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OVERVIEW OF THE 1995 HYOGO-KEN NANBU EARTHQUAKE AND PROPOSALS FOR EARTHQUAKE MITIGATION MEASURES

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ABSTRACT: Japan is subjected to frequent seismic activity. On January 17, 1995, the 1995 Hyogo-ken Nanbu Earthquake hit the Hanshin-Awaji region, a heavily populated area in western Japan. The Japan Meteorological Agency (JMA) reported that the magnitude was 7.2 and the epicenter was 16km underneath this region. About 6300 people died, and more than 150,000 buildings were destroyed in and around the area with seismic intensity of VII, which is the highest level on the JMA scale. Reports on this earthquake disaster are extensive, such as the 10-volumes for building series edited by the Architectural Institute of Japan (AIJ) and the 12-volumes for civil engineering series edited by the Japan Society of Civil Engineering (JSCE), both series in Japanese.
Here, based on these series edited by AIJ and JSCE, we give an overview of this earthquake, the related geological settlings, geotechnical conditions, strong ground motions, damage statistics, and structural damage to buildings, to infrastructures, to lifelines, and to other facilities such as associated mechanical equipment, elevators, and emergency power supply. Then, we report earthquake mitigation measures proposed by AIJ and JSCE based on lessons learned from this 1995 earthquake.

Key Words: 1995 Hyogo-Ken Nanbu Earthquake, Ground Motions, Soil Conditions, Structural Damages, Buildings, Civil Engineering Structures

INTRODUCTION

Kobe city in the Hyogo-ken Nanbu region is near the ancient capitals of Nara and Kyoto established more than 1500 years ago, and is spreading long along the Osaka Bay with the Rokko mountain rizing behind. Also Kobe is surrounded by the Osaka plain, the Sasayama basin, the Nara basin and etc. Numerous historical descriptions of natural and social phenomena related to strong earthquakes in this region are available for seismic study. Along the neighboring active fault system involed the Arima-Takatsuki tectonic line, a strong earthquake occurred in 1956. The 1995 Hyogo-ken Nanbu Earthquake with JMA magnitude of 7.2, however, was the first strong intra-plate earthquake in the recent seismic active period in this region. Based on historical records, this is the first recorded strong earthquake whose epicenter was located in the Kobe and Awaji regions where the fault plane of the

main shock of the 1995 Hyogo-ken Nanbu earthquake occurred.
The 1995 Hyogo-ken Nanbu Earthquake (hereafter called “the Earthquake”) struck the Hanshin area and Awaji Island, and killed about 6300 people and seriously damaged more than 150,000 structures and facilities in highly urbanized zones, such as the Kobe and Osaka areas. The most seriously damaged structures were concentrated near the active fault zone and/or in soft ground such as reclaimed landfills.
Here, based on reports on the Earthquake disaster edited by the Architectural Institute of Japan (AIJ) and the Japan Society of Civil Engineering (JSCE), we give an overview of the Earthquake, the related geological settlements, geotechnical conditions, strong ground motions, damage statistics, and damage to buildings, to infrastructures, to lifelines, and to other facilities such as mechanical equipments, elevators, and emergency power supplies. Then, we summarize earthquake mitigation measures proposed by AIJ and JSCE based on lessons learned from this 1995 earthquake.

OVERVIEW OF THE EARTHQUAKE

A JMA magnitude of 7.2 by the Japan Meteorological Agency (JMA) was registered for the Earthquake. The hypocenter of the Earthquake (34.6° N, 135.0° E, focal depth of 16km, origin time of 05:46.52 JT) was located about 20km southwest of downtown Kobe between the northeast tip of Awaji Island and the mainland. Based on analysis of the teleseismic body waves, the rupture process was as follows. The source parameters obtained for the total source, as a focal mechanism, were a nearly pure strike-slip with an EW compression axis, a seismic moment of 2.5×10^{19}Nm, a moment magnitude of 6.9, and source duration of 11s.The rupture process consisted mainly of three subevents whose source durations were 5-6s, two of which were nearly pure strike slip with slightly different fault strikes, and the third was bilateral rupture. The former two subevents are bilateral ruptures and the latter subevents are unilateral ruptures propagating NE and reaching the Kobe area. The total fault length was 40km, the average dislocation was 2.1m, and the average stress drop was 8 MPa. These source parameters indicate that the Earthquake was a typical shallow inland earthquake that occurred on a previously mapped Quaternary fault zone. The directivity toward Kobe is one of the main factors responsible for the heavy damage. All analytical studies, however, are based on limited number of near-field strong ground motion records, which number is not completely substantial for a through inversion analysis. Eventually the maximum estimates for the seismic moment as well as the maximum fault offset are about twice as large as the minimum estimates. But all these studies highlight the following common features of the Earthquake. The rupture initiated immediately beneath the Akashi Strait , and propagated in both northwest and southeast directions. The northeast rupture for the first 3 seconds, which was basically a right-lateral strike slip associated with a relatively large thrust component, was then followed by the southwest rupturing. The southwest rupture reached the ground surfaces about 4.5 seconds after the origin time. Also the source time functions indicated that the source mechanism on the shallowest part of the fault plane had relatively longer duration than those on the deeper part. The major slips on the northeast side of the fault plane occurred at the deeper part of the fault plane, and were limited to narrow regions. Figure 1 shows the locations of the aftershocks, and Figure 2 shows the focal mechanism and source processes.

TOPOGRAPHY AND GEOLOGY

Hanshin area and Awaji Island are tectonically located near the west vertex of the so-called “Kinki Triangle”, defined by three vertices, namely, Tsuruga Bay, Awaji Island, and Ise Bay. The Kinki Triangle block is tectonically located among three blocks: the Southwest Japan block, affected by the subducting slab of the Philippine Sea Plate, the Central-Northeast Japan block, affected by the subducting slab of the Philippine Sea Plate, and the Central-Northeast Japan block, affected by the subducting slab of the Plastic Plate. Accordingly, this Triangle is being deformed in a very complex manner. As the consequence, the Kinki Triangle, with some subsiding, uplifting and tilting blocks, has a lot faults among the other part of Japan.

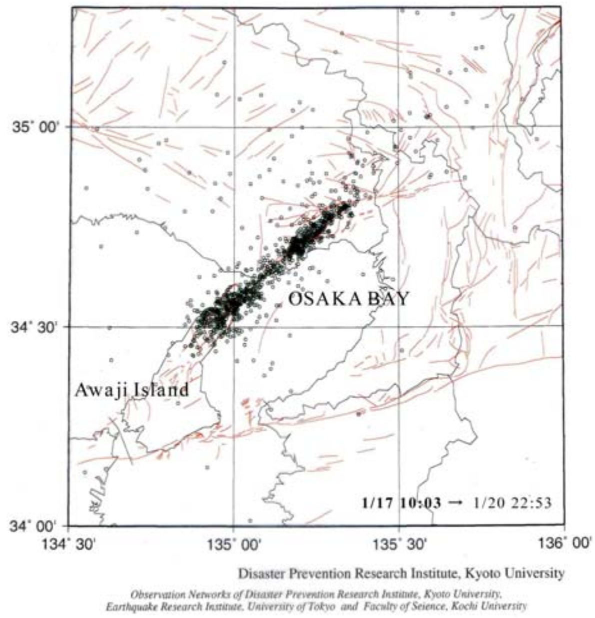


Fig. 1 Location of the aftershocks

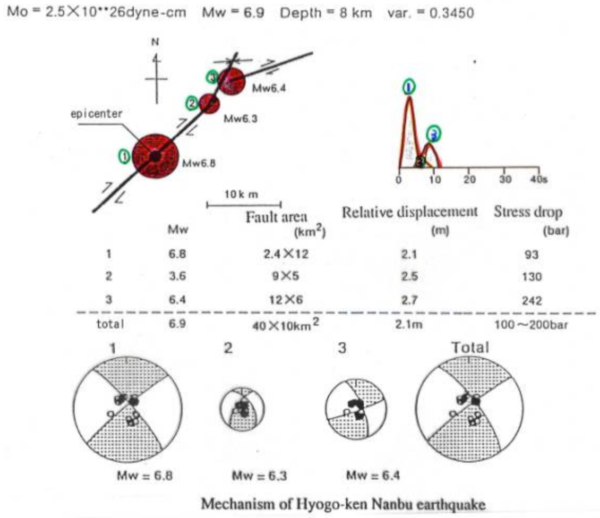


Fig. 1 Fig.2 Focal mechanism and source processes (Kikuch, 1995)

The present crustal stress condition in this region indicates uniform stress regime with E-W trending compression-stress axis, which had been estimated from the focal solutions of many micro-earthquakes or the technique of stress release by means of over-coring of the basement rocks. The tectonic stress in areas such as this Kinki Triangle region can therefore produce, for example, strike-slip faults in the NE-SW direction, reverse faults or thrust in the N-S direction, and normal faults in the E-W direction.

Topographically the Osaka Basin is a typical sedimentary basin. Its major plain is highly populated and developed with uplifting mountains rising east behind and the Osaka bay on the west.

The Hanshin area is geologically active with many active faults, especially in the late Quarternary. Mountains in this area were formed by geological movement. The Osaka basin has thick Quarternary, over 1000m thick, with widely distributed soft soils. In contrast, in the Kobe area, which is in a narrow region along the Rokko Mountains, the thickness of deposit layers suddenly changes from a few meter to 1000～2000m coinciding with faults from the Rokko Mountains to the Osaka Bay, and the thickness of soft soils reaches less than 20m, Furthermore, in the eastern part of the Kobe area, terraces and alluvial fans are lined up along the Rokko mountains, characterizing this area. The alluvial fan area rich in sand and other suspended matters that the river from the Rokko mountains have carried over centuries.

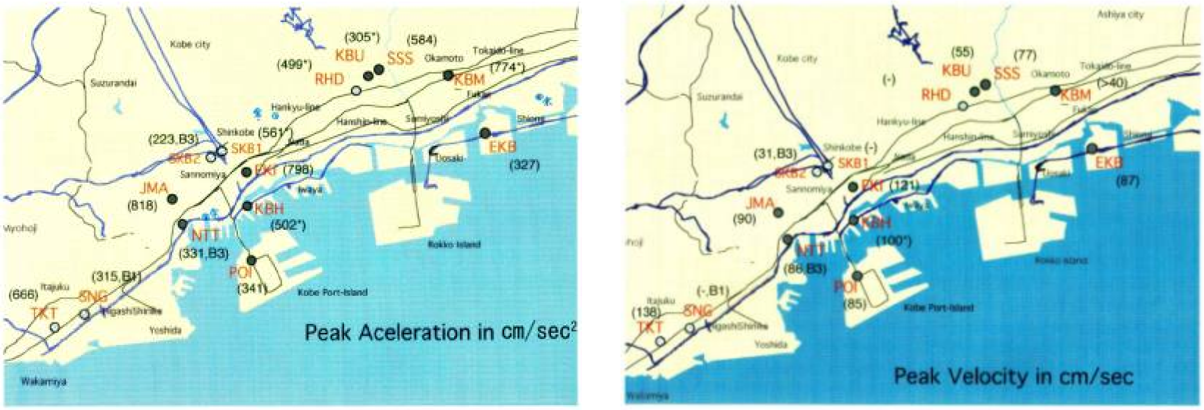
Distribution of damage and ground failure caused by the Earthquake, such as liquefaction, was clearly related to the geological condition. The source mechanism and local site conditions were reportedly responsible for both earthquake ground motions, the damage distributions, and distribution of urban structures.

Many seismic profilings and drilling surveys have revealed the detail features of the bedrock configuration and cover deformation in the Kobe-Hanshin area affected by the Earthquake. These geological structures and geomorphological features are due mainly from the latest Cenozoic crustal movements, and strongly affected the Earthquake disaster. The basement rocks consist mainly of

Ryoke granitic rocks, partially of Paleozoic, Mesozoic, and Miocene sedimentary rocks, and some volcanic rocks. The sedimentary cover overlying the basement rock consists of the Osaka Group, upper Pleistocene, and Holocene alluvial deposits.
The Osaka Group and the upper Pleistocene lie below the lowland area. Distinctive landform features include terraces and hills, where the Osaka Group and the upper Pleistocene are exposed sporadically, and have been developed between the lowland and the mountainous regions.
The large alluvial plains associated with the thick alluvium were generally formed in the tectonic sedimentary basin that has existed in the regional neo-tectonic belt since the Pliocene or Pleistocene age.

STRONG GROUND MOTIONS AND MICROTREMORS

A preliminary overview of strong ground motion characteristics presented herein is based on the recorded PGA (Peak Ground Acceleration) values and soil types at 287 recording stations during the Earthquake. The results show that the spatial distribution of PGA was affected strongly by the directivity of seismic waves radiated from the source and that the small PHGA/PVGA (H and V are horizontal and vertical directions, respectively) ratios of sediment sites in the near-source area were due to the strong nonlinear behavior of the subsurface soils. Figure 3 shows the distribution of maximum acceleration and velocity in Kobe.



(a) Maximum acceleration (b) Maximum velocity

Fig. 3 Distribution of maximum acceleration and velocity in Kobe.

In addition, the observed waveforms, site conditions, observation conditions, and soil profiles are reported to clarify the characteristics of the strong motion records at near-source sites, such as sites at CEORKA (Committee of Earthquake Observation and Research in the Kansai Area), Kansai Electric, and Osaka Gas. Observation records of seismic motions at structures were reported for the main shock of the Earthquake. Strong motion records were observed at 36 building structures and 40 civil engineering facilities (e.g., bridges, levees, road embankments, tunnels) located within 200km of the epicenter. Figures 4 and 5 show examples of observed strong ground motions and pseudo velocity response spectra with damping of 0.05, respectively.
Ground motions in the near-fault region in Kobe were characterized by two large long-period pulses (1 to 2 s) due to forward rupture directivity. At heavily damaged areas, the large long-period pulses, whose predominant period (1 to 3 s) depended on the asperity size, were further amplified due to the basin edge effect (based on a 3-D FEM simulation, showing two distinct pulse-motions with peak

acceleration of about 1000cm/s^2 and peak velocity of 130cm/s.)
Overviews of strong motion characteristics based on data in and around the large disaster area are discussed in the AIJ/JSCE reports based on maximum acceleration and velocity, pseudo velocity response spectra, and attenuation in distance.
After the Earthquake, collaborative measurement of microtremors at more than 2000 locations in the damage area was undertaken by 45 research organizations. Their preliminary analyses revealed several common features of the measured microtremors: (a) the amplitude of such microtremors was rather small in the mountainous zone and large near the sea coast, (b) sea waves in the Osaka Bay excited source of such microtremores, (c) shorter-period microtremors between 0.2 and 0.5 seconds occurred throughout the measured areas, and (d) areas having peak amplitudes and predominant periods between 0.2 and 0.5 seconds seemed to coincide with the heavily damaged areas during the Earthquake.

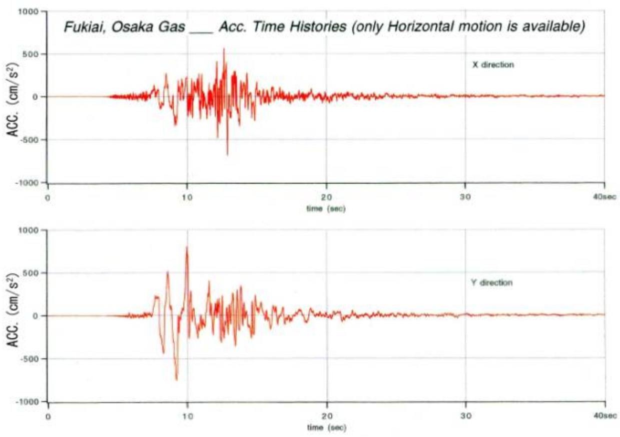


Fig. 4 Observed strong ground motion record

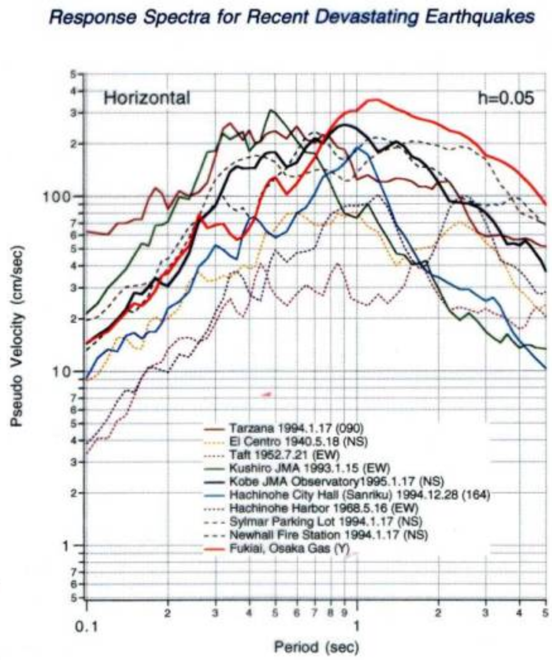


Fig. 5 Pseudo velocity response spectra (h=0.05)

DAMAGE TO BUILDINGS

Damage to reinforced-concrete (RC) buildings

Many organizations and groups investigated the damage to buildings in the areas, affected by the Earthquake. Each investigation had its own purpose, investigation areas, methods, and parameters. The investigation directed by AIJ and the City Planning Institute of Japan encompassed almost the entire area affected by the Earthquake. The investigation by the Kinki branch of AIJ covered the most affected areas, where the seismic intensity was VII in the Nada-ku and Higashinada-ku areas reported by the Meteorological Institute.

Distribution of damage

The percentage of buildings that suffered intermediate / severe damage in the region of high ground motion intensity was 12% for public and municipal buildings, 45.3% for school and cultural facilities, 64.6% commercial and industrial buildings, and 11.6% for residential buildings.

Buildings constructed in accordance with the present Building Standard Law withstood the Earthquake reasonably well, whereas buildings with pre-1971 construction suffered more significant damage mainly due to the insufficient amount of shear reinforcement. Middle-story collapses were dominant in pre-1981 constructed buildings and were initiated by the brittle shear failure of reinforced-concrete columns. The design of the weak-first-story system must be improved in the buildings conforming to present building codes.

Damage to each structural system

The structural system of RC buildings is classified into two groups. One is frame construction with columns, girders, and shear walls, and the other is the wall construction mainly with bearing walls and wall girders. Damage to building of wall construction was less than that of frame construction. Damage to buildings that have few or no shear walls at the first story with weak stiffness was remarkably higher than that to the other buildings. Though the dependence of damage on the number of stories in the building differed for each district, the percentage of 3~5 storied RC buildings, which were the most common type of building in the areas that experienced the most disastrous earthquake motion, was higher than that of other storied buildings.

Damage patterns of structures

The observed damage patterns of building structures include first-story collapse, intermediate-story collapse, overall collapse, tensional collapse, and miscellaneous damage patterns such as collision between adjacent buildings due to expansion joints, collision or collapse of connecting passageways between buildings, collapse or damage of penthouses and chimneys, damage to exterior stairs or oriel in rooms, and collapse of floor slabs. Among these damage patterns, the predominant patterns were first-story and intermediate-story collapses conspicuous in buildings built before 1981, the year in which a new seismic code was enforced. First-story collapse occurred predominantly in so-called buildings with pilotis. Such buildings with pilotis built after 1981 were much less likely to collapse than those built before 1981. However, buildings with pilotis were about 4 times more likely to collapse than those without pilotis, regardless of year when the buildings were constructed. First-story collapse was apparently caused either by insufficient shear capacity of columns, flexural or shear failure of columns influenced by the fluctuating axial force, structural mismodeling of secondary walls, soft stiffness at the first story, or structural torsion. Intermediate-story collapse was apparently caused by the vertical distribution mode of shear coefficient with respect to height in buildings constructed before 1981, existence of a floor where the building structure changes from steel-reinforced concrete (SRC) to RC and in many cases accompanied by smaller columns, change in wall area at some intermediate-story, insufficient shear capacity of columns, structural torsion, or influence of vertical motion of the Earthquake. Photo 1 shows an example of the collapse of a soft 1st story building, and Photo 2 shows an example of story collapse at 6th floor and the failure of an inside column at 5th floor of the building.

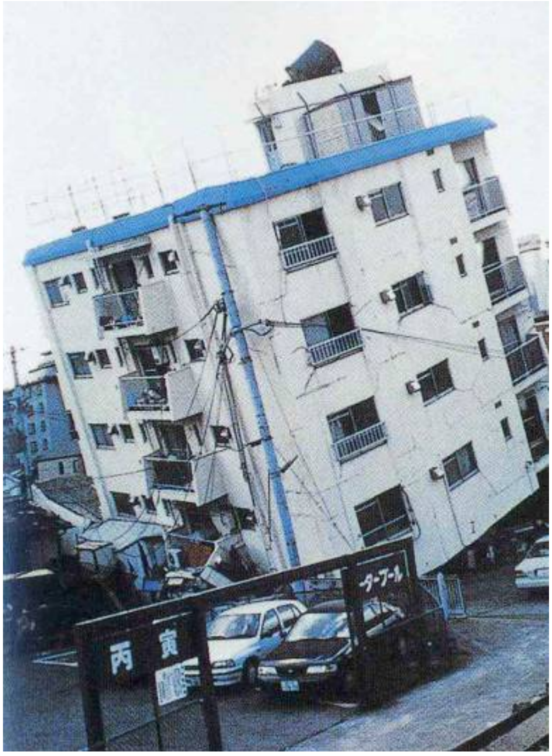


Photo 1　Building collapse at soft 1st story

(a)　Story collapse

(b)　Column failure

Photo 2　Story collapse at 6th floor and column failure at 5th floor inside of the building

Typical damage to structural members
Typical damage to RC structural members included the following.
1)
1) Columns: Typical failure patterns in columns were bending failure, shear failure, and bond splitting failure. Damage to columns was much more severe in buildings constructed before 1971 because the amount of shear reinforcement in their columns was very small. Brittle shear failure was observed in columns of story with soft stiffness and in short columns that were restrained by non-structural members such as spandrels or wing walls and columns subjected to bi-directional shear forces. Brittle fracture of longitudinal and lateral reinforcement in the columns was also observed.
2) Girders and beams: Similar to columns, typical failure patterns in girders and beams were bending failure, shear failure, and bond splitting failure. Brittle shear failure was observed in coupling beams and beams with openings.
3) Beam-column joints: Shear cracks and spalling of cover concrete were observed in beam-column joints. Photo 3 shows shear cracking of an interior beam-column joint , as an example.
4) Shear walls: Typical failure patterns in shear walls were brittle shear failure in the web, sliding shear failure at construction joints, and shear compression failure at corners of the web. Photo 4 shows an example of sliding shear failure of a wall at mid-height.
5) Footings: Brittle shear failure occurred in pre-stressed high-strength concrete piles. Manufactured concrete piles had only slight reinforcement against shear failure.
6) Other members: Damage to separation joints and corridors connecting adjacent building were observed.

Photo 3 Shear cracking of exterior beam-column joint

Photo 4 Sliding shear failure of wall at mid-height

Damage to steel buildings

The majority of damaged steel buildings were old and small and were designed and constructed using obsolete practices. In most of those old buildings, either wide-flange sections or bundled channel sections were used for columns, channel sections for trusses, and round bars for beams. Many of those buildings either collapsed or sustained severe damage that included a large lateral drift. Corrosion of

Photo 5 Steel-frame building with fracture of bracing members

Photo 6 Brittle fracture of base metal in 1st column of steel high-rise building

steel was also disclosed in many instances. Early urban development areas have a high density of such old steel buildings, which tend to have serious lack of seismic capacity. Photo 5 shows an example of a steel-frame building with fracture of bracing members , and Photo 6 shows an example of brittle fracture of base metal in the first-story column of a steel high-rise building.

Damage to interior structure

1) Beam-to-column connections: Damage to beam-to-column connections was classified according to the cross-sectional type used for columns, namely, wide-flange section (H), wide-flange section with cover plates , and rectangular hollow section (RHS).

   Damage to connections when columns with H sections were used was seen in older buildings constructed before 1981. Most of the connections that cracked and fractured at beam ends were fillet welded, and no signs of plastification of the connected members were observed. Many of the connections had no stiffening plates (continuity plates) at the beam-flange level and had inadequate details to enhance the strength capacity of the connected beams.

   Damage to cover plates was observed at welds along the cover plates and beam ends. Most of the damaged connections had fillet welding and had inadequate strength to enhance the strength capacity of the beams. Photo 7 shows an example of damage to the column-to-beam connection.

   Two types of failure patterns were observed in column connections with RHS: (i) cracking and fracture at welds without any sign of plastification, and (ii) cracking and fracture accompanied by significant plastification of beams.

Most through-diaphragm type connections that cracked and fractured without signs of plastification of the joining members were fillet welded. These fillet welds were apparently too small to enhance the strength capacity of the joining members, and many of the buildings having such connections suffered serious damage.

   Through-diaphragm type connections where full penetration welding was used were also damaged. Most cracks and fractures occurred in the lower flange of beams, and these beams exhibited clear signs of plastification as well as local buckling in many cases. Fracture initiation occurred from

Photo 7 Damage to column-to-beam connection

either (i) the tip of a scallop (welded access hole), or (ii) near a run-off tab. Fracture progressed either into the (i) base metals of the beam flange, (ii) base metals of the diaphragm, or (iii) heat-affected zones of the full penetration weld. Such fracture occurred in a brittle manner after the flange experienced significant yielding. In some cases, ductile failure involving partial necking was observed. Most of buildings that sustained such cracking and fracture did not exhibit large permanent deformation or significant damage to their exterior and interior finishes.

2) Columns: Damage occurred in numerous columns, but most damage occurred near or at beam-to-column connections. Damage to cold-formed RHS included local buckling near the column ends, fracture of base metals, splitting of column-shafts, and fracture of column splices. Damage to H columns with H sections included local buckling near the column ends and excessive bending. In particular, many wide-flange columns sustained excessive bending about their weak axis.
3) Beams: Many beams sustained damage to their beam-to-column connections. Damage to beams themselves included plastification and local buckling near beam ends, plastification and bolt fracture at beam splices, and out-of plane buckling of the beam web.
4) Braces: Typical damage to braces included buckling or fracture of steel bracing members and fractures at connections between braces and other structural members. Such damage decreased the lateral load resistance of frames, frequently causing large interstory drifts, and induced total collapse of the frame in some cases. The type of damage and its effect on the frame depended on the size and shape of the brace cross-section.

   Most of buildings that used braces with small cross-section were small and were designed by obsolete design and construction practices. Two types of failure patterns were observed: (i) fracture of braces at their ends or intersection, and (ii) fracture of bolts and welding at connections between braces and other structural members. In the majority of these failures, large residual interstory drifts were observed, sometimes resulting in the collapse of the building.

Photo 8 Pull-out of anchor bolts at column-to-base connection

Photo 9 Story collapse at 5th floor

5) Column bases: Among the 993 damaged buildings surveyed, 219 had damaged column bases. Such damage was structurally fatal in the overall damage to buildings. Photo 8 shows an example of pull-out of anchor bolts at a column-to-base connection.
Four types of failure were observed in base-plate connections: (i) fracture and pull out of anchor bolts, (ii) flexural deformation of base plates, (iii) fracture of fillet welds at column bases, and (iv) failure of concrete under the base plates. Four types of failure were also observed in concrete-encased column bases: (i) failure of the concrete that encased the column, (ii) failure of reinforcing bars, (iii) fracture and pull out of anchor bolts, and (iv) fracture of fillet welds at the column bases.

Damage to steel-reinforced-concrete (SRC) buildings

Composite encased-steel and concrete structures have been called SRC buildings. The Earthquake was the first time that a large number of SRC building were subjected to severe structural damage. The distinctive feature of collapsed SRC buildings was story failure at an upper floor level. In collapsed buildings with mid-height failure, most of the building was constructed of either SRC structures or mixed structures with SRC members in lower stories and RC members in the upper stories. Photo 9 shows an example of story collapse at the 5th floor.
Statistical analysis was performed based on construction date for 1307 buildings in and around Kobe city. Damage was classified into six groups: collapse, and severe, intermediate, minor, slight, and no damage. Statistical analysis of the degree of damage was described based on construction date, group of buildings, building use, and building stories. This statistical analysis of damage of SRC buildings revealed the following.

1) 32 SRC building structures collapsed due to story failure. All of them were constructed before 1972 and constructed with open-web type SRC. The distinctive feature of damaged SRC buildings was story failure at an upper floor level; 27 of the 32 buildings collapsed due to this failure type. No building constructed with full-web type SRC collapsed.
2) Buildings constructed with open-web type SRC before 1974 tended to sustain severe damage. In the area that experienced a JMA seismic intensity of VII, half of the buildings constructed between

1958 and 1970 collapsed or sustained severe damage. In contrast, only about 5% of the buildings constructed after 1981 (when a new seismic code was enforced) sustained severe damage. About 40% of all commercial buildings either collapsed or sustained severe damage, almost all of which had over 7 to 12 stories. Buildings that had fewer than 6 stories tended to avoid severe damage.

3) Some buildings with the full-web type SRC sustained severe damage. Characteristics of the damage were crushing of concrete at the column base and/or fracturing of anchor bolts, fracturing of steel flange plates, fracturing of splice plates at the joints, shear cracking of concrete at the column-to-beam connections, and shear failure of RC structural walls surrounding the SRC frames.

32 SRC buildings with open-web type SRC collapsed by story failure. Of these, 27 collapsed by story failure at an upper floor level and 5 at the first story. At the failed story, SRC columns with open web collapsed in brittle shear failure, and concrete in RC structural shear walls crushed to out of plane. Collapse by story failure at an upper floor level was characteristic of the damage to these buildings caused by the Earthquake.

In contrast, buildings with full-web type SRC did not collapse at all, but sustained the following damage.

1） 40 buildings with full-web type SRC were damaged at the column base. In many such buildings, the steel base plate was anchored at the ground floor level using a device known as "non-embedment type steel base."
2) 10 buildings were damaged by fracture of the encased steel flange plate.
3) 10 buildings were damaged by fracture of the steel splice plate at the joints of columns or beams.
4) 10 buildings were damaged at beam-to-column connections where diagonal shear cracks and spalling of cover concrete were observed, but severe damage at beam-to-column connections was not reported.
5) 40 buildings were damaged by shearing of the RC shear walls, although the surrounding SRC frame was strong enough.

Reasons for the damages summarized above in 1) to 4) were considered to be the large compressive and tensile axial forces in the columns generated by the overturning moment of motion of the Earthquake and the existence of multistory shear walls. A large number of columns and beams with flexural cracks and shear bond cracks were observed, but severe damage was not reported.

Damage to wooden houses

Damage to wooden houses, such as residential houses, was concentrated along the narrow band of plain. This most severely damaged region, called the "Earthquake Disaster Belt", is between the Rokko Mountains and the coastline. Since the 1923 Great Kanto Earthquake, damage to wooden houses was generally believed to have a strong linear correlation with the thickness of the alluvial layer. The damage distribution from the Earthquake, however, had no direct correlation with the thickness of the alluvial layer. Collapse of wooden houses in the Earthquake Disaster Belt was caused by severe seismic ground motion; that is, large acceleration or velocity of ground motion, and their spectral characteristics were the direct causes of the damage. In particular, the spectral characteristics have a predominant component in a long-period range that is close to the natural period of wooden buildings in the domain of large deformation. Seismological and earthquake-engineering factors that affected the concentration of the damage in the Earthquake Disaster Belt are not a single ground characteristic but rather the multiple effects of the characteristics of the fault, source mechanism, topography, structure of stratum, and site ground characteristics.

Wooden houses in the Earthquake Disaster Belt were classified according to the construction method, materials, and date. About 80% of houses with heavy clay roofs and walls were heavily damaged, whereas about 50% of houses with light roofs and braced shear walls without clay walls had minor or almost no damage. Damage to wooden buildings constructed after the revision of the Building Code in 1981 was generally minor. Most of the wooden houses that completely collapsed were old with a heavy clay roof and walls, and the inadequate connection between members also caused the complete collapse of such houses. Typical damage to collapsed houses was the collapse of the first story where shear walls were insufficient or eccentrically placed. In some wooden houses that had an RC garage in the first story, the second story collapsed due to lack of lateral resistance and to the subsequent concentration of horizontal displacement in the second story. A number of narrow houses were heavily damaged due to inappropriate application of shear walls. In general, well-designed and well-constructed three-story wooden houses had almost no damage. Photos 10 and 11 show examples of the collapse of an old wooden house and new wooden house with a garage, respectively.

Photo 10 Collapse of old wooden house

Photo 11 Collapse of new wooden house with garage

Photo 12 Extent of fire in Minatogawa-cho (contributed by Sankei Shimbum)

Damage due to fire

Fire damage caused by the Earthquake was very serious; over 7000 houses and buildings were destroyed by fire. This destruction was devastating, and the fires caused tremendous tragedy to many people in Kobe. The fires occurred almost evenly in proportion to the ratio of damaged buildings, even in areas other than Nagata-ward in Kobe city where the conflagration was concentrated.
Fire damage was characterized as follows: (1) fires occurred immediately after the Earthquake, (2) many fires involved in electricity, (3) widespread urban-area fires occurred, (4) the speed that the fire spread was slow, (5) the outbreak and spread of fire in fire-resistant buildings were marked, (6) flying sparks and re-igniting occurred, (7) obstacles such as infrastructures and lifelines hindered fire fighting, (8) damage to disaster-prevention and fire-fighting facilities were marked, (9) fire fighting by citizens was widespread, and (10) streets and parks were helpful in preventing fire from spreading. Photo 12 shows the extent of fire in Minatogawa-cho (contributed by the Sankei Shimbun).

DAMAGE TO INFRASTRUCTURE

Damage to bridge structures

Extensive damage to road and railway bridges occurred in Kansai, Takarazuka, Itami, Amagasaki, Nishinomiya, Asahiya, and Kobe cities. Unusable road and railway lines were located along a narrow corridor, and included Routes 2 and 43 of the National Highway, Routes 3 and 5 of the Hanshin Expressway, Meishin and Chugoku Expressways, Sanyo-Shinkansen Train Line, Tokaido Train Line, Hankyu Railways, and Hanshin Electric Railway. Damage to these roads and lines caused major interruption not only for daily traffic but also for restoration and emergency vehicles and equipment between Kansai District and Chugoku and between Kyushu and Shikoku Districts. Statistical analysis revealed that destructive damage occurred in bridges designed before the mid 1970’s, a time when the importance of ductility and shear strength of RC bridge columns was not well recognized. Shear

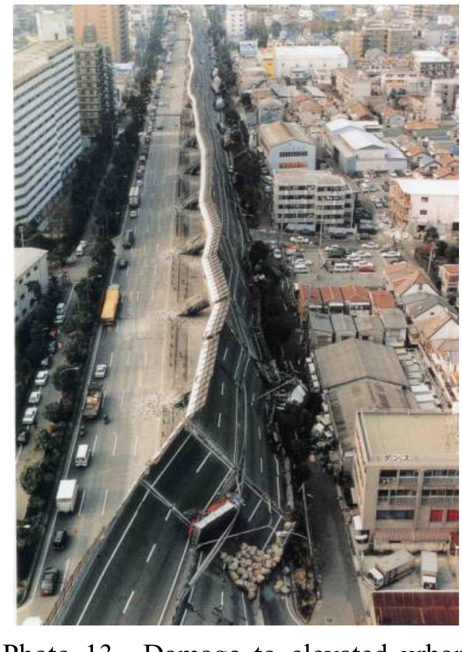


Photo 13 Damage to elevated urban highway (contributed by Yomiuri Shimbun)

Photo 14 Shear failure of RC Pilz-type bridge

failure of RC bridge columns due to inadequate anchoring length of main reinforcements at cut-off points was significant in road bridges, and shear failure of columns of frame-type piers was significant in railway bridges. Photo 13 shows an example of damage to an elevated urban highway (contributed by the Yomiuri Shimbun), and Photo 14 shows an example of shear failure of an RC Pilz-typed bridge.

For the first time anywhere, extensive damage occurred to steel columns. Rupture of welding developed by alternative lateral displacement at corners triggered the loss of bearing capacity to support the superstructure. Damage occurred to many devices used to prevent the collapse of the superstructure from the substructure, and consequently, such devices could not effectively prevent the collapse of superstructures. Damage also occurred due to soil liquefaction and movement of soils.

Girder bridges

Significant damage to girder bridges occurred at all parts of girders, piers, bearings, as well as damage to collapse-prevention devices. Various patterns of damage were reported, such as bending and shear failure of RC piers, local and over-all buckling of steel piers, local buckling of girders, and dislocation of bearings.

Rigid frame viaducts

Damage to RC rigid-frame viaducts of railways (JR Shinkansen, Hankyu, Hanshin, Electric and Sanyo Electric Railways) in the epicentral region was extensive and very severe. Many of the RC viaducts completely collapsed due to shear failure in the columns. Most of the heavily damaged viaducts were constructed in either the 1960s or 1970s. At that time, the seismic design force used in the code was 0.2 G and structural details such as placement of hoop re-bard were inadequate to resist strong shaking. Collapse or heavy damage occurred mainly in the viaducts located in the region where the seismic intensity by JMA was VII. Photo 15 shows an example of shear failure of a railway RC-frame viaduct.

Arch bridges

Damage occurred to five modern large steel-arch bridges and one old short RC-arch bridge. In the large arch bridges, their superstructure suffered minor damage, mostly in the steel bearings. These

Photo 15 Shear failure of railway RC-frame

Photo 16 Fallen span in port bridge

large bridges cross the channels between reclaimed lands, and some of the foundations in these bridges were displaced due to the seismic-induced soil residual movement. In the Rokko Island Bridge (double deck, 215m span), the pivot shoes on the south side failed, thus causing the superstructure to fall from the shoes down to the frame pier with a transverse displacement of 3.1m. Some of the lateral beams connecting two plane-arch frames were buckled. In the Nishinomiya Port Bridge (8 spans totaling 252m), one of the upper shoes had severe brittle fracture and was completely split into pieces. The two steel-frame piers were displaced toward the sea by several centimeters and, partly due to this displacement, one adjacent steel simple girder fell to the ground. In the Kobe Bridge (continuous 3 spans totaling 322m), one of the foundation caissons was inclined by 80 cm at the top, and some of the bearings were fractured, resulting in longitudinal displacement of the arch structure. The Nada Bridge (Nielsen-type, 2 spans) suffered minor damage; its expansion joint was damaged by large transverse motion of the adjacent girder. In the Portpia Bridge, the bridge pier was inclined due to soil liquefaction, causing damage to bearings and seismic restrainers. In the Hagoromo Bridge (RC, 12m span, construction completed in 1929), partial compressive failure occurred in both the abutment and arch top. Photo 16 shows an example of a fallen span in a port bridge.

Suspension and cable-stayed bridges

In the Higashi Kobe Bridge (cable-stayed type) of the Hanshin Bayshore Route, the end link connecting the girder and the end pier at the Kobe side failed due to large transverse motion of the girder. Consequently, the oil damper used to control the longitudinal girder motion also failed and the end of the girder was lifted approximately 30 cm. The Tempozan-Ohashi Bridge (cable-stayed type) in Osaka suffered minor damage; the seismic restrainers failed, the wind shoes and bearings were damaged, and several dampers against cable vibration were also damaged. The Akashi Kaikyo Bridge (suspension type) that was under tension of the cable was directly over the epicenter of the Earthquake. Due to the strike slip fault dislocation, the towers and foundations of this bridge were displaced by 1.3m, resulting in the central span increasing from 1990m to 1990.8m. Fortunately, this bridge suffered no major structural damage. The Rokko Bridge (cable-stayed type) suffered severe damage, including the inclination of the pylim, and longitudinally movement of the girder by approximately 200mm. In the Maya Bridge, damage was more significant; the girder moved transversely by 1 m, causing the tower to tilt.

Other types of bridges

Other types of bridges include truss road, pedestrian, and water-pipeline bridges. Damage to one of the steel-truss bridges occurred mainly to the bearings, but also a large relative displacement occurred between the truss girder and the high piers. Pedestrian bridges did not collapse nor were heavily damaged, although 7 needed urgent repair. Among 365 water-pipeline bridges, only 5 were severely damaged, resulting in disruption of water supply, and 66 suffered light or moderate structural damage.

Damage to earthen structures

Damage to road embankments was less than that to railway embankments, although some road embankments were distorted where the ground water levels were high. Among three parallel rail lines connecting Osaka and Kobe, the embankment of rail lines located on the coastal side was damaged severely; for example, non-reinforced concrete retaining walls were cracked and crumbled, resulting in their incline and failure in some locations along the wall. The foundation ground of this damaged embankment was mostly silt, and the ground water level was high. Housing lands on the colluvial deposit and soft embankment were distorted and failed in some locations. Pavement was severely damaged. Several damaged sites were excavated to examine the subgrade. At a few of these examined sites, no cracks or distortions in the subgrade were found.

Levees and dams failed by the soil liquefaction at many locations. Flooding was avoided, however, because of the low water level during the dry season.

Damage to tunnels and underground structures

The main damage and destruction to underground structures such as subways (station buildings and tunnels), mountain tunnels (roads and railways), multipurpose underground ducts (electrical power, waterworks, etc.), immersed tunnels, shield tunnels, and other underground structures (parking ramps and streets) were as follows.

1) The subway structures in Kobe, such as Daikai Stations and Kamisawa Stations, suffered severe damage. The major damage occurred at RC intermediate columns, and many diagonal cracks occurred along the walls in the transverse direction. Judging from the damage pattern, strong dynamic horizontal forces (earth pressure and shearing force) and shear deformations were applied to the structures by the surrounding ground due to the strong horizontal motion. Most of the damaged structures failed due to a lack of load-carrying capacity against shear in the center column. Photos 17 and 18 show settlement on the national road over the subway station and collapsed center pillar subsided upper floor slab of the subway station.
2) More than 100 mountain tunnels were in service in and around the area affected by the Earthquake. About 10 of these tunnels suffered significant damage and needed repair and reinforcement, and about 30 suffered minor damage. The geological conditions of the tunnel site was strongly related to the damage to the tunnel, and many of the damaged tunnels were located in existing fracture zones.
3) Other underground structures, such as common ducts, immersed tunnels, shield tunnels, and underground parking and streets, had less damage compared with subway structures. Damage to underground electrical supply tunnels was caused by permanent ground displacement, and occurred mainly along the alluvial plane by the sea, especially in the area with lateral spreading due to soil liquefaction.

Photo 17 Settlement of national road over a subway station

Photo 18 Collapsed center pillar and subside upper floor slab of

DAMAGE TO LIFELINES

Damage to lifelines, such as water supply systems, sewage facilities, waste management facilities, and electric power facilities, was as follows.

Water supply systems

Water supply systems were damaged in 12 cities and 7 towns in Hyogo prefecture and in 26 cities and 2 towns in Osaka prefecture. In total, over 1.2 million homes in Hyogo prefecture and over 23,000 homes in Osaka prefecture suffered disruption in water supply. The total damage to the water supply systems was estimated at a cost of over 55 billion yen in Hyogo prefecture and over 1 billion yen in Osaka prefecture. Kobe city was the last to completely restore water supply, about 13 weeks after the Earthquake. In terms of labor, over 71,000 man-days were required to maintain an emergency water supply, and over 54,000 of them were from other municipalities, the Self Defense Forces, and private organizations. Over 109,000 man-days were needed to repair damaged water pipes, and over 47,000 of them were from 241 water supply facilities from 43 prefectures. The industrial water supply systems of Kobe, Nishinomiya, Amagasaki, Itami, and Osaka cities were damaged.

Sewage facilities

Sewage facilities were damaged seriously by the Earthquake. About 200km of sewer lines were damaged and required repair, and 47 pumping stations suffered damage, 23 of which could no longer pump sewage. Sewage treatment plants were also heavily or slightly damaged in 37 stations. The total amount of the damage was estimated at a cost of about 75 billion yen.

Waste management

Solid waste management was seriously disrupted in the Hanshin-Awaji region by the Earthquake, with the physical destruction of conventional municipal solid waste treatment facilities. After the Earthquake, temporary facilities and systems, which were managed in combination with conventional systems, were developed for disaster solid-waste treatment, such as systems for waste separation, waste incineration, and waste recycling.

Electric power facilities

Electric power facilities, including thermal power plants, substations, and transmission and distribution facilities, suffered various degrees of damage from the Earthquake. About 2.6 million households were affected by power outages immediately after the Earthquake. Only six days after the Earthquake hit, however, power service was restored to customers throughout the entire region by implementing emergency arrangements. The damaged facilities did not therefore cause any prolonged disruption in electrical power.

DAMAGE TO OTHER FACILITES

Port and coastal facilities

Many port and port-related facilities were damaged. In particular, facilities at the port of Kobe were totally destroyed. The cost to resume port functionality has been estimated at 560 billion yen.

River management facilities

Damage to river management facilities administrated by the Kinki Regional Construction Bureau, Ministry of Construction, occurred at 77 locations on 8 rivers in 6 river systems. Levees in the Yodo River were seriously damaged in the Torishima and Nishijima areas. Disaster in the Torishima area was caused by the liquefaction of sandy soil distributed underneath the levee. The levee of Nishijima area was also destroyed by such liquefaction. Damage of river structures administrated by Hyogo Prefecture was concentrated in rivers flowing into Osaka Bay. Levees, revetments, and tunnel rivers were also damaged. Damage to 79 rivers at 297 locations and over 45 km in total length were recorded in Hyogo. In Osaka Prefecture, river structures were mainly damaged near the mouth of the Old Yodo River and Kanzaki River adjacent to Hyogo Prefecture.

Facilities to control sediment and slope movement

Facilities to control sediment and slope movement were damaged to various degrees. Among the 734 sediment control dams and channel works (total length of about 175 km), damage occurred to 11 sediment control dams , 9 groundsels, and 26 channel works (totaling about 1.2 km). Although most of the damage to these sediment control dams was slight, i.e. cracks, one plain masonry sediment control dam (effective height was about 6 m) was partially destroyed. Damage to revetments was localized and slight, sometimes resulting in partial destruction. Damage to groundsels was also slight, i.e. cracks. Damage to the sediment control facilities caused no direct damage to nearby houses or other structures, nor did any damage occur by the outflow of soil downstream.
Landside control facilities were provided at 23 points in this area, and only 2 showed structural damage. The damage was slight, such as minor slippage or displacement of the water channel.
About half of the facilities to control the steep slopes in Kobe City were damaged to some extent. Most of the damage was minor, however, and caused no consequent damage or loss of function to nearby houses or other structures.

Damage to industrial facilities, plants, and associated mechanical equipment

Equipment
Damage occurred to manufacturing facilities, electric and electronic production facilities, electronic units and information systems, semiconductor equipment, automatic control facilities, facilities using radioisotopes, and food production facilities.
Typical damage to machines with no anchor bolts in these facilities was tumbling and movement. Other damage included overflowing of molten aluminum alloys in manufacturing facilities, spilling of molten solder in electric and electronic production facilities, and collapse of various types of “sake” tanks.

Boilers and electric power facilities
Numerous department store buildings were damaged. Consequently, heating systems that used steam boilers installed on the floors of the buildings suffered from seismic failure. Almost all the failed boilers were made of cast iron and were not rigidly fixed to the floor. Subsequently, some boiler drums moved relative to the floor, thus causing the boiler casing, connecting pipes, valves, and pumps to either break or fail.
No damage was found in nuclear power facilities, because the nuclear station was located about 110 km from the epicenter. However, some damage occurred to 10 thermal power facilities located throughout the West-Hanshin area. Damage was concentrated at the connection devices between the boiler drum and supporting structures. Other damage included stem leakage from tubes and piping.

Pumps
In 60 damaged pump facilities, a total 90 incidents of damage occurred. Much of this damage occurred in pumping facilities for sewage or in the drainage systems for storm sewage. In contrast, no damage was found in pumps in thermal power plants and steel manufacturing facilities. Only 22% of all the pumps in all of the pumping facilities in the Earthquake region were damaged.
Damage to the pumps included pump submersion, shaft misalignment, “freezing” of the pump rotor, anchor bolt failure, cracks in the pump casing, and failure of the bearing box. Most of the damage was fundamentally caused by uneven sinking of the building foundation. Damage to the pumps was mainly caused by deformation or collapse of building structures, or by excessive forces being exerted on the pumps by the piping.

Power generation, transmission, sub-stations, and distribution/receiving facilities
Kansai Electric Power Co., Inc. reported damage to their facilities. Damage occurred to 10 of 21 of their fossil-fuel-powered plants, 50 of 861 substations, 23 of 1065 overhead transmission lines, and 102 of 1217 underground transmission lines. Power distribution facilities were impaired due to damage to concrete poles, collapse of houses, soil liquefaction, and broken or tangled lines. Power-receiving equipment installed in houses and buildings was also damaged. The Higashinada Gas Turbine Plant, constructed on reclaimed land in Higashinada Ward, Kobe city, was subjected to strong earthquake motion and subsequent liquefaction, resulting in extensive damage, such as exposure of foundation columns of oil storage tanks (maximum 60 cm settlement at ground level near foundations).

Emergency power supply
Many organizations, such as hospitals and telecommunication companies, needed an uninterruptible power supply to continue their services when power was disrupted and rectifiers failed. The main failure in diesel engine-generator systems that could not operate after the Earthquake hit occurred in engine beds, exhaust pipes, and cooling pipes. In the failure of engine beds, supports made from rubber mounts or spring mounts for reducing the engine vibration were damaged, and the flexible pipes attached to the engine to dampen the effect of earthquake excitation also failed. In the failure of gas turbine generator systems, no destructive failure occurred, but pipeline systems failed due to uneven settling of the foundation and to stopping of fuel supply. In one gas turbine, the amount of fuel was limited as a precaution against fire. Batteries essential for energy storage also sustained damage, such as cracks due to falls.

Elevators and escalators
Damage to elevators and escalators was concentrated in Kobe city. Although no personal accidents were reported, 5604 elevators (8.6% of all elevators), 22 (1.8%) home elevators, and 828 (10.6%) escalators were damaged. Moreover, damage to elevators designed according to the new regulations, which incorporated earthquake-resistant design, was less than that to elevators designed based on older regulations that did not incorporate earthquake-resistant design.

PROPOSALS BY AIJ AND JSCE FOR EARTHQUAKE MITIGATION MEASURES

Based on bitter lessons learned from the 1995 Hyogoken-Nanbu Earthquake, the Architectural Institute of Japan (AIJ) and the Japan Society of Civil Engineers (JSCE) each made three sets of proposals (original versions are written in Japanese) for future earthquake mitigation measures.
Here is the complete text of the first proposal and a brief list of the items in the second and third proposals by AIJ, and the titles and chapters of the three proposals by JSCE.

First proposal by AIJ

The first proposal by AIJ (made July 19, 1995) was titled " *Problem on the Improvement of Disaster Prevention of Buildings and Cities-Reflecting the Hanshin-Awaji Earthquake Disasters* ".

Introduction
The 1995 Hyogoken-Nanbu Earthquake, which occurred on January 17, 1995, caused devastating damage to structures in the Hanshin Awaji Area. Because many houses and buildings collapsed and were then destroyed by fire, there were heavy casualties and the fundamental urban systems , such as infrastructure and lifeline, in many areas were paralyzed for a long period after the Earthquake.
This was the largest earthquake disaster in Japan since World War II in terms of the number of casualties. The collapse of structures and the subsequent fires were responsible for most of these fatalities.

The main objective of AIJ is the improvement and development of research, technology, and artistic quality of structures and cities. AIJ has been playing an essential role in realizing safe and comfortable structures and cities to live in.
AIJ has taken this Earthquake disaster very seriously and has tackled a variety of academic investigations, analyses, research, and restructuring activities just after the Earthquake occurred. AIJ published the first investigative report on the Earthquake and held an urgent conference to facilitate further research.
A special research committee on the Earthquake (hereafter referred to as "the committee") was newly organized in 1995 by AIJ due to the bitter experience of this Earthquake. In the committee, members analyzed the Earthquake disaster and implemented detailed and broad-ranging studies, and have been in constant close contact with members of other related-research committees.
The fundamental policy of the committee was as follows.
"For disaster prevention or mitigation, strengthening the seismic performance of each structure is crucial. The disaster of the Earthquake, however, revealed that we were lacking an integrated plan for urban disaster mitigation, and that there was no such plan for disaster mitigation from the human-centered point of view. Therefore, AIJ, composed of a broad spectrum of researchers and engineers in the architectural field, should conduct detailed and broad-ranging studies."
Based on the above realization, the committee determined the following seven items as research areas required for future earthquake mitigation measures.

1. Relationship between strong ground motion records and design earthquake ground motion
2. Safety level required in earthquake-resistant design
3. Improvement methods for existing buildings that do not conform to current building codes
4. Community-wide disaster-prevention planning methods for built-up areas densely crowded with wooden houses
5. Emergency measures and evacuation planning
6. Restoration and reconstruction planning
7. Preservation and rehabilitation of history, culture, and landscape

These items cannot cover all the problems that cities in Japan are facing for disaster mitigation. Therefore, based on surveys conducted by AIJ standing committees, the committee reconsidered and proposed additional items to be investigated.
This proposal is a compilation of items, including the above seven specific research items, that the committee considered crucial based on in-depth discussions and survey results. It is the sincere hope of AIJ that this proposal will serve the needs of public and private sectors to work for the development of disaster mitigation measures.
The following five items are recommended by the committee as the first proposal for research goals.

A. Promotion of urban earthquake disaster management
B. Measurement of earthquake resistance of existing inadequate structures that don't meet the present seismic codes
C. Development of a new design method to clarify seismic performance
D. Establishment of a disaster information system
E. Promotion of basic research on disaster prevention and disaster mitigation

A. Promotion of Urban Earthquake Disaster Management

The Earthquake caused many structures to collapse and then be destroyed by fire. Infrastructure and fundamental urban systems, such as lifelines, were paralyzed immediately after the Earthquake. Until then, people enjoyed their comfortable urban life and admired the cultural assets in their hometown. It is quite regretful that the disaster deprived people of those assets along with the joy of their daily lives. Through this experience, we learned afresh the importance of promoting urban earthquake disaster management that is based on measurements of the seismic- and fire-safety measures.
Future urban development, including the restoration and reconstruction of damaged areas, requires reinforcement of urban structures, improvement in seismic-resistance measurement in response to the

characteristics of each region, and preservation and restoration of cultural assets.

A.1 General Urban Disaster Mitigation: To implement urban disaster management, a disaster mitigation plan for urban areas should consider the spatial infrastructure, such as topography, and should be based on the earthquake- and fire-resistance measurements of structures and urban functional infrastructure.

This plan requires reasonable land use and strict control of the space use as well as the construction of public transportation systems by rail, road, air, and sea. The construction of public transportation systems is essential not only for the post-earthquake rescue operation and the evacuation from fire or tsunami, but also for telecommunications. In addition, maintenance of parks and "green zones" and the establishment of buffer zones containing open spaces such as rivers should be promoted to realize intelligent use of space. The mitigation plan can be summarized into the following areas.

1) Promotion of intelligent land use in response to space infrastructure based on topography
2) Construction and development of public transportation systems
3) Evaluation and maintenance of open spaces as buffer zones
4) Establishment of a space system, such as systems for large-area evacuation, by the sectioning of urban areas

A.2 Forming Independent Urban Areas for Disaster Mitigation: Essential for urban disaster mitigation is improvement in regional seismic safety by considering each region's characteristics, such as natural environment and infrastructural environment.

For successful mitigation, through education about the disaster, people in the community need to gain an understanding to initiate self-help organizations and to participate in disaster mitigation activities. This will create "a community with disaster preparedness", is the basis for reconstruction supported by people in damaged areas.

In facility maintenance, community structures must be built that can provide basic lifelines, such as electricity and water, for people in the community during an emergency.

For an evacuation route, space should be sufficient such that pedestrians are protected against falling or collapsing fences and walls. To achieve these requirements, public organizations and institutions must be established and disaster mitigation projects must be improved on a regional basis. This mitigation plan can be summarized into the following areas.

1) Creation of a community with disaster preparedness
2) Construction of public facilities in the community for emergency use as independent self-supply and waste-disposal facilities
3) Planning and facilitate escape routes for evacuees in an emergency
4) Establishment of public systems to improve regional disaster mitigation

A.3 Improvement to Urban Areas Densely Packed with Wooden Structures: In urban areas of Japan, narrow and ill-maintained roads often prevent emergency vehicles from firefighting or rescuing victims in an emergency. Many of such areas are densely packed with old wooden structures that do not meet the present seismic codes, and thus are quite vulnerable to disaster.

Considering this situation that Japan is facing, an urgent need is to promote improvement and restoration of urban blocks. In particular, to form independent reliant urban areas for disaster mitigation, a specific unit zone densely packed with wooden structures should have a road designated for use as an emergency road when necessary. The road should be wide enough and should have a local fire station, parks for evacuation sites, and public facilities to be used as independent supply and waste-disposal facilities in an emergency. The earthquake-resistance performance and fire-resistance measurements of these structures should be improved.

A plan for road construction and maintenance should consider roads as integral facilities for disaster mitigation. In addition, public organizations and institutions that promote cooperative and collaborative reconstruction projects must be established. This content can be summarized into the following items.

1) Establishment of the project to maintain streets as effective facilities for disaster mitigation
2) Promotion of cooperative and collaborative reconstruction projects

A.4 Maintenance of Facilities for Disaster Mitigation and Evacuation, and Diversification of Temporary Shelters

Through the disastrous experience of the Earthquake, we learned that it is necessary to utilize public buildings as official disaster prevention facilities, including local government offices, police stations, hospitals, and schools. To maximize their use, the facilities must be maintained for emergency use and deployed appropriately as administrative centers for disaster mitigation. When the Earthquake occurred, almost all the public facilities and community centers were used as evacuation sites and later as evacuation centers. Therefore, those public facilities that are not designated as major centers for disaster mitigation also should have additional functions, such as a communication network system, and should be properly maintained. Another crucial factor is an effective layout for each facility.

Also important is to transfer victims to temporary shelters as smoothly as possible. A smooth transfer will help victims lead a physically and mentally healthy life and encourage them to restore order to their lives. For public facilities to regain their original function, government-funded temporary dwellings must be provided, and regional-based supply by private sectors and self-reconstruction by victims themselves are needed.

An important point is that temporary shelters should be barrier-free houses for the elderly and disabled. In particular, government-funded temporary shelters must acknowledge this need. This content can be summarized into the following areas.

1) Promotion of integrated maintenance and layout of local government offices, police stations, fire stations, and designated schools as administrative centers for disaster mitigation
2) Promotion of integrated maintenance and layout of community facilities, such as schools, community centers, and parks, for emergency use as evacuation centers
3) Establishment of various and diversified systems to supply government-funded temporary houses on a community basis
4) Promotion of layout and supply of barrier-free temporary dwellings

A.5 Preservation and Restoration of Cultural Assets including Historical Structures: The Earthquake revealed that cultural assets including historical structures and streetscapes are also vulnerable to earthquake disaster. The restoration of damaged historical monuments and cultural properties is crucial and should be promoted, along with preservation of cultural assets and the promotion of disaster mitigation.

The local landscape, the “living” culture so to speak, and local cultural assets were also damaged during the Earthquake. Although most of these sites are not designated as national cultural assets and are rather common, people in the respective community treasure them because they provide a healthy living environment and remind neighbors of being a member of the community. Equal importance should be placed on the rapid restoration of those sites, similar to the importance placed on historical monuments.

Urban development must include a system to facilitate restoration of structures ranging from historical assets as national or prefectural cultural properties to residential houses forming the local streetscape. Furthermore, research on improving seismic performance should be promoted. The content can be summarized into the following areas.

1) Promotion of research on improving seismic performance of historical structures and establishment of disaster mitigation measures
2) Correct understanding of distribution and characteristics of local “living” cultural assets and heritage, excluding designated cultural properties
3) Establishment of support systems to reconstruct and preserve the local streetscape that forms the character of the community

B. Earthquake-resistant Measurements for Existing Inadequate Structures

Based on the bitter experience of past disasters and the subsequent research on disaster mitigation, structural design codes have been repeatedly amended. For effective enforcement, the seismic design code of the Building Standard Law of Japan has been revised on a case-by-case basis.

The Earthquake caused severe damage, including collapse of numerous buildings. Many of the most heavily damaged structures were existing inadequate structures that did not meet the present structural standard code, nor did they have sufficient seismic performance to have met the standard even at the time when they were built. Degradation in seismic performance due to aging and inadequate construction methods caused the destruction of some of those structures.

In recent years, seismic performance evaluation and retrofit of existing public facilities designated inadequate have been promoted. Those earthquake-resistant measurements were also offered to private buildings. However, the offer was not effective because laws were not usually retroactive, except for large-scale rehabilitation that needs a legal permission. Therefore, many inadequate structures remain.

In addition, it is difficult to extensively repair and reconstruct damaged inadequate structures because other regulations, such as the volume-site ratio for the building , have been revised to exempt those structures.

Consequently, large-scale restoration projects, including seismic reinforcement of structures in areas other than the damage areas, are difficult to implement.

It is therefore urgent to develop earthquake-resistance measurements for existing inadequate structures. To avoid repeating the tragedy, the following measures should be realized.

B.1 Improvement in Seismic Performance of Existing Inadequate Structures: Promoting improvement in seismic safety is urgently needed for structures without reconstruction (i.e., structures that do not legally satisfy the structural codes) and facilities with poor seismic capacity. This requires the following items.

1) Enlightening the public about improvement in the seismic performance of existing structures and about fostering of technical experts
2) Development and standardization of seismic diagnosis and the technology for retrofitting, reinforcement, and maintenance of existing structures.
3) Repair and retrofit of damaged existing structures
4) Improvement in seismic performance of existing structures designated as critical facilities for disaster mitigation
5) Enriching the public organizations and institutions, including subsidies, low-interest rates, and tax incentives for seismic diagnosis and seismic reinforcement

B.2 Clarification of Measurements for Reconstruction and Restoration of Existing Inadequate Structures: Some damaged structures that need major restoration or reconstruction with seismic reinforcement either cannot be reconstructed or reconstruction must be postponed because they are designated as existing inadequate structures and therefore do not meet the codes regulating, for example, the floor-to-area ratio. In other damaged structures, reconstruction is difficult because their conformation cannot meet the regulations for fire safety or evacuation.

For urban seismic safety and fire-resistance, clarification of the legal measures for reconstruction of damaged structures is urgently needed.

1) Legal clarification of measures for the reconstruction of existing inadequate structures that do not meet codes regulating, for example, the floor-to-area ratio
2) Investigation of measures to secure fire and evacuation safety, whether legally adequate or not, and the review of legal managements

C. Development of a Design Method to Clarify Seismic Performance

Based on the review of the damage to structures by the Earthquake, the present seismic design code played a significant role in preventing severe damage to structures. Unfortunately, some structures sustained more serious damage than expected, despite being built after the enforcement of the present seismic design standard law.

RC buildings with pilotis were heavily damaged on the first floor, where the major displacement was concentrated because of imbalance in rigidity and strength between floors. SRC buildings were mainly damaged by brittle failure in and around welding joints. Some buildings had pile damage, and some suffered damage to nonstructural members that was unexpectedly expensive to repair but was not fatal to the structure. Due to damage, some facilities critical for disaster mitigation could not function after the Earthquake.

Damage occurred because the present design and construction methods do not consider the integrated seismic performance of finished buildings. During the Earthquake, strong motion records were obtained, although the total number of records was too small to determine the magnitude of the average earthquake motion or the amplification of local earthquake motion. In order to improve disaster prevention and mitigation measures, the number of strong ground motion records needs to be increased.

In the long term, seismic design methods of performance indication systems must be researched and developed. In the short term, current design and construction methods must be updated and widely disseminated.

C.1 Maintenance of the Present Seismic Design Methodology: Seismic design methods are successful only when they are based solely on preventing the building from collapsing against an earthquake whose return period of earthquake occurrence like the Earthquake is quite long. However, urgent measures for the following problems are required.

1) Measures to improve seismic performance of structures that have an imbalance in rigidity and strength distribution
2) Maintenance of function performed by structures critical for disaster mitigation
3) Promotion of structural design with a high tolerance

C.2 Upgrading the Construction and Administration Methodology: Adequate seismic performance level of a building can only be achieved by coordination among the design method, construction method, and administration system as follows.

1) Establishment of a quality control system that includes inspection by a third-party
2) Strict control for compliance with the related regulations on quality control of materials and building construction supervision

C.3 Development of a Seismic Design Method with a Seismic-performance Indication System: Seismic performance must be set at a high standard, and an evaluation method for this performance must be established. A design method must be developed and implemented in which the target design performance is clearly specified. This target design performance should be incorporated in the seismic zone factor by considering the risk of earthquakes, ground conditions, and topography. Furthermore, diversified safety levels to meet various requirements also must be established. Efforts by the industrial, government, and academia sectors should agree on the target criteria and safety levels that meet various requirements. To accelerate the agreement procedure, every standard and criterion in the structural design and construction should be reviewed and regulated to maintain compatibility.

Basic research on ground motion should be promoted, such as research on seismic design that considers characteristics of the earthquake motion near active faults and research on the earthquake response with brittle failure as follows.

1) Development of a design method that has a performance indication system and establishment of a performance evaluation method
2) Clarification of design criteria in response to performance level (target design performance)
1) 3) Establishment of performance levels to meet various requirements
4) Establishment of zoning, especially micro zoning
5) Promotion of research on ground motion in seismic design and structural response

C.4 Upgrade the Seismic Design Method for Structural Foundations: The objective of seismic design for structural foundations is to prevent soil liquefaction on soft ground, such as landfills and waterfront areas. Although both the design method for the superstructure and a suitable design method for the structural foundation to support the superstructure are crucial, design methods must be updated to include ground improvement and development of new technology for preventing soil liquefaction. Measures for the following items are required.

1) Development of a seismic evaluation method for structural foundation and establishment of a restoration and reinforcement method
2) Implementation and development of new technology to improve soft ground

C.5 Development of a Seismic Evaluation Method for Equipment and Nonstructural Members: Safety levels must be maintained for equipment, elevators, and nonstructural members, including exterior materials. The seismic design method for these items must be reviewed to determine if they need updating. Measures for the following items are required.

1) Clarification of seismic performance for nonstructural materials and equipment, including elevators
2) Development of measures to secure the targeted performance and to prevent furniture and other interior furnishings from falling

D. Establishment of a Disaster Information System

Areas damaged by the Earthquake had great difficulty in ascertaining the post-earthquake situation because communication was disrupted. No urban information database was available to serve as a basis for rescue activities and restoration plans. For urban disaster mitigation, disaster information systems must be established and then put into practical and appropriate use.

D.1 Maintenance of a Disaster Information Network: When a disaster occurs, collecting information to ascertain the extent of the damage is one of the most urgent tasks. Effective layout of public facilities to handle this information and to maintain a communication network is essential. A system to determine the reliability of this information must also be established. Measures for the following items are required.

1) Effective layout of public facilities to collect information on a national basis
2) Maintain the information network against disaster
3) Determine a strategy to obtain reliable information at an early stage in the post-earthquake period
4) Establish a telecommunication and management plan to secure information reliability

D.2 Systematize Urban Information Data: For disaster mitigation, urban information data, including distinctive topography, ground, roads, and lifeline systems, and data on buildings and residents should be obtained by using a geographic information system (GIS). Such data should be stored in a database. A real-time disaster mitigation system needs to be developed that facilitates appropriate initial response and supports restoration plans. With this system, rapid evaluation of damage based on seismic information is possible, and thus help determine possible countermeasures. Measures for the following items are required.

1) Collection of relevant information and data
2) Setting up of an urban information database
3) Development and application of a real-time disaster mitigation system

D.3 Utilization of Information Systems Based on the Principle of Information Disclosure and Sharing: Sufficient information about the damage is crucial to determine countermeasures against post-disaster destruction and future disaster mitigation. Information disclosure and sharing should be generally permitted among researchers and organizations in each relevant field. Measures for the following items are required.

1) Disclosure and sharing of information
2) Mutual collaboration among organizations in an emergency
3) Development and utilization of information system technology to support disclosure and sharing
4) Education and training on the disaster information system

E. Promotion of Basic Research on Disaster Prevention and Disaster Mitigation

Long-term experience and test results have gradually developed the research on disaster prevention and mitigation. In this research field, epoch-making discoveries are rare. More commonly, the procedure is that basic research develops into advanced research that can be applied to building construction and urban design. Researchers achieve significant success only after that process. Because demonstrating the benefits of research results is difficult, gaining public understanding about the investment in basic research for disaster mitigation is also difficult.

The promotion of disaster mitigation measures, however, depends on the continual basic research.

Realization of all the above proposals requires strong and continuous support on both national and municipal government levels, and requires support for the researchers involved.

The committee calls for greater understanding in the promotion of basic research on disaster prevention and mitigation.

Second proposal by AIJ

The second proposal by AIJ (made in January 1997) was titled "*Proposals of Reconstruction of the Stricken Area and the Improvement of Disaster Prevention of Cities –Reflecting the Hanshin –Awaji Earthquake Disaster* ". The following are the proposed items in brief.

Restoration of Damaged Areas

Proposal 1 Implementation of diversified, public support
Proposal 2 Analysis of damage details and implementation of restoration assessment
Proposal 3 Systematic maintenance of disaster mitigation infrastructure based on the waterway of greenery in the natural environment and formation of residential environment
Proposal 4 Promotion of integrated housing reconstructive program
Proposal 5 Development of new restoration technology in mixed-areas of residential, industrial, and commercial sectors

Support System to Encourage Victims to Restore Order to Their Lives

Proposal 6 Establishment of temporary restoration program for damaged housing
Proposal 7 Establishment of waste-disposal credit system
Proposal 8 Establishment of system encouraging the construction of emergency temporary dwellings for promotion of urban restoration
Proposal 9 Establishment of housing credit system for victims
Proposal 10 Maintenance of system allowing victims a certain level of living standard and daily activity in evacuation centers or emergency temporary dwellings

Response to a Disaster and System Establishment to Secure Safe Evacuation

Proposal 11 Preservation of life-saving large-area evacuation plan and extensive evacuation site
Proposal 12 Maintenance of community-based network linking public facilities for disaster mitigation
Proposal 13 Establishment of system to utilize vacant lots for emergency relief activities
Proposal 14 Improvement of disaster mitigation performance and self-reliant performance of emergency relief facilities as administrative centers in the post-disaster period
Proposal 15 Development of environmental standards and performance for emergency temporary housing and system for flexible utilization

Urban Disaster Mitigation in Areas Densely Packed with Wooden Structures

Proposal 16 Establishment of urban development system based on the participatory approach and autonomy in the community and storing the survey results of the vulnerability of each community
Proposal 17 Preservation of roads for disaster mitigation activities and safe evacuation in urban areas densely packed with wooden structures
Proposal 18 Promotion of retrofit of existing wooden structures as a disaster mitigation program
Proposal 19 Strict control of reproduction of urban areas densely packed with wooden structures
Proposal 20 Establishment of integrated residential environment laws for urban areas densely packed with wooden structures

Third proposal by AIJ

The third proposal by AIJ (made in January 1998) was titled "*Proposals on the Improvement of Disaster Prevention of Buildings and Cities* ". The proposed items were published in English in 1998 by AIJ [3)]. The following are the proposed items in brief.

Improving the Earthquake Resistance of Buildings

A.1. Establishment of rules for selecting earthquake-resistance level
A.2. Introduction and propagation of performance-based earthquake-resistant design
A.3. Selection of earthquake ground motion for earthquake-resistant design
A.4. Scheme to ensure comprehensive seismic capacity
A.5. Constructing a social system that ensures earthquake resistance
A.6. Scheme for improving the seismic performance of existing non-conformant buildings for current seismic codes
A.7. Preservation and rehabilitation of historical/cultural buildings

Promotion of Earthquake-resistant City and Community Planning

B.1 Forming disaster-prevention urban structures
B.2 Disaster preventing community planning for built-up area densely crowded with wooden structures
B.3 Community planning for resistance to earthquake disasters
B.4 Preservation of historical townscape with consideration to disaster prevention
B.5 Establishment of earthquake-disaster information systems

Emergency Measures during an Earthquake, Restoration of Living Standards of Victims, and Reconstruction of Stricken Area

C.1 Emergency measures and evacuation system during an earthquake disaster
C.2 Systematization of support systems for emergency dwellings for victims
C.3 System for reconstructing an urban district

Promotion of Research and Technology of Prevention and Mitigation of Earthquake Disasters

D.1 Promotion of basic research on improvement of earthquake resistance
D.2 Technology development of seismic-resistance evaluation and seismic improvement
D.3 Research and development of on-time disaster-prevention system technology
D.4 Research and development of community-wide planning of disaster prevention and urban reconstruction
D.5 Research on financial resources and taxation systems related to disaster prevention measures

First proposal by JSCE

The first proposal by JSCE (made in May 1999) was titled "*The First Proposal on Earthquake Resistance for Civil Engineering Structures*". The following are the proposed items in brief.

1. Introduction
2. Fundamental Observation of Earthquake Motions of the 1995 Hyogoken-Nanbu Earthquake
3. General Perspective on the Current Seismic Design Standard through the Damage to Civil Engineering Structures
4. Proposals for Seismic Design Standards
5. Promotion of Research and Development

Second proposal by JSCE

The second proposal by JSCE (made in January 2000) was titled "*Second Proposal on Earthquake Resistance for Civil Engineering Structures*". The following are the proposed items in brief.

1. Earthquakes and Earthquake Motions that Need to be Considered in Seismic Design
2. Seismic Design Method
3. Seismic Performance Evaluation and Retrofit of Existing Structures

4. General Seismic Safety Plan

Third proposal by JSCE

The third proposal by JSCE (made in June 2000) was titled "*Third Proposal on Earthquake Resistance for Civil Engineering Structures*". The following are the proposed items in brief.

1. Establishment of Infrastructural Systems against Earthquake Motions and Seismic Performance of Civil Engineering Structures
2. Level II Earthquake Motions for Seismic Design
3. Ground Liquefaction and Ground Displacement
4. Seismic Performance and Design Method for Steel Structures
5. Seismic Performance and Design Method for Concrete Structures
6. Seismic Performance and Design Method for Foundation and Soil Structures
7. Seismic Performance Evaluation and Retrofit of Existing Structures
8. Promotion of Research and Development of New Technologies

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This overview of the Earthquake and proposals is based on reports published by AIJ and JSCE, and portions of the overview and certain photographs are quoted from the reports listed in references [1-3]。 We sincerely thank all of the people involved in preparing the reports and proposals, and thank all members of the Committee for the Report on the Hanshin-Awaji Earthquake Disaster.

REFERENCES

1) Report on the Hanshin-Awaji Earthquake Disaster, Compendium of Earthquake Disaster including Stochastics Description (in Japanese), general issues vol.1, Architectural Institute of Japan (AIJ) , 2003
2) Report (in middle stage) on the Heisei-7 Hyogo–ken Nanbu Earthquake Disaster Investigation (in Japanese), Building Research Institute (BRI), Ministry of Construction (MOF), 1995
3) Leaflet: Proposals on the Improvement of Disaster Prevention of Buildings and Cities –Reflecting the Results of the Hanshin –Awaji Earthquake Disaster, AIJ, 1998

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