one-third of the damaging earthquakes in the 1980s seem to have been triggered by artificially created lakes. Systematic measurement programmes to monitor various geophysical signals near water reservoirs may help in identifying precursors of damaging earthquakes.

It is possible to study various precursory phenomena in order to predict an earthquake. However, an accurate earthquake prediction still seems to be a complicated task unless we have a good understanding of all the physical processes involved. The most valuable lesson learnt in the aftermath of the Kobe earthquake is that Japan is not so earthquake-resistant as had been believed. The numerous public facilities in the Kobe region, such as office buildings, freeways, railways and so on, were severely damaged. If the death toll had not been so high, we may not have regarded this earthquake as being so devastating, but destruction of many residential houses caused a large number of fatalities. In order to mitigate the loss of lives and property in the next large earthquake, as yet an unpredictable natural phenomenon, it is therefore imperative that we design and construct buildings with all the knowledge and insight so far gained from worldwide experience so that they can withstand the strong ground motion expected to occur in a region.

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Kobe earthquake: An urban disaster

Paul Somerville

The 17 January 1995 Hyogo-ken Nanbu earthquake was the most damaging to strike Japan since the great Kanto earthquake destroyed large areas of Tokyo and Yokohama and killed 143,000 people in 1923. As of 30 January, the toll from the earthquake in Kobe and adjacent cities had reached 5096 dead, 13 missing, and 26,797 injured. One-fifth of the city's 1.5 million population was left homeless and more than 103,521 buildings were destroyed. The Hyogo Prefectural Government estimated the cost of restoring basic functions to be about \$100 billion; the total losses, including losses of privately owned property and reduction in business activity, may be twice this amount, which would be 10 times higher than losses resulting from the 1994 Northridge, California, earthquake.

Earthquake mechanism

The hypocentre of the earthquake was located about 20 km southwest of downtown Kobe between the northeast tip of Awaji Island and the mainland (Figure 1). The earthquake was assigned a Japan Meteorological Agency (JMA) magnitude of 7.2. Seismological analyses indicate a strike-slip mechanism with a seismic moment of about 3×10^{26} dyne cm, corresponding to a moment magnitude of 6.9 (ref. 1). Teleseismic waveform

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17 January 1995 Hyogoken Nanbu Earthquake, M=6.9

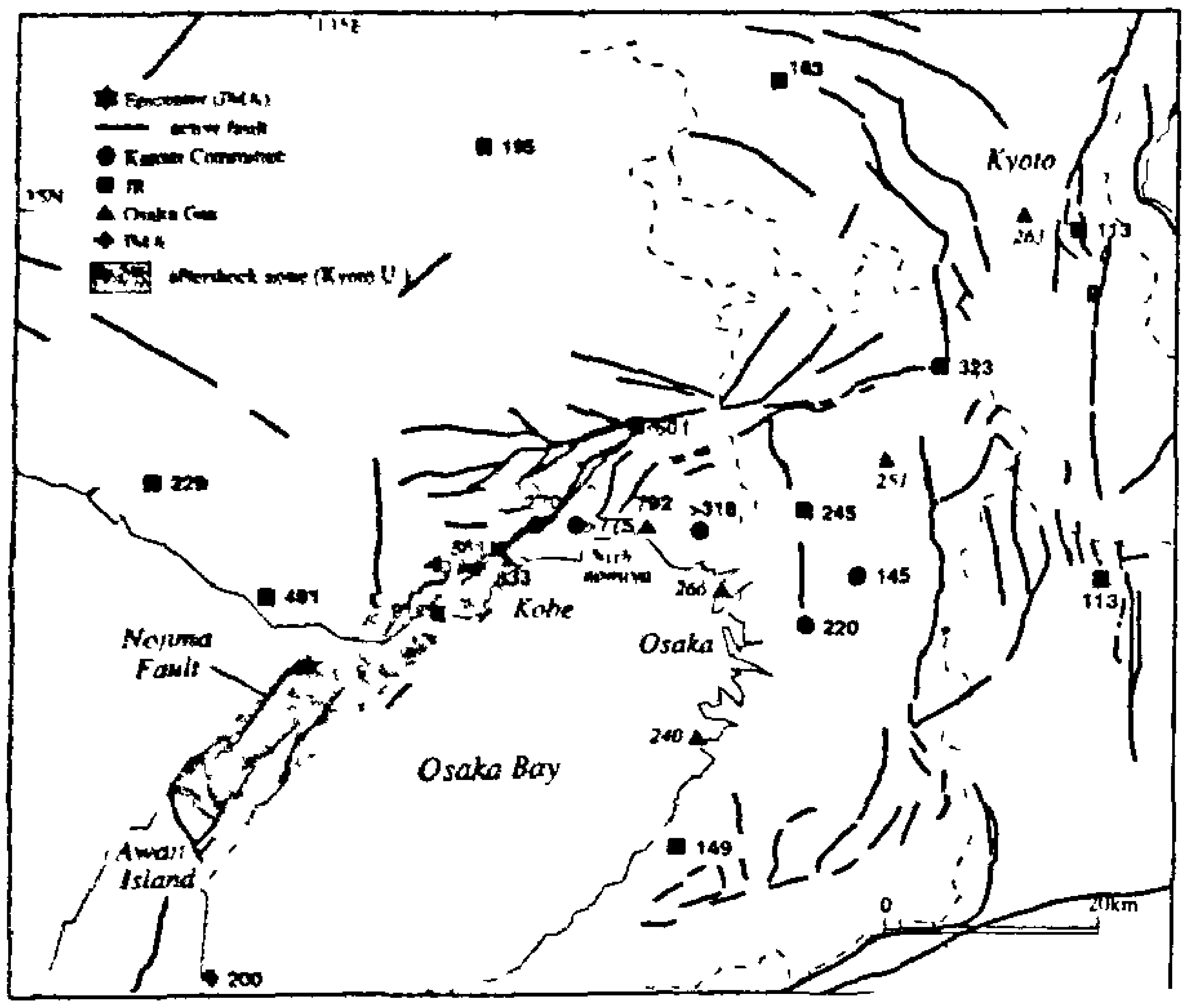

Figure 1. Main shock epicentre (JMA), aftershock zone, and peak ground motions of the 1995 Kobe earthquake, superimposed on a map of active faults. The aftershock zone is based on locations marked by the Disaster Prevention Research Institute, Kyoto University, using data from the microearthquake networks of Kyoto, Tokyo and Nagoya Universities. The strong-motion data are from the Committee of Earthquake Observation and Research in the Kansai Area, JR, Osaka Gas and JMA, and represent different measures of ground motion, as described in the text. The active faults are from ref 2. Modified from K. Koketsu Earthquake Research Institute, University of Tokyo

modelling and the distribution of aftershocks indicate a fault rupture about 30–50 km long produced by bilateral rupture from the hypocentre. The rupture of this strike-slip earthquake directly into downtown Kobe contributed to the high level of destruction.

The earthquake occurred in a region where a complex system of active faults had been mapped[2] (Figure 1). The focal mechanism of the earthquake indicates right-lateral strike-slip faulting on a vertical fault striking slightly east of northeast, parallel to the strike of the mapped faults. The earthquake produced surface rupture with an average horizontal displacement of 1–1.5 m on the Nojima fault, which runs along the northwest shore of Awaji Island (T. Nakata, K. Yomogida, J. Oada and T. Sakamoto, written communication, 1995). Marine seismic surveys by the Japan Maritime Safety Agency have found a 300 m long offshore extension of this rupture. The surveys also found two fault rupture segments that span a length of about 7 km in the region offshore from the northeast tip of Awaji Island, parallel to the Nojima fault but offset from it by about 5 km.

The earthquake mechanism is compatible with the tectonic environment of western Japan as revealed by historical seismicity. This seismicity contains a sequence of earthquakes between 1891 and 1948 that includes the magnitude 8 Nobi earthquake of 1891, the magnitude 7.3 Tango earthquake of 1927, the magnitude 7.2 Tottori earthquake of 1943, and the magnitude 7.1 Fukui earthquake of 1948 (ref. 3). All of these earthquakes, as well as the 1995 earthquake, had strike-slip mechanisms that accommodated east–west shortening of the Eurasian plate due to its collision with the North American plate along the Izu-Itoigawa line to the east in central Honshu[4].

Strong ground motions were recorded by several organizations, including the Committee of Earthquake Observation and Research in the Kansai Area, JR, Osaka Gas, Japan Meteorological Agency, Hankyu Railroads, Japan Highways, and Building Research Institute. The peak ground accelerations and velocities, mostly recorded on soil sites, are shown in Figure 1. The various contributing organizations present different measures of peak acceleration. The Kansai and JMA values are the largest of the three orthogonal components; the Osaka Gas values are the vector combination of the two horizontal components; and the JR values are vector combinations of the two horizontal components after they have been highcut-filtered at 5 Hz.

This is the first large set of strong-motion data including near-fault records from a crustal earthquake in Japan and will be useful for evaluating the criteria that are currently used in the seismic-resistant design of structures in Japan. The near-fault ground velocity time histories have large pulses of long-period motion, which are indicative of rupture directivity effects and are potentially damaging to multistorey buildings and other long-period structures such as bridges. The near-fault horizontal peak velocities were 55 cm/s on rock at Kobe University, and went off scale at soil sites at levels of 40 and 100 cm/s in central Kobe. These values are similar to those recorded close to comparable earthquakes in California.

Peak accelerations as large as 0.8 g were recorded in the near-fault region on soil sites in Kobe and Nishinomiya. To make a preliminary comparison of the recorded values with those predicted by empirical attenuation relations used in California, we have adjusted the Kansai and Osaka Gas values to approximate the average of the two horizontal components. The resulting adjusted values are comparable to those predicted for a strike-slip earthquake using empirical attenuation relations for soil, based mainly on California data (*Idriss*, 1991), as shown in Figure 2. Although it is known that most of the data are from ground level sites, some may be near or in buildings, and a few may be from above ground level in structures. Also, instrument corrections of the records have generally not yet been made, and the soil conditions at the sites have not been reviewed, so further information is required before definitive conclusions can be drawn from these data.

Damage to lifelines hinders rescue efforts

Kobe is located on a narrow strip of land between Osaka Bay to the southeast and the Rokko mountains to the

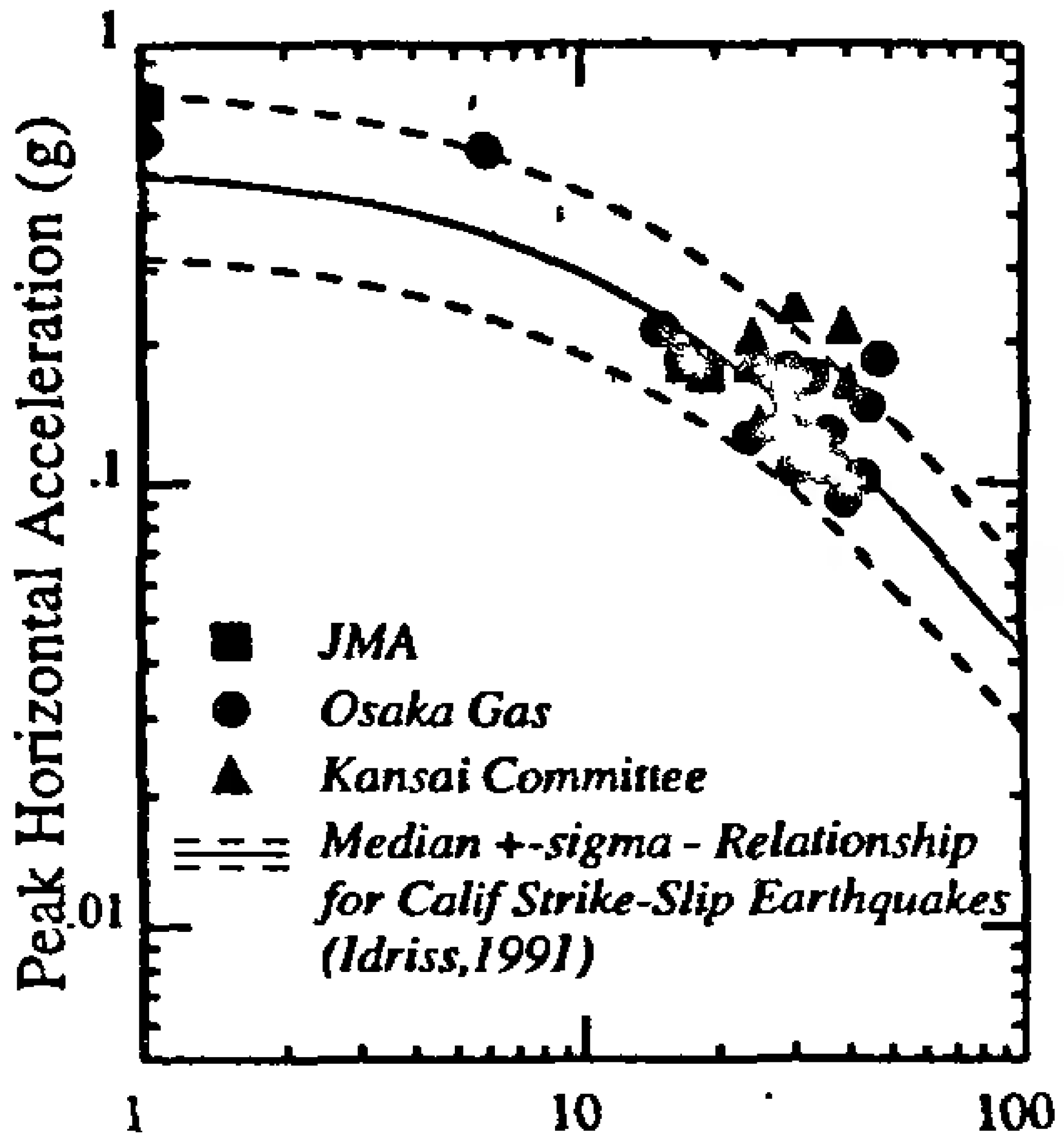

Figure 2. Attenuation of recorded peak acceleration at soil sites, adjusted to approximate the average of two horizontal components, compared with an empirical relation for soil, based mainly on strike-slip data from California (Idriss, 1991). Strong-motion data are from the Committee of Earthquake Observation and Research in the Kansai Area, Osaka Gas, and JMA

Figure 3. Collapse of the Hanshin Expressway in Nishinomiya. Photograph by the author

northwest. In this narrow transportation corridor, which links western Japan with northeastern Japan, all major transportation systems were severed by the collapse of elevated roads and railways, creating major dislocation of public and commercial traffic. The Shinkansen route – the high speed rail route between Tokyo and all of western Japan – was closed by the collapse of bridge spans in Kobe, as were two other rail lines. The elevated Hanshin Expressway, which is the main vehicular traffic artery through Kobe, was closed by collapses at three locations, one of which included a 630 m section of the expressway (Figure 3). Along this expressway, there was widespread evidence of ground failure: disrupted road pavement, subsidence of the pavement around manholes,

Figure 4. Storey collapse in a modern building in the Sannomiya district of downtown Kobe. Photograph by the author

and ejected silty soil. Ground level roads became the only transportation links, and their congestion greatly impeded emergency response and recovery.

In the Sannomiya district of downtown Kobe, large deformations of road pavements and of the ground around building foundations were observed. These deformations were typically of the order of tens of centimeters and may have helped cause severe damage, including tilting, collapse of individual storeys, or collapse of the entire structure experienced by many multistorey buildings in the downtown area (Figure 4). According to newspaper reports, only 20% of the buildings in downtown Kobe were currently usable after the earthquake.

Widespread ground failure was observed throughout the strongly shaken region along the margin of Osaka Bay. On the islands of Rokko and Portopia, which are reclaimed land in Osaka Bay near Kobe, liquefaction caused subsidence in the range of 50–300 cm, and large volumes of silty soil were ejected. Local lateral spreading of soils occurred along quay walls in many parts of the extensive port facilities in Kobe, rendering many of them inoperative and causing the disruption and collapse of cranes. Approximately 30% of Japan's commercial shipping passes through the Port of Kobe.

Utilities in Kobe were severely affected by the earthquake. About 70% of Kobe's water system was inoperable due to numerous distribution system breaks caused by widespread ground failure. The gas system was also severely affected, and the electric system was disrupted by the collapse of thousands of poles, due in many cases to the collapse of adjacent buildings.

The earthquake struck at 5:46 a.m., when most of the residents were still sleeping or beginning their morning routines. Most of the deaths and injuries occurred when older wood-frame houses with heavy clay tile roofs collapsed. The collapse of these buildings was followed by the ignition of over 300 fires within minutes of the earthquake. Response to the fires was hindered by the failure of the water supply system and the disruption of the traffic system. At least 12 major conflagrations developed and burned for 24–48 hours. Within 24 hours, fire companies had arrived from as far away as Tokyo. The number of homeless people requiring shelter was estimated to be approximately 300,000, which is 20% of the population of Kobe.

Implications for California

Currently, available evidence does not suggest any difference between the source characteristics of the Kobe earthquake and those of crustal earthquakes that occur in California, and our preliminary evaluation of the ground motions from the Kobe earthquake indicate that they were comparable to those we would expect from a California earthquake of the same magnitude. Since the 1933 Long Beach earthquake, California has not experienced a strike-slip earthquake that ruptured directly into a heavily populated urban region and has never seen a strike-slip earthquake rupture into the downtown region of a major city. Although the 1994 Northridge earthquake occurred within an urban region, almost all of the fault rupture occurred at depths greater than 10 km, and the great majority of the multistorey buildings in the San Fernando Valley were at least 20 km from the closest part of the fault rupture. However, many urban regions in California and other states contain strike-slip faults that can rupture to or near the ground surface, as occurred in Kobe. There is no doubt that these faults will produce earthquakes eventually. The urgent questions for earthquake scientists and engineers are whether the ground motions from these earthquakes will be as severe as those experienced in Kobe, and whether these ground motions will cause the tragic loss of life and disastrous damage to Californian cities that they brought to Kobe.

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Climate change studies: Need for a refocusing*

S. M. Kulshrestha

While there is considerable work done on global-scale assessments of the likely impacts of climate change, the confidence in regional-scale assessments based on global climate models is still low. But it is at the regional or country level where cost-effective response strategies and policy options have to be formulated and implemented. For this, we need to make a transition from global generalities to regional/country specifics. This calls for a refocusing in studies of climate change and its impacts.

THE subject of climate change is undoubtedly one of the areas that has received very considerable public exposure in the recent times and more so during the past 10 years. Thanks to the political and media attention and the varying perceptions emanating from these, it has also become controversial to a large extent and seems to have acquired a geopolitical complexion. At the same time, it is also an area of considerable scientific effort worldwide.

In such a situation, it is inevitable that a very large (and growing) body of scientific data, analyses and interpretations emanate from different parts of the world and different scenarios are put forth enthusiastically. But limited or selected observations may not constitute representative samples; short-term variations would not always indicate long-term changes; and above all, scenarios should not be taken as predictions.

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