Quake Builds Case for Strong Codes

Last week's disaster in Kobe is a reminder that better engineering can mitigate but not prevent damage to heavily populated areas from strong shaking

KOBE, JAPAN—News reports of the earthquake that devastated Kobe early in the morning of 17 January—leaving close to 5000 dead and 300,000 homeless—have focused on the human dimensions of the tragedy. But as the city's 1.4 million residents slowly begin to rebuild their lives and reclaim their property, another issue is already occupying seismologists and engineers around the world: How well did Japan's vaunted earthquake hazard mitigation program stand up to a 6.9 magnitude temblor that struck the city's downtown area with unprecedented lateral force (see box on p. 445).

Pictures of crushed buildings, toppled expressways, and crumpled train tracks seemed to show a city learning to its horror that its stringent building codes were sadly inadequate. But the idea that the earthquake delivered a rude shock to smug Japanese engineers may not be accurate, either. Indeed, experts say the real message of the southern Hyogo Prefecture earthquake is that cities around the world face a similar fate if they are unlucky enough to be sitting directly above a fault that ruptures. Like the quake that struck Northridge, California, a year ago, the Kobe temblor demonstrated that ground forces close to the fault appear to be higher than scientists previously thought—and higher than current design codes allow for. Moreover, extensive damage cannot be avoided, because older buildings will always fall short of state-of-the-art engineering codes.

"I think we're seeing most of the damage in older structures, which is the same thing we'd see in California," says Loring Wyllie, a structural engineer with the San Francisco–based consulting firm Degenkolb Engineers. Wyllie, along with about 40 other U.S. engineers, seismologists, and disaster-response experts, just happened to be in Osaka to meet a like number of their Japanese counterparts for the Fourth Japan–U.S. Workshop on Urban Earthquake Hazard Reduction. The earthquake struck just hours before the scheduled sessions were to begin and turned the academic exercise into a hands-on field trip.

AP/WIDE WORLD PHOTOS/NHK TELEVISION

Weak link. Older sections of the Hanshin Expressway between Kobe and Osaka could not withstand the shaking.

What turned the moderate quake into Japan's worst natural disaster since the Great Kanto earthquake of 1923 that leveled Tokyo was its proximity to the densely populated region in the western portion of Honshu Island. Kobe is squeezed into a 3-kilometer-wide plain between a mountain range to the north and Osaka Bay. The fault that ruptured runs along the base of these mountains and right through Kobe and the neighboring municipalities of Nishinomiya and Ashiya. "It is one of the largest near-field earthquakes to strike a dense urban area in modern times," says Makoto Watabe, former professor of architectural engineering at Tokyo Metropolitan University and a senior director of Shimizu Corp., one of Japan's giant general contractors.

Engineers reviewing the damage in Kobe say much of it, especially in residential neighborhoods, was not surprising. Japan's history of earthquakes to the contrary, the traditional method of home building in Japan is recognized as being vulnerable to the lateral forces that earthquakes deliver. A heavy clay tile roof, supported on a structure of vertical posts and horizontal beams, is fine for gravity loads acting straight down, but it lacks the X-bracing often seen in steel buildings or the plywood sheathing used in North American wood-frame housing to resist lateral loads.

Engineers also do not expect to learn much from many of the spectacular collapses of highway viaducts and older concrete buildings that made for such dramatic newscast footage. Shunsuke Otani, professor of architectural engineering at the University of Tokyo, says that most of the collapsed structures, including portions of the Hanshin expressway that toppled, appear to predate critical code changes enacted in 1971 and 1981.

The 1971 changes increased the amount of steel reinforcing required near critical joints in reinforced concrete columns, giving columns greater strength in transferring horizontal forces from the upper part of a structure into the ground. The 1981 revisions were intended to allow structures to deform under extremely large earthquake

Area Universities Weather the Blow

In contrast to the devastation inflicted on southern Hyogo Prefecture by the earthquake, universities in the region appear to have escaped major damage. A spokesperson for Kyoto University, 75 kilometers northeast of Kobe, says the campus was virtually unscathed. There appears to have been no serious damage to buildings at Osaka University, 30 kilometers to the east, although bookcases, cabinets, and lab tables were toppled. A research assistant who answered the phone in the biology department said the lab floors were covered with broken glass and spilled chemicals, and classes were canceled for 1 week.

Hardest hit, of course, was Kobe University. The school is fortunate to be halfway up the mountain that overlooks the city, and there are no reports of serious damage to any buildings or major facilities. Electricity and water service was not disrupted, although phones were out and university officials are still assessing internal damage to laboratories and equipment. Just down the hill, however, an older residential area—with inexpensive rooms that attract many students—lay in ruins. No official casualty figures are available, but an engineering department official said that five students from one research group had died in the earthquake. School operations have been suspended at least until next week.

–D.N.

An Unnerving Preview of a Northern California Quake?

Almost 9000 kilometers separate the quake that struck Kobe, Japan, last week and San Francisco's East Bay region. But the parallels between the Japanese disaster and what the future almost surely holds for the East Bay are unsettling U.S. seismologists, engineers, and emergency response experts. An East Bay earthquake will bear a striking resemblance to the one that just devastated Kobe, from its ultimate driving force to its location practically under the feet of a dense population. "It will be a real mess," says geologist Lloyd Cluff of Pacific Gas and Electric (PG&E) in San Francisco. "A lot of things we see at Kobe we expect in the East Bay; we're going to have localized devastation."

The fault that has Cluff and many others so worried isn't the notorious San Andreas; it passes 30 kilometers to the southwest. Their focus is the Hayward fault, which slices right through the East Bay from just east of San Jose through cities including Oakland and Berkeley. Concern about that fault was already running high enough that the Earthquake Engineering Research Institute (EERI) planned to devote a session at its meeting next month in San Francisco to a hypothetical magnitude 7 Hayward quake. Now Kobe's misfortune has given the engineers and hazard experts an early look at the kind of disaster that might strike the East Bay.

The ultimate driving force for earthquakes in Kobe and the East Bay is the same: the jostling of the tectonic plates around the Pacific. The great Pacific plate slides by North America along the San Andreas fault, snagging and triggering quakes as it goes; some of that slip is diverted onto branch faults, such as the Hayward. Likewise, the collision of the Philippine Sea plate with the Eurasian plate east of Japan drives slip along a San Andreas–like fault that passes south of Kobe. A smaller, usually quiescent branch fault much like the Hayward extends northeast toward the city.

It was a short segment of that branch fault that ruptured last week near Kobe, producing an earthquake bearing an uncanny resemblance to the hypothetical Hayward quake that experts on quake damage and disaster response will be considering at next month's EERI meeting. Program chair William Savage of PG&E and his colleagues had come up with this quake based on what is known of the last big quake on the Hayward fault in 1868. In 1990 the Working Group on California Earthquake Probabilities put the odds of another large Hayward quake by 2018 at 28%.

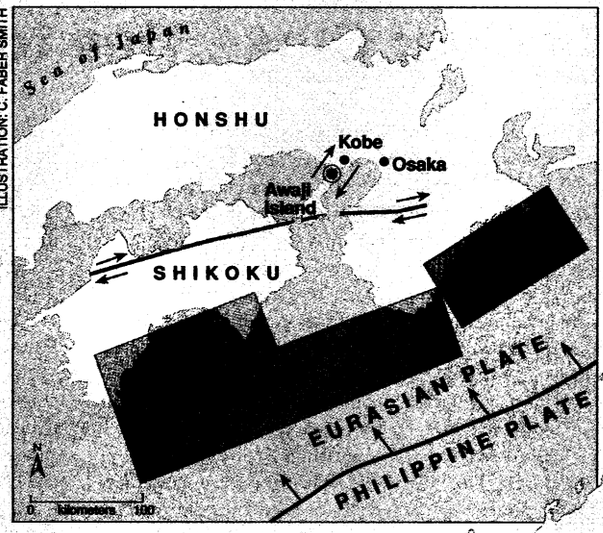

ILLUSTRATION: C. FABER SMITH

A seismic sideshow. Great quakes in 1944 and '46 relieved stress deep offshore, but the Kobe quake broke the surface on a branch of a San Andreas–like fault.

The event in the Hayward scenario has a magnitude of 7.0; seismologist Hiroo Kanamori of the California Institute of Technology puts the Kobe quake at magnitude 6.9 ± 0.1. The hypothetical Hayward rupture extends for 50 kilometers; at Kobe the fault ruptured along 25 to 50 kilometers, according to Masayuki Kikuchi of Yokohama City University. But the most unnerving similarity of all is the proximity of fault and people.

A quake rupture on the northern half of the Hayward fault would rip directly through the densely populated region just to the east of San Francisco Bay. The Kobe rupture began under the 3-kilometer-wide Akashi Strait between Awaji Island and the mainland, 20 kilometers from central Kobe. The rupture's northeast-southwest orientation put the Kobe metropolitan area smack in the path of the rupture to the northeast. No surface rupture has yet been found in Kobe proper, but Kikuchi thinks a line of especially heavy damage may trace the path of the rupture into the city. Alternatively, he says, the swath of heavy damage might be the result of the pulse of concentrated seismic energy that travels ahead of a fault rupture (*Science*, 13 January, p. 176).

Either way, the strong shaking was inflicted on a stock of older structures not designed to today's standards and built on soft, unstable bay muds. That deadly combination is yet another of the unsettling parallels that Kobe shares with the cities along the Hayward fault, and it made disaster inevitable.

–Richard A. Kerr

loads, allowing the building to absorb the earthquake's energy but not collapse. The idea was to save lives during a quake by keeping a building standing, even if it was so damaged during the quake that it had to be torn down afterward.

But codes usually apply only to new construction. Communities also face the problem of what to do about buildings designed under older, weaker codes. Otani says that massive retrofitting programs have been carried out in other parts of the country, particularly in Shizuoka Prefecture, 60 kilometers west of Tokyo, where seismologists convinced local and national government officials that the area was overdue for a magnitude 8+ quake. But officials in the Osaka-Kobe region apparently grew complacent about earthquakes because they hadn't had one in more than 75 years.

Hideki Kaji, a civil engineer now with the United Nations Centre for Regional Development, says the lack of awareness was evident in many ways. On 1 September, there are earthquake preparedness drills throughout the country to mark the anniversary of the 1923 Tokyo earthquake. "The participation in Tokyo is less than 30%, but in Kobe it is even less than 10%," he says.

Seismologists had recognized that major quakes could strike the Osaka-Kobe area. The area is crisscrossed by active faults, and an adjacent section of the same fault that ruptured last week saw a magnitude 6.1 rupture in 1916. Although that's a short period geologically, it's a lifetime for human memory. Masayuki Watanabe, a civil engineer who headed Kobe's office of disaster prevention in the 1960s, says that the disasters Kobe has faced in the past half-century have been floods and mud slides triggered by torrential rains. "Kobe has been focused on other kinds of disasters," he admits.

For structural engineers and seismologists, questions of retrofitting and prepared-

ness are less pertinent than whether the quake proves the need to consider revisions to the latest editions of building codes. Although it will be months before the pattern of damage in Kobe is fully assessed, preliminary data, combined with data from other recent earthquakes, suggest the forces transmitted through the ground during earthquakes may be much larger than previously thought at sites close to faults (*Science*, 13 January, p. 176). Several seismologists report that data not yet publicly released will show ground accelerations in Kobe exceeding 0.8 times the force of gravity, or 0.8*g*. Hiroyuki Kameda, a structural engineer and professor-in-charge of Kyoto University's Urban Earthquake Hazard Research Center, notes that the quake tossed railway cars off tracks throughout the area. "That can occur only when the acceleration is in the range of 1*g*," he says. The highest ground forces ever recorded during an earthquake were last year at Northridge, where ground accelerations reached about 1.8*g*.

Current codes do not allow for forces of that magnitude. And if that is true in Japan, it will also be true in the United States. "The design codes are fairly comparable," says Charles Scawthorn, who earned his doctorate in structural engineering at Kyoto University and is now vice president of the consulting firm EQE International in San Francisco.

For some experts, however, last week's earthquake demonstrated that current codes are adequate. Hirokazu Iemura, professor of civil engineering at Kyoto University, says that structures in the Kobe area may have been subjected to as much as three times the shaking they were theoretically designed for, yet they did not collapse. "I do not see any evidence that the current building standard law should be changed," says the University of Tokyo's Otani.

Charles Kircher, a consulting engineer from Mountain View, California, believes that the earthquake will provide further support for moves in the United States to stiffen lateral load requirements for buildings very close to faults. He says the Seismology Committee of the Structural Engineers Association of California, of which he is a member, is considering recommending that the design earthquake load for structures very close to fault lines be doubled.

The next step for the community is to review data now being collected. The local chapter of the Architectural Institute of Japan was organizing a task force this week to catalog the damage to buildings and to determine just how old they are. That information should tell engineers whether the southern Hyogo earthquake confirms what they already knew or serves as a call for new ways to mitigate loss of life and property when nature unleashes its awesome power.

–Dennis Normile

ENERGY LABORATORIES

Report to Stress Research Over Close Ties to Industry

A blue-ribbon panel appointed by Energy Secretary Hazel O'Leary has concluded that the Department of Energy's (DOE's) 10 major laboratories should focus more on basic research than on directly serving industry. The report, to be issued on 1 February by a 19-member commission headed by Motorola Chairman Robert Galvin, will not call for closing any labs, *Science* has learned, nor will it provide O'Leary with much help in reaching her goal of trimming $10.6 billion from DOE's budget over the next 5 years.

The panel's cautionary tone on pushing the labs into bed with industry contrasts sharply with that of the Clinton Administration, which has made strengthening the nation's economy a major mission for the labs. "There was a consensus that competitiveness should not be a primary mission," says Braden Allenby, a panel member and AT&T vice president. "The uniform view is that the labs are not in the business of helping industry," adds political scientist Harvey Sapolsky, one of four Massachusetts Institute of Technology professors on the panel.

The high-profile report is the first salvo in what is expected to be a pitched battle over the fate of the $6 billion DOE lab complex that stretches from New York state to the Pacific Northwest (see table). It's not the first time the labs' future has been debated, but DOE officials say the discussions have acquired new urgency thanks to pledges by the new Republican Congress to reduce government bureaucracy and curb spending, combined with O'Leary's promise last month to shrink DOE as part of a general restructuring of the 18-year-old agency. Moreover, the White House will add the commission's recommendations to the results of one large study, expected to be completed in April, that focuses on the laboratories and centers run by DOE, the Department of Defense, and the National Aeronautics and Space Administration. That combination of forces suggests the Galvin report will not gather dust. "I've seen reports come and go, but this one is going to be different," says Nicholas Samios, director of Brookhaven National Laboratory.

Last February, when O'Leary named industry executives, military leaders, and academics to the commission, she asked it to identify a role for the labs in the post–Cold War era—particularly the three that design and build nuclear weapons. After several public hearings and months of private discussions, its members have concluded that the 10 multipurpose labs—DOE supports others, like the Fermi National Accelerator Laboratory in Illinois, that concentrate on a single

DOE'S MULTIPURPOSE LABORATORIES

Name	Budget	# Staff	Research Focus
Argonne (IL) National Laboratory	$462 million	4502	Electron microscopy, neutron-scattering
Brookhaven (NY) National Laboratory	$275 million	3437	High-energy, nuclear physics; nuclear medicine
Idaho National Engineering Laboratory	$613 million	6586	Biotechnology, engineering sciences; instrumentation
Lawrence Berkeley Laboratory (CA)	$226 million	2408	Electron microscopy, heavy-ion physics; human genome
Lawrence Livermore Laboratory (CA)	$869 million	6009	Nuclear weapons, lasers, applied physics and chemistry, atmospheric sciences
Los Alamos (NM) National Laboratory	$1.07 billion	7024	Nuclear weapons, environmental technologies, neutron-scattering
Oak Ridge (TN) National Laboratory	$547 million	4690	Nuclear physics, ion-beam, neutron scattering
Pacific Northwest Laboratory (WA)	$479 million	4383	Environmental, molecular sciences
Sandia National Laboratories (NM & CA)	$1.16 billion	8458	Nuclear weapons engineering and manufacturing, radiation, and combustion
National Renewable Energy Laboratory (CO)	$214 million	913	Energy research on sun, wind, water, plants, and waste technology