Appendix C: International Earthquake Programs

C

Devastating earthquakes have been experienced all around the globe, at times with astounding loss of life (see table C-1). Figure C-1 illustrates recent world seismicity. Future occurrences of potentially damaging quakes are inevitable. As a result, many countries have mounted extensive research and development, hazard assessment, and disaster response programs related to earthquake hazards and seismic risk.

A comprehensive discussion of the many international mitigation programs and their achievements is beyond the scope of this report. Instead, this appendix briefly describes efforts under way in a few countries whose seismicity and mitigation practices may shed light on related U.S. efforts. It also outlines the framework that exists for cooperation and coordination among nations in understanding earthquake hazards and mitigating seismic risk.

To summarize, both Japan and China have sizable earthquake research and mitigation programs. Unlike the United States, however, the predominant focus of Japan's efforts is seismic monitoring and research applied toward predicting great earthquakes.

New Zealand also has a collection of efforts similar in scope, if not scale, to the U.S. national effort. One major difference is the inclusion of a government-sponsored earthquake insurance program and a move toward mitigating economic disruption along with threats to life safety. Several other countries have significant research programs or relevant data. For seismological or paleoseismological data from intraplate earthquakes, China and Australia are sources.[1] Russia, China, and Japan have data on potential earthquake precursors; Japan also has strong-motion data from subduction zone earthquakes and results from tsunami studies. In addition, Canada and the United States exchange data and analyses regarding seismic hazards in the west and east (e.g., subduction zone quakes in the Pacific Northwest and intraplate quakes in the northeastern United States).

[1] Few earthquakes that occur in relatively stable regions of continents have surface expression. Of the 11 historic intraplate earthquakes that have produced surface ruptures, five occurred in Australia since 1968. Michael Machette and Anthony Crone, "Geologic Investigations of Australian Earthquakes: Paleoseismicity and the Recurrence of Surface Faulting in the Stable Regions of Continents," *Earthquakes & Volcanoes*, vol. 24, No. 2, 1993, p. 74.

TABLE C-1: Selected Significant Earthquakes Worldwide

Location	Year	Magnitude	Impact
Northern China	1556	—	800,000 killed
Lisbon, Portugal	1755	—	60,000 killed, fire
San Francisco, California	1906	8.3	700 killed, fire
Messina, Sicily	1908	7.5	160,000 killed
Tokyo, Japan	1923	8.3	140,000+ killed, fire
Assam, India	1950	8.4	30,000 killed
Chile	1960	Mw 9.5	5,700 killed, 58,000 homes destroyed, tsunami
Alaska	1964	Mw 9.2	131 killed, tsunami
Northern Peru	1970	7.7	67,000 reported killed
Guatemala	1976	7.5	23,000 killed
Tangshan, China	1976	7.9	240,000-650,000 killed
Northern Iran	1978	7.7	25,000 killed
Mexico City	1985	8.1	10,000+ killed
Armenia	1988	6.8	55,000 killed
Loma Prieta, California	1989	7.1	63 killed, $5 billion to $10 billion damage
Northern Iran	1990	7.7	40,000 killed
Flores, Indonesia	1992	7.5	2,500 killed
Latur, India	1993	Mw 6.2	9,750 deaths
Northridge, California	1994	6.8	57 killed, more than $20 billion damage
Kobe, Japan	1995	6.8	5,500+ killed, more than $200 billion losses
Sakhalin Island, Russia	1995	Mw 7.0	Approximately 2,000 killed

NOTE: A significant earthquake is one that registers a magnitude of 6,5 or more, or one that causes considerable damage or loss of life On average, 60 significant earthquakes take place around the world each year. Mw representsmoment magnitude, a measure of the total seismic energy released

SOURCE: Office of Technology Assessment, based on Bernard Pipkin, *Geology and the Environment* (St Paul, MN: West Publishing Co , 1994), and references cited therein; and William Ellsworth, U S Geological Survey, Menlo Park, personal communication, June 14, 1995

The United States is actively involved in several cooperative programs established to share expertise and data. Joint research and technology transfer projects have been especially useful to the spread of seismic zonation practices around the world.[2] (In a similar vein, technology transfer from Japan to Chile has been integral to the latter nation's advances in earthquake mitigation, for example, in tsunami studies.[3])

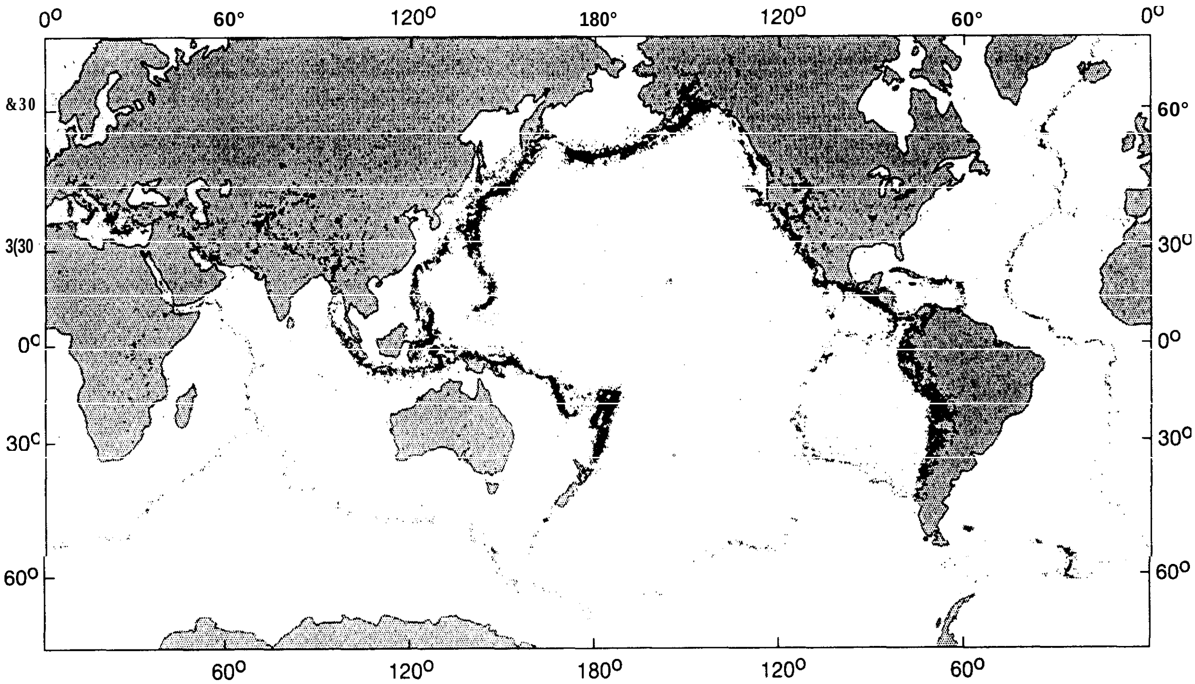
AUSTRALIA

Australia, a relatively stable continent far removed from the earth's plate boundaries, received

[2] Seismic zonation is the division of a geographic region into smaller areas or zones that are expected to experience the same relative severity of an earthquake hazard (e.g., ground shaking or failure, surface faulting, tsunami wave runup). Based on an integrated assessment of the hazard, built, and policy environments, resulting zonation maps provide communities with a range of options for ensuring resilience to earthquakes and sustainable development. U.S. Geological Survey, *Proceedings of the Fourth International Forum on Seismic Zonation,* July 14, 1994, Chicago, IL, and Aug. 30, 1994, Vienna, Austria, Open File Report 94-424 (Reston, VA: n.d.), appendix B, p. 1.

[3] See Maria Ofelia Moroni, "Technology Transfer on Earthquake Disaster Reduction Between Japan and Chile," *Bulletin of the International Institute of Seismology and Earthquake Engineering,* vol. 27, 1993, pp. 199-211. In 1960, a tsunami that originated off the coast of Chile caused nearly 1,000 deaths in that country and much destruction in Japan as well.

FIGURE C-1: Epicenters of 30,000 Earthquakes, 1961-67



SOURCE Office of Technology Assessment, 1995, adapted from F Press and R Siever, *Earth,* Second Edition (San Francisco, CA: W.H. Freeman and Company, 1978), p. 412.

a wake-up call with respect to urban earthquake hazards when a magnitude 5.6 (M5.6) earthquake struck Newcastle in December 1989. It resulted in about $2.86 billion (U. S.) in losses and 13 deaths.[4] The disaster led to increased studies of the region's intraplate quakes and a national program in seismic zonation.

The Australian Geological Survey Organization, in coordination with various state geological surveys and universities, conducts the national program in earthquake monitoring. With funding from the federal agency Emergency Management Australia and state governments, the Center for Earthquake Research in Australia (CERA) has completed seismic zonation maps for four of the largest cities (Sydney, Newcastle, Melbourne, and Brisbane and its environs). Maps for other urban areas are in progresse[5]

According to CERA, the outcomes of this mapping program have practical applications in many areas, including seismic code formulation, emergency management, and community education.[6]

[4] John M.W. Rynn, "The Potential To Reduce Losses from Earthquakes in Australia, " D.I. Smith and J.W. Handmer (cd.), *Australia's Role in the International Decade for Natural Disaster Reduction,* Resource and Environmental Studies No. 4, Journal of the Australian National University Center for Resource and Environmental Studies, 1991, p. 9.

[5] For a description of initial efforts, see John M.W. Rynn, "Mitigation of the Earthquake Hazard Through Earthquake Zonation Mapping: The Program for Urban Areas in Australia," *Proceedings of the Workshop Towards Natural Disaster Reduction,* June 27-July 3, 1993, Okinawa, Japan, S. Herath and T. Katayama (eds.) (Tokyo, Japan: International Center for Disaster-Mitigation Engineering, July 1994), pp. 115-136.

[6] John Rynn, Center for Earthquake Research in Australia, personal communication, June 7, 1995.

TABLE C-2: Canadian Organizations Involved in Earthquake Mitigation

Organization	Description	Activities
Geological Survey of Canada (GSC)	Agency of the Ministry of Natural Resources Canada	Seismic and strong-motion monitoring, hazard estimation; international cooperation.
National Research Council (NRC)	Established within the Ministry of Industry, Science and Technology	The agency's Canadian Commission on Building and Fire Codes promulgates the National Building Code.
Canadian National Committee on Earthquake Engineering	Committee with representation from GSC, NRC, and the private sector.	Develops seismic provisions for the National Building Code, advises the Canadian Commission on Building and Fire Codes, and provides advice to private industry on matters related to seismic hazard assessment for specific projects.
Emergency Preparedness Canada	Agency within the Ministry of Defence	Earthquake preparedness and response planning.

SOURCE Off Ice of Technology Assessment, based on Peter Basham, Geological Survey of Canada, personal communication, Nov 24, 1994

Collaboration between Australia and other countries (e.g., neighboring developing nations in the South Pacific, countries in Southeast Asia, and South America, as well as the United States) is rapidly increasing.

CANADA

Canada has experienced several large, damaging earthquakes during its recorded history. Seismicity along its west coast is relatively well understood in terms of plate boundary convergence offshore. The sources of intraplate earthquakes in eastern Canada are less well known, but may be related to compressional stresses acting on localized zones of weakness in the crust.[7] Table C-2 shows the primary agencies and organizations participating in Canada's earthquake mitigation effort. According to the Geological Survey of Canada (GSC), it is the only federal agency concerned with seismological aspects of earthquake loss reduction, and the only Canadian agency with expertise in seismic hazard assessment.[8]

Canada's primary earthquake-related research goals are to: 1) understand the causes and effects of earthquakes well enough to be able to assess seismic hazards accurately throughout the country, and 2) improve knowledge of earthquake-resistant design and construction in order to provide an adequate level of protection against future earthquakes. Currently, a major research program is underway to produce new zoning maps for trial use, modification, and formal adoption in the year 2000 National Building Code of Canada. The existing code was adopted in 1985 and is based on

[7] Dieter Weichert et al., "Seismic Hazard in Canada," *The Practice of Earthquake Hazard Assessment*, International Association of Seismology and Physics of the Earth Interior (Denver, CO: U.S. Geological Survey, 1993), p. 46.

[8] Unless noted otherwise, the material in this section is drawn from Peter Basham, Acting Director, Geophysics Division, Geological Survey of Canada, personal communication, Nov. 24, 1994.

probabilistic analyses of peak acceleration and peak velocity.[9] According to GSC, relatively little effort is devoted to microzonation, although some efforts have been undertaken as university research projects.

CHINA

Strong intraplate earthquakes frequently occur throughout China, which lies in the southeast part of the Eurasian plate. The seismicity is thought to be related to forces from the Pacific Plate to the east and the Indian Ocean Plate to the southwest. China's historic earthquake record extends back thousands of years; from 1831 B.C. to A.D. 1989, 17 great earthquakes, 126 major quakes, and almost 600 large earthquakes took place.[10] Because of their typically shallow depth and since relatively little building stock has been designed to resist shaking, severe damage and casualties are likely in the country's densely populated areas from large earthquakes (i.e., having magnitudes of 6 and higher).[11]

The Chinese government has a three-pronged effort to address seismic risks. Earthquake prediction, resistance, and emergency relief responsibilities are accorded to the State Seismological Bureau, the Ministry of Construction, and the Ministry of Civil Affairs, respectively.[12] A unified program is being assembled by the Chinese Ten-Year Committee, in cooperation with United Nations International Decade for Natural Disaster Reduction[13] (see table C-3.)

Prediction

The large-scale development of an earthquake prediction capability began after the 1966 Xingtai earthquake (M7.2), which resulted in 8,000 deaths.[14] Over the last couple of decades, a number of earthquake-monitoring systems have been set up in China's major seismic areas. The national network consists of six regional telemetry networks, 12 local radio telemetry networks, and 10 digital seismographic stations.[15] Data from these monitoring systems, and from other observations, support research in detecting precursors and correlating them with large earthquakes.

In 1975, hours before a M7.4 quake struck Haicheng, a series of foreshocks prompted residents to construct earthquake huts (temporary shelters adjacent to their homes) and local authorities to issue a warning of a major quake.[16] Even with these precautions, more than 1,000 people were killed. Without these measures, a much larger percentage of the 3 million people living in Haicheng might have died inside collapsed buildings.[17] However the Chinese prediction system has predicted earthquakes that did not occur and has failed to predict some that did. Several months after the Haicheng

[9] With seven zones, the 1985 edition maps have a finer subdivision of zoning in moderate-risk areas and additional zones in the high-risk areas relative to the previous edition (1970). P.W. Basham et al., "New Probabilistic Strong Seismic Ground Motion Maps of Canada," *Bulletin of the Seismological Society of America*, vol. 75, No. 2, April 1985, p. 563.

[10] Xiu Jigang, "A Review of Seismic Monitoring and Earthquake Prediction in China," *Tectonophysics*, vol. 209, 1992, p. 325. See chapter 2 for description of earthquake severity scales.

[11] Ma Zongjin and Zhao Axing, "A Survey of Earthquake Hazards in China and Some Suggested Countermeasures for Disaster Reduction," *Earthquake Research in China*, vol. 6, No. 2, 1992, p. 241.

[12] Wang Guozhi, "The Function of the Chinese Government in the Mitigation of Earthquake Disasters," *Earthquake Research in China*, vol. 6, No. 2, 1992, p. 254.

[13] Ibid.

[14] Zongjin and Axing, see footnote 11, p. 243.

[15] The six regions covered are Beijing, Shanghai, Chengdu, Shenyang, Kunming, and Lanzhou. Ibid.; and William Bakun, U.S. Geological Survey, Menlo Park, personal communication, June 15, 1995.

[16] Cinna Lomnitz, *Fundamentals of Earthquake Prediction* (New York, NY: John Wiley & Sons, Inc., 1994), pp. 24-26.

[17] Bruce A. Bolt, *Earthquakes* (New York, NY: W.H. Freeman and Co., 1993), p. 194.

TABLE C-3: Earthquake Efforts by the People's Republic of China

Organization	Description	Activities
Ministry of Construction (MOC), Office of Earthquake Resistance	Established in 1967, MOC is concerned with emergency response, technical codes and standards, development of International cooperation, and education and training in earthquake engineering.	Funds proposals in earthquake resistance research for buildings and engineering structures; seismic response research for special works, structures, and equipment; strong-motion observation,
State Seismological Bureau	Established in 1971, the bureau is responsible for central management of earthquake monitoring, prediction, and scientific and engineering research.	Plans and administers national seismological programs; conducts International cooperation and exchange programs in earthquake studies; performs field studies of societal responses to earthquake hazards and events. The bureau's Institute of Engineering Mechanics plays a key role in earthquake engineering research at the government level.
National Natural Science Foundation of China, Department of Architectural Environment and Structural Engineering	Supports research in basic theory, technical advances, and earthquake hazard mitigation.	Funds projects in hazard assessment; soil-structure interaction; structural dynamic response; seismic resistance of lifelines; base Isolation and structural control; and earthquake site investigation and aseismic experimental technology.
Ministry of Energy, Science and Technique Development Foundation of Power Industry	Established in 1989 by the China Association of Power Enterprises in affiliation with the Ministry of Energy,	Awards grants to researchers and technological workers for studies related to hydroelectric, thermoelectric, and electric systems.

SOURCE: U.S. Panel on the Evaluation of the U.S.-P.R.C. Earthquake Engineering Program, National Research Council Commission on Engineering and Technical Systems, *Workshop on Prospects for U.S.-P.R.C. Cooperation on Earthquake Engineering Research* (Washington, DC: National Academy Press, 1993), pp. 8-10,

quake, a M7.8 quake struck Tangshan, apparently without warning. Hundreds of thousands were killed.[18]

Seismic Zonation and Building Codes

In 1957, China adopted its first earthquake intensity scale, a 12-level scale similar to the Modified Mercalli Intensity scale, and initially focused its mitigation efforts on buildings in the highest hazard areas. In 1992, using data from recent earthquakes and geophysical studies, China promulgated a new edition of its seismic intensity zoning map. The Chinese zoning map reflects both subjective measures of intensity and probabilistic analyses of ground motion expected from future earthquakes. Grade 9 on the Chinese intensity scale is roughly equivalent to Zone 4 of the 1988 Uniform Building Code.[19]

The first seismic code was promulgated in China in 1974.[20] The Tangshan earthquake prompted

[18] The Official estimate is approximately 250,000 deaths; however, unofficial estimates suggest that over 800,000 may have been killed.

[19] The Unifom Building Code is one of three U.S. model codes on which state and local seismic codes are based. See chapter 3.

[20] Hu Shiping, "Seismic Design of Buildings in China, '' *Earthquake Spectra,* vol. 9, No. 4, 1993, p. 704. The first draft, in 1957, was based on the Soviet code.

BOX C-1: Japan's Earthquake Prediction Program

Six agencies participate in Japan's earthquake prediction program. The Japan Meteorological Agency (JMA) collects seismological data and oversees Japan's prediction efforts. The Earthquake Assessment Committee, consisting of six eminent seismologists, is responsible for analyzing potentially anomalous data and reporting to the director of JMA a verdict of: 1) imminent danger, or 2) no danger.[1]

The Geodetic Council of Japan acts as an advisory body to the Ministry of Education, Science and Culture with respect to earthquake prediction, and oversees development of five-year program plans. Other agencies revolved in the prediction effort include the Maritime Safety Agency, the Geographical Survey Institute, the Geological Survey of Japan, and the National Research Institute for the Earth Sciences and Disaster Prevention (part of the Science and Technology Agency).[2]

Now in its sixth five-year plan, the program has both harsh critics, which include an increasing number of Japanese scientists, and staunch defenders. Limited access to data, opportunity costs for other areas of earthquake research, and the program's narrow focus on the Tokyo region are among the motivations for criticism.

[1] Robert J. Geller, "Cash Falling Through the Cracks," *The Daily Yomiuri*, May 12, 1994, p. 6. The two options are designated *black* and *white* verdicts, respectively. A *gray* verdict, or statement of intermediate probability, is not permitted.

[2] Robert J. Geller, "Shake-up for Earthquake Prediction," *Nature*, vol. 352, No. 6333, July 25, 1991, pp. 275-276

SOURCE Off Ice of Technology Assessment, 1995

revision of this code; the effort was completed in 1978. The present code, promulgated in January 1990, was revised from the 1978 version by the China Academy of Building Research, along with other professionals.[21]

JAPAN

The Eurasian, Philippine Sea, Pacific, and North American Plates all converge in the vicinity of Japan. The relative movement of these plates causes Japan to experience strong to great earthquakes frequently, as well as face the threat of volcanic activity and tsunamis. The largest earthquakes have originated in the subducted Philippine Sea and Pacific Plates, although the havoc wreaked on Kobe by the 1995 Hyogoken-Nanbu earthquake reveals the hazard posed by shallow crustal quakes to densely populated cities.

Japan has a multipronged government program to address its many seismic risks. Unlike the United States, however, earthquake prediction is a primary focus of Japan's efforts to reduce losses from earthquakes.

Prediction

With spending on the order of $100 million per year-a figure that does not include salaries-Japan's prediction program receives funding comparable to the entire U.S. National Earthquake Hazards Reduction Program (NEHRP). Initiated in 1963, it is one of Japan's largest and oldest research projects[22] (see box C-l).

Pursuant to the 1978 Large-Scale Earthquake Countermeasures Act, 10 regions have been designated for special monitoring. The Kanto-Tokai Observation Network, for example, continuously

[21] Ibid., p. 705.

[22] Y. Ishihara, Office of Disaster Prevention Research, Japanese Science and Technology Agency, personal communication, June 16, 1995.

monitors crustal movements using more than 250 seismometers, strainmeters, and tiltmeters. In addition, 167 Global Positioning System stations operate in this area.[23]

The most recent five-year plan for the prediction program, adopted in 1993, continues intensive observation of the Tokai region, which is expected to experience the effects of a great earthquake on the nearby Suruga Trough.[24] Scientists hope to detect the onset of the quake by monitoring seismicity, strain, and crustal deformation. Previous major quakes on the Suruga and Nankai Troughs were preceded by rapid crustal uplift.

Building Codes and Engineering

Early in this century, Japan established one of the first seismic design codes based on the performance of certain buildings in Tokyo during the 1923 Great Kanto earthquake.[25] The years since then have seen many advances in earthquake engineering research, seismic codes, and construction practices, because of investment on the part of both the government and the private sector.

The most recent code went into effect in 1981.[26] The Japanese seismic design code differs from the current U.S. guidance document for building codes (i.e., the NEHRP Provisions[27]) in that it calls for a two-stage design process. The first phase follows an analysis approach similar to that used in the NEHRP Provisions; it is intended to preclude structural damage from frequent, moderate quakes. The second phase is an explicit assessment of the building's ability to withstand severe ground motions.[28] Design forces used in Japan also are typically significantly larger than in the United States. As a result, Japanese buildings tend to be stronger and stiffer than their U.S. counterparts, and will likely suffer less damage during moderate or severe shaking.[29]

Japanese construction companies annually spend a considerable amount on research and development, including testing of scaled building models in large in-house laboratories and research into passive and active control technologies. One result is that new technologies for seismic protection have been incorporated into new buildings at a faster rate than in the United States.[30]

The government's engineering research facilities include a large-scale earthquake simulator operated by the National Research Institute for the Earth Sciences and Disaster Prevention and used by other agencies. Future evaluation of the seismic performance of the built environment will likely be aided by the large set of strong-motion data obtained from the Hyogoken-Nanbu quake in January 1995; the data set includes near-fault re-

[23] Ibid.

[24] Dennis Normile, "Japan Holds Firm to Shaky Science," *Science*, vol. 264, June 17, 1994, p. 1656.

[25] The United States adopted its first code shortly thereafter, in 1927.

[26] The Building Standard Law, proposed in 1977. For a description of Japan's seismic design methods, see Andrew Whittaker et al., "Evolution of Seismic Design Practice in Japan and the United States," *The Great Hanshin Earthquake Disaster: What Worked and What Didn't?* SEAONC Spring Seminar Series, Engineering Implications of Jan. 17, 1995, Hyogoken-Nanbu Earthquake, May 25, 1995 (San Francisco, CA: Structural Engineers Association of Northern California, 1995), pp. 5, 10.

[27] Building Seismic Safety Council, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* (Washington, DC: 1991).

[28] Whittaker et al., see footnote 26. Exemptions to this second phase of design are permitted only for buildings less than 31 meters in height and having the requisite materials and configuration. Andrew S. Whittaker, Earthquake Engineering Research Center, University of California at Berkeley, personal communication, May 29, 1995.

[29] Whittaker, ibid.

[30] David W. Cheney, Congressional Research Service, "The National Earthquake Hazards Reduction Program," 89-473 SPR, Aug. 9, 1989, p. 35.

cords that reflect rupture directivity and other effects encountered in the immediate vicinity of the fault.[31]

Response and Recovery

Within the National Land Agency, the Disaster Prevention Bureau was established in 1984 to develop disaster countermeasures through coordination with various ministries and agencies. The countermeasure framework has three primary parts: 1) making cities more disaster resistant, 2) strengthening disaster prevention systems (e.g., tsunami warning systems) and raising awareness, and 3) promoting earthquake prediction. One related effort has been to set up the Disaster Prevention Radio Communications Network to link agencies at the federal, prefectural, and municipal levels.[32]

The primary responsibility for disaster response rests with local-level governments that must ensure adequate water, food, and medical supplies. As witnessed in the 1995 disaster, however, Kobe's capabilities were overstretched, and some argue that mechanisms for federal intervention were inadequate. Whether or to what degree Japan's earthquake research, mitigation, and response programs will change as a result of the Kobe disaster is not yet clear. It must be noted that the intensive monitoring programs intended to support Japan's prediction capability cover but a small portion of the nation.

MEXICO

Off the western coast of Mexico, the North American Plate overrides the Cocos Plate. Historically, the Cocos Plate is the most active in the Western Hemisphere. This subduction zone has generated almost 50 earthquakes greater than magnitude 7 in this century, including the M8.1 quake that caused extensive damage and loss of life in Mexico City in 1985.[33]

Mexico currently has a national network of nine broadband seismic instruments linked by satellite, plus a number of regional networks.[34] Six additional broadband stations will be installed in 1995, one of them through a cooperative project with the U.S. Geological Survey.[35] Since late 1987, the National University's Geophysics Institute has operated a nine-station, short-period seismic network in the earthquake-prone state of Guerrero.

To record and assess severe shaking, strong-motion instruments are located throughout the Mexico City area. In cooperation with some U.S. universities and the Japan International Cooperation Agency, arrays of digital strong-motion networks are also operated in Guerrero.

Seismic zonation maps (e.g., maps of maximum Modified Mercalli Intensity, and peak acceleration and velocity) have been incorporated into the Mexican Building Code since the 1960s. In the 1985 quake, many high-rise buildings in an area of the city underlain by a former lake bed collapsed or were severely damaged. These buildings could not withstand the resonance effects induced by the long-period, long-duration shaking that occurred on soft soils. Microzonation has since been completed in the portions of Mexico City most susceptible to seismic wave amplification and liquefaction.[36] Other cities (e.g., Acapulco and

[31] Earthquake Engineering Research Institute, *The Hyogo-Ken Nanbu Earthquake: January 17, 1995*, preliminary reconnaissance report (Oakland, CA: February 1995), p. 6.

[32] Disaster Prevention Bureau, Earthquake Disaster Countermeasures Division, *Earthquake Disaster Countermeasures in Japan* (Tokyo, Japan: National Land Agency, 1993), pp. 17-18.

[33] Bernard W. Pipkin, *Geology and the Environment* (St. Paul, MN: West Publishing Co., 1994), pp. 83-35. The earthquake catalog of the Geophysics Institute, National University of Mexico, contains 48 major quakes.

[34] U.S.Geological Survey, see footnote 2, p. 31.

[35] Ramón Zúñiga, Geophysics Institute, National University of Mexico, personal communication, June 12, 1995.

[36] U.S. Geological Survey, see footnote 2.

Guadalajara) have recently been included in the microzonation efforts. Based on recently collected data, new zonation maps are being prepared for Mexico as an extension of the Canadian-funded Seismic Hazard in Latin America and the Caribbean Project.[37]

NEW ZEALAND

New Zealand is located astride the boundary between the Australian and Pacific Plates; it is cut and deformed by many active faults and folds.[38] Not surprisingly, New Zealand has both an active research program in earthquakes and a longstanding effort to improve the seismic resistance of its built environment. In 1991, the nation adopted an integrated approach to natural hazards management, of which earthquake mitigation is a major part. Subject to certain constraints in the Resource Management Act of 1991 and Building Act of 1991, regional and local authorities are responsible for controlling land use and construction for the purpose of avoidance or mitigation of specific hazards.[39]

Research

The primary institutions conducting earthquake-related research include the Institute of Geological and Nuclear Sciences (IGNS), the Engineering Schools of Auckland and Canterbury Universities, and the Institute of Geophysics at Victoria University in Wellington. The latter has teaching and research programs in seismology, including seismic microzonation. Additional research is conducted by earth science departments in other universities and by some private civil engineering consultants.[40]

IGNS has six programs, funded at $27 million (U.S.) per year, which span the fields of geology, seismology, and engineering seismology.[41] For example, IGNS is currently pursuing a research program titled "Improvements to Earthquake Resistant Design" whose primary objectives are: improved modeling of strong ground motions; enhanced models of the effects of large earthquakes on buildings, other structures, and the natural environment; and improved antiseismic practices and technologies.[42]

The Earthquake Commission (EQC), which provides earthquake insurance for domestic property and contents, also funds approximately $340,000 (U.S.) of research per year. EQC, which administers the Natural Disaster Fund on behalf of the government, is the primary provider of natural disaster insurance to residential property owners.

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[37] Zúñiga, see footnote 35. The Canadian International Development Research Agency funds the Seismic Hazard Project, now in its final phase. The project has two major components: 1) establish a uniform catalog of earthquakes for Mexico, Central and South America, and the Caribbean; and 2) develop probabilistic seismic hazard maps for this region. The Panamerican Institute of Geography and History, Organization of American States, oversees the multinational effort. James Tanner, Seismic Hazard in Latin America and the Caribbean Project, personal communication, June 16, 1995.

[38] Russ Van Dissen and Graeme McVerry, "Earthquake Hazard and Risk in New Zealand," *Proceedings of the Natural Hazards Management Workshop*, Wellington, NZ, Nov. 8-9, 1994 (Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited, 1994), p. 71.

[39] See Christine Foster, "Developing Effective Policies and Plans for Natural Hazards Under the Resource Management Act," in *Proceedings of the Natural Hazards Management Workshop*, see footnote 38, pp. 34-35. One result of the recent legislation is increased demand on the part of regional and local authorities for seismic hazard and risk analyses.

[40] Unless noted otherwise, this section is drawn from personal communications with Warwick D. Smith, Chief Seismologist, New Zealand Institute of Geological and Nuclear Sciences, and John Taber, Institute of Geophysics, Victoria University of Wellington, Dec. 1, 1994.

[41] The Ministry of Research, Science and Technology provides the New Zealand government with policy advice, including recommended funding levels for different areas of research. Earthquake-related research is funded under the Earth Science and Construction categories, or *outputs*. The Foundation for Research, Science and Technology allocates monies for research programs within each output.

[42] A quarter of the program's funding comes from industrial sources. Description of the IGNS Program, "Improvements to Earthquake Resistant Design," provided by Don McGregor, Chief Scientist, New Zealand Ministry of Research, Science and Technology, personal communication, Jan. 17, 1995.

As of 1996, however, owners of nonresidential property will have to seek private coverage for buildings and their contents.

Roughly 25 percent of New Zealand's earthquake research is currently directed at microzonation. This work is included in both the Foundation for Research, Science, and Technology and EQC programs, and is also sponsored by regional and local governments.

Implementation

Under New Zealand's Resource Management Act, regional, district, and city councils are responsible for identifying and mitigating the effects of natural hazards. The councils exercise their duties with respect to earthquake hazards through zoning and microzoning, and by enforcing the New Zealand Building Code. This code is written in performance terms and was published in 1992, after preparation under the supervision of the Building Industry Authority. There were previous seismic loading requirements in building standards and other control documents dating back to 1935. The code requires building owners to maintain their buildings so that they continue to meet the earthquake resistance requirements that existed at the time the building was erected. In some of the more earthquake-prone areas, territorial authorities have required upgrading of older buildings to address possible seismic weaknesses that can be recognized.[43]

The New Zealand National Society for Earthquake Engineering is a nongovernmental organization with approximately 600 members, mostly civil engineers. The society plays a leading role in communication among parties interested in earthquake research, hazard and risk assessment, and mitigation via engineering solutions. Likewise, the Building Research Association maintains close ties with building control officials and manufacturers, who together expedite the introduction of research results into practice.[44]

Until recently, the main thrust of earthquake mitigation efforts in New Zealand was preventing building collapse and minimizing the hazard for occupants. However, this risk was considered to be less severe than for many other countries,[45] and today the reduction of economic disruption is receiving greater emphasis. Increasing the efficiency of restoration of infrastructure and lifelines is a primary consideration.[46]

For example, local councils in Wellington and later Christchurch established engineering exercises to coordinate efforts to sustain lifelines. They focused on the interdependence of these lifelines in urban areas to assess ways in which weakness might be identified and mitigated.[47]

RUSSIA

Microzonation of the largest cities in Russia and the former Soviet Union began in the 1950s, and seismic zonation maps were incorporated into the State Engineering Codes as early as 1957.[48]

Today, the primary institutions and organizations involved in Russia's earthquake efforts are:

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[43] Gerald Rys, Assistant Chief Scientist, New Zealand Ministry of Research, Science and Technology, personal communication, July 4, 1995.

[44] John Duncan, Research Director, Building Research Association of New Zealand, personal communication, Jan. 17, 1995.

[45] Reasons include: 1) ongoing implementation of simple antiseismic measures based on early colonial experiences in severe earthquakes, and 2) the fact that the majority of New Zealanders live in single-dwelling, typically wood-framed structures.

[46] Smith and Taber, see footnote 40.

[47] Interdependence relates to the effect of the outage of one utility service (e.g., power) on the time required by another service to recover. The lifeline effort also designated *critical areas*—that is, where a number of lifelines are vulnerable in one location (e.g., a bridge carrying water, gas, and power in addition to traffic). David Brundson, "Reducing Community Vulnerability to Earthquakes: The Value of Lifeline Studies," in *Proceedings of the Natural Hazards Management Workshop*, see footnote 38, p. 10.

[48] U.S. Geological Survey, see footnote 2.

the Ministry of Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Hazards; the Interdepartmental Commission for Seismic Monitoring; and the Russian Academy of Sciences. Russia operates several seismic and strong-motion monitoring stations. However, nearly all are still equipped with analog instruments and transmission methods that limit the quantity and quality of data. The number of stations in operation has decreased in recent years due to lack of funding.[49]

In 1994, the Russian government approved the establishment of a new program to develop a federal system of seismological networks and earthquake prediction, with several objectives:

- seismic hazard assessment,
- prediction of strong earthquakes based on comprehensive analysis of geophysical and geodetic precursors,
- epicentral seismological observations,
- strong-motion data for improvement of seismic resistant design and construction,
- implementation of mitigation measures in areas where strong earthquakes are expected in order to evaluate their effectiveness, and
- development of methods for predicting human-triggered seismicity and for minimizing seismicity induced by mining or reservoirs.

The means to these ends include modernization of observation stations, data transfer and storage techniques, and improved coordination of the efforts of many ministries and agencies. As of late 1994, however, the government had not allocated any financial resources to implement the program.[50]

VEHICLES FOR COOPERATION AND COORDINATION

A number of organizations and other mechanisms foster the international exchange of ideas and practices in the area of earthquake research, mitigation, and response. For example, the U.S. Geological Survey (USGS) and the National Science Foundation (NSF) maintain close working relationships with Japan in earthquake seismology.[51] In addition, for many years, the United States and Japan have held joint workshops under the auspices of the United States-Japan Panel on Wind and Seismic Effects (see box C-2). The United States has established and renewed scientific protocols with the People's Republic of China, and with Russia and other members of the Commonwealth of Independent States. Cooperation between the United States and Taiwan, and between Latin American states, is ongoing, and there are many such efforts with other countries.

Japan also has established cooperative exchanges with many countries, as have some other nations (e.g., Canada and France). There are multilateral forums as well—notably the United Nations International Decade for Natural Disaster Reduction (IDNDR), established in 1990 to promote mitigation and cooperation worldwide.[52] Over the years, several regional programs have

[49] According to one reviewer, the disastrous Sakhalin Island earthquake of May 1995 illustrates the decline of Russia's earthquake program: the seismic monitoring network had been shut off, there was apparently no plan to retrofit the apartment buildings that collapsed, and the emergency response effort suffered from a shortage of resources. William L. Ellsworth, U.S. Geological Survey, Menlo Park, personal communication, June 14, 1995.

[50] Yu S. Osipov, President of the Russian Academy of Sciences, letter to V.F. Shumeiko, Chairman of the Federation Council of the Federal Assembly of the Russian Federation, Nov. 1, 1994, in "The Shikotan Earthquake of October 4(5), 1994," *Russia's Federal System of Seismological Networks and Earthquake Prediction*, Information and Analytical Bulletin, Special Issue No. 1, November 1994.

[51] Federal Emergency Management Agency et al., "National Earthquake Hazards Reduction Program: Five-Year Plan for 1992-1996," September 1991, p. 91.

[52] The IDNDR sought, in part, to promote: the integration of hazard reduction policies and practices into the mainstream of community activities; funding of additional research into the physical and social mechanisms of natural hazards and the disasters they precipitate; and elimination of constraints on the use of scientific and technical knowledge. National Research Council, *The U.S. National Report to the IDNDR World Conference on Natural Disaster Reduction*, Yokohama, Japan, May 23-27, 1994 (Washington, DC: National Academy Press, 1994), p. 1.

BOX C-2: United States-Japan Panel on Wind and Seismic Effects

The panel consists of 16 U.S. agencies, led by the National Institute of Standards and Technology, and six Japanese agencies. Over the years, the panel has:

- held 25 annual technical meetings for prompt exchange of research findings,
- conducted more than 40 workshops and conferences on such topics as the repair and retrofit of structures,
- conducted cooperative post-earthquake investigations in Japan and in the United States,
- hosted visiting Japanese researchers and provided access for U.S. researchers to unique Japanese facilities, and
- organized cooperative research programs on steel, concrete, masonry, and precast concrete structures.

SOURCE. Richard Wright, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, testimony at hearings before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space, May 17, 1994, p. 31

been established, including projects in the Balkans, countries adjacent to the Mediterranean Sea, and central and South America.[53]

In general, there is extensive cooperation with respect to the collection and sharing of earthquake data. With the Global Seismographic Network (GSN), earthquake source data are collected from and distributed to Europe, Latin America, Asia, and Australia.[54] The Global Geodetic Network uses high-resolution, space-based geodetic techniques to monitor crustal motion and deformation around the world. It is supported by NSF, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration, and by agreements with some 45 countries to exchange data and coordinate activities.[55]

Post-earthquake investigations are another important means of collectively assessing the physical and societal impacts of damaging earthquakes and spurring further progress in mitigating against seismic risks. The Post Earthquake Evaluation Program, initiated in 1992 by USGS, the United Nations Educational, Scientific and Cultural Organization, and the Open Partial Agreement on Major Hazards of the Council of Europe, has the following objectives:

- create a mechanism for sharing information,
- strengthen interdisciplinary and interorganizational interfaces,
- increase the worldwide capacity for post-earthquake investigations, and
- foster the adoption of prevention, mitigation, and preparedness measures.[56]

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[53] Participating and sponsoring organizations include USGS, the U.S. Agency for International Development, the United Nations Educational, Scientific and Cultural Organization, and national governments. U.S. Geological Survey, see footnote 2, p. 11.

[54] Established by the Incorporated Research Institutions for Seismology (IRIS) and jointly operated with the USGS Albuquerque Seismological Laboratory, the University of California at San Diego's International Deployment of Accelerometers group, and other member universities, the GSN is a rapidly expanding network of high-quality seismographs installed around the world for the purposes of earthquake and nuclear test monitoring and related research. In addition to data from the GSN, the IRIS Data Management Center has recently begun collecting data from international seismic networks operated by the Federation of Digital Seismic Networks.

[55] Office of Science and Technology Policy unpublished material.

[56] U.S. Geological Survey, see footnote 2, p. 42.