The most devastating earthquake to hit Japan since the 1923 Tokyo earthquake occurred at 5:46 A.M. local time on January 17, 1995. As this report went to press, over 5,000 people were reported killed, more than 26,000 people were injured, and over 300,000 people were left homeless. At the time of the earthquake, about 40 American engineers, scientists, and government officials were in Osaka, 30 km east of Kobe, for a joint U.S.-Japan Workshop on Urban Earthquake Hazard Reduction, co-sponsored by the Earthquake Engineering Research Institute (EERI) and the Japan Institute of Social Safety Science (1555), and funded by National Science Foundation (NSF). The workshop participants immediately undertook preliminary postearthquake reconnaissance efforts. EERI wishes to express its immense gratitude to the Japanese hosts of the workshop, in particular Hiroyuki Kameda and Haruo Hayashi, both of Kyoto University, for their gracious help in making visits to the field possible.

This report summarizes preliminary information gathered by the workshop participants in the first week after the earthquake. The damage caused by the magnitude 6.8 Hyogo-Ken Nanbu earthquake (Great Hanshin Earthquake Disaster) is so extensive that field investigations and cooperative studies with other organizations will continue for some time. In the months ahead, more information will become available, and more definitive conclusions will be developed. Efforts will be made to establish collaborative relationships with Japanese engineers, scientists, and government officials in order to exchange additional information and insights that grow out of the research process.

The Earthquake Engineering Research Institute is a national, nonprofit, technical society of engineers, geoscientists, architects, planners, and social scientists. Since its inception in 1949, it has conducted more than 200 postearthquake investigations to improve the science and practice of earthquake engineering and the reduction of future earthquake losses by documenting the full range of impacts in a scientific and systematic way. These investigations are conducted on a volunteer basis in cooperation with the university community and governmental agencies.

Over the years, the Learning From Earthquakes Project has benefited from the active involvement of William A. Anderson, National Science Foundation Program Manager, who was in Osaka for the NSF-funded U.S.-Japan Workshop. EERI greatly appreciates his support.

The contributions of all those who took part in this preliminary reconnaissance effort are gratefully acknowledged, as is support from the Federal Emergency Management Agency for distribution of this report.
ACKNOWLEDGMENTS

All of the following were in Osaka at the time of the earthquake and participated in the reconnaissance effort:


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The Hyogo-Ken Nanbu Earthquake  
Great Hanshin Earthquake Disaster  
January 17, 1995

PRELIMINARY RECONNAISSANCE REPORT

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<th>Title</th>
<th>Page</th>
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</thead>
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<td></td>
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<td></td>
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<td>Buildings</td>
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<td>Transportation Structures</td>
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<td>5</td>
<td>Lifelines</td>
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<tr>
<td>8</td>
<td>Societal Impacts</td>
<td>89</td>
</tr>
<tr>
<td>9</td>
<td>Shelter, Housing, and Other Recovery Issues</td>
<td>101</td>
</tr>
<tr>
<td>10</td>
<td>Economic Impacts</td>
<td>111</td>
</tr>
</tbody>
</table>
Background
Japan is divided into prefectures, designated by the suffix “ken” or “fu.” Prefectures are divided into areas associated with major cities, designated by the suffix “shi.” City areas are divided into wards, designated by the suffix “ku.” Smaller cities have only one ward, while large cities typically have several wards. Wards are divided areas associated with local towns or neighborhoods, designated by the prefix “cho” or “machi.”

Affected Areas
The areas most affected by the Hyogen-Ken-Nanbu earthquake of January 17, 1995, include the Awaji-shima (island) and the southern portion of the Hyogo-Ken prefecture that borders the Osaka wan (sea). Other areas affected by the earthquake include north-western portions of the Osaka-Fu prefecture and the south-western portion of the Kyoto-Fu prefecture.

The eight major city areas most affected by the earthquake, their populations (x 1,000), and ward names (when there is more than one ward) are listed below:

<table>
<thead>
<tr>
<th>City/Area</th>
<th>Population (x 1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amagasaki-shi</td>
<td>488</td>
</tr>
<tr>
<td>Itami-shi</td>
<td>184</td>
</tr>
<tr>
<td>Kawanishi-shi</td>
<td>142</td>
</tr>
<tr>
<td>Nishinomiya-shi</td>
<td>412</td>
</tr>
<tr>
<td>Takarazuka-shi</td>
<td>203</td>
</tr>
<tr>
<td>Sanda-shi</td>
<td>79</td>
</tr>
<tr>
<td>Ashiya-shi</td>
<td>85</td>
</tr>
<tr>
<td>Kobe-shi</td>
<td>1,477</td>
</tr>
<tr>
<td>(Higashi-Nada-ku, Nada-ku, Kita-ku, Chuo-ku, Hyogo-ku, Nagata-ku, Suma-ku, Tarumi-ku, Nishi-ku)</td>
<td></td>
</tr>
<tr>
<td>Akashi-shi</td>
<td>278</td>
</tr>
<tr>
<td>Kakogawa-shi</td>
<td>247</td>
</tr>
<tr>
<td>Awaji-shima (island)</td>
<td>56</td>
</tr>
<tr>
<td>(northern section of island)</td>
<td></td>
</tr>
<tr>
<td>Other Hyogo-Ken cities</td>
<td>±100</td>
</tr>
<tr>
<td>All affected Hyogo-ken cities (approximate)</td>
<td>±3,700</td>
</tr>
<tr>
<td>Other Prefecture cities (estimated fraction of population affected by strong shaking)</td>
<td>±300</td>
</tr>
<tr>
<td>Total affected population (approximate)</td>
<td>±4,000</td>
</tr>
</tbody>
</table>
Areas Affected by the Earthquake
## Earthquake Casualty Data

<table>
<thead>
<tr>
<th>Location (City/Ward)</th>
<th>Total Population(^1)* (x 1,000)</th>
<th>Earthquake Casualties(^2)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Deaths</td>
<td>Injuries</td>
<td>Missing</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Higashi-Nada-ku</td>
<td>190</td>
<td>1,127</td>
<td>3,383</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Nada-ku</td>
<td>130</td>
<td>782</td>
<td>1,112</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Chuo-ku</td>
<td>116</td>
<td>207</td>
<td>3,327</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Hyogo-ku</td>
<td>124</td>
<td>384</td>
<td>1,755</td>
<td>10</td>
<td></td>
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<tr>
<td>Kobe-shi/Nagata-ku</td>
<td>137</td>
<td>673</td>
<td>533</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Suma-ku</td>
<td>188</td>
<td>314</td>
<td>637</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Tarumi-ku</td>
<td>235</td>
<td>2</td>
<td>1,020</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Nishi-ku</td>
<td>159</td>
<td>2</td>
<td>1,649</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi/Kita-ku</td>
<td>198</td>
<td>1</td>
<td>817</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kobe-shi (all wards)</td>
<td>1,477</td>
<td>3,492</td>
<td>14,224</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Ashiya-shi</td>
<td>85</td>
<td>393</td>
<td>2,759</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Nishinomiya-shi</td>
<td>412</td>
<td>843</td>
<td>2,987</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Amagasaki-shi</td>
<td>488</td>
<td>25</td>
<td>61</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Itami-shi</td>
<td>184</td>
<td>10</td>
<td>923</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kawanishi-shi</td>
<td>142</td>
<td>1</td>
<td>73</td>
<td>0</td>
<td></td>
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<tr>
<td>Takarazuka-shi</td>
<td>203</td>
<td>84</td>
<td>1,100</td>
<td>0</td>
<td></td>
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<tr>
<td>Sanda-shi</td>
<td>79</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Akashi-shi</td>
<td>278</td>
<td>5</td>
<td>965</td>
<td>0</td>
<td></td>
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<tr>
<td>Kakogawa-shi</td>
<td>247</td>
<td>2</td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Awaji Island (northern section)</td>
<td>56</td>
<td>56</td>
<td>712</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other Hyogo-Ken cities</td>
<td>~100</td>
<td>~14</td>
<td>29</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total for Hyogo-Ken cities</td>
<td>~3,700</td>
<td>~4,925</td>
<td>~23,863</td>
<td>~170</td>
<td></td>
</tr>
<tr>
<td>Total for Osaka-Fu cities</td>
<td>~200</td>
<td>~11</td>
<td>~1,941</td>
<td>~0</td>
<td></td>
</tr>
<tr>
<td>Total for other prefecture cities</td>
<td>~100</td>
<td>~0</td>
<td>~98</td>
<td>~0</td>
<td></td>
</tr>
<tr>
<td>Total all cities (estimated)</td>
<td>~4,000</td>
<td>~5,000</td>
<td>~25,000</td>
<td>~0</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) *Monthly Statistics of Japan, December 1994 (Kobe-shi ward populations), and Japan Local Government Data Book 1993 (Hyogo-Ken city populations).

\(^2\) *The Sankei Shim bun (newspaper). January 21, 1995.*
### Prefectural Statistics: Kyoto, Osaka, and Hyogo

<table>
<thead>
<tr>
<th>Prefectural Statistic</th>
<th>Individual Prefecture</th>
<th>All Prefectures of Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kyoto-Fu</td>
<td>Osaka-Fu</td>
</tr>
<tr>
<td>Area (sq. km)</td>
<td>4,612</td>
<td>1,882</td>
</tr>
<tr>
<td>No. of Large Cities</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td>No. of Towns and Villages</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>No. of Households (x 1,000)</td>
<td>915</td>
<td>3,148</td>
</tr>
<tr>
<td>Population (x 1,000)</td>
<td>2,541</td>
<td>8,552</td>
</tr>
<tr>
<td>Population Density (/Sq. km)</td>
<td>551</td>
<td>4,538</td>
</tr>
<tr>
<td>Per Capita Income (x 1,000 Yen)</td>
<td>2,794</td>
<td>3,348</td>
</tr>
<tr>
<td>Manufacturing Industry: No. of Business Establishments</td>
<td>26,885</td>
<td>73,641</td>
</tr>
<tr>
<td>Commercial: No. of Stores</td>
<td>36,757</td>
<td>112,185</td>
</tr>
<tr>
<td>No. of Employed Persons in Primary Industry (x 1,000)</td>
<td>46</td>
<td>30</td>
</tr>
<tr>
<td>No. of Employed Persons in Secondary Industry (x 1,000)</td>
<td>422</td>
<td>1,525</td>
</tr>
<tr>
<td>No. of Employed Persons in Tertiary Industry (x 1,000)</td>
<td>787</td>
<td>2,638</td>
</tr>
<tr>
<td>Agricultural Population (x 1,000)</td>
<td>43</td>
<td>28</td>
</tr>
<tr>
<td>No. of Pre-Schools</td>
<td>506</td>
<td>1,066</td>
</tr>
<tr>
<td>No. of Kindergartens</td>
<td>260</td>
<td>891</td>
</tr>
<tr>
<td>No. of Elementary Schools</td>
<td>490</td>
<td>1,063</td>
</tr>
<tr>
<td>No. of Jr. High Schools</td>
<td>207</td>
<td>524</td>
</tr>
<tr>
<td>No. of High Schools</td>
<td>104</td>
<td>285</td>
</tr>
<tr>
<td>No. of Colleges/Universities</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>No. of Hospitals</td>
<td>221</td>
<td>627</td>
</tr>
<tr>
<td>No. of General Clinics</td>
<td>2,273</td>
<td>6,862</td>
</tr>
</tbody>
</table>

Japanese Earthquakes in this Century

<table>
<thead>
<tr>
<th>Date</th>
<th>Place</th>
<th>Earthquake Magnitude</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1923</td>
<td>Tokyo, Yokohama</td>
<td>7.9</td>
<td>142,807</td>
</tr>
<tr>
<td>1925</td>
<td>Kita Tajima</td>
<td>6.8</td>
<td>428</td>
</tr>
<tr>
<td>1927</td>
<td>Kita Tango</td>
<td>7.8</td>
<td>2,925</td>
</tr>
<tr>
<td>1930</td>
<td>Kitaizu</td>
<td>7.3</td>
<td>272</td>
</tr>
<tr>
<td>1933</td>
<td>Sanriku</td>
<td>8.1</td>
<td>3,064</td>
</tr>
<tr>
<td>1943</td>
<td>Tottori</td>
<td>7.2</td>
<td>1,083</td>
</tr>
<tr>
<td>1944</td>
<td>Higashi Nankai</td>
<td>7.9</td>
<td>1,223</td>
</tr>
<tr>
<td>1945</td>
<td>Tokai</td>
<td>6.8</td>
<td>2,306</td>
</tr>
<tr>
<td>1946</td>
<td>Nankai</td>
<td>8.0</td>
<td>1,464</td>
</tr>
<tr>
<td>1948</td>
<td>Fukui</td>
<td>7.1</td>
<td>3,895</td>
</tr>
<tr>
<td>1949</td>
<td>Imaichi</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td>1952</td>
<td>Tokachi</td>
<td>8.2</td>
<td>33</td>
</tr>
<tr>
<td>1964</td>
<td>Niigata</td>
<td>7.5</td>
<td>26</td>
</tr>
<tr>
<td>1968</td>
<td>Tokachi</td>
<td>7.9</td>
<td>52</td>
</tr>
<tr>
<td>1974</td>
<td>Izu Oshima</td>
<td>6.9</td>
<td>38</td>
</tr>
<tr>
<td>1978</td>
<td>Izu Oshima</td>
<td>7.0</td>
<td>25</td>
</tr>
<tr>
<td>1978</td>
<td>Miyagi</td>
<td>7.4</td>
<td>28</td>
</tr>
<tr>
<td>1983</td>
<td>Sea of Japan</td>
<td>7.7</td>
<td>104</td>
</tr>
<tr>
<td>1984</td>
<td>Nagano</td>
<td>6.8</td>
<td>29</td>
</tr>
<tr>
<td>1993</td>
<td>Kushiro</td>
<td>7.8</td>
<td>2</td>
</tr>
<tr>
<td>1993</td>
<td>Okushiri</td>
<td>7.8</td>
<td>230</td>
</tr>
<tr>
<td>1994</td>
<td>Kuril Islands</td>
<td>8.1</td>
<td>8</td>
</tr>
</tbody>
</table>
The January 17, 1995, Hyogo-Ken Nanbu earthquake (the Great Hanshin Earthquake Disaster) is the most damaging earthquake to have struck Japan since the great Kanto earthquake destroyed large areas of Tokyo and Yokohama and killed approximately 150,000 people (mostly by fire) in 1923. As of January 24, the toll from the earthquake in Kobe had reached 5,090 dead, 17 missing, and 26,284 injured. More than 56,200 buildings were destroyed. Current estimates of losses in this city of 1.4 million people are about 20 trillion yen (200 billion dollars), one order of magnitude larger than that from the January 17, 1994, Northridge, California earthquake.

The earthquake was assigned a JMA magnitude of 7.2 by the Japan Meteorological Agency (JMA). Seismological analyses indicate a seismic moment of about $3 \times 10^{26}$ dyne-cm, corresponding to a moment magnitude of 6.9 (Kikuchi 1995). The hypocenter of the earthquake (34.6° N, 135.0° E, focal depth = 10 km, origin time 5:46:52 JST; JMA) was located about 20 km southwest of downtown Kobe between the northeast tip of Awaji Island and the mainland (Figure 1-1). Based on the distribution of aftershocks (Disaster Prevention Research Institute, Kyoto University; Figure 1-2) and teleseismic waveform modeling (Kikuchi 1995; Figure 1-3), the rupture length of the 1995 earthquake is inferred to have been in the range of 30 to 50 km, produced by bilateral rupture from the hypocenter. The rupture of this strike-slip earthquake directly into downtown Kobe, as inferred from the aftershock distribution and the information on surface faulting and strong ground motions that follows, appears to have contributed to the high level of destruction that occurred.

The earthquake occurred in a region where a complex system of active faults had been previously mapped (Research Group for Active Faults in Japan 1991; Figure 1-1). 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 (Kikuchi 1995; Figure 1-3). The earthquake produced surface rupture with an average horizontal displacement of 1 to 1.5 meters on the Nojima fault, which runs along the northwest shore of Awaji Island (Nakata, personal communication), as shown in Figure 1-4. Marine seismic surveys have found a 300-meter long offshore extension of this rupture (Japan Maritime Safety Agency). 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. Near the onshore projection of these underwater rupture segments, a small amount of right-
lateral faulting has been observed in a road in the Surna ward in western Kobe (Nakata, personal communication).

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 earthquake of 1927, the magnitude 7.2 Tottori earthquake of 1943, and the magnitude 7.1 Fukui earthquake of 1948 (Kanamori 1973), shown in Figure 1-5. 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 Jzu-Jtoigawa line to the east in central Honshu (Fujita 1980), shown in Figure 1-5. In summary, the 1995 Kobe earthquake occurred on a mapped system of active faults, and had a mechanism that is compatible
with the tectonics of western Japan as inferred from similar earthquake that occurred during the past century. 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.

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 1-1. The various contributing organizations present different measures of peak acceleration. The Kansai and JMA values are the largest of 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.
Figure 1-3  Focal mechanism and source process of the earthquake. The earthquake consisted of three subevents, whose relative locations are shown in the upper left, time functions in the lower left, and focal mechanisms and moment magnitudes to the right. The largest subevent was located at the epicenter. Source: Kikuchi, 1995.

Figure 1-4  Scarp of the Nojima fault on Awaji Island showing both vertical and horizontal offset. Source: Newsweek, February 1, 1995, Japan edition.
Figure 1-5  Collision of the North American plate with the Eurasian plate in central Japan. Plate boundary faults and active crustal faults in Japan. Epicenters of large earthquakes during the past century are shown. Source: Newsweek, February 1, 1995, Japan edition.
GEOSCIENCE AND GEOTECHNICAL ASPECTS 6

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 (Figure 1-6), which are indicative of rupture directivity effects and are potentially damaging to multi-story buildings and other long-period structures such as bridges. The near-fault horizontal peak velocities were 55 cm/sec on rock at Kobe University, and went off scale at soil sites at levels of 40 cm/sec and 100 cm/sec 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 1-7. 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.

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 to 300 cm, and large volumes of silt were ejected. Local lateral spreading of soils occurred.
along quay walls in many parts of the extensive port facilities in Kobe (Figure 1-8), rendering some of them inoperative, and causing the disruption and collapse of cranes (Figure 1-9). Approximately 30% of Japan’s commercial shipping passes through the Port of Kobe.

In the Sannomiya district of downtown Kobe, large deformations of road pavements and of the ground around building formations were observed. These deformations were typically on the order of tens of centimeters (Figure 1-10), and may have been responsible in part for the severe damage including tilting, collapse of individual stories, or collapse of the entire structure experienced by many multi-story buildings in the downtown area. Along the route of the elevated Hanshin Expressway, there was widespread evidence of ground failure as manifested by disruption of the road pavement, subsidence of the pavement around manholes, and ejected silt (Figure 1-11).

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 no experience of a strike-slip earthquake rupturing into the downtown region of a major city. Although the 1994 Northridge earthquake occurred within an urban region, almost all of the slip occurred at depths greater than 10 km, and the great majority of the
multi-story buildings in the San Fernando Valley were at least 20 km from the closest part of the fault because they are mostly located along the southern margin of the valley. However, numerous urban regions in California and other states contain strike-slip faults which can rupture all the way to or close to the ground surface, as occurred in Kobe during the 1995 earthquake. There is no doubt that these faults will produce earthquakes at some time in the future. 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 the city of Kobe.

ACKNOWLEDGMENTS
This report was compiled from information developed by many investigators, including Masataka Ando, Kyoto University (aftershock distribution); Kojiro Irikura, Kyoto University and Yoshinori Iwasaki, GeoResearch Institute (strong ground motion), Masayuki Kikuchi, Yokohama City University (faulting mechanism); and Takashi Nakata, Hiroshima University (surface faulting). Kazuki Kohketsu of Tokyo University prepared the base for Figure 1-2, including active faults and peak ground motions, the latter from strong motion data provided by the Kinki Strong Motion Observation Network, Japan Rail, Osaka Gas, and the Japan Meteorological Agency.
Figure 1-9  Collapsed crane, Port of Kobe.

Figure 1-10  Disruption of the road in the Sannomiya district of downtown Kobe.
Figure 1-11  Ejected silt along a side street abutting the Hanshin Expressway in Nishinomiya.

REFERENCES
2 ARCHITECTURAL AND PLANNING BACKGROUND

Kobe is one of the largest and busiest ports in Japan, with a population of 1.4 million, in south central Honshu. The city lies on a narrow coastal plain facing the Inland Sea and backs up against Mount Rokko, a 3,000-foot peak. Downtown Kobe is only about 2-1/2 miles wide, while the city as a whole is about 15 miles long. Kobe forms the western end of a continuous urban-industrial complex, stretching through Osaka, 30 km to the east, to the historic city and former capital of Kyoto, a further 30 km. Fifteen percent of the population of Japan live in this urban complex, exceeded in size only by the Tokyo-Yokohama urban area.

Kobe has been a port since the thirteenth century, trading with Okinawa and China, but the large international harbor developed in the nineteenth century as trading opened up with the West. Kobe became the cosmopolitan city that it is today with a large foreign population; 87,000 Koreans live in Kobe, together with many other nationals, and a famous foreign residential section developed in the hills overlooking the port. The poorer population was concentrated in high-density neighborhoods in the flatlands close to the harbor and in adjoining districts.

Shipping traffic to and from Kobe accounts for 19% of Japan’s total trade, and together with Osaka’s port, facing Kobe’s harbor across some 15 miles of sheltered bay, 30% of the country’s export/import is accomplished.

While Kobe developed before World War II into a thriving city, the war put a stop to development, and Allied bombing further destroyed the region: one third of Osaka was levelled in the war. Recovery started in 1945 and, as is well known, after a slow start, for a 15-year period beginning in the late 1950s, Japan enjoyed a phenomenal economic growth. This was characterized, among other things, by rapid growth of its cities, along western lines, and a dramatic rise in land prices which profoundly affected the nature of city development: in this period was born the new Japanese city which, in the eyes of western architects and planners, had no redeeming features. Traditional western city lovers had the same reaction: although some saw poetry in neon and sunsets, most saw only a grey concrete sameness, congestion, and a myriad of electrical wires.

Concurrent with the development of the 1960s, however, there occurred the recognition in the West that a number of important architectural works were appearing in Japan, and an important movement—the Metabolists—caught the attention of architects everywhere. This phenomenon has continued to this day and a number of Japanese architects have achieved international star quality, with works of brilliance and sophistication. But these works, like a Shinto shrine or a temple in Kyoto, must be sought out from a mass of grey concrete buildings, which are alternatively drab or commercially garish—both by day or night.
Figure 2-1  A typical Japanese city street showing the unplanned nature of development.

Figure 2-2  Nishinomiya in Kobe was an example of the marketplace aspect of Japanese cities.
Although planning laws do exist in Japan, they are very weak compared with western regulations, and the fragmented pattern of land ownership has made coherent development virtually impossible (Figure 2-1). More recent critics have seen virtues in the Japanese city, however, and the excitement and vitality of day and night life become increasingly appealing compared to the zoned boredom of a United States suburb or dead downtown after 5 o’clock.

Bognar (1985) has pointed out that, partly for sociopolitical reasons, cities in Japan never had the well-defined centers, marked by important buildings, that we expect in the West. The Italian writer Mariani (1975) makes a significant point: that the Japanese ideogram for city, ski, and the marketplace, icki, is the same. To the Japanese, the city is a market place, a shopping center. A city is not meant to beautiful, it is meant to be useful. Anyone who has spent time in the Ginza in Tokyo, in Shinsaibashi in Osaka, or in the now shattered area of Nishinomiya in Kobe will recognize the insight of this observation (Figure 2-2).

Moreover, the Japanese planning historian Watanabe (1981) has pointed out that western urban planning is biased with an anti-urban ideology: Britons hate the large city, whereas Americans dislike the central city. His general conclusion is that: “A sharp contrast is presented by Japanese planning, in which the anti-urban or anti-metropolitan bias is virtually alien. Pioneering Japanese planners, with strong urban tradition and centralized planning powers, tried to foster the metropolis rather than discourage it, as the Britons did, or dismantle it, as the Americans did. Japan is one of those rare cases in which the metropolis is still alive and doing well at the functional as well as ideological levels.” Most Westerners would agree that the Japanese city is a livelier and,
in a strange way, more human place than most U. S. cities, but it is only the innate patience and politeness of the Japanese that enables it to work.

The explosive development of the 1960s and 1970s--slowed in the mid-1970s by the oil crisis--resumed in the 1980s. By now most available land was built up, and, aside from building much higher, many large-scale waterfront developments on filled land were constructed in Tokyo, Osaka--including the huge new Kansai airport opened in 1994--and in Port Island in Kobe.

High density is characteristic of the Japanese city. One characteristic phenomenon is that of the underground shopping center, generally associated with a railway or subway station, and often developed by the real estate development branch of the railway company. In the city of Osaka seven underground malls occupy 269 acres. The Nishi-nomiya area around the main station in Kobe is developed as a huge underground shopping mall, and reportedly suffered little earthquake damage.

Because of the high land costs, commercial areas in Japanese cities are remarkable for narrow-fronted buildings, perhaps 3 or 4 meters wide and up to 8 stories tall; these densely developed commercial properties, individually owned, vie for attention with eye-catching architecture and graphics (Figure 2-3, 2-4).

Residential areas are also very densely built up. Some comparative figures show this. A 1970 comparison by Morris of the most dense areas of three cities showed Central London and Manhattan to be the most dense, followed by Tokyo:

London (Paddington) 131 persons/acre
Manhattan, New York 120 persons/acre
Tokyo 116 persons/acre

The significance of these numbers is that for London and New York the densities are achieved in high-rise buildings, while for Tokyo the occupants are in one- and two-story dwellings. The visual effects of this are shown in Figures 2-5 and 2-6 showing a traditional residential area in Osaka, and a high-density residential area in Oakland, California (Arnold 1982). The comparative densities are approximately:

Osaka 95 persons/acre
Oakland 33 persons/acre
In the U. S., street widths have been strictly controlled for some decades; the narrowest right-of-way in the Oakland example is approximately 50 feet, including sidewalks, parking, and traffic lanes. In Osaka, the street widths vary from less than 8 feet for a local access way to 35 feet for the widest right-of-way in the example area. The Oakland street widths are regulated to permit access for firefighting equipment: in Osaka, as is typical for Japanese cities, only the major streets are accessible to fire-fighting equipment and fire suppression policy lays stress on individual fire suppression: courses are conducted by fire department personnel to train people in firefighting in their homes.

Japanese governmental buildings, and those designed for major corporations and institutions, are very well designed and constructed, with great attention to detail and craftsmanship. But the vast bulk of commercial buildings are designed and built under conditions similar to their United States counterparts: minimum time for design and construction and a keen eye on the bottom line. While many Japanese buildings are, as noted, drab and unimaginative, this makes for a beneficial regularity in seismic terms. However, many smaller commercial buildings, in the effort to attract attention and distinguish themselves from their neighbors, often indulge in decorative or configurational excesses (Figure 2-7). Moreover, the very practical arrangement of providing living areas over first-floor stores makes for an intrinsic soft first story which, if not recognized and properly designed, is extremely vulnerable (Figure 2-8).

Indeed, the traditional Japanese house, with its heavy grey, brown, or blue tile roof over a flimsy wood frame is, of course, a natural weak story, and, unlike its American counterpart, is very prone to complete collapse, besides being vulnerable to fire.
Figure 2-8  Living areas are often built over a first-floor store.

REFERENCES:
MODERN AND ENGINEERED STRUCTURES
The Hyogo-Ken Nanbu earthquake of January 17, 1995, caused extensive and often severe damage to buildings located on the northern portion of Awaji Island and in the coastal cities of the Hyogo Prefecture that border Osaka Bay. These cities include: Akashi, Kobe, Ashiya, Nishinomiya, and Amagasaki. Inland cities of the Hyogo Prefecture located near the northern end of fault rupture also sustained significant damage. These cities include: Sanda, Takarazuka, Kawanishi, and Itami. Additional damage of a more limited nature was reported for nearby cities of the Osaka and Kyoto Prefectures.

The single most significant reason for the extent of severe building damage caused by the earthquake is the proximity of affected cities to fault rupture. The plane of fault rupture is located directly below the highly-developed band of land that includes Kobe and neighboring cities of the Hyogo Prefecture. Most buildings of these cities are located within 10 km of fault rupture.

Scope of Building Observations
The following statements of earthquake damage are based on limited and cursory observation of buildings located in the coastal wards of central and eastern Kobe (including Port and Rokko Islands), Ashiya, and Nishinomiya. Damage observations focused on commercial and residential buildings and did not include visits to industrial facilities. The Japanese media has also reported significant damage to buildings located in the western portion of Kobe and on Awaji Island.

Damage described in this report is based on limited observations of the exterior condition of buildings, typically performed during walking tours of areas reported to have heavy damage. The number of areas with damaged buildings and the large quantity of damaged buildings in these areas permitted only a few minutes at most at any one building site. Even though building observations were very brief, only a small fraction of all damaged buildings could be visited.

General Observations
In general, extensive and often severe damage was observed to a large number of buildings in the Kobe area. The most extensive damage was observed to the traditional Japanese residence, a wood-frame building with weak walls and a heavy clay tile roof (known as Shinkabe and Okabe) and to the smaller commercial buildings constructed with limited engineering design. Severe damage and often partial or full collapse of large commercial and residential buildings was observed throughout central Kobe and in other areas that were heavily damaged. While evidence of ground failure (liquefac-
tion) was typically observed in areas of heavy building damage, ground shaking appears to be the dominant contributor to damage of engineered buildings. In the Nagata and Suma wards of Kobe, fire following the earthquake contributed significantly to the fraction of buildings damaged. These areas were likely heavily damaged prior to conflagration, but it is now impossible to determine the extent of damage caused by ground shaking/ground failure prior to destruction by fire (Figure 3-1).

The pattern of severe building damage generally conforms to the zone of fault rupture (as described by the location of aftershock epicenters). In the center of Osaka, and other cities that were located at 15-40 km from fault rupture, strong ground shaking was felt, but building damage was limited to a relatively small number of buildings and typically of a moderate nature (for example, broken windows). Clearly, ground shaking was quite intense near fault rupture, but not necessarily of a uniform nature. Damage patterns vary between cities and wards that are equally close to fault rupture. These differences could not be explained by differences in construction or site characteristics and appear to reflect an inherent difference in ground shaking intensity at sites equally close to fault rupture.

In areas of heavy damage, severely damaged buildings were typically collapsed or leaning in the same direction. This pattern of damage indicates that a strong pulse was likely to have been present in the dominant horizontal component of the ground shaking. Strong directional pulses are predicted by theoretical models of ground motion and were recorded during the 1994 Northridge earthquake at sites near fault rupture. The implication of this observation is that buildings primarily collapsed due to single-cycle failure of a brittle structural system, rather than due to degradation during repeated cycles of earthquake demand.

**Building Damage Statistics**

It is not possible at this time to provide accurate statistics on building failure, but the following, very approximate information is known. As of late Sunday, January 22, 1995, the Japanese media reported about 20,000 buildings destroyed by the earthquake (100% damage), including buildings destroyed by fire following the earthquake, and about 35,000 buildings with severe damage (50% damage). Typically, a building designated as destroyed by ground shaking or ground failure has sustained partial collapse or is in a state of extreme structural distress (for example, out-of-plumb). The Japanese
Figure 3-2 Complete and partial damage to buildings, as of 1/21/95. Top figure indicates 100% damage count, bottom figure indicates 50% damage count. Source: Sankei Shinbun
media tend to report only official numbers known as of reporting date and the number of destroyed and severely damaged buildings will likely increase as detailed building inspections progress. In fact, by January 31, the media was reporting over 80,000 buildings were damaged.

Table 3-1 summarizes the breakdown of damaged buildings by city and ward (of Kobe). Damage is described as “100%,” “50%,” and “Fire.” All building with 50% or more damage is sum of 100% and 50% values. This sum includes buildings damaged by fire. Figure 3-2 illustrates the geographical distribution of building damage by city and ward (of Kobe). The hardest hit areas of Kobe include the Higashi-Nada, Chuo, and Nagata wards. The Chou ward is located at the center of Kobe and includes many large commercial buildings. About 20%-30% of all buildings in the Chou and Higashi-Nada wards have sustained 50% or more damage and about 50%-60% (including fire damage) or about 40%-50% (excluding fire damage) of all buildings in the Nagata ward have sustained 50% or more damage.

A rough estimate of the total number of buildings in the Kobe area and affected neighboring areas is about 800,000 (total of residential, commercial, and industrial buildings). Approximately 5% to 10% of buildings appear to be the larger commercial/industrial buildings (including also mid-rise apartment buildings), approximately 10% to 20% appear to be the smaller commercial and manufacturing buildings (including mixed commercial/residential buildings) and the remaining 70% to 85% are low-rise residences (typically of Shinkabe or Okabe construction). Based on these crude estimates of building type, Japanese media reports of damage, and observed damage patterns, the following may be stated: about 45,000+ single-family or low-rise residences, about 4,000 to 8,000 smaller commercial (and mixed-occupancy buildings), and about 1,000 to 2,000 of the larger commercial (and mid-rise apartment buildings) have been destroyed or severely damaged (50% or greater damage).
### Table 3-1 Building Damage Data

<table>
<thead>
<tr>
<th>Location (City/Ward)</th>
<th>Number of Buildings(^1) (x 1,000)</th>
<th>Number of Buildings Damaged(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Kobe/Higashi-Nada Ward</td>
<td>~40</td>
<td>2,788</td>
</tr>
<tr>
<td>Kobe/Nada Ward</td>
<td>~25</td>
<td>600</td>
</tr>
<tr>
<td>Kobe/Chuo Ward</td>
<td>~25</td>
<td>2,437</td>
</tr>
<tr>
<td>Kobe/Hyogo Ward</td>
<td>~25</td>
<td>1,000</td>
</tr>
<tr>
<td>Kobe/Nagata Ward</td>
<td>~30</td>
<td>6,672</td>
</tr>
<tr>
<td>Kobe/Suma Ward</td>
<td>~40</td>
<td>1,161</td>
</tr>
<tr>
<td>Kobe/Tsurumi Ward</td>
<td>~45</td>
<td>26</td>
</tr>
<tr>
<td>Kobe/Nishi Ward</td>
<td>~30</td>
<td>0</td>
</tr>
<tr>
<td>Kobe/Kita Ward</td>
<td>~40</td>
<td>1</td>
</tr>
<tr>
<td>Kobe (all wards)</td>
<td>~300</td>
<td>14,685</td>
</tr>
<tr>
<td>Ashiya</td>
<td>~15</td>
<td>359</td>
</tr>
<tr>
<td>Nishinomiya</td>
<td>~80</td>
<td>555</td>
</tr>
<tr>
<td>Amagasaki</td>
<td>~100</td>
<td>85</td>
</tr>
<tr>
<td>Itami</td>
<td>~35</td>
<td>99</td>
</tr>
<tr>
<td>Kawanishi</td>
<td>~30</td>
<td>170</td>
</tr>
<tr>
<td>Takarazuka</td>
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<td>1,339</td>
</tr>
<tr>
<td>Sanda</td>
<td>~15</td>
<td>56</td>
</tr>
<tr>
<td>Akashi</td>
<td>~55</td>
<td>111</td>
</tr>
<tr>
<td>Awaji Island (northern section)</td>
<td>~10</td>
<td>1,361</td>
</tr>
<tr>
<td>Other Hyogo Prefecture Cities</td>
<td>~70</td>
<td>4</td>
</tr>
<tr>
<td>Total for Hyogo Prefecture Cities</td>
<td>~750</td>
<td>18,824</td>
</tr>
<tr>
<td>Total for Osaka Prefecture Cities</td>
<td>~40</td>
<td>106</td>
</tr>
<tr>
<td>Total for Other Prefecture Cities</td>
<td>~10</td>
<td>2</td>
</tr>
<tr>
<td>Total All Cities (estimated)</td>
<td>~800</td>
<td>~20,000</td>
</tr>
</tbody>
</table>

1. Number of buildings estimated as one building per five of city or ward population.
Background-Commercial and Residential Buildings

Most of the buildings in the area of Kobe have been built since World War II (WW II) when the area was essentially destroyed. In this sense, most buildings in the Kobe area are considered "modern," although design codes and practices and construction methods have changed significantly in Japan from the post-WWII reconstruction period to today's standards. Changes in seismic codes and design practices are not unique to Japan and in many ways parallel changes in the codes and practice of the United States and other countries.

Commercial buildings in the Kobe area may be divided into two groups: smaller buildings, typically not more than three stories in height, and larger buildings, typically 4 to 15 stories in height. There are only a few very tall buildings (over 15 stories) in the Kobe area and these structures appear to have performed well during the earthquake (Figure 3-3). Smaller commercial buildings often include residences upstairs. The larger residential buildings (that is, mid-rise apartment buildings) appear to have construction similar to the larger commercial buildings.

Smaller Commercial/Mixed-Occupancy Buildings

The smaller commercial/mixed occupancy buildings appear to be constructed of a variety of materials. Typically, these buildings are framed with wood or light-steel members and have walls of stucco or other covering over wood slats (similar to Okabe houses) or in some cases masonry infill. In general, most of the smaller buildings appear to have limited engineering design.

A typical smaller commercial/mixed occupancy building might be two stories in height, with an open front at the first floor (roll-up doors are common). Thus, the first story of these buildings is typically soft, often without any significant length of wall at the side of the building facing the street. In many cases, the upper floors are used for office or living space.

The most common form of damage to the smaller commercial/mixed occupancy building was failure of a soft or weak first story. Such failures either caused collapse of the building (Figures 3-4 and 3-5) or more commonly affected a permanent offset of the first story (Figure 3-6). Smaller buildings are typically built immediately adjacent to each other and interaction (pounding) would often "push" the end or corner building.

Figure 3-4 Collapse (overturning) of three-story, steel frame/masonry wall building, Chou ward, Kobe.
out into the street. Often a whole line of adjacent buildings would have a soft first story and sustain a permanent offset (Figure 3-7). It was also quite common for these buildings to lose their external covering, revealing the structural system below (Figure 3-8).

The smaller commercial/mixed occupancy buildings do not have deep foundations and were often damaged by ground failure as well as ground shaking. Typically, ground settlement would compound distortion of the structural system caused by ground shaking. In a few cases, ground settlement was significant enough to cause the entire building to lean over (Figure 3-9).

**Figure 3-5** Collapse (first floor) of two-story, wood-frame building, Hyogo ward, Kobe.

**Figure 3-6** Racked, two-story, wood-frame building, Hyogo ward, Kobe.
Figure 3-7  Racked, row of adjacent low-rise buildings, Higashi-Nada ward, Kobe

Figure 3-8  Damage to three-story, steel/wood-frame building, Chou ward, Kobe.

Figure 3-9  Foundation settlement, four-story building, Chou ward, Kobe.
Larger Commercial and Residential Buildings

The larger commercial and residential buildings are constructed of reinforced-concrete, steel, or a composite of the two materials. It appears that reinforced concrete was the preferred material in the period immediately following WWII. Most of the taller buildings now under construction in Kobe were observed to have a steel structural system (both moment and braced frame systems were observed).

A typical larger commercial building in downtown Kobe might be four to eight stories in height and constructed of reinforced concrete. The building might be a frame system or a combination of frame and shear walls. Structural irregularities, in terms of an open first-floor, a set back, or plan irregularity are common. In many cases, the building is constructed on a small parcel and is quite tall compared to its base width.

Steel moment frame buildings now under construction in Kobe were observed to use "shop-welded" beam-column connections. These types of connections were also observed in buildings that had lost architectural cover. It appears common practice to weld beam studs to columns prior to erection and to bolt beams to beam studs during erection. It was not possible to examine these buildings to determine if any damage had occurred (that is, cracking of welds) to these types of connections.

It appears that most larger commercial and residential buildings have foundations that adequately supported the building even when there was local settlement and distortion of the ground. The base of larger buildings would typically appear to be level and a couple of inches higher than the adjacent sidewalk or street (Figure 3-10). Horizontal gaps between the base of the building and adjacent sidewalks and streets were also common, indicating building response may have been influenced by soil-structure interaction.

In the areas of the Kobe harbor and on Port and Rokko Islands liquefaction was common and ground settlements of 1-2 feet and more were typical. The larger build-
Figure 3-11  Typical ground-settlement near docks, Kobe Harbor.

Figure 3-12  Collapse (overturning), nine-story, shear wall building, Chou ward, Kobe.

Figure 3-13  Partial collapse, six-story, reinforced-concrete building, Hyogo ward, Kobe.
ings in these areas appear to be built on deep (pile) foundations and do not appear to have sustained damage due to ground settlement (Figure 3-11). Smaller buildings not supported by deep foundations in these areas typically sustained severe damage due to ground failure.

In central Kobe, and other hard hit areas, a large number of buildings sustained partial or full collapse. In one case, a relatively tall, narrow reinforced-concrete shear wall building had completely tipped over into the street (Figure 3-12). The roof/penthouse of this building cut through the building across the street (in what might be considered an extreme case of pounding damage). A number of buildings built on city-block corners sustained partial collapse at the corner of the building (Figure 3-13). These buildings were typically configured with walls on the sides of the buildings facing the block and framed with windows and openings on the sides of the building facing the street, creating severe plan eccentricities.

Partial or full collapse of a single story of buildings was the common "collapse" failure mode for most of the larger buildings. The particular story that sustained partial or full collapse varied from building to building (upper-story failure was just as common as first-story failure). In some cases, the collapsed story could be associated with a

Figure 3-14 Upper floor collapse (at set back), six-story, reinforced concrete building, Chou ward, Kobe.

Figure 3-15 Upper floor collapse, six-story, reinforced concrete hospital, Nagata ward, Kobe.
structural irregularity, such as a set back (Figure 3-14) or interaction with an adjacent structure (Figures 3-15 and 3-16). However, upper-floor failure often occurred in buildings that appeared (from the outside of the building) to be regular over the building’s height (Figures 3-17 and 3-18).

The larger buildings were often out-plumb, or leaning. This was usually caused by partial collapse of a floor on one side of the building or by permanent offset of the structural system (Figure 3-19). In general, the larger buildings did not seem to be leaning appreciably because of foundation settlement or ground failure.

In the center of Kobe it appeared as if every one-in-four or five buildings had collapsed a floor, was leaning, or had otherwise sustained severe structural damage. This fraction, although quite large, is consistent with the building damage statistics reported for the Chou ward (which includes most of central Kobe) and with surveys of properties reported by the Japanese media. As reported about a week following the earthquake, an association of commercial real estate agents surveyed a little over 100 large properties (each over about 20,000 sq. ft.) that were located in central Kobe and available for lease or purchase at the time of the earthquake. They found that about 25% were so damaged that they could not be rehabilitated, that about 50% would require at least two months for seismic repair and restoration, and that only about 25% could be restored and made available within a two-month period. This information indicates that significant and extensive damage to architectural elements, and mechanical, electrical and plumbing systems likely occurred to most of the larger buildings in central Kobe (that is, damage that could not be observed from outside the building).

While the majority of partial or complete collapses appear to be older, reinforced-concrete buildings (pre-1975), severe structural damage was also observed for buildings of steel or composite construction. Furthermore, many buildings of relatively recent vintage exhibited significant damage (Figure 3-20, 3-21, and 3-22).
Conclusions
The Hyogo-Ken Nanbu earthquake of January 17, 1995, exposed more modern and engineered buildings to intense near-source ground shaking than any earthquake to date. The performance of these buildings provides a basis to better evaluate seismic codes, design practice, and construction methods, and to make improvements based on these evaluations. The performance of older buildings, likewise, provides a basis for better understanding the need for seismic rehabilitation and the potential consequences if
such rehabilitation is not performed. It is premature, however, to attempt conclusions regarding the relative performance of buildings of different design codes and practices, different construction methods, materials, and configurations without a more detailed survey of damaged buildings, evaluation of ground motion records, and better understanding of the types and quantities of buildings that were exposed to strong ground shaking.
REPRESENTATIVE URBAN DAMAGE
The photographs in the section that follow provide an overview of the extent and nature of damage to buildings in central Kobe.

Damage to a modern building.

Collapse of unreinforced masonry building.

Undamaged masonry building.
Mid-level collapse.

Collapsed building.

Mid-level collapse.
Mid-level collapse.

Precast panel shedding and collapse.

First floor collapse.
Downtown Kobe.

Damage in Kobe.

Downtown Kobe.
Downtown Kobe.
TRADITIONAL SINGLE FAMILY HOME CONSTRUCTION

The typical low-rise wooden buildings in Japan did not change very much until the late 1970s. There are two main types of traditional residential construction called Shinkabe and Okabe. Both types of construction are highly vulnerable to earthquakes. Shinkabe is the oldest type of construction and consists of a post-and-beam vertical load-carrying system with lateral resistance deriving from mud-infilled, two-way, bamboo latticed exterior and interior walls. In Okabe, the exterior of bamboo-latticed mud is replaced with a thin, timber lath, stucco system. Little nailing is used in traditional Shinkabe or Okabe dwellings, which rely more on wood joinery for connections. Earlier construction uses no waterproofing paper to protect the wood framing against water infiltration and has no wire mesh to strengthen the exterior stucco or mud infills. Foundations in old buildings consist of isolated stone or concrete footings, and in the new ones are perimeter concrete walls. Other characteristics affecting vulnerability are:

- use of heavy tile roofs in which the tiles are set in a thick clay and mud mortar;
- Lack of partitions. Partitioning in a traditional Japanese house is called shoji or sliding paper wall;
- Dwellings are usually two stories, and in urban areas the ground floor is often used as a store with an open front that further reduces the capacity of the first floor walls;
- Widespread dry rot and water damage in the wood posts and sill plates due to lack of water proofing.

Shinkabe and Okabe buildings are still being built in Japan, but in much smaller numbers, especially since 1971, with the introduction of more standardized prefabricated timber housing in all the major urban areas. Western engineering and architectural principles are mixed with traditional Japanese architecture, wood joinery, and interior designs. The typical new timber house is now closer to those in California with a mix of post-and-beam and stud wall construction with light asphalt shingles roof covering. Two levels are predominant due to the high cost of land. More significant is the current predominance of prefabricated timber housing. These houses are generally symmetrical in layout with fewer openings and more room partitioning. The sill plates are always bolted to the concrete foundations, and cripple walls are not very common. Substantial bracing and sheathing cover the whole exterior of the building.
Performance

A significant proportion of the Hyogo-Ken Nanbu earthquake casualties is related to damage and collapse of traditional Shinkabe and Okabe dwellings. The inertia of the heavy tile roofs imposed large stresses and deformations on the walls, which cracked and crumbled, resulting in extensive damage and often collapse of the ground floor. The lack of interior partitions prevents any bracing or damping of the exterior walls. In regions of high intensities, houses were reduced to rubble, and one could see a block of houses turn into a pile of debris consisting of mud, broken tiles, broken timber elements, shattered glass, overturned furniture, and belongings. In most instances, moderate to severe dry rot was observed and may have been a factor in some collapses. Open store fronts in mixed use construction often resulted in collapse of the ground floor. Widespread dry rot and wood decay accelerated the failure of load-bearing elements. Collapse of houses also triggered fires from broken gas pipes. Presence of combustible and flammable material, in regions of mixed residential/commercial use, fueled the fires and resulted in conflagrations that burned several blocks, such as in Nagata ward, increasing the number of fatalities. Newer prefabricated construction performed quite well with very little damage reported.
Detail of Shinkabe residential construction.

Damage to residences in Nishinomiya.
More residentail damage.

Residential failure in Nishinomiya.
Damage to traditional house with severe dry rot.

Collapse of large, single-family residence in Nishinomiya.

Traditional and new construction in Kobe.
Damage to traditional housing in Nishinomiya.

Damage to traditional and more modern construction in Kobe.

Nagata ward after fire.
TRANSPORTATION STRUCTURES

PERFORMANCE OF BRIDGES AND HIGHWAYS

Introduction
This earthquake had a destructive impact on transportation systems in the Kobe, Ashiya, and Nishinomiya areas.

Kansai is the second most populated area of Japan with a population of over 15 million people. Trains, subways, and expressways are squeezed into a narrow corridor by the mountains surrounding the Osaka Bay. After the earthquake, all the transportation systems were heavily damaged. The only way to traverse the city in the main east-west direction was along city streets which were jammed by traffic, and in many locations, were also damaged or blocked by debris. People wishing to enter or leave Kobe after the earthquake had the options of travel on congested surface streets, a ferry that began operation from Kobe Harbor to Osaka, or a long walk to the Hanshin-Koshien station that remained open 20 km to the east. This created tremendous problems for ambulances and fire trucks trying to enter the stricken area and for the thousands of people made homeless after the earthquake. The Hanshin Expressway through the city was closed by a collapsed section, where the structure failed at the lower end of the single column supports and allowed rotation of the deck until the edge was resting on the roadway below. The columns appeared to have failed through a combination of shear and flexure failures at or near the base of the columns. The Hanshin Expressway is the major traffic artery through the city (Figure 4-1). There are no comparable parallel routes because the city is sited close to the mountains to the north and the coast on the south. A new highway along the port area was also closed pending inspection and repair of any damage, although no major damage was evident from a distance.

Nearly every column along the elevated Hanshin Expressway through Kobe was damaged. The most spectacular failure where the bridge "rolled over" was a segment of reinforced concrete column supports (Figure 4-2). Even though the steel sections did not fail, large movements between the concrete pier caps and the superstructure were evident. Bearings were thrown out and were found lying on the roadway below. At other locations the beams dropped onto the pier caps and caused damage to both the concrete pier cap and the end region of the steel beams. Longitudinal and lateral movements of the superstructure on the pier caps left offsets (displacements from the original position) of 25 to 30 cm.

Very large subsidence was observed in the roadways near the city center. There was damage to most ramps and interchange structures for the Hanshin Expressway in this area, and collapse of some spans.

This chapter attempts to give a perspective on why the transportation systems failed and what can be done to improve their performance for future earthquakes.
The Hanshin Expressway
This expressway is an elevated viaduct mostly on single column bents that travels above surface streets throughout the Kansai area (Figure 4-3). The superstructure constantly changes from simple span steel stringers to continuous steel box girders, to concrete T-girders with drop in sections. The columns also varied from concrete or steel circular sections to concrete or steel rectangular sections of varying heights and widths.

Major portions of the expressway were destroyed by the earthquake. This was due to several factors. The columns were short and stiff, creating large seismic forces during the earthquake. For the concrete columns, there was inadequate transverse reinforcement, making the columns very weak for shear and causing the longitudinal steel to birdcage and the concrete to fail at low stresses. This confinement reinforcement was typically a #4 or #5 rebar at 6 to 12 inches with no ties. At some locations, a double row of hoops was used (Figure 4-4).

The longitudinal steel had a weak weld that popped before the reinforcement saw appreciable tension. For the steel columns both local and member buckling was common due to the use of thin steel (Figures 4-5 and 4-6). Finally, there was inadequate seat width for the superstructure and many spans fell off their bearings and bents. The eastern portion of the Hanshin Expressway is nearly normal to the propagation of the fault and the movement was largely longitudinal (Figures 4-7 and 4-8). However, west of Highway 82 the expressway changes direction and consequently has a more transverse motion.

An interesting failure occurred in Nishinomiya. About 600 meters of the expressway collapsed transversely (Figure 4-9). This was at a location where the superstructure changed from steel to concrete. Apparently the increased mass of the concrete portion was enough to push this bridge section over.

Finally, the expressway had much more damage in Kobe than elsewhere. West of downtown Kobe, almost every column and several interchanges are damaged. A visit

Figure 4-1 A bus filled with holiday skiers stops just short of disaster on the Hanshin Expressway.
Figure 4-2 The Hanshin Expressway “rolled over” in places.
Figure 4-3 View of the Kansai area showing the Hanshin Expressway.
Figure 4-4  Column reinforcement on Hanshin.

Figure 4-5  Steel column failure.
to the Hanshin Expressway Corporation indicated that the engineers had been living in this damaged building for several days. Blankets were in every cubicle and food was stacked on tables. The engineers were conducting an inventory of all the bridge damage to the Hanshin Expressway (Figures 4-10 and 4-11). A few days after the earthquake, the damaged portions were being removed.

This expressway suffered so much damage because it was built before seismic details were developed for columns. New bridges in the area did not have nearly as much column damage. Columns with steel shell retrofits also performed well during this earthquake. If steel shells were wrapped around these weak columns, they may well have prevented a great deal of damage to this expressway. Also, single column bents were inadequate for the seismic forces. Portions of the bridge with multicolumn bents generally performed better during the earthquake. However, single column bent viaducts allow an unobstructed roadway below, essential for the congested traffic corridors of the Kansai Region. Therefore, single columns must be designed and retrofitted to allow continued performance after very large earthquakes. Finally, it is essential to provide sufficient bearing to prevent superstructures from falling. We will see much more of that in the next section.

The Harbor Highway
This highway also suffered major damage during the Hyogo-Ken Nanbu earthquake (Figure 4-12). It is a much newer route than the Hanshin Expressway, with modern bridge structures. However, the area along the coast was subject to severe liquefaction and large soil movements. Much of the harbor fell into the sea. Consequently, bridge foundations had less resistance from weak soils and rocked and displaced during the earthquake. Bridge superstructures fell off their bearings and in some cases off their substructure. Every bridge on the Harbor Highway from Nishinomiya to Rokko Island suffered this damage and the highway was closed after the earthquake. This may be a serious problem for modern bridges. Special bearings like inverse pendulums that return bridge decks to their original position should be used where large displacements are anticipated. This would allow bridges to continue to function after an earthquake.

The first bridge examined, like all the bridges on the Harbor Highway, was in an area of liquefaction. This is an arch bridge with cables supporting the deck (Figure 4-13). Some soil modification had been done to this area but with only limited success. There were signs of foundation movement (Figure 4-14) and the superstructure was pulled
Figure 4-7  Longitudinal column failure.

Figure 4-8  Longitudinal movement.
Figure 4-9 Transverse damage to the Hanshin Expressway.
Figure 4-10 Hanshin Expressway.
Figure 4-11  Damage inventory.
Figure 4-12  Map of Osaka Bay showing the Harbor Highway.

Figure 4-13  Fallen span on Nishinomiya Arch Bridge.
Figure 4-14  Two-column bent showing liquefaction and foundation movement.

Figure 4-15  Bearing and restoration failure on Nishinomiya Bridge.
off its bearings breaking the restrainers (Figure 4-15). Some of the cables supporting the bridge deck were also damaged (Figure 4-16).

There was damage at almost every expansion joint along the Harbor Highway; the entire highway was closed from Nishinomiya to Rokko Island. This damage was the result of bearing failures and large pier movements. This caused injuries to drivers as shown in Figures 4-17 and 4-18 and prevented a major artery from carrying emergency traffic after an earthquake.

Another example of bridge damage caused by excessive substructure movements is on the Rokko Island Bridge at the western end of the Harbor Highway (Figure 4-19). A bearing failure on one side of this bridge racked the arch which buckled the top crossframing (Figure 4-20). Other damage included approach settlements and shattered piers along the harbor (Figure 4-21). In general, though, columns performed well on newer bridges. However, the large pier displacements were not anticipated or designed for, resulting in partial collapse, bridge closures, and injuries.

**Other Transportation Systems**

Most transportation systems suffered some damage during the Kobe earthquake. Figure 4-22 shows the extent of damage to Shinkansen, train, and other facilities. For several days after the earthquake, entrance into Kobe, Ashiya, and Ishinomiya was only by clogged surface roads.

This damage was mostly the result of older bridge columns with inadequate seismic details. For good performance, a column should have every other longitudinal rebar tied with a 135-degree hook. Longitudinal reinforcement should be able to yield in tension without welds breaking. Concrete should be confined by spirals or hoops at 3 or 4 inches to provide continued support for large compressive loads. Newer bridge columns have these good seismic details. Most likely Japan’s fifth Seismic Retrofit Program would have addressed some of these issues. An example of inadequate column...
Figure 4-17  Expansion joint damage.

Figure 4-18  Expansion joint damage.
Figure 4-19  Rokko Island Arch Bridge.

Figure 4-20  Buckled crossframes.
reinforcement is shown in Figure 4-23. An example of brittle fracture in steel was observed in a railway bent in downtown Kobe (Figures 4-24 and 4-25). This is a portion of the Hankyu Train Line shown in Figure 4-22. It is two parallel reinforced concrete slabs with a longitudinal join between them. Note again the use of single column bents with very little transverse reinforcement. Undoubtedly, if these parallel structures had been joined, frame action may have protected the structure from overturning. As it is, several miles of these bridges were destroyed. This type of column damage was seen throughout the Kansai area after the earthquake.

On a positive note, the Akashi suspension bridge, which, when completed, will be the world’s longest span suspension bridge at 2 km, was directly over the epicenter of the earthquake. Except for some slight movement of the north tower, there was no damage to this bridge. This suggests that modern, well designed bridges can experience very large earthquakes with minimal damage.

Conclusions
A great deal of serious bridge damage occurred during the Hyogo-Ken Nanbu earthquake. This occurred mostly to the many older bridges designed before modern seismic details were developed. This damage was typically column shear and flexural failures due to poor reinforcement details. Modern bridges performed better but had problems with excessive superstructure movement and bearing failures. A contributing factor was the weak and liquefiable soils along the bay that allowed large foundation movements. Many modern bridges such as the Akashi Suspension Bridge took the brunt of the earthquake with essentially no damage. This shows that bridges can be designed with details that prevent damage during earthquakes. Japanese engineers and researchers have been working hard since the great Kanto Earthquake to improve the seismic performance of bridges. This, undoubtedly, has prevented further disaster. The lessons learned from this and other earthquakes will continue to improve the performance of Japanese bridges and bridges in general.

Figure 4-21 Damage along the Nishinomiya Harbor.
Figure 4-22 Diagram showing extent of damage four days after the earthquake.

Figure 4-23 Damage to Hankyu train line bridges.
Figure 4-24  Brittle fracture of steel column in railway bent.

Figure 4-25  Detail of Figure 4-24.
ELECTRIC POWER

Electric power performed very well in the earthquake, with very little reduction in service. Electric distribution was available to all parts of the cities, except where overhead distribution poles were damaged by collapsing buildings (Figure 5-1). In Osaka, which experienced JMA Intensity 4 (equivalent to MMI 6), electric power continued uninterrupted during and following the earthquake. A large fossil fuel generating plant in Kobe was in operation as of January 26. Two substations and five fossil fuel generating plants were reported to have sustained damage, including damage to nine generators. Extra high voltage substations at the base of the mountains in Nishinomiya were observed from the air on the afternoon of the earthquake to have no broken porcelain. Excess generating capacity was available due to the season, so that outage of several generating plants did not impair service.

Figure 5-1 Failure of electric distribution pole.
TELECOMMUNICATIONS
Telecommunications performed very well in the earthquake, with very little reduction in service. No information was available regarding damage to telephone exchange buildings. Telephone service was available in the most heavily damaged areas the day following the earthquake. By January 26, 28,500 telephone lines were still disconnected in 18 municipalities hardest hit by the earthquake. More than 2,000 telephones had been installed for public use at shelters and public offices, and 3,000 telephone personnel were involved in the recovery effort.

WATER AND WASTEWATER
Underground water pipelines sustained severe damage in the earthquake, with numerous breaks resulting in general lack of service in Kobe, Ashiya, and Nishinomiya. Nine days after the earthquake, 367,000 households in Kobe still had their water supply cut, while 98% of households in Ashiya and 85% of households in Nishinomiya were lacking service. The population in the heavily impacted areas had been informed to plan for no water service for about two months. Emergency water distribution was very limited in the days following the earthquake, with citizens resorting to buckets, tubs, and other makeshift containers in order to haul limited quantities of water to their homes from a relatively few tank trucks (Figure 5-2). In areas near the harbor, private construction and shipping companies brought in tugboats and other smaller vessels and privately set up water distribution centers for nearby neighborhoods, supplied by condensers on the ships. The condition of the sewer system was unknown but probably similar to the water supply system. The damage was of less consequence since water was not available for flushing toilets. Public bathrooms overflowed and sanitation was a concern.

Figure 5-2 Citizens wait for water in Nishinomiya.
GAS AND LIQUID FUELS

The gas system sustained numerous breaks in its underground distribution system, with general curtailment of service. The population in the heavily impacted areas were informed to plan for no gas service for about two months. Wormation on other gas system facilities was not available, although a large gas holder in Kobe, near the port, was observed to have no obvious structural damage. A number of petroleum and other at-grade fuel tanks exist in the port area, the largest being perhaps 25 meters in diameter and 15 meters high. Only a few were observed to have sustained any damage, although none was observed to have collapsed. Many of these tanks were at grade and freestanding, while some were bolted to their foundations. Most appeared to have fixed roofs. Several LNG tanks exist in the port area, and one was reported to have cracked, resulting in the temporary evacuation of 80,000 people. Two groups of three large spherical tanks, possibly butane, exist in Kobe. They were well braced with heavy diagonal pipe bracing between column supports, and appeared to have no damage. There were no reports of liquid fuel pipe breaks.

RAIL

Rail facilities were particularly hard hit in this earthquake. Three main lines (JR West, Hankyu, and Hanshin) run through the corridor, in general on elevated embankments, and all sustained embankment failures, overpass collapses, distorted rails, and other severe damage (Figures 5-3, 5-4, and 5-5). As a result, a number of cars were damaged, collapsing into city streets, and the lines will be closed for an estimated three to six months. It is clear that, had the earthquake occurred during the commute period, numerous crowded trains would have been derailed, in some cases plunging into city.
Figure 5-4  Major railway damage on the Hankyu line.

Figure 5-5  Distorted rail tracks.
streets. A number of stations and overpasses sustained major damage, and the Rokkomichi station of the Hankyu line was virtually totally destroyed. It had been built in 1972. Kobe has an underground subway, which was closed due to damage. Little information was available except for reports that the Daikan station had sustained numerous column failures, resulting in the collapse of the roof and street above. In Kobe, the Shinkansen (Bullet Train) is generally in a tunnel through Rokko mountain. No information was available regarding the tunnel. At the east portal of the tunnel, the line is carried on an elevated viaduct, built in the 1960s. For a length of 3 km, this viaduct was severely damaged, with a number of the longer spans collapsing (Figure 5-6).

The railway structures failed for a number of reasons; shear failures in support structures, inadequate restraint between spans at critical joints, large ground movements causing spans to fall from pier caps or abutments. The closure of the Shinkasen was the first due to collapse of structures during the life of the system. Some lines were closed due to rolling or derailment of cars due to large ground motion or due to failure of the support structures.

Shinkansen service was estimated to be disrupted for three months, while the Hankyu line was estimated to be out for six months, and the JR and Hanshin for intermediate periods. Within about a week, rail service was restored to Kobe from Osaka via a major detour, which resulted in a two-hour trip, versus the normal half hour.

The many major bridge structures in the port area did not appear to be heavily damaged but no close inspection was possible. However, approach spans and approach structures failed and rendered the routes inaccessible. Embankment approaches were reported to have experienced considerable settlement in the harbor area. Downtown Kobe and Rokkō Island are served by a monorail, which collapsed at several locations, and on a major cable stayed crossing to Rokkō Island.
Figure 5-7  Parked railway cars toppled from their tracks.

A multi-span crossing of a river in the area consists of approximately 40 meter spans carried on large single, reinforced concrete piers, all of which had severe cracking and transverse reinforcement failure. A nearby similar highway bridge (steel deck as opposed to the heavier concrete girder and rail roadway) was undamaged.

The ground motion appeared to be very large in Central Kobe. Many of the transportation systems ran parallel to the fault which triggered the earthquake. There was evidence of large longitudinal movements in many structures. The Hanshin Expressway structure failed in a direction nearly perpendicular to the fault. On Awaji Island surface movement along the southwest end of the fault-nearly a meter of displacement was observed.

Many railway cars were parked in storage areas, some at ground level and others on elevated structures. Some cars rolled onto cars on adjacent tracks creating what looks like a "domino" effect (Figure 5-7). The cars may have to be lifted from the tracks before any work can be started.

Because the space available for transportation systems was so scarce, many systems were built above one another, with elevated rail lines or expressways occupying air space over city streets and on top of each other. A failure in one system rendered the others useless as well and reduced whatever redundancy existed.

PORTS AND HARBORS
The Port of Kobe, one of the largest container facilities in the world, sustained major damage (Figures 5-8 to 5-12). The main port facility is spread over three man-made islands with approximately 9,000 meters of container quay length and 9,000 meters of break built wharf and warehousing. The three main facilities are:
<table>
<thead>
<tr>
<th>FACILITY</th>
<th>BERTHS</th>
<th>QUAY LENGTH</th>
<th>BERTH AREA</th>
<th>QUAY CRANES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Island</td>
<td>11</td>
<td>3,400 m</td>
<td>64 ha</td>
<td>23</td>
</tr>
<tr>
<td>Rokko Island</td>
<td>9</td>
<td>3,400 m</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Maya Terminal</td>
<td>7</td>
<td>1,650 m</td>
<td>35.5 ha</td>
<td>7</td>
</tr>
</tbody>
</table>

Figure 5-8 Quay wall failure.

Figure 5-9 Quay wall failure.
Figure 5-10  Kobe waterfront.

Figure 5-11  Liquefaction and block sliding at Port Island.

Figure 5-12  Container damage at Port Island.
Wharf Construction
The construction is similar at all three facilities. Each is contained within perimeter quay walls and filled with reclaimed granular fill material hydraulically placed over natural sea bottom clay. The quay walls are made of hollow concrete caissons 10 meters wide and 13 meters deep and filled with granular material.

Waterside rail girders are placed over the caisson wall. Landside rail girders for 15 meter gage cranes are supported on steel piles. Landside rail girders for 30.5 meter gage cranes are supported on grade beams on engineered fill.

Seismic Design Criteria
The caissons were designed for a lateral coefficient of 0.1g. A seismic coefficient of 0.2g was normally specified for the existing dockside container cranes. The criteria for the second phase of the Port Island, under construction now, may be different.

Reported Seismic Event:
Port of Kobe engineers have reported that the main seismic event had a duration of 20 seconds and produced approximate peak effective accelerations near the Port of Kobe as shown below and confirmed by California Institute of Technology.
  a. Lateral accelerations of 0.8g in NS direction.
  b. Lateral accelerations of 0.6g in EW direction.
  c. Vertical accelerations of 0.3g.

Damage Assessment
Damage at Port Island and Maya Terminal is extensive and similar (Figure 5-13). Damage at Rokko Island is less than the other two areas. Rokko, built in 1972, is the newest
of the three facilities. The entire 9,000 meters of container wharf at the three facilities is damaged. Large sections of breakbulk wharf and warehousing areas are under water.

The caissons at Port Island and Maya Terminal have settled between 0.7 meters and 3 meters and rotated up to 3 degrees. The rotation outward has caused the crane rails to spread (Figure 5-14). The top of waterside rail girders are submerged in places. The fill adjacent to the caissons has dropped an additional 2 to 3 meters.

The pile-supported landside rail girder, at 16 meter gage, has not settled appreciably but has rotated 3-5 degrees in places. The grade beam on the fill-supported landside rail girder, at 30.5 meter gage, has settled in places. The crane rail girders have spread between 1 and 2 meters at Port Island and 4 to 5 meters at Rokko Island. In most areas, the backlands have settled by as much as 1 meter.

Most pile supported structures, such as APL's administration building, have performed well. The grade adjacent to the building has settled about 0.7 meter, although the building has no visible damage. A number of older buildings, in other areas of the port, were in various stages of collapse due to ground settlement and/or structural fail-

![Figure 5-14](image1.png)  
**Figure 5-14** Crane derailment due to movement of quay wall at Port Island.

![Figure 5-15](image2.png)  
**Figure 5-15** Crane damage at Rokko Island.
Crane damage varies at different locations (Figures 5-15, 5-16, and 5-17). Approximately 50 cranes have significant structural damage, with some cranes in danger of collapsing in the event of a strong aftershock. The damage to the cranes is primarily due to the rails spreading and settling. Crane damage consists of buckling of legs at the portal ties.

Figure 5-16 Collapse of crane at Rokko Island.

Figure 5-17 Close-up of crane failure.
Failure Analysis
The entire interior of Port Island has settled due to liquefaction of the underlying fill (Figures 5-18 and 5-19).

The failure of the caisson quay wall foundation appears to be due to pressure from the liquefaction of the fill material behind the caisson and lateral seismic forces (Figures 5-20 and 5-21). Original construction data, including the compaction procedures, is unavailable. Until further investigations are made, it is not clear whether the caissons rotated due to stress failure in the underlying granular fill or liquefaction of this fill.

The design criteria of 0.1g lateral force is much less than is used today in seismically active regions. Liquefiable soils can now be identified, and the effects of liquefaction can be mitigated. Even if the design had conformed to the current practice, severe damage may have occurred. But it would have been less.

Shipping, in general, had to be diverted to other ports (Osaka, Nagoya, Yokohama) while passenger and some vehicle ferry service was gradually re-established in the days following the earthquake. The Port of Osaka experienced almost no damage.

AIRPORTS
Kansai International Airport was only recently completed (1994) on a manmade island some 30 kilometers to the southeast of the epicenter. Itami is the former international airport for Osaka, and now handles much of the domestic traffic. It lies about 10 kilometers east of the heavily damaged area. Neither airport appears to have sustained significant damage.
Figure 5-19  Settlement and liquefaction at Kobe waterfront.

Figure 5-20  Dramatic lateral spreading at Kobe waterfront.

Figure 5-21  Ornamental cabbages were blasted out of the ground at Kobe waterfront during the earthquake.
EMERGENCY RESPONSE

FORMAL ORGANIZATIONAL EMERGENCY RESPONSE
This earthquake called for more than normal emergency response activities within and between jurisdictions; the scope of the system failures created a disaster that called for major adjustments in leadership and delivery mechanisms. Observations from a short time frame of days can only highlight issues that will continue to unfold during the coming months.

A major problem in the initial hours of a major disaster of this nature is getting a true reading on the extent of damage. Unless planning efforts and emergency exercises have carefully prepared response organizations for this task, there are many barriers to a coordinated response in the first few hours. Communication systems are likely to be disabled, curtailing information flow. Attention tends to be focused on the damaged areas, and on fire and rescue needs that are observed nearby or are reported immediately, rather than on obtaining a systematic overview of the damage so priorities can be set. Individual first responder organizations, even if undamaged and able to mobilize quickly, tend to follow their normal operating procedures and to work within their own jurisdictions, which may lead to an ineffective use of the available resources.

Our observations confirm the often-repeated warning that citizens should be prepared to be largely on their own for the first 72 hours after a disaster (Figure 6-1). It takes time for government and non-government agencies to identify and locate problems and organize resources. Local governments and non-government agencies need to strive for the fastest possible response. But in a disaster affecting this many people, unsafe and uncomfortable situations that would not be acceptable in normal times, or even in smaller disasters, will occur.

Emergence of Emergency Operations
Observations made within the first 32 hours indicated that there was not yet evidence of significant efforts to control access to or movement within high hazard or several damaged areas. Observations made several days later indicated that this still was generally true, and thus may be normal procedure, or at least of low priority. The importance of access control was most evident in the first few days, when fires continued to burn and new ones break out, and when search and rescue efforts could still prove successful. The lack of emphasis on controlling traffic flow to the area and on repairing access routes was reported by some to have hampered the ability of emergency responders to get to the damaged areas to carry out first response activities, such as fire suppression, or rescue (Figure 6-2). On Days 2 and 4 after the earthquake, we observed emergency vehicles with flashing lights stuck in traffic (Figure 6-3). Of less life-threatening consequence, continuing traffic congestion on routes between Osaka and
Kobe hindered the delivery of relief supplies such as water, food, and blankets in subsequent days. Minor repairs to roads and bridges, such as providing small temporary asphalt or wood ramps at breaks in roads, were not observed until Day 4, despite their contribution to major traffic snarls.

In the first few days after the earthquake, it was not possible for local officials to secure, or even identify, all unsafe structures. Peoples’ options for leaving unsafe buildings or avoiding unsafe structures were limited. Buildings that were obviously unsafe and possibly in imminent danger of collapse were being entered and even occupied. We often found ourselves in structures and locations much more hazardous than would, in ordinary circumstances, be tolerated (Figure 6-4). On Day 5 some inspectors from the nearby city of Kyoto were seen tagging some buildings as “Hazardous. Do Not Enter”, however, no large scale building evaluation system was yet implemented.

Few preparations were seen to forestall further damage from serious aftershocks. We saw few buildings with temporary bracing. Damaged small scale buildings with heavy tile roofs and no lateral resisting systems posed obvious collapse hazards. We observed no actions, such as the removal of tiles or the provision of diagonal bracing, to reduce this risk.

We observed many structures, large and small, that had completely or partially collapsed (Figure 6-5). Demolition, dismantling, and debris removal will be enormous tasks in Kobe. By Day 5, demolition of collapsed freeway structures was underway, undoubtedly because of the critical role these routes play in both the city and the region. Larger collapsed buildings which were blocking major streets were also being removed by Day 6. By Day 5, signs were posted in some neighborhoods giving the schedule for debris pick-up.

With respect to coordination, those visiting the field on the second day reported that there was no apparent coordination (at the "street level") of public safety and response personnel (police, firefighters, transportation repair personnel, medical assis-
Crowds were permitted uncontrolled access to damaged structures. This does not mean that they were not engaging in their assigned first responder responsibilities, but that the personnel engaged in these activities did not appear to be used, in this early stage, in an effective manner. There was evidence later in the week that emergency operations centers had been established and coordination was becoming more evident. Media coverage, and reports from the ad hoc field team members, indicated that these centers had operating procedures and were purposeful in their activities (Figure 6-7).

Coordination of resources coming from outside the area is also important. Resources take time to marshal, organize, and transport. This suggests that mutual aid agreements might need multiple triggers so that aid, especially fire and search and rescue, can be swift. Emergency response personnel and equipment from other localities were observed at the end of Day 2 (Figure 6-8). There was serious confusion about the provision of international mutual aid.
Figure 6-3  Emergency vehicles stuck in traffic.

Figure 6-4  Damaged buildings continued to be used in the days following the earthquake.
As time passed, more and more assistance arrived. Staging areas for fire trucks from other prefectures and defense force trucks and other vehicles and equipment for transportation and debris removal were observed. Many search and rescue teams arrived still hoping to find survivors (Figure 6-9). Organized efforts to locate victims’ remains in the burned areas were also observed. The Prime Minister announced on Friday, some 72 hours after the earthquake, that more than 32,000 Self-Defense Force members, and police, and firefighters, were engaged in response and relief activities. The news media on Sunday provided an estimate of some 36,000 response and relief workers working in the damaged areas. By that day, efforts to prevent further loss of life and property from the increased risk of landslides in the northern neighborhoods against the mountainside had to be added to the other duties.

Media accounts indicated that some of the rescue and relief teams were staged on islands in the Port of Osaka. At nightfall, we observed teams embarking on ferries and other smaller boats in the Port of Kobe.

Public Information Dissemination
Beyond the area of power loss, most of the regional television stations provided virtually non-stop coverage of the earthquake for the first few days. Within 10 minutes of the principal earthquake, several networks displayed a diagram of the southern region of Japan, indicating apparent telecommunicated data on the shaking intensities at various locations, which was updated somewhat in the first hour. Numbers were provided on the seven point Japanese intensity scale, and made it possible to get a very quick idea of where the earthquake had been the worst. This display indicated an Intensity 6 for the Kobe area and an intensity 4 for the Osaka area. The radio stations also provided coverage of the effects, which would have made whatever information they had available to those in the most damaged area who had battery-powered radios.
Figure 6-6 Collapsed police station in Kobe.

Figure 6-7 Police established temporary quarters across the street from the damaged police station.
Figure 6-8 Emergency equipment arriving from outside the area.

At least one television station participated in helping people from outside the damaged area get information on relatives and friends, since communication and transportation were both greatly curtailed (Figure 6-10). The channel continuously scrolled a list with the names and phone numbers of people seeking information on relatives or friends; and in the opposite column, the name of the person or family being sought. Another channel spent many hours a day scrolling the names and other information (for example, age, neighborhood) of the confirmed fatalities. Radio stations provided similar information.

Newspapers, television, and radio media began to provide lists of shelter locations and other services available to victims. It was observed that the Emergency Operations Center in Kobe provided and staffed an office where citizens could come to get information on a variety of aspects, including the names of victims, the status of neighborhoods, shelters, and so forth. This may have been true elsewhere as well.
Figure 6-9  An army platoon preparing to search for victims.

Figure 6-10  The media provided detailed information to families of those missing and injured.
7

FIRE RELATED ASPECTS

As of January 27, information is based on personal observations and limited data released by cognizant authorities who were occupied with recovery efforts. The majority, and the largest, fires occurred in the City of Kobe (1993 population 1,477,410), which will be the focus of this article, although the City of Ashiya (1993 population 87,524) will be treated to some extent.

KOBE FIRE DEPARTMENT

The Kobe Fire Department (KFD) is a modern, well-trained fire response agency, organized into Prevention, Suppression, and General Affairs sections, and a Fire Academy. The city is divided into eleven wards for fire protection purposes. KFD maintains eleven fire stations and 15 branch stations, served by 1,298 uniformed personnel. Equipment includes 2 helicopters, 2 fireboats, and 196 vehicles. Other equipment includes 72 portable pumps. Fire engines carry predominantly 50 and 65 mm hose, and a larger hose is not available except for drafting purposes. KFD fire statistics for previous years are:

<table>
<thead>
<tr>
<th></th>
<th>Bldg</th>
<th>Wildland</th>
<th>Vehicle</th>
<th>Marine</th>
<th>Other</th>
<th>Total</th>
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<tr>
<td>1993</td>
<td>396</td>
<td>44</td>
<td>136</td>
<td>2</td>
<td>236</td>
<td>814</td>
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<tr>
<td>1992</td>
<td>449</td>
<td>28</td>
<td>101</td>
<td>1</td>
<td>233</td>
<td>812</td>
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KFD has a civil disaster prevention program as well as a cadre volunteer fire corps with about 4,000 members. This corps provides the first on-scene engagement of the fire, giving directions to arriving emergency vehicles, helping to guide people to safety, and so on.

WATER SYSTEM

Firewater is provided primarily by the city water system, which includes approximately 23,500 fire hydrants throughout the city. The standard hydrant provides one hose connection, with the majority being 150 mm in diameter. The city has provided underground storage of water for disaster firefighting in 968 cisterns, generally of 40,000-liter (10,000-gallon) capacity, sufficient for about 10 minutes supply of a pumper. All engines carry hard suction, so that additional water can be drafted from Osaka Bay,
or the several streams running through Kobe. Little information is available (as of this writing) regarding the performance of the city water system in the earthquake, except that it sustained numerous breaks, with loss of water pressure.

**EARTHQUAKE AND FIRES**

**Kobe**

KFD had minimal staffing on duty at the time of the 5:46 a.m. earthquake. Initial actions included recall of off-duty personnel, and response to fire calls. Approximately 100 fires broke out within minutes, primarily in densely built-up, low-rise areas of the central city (Nada, Higashinada, Hyogo, and Suma wards) which are comprised of mixed residential-commercial occupancies, predominantly of wood construction (Figures 7-1 and 7-2). The total number of fires for January 17 is 142. Modes of fire reporting are unclear as of this writing, and fire response was hampered by traffic congestion. Water for firefighting purposes was available for 2-3 hours, including use of the underground cisterns. Subsequently, water was available only from tanker trucks. Details of the fire response are not available as of this writing, but the first author overflew the area at about 5 p.m. on January 17 and was able to observe all of the larger fires (about eight in all) from an altitude of less than 1,000 ft. No fire streams were observed, and all fires were burning freely, several with flames 20 ft. or more in height. No fire apparatus was observed in the vicinity of the large fires, although fire apparatus could be observed at other locations (their activities were unclear from the air). Fire spread was via
Figure 7-2  Burnt-out area Nagata ward.

Figure 7-3  Nagata ward sustained the most fire damage.
radiant heat and flame impingement, building to building in the densely built-up areas. Wind was calm, and fire advance was relatively slow. In a number of cases, fires are observed to have stopped at relatively narrow fire breaks, for example, 10 meters, or, in at least one case, at a high-rise apartment building-concrete walls but well fenestrated, so it is not clear why that building did not become involved (Figures 7-3 and 7-4). Final burnt area in Kobe is estimated at 1 million sq. meters, with 50% of this in Nagata ward (Figures 7-5 and 7-6).

No investigation has yet been performed regarding cause of the various fires, but ignition sources may be assumed to include electricity, gas (propane and city gas), and chemical spill/reactions.

Ashiya
The Ashiya Fire Department (AFD) reported eleven fires on January 17, nine prior to 7:30 a.m. Distribution of the fires was along an east-west line about 1 km wide centered on National Rte. 2.

SUMMARY
Previous discussion with Japanese officials have revealed that post-earthquake residential fires have always been a major concern. The over-abundance of structures with flammable materials (wood and paper) create a fuel-rich scenario for major conflagrations. The tile roofs, so common in many residential areas, are a hazard mitigation effort. Ironically, these same roofs, due to their weight, probably led to the collapse of some of the older wooden structures.

Rubble and debris in the already narrow streets prevented fire apparatus from providing a rapid response to the various fires. Reporting of these fires was also a problem.
due to the loss of telephones. The lack of alternative firefighting systems, such as above ground portable hydrants and pumps and aerial firefighting support, also hampered a quick response. Many residential homes and commercial buildings have automatic gas shut-off valves. If this was the case in Kobe, not all the fires can be attributed to gas leaks. Since this was winter time, one can assume a large number of heating devices were in operation. The large number of downed power lines could also have contributed to the event.

Loss of water was a definite problem for the firefighters. Japanese fire departments use smaller pumper trucks with limited water-carrying capacity. These trucks needed to replenish their supply more often and travel through heavy traffic to ditches and creeks to do so.

Japanese firefighters did not use or did not have self-contained breathing apparatus to fight the fires, resulting in many of them needing treatment for smoke inhalation.

Weather conditions were mild and prevented the fires from spreading. Had there been high winds, a "firestorm" could have resulted.

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**Figure 7-5** By the time the fires died out, large areas of Kobe had been destroyed.
Figure 7-6  Map showing burned area (in square meters) from the fires following the earthquake, as of 1/20/95. Source: Yomiuri Shinbun
SOCIETAL IMPACTS

INTRODUCTION
The January 27, 1995, Great Hanshin Earthquake Disaster was the most damaging earthquake to affect a major urban area in Japan in 50 years. Such an earthquake, with consequences of such magnitude, has not occurred in the U.S. since the 1906 San Francisco earthquake. As a result, the lessons learned from this event will not only be of importance to the people of Japan, but also to the citizens of the U.S.

Many observations reported here were made in the first 36 hours after the event by groups of workshop participants from both the Japanese and U.S. delegations, who traveled to the disaster scene. Observations from later in the week include reports from persons who continued to return to the Kobe area throughout the week, and from the collection of information from media reports through Monday, January 23. These observations reflect the earliest stages of the response period, and were collected in a nonsystematic manner. Their value, however, is that they reflect the observations of binational experts convened to discuss progress and problems in earthquake engineering, response, and preparedness, many of which were then validated by this earthquake.

To a certain extent, building and soils damage speaks for itself more readily than does the stuff of human behavior, motivation, and emotion. Much can be learned or surmised from the simple viewing of the visible physical evidence. However, to really know what has happened, and to know if the damage occurred in some predictable pattern, it is necessary to delve beneath the surface, into structures, materials, procedures, and processes.

The collection of data on human response and societal responses is in many ways more difficult to obtain in the early stages. And it is equally necessary to delve beneath the surface to truly understand what has happened in terms of human behavior and motivation.

OBSERVATIONS OF SOCIETAL IMPACTS
Unlike the Tokai region, which has been preparing for a major damaging earthquake, the Kansai region had not engaged in a similar level of earthquake planning. Although recent efforts had been made to prepare the region (especially Kobe City) for mud/debris-flow and flood disasters, that planning did not prepare either citizens or government for the catastrophe created by this earthquake, especially with respect to housing losses and lifeline disruption.

Deaths and Injuries
Earliest reports of less than 200 persons killed by the earthquake created an initial impression that perhaps the damage had been severe in only a few places. However, by
the second day, the death toll was growing hour by hour. By the afternoon of the seventh day (January 23) the confirmed death toll exceeded 5,000 and reported injuries exceeded 25,000. The number officially reported as missing has dropped below 100. It is likely to be several more weeks before the exact extent of the loss of life is known. Newspapers reported that initial analysis indicated that over half of the first 3,000 of the confirmed fatalities occurred among those over the age of 60; within that group about two-thirds were women. To some extent this reflects the population characteristics of housing areas that received the most damage, such as the Nagata Ward of Kobe.

**Residents’ Displacement**

Many have been made homeless by the damage. The general damage figure being used by the tenth day, of 80,000 buildings damaged or destroyed, does not provide any clear indication of what proportion of these damaged buildings are residential or commercial. Also, it appears to apply to buildings in general, so that the actual numbers of residential units would be obscured at this point, depending on the extent to which multiple unit buildings were damaged or destroyed. By Monday, January 23, the figure for the number of people using emergency shelters had topped 300,000. Media accounts indicated that the number had climbed by the thousands over the weekend due to heavy rain that began on Sunday, driving people from their own makeshift arrangements in or near their damaged homes into the official shelters in schools and public buildings. Several thousand others were asked to evacuate their homes in areas at increasing risk from landslides due to the rain.

**Disruption of Family Life**

A large number of families experienced major disruptions to their routines and life style, due to the loss of their loved ones, their homes, their possessions, their neighborhood, their sources of income, and their ability to move between home and work (Figures 8-1 and 8-2). Media accounts indicated that people were also beginning to express
their anxiety about how they would cope in the near future with their economic losses and the need for resources to rebuild. Medical personnel reported an increasing number of persons presenting themselves for what could be interpreted as stress-related symptoms. Fortunately, school buildings apparently performed well, and besides being used for shelters, began opening for classes on the Monday following the earthquake, providing some normalcy to the situation.

**Commercial and Industrial Disruption**

Many small commercial and manufacturing establishments, both downtown and in the neighborhoods, were damaged or destroyed, as were larger corporate offices in Kobe and nearby areas (Figures 8-3 and 8-4). Some industries may be out of production for a few weeks due to the continued lack of water or gas. Such disruptions lead to temporary or permanent loss of employment for many of the region’s households, as well as to regional losses in commercial activity and tax revenues. Nonetheless, there were also reports of the rapid re-establishment of economic activities (Figure 8-5).

**Business Restoration**

Some of the specific problems and recovery indicators mentioned in press accounts at the end of the first week included the following. Kansai Electric Power Company had resumed operations in seven of ten thermal electricity generators shut down as a result of the quake. Kobe Steel Ltd. had resumed partial operation of one of its steel plants, but the headquarters facilities were badly damaged, and other plant facilities were expected to be inoperable for at least a month. The Kobe Central Wholesale Market had held its first auction of seafood. The Bank of Japan (the central bank) was open for operation in downtown Kobe and routine financial transactions between banks were expected to begin around February 1. About two-thirds of the gasoline stations in the damaged area were open for business again. Several of the railway companies had
Figure 8-3 Many small commercial and manufacturing establishments were damaged or destroyed.

Figure 8-4 Detail of damage to one commercial establishment.
begun shuttle bus services in the quake area to replace disabled rail services. The Kobe beef cattle herds came through the earthquake unscathed. Less optimistic predictions were made about the quick revival of tourism, and about recovery of the shoe manufacturing industry long centered in Kobe, since most of the factories had burned to the ground (Figure 8-6).

**Implications of Transportation Disruptions**

The disruption of shipping, rail, and truck traffic (Figures 8-7 and 8-8) had resulted in temporary shutdowns or slowdowns in some of the automobile production outside the region, due to delays in the timely delivery of parts needed for the practice of “just in time” inventory for production lines. For example, it was reported that Toyota Motor Corporation had closed about a dozen of its domestic plants for three shifts, resulting in lost production of 20,000 vehicles. There was speculation that some U.S. auto manufacturing may also undergo temporary slowdowns eventually, due to delays in obtaining parts that come from the Kobe region.

**The Context for Immediate Response**

Because this earthquake occurred at 5:46 am, casualties were focused mainly in residential areas, rather than distributed across neighborhoods, businesses, and factories, and transportation routes, as was the major physical damage. Families escaping from their falling homes in the most damaged neighborhoods found themselves in the pre-dawn dark, in areas littered with debris and downed power and phone lines. Traffic was relatively light on the expressways, the train systems were not in full operation, and the cranes at the container loading berths were not in use. Business, factories, and other organizations were either not staffed, or likely to have only a smaller night shift of workers.
Response of Citizens, Families, and Volunteers

The immediate responses of the citizens in the damaged areas were consistent with what has been observed in many other post-disaster settings. Citizens were observed engaging in a variety of voluntary helping actions in the hours after the earthquake-search-and-rescue, firefighting, and establishment of neighborhood shelters.

In general, citizen behaviors were pro-social. Not only was there the expected lack of anti-social behavior, but a marked atmosphere of courtesy, politeness, and dignity similar to what characterizes day-to-day social interactions under normal conditions in Japan. People were observed politely and patiently queuing for water, and to use the phone banks. Shelter floor space was almost completely covered with the sleeping futons of the shelter populations (Figure 8-9), and television coverage showed families sitting together as small groups on their futons, chatting quietly or eating rice balls as food distribution became more organized later in the week.

Figure 8-6  Shoes piled in the corner of the parking lot of a burned out shoe factory.
Figure 8-7  Transportation networks were disrupted throughout the area.

Figure 8-8  Kobe residents lined up at the port for the ferry to Osaka.
Figure 8-9  Inside a shelter.

Figure 8-10  People searched for personal possessions in the rubble of collapsed houses.
During the daytime hours, people could be observed retrieving goods from their own partially or totally collapsed structures (Figures 8-10 and 8-11). It was reported that respect was shown for the property of others, which often lay untouched in the rubble (Figure 8-12). Only later in the week did the media begin to report tales of pilfering of items from store fronts, but these acts were typically attributed to foreigners or persons from outside the Kobe area.

Bodies retrieved from the rubble were carried to makeshift morgues, often in the same school buildings as the shelters. Bodies were placed in coffins where available, or remained wrapped in the blankets in which they were carried. News coverage indicated that at least in some locations, relatives of the deceased were permitted to come and go from these morgues to identify their kin, leave offerings of flowers and food, and to spend a ritual night by the body, as is the practice in Buddhism. Small offerings of flowers and fruit also were observed in the rubble and burned areas, presumably at the spot where someone had died in the earthquake, or where it was believed someone remained buried in the debris.

In Japan cremation is the typical pre-burial procedure. The news media reported that due to a shortage of physicians to provide death certificates, difficulties with transportation, and a shortage of gas for the nearest crematoria, burials were delayed.

Observations and media accounts indicated many different adaptations to sudden homelessness or loss of utilities. The shelter population peaked at over 300,000. However, others took a few possessions and evacuated from the area, either to share homes of others, or to rent available hotels or apartments beyond the disaster area; Media accounts suggest that families may have split up, in particular in order to get young children and the elderly into more healthful surroundings. Phone banks set up for the use of the disaster victims permitted those beyond the area to understand the needs of their relatives. This led to a noticeable effort on the part of many to surmount the considerable transportation difficulties and individually carry water and food into the area for

Figure 8-11 A resident retrieving personal possessions from her house.
Figure 8-12 Untouched property amongst broken tiles.

Figure 8-13 Neighbors share a common source of heat to prepare tea.
their relatives and friends. At the same time, the collective provision of water, food, blankets, and tents by various governmental agencies and non-governmental organizational donors became more evident at the shelters as the week progressed (Figures 8-13 and 8-14).

After a few days, formal requests were issued by the government for volunteers to help with cleanup and in shelters and clinics. Lists of organizations and phone numbers appeared in the media. Media accounts indicated that initially there was a good response to these calls, but no organization was established that could take the lead in coordinating the dispatch of those who volunteered.

Figure 8-14 People check listings for missing relatives and friends.
The magnitude of the housing loss is staggering. Two days after the earthquake at least 230,000 people were homeless. Five days after the earthquake the figure was 300,000. At least 20,000 residential buildings were destroyed, and up to 200,000 additional residential buildings were damaged and are probably unsafe to occupy. By Sunday January 22, the number of collapsed or seriously damaged buildings was being reported at 50,652 and by the middle of the next week the number exceeded 80,000. We observed a mix from complete to partial to no damage in neighborhoods over a very large area (Figures 9-1, 9-2), stretching for many kilometers from the suburbs of Nishinomiya and Ashiya through the city of Kobe. It should be pointed out that the number of seriously damaged buildings will continue to rise as buildings that don’t appear to be damaged are discovered to have serious structural damage. The number of displaced residents and the number of damaged buildings suggest that 60,000 to 100,000 housing units have been affected.

Figure 9-1  Housing damage in Nishinomiya. Note complete collapse in foreground, as well as intact roofs.
Figure 9-2  A damaged house in Nishinomiya.

Figure 9-3  People gathered for warmth on the street.
In the first few days, people stayed near their damaged homes (on sidewalks, parking lots, or playgrounds). The night time temperatures approached freezing, so being outside presented a hardship, especially for the very young and very old (Figure 9-3). Many were observed on the second day to have stayed in or returned to structures that were clearly hazardous (partially collapsed; structurally damaged such as those shown in Figures 9-4 and 9-5). Within a few days of the earthquake approximately 1000 shelter locations had been set up, as planned, in school buildings, or on an ad hoc basis in the lobbies and corridors of public buildings (Figure 9-6).

In the first two days, these shelters had minimal services. For example, in one shelter only bread had been delivered and just once in the first two days after the earthquake (Figure 9-7). In another, only two portable toilets were available to serve a substantially destroyed neighborhood that did not have water. One shelter manager, normally a library employee, indicated that the library would be open as a shelter until temporary housing was available. At another shelter, an elementary school, the teachers served as volunteers and the principal was the shelter manager.

In addition to community facilities, people also slept in tents. By Saturday it was reported that the Self Defense Force had brought in 400 tents, and private organizations had brought in another 200. By Sunday there were tents in 10 locations being set up by Self Defense Forces. Over 3,800 people were reported to be sleeping in parks. People also slept in their cars and vans in the parking lots of community facilities being used as shelters. The lack of individual yards and public open space contributed to the need for shelters (Figure 9-8).

The rain which arrived at the end of the week may have increased the number of people staying in shelters. The Director of the Kobe City Disaster Special Task Force reported that the number of people in shelters was increasing with the aftershocks and the rain. He estimated the numbers in shelters at approximately 200,000. He stated that to that point (Saturday) Kobe City had been using only the gymnasiums in elementary and high schools and would then begin using classrooms.
Figure 9-5 Another example of typical residential damage.

Figure 9-6 School gymnasium being used as shelter.
The rain also caused people who were otherwise staying in their homes to come to the shelters to get plastic sheeting which the Kobe Municipal Government made available. The government distributed 10,000 plastic sheets to be used to protect households from the rain. In addition people also constructed several sheds on school grounds to secure space for their bonfires and cooking, and to keep items from getting soaked.

The U.S. Marines shipped 20 tents by Sunday from their base in Okinawa, each capable of housing 24 people. Two tents were set up in Amagasaki, another city in Hyogo Prefecture.

While we observed organized efforts to deliver water to various shelter sites, we also observed thousands of people bringing supplies individually to affected family members. Blankets, water and food were being carried in by car, backpack, motorcycle and bicycle to individual families. It was reported to us that most typically an affected individual or family would call relatives or friends not affected by the earthquake and ask them to bring supplies. This greatly contributed to traffic congestion in the area (Figure 9-9).
If a rough estimate is made using an average family size of just over three persons, this would suggest the number of family units seeking shelter during the first week was around 100,000. However, some of these families may have sought shelter based on a lack of utilities in their residence rather than damage. At the same time, the number of persons observed to be leaving the city with only a small bundle of possessions, and the reports of inquiries to rental agents of apartment developments, and of hotel rooms filling up beyond the damaged area, indicate that an undetermined number of persons used their own resources to find a place to stay by renting or doubling up with relatives.

The earthquake occurred in an area with a very tight housing market. There was a very low vacancy rate prior to the earthquake, meaning few options are going to be available to the thousands of displaced residents. By the end of the first week, plans for the building of interim housing were already being announced. The central government announced that the Post and Telecommunications Ministry had vacant land in the area and that 28 sites had been identified in eight cities in the Hyogo and Osaka Prefectures. Five hundred houses were being planned for these 28 sites.

The Hyogo Prefecture announced that 11,000 temporary housing units were going to be built and that some could be completed as early as the end of the second week after the earthquake. They originally planned for 5,000 and decided to increase that number to 6,000. It was reported that the Construction Minister was ordering a public organization to build an additional 5,000 houses. Three thousand units had already been ordered, while construction workers started building 760 houses in Kobe’s Kikusui Park. The houses were expected to be completed in one week. On January 30 the government announced that it had secured 40,000 emergency housing units, but that another 20,000 might still need to be imported from abroad. According to one media account, "applications are reportedly being accepted in some parts of Kobe for the temporary houses and available housing run by the prefecture or the city." It was not clear how the process of selection would work.
Figure 9-9 Traffic in Ashiya the second day after the earthquake. Note emergency vehicles in traffic.

Figure 9-11 Almost every street suffered damage and will have to be rebuilt.
Neighboring prefectural governments, including the prefectures of Osaka, Yamaguchi, Aichi, Toyama, Nara, and Ishikawa, and some municipal governments, were making available vacant units of public housing. In most cases this housing was being offered rent-free or for very low rents. Initially, approximately 2,155 units were being offered by these governments. Newspaper accounts included phone numbers and other information regarding who might qualify for housing. In addition, Kamakura City developed an innovative home-stay program.

As of the fifth day, the media was reporting that people were said to be concerned about housing loans and other "future" issues. These concerns were said to be causing stress in the displaced population.

The Rebuilding Effort

According to the newspaper, after several days, the earthquake was officially designated as a "severe disaster," which apparently signifies the basis for the nature of the disaster recovery assistance from the national government. At that time, the relief law was invoked for nine cities and six towns in Hyogo and Osaka prefectures. Under this designation, public and medium-sized and small financial corporations and other financial institutions reportedly will have access to low-interest government funds for earthquake survivors to rebuild. Corporations receiving loans from government financial institutions will be able to borrow more than usual, as well as be able to postpone repayment. It was reported that few households were insured against earthquake damage, and also that for those homes destroyed in quake-caused fire, residential fire insurance would not cover the loss unless the home was also covered by earthquake insurance. Commentators on the disaster observed that private individuals and small businesses would need to use their own savings or take out loans to bring about recovery.

The massive scale of the disaster and the magnitude of the rebuilding challenge suggests that special measures may be necessary. On Friday after the earthquake it was announced that the Vice General of the National Land Agency will head a rebuilding task force located at the site. However, by the second week the National Land Agency was being criticized for the way it managed the earthquake response. There were media reports that the Hokkaido and Okinawa Development Agency Director General had been named to take over the duties of the National Land Agency Chief. The implications of this for the rebuilding effort remain unclear.

One of the first tasks of those in charge of rebuilding will be to determine whether new legislative measures may be necessary in order to most effectively guide the rebuilding. Such measures include studying the rights of land owners as well as the need for a supplementary budget.

Emergency response moves very fast as opposed to the physical and economic recovery. People may have very high expectations for long-term rebuilding and recovery that may be disappointed. Recovery is a long and complex process. On the other hand, in view of the very large tracts of land virtually destroyed, the affected cities must decide very soon if the pre-disaster land-use patterns, ownership patterns, densities, circulation systems should be rebuilt or whether they should be redesigned (Figure 9-10).

According to reports from planning professionals in Japan, the central government considered amending their Building Standard Act, which currently prohibits quick rebuilding for up to two months, to prohibit rebuilding for a longer period of time. However, they gave up on the idea after recognizing that simple prohibition without proper reconstruction plans, which could take months or even years to prepare, would only frustrate residents. Instead the Government decided to enact a law which would authorize the local government to designate the destroyed area for land readjustment projects more flexibly than the present system.
The resources that will be required for the rebuilding, whether public or private, are enormous (Figure 9-11). According to newspaper accounts, the Hyogo Prefecture has already appealed to the national government for an emergency outlay of 4.6 trillion yen to pay for initial reconstruction costs, particularly for roads and railways. Normally the Finance Ministry formulates an additional expenditure program after ascertaining damage caused by a disaster, but Finance Minister Takemura said his ministry will skip this process and take the necessary measures in view of the severity of the disaster.

How the earthquake affected ongoing political tides in Japan was also a matter of speculation by media commentators. Japan has had four prime ministers in the past 18 months and the current prime minister, Tomiichi Murayama, was also under attack as the Japanese Diet (parliament) prepared to begin its 1995 session on January 20. Murayama took the opportunity in his policy speech to the Diet to state the government's intention to institute financial and budgetary measures to assist with the recovery, such as monetary assistance to local municipalities and the compilation of a supplementary budget at the national level to help speed recovery. Past research on earthquake reconstruction issues suggests it is much too soon to have any idea of how much the national government will share in the recovery and reconstruction. Commentators indicated that several national economic and administrative policy issues that had been controversial prior to the earthquake would now bear watching, to see if the earthquake recovery would speed or impede resolution. These include the survival of the current ruling coalition, restructuring of disaster-relief policies that had already been called into question following the earthquakes last year in northern Japan, changes in building codes for seismic safety in construction and transportation, and reform in the current administrative system through deregulation, decentralization, and streamlining of the system that had originally been put in place to support the WWII post-war development.

Discussions among the experts indicated that many major policy questions will have to be addressed by the national and local recovery organizations being established, such as whether or not to change building standards or land use patterns for residences, how to use foreign assistance, how to finance the recovery, and whether or not the 1981 building codes for engineered buildings need to be altered in view of the greater degree of risk now documented for the region.
ECONOMIC IMPACTS

The cost of reconstructing Kobe and the surrounding communities will be staggering—far exceeding any natural disaster to date. The total economic impact of the earthquake goes beyond the physical damage caused by the ground shaking and subsequent fires. Business interruption losses caused by damage to business and manufacturing facilities, as well as disruptions of normal business operations caused by infrastructure and life-line damages, may contribute even more than the physical damages to the event’s overall impact. Supply channel disruptions will be effects reaching far beyond Japan’s shores, as will the reaction of world financial markets. Estimates released a week after the event by officials from the Hyogo Prefecture government project that the reconstruction costs will be US$64.2 billion. However, all observations and analyses indicate that such early estimates significantly understate the total costs.

In the affected area, the total insured value of fire policies for residential, commercial, and industrial building stock is estimated to be US$1,000 billion. Including the value of the contents, equipment, and business inventory adds at least an additional US$400 billion (Figure 10-1). By comparison, the Northridge earthquake, which caused between US$20 and US$30 billion in property damage, had approximately US$330 billion in building stock values in the affected area. In addition, the Northridge event did not cause the liquefaction and ground failure of the Kobe event, factors which will magnify the resulting losses. Given the number of collapsed structures in Kobe, even the costs to remove debris will be substantial (Figure 10-2).

In addition to losses to the building stock, damage to Kobe’s transportation infrastructure, including its port facilities, highways, and roads (including bridges and tunnels), railways, ferries, and airports, will be significant. In Kobe, city officials estimated on January 24, 1995, that the damage to the port could be as high as US$14 billion. The costs to repair the region’s highway system, including the collapsed portion of the Hanshin highway, will also be staggering (Figure 10-3). For example, the ongoing repair to the Cypress Structure, following its collapse in the 1989 Loma Prieta earthquake, is approaching US$1 billion. Furthermore, repair costs for the region’s lifeline infrastructure, including damaged water, power, communications, and fuel systems will amount to billions of dollars. A week following the earthquake, Nippon Telephone and Telecommunications estimated the damage to their systems exceeds US$500 million.

Adding to the direct repair and replacement costs will be the demand surge that follows a major catastrophe. The demand for labor, materials, and equipment will far exceed the supply for such services, causing short-term increases in the associated reconstruction costs. Further increases in direct costs of reconstruction will result due to the disruption of the transportation infrastructure and the associated difficulties for heavy construction equipment to reach the affected areas.
In addition to the direct costs of reconstruction, economic losses will also stem from the interruption of business activity. The Kobe region is a highly industrialized, complex economy. In Hyogo Prefecture, with over 18,000 manufacturing facilities, 1993 non-agricultural production was approximately US$150 billion. This represents 4.8% of the total industrial output in Japan, and is comparable to the economy of the San Francisco Bay Area. The damage and destruction of commercial and industrial facilities in Kobe will result in significant business interruption losses.

For example, the shoe industry in Kobe accounts for 80% of the output of the synthetic rubber shoes in Japan (Figure 10-4). A Ministry of International Trade and Industry survey reports that 140 shoemakers out of 192 in Kobe have been destroyed either by the shaking or by subsequent fire conflagrations. Most vulnerable to business interruption losses are small companies, which lack alternative production sources with excess capacity or inventory. However, even major industrial corporations will be affected by the event. Kobe Steel, hard hit by the earthquake, estimated on January 26, 1995, that it will take at least one month to resume even partial operations.

The tremendous disruption of the infrastructure will have worldwide implications, particularly given the world’s growing economic interdependence and the widespread adoption of just-in-time manufacturing techniques. For example, both Apple Computer and the Boeing Company have been impacted because one of their major suppliers of LCD displays was forced to shut down its factory near Kobe.

City officials in Kobe report that the port facilities may take six months to repair. The Port of Kobe is the largest container port in Japan, accounting for over 12% of the nation’s export volume, and 8% of its imports, so its disruption will have serious implications (Figures 10-5 and 10-6). Firms which previously relied on the Kobe port must now utilize alternative facilities. Because the costs of hauling raw materials and goods between Kobe and Tokyo by road are comparable to the costs of shipping across the Pacific, such disruptions will be very costly. In addition, it may take longer than six months to restore the functionality of the regional highway system, so even road shipments may be hindered (Figure 10-7).
Figure 10-2  Removal of damaged debris began within days of the earthquake.

Figure 10-3  The cost of removal of the Hanshin Highway will be substantial.
The burden of the economic losses will be distributed over a number of economic sectors, including property owners, financial institutions, and the government. In many other countries, much of the loss would be covered by the insurance and reinsurance industries. For example, in the 1994 Northridge earthquake in Los Angeles, the insurance industry paid over US$10.5 billion in claims for property and business interruption coverage, representing over 35% of the total direct losses. However, due to the limited amount of earthquake insurance written in Japan, the amount of losses covered by insurers will be only a small proportion of the total cost. As of January 24, the Non-Life Insurance Association of Japan estimated that non-life insurers would only pay between US$2 and US$3 billion in claims. Even if the total physical damage reaches US$100 billion, only US$8 to US$12 billion would be covered by the property insurance industry.

Foreign property insurers, however, may experience more substantial losses than the domestic Japanese insurance industry. Over 120 multinational companies have established their principal Japanese business bases in the Hyogo Prefecture, and the Port of Kobe is a major hub of international trade. Furthermore, Japanese insurers reinsure over 80% of their earthquake exposures in international markets.

Financial markets in Japan have reacted strongly to the event. The Nikkei lost 8% of its value over the course of a 10-day period, representing a reduction in the market’s capitalization greater than the largest estimates of the damage. Furthermore, the declines appear to be broad-based, indicating that investors gave little consideration to the nature of the losses. Kobe Steel, which suffered direct physical damage to its plant and will be impacted by significant business interruption losses, lost 7% of its value, the same as Nippon Glass and the Bank of Tokyo, neither of which were directly impacted.

Overall, the long-term economic impacts of the event should not be catastrophic. The strength of the Japanese economy will allow it to overcome the short-term disruption caused by this event. While the magnitude of initial losses will cause economic dislocations and delays in shipments, the stimulus from rebuilding Kobe may outweigh some of the negative consequences.
Figure 10-5  Damaged container cranes at the Port of Kobe.

Figure 10-6  Damage to the Port of Kobe.
Figure 10-7  Damage to the Hanshin Highway will greatly hinder road shipments.