannot be resolved through this process will be referred to the National Security Council for discussion and Presidential decision. The EMPB is supported by 12 working groups, each responsible for a specific area of preparedness and chaired by an Assistant Secretary-level official from one of the member agencies.

Earthquake Working Group

One EMPB working group—the Earthquake Working Group—is concerned with the consequences of a catastrophic earthquake.

Membership: Various Federal agencies involved in earthquake-related activities. During fiscal year 1983, FEMA replaced the OSTP as chairman for the Earthquake Working Group.

National Earthquake Prediction Evaluation Council

In 1981, the USGS Director established the National Earthquake Prediction Evaluation Council (NEPEC) to aid the Director in evaluating and issuing earthquake predictions. The NEPEC meets at least once a year to review progress in the field of earthquake prediction and to handle any administrative matters.

Membership: Twelve experts in scientific disciplines related to earthquake prediction, at least one-half of which cannot be USGS employees. The chairman is an NEPEC member who is not a USGS employee.

Committee on Earthquake Engineering

A continuing Committee on Earthquake Engineering was organized at the National Research Council under the National Academy of Sciences and the National Academy of Engineering. The committee tasks are to assess progress being made in the earthquake engineering portion of the NEHRP; to identify areas in need of additional research; and to recommend to Federal agencies, industry, and the universities changes in the program's emphasis and direction as needed to improve effectiveness. Also, the committee is to select elements of the earthquake engineering program for in-depth study, to organize appropriately manned panels for making such studies, oversee their work, and to report findings and recommendations to the appropriate government agencies and the public. Initially, the committee is to organize panel studies on strong ground-motion instrumentation and on application of research results.

Membership: Eight specialists of various fields selected on the basis of their expertise and judgment in their respective fields. Panels will include additional noncommittee members, also chosen on the basis of expertise in their particular field, and representatives from relevant agencies.

NON-FEDERAL ROLES AND RESPONSIBILITIES

However, in creating the NEHRP, the responsibilities of carrying out the Act were seen by Congress, and have been viewed by the Executive Branch in administering the program, as involving all levels of government and the private sector, each with its own roles and responsibilities. In outlining the Federal responsibilities for the program, therefore, the Presidential Plan also delineated between the roles and responsibilities of the Federal Government and those of the State and local governments and private sector as follows.

State and local governments, which are responsible for public safety and welfare and have the power to regulate construction, land use, and other measures needed to ensure public safety and welfare, bear the primary responsibility for preparedness, mitigation, warning, response, and recovery activities associated with natural and manmade disasters. The Federal Government provides supplementary support to these local, State, and regional efforts. The public sector roles at all levels are strongly interrelated and should be complementary rather than duplicative.

As can be seen by many key points in this program, the success of a national effort to mitigate losses and suffering from earthquakes rests largely in private hands. The role of the Federal Government is limited, as are the roles of State and local governments.

Business, industry, and the services sector play the lead roles in constructing new buildings and in developing land. Earthquake-resistant design provisions in local codes, whether modern or outdated, are minumum standards. Thoughtful businessmen interested in providing a safe environment for their consumers and employees, and in protecting their capital investment will want to give careful consideration to earthquake hazards in planning, constructing, and maintaining their facilities. The success of much of this program requires the leadership of these elements of the private sector. The interest of business and industry must be maintained to accomplish our objectives. In some instances short-term profits may be reduced to increase the long-term benefits of saving lives, reducing property damage, and maintaining the functioning of the economy in the face of a major earthquake. Private financial institutions, including lending agencies and insurance companies, must continue their important role. These institutions may identify opportunities to effect hazards reduction that can be beneficial to all concerned.

Voluntary organizations have traditionally played a major part in providing specialized assistance to victims of disasters. The Nation places a continuing reliance on the efforts of these citizens. Opportunities exist for these same organizations to provide even greater public service by initiating actions to mitigate losses before the disaster, particularly through the dissemination of information. This capacity will be even more important as the ability to predict earthquakes develops. Money and people do not add up to capability. What is required is the development of interest, experience and expertise.

Individuals and organizations from the research and professional communities, especially practicing professionals, have developed the degree of awareness of earthquake hazards that we have today. Government must work to assist, rather than to replace, these efforts. Professional organizations have a continuing and vital role to play. The improvement of model codes and their testing, and adoption by State and local governments require the vigorous participation of the professional community. Of course, any code is only as good as its implementation. High-quality workmanship and improving implementation are responsibilities shared by all elements of the construction industry and local building officials.

The professional organizations also have a particularly important part in communication and the exchange of information. Opportunities for training programs focused on techniques for earthquake hazards reduction should be identified and carried through these organizations.

As the Presidential Plan states; "Ultimately, the success or failure of the NEHRP will depend on the resolve of the American people, particularly in the private sector. The expenditure of dollars alone does not make a successful program. The enthusiasm, the expertise, the willingness to work, and the perseverence of the people are required to make the program effective."

GLOSSARY

Accelerometer. A seismograph for measuring ground acceleration as a function of time.

Active fault. A fault along which slip has occurred in historic or recent geologic time (typically, the past 10,000 to 2,000,000 years), and along which future movement is expected.

Aftershock. An earthquake that follows a larger earthquake or main shock and originates at or near the focus of the larger earthquake.

Amplification. The increase in earthquake ground motion that may occur to the principal components of seismic waves as they enter and travel through different earth materials.

Amplitude (wave). The maximum height of a wave crest or depth of a trough.

Dip. The angle that a structural surface (for example, a bedding or fault plane) makes with the horizontal, measured downward in the vertical plane perpendicular to the strike of the structure.

Dyne. A centimeter-gram-second unit of force, equal to the force required to impart an acceleration of 1 centimeter per second per second to a mass of 1 gram.

Earthquake. The vibrations of the Earth caused by the passage of seismic waves radiating from a natural source of elastic energy.

Epicenter. The point on the Earth's surface directly above the focus (or hypocenter) of an earthquake.

Erg. A centimeter-gram-second unit of energy or work equal to the work done by a force of 1 dyne acting over a distance of 1 centimeter.

Fault. A fracture or zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Fault creep. Slow slip occurring along a fault without radiating seismic waves.

Focus (hypocenter). The point at which an earthquake rupture commences.

Hertz. A unit of frequency equal to 1 cycle per second.

Isoseismal. Contour lines drawn to separate one level of seismic intensity from another.

Liquefaction. The transformation of a granular soil to a liquefied state usually caused by strong earthquake shaking.

Love wave. A seismic suface wave with only horizontal shear motion transverse to the direction of propagation.

Main shock. The largest earthquake in a sequence.

Normal fault. A vertical or steeply inclined fault along which the overhanging block above the fault has moved downward relative to the block below.

P wave. The primary, or fastest, wave traveling away from a seismic event and consisting of a train of compressions and dilatations of the material.

Rayleigh wave. A seismic surface wave with ground motion only in a vertical plane containing the direction of propagation of the wave.

Reverse fault. A steeply to slightly inclined fault in which the block above the fault has relatively moved upward or over the block below the fault.

Right-lateral fault. A fault in which the block across the fault from an observer has moved to the right.

S wave. The secondary seismic wave, traveling more slowly than the P wave, and consisting of elastic vibrations transverse to the direction of travel.

Seismic moment. The product of the surface area of the fault, the average displacement on the fault plane, and the rigidity of the material of the fault. Symbol, M_0.

Seismic wave. An elastic wave in the Earth usually generated by an earthquake source or explosion.

Seismograph. An instrument for recording as a function of time the motions of the Earth's surface that are caused by seismic waves.

Slip. The relative motion of one face of a fault relative to the other.

Strain (elastic) . The geometrical deformation or change in shape of a body. The change in an angle, length, area, or volume divided by the original value.

Stress (elastic). A measure of the forces acting on a body in units of force per unit area.

Strike. The direction or trend taken by a structural surface (for example, a bedding or fault plane) as it intersects the horizontal.

Strike-slip fault. A fault on which the movement is principally horizontal, parallel to the fault's strike.

Strong ground motion. The shaking of the ground near an earthquake source made up of large amplitude seismic waves of various types.

Surface wave. A seismic wave that follows the Earth's surface only, with a speed less than that of an S wave. There are two types of surface waves—Rayleigh waves and Love waves.

Thrust fault. A fault with a dip of 45 degrees or less over much of its extent, on which the overhanging block has moved upward relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.

Tsunami. A long ocean wave usually caused by sea floor displacements in an earthquake. Etymology: Japanese, "harbor wave." Erroneous synonym: tidal wave.

Wavelength. The distance between two successive crests or troughs of a wave.

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