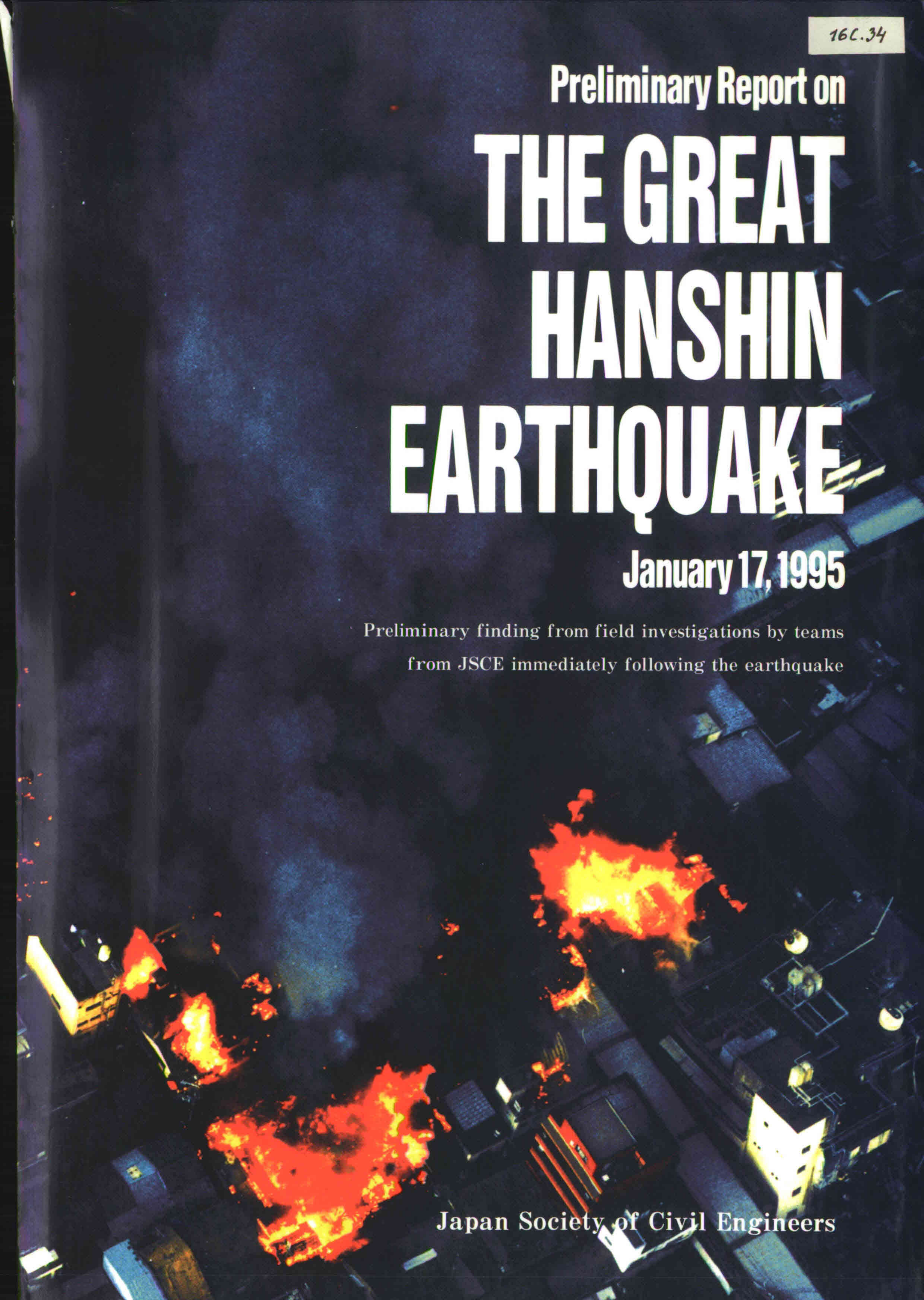
Preliminary Report on

THE GREAT HANSHIN EARTHQUAKE

January 17, 1995

Preliminary finding from field investigations by teams
from JSCE immediately following the earthquake



Japan Society of Civil Engineers

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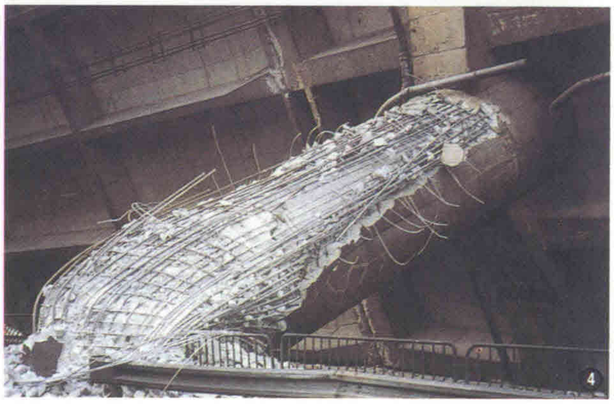
Report on the Damage due to the Hyogoken-Nanbu Earthquake

Around 5.46 a.m. on 17th January, 1995, the Kinki Region of Japan was struck by a *chokka-gata* (directly-below-land type) earthquake registering a magnitude of 7.2, with its hypocentre approximately 20 km below the northern part of Awaji Island (34.6° north, 135.0° east). The earthquake caused serious damage throughout the Kinki Region including a great number of deaths and injuries. As an emergency report, the conditions of the damage, mainly to engineering structures, are illustrated here with photographs.

Editorial Board, Journal of Japan Society of Civil Engineers

Expressways

<Hanshin Expressway Route 3 (Kobe Route): in Higashinada-ku, Kobe City>



<Hanshin Expressway Route 3 (Kobe Route): near Nishinomiya Interchange, Nishinomiya City>

With our heartfelt condolences to all those affected by the Hyogoken-Nanbu Earthquake, and our prayers for their early recovery from the disaster

January 1995 Japan Society of Civil Engineers

<Hanshin Expressway Route 3 (Kobe Route): near Nishinomiya Ebisu Shrine, Nishinomiya City>

<Meishin Expressway: near Nishinomiya Barrier, Nishinomiya City>

<Hanshin Expressway Route 5 (Coastal Route): Nishinomiya Bridge, Nishinomiya City>

Railways:
Shinkansen

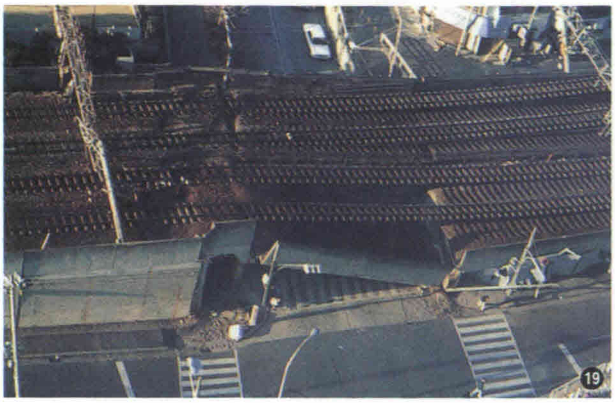
<Sanyo Shinkansen Line: at Noma, Itami City>

<Sanyo Shinkansen Line: at Shimokema, Amagasaki City>

<Sanyo Shinkansen Line: at Kamioichi, Nishinomiya City>

Railways:
Non-Shinkansen Lines

<JR Tokaido Line: between Rokkomichi and Nada, Kobe City>



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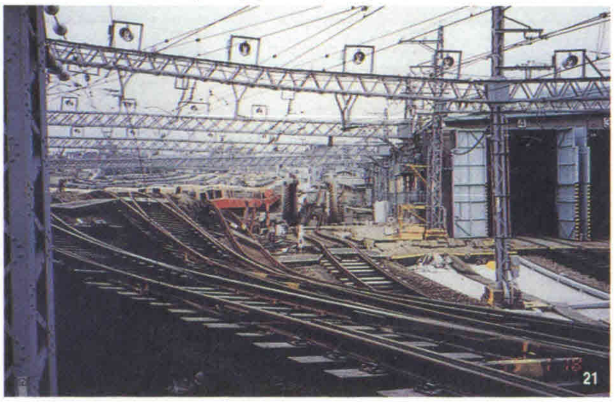
<JR Tokaido Line: between Sumiyoshi and Rokkomichi, Kobe City>

20

<Hanshin Electric Railway: Ishiyagawa Depot, Higashinada-ku, Kobe City>



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<Hanshin Electric Railway: Stub track at Mikage, Higashinada-ku, Kobe City>

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<Hanshin Electric Railway: between Shinzaike and Ishiyagawa, Kobe City>

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<Hanshin Electric Railway: between Oishi and Shinzaike, Kobe City>

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<Hankyu Railway: Itami Station, Itami City>

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Port Facilities etc.

<Container berth on Rokko Island, Kobe City>

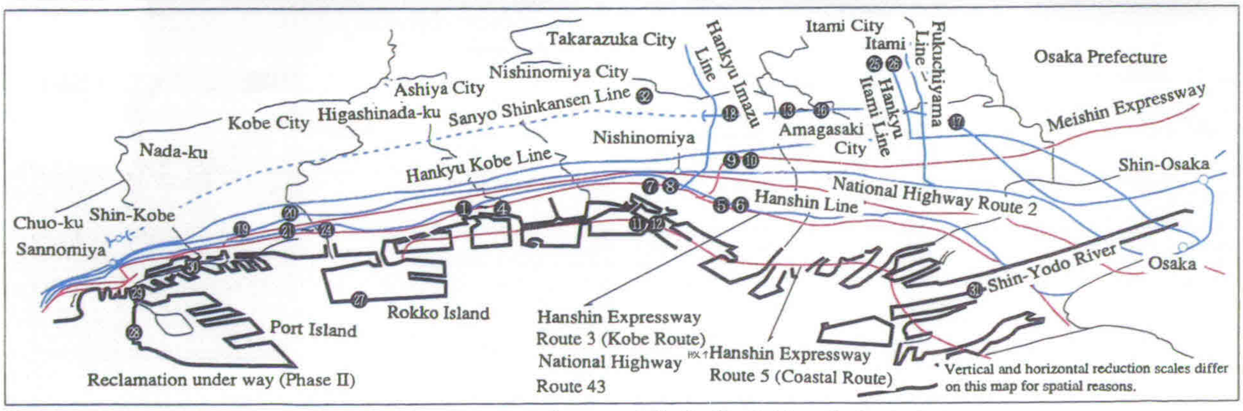
<Container berth on Port Island, Kobe City>

<Port Terminal access to Kobe Bridge, Kobe City>

<Maya Bridge, Kobe City>

<Near the mouth of Shin-Yodo River, Torishima, Konohana-ku, Osaka City>

<Landslide at Nigawa, Nishinomiya City>



Photographs by courtesy of Asia Air Survey Co. (No. 1, 13, 25), Ministry of Transport and Hanshin Electric Railway Co. (No. 21, 22, 23, 24), Ministry of Transport and West Japan Railway Co. (No. 17, 18, 19, 20), Ministry of Transport (No. 28), National Land Agency (No. 29)

* We apologise to our readers for the delay caused in the publication of our February Issue by the insertion of this "Emergency Report."

Preliminary Report on
THE GREAT HANSHIN EARTHQUAKE
January 17, 1995

Preliminary finding from field investigations by teams
from JSCE immediately following the earthquake

Japan Society of Civil Engineers

PREFACE

The Japan Society of Civil Engineers (JSCE) received in an extremely serious light the severe damage to various infrastructures, caused by the Hyogoken-Nanbu Earthquake, which occurred in early morning of 17th January. It immediately took the step of organising investigation teams and dispatched them to the disaster area with the aim of elucidating the causes of the damage and thus contributing to the progress of seismic engineering and to the implementation of disaster prevention measures.

On the day following the occurrence of the earthquake, the First Study Team, headed by Prof. Jushiro Tamura of Nihon University, chairman of the JSCE Committee on Seismic Engineering, and consisting mainly of researchers in seismic engineering and structural mechanics, was sent to the area for an emergency survey of the damage to the infrastructures. This was followed by the formation and dispatch of the Second Team, headed by me (Prof. Hideo Nakamura of the University of Tokyo), on 22nd January, for a comprehensive survey of the structural and functional damage to and progress of restoration work on railways, roads, port facilities and lifeline utilities.

This emergency symposium is being held to provide an opportunity for making brief presentations of the findings of these two study teams. The damage was so extensive to a variety of structures and so broadly spread one different areas, the further detailed studies and analyses will be required before any firm conclusions may be drawn on many of the items studied. The views presented here are, in a large number of cases, not consensual description by the Society, but the opinions of individual members of the study teams. However, I am sure that it is our duty to hold an emergency symposium and to make known to the public the findings as quickly as possible.

To continue with the surveys on the damage and restoration work, a Third Study Team, headed by Prof. Minoru Matsuo of Nagoya University, was sent to the disaster area on 1st February. The JSCE will take steps to report the findings of this and subsequent study teams at the earliest date possible. In addition, the JSCE will conduct detailed and systematic studies and analyses of the survey results, and present its findings to the public both in Japan and abroad in the form of a “Report of the Study on the Great Hanshin Earthquake”.

As members of the JSCE, we intend to devote the maximum amount of effort possible to restoration and reconstruction work in this wake of the earthquake and to the reduction of potential damage in future earthquakes. We entreat all those concerned to favor us with their cooperation and support to these ends.

8th February, 1995

Hideo Nakamura
President,
Japan Society of Civil Engineers

Preliminary Report on THE GREAT HANSHIN EARTHQUAKE

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BRIEF REPORT BY THE FIRST SURVEY TEAM ON THE DAMAGE CAUSED BY THE GREAT HANSHIN EATHQUAKE

(JANUARY 18 TO 20, 1995)

Earthquake Motion

Kenzo Toki, Engineering Department, Kyoto University

An earthquake of Magnitude 7.2 having its epicenter in the vicinity of the Akashi Straits occurred at 5:46 am on January 17, 1995. That the motion of this earthquake was severe to an extreme, causing the death of many people, is now a well known fact.

Figure 1 shows the distribution of active faults in the Kobe vicinity.(1) Numerous active faults exist in the Kansai region, including the Rokko Fault System, the Ikoma Fault System, the Arima-Takatsuki Tectonic Line, the Hanaori Fault System and the Yamazaki Fault System, and the risks has been pointed out by seismologists for some time past.(2) However, no actual prediction had been made. Figure 2 shows the focal mechanism of the earthquake. It can be seen that a right lateral strike slip occurred in the Rokko Fault System although it is thought that the vertical component of motion was predominent. Figure 3 shows the distribution of aftershocks, from which it is clear that movement in the Rokko Fault System was undoubtedly the cause of the earthquake. As Kobe is a city which has been built directly above the Rokko Fault System and it was the Rokko Fault System which became active this time, the earthquake occurred directly beneath the city.

In the Kansai region, the Kansai Earthquake Observation and Research Committee was established in December 1992 as an organization for cooperation between government, private enterprise and scholars for the purpose of achieving mutual utilization of observation records individually possessed by the members, and to establish new high precision seismic observation points to be jointly owned by the Committee at 10 locations in the Osaka Plain and surrounding area. These new observation points have been in operation since April 1994.(3). Figure 4 shows the velocity waves observed by the committee. The Kobe University Observation Point recorded a maximum horizontal velocity of 55 cm/sec in the north-south direction. At this observation point the seismic observation system is located at a depth of approximately 10m below the ground surface within a tunnel having a square cross section of about 3m wide. No remarkable damage occurred within the Kobe University campus and condominiums in the close vicinity remain in good condition, but damage to wooden houses becomes apparent approximately 400m south of here, and further south the area around the Japan Railway Rokkomichi Station is the site of great damage including damage to the railroad's elevated structure. On the other hand, at the Kobe-motoyama Observation Point the maximum scale reading of 40 cm/sec was exceeded in all three components. No remarkable damage is to be seen in the vicinity of this observation point, but south of the JR line, which is about 200m south of here, the situation changes completely, with collapsed buildings and houses to be seen. At the Amagasaki Observation Point also, the horizontal components exceeded 40 cm/sec, indicating that a considerably large earthquake motion occurred over a wide area. The distribution of maximum acceleration obtained by differentiating these velocity waves is shown in Figure 5. The distribution of maximum acceleration observed by other organizations is shown in Figure 6.

References

(1) Active Fault Research Committee. 1991. Active Faults in Japan. Tokyo University Press. (in Japanese)

(2) E.g., Ishikawa, Y. 1990. Seismicity Gap in Interior Areas of the Japanese Islands. Monthly Earth, Vol.12, No.6. (in Japanese)

(3) Kansai Earthquake Motion Observation and Research Committee., 1994. Earthquake Observation by the Kansai Earthquake Motion Observation and Research Committee. Proc. Fall 1994 Conf. of Seismic Society 230-231. (in Japanese)

Fig. 1 Active Faults in the Kobe Vicinity

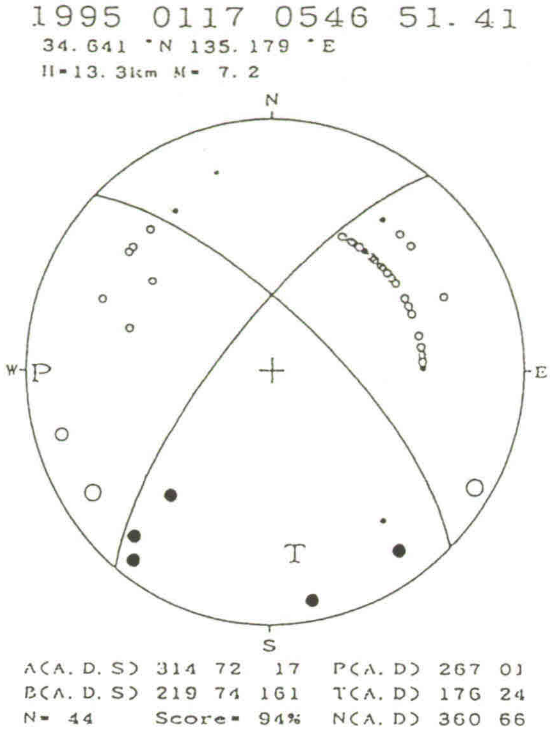


Fig. 2 Focal Mechanism Obtained from Primary Wave
(Prepared by Kyoto University Disaster Research Institute from data provided by Kyoto University and Nagoya University)

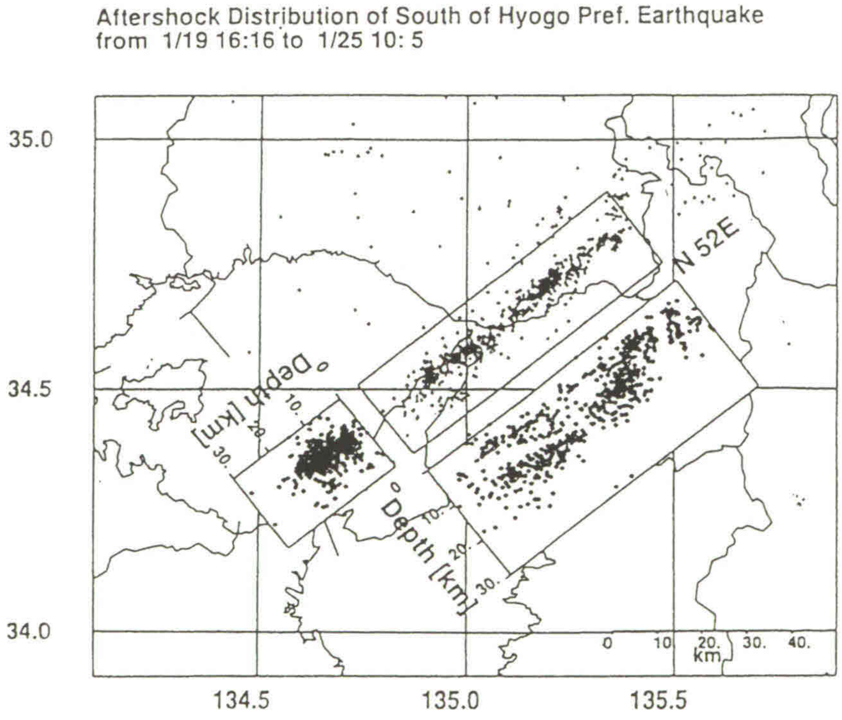


Fig. 3 Distribution of Aftershocks
(Prepared by Kyoto University Disaster Research Institute)

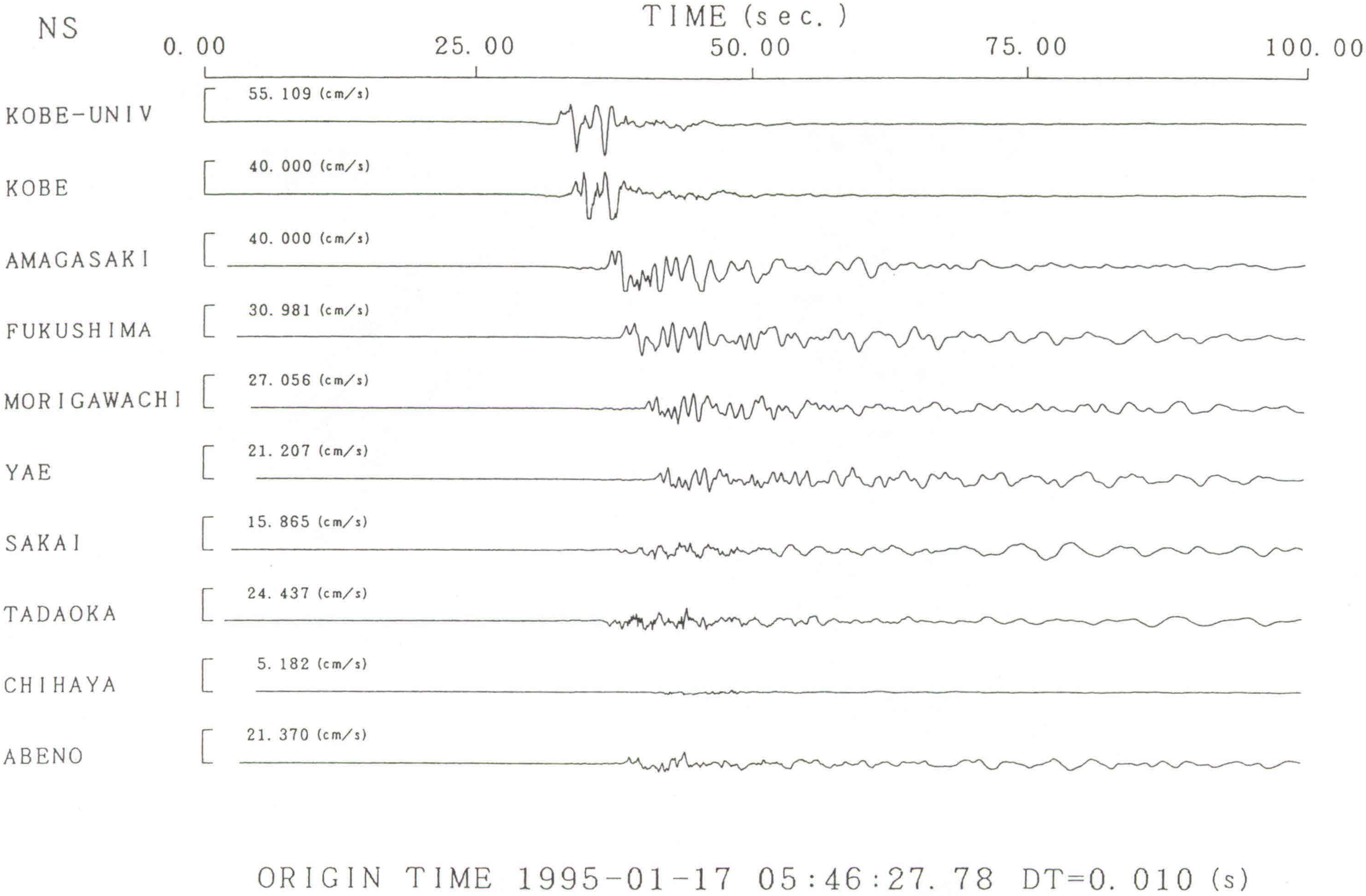


Fig. 4 (a) Velocity Waves Observed by Kansai Earthquake Motion Observation and Research Council (NS Component)

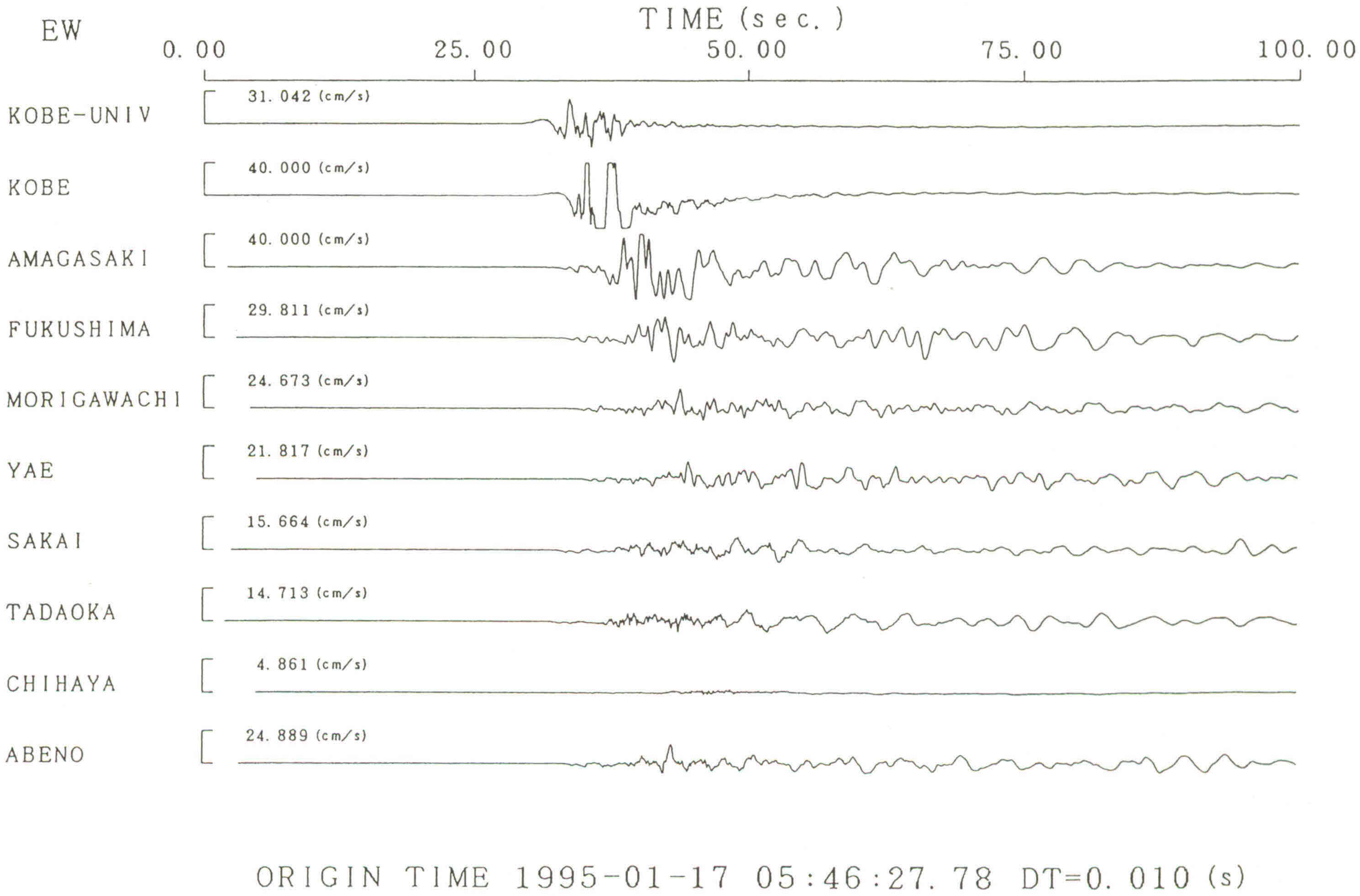


Fig. 4 (b) (EW Component)

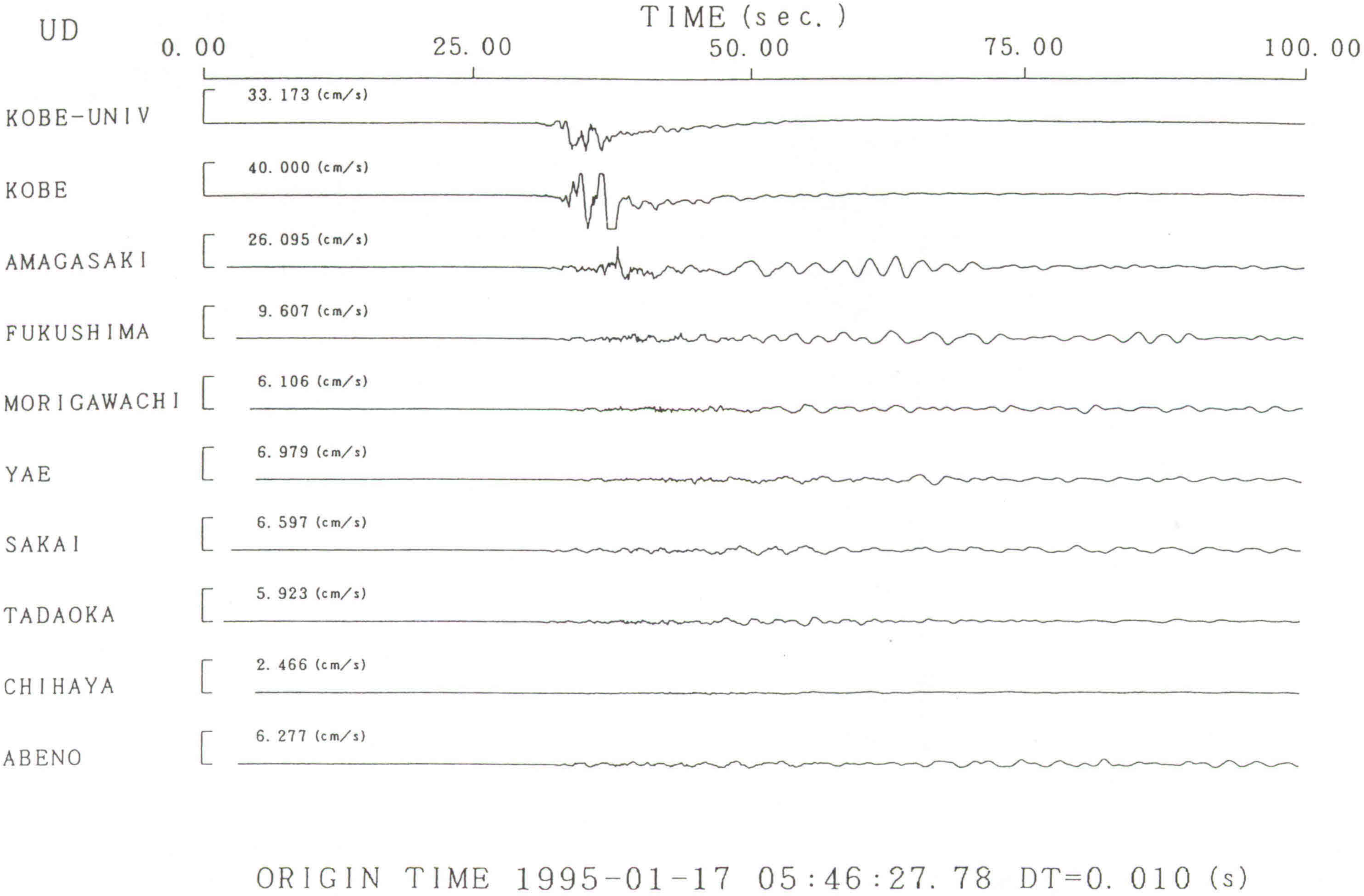


Fig. 4 (c) (UD Component)

Seismic Observation Points of Kansai Earthquake Motion Observation and Research Council

Organization of Kansai Earthquake Motion Observation and Research Council

MembersP 24 university researchers, Kansai Electric Power Co., Osaka Gas Co., Nikken Sekkei, Hanshin Consultants, Hanshin Expressway Public Corp. Management Technology Center, Obayashi Corp., Kajima Corp., Kumagai Gumi Co., Konoike Construction Co., Sato Kogyo Co., Shimizu Corp., Matsumura-Gumi Corp., Kansai Information Center, Osaka Soil Testing Laboratory

Cooperating Members: West Japan Railway Co., Osaka District Meteorological Observatory, Shiga Pref., Kyoto Pref., Osaka Pref., Hyogo Pref., Wakayama City, Kyoto City, Osaka City, Kobe City

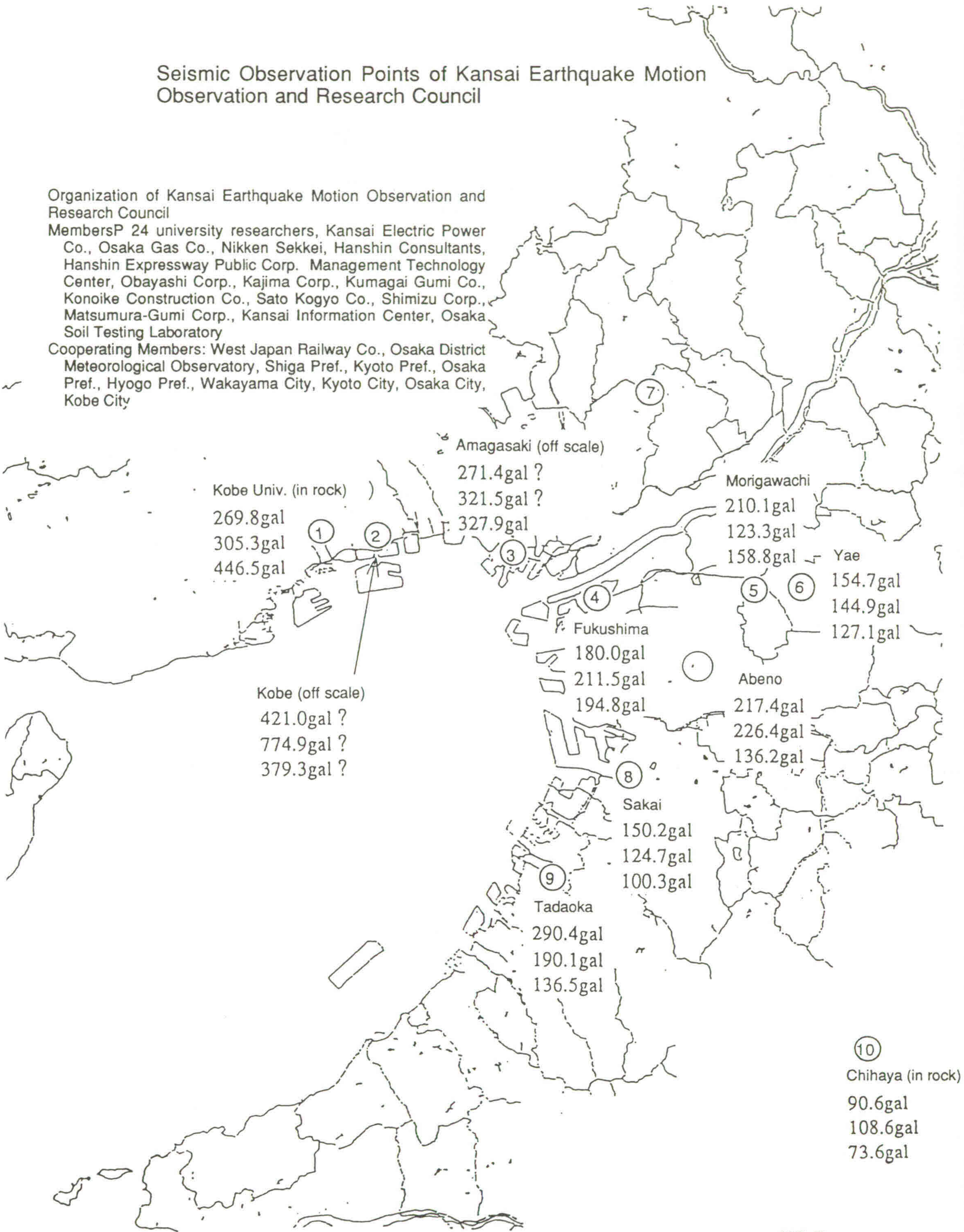


Fig. 5 Distribution of Maximum Acceleration Obtained from Velocity Waves Observed by Kansai Earthquake Motion Observation and Research Council

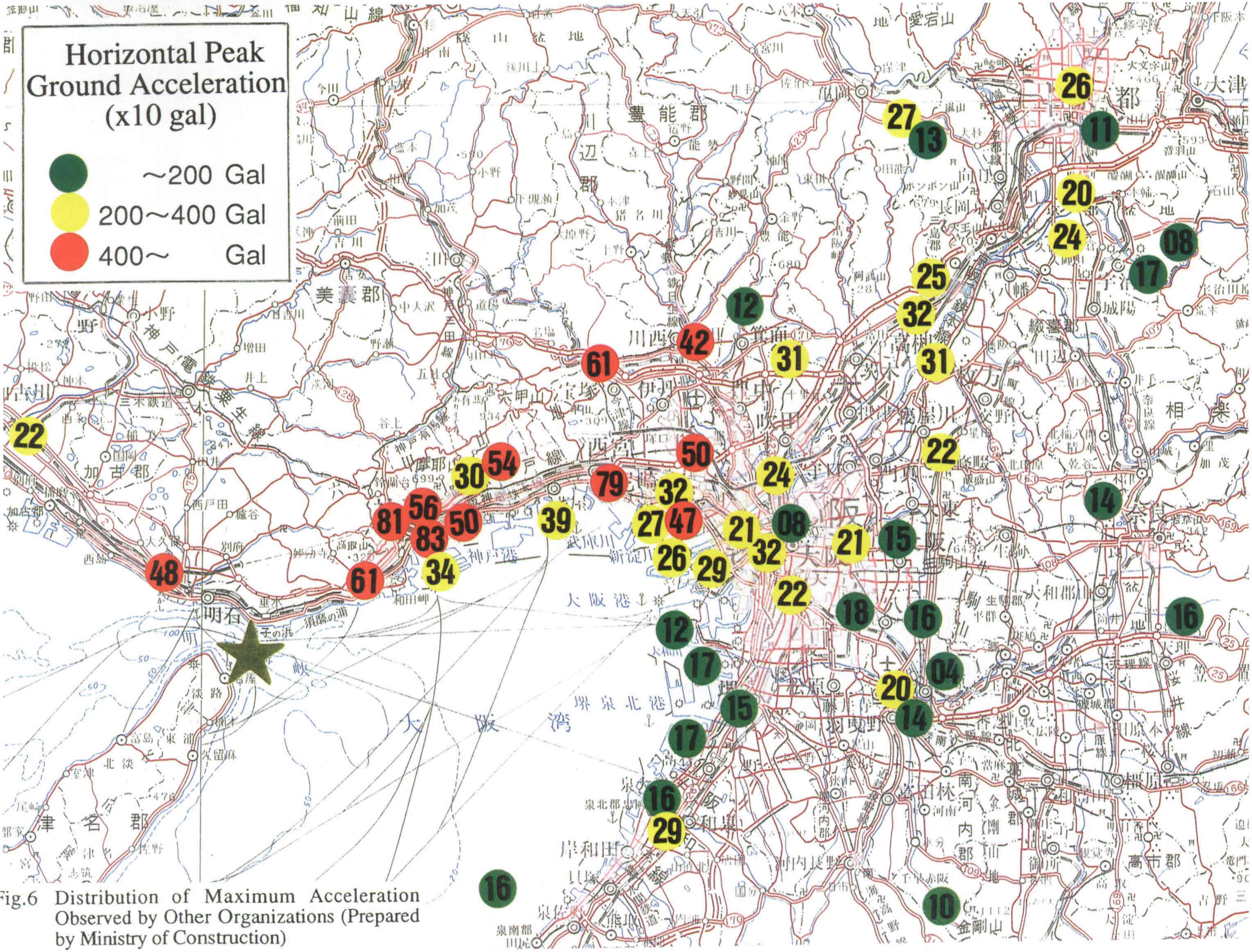


Fig.6 Distribution of Maximum Acceleration Observed by Other Organizations (Prepared by Ministry of Construction)

Ground Damage in Coastal Areas

Kenji Ishihara, Faculty of Engineering, The University of Tokyo
Susumu Yasuda, Tokyo Denki University

1. GEOLOGICAL OUTLINE

The city of Kobe has developed in an area of thick diluvial and alluvial deposits south of the steep flank of the Rokko mountain range. The disaster-stricken area is a long, narrow belt of land about 3 km in width and 30 km long. Topographically, this area can be categorized into the alluvial fans at the foot of the mountains, diluvial and alluvial deposits spreading outward to the south, and reclaimed lands in coastal areas.

The heavily damaged Port Island and Rokko Island were originally man-made by reclaiming the near-shore water area 12 to 15 m deep using decomposed granite quarried from nearby mountains during the periods of 1967-1981 and 1973-1992, respectively. The granite-based soil used for this reclamation work contained particles ranging widely in size, from gravel to silt. Figure 2 shows a typical particle size distribution of this reclaimed soil where it can be seen that the soil is composed of about 30% gravel, 50% sand, and 20% silt. The SPT N-value of the soil ranges from 5 to 20, but predominantly 5 to 10. The N-value of the alluvial clayey soil in the seabed underlying the reclaimed land was about zero to one. Various soil improvements were implemented before constructing foundations for structures on the islands with an aim of accelerating consolidation settlement. However, when viewed overall, most of the areas in the islands were left unimproved in any way.

2. DISTRIBUTION OF LIQUEFACTION

Figure 1 plots the locations where traces of sand boiling can be clearly seen in aerial photographs. In fact, liquefaction must have occurred more extensively than displayed on this map. Although the map does not cover the entire area, it is clear that liquefaction occurred extensively in reclaimed coastal areas, including the two reclaimed islands. Influences of liquefaction were manifested in four major forms: ground settlement in flat areas, damage to port facilities due to horizontal movement of the ground, damage to buried objects including lifelines, and damage to bridge piers on the coast.

3. OUTLINE OF DAMAGE TO RECLAIMED ISLANDS

The damage to Port Island can be classified roughly as destruction to quay walls around the shore and ground settlement over the whole island. Ground settlement of 20 to 50 cm was found extensively over the island, probably as a result of liquefaction. Photo 1 shows the head of a cast-in-situ concrete pile now protruding above the ground after the surrounding ground had settled. Piles, previously driven in and cut off at the head in preparation for future building construction, were found to be projecting about 50 cm above the surrounding ground. The foundations of high-rise apartments and warehouses behind the quay walls now protrude about 50 cm above the new ground level. The ground surrounding the foundations of the Shinkotsu monorail, which runs north-south across the island, has also settled by about 50 cm, as shown in Photo 2. The subsidence of the 12 to 15 m-thick layer of reclaimed soil by about 50 cm is equivalent to a one-dimensional compressive strain of 3% to 4%. Judging from the results of laboratory experiments on loose sand, this figure appears not unreasonable.

At container berths on the east and west shores and the liner berth on the east shore of Port Island, quay caissons moved seaward by about 2 to 3 m, with the aprons behind them caving in through a depth of 2 to 4 m. The cave-in took place about 10 m behind the revetment line over a belt zone about 10 m wide. Practically the whole length of quay walls along the periphery of the island were damaged in a similar fashion. Earthquake damage of this type has frequently been seen in the past, but its extent was much more severe in this case. The cause of the damage seems to have been an increase in lateral pressure and reduction in underlying fill material due to liquefaction and the extraordinary intense shaking during the earthquake.

On Rokko Island, quay walls along the periphery, except for one section on the south shore, suffered damage in a manner similar to that observed on Port Island. The central part of the island, however, suffered no liquefaction with much less damage to the ground.

4. EFFECTS ON BRIDGE FOUNDATIONS

On the coastal route of the Hanshin Expressway, a bridge girder fell off from the pier at one end of Nishinomiya Bridge. The pier was in close proximity to the quay wall retaining reclaimed land composed of gravel and sandy soils. Extensive liquefaction and cracking occurred with spurting and boiling of seabed sand. Quay walls adjacent to the pier moved about 2 m seaward, and the ground right behind subsided by about 1 m. The influence of this subsidence extended inland by about 30 m, and caused lateral ground movement. The bridge pier was located about 20 m inland from the revetment line of the quay walls. It appears that the lateral earthquake tremors were amplified by liquefaction.

Furthermore, the bridge pier must have undergone considerable lateral loading as a result of the ground tending to move laterally, as shown in Photo 3.

The arch-type Kobe bridge spanning between the Port Island and the city experienced a horizontal movement of about 50 cm at one free end of its support on the northern pier. The sliding on the free support appeared to accrue as a result of backfilled ground moving seaward by about 2 m. Due to its stiff structure, the main body of the bridge remained intact, whilst causing movement to the pier.

The two examples of damage described above to bridge piers adjacent to quay walls appears to demonstrate an issue of engineering significance; that is, a bridge abutment to be constructed in a waterfront area must be capable of withstanding lateral movement of the ground due to liquefaction.

5. CONCLUSIONS

The areas suffering heaviest liquefaction damage caused by this earthquake were the coastal areas, including two large artificial islands. The most prominent damage was to revetments and port facilities. There seems to be a need to improve the earthquake resistance of all waterfront facilities.

The widespread liquefaction of the ground caused by the earthquake was unprecedented in that it occurred in sandy ground containing gravel and silt. The well-graded material as described above has been deemed to be immune to the occurrence of liquefaction. However, the present earthquake demonstrated susceptibility of this type of soil to liquefaction under the action of intense shaking during a strong earthquake and resulting in settlements and lateral spread of the ground.

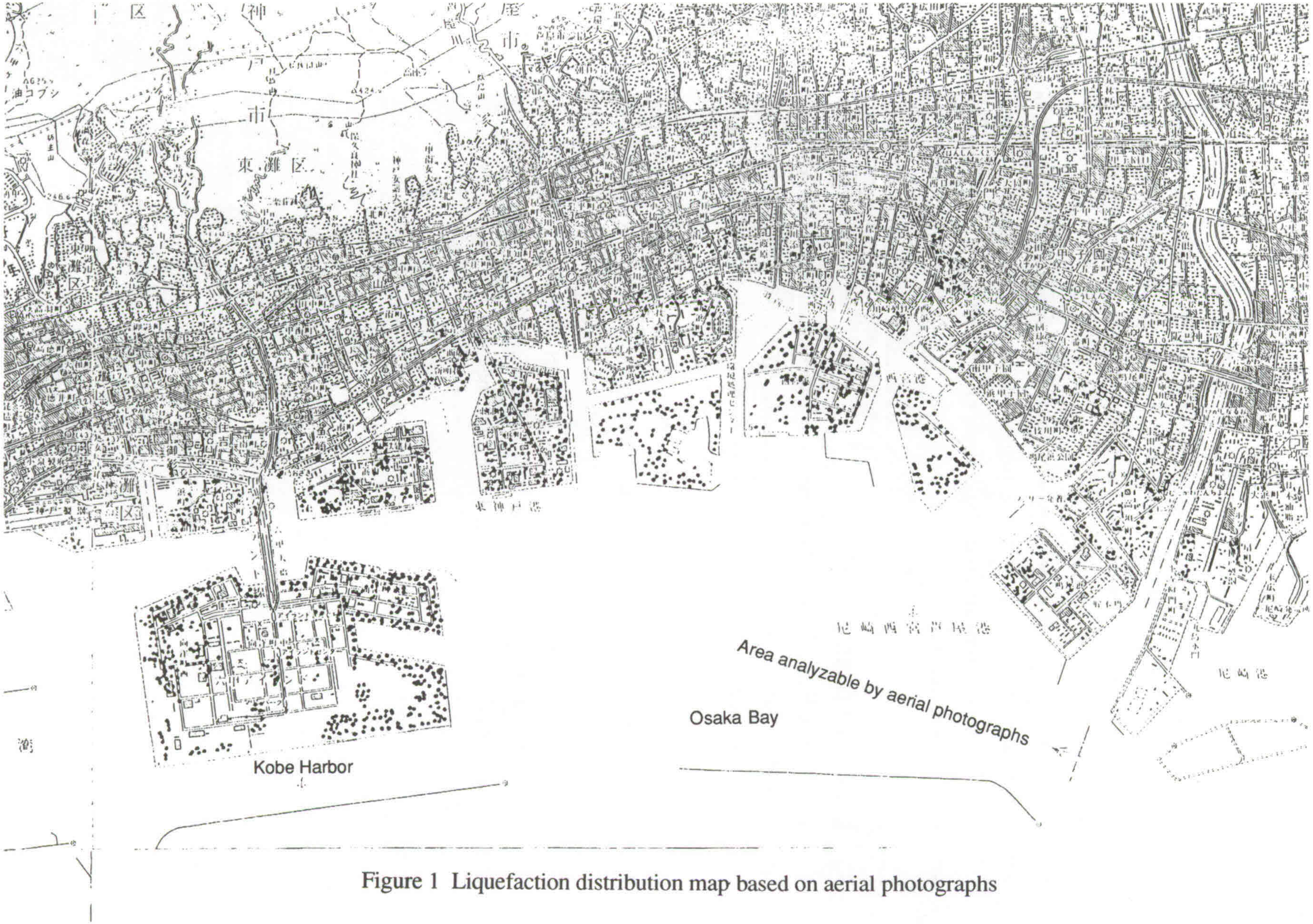


Figure 1 Liquefaction distribution map based on aerial photographs

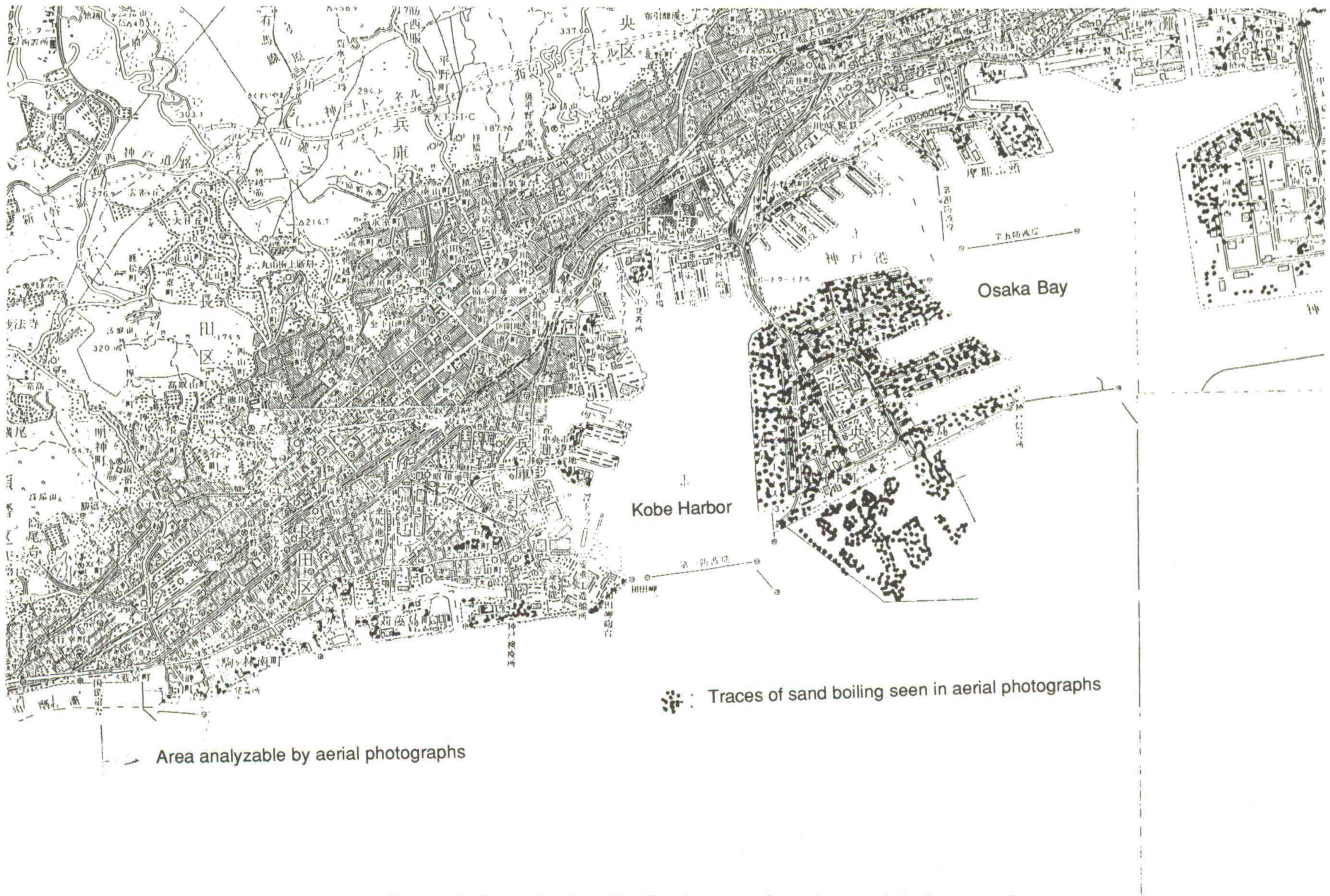


Figure 1 Liquefaction distribution map based on aerial photographs

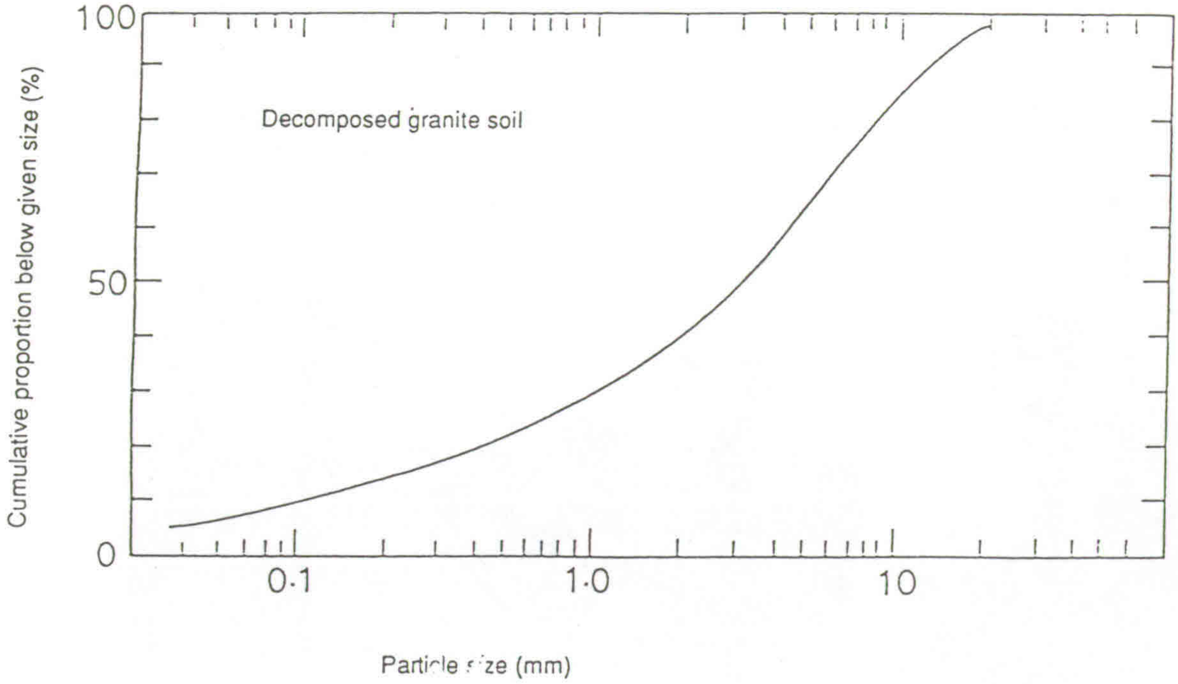


Figure 2 Typical particle size distribution curve of reclaimed soil (in Port Island)

Photo 1 Cast-in-situ concrete pile protruding above ground after settlement of surrounding ground

Photo 2 Ground settlement around Shinkotsu monorail support column foundations

Photo 3 Cracks on the ground around the Nishinomiya Bridge abutment

Damage to RC Structures

Atsuhiko Machida, Faculty of Engineering, Saitama University

This survey on the damage to concrete structures was carried out by members of the First Reconnaissance Committee and some observers. However, the contents of this report are taken mainly from the surveys conducted by the author and one of the observers, Kazuo Konagai, associate professor at the Institute of Industrial Science, University of Tokyo.

1. Areas Surveyed and Outline of Damage

Figure 1 and Table 1 summarize the major RC structures damaged by the earthquake based on data provided by relevant organizations (the Kinki Bureau of the Ministry of Construction, the No. 2 Construction Department of the Japan Highway Public Corp., the No. 3 Ports and Harbors Construction Bureau, and the Kobe Traffic Bureau). Also described in this paper is the damage to the Sanyo Shinkansen (Bullet Train) line, which was surveyed without a visit to the relevant administrative organization. The encircled areas in the figure indicate the areas of the disaster-stricken region surveyed.

The author concentrates on the following concrete structures which suffered severe damage in the earthquake: the Kobe Route of the Hanshin Expressway near Fukae Ramp; the RC expressway piers between the Nishinomiya and Amagasaki Interchanges on the Meishin Expressway; and the Sanyo Shinkansen line near where it crosses over the Hankyu Imazu line.

2. Damage to Kobe Route of the Hanshin Expressway

The RC piers of the Hanshin Expressway suffered heavy damage near Fukae Ramp. Piers over a length of about 500 m overturned sideways. The collapsed segment was of Pirtz construction, with RC girders joined rigidly to T-shaped piers of circular section. The damage to the structure was without doubt due to the large earthquake loading. The mechanism by which the collapse occurred, at least with regards to the horizontal earthquake loading, can be outlined qualitatively as follows:

1. Flexural cracks due to bending moments occurred around the circumference.
2. Shear cracks began developing diagonally from some of the flexural cracks.

3. Concrete near the end portion of the shear cracks crushed.
4. Concrete failure caused the lap-spliced hoop reinforcements to loose their capacity of carrying the shear forces and confining the internal concrete. As a result, concrete crushing developed deeper into the interior.
5. The piers collapsed.

Generally speaking, it is extremely difficult to clarify how a collapse had occurred by merely looking at the damage condition after collapse. This qualitative outline was infered with reference to nearby piers that were damaged but did not collapse. In order to draw more detailed conclusions, it is necessary to compare the actual damage with the results of precise analysis, including three-dimensional inelastic response analysis. Based on these analytical results, it may be possible to clarify the real collapse mechanism and, to a certain degree, clarify the effects of vertical earthquake forces and the rotational inertias of the superstructure.

Assuming that the above inference is correct, there are two problems to be resolved:

1. whether the piers had advanced bending yielding characteristics in the cross sections.
2. at what location did the shear cracks inducing the collapse initiate.

Regarding the first point, a rough calculation made in accordance with the JSCE's latest standard specifications indicates that piers with such cross-sectional characteristics are susceptible to shear failure because the ratio of bending strength to shear strength is close to unity. Concerning the latter point, the opinion of the committee is divided because a number of possible starting points had been observed: at sections where a portion of the longitudinal steel reinforcements were terminated as frequently observed in past earthquakes; at the joints where steel reinforcements were pressure-welded; and at points visually indistinguishable between these two. However the fact that not a few steel reinforcing bars had fractured at welded joints indicates that full ductility of the steel reinforcement after yielding could not be expected, even if the weld failure occurred midway through the collapsing process. There is thus a need to study the failure mechanism further.

Near the overturned piers, many RC expressway piers suffered damage of the following types: flexural cracking; concrete partially crushed due to bending at the base; shear cracking and crushed concrete in piers about to collapse; and piers remaining upright but with longitudinal reinforcement bulging out of the concrete surface. At least two bridge abutments failed in the form of short-column shear failure, which has rarely been observed in bridge abutments damaged in past earthquakes. If failure of this type is identified in other locations in the disaster-stricken area, it will be necessary to study methods of checking and reinforcing such structures and providing countermeasures against this type of failure.

3. Damage to the Meishin Expressway of the Japan Highway Public Corp.

Between the Amagasaki and Nishinomiya Interchanges along the Meishin Expressway, heavy damage to wall-type RC bridge piers was observed within the segments between the Amagasaki Interchange and the Mukogawa River. As shown in the attached photos, X-shaped shear cracks extending over the whole width of the wall also penetrated in the thickness direction. This can be considered as a result of the same process inferred to in the previous section, except for the following differences: there was almost no concrete crushing near the end of the shear cracks; only the longitudinal reinforcements were significantly bent outwards; and the piers did not overturn. Although it was not possible to completely identify the location of the flexural cracks that initiated shear cracking, some could be identified at sections of piers where portions of the longitudinal reinforcements were terminated.

Conventionally, little emphasis has been placed on the shear strength of plate structures such as walls which are subjected to out-of-plane shear loading, except in the case of punching shear loads, because they are relatively wide. In contrast, where plate structures undergo uniform loading in the width direction, it has been pointed out that shear failure similar to those encountered in piers and girders might occur. This is also spelled out clearly in the JSCE specifications. The damage observed here demonstrates the real occurence of this phenomenon. Our judgment is that the damage was caused by uniform horizontal motion acting at right angles to the surface of the wall-type piers. The type of damage indicates the need to arrange shear reinforcing bars around the main reinforcements.

Another type of damage was shear cracking in RC expressway bridge piers of rigid frame construction. As shown in the attached photos, although the damage was not particularly severe, concrete spalled off and longitudinal reinforcements bulged outward. The reason for the limited damage seems to be the presence of sufficient amounts of hoop reinforcements. Regretfully, however, the perpendicular hooks at the ends of the hoop reinforcements might have contributed to the damage seen.

4. Damage to the Sanyo Shinkansen

Regarding damage to the Sanyo Shinkansen line (Sanyo Line of the Bullet Train), we describe here the collapsed overbridge crossing the Hankyu Imazu line and nearby damaged bridge piers of rigid frame construction. The cause of the overbridge collapse was damage to the bridge abutments, which were of four-pier rigid frame construction. It can be assumed that the damage progressed as follows: shear cracking initially occurred in all four piers near the top of the west abutment and near the base of the east abutment; the cracks developed further along the piers; and finally the piers collapsed downward at severely cracked sections due to their incapacity to sustain the dead load and other loads. To the east of the overbridge, another railway girder was similarly damaged. In both cases, it was not possible to locate the initiation points of the shear cracks in any of the damaged piers. Although it can be said that the small shear span ratio of the piers might have had some influence, further study will be needed to fully clarify the cause.

Between the two collapsed railway girders, two heavily damaged 3-span double-deck rigid frame railway bridges were observed to have suffered large horizontal and vertical displacements. One of the two exhibited shear failures at the top ends of some of the lower deck and upper deck piers, while the other had shear failures only at the top of all the lower deck piers. Further east of this bridge structure, there were many 3-span single deck rigid frame bridges which had not suffered large displacements, yet had shear failure at the top ends of the piers. Although it was also not possible to locate the shear cracking initiation points, we were certain that they were at the points where large sectional stresses were induced.

The common characteristic among the damaged RC railway bridge piers near the railway overpass crossing the Hankyu Imazu line was that shear cracking occurred at sections in piers where large cross-sectional stresses developed and these sections tended to become plastic hinges. Judging from this, when designing structures of this type to have ductility, besides taking care to prevent the development of plastic hinges, it seems necessary to study the effects of curvature ductility expected at plastic hinges and how the amount of lateral reinforcement affects this ductility.

5. Conclusions

Judging from the earthquake records and the devastating damage, there is no doubt that the Hyogo-ken Nanbu Earthquake imparted extremely large external forces to structures. For this, further study is needed to determine whether the earthquake loading actually exerted on structures was greater than that specified by design seismic coefficients. Since the pre-1965 design seismic coefficient of 0.2 was abandoned, the coefficient has been increased based on the lessons learned from large earthquakes; that is, the earthquake loads assumed in various current design codes and standards take earthquake experience into account. In particular, the following studies will be necessary in this case: detailed investigations of the damage to structures designed in accordance with current design standards; verification of the strength of heavily damaged structures based on current standards (although this may have already been done); and inelastic analysis of structures designed in accordance with current earthquake-resistant design standards. After completing these studies, it will be possible to reconsider, and make the necessary revisions to, earthquakes assumed in design, ductility standards, and structural details related to earthquake resistance. In this way, we can turn this disaster into an engineering lesson.

RC structures suffered unprecedented damage in this earthquake. In this interim report, the author has attempted to give an outline of the damage and critical analysis of the causes, but has done so under time and other constraints. The author apologies for giving some personal opinions here, without full discussions with members of the Reconnaissance Committee and the Concrete Committee. Moreover, in giving many of the critical analyses herein, the author has at his disposal modern knowledge as reflected in the current JSCE specifications, knowledge which were not available in the days when many of the damaged structures were constructed.

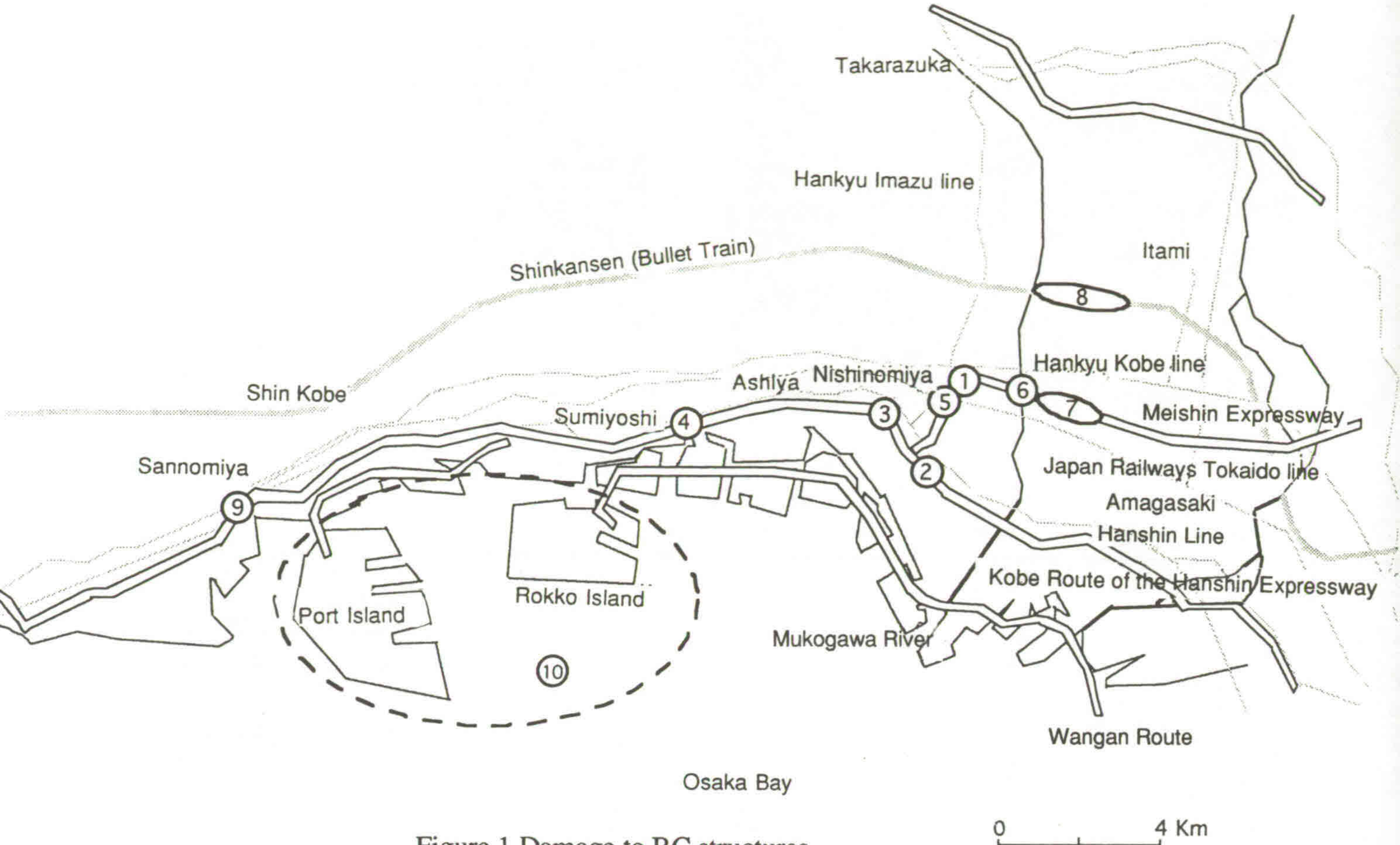


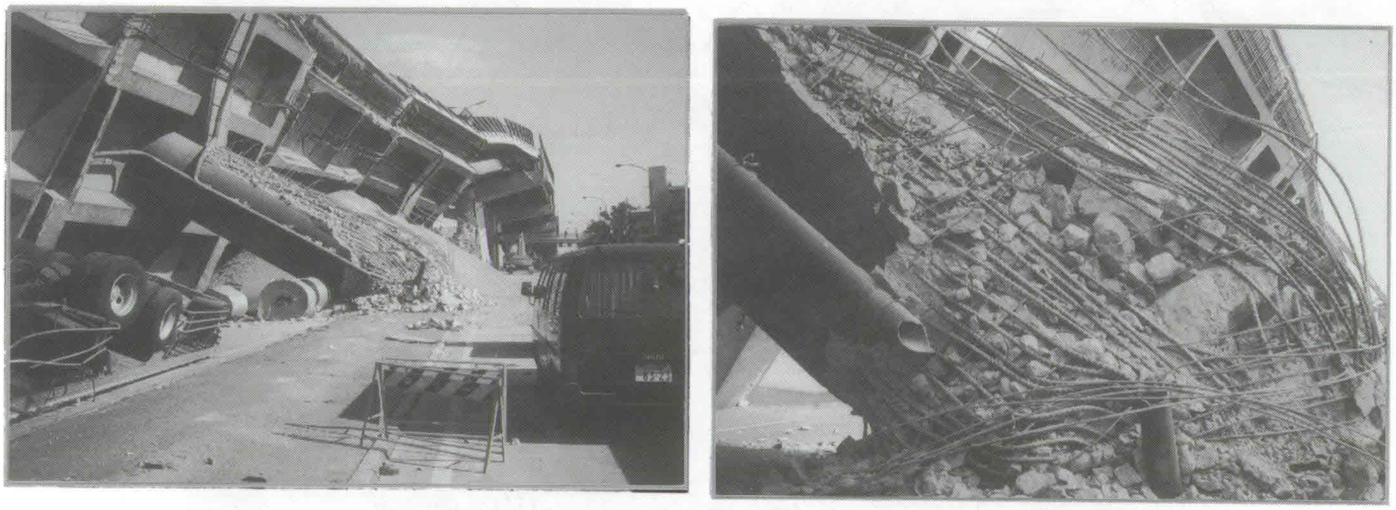
Figure 1 Damage to RC structures

Table 1 Major damage to RC structures

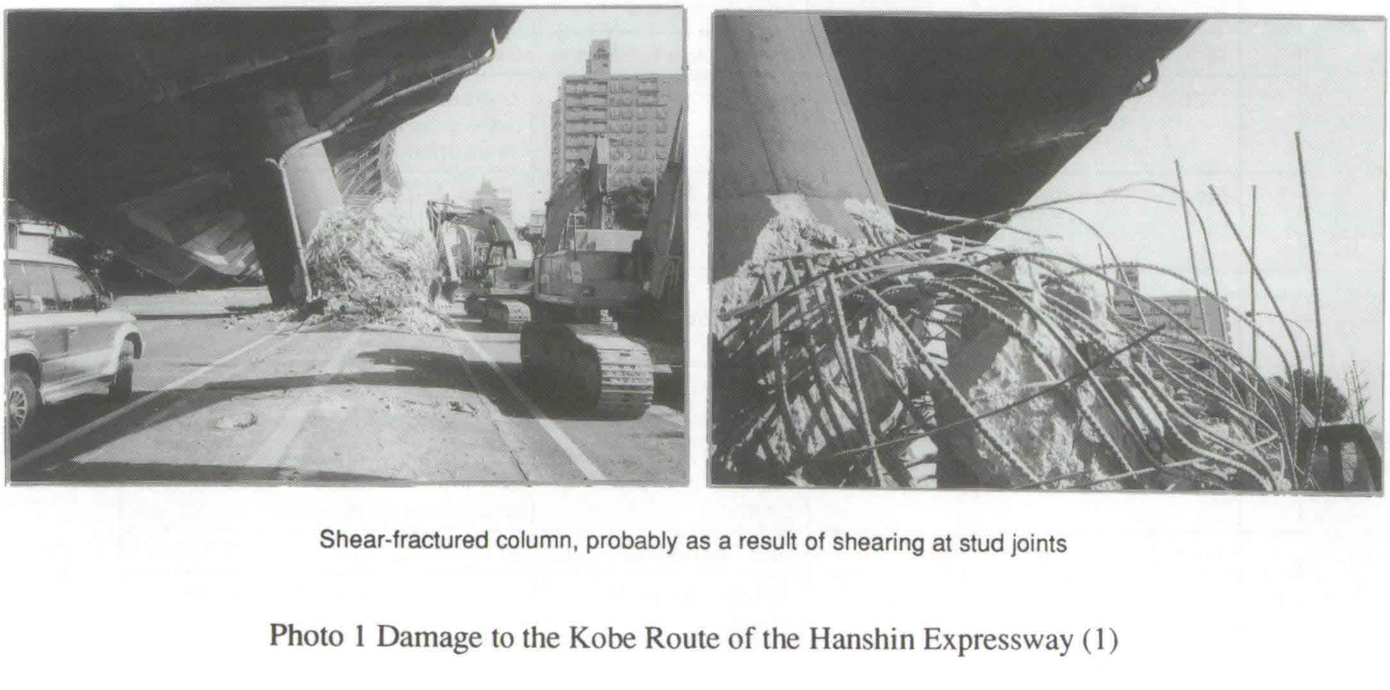
	Name of line, route, etc.	Location		Major damage
1	Meishin Expressway	Nishinomiya	near Nishinomiya toll barrier	Expressway bridge collapse
2	Kobe Route of Hanshin Expressway	Nishinomiya	near Nishinomiya Interchange	Expressway bridge collapse
3	Ditto	Nishinomiya	Nishinomiya Kai Shrine	Expressway bridge collapse
4	Ditto	Kobe	near Fukae Ramp	Expressway bridge columns and girders over a span of 500 m overturned to the north
5	Meishin Expressway	Nishinomiya	between Amagasaki and Nishinomiya Interchanges	Shear cracking
6	Ditto	Amagasaki & Nishinomiya	between Amagasaki and Nishinomiya Interchanges	Rocker highway bridge tilted
7	Ditto	Amagasaki	between Amagasaki and Nishinomiya Interchanges	Shear-fractured expressway bridge columns of wall type
8	Sanyo Shinkansen	Amagasaki	Hankyu Imazu line crossing	Shear-fractured bridge column of rigid frame construction
9	Kobe City Subway	Kobe	near Sannomiya Station	Shear-fractured mid- length columns
10	Kobe Harbor	Kobe	Rokko Island & Port Island	Large displacement and deformation

General view

Rear view

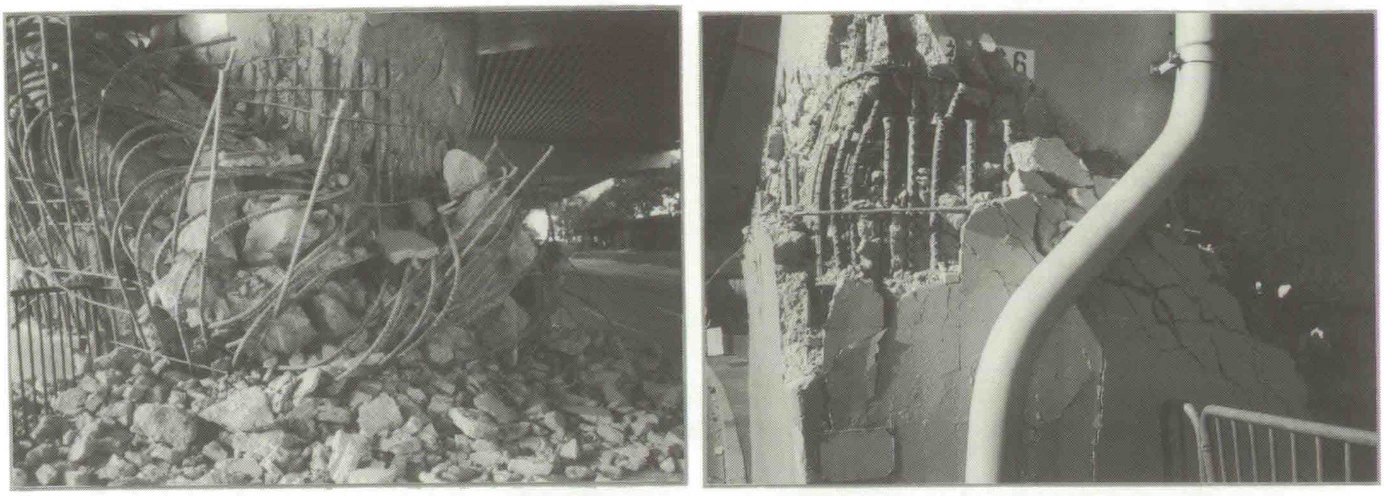


Fractured column, probably as a result of shearing where the quantity of steel reinforcement changed

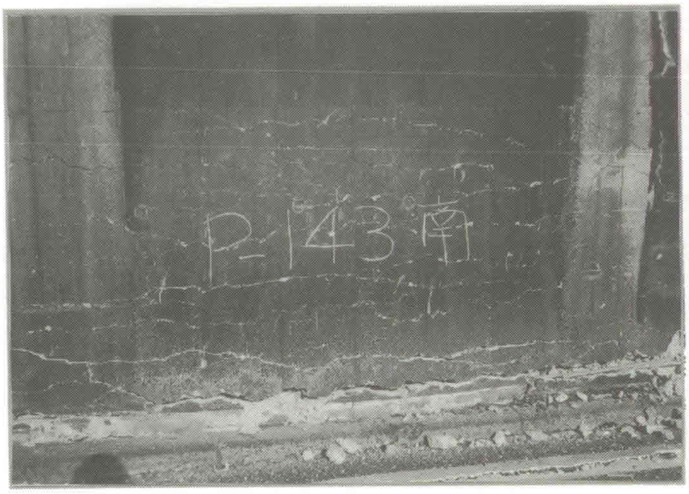


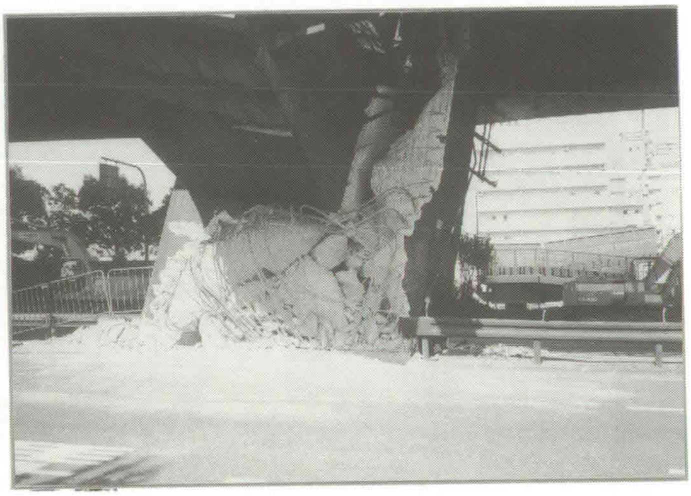
Shear-fractured column, probably as a result of shearing at stud joints

Photo 1 Damage to the Kobe Route of the Hanshin Expressway (1)



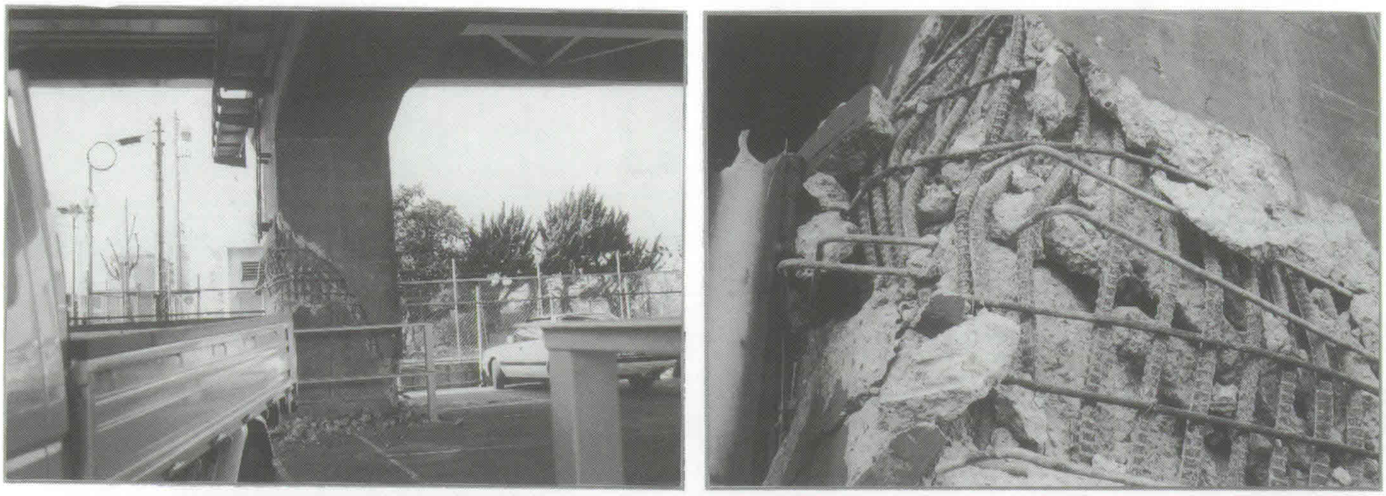
Fractured column at stud joints



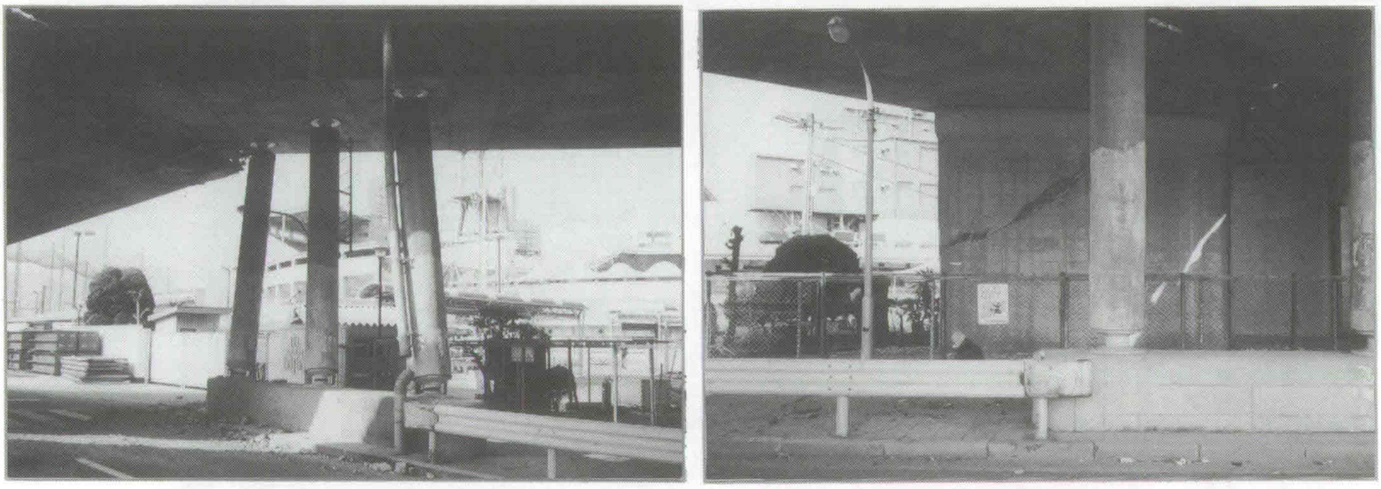


Fractured short column, probably due to shearing

Photo 2 Damage to the Kobe Route of the Hanshin Expressway (2)



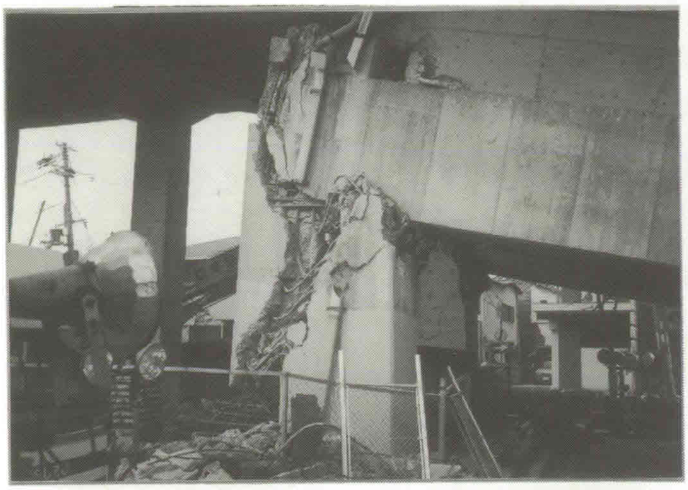
Shear-fractured expressway bridge column of rigid frame construction

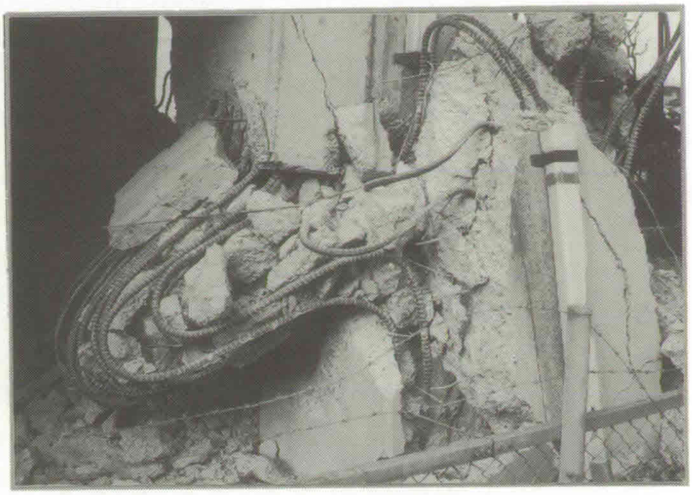


Tilted **rocker** column

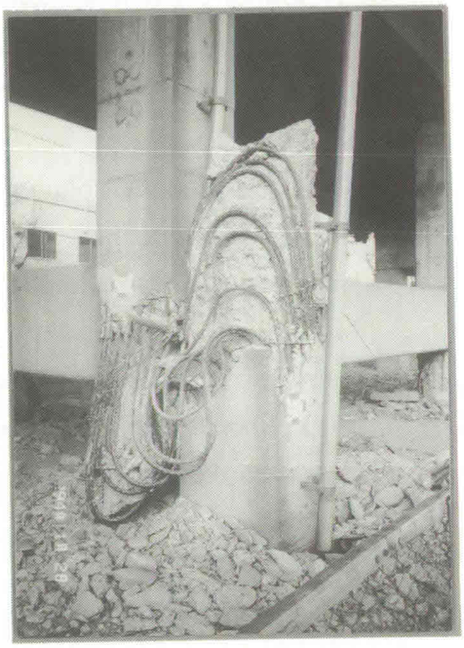
Shear-fractured column of wall type

Photo 3 Damage to the Meishin Expressway





Shear-fractured abutment of rigid frame construction



Shear fractured column of rigid frame construction

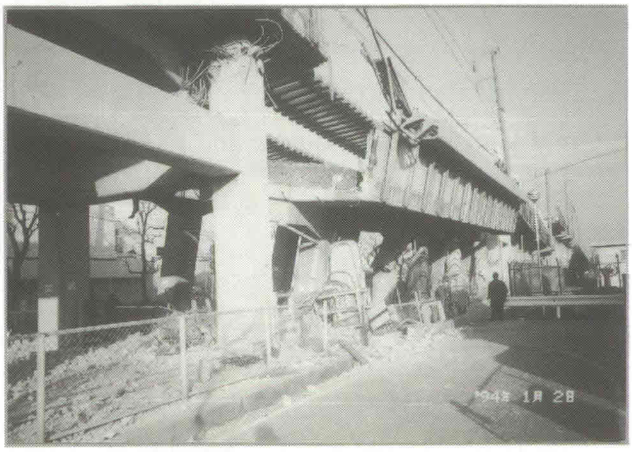


Photo 4 Damage to the Sanyo Shinkansen

Damage to Steel Structures

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1. HISTORY OF EARTHQUAKE DAMAGE AND EARTHQUAKE-RESISTANT DESIGN CODES IN JAPAN AND THE U.S.

The attached table shows how Japan and the U.S. (California) have suffered remarkably similar earthquake damage over the past hundred years or so, and thus have much to learn mutually. Examples of this similarity are listed below.

- Great fires caused by the 1906 San Francisco Earthquake and the 1923 Great Kanto Earthquake
- Shear-fractured RC columns in the 1968 Tokachi-oki Earthquake and the 1971 San Fernando Earthquake
- Lifeline facilities damaged by the 1971 San Fernando Earthquake and the 1978 Miyagiken-oki Earthquake
- Damage at great distance from the epicenter due to long-period oscillations in the 1983 Nihonkai Chubu Earthquake and the 1985 Mexico Earthquake
- Inland earthquake damage in the 1995 Great Hanshin Earthquake and the 1994 Northridge Earthquake

2. NEAR-FIELD EARTHQUAKE MOTION AND DAMAGE TO STEEL STRUCTURES IN THE NORTHRIDGE EARTHQUAKE

2.1 Characteristics of ground motion near the epicenter

The information given here is quoted from "Near-field Consideration in Specification of Seismic Design Motions for Structures," submitted to the 10th European Earthquake Engineering Conference by Professor W. D. Iwan of the California Institute of Technology.

Figure 1 shows the location of the epicenter of the 1994 Northridge Earthquake as well as the positions of the seismographic stations, and Table 1 gives peak accelerations, velocities, and displacements in the two horizontal directions and the vertical direction as measured at each station. The abbreviations LUC and ELC in the table indicate records taken in Lucerne Valley during the 1991 Landers Earthquake and in El Centro during the 1940 Imperial Valley Earthquake respectively. The paper concludes with the following statements:

- Not only was the peak horizontal acceleration large (0.88 g), but a high peak vertical acceleration (0.85) was also measured.
- The peak pulse-like ground velocity was extremely high at 157 cm/sec. Consequently, although there was no significant difference in acceleration response spectra from past earthquakes, the relative displacement spectra were extremely large. A trial calculation indicates that the maximum interstory drift of buildings with a height corresponding to 10 stories was approximately 4% of the story height.

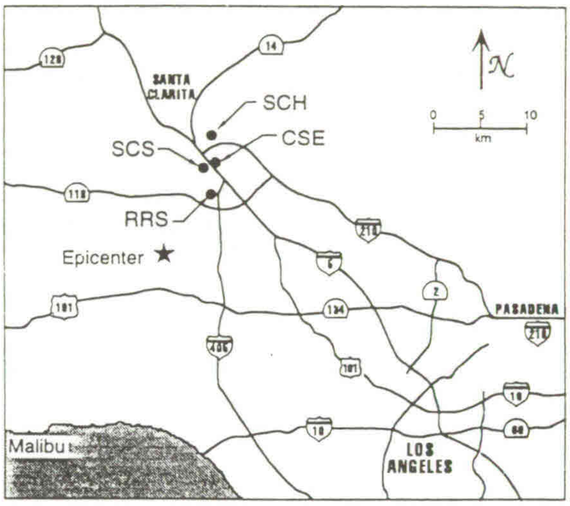


Figure 1. Epicenter of January 17, 1994 Northridge earthquake and near-field stations studied.

Table 2 Peak acceleration, velocity, and displacement for selected accelerograms

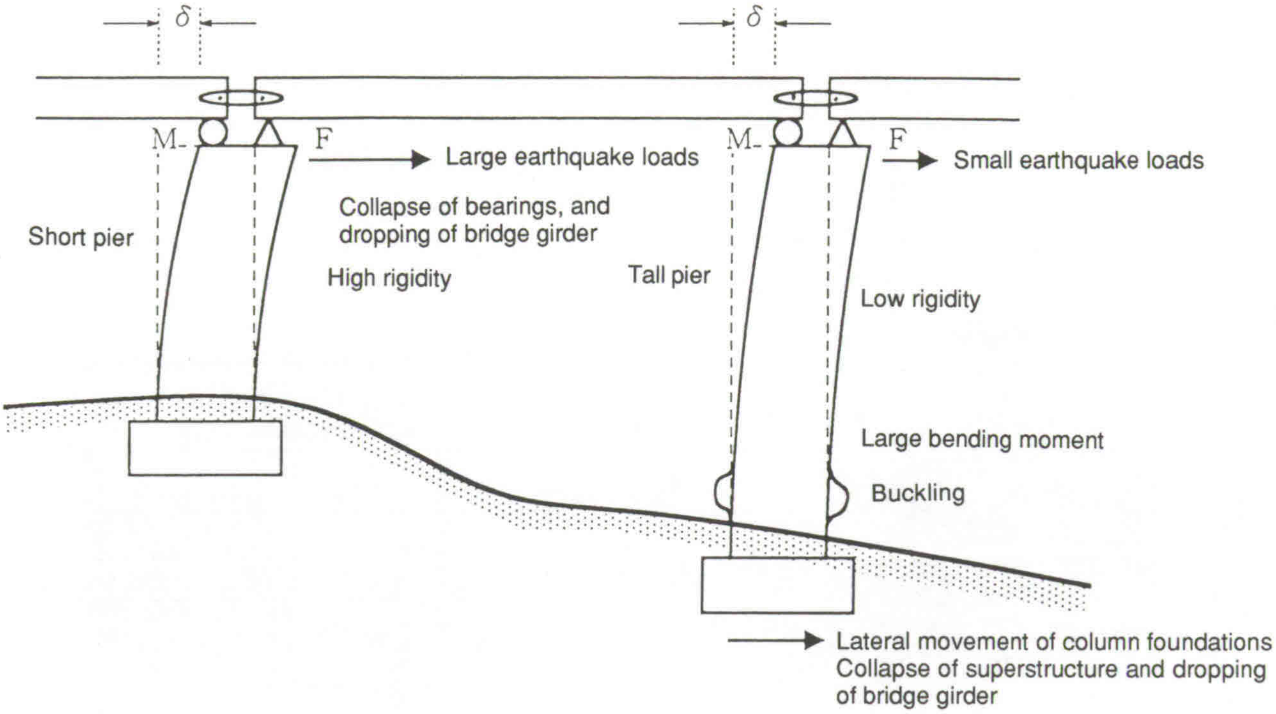
Station	Dir.	PGA (g)	PGV (cm/s)	PGD (cm)
RRS	N-S	0.82	157	51
	E-W	0.57	102	73
	Up	0.85	42	33
SCS	N-S	0.63	84	58
	E-W	0.71	149	126
	Up	0.59	37	55
CSE	N-S	0.75	118	59
	E-W	0.47	71	42
	Up	0.41	26	47
SCH	N-S	0.88	139	57
	E-W	0.61	79	41
	Up	0.55	21	16
LUC	N-S	0.83	33	76
	E-W	0.75	146	261
ELC	N-S	0.35	33	11

2.2 Damage to steel structures

It is estimated that steel frame buildings of up to about 20 stories underwent interstory drifts of 2% to 4%. Post-earthquake surveys revealed many cracks around welded beam-column joints in steel frame buildings. This type of damage is a serious problem. The cracking was due to the large relative deformation of the structures.

3. CAUSES OF LONGITUDINAL DAMAGE TO ROAD BRIDGES

Let us consider the causes of damage to simply supported bridge girders on piers of different heights and linked with the connecting members as shown in the figure overleaf.



- The bridge girder undergoes large relative displacement due to earthquake loading. The girder follows almost the same horizontal displacement through the action of connecting members.
- The short pier is more rigid to horizontal displacements at the top and is subjected to a larger earthquake loads than the tall pier, even when the top displacement is the same. If the bearings fail, the girder may fall off the pier. If the bearings are strong, a large load acts on the piers, causing shear failure of RC piers. If the girder falls or the piers are damaged, this will have an effect on adjacent girders and piers.
- Steel piers are less rigid, and exhibit greater deformation than RC piers. Accordingly, for a given deformation, steel piers are subjected to lower earthquake loading than RC piers. This tendency is particularly clear for tall piers. On the other hand, large bending moments are induced at the base of tall columns, possibly resulting in the local buckling of the steel pier.

4. OUTLINE OF DAMAGE TO STEEL STRUCTURES

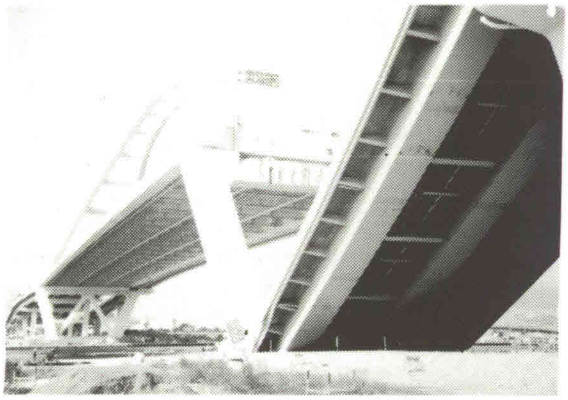
Kobe Route of the Hanshin Expressway

The dead load of each elevated expressway girder overhangs in both transverse and longitudinal directions, since it is supported on steel bridge columns of single-post type. As a result, the columns suffered serious collapse and broke away at the corners. The cause of the damage seems to have been extremely large vertical loading. Beams overhanging in the transverse direction buckled seriously at the diaphragm.

Wangan Route of the Hanshin Expressway

(Side span of the Nishinomiya Port Bridge)

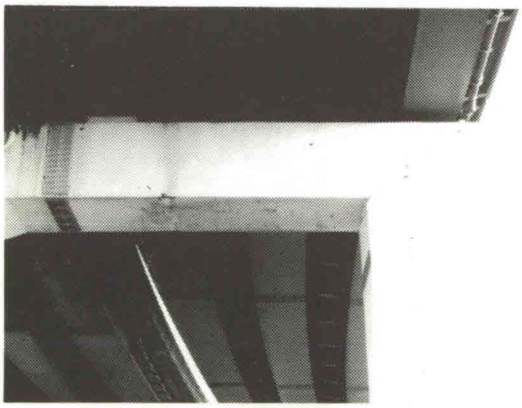
A side span of a Nielsen Lohse bridge archgirder of basket handle type fell from its piers. The cause of this damage was westward movement of the bridge piers. Bearings failed and girders buckled. The span of the Nielsen Lohse bridge widened considerably.



Harbor Highway at Maya Pier

To the north of No. 1 Pier (east end of No. 2 Maya Bridge)

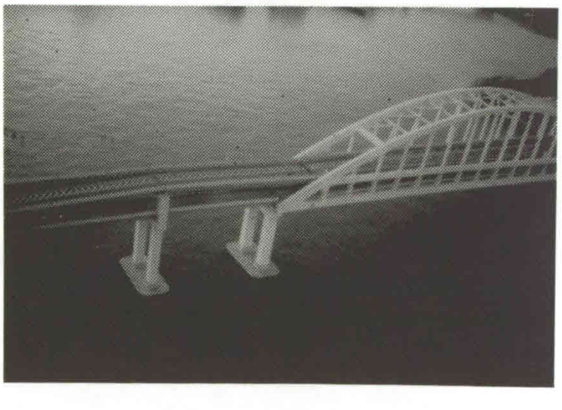
A single-layer frame structure cracked in an upper corner and the upper central section buckled. Welds cracked because of settlement of the bridge columns at the south end. Adjacent single-post RC bridge columns also cracked at the base.



Wangan Route of the Hanshin Expressway

Rokko Island Bridge

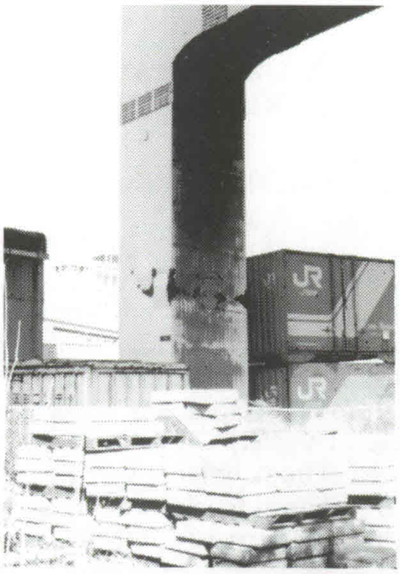
Side bearings of this double-deck Lohse bridge were damaged at the Rokko Island end, causing a great discontinuity in level between the bridge girder and the side span. The cause of this damage appears to have been extraordinary earthquake loading on the bearings.

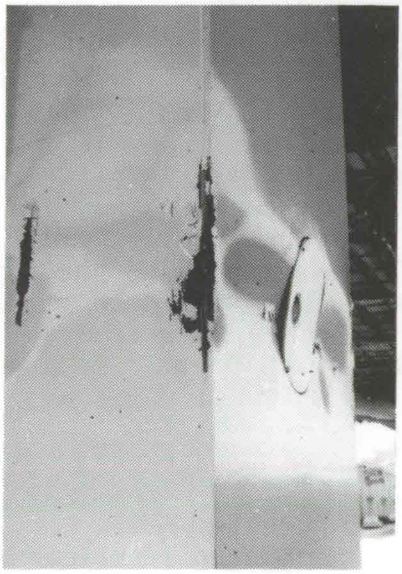


Harbor Highway

To the north of Shinko No. 5 Pier

A double-deck highway column of rigid frame construction buckled toward the north at two thirds of its height in the first layer. The cause of this damage seems to have been large motion in the transverse (north-south) direction or settlement of bridge columns at the south end (toward the sea).

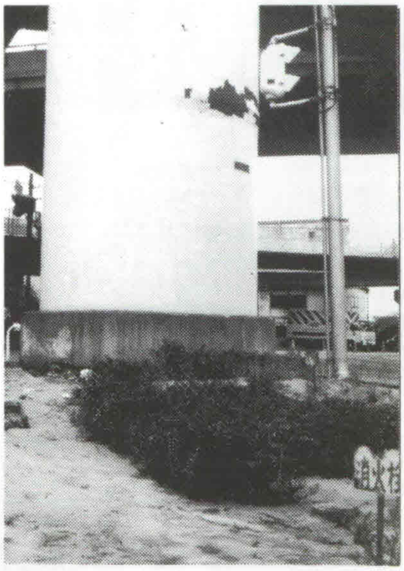




Harbor Highway

To the north of Shinko No. 6 Pier

A single-post two-deck highway bridge column (2 m square) buckled at one fourth of its height up from the base. The cause of this damage seems to have been large motion in the transverse (north-south) direction.



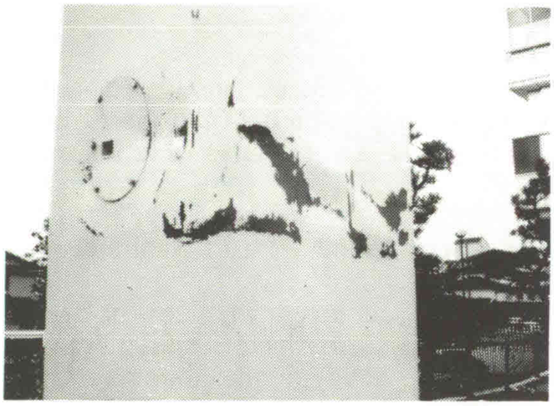
Harbor Highway at Junction with Kobe Route of the Hanshin Expressway

To the north of Shinko No. 4 Pier (on the approach to Port Island)

A double-layer cylindrical column of rigid frame construction buckled toward the west about 2 m above its base. Considering the fact that adjacent highway bridge columns of the same type buckled circumferentially at the base, the cause of this damage seems to have been the cyclic motion.

Shinkotsu Port Liner near Trade Center Station

One end of a continuous girder came away from the top of a high pier and was left hanging in the air. The cause of this damage seems to have been serious deformation. No severe damage to the steel columns was noted. The girder in front of the two-column bent in the background of the photo also buckled.

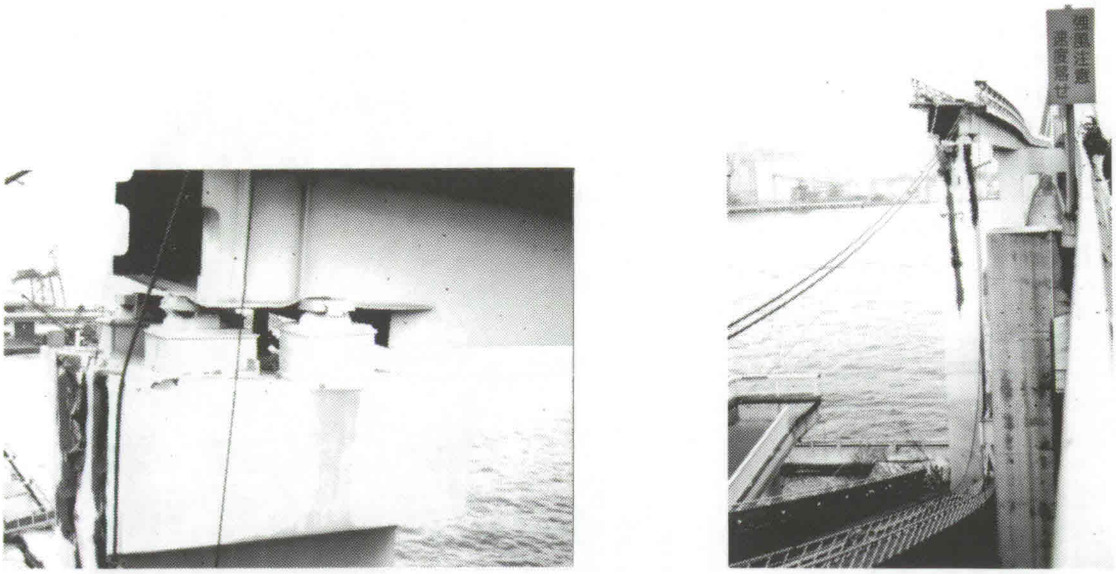


Shinkotsu Port Liner to the north of Uozaki Station

A cylindrical single-post bridge column buckled. Another column to the north of this column and other columns supporting Uozaki Station were not severely damaged.

Shinkotsu Rokko Liner where it crosses the Kobe Route of the Hanshin Expressway

A three-span continuous-girder highway bridge of the Hanshin Expressway was damaged at its support bearings. As a result, the girder dropped by about 70 to 80 cm, forcing closure of the Rokko Liner immediately below the expressway because adequate clearance could not be secured.



Shinkotsu Rokko Liner to the south of Rokko Bridge

The northernmost railway bridge columns on Rokko Island moved laterally toward the sea. Consequently, the northern girder pushed the southern girder off the top of its column. This can be inferred from the damage to the bearings. Large marks were left on the side face of the column by the girder as it fell.

Kobe Kosoku Railway to the west of Sannomiya Station

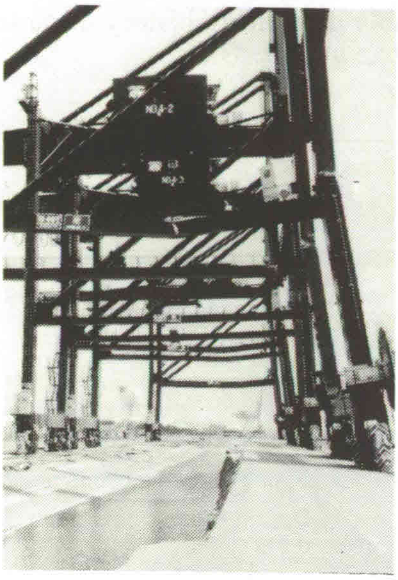
Brittle fractures occurred in steel bridge columns. This damage seems have resulted from considerably large forces acting on the columns with high stress rates in the direction of the mountains (visible side).

Japan Railways and Hankyu Lines at Sannomiya Station

Steel railway bridge girders moved towards the mountains (visible side), causing considerable inclination of steel columns hinged at top and bottom.

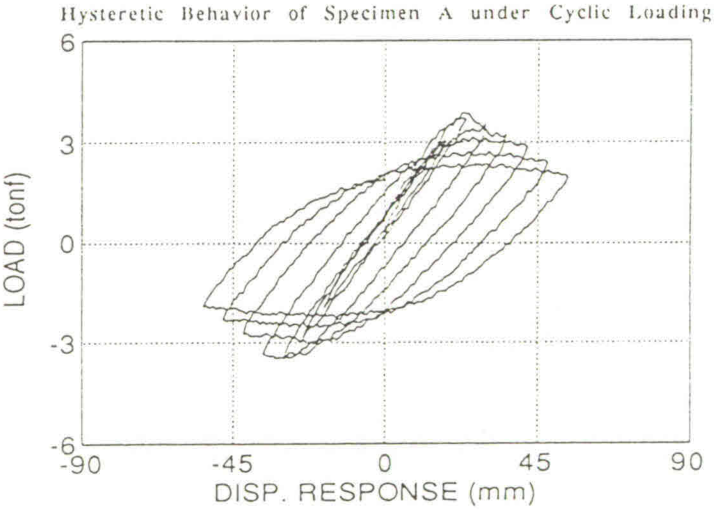
Rokko Island south quays

Gantry cranes buckled and toppled. Quay structures moved seaward by some meters, and the ground behind them settled by a few meters. As a result, the legs of gantry cranes were forced apart and plastic hinges developed in the lower sections of double-layer legs and lateral frames. A few gantry cranes collapsed.



5. LOADING TESTS ON A STEEL BRIDGE COLUMN MODEL

The following hysteresis characteristics and buckling modes were observed in loading tests carried out by the Earthquake Engineering Laboratory of Kyoto University. Buckling, as shown in the photo below, caused a sudden loss of load bearing capacity.



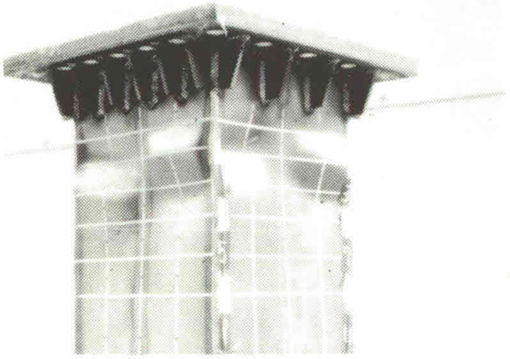


Table comparing history of earthquake damage and seismic design codes for bridges in Japan and the U.S.

Prepared by Hirokazu Iemura, Kyoto University

U.S. (and other countries)		Japan	
		1891	Nobi Earthquake
1906	San Francisco Earthquake		
	Great fires		
	AWSS completed	1923	Great Kanto Earthquake
1933	Long Beach Earthquake		Great fires
	Strong ground motions recorded		Design seismic coefficient: 0.1
	Design seismic coefficient (Riley Act 0.02)		
1936	Bay Bridge completed		
1937	Golden Gate Bridge completed	1939	Specifications for design of highway bridges
1940	Imperial Valley Earthquake		Design seismic coefficient: 0.2
	Records at El Centro		
		1944	To-Nankai Earthquake
		1946	Nankai Earthquake
		1948	Fukui Earthquake
			SMC developed seismic design codes
1955	UBC (Uniform Building Codes)		
	Design seismic coefficient: 0.6		
1956	The 1st World Conference on Earthquake Engineering (WCEE, in San Francisco)	1956	Specifications for road bridges
			Design seismic coefficient: 0.1-0.35
1957	I-880 Cypress Viaduct completed		
		1964	Niigata Earthquake, liquefaction
		1968	Tokachi-oki Earthquake, records at Hachinohe (2 seconds)
			Shear-failure of RC columns
1971	San Fernando Earthquake	1971	Specifications for earthquake-resistant design of highway bridges
	Shear-failure of RC columns, collapse of girders, and damage to lifeline facilities		Design seismic coefficient: 0.1 to 0.24
1975	AASHTO, Interim Spec., Bridges		Modified seismic coefficient method
	Design seismic coefficient: 0.5 (plastic design)		
	Seismic retrofit program started		
	Earthquake restrainers	1978	Miyagiken-oki Earthquake, damage to lifeline facilities
		1980	Specifications for highway bridges (new earthquake-resistant design provision)
			Ductility requirement
1981	ATC-6 design seismic coefficient: 0.4 (plastic design)		

1983	AASHTO, CALTRANS	1983	Nihonkai-Chubu Earthquake
(1985	Mexico Earthquake, 2 seconds)		Long-period ground motions: 10 seconds
1987	Whittier Narrows (Los Angeles) Earthquake		
(1988	Armenia Earthquake, 1 second)	1988	Kojima-Sakaide Route of the Honshu Shikoku Bridges completed
1989	Loma Prieta (San Francisco) Earthquake	1989	Specifications for highway bridges, earthquake-resistant design spectrum revised
(1990	Philippines Earthquake)		Dynamic analysis, load-carrying capacity, tripled earthquake loads considered, response at 1 g
			Research and construction of vibration control devices
1990	IDNDR	1990	
(1992	Erzincan (Turkey) Earthquake		
1992	Los Angeles Earthquake (long period)	1992	Design manuals for base-isolated highway bridges
		1993	Kushiro Earthquake
			Hokkaido Nansei-oki Earthquake
1994	Northridge Earthquake	1994	Hokkaido Toho-oki Earthquake
	(Inland earthquake, large acceleration, and large velocity)		Sanriku-Haruka-oki Earthquake
		1995	Great Hanshin Earthquake
			(Inland earthquake)

BRIEF REPORT BY THE SECOND SURVEY TEAM ON THE DAMAGE CAUSED BY THE GREAT HANSHIN EARTHQUAKE

(January 22 to 24, 1995)

Members of the JSCE (Japan Society of Civil Engineers) Second Survey Team on the Great Hanshin Earthquake

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Outline of Surveys by the Second Survey Team

Hideo Nakamura, Professor
University of Tokyo, President of JSCE and Leader of the Second Survey Team

1. THE SURVEY WORKS OF THE TEAM

This survey team was organized in the wake of the First Survey Team, whose brief was to carry out a quick review of the damage to infrastructures in the areas hit by the Great Hanshin Earthquake. This Second Survey Team was charged with making a thorough survey of physical damages, and to propose measures for quick restoration of the functioning of various urban facilities. The facilities include railways, highways, harbors, airports, and the so-called "lifeline" facilities (utilities such as electric power, tap water, sewage, city gas, telephone, etc.). The hope is that this will contribute to restoration and rehabilitation efforts in these areas as well as to the development of improved measures to cope with urban disasters in the future.

The members of the team arrived in Osaka in the morning of Sunday, January 22, and held a preparatory general meeting before immediately setting out to begin their surveys. For the most part, they acted in the following four special groups:

1) Railway group (leader: Shigeru Morichi, Professor at the Tokyo Institute of Technology)
2) Highway group (leader: Yasutaka Iida, Professor at Kyoto University)
3) Harbor, airport, and rivers group (leader: Katsuhiko Kuroda, Professor at Kobe University)
4) Urban utilities group (leader: Mitsuyuki Asano, Professor at Waseda University)

All members of the team investigated the damages at site during daytime, and the results of each day's investigations collected by the different groups were reported and discussed by them at team meetings every night. On the basis of these meetings, the main study points and scheduling of the following day's survey work were determined. The surveys were completed on Wednesday, January 25 after four days of activity.

This report will, in the first place, give an account of the study team's almost unanimous opinion regarding the earthquake damage and the implications of this for future schemes of structural design and redevelopment of facilities for urban systems. More detailed discussions of the results of each specific survey by the different working groups will be available in their respective reports.

In any investigation of urban facilities, there are a substantial number of issues which can only be examined once restoration work has progressed to a certain degree; and the collected data are sorted for evaluation. For this reason, it must be made clear at this stage that the ideas presented here make up no more than a status report. The discussion is based on hurried local surveys and the rather limited information available at the present time. Furthermore, this survey excludes any discussion of damage to residential buildings, building structures, commercial property, factories, etc. because this kind of survey is being carried out by Japan Institute of Architects.

2. Discussion of the Devastation

(1) This earthquake was the first violently disastrous earthquake with an epicenter directly under a large city area with modern urban infrastructures. The members of the survey team were all shocked by the enormous scale and breadth of the disaster.

(2) The earthquake forces which acted on structures in the area were of unprecedented strength; such seismic power has never before been noted in earthquake disaster surveys, either in Japan or abroad, to date. Destruction on this scale is so enormous that it could not be reproduced in laboratory experiments.

(3) Huge damage was in evidence in all types of structures, but in terms of the number of cases, damage to the columns of reinforced concrete structures was particularly prominent.

(4) Generally speaking, light structures with good flexibility — such as pedestrian bridges — suffered little damage. Structural types, however, could be selected in consideration of many factors, such as susceptibility to external forces, environmental suitability, and the cost of construction and maintenance.

(5) In the areas surveyed directly by the members of this team, highway and railway bridges, viaducts, harbor facilities, water pipelines, and sewage networks and plants suffered particularly badly. In comparison, the surface streets and railways, underground shopping areas and parking lots were apparently damaged much less. As for subways, some sections were seriously damaged, but the damage was only local, and the majority escaped severe damage.

3. Future Focus of Structural Design and Urban System Planning

(1) In view of the enormous damage to structures that this powerful earthquake caused, it is necessary to introduce structural standards for robustness that prevent buildings collapsing or toppling even if partial destruction happens to occur.

(2) To better cope with such unprecedented disasters as this one, it is of vital important to ensure greater functional redundancy in urban systems; to secure alternative road routes and other transportation facilities to take the place of damaged sections.

(3) It is important to ensure that certain selected facilities are built with greater earthquake resistance — an example might be an earthquake-proof berth in Kobe port — so as to secure minimum functionality in a time of emergency, thus reducing limitations on relief and restoration efforts and avoiding complete breakdown of urban activities.

(4) There is an urgent need to look closely at the type of earthquake forces assumed in our design standards and review the criteria for earthquake resistant design presently in use.

4. Toward Reconstruction

(1) To ensure that the devastated area never again suffers such serious damage, not only strengthening structures but also city planning which emphasizes safety in disaster must be applied. It is strongly recommended that rebuilding plans be developed that guarantee future integrity, and practical working

measures must be taken as early as possible to ensure that such plans are implemented.

(2) Naturally, the most important task at present is to do everything for the earliest possible restoration of the stricken area. Great effort of motivated manpower with adequate technical skills is now needed. Those engaged in this survey were all greatly impressed by the large number of technical specialists who were struggling with restoration tasks without regard to their own personal safety.

Report by the Railway Group

Shigeru Morichi, Professor, Department of Civil Engineering, Tokyo Institute of Technology (Transportation Planning)
Hirokazu Iemura, Professor, Department of Civil Engineering, Kyoto University (Aseismic Engineering)
Chitoshi Miki, Professor, Department of Civil Engineering, Tokyo Institute of Technology (Bridge Engineering)
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1. OUTLINE OF RAILWAY SYSTEMS AND FACILITIES SURVEYED

West Japan Railways:
  Sanyo Bullet Train : Viaducts and bridges between the Muko River Bridge and the Rokko Tunnel, viaducts near Nishi-Akashi, the Ikawa River Bridge
  Tokaido Main Line : Viaducts near Rokkodomichi
  Sanyo Main Line : Embankment near Shin-Nagata, Takatori Overbridge
  Fukuchiyama Line : An area near Nakayamadera
Hankyu Railway : Flat section near Nishinomiya-Kitaguchi on the Kobe Line, Itami Station on the Imazu Line (elevated structure)
Hanshin Railway : Viaducts near Shin-Zaike, flat section near Fukae
Kobe Express Railway : An area between Taikai and Kosoku-Nagata (box-section tunnel), viaducts near Sannomiya
Kobe Municipal Subway : Sannomiya Station (box-section tunnel)
Kobe Railway : the Sanda and Arima Lines (between Sanda and Yakami; mainly in cuttings or on embankments)
Hokushin Kyuko Railway: An area between Yakami and Shin-Kobe (tunnel through a mountain)
Kobe Shinkotsu System : Port Island and Rokko Island Lines (elevated structures)
Sanyo Railway : An area near Suma Station (in cuttings or on embankments)

Additionally, interviews were carried out with the following sections: Kinki Transport Bureau, West Japan Railways, Hankyu Railway, Hanshin Railway, Kobe Express Railway, and the Kobe City Bureau of Transportation.

2. STATE OF DAMAGE

Here we summarize the state of damage to railway structures and facilities as found in this survey.

2.1 Outline of Damage

The following list indicates locations where damage occurred to the railbed itself (see Fig. 1).

(1) Damage to railways themselves was noted in the following areas. (Locations marked with an asterisk * were particularly badly damaged.)

* The area ranging from Nishi-Akashi to Akashi, Akashi City;

* Flat stretch of land between the vicinity of Suma, Kobe City and Nikawa, Nishinomiya City; the area near Arima Hot Spring: the area near Takarazuka and Nakayamadera

* The area near Itami Station on the Hankyu line; and Bullet Train8 structures within Takatsuki City

(2) The following damage to railway structures was also noted. (Locations marked with an asterisk were particularly badly damaged.)

* Failure or collapse of overhead elevated concrete roadways
* Failure or collapse of railway and highway overbridges
* Damage or collapse of cut-and-cover subway tunnels
* Destroyed train yard (elevated) and rolling stock repair facility
Partial damage to mountain tunnel
Settlement or misalignment of sub-base railbed
Damage to embankments and retaining walls
Collapse of cut faces of cuttings
Collapse or partial collapse of electricity poles
Damage to platforms
Damage or collapse of station buildings

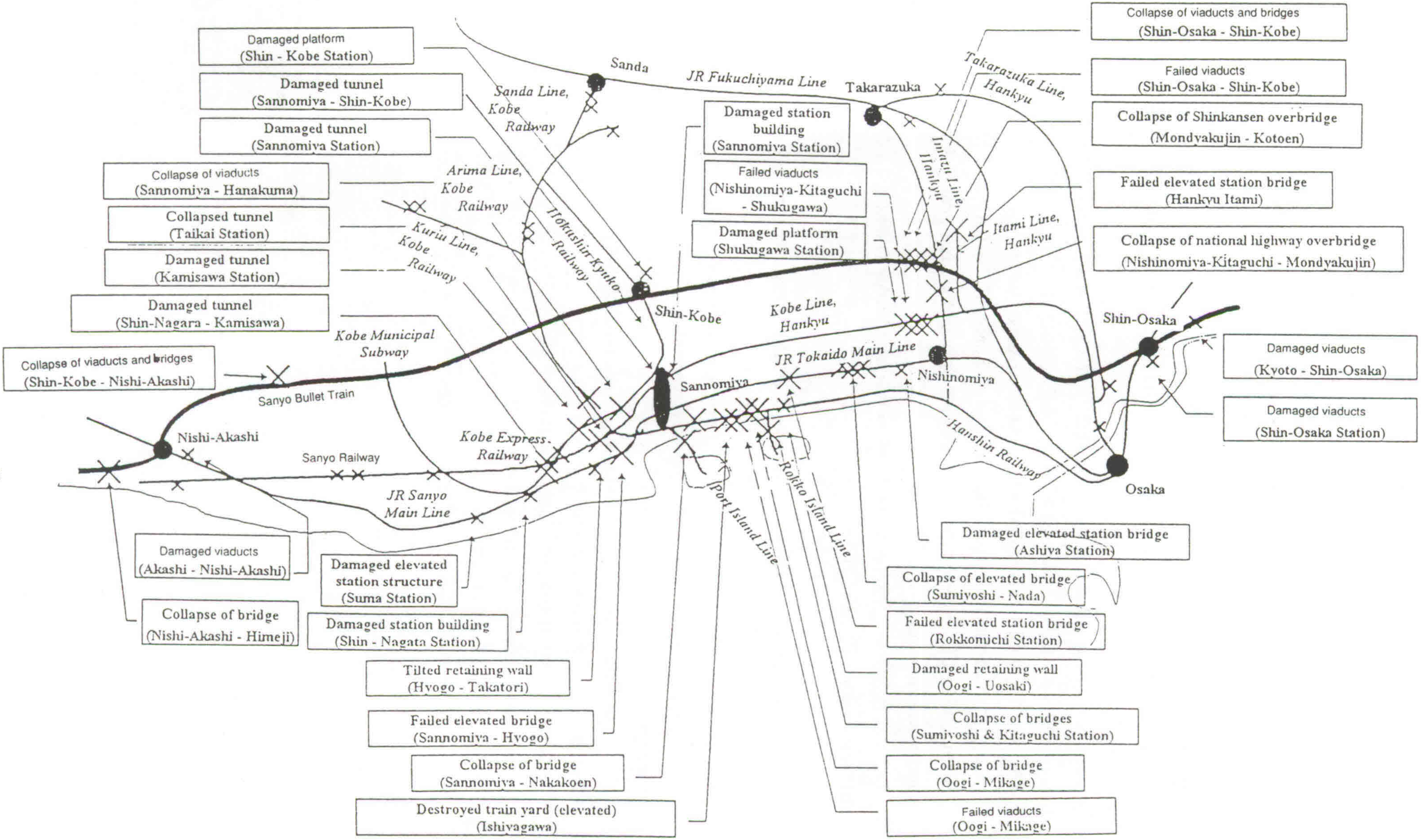

Fig. 1 Damage to Railway Structures

2.2 Major Damage

(1) Rigid-Frame RC Viaducts

Rigid-frame viaducts were surveyed at locations in the section between the Muko River Bridge and the Rokko Tunnel on the Sanyo Bullet Train System, in the section between the Ikawa River Bridge and Nishi-Akashi Station, and near Rokkomichi Station on the Tokaido Main Line. Damage was observed in the columns of these rigid-frame viaducts, but the type and degree of damage in these three sections differed.

In the section between the Muko River Bridge and the Rokko Tunnel, almost all the viaducts were damaged. The degree of damage varied, however. In some cases, the upper or lower columns of the double-deck rigid-frame structure had completely collapsed, dropping track levels to lower deck height. These viaducts are completely deformed (see Photo 1). In other cases, the concrete cover spalled away and the internal concrete failed, and there was considerable deformation of the reinforcing steel bars, but the shape of the viaduct was basically maintained (see Photo 2). In still other cases, shear forces had caused cracking or spalling of the concrete cover, but without any deformation of the main reinforcement. Observations of those viaducts with such relatively slight damage demonstrated that of the four support bents in a three-span rigid-frame bridge, the outer two were typically damaged considerably, with conspicuous damage occurring at the top end of the column below the haunch. To all

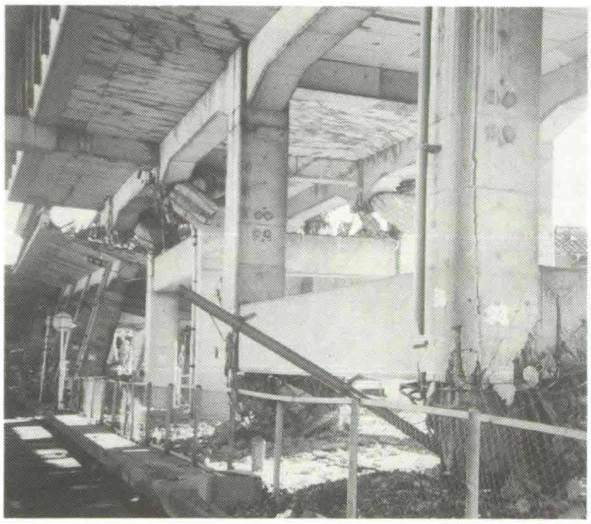

Photo 1 Collapse of double-deck rigid-frame viaduct (Hansui Viaduct, Sanyo Bullet Train in Nishinomiya City)

Photo 2 Damage to tops of columns of rigid-frame viaduct, just below haunch

appearances, the upper deck was not damaged in such cases; the track level was, therefore, maintained except where the suspension girder between rigid-frame structures collapsed. There was no visible scattering of ballast (see Photo 3). This appears to be partly because the earthquake took place early on a winter morning, meaning the rails were under axial tension — thus there was no buckling of the ballasted track.

In the area to the east of Nishi-Akashi Station, rigid-frame viaducts of the standard three-span design were damaged, though not seriously. Characteristically, the damage was seen in the two middle bents of the rigid-frame structure in cases where the middle span was wider than the other two. These columns were damaged around their mid-section (see Photo 4).

The rigid-frame viaducts near Rokko-michi Station on the Tokaido Main Line suffered the heaviest damage of all rigid-frame viaducts surveyed. In this section, the rigid-frame structure had twisted considerably in a direction perpendicular to the rails (see Photo 5) and the relatively short columns had collapsed completely (Photo 6). Observations of the columns with relatively less damage indicate that most damage occurred toward the top of the column just below the haunch.

(2) PC and RC Girder Bridges and Viaducts

Inspections were carried out on a number of bridges and viaducts: the Muko River Bridge, the Kotoen viaduct over the Hankyu-Imazu line, the Kaminoro Overbridge,

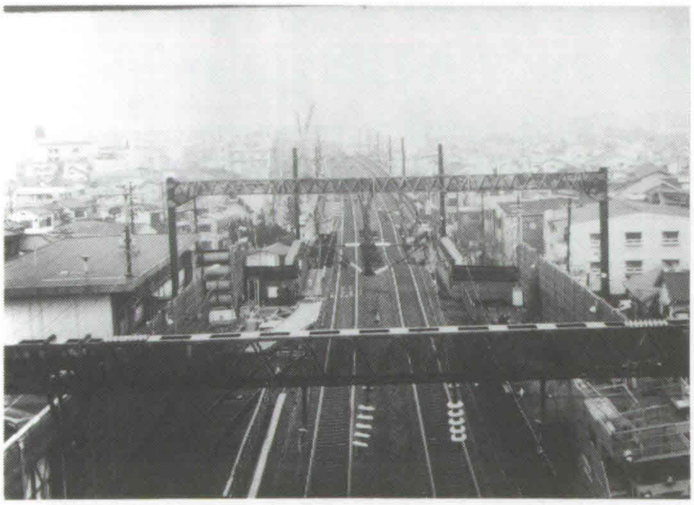

Photo 3 Track of Sanyo Bullet Train Line as seen from the eastern entrance to the Rokko Tunnel: damage to the ballast and rails is slight despite failure of the viaduct

Photo 4 Damage to rigid-frame viaduct with three unequal spans (near Nishi-Akashi Station, Sanyo Bullet Train Line)

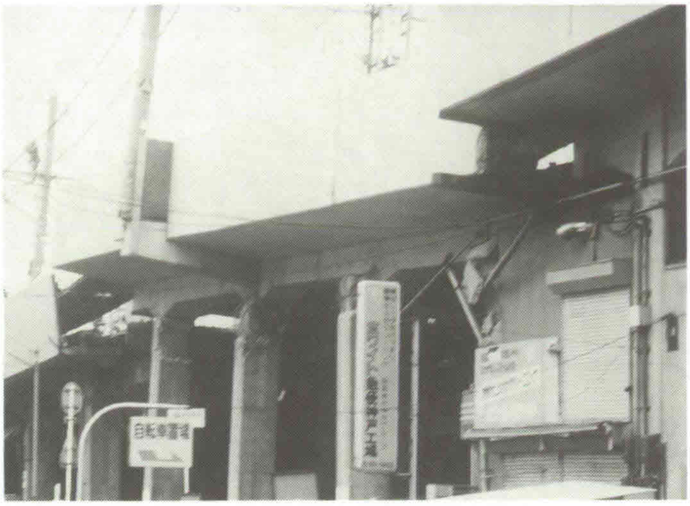

Photo 5 Failure of rigid-frame viaduct and twisted rails (near Rokkomichi Station, Tokaido Main Line)

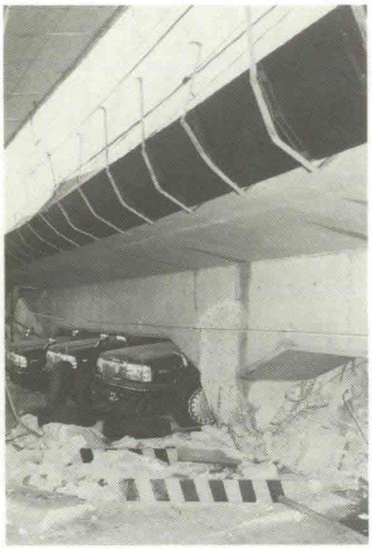

Photo 6 Failure of columns of rigid-frame viaduct

the Ikawa River Bridge, and the Akashi River Bridge on the Sanyo Bullet Train Line; the viaducts near Rokkomichi Station and Nishi-Akashi Station on the Tokaido Main Line; and the viaduct near Sannomiya Station on the Kobe Express Railway. Of these, the Kotoen viaduct over the Hankyu Imazu Line, the Kaminoro Overbridge, and the Ikawa River Bridge on the Sanyo Bullet Train were found to have collapsed or almost collapsed. In all cases, however, the girders were intact or damaged only to the extent that concrete had spalled at the ends.

The damage was concentrated in the abutments and piers of these structures. The columns of the rigid-frame abutments of the Ikawa River Bridge were particularly badly damaged. The columns appear to have been crushed under great stress, with the steel reinforcement bars deformed in all directions. The damage is so severe that their original size is not at all clear (see Photo 7). The same is true of the rigid-frame abutments of the viaduct over the Hankyu Imazu Line. The piers of the overbridge located at the Osaka end of Rokkomichi Station were also considerably damaged (see Photo 8). There is now a need to determine in greater detail how the compressive and shear forces generated by a combination of vertical and horizontal earthquake motions acted on these structures, and how this unprecedented destruction occurred as a result.

The Ikawa River Bridge is about 1.7 kilometers away from the Akashi River Bridge. These two girder bridges, of prestressed concrete construction, are almost identical in size. In both cases, the middle pier of the bridge fissured in the center as a result of shear forces, and the concrete cover spalled. In the case of the Akashi River Bridge,

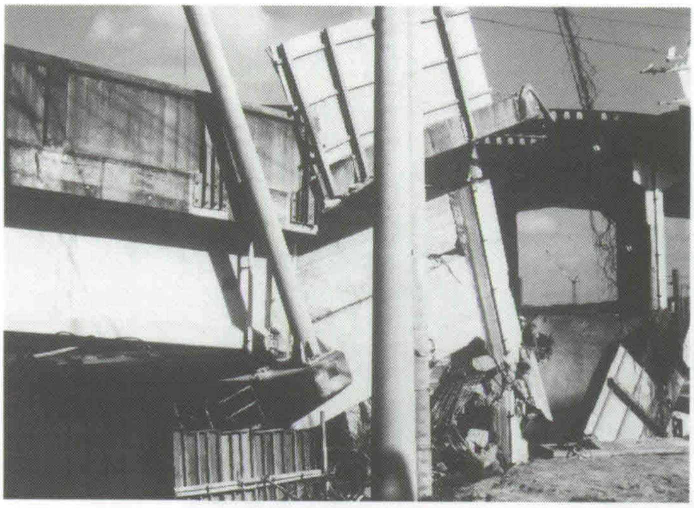

Photo 7 Failure of rigid-frame abutments (Ikawa River Bridge, Sanyo Bullet Train Line); upper and middle girders in contact after destruction of the upper-deck side columns

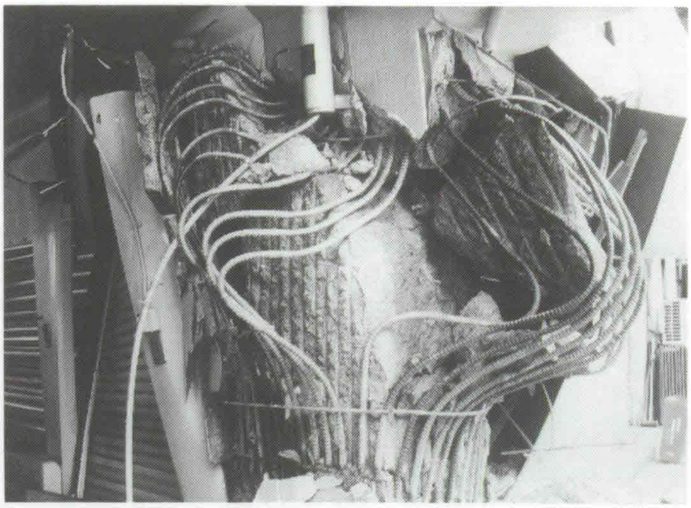

Photo 8 Failure of reinforced concrete piers of an overbridge (near Rokkomichi Station, Tokaido Main Line)

the steel reinforcement bars of the piers buckled. The damage, however, was concentrated in different directions; in the case of the Akashi River Bridge, the fissures and separations occurred on the side face of the bridge axis, while in the case of the Ikawa River Bridge they occurred on the internal faces.

The Muko River Bridge suffered damage including buckling of the steel reinforcement bars on the sides of the oval piers. Damage to all piers occurred at a cross section at a constant distance below the girder surface, apparently where the amount of steel reinforcement was reduced.

Many concrete bridges suffered lateral movement of the girders. In the case of the Kaminoro Overbridge, all bolts in the metal components designed to prevent lateral movement, which had been retro-fitted, were snapped by the shear force, and some of the metal parts even dropped away (see Photo 9). The girders of the prestressed concrete viaduct near Sannomiya Station on the Kobe Express Railway moved and then collapsed, tearing off the anchor bolts. This viaduct, constructed before 1965, had no means of preventing lateral movement in its girder bearings (see Photo 10).

(3) Steel Piers

In the sections inspected, few railway bridges were supported on cast steel piers. The two rigid-frame piers bearing the steel plate girder overbridge near Sannomiya Station on the Kobe Express Railway collapsed due to brittle failure of the steel columns (see Photo 11). This damage is probably the first of its kind, and needs to be

Photo 9 Failure of devices to check the lateral movement of girders (Kaminoro Overbridge, Sanyo Bullet Train Line in Nishinomiya City); failed bolts

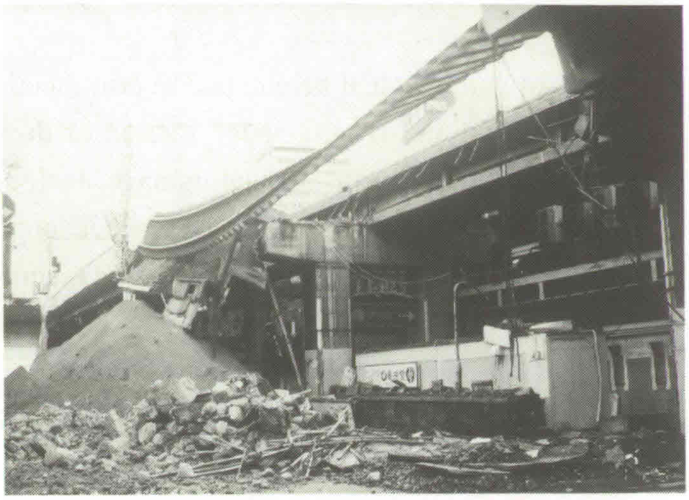

Photo 10 Girders moved laterally and collapsed (near Sannomiya Station, Kobe Express Railway)

investigated in detail. This mode of destruction implies an extremely rapid displacement.

All of the large number of rocker piers comprising the overbridge near Sannomiya Station of the Tokaido Main Line collapsed in the direction of the mountains (see Photo 12). This is probably because of the movement of plate girders .

(4) Steel Girder Bridges

The Sanyo Bullet Train Line has very few girder bridges made of steel, and we inspected only the overbridge to the west of the Ikawa River Bridge and the overbridge to the west of Nishi-Akashi Station. The former appeared to be basically undamaged, but the lower bearings of the transverse box-shaped girders, which support the structure, failed (see Photo 13). This is a result of sudden, strong transverse forces, and is similar in nature to the destruction of a number of viaducts on the Tohoku Bullet Train and other lines in the Miyagi Offshore Earthquake.

The girder ends of the overbridge at Nishi-Akashi Station were locally buckled. This was probably caused by displacement of the reinforced concrete piers.

All of the large number of steel girders along the Tokaido Main Line and the private railways, etc. were either undamaged or only slightly damaged at the girder ends. The Shinmei Overbridge, where the Second Shinmei Highway crosses the Sanyo Main Line near Takatori, is a continuous-girder bridge of steel box design. The piers at the fixed ends were damaged considerably (see Photo 14). They have collapsed to about one half of their original height, and in cross section they have expanded about twofold in most directions. The elevated section of this highway on the seaward side of the bridge suffered rare or unusual damage, including stress-induced failure of concrete in the transverse girders below the bracket supporting the bearings of the steel box girders and local buckling of the end stiffening members of the steel plate girders.

(5) Tunnels (cut-and-cover type)

The underground section of the Kobe Express Railway between Taikai and Kosoku-Nagata Stations, and the Sannomiya Station of the Kobe Municipal Subway were investigated. This section of the Kobe Express Railway was constructed by the cut-and

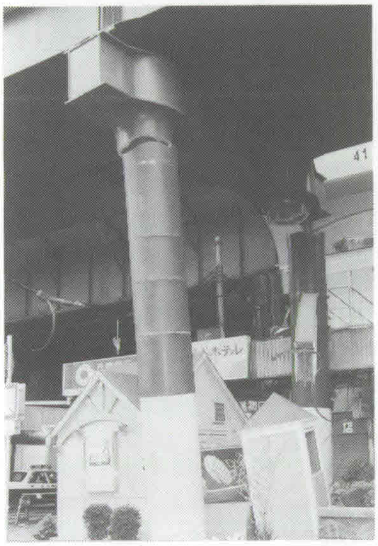

Photo 11 Brittle failure of steel piers (near Sannomiya Station, Kobe Express Railway)

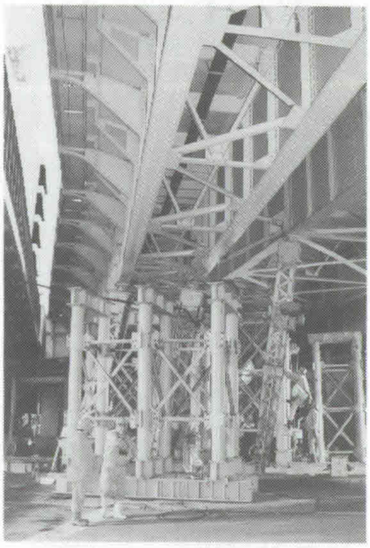

Photo 12 Tilting rocker piers (near Sannomiya Station, Tokaido Main Line)

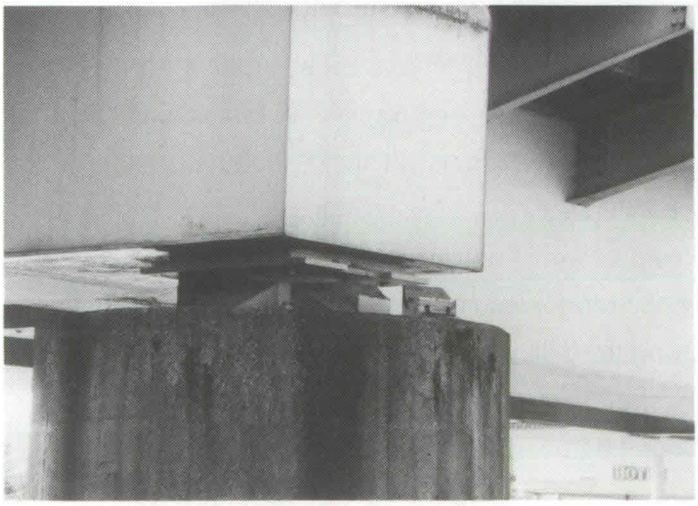

Photo 13 Failure of lower shoes on transverse box girders on a steel girder bridge (Ikawa River Bridge, Sanyo Bullet Train Line)

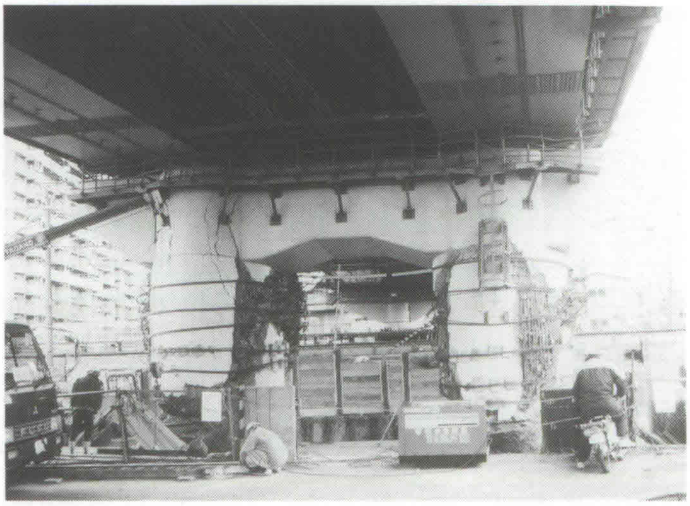

Photo 14 Failure of piers of the Second Shinmei Overbridge, with continuous steel box-girder superstructure

cover method in 1962 or thereabouts. At Taikai Station, which has a rigid-frame box structure, the central columns were destroyed completely and the upper slab of the rigid frame cracked and sunk by 2 to 3 m. The cross section of the box was deformed into an "M" shape, with the lower slab unaffected (see Photo 15). The road surface directly above the underground station subsided considerably (see Photo 16). Tunnel sections other than at station areas also suffered considerable damage to the central columns of the rigid-frame box structure. The lower ends of the columns were damaged to an especially large degree, with the concrete cover spalling or the steel reinforcement buckling in some cases. It was noted that where the lower end of a column was damaged on the right-hand side, the upper end of the same column was likely to be damaged on the left-hand side. In addition, the side walls of the box-section rigid-frame structure were displaced toward the box interior above the haunches in the bottom corners of the rigid-frame structure.

At Sannomiya Station of the Kobe Municipal Subway, which consists of a three-deck rigid-frame structure, the central reinforced concrete columns in the switch and machine rooms on the Basement 1 and Basement 2 levels suffered spalling of the concrete cover, and the steel reinforcement buckled in some cases. The round central columns of cast steel in the Basement 2 and Basement 3 concourses, which are public areas, were not damaged. The box-section tunnels adjacent to Sannomiya Station appeared to be undamaged, despite the damage to the interior of the station.

Photo 15 Failure of central subway columns holding up slab of rigid-frame box structure (Taikai Station, Kobe Express Railway)

Photo 16 Subsided road surface directly above Taikai Station

2.3 Physical Damage to Rolling Stock and Other Railway Systems

(1) Derailment and Damage to Rolling Stock

A total of 49 trains were damaged at 25 locations (including partial derailments). Since the earthquake happened early in the morning, 26 of the damage cases occurred in storage yards. Aside from the stress-induced destruction of the Hanshin Railway's elevated rolling stock yard (the Ishiya River Train Depot), most rolling stock was not damaged badly enough to cause serious delays in the restoration of train services. This is partly because the earthquake occurred so early, and only a small number of trains were actually on main tracks.

(2) Damage to Power Supplies, Signals, and Communications Systems

Although some overhead cable supports collapsed when elevated structures were damaged, no serious damage has so far been reported to substations and communications systems, although there are a few exceptions. Radio communications systems appear to have proven effective. Operation control centers were also undamaged, partly because they are mainly located in the Osaka area.

2.4 Personnel Losses

Passenger injuries:

Dead: none; seriously injured: five; slightly injured: 36

Workers and the general public under elevated structures:

Dead: three; seriously injured: none; slightly injured: one

2.5 Impairment of Transport Functions

(1) Paralyzed Urban Railways

- The urban railway network was severed at many points, causing considerable difficulties in daily movement. This affected commuter trains, railway services for refugee evacuation and the delivery of materials and relief activities. The inevitable result was increased traffic on the roads, greatly exacerbating problems with road capacity.
- All lines connecting Kobe and Osaka were brought to a halt: the JR Tokaido Main Line, the Hankyu Kobe Line, and the trunk line of the Hanshin Railway. This not only disrupted the transport of about 430,000 passengers per day and 120,000 passengers per rush hour, but also paralyzed railway services for the evacuation of refugees and prevented relief supplies coming in from outside. Normal railway usage is so great that it cannot be replaced by emergency bus

services, which will be discussed later. (On Jan. 23, the daily capacity of all JR, Hankyu, and Hanshin emergency bus services was 35,000 people.) Furthermore, the substitute buses turned out to place a heavy load on the already overburdened highways, causing traffic jams despite the special lanes set aside for them. This demonstrates how important the functions of railways and highways in large cities are.

A special bus lane was very quickly set up on National Highway No. 43, a point which deserves particular mention. Between Osaka and Shin-Kobe, a round-about railway route quickly became available by way of Sanda (Osaka - <Fukuchiyama Line> - Sanda - <Kobe Railway> - Yakami - <Hokushin Railway> - Shin-Kobe) which took 2 hours and necessitated two changes. This indicates the importance of a certain level of redundancy in public railway facilities to serve as an emergency network in case of need.

(2) Paralyzed Inter-City Railways

- The damage to the Sanyo and Tokaido Bullet Train Lines severed the arteries of Japan. Each day, 120 return journeys were prevented from operating in the section between Kyoto and Shin-Osaka, and 90 in the section between Shin-Osaka and Shin-Kobe. The airlines made rapid efforts to bring in extra planes, and much was made possible by the recently opened Kansai International Airport. This again shows the importance of functional redundancy in traffic systems: alternative railway and airline routes, multiple airports, and a greater runway capacity than is needed for normal operations.
- Regarding the Tokaido and Sanyo Main Lines, about 360 trains in each direction were canceled each day (including 50 freight trains and 150 expresses).
- Bringing the Fukuchiyama Line back into service on January 21 opened up a second route linking Osaka with Himeji and other western cities: the round-about routes by way of the Kakogawa and Fukuchiyama Lines and by way of the Bantan and Fukuchiyama Lines. Although the Bantan and Kakogawa Lines are not electrified and do not have high-grade track — and therefore do not allow the high-speed running which would be needed for full substitution — it can be said that the existing railway network proved to be operative to some extent.

On January 27, substitute bus services began to operate on the Chugoku Expressway between Shin-Osaka and Himeji, but operational problems due to traffic jams remained unsolved.

2.6 Values of Direct Losses

As of the time of this survey, the three JR companies and the five private railway companies were estimating the total cost of restoration at around ¥353 billion. Of this, the greatest losses are borne by West Japan Railways (¥120 billion), Hankyu Railway (¥66 billion), and Hanshin Railway (¥70 billion). Naturally, such costs will place a heavy burden on these companies. Other companies are also in a precarious situation, judging by the losses as compared with their annual income. Besides these direct costs, the income of all these companies is reduced due to the stoppage of services. For JR Tokai, too, a sharp drop in the number of passengers coming directly from the Sanyo Bullet Train Line has resulted in significantly reduces income. Some of the railway companies may be affected by these problems to the extent that their very existence is endangered, given their annual fare income and their investment in equipment. Special measures to protect them are now being studied, since relief measures specified in the Railway Track Servicing Law and the Enforcement Ordinance and Enforcement Regulations of the same law are limited. (In outline, the law provides for not more than 25% of the cost of restoration to be covered by national funds where any railway company has suffered operating losses for three years to the present or will definitely suffer operating losses for the coming five years.)

Further problems may arise with differences in fare levels due to the varying cost of losses once restoration is complete, since these are private companies. The management of the seriously affected companies, and their passengers, will thus continue to shoulder the burden of this calamity for many years to come.

3. RESTORATION WORK IN PROGRESS

(1) Restoration of Train Services

A total of 3,552.8 km of track was closed on the day of the earthquake, and the restoration efforts made so far are summarized in Table 1.

Structural damage was assessed within the day, and then the necessary emergency measures were worked out. Restoration work began late into the night. This quick action certainly resulted in early restoration of services.

Table 1 Restored Train Services (excluding lines restored on the first day)

Date	Company	No. of lines restored	Restored length (km)
Jan. 18	West Japan Railways	4	152.0
	Hankyu Railway	2	17.9
	Hanshin Railway	1	14.1
	Transportation Bureau, Osaka City	2	9.5
	Transportation Bureau, Kobe City	1	13.9
	Kita-Osaka Kyuko Railway	1	1.9
	Sanyo Railway	2	47.5
	Hokushin Kyuko Railway	1	7.5
	Osaka Express Railway	2	10.2
Jan. 19	West Japan Railways	2	25.3
	Hankyu Railway	1	6.4
	Kobe Railway	4	56.0
Jan. 20	JR Tokai	1	39.0
Jan. 21	West Japan Railways	1	15.3
	Hankyu Railway	1	2.2
Jan. 23	West Japan Railways	1	15.5
	Hankyu Railway	1	2.9
Jan. 25	West Japan Railways	1	6.3
Jan. 26	Hanshin Railway	2	10.2
Jan. 28	Sanyo Railway	1	5.0
Jan. 30	Sanyo Railway	1	7.3
	Hankyu Railway	1	4.5
	Sanyo Railway	1	2.9
Feb. 21	Hanshin Railway	1	0.9
	Kobe Express Railway	1	1.5

As for rolling stock, there are currently few problems related to providing services in the partially and temporarily restored sections, thanks to the location of the rolling stock yards and the local nature of the damage. As the length of restored sections increases, however, problems concerning the supply, repair, and procurement of rolling stock may arise.

Whereas there are effective nationwide mutual aid systems between local governments, gas companies, and power companies for special vehicles (fire fighting vehicles, ambulances, garbage trucks, electrical work vehicles, gas fitting vehicles, etc.), mutual support in terms of rolling stock is difficult because there is no unified track gauge, power requirement, or signal system. It is possible to exchange engineers only. Unlike the JR companies, which were able to successfully set up alternative routes, the private railways with their different operating systems have limited opportunities to set up networks.

One other point deserving special mention is the fact that there was no serious damage to operation centers, thus making possible this rapid temporary response.

(2) Substitute Buses

On Monday, January 23, substitute bus services began operating over sections between JR Koshienguchi and Sannomiya, between Hankyu Nishinomiya-Kitaguchi and Sannomiya, and between Hanshin Koshien and Sannomiya (at intervals of 15 minutes, respectively, or one bus every five minutes). As railway restoration work proceeds as listed above, these sections are being gradually shortened.

On Saturday, January 28, 940 daily runs began on routes between JR Ashiya and Sannomiya, between Hankyu Nishinomiya-Kitaguchi and Sannomiya, and between Hanshin Oogi and Sannomiya, all using special bus lanes set up on National Highway No. 43. As a substitute for the Bullet Train, a bus route linking Shin-Osaka with Himeji began when the Chugoku Expressway was reopened to traffic. All services on these bus routes face traffic congestion problems.

4. DISCUSSIONS REGARDING THE FUTURE

- The damage caused by this earthquake to railway structures was unprecedented. It is therefore necessary to return to basics and consider the following issues before carrying out any review of the structural design criteria.
    1) Detailed analysis of the intensity and type of the earthquake motion
    2) Analysis of the response of various structures to this earthquake motion
    3) Possible methods of modeling structures for design purposes

- Hurdles to be cleared in restoration
    1) Emergency restoration (operation at lower speeds) and permanent restoration
    2) Financial and technical aid
    3) Structures collapsed on tracks, the way lines are used, and how space under elevated structures can be used, as seen from a restoration viewpoint

- Future Planning issues
    1) Planning and structural design issues, as seen from the viewpoints of safety, the environment, and financial problems

2) Securing functional redundancy among different systems in consideration of emergency measures and restoration programs in case of disaster.

(Responsibility for the wording of this report
lies with S. Morichi, C. Miki, and H. Ieda)

Report by the Road Survey Group (on Road Traffic)

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1. ROAD SECTIONS AND FACILITIES SURVEYED

The Kobe Route of the Hanshin Expressway, and National Highways 42 and 43 between Nishinomiya and Sannomiya in Kobe

Streets and back streets in Nishinomiya and Kobe (Nagata, Hyogo, and Chuo Wards)

Roads along a temporary bus route (Hanshin Bus route between the Sannomiya and Hanshin Koshien bus-stops), and the Meishin Expressway (in Nishinomiya only)

2. DAMAGE

a. Looking first at the Kobe Route of the Hanshin Expressway, bridge girders fell or toppled at six points between the Koshien District of Nishinomiya and the Fukae District of Kobe. In Fukae, the elevated expressway suffered particularly devastating damage: bridge girders together with the columns overturned to the north over a length of about 500 m. In many other places, expressway bridge columns were severely damaged and girders came loose at their bearings although the girder did not collapse. As a consequence of the damage, the entire Kobe Route of this expressway had to be closed. As regards the Wangan Route of the Hanshin Expressway, the whole route was affected because a bridge girder fell at Nishinomiyahama.

b. National Highway 43 runs directly below the elevated Kobe Route of the Hanshin Expressway, and lanes in both directions of the route were blocked in places where the elevated expressway girders fell or overturned. As removal work proceeded after the earthquake, the road gradually became passable in one direction and then with limited lanes. The Iwaya overpass (in Chuo Ward) which crosses National

Highway 2 collapsed, so traffic on this road was also halted. Aside from this damage, few serious driving problems arose elsewhere because damage to the road surface itself was generally relatively slight, although subsidence, changes in road level, and cracking of the pavement were noted in many places.

c. With regard to National Highway 2, the entire Hamate Bypass (in Kobe's Chuo Ward) was closed as a consequence of damage to the bridge columns of the Kobe Route of the Hanshin Expressway. The road was also partly closed in the Harbor District of Chuo Ward where bridge columns of the same expressway overturned and in front of the Shinbun Kaikan Hall (in Chuo Ward) where a bridge girder of the Port Liner (an automated guideway transit system) collapsed. This latter problem, in front of the Shinbun Kaikan Hall, was rectified by carrying out temporary reinforcement work.

   Although subsidence, changes in road level, and surface cracking were found in many places, most roads on the ground level did not themselves suffer very severe damage on the whole. As a result, most roads became passable after minor repair work.

d. Many main streets in the areas surveyed were partly closed where railway and road overbridge girders collapsed. There were also reports of serious subsidence where streets were directly above underground structures. As a whole, however, there seemed to be no severe damage to the road surface itself. As far as streets in Nishinomiya are concerned, there seemed to be no devastating damage except in the case of the main Yamate street, which was blocked by the collapse of the Meishin Expressway girders. Although many streets suffered light damage, traffic flow was not seriously impaired after appropriate temporary repair work. The degree of damage to local streets varied from place to place, and some pavements were cracked in the longitudinal and traverse directions. Sidewalks had also settled and subsided. Near the shore (probably on reclaimed land), traces of sand boiling — a sign of soil liquefaction — were found on some road surfaces and sidewalks. Although this did not impair traffic flows, it did affect bicycles and pedestrians. Quite large numbers of buildings and houses had collapsed alongside the roads, impeding traffic. As regards back streets in the areas surveyed, many streets — in Nagata Ward in particular — failed to prevent fires from spreading. Figure 1 shows the major damage to expressway structures.

3. EFFECTS OF EARTHQUAKE DAMAGE ON ROAD TRAFFIC

(1) Traffic conditions

a. Despite the fact that all railway and expressway traffic halted immediately after the earthquake struck, there is no evidence that traffic on main roads was brought promptly under proper control. Without proper traffic control, the movement of emergency vehicles being used for evacuation and rescue operations would have been seriously hampered by traffic congestions as time passed.

b. National Highway 2 was restricted to emergency vehicles taking part in relief activities as from January 20. Despite this, however, traffic other than emergency vehicles entered intersections from other roads without control, and traffic almost ceased flowing. This was particularly noticeable in the east of Kobe during observations for this survey. The reason for the heavy congestion was probably that many roads were blocked by collapsed houses in this area, making many local roads unusable.

c. A major cause of traffic congestions was the increase in the number of pedestrians, bicycles, and motorcycles in the absence of railway services. With many collapsed buildings or buildings in danger of collapse lining the main roads, sidewalks were blocked and pedestrians and bicycles had to use the roadway. This aggravated the traffic congestions. In addition, excessive parking on the roadway also caused congestion.

d. Bus routes to replace non-operating railways did not come into operation until January 23. Survey members were themselves caught up in heavy traffic jams, and movements slowed to a crawl because of a lack of proper control over private vehicles. A journey from Sannomiya to Hanshin Koshien by bus at around 4 p.m. on January 24 took 3 hours 15 minutes for a distance of about 14 km.

(2) Loss in transportation capacity

a. National Highway 43 was closed at several points due to damaged and overturned sections of the Hanshin Expressway, and the Expressway's Wangan Route was unusable because a bridge girder had collapsed. In consequence, road traffic concentrated on National Highway 2, the only usable main route between Kobe and Osaka. The result was heavy traffic congestion. Looking at a north-south cross section through the road network between

Nishinomiya and Ashiya, normal traffic volumes on the closed main roads before the earthquake were approximately 65,000 vehicles/12 hours on National Highway 43; 115,000 vehicles/24 hours on the Kobe Route of the Hanshin Expressway; 32,000 vehicles/24 hours on the Expressway's Wangan Route; and 28,000 vehicles/24 hours on National Highway 2. These data are taken from a Road Traffic Census in October 1990 in the case of the national highways, and are the average traffic volumes measured by traffic detectors in October 1994 in the case of the expressways. Assuming the 12-hour traffic volume (from 7 a.m. to 7 p.m.) to be 0.75 times that over 24 hours (the actual average for National Highways 2, 38, 43, and 428), the total traffic volume across this section is about 203,000 vehicles/12 hours. Accordingly, National Highway 2 accounts for about 14% of total traffic volume across the section. Given this, the hourly traffic on National Highway 2 is approximately 600 vehicles per lane during the day, a volume close to its capacity. Taking into account damage to the road surface, remains of buildings blocking the roadway, and the large number of bicycles and motorcycles, this original capacity would now seem to be considerably lower. Roughly speaking, present traffic through this north-south section is about 10% of that before the earthquake. Figure 2 shows normal road traffic volumes at major points.

b. Looking at the railways, passenger numbers before the earthquake were as follows: about 210,000 on the Hankyu's Kobe Line (between Nishinomiya Kitaguchi and Shukugawa); about 140,000 on the Hanshin's Main Line (between Ogi and Uozaki); and about 300,000 on Japan Railway's Tokaido Line. (Hankyu data are from the 1994 Urban Traffic Annual Report and Japan Railway's data from the 1992 Urban Traffic Annual Report.) This is a total of about 650,000 passengers per day through the north-south cross section. Closure of all three lines dealt a sharp blow to the movement of people between Kobe and Osaka. Since the damage sustained by these railways will take some time to restore, it is essential to rapidly set up alternatives. Figure 3 shows the cross-sectional traffic volumes on major roads and railways between Higashinada and Nishinomiya in Kobe.

4. RECOMMENDATIONS ON TRAFFIC CONTROL IN THE CASE OF EARTHQUAKES

(1) Traffic control measures needed immediately after an earthquake

Naturally, the first priority in a disaster is to save lives. This should have been the case in this earthquake, even to the extent of implementing traffic control. Buildings can collapse, and fires can break out and spread across city blocks after an earthquake. Until things calm down, strict traffic control should be implemented in the earthquake disaster area. A state of emergency should be declared in the stricken area, and movement of all passenger vehicles should be prohibited. Those permitted on the roads should be limited to rescue, fire fighting, and emergency supply vehicles. Also, to give priority to the transportation of emergency relief equipment, private cars should, in principle, be prohibited from using the roads; use should be limited to vehicles operated by the government and other relief groups. The delivery of emergency equipment by individuals should only be allowed after the situation calms down.

Emergency traffic control systems should be designed to suit different levels of damage. In the case of a devastating disaster such as this earthquake, the system should be as simple as possible. We are now nearing the time when the next generation of traffic control systems using intelligent transportation systems will come into use. Yet it is quite evident to everyone that such systems are quickly rendered useless in a disaster, since it is impossible to collect real-time data if there is widespread damage to the roads. Such systems can remain usable only if the damage is very limited. In such limited-damage situations, the concept of reliability as often adopted in systems engineering can be applied. This means that the system should be designed such that it remains functional even if part of the system is damaged. When applied to a road system, this means that there are always alternative roads even if some are blocked.

In the case of large-scale collapse as experienced in this disaster, however, the theory is difficult to apply since it is not easy to secure alternatives. In such a situation, it is necessary to adopt a plan in which roads are secured in order of decreasing priority. In the confusion of a disaster, a straightforward and clear road utilization system requiring the minimum of technology would seem the most practical and effective solution. In concrete terms, specific regional main highways and main roads should be designated as for use by emergency vehicles only.

(2) Traffic control during the restoration period

When the situation calms down, and everyday life once again becomes possible, the road traffic control measures must focus on restoration work. At this stage, there is some need for passenger vehicles to use the roads, yet some degree of traffic control is required depending on how well road functions have been restored and on traffic volumes. Even at this stage, emergency medical vehicles and vehicles taking part in restoration work should have right-of-way, and special lanes should be provided wherever possible. During surveys on the fifth to seventh days after the earthquake, large numbers of passenger cars did not appear to be taking part in emergency activities. This is an issue to consider in drawing up future measures.

The fundamental aim is to give first priority to major inter-district main roads and main city routes, restoring them as soon as possible to serve as main routes for emergency vehicles. Passenger cars may be permitted on other major roads if there are sufficient lanes. If not, passenger vehicles and private cars should be limited to other main roads or local distribution roads.

One traffic control measure that might be considered during the restoration period is the use of the median strip. These days, many roads have island-type medians for improved landscaping and accident prevention reasons. Instead of the permanent designs currently used, some kind of flexible structure easy to remove in case of emergency would seem convenient. This would provide space for at least one, and perhaps two, lanes for use by emergency vehicles. This might appear incompatible with the idea of using the median strip as a safety and landscaping device. However, in consideration of traffic measures in an emergency, this is an issue worthy of future study.

(3) Alternative means of transportation until restoration is complete

All railway services between Sannomiya and Nishinomiya on Japan Railway's Tokaido Line, the Hankyu’s Kobe Line, and the Hanshin’s Main Line were suspended as a result of damage to railway facilities. This halted the movement of about 600,000 to 700,000 people per day between these stations. Such a huge volume of people cannot be moved by any conceivable alternative means. However, considering the present situation, alternatives should have been brought into operation as soon as possible to help with emergency communications and restoration activities. Buses are the first means to consider. However, in this case, despite some problems in securing drivers and buses, the reason for the delay in starting bus operations was that almost all main roads were not functioning. Once again, it is clearly important to promptly secure special lanes for emergency vehicles which might also be used by buses. Further study of ideal patterns of road lane utilization is needed.

Sea routes played a great role in this disaster because Kobe is a port city. With severe damage to port facilities, however, capacity was insufficient here too. Mooring facilities, in particular, were a problem; rather than fixed moorings such as quays, a simple type of floating pier would ease the transportation of passengers in an emergency.

In developing future disaster recovery plans, comprehensive plans for emergency transportation — including preparations for alternative transportation by bus and ship — should be drawn up.

(4) Review of design standards for transportation facilities

The seismic design standards for road structures will have to undergo a thorough review by specialists in the field of structural design. Besides the strength and safety of the structures themselves, a systematic look at their functions will also be required; for instance, it will be necessary to take into account how critical a particular component is to the entire system, as well as its significance from a social and industrial point of view. That is, it will be necessary to incorporate the ideas of what it called risk engineering into the design standards for transportation facilities.

(5) Others

a. In a disaster situation, road, railway, and marine transportation organizations must make every effort to make their own systems functional, while at the same time coordinating fully with each other. It is desirable to set up a system or organization capable of communicating between these organizations and coordinating their activities such that systematic operation plans and traffic controls can be brought into action.

b. In order to build cities that are prepared for disasters, it would seem important not only to ensure the flow of resources, but also to look into the question of inventory. The just-in-time system, in which needed amounts of goods are delivered as required, has come to be regarded as the most economic and rational means of freight transportation. However, if delivery routes are suddenly blocked, as in this devastating earthquake, production and business activities are soon brought to a halt. Many shopkeepers receive their supplies using this system to reduce inventory wherever possible. If they had storage systems, the volume of traffic dedicated to freight transportation would be reduced and production activities and everyday life could continue even if there is serious road congestion.

Reservoirs of drinking and fire fighting water, parks, and evacuation centers are a kind of capital stock. Median strips and road shoulders can also be regarded as such when they can be utilized as extra lanes for emergency vehicles. It must be realized that such capital stock can be very useful in an emergency situation, although it may seem a waste at first glance.

c. In thinking about the ideal road network with regard to disaster prevention, it is useful to go back to basics. We need a hierarchical structure in which roads with different functional characteristics are clearly separated: expressway, arterial roads, collector roads, and local roads. In this way, traffic within districts can be separated from inter-district traffic, and it is also easier to secure emergency services and evacuation routes. Furthermore, such a layout will help prevent fires from spreading. Concerning the road network in the Kobe and Osaka area, there is a need for more trunk roads in these districts both in the north-south and east-west directions.

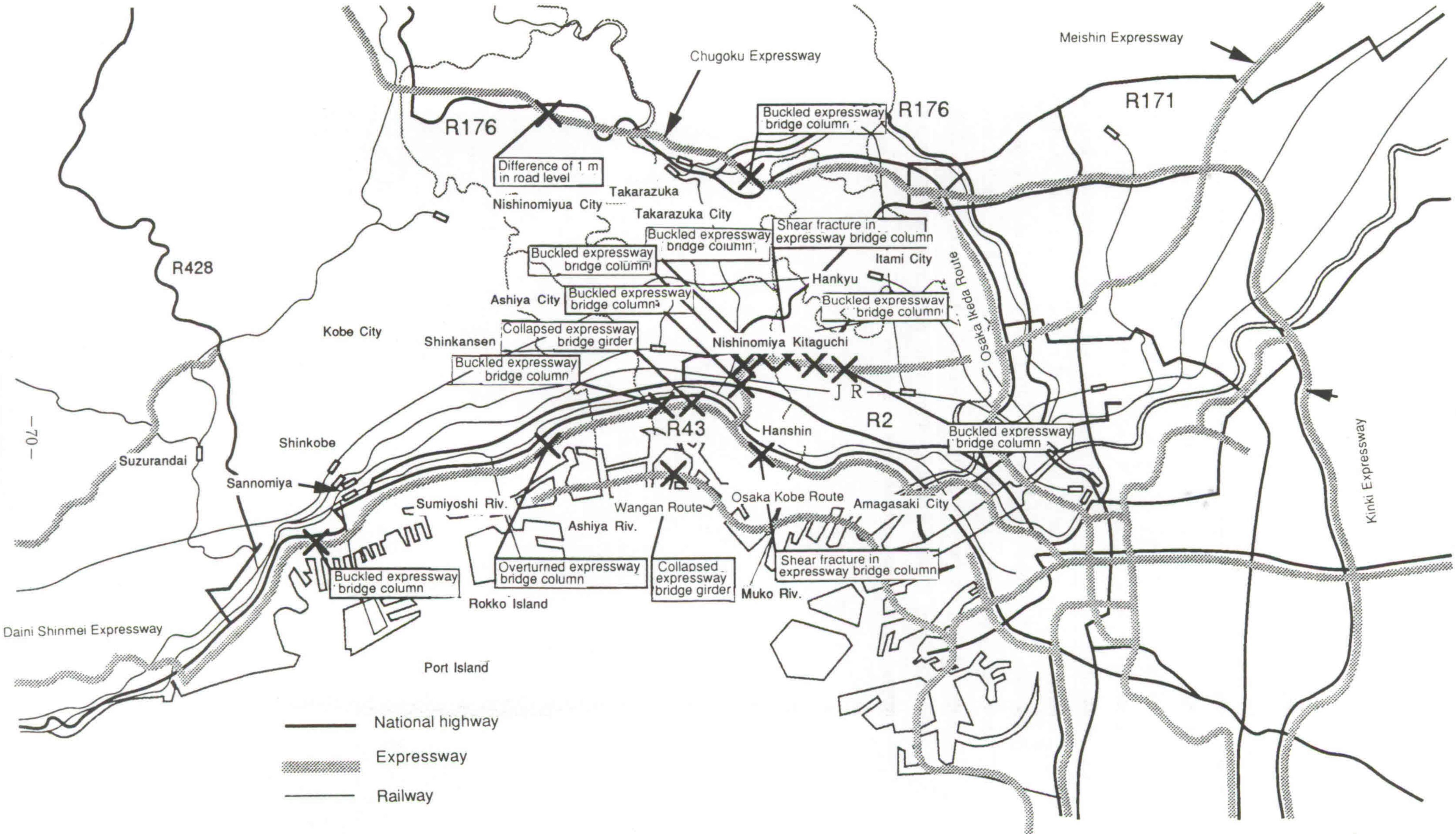

Figure 1 Major damage to expressway structures in the Great Hanshin Earthquake

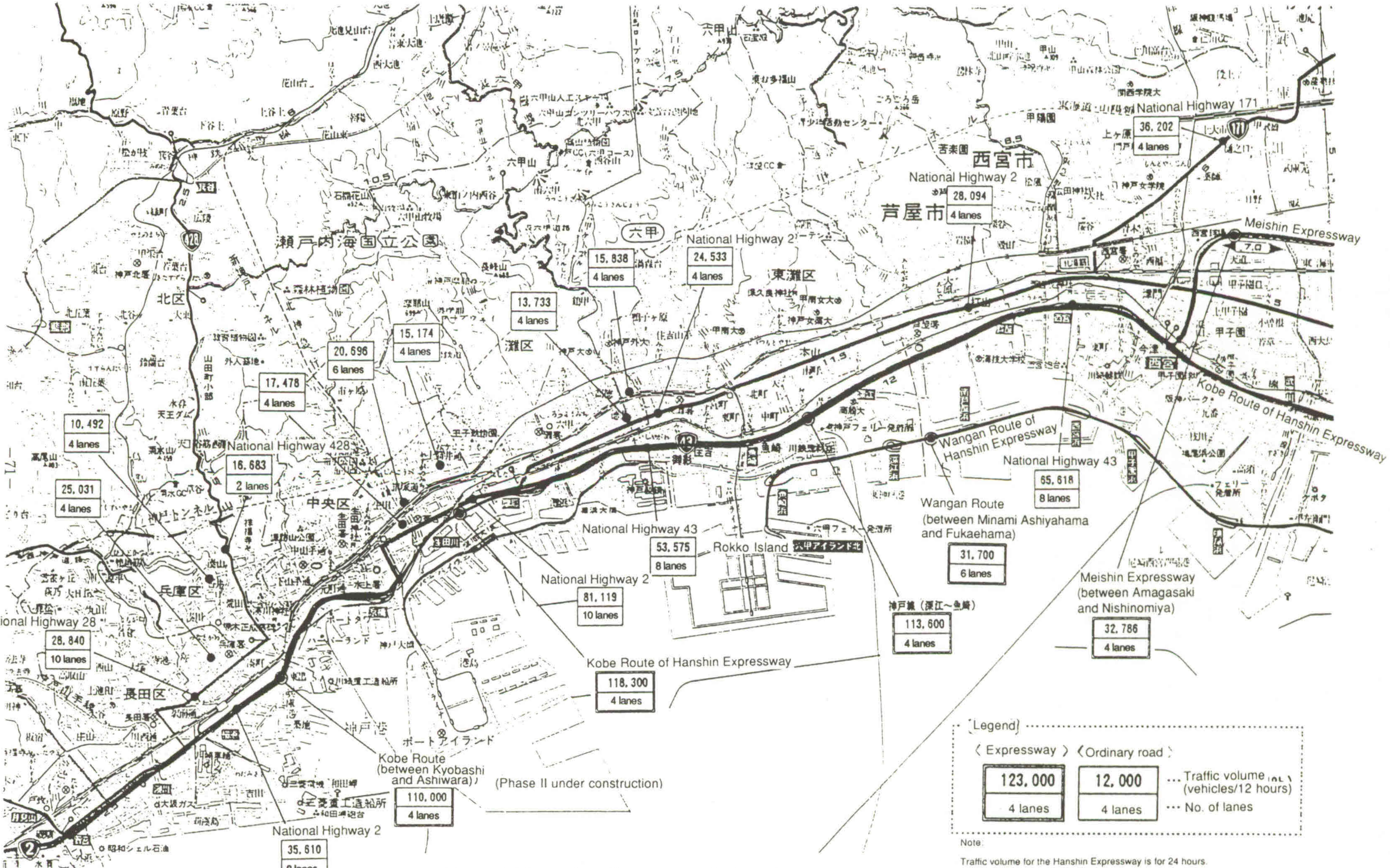

Figure 2 Normal traffic volumes before the earthquake

Note:

Traffic volume for the Hanshin Expressway is for 24 hours.

Data sources:

Traffic volume on the Hanshin Expressway: Average traffic volume surveyed in October 1994

Traffic volume on other roads: 1990 Road Traffic Census

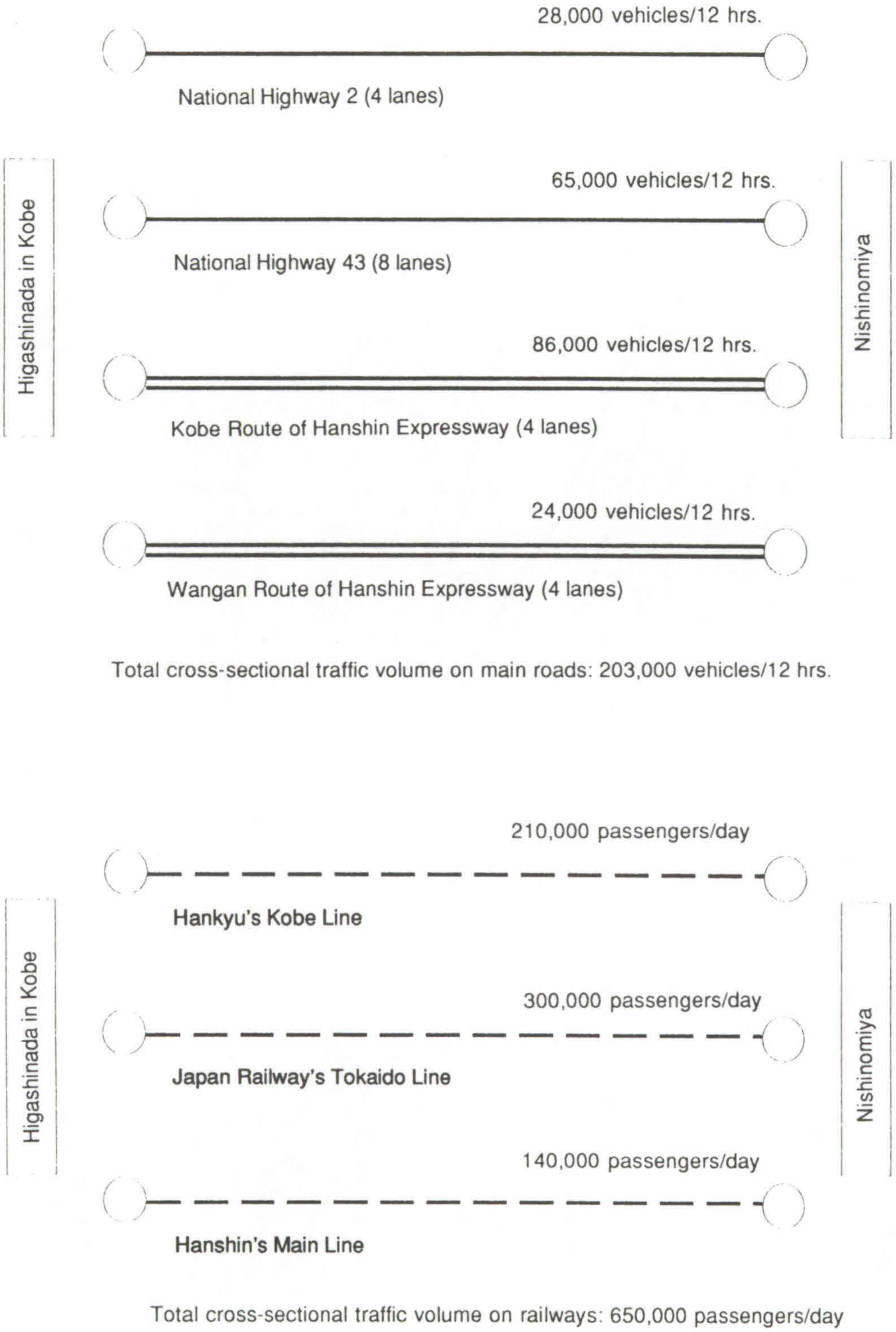

Figure 3 Cross-sectional traffic volumes on main roads and railways

Report by Road Survey Group (on Structures)

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1. ROAD SECTIONS AND STRUCTURES SURVEYED

The Hanshin Expressway Public Corporation:	Osaka-Nishinomiya Route, Kobe-Nishinomiya Route (Koshien and westward; Higashinada Ward and eastward), and the Bayshore Route (Nishinomiya and westward).
The Japan Highway Public Corporation:	Meishin Expressway (near Nishinomiya Stadium).
Roads in Amagasaki, Nishinomiya, and Kobe.	
Office visit:	Head Office of Hanshin Expressway Public Corporation.
Information coverage:	Entire Osaka-Nishinomiya Route, Kobe-Nishinomiya Route, and Bayshore Route of the Hanshin Expressway Public Corporation.

2. DAMAGE TO ROAD STRUCTURES

Details of the damage to road structures, as obtained in this survey, are given below.

2.1 Outline of damage

The damage to expressway structures was as follows.

(1) Loss of life

Despite the low volume of traffic on the Hanshin Expressway because the earthquake struck so early in the morning, 16 lives were lost due to damage to expressways; seven drivers were killed where the elevated expressway overturned at Fukae in Higashinada Ward and seven passersby were trapped under fallen expressway girders and bridges on the Kobe Route; In addition, two drivers were killed on the Bayshore Route where a bridge girder fell down.

(2) Damage to the Kobe Route of the Hanshin Expressway Public Corp.

Cracking, shear fractures, and buckling fractures occurred on many RC bridge piers in all of the areas surveyed:

Locally buckled steel piers near Koshien
Fractured RC bridge piers and fallen girders near Takashio in Nishinomiya
Fallen simply supported steel girders near Fudaba in Nishinomiya
Collapsed steel and concrete piers and fallen girders near Tateishi in Nishinomiya
Overturned RC piers near Fukae in Kobe
Fractured RC piers and fallen steel girders near Hamanaka in Kobe
Fractured RC piers, locally bucked steel piers, and fallen girders near Minatogawa in Kobe

(3) Damage to the Bayshore Route of the Hanshin Expressway Public Corp.

Fallen girders at the east end of Nishinomiya Harbor Bridge
Fractured bearings at the east end of Nishinomiya Harbor Bridge
Broken Pendel bearings at the Kobe end of the Higashi Kobe Bridge
Lateral buckling of the Rokko Inland Bridge

(4) Damage to the Meishin Expressway of the Japan Highway Public Corp.

Tilted RC piers and fallen girders near Nishinomiya Stadium

(5) Damage to other road structures under the control of the Ministry of Construction and Kobe City

Damage to grade-separated crossings at National Highways 43 and 2, the Harbor Highway, etc.

2.2 Major damage

(1) Damage to the Kobe Route of the Hanshin Expressway Public Corp.

The Kobe Route, comprising the Osaka-Nishinomiya Route and the Kobe-Nishinomiya Route, is a trunk expressway connecting Nishimoto in Osaka with Tsukimisan in Kobe. It has a total length of 39.6 km. There are four lanes on a girder width of about 19 m. One of the features of the Kobe Route is the widespread use of the single-pier bridge structure. This structural type was adopted to secure space for National highway 43, which is directly beneath the expressway, as well as to reduce the oppressive atmosphere often caused by elevated expressways. In terms of numbers, there are about 800 piers at the Kobe end of the expressway, beginning with P119 on the Osaka-Nishinomiya Route. Of these, about 80% are of the single-pier type. In addition, there are more RC piers compared with steel piers; approximately 85% of the piers are RC.

Almost all the structures damaged in this earthquake are located westward of Mukogawa toward Kobe. They were constructed between 1965 and 1970. Almost all major damage consisted of fractured and collapsed bridge piers. Figure 1 shows a map of the major damage to road structures. The worst damage was concentrated near Fukae in Kobe, where Pilz-type single piers overturned, and in Hamanaka, Kyobashi, and Minatogawa.

Regarding the damage to RC piers, on the Kobe Route westward of Koshien, many RC piers had buckled and cracked at the base, with flexural and shear cracking and shear fractures (Photo 1). In our estimation, of the 800 piers mentioned, more than 500 were deformed in one way or another. The dominant orientation of shear and bending fractures was perpendicular to the bridge axis. Dice-shaped concrete chips of about 20 cm size were noted within piers which had fractured by bending at the base (Photo 2). Near Takashio in Nishinomiya, a road girder fell probably as a result of its RC piers leaning over in the longitudinal direction. At the east end of the fallen girder, shear cracking had occurred in the RC pier and the pier was greatly deformed toward the east in the longitudinal direction (Photo 3). Near Tateishi in Nishinomiya, steel girders had tilted and settled where steel and RC piers had buckled and collapsed (Photo 3). RC road bridge piers in this area were once again greatly deformed in the transverse direction, and many reinforcing bars had failed at pressure-welded joints where these were all aligned at the same cross section. In the RC road bridge piers between the Tateishi district and westward as far as the Fukae district in Kobe, much buckling and shear fracturing was noted. Many reinforcing bars had failed at pressure-welded joints, just as in the case at other locations.

In Fukae, the Pilz-type elevated expressway overturned to the north (perpendicular to the bridge axis) over a length of about 600 m (Photos 4 and 5). In total, this section comprised 16 piers supporting 22 m Gerber girders at 35 m centers. This design was originally adopted for its ease of construction, reduced noise and vibration, and economical cost. The Gerber girders and girders on piers were connected using prestressing steel wires. With this type of structure, the whole inertia of the girder during an earthquakes acts on the piers. It seems that this structural characteristic, coupled with inadequate pier ductility and the huge earthquake forces led to the expressway overturning. As can be seen in Photos 4 and 5, the concrete fractured and spalled from the steel reinforcement at the base of the RC piers. In these RC piers, it was noted once again that many steel reinforcing bars had failed at pressure-welded joints. In some of the piers, the concrete had fractured internally into dice-shaped chips.

One remarkable type of damage to steel piers was the collapse of T-shaped steel piers supported on a pair of RC piers (Photo 6). The mechanism of this collapse is still not clear, but it is likely that pins between the RC piers and the steel girders separated first, making the steel piers vulnerable to large earthquake forces in the transverse direction. Damage to the piers then reduced their compression load-bearing capacity, and they finally collapsed. Since the axial stress developed within a pier by the dead load is normally at most about 20% of the load bearing capacity, it is hard to imagine that the inertial forces induced by vertical earthquake motion would have been the direct cause of the collapse.

Other types of damage to steel piers consisted of locally buckled steel plates (Photo 7) and bulging at the base (Photo 8).

Concerning the damage to steel girders, there were many cases of steel girders sliding off their bearings, forcing out the anchor bolts holding them in place (Photo 9). As to girder displacement, besides the many girders that had moved in the longitudinal direction, many had also moved toward the mountains (northward) along the sections of expressway between Koshien and Fukae. Other damage to steel girders was distortion of lower flanges due to large transverse forces (Photo 10). Considering this mode of damage, and the fact that many RC piers had fractured due to bending and shear in the transverse direction, it seems that there were very large earthquake motions in the transverse (approximately north-south) direction.

Other damage included the collapse of bridge approach girders, a series of girders displaced in the longitudinal direction, girders forced of piers, and failure of earthquake-resistant connecting bars, although in this latter case the girders themselves were sound (Photo 11).

Sections of a pair of RC rocker piers at some distance from the Meriken Park in the Kobe direction were severely damaged, and 24 spans of piers and girders were removed. Many PC single-post bridge piers (some of them steel rigid-frame bridge piers) near Minatogawa to the east of the damaged rocker piers were severely damaged over a distance of several hundreds of meters as far as the Wakamiya ramp area. Removed piers and girders numbered quite highly.

(2) Damage to the Bayshore Route of the Hanshin Expressway Public Corp.

The Bayshore Route runs from Kobe itself to the link bridge for the new Kansai International Airport. Sections subjected to strong tremors in this earthquake are those on reclaimed land in Amagasaki and westward. It should be noted that this section opened in 1994 and was designed according to the new earthquake resistance standards. No damage was noted in Nishinomiya and further westward. On the border of Nishinomiya, damage increased in the direction of Rokko Island. The damage to long-span bridges and expressway girders is described below.

- The Nishinomiya Harbor Bridge (Nielsen arch with a center span of 252 m) and approach span

  A simply-supported bridge span (with a span of about 25 m) linking to the Nishinomiya Harbor Bridge collapsed (Photo 12). The cause of this must be that the bridge foundations moved as revetment caissons moved seaward, thus increasing the approach span and damaging devices to prevent the span from falling.

  Many revetment caissons moved seaward near the bridge foundations. Both here and around other bridges, the foundations must have moved seaward. The fixed-bearing upper shoe had broken into two and fallen to the ground (Photo 13). One loosened cable was noted, and this was probably caused not by rupture but by damage to the anchorage.

- Higashi Kobe Bridge (cable-stayed bridge with a span of 485 m, double deck structure)

  A pendel-type bearing pin at the end link of the side span on the Kobe side had dropped off (Photo 14). As a result, the side span lifted, resulting in damage to the expansion joints (Photo 15).

It is difficult to determine the cause of the damage to this Pendel bearing. Shear buckling was noted on the lateral girders of the bridge end pier and on the intermediate pier below the bearing, and local buckling had occurred on the outer web (in the longitudinal direction) near the base of the bridge end pier (Photo 16; this photo shows the locally buckled flange, but the locally buckled outer web cannot be seen.). This indicates that the bridge piers were subject to large earthquake forces in the transverse direction. This is also supported by the ground motion measured at the Higashi Kobe Bridge. The wind shoes had failed. Taking this into consideration, it seems that the bridge girders must have swayed excessively in the transverse direction. The cause of the damage to the Pendel bearing seems to have occurred because Pendel bearings and vane dampers (also damaged) are designed to restrain displacement in the longitudinal direction, but not to withstand forces in the transverse direction.

- Rokko Island Bridge (Lohse arch bridge with a span of 214 m; double-deck structure)

The Lohse bridge was horizontally displaced by about 3 m in the Osaka direction at the Rokko Island bridge pier. The arch chord on the Kobe side dropped off its bearing, and that on the Osaka side was overhanging the bridge pier (Photo 17). Securing bolts for the blocks designed to prevent the upper shoes from lifting had been ejected, and brittle fractures occurred in the blocks. The arch bridge must have moved considerably on the piers, since the bridge deck was rendered discontinuous by the large vertical earthquake motion.

Buckling was noted on the upper lateral horizontal and diagonal steel channel-section members (Photo 18). This was probably caused by large forces when the arch chord dropped off its bearing onto the bridge pier.

- Girder bridges

The most noticeable damage to girder bridges was the damage to bearings. A few bridges had to be closed as a result of one particular type of damage: the rollers at the movable bearing end dropped off their bearing surfaces, creating a difference in level between two girders at the expansion joints (on the road surface). Many girders came off their bearings and dropped onto the piers, causing local buckling of the flanges and webs. Deformation of bearings and girders seems to have occurred at 20% of all bearings.

- Bridge piers

At the Nishinomiya Harbor Bridge, as described above, and also at the Shukugawa Bridge, foundations close to revetment caissons appeared to have been displaced seaward due to caisson damage, but structural damage to the bridge piers themselves was not severe. With regard to the damage to steel bridge piers, the above-mentioned shear buckling (Photo 19) and local buckling due to bending were noted, but no piers were badly damaged.

The shear buckling of the web shown in Photo 19 was not only at an angle of 45°; it also caused the web to bulge in the form of an X. This is probably due to alternating loading caused by earthquake forces.

Some tens of the RC bridge piers in Koshienhama, Nishinomiyahama, and Ashiyahama are of the single-pier rigid frame type. Of these, only one had cracked (probably due to the impact of a girder dropping from its bearing on the bridge pier), and the remainder looked sound. These bridges were designed in accordance with the new earthquake resistance standards (amended in 1990) which take ductility into account in the design. The Nishinomiya Harbor Bridge, completed in 1975 and located relatively close to the shore, was designed based on the old standards and its piers were severely damaged. At the nearby Nishinomiya Plant of Osaka Gas Co., Ltd., a strong-motion seismograph (on the ground) recorded the maximum acceleration of 792 gals. This would seem to indicate that RC bridge piers on the Bayshore Route were also subjected to very severe earthquake motions similar to those in the Fukae district on the Kobe Route. Although detailed studies should be given in future regarding reviews of the current earthquake resistance standards, the fact that there was almost no damage to RC bridge piers designed with consideration of ductility should be noted.

(3) Others

In the case of bridges and road bridges under the control of the Ministry of Construction, the Japan Highway Public Corp., and Kobe City, RC bridge piers and piers suffered similar damage to that described above (Photos 20 and 21). As for damage to steel road bridge piers, T-shaped steel piers at the grade separated crossing of National Highway 43 collapsed (Photo 22). The steel rigid-frame bent on the Harbor Highway cracked in one corner, almost resulting in fracture (Photo 23). No report has yet been made on these brittle fractures, so causes have yet to be diagnosed.

Of the many (steel) pedestrian bridges in Nishinomiya, Ashiya, and Kobe, none were severely damaged as far as we could see. This was fortunate, as pedestrian bridges would cause severe road congestion if they fell.

3. CONCLUDING REMARKS

The damage caused by this devastating earthquake extended over a large area, so even this survey of road bridges did not necessarily cover all the damages. In addition, because the day-after survey was carried out at running pace, some of the findings need to be further checked in more detail. Much will be clarified once damage is investigated item by item in more detail, and the correlation between damage and earthquake motion, soil conditions, structural characteristics, and design standards has been analyzed theoretically and experimentally. Thus the following is a summary of the author's observations on the damage at this early point in time.

1) Of the RC bridge piers which suffered particularly heavy damage, most were built to the old design standards enacted before 1990. These standards included no requirement for ductility checks. In contrast, there was almost no damage to RC bridge piers designed in accordance with the new standards, which do take into account ductility (the Bayshore Route of the Hanshin Expressway). This proves that they are resistant to strong tremors such as those experienced during this earthquake.

2) Steel bridge piers, including older piers, proved to be resistant to very large ground motions of this scale in general, although they were damaged locally. It is necessary to investigate the cause of the collapsed steel piers and the brittle fractures.

3) One of the features of this earthquake was the large vertical motion. However, in the authors observations, there was little evidence of severe damage in which vertical earthquake motion was the determinant leading to fracture. Although pier base bulging was noted, as shown in the photos, investigations should be carried out to determine whether it was actually caused by vertical earthquake motion or not. Although both RC and steel bridge piers (Photo 8) collapsed, it seems that their compressive strength reduced as a result of horizontal forces, leading to collapse under gravity and vertical earthquake movement. It is necessary to study in detail whether vertical earthquake motions need to be taken into account in reviewing earthquake resistant design standards.

Major damage to road structures

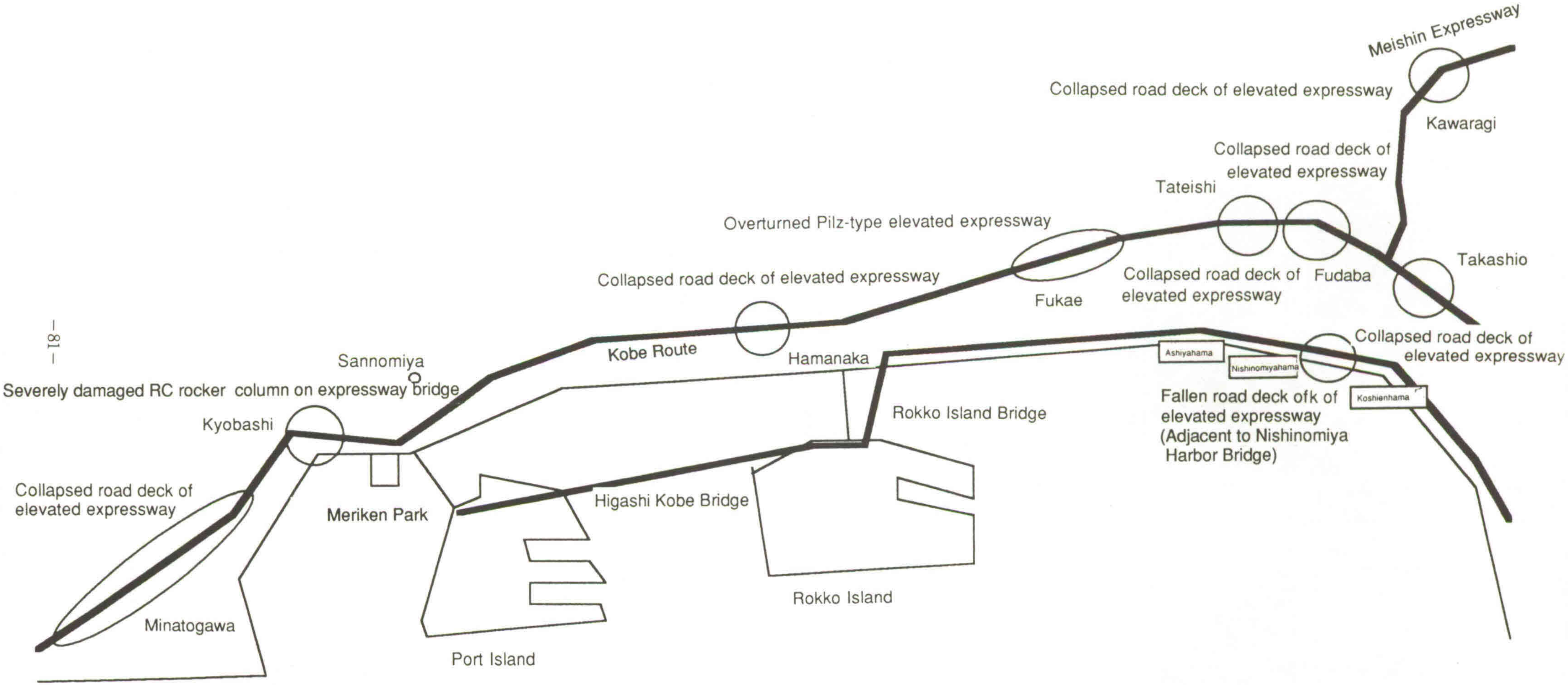

Figure 1 Map of major damage to road structures

Harbor Way

Photo 1 Shear-fractured RC pier on elevated expressway (Kobe Route)

Photo 2 Base fracture in RC pier of elevated expressway (Kobe Route, near Koshien)

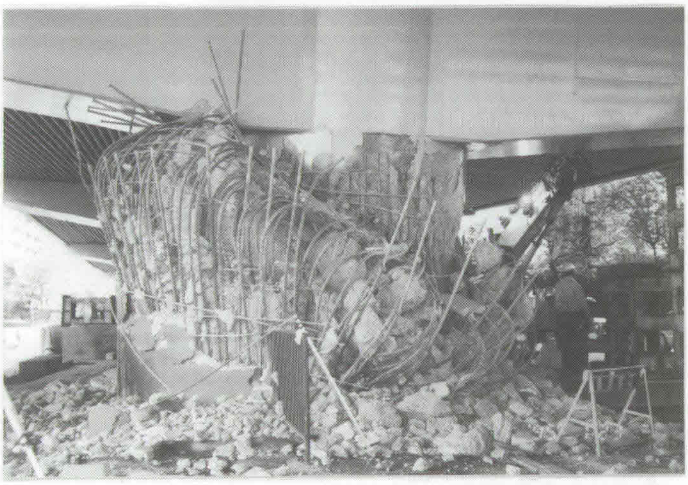

Photo 3 Collapsed RC pier of elevated expressway (Kobe Route, near Tateishi intersection in Nishinomiya)

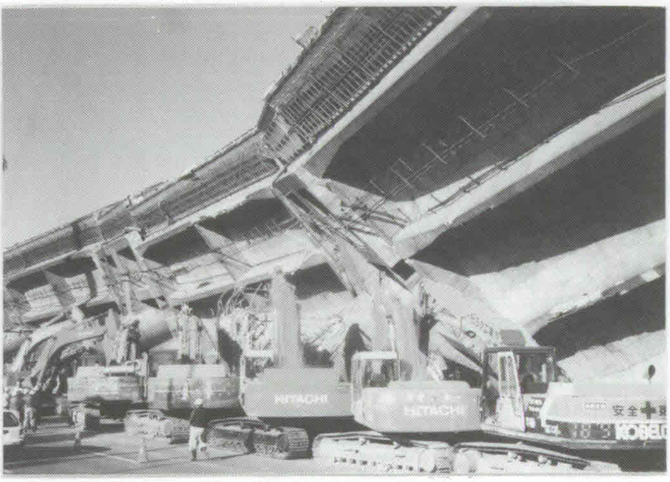

Photo 4 Overturned Pilz-type RC elevated expressway (Kobe Route in Fukae District)

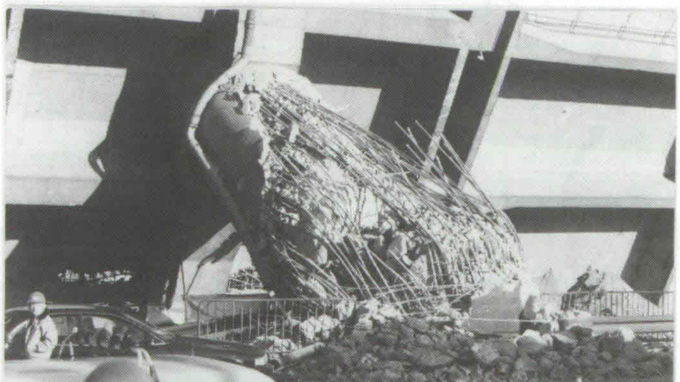

Photo 5 Overturned Pilz-type RC elevated expressway (Kobe Route in Fukae District)

Photo 6 Collapsed T-shaped steel pier supported on two RC piers; transverse girders failed at center (Kobe Route, near Tateishi intersection in Nishinomiya)

Photo 7 Locally buckled steel pier of rigid-frame elevated expressway (Kobe Route, near Koshien)

Photo 8 Locally buckled steel pier of single-post elevated expressway; pier bulging where the paint has fallen away around nearly 360° in what we call elephant foot buckling (Kobe Route, at a ramp near Japan Railway's Hyogo Station)

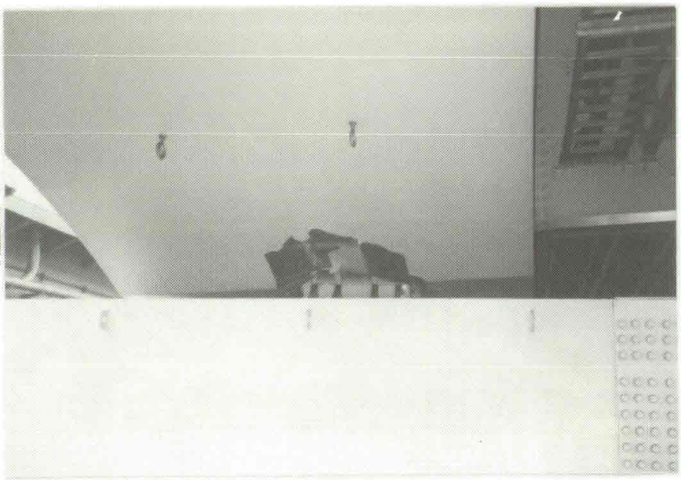

Photo 9 Road girder displaced from bearing, and bearing girder thrust into box girder (Kobe Route, near Koshien)

Photo 10 Distorted lower flange due to transverse movement of girder

Photo 11 Collapsed expressway girder due to longitudinal movement of girders; device to prevent girder from falling destroyed along with bearings (Kobe Route, at Honcho intersection in Nishinomiya)

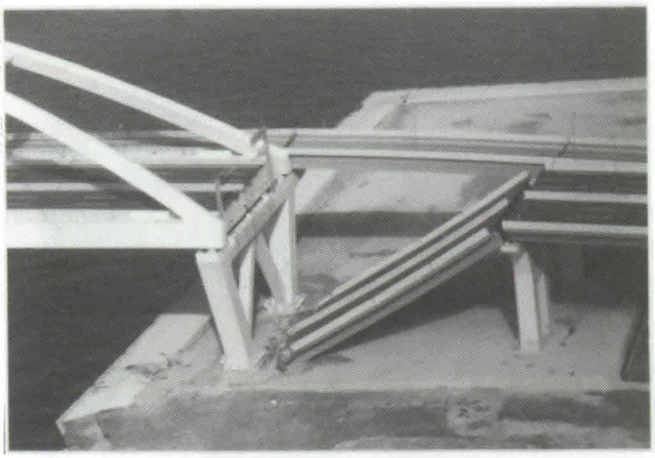

Photo 12 Collapsed approach road girder due to the seaward movement of Nishinomiya Harbor Bridge foundations (Bayshore Route)

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Photo 13 Broken section of upper shoe fallen from fixed bearing to the ground

Photo 14Fractured Pendel bearing support (web) on the Higashi Kobe Bridge (at the Kobe end)

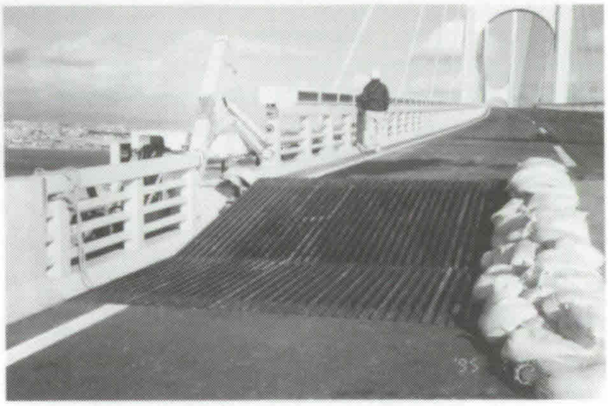

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Photo 15 Lifted side span and fractured expansion joints due to broken Pendel shoes (Bayshore Route, Higashi Kobe Bridge)

Photo 16 Buckled transverse girder at mid and end piers below fractured Pendel bearing (Bayshore Route, Higashi Kobe Bridge)

Photo 17 Bridge girder near collapse (Bayshore Route, Rokko Island Bridge)

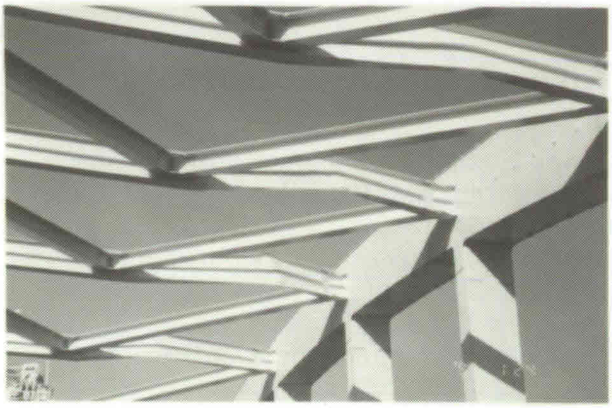

Photo 18 Buckled upper lateral horizontal and diagonal steel channel members (Bayshore Route, Rokko Island Bridge)

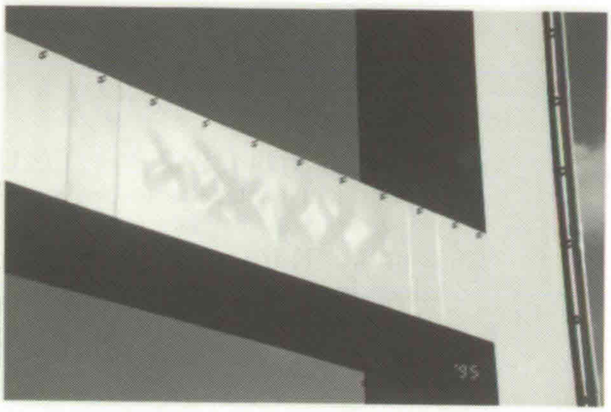

Photo 19 Locally shear-buckled steel rigid-frame bridge pier (Bayshore Route, Shin Ashiya River Bridge)

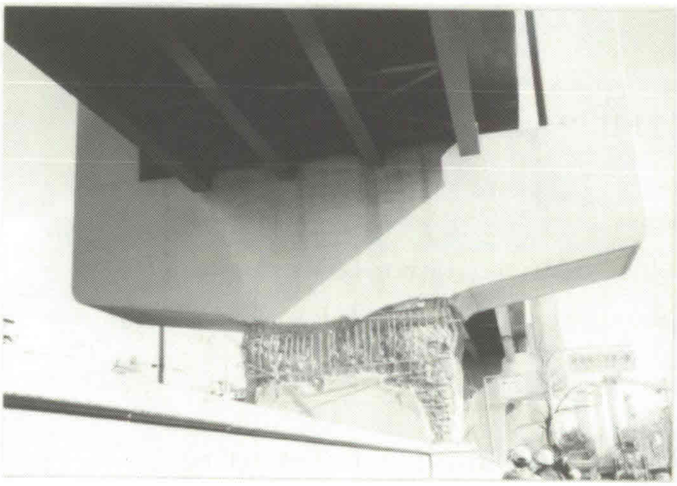

Photo 20 Bending fracture of racket-type double-deck rigid-frame RC bridge (Harbor Highway, Komachihama in Kobe)

Photo 21 Overturned rocking column and collapsed RC hollow-slab girder (Meishin Expressway of Japan Highway Public Corp., at Kawaragi Nishi)

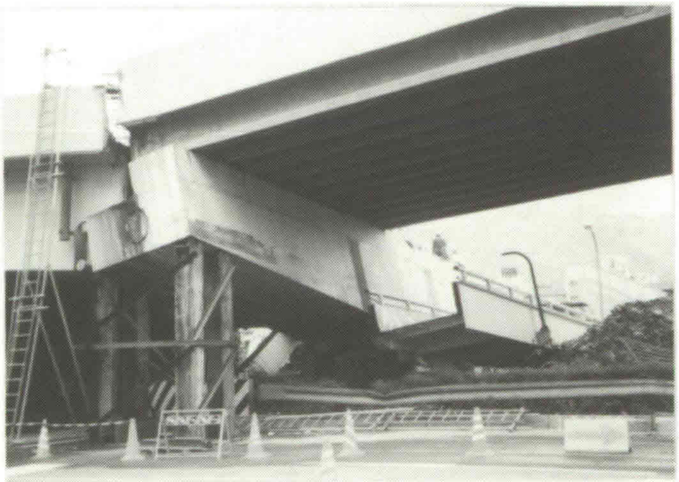

Photo 22 Collapsed steel T-shaped road bridge pier; RC T-shaped road bridge piers both before and behind also overturned (at the grade separated crossing of National Highways 43 and 2, Iwaya in Kobe)

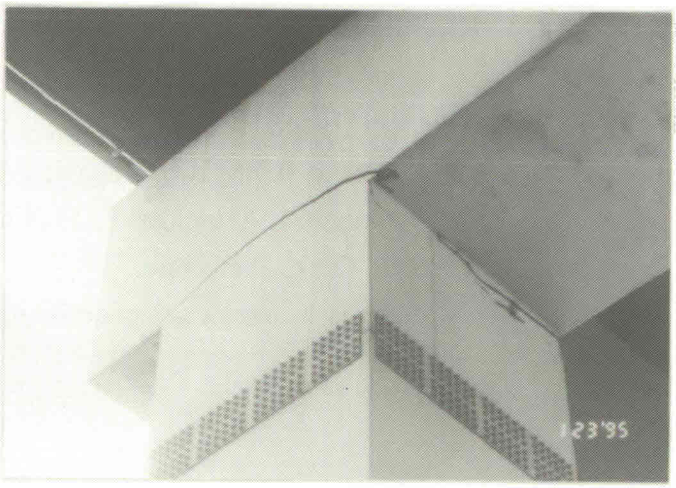

Photo 23 Cracking at the corner between pier and girder on steel rigid-frame bent supporting road bridge: extending nearly 360° (Harbor Highway in Kobe, near No. 1 Jetty at Suma in Nada Ward)

Report on survey by the Port, Airport, and Rivers Group

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Katsuhiko Kuroda, Professor, Faculty of Civil Engineering, Department of Engineering, Kobe University; Port, Harbor, and Airport Planning

Yoshiaki Goto, Professor, Faculty of Social Development Engineering, Department of Engineering, Nagoya Institute of Technology; Structural Engineering

Toru Sawaragi, Professor, Faculty of Civil Engineering, Department of Engineering, Osaka University; Coastal Engineering

Masatsugu Nagai, Assistant Professor, Faculty of Construction Systems, Department of Engineering, Nagaoka University of Technology; Bridge Engineering

1. AREAS AND FACILITIES SURVEYED

Kobe Port:

Hyogo jetty, Takahama ferry terminal district (Harbor-land), Naka jetty (International Waterfront Park), Shinko district, Maya wharf, Port Island, and Rokko Island

Main roads:

Roads between Maya wharf and Port Island, and between Port Island and Takahama

Kansai International Airport:

Peripheral revetments, ferry terminal, runways, peripheral road, and terminal buildings

River under the jurisdiction of the Ministry of Construction:

Yodogawa River

Rivers in Hyogo Prefecture:

Ujigawa, Ikutagawa, Takawagawa, Tenjingawa, Sumiyoshigawa, Tenjogawa, Syukugawa, Azumagawa, Tsumongawa, and Mukogawa rivers

Rivers in Osaka Prefecture:

Nakanoshjmagawa, Samondonogawa, Kanzakigawa, Shorenjigawa, and Okawa rivers

Government authorities visited:

Ports and Harbors Bureau of Kobe City: Kobe Port Construction Office, No. 3 Ports and Harbors Construction Bureau; the Ministry of Transport: Kansai International Airport Co., Ltd.; Kinki Regional Construction Bureau of the Ministry of Construction; Rokko Sediment Control Construction Office of the Ministry of Construction; Public Works Bureau of Hyogo Prefecture; Public Works Bureau of Kobe City; Public Works Bureau of Osaka Prefecture; and Construction Bureau of Osaka City

2. OUTLINE OF DAMAGE

2.1 Port facilities

Figure 1 shows the damage to port facilities in the areas surveyed. It is clear that only 5 to 7 quays remained somewhat serviceable. Almost all functions of Kobe Port, which is the world's sixth largest and handles more than 20% of Japan's foreign trade, were incapacitated. Particularly noteworthy, however, is that the quay wall to the west of the No. 1 jetty at Maya wharf, an earthquake resistant berth, remained sound. Details of the damage to jetties in the areas shown in the figure are described below.

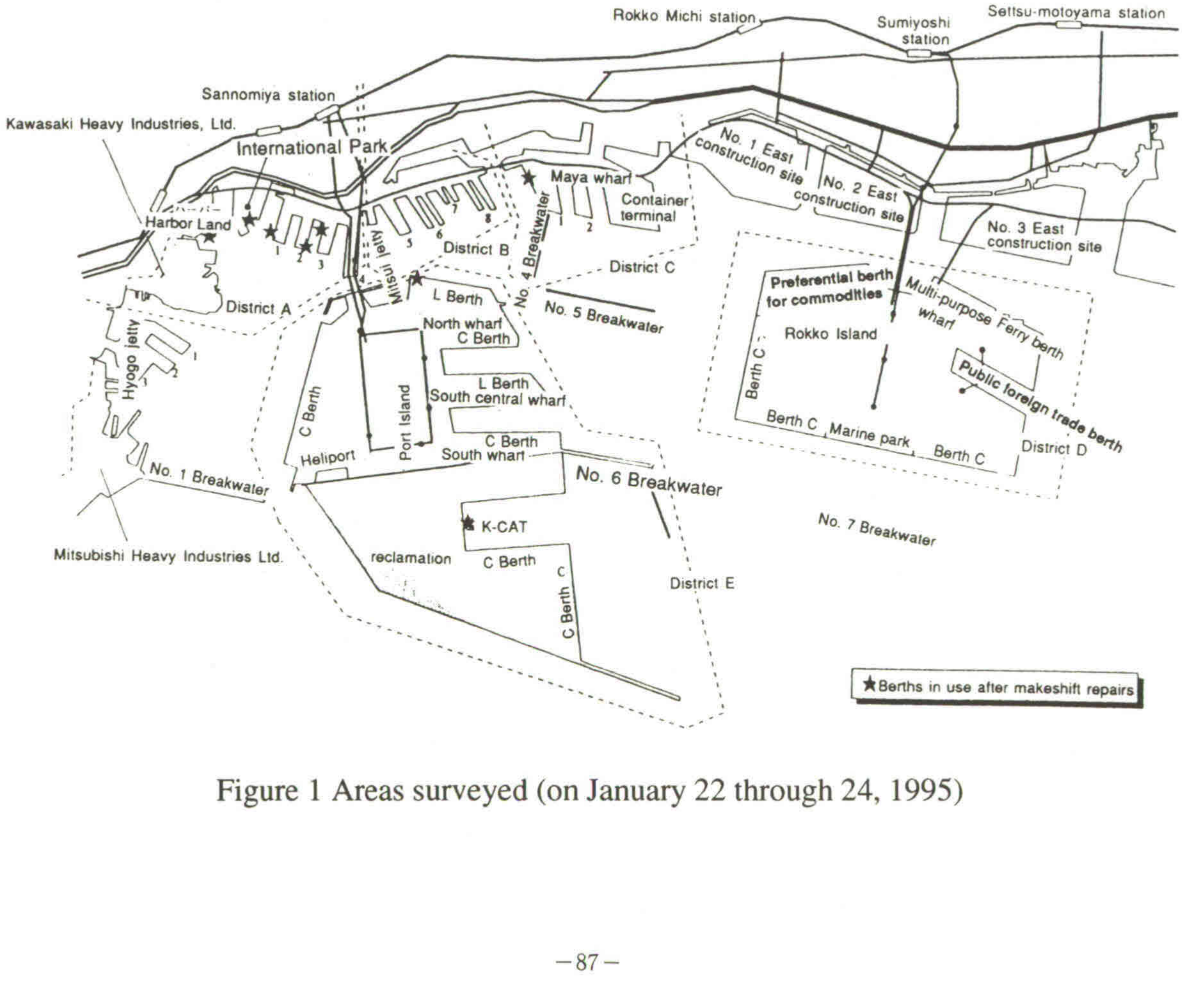

Figure 1 Areas surveyed (on January 22 through 24, 1995)

2.1.1 District A (Takahama quay walls, Naka jetty, and Nos. 1 through 4 Shinko jetties)

District A is one of the historical areas of Kobe Port, and a number of waterfront development projects were in progress: Harbor Land, being built on Takahama ferry quay; and International Waterfront Park on Naka jetty alongside the remaining passenger terminal. In these two project areas, some civil structures suffered relatively slight damage, including Takahama ferry quay, the north end of the western quay wall of Naka jetty, the southeast end of International Waterfront Park, the southwest quay wall of No. 1 Shinko jetty, the east quay wall of No. 2 Shinko jetty, and the west quay wall of No. 3 Shinko jetty. Other quay walls were destroyed or had settled so drastically that their original outline could not be made out. Many traces of liquefaction were observed in Harbor Land and International Waterfront Park. Buildings such as the ferry terminal "Mosaic" were also damaged severely. Buildings in Harbor Land, such as the Hotel Okura and the Marine Museum, were not surveyed, but a passenger terminal building also housing the Oriental Hotel which was under construction on Naka jetty suffered damage related to destroyed quay walls and liquefaction. Photo 1 shows the Santa Maria, a pleasure boat in service as emergency transport between Takahama ferry quay and Tenpozan quay in Osaka. Photo 2 shows the destroyed south revetment of International Waterfront Park. The mechanism by which this destruction took place could not be elucidated because data about the structural design and undersea ground conditions were unavailable.

Photo 1 The Santa Maria, a pleasure boat in service as an emergency transport ship

Photo 2 Destroyed south revetment of International Waterfront Park

The less severely damaged east and west quay walls of No. 1 jetty were used to unload emergency supplies from vessels (mainly Marine Self-Defense Force vessels) after makeshift repairs of subsidence on the apron. No. 2 jetty, the west quay wall of which suffered severe damage, was not available for emergency use because loaded trucks on the apron could not be removed. Damage to the east quay wall of No. 2 jetty and both east and west quay walls of No. 3 jetty was relatively minor. Accordingly, the east quay of No. 2 jetty was used by the Marine Safety Agency's patrol boats, and the west quay of No. 3 jetty was used by other small boats once liquefaction-induced settlement on the apron had been backfilled with soil and sand. The east quay of No. 3 jetty remained unserviceable, since containers and trucks had fallen into cracks in the apron. No. 4 jetty, on which stood piers of the Kobe-Ohashi Bridge carrying both the Hamate by-pass and the Port Liner to Port Island, was severely damaged on both east and west quay walls. Around the quays, several tens of containers had fallen into the sea. Both quays were unserviceable because of excessive settlement and depressions in the apron due to liquefaction, and they were scattered with damaged trucks and containers. Figure 2 shows the damage to quaywalls in District A.

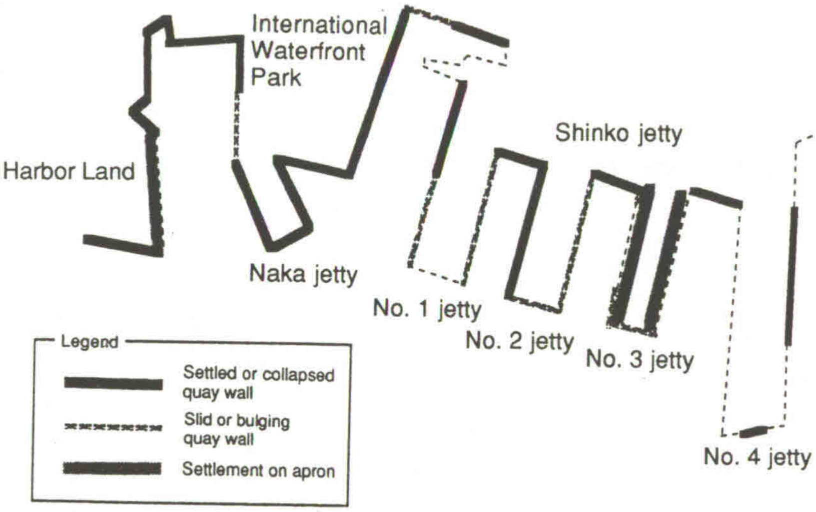

Figure 2 Damage to quays in District A

2.1.2 District B (Shinko Nos. 5 through 8 jetties)

Details of the damage to the Mitsui Private Pier could not be clarified because entry was prohibited, but the Mitsui Warehouse on the wharf suffered heavy damage. No. 5 Shinko jetty was not severely damaged on either west or east quay walls, except that the west quay wall had bulged slightly at the base. Silos on the jetty had cracked and the Mitsui and Kawanishi Warehouses had subsided slightly owing to liquefaction. The damage to the Mitsubishi Warehouse at the base of No. 5 jetty was serious. No. 6 jetty comprises east and west jetties. The east quay of the east jetty and the west quay of the west jetty carry part of a road under construction which is to connect with the Ikuta Interchange of the Hanshin Expressway's Kobe Route to Port Island. The damage to the east quay of the east jetty was slight, but the west quay of the west jetty bulged outward.

The Mitsubishi Warehouse on the west jetty and sheds on the east jetty settled slightly. With regard to No. 7 jetty, which also has both east and west jetties, almost all the first-floor columns of the sheds had collapsed, although the quay walls suffered from only slight damage. With regards to the two jetties making up No. 8 jetty, the first-floor columns of sheds were destroyed although once again damage to the quay walls was slight. Photos 3 and 4 show the damaged No. 6 and No. 8 jetties. Figure 3 shows the damage to quays walls in District B.

Photo 3 Damaged west quay of No. 6 Shinko jetty

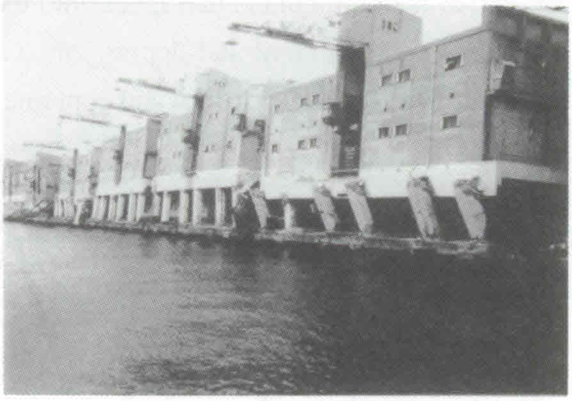

Photo 4 Damaged sheds on No. 8 Shinko jetty

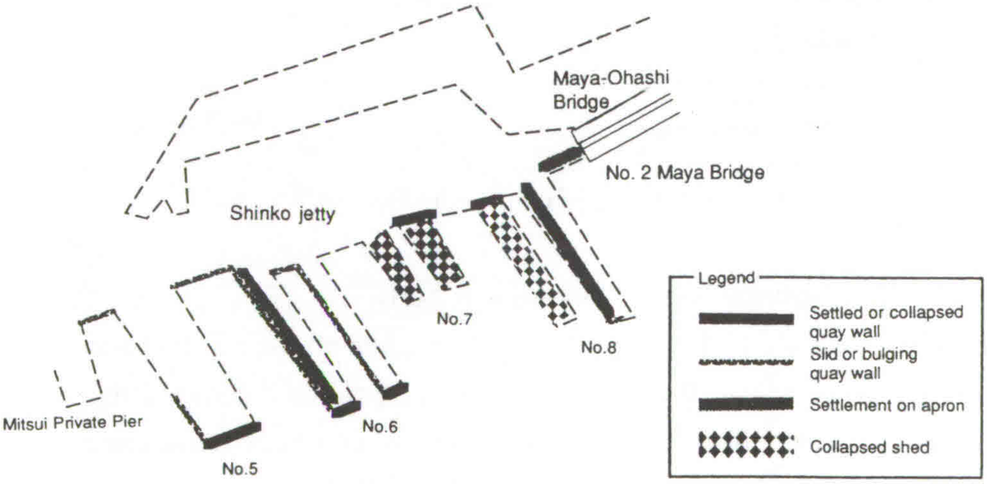

Figure 3 Damage to quays walls in District B

2.1.3 District C (Maya Wharf)

The Maya wharf consists of No. 1 and No. 2 jetties and also a container terminal that was Japan's first. There was no damage whatsoever to the west quay wall of No. 1 jetty.

The seismic resistance of this quay wall had been improved as follows: the original cellular-bulkhead design had been updated to a design in which cellular blocks are supported on steel pipe piles; this increased the design (horizontal) seismic factor to 0.25 from the 0.18 applied to other quay walls. On the contrary, the east quay wall of the same No. 1 jetty collapsed or settled, and sheds collapsed as a result. The paved apron settled as a result of liquefaction. The quay walls of No. 2 jetty and the container terminal seemed to be damaged only slightly as observed from the sea, but this was not verified from the ground. Cranes tilted over to the landward side as the apron settled due to liquefaction, and containers fell into depressions in the ground. Photos 5 and 6 show the surviving earthquake-resistant berth and the damaged east quay wall of No. 1 jetty, respectively. Figure 4 shows the damage to quay walls in District C.

Photo 5 Surviving earthquake-resistant berth (west quay wall of No. 1 jetty)

Photo 6 Damaged east quay wall of No. 1 jetty

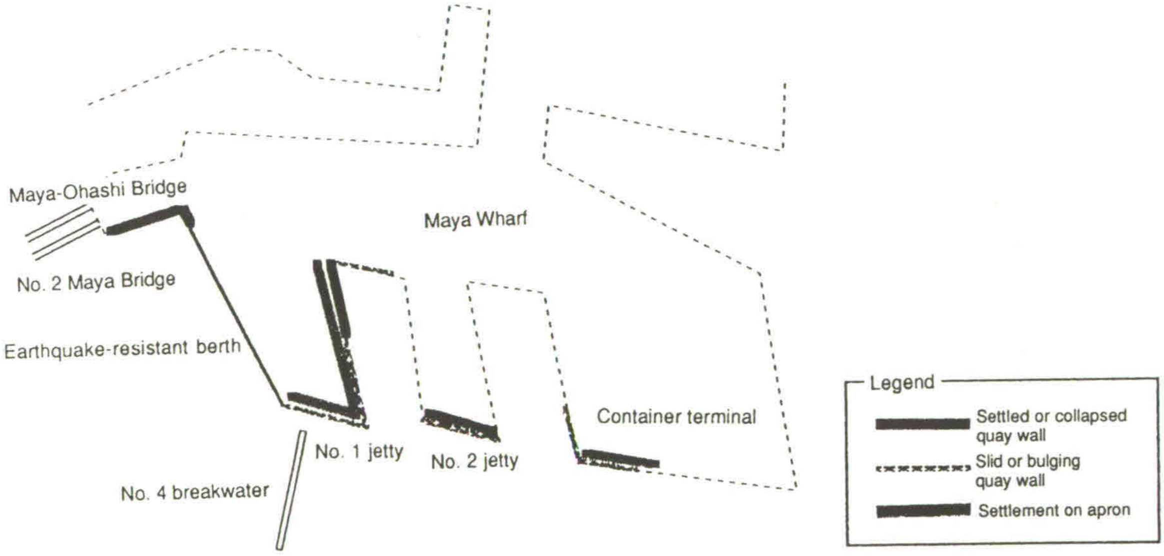

Figure 4 Damage to quay walls in District C

2.1.4 District D (Rokko Island)

Rokko Island is a large area of reclaimed land forming an artificial island which has port facilities and all the functions of a city. In this respect, it is similar to Port Island, and is a crucial part of Kobe's port facilities. Damage to the quay walls of shipping companies' private container berths was not conspicuous. However, in the container yards — which suffered severe settlement due to liquefaction — crane foundations seemed to be damaged and whole cranes had overturned or suffered fractured support columns. Photos 7 and 8 show an overturned crane and a settled ferry terminal, respectively. Figure 5 shows the damage to quay walls in District D (Rokko Island).

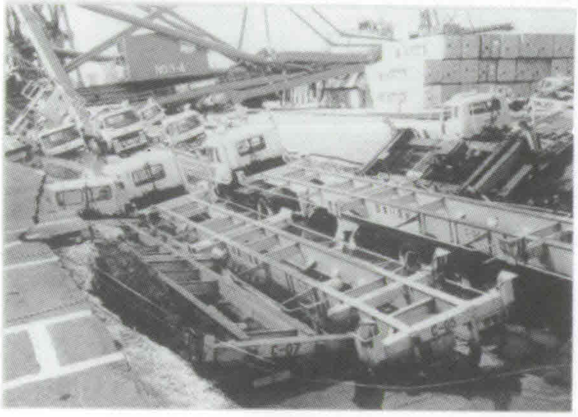

Photo 7 Crane overturned as a result of settlement

Photo 8 Settled ferry terminal

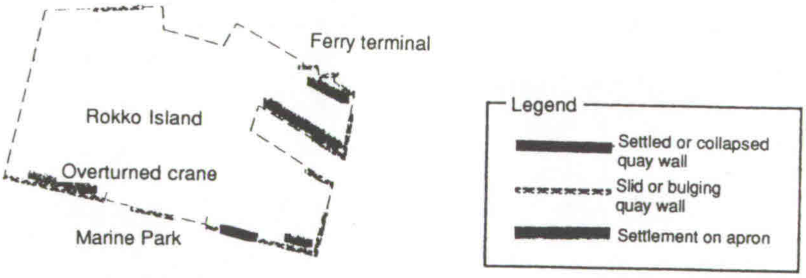

Figure 5 Damage to quay walls District D (Rokko Island)

2.1.5 District E (Port Island)

At the south end of Port Island, a port development on an artificial island larger in scale than Rokko Island, the Phase II reclamation project had been ongoing. The damage to quay walls was slight, but settlement and traces of liquefaction were severe; around the quay walls surveyed, there were many places where settlement had exceeded 2 m, and cargo handling equipment had tilted over exposing its foundations. Some revetments near North Park had settled completely, as had the apron of the unloading yard at a packaging plant complex. At K-CAT, a jetfoil terminal serving Kansai International Airport, jetfoils were serviceable and functioned well on routes to Osaka and the airport. However, the boarding bridge from the terminal building was destroyed because liquefaction caused loss of the ground's ability to support it. The heliport remained sound and functioned as a means of transporting emergency supplies and passengers. This served as a valuable access to the artificial island since the land access route was devastated. The K-CAT was able to continue functioning, albeit with restrictions, because pier-type quaywalls of strong earthquake-resistant design had been used. Photos 9 and 10, respectively, show liquefied and settled ground behind the North Wharf container berth and the K-CAT in service. Figure 6 details the damage to quay walls in District E.

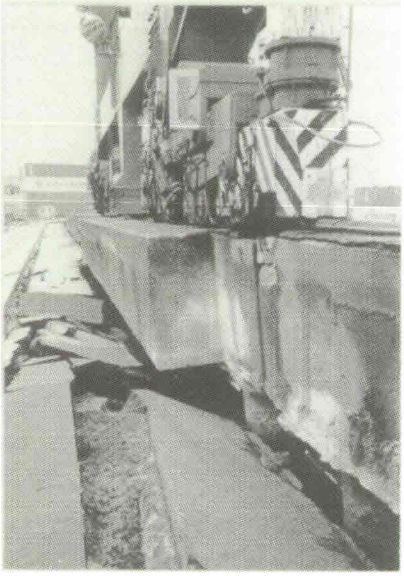

Photo 9 Settled North Wharf

Photo10 K-CAT under service

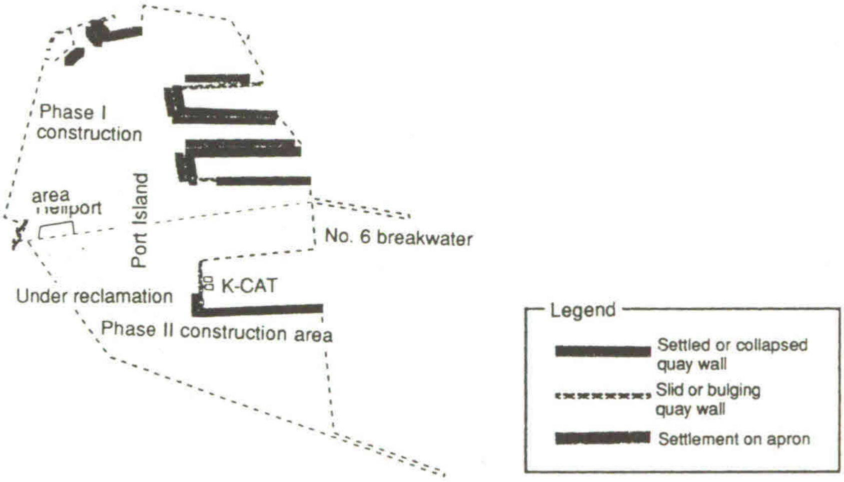

Figure 6 Damage to quay walls in District E (Port Island)

2.2 Cargo handling equipment

2.2.1 Outline of damage

The container cranes on Rokko Island quays consisted of 2-level 1-span steel space frames supporting crane units. Most were damaged in almost the same manner: plate elements of columns and girders buckled locally at corners and at around the first level. Plastic hinges formed at many places. Some cranes had completely overturned. According to reports by the Ports and Harbors Bureau of Kobe City, no container crane remained serviceable. Some cranes in shipyards overturned and were bent at the top. (Details could not be obtained because they were inaccessible.)

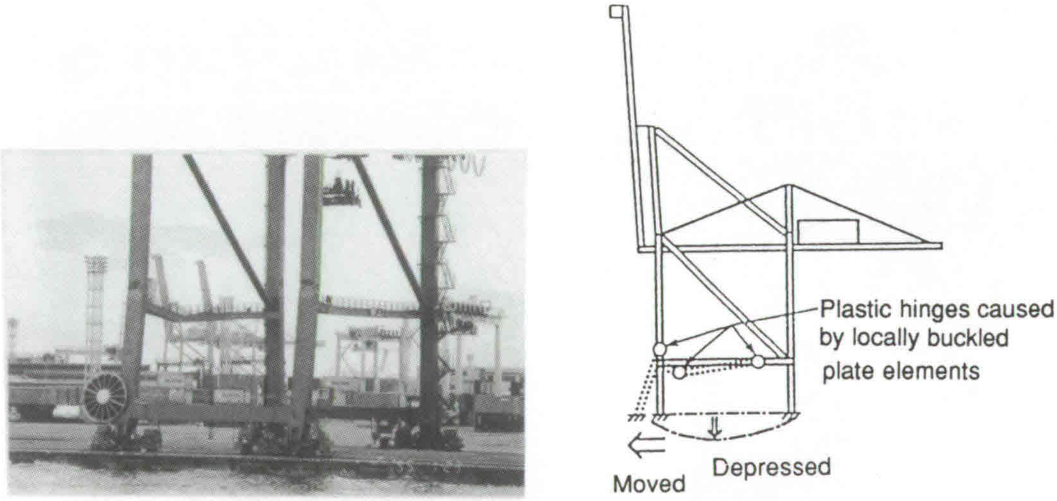

Photo 11 Collapsed column and girder plate elements and plastic hinges

Photo 12 Collapsed container cranes

2.2.2 Main causes of damage

The container crane columns on the seaward side stood on quay walls. Since the quay walls moved in the seaward direction by a large amount, the ground between the landward and seaward columns settled. As a consequence, the steel frames underwent forced displacement, plate elements buckled locally, and the steel frames deformed. Many of the damaged cranes indicated this failure mode. Thus the leading cause of damage seems to be the large movement of the ground on which the seaward side of the cranes stood.

The moment frames of the damaged container cranes were very slender. Response analysis of these cranes to the earthquake motion is now under way. However, it seems that the crane columns were displaced horizontally due to movement of the quay walls as soon as the earthquake struck. It is not clear, and needs to be studied, how the cranes would have responded had there been no movement of the quay walls.

2.3 Port access roads

2.3.1 Bridges connecting Port Island

The bridges linking Port Island with the mainland are the Kobe-Ohashi Bridge (an arch bridge with a center span of 217 m constructed in 1970) and the Portpia Bridge (an arch bridge with a center span of 250 m constructed in 1979) for the New Transport System. There was no observable structural damage to the Kobe-Ohashi Bridge, but a sliding bearing at the north end had moved 30 to 40 cm toward the south. (Photo 13) As a result, fastening bolts were shear fractured by the tension of a few diagonal (secondary) members right above the bearings. Some of the expansion joints on the Port Island side were also damaged. A clover leaf bridge connecting No. 4 Shinko jetty to the Kobe-Ohashi Bridge collapsed because of movement of its foundations. (Photo 14)

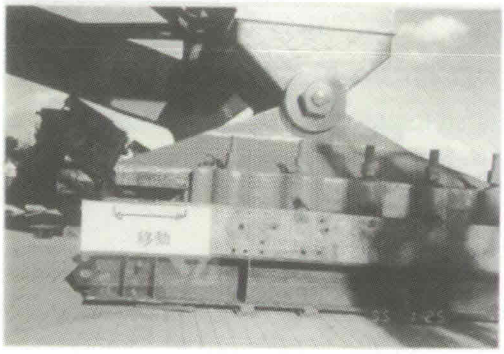

Photo 13 Displaced bearing on the Kobe-Ohashi Bridge

Photo 14 Fallen loop bridge on the approach to the Kobe-Ohashi Bridge

There was also no noticeable structural damage to the Portpia Bridge, but the bearings were damaged. On the other hand, the approach at the Sannomiya end was damaged severely — bending fractures were conspicuous at the RC piers of the two-level moment frame construction. (Photo 15) On the approach to the Portpia Bridge, the steel bridge pier itself suffered no damage, but it had tilted over because of deformation at its foundations.

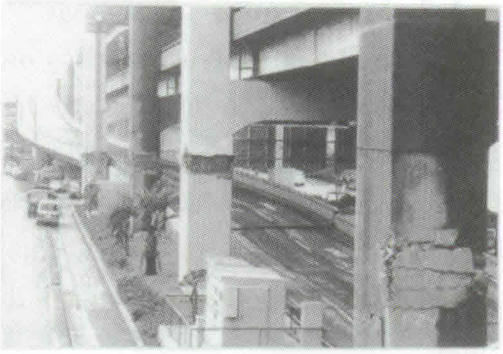

Photo 15 Collapsed RC bridge columns of moment frame structure at an approach to the Kobe-Ohashi Bridge

With regard to the elevated railway bridge for the New Transport System, the steel columns suffered from no damage. However, in Sannomiya, a RC bridge column (single-pier type) for the New Transport System suffered flexural damage, and the RC cantilever girders immediately beneath the bearings fractured in bending and shearing, causing the bridge girders to fall. As a result of this damage, operation of the New Transport System was suspended. The connecting bridge was made passable for emergency vehicles and pedestrians, although heavy vehicles were not permitted to use it.

2.3.2 Main roads

At a junction of elevated main roads near the Shinko jetty, hollow cylindrical steel columns of a two-level two-span structure were locally deformed by plastic buckling. (Photo 16) Many RC columns supporting the elevated roadway between Shinko jetty and Maya Wharf, which were of single pier type, were damaged. Particularly prominent damage was bending (shear) and fractures at the point where the cross sectional shape changed. (Photo 17) Two steel elevated roadway columns (of both single pier and moment frame structure types) buckled locally at weak points where there were manhole flanges. (Photo 18) Around the damaged columns, liquefaction of the ground was noticed. However, low-rise buildings and concrete block walls appeared undamaged, so the damage was concentrated on elevated roadway columns.

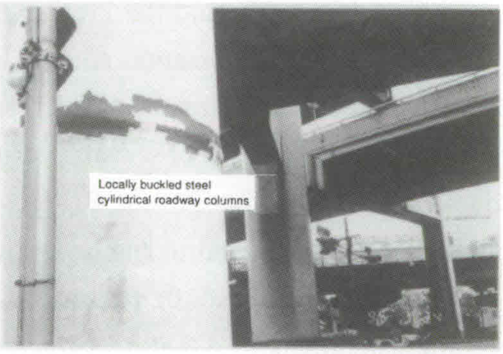

Photo 16 Locally buckled hollow cylindrical roadway columns at a junction

No. 2 Maya-Ohashi Bridge (a box girder bridge with a center span of 210 m constructed in 1975) linking Shinko jetty and Maya Wharf suffered damage to its RC support piers at both east and west ends. The east bridge pier suffered particularly severe damage. (Photo 19) In contrast, damage to the parallel Maya-Ohashi Bridge (a cable stayed bridge with a center span of 139 m constructed in 1966) was slight. At Maya wharf, many RC elevated roadway piers were damaged. Brittle fractures occurred at a joint between the girder and column parts of a steel moment-frame-structure bridge pier. Both the lower section of the column and the center of the girder buckled locally. (Photo 20) This failure mode was not seen in any steel elevated roadway columns elsewhere.

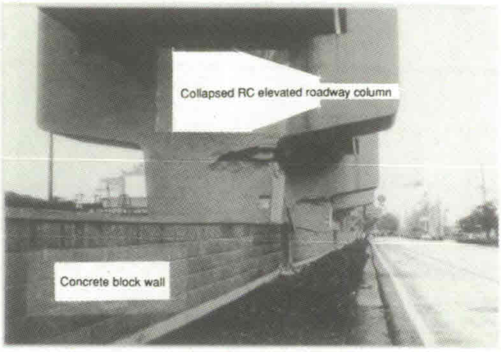

Photo 17 Fractured RC bridge pier of harbor by-pass

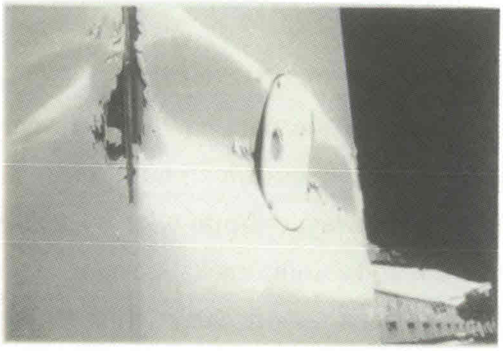

Photo 18 Steel pier buckled locally at a manhole flange of the harbor by-pass

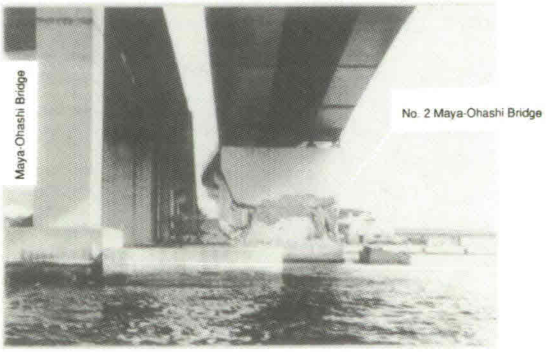

Photo 19 Fractured RC piers of No. 2 Maya-Ohashi Bridge

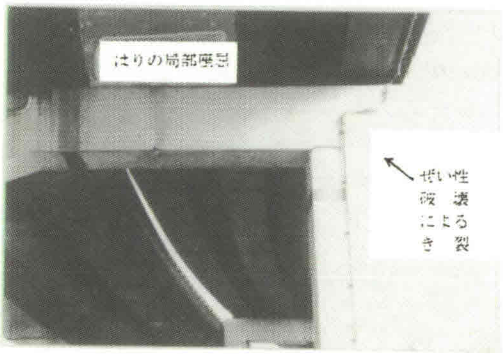

Photo 20 Brittle fracture at a joint between the girder and column on a steel moment frame pier of an elevated road bridge

2.3.3 Main causes of damage

The north ends of bridges linking the mainland with Port Island stood on No. 4 Shinko jetty, where large ground deformation, settlement, and movement by liquefaction took place. A major cause of the displaced bearings on the Kobe-Ohashi Bridge, the fallen loop bridge, and the tilted steel columns on the approach to the Portpia Bridge seems to be, besides the large earthquake motion, movement of the bridge column foundations due to ground deformation.

On the other hand, the main cause of damage to elevated main roads around the port was the large earthquake motion. The bulging of cylindrical steel moment-frame columns due to plastic buckling indicates that both horizontal and vertical shaking were very strong. From a structural viewpoint, the damage tended to be concentrated on columns supporting top-heavy two-level RC bridges and at places where the cross section changed. Many steel columns buckled locally at the weak points caused by manhole flanges. To further clarify the causes of damage, quantitative studies taking into account details of the damaged structures and the earthquake motion will be necessary.

2.4 Airport

At Kansai International Airport, there was almost no damage to civil engineering structures, aside from fifteen 60-m long hair cracks on a runway, thirteen 45-m long hair cracks on a taxiway, 0.2-mm wide by 100-m long hairline cracks in the maintenance apron (Photo 21), and minor cracks in roads. Quay walls for marine access moved slightly, but would have been unnoticeable without a detailed inspection. (Photo 22) Train runs to the airport halted for a while after the earthquake, but this was not due to specific damage to bridges or track, but rather as a result of an automatic train control system halting trains immediately after detecting a tremor of greater than 60 gals. The airport was returned to normal service immediately after a check of all airport facilities to ensure safe aircraft movements.

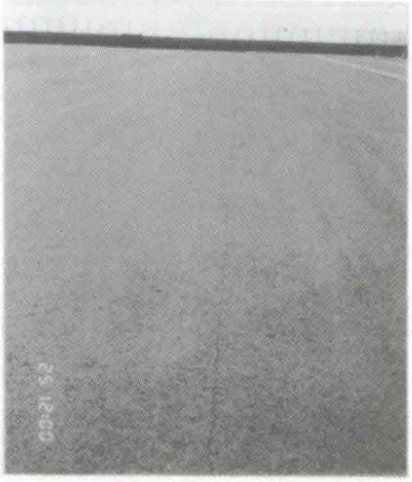

Photo 21 Hairline cracks in apron

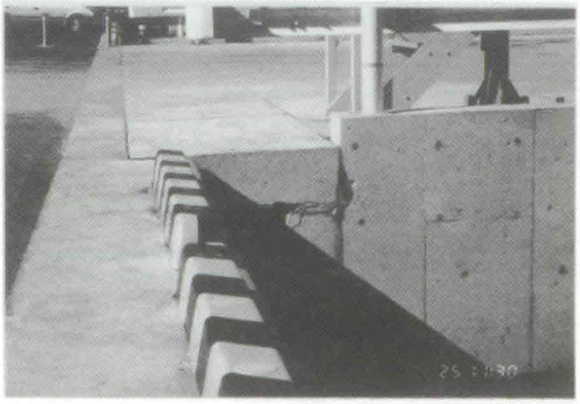

Photo 22 Slightly damaged quay walls

2.5 Rivers

2.5.1 Outline of damage to rivers

(1) Structures were damaged along the rivers listed below. (Asterisks mark those seriously damaged.)

Takawagawa*, Tenjingawa, Sumiyoshigawa*, Tenjogawa, Shukugawa*, Mukogawa, Yodogawa*, Nakanoshimagawa, Samondonogawa*, Kanzakigawa*, and Syorenjigawa*

(2) Damaged river structures include the types listed below. (Asterisks mark those seriously damaged.)

Cracked levee crowns, collapsed levees*, collapsed dams*, and collapsed rear slopes of levees

2.5.2 Major damage

(1) Collapsed levees and parapets

In the Nishijima district (0-3^{K}) on the left bank of the Yodogawa river, a levee settled and the concrete top layer collapsed due to the liquefaction of the sandy ground below. (Photo 23) A 1.6-m high parapet for flood control on top of the levee also collapsed with the levee. Before the earthquake, the elevation of the top of the parapet was OP+8.1 m. With settlement of the levee approaching almost 3 m after the collapse, the effective levee elevation dropped to about OP+3.5 m, barely clearing the high tide level in the Yodogawa at the time. Sections of river without sheet piles to block water at the foot of levee slopes were damaged more severely than those with the piles. This indicates that the sheet piles prevented levees from collapsing.

Photo 23 Collapsed levee on the left bank of the Yodogawa river

(2) Depressed levee crowns

On the right bank of the Kanzakigawa upstream of Kanzaki-Ohashi Bridge, the entire levee settled about 10 to 15 cm, cracked over 680 m in length at the center of the levee crown, and settled 60 cm at maximum on the rear side. As tide gates installed on the river side did not suffer from damage, the functions of the levee were maintained. Earthquake-resistant construction methods using steel pipe piles, steel sheet pipe piles and tie rods adopted in the construction of levees near the site were valued highly for successfully preventing levees from collapsing.

3. EMERGENCY REPAIRS AND TRANSPORTATION OF RELIEF SUPPLIES AND PERSONNEL

Emergency relief supplies were brought in by both land and sea. Figure 7 shows both the regular and emergency routes used to link the disaster area with surrounding cities by sea. (Source: morning issue of the *Asahi Shimbun* on January 25.) The serviceable quays at Kobe Port after makeshift repairs were as follows: Takahama ferry quay, a quay to the southeast of International Waterfront Park, Nos. 1 through 3 Shinko jetties, the west quay (earthquake-resistant quay) of No. 1 jetty at Maya Wharf, and the K-CAT quay on Port Island. Besides the above, the heliport on Port Island played an important role in transporting materials from Kansai International Airport.

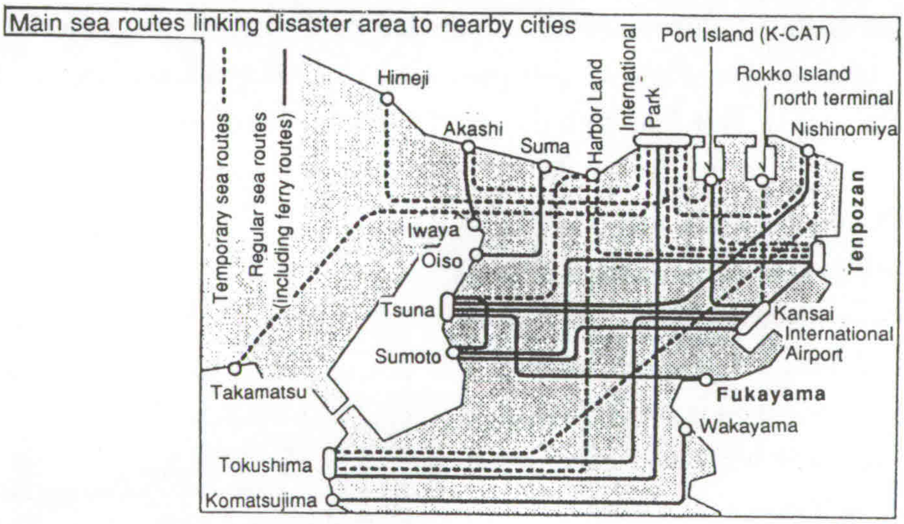

Figure 7 Regular and temporary sea routes (source: *Asahi Newspaper*)

4. STATE OF RECOVERY

Regarding port facilities, only visual inspections of the damage have so far been carried out. Accordingly, actual restoration work cannot begin until the results of detailed investigations are available. This will entail surveying damaged port facilities and the use of divers since most are under the sea. Removal work of damaged trucks and containers scattered on aprons and storage yards has just begun. In addition, the collapsed cranes are about to be removed.

Concerning the Kobe-Ohashi Bridge, which suffered some damage, temporary measures were taken to restrain the movement of bearings and bring the lower deck back into service. Other bridges remained out of use because of severe damage. Although damage to the Portpia Bridge for the New Transport System was slight, it will take time to restore the tilted piers of the approach bridge and the collapsed columns in Sannomiya. Regarding main roads, no restoration work has yet begun on damaged RC elevated roadway columns at the No. 2 Maya-Ohashi Bridge.

Damaged river structures, including damaged and cracked minor levees, ocurred at 77 locations along 8 rivers in 6 river systems under the jurisdiction of the Ministry of Construction, 228 locations along 67 rivers in Hyogo Prefecture, and 34 locations along 12 rivers in Osaka Prefecture. Damaged locations that posed immediate danger of inundation were temporarily repaired by filling with earth or sandbags. Temporary repairs have also been completed in many other places. Besides earthquake resistant construction methods using steel sheet piles, steel pipe piles, and tie-rods, another issue being studied is the improvement of existing levees into super-levees.

5. SUGGESTIONS REGARDING FUTURE PLANS

5.1 Ports and airports

(1) Delays in the recovery of Kobe Port will have a serious impact on Japan's economy, since this is a very important port handling more than 20% of the country's foreign trade. At the same time, limitations on use of the port will cause considerable problems in reconstructing the earthquake-devastated city. The priority that should be given to port restoration efforts must be determined according to its impact on the restoration of both trade and city functions.

The disposal of rubble generated by this disaster has become an issue of urgency. The use of reclaimed sites in accordance with the Phoenix Plan will continue for some time, but the use of final disposal areas throughout the Kinki district will have to be considered in the near future. Policies for this need to be formulated as soon as possible.

(2) Given that the functioning of roads and railways connecting artificial islands to the mainland was disrupted by the earthquake, redundancy needs to be considered in the future to ensure that at least one means of transportation can survive. Failure to do so will mean these islands could again be cut off.

(3) One of the lessons of this disaster is the significance of emergency marine transportation. As often predicted in disaster prevention plans, the delivery of emergency relief supplies by land was delayed by congestion. This underlines the importance of

earthquake-resistant berths. After further proving the effectiveness of earthquake-resistant berths through analysis, a study of how to improve some of the existing berths will be necessary.

(4) It should be a matter of great concern that many recently constructed public accessible revetments collapsed. Fortunately, this caused no casualties because the earthquake happened to strike early in the morning. The collapse of this type of revetment could pose significant risk to people gathered on beaches, for example. A rethink of public accessible revetments in terms of both design and strength is required.

(5) Every container crane buckled or collapsed in this disaster. Since this damage to cranes will prove to be an important factor delaying recovery in this case, a study of the earthquake-resistance of container cranes and their foundations will be necessary.

5.2 Rivers

The ability to control floods is lost if a levee suffers damage even in just one location. Levees should be constructed such that they survive any event. Levees constructed using earthquake-resistant methods did not suffer heavy damage, although some collapse of rear slopes was noticed. Thus these methods are to some extent proven effective against big earthquakes. It remains necessary, however, to study ways to improve levee structures by constructing super-levees, reducing the weight of levees, and reducing drainage through levees.

Acknowledgments

The authors are grateful to employees of the government authorities who assisted our surveys despite being very busy. Thanks also go to Takashi Uchida, Lecturer in the Faculty of Transportation Engineering at the Department of Engineering, Kyoto University, for his help in compiling this paper.

(Responsibility for this text lies with K. Kuroda, H. Imamoto, Y. Goto, and M. Nagai)

Report on the Survey by the Urban Facilities Group

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1. AREAS AND FACILITIES SURVEYED

The urban structures and facilities surveyed were classified into the three categories given below. The survey consisted of visual checks of the damage to these structures/facilities and their functionality in built-up areas. One point to note at this stage is that the report does not necessarily give detailed explanations of underground systems such as gas piping due to the limitations of visual observations, but additional information collected afterwards is given.

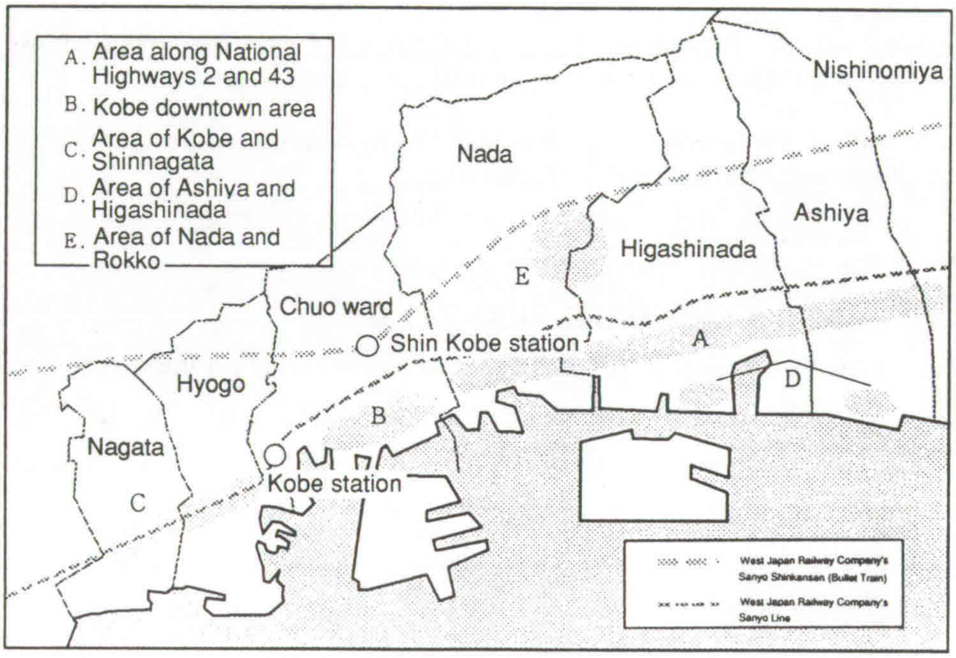
1. Transportation-related facilities: streets and underground parking lots
2. Utilities: potable water, sewage, refuse treatment, and gas supply systems
3. Built-up areas: overturned/damaged buildings, fire damage, underground malls, private houses, and development areas for residential land

The areas surveyed are mapped in the figure below. The specific structures/facilities surveyed were the following:

1. Area along National Highways No. 2 and No. 43 (between Nishinomiya and Sannomiya)
   Main roads, built-up areas along roads, etc.
2. Kobe downtown area
   Streets, built-up areas, buildings, underground malls, underground parking lots, New Transport System, etc.
3. Area of Kobe and Shinnagata
   Fire-damaged areas, built-up areas and underground parking lots, roads, etc.

4. Area of Ashiya and Higashinada
   Sewage treatment facilities, etc.
5 Area of Nada and Rokko
   Built-up areas, private houses, development areas for residential land, etc.

Areas surveyed



2. OVERVIEW OF DAMAGE

The physical damage caused by the earthquake was devastating. Damage was widespread in the built-up areas of the large urban region, affecting major infrastructural facilities such as highways, railways, and port facilities. Many urban facilities and buildings collapsed, overturned, or were destroyed by fire. The loss of various city functions as a result of the physical damage was so wide-ranging and disastrous that the urban system itself collapsed.

Tables 1 and 2 summarize, respectively, the physical damage to urban facilities and the loss of city functions as of the end of January. This data comes from a variety of information sources, including newspapers, magazines, and other documentation. Besides direct physical damage, it is clear from the tables that the loss of city functions was very wide ranging.

Table 1 Physical damage to urban facilities

Type of facility	Damage	Details of damage	Remarks
Railways	Collapsed bridges	5 locations	
	Derailed trains	19 lines	
	Other damage	41 locations	Collapsed bridge columns, girders, station buildings, etc.
Roads	Hanshin Expressway	34 locations	Collapsed or overturned bridges in 13 locations
	National highways	12 locations	Collapsed or buckled roadbed in 4 locations
	Other highways	3 locations	
	General national roads	28 locations	
	Other roads	Not yet surveyed	
Telephone system		Not yet surveyed	
Electrical system	Power stations	5 power stations, 9 subsidiary plants	Himeji No. 2, Amagasaki Higashi, Osaka, Sakai-ko, and Sanpo
	Substations	4 failed substations	Kobe, Nishi Kobe, Shin Kobe, Yodogawa in Osaka
		Fire in one location	Izumio
Gas system	LPG tanks	Gas leakage from one tank	
	Main gas piping (Class A medium-pressure piping)	No damage (in a total length of 140 km)	
	Class B medium-pressure piping	Damaged at one connection to a hospital	
	Terminal low-pressure piping	Damaged at many screw connections	
	Gas holders (tanks)	No damage	
	Spherical storage tanks	No damage	
Water supply system	Water intakes	Not yet surveyed	
	Water main piping	Not yet surveyed	
	Water distribution piping	2,034 locations	Kobe, Ashiya, and Nishinomiya
	Water supply piping	Not yet surveyed	
Sewage system	Sewer piping	1,600 locations	Hyogo Prefecture
	Sewage treatment plants	21 locations (46%)	Hyogo Prefecture
		22 locations (39%)	Osaka and Kyoto Prefectures
Collapsed houses		105,564 houses	
Fires	Number of fires	280	As of 22:45 on January 19
	Area burnt	690,000 m^2	As of 22:45 on January 19
Breakdown of fires	Near Nagata Station of West Japan Railways Company's Sanyo Line (in Nagata Ward)		3,400 houses, 480,000 m^2
	Near Kamisawa and Sugano Streets (in Hyogo Ward)		15 districts, 200,000 m^2
	Along National Highway No. 2 (in Nada Ward)		10,000 m^2
	In front of Sumiyoshi Station of West Japan Railway Company		10 houses and station buildings

(Damage to port facilities is not included in this table.)

Table 2 Loss of city functions

Type of facility	Loss of function	Functions lost immediately after the earthquake	Functions still suspended as of January 31 (percentage restored)	Remarks
Railways	No of lines halted	18	16	
	Total route length affected	326.4 km	188.0 km (42.4%)	
Roads	Hanshin Expressway	4 routes	1 route	Entirely closed
	Hanshin Expressway	5 routes	5 routes	Partly closed
	Highways	51.2 km	11.8 km (77.0%)	
	Other roads	31.9 km	25.3 km (20.7%)	
Telephone system		285,000 lines	Restored (100%)	
Electrical system	Electricity supply	1,000,000 households	20,000 households (98%)	Only in areas where houses collapsed
Gas system	Gas supply	855,900 households	808,000 households (5.6%)	
Water supply and sewage systems	Water supply	923,900 households	392,000 households (57.6%)	Certain parts of Kobe, Ashiya, Nishinomiya, Itami, Amagasaki, and northern Awaji Island
	Sewage discharge	Not yet surveyed	Not yet surveyed	

3. TRANSPORTATION FACILITIES (ROADS)

(1) Outline of damage

1) Main roads

Although expressways, and elevated structures in particular, were severely damaged, the damage to main city roads, including National Highways No. 2 and No. 43, appeared slight as a whole. Collapsed elevated road structures and settlement due to collapsed subway stations was a type of damage never expected from an earthquake. This led to considerable delays in the opening of main trunk roads for the delivery of emergency relief supplies.

Roadways

Although uneven road surfaces were noted in some places, this did not appear to present an obstacle to the passage of vehicles. Roads in Kobe near the shore were damaged more severely. Traffic on some sections of road had to be controlled because medium-rise buildings had completely overturned onto the road, blocking traffic, and there were buildings leaning over and in danger of collapse.

The earthquake struck early in the morning, so the main roads were almost empty of parked vehicles; parking was expected to cause problems in the event of an earthquake. During the survey, illegally parked or damaged vehicles were hardly noticed on main roads.

Traffic signals failed to function extensively. This led to congestion, holding up emergency vehicles in use for fire fighting, medical, and police services as well as those being used for recovery work, delivery of relief supplies, movement of earthquake victims, special buses, passenger cars, motorcycles, and bicycles.

Sidewalks

Sidewalks were damaged more severely than roadways. Near the coast in particular, many cracks, unevenness, and scattered paving blocks were noted. This is probably because of the difference in thickness and degree of compaction of the sub-base courses for sidewalks and roadways.

Collapsed buildings and their remains obstructed the passage of pedestrians and bicycles on sidewalks. There was almost no damage to roadside trees.

2) Minor streets

Throughout the disaster area, large numbers of minor streets were blocked or had access restricted due to collapsed houses. It was necessary to formulate a policy for their selective removal at an early stage.

(2) Discussions for the future

The fact that the earthquake damage to trunk roads was slight proves how strong they are. The many buildings that collapsed onto roads raise the future planning issue of how to find the ideal relation between road function and roadside buildings. How to best use the space under/over roads is another subject for future study; for instance, it appears that some control over the use of space under/over roads needs to be exercised, and the accessibility of such space must be increased in planning roads for emergency transportation in disasters. The disaster-hit area had a weak north-south structure of roads. An important issue for the future will be how to improve road networks such that priority is assigned from a disaster prevention viewpoint.

4. UTILITIES

4-1 Water supply system

(1) Details of damage and actions taken

1) Water intakes and main supply piping

Four of five water intakes and the supply pipes bringing water to Kobe, Amagasaki, Nishinomiya, and Ashiya — operated by the Hanshin Waterworks Corporation — survived the earthquake and continued to operate normally. Because of damage to water intakes, the drawing of water from the Ashiyagawa river in Ashiya and from the Yodogawa river in Itami was stopped. However, this caused no problem in any of the cities affected since each has multiple intake facilities.

2) Water purification plants and water supply reservoirs

Although piping failures caused turbidity at some water purification plants, including the Koshimizu Plant in Nishinomiya, all plants returned to full operation after emergency repairs.

3) Distribution and service piping

Distribution and service piping suffered damage in many places. In one distribution area on the side of Ashiya toward the mountains, 450 mm water mains were damaged at joints. To the south of National Highway No. 43, 700 mm water mains cracked in two locations. In many places, the return to full pressure once one leak was repaired caused leakage at another location, so it was very difficult to grasp the full extent of the damage. Full restoration of services will take some time.

(2) Discussions for the future

1) Multiple water sources

The Hanshin Waterworks Coproration had five water intake and delivery systems, and each city affected also had at least two of its own water sources, so there was no problem with complete loss of water supplies. However, one issue that will need to be considered in the future is that so much reliance had to be placed on the Yodogawa river.

2) Topographical characteristics of cities

The built-up area of Kobe includes considerable variation in elevation, so when local reservoirs suddenly drained off after the earthquake water supplies soon dried up. In Amagasaki, where there is little variation in elevation, water supplies did not stop at all in the south, but were cut off to the north because of natural drain-off. In planning water systems in consideration of emergencies, it is necessary to study water distribution and fire extinguishing systems taking into account the topographical characteristics of the area.

3) Water distribution systems taking into account functions assigned

In Kobe, 22 of the 24 emergency shutdown valves at the reservoirs were actuated by the earthquake. Water from the reservoirs then had to be supplied using tankers. There is a limit to how well water supply piping can be protected from damage in an earthquake as big as this one; some damage is inevitable. In the future, risk management should be used to determine which facilities should be secured and to what extent, and how to prepare other facilities for an emergency situation. One suggestion is to rank water distribution piping, and then to locate fire hydrants and emergency water supply bases on networks with the greatest strength.

4) Strengthening structures

As a measure to improve the earthquake resistance of water supply structures, studies will be necessary to find ways to strengthen pipe joints, which were the most commonly damaged points in the water supply system. It is worth considering the idea of placing water pipes in utility tunnels together with gas pipelines in view of the increased structural strength this gives and the ease of restoration work.

5) Efficient recovery systems

As work proceeded to restore water service, water leaks in houses began to have an effect on the process. One way to overcome this problem is to call on households to close the main valve at the meter to allow work to go ahead more efficiently. The sharing of network maps of gas and water pipes is also a subject worthy of future study.

4-2 Sewage system

(1) Details of damage and actions taken

1) Facilities

Serious damage was caused to sewage systems in Kobe. Turbidity arose in many places due to broken pipes and cracked basins. At two out of three sewage treatment plants in central and western areas of the city, performance dropped to some tens of percent of normal capacity. Higashinada sewage treatment plant was in such poor condition that operation was totally impossible.

In other cities, treatment plants were so badly damaged that treatment was barely possible until emergency measures were taken. Sewer pipes for pumping from sand settling basins failed (in Ashiya) and unidentified water was found mixed with sea water near an outlet (in Nishinomiya.) Unidentified water was found in many locations, the main cause of which was apparently leaks from water supply piping. Many treatment plants could be operated only with great difficulty. Many residents are concerned about the schedule for restoring the sewage system and measures to deal with rain.

2) Pipework

Damage to sewage pipes is still under investigation and the situation has yet to be fully elucidated. According to interviews at sites where investigations are in progress, damage was concentrated particularly at joints between pipes and manholes. In Akashi, where repair work started relatively early, reverse flows of sewage into houses occurred as early as January 28. This seems likely to happen in many other cities.

(2) Discussions for the future

1) Problems caused by earthquakes

If it takes a long while to implement emergency measures after a disaster such as an earthquake, the loss in functionality of piped systems has the potential to become a long-term burden. In a modern city where flush toilets are the norm and stormwater seepage is minor, drainage systems rely greatly on sewage works. New problems not presently apparent may arise over the course of time as a result of suspended water supplies and water shortage. The potential problems include the fear of leaked sewage finding its way into water supply systems during a period of low pressure, and the erosion of road sub-base layers as a result of inadequate stormwater drainage and sewage leaks. Further, the removal of sewage from temporary toilets and treatment systems may be a burden in cities where flush toilets are widespread.

2) Location of treatment plants and earthquake resistance of pipe joints

Sewage treatment plants are usually located along rivers or in coastal areas which are susceptible to damage from liquefaction. In new plants, this is taken into account in design, but disaster-alleviation measures are needed at older plants. With regard to the piping system, damage was concentrated at weak points, mainly where pipes were joined to concrete structures that moved under the action of liquefaction. The earthquake resistance of piping systems needs to be improved. The survey of damage to sewers and manholes has not yet been completed, but damage occurred at many joints between public sewers and domestic sewage manholes. Sewage blockages mean that the demand for house-to-house repair work is likely to grow for the time being.

4-3 Waste disposal

(1) Details of damage and action taken

1) Refuse incineration plants

Immediately after the earthquake, refuse incineration plants were found to be in such bad condition that incineration was almost impossible. Since most plants have multiple incinerators, at least some could be brought into operation after taking emergency measures. However, the capacity to treat refuse dropped in many cities. One of the main reasons incinerators were rendered unserviceable was that boiler water and cooling water were unavailable, a result of supplies of city water or recycled water being cut off.

2) Refuse collection

Refuse collection was left undone in many areas because of traffic jams and a shortage of garbage trucks, but was almost back to normal as of January 23. Refuse included broken chinaware and glass, and classification proved impossible under the circumstances. Some sites chosen as temporary refuse dumps had already been filled to capacity.

(2) Discussions for the future

1) Strengthening water supply systems

If this earthquake had occurred in summer, the loss of refuse collection and treatment services for several days would have led to serious sanitation problems. It was very clear that it is not only incineration plants that must be earthquake resistant; the water supply system also plays an important role in the operation of incineration plants. The water supply systems for facilities related to public sanitation need to be improved. It would seem important to study the idea of building emergency water supply networks linking evacuation centers — including schools and hospitals — and facilities such as incineration plants.

2) Disposal of rubble

The demolition and removal of destroyed and partly collapsed buildings has already started. The decision was made by the cities involved to dispose of rubble from collapsed houses as general waste. Taking into account the massive amount of rubble in question, it will be important to set up temporary waste dumps, find final reclamation sites, and other disposal methods.

4-4 Gas system

(1) Outline of underground gas piping system

The underground gas pipes operated in the Hanshin district by Osaka Gas Co., Ltd. are as follows:

- 600 mm high-pressure gas piping: None
- 600 mm medium-pressure Class A gas piping: 140 km (main gas piping)
- 440 mm medium-pressure Class B gas piping: 430 km (about 10% of the total length)
- 50 to 300 mm low-pressure gas piping: 4,500 km (domestic supplies)

(2) Details of damage and action taken

Medium-pressure Class A gas piping:

Pipes in the Hanshin district run in an east-west direction, including one pipe along National Highway No. 43. No damage has been reported so far. The steel pipes were welded. It is judged that the piping resisted the strong vertical ground motion caused by the earthquake on account of its elasticity.

Medium-pressure Class B gas piping:

This class of piping mainly forms the connections to major companies, hospitals, and other large consumers. Damage at pipe joints in a hospital in the Hanshin district was quickly restored.

Low-pressure gas piping:

The low-pressure piping forms the outermost end of the gas piping system. Most of the reported damage occurred at this low-pressure end. The pipes are connected to individual houses using two different methods: welding and mechanical joints. Most damage occurred at joints where screwed joints were used.

Since air tightness tests had to be carried out after releasing the pressure from this low-pressure piping, repair work took a long time.

There was no damage to gas holders (tanks). This is because of the sound earthquake-resistant design of the spherical tanks and the joints between aboveground gas holders and underground gas piping.

5. BUILT-UP AREAS

5-1 Overturned and collapsed buildings

(1) Outline of damage in downtown area

The survey focused mainly on the Sannomiya district, which is pivotal to the business functions of Kobe. In this area, severe tremors of 7 on the Japanese seismic intensity scale were recorded. Almost every office building suffered heavy damage. From a structural viewpoint, the damaged buildings fall into the following categories of damage or a combination of them.

1) Collapse of certain floors, as in the case of the Kobe City Office and the Traffic Center Building
2) Shedding of the cladding, as in the case of the Hankyu Terminal Building and the Sun Plaza Building
3) Buildings tilted at an angle, as in the case of medium and small buildings on Ikuta Shindo street

There was no structural damage to high-rise buildings such as the new Kobe Office Building, the Trade Center Building, and the Hotel Okura.

Utility poles overturned and were damaged irrespective of the area, both in midtown and residential areas. Many utility poles failed and overturned under the weight of transformers.

(2) Outline of damage to residential areas

Houses collapsed or were damaged in every part of the disaster area. A survey of damage in residential areas mainly in Kobe's Higashinada and Nada Wards covered extensive areas from the coast to the foot of the Rokko Mountains.

Wooden houses had overturned in Higashinada and Nada Wards irrespective of location. In some blocks, all houses were completely destroyed. Serious damage was noted to almost all concrete houses, including apartment buildings of concrete construction. Generally, light-weight prefabricated houses suffered from slight damage, but in many cases all the exterior wall paneling had come off despite minor structural damage.

In contrast with the devastating damage to old midtown areas, the damage in areas cut from the slopes of the Rokko Mountains under new urban development plans, as in the Tsuruko district of Nada Ward, was relatively slight. This seems to show that land where residential areas have been developed on solid ground is relatively safe. Some landslides occurred where these residential areas met the slopes of the Rokko Mountains.

(3) Discussions for the future

1) Restoration of city functions

Almost no office building remained serviceable in Kobe after the earthquake. The pivotal functions of the city will remain completely suspended for some time. A matter of urgency is how to demolish and remove the buildings which are structurally beyond repair but which still maintain their shape (almost all buildings in the Sannomiya district) as promptly as possible. The damaged areas need to be restored with improved resistance to disasters taking into account the damage this earthquake caused. It is important to improve the resistance of lifeline utilities such as by moving electricity cables underground.

2) Improving residential areas

Wooden houses and weaker collective housing units was damaged almost without exception. Accordingly, it will be necessary to begin discussions as soon as possible on how housing should be prepared against directly underground earthquakes, as well as to check existing houses for safety once again.

Damage varied greatly; in one district almost all houses and buildings were completely destroyed while there was almost no damage in a neighboring district. A study on how to return to daily life in residential areas is a matter of urgency.

5-2 Underground malls and parking lots

(1) Outline of damage to underground malls

Surveys and interviews were carried out in Sanchika, an underground mall in Sannomiya, and at the Harbor Land underground mall. Sanchika suffered from damage to the degree that glass was broken and decorative wall panels came partly away. Almost half of the books in bookstores remained on the shelves. Thus the tremors underground must have been substantially smaller than those aboveground. The Harbor Land underground mall and parking lot suffered almost no damage, in spite of the fact that the overburden was only about 2 m. There was some problem with water inflows, probably resulting from damaged water supply pipes.

Although details of the damage will not be fully clarified until the decorative wall panels are removed, no damage was noted where the underground malls connect to the surface, although damage had been expected. With regard to gas supply systems in these underground malls, the main shut-off valves and shut-off valves at each user actuated normally, and there was no leakage.

(2) Details of damage to underground parking lots

Surveys and interviews were carried out at two parking lots near the two underground malls mentioned above and at one underground parking lot in Nagata ward. The damage was slight. The parking lot in Nagata ward (with a capacity of 230 cars on two basement levels) suffered no structural nor visual damage except that a few fluorescent lamps and ducts came loose, in spite of the fact that an adjacent medium-rise building was damaged.

(3) Discussions for the future

In comparison with the damage to aboveground structures, underground malls and parking lots suffered very slightly as far as was elucidated in this survey. It will be necessary to compare the reported damage with other damaged underground structures, such as Daikai station. Based on the experience of this earthquake, it will be necessary to review the safety of underground structures including utility tunnels, CAB (cable box) systems, and basement floors of buildings.

Power failed in both underground malls and parking lots immediately after the quake. Assuring the safety of users as well as structural safety is a subject for future study.

5-3 Fires

(1) Details and features of damage

A survey was carried out in Nagata ward where large fires broke out. Despite the early hour of the earthquake, fires broke out in many areas and these took a heavy toll of human lives. The large fires can be characterized as follows:

1. Firefighting operations were considerably hampered by the lack of water supplies and traffic jams.
2. Fires broke out concurrently with the destruction of houses in the earthquake.
3. Fires broke out in many areas densely filled with old wooden houses where no improvement projects have been carried out, and those houses that caught fire were totally consumed.
4. Flames spread rapidly to neighboring houses, but there were few cases where fires leapt large distances.

With little firefighting activity, fires stopped at certain locations: streets, concrete buildings, concrete block walls, open parking lots, and vacant lots. In one case, a fire was stopped by a gas station.

(2) Discussions for the future

Besides ensuring that water supplies continue to operate and that firefighting water reservoirs are available, future city plans should look carefully at the layout of streets, vacant lots, and fire resistant buildings which in this case prevented fires from spreading.

6. CONCLUSIONS

As described above, many issues for future consideration have been elucidated through this survey. With regard to the earthquake resistance of the infrastructure, new construction has followed the latest structural design specifications which embody advances in research and technology. It must always be born in mind, however, that many of the existing structures — bridges, buildings, and so on — remain inadequate in terms of earthquake resistance whenever new information comes to light. If the measures that result from this earthquake consist only of the rather simple idea that structures should be able to withstand the seismic loading imposed this time, there is a great possibility that a similar disaster will occur again.

Accordingly, in order to improve the reliability, durability, and restorability of the urban infrastructure, its elements must be treated not merely individually but as an entire urban system considering risk management. At the same time, the results of joint investigations and research activities looking comprehensively ahead to planning, design, and implementation must be carefully considered.

(Responsibility for this text lies with M. Asano.)

BRIEF REPORT BY THE THIRD SURVEY TEAM ON THE DAMAGE CAUSED BY THE GREAT HANSHIN EARTHQUAKE

(February 1 to 3, 1995)

Japan Society of Civil Engineers' Third Report on the Great Hanshin Earthquake
(Concrete Structures)

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1. Introduction

The first and second investigations outlined the damage caused by the Great Hanshin Earthquake in Kobe and the northern part of Awaji Island on January 17, 1995. The aim of this report is to provide clues to five major questions: (1) does the severity of damage vary according to structural type and if so, why?; (2) did concrete structures suffer more damage than steel structures and if so, why?; (3) are there failings or inadequacies in the current JSCE Standard Specification for Design and Construction of Concrete Structures with respect to structural details?; (4) did any phenomena conflict with our current understanding of characteristics and behavior of concrete structures?; and (5) are there any differences between the seismic motion considered in the aseismic design standards currently applied to roads and railways and that actually observed in the Great Hanshin Earthquake? The report thus covers not only the damaged structures, but also those which were built according to the same standards as damaged ones but survived.

The investigation was carried out in four areas, as follows:

(1) Sanyo Shinkansen line from the west of the Hankyu Imazu Line to the Mukogawa Bridge
(2) Hanshin Expressway Kobe Route from the west of the Pilz type bridge pier to the Yanagihara ramp
(3) Hanshin Expressway Wangan Route near Nishinomiya Bridge
(4) Harbor Highway near Maya Bridge

The investigation also covers areas with particularly severe damage, including the Kobe Express Railway's Daikai Station, the JR Tokaido line Rokkomichi Station, Hanshin Railway's Shin-Zaike Station, and the vicinity of these structures.

This report summarizes the results related to concrete bridge piers, although the investigation itself also covered other structures. Some structures had already been removed or were being repaired when this investigation was carried out. However, these structures were also examined, using photos taken during the previous investigations.

2. Damage to the Sanyo Shinkansen line (from the west of the Hankyu Imazu Line to the Mukogawa Bridge)

(1) Three-span continuous rigid-frame elevated bridges with intermediate beams (Photo S1)

This type of structure, which is dominant in this section, suffered the most severe damage next to rigid-frame abutments. This type of structure collapsed mainly because of an insufficient resistance to shear forces, which is relatively low compared to the level of its flexural resistance. The center span of the three has no intermediate beam, and the effect of this structural characteristic should be investigated.

(a) Damage due to the propagation of shear cracking just below the upper beam or intermediate beam (Photo S2).

(b) The damage seen in Photo S2 reduced the strength of the concrete columns, which finally failed to support the load imposed by the beams. The section above the damaged zone slid northward in a direction normal to the bridge axis and collapsed (Photo S3).

The above two kinds of damage are typical of those found in this type of structure.

(2) Rigid-frame elevated bridges without intermediate beams

The dominant kinds of damage seen in this type of structure are the following:

(a) Yielding of concrete in bending occurred just below the haunch at the upper end of the column (Photo S4).

(b) After yielding in bending, shear cracking occurred and propagated (Photo S5).

This damage, however, was relatively minor. Unlike the structures with intermediate beams, no collapse occurred. Generally, in the case where the ratio of bending resistance to bending force is the same, the longer the column, the larger the sectional area and the amount of reinforcing bars. Therefore, as the columns of the rigid-frame elevated roadways without the intermediate beam are taller than the columns of the frame with the intermediate beam, it appears that there was a surplus in the shear resistance. However, at some horizontal construction joints just below the haunch, there seems to have been almost no shear resistance at all (Photo S5).

(3) Rigid-frame abutments

This type of structure supports PC simple beams where they span large widths, such as roads. At the same time, the structure serves to support the train load on the upper beam. The beams used in this type of structure have large depth (Photo S6). In the area investigated, rigid-frame abutments collapsed, causing the PC beams to fall to the ground. Since the columns used in this type of structure are shorter, the structure's resistance to shear failure does not match its resistance to flexural yielding. The ductility of the structure was insufficient. The collapse of this type of structure is thought to have occurred in the following manner:

(a) Columns just below the PC beam supports suffered shear cracking.

(b) The cracked columns lost their ability to support the load imposed by the PC beams and began to tilt over in the direction of the beams they supported (Photo S7).

(c) The beams collapsed.

(4) Rigid-frame bridge piers

This type of bridge pier structure is used to support PC beams. All four piers survived without almost any damage (Photo S8). In this structure, all the seismic forces along the bridge axial direction must be resisted by a single line of columns, so the columns have a larger cross section (160 x 160 cm) than the columns of a rigid-frame elevated bridge (90 x 90 cm). The sectional area of the column is considered to have been determined based on the load in the direction of the bridge axis. Along the bridge axis, the shear capacity is not considered to be remarkably larger than the flexural capacity. At the investigated locality, however, the seismic motion acted almost normal to the bridge axis, and the structure was amply able to resist the lateral forces in that direction. This may be why this type of structure suffered almost no damage. If the earthquake had caused seismic motion in the axial direction, the damage would possibly have been more severe.

(5) Oval-shaped bridge piers

The Mukogawa Bridge consists of oval piers supporting PC beams (Photo S9). In these piers, the amount of reinforcement is reduced about 30 cm above the horizontal construction joints located mid-way up the pier height. All the piers except one toward the western end suffered the damage described hereafter. The axial rebars at the point of reinforcement reduction were subjected to tensile forces, which caused the bars to yield and strain. When the piers deformed in the opposite direction, the rebars buckled due to compression, the concrete cover spalled off, and improperly anchored hoops broke out (Photo S10). However, none of the piers collapsed. The structure contained relatively few bars in the axial direction compared with the sectional area of the concrete, and its shear resistance was higher than its flexural resistance. This explains why the structure did not collapse despite extreme deformation which occurred after yielding in bending occurred. Rebars in one pier at the western-most end of the bridge yielded slightly at the southeastern corner of the bottom (Photo S11).

Seismic intensity seems to have been less in the long section west of these piers than in the section further west, where greater damage occurred. Rigid-frame elevated bridges with intermediate beams in the former section suffered almost no damage (Photo S1). Further analysis is required to clarify why this damage occurred to the Mukogawa Bridge: whether the bridge was subjected to greater seismic forces than the adjacent section west of the bridge as a result of local geological features, or whether the oval-shaped pier structure is weaker to seismic motion than the rigid-frame elevated bridge structure, or both. For reference, there are bridge piers supporting steel beams of the National Highway 171 some 100 m north of the section in question. Although having almost the same structure as the Mukogawa Bridge, they suffered only minor damage (Photo S12).

3. Damage to the Hanshin Expressway Kobe Route (between the Pilz type bridge and the Yanagihara ramp)

(1) Single-column circular bridge piers (Photo K1)

This type of bridge pier is typical of this section. Commonly occurring damage can be categorized into the three following types:

(a) Horizontal cracking near the bottom of the bridge pier due to bending in the direction normal to the bridge axis (Photo K2).

(b) Development of the above, or yielding of reinforcing bars (Photo K3).

(c) At the point where two layers of rebars were reduced to one, yielding and straining of rebars in the axial direction due to tensile forces occurred. During deformation of the piers in the opposite direction, buckling of the rebars under compressive force, spalling of the concrete cover, and failure of improperly anchored hoops took place.

A small number of piers were found to have suffered almost no damage.

Half of the outer rebars was joined by gas pressure welding in the vicinity of where the amount of reinforcement was reduced. These joints did not buckle, but failed before yielding fully developed. Rebars which did not fail at the joints suffered local buckling (Photo K4), but these piers did not collapse. In this type of structure, there are relatively fewer rebars in the axial direction and the structure has higher resistance in shear than in bending. This is thought to be why the structures did not collapse, even though they deformed extensively after having yielded in bending.

(2) Single-column rectangular bridge piers (Photo K5)

This type of pier is used where the span is long, such as at road crossings. The cross section of the rectangular pier is larger than that of the circular pier. The damage to these piers is quite similar to that in the case of the circular piers, but is much severer. In the investigated section, no piers collapsed. In the area east of the Pilz type bridge piers, some piers of this type had a larger cross section. Some suffered shear cracking (K6) while others collapsed due to shear failure (K7). The possibility of shear failure seems to be greater when the columns are relatively short compared with their cross-sectional area.

(3) Pilz type bridge piers (Photo K8)

This type of pier is integrated with the superstructure. There are 17 such piers in this section. All of these fell in the direction normal to the bridge (northward). At the time of this investigation, they had all been broken out and removed. It is usually very difficult to determine the process of collapse only through observations after a structure has collapsed. We will therefore report on the reasons for the collapse of these piers only after comparing the observations with the results of seismic response analyses.

(4) Rigid-frame bridge piers (Photo K9)

This type of pier is used where the road deck is wider than normal, such as at on- or off-ramps. These piers suffered almost no damage. The investigators were confused as to why this should have been the case, but had to accept it given the stark facts. Generally speaking, in this type of structure, the sectional area of the column is determined based on the seismic force along the bridge axis. In the direction normal to the bridge axis, however, the sectional area is determined based on the load of the superstructure and not on the seismic force. As a result, it is assumed that the piers actually had sufficient resistance to the seismic motion in the normal direction. In the case of this earthquake, the seismic forces in the vicinity of these piers acted almost normal to the direction of the bridge axis. This may be the main reason why the piers suffered almost no damage. This reasoning can be also applied to certain steel rigid-frame bridge piers in the investigated area.

4. Damage to the Hanshin Expressway Wangan Route (in the vicinity of Nishinomiya Bridge)

Most of the bridges in the investigated area were rigid-frame structures. As reported earlier, rigid-frame structures of both RC (Photo K10) and steel (K11) almost completely escaped damage. The main reason for this is that the seismic motion on January 17 acted in a direction almost normal to the bridge axis. It is currently not known what damage these piers, which were built according to new standards, would have suffered if the seismic forces had acted in the axial direction. We suggest that this should be investigated once a detailed analysis of the RC single-column and rigid space-frame pier structures, many of which were destroyed, is completed and the analytical results compared with the actual damage.

5. Damage to the Harbor Highway (in the vicinity of Maya Bridge)

(1) Single-column (wall-type) two-layered rigid-frame bridge piers (Photo H1)

The damage to these piers is described as follows:

(a) Continuous reinforcing bars on either the north or south side yielded at a location slightly below the rigid-frame (Photo H2).

(b) When the pier underwent strains in the opposite direction, these rebars buckled under compressive forces, the concrete cover spalled off and improperly anchored hoops broke up (Photo H3).

(c) The damage spread all around the pier, causing more serious buckling of the rebars (Photo H4)

At the same time, it was found that many piers suffered almost no damage.

The damage occurred at the cross-section where the two rings of axial rebars had been reduced to only one outer ring. Half of the rebars of the outer ring were joined at this point by gas pressure welding. This reinforcement did not have a chance to buckle, since many of the gas pressure welded joints fractured before the rebars underwent full yielding. From a two-dimensional viewpoint, reduction of the rebars at this cross-section seems to be inadequate. The upper rigid-frame structure was able to resist forces in the direction normal to the bridge axis, and thus suffered no damage. No piers of this type collapsed.

This type of pier incorporates relatively less reinforcement in the axial direction for a given cross-sectional area of concrete, and has comparatively higher resistance in shear than in bending. This probably explains why these piers did not completely collapse, even though they were seriously deformed after reaching the yield point. Some steel bridge piers also had the same structure, and these suffered almost no damage at all; just one exhibited local buckling in a north-facing steel plate at a position one third up from the column base (Photo H5). This case is interesting because the RC piers of the same type on either side of it were not damaged (Photo H6).

(2) Single-column rectangular bridge piers

The damage observed in this type of piers was as follows:

(a) At the pier base, or slightly above it where the amount of reinforcement was reduced (Photo H7), the axial rebars yielded and burst out.

(b) When the pier deformed in the opposite direction, the rebars buckled under compressive loading, the concrete cover spalled off, and improperly anchored hoops broke up (Photo H8).

Near the cross-section where the two rings of axial reinforcement were reduced to just the single outer ring, half of the outer rebars were joined by gas pressure welding. Many of the welds fractured, and did not buckle. Most piers of this type were free of damage, and none collapsed. Many of them were tall (Photo H7) or had small reinforcement ratios in the axial direction, and had comparatively higher resistance in shear than in bending. That is probably why they did not collapse even though they experienced large deformation after yielding in bending.

(3) Wall-type bridge piers

There are few piers of this type, but the three types of damage described below were peculiar to them. These piers were all near the coastline. Despite some tens of centimeters of settlement of the surrounding ground, the pier's foundations were sound (Photo H9).

(a) Half of the main rebars in the outer ring were joined at one cross section by gas pressure welding. Most fractured by tensile rupture at the welded points. The remaining rebars were welded at another section about 1 m away, and most of these welds also fractured (Photo H10). These two joint positions are about 1 m apart in the vertical direction, but considering the overall cross section of the pier, they might be considered as belonging to a single section. This indicates that when designing the reinforcement arrangement it is necessary to consider the sectional size when choosing the distance by which these types of joints are staggered (Photo H11). In these piers, although most of the rebars in the outer ring failed, the pier itself did not collapse.

(b) Piers supporting the Second Maya Bridge, which is a continuous large-span steel box-girder bridge, suffered unusual forms of cracking (Photo H12). The steel girder was rigidly fixed to the bearing on the pier. The girder has a large curve to the north from around the next support on the west side. At the western end, the southern girder remained on the sliding bearing, while the northern girder had slid off its sliding bearing by a few tens of centimeters to the north in the direction normal to the bridge axis (Photo H13).

This resulted in a horizontal force acting northward in the direction normal to the bridge axis on the upper side of the pier where the northern girder was attached. Cracking began at that point, spreading downward until finally curving northward. The relative abundance of hoops prevented the pier from collapse, saving the bridge from a complete failure. This type of force is not considered in ordinary design. We need to seriously consider ways to incorporate this experience in future design improvements.

(c) In another pier of the Second Maya Bridge, two rings of main D22 rebars were used. The inner reinforcement was about one fifth of that used in the outer ring, and it seems that this reinforcement was not sufficient. The inner reinforcement extended about 30 cm above the horizontal construction joint. At that point, most of the rebars which extended further upward fractured due to tensile forces. A part of the pier at the northern side below the horizontal construction joint then collapsed (Photo H15).

(4) Rigid frame bridge pier

The reason this structural type survived the earthquake without damage is the same as for the elevated roadways that has been mentioned earlier (Photo H16). While steel rigid-frame bridge piers of the same structural type had almost no damage, one case with horizontal cracking from the inside corner of the upper corner angle section on the southern side was found (Photo H17). It is considered that this occurred due to the brittle fracture along the welds. Also, local buckling was observed on the column face on the northern side.

6. Summary

(1) All 17 Pilz type bridge piers collapsed. Among the concrete structures, many rigid-frame elevated piers and single-column piers were damaged, while rigid-frame bridge piers suffered almost no damage. Among the steel structures, damage was frequently seen in single-column piers. Tall thin piers suffered relatively less damage, while short stubby ones generally suffered more damage. This does not indicate that the aseismic performance depends on the type of structure but that aseismic performance varies depending on the characteristics of the earthquake, the seismic intensity presumed in the design, the design details, the capability of the designers, and the technological excellence of the contractors.

(2) Pilz type bridge piers, rigid-frame elevated bridge piers, and single-column bridge piers are designed to have almost equal resistance in the axial and normal directions to the bridge. In many structures, the earthquake induced forces exceeded the steel yield point. It is clear that the Great Hanshin Earthquake was larger than the one in which the stress associated with a static horizontal seismic coefficient of 0.2 remains less than the allowable stress. Most piers that did not suffer shear failure did not collapse. Structures built according to the JSCE's current standards would have a high probability of surviving the seismic motions experienced in the January 17 earthquake.

(3) It can be concluded that in many cases where damage to piers was responsible for the collapse of bridges, yielding of the main reinforcement in bending triggered shear failure, and consequent inability to support the superstructure. In such cases, except for non-symmetrical designs, most piers fell northward in a direction normal to the bridge axis. This may be attributed to the characteristics of the seismic motion, and particularly, to the effects of vertical seismic motion.

(4) Rigid-frame bridge piers, both steel and concrete, suffered extremely slight damage. This is because the seismic forces acted in the direction normal to the axis of most of the bridges. It is possible that rigid-frame piers are inherently resistant

to seismic motion in that direction, but the resistance in the bridge axis direction is the same as that of single-column piers. Luckily, most of the bridge piers investigated faced east-west while the earthquake ground motion occurred mainly in the north-south direction. Whether made of steel or RC, the damage of structures of the same type was essentially the same.

(5) It can be concluded that structural specifications given in the current JSCE standards for concrete bridge piers are basically adequate. However, we recommend that in designing the transfer of force from supports to piers, the situation where the girder moves off its supports be considered. The investigators are keenly aware of the necessity to prepare a manual for structural specifications that is comprehensive for designers and structural engineers.

7. Future Tasks

The concrete committee of the JSCE must direct its efforts to the tasks listed below; this is the only way the committee can help console the souls of the many victims of the Great Hanshin Earthquake. This report should form the first step towards more detailed investigations in the future.

(1) To make a thorough and extensive study of the concrete structures damaged in the Great Hanshin Earthquake and to use the results to study the aseismic characteristics of concrete structures by carrying out analysis and necessary experiments.

(2) To reflect upon the results of the studies in the aseismic design methods specified by the JSCE so as to help improve the design and construction of concrete structures in the future and improve the strength of existing structures, if necessary.

(3) To present the results of these studies and investigations within a year at the latest, so as to disseminate the findings to as many engineers and specialists as possible through seminars and lectures in both Japan and abroad.

Reference: Stipulations on Aseismic Capability in the Standard Concrete Specifications of the JSCE

The design section of the JSCE's Standard Concrete Specifications was totally revised based on the Limit State Design Method in 1986. At the same time, the aseismic design section of the specifications was comprehensively revised based on the latest knowledge. This section of the present specifications follows that version. Its outline is presented for reference:

Aseismic design should basically ensure the safety of a structure during an earthquake and enable a structure to satisfy its purpose of use after an earthquake. During the design process, damage is categorized as "soundness maintained," "minor damage," "medium damage," and "serious damage." The maximum response displacement during an earthquake for each damage category corresponds to once, twice, three-times, and four-times the yield displacement, respectively. The aseismic design process assumes that, in the case of medium damage, the structure should remain usable and that repairs or inspections can be carried out at any appropriate time after an earthquake. In the case of serious damage, the structure requires repair and reinforcement at the earliest possible opportunity. The specifications recommend that the damage expected to occur to general civil engineering structures during a design earthquake should be "minor damage" or less, taking into account public use, economic efficiency, and common use after the earthquake, and service life.

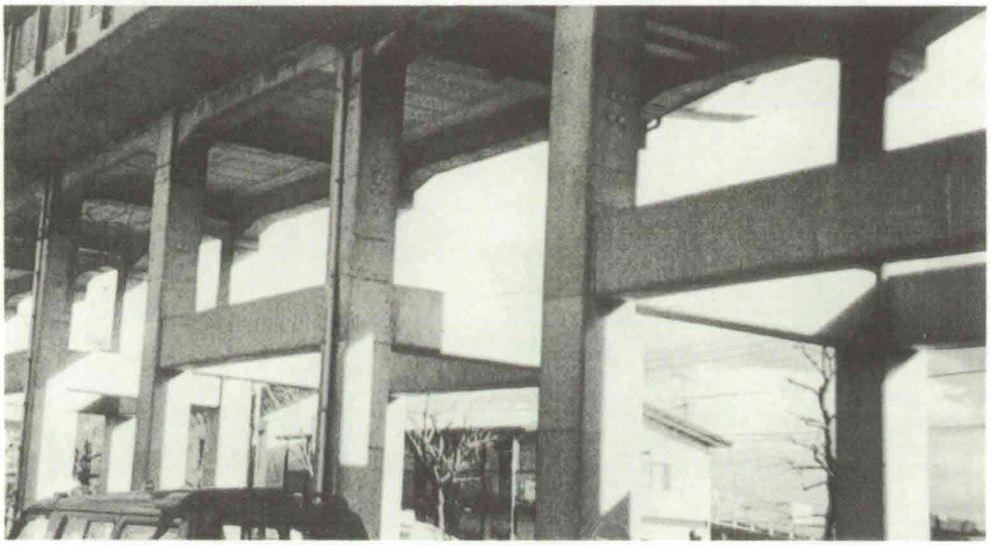
The earthquake assumed in design is generally that with a probability of once during the service life of the structure as at the time of construction. The inertia force assumed to act upon a structure is the weight of the structure itself plus the load on it multiplied by the design seismic intensity. The design horizontal seismic intensity is based on the standard value of 0.2, duly corrected according to the characteristics of the location and the ground, natural frequency of the structure, required functionality after the earthquake, and the seismic resistance of members not included in the calculation. Take, for instance, a structure that stands on rock in an area with inert seismic activity; the natural period of the structure is 0.1 to 0.7 seconds; no components other than major structural members have any effective seismic resistance and some noticeable damage is permissible. The design horizontal seismic intensity for such a structure would be 0.10. However, to ensure structural soundness under the same conditions except that the structure is built on soft ground would require that the design horizontal seismic intensity be set at 0.48.

The safety factor for bending moments is specified as 1.15 in general, while that for shear force is 1.8 for concrete and 1.38 for hoop reinforcements. The safety factor specified for the zone from member connections to the range of the width of the column is a value 1.25 times for each of the above. This stipulation is to prevent shear failure after flexural yielding and to enhance the overall strength of the column so that the structure will not collapse even if struck by an earthquake larger than the design one.

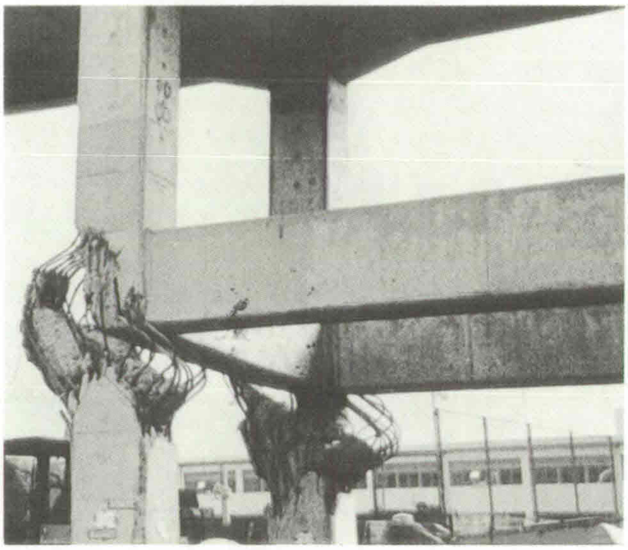
The aseismic structural specification stipulates that the ends of hoops be bent by more than 135 degrees to ensure firm anchorage to the concrete inside, or alternatively be constructed as a continuous rebar spiral. The ratio of hoop reinforcements must be not less than 0.2%. The anchoring of the main tension bars, i.e. the curtailment of the reinforcement, is limited to one half of the total reinforcement at the same cross-section and requires the extension of bars from the section at which the reinforcement becomes unnecessary by the length of the effective height of the member plus necessary anchoring length. The design shear strength in this section should be more than 1.5 times the design shear force. For positions of lapping or joining rebars, the specification only requires them to avoid sections that receive large stress. This specification lacks clarity.

The current Specifications for Highway Bridges (1990) incorporate a new recommendation in addition to the conventional allowable stress check. This is that the design strength of a reinforced concrete bridge pier should be checked against an earthquake considerably greater in intensity than those specified in the JSCE's Standard Specifications, so as to prevent brittle failure. According to the Specifications for Highway Bridges (SHB), when it is judged that failure in bending will precede shear failure, the admissable plasticity should be calculated with a safety factor of 1.5 assuming that the ultimate displacement is reached when the concrete compressive edge strain reaches its limit (0.0035), and the equivalent horizontal seismic intensity is then calculated. As a result of assuming a larger earthquake, the safety factor used in the calculation of design strength is fairly conservative as compared with the JSCE's Standard Specifications. The aseismic structural specifications in the SHB are basically the same as those given by the JSCE.

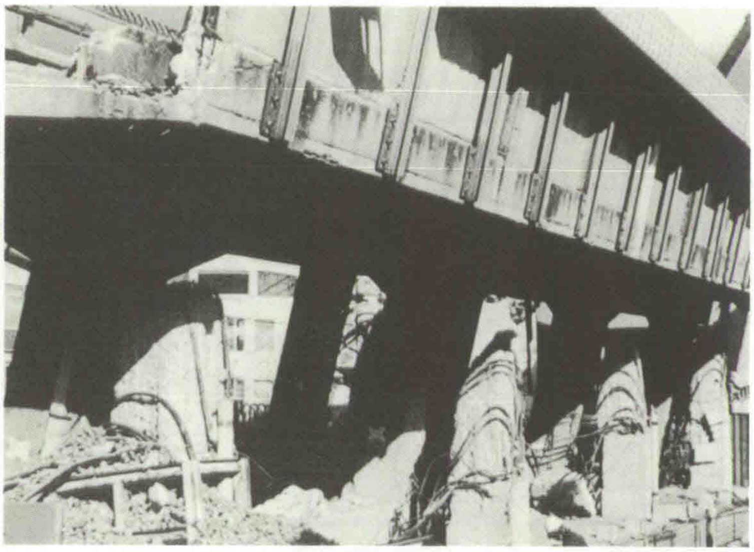
The earthquake assumed in the Design Standards for Railroad Structures (DSRS) developed in 1992 is principally the same as those assumed in the SHB. However, the DSRS offer equations for calculating the amount of hoop reinforcements needed to meet the ductility specifications given in the design depending on the slenderness ratio of the member, the reinforcement ratio, the acting compressive stress, and the height of the structural member. According to the DSRS, this specified amount of hoop reinforcements should be used in piers from the base to a height twice of the height of the cross section, in a column from a joint to a height twice of the column's cross section height, and in a beam from member connections to a length up to 1.5 times of the beam height. Other structural specifications are basically the same as those in the JSCE's Standard Specifications.



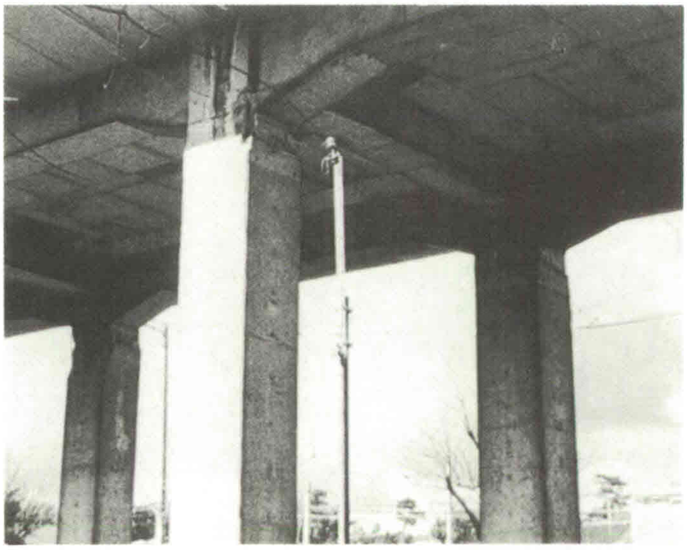
S1: Rigid-frame elevated bridge with intermediate beam



S2: Shear cracking below intermediate beam

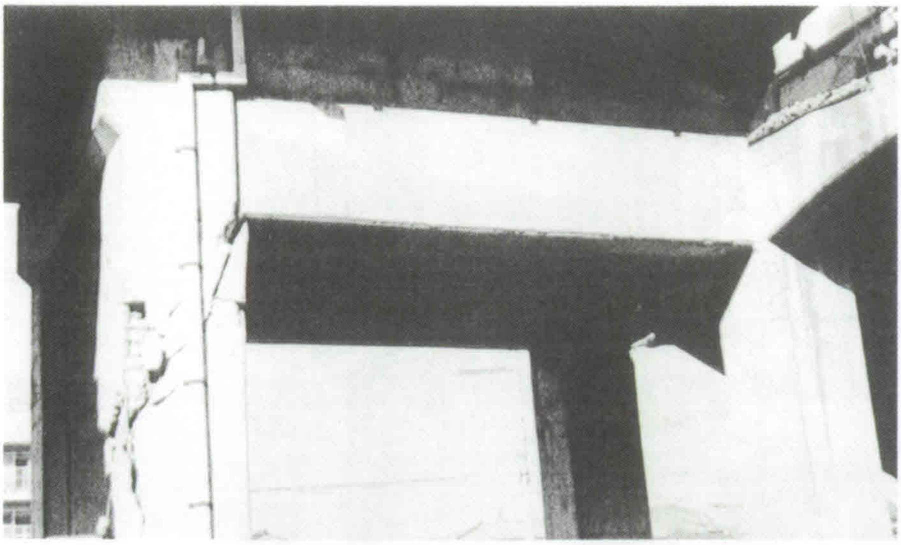


S3: Upper section collapsed to the north in the direction normal to the bridge axis

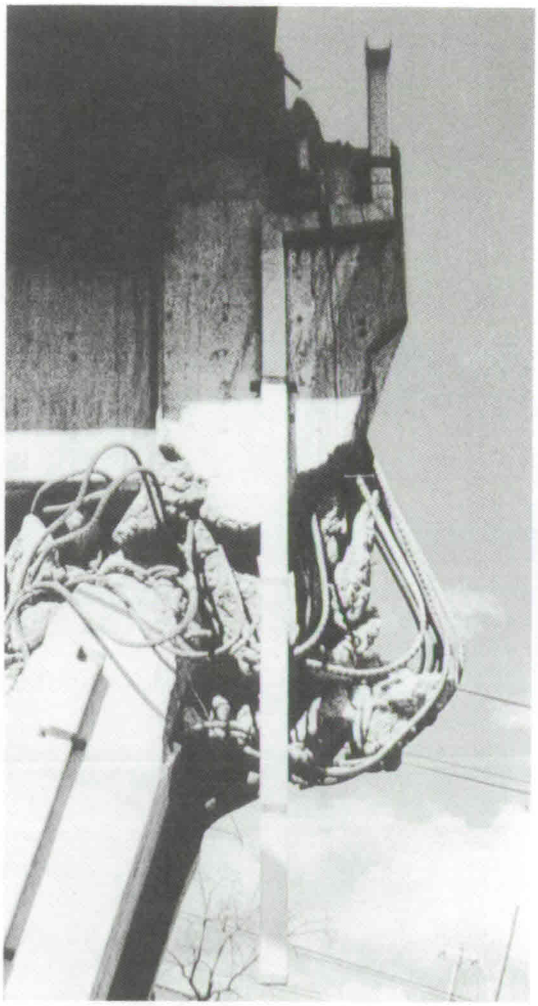


S4: Rigid-frame elevated bridge with no intermediate beam. Flexural yielding just below the haunch

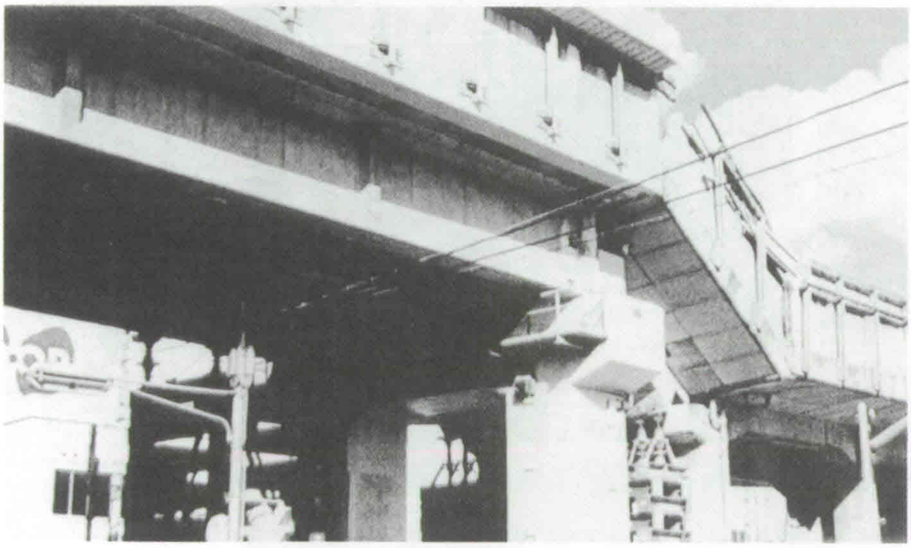
S5: Shear cracking just after flexural yielding



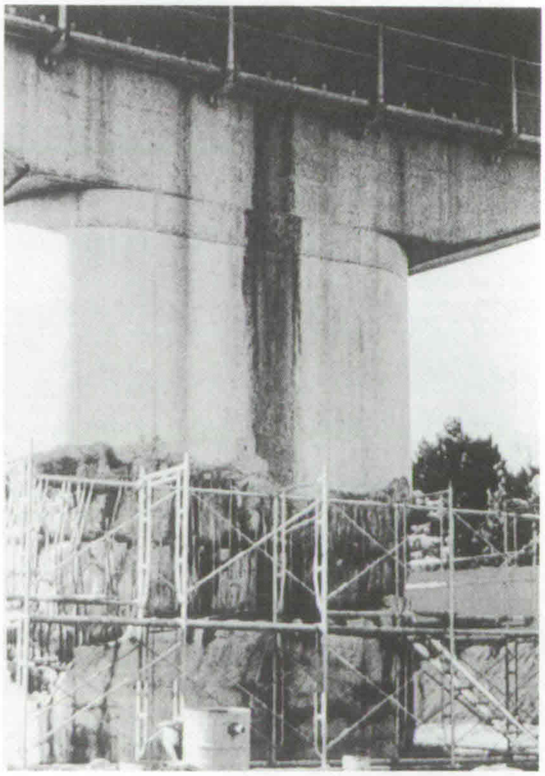
S6: Tall beams used in a rigid-frame abutment



S7: Shear failure just below the rigid-frame abutment support. Collapse of PC beam bridge

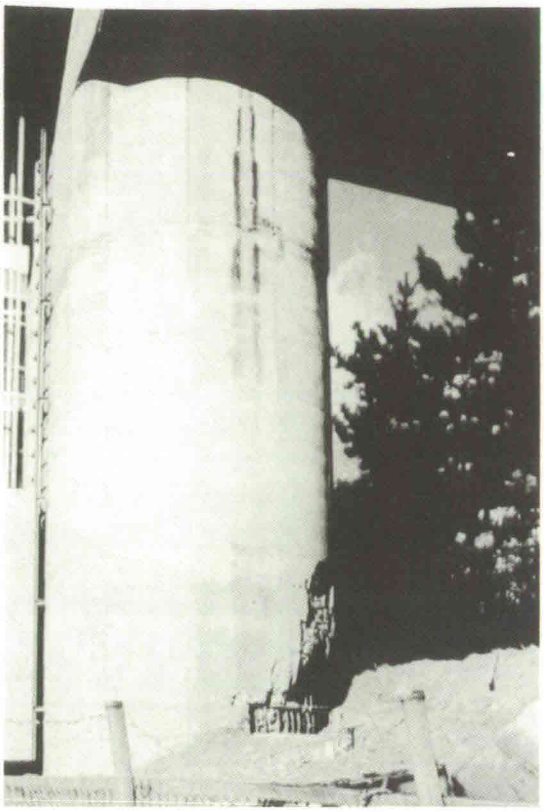


S8: Sound rigid-frame bridge pier supporting PC beam

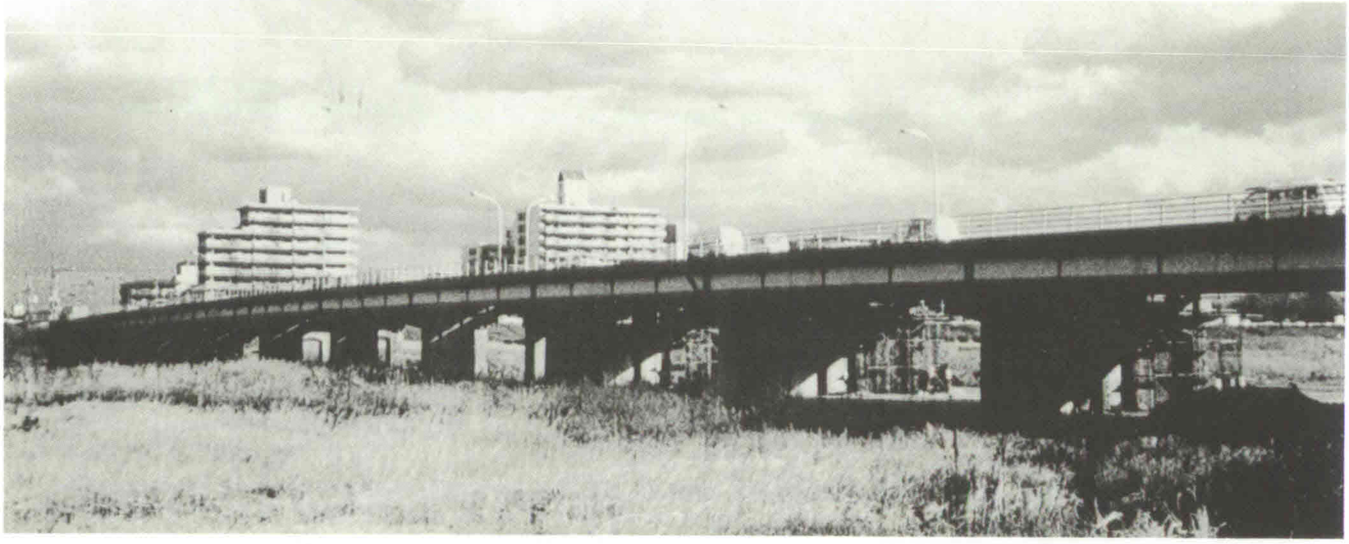


S10: Local buckling of rebars where amount of reinforcement reduces where rebars have yielded in bending. Concrete cover spalled off. Ruptured hoops. Horizontal construction joints seen at pier mid-height

S9: Mukogawa Bridge with oval-shaped piers

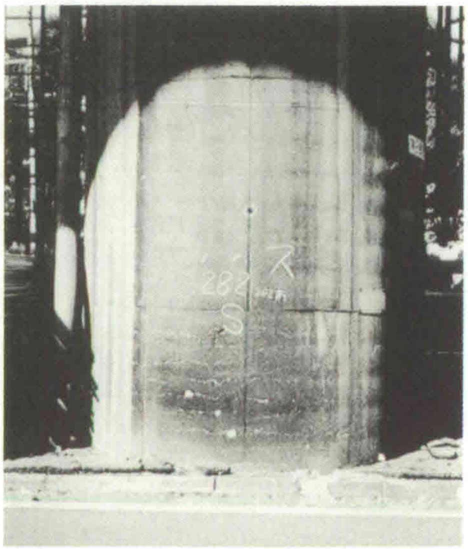


S11: Flexural yielding at the base of a pier

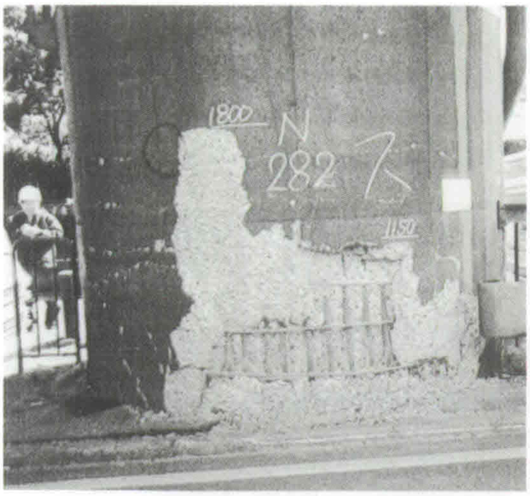


S12: Bridge piers supporting National Highway 171 with minor damage

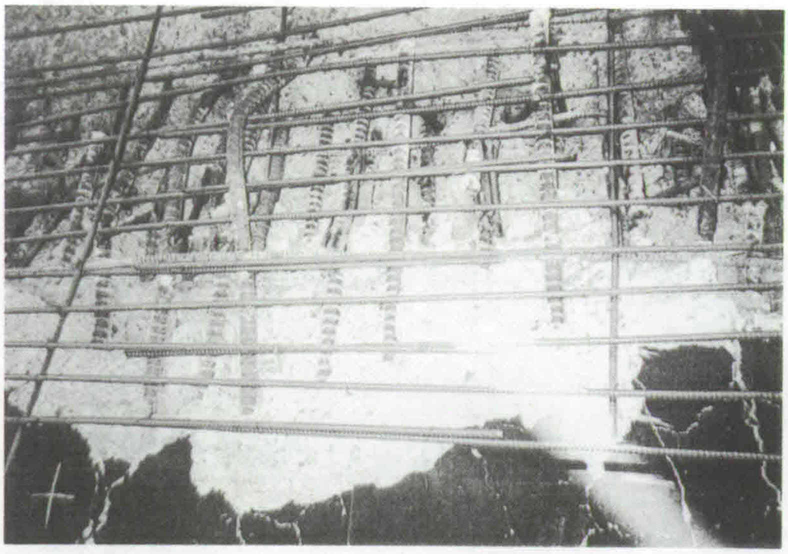
K1: Single-column circular bridge pier supporting the Hanshin Expressway



K2: Flexural cracking



K3: Yielding of reinforcement

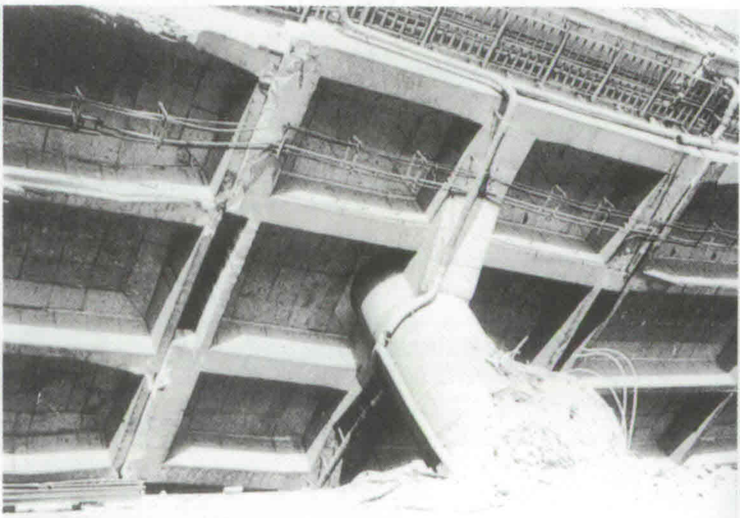


K4: Failure of welded joints
Joints which did not fail suffered local buckling

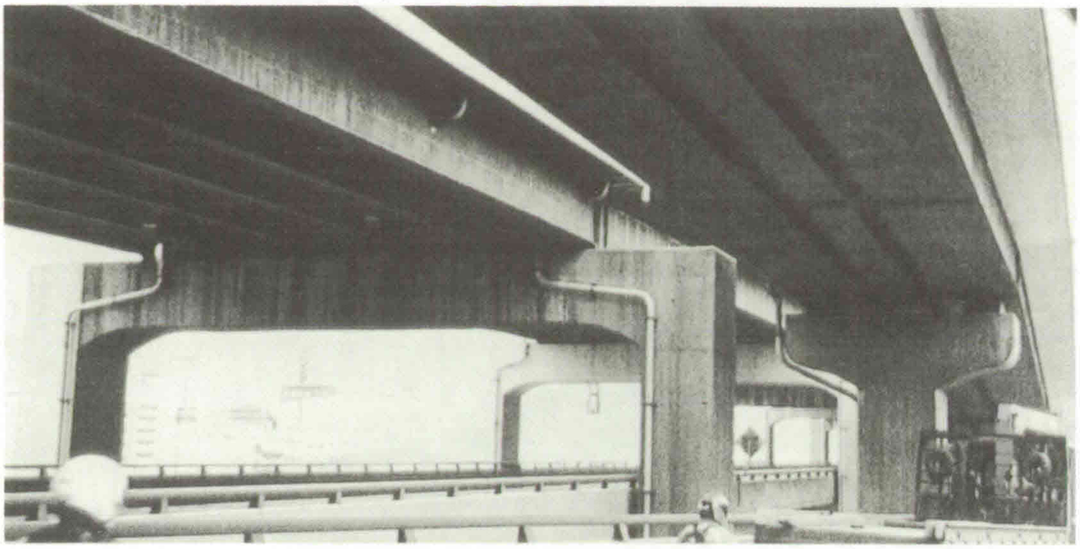
K5: Bridge pier with rectangular section.
Flexural yielding.

K6: Shear cracking

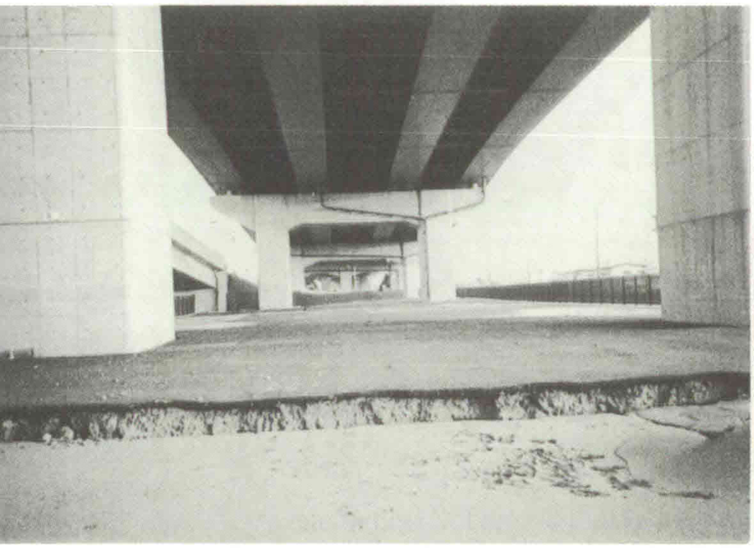
K7: Collapse of single-column rectangular bridge pier



K8: Collapse of a Pilz type bridge pier

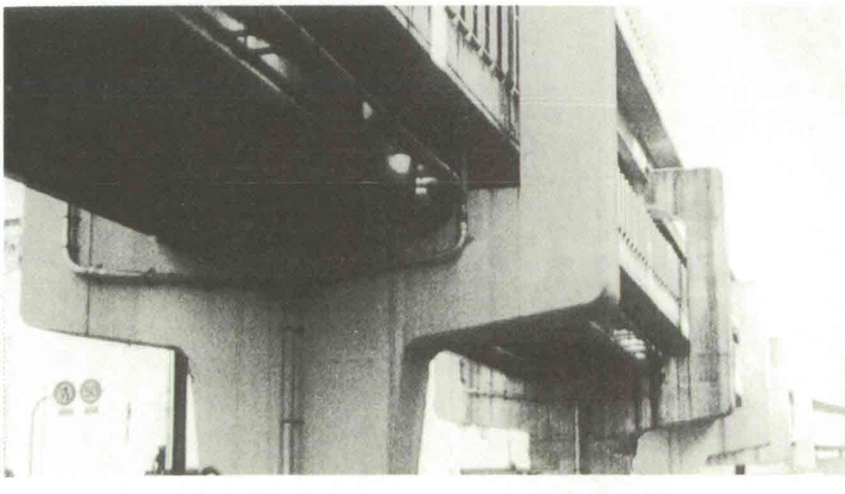


K9: Sound rigid-frame bridge pier



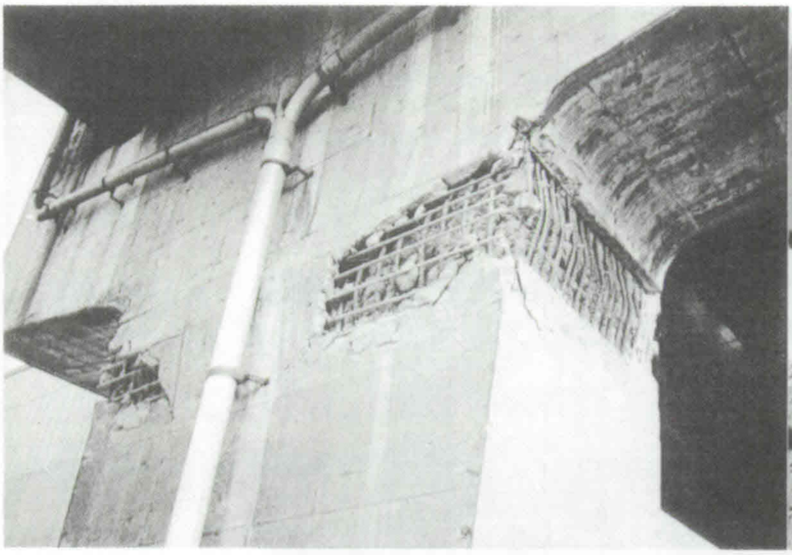
K10: Sound RC rigid-frame bridge pier supporting the Wangan Route

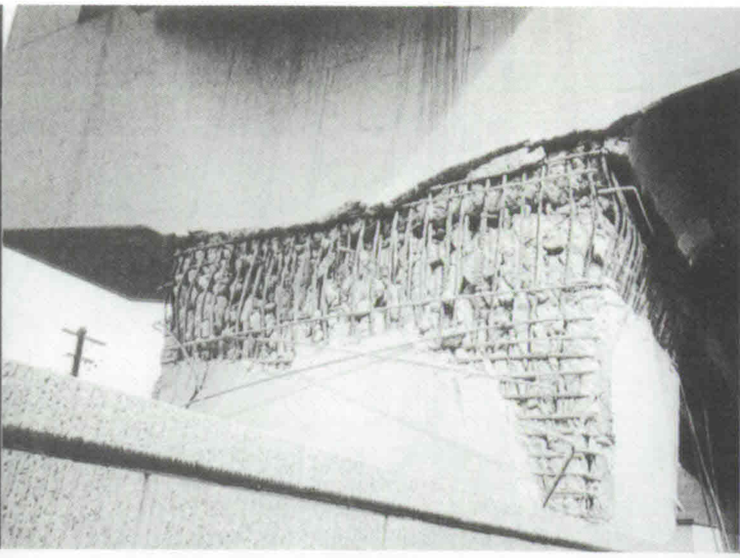
K11: Sound steel bridge pier supporting the Wangan Route

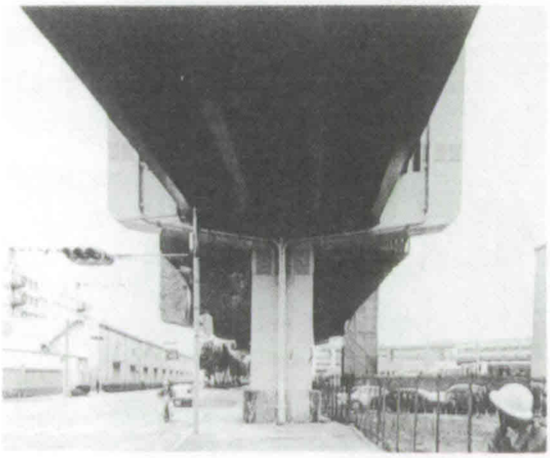


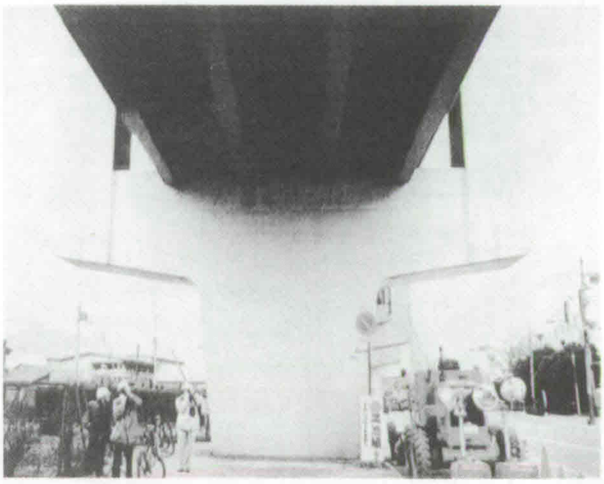
H1: Single-column (wall-type) two-layered rigid-frame bridge pier

H2: Rebars yielded where reinforcement is reduced

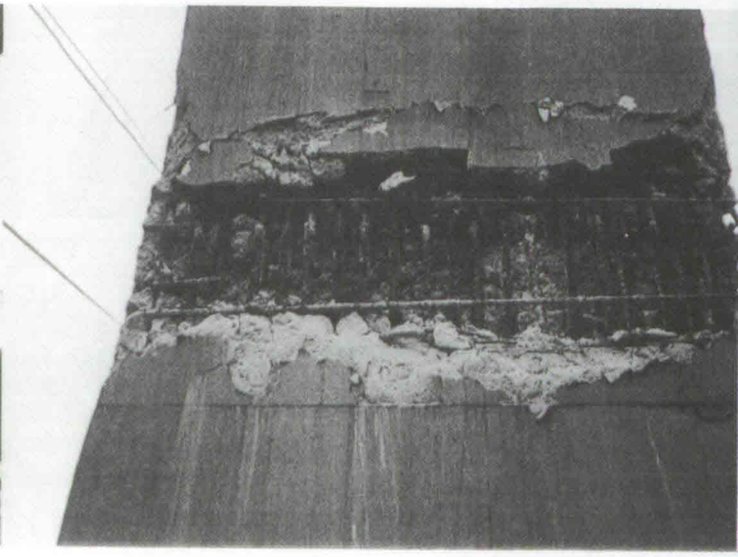

H3: Local buckling of rebars after flexural yielding

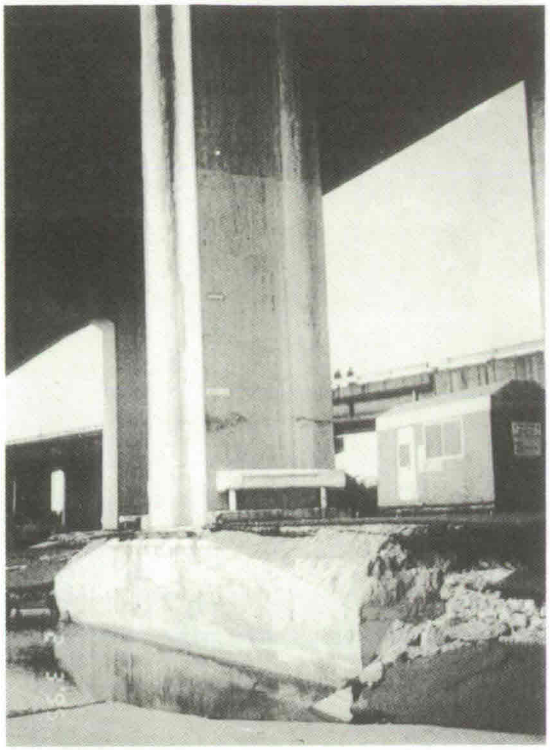

H4: Horizontal construction joints. Rebars reduced in quantity. Failure at welded joints. Improper anchorage of hoops.


H5: Locally buckled steel bridge piers

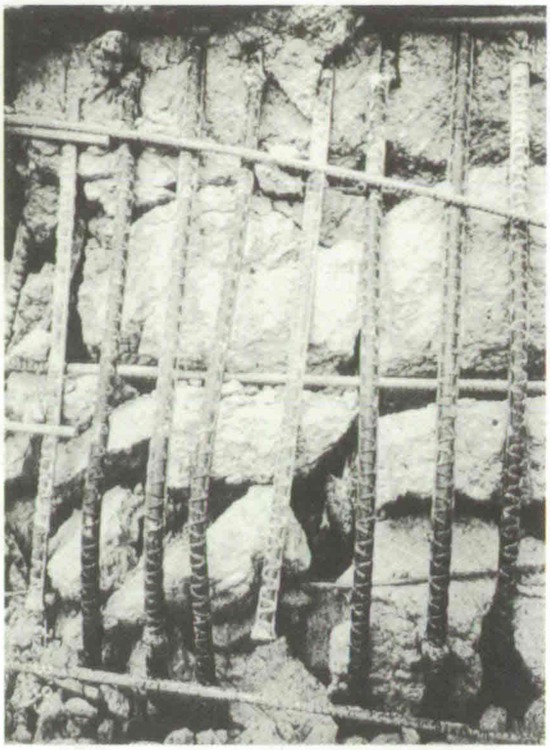

H6: Sound RC bridge pier


H7: Damage to tall single-column bridge piers. Rebars yielded at point of reinforcement reduction

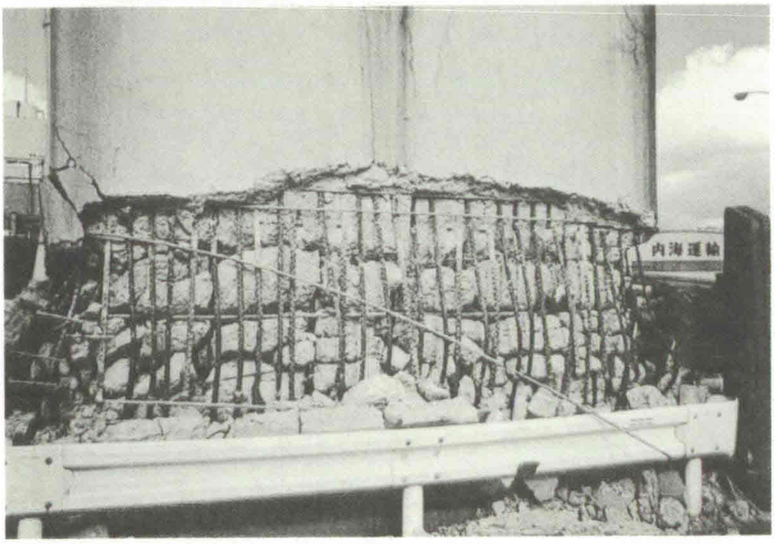

H8: Failure at welded joints. Hoops improperly anchored



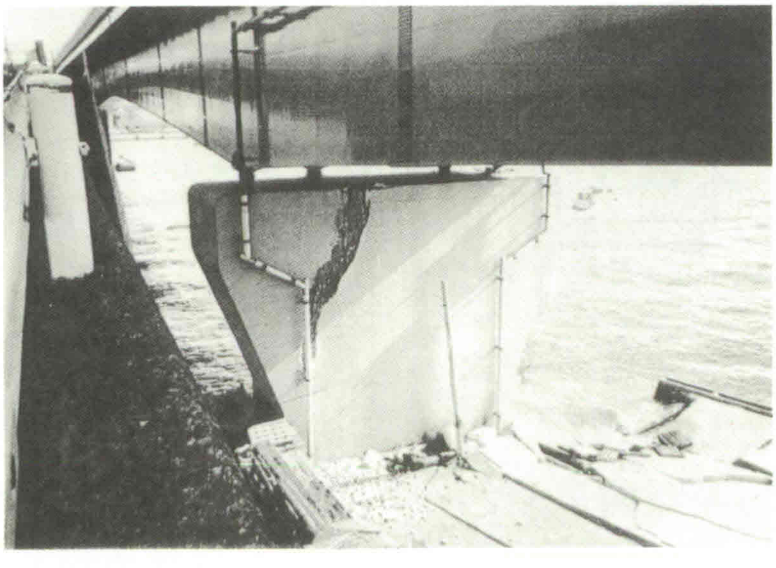
H9: Sound footing. Some settlement of nearby land in evidence.



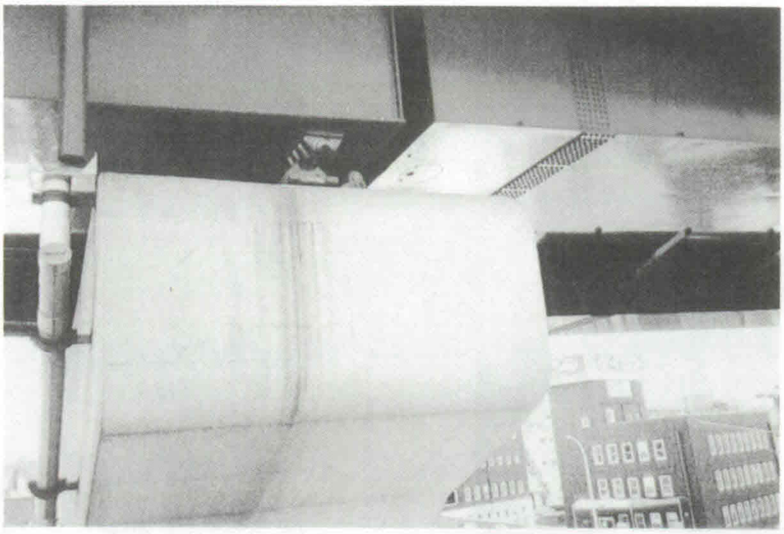
H10: Failure of welded joint



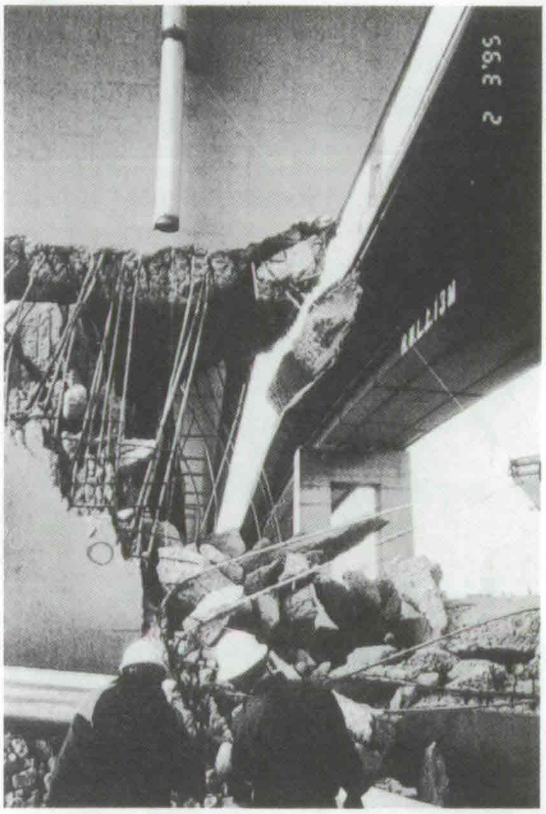
H11: Relationship between welded joints at two positions and cross section of bridge pier

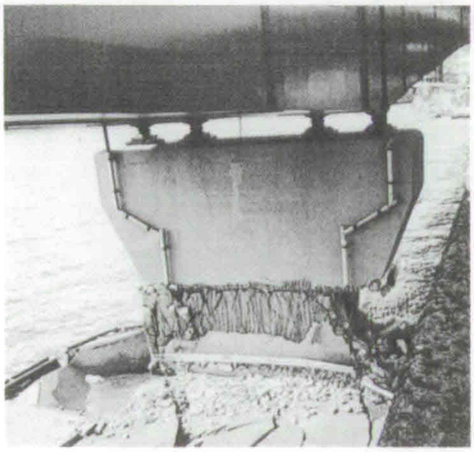


H12: Unusual cracking on a pier of the Second Maya Bridge



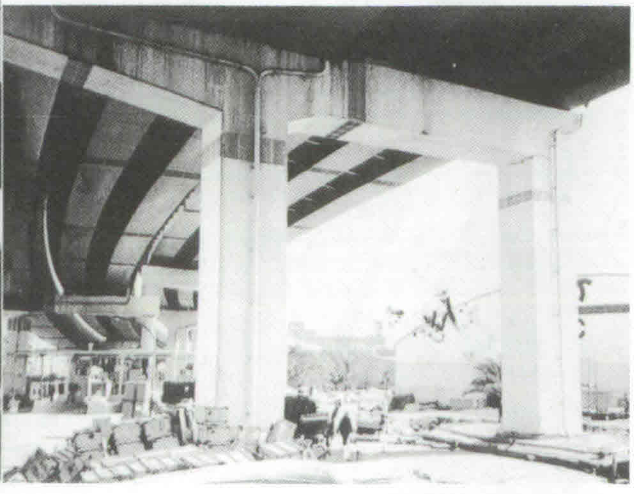
H13: Steel beam slid off bearing





H14: Horizontal construction joint and failure of rebars

H15: Failure of rebars and collapse of concrete



H16: Sound rigid-frame bridge piers

H17: Cracking of steel bridge piers

Report by Underground Structures Group

Toshihisa Adachi, Professor, Civil Engineering Department, Faculty of Engineering, Kyoto University: Geotechnical Engineering

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1. INVESTIGATION POLICY AND INVESTIGATION LOCATIONS

The epicenter of the Great Hanshin Earthquake was directly under the disaster area. There is a need to investigate the damage to various underground structures and examine their aseismicity; this will lead to a reexamination of the design criteria — including aseismicity — of underground structures. This requires a comprehensive analysis not only of the destroyed or damaged structures, but also of the unharmed structures, in consideration of earthquake motion (particularly the severe up-down movement peculiar to this earthquake), topography, ground (subgrade structure), structural shapes and dimensions, construction materials, earth covering, etc.

An investigation was carried out over three (3) days between February 1 and February 3, 1995 with a focus on structures such as subways (station buildings and tunnels), underground shopping arcades, multipurpose underground ducts, telephone tunnels, etc. The locations of these investigations are shown below.

• Kobe Express Railway Co., Ltd.	Daikai station
• New Port No. 4 Pier	Port Terminal Multipurpose underground duct
• Chuo-ku, Kobe	NTT Kobe telephone tunnel
• Kobe Municipal Subway	Station buildings and subway Track between Sannomiya and Kenchomae stations
• In front of Sannomiya station in Chuo-ku, Kobe	Sanchika underground shopping mall
• Chuo-ku, Kobe	Kansai Electric Power Company Isobe Dori shield tunnel

2. DETAILS OF INVESTIGATIONS

2.1 Damage to Daikai station of the Kobe Express Railway Co., Ltd.

(1) Description of station

The station is located in Hyogo-ku, Kobe, and is a two-story underground reinforced concrete structure. It was completed on January 31, 1964. Figure-1 is a structural drawing of the station. The station extends down to GL-12 m and the earth covering is about 1.9 m and 4.8 m, respectively, at the B1 and B2 floors. As can be seen from the drawing, the ground consists of sand, sandy loam, gravel, and a cohesive alluvial deposit. Its N-value varies widely, from about 10 to greater than 50 and the groundwater level appears to be about 3 to 4 m below the surface. Both the station itself and the track tunnels were constructed using the cut-and-cover method.

(2) Damage Suffered

One reinforced concrete pillar (rectangular; 70 cm in width x 450 cm in depth x about 2.6 m in height) centrally located in the center concourse on the B1 floor of the station was completely destroyed, and parts of several remaining pillars suffered spalling concrete and exposure of reinforcing bars. On the side walls, both horizontal and diagonal cracks appeared. Photo-1 shows the damage incurred.

Further, on the B2 floor, almost all of about 25 reinforced concrete pillars (rectangular; 100 cm in width x 40 cm in depth x about 4 m in height) were completely destroyed; the center of the B2 floor area of the station collapsed alongside the track. Photos-2 and -3 illustrate the situation. Pillars near the center were completely crushed, exposing twisted reinforcing bars both in the direction of the track axis and at right angles to it. Many of the hoop reinforcements were found to have completely failed. These destroyed sections of reinforced concrete pillars can be roughly divided into two categories, those which bulged at the foot and those which bulged where they met the roof. These two types of damage appeared to have occurred on alternate pillars in some places. However, the cracks that had occurred in the corner angles at four points on the side walls appear to have been secondary damage resulting from destruction of the center pillars, and the damage was milder than that to the center pillars. There were no indications of increase of water leakage.

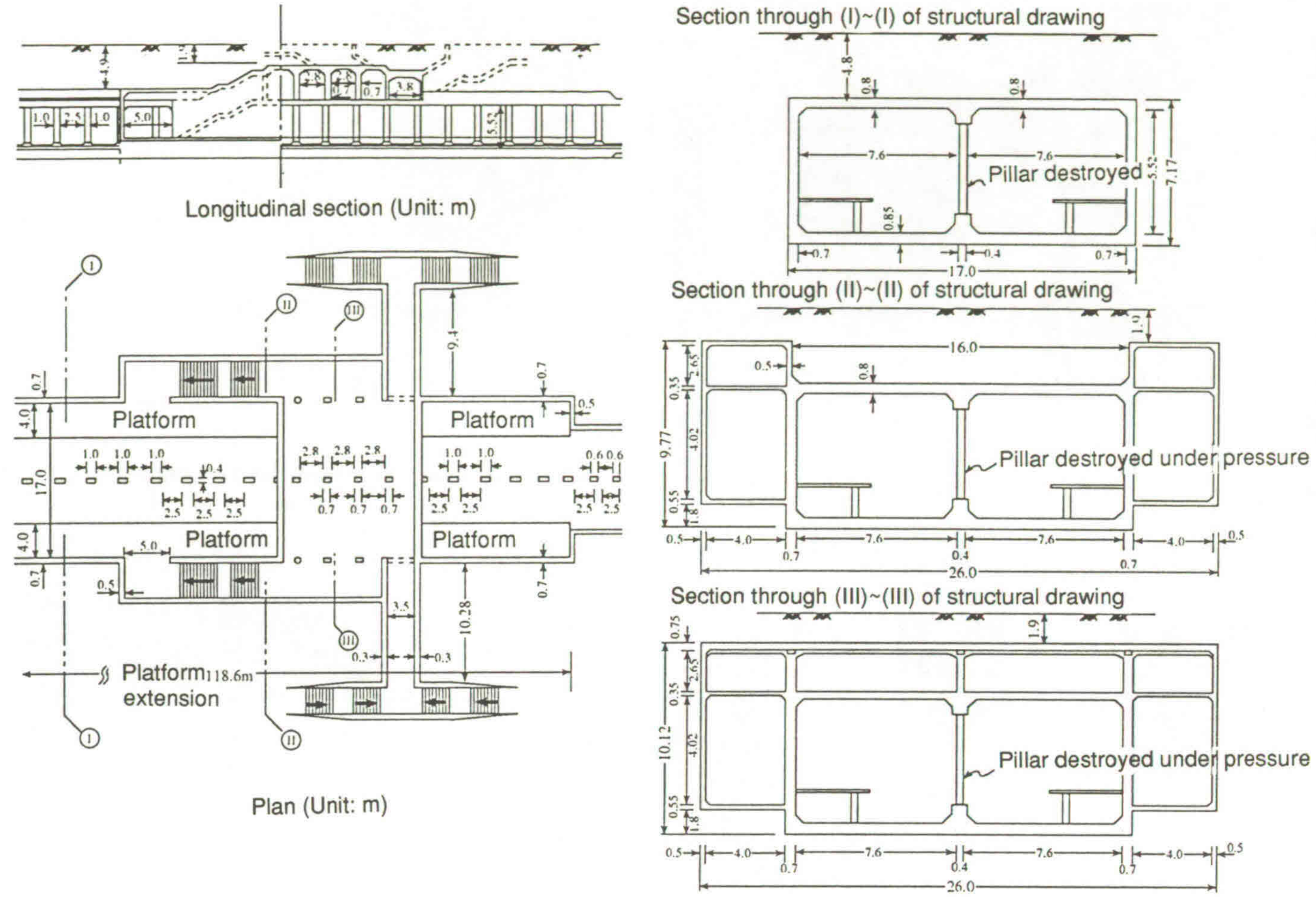

Fig. 1 Structural outline of Daikai Station (Subway Portion) of the Kobe Express Railway Co., Ltd.

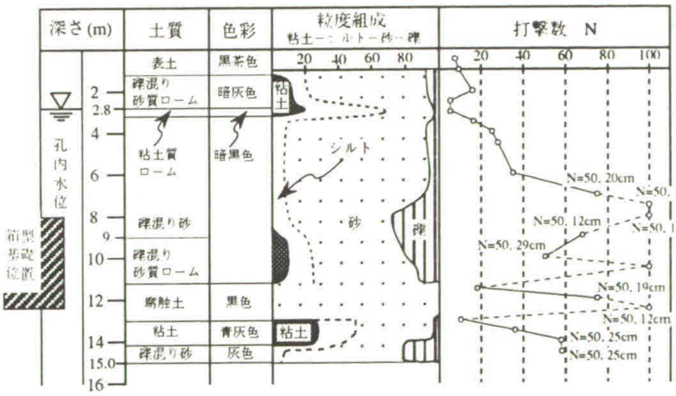

Fig. 2 Typical soil profile along railway track on east side of Daikai station

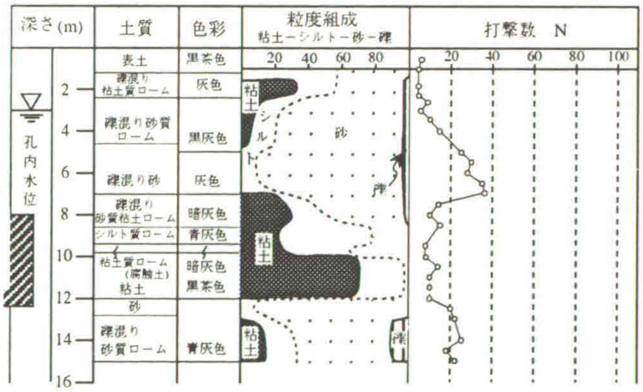

Fig. 3 Typical soil profile along railway track on west side Daikai station

Photo 1 Damage to B1 floor of Daikai station

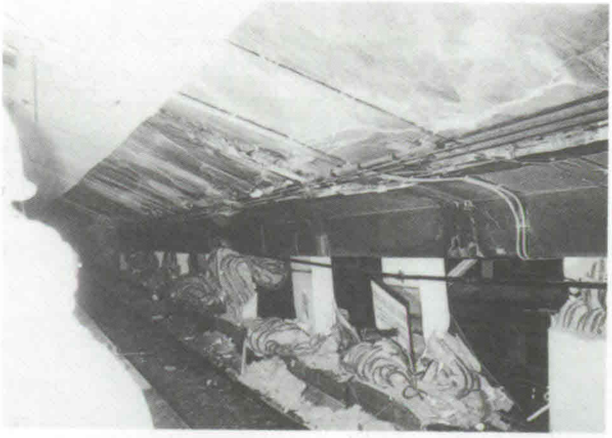

Photo 2 Damage to B2 floor of Daikai station (Nagata-cho side)

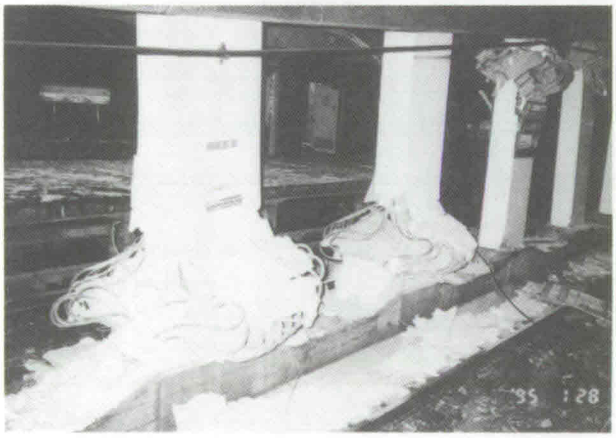

Photo 3 Damage to B2 floor of Daikai station (Sannomiya side)

Photo 4 Road subsidence on surface above Daikai station

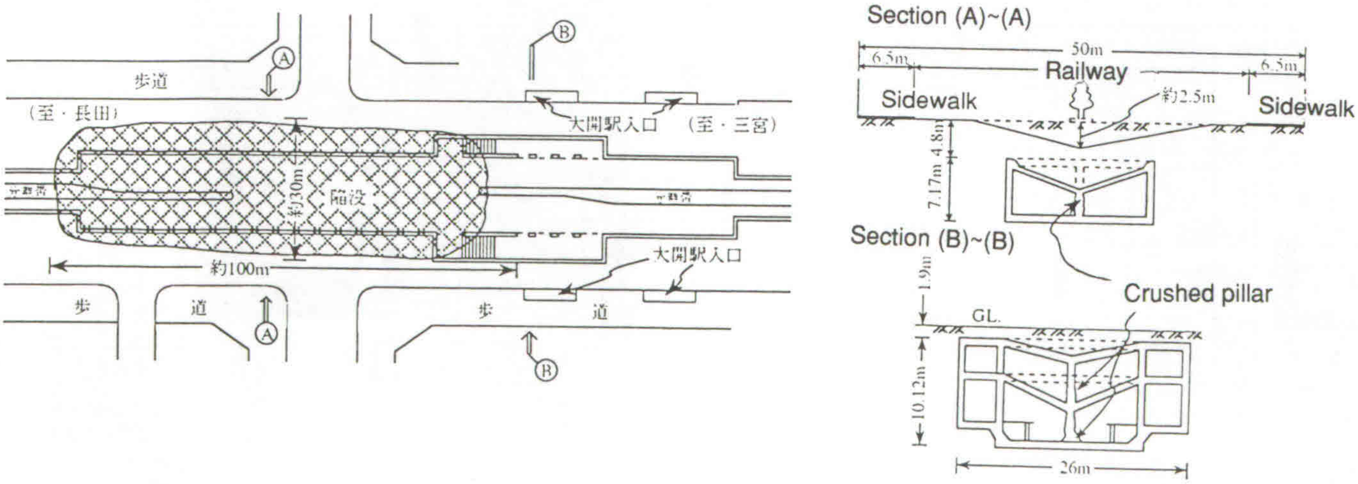

Fig. 4 Road subsidence on surface above Daikai station

In a related observation, it was noted that about 100 m of National Highway 28 on the surface above Daikai Station had settled by up to 3 to 4 m over a width of 30 m. In other places, there were continuous cracks extending up to tens of meters in length on the surface above the subway tunnel. There was little disturbance, however, and the alignment of curbstones along the median strip was preserved. Figure-4 and Photo-4 show these disturbances on the ground surface.

(3) Synopsis

As described, the station is an underground box structure with a large volume. Its width to length ratio is about 7.1:17 and judging from the typical mode of destruction — damage to center pillars rather than shear rupture in the vicinity of the four corners of the box structure — it appears that the whole station building was lifted vertically by the earthquake forces. The center of the floor probably rose upward in an "A" shape, while the slab forming the top of the station was forced downward in a "V" shape as a reaction to this. The result was that the central pillars failed to bear the load, especially given the excessive horizontal loading that also occurred, and they ruptured. In other words, although confirmation must await results of detailed analysis of the observed earthquake motion, etc., it is appears that significantly larger loads were experienced in both horizontal and vertical directions than were considered at the time of design.

2-2 Damage to Underground Multi-purpose Duct at New Port No. 4 Pier Terminal

(1) Description of Underground Multi-Purpose Duct

The underground multi-purpose duct investigated here was the No. 2 duct, part of an approximately 1-km long duct built between New Port No. 4 pier at Shinko-cho, Chuo-ku, Kobe and Port Island. It is shown in Fig-5. Figure-6 shows a structural section through the center of the duct and a conceptual drawing of the common enclosure bulkhead. In this case, five types of cables and pipes — namely gas, NTT telephone, water, electricity, and OMP — used the duct. The earth overburden appeared to be about 2 - 3 m. From observations of the soil constitution in the area, the ground in which the multi-purpose duct was constructed is assumed to consist of an alluvial sand, sandy loam, silt, or gravel stratum, but it is not known how the ground was treated for the foundations.

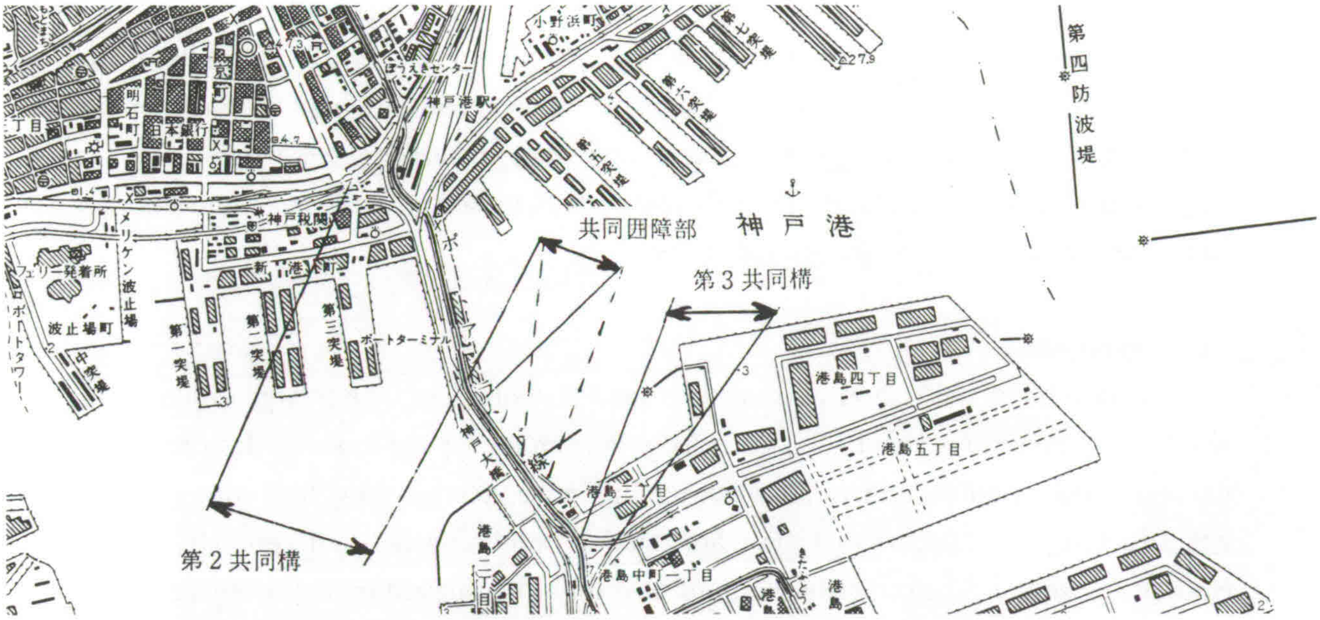

Fig. 5 Route of duct placed between New Port No. 4 Pier Terminal and Port Island

(2) Damage Suffered

The investigation undertaken at this time focused on the entrance to the No. 2 duct near the Kobe Bridge and a portion of about 15 m of the common enclosure in the shaft. No significant disturbance or damage could be seen on the concrete box of the duct itself. However, at an inclined section near the entrance, some of the insulators holding the cable brackets were seen to have broken free. Also, groundwater had entered, apparently through openings in concrete box joints, and water was discovered to have pooled to a depth of about 10 - 20 cm on the floor of the concrete box, as shown in Photo-5. Although the total amount of water leaking into the duct was not known, workers explained that the duct was completely filled with water about 150 m ahead and no investigation could be accomplished.

On the ground surface above the duct was a parking lot for the pier terminal, as well as one pier of the Kobe Bridge and an access bridge. Both of the latter were seriously damaged; Photo-6 shows how the parking lot suffered a wave-like cave-in. However, the ground surface directly above the duct in the parking lot and at No. 4 pier showed almost no sign of disturbance.

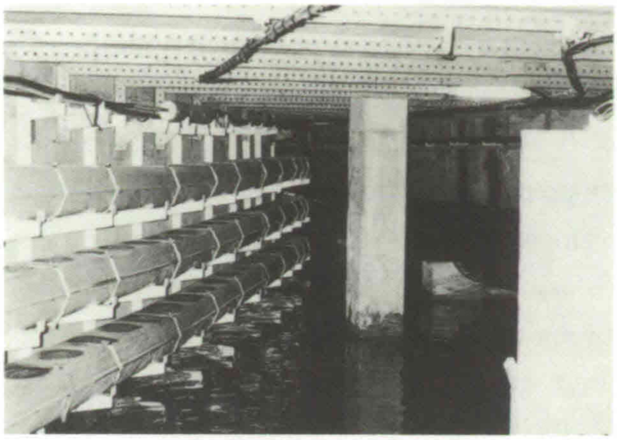

Photo 5 Flooding in duct due to water in-flow

Photo 6 Damage to parking lot above duct route

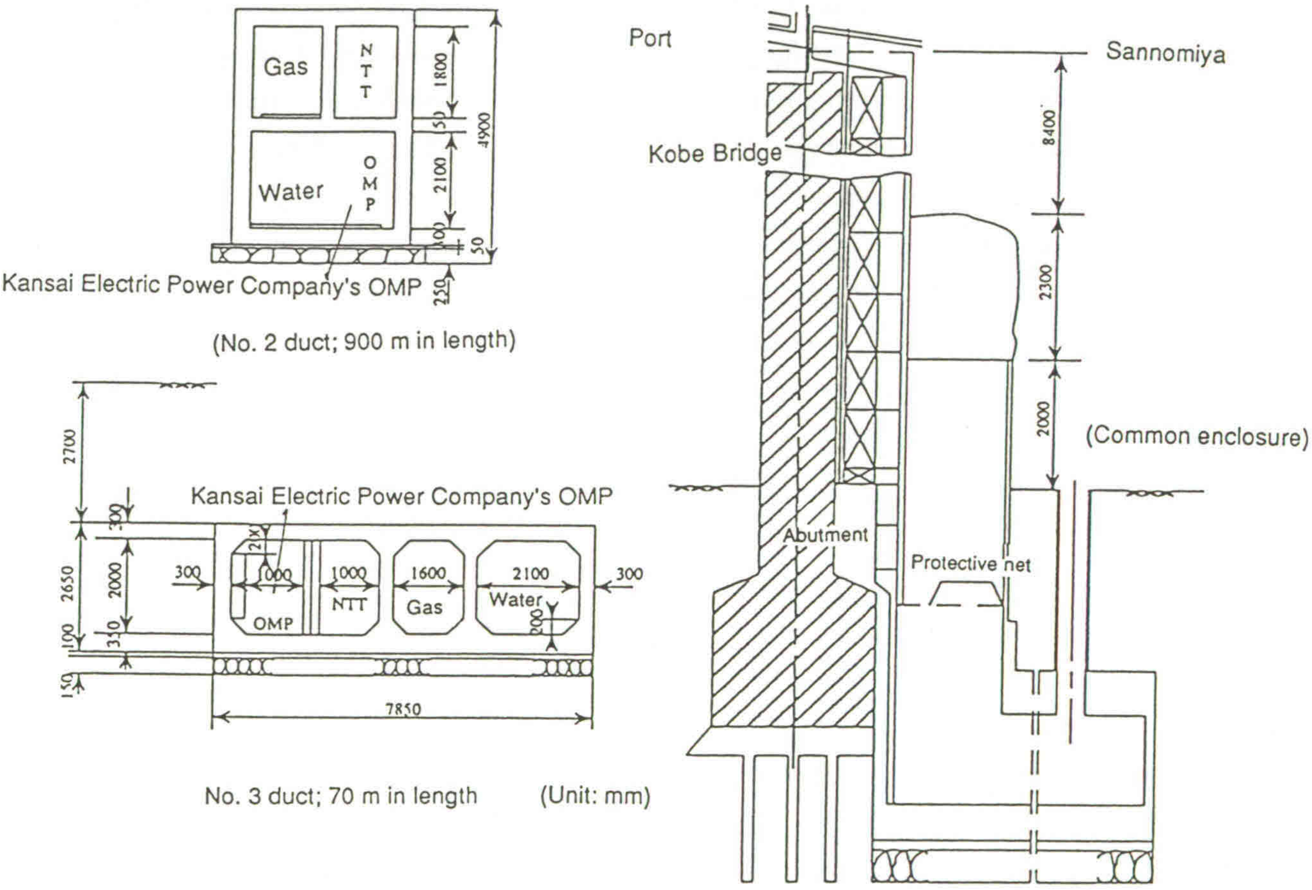

Fig. 6 General structural drawing of underground multi-purpose duct

(3) Synopsis

The underground multi-purpose duct suffered little damage as compared with the significant destruction caused to nearby above-ground structures. Moreover, since almost no disturbance could be seen on the ground directly above the route of the duct, it can be assumed that the ground below the duct had been prepared with some kind of foundation treatment such as ground improvement, reinforcement measures, etc. The dislodging of support insulators near the entrance to the duct is assumed to have occurred because of a difference in seismic motion characteristics between the shaft of the common enclosure and the underground duct itself, or a difference in seismic motion characteristics between the concrete box and the cables in the conduit. It should be noted that the damage to the cables themselves is not yet known.

2-3 Damage to NTT Kobe Telephone Tunnels

(1) Description of Tunnels

These are the Fukiai, Sannomiya, and Yamate telephone tunnels, all of which are basically similar and have a total length of about 8 km. They mainly run in an east-west direction, though in parts north-south. They were partly constructed using the cut-and-cover method, giving a rectangular cross section of about 2.5 m x 1.5 m, and partly as shield tunnels about 4 m in diameter. The ground through which the tunnels were constructed is assumed, from observations of the soil constitution in the area, to consist of an alluvial stratum and a terrace stratum consisting of gravel, sand, and cohesive soil. The earth overburden in the case of the rectangular sections is thought to be about 2 - 3 m, and about 10 m in the case of the circular shield tunnel.

(2) Damage Suffered

The investigation undertaken at this time focused on the service shaft in the vicinity of the Kobe Branch Office, several tens of meters of shield tunnel, and a section of rectangular tunnel. No exceptional damage was seen in the shaft nor in the shield tunnel themselves, aside from some cracking that had occurred — mainly towards the top of the arch at the portal. With regard

Photo-7 Opening resulting from damage to expansion joint to the rectangular tunnel, slippage or opening of expansion joints had occurred at several locations, as shown in Photo-7. Inflows of groundwater were also noted, but these did not tax the existing drainage system when assisted by some submerged pumps. These problems with expansion joints were especially prominent where the tunnel connected with a building or where the cross-section changed. In any event, the observed damage was not serious enough to greatly inhibit the functioning of these telephone tunnels, as far as could be discerned from the locations investigated. In addition to the damage actually observed, NTT themselves came across certain other damage, though all cables carried by the tunnels were unharmed:

a) In rectangular tunnel sections, influxes of water occurred at more than ten points as a result of slippage of expansion joints, and in two or three locations the structure itself had cracked. This led to concern that the retaining strength of the structure might have deteriorated. The total influx of water was estimated at 10 to 50 liters/min.

b) In shield tunnel sections, some cracking was identified at several points around portals, though no damage to the structure itself was noted despite some water inflow. The total inflow of water was estimated at approximately 10 to 20 liters/min.

c) At the telephone tunnel service shaft in Sannomiya, cracking had occurred at a manhole flange and at construction joints, causing some water leakage in addition to ground and building subsidence as a result of ground liquefaction.

(3) Synopsis

As described, it is clear that damage to telephone tunnels was relatively light and of little significance compared with the serious damage caused to above-ground structures in Sannomiya and Nagata. Although the incidence of damage was relatively high in the rectangular tunnel, it was mostly concentrated at expansion joints; it can therefore be considered to have occurred as expected given that the seismic forces exceeded those considered in design. Overall, the tunnel was considered to still function as a structure. In contrast, the shield tunnel sections can be considered to have retained complete functionality in the face of the seismic forces experienced in this earthquake.

Despite these observations, it is clear that the incidence of damage in sections of the telephone tunnel running east-west was relatively greater than in sections running north-south; thus it may be necessary to carefully examine and analyze the damage from the viewpoints of fault behavior, seismic motion characteristics, ground structure, etc.

2-4 Damage to Sannomiya and Kenchomae Subway Stations and Kobe Municipal Subway Track

(1) Description of Sannomiya Station

Sannomiya station is located in Kobe's Chuo-ku, and is a three-story underground reinforced concrete structure consisting of a box-type tunnel as commonly used in urban areas. It came into service on June 18, 1985. The station building is about 310 m in length, about 15 m in width at the platforms and about 20 m in height. Its B1, B2, and B3 floors form a monolithic construction. On the B1 floor there is an electrical room and a machine room for ventilation, while the B2 and B3 floors are for eastbound and westbound platforms, respectively. The structure of the surrounding ground consists of an alluvial sand stratum and a gravel stratum at the B1 level, with alternating layers of diluvial sandy soil and cohesive soil below that. The earth overburden is about 3 m and both the station building and subway track were constructed using the cut-and-cover method.

(2) Damage Suffered

In the ventilation machine room at the B1 level, and the western electrical room and ventilation machine room on the B2 level, about 30 reinforced concrete pillars (rectangular; 0.9 m in width x 0.7 m in depth x 4 m in height) were found to have been damaged. Figure-7 shows an example of the damage. In all cases, the damage exhibited was bent axial reinforcing bars, with both axial bars and hoops having separated from the concrete. In some places, concrete had spalled off, exposing the reinforcing bars. This kind of damage to pillars was found scattered over many locations, and occurred either at the foot of the pillar, at the junction with the roof, or around the mid-point. Adjacent pillars had similar damage in each case. Temporary support was being put into place using H-shaped steel columns and jacks, as can be seen in Photo-8.

On the other hand, on the B2 and B3 levels of the station building, steel pipe pillars 0.55 m and 0.65 m in diameter suffered no damage. Moreover, no unusual leakage of groundwater could be seen. The distribution of damaged pillars on each floor was very interesting, and this will require thorough examination in the future; details are omitted here.

The condition of the track between Sannomiya and Kenchomae stations (about 1 km) was investigated. The reinforced concrete box sections were found to be sound and without damage, and the concrete pillars of Kenchomae station were undamaged.

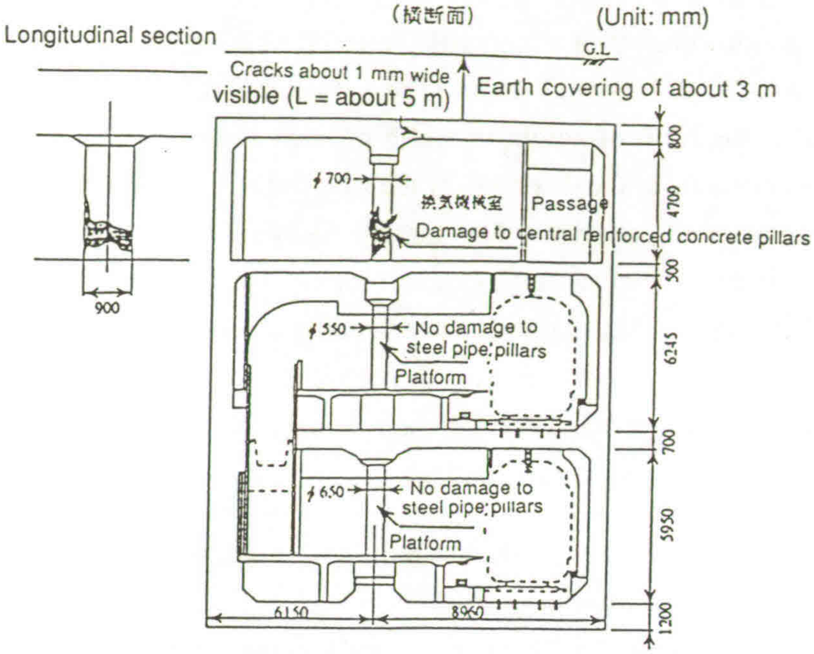

Fig. 7 Example of damage to Sannomiya station of the Kobe Municipal Subway

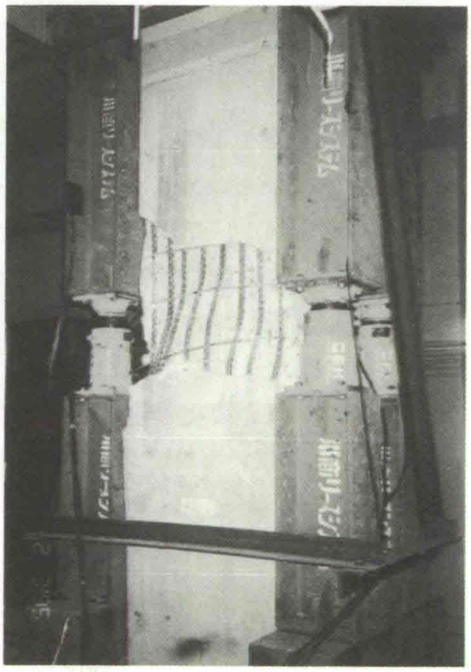

Photo 8 Temporary reinforcement to central pillars at Sannomiya station of the Kobe Municipal Subway

(3) Synopsis

Sannomiya station consists of a monolithic reinforced concrete box construction, as described above, with B1, B2, and B3 floors. The overall ratio of height to width is about 20:15. Structurally, the ratio of height to width of each floor is 4:15, and rather than damage due to shear rupture at the 4 corners of the side walls of the concrete box, damage to the RC pillars was more apparent. The damage to these reinforced concrete pillars may be considered to have been caused by shear rupture or brittle rupture under uniaxial compression, rather than by shear failure under bending or horizontal loading. In other words, although it will be necessary to carry out detailed analysis in the future as in the case of Daikai station, it seems that loading in both horizontal and vertical directions was very severe, exceeding the values assumed in the initial design.

2-5 Damage to Sanchika Shopping Mall at Sannomiya Station

(1) Summary of Sanchika Shopping Mall

This underground shopping mall was constructed on the former river about the same time as the Yaesu Underground Shopping Mall in Tokyo Station, in 1965. At 30 years old, this makes it one of the oldest underground shopping arcades on the former river. As shown in Photo-9, the mall itself occupies the B1 level and is divided into sections — City Elegance, Home and Life, Roza Avenue, Sweet Mates, Gourmet Square, etc. Sannomiya station of the Hanshin Railway Co., Ltd. is located on B2 floor to the left center.

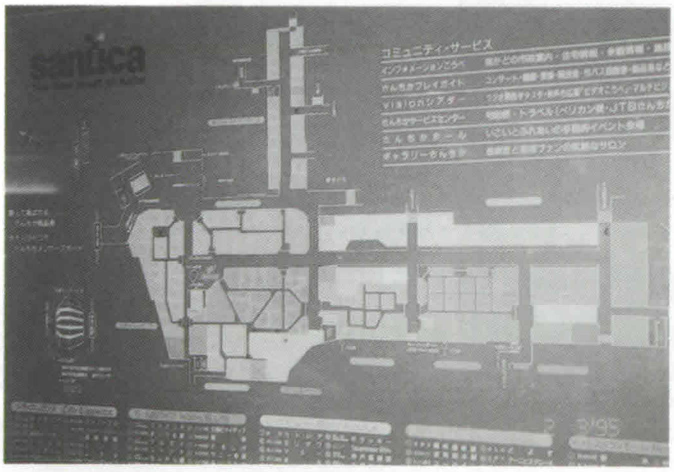

Photo 9 View of Sanchika Shopping Mall

Photo 10 View of Sanchika Shopping Mall

(2) Damage Suffered and Synopsis

The damage sustained by this mall was almost nonexistent, except for two broken panes of glass, as shown in Photo-10. The main reason for this lack of damage is thought to be that the original design was based on a horizontal seismic intensity of 0.1, and that all pillars are steel pipes (about 60 cm in diameter) filled with concrete. Moreover, the left part of the central structure shown in Photo-9 was a new extension; the vertical dividing wall between the two parts is thought to have played a role as an earthquake resisting wall. This underground mall runs below Flower Street to the south of Hankyu Sannomiya Station. Witnessing the enormous difference in the degree of damage between this underground structure, located 20 steps down from the street, and the above-ground structures in the Sannomiya area, the strength advantage enjoyed by buildings underground was vividly illustrated.

Although there were no structural problems as far as this underground mall was concerned, it was not open as of February 3 because the sprinkler was not functioning due to the lack of water supply.

2-6 Damage to Kansai Electric Power Company's Isobe Dori Shield Tunnel

(1) Description of Tunnel

Kansai Electric Power Company was planning to build a new substation in Edogawa-cho, Chuo-ku so as to increase the supply of electricity to the center of Kobe (Sannomiya and Hyogo Districts). This involved bringing in a 275 kV transmission line. As part of this plan, an underground conduit was being laid from the proposed Sannomiya Substation to Isokamidori-2 chome, Chuo-ku. This consisted of a tunnel being excavated by the pressurized slurry earth shield method. Construction of the tunnel had begun in May 1992, and excavation of the entire length was complete, all segments had been assembled, and secondary lining was about to start in the tunnel (placing of an invert). At the arrival shaft, concrete of 1 m in thickness had been placed to 5 m below the ground surface. The tunnel is 4.95 m in diameter and segments are 20 cm thick. Soil column strip sheathing (ø550 mm, about 23 m in length) was adopted for the arrival shaft and its dimensions are 8.0 m in width x 9.3 m in length x about 18.5 m in depth. The ground consists mainly of a diluvial gravel stratum with an N-value of more than 50, and the groundwater level is 2~3 m below the surface. The shield proceeded with simultaneous injection of backfill, and the amount of backfill injected was as planned thanks to the solid conditions encountered.

(2) Damage Suffered and Synopsis

The investigation was undertaken at the arrival shaft and a portion of the shield tunnel extending about 300 m from the arrival shaft, as shown in Fig-8. The earth overburden over the tunnel was found to vary from 11 to 15 m. Cracks about 0.2 mm in width and 90 cm in length had occurred in the shaft, and there was some spalling in the grooves in the segments between segment rings; otherwise, however, the structure remained undamaged, as can be seen in Photo-11. According to those in charge, many buildings collapsed and fissures opened up in the ground near the site, and workers anticipated serious damage before entering the tunnel. Immediately after the occurrence, inspections were carried out to check for the following: 1) detection of gas, methane in particular; 2) loosening of segment bolts and cracking.

As shown in Fig-8, an NTT shield tunnel ran directly above this tunnel. During construction, measurements (mainly of settlement) were being taken in the NTT tunnel to check for any unusual behavior. Although we were not able to confirm whether or not measurements were still going on at the time of the earthquake, this data would be very valuable, even if it consisted only of measurements of stress on segments in one section.

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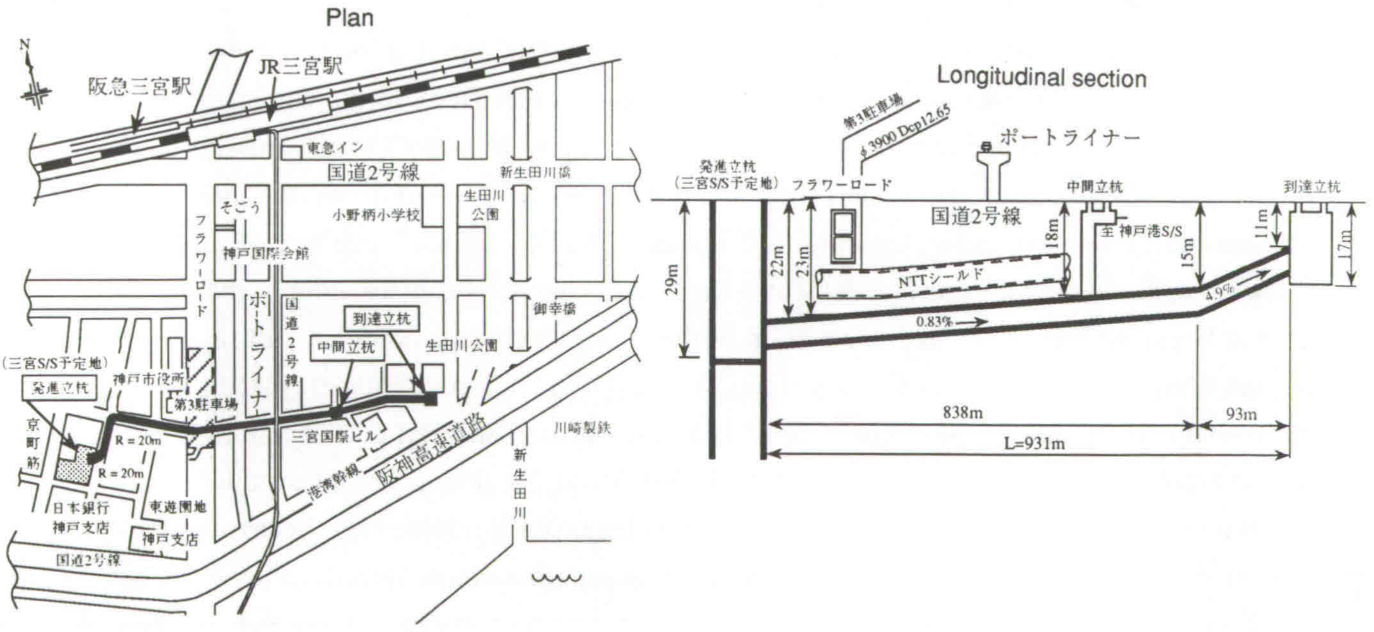

Fig. 8 Kansai Electric Power Company's Isobe Dori Shield Tunnel

Photo 11 View of Kansai Electric Power Company's Isobe Dori Shield Tunnel

As has been witnessed, there is absolutely no doubt that the aseismicity of underground structures is far superior to that of above-ground structures, although it has to be said that certain underground structures were totally destroyed or partially damaged. However, it is still essential to judge whether or not existing standards are adequate by examining the performance of both destroyed and sound structures.

3. Conclusions and Future Investigations

This investigation leads us to the following conclusions:

1) Underground structures have excellent aseismicity as compared with above-ground structures.
2) There is a need to propose design and construction methods able to withstand an earthquake whose epicenter is directly underneath, and this will entail carrying out thorough investigations, analysis, and surveys.

As themes for these future examinations, we can at present point to the need for the construction and analysis of models, comparison of the models with the actual disaster, determination of the validity of existing design criteria, and proposals for new design standards.

Structure Foundation Group Report

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1. PURPOSE OF INVESTIGATION

The earthquake that hit the southern part of Hyogo Prefecture and northern Awaji Island on January 17, 1995 was the biggest to occur so far under a modern urban area. The earthquake consisted of horizontal and vertical shaking of short duration and of greater severity than anticipated, as outlined in the first investigation report by the Japan Society of Civil Engineers (JSCE). These shocks resulted in devastating damage to the social infrastructure, including expressways, railroads, and harbor facilities, to name only a few civil engineering structures.

All structures are, in some way, supported by the ground. Since most civil engineering structures are heavy, the foundation that supports the superstructure plays a crucial role. A sound structure, therefore, is one with a sound substructure as well as a sound superstructure. In a major earthquake situation, it is very important to understand the behavior of the entire structure as an integrated whole consisting of the superstructure and the substructure.

Most visible damage is observed on the superstructure. Yet it is very possible for the substructure to suffer invisible damage that is then the cause of visible damage on the superstructure. Taking this view, the investigation reported here focused on the damage suffered by foundations of structures, together with the aim of learning what damage the ground surrounding the foundations suffered — liquefaction or lateral flow of ground, for example. The intention is to reveal the causes of damage as deduced from a geotechnical engineering viewpoint, thereby contributing to future detailed research. Due to time and geographical constraints, the investigation was confined to waterfront structures (road bridges) on reclaimed land only. This type of area was selected since the geotechnical conditions of such landfill sites can be expected to result in numerous problems in terms of geotechnical engineering.

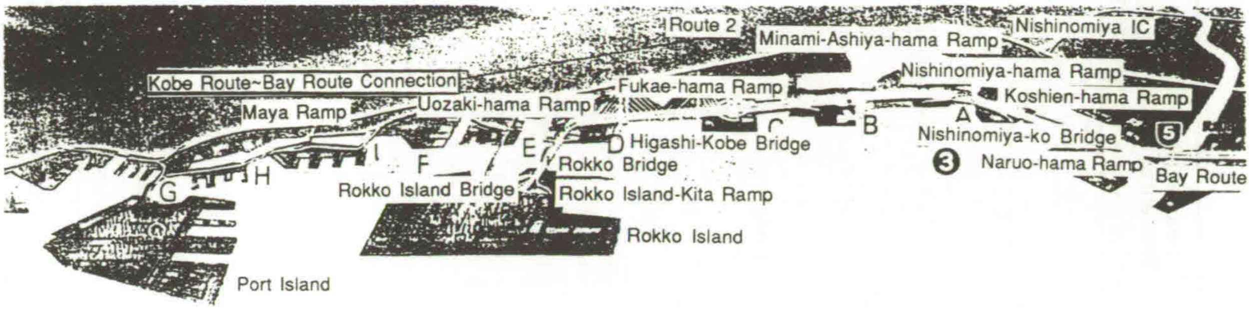


Fig. 1 Map of bridges covered by the investigation

2. INVESTIGATION COVERAGE

The investigation covered the following bridges:

Hanshin Expressway Bay Route:

A. Nishinomiya-ko Bridge
B. Shin-Shukugawa Bridge
C. Shin-Ashiyagawa Bridge
D. Higashi-Kobe Bridge
E. Rokko Island Bridge

Connecting bridges to man-made islands:

F. Rokko Bridge
G. Kobe Bridge

Harbor Highway:

H. Maya Bridge and Second Maya Bridge
I. Nadahama Bridge

The investigation also covered elevated approach spans to these bridges. The map in Fig. 1 shows the bridges covered by this investigation. All these bridges cross waterways between reclaimed lands, and so are referred to as "waterfront structures."

3. DAMAGE TO WATERFRONT STRUCTURES AND ITS CAUSE

Table 1 lists the damage to each bridge investigated and also details liquefaction of the surrounding ground, distance from revetment to bridge pier, and damage to the revetment. It is clear from the table that damage to bridge beams was concentrated on the supports. Some beams moved in the direction of the bridge axis and others in the direction perpendicular to the bridge axis. Some bridge piers had visibly moved laterally, settled,

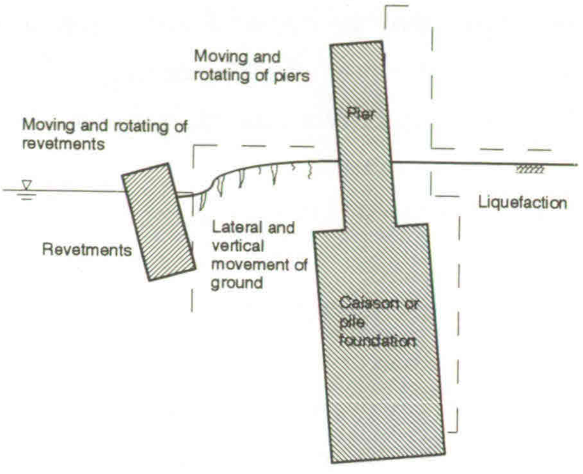
Table 1 List of bridges covered by the investigation and their damage

Investigation point	Damage	Liquefaction of surrounding ground	Distance from revetment to bridge pier	Collapse of nearby revetment
A. Nishinomiya-ko Bridge (Koshien-hama)	Fall of girder connecting to end	△	△	△
A. Nishinomiya-ko Bridge (Nishinomiya-hama)	Damage to support	○	△	△
B. Shin-Shukugawa Bridge (Nishinomiya-hama)	Damage to support; tilting of bridge pier	△	○	△
B. Shin-Shukugawa Bridge (Ashiya-hama)	Damage to support	△	○	△
C. Shin-Ashiyagawa Bridge (Ashiya-hama)	Damage of support; tilting of bridge pier	○	×	△
C. Shin-Ashiyagawa Bridge (Fukae-hama)		△	Under sea	○
D. Higashi-Kobe Bridge (Fukae-hama)		△	○	○
D. Higashi-Kobe Bridge (Uozaki-hama)	Damage to support	○	Under sea	○
E. Elevated bridges behind Rokko Island Bridge (Uozaki-hama)	Damage to support	△	○	△
E. Elevated bridges behind Rokko Island Bridge (Rokko Island)	Damage to support	△	○	○
F. Rokko Liner elevated bridges behind Rokko Island Bridge (Rokko Island)	Fall of girder; tilting of bridge pier	○	○	○
G. Kobe Bridge (Kobe Port)	Movement and damage to support	×	○	○
G. Elevated bridges behind Kobe Bridge (Kobe Port)	Damage to support; damage, subsidence, and tilting of bridge pier	○	×	—
G. Kobe Bridge (Port Island)		○	○	○
H. Maya Bridge (Ono-hama)	Damage to support; tilting and movement of girder	△	○	○
H. Second Maya Bridge (Ono-hama)	Damage to bridge pier	△	○	○
H. Maya Bridge (Maya Pier)	Damage to support; tilting and movement of girder	○	○	○
H. Second Maya Bridge (Maya Pier)	Damage and movement of bridge pier	○	○	○
H. Elevated bridges behind Second Maya Bridge (Maya Pier)	Movement of bridge pier in direction perpendicular to bridge axis	○	○	○
I. Nadahama Bridge (Maya Pier)	Movement of girder at end; damage to connection	○	Under sea	○
I. Nadahama Bridge (Nada-hama)	Movement of girder at end	○	Under sea	○

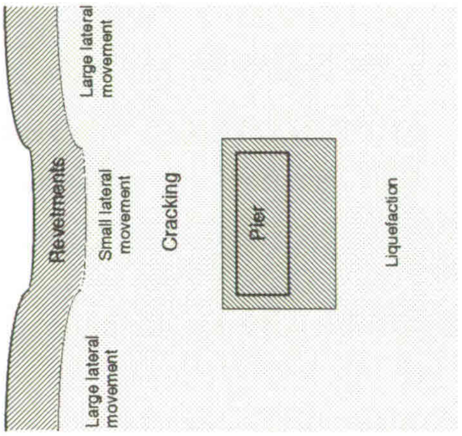
* 1. Liquefaction of surrounding ground: ○ → Significant ground subsidence, cracking, and sand spout traces visible; △ → Sand spout traces; × → No visible damage
2. Distance from revetment to bridge pier: ○ → Near revetment; △ → 30 to 40 m from revetment; × → more than 40 m from revetment; Under sea → situated in the water
3. Collapse of nearby revetment: ○ → Noticeable movement of revetment and ground cave-ins behind it; △ → Only movement of revetment.

or tilted out of vertical, and this may be the cause of these beam movements. Damage was also seen to be concentrated on waterfront structures, that is, elevated bridges crossing waterways. Some elevated bridges further away from the water were almost free of major damage aside from damage to their ramps. No damage was also observed in the case of bridges with piers in the water.

Figure 2 consists of schematic drawings of typical damage to the foundations of structures near the water. As indicated in Fig. 2-a), most revetments on landfill moved toward the sea and suffered settlement. The destruction of these revetments caused significant deformation of the ground behind them, and in some cases even cave-ins. Ground deformation typically took place in the range of 30 to 40 m from the revetment, and up to 70 to 80 m inland in some cases. In most of the cases investigated, cracks parallel to the revetments were observed. Large traces of sand spouting, caused by liquefaction, were found in inland areas, while there were almost none on the ground near the revetments. This does not imply, however, that responsibility for the collapse of the revetments does not lie with liquefaction. On this point, further investigations of the ground, or even on the seabed, will be necessary.



a) Cross section



b) Plan

Fig. 2 Schematic drawings of typical damage to waterfront structure foundations

When there was a structure just 20 to 30 m away from a revetment, the part of the revetment nearest the structure suffered somewhat less movement in the direction of the water. This is probably because the ground was prevented from moving by the structure foundations. This means, from the viewpoint of the foundation structure, that the foundation was subjected to lateral pressure from the ground as it flowed, and was possibly forced into a more severe condition for foundation deformation during the earthquake. A pile foundation put under such a situation is called a "passive pile during an earthquake," that is a pile subjected to lateral flow pressure during an earthquake (see Chapter 4, "Lateral Flow of Ground" published by the Japanese Society of Soil Mechanics and Foundation Engineering)

Based on an analytical study of the damage described above, the cause of lateral movement, settlement, or tilting of substructures followed by damage to waterfront structures may be deduced and categorized into the following three types from the viewpoint of geotechnical engineering:

(1) Synergy between the phenomena of liquefaction and lateral flow (due to collapse of the revetment)

(2) Only lateral flow phenomenon

(3) Others

Liquefaction may have reduced the lateral resistance of foundations. At the same time, settlement of the surrounding ground may have reduced vertical bearing capacity. As for lateral flow phenomenon, the pressure of the lateral flow when large, and the eccentric earth pressure where it is small, act on the foundation and aggravate the lateral deformation. Other causes of damage are the difference of foundation shape and the three-dimensional behavior of the structure as a whole.

4. FOUR DAMAGED WATERFRONT STRUCTURES

Four waterfront structures which suffered particularly serious damage are described below.

4.1 Nishinomiya-ko Bridge

Photo 1 shows Nishinomiya-ko Bridge. One of the girders carrying the main route onto the bridge fell at Koshien-hama where it connected with the bridge. Photos 2 and 3 show, respectively, the revetment in front of the bridge pier and the nearby conditions, and damage to the revetment. Compared with the area in

Photo 1 Collapse of girder of Nishinomiya-ko Bridge at the Koshien-hama

front of the pier, other sections of the revetment had moved considerably in the direction of the waterway. The entire revetment is deformed in a concave shape centered on the section just under the bridge axis (Photo 3 and Fig. 2) and the amount of concavity is about 70 to 80 cm.

Figure 3 shows the ground around the bridge pier. This pier is situated about 23 m away from the revetment. Numerous cracks parallel to the revetment are visible between the pier and the revetment. Some of these cracks have separated by up to 50 cm. Inland from the pier, numerous cracks can also be seen extending radially from the pier. Some of these are up to about 1 m wide and over 50 m long (Photo 4). There are no significant signs of liquefaction on the ground surface around the cracks. The type of cracks shown in Fig. 3 radiating from the bridge pier would usually be expected to occur if the pier moves landward (eastward, or toward Osaka) or the ground moves toward the waterway (westward, or toward Kobe). Considering the way the girder fell, it is likely that the latter is the case.

Photo 2 Revetment in front of bridge pier and nearby conditions

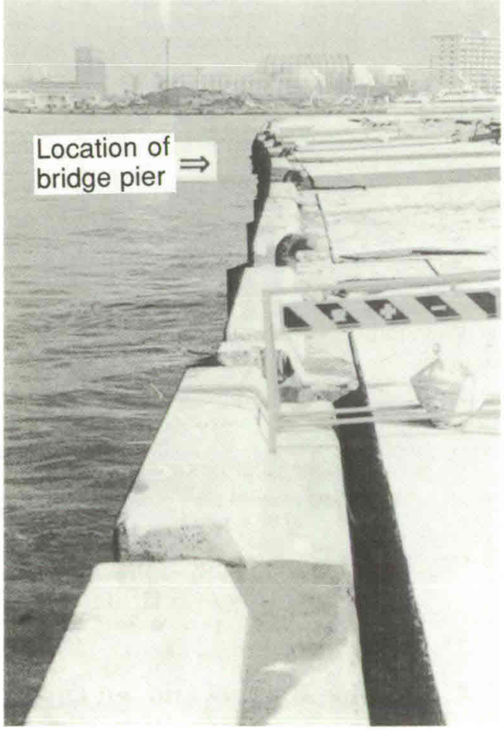


Photo 3 Damage to revetment

4.2 Shin-Shukugawa Bridge (Nishinomiya-hama)

Photo 5 shows a pier of the Shin-Shukugawa Bridge on the Nishinomiya-hama side. The pier is tilted toward the waterway, which cannot be seen in the photograph but is located at the left of this frame. Photo 6 shows the top of the pier and its connection to the girders. The girder remains barely balanced on the edge of the pier, avoiding collapse. The support is damaged and there is a difference in level with the neighboring girders.

Photo 7 shows the ground between the revetment and the pier. The ground in front of the pier slid toward the waterway and caved in. There were no noticeable sand spout traces in this area. It is therefore probable that this pier was pushed over, as the resistance of the foundation toward the waterway direction was reduced and also as the lateral flow pressure acted on the foundation due to the ground movement toward the waterway.

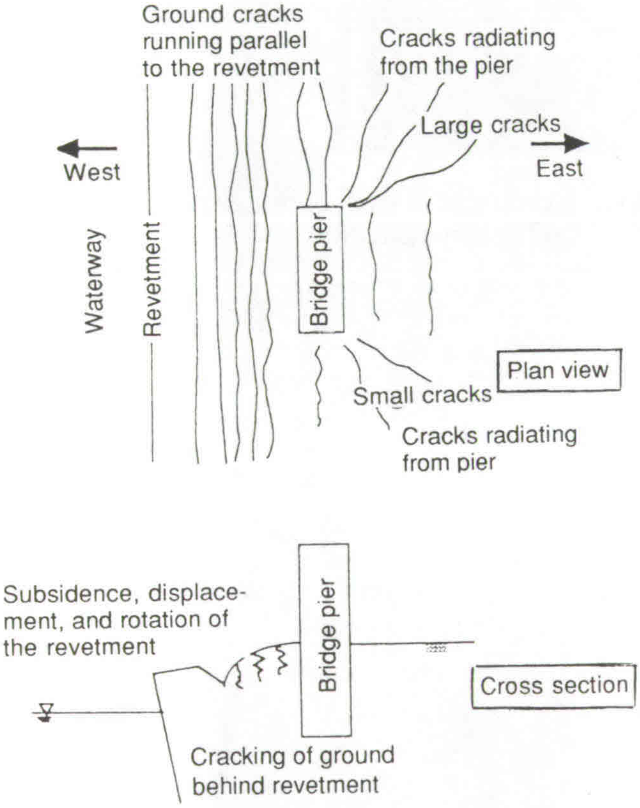


Fig. 3 Ground around a pier of the Nishinomiya-ko Bridge

Photo 4 Cracks radiating from bridge pier

4.3 Kobe Bridge and elevated approach span (No.4 Jetty, Kobe Port)

Photo 8 shows the support of the Kobe Bridge at the Kobe side. The abutment moved about 60 cm toward the waterway. Except adjacent to the bridge abutment, the jetty edge revetment moved 1.5 to 2 m in the waterway direction and also subsided by 1 to 1.5 m (Photo 9). The revetment behind the abutment has caved-in extensively (Photo 10). Judging from this situation, it seems that lateral flow pressure due to collapse of the jetty is responsible for the movement of the abutment. The displacement of the bearing, however, was probably partly attributable to movement of the abutment at the Port Island side. There were no sand spout traces on the ground near the abutment.

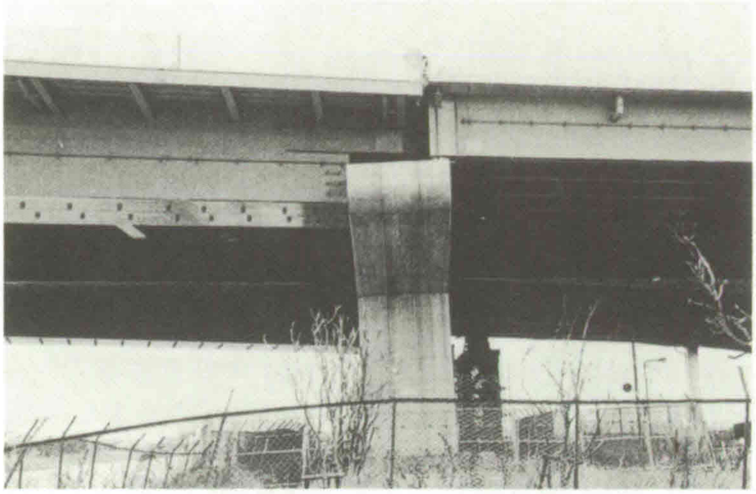


Photo 5 Pier of the Shin-Shukugawa Bridge at Nishinomiya-hama

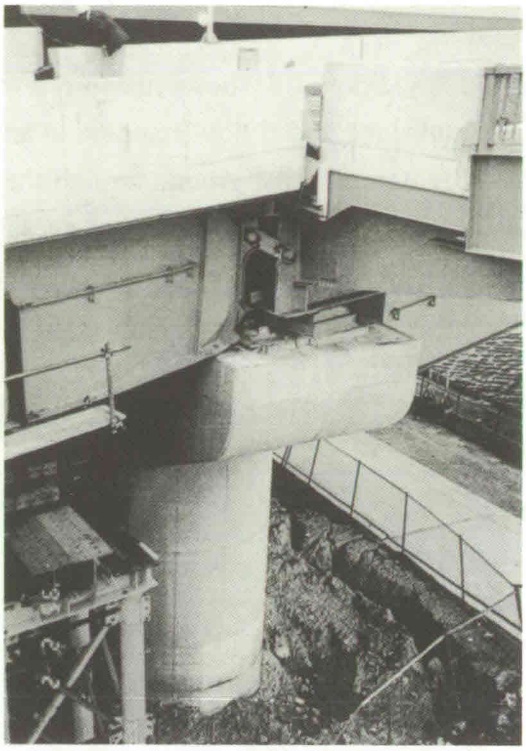


Photo 6 Connection between bridge pier and girders

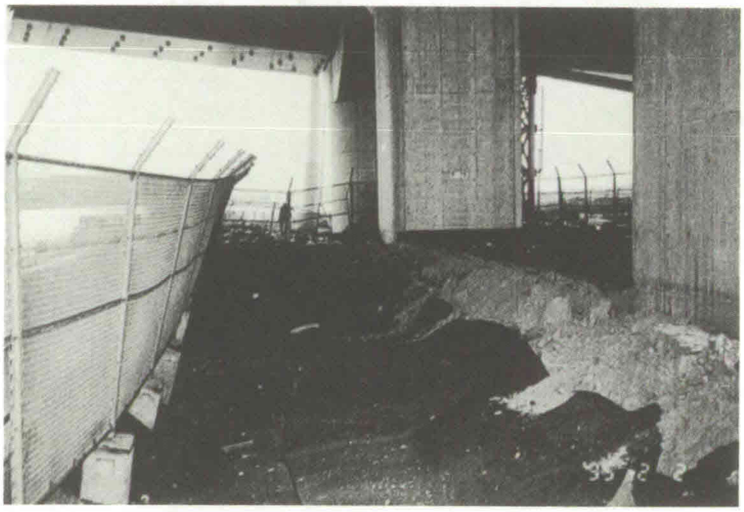
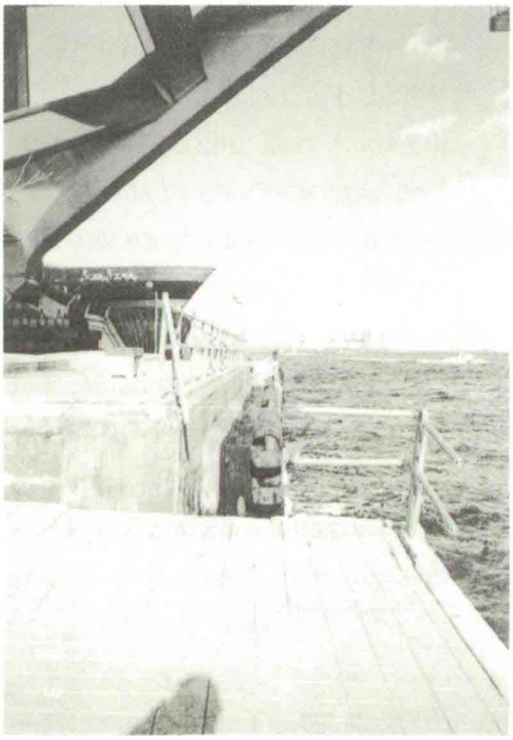


Photo 7 Ground between revetment and bridge pier



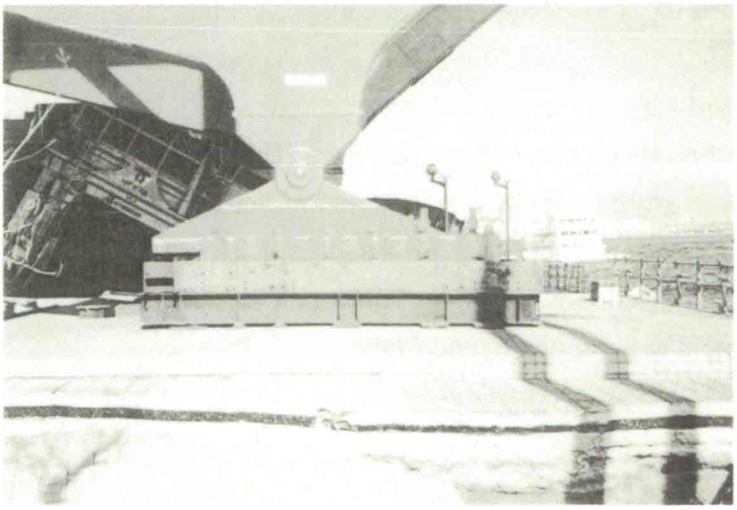


Photo 8 Support of the Kobe Bridge at Kobe side

Photo 9 Damage to revetment at foot of the jetty

Photo 11 shows the piers of the elevated approach span. The right-hand pier subsided and is now standing at an angle. Sand spouts resulting from liquefaction are in evidence on the ground around the foot of the pier. Most piers supporting this approach span subsided to some extent, probably as a result of loss of vertical bearing capacity when the ground liquefied, because these piers have spread foundations.

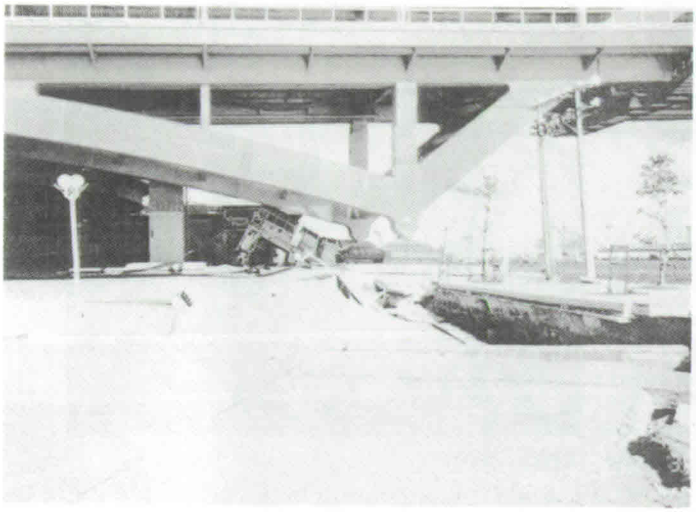


Photo 10 Damage to ground behind the abutment of the Kobe Bridge (Kobe side)

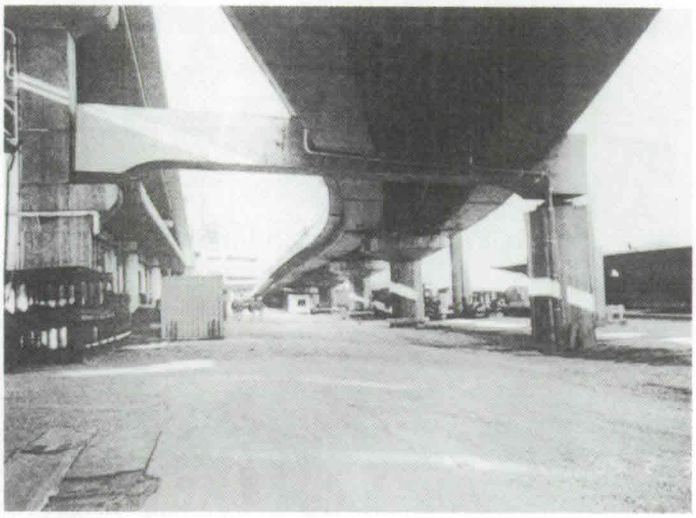


Photo 11 Piers of the elevated approach span connecting to the Kobe Bridge

4.4 Second Maya Bridge and elevated approach span

The Maya Bridge and its approach span cross the mid-part of the west jetty at Maya Wharf. Parallel to the bridge, the Second Maya Bridge and its approach span are located to the south (sea side). Toward the north of the wharf (inland side) there is an area of landscaping. Photo 12 shows the end of the jetty as seen from the foot of the south side of the jetty. The jetty revetment moved toward the sea. Some sections collapsed (Photo 13) and a footing of the elevated approach span to the Second Maya Bridge is exposed. This exposure reaches the head of the pile (Photo 14).

The reinforced concrete piers supporting the Second Maya Bridge at the end of the jetty are badly damaged (Photo 13). The elevated approach span standing on the jetty moved landward (north) relative to the wharf. This is either because the girder itself moved landward under seismic forces or the footing moved seaward (south) due to the lateral flow pressure on the foundation when the revetment at the southern end of the jetty collapsed.

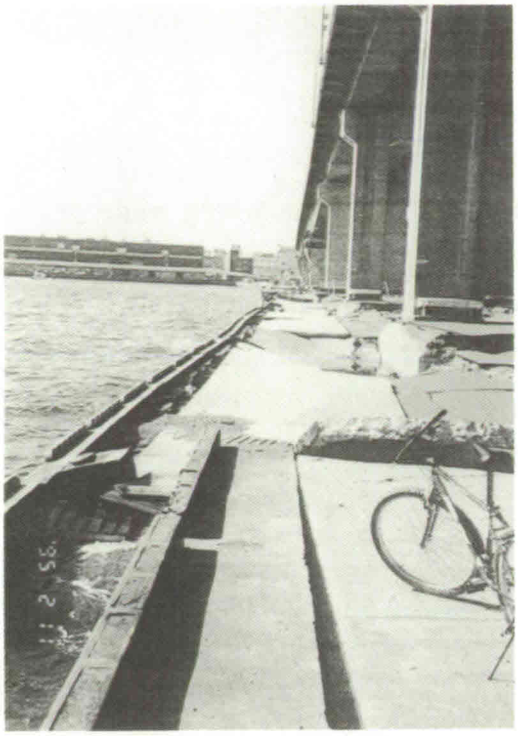


Photo 12 Collapse of southern revetment of the jetty

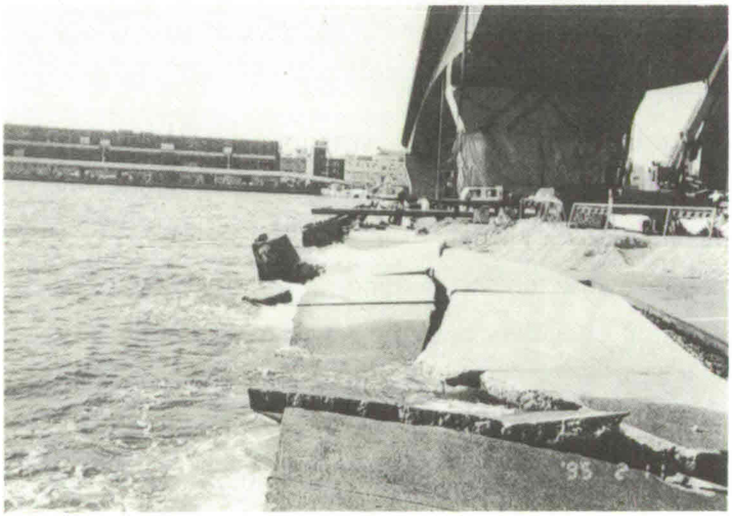


Photo 13 Collapse of revetment of the jetty

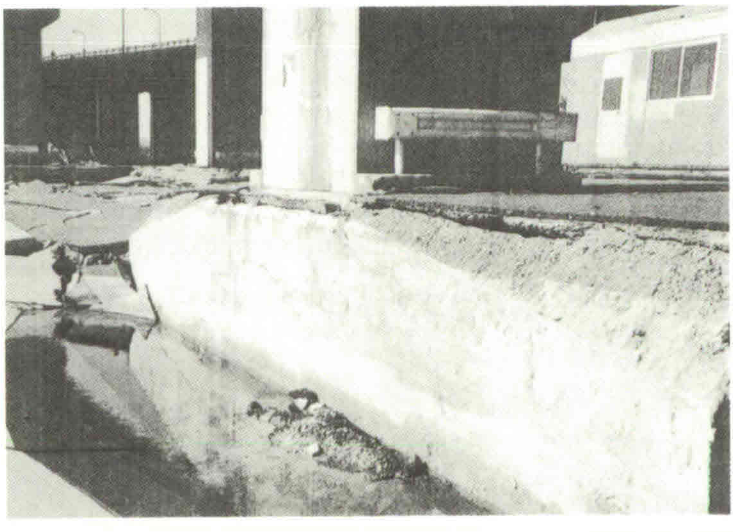


Photo 14 Foundation of elevated approach span connecting to the Second Maya Bridge

5. SUMMARY AND FUTURE TASKS

This investigation focused on foundations of waterfront structures which were constructed on landfill, and the damage to such structures and the ground around them was studied. In the visual observations, some bridge piers were found to have moved laterally, subsided, or tilted over. These foundations probably suffered some damage. The cause of this damage was deduced from the viewpoint of geotechnical engineering. As a result, it is concluded that the phenomena of liquefaction and lateral flow of the ground played a major role.

To conclude, a number of technical problems related to the investigation are summarized as follows:

(1) There is a need to check the soundness of foundations, both in the case of structures which were clearly damaged as well as where damage is not visible. It is also necessary to analyze the ground conditions and the types of foundations, relating to the damage. Based on such comprehensive investigations, repair methods and aseismic design methods should be established in the future.

(2) It is necessary to consider the positional relationship between a structure and nearby revetments in planning and designing a waterfront structure. To be specific, it seems recommendable to construct a structure either on the inland at some sufficient distance from a revetment or in the water. Where a structure must stand on ground near a revetment, a systematic design method that considers both the foundation and the revetment is necessary.

(3) As for the systematic design method mentioned above, when pile foundations are used, a design method which takes into account lateral flow pressure during earthquake can be applied, such as the "passive pile during an earthquake." In the case of caisson foundations, conventional design methods take no account of lateral flow pressure. This must be remedied in the future.

(4) As for fail-safe design and the need to maintain lifeline facilities in an emergency, nothing could be less acceptable than the falling down of bridge girders. The issue to be considered in the future is how to draw up a consistent method of aseismic design for a whole structure comprising a superstructure and a substructure (foundation).

Ground Damage due to the Great Hanshin Earthquake

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1. INTRODUCTION

The Great Hanshin Earthquake, which occurred at dawn on January 17, 1995, did severe damage to various civil engineering structures and urban facilities. In addition, severe damage was caused to various soil structures. This report is a summary of the observed damages to reclaimed lands, man-made islands, man-made lands, steep hillsides, railway cuts and embankments, and river and reservoir embankments. The observations were made during an investigation conducted between February 1 and 3, 1995, by the Third Investigation Group in charge of ground damage.

2. SUMMARY OF INVESTIGATION

The locations investigated include five in Kobe, two in Ashiya, two in Nishinomiya, and three in Osaka. Figure-1 shows a map of these locations and Table-1 classifies them according to the type of facility observed.

Table-1 List of Investigated Locations

Classification	Legend	Location
Reclaimed lands, man-made islands	I-1	Port Island, Kobe
	I-2	Osaka Hokko Yacht Harbor
	I-3	Tenpozan mound, Minato-ku, Osaka
Man-made lands, steep hillsides	H-1	Okamoto 6-chome, Higashinada-ku, Kobe
	H-2	Nishi-okamoto 7-come, Higashinada-ku, Kobe
	H-3	Nikawa-yurino-cho, Nishinomiya
Railway cuts and embankments	R-1	JR Kobe Line (Tokaido Line) Okamoto 3-chome, Higashinada-ku, Kobe (About 360 m from Settumotoyama station in the direction of Sumiyoshi station)
	R-2	West of Ishiyagawa station, Hanshin Railway Line, Mikage-cho, Higashinada-ku, Kobe
	R-3	Hankyu Railway Kobe Line, Iwazono-cho, Ashiya (About 1 km from Shukugawa station in the direction of Ashiyagawa)
	RL-1	JR Kobe Line (Tokaido Line) Ashiyagawa tunnel, Narihira-cho, Ashiya
River and reservoir embankments	L-1	Shinyodogawa river embankment, Konohana-ku and Nishoyodogawa-ku, Osaka
	RL-1	JR Kobe Line (Tokaido Line) Ashiyagawa tunnel, Narihira-cho, Ashiya
	L-2	Niteko pond embankment, Manjiya-cho, Nishinomiya

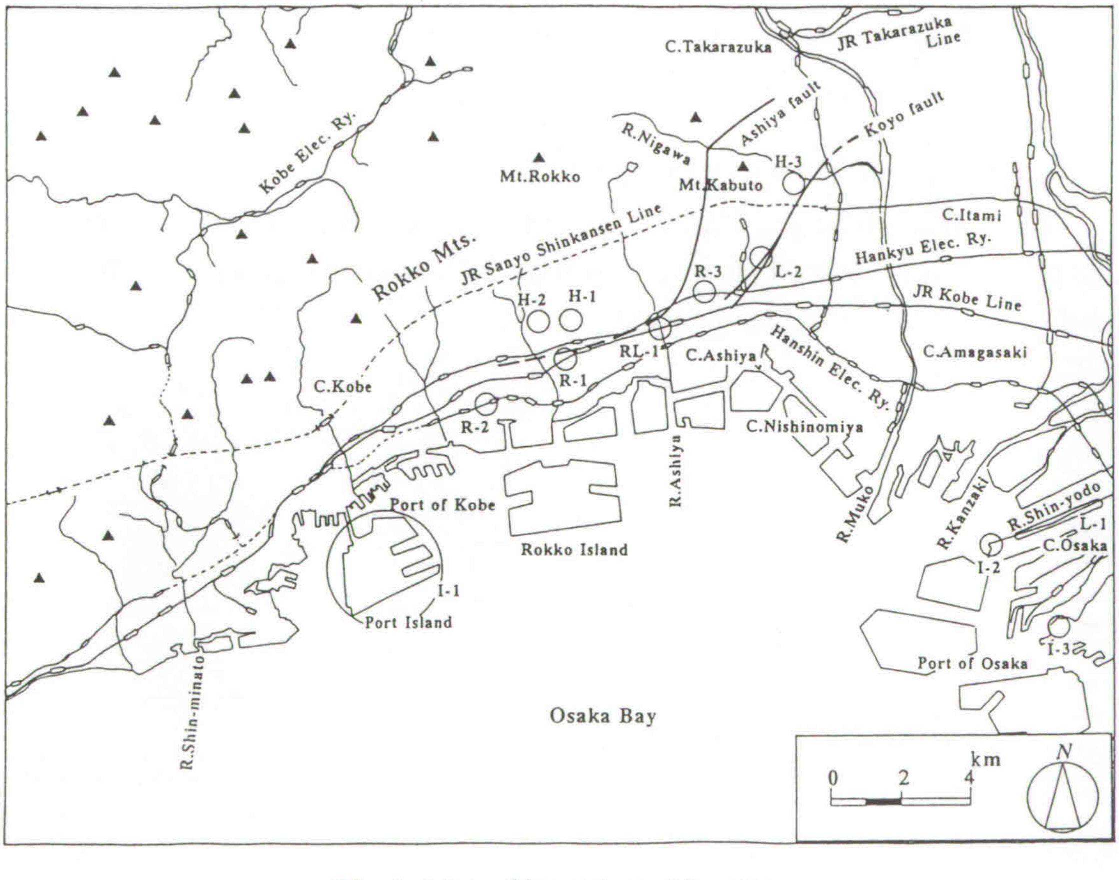

Fig. 1 Map of investigated locations

3. DAMAGE TO RECLAIMED LAND AND MAN-MADE ISLANDS

The investigation focused on examining the differences in damage due to liquefaction with respect to the different methods of soil improvement applied.

3.1 Port Island

As reported by the media, as well as in the First and Second Ground Disaster Investigation Reports, Port Island suffered widespread liquefaction, and severe damage was caused to gravity-type quay walls by displacement and settlement.

Figure 2 shows places where soil improvement work had been carried out on the island. The investigation concentrated mainly on the north side of the island, where the traces of liquefaction in the warehouse and container berth area were very clear. Among areas of liquefaction alongside roads, sand boiling was very pronounced on vegetation strips because road surfaces were covered by asphalt. On the landward side of gravity-type quay walls, gaps had opened up, and gravel and stones of up to about 50 cm in size, which formed the base of the quay walls, had erupted in great quantities, reflecting the incredible pore water pressure that had built up during liquefaction (Photo 1). The whole island settled somewhat due to liquefaction, so structures built on piles now look as though they are floating (Photo 2).

According to the accounts of island residents, the sand boiling continued for about an hour after the earthquake.

As shown in Fig. 2, soil improvement works such as rod compaction and sand drain methods were implemented in the central part of the island. In areas where such improvement works had been carried out, there was little hindrance to the normal use of facilities after the earthquake, although some road surfaces had cracked and there was some settlement as a result of the seismic motion. Thus, in such areas, the damage as a whole was insignificant compared with that to the harbor facilities on the periphery of the island. The effectiveness of the rod compaction work on areas where it had been used was particularly striking. Also noteworthy is that in areas where sand drains were used, liquefaction was less severe, although this is not particularly known as a technique to counter liquefaction.

Almost all quay walls were displaced in the direction of the sea and had settled or tilted. An examination of their aseismicity is necessary.

Photo 1 Traces of sand boiling on Port Island

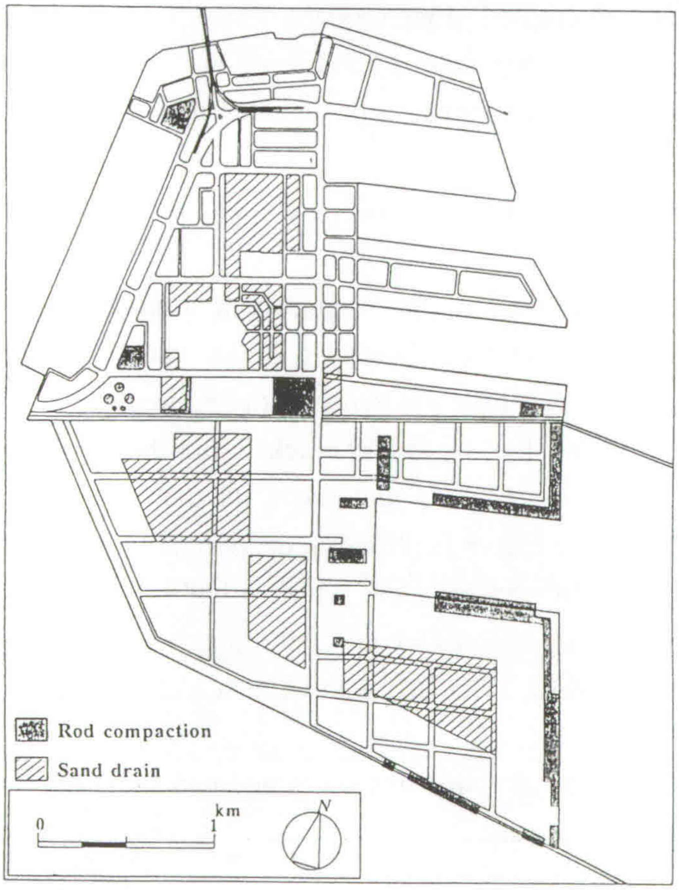

Fig. 2 Map of Port Island

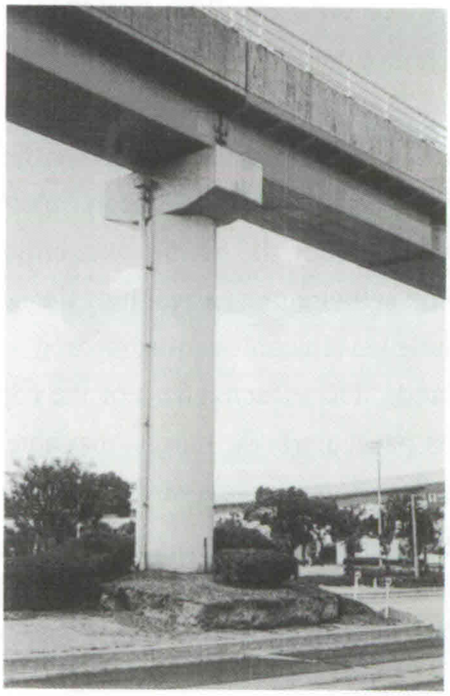

Photo 2 Quasi-floating pier
after ground settlement

3.2 Osaka Hokko Yacht Harbor

This facility is located in the mouth of the Shinyodogawa river. The ground at this location had been improved by means of the sand compaction method. The harbor escaped serious damage, despite problems of liquefaction of the embankment between 1 and 3 kms upstream. The countermeasure appears to have been effective.

3.3 Tenpozan Mound

Tenpozan is a small man-made hill rising about 10 m above its surroundings; a tract of land on its periphery constitutes a park. A landslide was witnessed on the south-facing slope of this man-made hill, with the result that a steep cliff now remains (Photo 3). Traces of sand boiling and settlement can be seen at the center of this sliding soil mass and around the periphery. This proves almost certainly that the landslide was caused by liquefaction. Since nothing unusual whatsoever was noted on the roads and in the vicinity, only the cause of liquefaction that occurred in the park needs to be further investigated.

Photo 3 Landslide at Tenpozan mound

4. DAMAGE TO MAN-MADE LAND AND STEEP HILLSIDES

The plain on which Kobe is built consists of a narrow band of land on which houses stretch from the coast back to the lower slopes of the Rokko mountains. Compared with previous disasters where areas developed for housing on the mountain slopes suffered severe damage, the damage resulting from the Hanshin earthquake was relatively slight.

4.1 Okamoto 6-chome

Collapse of this access road and its sprayed concrete embankment was observed.

The collapse of the access road was of a type often seen in other earthquake disasters; some of the earth filling on which the road was constructed — which had been cut back on the side toward the slope and packed down to form the required roadbed — had crumpled downward (Photo 4). Since this is a common form of earthquake damage, it is necessary to find ways to make this type of cut and fill monolithic. Furthermore,

Photo 4　Collapsed fill at Okamoto 6-chome

Photo 5　Collapsed sprayed concrete

Photo 6　Collapsed embankment at Nishi-okamoto 7-chome

where concrete had been sprayed on embankments, splitting and tearing of concrete had occurred widely (Photo 5). Although this sprayedconcrete was clearly designed to prevent the collapse of decomposed granite slopes, the measure failed to be effective against this earthquake.

4.2 Nishiokamoto 7-chome

A road built along a steep slope had collapsed over a width of about 10 m and a length of about 100 m (Photo 6), and countless cracks were visible on the road surface. The portion that had collapsed, as in the case of Okamoto 6-chome, consisted mostly of a section where the roadbed was partly on filled ground and partly on natural ground. The hillside at this point is very steep. As Photo 6 shows, because sliding had occurred along other points on the slope, restoring the site to its original layout will be difficult. However, some measure to prevent further collapse will have to be taken prior to the rainy season.

4.3 Nikawa-yurino-cho

This is where the greatest death toll occurred at one location as a result of the earthquake; more than thirty people died when a slope failed (Photo 7). The slope that failed is on the right bank of the Nikawa river, and judging from the remains, the original gradient may have been gentle at around 15-20 degrees. At the upper part of the failed slope, there is a water purification plant operated by the Hanshin Waterworks Corporation, and the residential area had stretched down along the Nikawa valley to the toe of the slope.

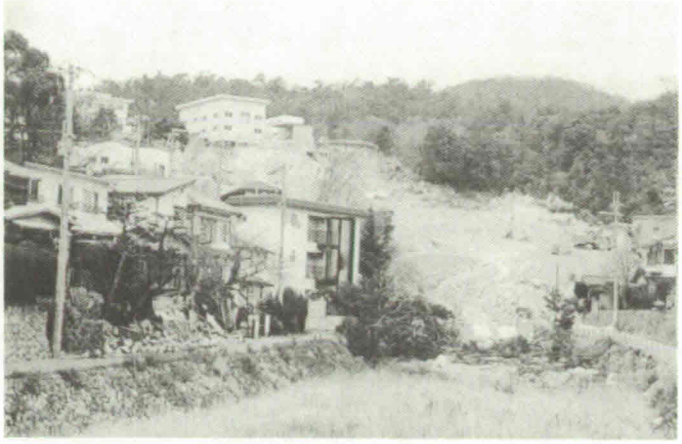

Photo 7 Overall view of slope failure at Nikawa

According to a topographical map (Fig. 3), there was a stone-lined creek running across the now failed slope. Furthermore, since the area around the Uegahara Water Purification Station was depicted as a marsh in a topographical map from a 1932 survey, the conclusion reached is that the groundwater level near this slope was quite high.

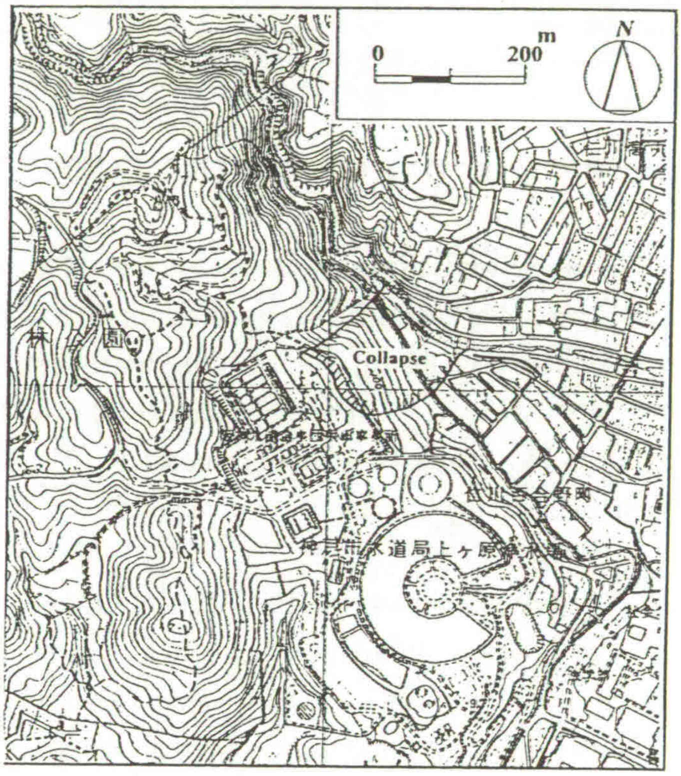

Fig. 3 Topography in neighborhood of slide location at Nikawa [taken from topographical map (1/10,000 scale) by the National Geographic Agency]

Photo 8 Collapse of fill near Settsumotoyama station

The geology of the failed area consists of the Osaka Layer group of sedimentary deposits overlying Rokko Granite;

with gravel, sand and non-marine clay layers from bottom to top, respectively. Additionally, the site is located several hundred meters northwest of the Koyo fault, which is said to have moved when this earthquake occurred (Fig. 1). The slope failure was approximately in the north-east direction which is thought to have been the direction of the fault displacement. This resulted in large accelerations in the direction in which the slope moved.

Since the failure occurred because of apparently complex interactions between different factors, more detailed investigations are clearly necessary to explain the failure mechanism.

5. DAMAGE TO RAILWAY FILLS AND CUTS

5.1 Near Settumotoyama Station, JR Kobe Line (Tokaido Line)

The embankment fill was about 5 m high at this point, and although the masonry wall holding back the fill had failed, the track was not affected and damage was relatively insignificant (Photo 8). The embankment fill was of decomposed granite soil, which was found to have been very well compacted. The failure happened in the embankment itself, and nothing unusual was noticed on the ground surface.

5.2 West of Ishiyagawa Station, Hanshin Line

In this case, the fill was held back by a vertical concrete wall, the upper part of which was forced open on both sides. The wall had overturned, leading to sliding ruptures within the fill, and as a consequence the track had failed together with the fill (Photo 9). This type of failure could have been prevented if the upper parts of the two vertical concrete walls had been connected. It is hoped that a construction method in which connections are made with tie rods or anchors will be used in the future.

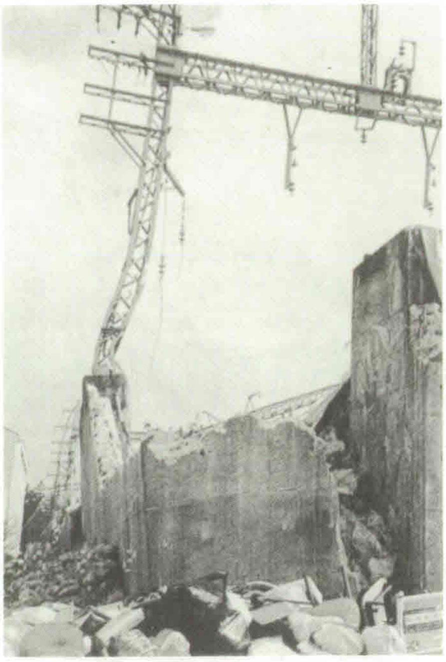

Photo 9 Collapse of fill at Ishiyagawa station

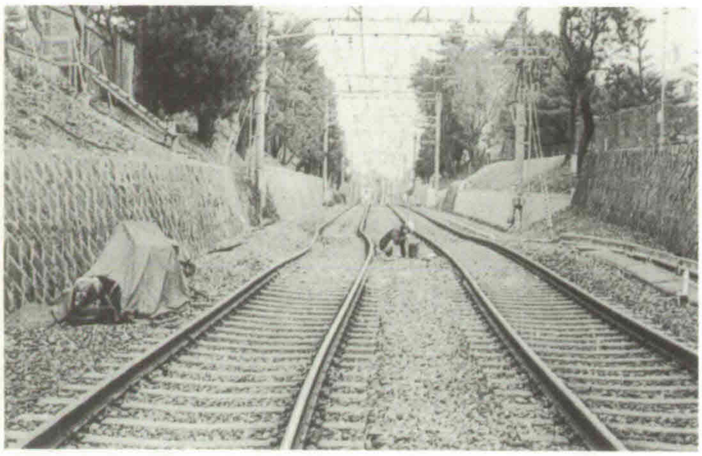

Photo 10 Landslide at Iwazono-cho

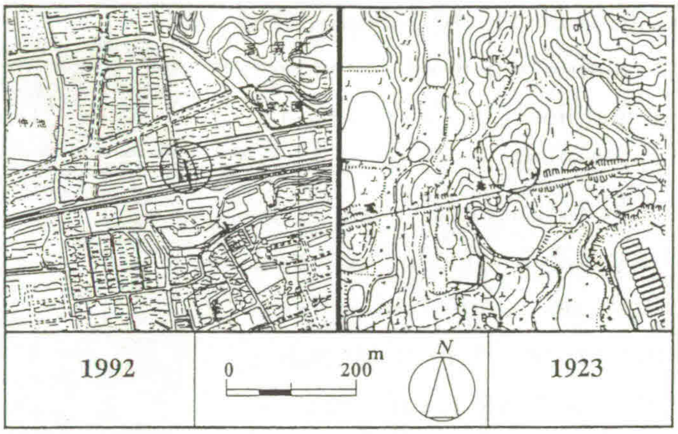

Fig. 4 Relationship between landslide site at Iwazono-cho and old topography [taken from topographic map (1/10,000 scale) of the National Geographic Agency]

5.3 Along Hankyu Kobe Line, Ashiya City

The line is located on a gentle slope in a residential area, and slides occurred in the direction of the cuts. In the cut, ground heaving, which caused the track to twist, was evident. Ground heaving at two locations was witnessed on the toe of the sliding surface (Photo 10). Since a topographical map of 1923 indicates that this area was once a valley before being developed into a residential area (Fig. 4), the slide is likely to have been caused by the former topography.

5.4 Ashiyagawa Tunnel, JR Kobe Line (Tokaido Line)

The slope of the cut near the portal of this tunnel, which takes the line under the Ashiyagawa river (Tenjyogawa river), is 10 m in height and has an angle of about 60°. It was spared damage apparently because the geology of this location consists of sedimentary alluvial deposits which made it able to withstand the severe seismic motion.

6. DAMAGE TO RIVER AND RESERVOIR EMBANKMENTS

6.1 Embankment of Shinyodo River

Over 1.8 km of the left bank and about 200 m of the right bank were damaged (Photo 11). Many traces of sand boiling were visible at the edges of the embankment, suggesting that the embankment body collapsed due to sliding when its foundation ground liquefied. Under the left bank there is a sand stratum over 12 m in thickness with an N-value of 2-3, while the right bank stands on a thin, uniform sand stratum over 3 m in thickness with an N-value of about 4. Liquefaction must almost certainly have occurred in these strata. Although sliding of the outer side of the embankment had occurred in many places, at one point where the flood plain is toward the left bank and there are wave dissipation blocks on the inside of the right bank, the embankments had slid inward, causing damage to houses near the river, including tilting, cracking, etc.

Since residential land may extend to the brink of river embankments in urban areas, this type of inward sliding of the river

Photo 11 Shinyodogawa river embankment damage

Photo 12 Damage to the Niteko pond embankment

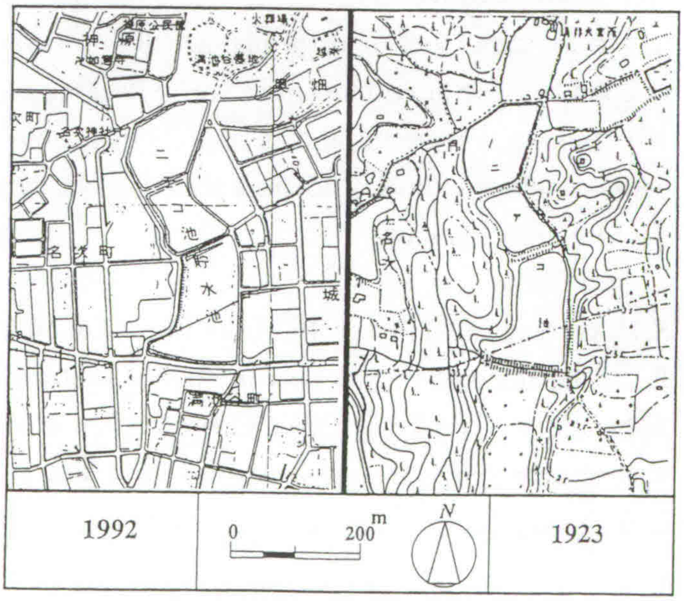

Fig. 5 Former topography near the Niteko pond [taken from topographic map (1/10,000 scale) of the National Geographic Agency]

banks can cause a great deal of damage. In such situations, soil improvement measures including measures against liquefaction of the foundation ground appear necessary.

6.2 Ashiyagawa Tunnel, JR Kobe Line (Tokaido Line)

At the point where the JR Kobe Line passes under the Ashiyagawa river, the river bed is above the level of the surrounding ground and damage was caused to the joint between the revetment and an overbridge crossing the Ashiyagawa river. Details could not be ascertained because the joint had already been removed at the time of the investigation. The cause is thought to be in the difference in vibration modes of the brick construction of the revetment and the concrete construction of the overbridge.

6.3 Niteko Pond Embankment

The Niteko pond actually consists of three ponds divided by internal partitions. The pond revetment on the north-east side and the two banks forming the internal partitions had failed (Photo 12). Both this revetment and the banks were built with decomposed granite soil, and they had failed by crumbling. Traces of soil indicate that liquefaction had taken place in the decomposed granite soil. The failure is assumed to have been induced by liquefaction of the base of the embankment below water level. Further, a topographical map of 1923 (Fig. 5) shows that there were previously many valley-like configurations opening out toward the north-east side of the pond. Therefore, the likely cause of the overall failure in the north-east is the former topography.

7. SUMMARY AND CONCLUDING REMARKS

1) Reclaimed Land and Man-made Islands

The variation in the degree of damage due to liquefaction was quite remarkable; there was little damage where soil improvement works had been done, while great damage was evident where no improvement had taken place. The effect of such improvement work was very clear.

2) Man-made Land and Steep Hillsides

Where land has been developed for residential purposes, many slopes had failed at the boundary between the fill and natural slope. There is a need to make these parts monolithic. In many cases it will prove difficult to restore damaged locations to their former state, but urgent action is necessary to make them safe through the rainy season.

Where a major collapse took place in Nikawa-yurino-cho, it is necessary to elucidate the detailed mechanism of the collapse and to examine the relationship between this mechanism and fault behavior.

3) Railway Cuts and Embankments

A common failure mode in vertical embankment walls was one in which the upper part of such walls opened up on both sides. The development of a construction technique is hoped for in which the upper sections of these walls will be connected using tie rods or anchors.

In many places where the slope was gentle, the cause of failure was probably the topography of the area before being developed.

4) River and Reservoir Embankments

Where river and reservoir embankments had been damaged, one of the main causes was liquefaction. There is a need for improvement of the foundation ground for embankments, including measures to secure the structures against liquefaction.

In conclusion, a significant amount of ground damage took place along a northeast-southwest line from Nikawa-yurino-cho to the JR Ashiyagawa tunnel. This damage took place along the Koyo fault, which is thought to have been displaced sideways to the right. The weaker sections of the originally natural topography are assumed to have failed when this fault moved.

The Kobe area stands on many alluvial fans, and there used to be a large number of irrigation reservoirs on this alluvial material to cope with local water shortages. As urbanization has progressed, however, most of these irrigation reservoirs have been filled. This abundance of reclaimed land is now thought to have been a major contributory factor to the scale of the disaster caused by the Great Hanshin Earthquake. It is important that civil engineering and architectural structures in an area like this be designed as a system which includes the ground. A "ground" disaster might be defined as a situation where phenomena related to the ground itself damage human life, property, or social activities. To mitigate such disasters, we must work to bring city, social, and scientific policies together.

Report by the River Damage Survey Group

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1. OUTLINE OF DAMAGE

The Great Hanshin Earthquake did a great deal of damage to the embankments of rivers flowing through the alluvial areas of Hyogo and Osaka Prefectures within a 10 km range of Osaka Bay. Serious damage was concentrated on embankments constructed on weak ground consisting of alluvial deposits, the newest stratum formed during the past 20,000 years.

Figure 1 shows that major embankment reaches of this damage type totalled 13 locations along seven rivers — the Yodo, Shorenji, Ina, Mogawa, Kanzaki, Samondo, and Nakajima Rivers. The forms and degrees of damage in these locations differed according to the intensity of the earthquake motion, the ground state, and the embankment structure. Particularly serious damage was witnessed in embankments constructed on weak ground to protect against high tides in the tidal reach of the Yodo River. The embankments of the Muko and Sumiyoshi Rivers (inside Kobe) near the focus of the earthquake suffered damage such as cracking, settlement, sliding of the levee crown, and fissures of flood channel, but the embankment structures themselves did not collapse. As of the date of this survey (Feb. 1 to 3, 1995), seriously damaged reaches had already been temporarily repaired in preparation for the wet season.

2. DAMAGE SURVEYED

(1) Yodo River

The survey covered damaged sections needing repair in the river section under the jurisdiction of the Ministry of Construction of the Yodo River, which numbered 18. Three sections constructed to prevent tidal flooding, shown in Fig. 1 (① to ③), suffered particularly serious damage.

① Torishima district (left bank of the 0.2 km through 2.0 km point from the river mouth);

② Nishijima district (right bank of the 1.1 km through 1.9 km point from the river mouth); and

③ Takami district (left bank of the 2.5 km through 2.7 km point from the river mouth).

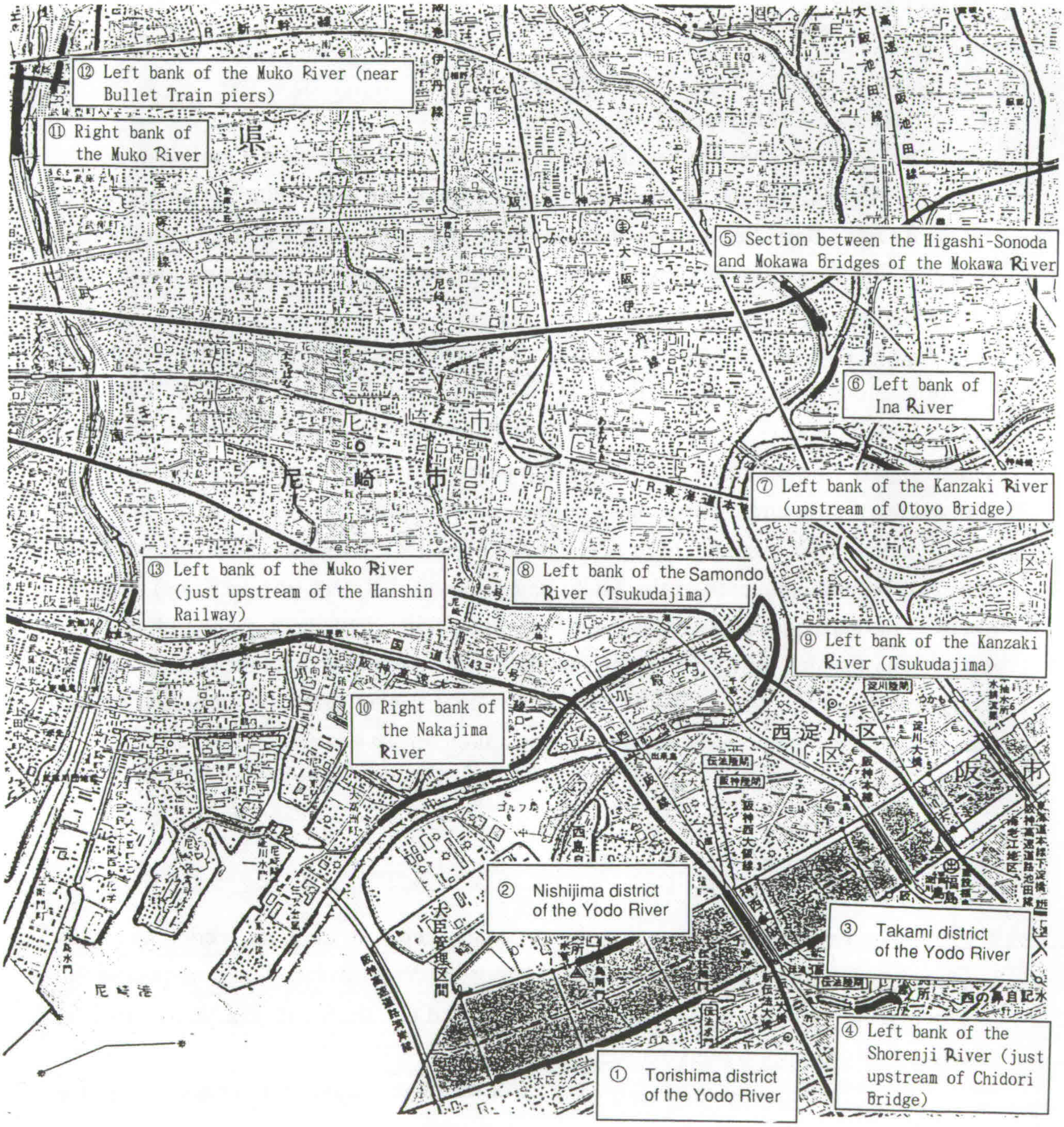


Fig. 1 Embankment sections suffering major damage in the earthquake (damaged sections indicated by thick lines)

1) Torishima district on the left bank of the Yodo River (Fig. 1 ①)

This area suffered greater embankment damage than any other. The embankment structure collapsed, settled, and broke open in many places, with swelling of the revetment, caused by liquefaction of the ground and lateral flows of soil inside the embankment (see Fig. 1 ①). The parapet suffered a maximum settlement of 3 m (see Fig. 2 and Photos 1 (a) and (c)). Here, the sand layer extends to a depth of about 10 m.

2) Nishijima district on the right bank of the Yodo River (Fig. 1 ②)

Large cracks appeared in the levee crown along its length, with swelling of the embankment on the landward side and collapse of the slope end (see Fig. 3 and Photo 2 (a)). Access to the Nishijima Gate was damaged from the levee crown to the rear slope of the dike (to protect against high tides), but the gate itself appeared to be undamaged. Since the weak ground in this area had been improved to prevent the Nishijima Gate from settlement, less damage was evident than in the Torishima district on the left bank of the river.

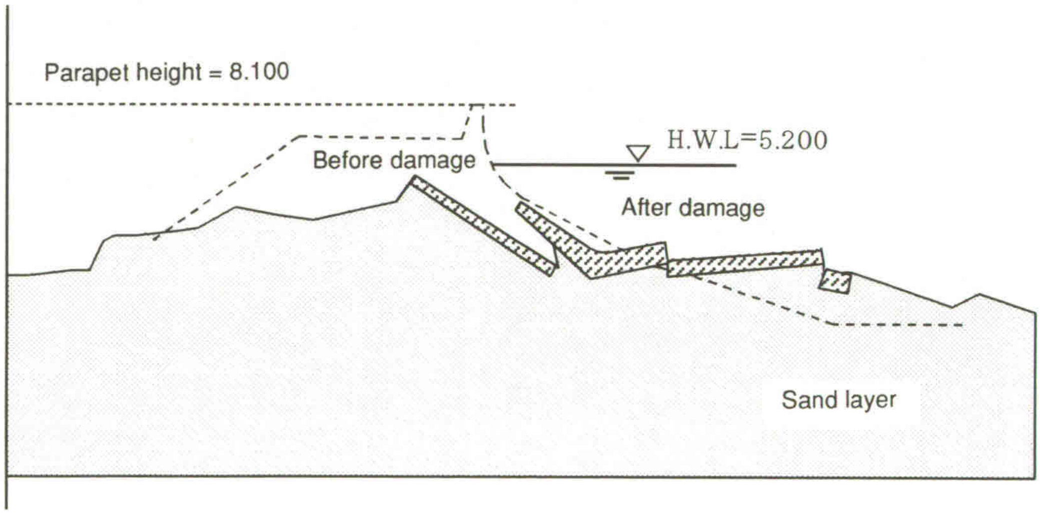
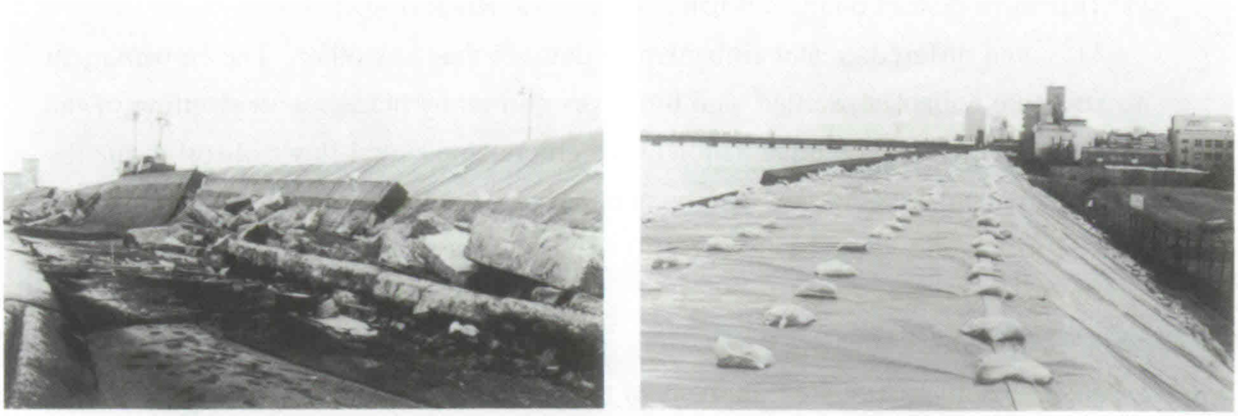


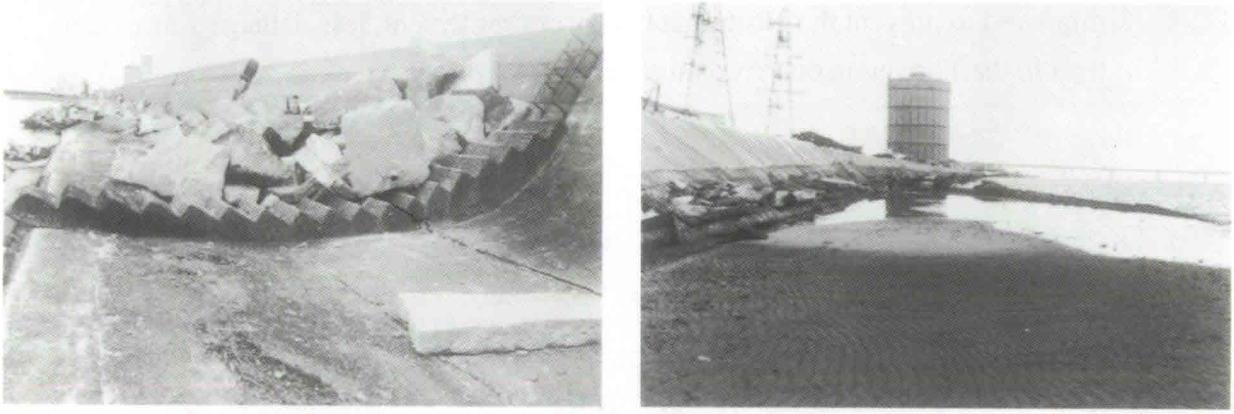
Fig. 2 Destruction of embankments in the Torishima district of the Yodo River (according to data from the Yodo River Work Office of the Ministry of Construction)



(a) Collapse of dike

(b) Emergency repair work

(The sheeting covers the section under emergency repair; the levee crown height is being restored to its level before damage (O.P. = 6.5 m).



(c) Collapse of dike

(d) Soil flowing out from embankment structure

(Soil within the embankment flowed laterally due to earthquake motion, with the parapet and the levee crown settling. At the point shown in Photo (d), the slope toe moved horizontally by a maximum of 20 m, accompanied by liquefaction of the ground.

Photo 1 Torishima district of the Yodo River (at 1.3 km point on the left bank)

3) Takami district on the right bank of the Yodo River (Fig. 1 ③)

The section between the parapet and the levee crown slipped out of place, with cracking of the levee crown also evident. The revetment and the skirts of the rear slope were also damaged; the rear slope of the embankment swelled landward and the road on the landside rose.

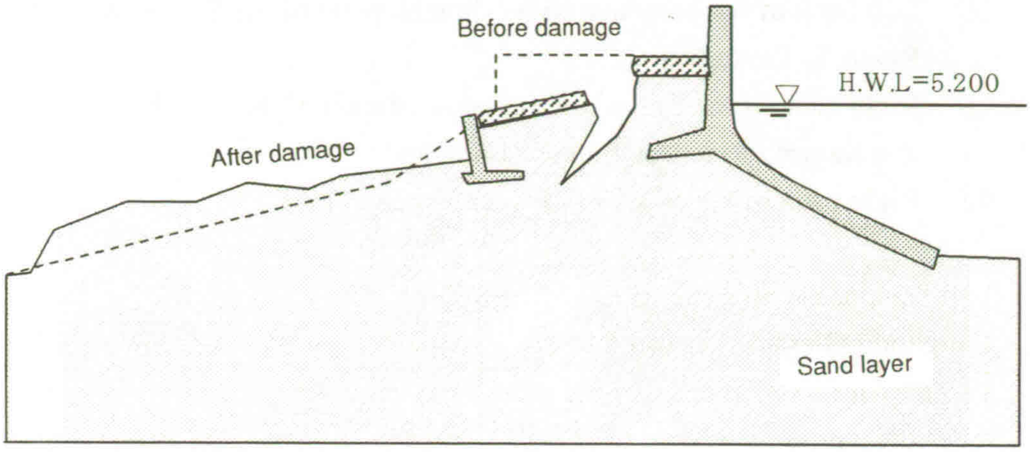
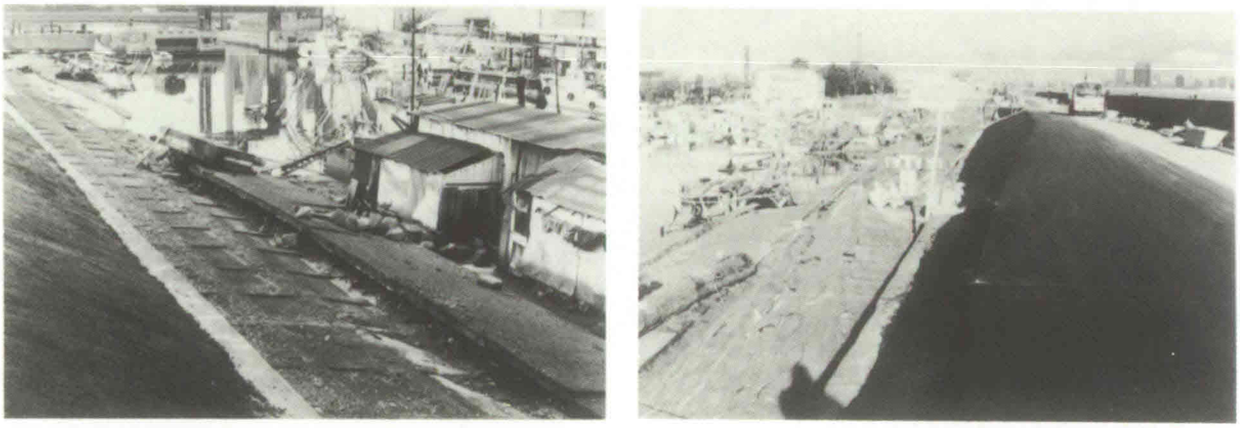


Fig. 3 Destruction of embankment in the Nishijima district of the Yodo River (according to data from the Yodo River Work Office of the Ministry of Construction)



(a) Collapse (sliding) of rear slope (b) Levee crown after emergency repair

Photo 2 Nishijima district of the Yodo River (at the 1.8 km point on the right bank)

(2) Shorenji, Ina, Mokawa, Kanzaki, Samondo, and Nakajima Rivers

Serious damage was witnessed to seven embankments against high tides, as shown in Fig. 1 (④ to ⑩).

④ Left bank of the Shorenji River (just upstream of Chidori bridge);

⑤ Mokawa River (from the 0.4 km to 0.6 km point above the confluence of the Mokawa and Ina Rivers, section between the Higashi-Sonoda and Mokawa bridges);

⑥ Left bank of the Ina River (dike against high tides);

⑦ Left bank of the Kanzaki River (about 10 km from the river mouth (Kashima));

⑧ Left bank of the Samondo River (branch point of the Samondo and Kanzaki Rivers at Tsukudajima);

⑨ Right bank of the Kanzaki River (downstream of the branch of the Samondo and Kanzaki Rivers at Tsukudajima); and

⑩ Right bank of the Nakajima River (2 km to 6 km)

1) Left bank of the Shorenji River (Fig. 1 ④)

Longitudinal cracks occurred in the levee crown on the landward side of the L-shaped parapet. Emergency repair work is now being carried out by breaking away the damaged parts of the levee crown and replacing the soil. The L-shaped parapet had not markedly settled. The parapet foundations are supported on pine piles. On the rear slope of the levee crown there is concrete-block pitched slope work constructed as a repair after the Second Muroto Typhoon in 1961 (see Photo 3).

2) Mokawa River (Fig. 1 ⑤)

Along the Mokawa River, a tributary of the Ina River, the embankments suffered damage including longitudinal and lateral cracking of the levee crown, cracking of the river and landward slopes, damage to the main channel revetment, and sand boiling in the flood channel. On the left bank of the Mokawa bridge, the original alignment of the embankment is distorted. A sluiceway in the damaged embankment indicated no anomaly.

3) Left bank of the Ina River (special dike, Fig. 1 ⑥)

Cracks occurred in some parts of the concrete revetment along its entire cross section, with swelling of the main channel revetment toward the river. No conspicuous damage was noted in the sheet-pile revetment (about 12 m to 13 m deep) on the opposite bank.

4) Left bank of the Kanzaki River (Fig. 1 ⑦)

Longitudinal cracks and depressions occurred in the levee crown which has an L-shaped parapet, with swelling of the (hexagonal and circular) blocks of the rear slope and rising and sand boiling on roads in the landside area. At the time of the survey, emergency repair work consisting of peeling the levee crown concrete and replacing the soil was under way.

Photo 3 Shorenji River
(damage to levee crown)

Photo 4 Kanzaki River
(cracking and settlement of levee crown)

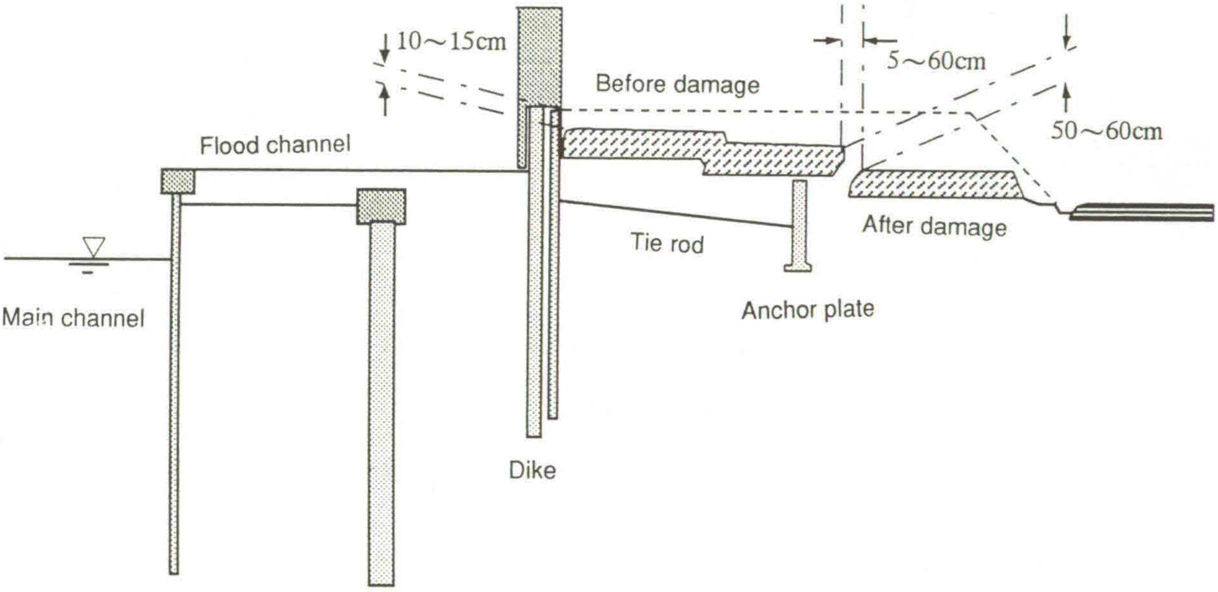


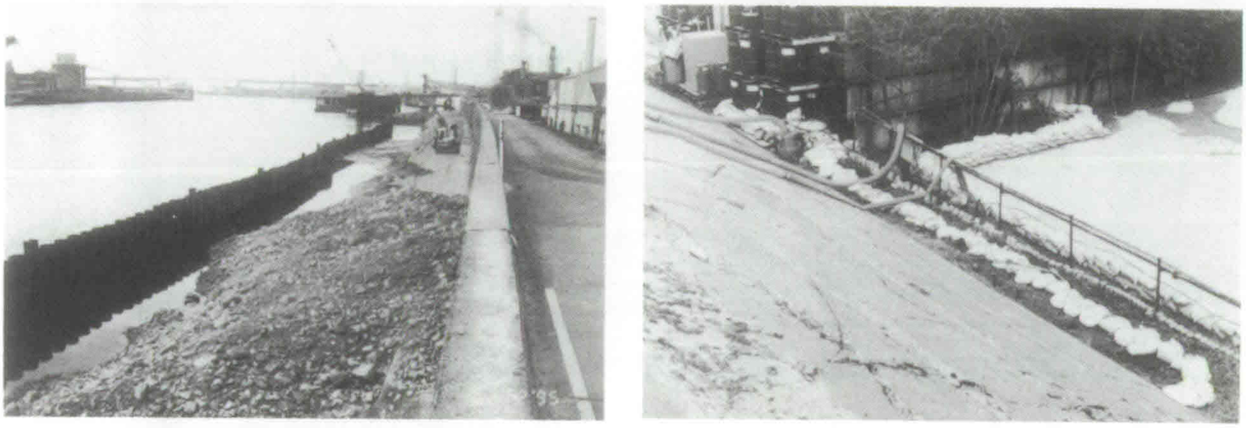
Fig. 4 Destruction of embankment along the Kanzaki River
(Tsukudajima) (according to data provided by Osaka prefecture)

5) Left bank of the Samondo River (Fig. 1 ⑧)

As shown in Fig. 4, the whole structure — comprising a single-line dike, tie rod, and anchor plate moved as one, thus giving rise to faulting in the levee crown over a length of about 300 m. The soil on the landside liquefied. The gravity-type retaining wall dike sank by about 0.15 m at one point and tilted toward the river at the Kensaki area, resulting in sliding and faulting between the retaining walls. The height of this area is zero meters above sea level.

6) Right bank of the Nakajima River (Fig. 1 ⑩)

Damage to this embankment included movement of the parapet, depression of the levee crown, cracking of the surface and top of the slope, and leakage of river water. Over a length of about 1 km, water leaked from the toe of the rear slope, but this was stopped by emergency sheet piling on the front face of the embankment, as shown in Photo 5 (a). Sections of the embankment with access roads and bridges were damaged to a particularly large degree.



(a) Sheet piling as the preventive measure of water leakage

(b) Flood prevention method

Photo 5 Right bank of the Nakajima River

(3) Muko River

Damage was found in the three sections shown in Fig. 1 (⑪, ⑫, ⑬).

⑪ Right bank (downstream from National Highway No. 171)

⑫ Left bank (section from the JR Shinkansen piers to a position slightly upstream)

⑬ Left bank (just upstream of the Hanshin Railway)

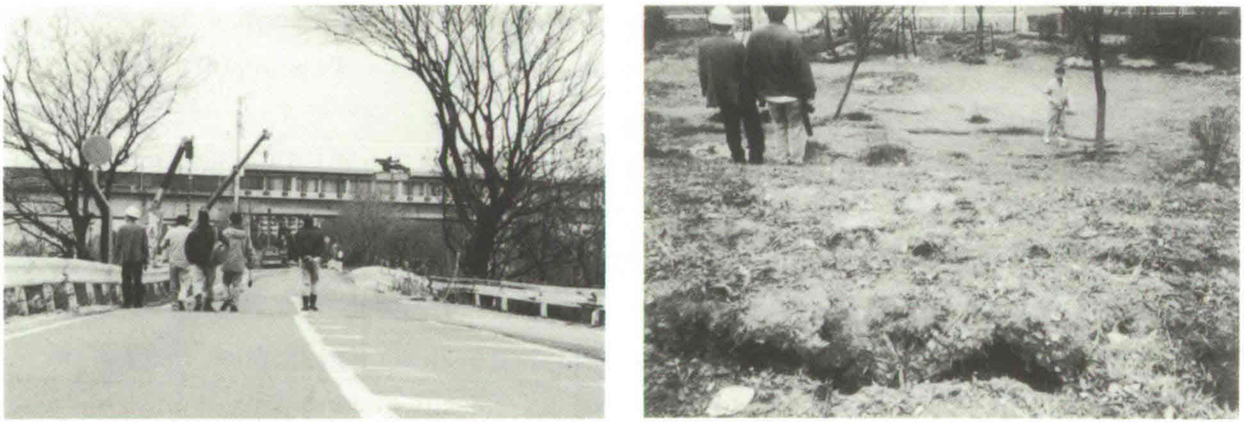
1) Right bank of the Muko River (Fig. 1 ⑪)

A number of large cracks were seen in the embankment on the right bank of the Muko River (see Photo 6 (a)). Surveys before emergency repair work began showed that the deepest crack in the levee crown had not reached HWL. Other damage included settlement of the embankment, sliding of the slope, and cracking of the road shoulder. In this section, no conspicuous damage was seen on the rear slope. Several longitudinal cracks were visible in the flood channel (see

6 (b). This embankment was constructed of decomposed granite dredged from the river bed.

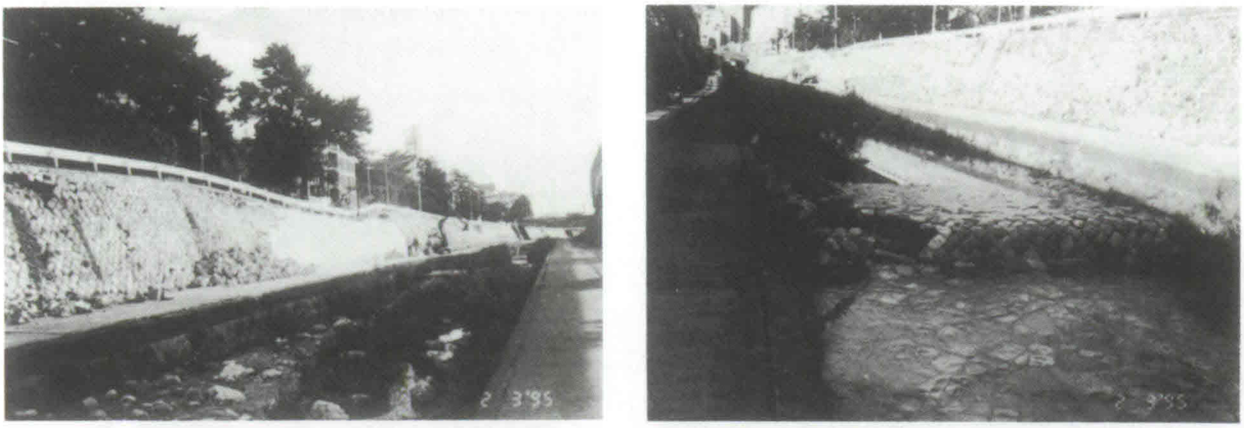
(a) Cracked embankment slope on river side (b) Cracked flood channel

Photo 6 Muko River (right bank about 8 km from the river mouth)



(a) Wavy levee crown (b) Cracked inland slope of embankment

Photo 7 Muko River (left bank about 8 km from the river mouth)



(a) Collapsed stone-masonry revetment (b) Damaged main channel revetment and consolidation work

Photo 8 Sumiyoshi River (within Kobe City (between the 0.7 and 1.7 km points)

2) Left bank of the Muko River (Fig. 1 ⑫)

The settled and wavy levee crown was observed in this area (see Photo 7 (a)). The landward slope suffered swelling, cracking, and sand boiling connected with the settlement of the levee crown (see Photo 7 (b)). Nothing unusual was seen in the consolidation work which had taken place at intervals of about 800 m.

(4) Sumiyoshi River (within Kobe City (between the 0.7 and 1.7 km points)

The Sumiyoshi River forms the border between Nada and Higashi-Nada wards, and serious damage to houses, buildings, and roads took place nearby. The river width is about 7 m, of which 3 m is excavated as a main channel, and there are stone-masonry revetments. Probably as a result of the naturally excavated-river channel, the section surveyed was not that badly damaged in spite of the intensity of earthquake motion; only the high water revetments had collapsed, with a road running along it suffering settlement (see Photo 8 (a)).

3. SUMMARY

Damage to embankments due to the earthquake was extremely serious and wide-ranging in nature. Much of the damage occurred at points very little above sea level, where ground conditions were poor. Before the wet season begins, the damaged sections of embankments must be thoroughly investigated; it is important to understand the forces induced by the earthquake, the form of damage, the ground structure characteristics, and the embankment structure, so that methods for sound and effective repair will be devised to prevent similar earthquake damage in lowland areas.

From a long-term point of view, it is desirable to prepare information of geological profiles of the embankments and surrounding areas by making boreholes into the ground structure under the embankments, flood channels, and adjacent residential areas, thus obtaining basic records for every river. This data and the history and form of levee damage can then be used to improve the embankments and revetments, and the accumulated data will help maintain the embankments in good working order.

Water and Sewage Works

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1. OUTLINE OF FACILITIES SURVEYED AND DAMAGE SUSTAINED

The survey team arrived at Kobe Municipal Office by way of Kyoto and Osaka JR stations in the afternoon of Feb. 1, taking the Hanshin Railway from Umeda to Oogi and a shuttle bus from Oogi to Sannomiya. The No. 2 Building of the municipal office, which housed the Bureaus of Water and Sewage Works, had suffered complete collapse of its sixth floor (used by the Bureau of Water Works) and the fifth floor (housing the Bureau of Sewage Works) could not be entered because of the dangerous condition of the building (see Photo 1). These two bureaus had moved into the undamaged No.1 Building, but without any paperwork, data disks, or hardware for their operations. This being the case, we obtained information about damage to the water and sewage works from those in charge and selected sites for the survey.

Table 1 lists the damage to the sewage treatment plants and pumping stations in Kobe as of Jan. 28. Based on this information, we began an investigation on Feb. 2 of these sewage works, centering on the Higashi-Nada Sewage Treatment Plant — which had suffered the worst damage of all treatment plants — and the Port Island Sewage Treatment Plant which suffered almost no damage.

Table 2 lists the damage to water supply facilities in Kobe. According to data made public by the Water Supply and Environmental Sanitation Department of the Ministry of Health and Welfare on Jan. 26, 359,600 out of the 650,000 customers in Kobe were suffering from cut-off of water supply. By that day, 521 tank trucks and other vehicles, about 70,000 polyethylene tanks, about 1,410 workers, and some 180,000 polyethylene water bags had been supplied to the city as emergency aid by 424 water departments in 41 prefectures. Rather than directly surveying the damage to the water works, we set out on Feb. 3 to look at the emergency water supply situation and the impact of the damage on the life of citizens.

2. HIGASHI-NADA AND PORT ISLAND SEWAGE TREATMENT PLANTS

Figure 1 shows a plan view of the Higashi-Nada Sewage Treatment Plant and an outline of the damage. It stands on reclaimed land, and the channel revetments had been displaced laterally, causing damage to inlet pipes bringing sewage in from the Uosaki

Pumping Station. This is shown in Photos 2, 3, 4, and 5. The retaining wall on the southern bank of the channel moved outward by about 2 m, thus causing sliding and settlement of the group of facilities located on the northern side of the site. (Photo 6 shows approximately 2 m movement of stairway foundations on the south bank of the channel.) As a consequence, the inlet conduit (1.5 m x 3 m) for the primary sedimentation basin shifted about 50 cm out at the expansion joint. This rendered the treatment of sewage totally impossible, although the pumping station was operable. To cope with this, the channel was blocked off to serve as a temporary sedimentation basin, and waste water was chlorinated and discharged. Photo 7 shows the blocked channel. The pile foundations of the treatment facilities consisted of PC, CC, and Benoto piles driven into the substratum under Osaka Bay. Facilities nearer the channel suffered more failed expansion joints, since they were unable to absorb the huge displacement. Joints to vessels making up the sewage treatment facilities also suffered failure, as shown in Photo 8, and sewage in such facilities spilled out. Photo 9 shows the sludge scraper in the primary sedimentation basin with its broken arms. On the opposite side of the channel (southern side of the site), a massive structure containing a bus terminal (belonging to the Bureau of Transportation) (see Photo 10) was completely undamaged.

The Port Island Sewage Treatment Plant was constructed on reclaimed land, and was not damaged at all. This was because adequate measures had been taken against soil liquefaction: soil improvement (replacement, sand drainage, and land fill loading for one year) and the division of facilities with different loadings into separate buildings (machinery, management, and treatment buildings) on floating foundations. Photo 11 shows a connecting corridor between the machine and management buildings, and Photo 12 shows part of a treatment building; neither was damaged in the slightest. Land adjacent to the treatment plant had completely liquefied (see the road beside the old embankment, shown in Photo 13, for example).

At the time of the visit, about 4,000 tons of sewage per day was being treated by the plant, as compared with 10,000 tons before the earthquake. Since the foundations of the bridge connecting the island with the mainland had been displaced by the earthquake, water supply pipes were damaged and the island lost its supply of water. Emergency water was supplied by tank trucks, but this would contribute little to sewage production, and the cause of this large quantity of sewage seems to be a little salty water leaking into broken sewer pipework. Some of the 4,000 tons of treated water was filtered through sand and distributed by tankers for flushing toilets at evacuation centers and damping down clay dust caused by liquefaction. Photos 14 and 15 show tankers distributing this recycled water.

3. SEWERS

At the end of fiscal 1993, Kobe's sewer system comprised a total of 3,315 km of sewage pipes and 484 km of rainwater pipes. According to surveys by the city government between Jan. 17 and 22, the damage listed in Table 3 was caused by the earthquake. Damage to sewer pipes can be inspected by two methods after draining the pipes of standing water (see Photo 16): (1) inspecting the interior through manholes (see Photos 17 and 18), and (2) using TV cameras (see Photo 19). However, until water supplies are restored and sewage begins to flow in from residences and industry, it is difficult to obtain full details of the damage. It is likely that almost all end points, such as connections to buildings, have been damaged.

Photo 20 shows a connection to an apartment building being repaired by residents. Since the gradient of this pipe was reversed, sewage had stopped flowing. Water in the nearby Fukuike Elementary School swimming pool (see Photo 21) was being used to flush toilets, but since sewage was not being discharged from the premises, waste from the repaired pipe was collecting in a hole excavated on the premises (where a blue vinyl sheet can be seen). Fortunately, the swimming pool was kept full of water through the winter, and this was used to fight fires in the neighborhood; thus fire damage in the area was minimized. Later, the pool was put to use as a reservoir for miscellaneous water uses.

4. INFLUENCE OF WATER WORKS FAILURES ON CITY LIFE

Five sixths of Kobe's water comes from the Yodo river. It is treated at purification plants run by the Hanshin Water Agency. Although parts of the pipework bringing water from the Yodo river to various purification plants were damaged, supplies of water from the purification plants to the 119 distribution reservoirs in the city were partially maintained. Twenty-five major distribution reservoirs were equipped with emergency shut-off valves to prevent water leakage in the case of earthquake. When the earthquake occurred, these emergency valves were closed by radio from the central control room, preserving water in the reservoirs for later delivery by tank truck. Photos 22 and 23 show tank trucks being loaded at the Higashi-Nada Low-Rise Distribution Yard of the Bureau of Water Works. At elementary schools designated as water distribution points, local residents took water (see Photos 26 and 27) from polyethylene tanks filled by large tank trucks (see Photo 24) or directly from small tank trucks (see Photo 25). At the Higashi-Nada Low-Rise Distribution Yard, water was pumped up and supplied directly from the distribution basin (see Photos 28 and 29). Unfortunately, emergency water supplies by tank truck could do little more than meet minimum drinking water needs, because of the manpower required in loading, driving, and distribution. Traffic jams also had a negative effect. For water other than drinking water, people made use of sudden new springs (see Photos 30, 31, and 32), water spilling from broken water pipes (see Photos 33 and 34), and nearby rivers (see Photo 35).

5. CONCLUSION

This survey covered two main aspects of the earthquake damage: (1) the aseismicity of water and sewage works as infrastructures; and (2) the serviceability and functioning of water supplies and sewage works as urban "lifeline" facilities.

Water purification plants, distribution reservoirs, sewage treatment plants, and other basic facilities were generally little damaged, except in the case of Higashi-Nada Sewage Treatment Plant which had been constructed on very poor ground. In particular, very little damage was reported at the Port Island Sewage Treatment Plant, where great care was taken as regards aseismic design to cope with soil liquefaction, and at the Tarumi Sewage Treatment Plant which was constructed on bedrock. In view of this, it can be concluded that basic facilities of water and sewage works can be made secure against earthquake if they are constructed on suitable land or if existing poor soil is improved. On the other hand, some damage to these basic services, especially at end points such as where sewers enter buildings, is unavoidable. This type of damage to underground components takes time to locate and repair, thus having a serious impact on the life of citizens. We would like to propose that existing water and sewage works, which are truly "lifeline" utilities, should be restructured so as to incorporate storage functions. Although the city maintains supplies of water in distribution reservoirs bordering the mountains and sewage treatment plants on the coast have abundant water, there are no storage facilities within the urban area. As a result, damage to piping systems responsible for the effective supply of water caused supplies to stop, aggravating fire damage and causing subsequent shortages of water.

Drawing a lesson from the unhappy experience of Kobe residents, we would like to conclude this report by making the following proposals for the construction of effective urban water metabolism systems (water supply and sewage facilities in the widest sense) that can withstand any earthquake.

(1) Equipment and instrumentation:

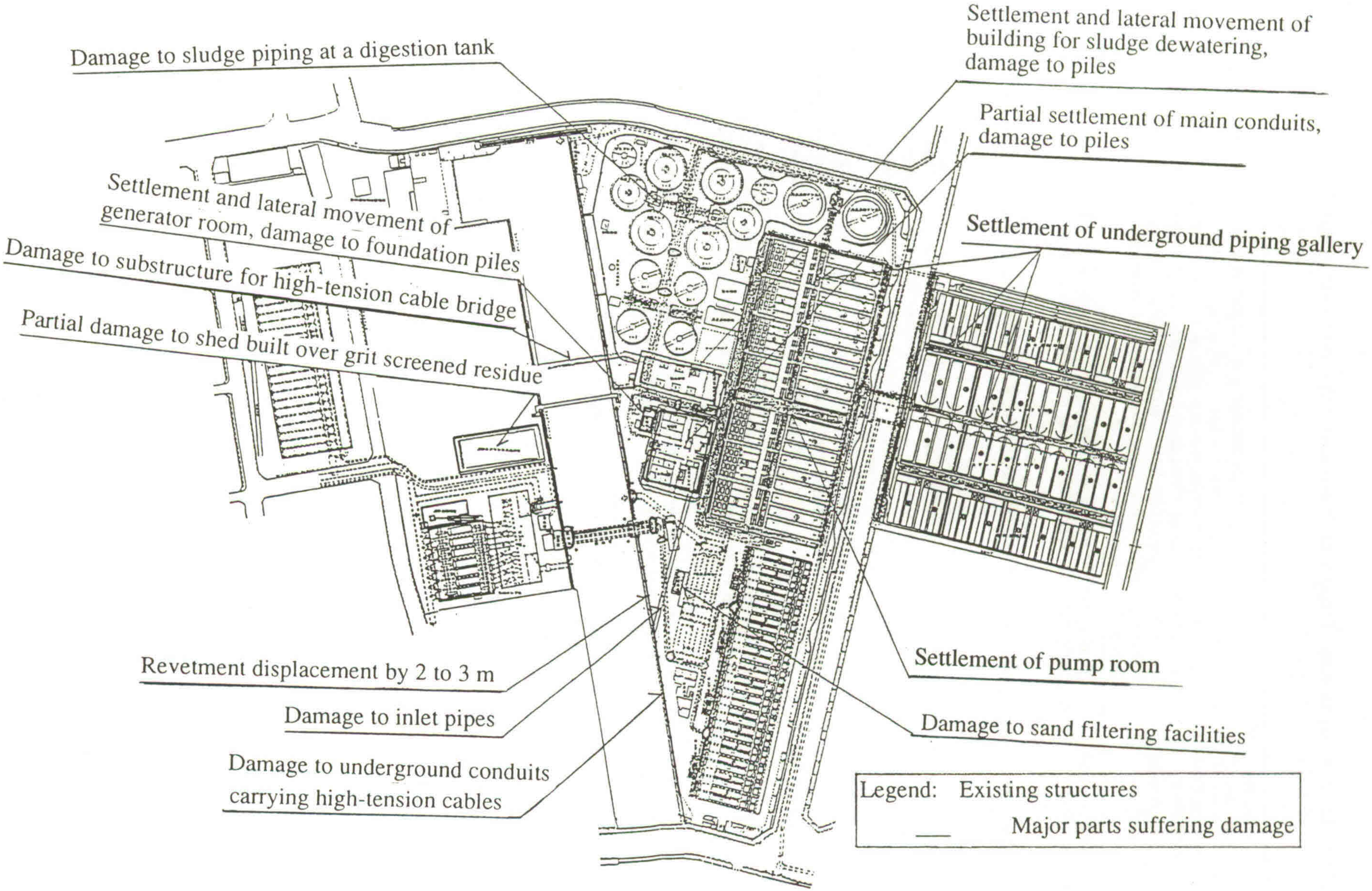
The most important facilities (water purification plants, aqueducts, distribution reservoirs, water mains, sewage treatment plants, trunk sewers, etc.) should be designed with high levels of earthquake resistance and equipped with links to other distribution reservoirs or sewage treatment plants for use in an emergency. Other facilities (sewer end points, etc.) should be designed to enable ready location, identification, and repair of damage.

(2) Water storage function to secure local water supplies:

Wells drawing from underground water should be provided at elementary schools and other public locations for use in emergency. To this end, underground water must be properly maintained in terms of quality and quantity.

(3) Dense water storage within urban areas:

Advanced treatment plants able to recycle sewage and special tanks of treated water under school yards, etc. need to be provided within urban areas.



Damage to sludge piping at a digestion tank

Settlement and lateral movement of building for sludge dewatering, damage to piles

Partial settlement of main conduits, damage to piles

Settlement and lateral movement of generator room, damage to foundation piles

Damage to substructure for high-tension cable bridge

Partial damage to shed built over grit screened residue

Settlement of underground piping gallery

Revetment displacement by 2 to 3 m

Damage to inlet pipes

Damage to underground conduits carrying high-tension cables

Settlement of pump room

Damage to sand filtering facilities

Legend: Existing structures

___ Major parts suffering damage

Figure 1 Plan view of Higashi-Nada Sewage Treatment Plant

Table 1 Damage to Sewage Treatment Plants and Pumping Stations due to the Great Hanshin Earthquake

Facility (capacity)	Major damage and restoration work
Higashi-Nada Sewage Treatment Plant (225,000 m^3/day)	Damage to inlet channels, leakage from air tank joints, tilting of control and dehydrator buildings, collapse of canal revetment, heavy damage to site pavement, tilting of filter basin; repair of treatment pumps, repair of sludge scraper, replacement of sand filter equipment, reinstallation of dehydrator, replacement and repair of panels
Port Island Sewage Treatment Plant (20,300 m^3/day)	Settlement and damage to site pavement, apertures and faulting in expansion joints, cracks in walls, damage to ventilation ducts
Suzurandai Sewage Treatment Plant (43,825 m^3/day)	Displacement and cracking in elevator building, damage to site pavement
Chubu Sewage Treatment Plant (77,900 m^3/day)	Damage to site pavement, damage to air tank cover slabs, cracks in wall of final sedimentation pond, uneven settlement of final sedimentation pond, damage to connecting passage, significant leakage from underground piping gallery; repair of deodorizing ducts
Seibu Sewage Treatment Plant (161,500 m^3/day)	Damage to air-tank inlet channels, air-tank expansion joints, and discharge ditches, heavy damage to site pavement, tilting of hydrochlorite room; repair of sludge scraper, pumps, and pipes, reinstallation of air mixing tank, repair of sewage pumps and motors
Tarumi Sewage Treatment Plant (133,890 m^3/day)	Displacement of revetment caisson, failure of overwash channels, cracks in expansion joints, settlement of pavement and gutters; repair of sludge pipes
Tamatsu Sewage Treatment Plant (75,000 m^3/day)	Damage including settlement and cracks to site pavement, damage to joints; repair of sludge dehydrator and pipes
Tobu Sludge Center (600 tons/day)	Damage to site pavement; installation of sea water intake equipment
Subtotal	

Table 1 (cont'd)

Facility (capacity: m^3/min)	Major damage
Honjo Pumping Station (wastewater 29.0, rainwater 644.6)	Cracks in generator room and expansion joints; reinstallation of generating system
Fukae-Ohashi Pumping Station (wastewater 15.4)	Damage to roads on site
Uosaki Pumping Station (wastewater 338.7, rainwater 1,763.3)	Partial destruction of piping bridge over canal, failure of discharge outlet joints, tilting of residue washing building; repair of screened residue conveyors, sewage pumps, and rainwater pumps, replacement of control panels
Oishi Pumping Station (wastewater 81.6)	Cracks in basement, damage to gate and outer walls, reinstallation of generating system
Kyoto Pumping Station (wastewater 50.0)	Damage to site pavement
PI First Pumping Station (wastewater 13.0)	Damage to site pavement, damage to north gate; repair of high-tension cables
PI Second Pumping Station (wastewater 1.0)	Damage to site pavement; replacement of water level gauges.
PI Third Pumping Station (wastewater 1.0)	Tilting of building, damage to site pavement and concrete retaining walls, repair of generators
Uji River Pumping Station (wastewater 116.9, rainwater 13.2)	Damage to site pavement (interlocking)
Minato River Pumping Station (rainwater 417.0)	Damage to retaining walls; repair of pump room overhead cranes

Table 2 Major Damage and Current Condition of Water Purification Plants, Distribution Reservoirs, and Other Water Works Facilities

	Damage	Current Condition
1. Reservoirs		
(1) Nunobiki Reservoir	Cracks in walkway handrails on top of dam Damage to control bridge piers. Full-scale repairs required	Safety review of the reservoir scheduled
(2) Karasuhara Reservoir	Minor vertical crack in end surface of dam Collapse of control road masonry	Safety review of reservoir scheduled
2. Purification plants		
(1) Uegahara Purification Plant	Several cracks in structure of slow filter bed Damage to expansion joints of fast filter bed (with leakage). Leakage from washing vessel piping in fast filter bed. Great damage to the structure, piping, and equipment of the wastewater treatment system (emergency repair completed). Damage to other pipes, embankments, and electrical/mechanical facilities	Study of best methods for repairing the whole plant scheduled
(2) Motoyama Purification Plant	Failure of inlet pipe to washing vessel. Cracks in reinforced concrete washing vessel	Methods of repair being studied
3. Distribution Reservoirs	Almost no damage to 119 distribution reservoirs within the city, but damage with leakage to junction well joints and vertical cracks in submerged expansion joints at Kaishimoyama Low-Rise Reservoir. Damage to site pavement and masonry at about 10 points	Emergency repairs to Kaishimoyama Reservoir completed; water supply resumed
4. Other facilities		
(1) Water Pipes	Leaks at more than 10 locations at the Uegahara Purification Plant (1,200 x 100 m) and Kaishimoyama medium-rise pipes (500 x 10 m). Submergence and failure of water pumps inside Karasuhara Tunnel. No marked leakage and probably little damage to two water tunnels (40 m x 2) penetrating the Rokko Mountains, which play a pivotal roll in water supply	Repair work at Kaishimoyama middle-rise pipes completed Repair of Karasuhara water pumps completed
(2) Water Distribution Pipes	Leaks from distribution pipes at tens of thousands of locations both inside and outside properties, amongst 650,000 consumers in Kobe	Emergency repair teams at work
(3) Buildings	Collapse of the 6th-floor main offices of the Water Bureau (in the 2nd Kobe City Office building). Collapse of 3rd floor of building housing the Tobu Branch Office (1st and 2nd floors). Partial fire damage at the Seibu Center building. Destruction of extension at the Tarumi Center building. Repair work needed at several other buildings	Methods of repair under study

Table 3 Damage to Sewer Piping (as of Jan. 22; 1st survey)

Damage	Wastewater piping			Rainwater piping			Total
	By 1/23	1/24	Total	By 1/23	1/24	Total	
A. Damage to manholes (floating, sinking, displacement of blocks)	672	0	672	138	0	138	810
B. Anomalies in road surface	289	25	314	57	1	58	372
C. Sewer damage and blockage	76	0	76	57	0	57	133
D. Flooding	0	0	0	0	0	0	0
E. Influx or deposits of soil	41	0	41	4	0	4	45
F. Others	44	0	44	10	0	10	54
Total (unit: No. of cases)	1,122	25	1,147	266	1	267	1,414

Photo 1 Damaged No.2 Building of Kobe City Office

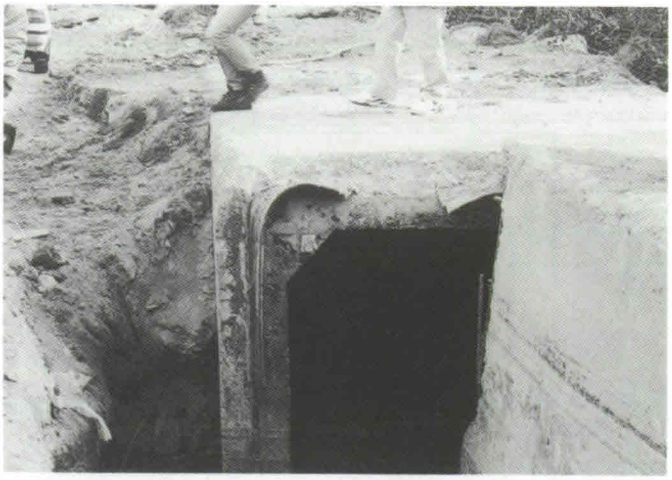


Photo 2 Damaged Higashi-Nada Sewage Treatment Plant

Photo 3 Damaged Higashi-Nada Sewage Treatment Plant

Photo 4 Damaged Higashi-Nada Sewage Treatment Plant

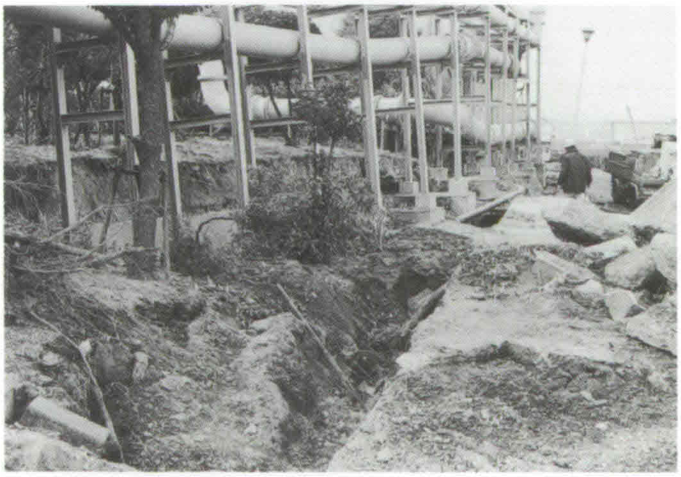


Photo 5 Damaged Higashi-Nada Sewage Treatment Plant

Photo 6 Damaged Higashi-Nada Sewage Treatment Plant

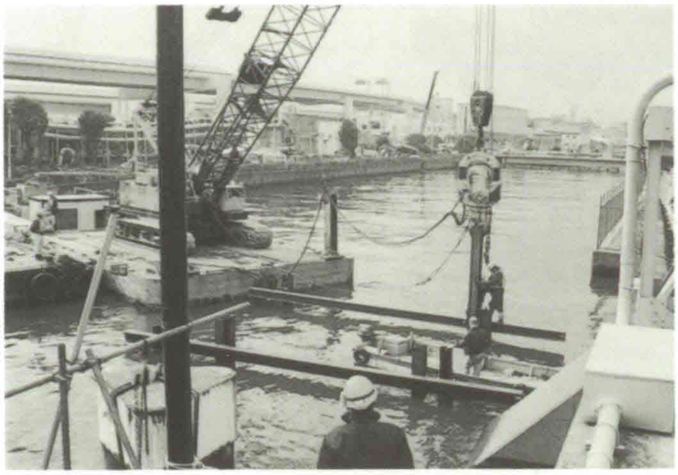


Photo 7 Closed off canal

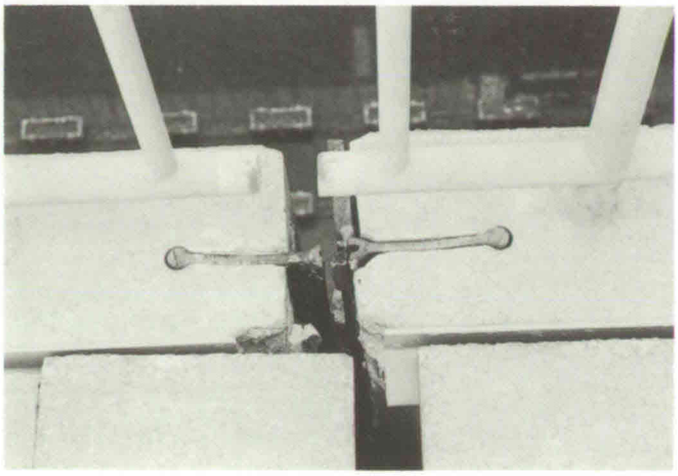


Photo 8 Damage to joints on water tank walls

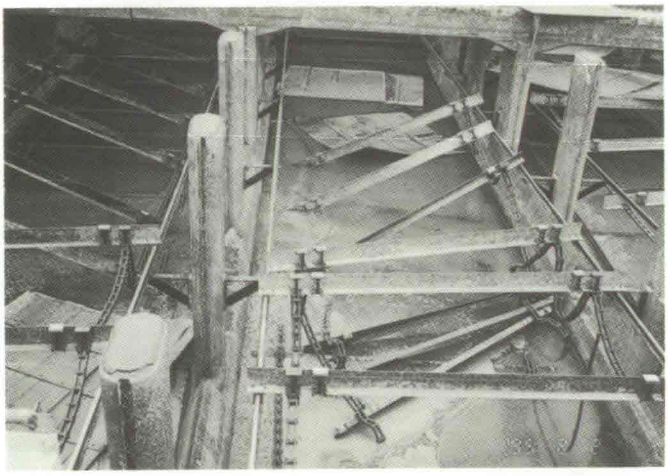


Photo 9 Sludge scraper of primary sedimentation basin

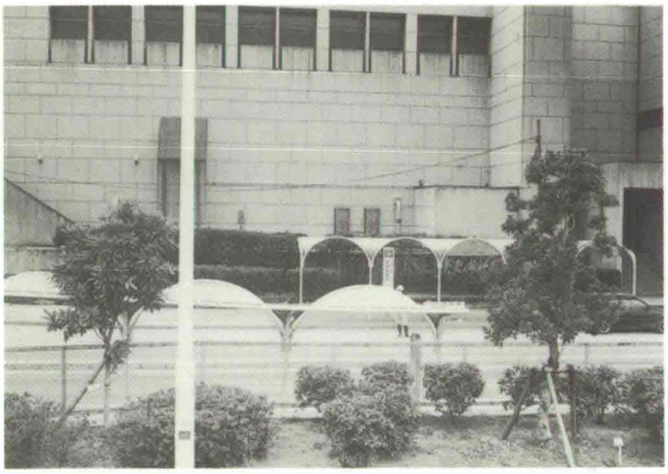


Photo 10 Sound treatment facilities on southern side of site

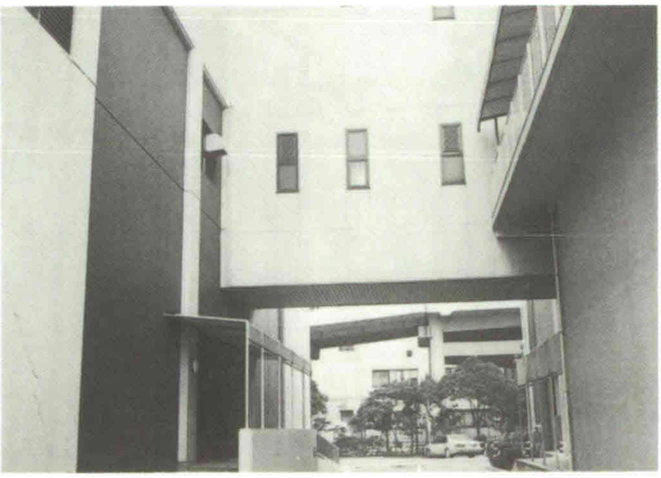


Photo 11 Port Island Sewage Treatment Plant

Photo 12 Port Island Sewage Treatment Plant

Photo 13 Liquefied soil on Port Island

Photo 14 Treated sewage water being distributed

Photo 15 Treated sewage water being distributed

Photo 16 Survey of sewer pipes

Photo 17 Survey of sewer pipes

Photo 18 Survey of sewer pipes

Photo 19 Vehicle fitted with TV system for sewer inspection

Photo 20 Apartment building sewer being repaired

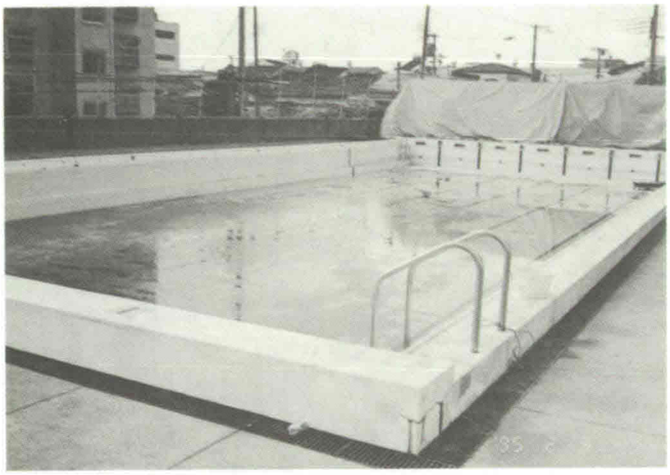


Photo 21 Elementary school swimming pool

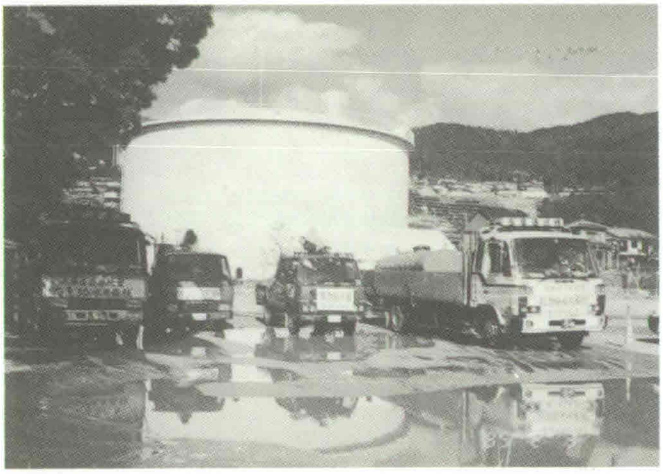


Photo 22 Loading tank truck with water at distribution yard

Photo 23 Loading tank truck with water at distribution yard

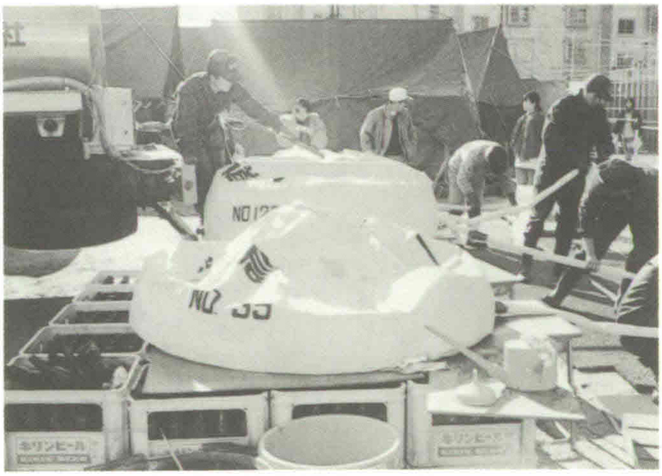


Photo 24 Water distribution point

Photo 25　Water distribution point

Photo 26　Water distribution point

Photo 27　Water distribution point

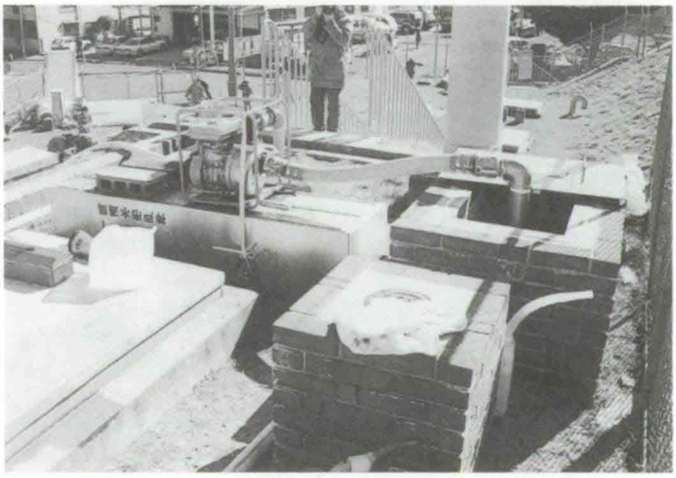


Photo 28　Water supply at distribution yard

Photo 29　Water supply at distribution yard

Photo 30　Citizens ladling from spring

Photo 31 Citizens ladling from spring

Photo 32 Citizens ladling from spring

Photo 33 Citizens ladling leaking water from supply pipe

Photo 34 Citizens ladling leaking water from supply pipe

Photo 35 View of Sumiyoshi River

Damage to Lifelines and Temporary Repairs

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1. PREFACE

The Great Hanshin Earthquake caused great damage to widely distributed systems which support urban activities, including the so-called "lifeline" facilities and railways. As they affected emergency relief efforts and subsequent steps for recovery, failure of these systems had a serious influence on large numbers of people and organizations. The paralysis of lifelines and railways not only halted everyday life, but also hindered important activities such as damage estimation, fire fighting, and the delivery of relief supplies and aid to evacuees. Temporary repairs to electricity supplies and telecommunication services were swift, but city water and gas supplies still await full restoration.

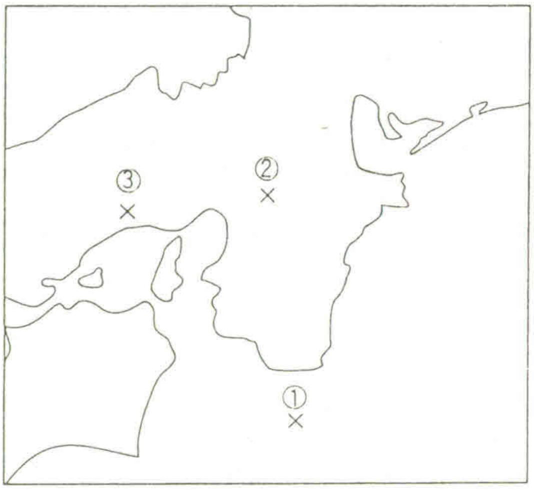
Before this earthquake, it was generally believed that modern preparations for earthquakes were fairly advanced, thanks to lessons drawn from past earthquakes and storm and flood disasters. The Great Hanshin Earthquake, however, not only halted supplies of water and gas because earthquake motion exceeded anticipated levels, but also caused damage that is taking considerable time to restore.

Of the various lifeline facilities, the present group surveyed damage and emergency repairs to electricity, telecommunications, and city gas systems. The surveys were preliminary, and we obtained information about damage and restoration work from public relations documents prepared by controllers of these lifelines. At the same time we held interviews, with the assistance of PR representatives of these services, to obtain further information on damage to the facilities and restoration work, both temporary and permanent. This report includes the results of these surveys, and also explains problems which now have to be solved as well as some lessons to be learned.

2. DISASTER PREVENTION CONTROL PLANS FOR LIFELINES

(1) Damage Estimates

The damage expected from an earthquake of seismic intensity 5 on the Japanese scale (strong earthquake) was explained in "Countermeasures against Earthquakes," one volume of the "Urban Area Disaster Prevention Control Plan for Kobe City, Fiscal 1994." This seismic intensity was used for the estimate on the basis of past earthquake records in the area since recorded history began. Figure 1 shows the location of the earthquake in this scenario, and Table 1 outlines the expected damages. These estimates were made by adopting worst possible cases of earthquake acceleration, geological condition, proportion of wooden buildings, inter-building spacing, meteorological conditions at the time of the earthquake, and other factors.



(1) Scale: Higher end of Japanese seismic intensity 5 (strong earthquake)
(2) Hypocenter
  ① Off Nankaido (magnitude 8.4; 180 km south of Kobe)
  ② Around Hirakata (magnitude 7.0; 70 km north east of Kobe)
  ③ Around Yamasaki (magnitude 7.1; 50 km west of Kobe)
(3) Earthquake occurrence: During a meal in winter

[Expected earthquake locations] x Hypocenter

Fig. 1 Anticipated Earthquakes in Kobe

Table 1 Estimates of Earthquake Damage

	Off Nankaido	Around Hirakata	Around Yamasaki	Southern Hyogo Pref.
Collapse of wooden buildings	500	1,500	3,000	26,000
Fires	30	70	110	358

The earthquake that actually occurred in the Kobe urban area, however, measured 6 and 7 on the intensity scale, far exceeding the anticipated level. The plan had presumed that an earthquake of seismic intensity 5 would cause no damage to the electrical power supply, city gas supply, and telecommunications systems, which were designed to withstand such an earthquake. The scenario also failed to predict such damage as the tilting of utility poles, the severing of cables by landslides, heavy ground motion, and the collapse of buildings, the failure of joints in low-pressure gas delivery pipework, and various types of damage to the telecommunications network. The plan had anticipated damage to weak sections of underground cables due to major ground motion only in areas with poor ground conditions. In short, estimates based on a seismic intensity of 5 indicated that lifelines would survive without substantial damage. Under this regional disaster prevention control plan, government agencies considered there was no need for new investment. According to newspaper reports, earthquakes of seismic intensity scale 6 had been discussed in the preparation of the plan, since there are several active faults below Kobe, but such a serious calamity was not considered in the final plan because of the vast investment required in lifelines and other public facilities.

(2) Hazard Prevention and Recovery Programs

The regional disaster prevention control plan describes a program for hazard prevention, pointing out the effectiveness of underground multi-purpose ducts in protecting lifeline and other underground systems. It proposes use of this type of ducting, together with other earthquake-resistant design methods, in districts meeting certain construction and economic conditions including effectiveness of the investment. The plan also includes a recovery program. With particular regard to the restoration of lifelines, it proposes that measures to promote hazard control and restoration after an earthquakes should be taken by the city in full cooperation with regional organizations in charge of disaster prevention, the media, road and traffic administrators, administrators of underground facilities, and local governments, etc. However, the program offers no specific procedures based on earthquake damage estimates.

3. ELECTRICITY

(1) Damage

Immediately after the earthquake, about one million households in a wide area centered on Kobe, Amagasaki, Itami, Nishinomiya, Takarazuka, Ashiya, and Osaka suffered electricity failure. Compared with other power interruptions caused by earthquake since World War II — about 1.05 million households in the Tokachi-oki Earthquake in 1968 and about 680,000 households in the Miyagi-oki Earthquake — this was the worst since the Tokachi-oki Earthquake. The Great Hanshin Earthquake brought to a total stop the 275 KW Nishi-Kobe, Shin-Kobe, Kobe, Yodogawa, Kita-Osaka, and Itami Substations and the 154 KW Nishi-Osaka and Torishima Substations. Hydroelectric and atomic power stations, on the other hand, suffered no damage. Table 2 lists the damage to various power facilities. As the table demonstrates, thermal power stations, substations, power transmission lines, and distribution lines were damaged. In addition, many utility poles collapsed or suffered damage as a result of the strong earthquake motion, collapsed buildings, or serious ground movements.

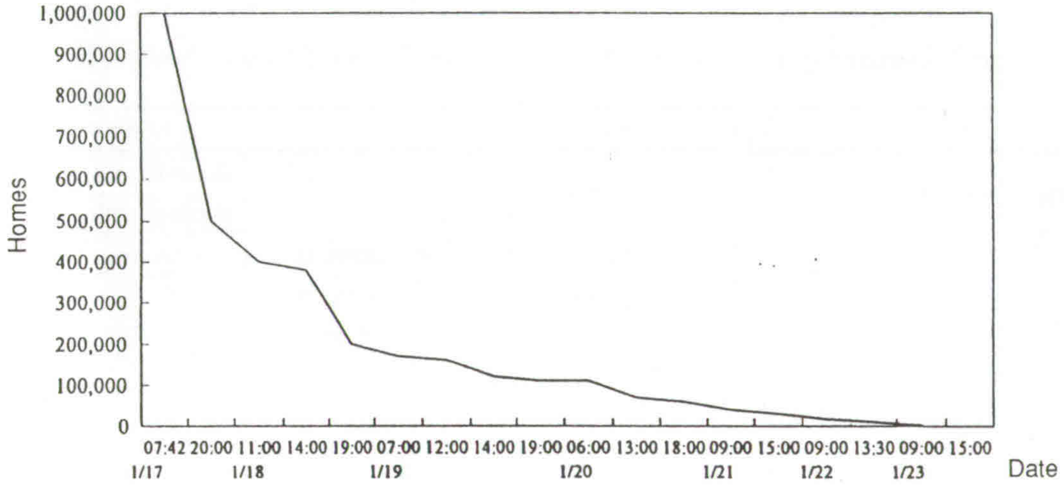
Table 2 Damage to Electric Power Facilities (by Kansai Electric Power Co.)

Facility	Damage		Remarks
Thermal power stations	10 plants		Boiler tube leaks Ground settlement
Substations	275 KV system	10 locations	
	154 KV system	6 locations	
	77 KV system	32 locations	
Power transmission lines	275 KV system	4 lines	
	154 KV system	7 lines	
	< 77 KV system	27 lines	
Power distribution lines		446 circuits	
Maintenance-related communications equipment		9 systems	Failure of communication cables

(2) Recovery

At 7:30 a.m. on Jan. 17, the Kansai Electric Power Co. established an emergency headquarters to handle the situation at its main office and at the Kobe, Osaka-Kita, and Kyoto branch offices. The initial aim was to catalog the damage and map out programs for earliest restoration. Restoration work was aided by six other electric power companies (Tohoku, Chubu, Hokuriku, Chugoku, Shikoku, and Kyushu) who provided 46 mobile power generators, materials, and manpower. The total number of workers assigned numbered 3,000 on Jan. 18, 4,000 on Jan. 19 and 20, (up by 1,000), and 4,700 on and after Jan. 21 (up by 700). In areas destroyed by fire or which could not be accessed because of road closures, etc., emergency power from mobile generators was provided until power could be supplied using temporary facilities.

The total number of homes without power changed with time as shown in Fig. 2. Except for some 20,000 homes that had collapsed or were too badly damaged to be supplied with power, power was fully restored by 15:00 on Jan. 23, six days after the earthquake. This was much longer than the half day taken after the Mid Japan Sea Earthquake in 1983, the one day after the Kushiro Earthquake in 1993, and the one and a half days after the Miyagi-oki Earthquake in 1978 (Note 1). Electric power, however, was restored earlier than any of the other lifeline facilities damaged by the earthquake. According to Kansai Electric Power, losses caused by the earthquake have totaled ¥230 billion — ¥96 billion in damaged power distribution facilities, ¥55 billion in damaged power transmission facilities, and ¥35 billion in damaged thermal power stations.



* Excluding some 20,000 facilities and houses without power supply

Fig. 2 Recovery from Power Failure (by Kansai Electric Power Co.)

(3) Outstanding Problems in the Restoration of Electricity Supplies

An increasing number of power distribution cables have been laid underground to avoid unsightly cable runs above ground. This earthquake, however, has shown that underground cables, once damaged, take a long time to restore. Consequently, emergency power was restored by laying temporary overhead cables, delaying permanent work. Underground cables should be fully designed to resist failure in accidents and disasters. In Kagoshima Pref. in August, 1993, a flood inundated a control box for an underground power cable, thereby causing power failure.

On Jan. 18, the Kansai Electric Power Co. began using the news media to make announcements such as "Do not touch fallen electricity cables" and "When power is restored, check electric heaters, ovens, and *kotatsu* (heated tables) for problems." As electricity supplies were resumed, reports came in of fires caused by short-circuits in domestic wiring and overheating of electric appliances. Fires of this type became a problem after the Northridge Earthquake in the U.S. in January 1994, and similar accidents have also been reported here in Japan. This has been made clear in surveys by Prof. Murosaki of the Dept. of Technology at Kobe University, and by the Fire Bureau of Kobe City. Such fires are probably attributable to the fact that, in a disaster of this scale, there is no time to check for damage to cabling and electrical appliances in each and every house before power supplies can be resumed. The earliest possible resumption of electricity is essential, since it not only affects everyday life but is also crucial to other recovery work and the operation of telecommunications and traffic systems. Nothing can replace electricity in this situation. In view of this, we would like to propose making efforts to develop automatically breakers which trip in the case of a big earthquake, and systems that give the user control at the distribution level. Only in this way can the problem of fires breaking out when power is resumed be resolved.

4. GAS

(1) Service Interruptions

Osaka Gas Co. supplies gas to eight large districts in the Kinki area, and these are subdivided into 55 blocks. Following the earthquake, numerous reports of gas leaks were received, and the company closed medium-pressure pipes in five blocks in the Hanshin area (namely, between Osaka and Kobe) so as to prevent secondary problems such as gas explosions. Gas supplies were also stopped in areas surrounding reports of leaks. As a result, a total of 857,000 customers were cut off. This is more serious than any other earthquake-related gas interruption in the past; in comparison, 135,000 customers were affected by the Miyagi-oki Earthquake in 1978, some 2,600 by the Mid Japan Sea Earthquake in 1983, and 9,301 by the Kushiro Offing Earthquake in 1993.

The Great Hanshin Earthquake cut off supplies of gas to the whole of five districts, including Kobe and Ashiya Cities which suffered serious damage. Osaka Gas has remote control systems for the large districts, but operates the blocks manually. They have no seismograph and no systematic response to earthquakes including estimates based on seismic intensity. Consequently, valves controlling these blocks have to be closed manually by company employees after assessing the condition of piping and other facilities. Since it takes a long time to resume supplies once they have been interrupted, the decision to close valves is a serious one. According to a newspaper (the Asahi Shimbun, Jan. 19), the decision was made by the president of Osaka Gas, with the result that gas was turned off at 11:50 a.m. on the day of the earthquake; that is, six hours after it occurred. This decision came rather late, compared with past cases in which gas was cut off about one hour after the earthquake. Large-scale disasters are often accompanied by information blackouts and traffic disorder, and it may be a long time before a person in charge can make the necessary decision; such a decision cannot be made without sound information. There is a need for full utilization of automatic cut-off systems, as well as the use of beepers and cellular telephones. It is possible to cut off gas supplies to individual houses if microcomputer-controlled gas meters are installed. Osaka Gas has already introduced this type of gas meter to 72.2 percent of users (as of the end of October 1994).

These microcomputer gas meters incorporate an earthquake sensor. Gas is automatically shut off if an earthquake of seismic intensity 5 or more occurs, or if large quantities of gas leak, a gas appliance is carelessly left on, or where the gas pressure falls to an abnormally low level. This effectively prevents such secondary accidents as fire, explosion, and intoxication. It also has the advantage that the user can manually reset it if there is no danger of gas leakage in the area. To make rapid recovery possible, Osaka Gas has decided to install microcomputer gas meters for all customers.

Osaka Gas started broadcasting public information notices in the evening newspapers of Jan. 18. These explained the gas stoppages, explained what to do in the case of gas leakage, and how to reset the microcomputer gas meters. The earthquake exceeded the seismic intensity of 5, but some meters failed to work, allowing fires to burn out of control. There were also reports of fires after electricity supplies were resumed. These accidents must now be investigated in detail.

(2) Recovery

Repairs to gas supply equipment generally begin with checks of the upstream high-pressure pipes, moving on to the medium-pressure and low-pressure pipes as repairs are completed. The supply of gas is then restarted step by step, checking for leaks from pipes in the surrounding areas. Using an estimate of around 20,000 households being reconnected a day in reference to the Kushiro Offing Earthquake in 1993 (and thus taking one and a half months for full recovery), the company made a public announcement about their recovery work on Jan. 18.

As a rule, the schedule for restoration of supplies is drawn up based on the results of inspections of buried pipes. In this case, repairs to low-pressure pipes took longer than had been expected. There were no reports of damage to the Senhoku and Himeji gas generating plants and to high-pressure pipes. Medium-pressure pipes were damaged, but repairs were complete by Feb. 2. The low-pressure pipes supplying gas to individual buildings, on the other hand, were extensively damaged. These low-pressure pipes are being restored using the procedure shown in Fig. 3; the supply to blocks of 3,000 to 4,000 customers is stopped, gas pipes buried in the streets are checked and repaired, pipes and appliances within the buildings are checked and repaired, and then supplies are resumed. Many low-pressure pipes were damaged, allowing water to enter gas pipes. Removing the water is a slow process, thus holding back restoration work. The pace of restoration has now dropped to less than half the original estimate: 7,000 customers a day.

1. Gas supply system

Generating plant → High-pressure gas → Medium-pressure gas → Low-pressure gas → Houses

No damage ← → Damaged

2. Restoration procedure

(1) Medium-pressure gas

(2) Low-pressure gas

1st day	Shutting off gas to 3,000 to 4,000 customers
	Closing gas cocks in the district
2nd to 3rd day	Checking and repairing gas pipes buried in the streets
4th day and after	Checking and repairing gas pipes in separate buildings
	Checking gas appliances and resuming supplies

Fig. 3 Damage to City Gas Facilities and Restoration Procedure

Damage to the low-pressure pipes was concentrated on threaded joints, where two pipes are connected by means of a slightly thicker collar into which the pipe ends are screwed. This type of joint was prone to cracking or coming loose, causing gas leakages. These earthquake-susceptible joints were being replaced with welded pipes and other earthquake-proof designs, but 30 percent still remained at the time of the disaster. Losses suffered by Osaka Gas are estimated to amount to some ¥190 billion.

The restoration of gas supplies began on Jan. 18, with about 6,000 employees of Osaka Gas and about 1,800 assistants from the Japan Gas Association and other gas companies taking part. With the gradual completion of repairs to medium-pressure pipes, the target area for repairs was enlarged. As central Kobe was approached, where damage to buildings and roads was severe, greater difficulty in restoration work was expected. Osaka took on an additional 500 workers from gas companies throughout the country, so 8,300 workers were engaged in the work on Feb. 1. Despite this, there are no estimates as to when gas will be restored to the heavily damaged areas of Kobe and Nishinomiya. Figure 4 shows the early progress of restoration, during which the main work was the checking and repair of medium-pressure pipes.

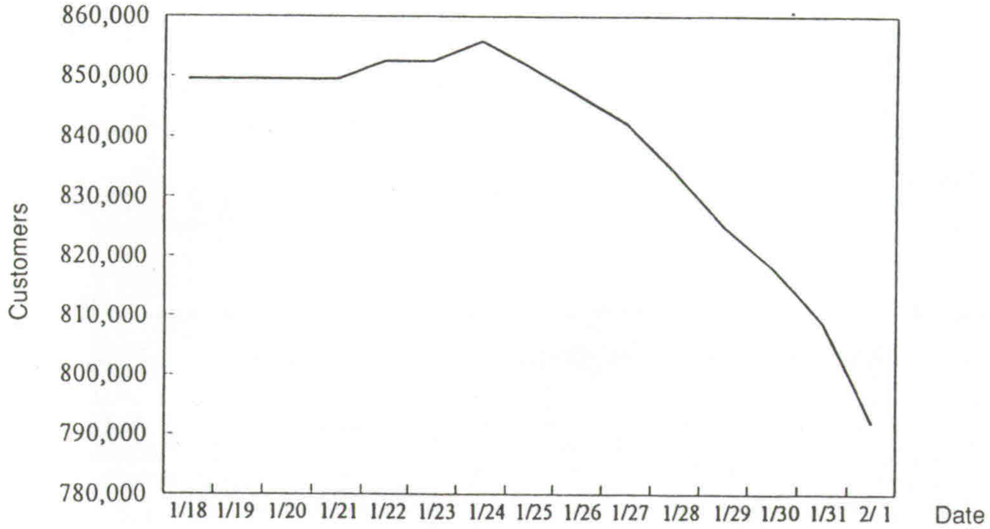


Fig. 4 Restoration of City Gas Supplies (data provided by Osaka Gas Co.)

Since Jan. 22, Osaka Gas has provided a total of 114,506 bottled gas heaters and 526,500 gas bottles (in sets of one heater and three bottles) to support the cities and towns without gas supplies (see Table 3). At first, Kobe City rejected these heaters for fear of fires in private houses and evacuation centers, but accepted half of them on Jan. 28 and the remaining half on Jan. 30. To help prevent accidents related to gas, Osaka Gas appealed to the general public for the safe use of gas through the media and by distributing handbills.

Table 3 Distribution of Bottled Gas Heaters (data provided by Osaka Gas Co.)

	Bottled gas heaters	Bottles
Kobe City	52,000	312,000
Takarazuka City	8,000	24,000
Ashiya City	9,000	33,000
Akashi City	9,000	33,000
Nishinomiya City	21,000	78,000
Kawanishi City	10,000	30,000
Itami City	1,500	4,500
Amagasaki City	2,000	6,000
Toyonaka City	1,000	3,000
Toyono Town	1,000	3,000
Total	114,500	526,500

(3) Problems with Gas Restoration

The restoration of gas supplies takes more time than any other lifeline facility. This is because detection of damaged pipes is time-consuming and the damaged sections have to be fully inspected before gas can flow. It took 28 days to restore gas supplies in Sendai after the Miyagi-oki Earthquake in 1978. In Noshiro, it took 30 days after the Mid Japan Sea Earthquake in 1983, and in Kushiro it took 22 days following the Kushiro Offing Earthquake in 1993. Quicker restoration, in 10 days, was possible in Nagasaki after a flood disaster in 1982. Now it seems necessary to develop plans for alternative energy sources, on the premise that gas supplies will be interrupted for a long time if damage is caused by an earthquake. The Agency of Natural Resources and Energy of the Ministry of International Trade and Industry is studying the possibility of providing city gas in bottles as a substitute when gas pipes are damaged in an earthquake.

5. TELECOMMUNICATIONS

(1) Damage

Damage to the telecommunications systems under the jurisdiction of the Kansai Branch of NTT is listed in Table 4. Lines to subscribers were severed by falling buildings and fires, while switchboards (exchanges), which are largely digital, stopped working in many places. It was not the switchboards themselves which stopped operating, but rather the interruption of commercial power supplies, the destruction of back-up power supplies, and the failure of the automatic switchover to back-up supplies that caused the problems. During the night of Jan. 17, back-up power supplies stopped operating due to lack of capacity, and the switchboards in the Chuo and Higashi-Nada wards of Kobe stopped operating. These back-up power supplies were installed on the assumption that power interruptions would be rectified within several hours, and blackouts of the length experienced this time were not anticipated. Switchboard failures disabled phone lines to some 265,000 subscribers out of the 1,440,000 in the Kobe area. NTT brought in 11 mobile power supplies to restore services.

Trunk lines were somewhat affected by the disaster, but there was no substantial damage because of automatic switchovers to alternative routes. As for buildings, three in Kobe City were impaired, with damage to rooftop water tanks and cracks in the walls. One (used for office work) became unusable, but this did not affect services. The two 60 m antenna towers on top of NTT buildings in the city tilted over as a result of buckling in some structural members, and the people living nearby were advised to evacuate. The towers were removed after emergency measures to prevent them collapsing.

Table 4 Damage to Telecommunications Facilities

Item	Damage	Restoration
Communications services		
Damage to switchboards	Failure of the commercial power supply and breakdown of back-up systems (285,000 subscribers)	Mobile power supplies brought in
Subscriber lines	193,000 circuits	Mostly restored
Trunk lines		Automatic switching to bypass routes
Leased lines	3,170 lines	2,730 lines restored
Congestion	50 times normal peak levels (Jan. 17) 20 times normal peak levels (Jan. 18)	Addition of 5,000 circuits Controls on congestion
Extra public telephones	2,700 units (including 350 faxes) installed placed in some 760 locations in the area. Mobile satellite stations, portable satellite communication units	
Reception/delivery of telegrams	For evacuees in local evacuation centers	
Buildings and towers		
Buildings	Three (Miyuki Building unusable)	Permanent rebuilding planned
Towers	Two (on top of Kobe and Taikai Buildings)	Emergency repairs

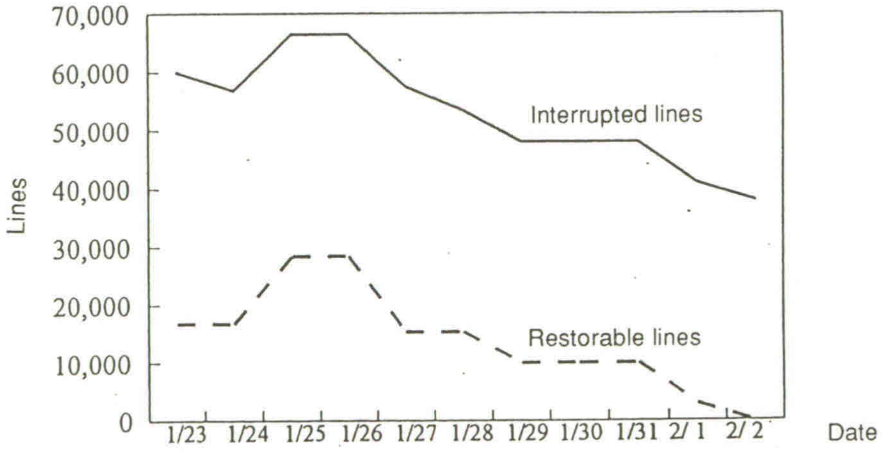
(2) Telephone Line Congestion

This is a phenomenon that occurs when calls come in from all over the country to the scene of a disaster. Once call levels reach 1.5 to 2 times the normal level, calls to the area in question are controlled automatically. On Jan. 17, as many as 50 times the normal peak level (20 times on Jan. 18) was recorded in the Kobe area, thus causing congestion. The area code 078 was controlled by NTT, giving priority to emergency calls and calls from public telephones, until Jan. 21. The company added 5,000 circuits to links going outside Hyogo Pref., and secured emergency communications by bringing in five mobile satellite communications units mounted on vehicles as well as 12 portable satellite communications units. Following this, communications generally returned to normal, though the volume of traffic into Kobe remained at double the normal level.

Telephone congestion always accompanies disaster, whether caused by storm, flood, or volcanic eruption, not to mention earthquakes. Various steps can be taken to avoid such congestion, but there are limits. The use of communications other than telephone is desirable. As in the past, the broadcasting of safety information on television and radio, personal-computer communications, the INTERNET, and mobile telephones (hand-held and automobile) drew attention. Mobile telephones was the easiest, probably because the number of such telephone users is still small. As this type of system becomes more popular in the future, congestion problems are likely to occur. Some telephones are susceptible to power failures; multi-functional telephones and facsimiles (and telephone cards) cannot be used during power failures.

(3) Recovery

Switchboards were quickly restored when electricity supplies returned or mobile power generators were brought in. Fires and damage to lines, however, required more inspections and repair. Since a telephone cable fire in Setagaya Ward (Tokyo) in 1984, NTT has introduced incombustible or fire-resistant underground cabling to connect switching centers. Such cables remained almost intact after this earthquake, but lines above the surface making connections to subscribers were seriously damaged. On Jan. 18, survey groups from NTT's Kansai Branch began to survey the damaged areas, summarizing the results of their surveys and collecting information necessary for restoration. Restoration work was being carried out by 150 workers on Jan. 18, by 1,000 on Jan. 19, by 1,500 workers on Jan. 20 to 22, and by 3,000 workers thereafter. Of some 66,500 disconnected lines, about 28,500 were assessed as suitable for emergency repair, and all were restored by Feb. 2 (see Fig. 5).



* 38,000: Cannot be quickly restored.

Fig. 5 Restoration of Telephone Lines (data according to NTT Kansai)

The restoration effort was aided by more than 100 flights by two helicopters and 14 return journeys by two submarine cable-laying vessels, which brought in materials. To give immediate relief, some 2,700 extra public telephone lines (including about 350 faxes) were installed at some 760 locations in the damaged area. The faxes were located at evacuation centers for the aurally handicapped. According a survey by the Ministry of Posts and Telecommunications, the total length of damaged surface lines controlled by the two branch offices of NTT (Kobe, etc.) amounted to about 100 km, or 2.3 percent of all lines. Underground telephone cables, on the other hand, only suffered about 700 m of damage, or 0.03 percent. Thus, underground telephone lines proved safer than surface lines (according to the Jan. 25 issue of *Asahi Shimbun*). The proportion of underground lines administered by NTT is currently about 20 percent over all prefectures, and this will increase further. However, once damaged, underground cables require considerable time to restore. Easier methods of control need to be adopted. Losses due to damage to NTT facilities are estimated to amount to some Y30 billion, and to almost ¥100 billion if the cost of restoring/renewing the facilities is included.

Table 5 NTT Services Other than Telephone Communications (NTT Kansai)

Item	Description
Free charge for Dial Q collection agency	Seven charity programs for the "Great Hanshin Earthquake" using the Dial Q system. Total No. of calls: about 2.2 million Total estimated amount about ¥230 million (as of Jan. 30)
Free telephone answering service regarding fatalities	Giving names on the "Register of Names of the Dead in the 1995 Great Hanshin Earthquake"
Message service for refugees	Accepting messages using the free dial system and faxing them to evacuees
Free inquiries regarding phone numbers of public organizations	Free information about telephone numbers of public organizations in charge of information related to safety and survival
Lifeline telephone directory	Issuing a directory covering water, gas, electricity, and other systems in the damaged areas
Video-conference system for disaster control	Establishing a video-conferencing system linking the Countermeasures against Disaster Headquarters of Hyogo Pref. and rooms in six city offices using 12 TV sets
Donating 30,000 telephones	Donating home telephones to Hyogo Pref. They are now being installed in temporary housing, etc.
Providing facilities for evacuees	Offering vacant rooms in dormitories and health and welfare facilities for evacuees (maximum capacity, 140 persons; now accommodating about 50)
Carrying disaster information on the INTERNET	

To secure information systems in the damaged areas, carefully thought-out measures are required. NTT has been providing services other than telephone communications, as listed in Table 5. Kobe City and the Ministry of Transport offer facsimile services giving the latest information on the disaster, the lives of people in the damaged areas, and the condition of transportation systems, roads, and expressways. These are accessible from any part of Japan 24 hours a day. This is just one example of new communications methods.

(4) NTT's Future Plans for Large Earthquakes

Since the Tokachi-oki Earthquake in 1968, NTT has been implementing measures to cope with earthquakes up to a seismic intensity of 6 on the Japanese scale, adopting improvements based on experience in past disasters. The Great Hanshin Earthquake caused considerable damage to telecommunications systems, which are becoming more and more important in today's information-oriented society. Since this is of serious concern, NTT has begun reviewing its hardware and software systems to give even greater safety in a disaster. A committee on countermeasures against large disasters is now studying the following issues:

① Earthquake-proofing methods for telecommunications;
② Measures to secure emergency communications; and
③ Suitable information and reception systems in the disorder following an earthquake

6. LESSONS FROM THE GREAT HANSHIN EARTHQUAKE AND PROBLEMS AWAITING SOLUTION

This latest disaster has revealed the limitations of our disaster control plans for electricity and gas supply systems and the telecommunications system. Many lessons have been learned, as listed here.

(1) Disaster Control Plans

① The need to upgrade the earthquake resistance of critical facilities: This earthquake caused serious damage to the buildings of Kobe City Office, telecommunications stations, hospitals, electricity companies, newspaper publishing companies, NHK's broadcasting center, other central facilities which take part in the emergency response. Some became unserviceable. Buildings which play such a central role should be constructed with greater earthquake resistance.

② The need to improve cooperation between administrative organizations and lifeline companies: Since administrative organizations and utilities are separate, there have not necessarily been thorough discussions in the preparation of regional disaster control plans, including systems for supplying electricity, gas, and telecommunications. This is sure to cause major problems during a disaster and as reconstruction proceeds. When preparing such plans, therefore, persons in charge of lifelines should also participate, so as to ensure easy and adequate exchange of information.

③ The need to establish good information exchange systems as recovery proceeds: Systems which ensure clear exchanges of information and expedite strategic planning for reconstruction need to be established so that city offices, fire departments, and the lifeline providers can implement reconstruction work in good mutual cooperation. There are many lessons which must be put into practice, for instance:

- Water supply repairs should precede gas supply restoration in the same area;
- Telephones and other utilities should not be restored to buildings which are to be demolished;
- To prevent fires when the electricity supply resumes, electric company employees and the fire department should be present at the site; and
- Measures to safeguard underground facilities should checked among the parties concerned before demolishing a building.

④ The need to establish tie-ups with urban planning departments: A department specializing in disaster response has limited ability to prepare regional disaster control plans for earthquakes. In the case of an earthquake, in particular, the plans are intricately linked with the urban structure, including the layout of urban facilities and the use of buildings and land. Thorough discussions with the urban planning and building control departments are necessary.

(2) Plans for Restoration and Reconstruction

① The need to improve lifeline facilities together with the regional infrastructure: In making plans for reconstructing the damaged areas, lifeline facilities should be improved in line with improvements in the regional infrastructure. To this end, lifeline administrators should take part in the planning process.

② The need to promote the multi-purpose use of underground ducts: It has been confirmed that facilities buried underground generally suffer less damage than those on the surface. The use of underground ducts should be promoted, and water, gas, electricity, and telecommunications systems should make systematic use of them.

(3) Lifelines

① Restoration information: Large-scale disasters reach beyond the boundaries of administrative units (prefectures, cities, towns, etc.). Since the blocks in which lifeline facilities are administered differ from administrative units, it is very difficult to issue recovery information for a particular block comprising areas under different administrations. Information systems in line with administrative units should be established beforehand.

② Newly identified problems and their solution: Following this disaster, fires broke out when electricity supplies resumed, while microcomputer gas meters failed to stop the flow of gas in some cases. These problems must be investigated thoroughly and solved.

③ The need to secure communications in a serious disaster: Communications should be planned in consideration of the likelihood that the public telephone system will be seriously congested. In the case of the Great Hanshin Earthquake, portable telephones, satellite communications, personal computer communications, and the INTERNET proved effective. Faxes offer the advantage that they can send large quantities of information in a visually verifiable form, thus helping avoid errors. They should be utilized to provide information services on survival and safety, and for getting messages to evacuees. It is also important to remind citizens of possible impairments to multi-purpose telephones and public telephones in the case of disaster and power failure.

④ The need for better earthquake resistance in back-up power supplies: In this earthquake, certain private emergency power generation systems and batteries were damaged and could not be used. Since these play an essential role in case of emergency, they should be fully earthquake-proofed.

⑤ Restoration of city gas supplies: Once supplies of city gas are cut, it takes at least a month to restore them. It is clear that anti-earthquake measures minimize damage. The use of automatic gas shut-off systems and pipes with greater earthquake resistance should be a priority, together with the development and use of alternative means of supplying gas.

⑥ Public subsidy for lifeline restorations: Disasters of this scale cause losses of hundreds of billions of yen. In cases where companies concerned cannot afford such outlay, public funding of some kind or other is essential.

Acknowledgments

We express our gratitude to the Countermeasures against Earthquake Disaster Headquarters of Kobe City, the Countermeasures against Earthquake Disaster Headquarters of Hyogo Pref., the Kansai Branch of NTT, Osaka Gas Co., and the Kansai Electric Power Co. for their cooperation in this survey. In making the survey, we received the cooperation of Professor Keinosuke Gotoh of the Faculty of Engineering, Nagasaki University, and in writing this report we referred to articles published in the Osaka editions of the *Asahi Shimbun*, the *Sankei Shimbun*, the *Nihon Keizai Shimbun*, the *Mainichi Shimbun*, the *Yomiuri Shimbun*, the *Kyoto Shimbun*, the *Kensetsu Tsushin Shimbun*, and *Shinsai Kobe*.

Note (reference materials)

1) Fumio Yamasaki, Earthquakes and Damage to Industries, the Marine and Fire Insurance Association of Japan, March 1994

Damage to Road Pavements

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1. OUTLINE

The Great Hanshin Earthquake caused less damage to road pavements than to adjacent buildings. This is probably because pavements are layered structures covering the ground, and asphalt pavements in particular, have flexibility. Harbor pavements on reclaimed land were seriously damaged because of liquefaction and collapse of the ground, but the damage to road pavements was generally slight, except where local soil conditions were poor.

2. SURVEY LOCATIONS

This survey took place during the period Feb. 1 to Feb. 4, 1995, about two weeks after the occurrence of the earthquake. Locations in six districts were surveyed: Nishinomiya, Fukae, Oogi, Port Island, Sannomiya, and Taikai. These locations were chosen from among areas where damage to buildings along the roads was particularly great. The survey was limited and was only a partial investigation because of the extremely difficult traffic conditions and restrictions on time. However, we believe it has enabled us to grasp certain characteristics of the damage caused by this earthquake.

3. EXAMPLES OF DAMAGE

Let us describe the damage to road pavements by citing several characteristic examples.

(1) Faulting behind abutments

The ground behind the abutments of bridges subsided, thereby forming faultings 20 to 40 cm in depth on the road surface. This made it difficult or in some cases impossible for traffic to pass the bridges. As an emergency measure, sand, soil, or timber was used to temporarily allow the passage of vehicles over these steps.

As a more permanent emergency measure, an asphalt mixture was laid in the case of national highways and other important trunk roads on the same day as the earthquake. In the case of other trunk roads, however, this measure was greatly delayed, and in some cases was not done for more than 10 days after the earthquake. Photo 1 shows the surface of a road behind an abutment after this treatment.

(2) Waving of road surfaces

Young ground on reclaimed land liquefied and subsided. Accordingly, the pavement surface of roads built parallel to elevated expressways became uneven, taking on a wavy form where the pavement was prevented from sinking by the foundations of the elevated structure (see Photos 2 and 3).

(3) Cracks near intersections

Where roads had intersections with other roads, cracks several millimeters to several centimeters in width formed (see Fig. 1 and Photos 4 and 5). This is probably because cracks were concentrated in these spots as the pavement distorted during large displacements of the ground surface, which was one of the characteristics of this earthquake. These cracks had no particular effect on traffic, however.

(4) Damage to ornamental paving and sidewalks

In contrast to the pavement of trunk roads, which was damaged relatively lightly, many areas of ornamental paving in passageways and housing areas, sidewalks, and thin-layered pavements cracked or broke at the surface layer (see Photos 6 and 7).

(5) Damage caused by underground structures

One area of road surface subsided considerably due to the collapse of a subway structure in the underground space beneath the road (see Photo 8).

4. FUTURE MEASURES

The damage to roads caused by this earthquake was outlined in the preceding section. Roads are very important for the emergency transportation of relief supplies just after an earthquake. For this reason, they should be constructed with a high degree of earthquake resistance, and emergency supplies of repair materials should be readily available in case they are damaged. For damage of the type mentioned in Paragraph (1) of the preceding section, in particular, the possibility of the measures outlined below should be studied.

(1) Use of approach cushion slabs

Approach cushion slabs made of reinforced concrete are used to prevent the formation of faulting in the road surface caused by subsidence behind abutments. Such approach cushion slabs are also effective in the case of earthquake. The use of such approach cushion slabs where the pavement is asphalt, however, seems to be rare, since their design is described in "Manual for Design and Construction of Cement Concrete Pavements (Note 1)." To prevent the formation of faulting, approach cushion slabs should also be placed in the base structure of asphalt pavements connected to abutments.

(2) Emergency repair materials

When an earthquake occurs, electricity failures disable asphalt concrete mixing plants, thus often making it impossible to use hot asphalt mixtures for repair work. As emergency repair materials, therefore, cold mixtures based on asphalt emulsions or cut-back asphalt should be kept in store.

These cold mixtures can be preserved in bags for one to three months, and can also be used for the routine maintenance of pavements. The "Manual for Design and Construction of Asphalt Pavements (Note 2)" states that cold mixtures have poorer initial stability and durability than hot mixtures, which need curing, but they can be temporarily used for emergency purposes even where heavy traffic and large vehicles use the roads.

Notes (reference materials)

1) Manual for Design and Construction of Cement Concrete Pavements, Japan Road Association, 1986
2) Manual for Design and Construction of Asphalt Pavements, Japan Road Association, 1992

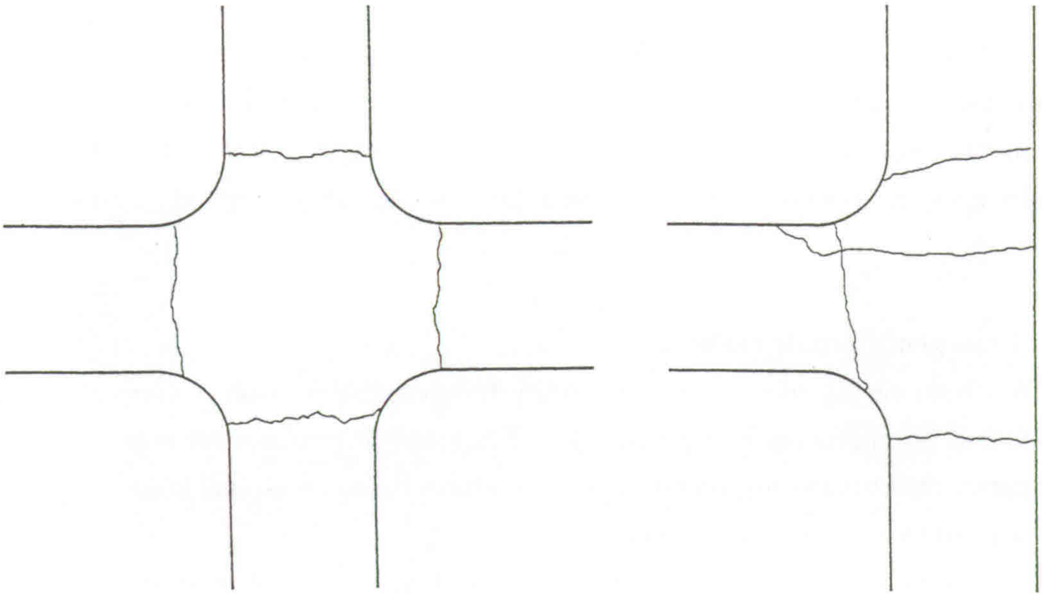

Fig. 1 Typical cracks near intersections

Photo 1 Laying asphalt mixture on road surface behind abutments

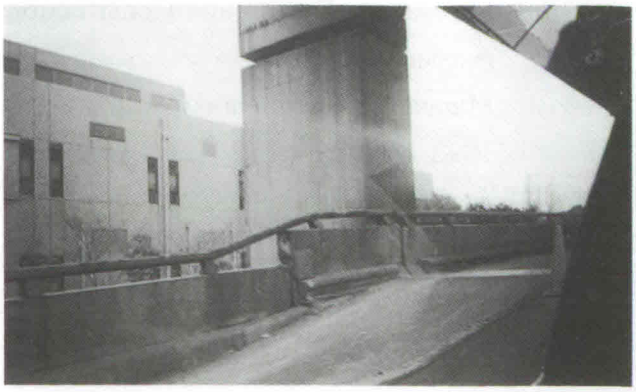

Photo 2 Wavy road surface (No. 1)

Photo 3　　Wavy road surface (No. 2)

Photo 4　　Cracks near intersection (No. 1)

Photo 5　　Cracks near intersection (No. 2)

Photo 6　　Damage to sidewalk (No. 1)

Photo 7　　Damage to sidewalk (No. 2)

Photo 8　　Collapse due to subsidence

A Survey of Transportation Planning

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1. INTRODUCTION

The Great Hanshin Earthquake caused devastating damage to the cities of Kobe, Ashiya, and Nishinomiya, and to Awaji Island. Transportation facilities also did not escape destruction. Roads, railways, and harbors suffered unprecedented damage. Besides being expensive to restore, this damage has had a profound effect on rescue work and the transportation of relief goods immediately after this disaster, as well as on the repairs now in full swing.

It goes without saying that one of the serious problems which the disaster area is now confronting is traffic jams. The congestion in the area and its vicinity is causing bottlenecks in the resumption of operations by industries not severely affected apart from the delivery of relief supplies, waste caused by the disaster, and repair materials. It is a matter of urgency to relieve traffic congestion. An adequate transportation plan is now required.

Great efforts have been concentrated on the restoration of devastated transportation networks by JSCE members in other fields. The objective of this survey was to determine how to efficiently meet the demand for transportation services; that is, how to develop appropriate plans for transportation management and control for the given transportation network. Kobe's port facilities, which are now in the throes of reconstruction, are outside the scope of this study, since they do not form the bottleneck to the transportation of general cargo.

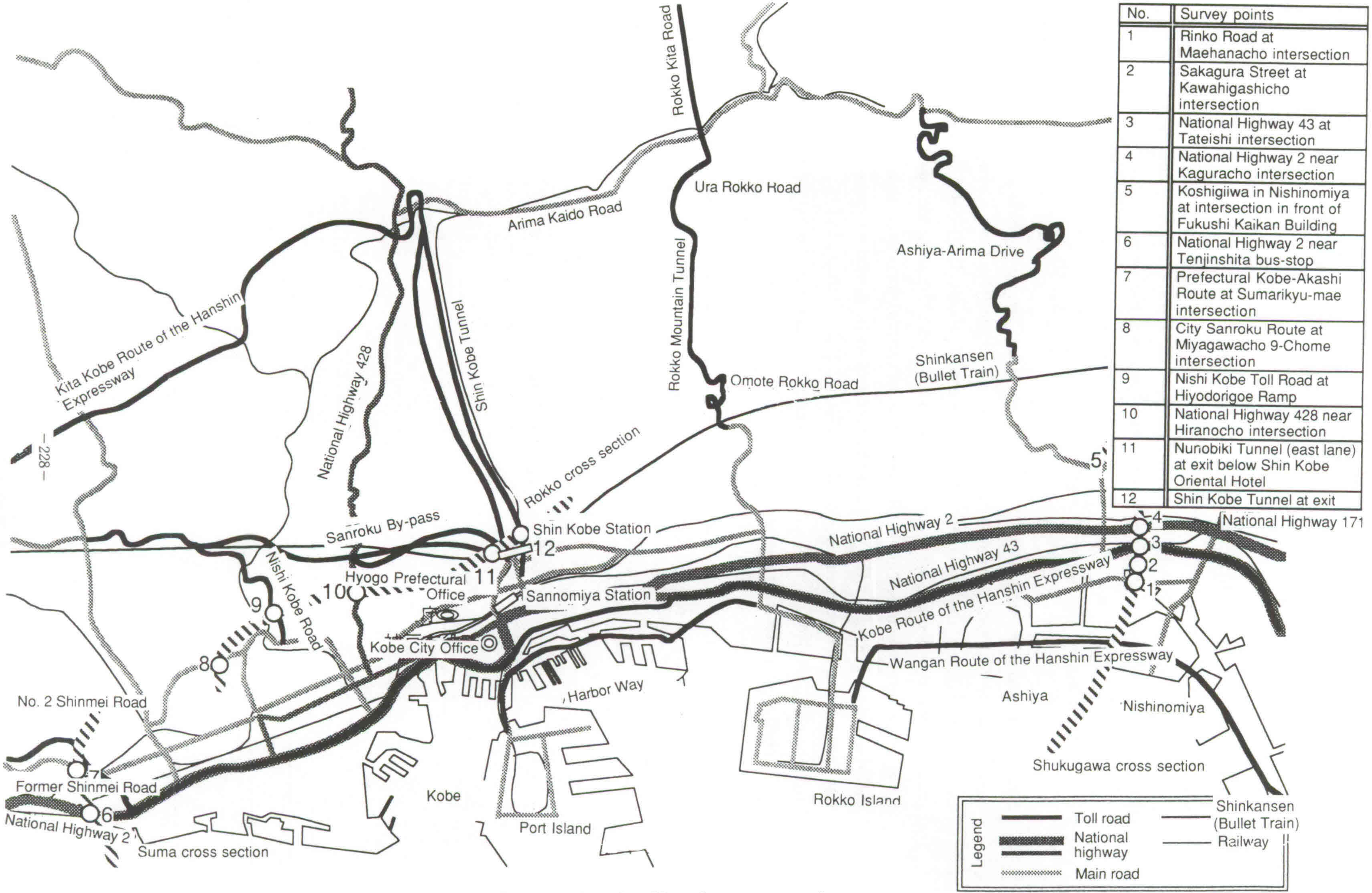
2. THE STATE OF ROAD TRANSPORTATION

2.1 Objectives of the survey

It is first necessary to establish which parts of the transportation system need management and traffic control, and then to determine current traffic conditions there.

1) Establishment of control locations

Within the extensive disaster area, the area suffering traffic jams, and consequently hindrance to reconstruction activities, is a belt-like strip 5 km north-south and 25 km from east to west, stretching from Nishinomiya westward and from Kobe's Suma Ward eastward just south of the Rokko Mountains. Site investigations clarified that the main road-transportation bottlenecks occurred within a north-south line along the Shukugawa River to the east (which we call the Shukugawa cross section), a north-south line along the Myohojigawa River to the west (the Suma cross section), and an east-west line intersecting routes crossing the Rokko Mountains into Kobe, Ashiya, and Nishinomiya from the north (the Rokko cross section). However, the damaged area extends outside this limited area, which is termed here the traffic control area. The traffic control area is bounded by the outermost limits of the area posing transportation planning problems as shown in Figure 1. Table 1 summarizes the number of usable road lanes intersecting the three cross sections before and after the earthquake.



No.	Survey points
1	Rinko Road at Maehanacho intersection
2	Sakagura Street at Kawahigashicho intersection
3	National Highway 43 at Tateishi intersection
4	National Highway 2 near Kaguracho intersection
5	Koshigiiwa in Nishinomiya at intersection in front of Fukushi Kaikan Building
6	National Highway 2 near Tenjinshita bus-stop
7	Prefectural Kobe-Akashi Route at Sumarikyu-mae intersection
8	City Sanroku Route at Miyagawacho 9-Chome intersection
9	Nishi Kobe Toll Road at Hiyodorigoe Ramp
10	National Highway 428 near Hiranocho intersection
11	Nunobiki Tunnel (east lane) at exit below Shin Kobe Oriental Hotel
12	Shin Kobe Tunnel at exit

Figure 1 Map of traffic volume survey points

Table 1 Number of usable road lanes before and after the earthquake at cross sections on the boundary of the traffic control area

Cross section	Road name	Number of lanes	Usable lanes after earthquake
Shukugawa	Wangan Route of the Hanshin Expressway	4	Closed
	Rinko Road	2	Passable
	Kobe Route of the Hanshin Expressway	4	Closed
	National Highway 43	8	Only 4 lanes passable
	National Highway 2	4	Passable
	Ashiya-Takarazuka Route	2	Passable
	Subtotal	24	12 lanes passable
Rokko	Omote Rokko Driveway	2	Passable
	Shin Kobe Tunnel	4	Passable
	Nunobiki Tunnel	4	Passable
	Nishi Kobe Toll Road	4	Passable
	National Highway 428	2	Passable
	City Road Sanroku Route	2	Passable
	Subtotal	18	18 lanes passable
Suma	No. 2 Shinmei Road	4	Passable
	Prefectural Road Kobe-Akashi Route	4	Passable
	National Highway 2	4	Passable
	Subtotal	12	12 lanes passable
Grand total		54	42 lanes passable

Table 2 Traffic characteristics survey

Cross section	Road name	Observation point	Time (min.)
Shukugawa	Wangan Route of the Hanshin Expressway	—	
	Rinko Road	Maehamacho intersection (grade)	20
	Sakagura Street	Kaguracho intersection (grade)	10
	Kobe Route of the Hanshin Expressway	—	
	National Highway 43	Tatena crossing (pedestrian bridge)	20
	National Highway 2	To the west of Kaguracho intersection (stairways)	20
	Ashiya-Takarazuka Route	Intersection in front of Mukiiwa Fukushi Kaikan Building (grade)	10
Rokko	Omote Rokko Driveway	Not surveyed	
	Shin Kobe Tunnel	Tunnel exit	20
		Shin Kobe Station entrance	20
	Nunobiki Tunnel	Tunnel exit	20
		Oper exit	20
		Shin Kobe Station cutting (included in the above)	-
	Nishi Kobe Toll Road	Hiyodori exit (pedestrian bridge)	20
	National Highway 428	Near Hiranocho intersection (park)	15
	City Sanroku Route	Miyagawacho 9-Chome intersection	15
Suma	No. 2 Shinmei Road	Blocked	
	Prefectural Kobe-Akashi Route	Rikyu Nishicho intersection (pedestrian bridge)	20
	National Highway 2	Near Tenjin-shita bus-stop	20

2.2 Traffic volume surveys

To implement management and traffic control of the transportation system, the most important information needed was the following:

① OD (origins and destinations), traffic volume, and route by area and vehicle type

② Traffic volume on all links by vehicle type

Obtaining such information over the large traffic control area appeared impossible. Accordingly, we conceived survey methods which yielded the maximum information with minimum effort.

1) Assuming that the main cause of congestion in the area was inflows from outside the area, management and traffic control on the boundary of the area was made the priority. By adopting this as an assumption, it became possible to make basic management suggestions by conducting an analysis of traffic at the cross sections ①.
2) In order to pin down the causes of traffic jams and then propose remedial measures, it was necessary to carry out roadside OD surveys ② and estimate traffic volumes generated and attracted ③. Once generated and attracted traffic volumes classified according to journey objectives were obtained, it would become possible to understand the influence of traffic coming in from outside the area.
3) Traffic volumes within the area appeared very large and difficult to measure. However, it seemed possible to gain partial information on vehicles being used to transport waste and as part of reconstruction activities by carrying out further surveys, as follows: an OD survey on waste arriving at waste disposal dumps ④, survey on the flow of waste and the location of waste disposal dumps ⑤, and a survey of the number of vehicles and average length of trips by vehicle type ⑥.
4) It was also necessary to estimate the volume of business and private traffic. This was done with two further surveys: a roadside OD survey ⑦, and a cross-sectional traffic volume survey ⑧.

2.3 Traffic volume survey methods

The methods of surveying cross-sectional traffic volumes on the boundary of the area and the way the data was analyzed are outlined below. To obtain traffic condition data at the locations given in Section 2.1, surveys were conducted at the observation points listed in Table 2.

Observation time was very short, 10 to 20 minutes, and video cameras were used. Because of this limited time, cross-sectional traffic volumes could not be properly determined at the following observation points:

1) Rinko Road at Maehamacho intersection
2) National Highway 43 at Tatena intersection

3) Shin Kobe Tunnel exit
4) Nunobiki Tunnel exit
5) City Sanroku Route at Miyagawacho 9-Chome intersection

Given the objective of the survey — to propose remedial measures for traffic congestion through understanding of cross-sectional traffic volumes — it was necessary to categorize the measured volumes as follows:

1. Bicycles and motorcycles: small footprint
2. Passenger cars and vans: holding up traffic
3. Pickups (2 tons or less): susceptible to improvement
4. Medium-size trucks (4 tons or less): very many; unable to enter narrow streets
5. Large trucks (5 tons or more): very efficient but unable to enter narrow streets
6. Construction vehicles and garbage trucks: necessary for reconstruction work

2.4 Results of survey

Tables 3 and 4 list the volumes of vehicles flowing in and out of the traffic control area, obtained by counting the number of vehicles recorded on the video tapes. Traffic was reduced at the time of the measurements as compared with earlier because of traffic jams holding up the inflow from Rinko Road, the inflow and outflow on National Highway 43, and the inflow at the Shin Kobe exit, Nunobiki exit, and Sanroku Route at Miyagawacho in the Rokko cross section. It is therefore clear that the estimates of traffic volume made through the survey have large errors. However, it is surprising that the results from this survey are quite close to the results given by detailed surveys by other universities (see table on page 7).

2.5 Discussion

Traffic volumes surveyed are compared with those before the earthquake in the table below.

	Before the earthquake (vehicles)	February 1 (vehicles)	Percentage	February 8* (vehicles)	Percentage
Wangan Route of the Hanshin Expressway	24,000	0			
Kobe Route of the Hanshin Expressway	86,000	0			
National Highway 43	65,000	11,000	17	14,200	22
National Highway 2	28,000	30,000	107	25,600	91
Sakagura Street	-	2,700	-		
Rinko Road	-	9,500	-	13,900	-
Ashiya-Takarazuka Route	-	3,400	-		
Four main roads	203,000	41,000	20	39,800	20
Four main roads + Rinko Road	-	50,100	-	53,700	

*Surveyed jointly by five Kansai area universities (over 11 hours)

Since the above 12-hour data were extrapolated from the results of very short-time surveys as already mentioned, it is difficult to draw any conclusions. Despite this, it is known that the number of lanes decreased to 45% of the pre-earthquake number, from 22 to 10, and traffic volumes to about 20% (although this is fairly uncertain). This is probably a result of the road conditions and the effects of congestion. (Traffic volumes on Sakagura Street and the Ashiya-Takarazuka Route are excluded from this discussion because large numbers of passenger cars used these routes and they merged into other main roads along the way.) The surveys also demonstrated that vehicles designated as emergency vehicles accounted for more than 90% of the total at the Shukugawa cross section as a result of traffic controls. It would seem possible to increase the traffic volume by about 15,000 vehicles by increasing the capacity of the two main roads and Rinko Road to about 65,000 vehicles through appropriate control of traffic volumes and improving intersections on the 10 undamaged lanes.

Taking only open trucks, which are distinguishable, there were 394 empty trucks against the total of 972, accounting for no less than 40%. If the same percentage applies to box trucks also, reducing the number of empties would appear to be an important issue during this period of reduced capacity.

As is evident from the tables, passenger cars were numerous at the Suma and Rokko cross sections where traffic was uncontrolled. This seems to be a leading cause of traffic jams in central Kobe, such as on the Yamate main roads.

Table 3 Results of survey (traffic inflow into the traffic control area)

Traffic cross section and road name	Bicycles	Motorcycles	Passenger cars	Pickups (2 tons or smaller) and vans			Medium-size trucks (4 tons or smaller)			Large trucks (5 tons or more)			Construction vehicles & garbage trucks	Total four-wheel vehicles
				Box vans	Loaded	Loaded	Box trucks	Loaded	Loaded	Box trucks	Loaded	Loaded		
Shukugawa cross section: to the west														
Rinko Road at Maehamacho	16	23	51	17	8	5	8	4	4	12	5	5	4	123
Sakagura Street at Kawaracho	4	4	19	2	2	0	1	0	1	0	0	0	0	25
National Highway 43 at Tatena	1	20	23	10	6	8	5	5	5	6	4	6	1	97
National Highway 2 to the west of Kaguracho	59	59	130	67	13	8	18	15	17	26	17	20	21	352
Ashiya-Takarazuka Route in front of Fukushi Kaikan Building	3	9	51	5	1	4	0	0	1	3	0	0	0	65
Subtotal	83	115	274	101	30	25	32	24	28	47	26	31	44	662
Rokko cross section: to the south														
Shin Kobe exit	0	3	50	9	9	1	10	4	3	5	1	0	3	95
Nunobiki exit	0	6	38	5	1	0	21	1	1	8	6	3	4	88
Oper exit	0	13	77	9	1	5	3	2	1	0	0	0	1	98
Nishi Kobe at Hiyodori	0	14	77	9	1	5	3	2	1	0	0	0	1	98
National Highway 428 at Hiranocho	0	37	338	28	17	32	9	2	8	7	3	5	5	454
Sanroku Route at Miyakawacho 9-Chome	1	18	103	11	11	11	1	0	0	0	0	0	3	140
Subtotal	1	91	732	86	50	54	47	10	15	22	10	8	16	1,049
Suma cross section: to the east														
Kobe-Akashi Route at Rikyu	0	51	242	38	23	16	3	7	6	9	11	11	6	372
National Highway 2 Tenjinshita Bus-stop	35	201	282	31	17	18	10	3	6	2	6	7	18	400
Subtotal	35	252	524	69	40	34	13	10	12	11	17	18	24	772
Total	157	458	1,530	256	120	113	92	44	55	80	53	57	84	2,484

Table 4 Results of survey (traffic outflow into the traffic control area)

Traffic cross section and road name	Bicycles	Motorcycles	Passenger cars	Pickups (2 tons or smaller) and vans			Medium-size trucks (4 tons or smaller)			Large trucks (5 tons or more)			Construction vehicles & garbage trucks	Total four-wheel vehicles
				Box vans	Loaded	Loaded	Box trucks	Loaded	Loaded	Box trucks	Loaded	Loaded		
Shukugawa cross section: to the east														
Rinko Road at Maehamacho	10	15	81	20	11	5	6	6	2	0	5	3	0	139
Sakagura Street at Kawaracho	1	2	9	1	2	1	0	0	0	0	0	0	0	13
National Highway 43 at Tatena	5	76	66	13	15	11	26	11	15	19	11	5	27	219
National Highway 2 to the west of Kaguracho	68	134	237	80	44	18	26	27	8	11	13	7	22	493
Ashiya-Takarazuka Route in front of Fukushi Kaikan Building	0	10	83	12	4	4	2	2	1	1	0	0	0	100
Subtotal	84	237	476	126	76	39	60	46	26	31	29	15	49	973
Rokko cross section: to the north														
Shin Kobe at cutting	0	62	341	48	41	11	20	21	12	5	16	3	11	529
Nishi Kobe at Hiyodori	0	18	142	18	7	3	6	8	1	0	0	0	0	185
National Highway 428 at Hiranocho	1	31	207	13	20	8	9	14	3	3	7	1	4	289
Sanroku Route at Miyakawacho 9-Chome	3	26	72	7	13	4	3	1	0	0	0	0	2	102
Subtotal	4	137	762	96	91	26	38	44	16	8	23	4	17	1,105
Suma cross section: to the west														
Kobe-Akashi Route at Rikyu	1	27	137	14	7	11	2	7	4	4	9	1	5	201
National Highway 2 Tenjinshita Bus-stop	10	39	159	30	25	16	15	11	2	5	3	9	17	292
Subtotal	11	66	296	44	32	27	17	18	6	9	12	10	22	493
Total	99	440	1,534	256	189	92	115	108	48	48	64	29	88	2,571

2.6 Suggestions for the disaster area

The areas most heavily damaged by the earthquake are central Kobe, and Ashiya and Nishinomiya to the east. Damage to transportation facilities in these areas was disastrous. This damage, together with the devastation of Kobe Port, dealt a serious blow to the daily life of residents and to the area's economic activities. Naturally, restoration of transportation routes is an urgent priority. Now that it will evidently be a long time before all routes can be restored, the immediate need is to control the transportation problem by making the most of the remaining undamaged facilities. Regretfully, there is a limit to the recommendations that can be made as of now because of a lack of survey data. However, the authors will stick their necks out and make the suggestions below. Naturally, the authors alone are responsible for any consequences arising from making these suggestions.

1. It is clear that roads were congested by emergency vehicles alone at the most important Shukugawa cross section. This is because of a traffic permit system operated by the prefectural safety committees and police stations throughout Japan for the three days following the earthquake when all goods were in short supply. Now, two weeks after the disaster, things are more stable and the volume of emergency vehicles during the night is lower. To make best use of night-time capacity, the method of issuing traffic permits for emergency vehicles must be reviewed. In our opinion, traffic control areas need to be set and the vehicles flowing in/out of each area should be regulated as follows.

   Vehicles permitted only at night:

   Vehicles transporting daily needs, trucks related to reconstruction work, vehicles transporting reconstruction supplies (categorized as less urgent), and media vehicles

   Vehicles needed urgently:

   Emergency police and firefighting vehicles, vehicles transporting reconstruction supplies (categorized as highly urgent), vehicles transporting materials essential to ordinary commercial and manufacturing activities, and buses

2. The proportion of passenger cars is very high on the Takarazuka-Ashiya Route at the Suma cross section and toward the west of the Rokko cross section. Accordingly, it seems necessary to control the movement of passenger cars and improve the bus services.

3. The proportion of empty trucks was very high at all cross sections. These seemed to be trucks returning after transporting goods and waste. It seems necessary to

take the following measures to reduce the proportion of empty trucks so as to make more efficient use of the limited traffic capacity: set up stock yards equipped with handling equipment for materials needed by the restoration effort near the borders of the traffic control area so as to reduce the inflow of empty trucks into the area; provide dumps for materials such as waste within the traffic control area so as to reduce the outflow of empty trucks.

4. The delivery of materials urgently needed by manufacturing industry and commercial activities should take first priority to prevent bankruptcy. Accordingly, it is necessary to ensure that measures implemented to carry out reconstruction work do not interfere with the use of undamaged roads. For instance, it is expected to take about two years to rebuild the Kobe Route of the Hanshin Expressway. The four lanes of National Highway 43 should not be used by construction vehicles for those two years. It is necessary to devise methods of proceeding with the work while keeping the eight lanes of National Highway 43 open, even if this means slowing the reconstruction work. Kobe's industries will decay if freight distribution is restricted, and the process will be irreversible.
   As regards port facilities, the reconstruction of feeder berths for domestic cargo, quays for loading waste, and unloading reconstruction supplies should similarly take priority over berths for international containers.

5. As mentioned, the Kobe Route of the Hanshin Expressway carried traffic accounting for 86,000 vehicles per day. Loss of this capacity cannot be borne for two years. Priority should be placed on developing alternative routes rather than restoring this route. (For an overview of the restoration process, refer to the end of this section.)

6. The capacity of roads is determined mainly by the operation of intersections. Since it is difficult to expect full restoration at an early stage, an urgent issue is increasing the capacity of the existing roads, even if only slightly, by improving the intersections. Roads in urgent need of increased capacity at the moment are National Highways 2 and 43 and Rinko Road. It is not easy to decide which roads can be improved with ease by improving intersections, but it is critical that surveys are carried out and appropriate suggestions made as promptly as possible. In doing so, care should be taken to avoid simply moving traffic jams at one intersection to another.

Supplementary notes:

Giving high priority to vehicles delivering materials needed by ordinary production and commercial activities may invite suspicion. However, although little reported by the media and forgotten by the public, it is important that deliveries of ordinary production materials and products continue. This should be regarded as the key to the restoration of Kobe. Almost all the industries in Kobe rely directly or indirectly on Kobe Port and the roads intersecting the Shukugawa cross section. Port facilities were devastated, as stated above, and the traffic capacity of the Shukugawa cross section dropped to one-third of its previous level even by conservative estimates. Comparing the expected progress in restobeltways with the demand for commercial deliveries, circumstances will not improve for a year or so. It would appear difficult for Kobe's industries, whether damaged or not, to run at 100% capacity with such transportation problems. Yet no enterprise can survive without operating for a year. How many industries will be able to recover with these transportation problems? The answer to this depends both on how soon the transportation network is restored as well as on how efficiently the undamaged sections are utilized. A decline in manufacturing and transportation could result in unemployment, which in turn would lead to population migration and a consequent decrease in commercial activities. Preventing such damage depends greatly on efforts related to transportation systems.

As previously mentioned, the traffic volume through the Shukugawa cross section before the earthquake amounted to 203,000 vehicles every 12 hours on 20 lanes of main roads. Kobe Port was used by 92,000 vessels and 8.3 million people a year, and handled 170 million tons of cargo in 1991. This was the backbone of the city of Kobe's economy.

2.7 Suggestions for future traffic planning

This earthquake hit parts of a key city in the transportation network, with considerable consequences for the area. The problems this caused were exacerbated by the following unique features of Kobe:

1) Kobe extends linearly in an east-west direction hemmed in by the Rokko Mountains to the north and the sea to the south. As a consequence, all traffic systems are concentrated in the east-west direction.
2) Kobe is one center of the Hanshin Industrial Zone, and has particularly strong ties with Osaka and Kyoto to the east. The traffic cross section to the city's east was worst hit by the earthquake.
3) As compared with similarly sized cities such as Sapporo, Sendai, and Fukuoka, Kobe has more secondary industry dependent on port and road systems.

The disaster was characterized by relatively minor damage to grade roads in contrast to the heavy damage suffered by elevated roads and road bridges. The damage in the narrow belt hit by this onshore earthquake was considerably large. Taking into account these features, the authors have made the following suggestions as to the future of traffic planning in the disaster area:

1) Since there was so much difference in damage between elevated roads and grade roads, a good balance of traffic flows on roads of the two types would raise the proportion of surviving lanes after a disaster, forming a disaster-resistant traffic system. Three quarters of the traffic across the eastern cross section, i.e. 150,000 out of 200,000 vehicles per day, relied on an elevated expressway (the Hanshin Expressway) and a road running below it (National Highway 43).

2) Since the damage caused by onshore earthquakes tends to be focused on a small area, road survival would be enhanced if multiple elevated roads were constructed along geographically distinct routes.

3) It is very important to secure alternative roads which provide detours around damaged cross sections. The minimum requirement is a ring road. Multiple ring roads would make it possible to make the most use of any surviving road.

4) As regards port facilities, the first need is to improve the earthquake-resistance of quays. It is also essential to provide alternative port facilities. Naturally, access roads to such alternative ports are of great importance.

Given the topography of Kobe, it would seem almost impossible to put all these suggestions into practice. However, making this a lesson for transportation planning in other cities will lead to greater disaster resistance.

3. THE PRESENT STATE OF PHYSICAL DISTRIBUTION

3.1 Objectives of the survey

The movement of materials is a fundamental concern in terms of supporting victims and rebuilding the disaster area. Day-to-day stability and smoother progress with reconstruction work are the main benefits of efficient physical distribution. Relief of traffic congestion in the area is another benefit. The essential needs requiring transport into/out of the area include ① supplies to support peoples lives,② waste, ③ materials relating to reconstruction work, and ④ raw-materials and finished products for industry. All of these are important, but our survey looked at the flow of life-support supplies in particular, since it is initially most important.

3.2 Survey methodology

Looking at Kobe, the flow of life-support supplies can be classified roughly as follows:

① Relief supplies coming to residents from national organizations and citizens via Kobe City Office

② Supplies procured and distributed to residents by Kobe City Office

③ Supplies transported directly to individual ward offices by national organizations and citizens for distribution to residents

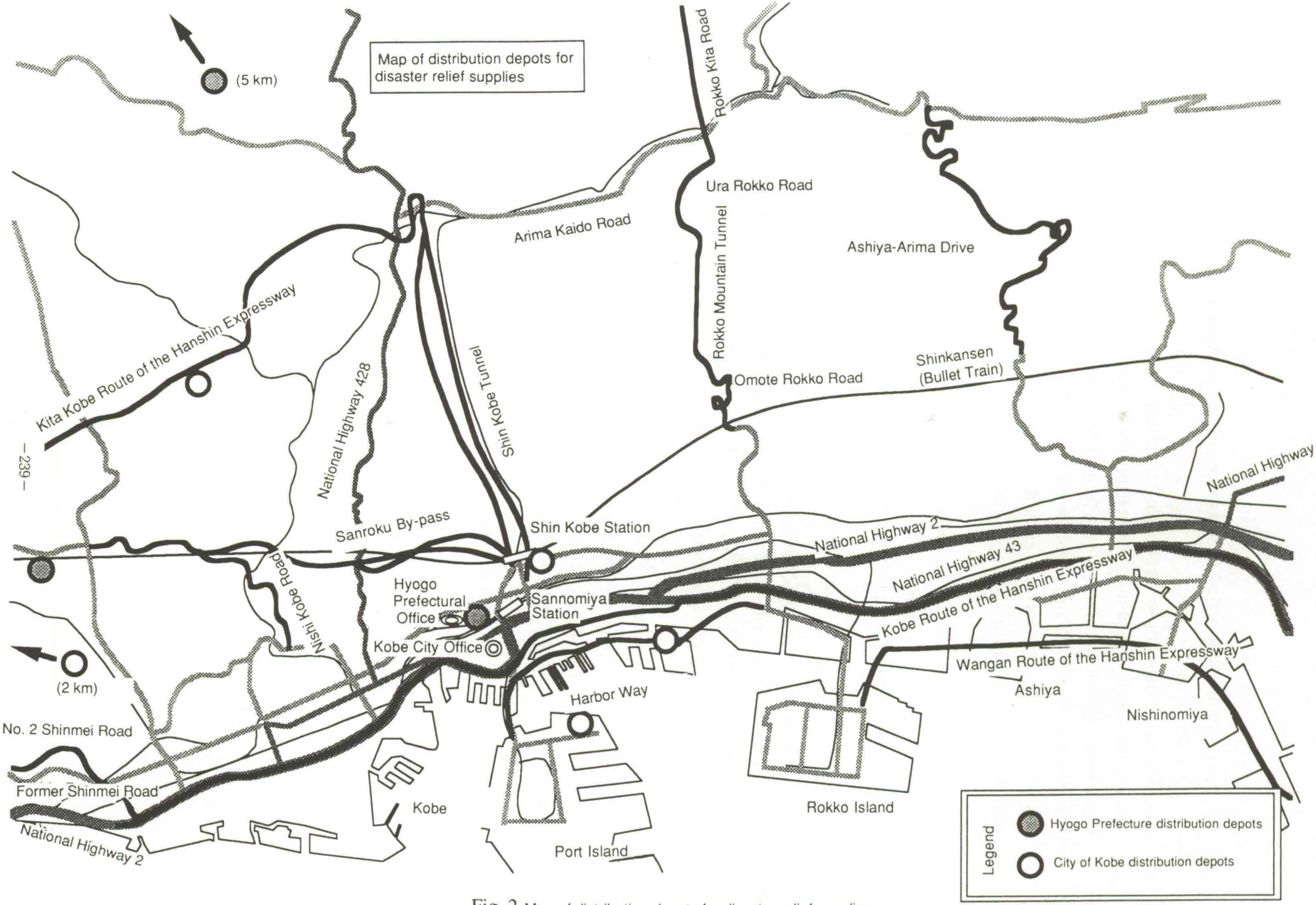


Fig. 2 Map of distribution depots for disaster relief supplies

④ Supplies transported from citizens across the country to individuals in the disaster area

The movement of these supplies has been changing rapidly since the disaster. At the time of the survey, on February 1 through 4, two weeks had already passed since the earthquake. It was hard to find out how supplies had flowed immediately after the disaster, and this is probably of little significance in developing material distribution plans. Accordingly, the survey focused on information about material flows in the two weeks until the survey was carried out.

As categorized above, the flow of life-support supplies was subject to congestion because many flowed through administrative offices such as city and ward offices. We decided to implement the survey by interviewing workers at administrative offices and at final destinations, which included the makeshift shelters.

3.3 Survey results

As stated above, the flow of life-support supplies was changing daily. The following summary of interviews with Kobe Chuo Ward Office (Mr. Imamura; Head of Regional Welfare Section) and Kobe City Office (Mr. Nabeshima; Head of National Pension Section of Public Welfare Bureau) is therefore divided according to time after the quake.

(1) In the three days after the earthquake

Kobe City Office sent relief supplies from organizations and individuals directly to ward offices immediately after the earthquake, so as to ensure prompt delivery to destinations. In the case of Chuo Ward, the ward was divided into four blocks — Fukiai Kita, Fukiai Minami, Ikuta Kita, and Ikuta Minami — and most supplies went to about 80 evacuation centers with delivery by four teams. Relief supplies such as food, clothing, and blankets were in short supply on January 17 and 18, but the supply system worked successfully. Supplies were loaded, distributed, and unloaded mainly by ward employees and volunteers (members of the Safety Cooperation Committee organized by local construction firms). Since supplies were arriving round the clock, the system gradually became overloaded. Supplies started piling up not only in the ward office's basement parking lot but also on sidewalks in front of the office and along a national highway, and it became difficult to unload and distribute supplies on January 19 (the third day after the earthquake). As time passed, and once sufficient food was available, requirements diversified.

(2) Up to two weeks after the earthquake

As the distribution of supplies clogged up, Kobe City Office responded by setting up five relief supply distribution depots on the fourth day after the quake: ① warehouses at Maya Wharf, ② Shin Kobe Station, ③ Silver College (in Kita Ward), ④ Green Arena (in Suma Ward), and ⑤ Rokko Island. The depot in Rokko Island was afterwards moved to warehouses at No. 6 Container Berth on Port Island. (Refer to Figure 2.)

Relief supplies were then received and transported to these depots under the central control of the Welfare Pension Section of Kobe City Office using receipt slips. Data on the movement of relief supplies were input into databases by volunteers under the control of the Regional Welfare Section. Soon afterwards, the sorting and distribution of supplies by city officers and volunteers became impractical because of the quantity and the distance they had to be transported. At that point, the Kobe City Office decided to subcontract the work. The deployment of personnel and vehicles as of February 3 is shown in the following table.

Personnel and vehicle deployment plan (as of February 3)

1. Public Welfare Bureau (Distribution of materials between Kobe Office, wards, and depots)

	Number of trucks	Number of people
Safety Cooperation Committee	23 during the day, 5 at night	12 (round-the-clock operation/3 shifts)
Shimane Prefecture	10 (2-ton and 10-ton trucks)	29 (only during the day)
Nissan Diesel Motor Co., Ltd.	2	
Mitsuboshi		19 (only during the day)
Total	35	93

2. Wards (distribution of materials between ward offices, wards, and evacuation centers, as of February 1)

Kobe City officers: 2 x 3 shifts

Ward name	Number of evacuation centers	Number of evacuees	Trucks	Total number of trucks
Higashinada	134	54,585	2 (Nippon Express Co., Ltd.) 2 (Yamato Transport Co., Ltd.) 1 (Yahagi) 3 (Seino Transportation Co., Ltd.)	8
Nada	93	40,394	2 (Nippon Express Co., Ltd.) 5 (Yamato Transport Co., Ltd.) 1 (Yahagi), 4 (Seino Transportation Co., Ltd.)	12
Chuo	85	37,062	1 (Nippon Express Co., Ltd.) and 2 (Footwork)	3
Hyogo	92	22,255	1 (Nippon Express Co., Ltd.) 4 (Akabo), 3 (Yamato Transport Co., Ltd.) 2 (Yahagi)	10
Kita	19	947	1 (Akabo)	1

Nagata	79	54,040	1 (Nippon Express Co., Ltd.) 3 (Cooperation Committee of Building Construction Firms) 3 (Sankyu), 3 (Tonami) 3 (Akabo), 3 (Yamato Transport Co., Ltd.) 1 (Adachi Construction Co., Ltd.)	17
Suma	49	19,810	3 (Footwork)	1
Kita Suma	17	515	1 (Nippon Express Co., Ltd.)	1
Tarumi	30	2,076	1 (Nippon Express Co., Ltd.)	4
			1 (Yahagi), and 2 (Shiroishi)	
Nishi	13	515		

3. Relief material distribution depots

Depot name	Destination ward	Distribution firm	Number of trucks	Number of people
(1) Warehouses at Maya Wharf	Higashinada and Nada	Nippon Express Co., Ltd.	60 (4 fork lift trucks)	19
(2) Shin Kobe Station	Chuo, Hyogo, and Nagata	Sagawa Kyubin	40	120 (on a 24-hour basis)
(3) Silver College	Kita	Hitachi Butsuryu	28	58, 45 (Safety Cooperation Committee), 10 (Shibusawa), and 10 (Middle-aged and Elderly Association, during the day and night)
(4) Green Arena	Tarumi and Suma	Yamato Transport Co., Ltd.	3	12, 7 (Safety Cooperation Committee, 2 shifts)
Total			131	348

4. Warehouses

(5) K-ACT	Storage of materials not scheduled for immediate delivery	4 fork-lift trucks	20 people (Port Civil Work Cooperation Committee)
(4) PC6	Ditto	1 fork-lift truck	30 (Inoue, on a 24-hour basis)

5. Distribution of postal packets (at Nishi Gymnasium)

5 trucks and 16 people (Safety Cooperation Committee)	4 trucks and 4 people (Osaka City) (Osaka University of Foreign Studies from February 4 onward)

6. Distribution of parcels (Sakai City Office)

One truck, two pickups, and 6 people ((Osaka University of Foreign Studies)

7. Health Bureau (Medical Team)

10 taxies, one van, and 6 people (**Kinki Taxi**)

8. Environmental Bureau (roadside garbage collection)

5 trucks (Middle-aged and Elderly Association), and 34 trucks (Hyogo Prefecture Construction Industry Association)

9. Economic Affairs Bureau

One van (Civil Work Cooperation Committee)

10. Nagata Ward

One truck (Akabo)

Total: 284 trucks, 549 people, and 13 fork-lift trucks, as of February 3)

(Reference data: 294 trucks, 547 people, and 13 fork-lift trucks, as of February 2)

(3) Two weeks after the earthquake and later

1) Life-support supplies

Regarding food, main meals in boxes were ordered by the Kobe City Office and transported to evacuation centers from processing plants twice a day, morning and evening. Supplies such as extra food (cookies, etc.) and daily necessities were also delivered from the depots, but demand was decreasing. Once clothing and blankets had been delivered, kerosene and shampoo, etc., was distributed. Many volunteers were at work in evacuation centers.

2) Waste

Piles of domestic waste on the streets were prominent in walking around the disaster area. Almost no waste accumulated during the disaster had yet been collected: probably less than one percent of the total. Few garbage disposal trucks were operating in the area. A detailed survey of waste collection proved impossible.

It is clear, however, that the disposal of waste will become critical in the near future. It is estimated that the amount of waste generated by the disaster amounts to 10 million tons. Assuming that this will all be transported using 4-ton trucks, 2.5 million truck journeys will be needed. With a capacity of only 20 thousand vehicles per day at the Shukugawa cross section, this amount of disaster waste comes into clear perspective. Naturally, there is a considerable amount of combustible waste such as wood. At present, waste trucks are operating in the north-south direction, taking waste to reclaimed land where it is being incinerated, so this is not a problem in terms of traffic. However, a massive amount of waste will still need to be disposed of on reclaimed land outside the traffic control area. From this viewpoint, the devastation of port facilities is a serious blow. The massive amount of disaster waste involved is almost certainly too much to pass through the Shukugawa cross section. Accordingly, urgent temporary repairs to port loading facilities are essential, and the demand for transportation must be estimated and used as soon as possible as a basis for transportation planning.

3) Reconstruction-related materials

Lack of time prevented a thorough survey of the distribution of reconstruction-related materials. Roughly speaking, however, it is clear that the amount of reconstruction-related materials required will be approximately equivalent to the amount of waste. Since construction materials are packed differently from waste and can be delivered by heavy truck, the transportation loading is somewhat different, however. Despite this, it will be difficult for the Shukugawa cross section to handle the demand. This also awaits the restoration of port facilities. The port should be used wherever possible for the delivery of reconstruction materials, but it will also be necessary to make use of land transportation in many cases. Accordingly, in this regard too, it is necessary to estimate the demand for transportation and use this as the basis for transportation planning as promptly as possible.

4) Industrial raw materials and finished products

Regretfully, we were unable to investigate the flow of raw materials for industry. Besides direct losses of about ¥10 trillion caused by the disaster, industry will also begin to suffer indirect losses resulting from inadequate flows of production materials, as mentioned previously. A survey needs to be carried out as soon as possible, and the necessary countermeasures should be taken jointly by the government, private, and academic sectors.

4. CONCLUSIONS

Since there was little time to set up a survey, it was impossible to make scientifically based suggestions for effective improvements. With regard to physical distribution covered in Section 3 in particular, we were only able to survey some of the life-support supplies and could not even touch on the flow of people. Naturally, reliable suggestions should be made only once the movement of traffic, supplies, and people have been fully elucidated. In view of the urgency of things, however, the authors have in fact stuck their necks out and made some suggestions in Section 2.6. Differences of opinion and repudiations are inevitable, and it is possible that the authors have wrongly interpreted the situation. Responsibility for all such shortcomings lies not with the survey teams nor the JSCE, but rather with the authors. More concrete suggestions will have to await detailed surveys and the results of analysis. The authors look forward to the collaboration of those concerned and volunteers across the country.

5. FUTURE DIRECTION OF SURVEYS

5.1 Traffic surveys

As already stated, the limited time available means that road traffic data are as yet inadequate. This preliminary survey aimed only at attaining a rough understanding of the situation. On-going surveys of road traffic will be necessary. Fortunately, many universities are now gearing up for collaboration over such surveys. These surveys need to focus on the following issues:

① An analysis of the characteristics of traffic flows at cross sections on the boundary of the disaster area

- A continuous survey for 12 hours because of the large hourly fluctuations
- A continuous survey for a week because of the large daily fluctuations
- An on-going survey to elucidate long-term trends consisting of:

  A survey once a week for the first three months
  A survey once a month for six months afterwards
  A survey of cross sectional traffic volumes at peak periods, if possible
- An analysis on traffic volumes at congested locations using aerial photographs

② A roadside OD survey
A roadside OD survey on the boundaries of the area by vehicle type

③ A stochastic analysis of traffic volumes generated and attracted
A roadside OD survey at points of congestion, if possible

④ An OD survey at waste disposal sites
Development of plans for treating domestic and disaster waste through interviews with administrative offices
Interviews with drivers at waste disposal sites

⑤ A survey on the distribution of waste
Collection of distribution data on collapsed houses and buildings from administrative offices

⑥ A survey of the number of vehicles and average trip distance by the type of construction service

Elucidation of the total number of vehicles involved in restoration work by organization to estimate the average trip distance from the range of operation: for instance, water supply work and civil engineering work

5.2 Physical distribution surveys

The survey mainly covered the transportation of life-support supplies. The significance of these supplies was high during the initial emergency (of three days to one week after the earthquake), but has since been decreasing, at least in terms of traffic. Further detailed surveys needed as regards life-support supplies are as follows:

① Collection of the databases from the Regional Welfare Section of Kobe City Office to allow an analysis of the characteristics of material flows

② Collection of the databases from Hyogo Prefectural Office in the same manner

③ Collection of databases from Ashiya and Nishinomiya City Offices in the same manner

As regards disaster-related waste, priority should be given to the estimation of the amount of combustible waste, and the demand for transport out of the area should be predicted.

④ An analysis of the quantity and distribution of waste needing to be burned or transported out of the area

⑤ A survey of the distribution and capacity of treatment facilities by type of waste

⑥ A survey of treatment capacity within the area generating the waste

Further, in order to obtain temporal information on traffic loading:

⑦ A survey of treatment capacity within the area generating the waste

⑧ An analysis of transportation routes

In order to analyze the amount of reconstruction materials attracted and transported, and the means used to transport them:

⑨ Elucidation of rebuilding plans and plans for the transport of reconstruction materials

In order to analyze the flow of raw materials and finished products for industry:

⑩ A survey of the details and distribution of damage by industry

Materials needed by industry can be elucidated by analyzing the following data:

⑪ Material flows in the Hanshin metropolitan area

⑫ The net flow of freight on main roads across the country

⑬ Inter-industrial relation tables for Kobe

Once these surveys and analysis are complete, it will be possible to make suggestions regarding transportation policies that will assist in restoring the damage to industry in Kobe and minimizing future losses.

A Report by the Waste Disposal Survey Group

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1. INTRODUCTION

The amount of rubble generated by the Great Hanshin Earthquake is estimated at ten to twenty million tons. Most of this rubble can be regarded as construction by-products, and must be disposed of properly in accordance with Recycle Plan 21. The generation of such a massive amount of rubble in an extremely limited area in a few minutes poses many difficulties and questions. Given the urgent need to remove the rubble, recycling would seem difficult. Although it is essentially a construction by-product with the potential for use as raw material, there is in practice no alternative but to suitably dispose of it as waste. In this paper, we regard the rubble as "disaster waste" and describe the current problems facing disposal.

Supplementary notes:
A construction by-product is something generated as a result of construction work. It can be classified into three types: soil generated by construction activities which can be used as a raw material without processing; waste usable after recycling such as concrete and asphalt blocks; and waste that cannot be used as raw material.
According to the Waste Disposal and Public Cleaning Law, waste is defined as bulky refuse, cinder/ash, sludge, human waste, waste oil, waste acids/alkalis, carcasses, other dirt, and surplus materials. Of the waste generated in normal business activities, 19 categories prescribed by a Cabinet order, including cinder/ash, sludge, waste acids/alkalis, and waste plastics, are known as industrial waste. The remainder is called general waste. Explosive, toxic, or infectious waste which pose danger to human health and the environment are called specially controlled waste. The law defines only these classes of wastes. Waste generated by disasters is not specifically defined in law. However, Article 22 of the Waste Disposal and Public Cleaning Law prescribes that some of the cost of waste disposal, particularly after a disaster or similar event, is to be covered by government subsidy. The rubble generated in this earthquake is idiomatically referred to in this paper as disaster waste. This paper defines disaster waste as rubble from structures (i.e. houses, buildings, and civil engineering structures) destroyed by the earthquake.

2. SURVEY METHODS

Surveys were carried out by conducting interviews in relevant governmental offices, site surveys of temporary waste sites, and observation of waste movement on main roads.

Government offices visited: Waste Disposal Control Headquarters in the Kobe City Office, the Collapsed Houses Disposal Section of the Nishinomiya City Office, and the Construction and Development Coordination Division of the Economic Affairs Bureau at the Ministry of Construction

Temporary waste sites surveyed: Koshienhama, Nishinomiyahama, Uozakihama, and Nadahama

Roads observed: Shukugawa cross section in Nishinomiya (National Highways 2 & 43, Rinko Road, etc.); Myohoji cross section in Suma Ward (National Highway 2, Prefectural Suma-Akashi Route, etc.); Rokko cross section (National Highway 428, Shin Kobe Tunnel, etc.)

3. CURRENT SITUATION OF WASTE

3.1 Disaster waste

(1) Quantity and distribution

First estimates of the quantity and distribution of waste by source have been released. According to an announcement on January 26 by a liaison committee consisting of the Ministries of Health and Welfare, Construction, and Transport, disaster waste from houses and buildings amounts to about 5 million to 6 million tons, and that from public facilities such as roads, railways, and port facilities as about 3 million to 5 million tons. According to an announcement by Hyogo Prefecture, the amounts are 6.5 million to 7.8 million tons from houses and buildings, and 3 million to 5 million tons from public facilities such as railways, not including roads and rivers. These estimates were obtained by multiplying the volume of the damaged and destroyed structures by a unit quantity of waste. The reason for the higher estimates by Hyogo Prefecture is probably that the details of the damage have been further clarified. There is a need to estimate the quantity and distribution of disaster waste more accurately to allow the development of future waste disposal plans.

(2) Removal

The removal of disaster waste has just began. Until now, much of it has been left as it was, interfering with traffic on the streets (Photo 1). Disaster waste from houses and buildings includes furniture, appliances, everyday items, and documents, besides wood, metal, and concrete . These types of waste need to be classified before disposal because their properties and disposal methods are different. So far, however, they have been transported to temporary waste sites as is after separating metal, such as steel frames and reinforcement, at the disaster site (Photos 2 and 3). Another problem at waste disposal sites was that water could not be sprayed to keep down dust since water supplies had not been restored yet. Aside from the need to apply flexibly the disposal standards after a disaster, there is clearly also a need to consider these issues to ensure that the waste is properly disposed of as quickly as possible.

Photo 1 Street rendered impassable by the collapse of a parking building (at West Japan Railway Company's Ashiya Station)

Photo 2 Disaster waste from collapsed buildings (in Nagata Ward, inadequately classified and sprayed with water)

(3) Temporary waste sites and classification

Since it was necessary to remove promptly disaster waste from the immediate area of disaster, and the classification was difficult on site, it was transported to temporary waste sites for the time being. Until early February, however, only 22 sites of about 60 hectares were available within Hyogo Prefecture. This was inadequate. Devastated port facilities made it impossible to remove concrete fragments by ship. Little progress was made for the incineration and volume-reduction of wooden waste at incineration plants, because these could not be operated around the clock for lack of cooling water. This caused accumulation of waste at temporary sites as residence time at these sites increased. This led to difficulties for classifying waste sufficiently. It is easy to

Photo 3 Disaster waste being transported by truck (on Nishi Kobe Toll Road to Fusehata temporary disaster waste disposal site)

see that the demand for the transport of disaster waste to reclamation sites will increase as reconstruction efforts pick up. But if things continue as now, the situation would become more serious. Already, waste wood is being burned in the open at the dumps, leading to concern about the ill-effects on the environment. There is now an urgent need to secure more temporary waste sites and to install mobile plants for crushing, classifying, and recycling waste (Photos 4, 5, and 6).

Photo 4 Temporary disaster waste site
(at Koshienhama in Nishinomiya)

Photo 5 Temporary waste wood dump
(reaching a height of about 10 m)

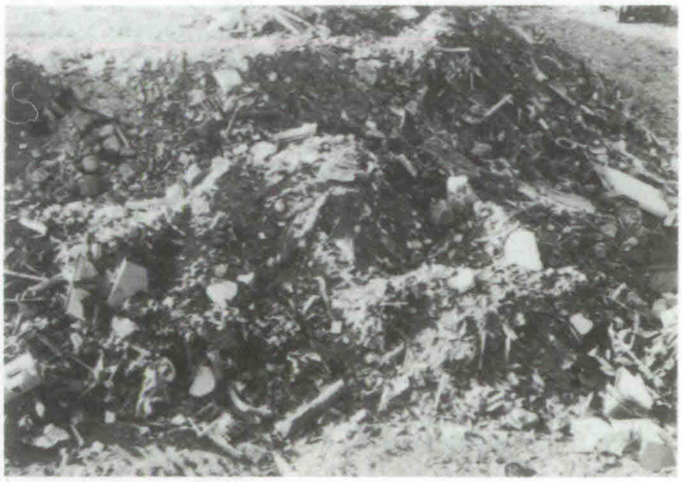

Photo 6 Concrete waste (classified roughly but still containing wood, etc.)

(4) Final disposal and recycling

Ash and concrete fragments are to be brought to landfills either at sea or inland, while metal waste will be recycled as scrap. The capacity of large-scale public waste disposal facilities around the disaster area exceeds the estimated amount of disaster waste, as shown in Table 1. At first glance, the situation seems under control. It should be pointed out, however, that there is increasing need to reduce waste volume by classification and incineration, and that finding further available space is also critical. Transportation of disaster waste is also an important problem. It will be necessary to secure final disposal sites as close to where it was generated as possible. The dumping of wooden waste, furniture, appliances, and documents in reclamation sites may lead to danger of gas generation as decomposition and decay proceeds, or ground settlement, and reduced bearing strength. This may have an adverse effect on the future use of reclaimed land. In this regard, the need to classify fully the disaster waste cannot be over-emphasized.

Table 1 Remaining Capacity of Disposal Facility

Disposal facility	Remaining capacity (million m^3)
Phoenix Center (Offshore reclamation site in Amagasaki)	400
Phoenix Center (Offshore reclamation site in Izumi-otsu)	1,100
Kobe (Fusehata landfill site)	800
Kobe (Augo landfill site)	700
South District at Osaka Kita Port	200
Sakai 7-3 District at Senpoku Port in Sakai	40
Total	3,240

According to Recycle Plan 21 announced by the Ministry of Construction on April 4, 1994, 48% of concrete waste is being recycled and 90% is targetted for the year 2000. Because of this sudden and massive waste burden in the limited area of the disaster, the balance between supply and demand in terms of recycling has been disturbed. Reclamation seems to be the best method of disposal, given the constraints of both time and cost. As stated in Recycle Plan 21, however, concrete waste is a valuable resource. Accordingly, it appears necessary to extend the bounds of the supply and demand balance; that is, to seek the possibility of disposal over a wider area.

(5) Transportation

The report on transportation facilities pointed out that emergency vehicles transporting relief and reconstruction-related supplies became stuck in traffic jams on main roads and that emergency vehicles themselves were a cause of congestion. As with domestic waste, disaster waste really needs to be disposed of within the area where it is generated. However, the transport of disaster waste to temporary waste sites mainly entails north-south movements, so the load on the more heavily used east-west routes is probably very little. Waste concrete and asphalt-concrete blocks will be used for landfill, mainly in the sea. However, ground transportation of waste to the Phoenix Center, the assumed final disposal sites (in Amagasaki and Izumi-otsu), through the Shukugawa cross section in Nishinomiya would be impossible, as stated in the report. Transportation would have to be mainly by ship rather than by land. Thus the temporary repair of port facilities to allow waste to be loaded onto ships is an urgent necessity. The effective use of port facilities and transport of disaster waste needs urgent study from a broad perspective outside the government sector. It is certain that the demand for waste transport, and hence traffic volumes, will suddenly increase as reconstruction work accelerates. The establishment of transportation and traffic control plans which make the most of limited road capacity is an issue requiring urgent attention. Another matter of concern is dust generation and related problems during transportation; it may be required to make the covering of disaster waste with sheets during transportation mandatory.

3.2 Domestic waste

The disposal of domestic waste is also becoming a major problem. It was noticed that the collection and disposal of domestic waste was lagging behind in the disaster-hit area (Photo 7). At Kobe's Clean Center, an incinerator complex for domestic waste, three incinerators out of five were not operating as of February 3 owing to the lack of gas and water supplies. Consequently, temporary storage has further become a problem due to lack of storage areas. It has become difficult to classify domestic waste in the available storage areas (Photo 8). In the less-severely damaged districts within the disaster area, it is clear that the amount of domestic waste will soon increase as normal life and economic activity recover. Thus, the accumulation of domestic waste will become another matter of concern.

Photo 7 Domestic refuse blocking a sidewalk

Photo 8 Temporary domestic refuse dump (at Uozakihama in Kobe)

4. SUGGESTIONS

The authors are open to criticism since the suggestions they make here are rough-and-ready and lack hard data and analysis to back them up; this is inevitable given the limited time available for the survey. Thus the ideas presented here are purely their own personal opinions regarding the disposal of domestic waste including its removal, temporary storage, classification, disposal, recycling, and transportation. The authors do not hesitate to accept responsibility for any consequences of making these personal opinions known.

(1) Efficient use of temporary waste sites and classification

As a consequence of the shortage of temporary waste sites mentioned previously, it is clear that the temporary storage sites will soon reach capacity if waste continues to arrive at the present rate. It is necessary to formulate measures to secure more temporary waste sites as well as to utilize them more efficiently. Such measures can be classified roughly into the following types: improvement of temporary waste sites such as by adding mobile crushers and classifiers; improvement of the overall waste disposal system such as by restoring incineration plants to operation; temporarily restoring port loading facilities for waste; and establishing waste transportation systems.

(2) Establishment of transportation systems

The demand for road transportation will rise as reconstruction work, disaster waste removal, and commercial and business activities pick up and daily life gradually returns to normal. Given that the capacity of main roads cannot be increased over the short term, traffic jams will get worse. To prevent this, it is necessary to improve regulations, implement controls to smoothen the present rapid swings in road use with time, and improve the operation of transportation systems. As part of this overall scheme, there should be discussions on what routes should be used for the transportation of waste. It may even be necessary to permit vehicles carrying waste to operate only at night. In this regard, studies must look into how to ensure the availability of transportation routes to loading sites, improve traffic regulations, and coordinate land and ship transportation.

(3) Work toward recycling

The rational way to dispose of waste generated by this disaster seems to be to classify the waste, reduce its volume, and finally use it as landfill. As restoration work moves into top gear, large quantities of construction materials such as gravel will be needed and large amounts of construction by-products will be generated. In preparation for this, efforts should be made to recycle concrete fragments.

(4) Need for disposal over a wide area

In order to maximize use of available crushing and classification facilities to ensure a balance between supply and demand in the recycling of construction by-products and to increase the efficiency of transportation, a solution to the problems should be sought over a wide area. The same can be said for the time being as regards general waste.

(5) Developing disaster waste disposal programs

Suggestions (1) through (4) above correlate closely. This means that a significant issue for developing these programs is to ensure that they are mutually consistent and coordinated. Thus far, each local government has set up its own disaster control section and headquarters, making great efforts to alleviate problems. The need now for coordination of related functions and systematic management and implementation of programs cannot be overemphasized.

It is also important to develop removal programs for waste that cannot be taken away immediately because of limitations in space at temporary sites. It has already been decided to remove damaged houses, apartments, and minor business structures at public expense in accordance with a removal program. (Removal earlier than scheduled in this program will have to be paid for by the owner, although this issue is still under discussion.) In developing the removal program, transportation capacity, classification capacity, and minimization of secondary effects such as dust should be simultaneously considered. Efforts should focus on coordination with reconstruction and housing improvement plans.

Earthquake Engineering

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1. INTRODUCTION

The sequence of events in a disastrous earthquake might be summarized as follows: crustal movement at the seismic source, seismic waves radiating from the source, seismic waves traveling through the ground, response of structures to the ground motion, damage to structures and people, and finally, remedial action. Earthquake engineering is a field of study that aims to regard such an earthquake in its entirety. However, the remedial phase is not described in this paper. Discussions of urban planning appear in a separate document.

When an earthquake-stricken area is far from the hypocenter, there is no strong correlation between the seismic wave radiated from the hypocenter and the wave hitting the area. Much of the information we have about seismic sources does not help directly in estimating earthquake damage, and standard earthquake resistance requirements are based on this assumption. However, since source characteristics and earthquake damage are strongly correlated in the case of near earthquakes like the present one, the comprehensive approach of earthquake engineering is necessary. To this end, it is necessary to first formulate a model which can explain a diverse range of geoscientific knowledge and opinions related to crustal movements in a consistent manner, and then systematize it without inconsistency with structural engineering knowledge of the process by which structures are damaged. This is the concern of the author.

Observing transient events and phenomena immediately after an earthquake and gathering information on which to base reconstruction plans (including the review of design codes) are important activities of urgency second only to immediate relief activities. These objectives have been met on the whole by the 1st and 2nd Site Investigation Team. Accordingly, the purpose of the 3rd Investigation Team is to implement a deeper investigation based on the results of these earlier surveys. The aim of site surveys is to pick up relevant clues. This report makes use of other knowledge as well as information obtained in the site survey to determine the points at issue.

2. AREAS SURVEYED AND DAMAGE OBSERVED

(1) Areas surveyed and major damage modes

(a) West Japan Railway Company's Sanyo Shinkansen (Bullet Train Line) between the Muko River and Rokko Tunnel east entrance (damaged RC elevated railway columns)

(b) West Japan Railway Company's Tokaido Line between Sumiyoshi and Rokko-michi Stations (damaged RC elevated railway columns)

(c) Kobe Express Subway at Daikai Station (damaged central RC columns)

(d) Meishin Expressway to the north of Nishinomiya Toll Gate (overturned RC bridge columns)

(e) Chugoku Expressway to the north of Takarazuka Interchange (damaged and settled RC bridge columns)

(f) Wangan Route of the Hanshin Expressway between the east end of the Maya Bridge and the area to the south of West Japan Railway Company's Kobe Station (damaged RC bridge columns, steel bridge columns, steel girder bearings, etc.)

(g) Kobe Route of the Hanshin Expressway at the Tsuga River and westward (damaged RC bridge columns)

(h) Built-up areas in Nada and Higashi Nada Wards in Kobe and Ashiya (damaged RC buildings)

(i) Nikawayurino-cho (collapsed hillsides)

Of the above sites, (a) through (h) with the exception of (e) were surveyed in conjunction with the Concrete Structure Survey Group of the 3rd Survey Committee. During and after the survey, the author consulted with concrete structure experts regarding analytical methods and conclusions, obtaining not only the results of analysis but also the latest data on concrete structures. Since elevated RC railway and roadway structures are distributed widely over the disaster area and were heavily damaged, they became optimum structures for use in constructing indexes for the comparative evaluation of input earthquake motions. As a researcher holding interdisciplinary discussions with scientists on a daily basis, the author found the survey a helpful reminder of the importance of interdisciplinary research in civil engineering.

(2) Other areas surveyed and major damage modes

This survey was the second for the author, who had previously made observations in the areas listed below. Information obtained in these previous observations is also used in this report.

(a) The northern part of Awaji Island and areas around the Akashi Strait (damaged houses and slightly altered ground conditions)

(b) West Japan Railway Company's Tokaido Line around Kobe and Sannomiya Stations (damaged civil structures and buildings)

(c) Hanshin Railway between Ishiyagawa and Shinzaike Stations (damaged RC bridge columns)

(d) West Japan Railway Company's Sanyo Shinkansen at Rokko Tunnel (slightly damaged RC tunnel)

(e) National Highway 43 between Sannomiya and the Ashiya River (damaged RC elevated bridges and houses)

3. DETAILS OF DAMAGE

(1) Development of observation networks after the earthquake

Researchers developed a nationwide network for geophysical and geochemical observations immediately after the earthquake and began surveying the faults. The Earthquake Research Institute (Earthquake Prediction Data Center) set up a special mailbox to support the exchange of information. In peak periods, 300 items of scientific exchange were distributed daily, and a number of applications for registration came from abroad. Although initially there was some trouble when one institute halted the dispensing of information after the media picked up on it and used it incorrectly in a broadcast, this system did enable researchers to take action on the basis of the most up-to-date scientific information, including the location of research teams and traffic information. The possibilities opened up by this milestone event deserve further study within the JSCE.

Of the diverse range of observations and items surveyed, those considered to be important from an engineering viewpoint are described here. Large-scale networks for earthquake observation consist of seismographic and GPS (Global Positioning System) geodetic networks. Of these, the observation stations operated by national universities are mapped in Figure 1. Another seismographic concern is strong ground motion and, further, the active faults on the ground and under the sea have been investigated by many seismologists.

(2) Widespread crustal movement

The first task is to ascertain what happened on a large scale. Generally speaking, large-scale observations are limited in what they can tell us about small-scale events. For instance, crustal movements on the large scale tell us almost nothing about local movements which are important from an engineering viewpoint. Similarly, an understanding of large scale hypocentral mechanisms does not allow us to specify the characteristics of strong ground motion which are significant in terms of engineering, such as maximum acceleration. However, since such large-scale data are stable — meaning that the large library of existing data does not contradict itself — it can provide important information as a basis for discussion.

Of such large-scale data, the most abundant is ground deformation data. This is obtained from GPS data and interference-processed images using synthetic aperture radar. Both are based on microwave transmissions from artificial satellites. These data provide the following understanding:

(a) Kobe and its vicinity was uplifted towards the mountains (north) and subsided on its seaward side.

(b) The west coast of Awaji Island was uplifted towards the mountains (southeast) and subsided on its seaward side.

Point (a) is in harmony with the formative history of the Rokko Mountain system and (b) is consistent with the results of surveys on ground slip at the Nojima Fault. Furthermore, both are consistent with the distribution of gravity, which reflects underlying faults. Accordingly, these can be regarded as describing the fundamental earthquake behavior.

(3) Identification of main shock events and faults generating the earthquake

According to CMT analysis on the long-period components of seismograms obtained from an international network of broad band seismographs, the main shock consisted of three main seismic events. All were nearly pure lateral displacements and the vertical component was small. Since some seismologists interpreted the second and third seismic events as showing marked vertical components, it may be deduced that the vertical motion was characterized by high acceleration although the displacement was small. (It is impossible to see this in CMT analysis because of the limitation of the latter's resolving power.)

The first seismic event (a moment magnitude of 6.8) seems to have been caused by slippage at the Nojima Fault on the west coast of Awaji Island. The second and third events (with moment magnitudes of 6.3 and 6.4, respectively) are thought to have been caused by motion of faults on Honshu, but there is no accurate location information to identify the faults.

Roughly speaking, there are two schools of thought as regards the location of the fault which generated the devastating third seismic event:

(a) A powerful unidentified fault possibly existing to seaward (and immediately below the devastated belt described later) of the existing active fault groups slipped. (This is referred to in this paper as the unidentified Kobe-Nishinomiya fault.)

(b) A known fault system existing in the Rokko Mountains to the north of Kobe slipped.

Further study is required to check for unknown faults, since this could affect future city planning. The Earthquake Prediction Committee does not accept that the unidentified Kobe-Nishinomiya fault was the source of the damaging motion. Their primary reasoning is that the horizontal movement on GPS records at Kobe University was only a few centimeters, and that if the unidentified fault slipped by the order of one meter — as shown in seismological data such as CMT — this would be inconsistent with deformation on the ground. Another argument is that all of the hypocenters of aftershocks were concentrated on the existing Rokko fault system. (Figure 2)

However, since there are major assumptions in computing ground displacements from the amount of crustal slippage, there is a need to understand the three-dimensional structure, such as the curvature of the fault faces, in more detail. Since the same can be said for the relationship between the location of aftershock hypocenters and faults, it would be risky from the engineering viewpoint to reject the hypothesis of the unidentified fault. Geologists are planning to conduct an acoustic exploration to obtain conclusive evidence.

(4) Tectonic lines and the distribution of aftershocks

There are three tectonic lines (active fault systems) in the disaster area. (Refer to Figure 2.)

(a) The tectonic line of the Nojima Fault on the west coast of Awaji Island

(b) A tectonic line connecting the Kusumoto Fault on the east coast of Awaji Island with the Egeyama Fault and the Rokko Fault system (Suwayama and Gosukebashi Faults) on the mainland. This line is nearly parallel to (a).

(c) The Arima-Takatsuki tectonic line demarcating the Rokko Fault system at its northeast end. Although there is not enough information so far, this tectonic line needs to be carefully considered both as regards this earthquake and those in the future.

Of the three tectonic lines, (b) is continuous as shown by some faults surveyed on the seabed along its length, but (a) comes to an end at the northern tip of Awaji Island and there is no evidence as yet of an extension northwards. Generally speaking, stresses concentrate and the crust movement is complex at the ends of a fault. The northern end of Awaji Island and the vicinity of the city of Takarazuka are at these points.

Most aftershocks occurred at the relatively shallow depth of about 10 km, and mostly along the tectonic lines (a) and (b). Aftershocks along tectonic line (b) were concentrated in Hyogo and Higashinada Wards in Kobe. Many aftershocks occurred in a tiny area to the west of Takarazuka.

(5) Crustal movements in the Akashi Strait

As previously stated in Section (2), the large-scale crustal movements in the area caused warping at the surface. Particular attention should be paid to movements around the Akashi Strait, since this is on the saddle (theoretically, a singular point) and is active as described below.

(a) The main shock of the Hyogoken-Nanbu Earthquake occurred there.
(b) An earthquake of magnitude of 6.2 occurred there in November 1916.
(c) Many relatively large-scale aftershocks occurred at the northern part of Awaji Island.
(d) The Akashi Strait Bridge suffered large relative vertical and horizontal movements between its mainland and Awaji Island abutments of more than 1 m.

Some regard the Akashi Strait as the starting point of the two fault lines (a) and (b) described in Section (4). If this is true, then it is also true that the seabed in the strait forms a tension field. As evidence of this, earthquakes have occurred there with a hypocentral mechanism of normal fault type. The faults on the seabed under the Akashi Strait are now undergoing sonic explorations. (But no additional fault has been detected so far.) Thus, the Akashi Strait forms a singularity in the large-scale crustal movement and consists of a complex stress field. The overall mechanism of crustal movement in this earthquake cannot be explained in terms of slippage of plane faults. This will be studied in detail later.

Around the north end of Awaji Island (near the anchorage of the Akashi Strait Bridge), there is exposed granite of the Ryoke belt which forms the bed of the strait. This granite offers the potential for monitoring of crustal activities in the strait. The author and other survey members began continuous observations using high-sensitivity tiltmeters as part of the emergency survey. Depending on how things work out, consideration should be given to continuous monitoring of crustal activities using a compound measuring system integrated with high-accuracy seismographic and geodetic instrumentation. This is now under review by an interdisciplinary team at the institute as a way to predict crustal activities of the strait in the future.

(6) Crustal activity to the northeast

A survey independent of that undertaken by the Concrete Structure Survey Group was made in the northeast of the disaster area because seismic motion in the area was considered very important for the reasons in (4) above. Surveys of faults in this area are now being undertaken by experts. It is expected that the source of the earthquake motion will be clarified as this detailed survey progress. The relation between collapsed hillsides in Nikawa Yurino Town and crustal movements is also expected to be clarified. Here, we look seismo-geologically at the effects of crustal movements caused by the earthquake on crustal stress along the Arima-Takatsuki tectonic line.

The objective of the survey in the area was to observe damage (e) and (i) in Section 2. (1). The percentage of damaged houses was found to be unexpectedly high. The modes of damage to the Chugoku Expressway are described here. The damage occurred on the south-facing slopes of Mefugaoka (in Takarazuka City) to the south of the Arima-Takatsuki tectonic line. Bridge columns fractured due to shear forces induced by ground motion in the longitudinal (southeast-northwest) direction, particularly in the southeast direction. (However, no bridge girders fell.) This type of damage can be explained because the bridge columns are very low. In contrast with the bending fractures commonly noted in Kobe, there was almost no damage to the internal steel reinforcement in these columns. The damaged bridge columns were confined to this small area. The damage seems to be closely related to the amplification of earthquake motion on the slope and the movement of the slope itself. The reasons for this are as follows:

(a) Because the slope consists of terraces of soft gravel, sand, and clay overlaying a slope of the Osaka stratum group tilted upward in the northern part, it appears that it has a tendency to move laterally during earthquakes. In fact, bridge columns with residual displacements corresponding to the lateral movement were observed.

(b) Bridge columns were found to have settled at about 300 m to the south of the damage location.

Since the damage location is located right above the Kiyoshikojin Fault, a branch of the Arima-Takatsuki tectonic line (and also on a direct extension of the above-mentioned Gosukebashi Fault), careful analysis of its behavior during earthquakes is needed.

(7) Strong ground motion characteristics

Strong ground motion seismograms recorded at Kobe Marine Observatory and Kobe University were made public at an early stage. This contributed greatly to the work of researchers. The earthquake was featured not only by large amplitudes but also by slow motion. This was estimated from the maximum velocity of 90 cm/sec. in contrast to a maximum acceleration of 1 g at most. Compared with recent large earthquakes, such as the Northridge Earthquake in the U.S. and the Kushiro-oki Earthquake in Japan, computations indicate that the response spectrum was small for periods of less than one second but extraordinarily large for periods between one and two seconds.

All seismograms indicate that the waveforms of principal motion were very simple. The horizontal north-south components were very strong, with two large peaks in the south direction. That is, the motion changed rapidly from north to south, and the change in velocity reached 100 cm/sec. The magnitudes of the two peaks on the university's seismograms were almost the same, but the data taken at the observatory shows that the two waves forming the first peak were larger and the change in velocity reached 140 cm/sec. (A change in velocity from 50 cm/sec. toward the north to 90 cm/sec. toward the south.) The direction of ground motion continued from north -> south -> north -> south, and the maximum displacement of the second wave to the north was synchronized with the maximum acceleration in the southerly direction. This can be interpreted as meaning that this second wave was the one with the most power. The steel reinforcement in RC bridge columns appears to have undergone hysteresis in yielding, elongation, and buckling during this one cycle, losing cross-sectional resistance in a moment that resulted in collapse.

Large vertical accelerations were reported by the mass media after the earthquake, but the reliability of this information is low as a result of questionable data processing. Many data support the view that the vertical acceleration was about half the horizontal acceleration. This would be in harmony with the results obtained by the Concrete Structure Survey Group, which visited the sites with the author. Section 6.(3) of their survey report seeks to link the contribution made by vertical earthquake motion to the many overturned bridge columns in the same (northerly) direction, but the author considers there is no need for this.

Clarifying the mechanism by which waves with these distinctive frequency characteristics were generated will be a subject for future study. If it is found to be true that the principal motions were in the north-south direction, this would have great value in the design of elevated structures of the main traffic routes running east-west.

(8) Existence of particularly hard-hit belt

Geologists reported after their surveys that a very narrow belt-like area about 3 km wide along the coast between Kobe's Suma Ward and Nishinomiya was particularly badly hit. This is backed up by the 7 on the seismic intensity scale registered by the Japan Meteorological Agency in this area. We now have to determine why there was such a concentration of damage in this area. There are two schools of thought on the primary causes of this damage, corresponding to the argument over the location of the faults that were the origin of the earthquake described earlier.

(a) The unidentified Kobe-Nishinomiya fault moved immediately below the hard-hit area.

(b) There was no specific fault movement immediately below the belt, but large amplification resulted from the relationships between ground structures and the input earthquake motion.

The latter argument contends that the strong earthquake motions in the area were amplified during the process of propagation. The mechanism of this amplification was determined through a comparison of the amplitudes of aftershocks at many locations. It is quite easy to imagine that the main shock was amplified considerably, and in fact it is comparatively easy to reproduce such a phenomenon in numerical calculations. However, it is not so easy to select the true one among the computational results, since the conditions under which the amplificaiton occurs are not unique; there are many combinations of parameters that yield amplification, and tiny changes in the combinations may lead to great differences in the results (that is, the model has large parameter sensitivity). Accordingly, it is difficult to reach the truth using these results.

Whichever of (a) or (b) above is true, it is important to be able to explain the characteristics of the seismic motion in a qualitative and consistent manner. A detailed survey of the direction in which tombstones overturned points to the role of a fault immediately below the belt zone, but the location of such a fault has not yet been determined.

In terms of engineering, simply demonstrating the reason of the generation of the east-west hard-hit belt zone is not enough, because even within the belt zone, the damage occurred in an uneven pattern. There are some north-south lines of particularly intense damage, including one from the west end of the Egeyama Fault (between Yumeno Town and Kamisawa Road), one around Sannomiya, one around from West Japan Railway Company's Rokko Michi Station to Hankyu Railway's Shinzaike Station, one to the east of the Sumiyoshi River. This is a subject of future study.

4. CAUSES OF DAMAGE

(1) Lack of disaster prevention measures and alert systems

According to news reports, the disaster area (the Kobe area) was insufficiently prepared for earthquakes. There are some demands for the local government to take administrative responsibility for the disaster. Although it has been known for certain that the Kobe area lies over major fault systems, and some seismologists have warned of the danger of earthquakes, there was also opposition to this view. As a consequence, the warnings failed to serve as an effective alarm. (By "effective," we mean having enough weight to cause local administrative bodies and residents to admit the need for adequate anti-earthquake measures.)

Generally speaking, the incidence of earthquakes at onshore active faults has a period of the order of a thousand years. For instance, if many faults with the highest certainty level exist, as in the Kobe area, but the activity level of the faults is B, this only describes the formal the possibility of an earthquake; it gives no information about the imminence of the earthquake. On the other hand, data on seismic activity and crustal movements is commonly used as evidence that there is no specific change suspected and that the occurrence of a big earthquake is unlikely. As far as we can see so far, our techniques for detecting precursory indications were in this case powerless. (Researchers who are saying that an earthquake was predicted are obliged to indicate the level of certainty in the predictions and inference.)

We need more efforts aiming at a short-term earthquake warning method based on observations of precursory phenomena. The present earthquake also demonstrates that medium-term predictions over a time span of ten years or so are also very important as regards city planning and disaster prevention planning. Since warnings of this type would be very different in nature, in terms of both natural science and political science, from predictions with warning made immediately before the occurrence of an earthquake, a new methodology needs to be developed. For this purpose, a joint research consisting of earthquake engineers and civil planners will be necessary.

Now that it is known that our techniques of monitoring abnormalities using geoscientific and seismological observation methods are ineffective, we must take measures against earthquakes based on accurate information about active faults. To this end, we need to develop a technology capable of detecting major underground faults at high resolution. At present, only those active faults which are exposed to the surface are surveyed by geologists. Underground data, even where it comes from close to the surface layer, is collected using large-scale geodetic and gravity data. Yet underground discontinuities can be detected even by acoustic explorations. On the other hand, active faults below thick alluvial deposits, such as the one that caused the Ansei Edo Earthquake, are considered difficult to detect with current technology. However, there are good possibilities of greatly improving subterranean resolution as borehole technology moves steadily forward and non-destructive active elastic wave exploration methods improve with study.

(2) Earthquake-resistant design codes

The assumption that modern civil structures in Japan would be resistant to the 1923 Great Kanto Earthquake has been shaken; more exactly, the new earthquake has shown that the proposition was false. In reality, civil structures in Japan are resistant to earthquakes far more intense than the *assumed* Kanto Earthquake. On the other hand, the strong ground motions of the *real* Great Kanto Earthquake are likely to have been more intense than the assumed earthquake. In this sense, the term "assumed Kanto Earthquake" is meaningless. Consequently, it is necessary to review our earthquake-resistant design codes.

The most important task of an earthquake-resistant code for structures is to guarantee the safety of structures against the assumed seismic motion. However, the assumed motion does not correspond to that actually experienced in the real Great Kanto Earthquake. What must be considered second is the durability of structures against violent tremors corresponding to the real Kanto Earthquake. Since there are considerable variations in the input seismic motion (statistically speaking, as a result of the properties of the extreme-value distribution) and the parametric sensitivity of structures — that is, the characteristics common to fracture phenomena — a concept different from that of assumed seismic motion is needed. This will be discussed separately.

The Concrete Structure Survey Group pointed out in their conclusions the significance of structural details and the engineering ability that forms the basis of such details. The author is in broad agreement with this, but would like to put forward the following ideas:

(a) Before discussing the significance of engineering ability, it is necessary to summarize the merits and demerits of each structural type.

(b) With regard to structural details, studies should look into the question of whether there is room for increasing the foolproof nature of designs by reducing dependence on engineering ability. Naturally, the author understands the significance of engineering skills and the real existence of engineering disparity. However, it is also necessary to consider seriously the fact that our ability to come up with designs capable of handling violent tremors, which requires intellectual ability and experience, is fundamentally limited. (For instance, in my opinion, changing the volume of steel reinforcement in a structure requires great expertise.)

(c) It is also necessary to study the balance of strength among structural members during violent tremors. (For example, over-designed devices to prevent girders falling resulted in heavy damage to the main structural body, and intermediate highly rigid girders were safe while bridge columns were severely damaged.)

(3) Damage to subways

The problems concerning the damage to subways have not yet been mentioned. Concerning the RC columns failed at right angles to the cross section in the center of Daikai Station on the Kobe Express Subway Tozai Line, no cause-effect relationship has been determined as of now. Although it has been postulated that this type of damage is consistent with vertical seismic motion, it is questionable whether this is a rational explanation. The failure mode at the survey point was flexure-shear fracture in the cross section close to the lower or upper ends of columns. Initially, a lack of rigidity in the ceiling and at joints between the ceiling and side walls was suspected as the cause. However, since the side walls themselves failed at other survey points, it appears that this damage cannot be explained by any simple means. Anyway, extraordinarily large ground deformations must have occurred. Accordingly, we need to determine what kind of input seismic motion can explain it.

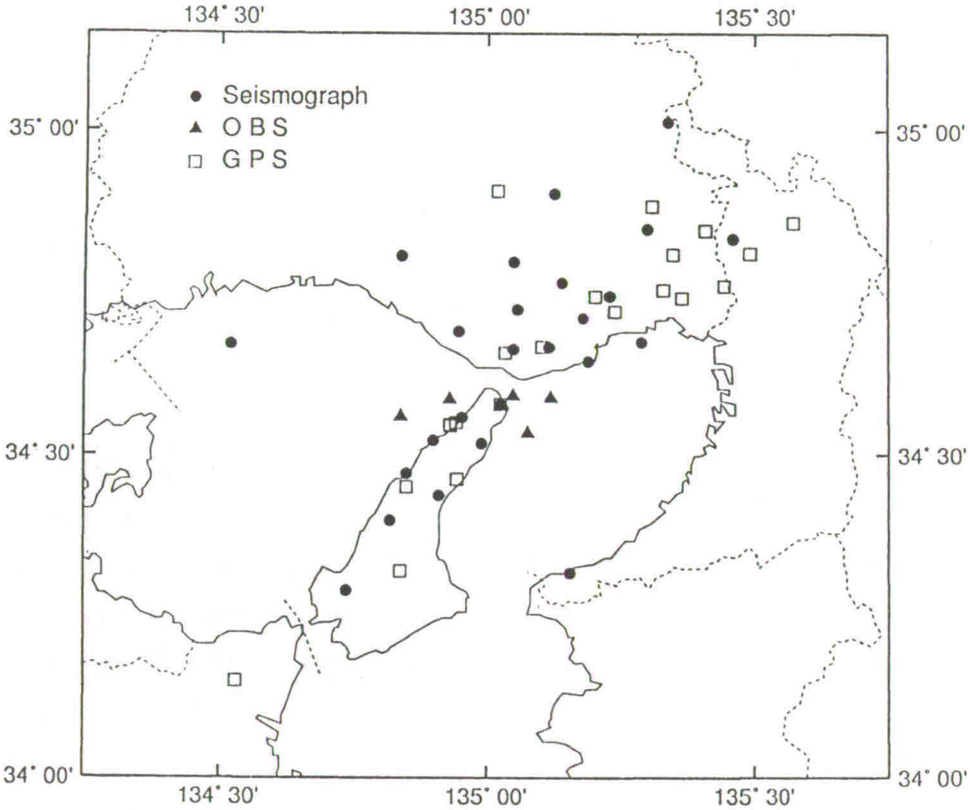

Figure 1 Large-area observation networks after the earthquake
(Maps edited by Prof. Yoshii of the Earthquake Research Institute)

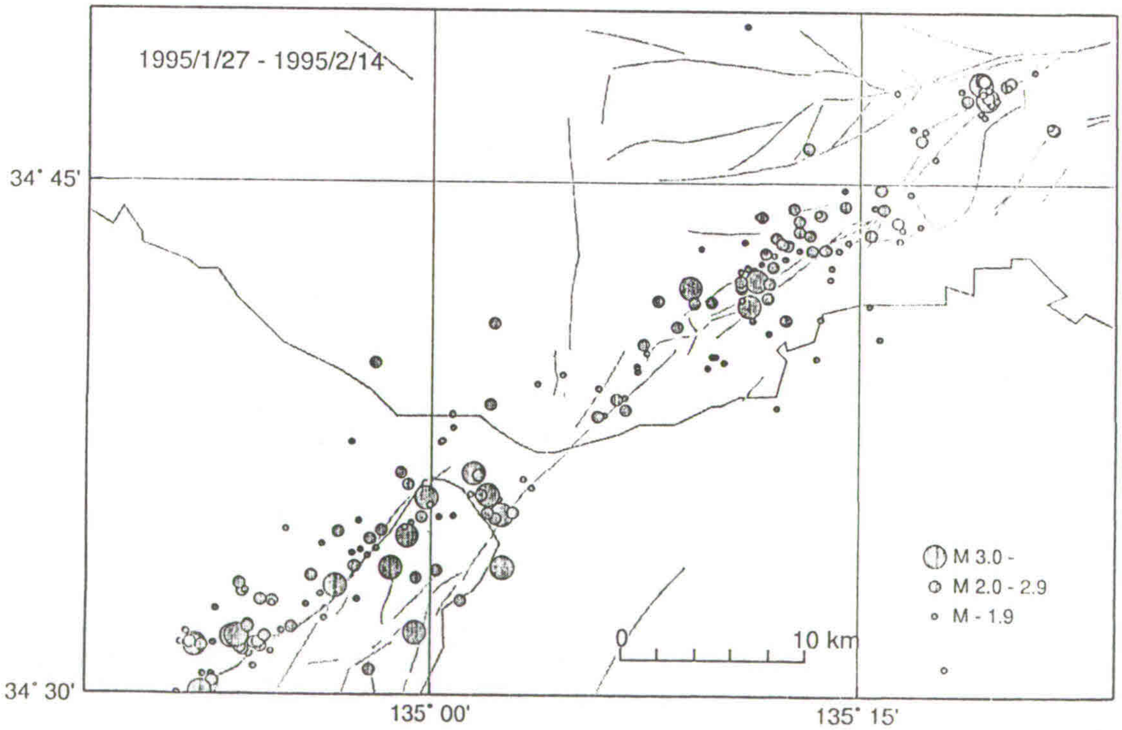

Figure 2 Distribution of aftershocks

BRIEF REPORT BY THE FOURTH SURVEY TEAM ON THE DAMAGE CAUSED BY THE GREAT HANSHIN EARTHQUAKE

(February 15 to 17, 1995)

Seismic Motion and Damage Characteristics

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1. Outline of Earthquake

A powerful earthquake, registering a magnitude of 7.2 on the Richter scale, rumbled through Awaji Island, Kobe City and other parts of the Hanshin (Kobe-Osaka) region, at around 5.46 am. (local time, GMT+9 hrs) on 17th January, 1995. It was named the "1995 Hyogo-ken Nanbu Earthquake." It's epicenter is thought to have been located approximately 14 km underground, directly below the northern end of Awaji Island in Hyogo Prefecture (34°6' North, 135°0' East), where the earthquake registered an intensity level of VI on the seven-level Japanese Intensity Scale.

There was extensive damage in major cities in the Hanshin area, including Kobe, Ashiya and Nishinomiya, among many others. The quake registered an intensity of level VII in Kobe and Nishinomiya, VI in Sumoto, and V in Kyoto.

As is shown in Fig. 1.1, the zone where a seismic intensity of level VII occurred extends along a line from Suma Ward of Kobe City to Nishinomiya City, on the southern side of Suma, on the Suwayama and Gosukebashi faults. It is the first time since the 1948 Fukui Earthquake when level VII has been registered on the Japanese Intensity Scale. The intensity level of VII is defined by the Japanese Meteorological Agency (JMA) as the level at which 30% or more of wooden houses in a quake-stricken area collapse.

As of 11th March, 1995, the death toll caused by the earthquake was 5,472, the number of houses totally destroyed was 83,536 and those partially destroyed numbered 68,761. Fires broke out at 258 locations, burning a total area of 671,253 m^2. The total damage is expected to exceed ¥ 9 trillion.

2. Characteristics of Seismic Motion

No earthquakes of magnitude M7.0 or more had occurred in the southern part of Hyogo Prefecture since the year 868, when an earthquake of such magnitude struck off the province of Harima in southern Hyogo. An M6.1 earthquake, which occurred on 26th November, 1916, had its epicenter very close to the latest earthquake, but the damage then was small. Since then, no major earthquakes are known to have occurred in the system of faults covering this area. The locations of active faults in the Kinki Region are shown in Fig. 2.1. The epicentre of the 1995 Hyogo-ken Nanbu Earthquake was located in Hokudan Town, on the northeastern coast of Awaji Island. The earthquake is thought to have been caused by a slip along the Nojima Fault, which shows traces of an earlier movement approximately 1,000 years ago. The fault plane underwent a right lateral strike-slip and was offset by around 1.2 m. The Nojima Fault runs towards the

Rokko-Arima-Takatsuki tectonic line, and is integrated with the Suma, Suwayama, Ashiya, Koyo and Itami faults. Through an analysis of the seismic waves observed at 24 sites in Southeast Asia and the U.S.A., Kikuchi[1] has shown that failure progressed towards the southwest and northeast from the epicentre, located approximately at the centre of the Nojima Fault. It caused the fault to undergo a right lateral strike-slip. A survey on the seabed has also revealed the presence of a fault crack parallel to the Nojima Fault on the seabed below Osaka Bay.

The magnitudes of the aftershocks from 19th January onwards are shown in Fig. 2.2. The largest aftershock occurred around two hours after the main shock and had a magnitude of 4.9. As can be seen in Fig. 2.3, the epicentres of the aftershocks are distributed in a belt stretching from central Awaji Island to the southern part of Kobe City and into the northern part of Nishinomiya City. On the basis of the observation records of the main shock and aftershocks, one study group[2] has shown that the P-S time is generally short, the ratio of the vertical movement to the horizontal movement increases as one approaches the epicentre, and the shapes of the horizontal and vertical spectrums are very similar to each other. High-frequency components predominate in tremors near the observation sites while low-frequency components predominate in tremors occurring further away. It is also known that the predominant frequency of the ground and the natural frequencies of structures have played a major role in increasing the structural damage through the "resonance effect." The seismic intensity levels recorded by JMA in various parts of the country are shown in Fig. 2.4. The top level shown here is VI, which corresponds to the highest level that can be registered on seismometers. On the basis, however, of field surveys which were carried out three days after the earthquake, the intensity level was upgraded to level VII at several locations in Kobe and Nishinomiya cities. The intensity level of VII was registered in a belt extending northeastwards from Kobe, towards Kyoto and Hikone. This belt extends in the same direction as the fault lines. The intensity level was not as high as might have been expected on soft reclaimed land along the edges of the Seto-Naikai (Inland Sea) and Osaka Bay, a fact which is suggestive of the major role played by active faults in the transmission of the seismic motion.

The ground accelerations and the corresponding response spectrums recorded on the JMA Model 87 electromagnetic strong-motion seismograph at the Kobe Marine Observatory are shown in Fig. 2.5. The maximum acceleration was as high as 818 gals (north-south), 617 gals (east-west) and 332 gals (up-down). The Marine Observatory is situated in a hill-plateau area at the foot of the Rokko Mountains. The vertical motion began slightly earlier than the horizontal motion, but the time lag before the onset of strong lateral motion was only 2 seconds. While the values for the maximum acceleration this time were very similar to those observed in the 1993 Kushiro-Oki Earthquake, the ground displacement was 1.5 to 3.0 times as large as those observed in that earthquake. In terms of the acceleration records, however, the duration of the seismic motion was no more than about one-half of that of the 1993 Kushiro-Oki Earthquake. The latest earthquake was also slightly shorter when seen in terms of the displacement records. The predominant frequency in the acceleration records ranged 1 to 2 Hz for the horizontal (east-west and north-south) motion, and around 1 Hz for the vertical motion. The acceleration response spectrums show that the maximum structural response to both the east-west and north-south components of the horizontal motion was observed on structures with natural periods of 0.3 to 0.4 seconds, followed by those with natural periods of 0.7 to 0.8 seconds. The maximum response to the vertical motion was observed on structures with natural periods of around 0.25 seconds.[3] Fig. 2.6(a) shows the acceleration recorded on a seismometer situated at the ground surface on the reclaimed Port Island. The maximum acceleration here was 341.2 gals (north-south), 284.4 gals (east-west) and 555.9 gals (up-down). The ground acceleration records taken on a seismometer installed in a diluvial layer 83 m below the ground surface on Port Island are shown in Fig. 2.6(b). The maximum acceleration here was 678.8 gals (north-south), 302.6 gals (east-west) and 186.6 gals (up-down). Whereas the maximum vertical acceleration is 1.6 times as large as the maximum horizontal acceleration at the ground surface, the maximum horizontal acceleration is 3.6 times the maximum vertical acceleration in the records taken under ground in the diluvial layer. The amplification between the underground observation site and the ground surface was by a factor or 1.9 for the horizontal motion, and 0.33 for the vertical motion, indicating a particularly large amplification for the horizontal motion. The maximum accelerations recorded at various sites are listed in Table 2.1. The distribution of the maximum accelerations is shown in Fig. 2.7. In the zone extending from Kobe City to Takarazuka City, where an intensity level of VII was recorded, the maximum horizontal acceleration ranged between approximately 600 and 800 gals, while the maximum vertical acceleration ranged between 300 and 400 gals. It is also known that the ratio of vertical acceleration to horizontal acceleration exceeded 1/2 at a large number of observation sites.

3. Characteristics of Damage

(1) Distribution of Damage to Buildings

The conditions of the damage to buildings were surveyed by an emergency study group organised by members of the Civil Engineering Department of Kobe University. Their findings are shown in Figs. 3.1, 3.2 and 3.3, superimposed on to geological maps using a Geographic Information System (GIS). It may be seen that the worst damage is concentrated in a strip sandwiched between the Hankyu Railway Line and National Highway Route 43. A closer look at these maps reveals an insular distribution of the areas of damage, which are concentrated on composite alluvial fans. The severity of the damage in Itami City, despite its sound ground conditions, may be attributed to the presence of the Itami Fault. The distribution of the damage may be described as follows.[4]

1) In terms of the medium-scale topography, Kobe City may be classified into the Rokko Mountains, piedmont terraces, composite fans below these terraces, the old coastal strip and reclaimed land along the sea. The areas where "total collapse" of housing occurred are found distributed on the composite fans. In terms of the geological classification, these areas correspond to the medium to low-level terraces and alluvial deposits.
2) A closer examination of the distribution of the damage within these composite fans shows that the damage is relatively small in areas closer to the higher piedmont terraces.
3) The damage is also relatively small in the old coastal strips below the composite fans.
4) Ground liquefaction is observed on reclaimed land, but the damage to wooden-frame dwellings in such areas is relatively small.
5) On a larger view, the damage is concentrated in a belt 0.7 to 1.2 km in width stretching from southwest to northeast along the foot of Rokko Mountains.
6) Areas with higher and lower concentrations of damage are found within this belt, and the differences here may be attributed to topographical or ground conditions.
7) After entering Nishinomiya, this belt of severe damage turns northwards near Shukugawa and heads towards the eastern side of Kotoen Station on the Hankyu Imazu Line.
8) Pockets of severe damage occur along faults and tectonic lines in Takarazuka and Itami cities.
9) On Awaji Island, the worst damage occurred in Hokudan and Ichinomiya towns. The damage was smaller in comparison in Awaji Town, which was closest to the epicentre.

(2) Distribution of Damage to Roads and Railways

The locations of the damage on roads and railways are shown in Figs. 3.4 and 3.5. The locations of known faults are also shown in the figures. Extensive damage occurred in viaduct sections of both roads and railways. Embankment failure was also widespread, but no local concentrations of these have been recognised. While the damage on the Hanshin Railway Line was concentrated around Ishiyagawa Station, the damage on the Hankyu Line was concentrated around Shukugawa Station. The ground conditions and positions of faults in these areas are thought to have influenced the severity of the damage. The types of damage observed may be classified as follows.

1) Bridge fall-off (complete collapse of bridge piers, dislocation of girders from piers etc.)
2) Shear, flexural and buckling failure of concrete bridge piers
3) Buckling and brittle failure or deformation of steel bridge piers and girders
4) Tilting of bridge piers due to liquefaction and other forms of ground failure (tensile cracks etc.)
5) Embankment collapse due to loss of stability

(3) Distribution of Liquefaction

The distribution of areas where liquefaction occurred is shown in Fig. 3.6. Unlike the zone of the worst damage to housing, the zone where liquefaction was observed is centred around Kobe City and extends along the coast from Suma to the mouth of the Shin-Yodo River. Liquefaction also occurred on reclaimed land and in areas close to the coast line. The severest level of liquefaction was observed on Port Island, followed by Ashiyahama Seaside Town and Rokko Island. On Port Island, boiling sand, brownish in colour, covered the whole island. It is thought that the reclamation soil, with an N-value of 5 to 10 and consisting of fine silty and sandy gravel, underwent liquefaction here. The entire island underwent a subsidence of several tens of centimetres due to liquefaction, but little damage occurred on buildings. This is because a majority of the buildings here were supported on pile foundations reaching down to the diluvium. Boiling sand was observed in reclaimed land in Sakai City, a long way away from the epicentre. Liquefaction was also the cause of dyke failure along the Yodo River in Konohana Ward, Osaka City. Liquefaction led to serious damage of port facilities, including seaward movement and apron subsidence. The types of damage caused by liquefaction include ground subsidence, lateral movement and sand boiling.

(4) Distribution of Damage to Utility Poles

The distribution of the damage to utility poles and other power supply equipment is shown in Fig. 3.7.[5] The positions of known faults are shown together in the figure. It may be seen that the distribution of the damage here corresponds closely with that of housing damage. The damage is concentrated around Shin-Nagata and Rokkomichi. The low density of the damage west of Suma Ward and east of Nishinomiya City may be explained by the lower density of housing here, and the fact that the damage to utility poles is influenced by the extent of housing collapse and their installation density in addition to the ground conditions and presence of active faults. No damage occurred on Rokko Island and Port Island as the power cables are installed underground in these areas.

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2) Kajima Corporation, "Study Report on the Damage due to 1995 Hyogo-ken Nanbu Earthquake (First Report)," 1st Feb., 1995

3) Taisei Corporation, "Emergency Study Report on the Great Hanshin Earthquake," 8th Feb., 1995

4) Department of Civil Engineering, Faculty of Engineering, Kobe University, "Emergency Study Report on the Damage due to Hyogo-ken Nanbu Earthquake (First Report), 17th Feb., 1995

5) Kansai Electric Power Co.

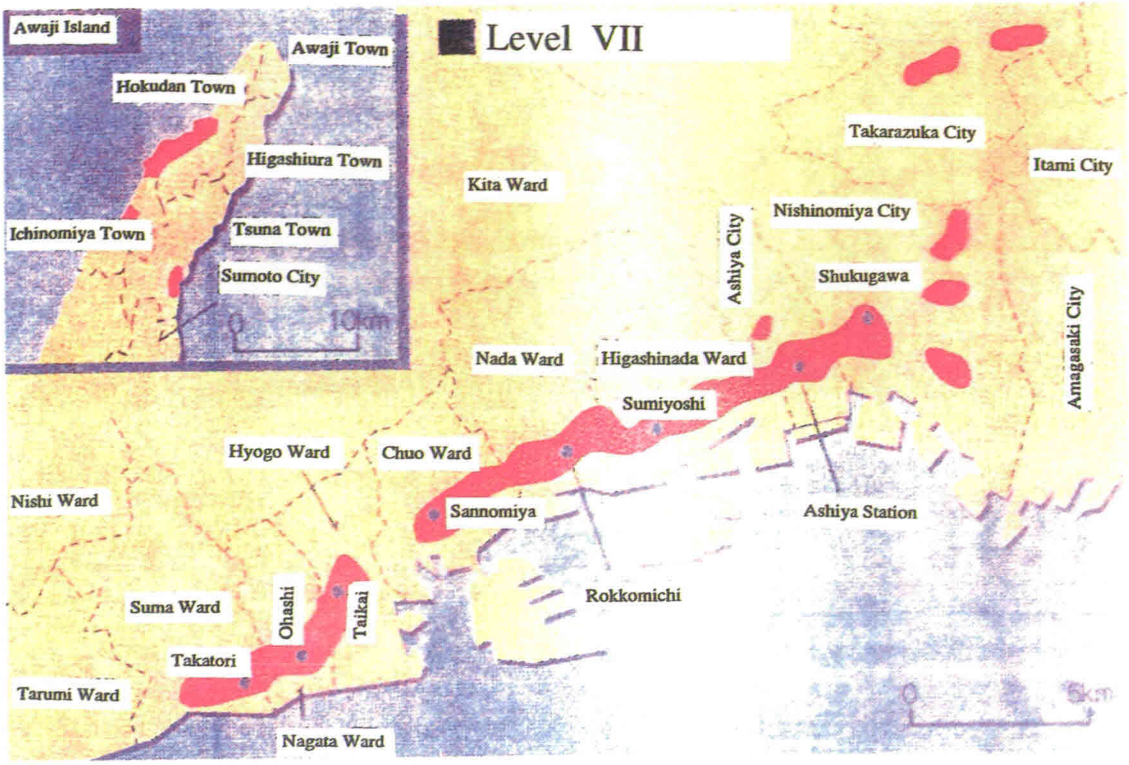


Figure 1.1 Distribution of Areas Subjected to Intensity Level VII

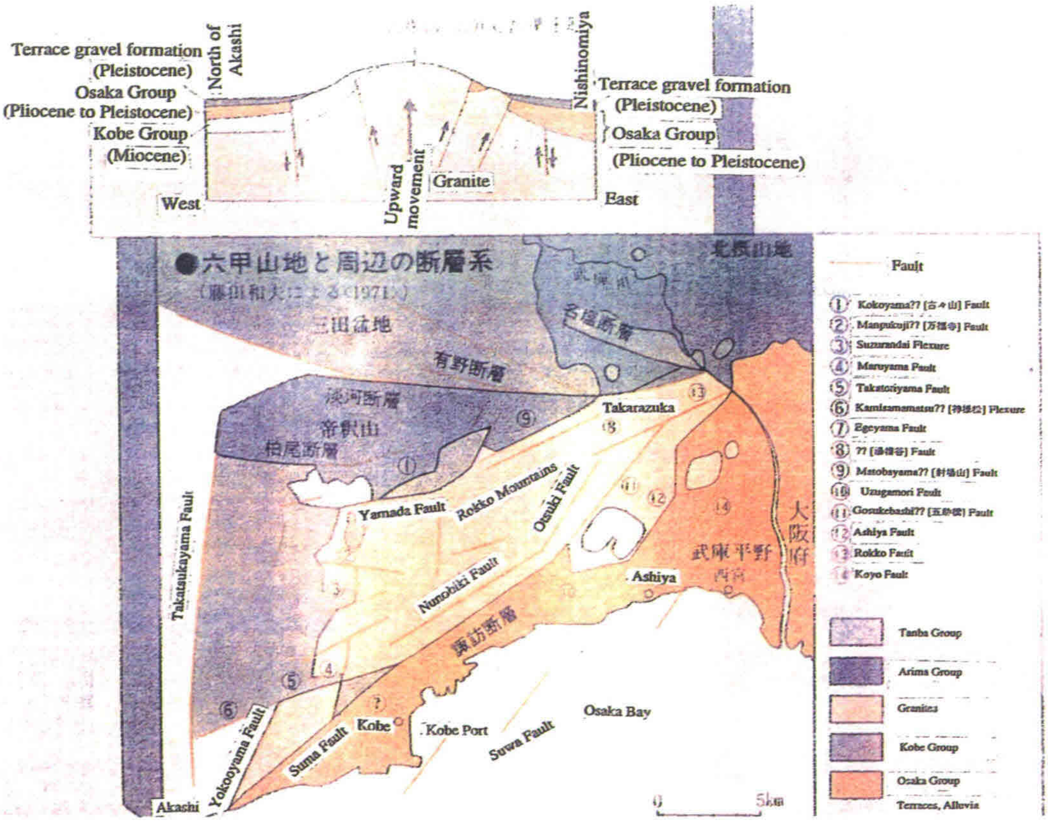


Figure 2.1 Active Faults around Kobe

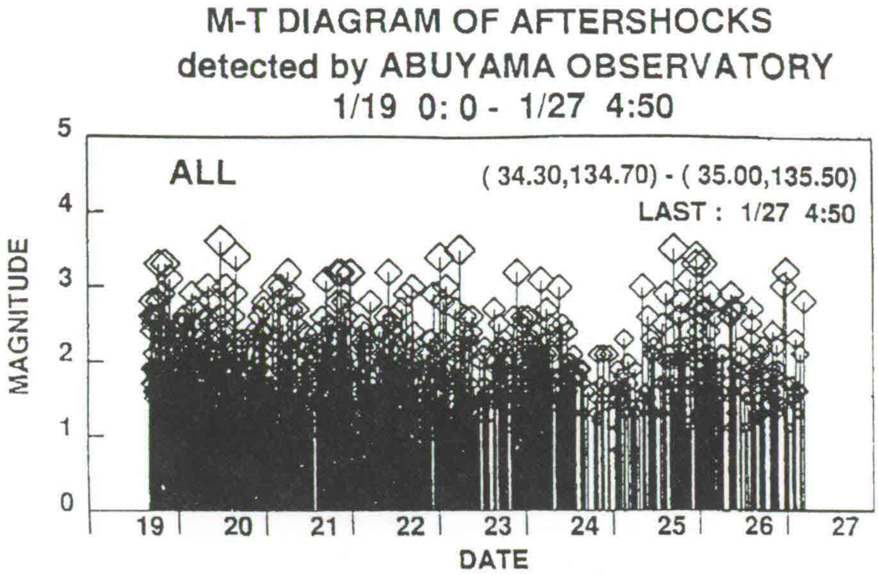


Figure 2.2 Frequency and Magnitude of Aftershocks

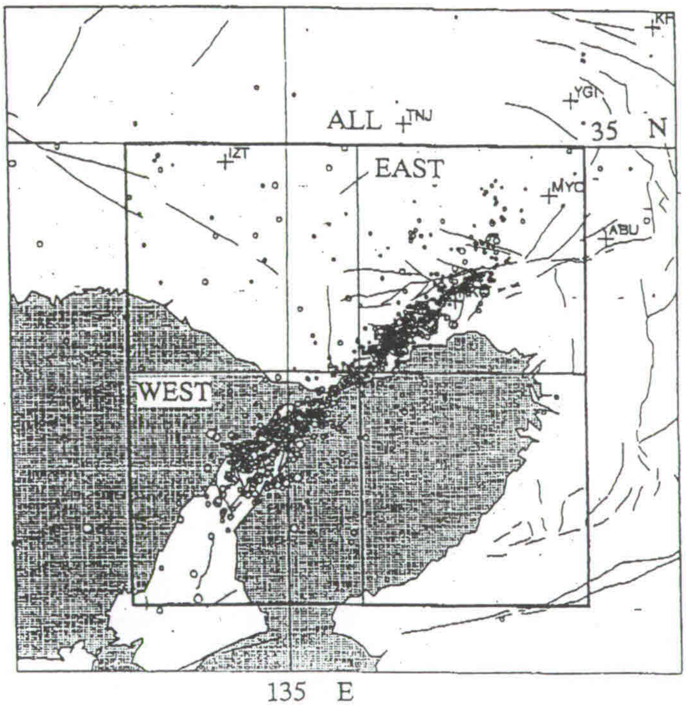
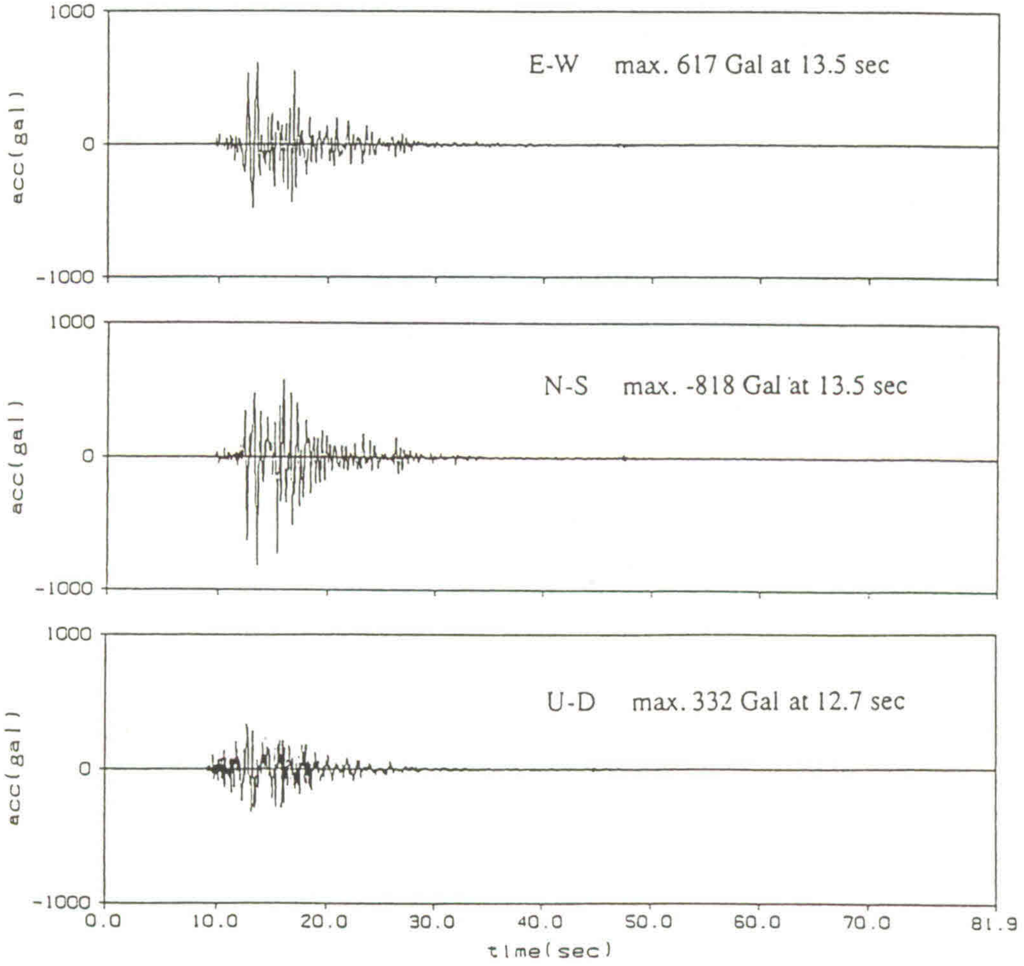
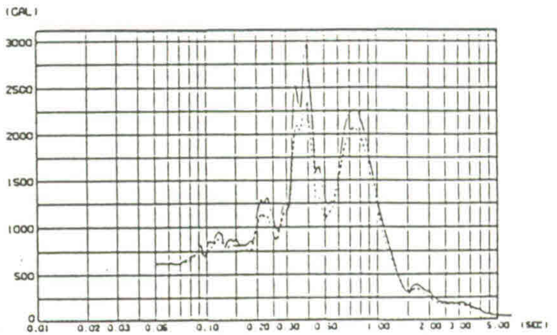


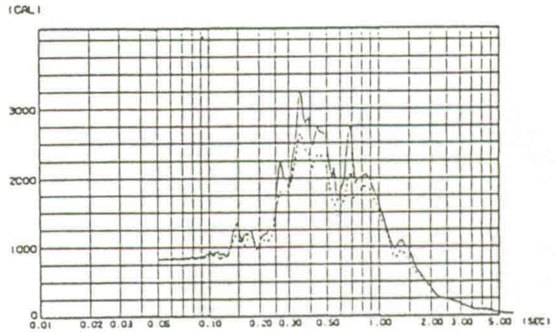
Figure 2.3 Distribution of Aftershocks (source: Earthquake Prediction Centre?? [地震予知センター], Disaster Prevention Research Institute of Kyoto University)

Figure 2.4 Seismic Intensity Levels

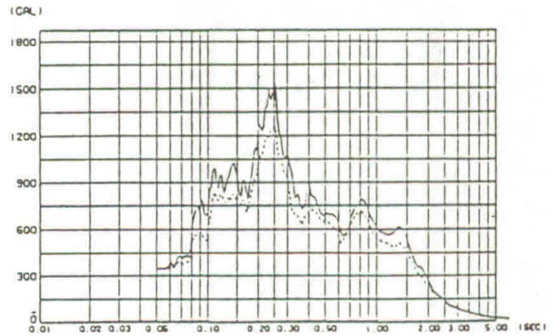




(a) East-West Component



(b) North-South Component



(c) Up-Down Component

Figure 2.5 Acceleration Wave Forms and Response Spectra at Kobe Marine Observatory

——— Damping constant 3%

• • • • • • • • Damping constant 5%

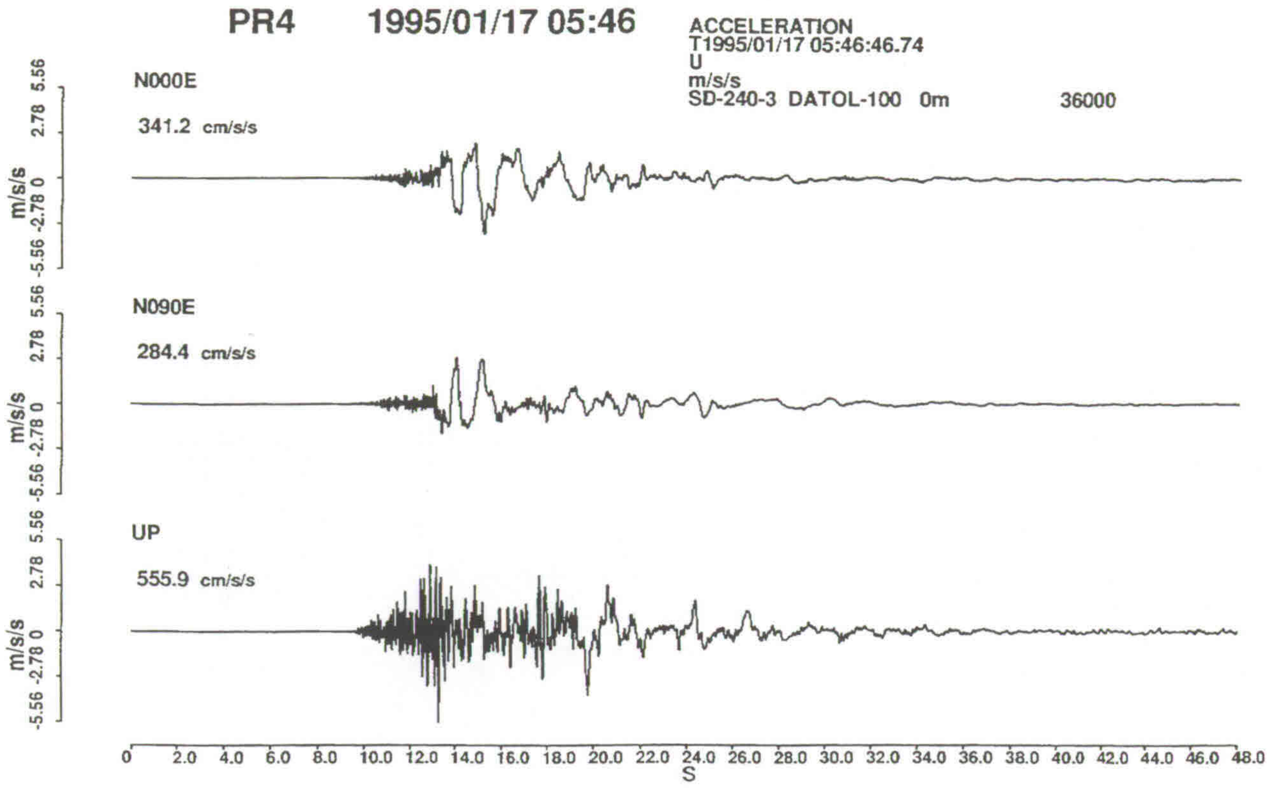


Figure 2.6(a) Wave Forms Observed on Port Island

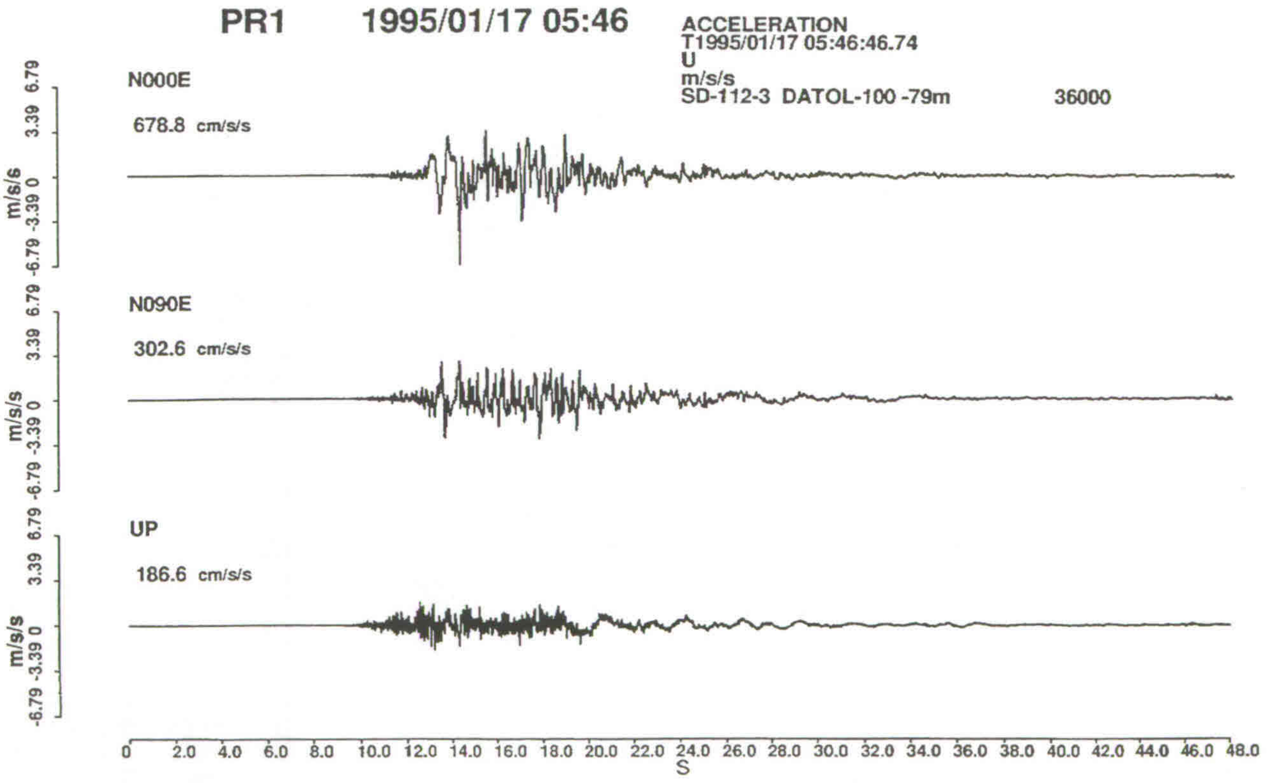
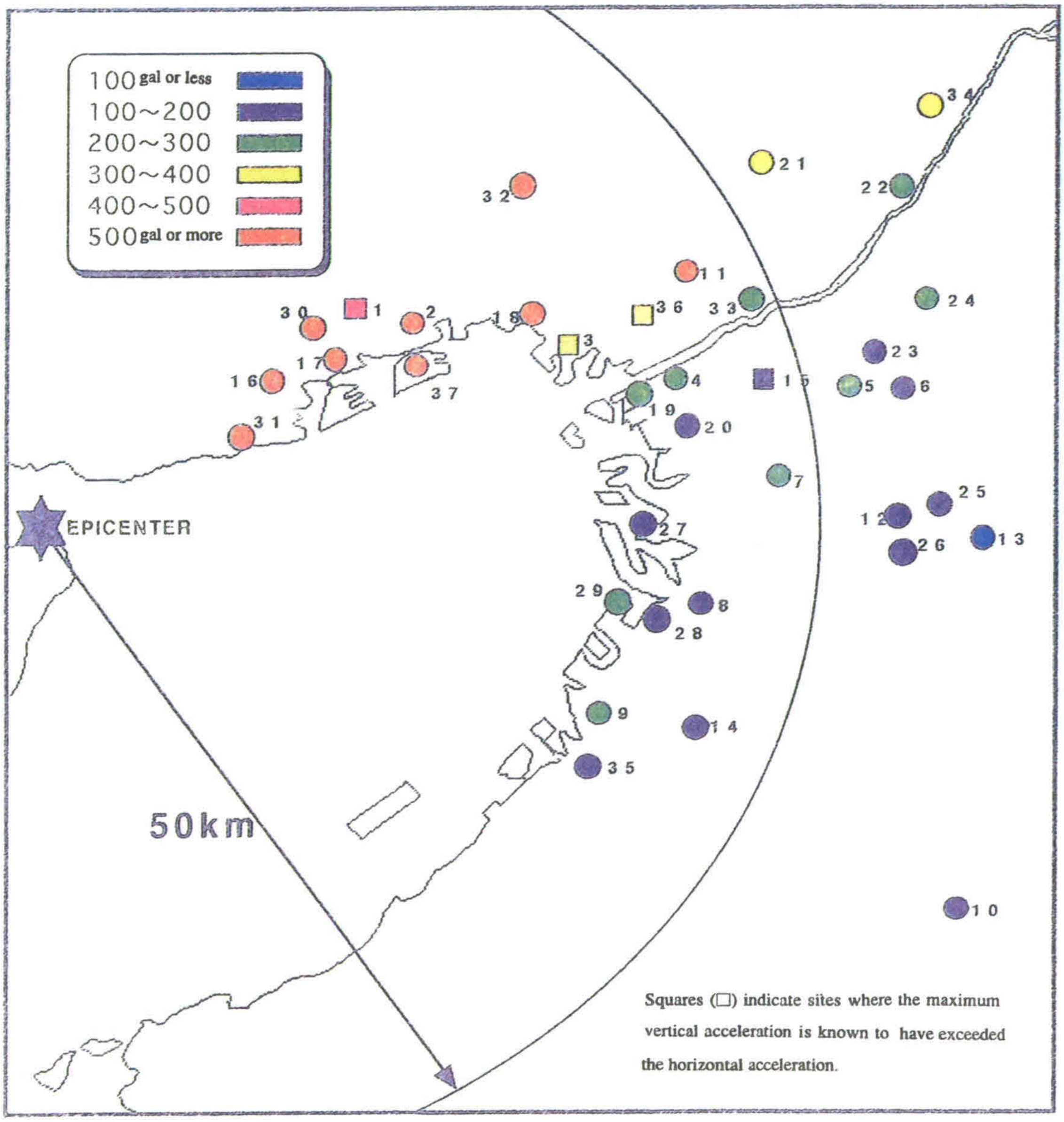


Figure 2.6(b) Wave Forms Observed on Port Island

Table 2.1 Maximum Acceleration Recorded by Various Institutions

Organization Location		Maximum acceleration			Remarks	Number on Map (Fig.2.7)
		N－S	E－W	U－D		
Kansai Earthquake Observation & Research Council	Kobe University (rock)	269.8	305.3	445.5?	?Tilting suspected	1
	Kobe Motoyama	421.0?	774.9?	379.3?	?Exceedance of measurement limit suspected	2
	Amagasaki	271.4?	321.5?	327.9	?Exceedance of measurement limit suspected	3
	Fukushima	180.0	211.5	194.8		4
	Morikawachi	210.1	123.3	158.8		5
	Yasaka	154.7	144.9	127.1		6
	Abeno	217.4	226.4	138.2		7
	Sakai	150.2	124.7	100.3		8
	Tadaoka	290.4	190.1	136.5		9
	Chihaya	90.8	106.6	73.6	On rock	10
Kansai Electric Power Co.	Yamazaki Test Center	131 34	92 32	 29	G.L.－0.7m (fill soil) G.L.－30.0m (vertical shaft)	
	Takasago Power Station	191 103 86	198 107 109	182 65 82	Ground surface (reclamation soil) G.L.－25m (sandy gravel) G.L.－100m (Akashi Formation)	
	Suma Substation					
	Goshiki Substation					
	Research Institute	299 (312) 181 294	607 (648) 239 320	205 (228) 162 199	Ground surface (alluvium) ( ) : values taken on maximum acceleration indicators G.L.－34.9m (diluvium) G.L.－97.0m (Osaka Formation)	11
	Nanko Power Station				Near intake port (reclamation soil) Near main building (reclamation soil), measurement limit exceeded Near chimney (reclamation soil)	
	Yao Substation	133 148 123	141 139 140	88 82 67	Ground surface (alluvium) Ground surface (alluvium) Ground surface (alluvium)	12
	Shigi Substation	42 22 25	45 20 20	27 11 10	G.L.－1m (fill soil) G.L.－22m (rock) Ground surface (cut rock)	13
	Minami Osaka Substation	122 144 146	84 145 105	90 93 92	Ground surface (alluvium) Ground surface (alluvium) Ground surface (alluvium)	14
	Tanagawa Substation				Ground surface (cut rock)	
	Kainanko Substation	98 71 28	128 60 25	82 39 21	Ground surface (reclamation soil) G.L.－25m (alluvium) G.L.－100m (rock)	
	Yuzaki Substation	18	19	8	Ground surface (cut rock)	
MOC Building Research Institute	Osaka No.3 Joint Government Office Building	90.2 412.3	82.5 316.3	108.8 209.4	3rd basement 17th floor	15
	Maizuru Municipal Office Building	84.7 153.4	69.9 148.7	19.3 34.8	Ground floor 4th floor	
	Matsuzaka Joint Government Office Building	69.8 173.8	63.5 132.6	34.3 51.2	Ground floor 6th floor	
	Yonago Municipal Office Building	26.3	21.9	6.5	1st basement	
	Hirosima No.2 Joint Government Office Building	17.2 75.2	19.3 85.6	5.2 9.1	1st basement 10th floor	
	Ishikawa Prefectural Office Building	13.5 34.9	13.2 24.4	8.2 8.9	2nd basement 4th floor	
	Oita Municipal Office Building	7.1 37.6	7.2 15.2	2.9 3.5	Ground floor 8th floor	
Koube Marine Observatory	Chuo－ku, Kobe	818	617	332		16
Osaka Gas Co.	Fukiai, Chuo－ku, Kobe City	833				17
	Imazu, Nishinomiya City	792				18
	Nishijima, Konohana－ku, Osaka City	266				19
	Iwasaki, Nishi－ku, Osaka City	185				20
	Suita City, Osaka Pref.	312				21
	Hashiramoto, Takatsuki City, Osaka Pref.	261				22
	Higashi－Osaka City, Osaka Pref.	177				23
	Shijonawate City, Osaka Pref.	224				24
	Yao City, Osaka Pref.	169				25
	Fujiidera City, Osaka Pref.	149				26
	Sakai City, Osaka Pref.	173				27
	Sakai City, Osaka Pref.	178				28
	Sakai City, Osaka Pref.	240				29
	Heijo, Nara City, Nara Pref.	142				
Japan Railway	Shin－Kobe, Kobe City	581				30
	Takatori	616				31
	Takarazuka, Hyogo Pref.	601				32
	Nishi－Akashi	481				
	Kakogawa	229				
	Himeji	125				
	Shinoyamaguchi	195				
	Fukuchiyama	110				
	Toyooka	24				
	Ikuno	59				
	Shin－Osaka, Osaka Pref.	245				33
	Shin－Takatsuki	323				34
	Higashi－Kishiwada	149				35
	Gobo, Wakayama Pref.	170				
	Nara, Nara Pref.	113				
	Higashiyama, Kyoto Pref.	113				
	Nijo	84				
	Sonobe	163				
	Nishi－Maizuru	87				
	Ritto, Shiga Pref.	67				
	Gokasho	128				
	Shin－Maibara	227				
	Shin－Sekigahara, Gifu Pref.	106				
	Hashima	57				
	Tsuge, Mie Pref.	97				
	Obama, Fukui Pref.	74				
Ministry of Construction	JR Amagasaki Amagasaki	300	273	307	Mainichi Shinbmn, Jan. 24, morning edition	36
		475			Mainichi Shinbmn, Jan. 24, morning edition	
Takenaka Komuten Co.	Rokko Island	319		807	Asahi Shinbmn, Jan. 28, morning edition	37
Matsumura－Gumi Corporation	Kita－ku, Kobe City	274			Nihon Keizai Shinbmn, Jan. 24, morning edition	
Yomiuri Shinbum, Jan. 23, evening edition	Fushimi	208				
Yomiuri Shinbum, Jan. 23, evening edition	Kyoto	263				
Yomiuri Shinbum, Jan. 28, evening edition	Chihaya	111				



Squares (□) indicate sites where the maximum vertical acceleration is known to have exceeded the horizontal acceleration.

Figure 2.7 Maximum Acceleration Distribution

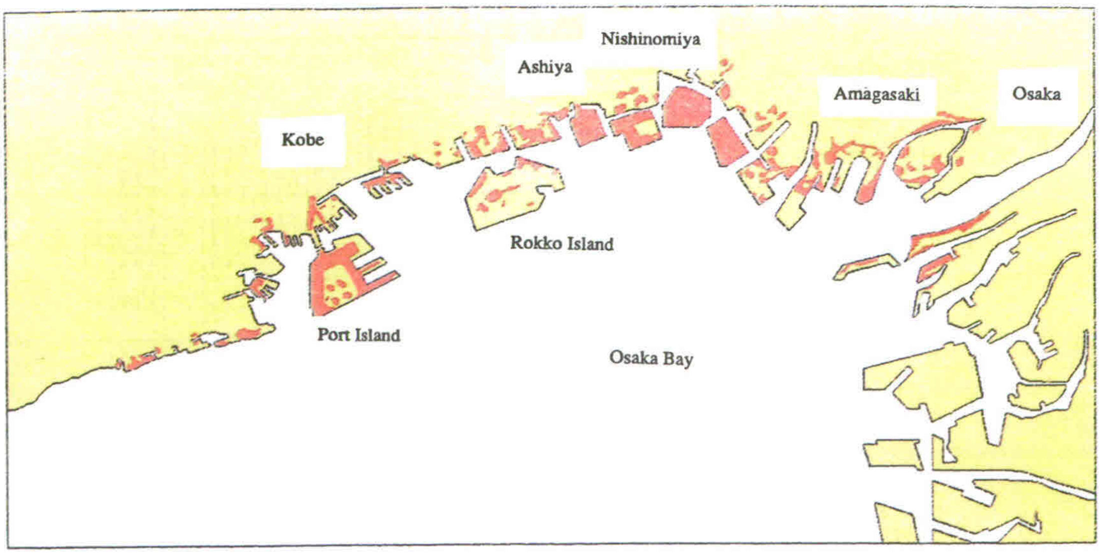


Figure 3.6 Distribution of Liquefaction (Hyogo Prefecture only)

Figure 3.1 Distribution of Building Damage and Geology: Awaji Island

(Red: total collapse Yellow: major damage Green: minor damage)

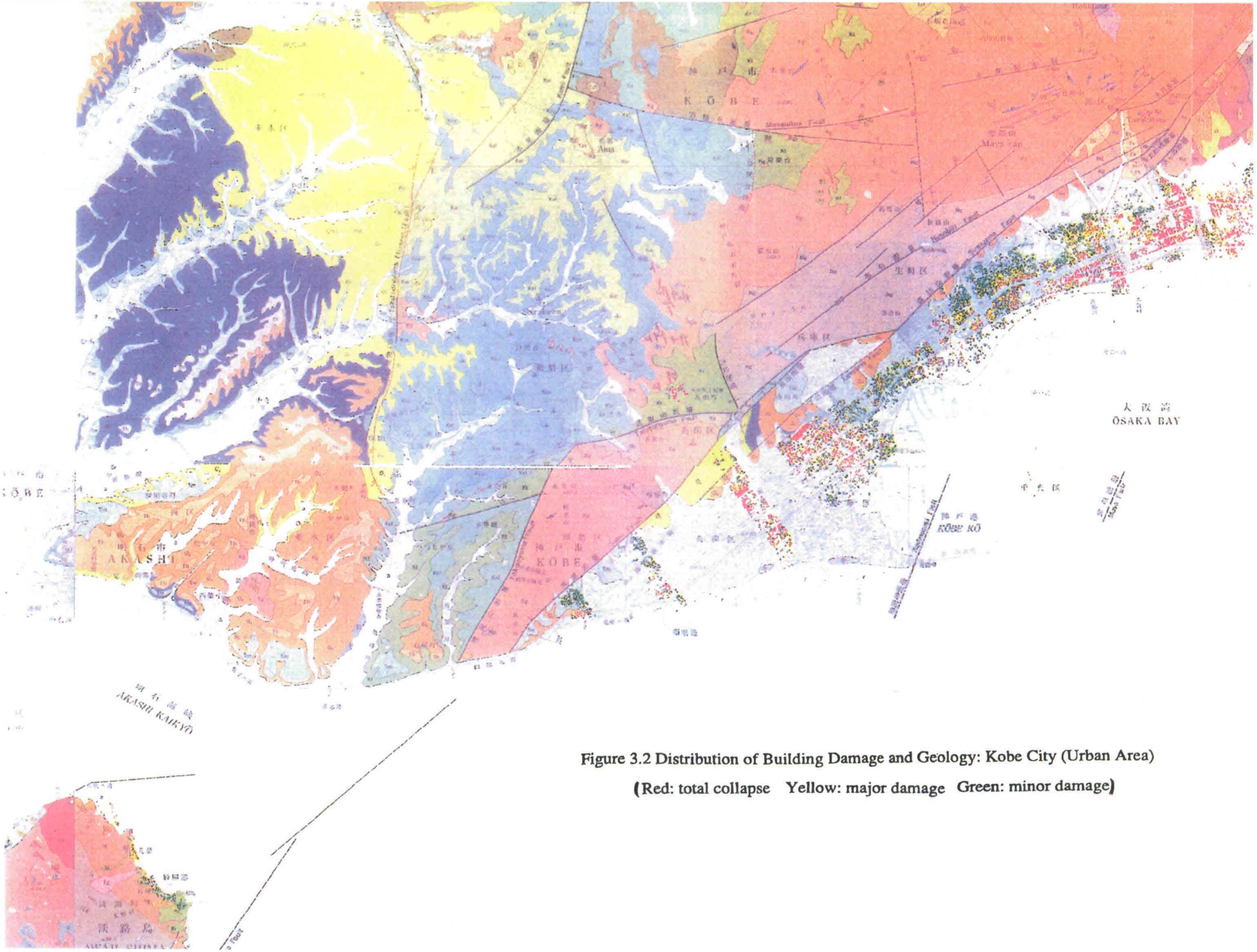


Figure 3.2 Distribution of Building Damage and Geology: Kobe City (Urban Area)

(Red: total collapse Yellow: major damage Green: minor damage)

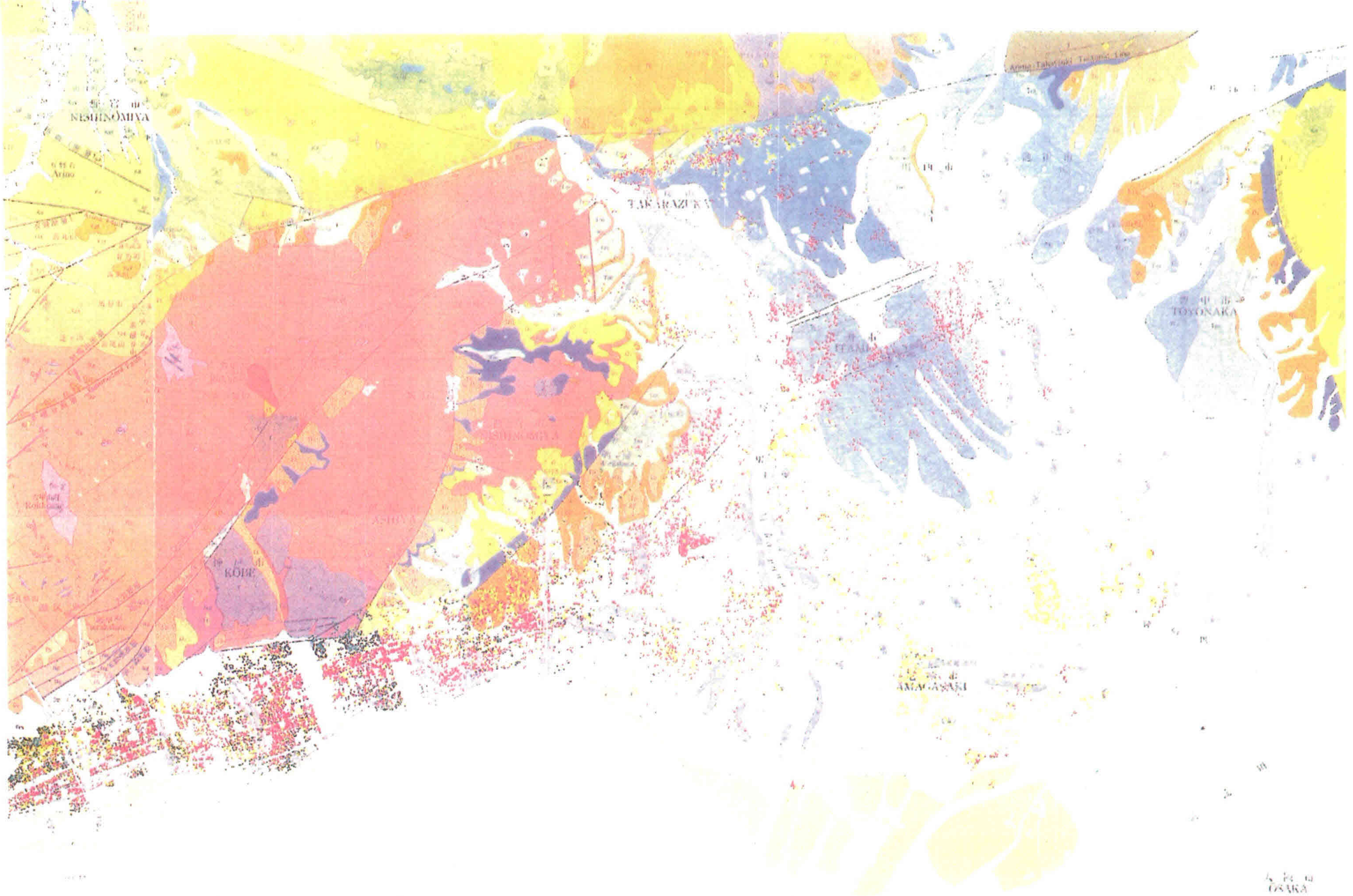


Figure 3.3 Distribution of Building Damage and Geology: (Ashiya, Nishinomiya, Takarazuka and Itami)

(Red: total collapse Yellow: major damage Green: minor damage)

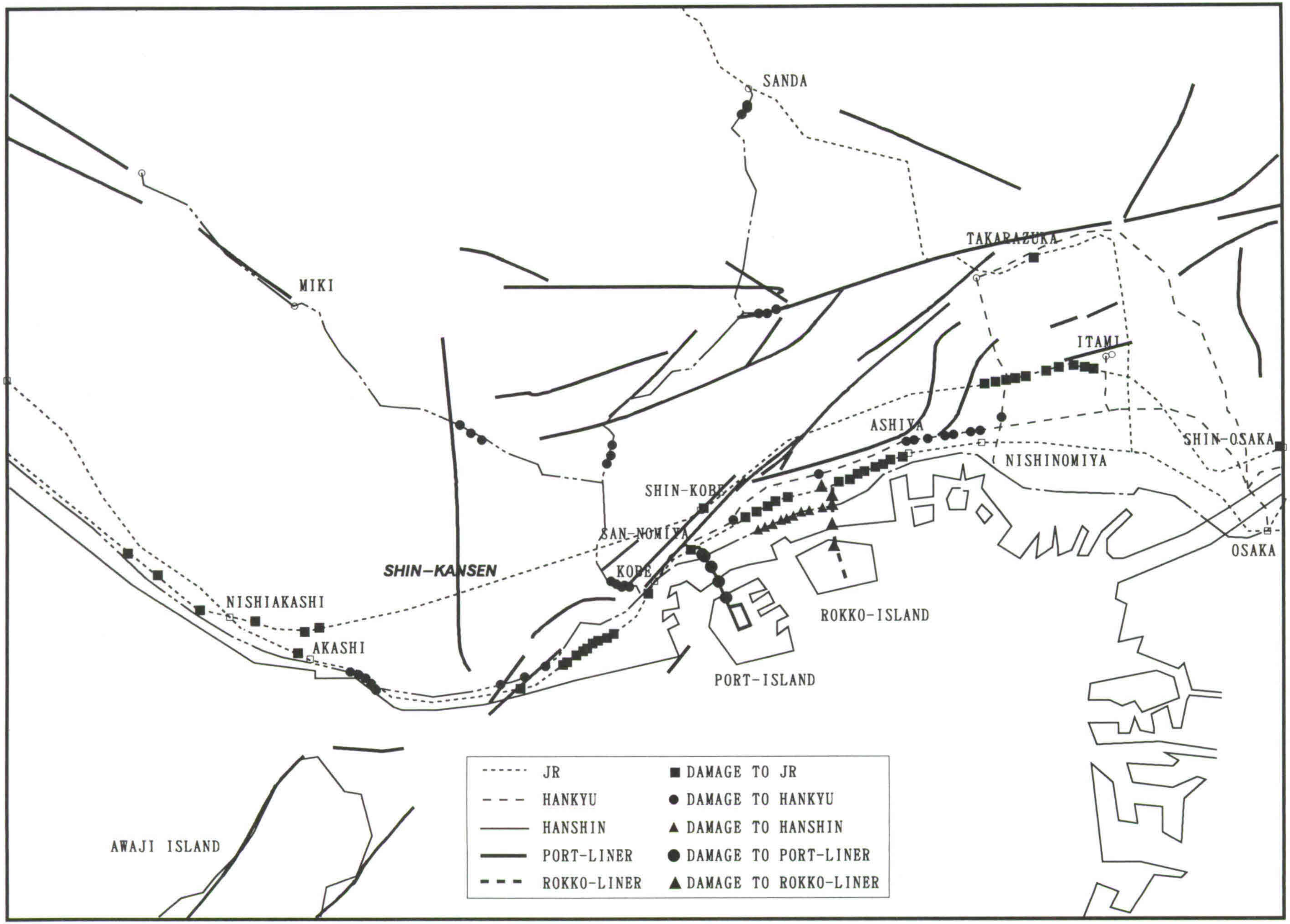


Figure 3.4 Damage to Railway Facilities and Fault Locations

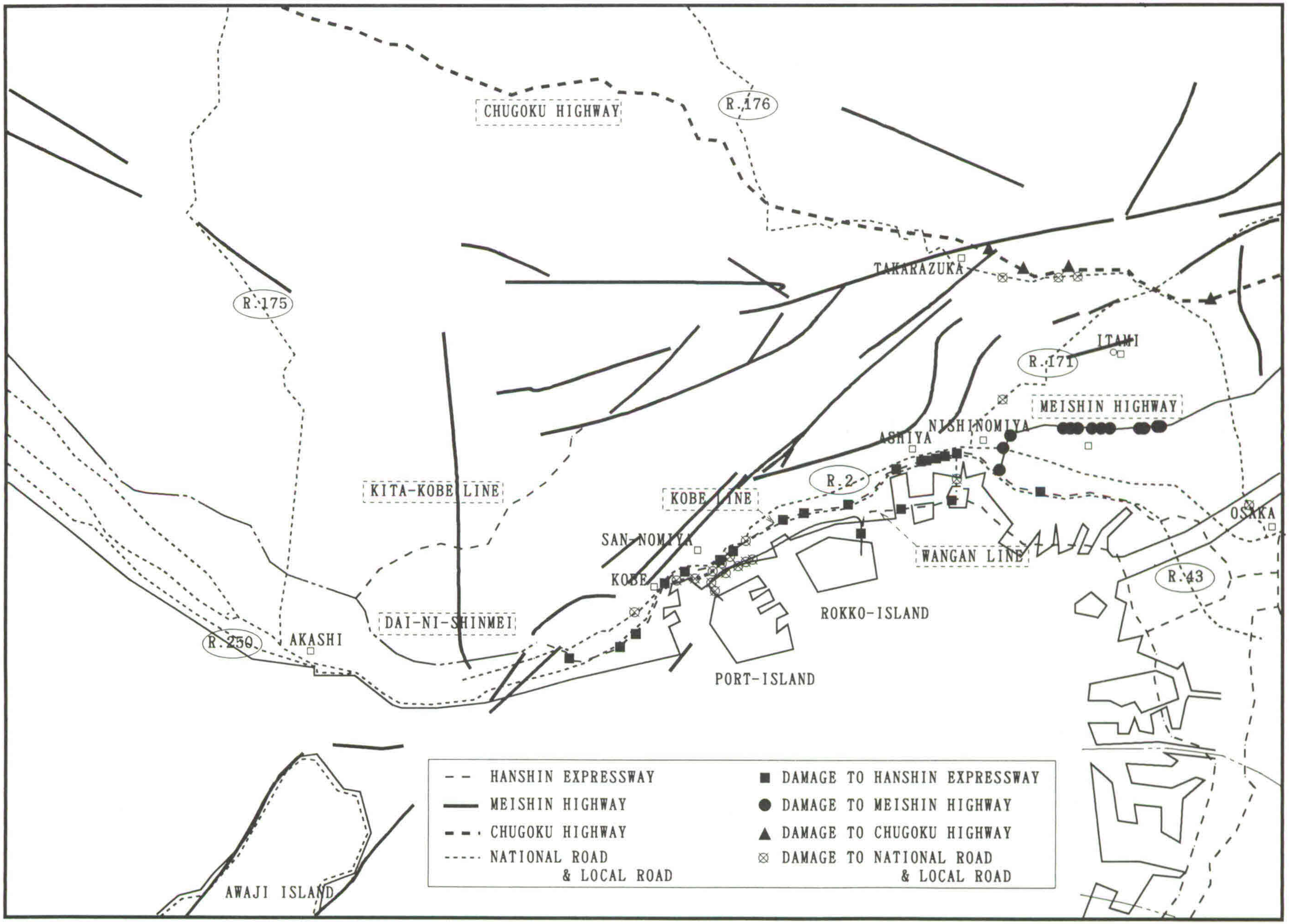


Figure 3.5 Damage to Roads and Bridges and Fault Locations

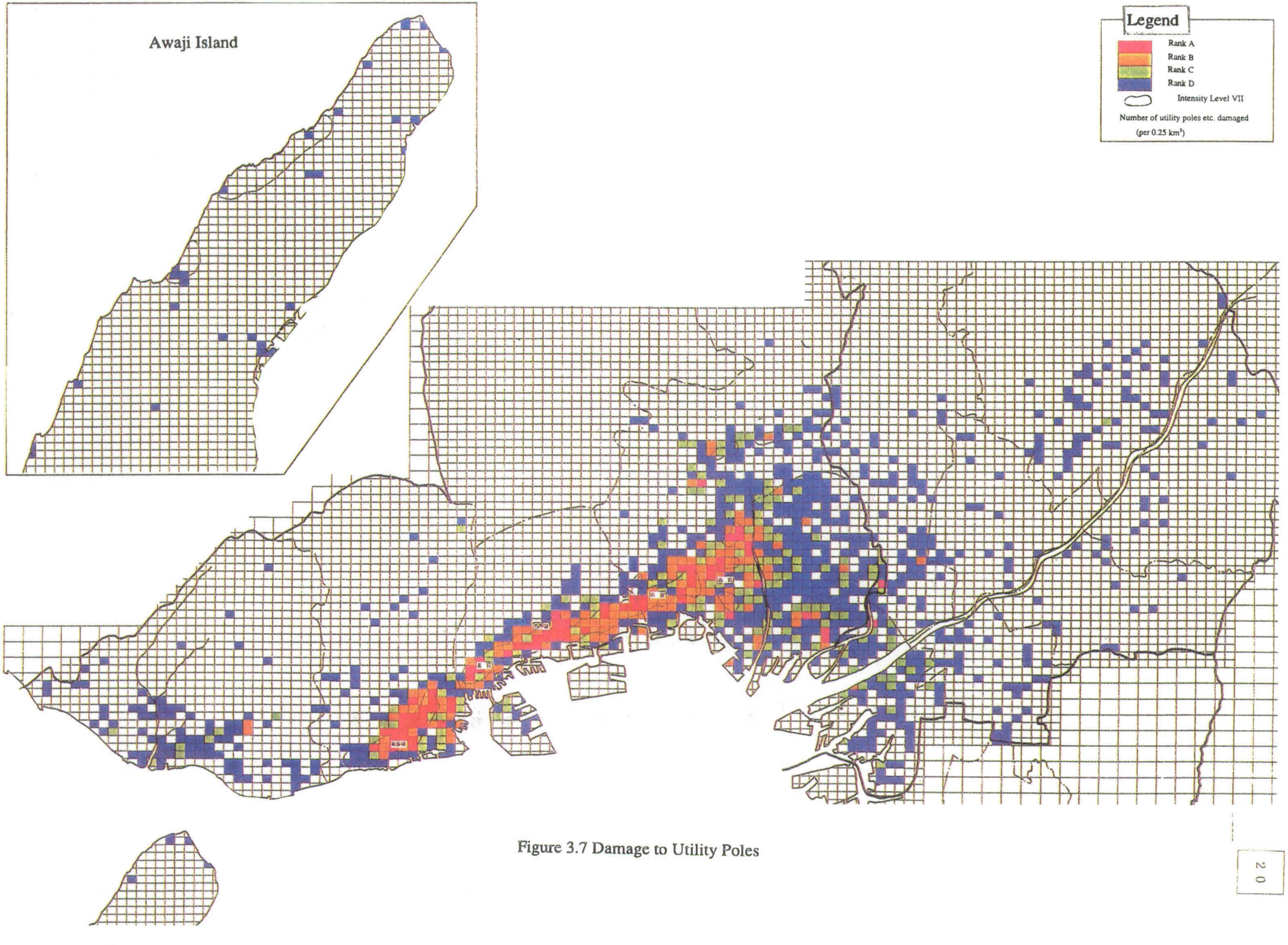


Figure 3.7 Damage to Utility Poles

Group Report: Roads and Railways I

Mutsuto Kawahara, Professor in Applied Mechanics, Chuo University
Kazuo Kashiyama, Associate Professor in Applied Mechanics, Chuo University
Hirokazu Hirano, Lecturer in Disaster Prevention Studies, Chuo University

1. Study Area

Hanshin Expressway (Kobe, Wangan, Osaka-Shinai and Ikeda routes), Chugoku Expressway, trunk coastal roads (" Harbour Highway"), ordinary national highways (Route 43 etc.), underground railway facilities (Kobe Municipal Subway)

2. Conditions of Damage and Restoration Work

(1) Hanshin Expressway: Kobe Route

Restoration work is under way on the Kobe Route with the aim of preventing secondary disasters. Collapse of steel viaduct piers led to the fall-off of the steel girders supported by them on the viaduct passing through Araebisu-cho and Shake-cho areas of Nishinomiya City, while the Higashinada Viaduct with its mushroom-shaped slab (*Pilz*) structure turned over sideways in Higashinada-ku, Kobe City, and the collapse of reinforced concrete piers caused the fall-off of steel girders on the viaduct above Kaigan-Dori Street in Chuo-ku, Kobe City. The debris from all these viaducts were removed within around ten days of the earthquake to allow passage of traffic on National Highway Route 43, which passes below these viaducts (Photograph 1). Surveys are being conducted on the bearing capacity of the foundation ground at these sites.

Partly to minimise the feeling of oppression exerted by the viaduct, the superstructure is supported on single-column piers at a large number of points on the Kobe Route, which was built in the form of a viaduct above an existing national highway. Damage was observed on a large number of such single-column piers and repair work is under way at present at these sites. Where the damage was minor, concrete piers are being reinforced through injection of resin into the cracks as shown in Photograph 2. For reinforcement of damaged sections of piers, falsework is first constructed to prevent the collapse of girders and piers; steel plates are then wound around the piers and concrete is placed inside the steel plates (Photograph 3). Where the damage is comparatively severe and reinforcement bars are exposed on the surface, the construction of falsework for prevention of girder collapse is followed by mortar spraying (Photographs 4 & 5) or placement of additional concrete around the exposed sections (Photograph 6). On steel piers, their stability is being improved through attachment of stiffening members as shown in Photograph 7.

In a section near Nishinomiya Ramp, there is a danger of superstructure fall-off due to lateral movement of viaduct piers. The possibility of fall-off is being reduced here by supporting the girders with falsework as shown in Photograph 8. Near Minatogawa

Access, horizontal movement of the piers at the fixed support points for a continuous girder led to the fall-off of the superstructure, which now hangs down near the centre of the span. Reinforcement and supports have been provided here as shown in Photograph 9 while awaiting future repair. These measures were taken as emergency measures aimed at the prevention of further damage due to aftershocks.

(2) Hanshin Expressway: Wangan Route

The damage was relatively small on the Wangan (Coastal) Route despite the fact that much of this route passes through reclaimed land.

On a three-span continuous girder bridge near Minami-Ashiyahama Toll Gate, bearings were damaged and a drop was created on the road surface. As a result, this section is now closed to ordinary traffic.

An access girder bridge fell in the side span of Nishinomiya Port Bridge. This access bridge had been built as a simple-girder bridge, as the bridge is located on reclaimed ground and uneven settlement was expected. In this case, however, lateral movement of the ground caused the bridge piers to move parallel to the bridge axis and led to the fall-off the girder. For restoration work here, it was decided that, after checking the soundness of the pier, the pier crowns should be partially expanded and the girder, with its ends repaired, should be lifted back into position. The pavement and floor slabs have now been removed from the fallen girder, and the girder is being lifted up into position (Photographs 11 & 12).

Higashi-Kobe Bridge is a three-span cable-stayed bridge. Although the bearings were partially damaged, the main body of the bridge was unscathed thanks to the presence of seismic dampers. Pins flew out of the pendulum bearings in the Kobe-side (western) span of the bridge (Photograph 13), causing the girders in this span to rise out of position, damaging the expansion joint, and creating a drop on the road surface. The bridge, as a result, is closed to ordinary traffic. The method adopted for restoration work here is to place counterweights on the side spans to lower the dislocated girders and to replace the pins. It will take time, however, to manufacture the specially-designed pins. It is expected that the bridge will be reopened in late April.

Rokko Island Bridge is a double-deck Lohse bridge with a total weight in excess of 10,000 tons. A major transverse movement of girders here on the pier at the Rokko Island end led to their dislocation from the bearings and displacement of chord members beyond the edge of the pier (Photograph 15). No major damage, however, was observed on the main body of the bridge beyond buckling deformation of some of the horizontal and diagonal members on the top lateral bracing. In the restoration plan under way, bearings are to be installed in their proper positions on the pier and the superstructure is to be lifted back into position in one body using three floating cranes of the largest class in Japan. When the superstructure is lifted, however, this will create stress conditions which are completely different from those originally expected on the bridge, and the members will have to be reinforced for this purpose. A further difficulty is created by the fact that suspension pieces manufactured by welding may not be safe. Investigations are under way for these reasons on the details of this scheme. The expected date for the reopening of the bridge is around October.

(3) Hanshin Expressway: Osaka-Shinai Route

Although damage was observed of some of the bearings on the Osaka-Shinai (Intra-Osaka) Route, the main parts of the girders and piers were more or less unscathed and the overall damage was small. In the restoration work here, the girders were lifted up with jacks while the bearings were exchanged. Due to the trouble involved in this work, it took longer than might have been expected before the route could be reopened despite the apparent absence of damage to girders.

(4) Ikeda Route (Hanshin Expressway) and Chugoku Expressway

The section of the Ikeda Route near Toyonaka-Minami Interchange had been renovated by the so-called " no-joint method," in which the old girder bridges were given a continuous structure and seismic isolation bearings were used to raise their seismic resistance (Photograph 16). No damage was observed in this section. There were indications, however, that the girder ends had collided with piers, a fact which suggests that there was a significant horizontal displacement. The same method had been applied to the Namaze Viaduct on the Chugoku Expressway (Photograph 17). The absence of damage in these sections provides an indication of the effectiveness of the " no-joint method," and points to it as a useful method for improvement of seismic resistance on existing bridges.

(5) Trunk Coastal Roads

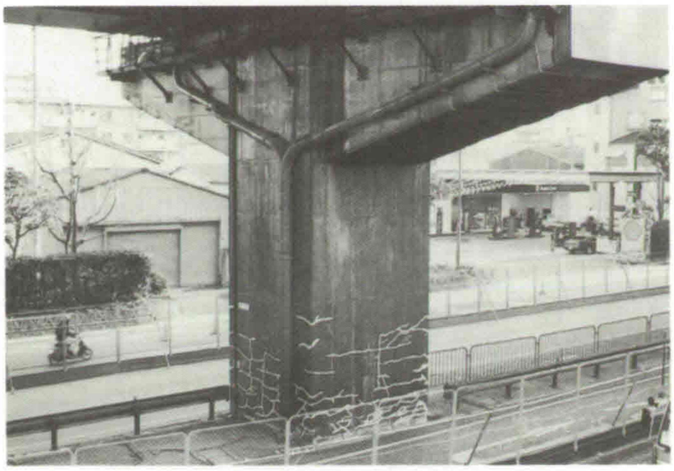
Maya Bridge is a two-span cable-stayed bridge. Despite the fact that the bridge is closed to ordinary traffic, it is being used by motorbikes and pedestrians (Photograph 18). In view of the extensive damage to the main body of the bridge, the plan here is a complete removal of the existing bridge. The adjacent Second Maya Bridge is a three-span continuous box girder bridge. Although the bearings and piers have suffered damage (Photographs 19 & 20), there is little damage on the main body of the bridge. A case may be observed here where the restoration methods will differ according to bridge types and the level of damage.

(6) Kobe Municipal Subway

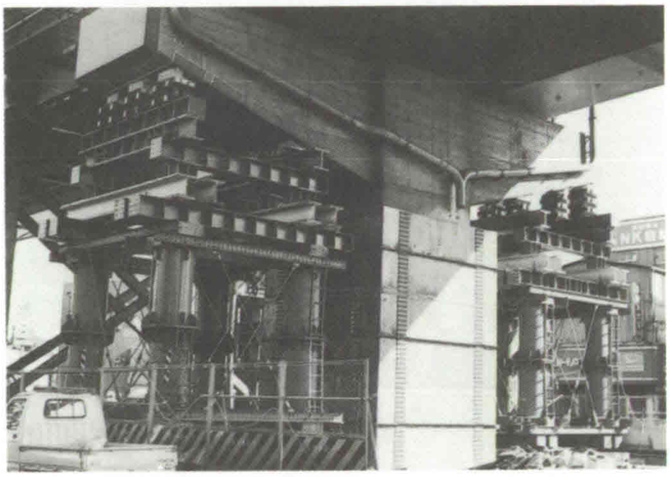
In the subway system operated by the Transportation Department of Kobe City, damage occurred to the reinforced concrete columns in the middle of the urban-type box tunnel at

Kamisawa Station on Yamate Line and in the section stretching for around 260 m to the west of the station. Concrete failure has led to the exposure of the reinforcement bars here (Photograph 21). In some places, the axial reinforcement has bent bending, and the concrete and reinforcement has become separated. These columns have been provided with temporary supports, and displacement gauges have been installed for constant measurement of their displacement, but no progress of displacement has been observed so far. The subway line is now in operation and trains pass through the damaged section, but Kamisawa Station itself is closed to passengers so as not to obstruct the restoration work. The Transportation Department hopes to reopen the station when the restoration work has been completed and the safety of passengers can be guaranteed.

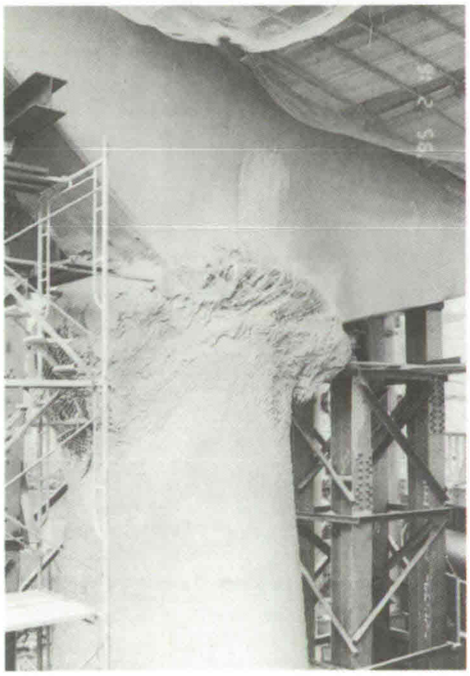
Photograph 1 National Highway Route 43 (Near Fukae)



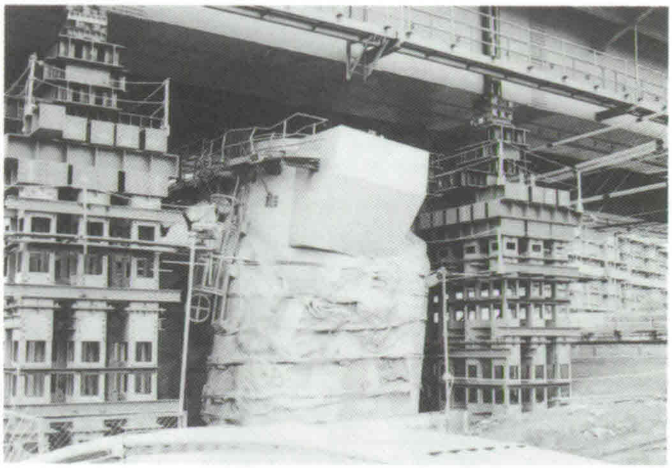
Photograph 2 Concrete viaduct pier repaired by resin injection



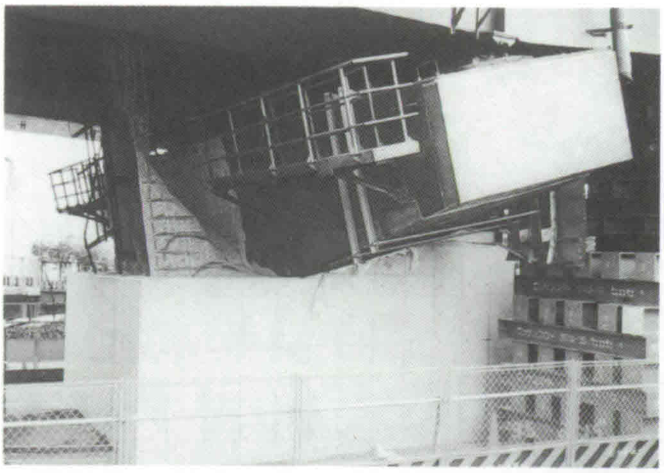
Photograph 3 Concrete viaduct pier under repair



Photograph 4 Mortar spraying on concrete viaduct pier



Photograph 5 Preventing the collapse of concrete viaduct pier (1)



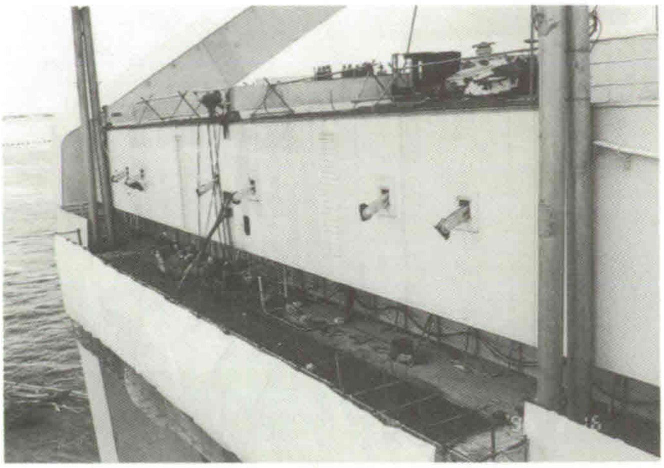
Photograph 6 Preventing the collapse of concrete viaduct pier (2)

Photograph 7 Steel viaduct pier under repair

Photograph 8 Prevention of superstructure fall-off (1)

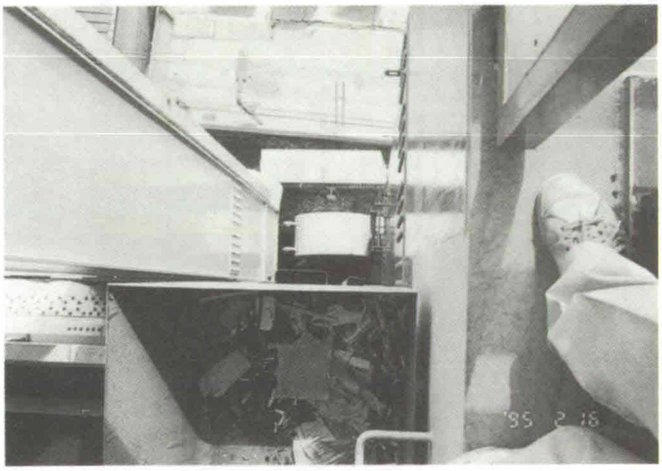
Photograph 9 Prevention of superstructure fall-off (2)

Photograph 10 Drop on the road surface near Minami-Ashiyahama Toll Gate

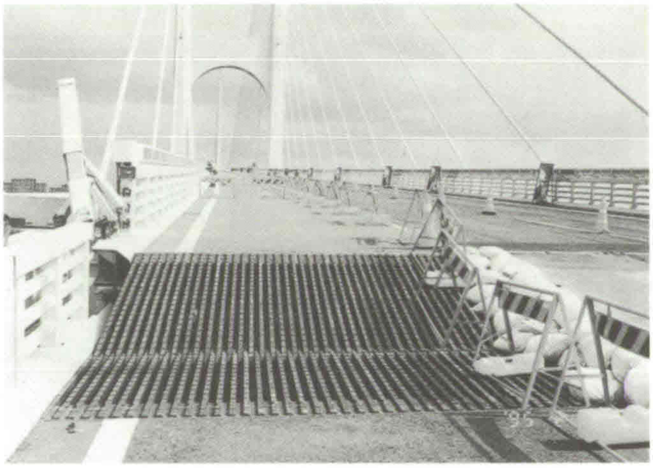


Photograph 11 Repair work on side span of Nishinomiya Port Bridge

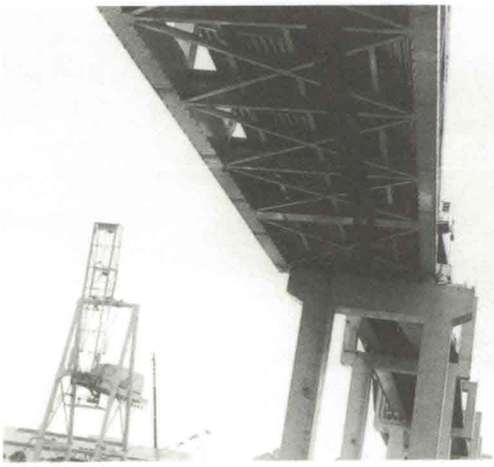
Photograph 12 Removal of floor slabs on side span of Nishinomiya Port Bridge



Photograph 13 Damage to a bearing on Higashi-Kobe Bridge

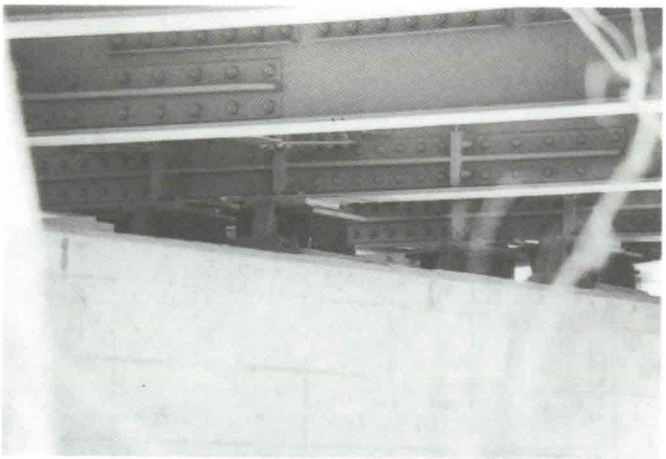


Photograph 14 Drop on the road surface on Higashi-Kobe Bridge



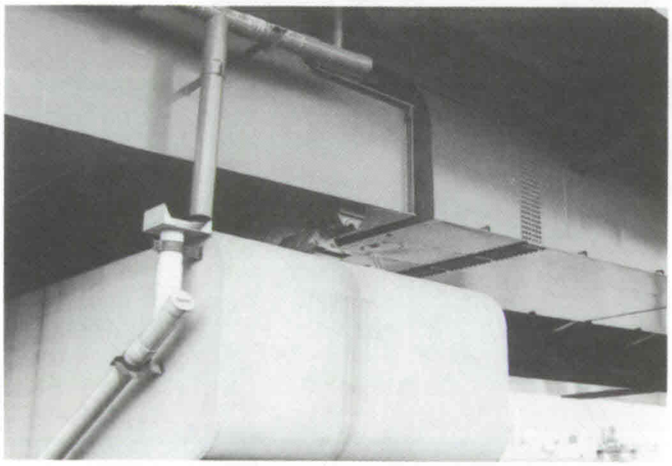
Photograph 15 Transverse movement of girders on Rokko Island Bridge

Photograph 16 Near Toyonaka-Minami Interchange ("No-Joint Method")

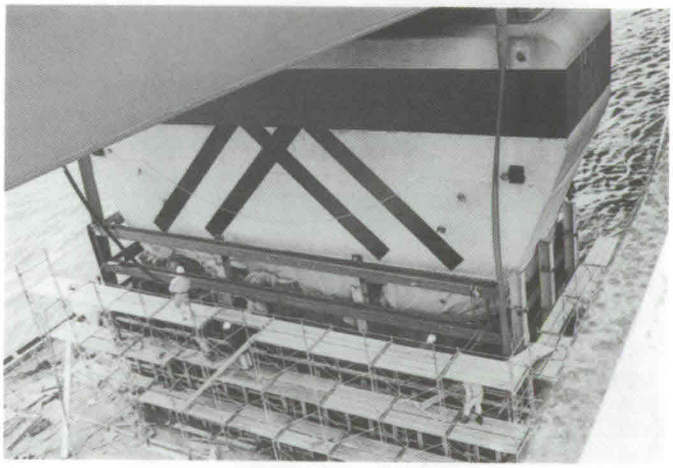


Photograph 17 Seismic isolation bearing on Namaze Viaduct

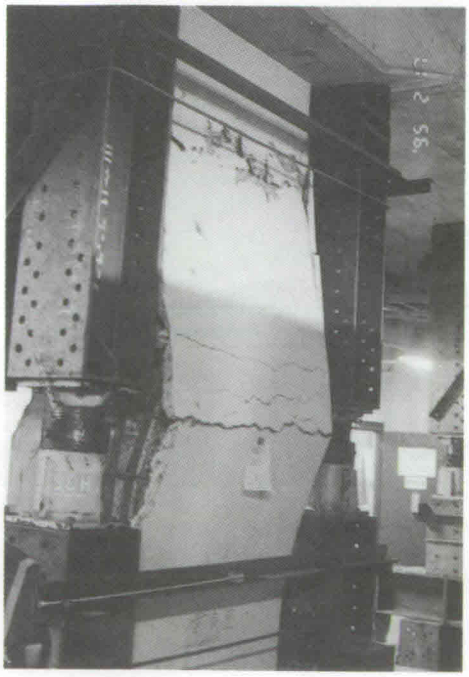
Photograph 18 Maya Bridge



Photograph 19 Damage to a bearing on Second Maya Bridge



Photograph 20 Pier under repair on Second Maya Bridge



Photograph 21 Middle columns at Kamisawa Station, Kobe Municipal Subway

3. Recommendations

The findings of the surveys conducted by the study group may be summarised as follows.

1) Little damage occurred on superstructures which had been subjected to careful planning (e.g. Lohse bridges, Nielsen-Lohse bridges, rigid-frame bridges, cable-stayed bridges). Among girder bridges, fall-off occurred on some simple-girder bridges. This fact suggests that, for the purpose of fall-off prevention, continuous structures are more desirable.
2) Seismic connection plates between girders were damaged in some cases, but in a large number of cases were judged to have prevented girder fall-off, and in this respect are thought to have been effective. There is a possibility that the presence of seismic connection plates aggravated the structural damage in certain cases, but this problem may be overcome by assuming a rigid connection for the superstructure in design. Such systems have normally been designed as linear structures so far; it is hoped that they will be treated more as planar structures in future.
3) On girder bridges, damage occurred in a large number of cases on concrete piers. This is thought to be due to the inability of the concrete structures to keep pace with the displacement caused by the earthquake. There will therefore be a need in future to take steps to raise the ductility of concrete piers.
4) With one or two exceptions, no fatal damage was observed on steel piers. The collapse of a steel pier, however, occurred near Nishinomiya on the Kobe Route of the Hanshin Expressway. A speedy elucidation of the causes of the damage here is hoped for. Near Nakanoshima-Nishi Access (in Osaka City) of the Kobe Route of the Hanshin Expressway, some of the concrete piers have been reinforced by placing steel plates around them and injecting resin. It is hoped that more consideration will be given in future to such repair methods and to composite piers that take advantage of the material properties of both concrete and steel.
5) Bearings were damaged on a large number of bridges. These bearings may be said to have played the role of a fuse in an electric circuit. The failure of the bearings, in other words, protected the piers and the main parts of the bridges from damage. The fact that bearings and displacement control devices underwent brittle fracture, however, causes one to hope for the development of products with greater ductility to replace cast iron products.
6) Loosening of anchor bolts was observed on some of the damaged bearings. This is thought to have resulted from the application of a vertical, upward force. The bearings in use at present have little resistance to upward forces. Regardless of the debate as to the need to consider the vertical motion in seismic design in general, there will be a need to devise a means for preventing the loosening of anchor bolts.

7) The fact that bearings have proved to be the weak points will give impetus to investigations in future on bridges on which the superstructure and substructure are structurally integrated. No damage was observed, for example, on Nadahama Bridge, which is a five-span continuous girder bridge.

8) There are cases where lateral movement of the ground caused the piers to move and led to the fall-off of the superstructure. There will be a need in future for careful planning against such lateral movement.

9) Seismic isolation bearings made of laminated rubber are thought to have been effective. Problems still remain, however, with these bearings over their performance under extremely large displacement, guarantee of rupture strength during earthquakes and guarantee of durability. It is hoped that investigations will be conducted in future on these points in conjunction with the improvement of the rubber materials themselves.

10) Dampers and other seismic response control devices are thought to have been effective. Further development of improved products is hoped for in future.

11) Further development of devices for active control of seismic response is also hoped for. At the same time, however, it is important that structures are made earthquake-proof in themselves without such control devices. Active control should, for the time being, be used in a supportive role for reduction of the damage.

12) One major problem encountered in the implementation of restoration work is the difficulty of securing accommodation for the restoration workers. In a large number of cases they could only be accommodated at remote locations, and much valuable time is spent on commuting. There is also the problem of ensuring their safety from aftershocks. There is a need in general to take steps to guarantee the safety and sanitation of workers and to ensure that they are given sufficient rest.

The foregoing are the reflections of the members of the study group on completion of their survey in the disaster area. It is hoped that these thoughts will provide something of a basis for future discussions.

Group Report: Roads and Railways II

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1. Study Area: Outline of Facilities

(The report here includes the findings of the study conducted by the Japan Railway Construction Public Corporation between 23rd and 25th January, which a member of the study group accompanied.)

Sanyo Shinkansen Line (8 km section east of Rokko Tunnel, 4 km section near Nishi-Akashi Station)

Non-Shinkansen JR Lines (Sumiyoshi to Rokkomichi)

Kobe Rapid Transit Railway (Motomachi to Kosoku-Nagata)

Hankyu Railway (Shukugawa to Nishinomiya-Kitaguchi)

Hanshin Electric Railway (Near Ishiyagawa Depot)

Kobe Route of Hanshin Expressway and National Highway Route 43 (3 km section in Nishinomiya, Fukae to Iwaya)

Meishin Expressway (4 km section near Mukogawa Bridge)

Chugoku Expressway (Near Mefu, Takarazuka City)

2. Conditions of Damage

Sanyo Shinkansen Line, Non-Shinkansen JR Lines and Hankyu Railway

* Girder/slab fall-off due to shear failure of columns on reinforced concrete rigid-frame viaducts
* Shear failure of columns on reinforced concrete rigid-frame viaducts/abutments
* Shear failure of reinforced concrete piers
* Flexural failure of reinforced concrete rigid-frame viaducts
* Fall-off due to dislocation of reinforced concrete/prestressed concrete simple girders

Kobe Rapid Transit Railway

* Fall-off due to dislocation of prestressed concrete simple girders
* Dislocation of prestressed concrete simple girders
* Shear failure of columns on reinforced concrete rigid-frame abutments
* Shear failure of reinforced concrete columns in underground railway station and resulting subsidence of road above
* Shear and flexural failure of underground reinforced concrete columns
* Flexural failure of underground reinforced concrete columns
* Horizontal rupture due to shear of cast steel pipes
* Damage to shoes, dislocation of girders from shoes

Hanshin Electric Railway: Ishiyagawa Depot

- Girder/slab fall-off due to shear failure of columns in single-level reinforced concrete rigid-frame raised depot

Hanshin Expressway: Kobe Route

- Shear failure of reinforced concrete piers
- Flexural failure of reinforced concrete piers
- Fall-off due to dislocation of simple girders
- Damage to shoes, dislocation of girders from shoes

Meishin Expressway

- Girder fall-off
- Shear failure of reinforced concrete wall-type piers
- Girder sinking and damage

Chugoku Expressway

- Shear failure of reinforced concrete piers
- Flexural failure of reinforced concrete piers
- Inclination of reinforced concrete piers
- Girder sinking and damage
- Dislocation of girders from shoes

3. Shear Failure of Reinforced Concrete Columns and Piers

Among the types of failure observed on this occasion, the mechanism of the shear failure of reinforced concrete columns and bridge/viaduct piers is perhaps the most difficult to explain (the same mechanism applies to the collapse of middle and lower storeys of buildings). What is presented below is a personal opinion concerning the mechanism of this failure.

Photograph 1 shows the conditions of shear failure on a reinforced concrete rigid-frame viaduct column on the Shinkansen Line. When, with the progress of the failure, a slip occurs along the face of the shear, the result is as shown in Photograph 2. In some cases, shear failure has led to the complete collapse of columns. Photograph 3 is an example of shear failure of a reinforced concrete pier at Mukogawa on the Shinkansen Line, while Photographs 4 and 5 show cases of shear failure on reinforced columns at the underground Daikai Station on the Kobe Rapid Transit Railway. Such shear failure may occur at any position along the vertical direction of columns and piers (although cases occurring near the top and bottom ends of columns are the most frequent). Lines of cleavage are found at angles of 15° to 35° from the vertical.

Concrete failure may be explained through the application of a failure curve based on Mohr's theory. According to this theory, concrete failure may take the form of either shear failure or tensile failure. Compressive strength, as obtained in compression tests on concrete test pieces, is defined as the compressive stress on the plane orthogonal to the loading direction at shear failure when there is no lateral pressure. When hoop reinforcement is provided, however, this hoop reinforcement will restrain the lateral expansion of the concrete placed under a vertical force (a phenomenon which may be explained in terms of Poisson's ratio and dilatancy) and will thus exert a lateral pressure. As a result, the stress conditions will fall below the failure curve, and a greater vertical force will be required to cause failure. This is the effect of hoop reinforcement in increasing the resistance of concrete to vertical forces.

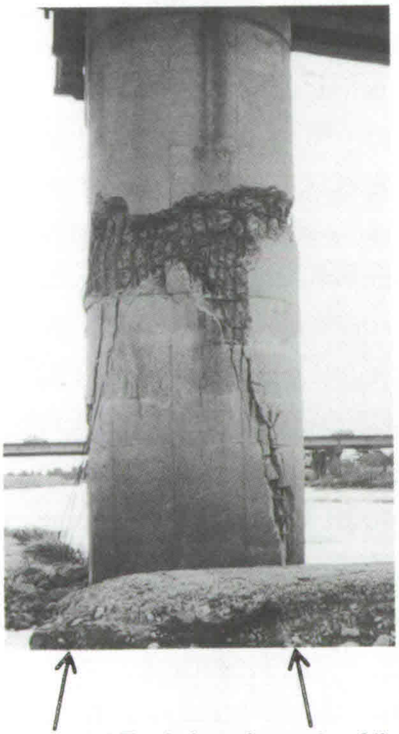
Under ordinary conditions, however, the stress inside a column is far lower than the stress corresponding to the compressive strength. Even if the considerable shear stress applied during an earthquake is taken into account, a large vertical force, large enough to generate a stress approaching the compressive strength, will be required to cause shear failure. On a rough estimate, it was found that this exceptionally large vertical force would correspond to over ten times the weight supported by the columns. The application of such a force is virtually unthinkable. Even if it is assumed that the vertical acceleration reached 1 G during the recent earthquake, the resulting vertical force will only be 2 times the weight supported and will be nowhere near 10 times.

When, on the other hand, an exceptionally large horizontal force is applied to a concrete structure, as occurred during the earthquake (together with a torsional moment, since a rotational motion is observed on a video tape record taken in a convenience store, and the analysis of displacement records conducted by the Railway Technical Research Institute also gives indication of rotational motion), a stress condition approaching the tensile failure stress is generated in the concrete, accompanied by a shear stress. Using Mohr's stress circle, one can provide a theoretical explanation as to how, in such a case, the shear resistance (or, in other words, the failure curve) of the concrete will be greatly reduced, creating a possibility of X-shaped shear failure, and how the failure plane will be positioned at a certain angle from the vertical. Mohr's stress circle can also be used to explain why the application in addition of a vertical force here will cause the plane of shear to approach the vertical. In this mechanism, failure will occur where the shear strength is at its lowest (the strength not being uniform), and can therefore occur at any position in the column. The reason why the shear failure in fact occurred most frequently near the top and bottom of the columns is thought to lie in the related generation of tensile stress due to bending.

Rough test calculations for the Shinkansen viaduct showed that a horizontal force corresponding to an acceleration of around 2 G (if there is a concentration of stress; less than 2 G if torsion and impact are also applied) would be sufficient to cause such a phenomenon, and the directions of the shear obtained in these calculations also coincided more or less with the actual directions (15° to 35° from the vertical).

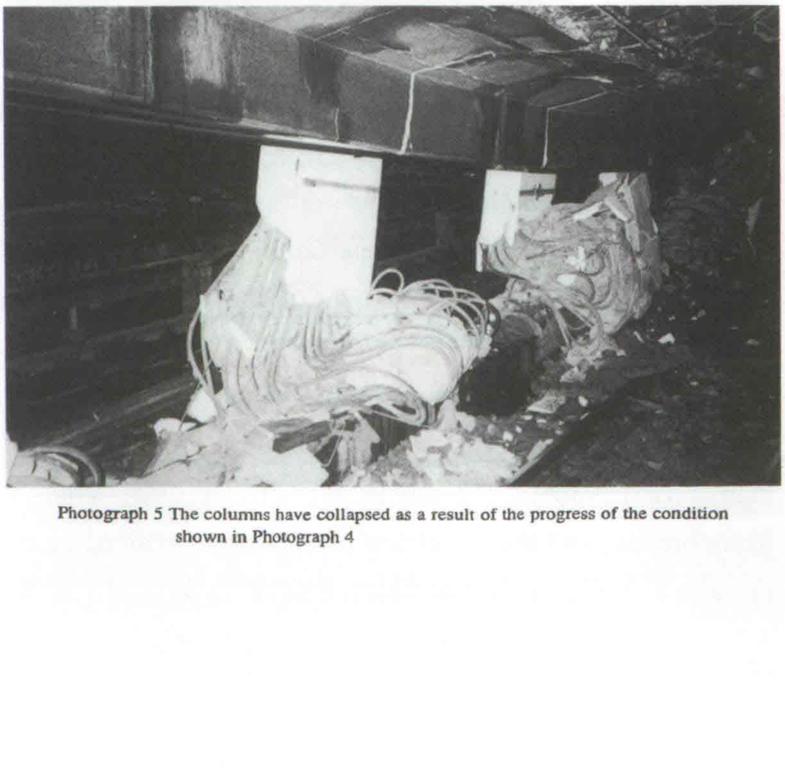
Photograph 1 The column has undergone shear failure along a plane whose orientation is indicated by the arrow.

Photograph 2 The column has collapsed as a result of the progress of the condition shown in Photograph 1



Photograph 3 The pier has undergone shear failure along planes whose orientation is indicated by the arrows.

Photograph 4 These columns have undergone shear failure along planes whose orientation is indicated by the arrows.



Photograph 5 The columns have collapsed as a result of the progress of the condition shown in Photograph 4

The effects of hoop reinforcement against such shear failure may be explained as follows. For concrete to undergo shear, there must be dilatancy, but such dilatation is restrained by hoop reinforcements, and this is why hoop reinforcement serves to hinder the occurrence of shear failure. This may be explained as follows using failure curves. Restraint due to hoop reinforcement generates a horizontal compressive stress, drawing the overall stress towards the compressive side and making it more difficult for the stress condition to approach the failure curve. Hoop reinforcement, in other words, raise the resistance to failure and hinder the sudden occurrence of shear failure, and as a result, raise the ductility.

Deally, one should provide a fuller explanation of the mechanism of shear failure using failure curves (only a conceptual drawing is provided here in Figure 1) .

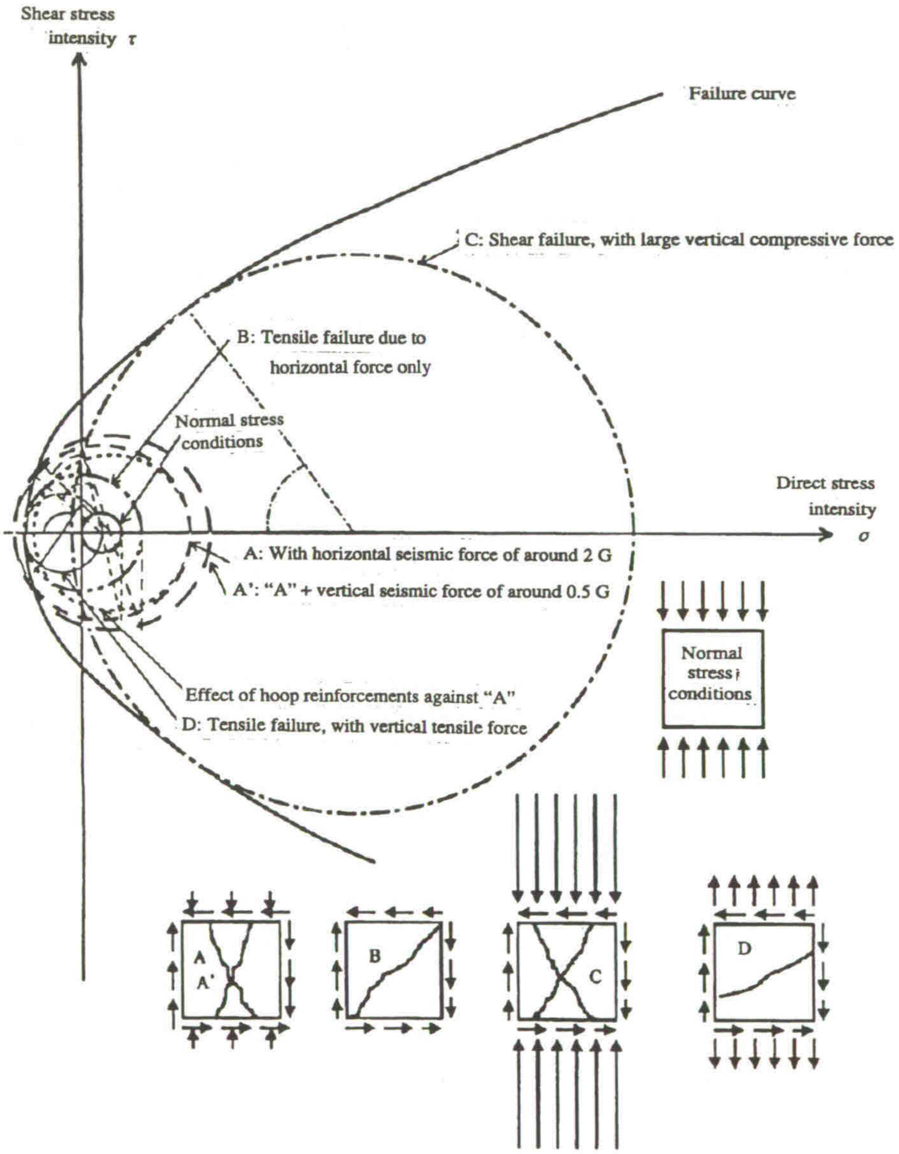


Figure 1 Mechanism of Shear Failure of Concrete (Conceptual Drawing)

Unfortunately there is no time and space for this here, and the indulgence of the readers is sought with a promise by the author to present such an explanation elsewhere. For reference, although this has not yet been confirmed by the author, it appears that there were a small number of cases, where the plane of shear was located at angles greater than 45° from the vertical. This may be due to the action of a tensile axial force.

It cannot be said that the explanation outlined above is completely free from difficulties.

One of these difficulties is the effect of reinforcement bars in resisting shear failure. This, however, may be explained away as follows. Reinforcement that is effective against shear with its planes at angles between 15° and 35° from the vertical are those installed at right angles to such planes, but there were no such reinforcement in this case. The main reinforcement in columns are located at shallow angles to the direction of the shear, and therefore one cannot expect them to be very effective. It is also possible for the concrete around the reinforcement to undergo shearing parallel to the reinforcement and for these shears to join each other along a diagonal direction. Hoop reinforcement is more effective, but the quantity is normally extremely small. One can therefore assume that reinforcement will not be sufficiently effective to prevent the type of shear failure whose mechanism has been explained here. The equations used in the design of hoop reinforcement at present are basically intended to ensure safety against diagonal tensile stress, and are not directly concerned with shear failure. It seems that there is a need to reconsider the equations used for calculation of hoop reinforcement volumes.

The next difficulty entailed in the explanation is as follows. While there are a large number of cases where shear failure was influenced by bending, a question arises here as to why the failure took the form of shear failure even in those cases where flexural failure would have been more likely to precede. The answer to this difficulty may be sought in the fact that, while shear failure has been explained so far in terms of force and stress, it would be more accurate to say that shear failure occurs when the deformation and strain of the concrete have reached stages corresponding to certain force and stress levels. There is an important difference between flexural and shear failure in that flexural failure does not take place until a given structure has undergone a significant displacement, but shear failure can occur suddenly without any significant displacement. One can therefore expect a given structure to reach the critical deformation and strain levels corresponding to the critical force and stress levels under shearing earlier than under bending. When shear failure occurs halfway down a column, the seismic energy is used up in the form of failure and sound energy, and will not reach the bottom of the column. As a result, no large bending moment will be generated and flexural failure too will be unlikely to occur. It is also possible to say that flexural failure is prevented by the application of opposite forces before displacement reaches a level where flexural failure can occur.

If the author is correct in his explanation of the mechanism of shear failure, considerable difficulties will be involved in the confirmation of these conditions in static laboratory tests. In this sense, the expression used by Prof. Hideo Nakamura, the Chairman of JSCE, who led the Second JSCE Study Team and described the damage caused by the earthquake as one “of a scale which it would be difficult to reproduce in laboratory tests,” is one that is very pertinent to the problems encountered here.

It seems, on the whole, that complete collapse was more frequent on thinner columns. This may be explained by the fact that they have relatively small shear resistance in comparison with thicker columns. The overturned viaduct on the Hanshin Expressway with its single-column piers, seems to have undergone shear and flexural failure simultaneously. It may be that the relatively large cross sections of the piers here, by providing large shear resistance, allowed the seismic energy to be transmitted to the bottom. It may also be that some of the piers underwent shear failure first and caused the remaining piers to overturn. An eye-witness has stated that the eastern end of the viaduct was overturned by the earthquake and pulled down the remaining sections after it. If this is the case, this will explain why the eastern end of the viaduct has undergone shear failure while the main cause of the collapse in the remaining sections is flexural failure.

Finally, it should be noted that, while the observations here have concentrated on shear failure of reinforced concrete columns and piers, the author does not mean to say that there were no cases of no flexural failure. There are cases, of course, where the collapse seems to have taken the form of flexural failure.

4. Progress of Restoration Work

Sanyo Shinkansen Line, Non-Shinkansen JR Lines & Kobe Rapid Transit Railway (Aboveground Sections)

The policy being adopted seems to be to reuse those fallen girders and slabs that can be used, to utilise those sections of columns that can be used, and where necessary to repair them by installing new reinforcements or wrapping steel plates around them and injecting cement mortar. There were cases where resin mortar was being injected into relatively minor cracks in columns and beams. Irreparable members were being replaced with newly-constructed ones.

Meishin Expressway & Chugoku Expressway

The policy seems to be to lift up the girders and repair the shoes, while piers are being repaired by wrapping steel plates around them and injecting cement mortar.

While these repair methods may be deemed the best that can be done under these emergency conditions, it is hoped that the desire to reopen the roads and railways at the earliest date possible does not lead to excessive haste in their implementation. The maximum care possible should also be taken in construction management, given that the urgency of the restoration work does not allow the attendance of a sufficient number of engineers.

Since what is taking place at present is emergency restoration work, there will be a need to take further measures as appropriate once the preliminary restoration work has been completed and the roads and railways in questions are in service again.

5. Points at Issue and Recommendations

While it is only natural that academics/experts and journalists have been putting forward various views concerning the disaster caused by the Great Hanshin Earthquake, it seems that much of the discussion has been grounded on baseless assumptions, presumptions and expectations. As a result, it is to be feared that, wrong conclusions may be accepted as truth and misdirect the courses of future action.

What one must do in such a situation is to reject any unfounded predictions and presumptions or expectations, and to take as calm a view as possible of the facts. If this is done, people, in all positions, will realise that they are being faced with so-called "facts" which cannot be backed up by any credible explanation, and that they are being fed with a large amount of "information" which carries little conviction.

I would like to take up some of these "facts" that lack any ready explanation and to offer my personal comments.

1) What was the cause of such abnormal damage?

The phenomenon we have before us seems to be one in which vibration of an unimaginable scale occurred in areas close to a number of localised lines, and structures located in these areas suffered exceptionally serious damage. How can this "vibration of an unimaginable scale" be explained in scientific terms? The force of the earthquake, as expressed in terms of acceleration, and its period, in connection with resonance, have been pointed out in the past as factors affecting building structures. Because what happened this time could not be explained in terms of these factors, some people have been talking of the velocity of the seismic motion and simultaneous occurrence of vertical motion with the horizontal, but no convincing explanation has yet been offered along these lines. It is true that the velocity seems to have been exceptionally large, and since impact energy is proportional to the product of mass and square of velocity, it is not to be doubted that the velocity has had a major part to play in the damage caused by this earthquake. A further possibility, which has been my personal opinion for some time, is that the period (though not in connection with resonance) has had a role to play. In any case, it seems to me to be rather premature on the part of academics and experts to be putting forward conclusive views concerning the actual phenomena and the measures to be taken, when this question, which is the most important one, has as yet to be solved.

2) Were academics/experts mistaken into their estimation of the potential damage?

There are academics and experts who have been making statements to the effect that " there is no need for any major revision of the seismic design standards, since those designed according to the new standards have been relatively free of any fatal damage." This view has to be examined under the following three questions.

a) Is it possible to say with confidence at the present stage that "structures designed according to the new standards have been relatively free of any fatal damage"?

b) Was the level of the "damage to structures designed according to the new standards" as expected?

c) Had those academics/experts warned the public that such a situation might arise?

My impression, at least, is that the answers to all three questions have to be "no."

I suspect the scale of the earthquake this time went beyond the expectations of most academics and experts. It may be that we were mistaken in our evaluation of the Great Kanto Earthquake of 1923. Another possible reason for our unpreparedness is the relatively small scale of the damage (at least to civil engineering structures) in past earthquakes, even on those occasions when relatively large accelerations (accelerations on par with those observed this time) were observed. As a result - without going into the question here of how the expected effects of earthquakes should be reflected in seismic design (i.e. whether structures should be designed so that they will be more or less free of any damage or whether they should be allowed to suffer a certain amount of damage when a given force is applied, and the types and locations of structures such seismic design should deal with) - most of us had, inadvertently, come to underrate the possible effects of earthquakes and had become over-confident in our assessment of the validity of seismic design.

It is to be granted that none of us would have gone so far as to believe that our new seismic structures would be safe under all possible conditions, but there is no doubt that those engaged in seismic design, including myself, were mistaken in our estimation of the effects of what we considered to be the largest earthquakes that were likely to occur. Self-examination of engineers is called for on this point.

I had always said that seismologists and engineers had a tendency to overstate the case for safety and that they should be more honest in their statements. No one will believe them when they say after the event that they had done their best to prevent such a fatal disaster (Can they really say this with conviction?).

3) How can the various types of structural failure be explained in scientific terms?

The earthquake caused various types of failure to large-scale engineering structures. The type of failure which is perhaps the most difficult to explain scientifically is the shear failure of reinforced concrete columns and piers. I have put forward one possible explanation for the mechanism of such failure in Section 3 above. We must undertake the work of elucidating this mechanism at an early stage.

4) Why does hoop reinforcement serve to raise the ductility of structures?

That hoop reinforcement serves to raise the ductility of concrete (that this hinders the sudden occurrence of shear failure) is a fact. A non-specialist will perhaps be surprised to hear that no satisfactory theoretical explanation has as yet been offered for this phenomenon. I believe that I have been able to offer a plausible explanation in my attempt to elucidate the mechanism of shear failure. What we must do, however, is to go beyond a qualitative statement of the fact that ductility can be increased by increasing the volume of hoop reinforcement to a point where we can provide a clear quantitative explanation of the relationship between the hoop reinforcement volume and the resulting increase in ductility.

5) What was the cause of the decisive difference in the damage on structures separated by only a short distance?

Before embarking on the field study, I had hoped to derive suggestions for measures to be taken in future from structures that remained relatively free of damage. Of course, there were cases where useful conclusions could be drawn from such structures, but there were also cases where a certain structure had collapsed under the influence of an exceptionally large force, while exactly the same type of structure right next to it remained more or less unscathed. The scene was not one in which a given section with the same structure was found to have collapsed en masse or one in which a gradual decrease could be observed in the damage over a given section. The impression I received was that the difference in the damage was dependent not so much on the seismic resistance of the structures themselves as on the forces applied to the structures; that exceptionally large forces occurred in extremely localised areas for reasons relating to ground conditions and presence of faults, and that there were extremely large fluctuations in the scale of the seismic motion over short distances (an impression of lines of exceptionally large vibration running through the area like lightning). If this is so, it means that one cannot necessarily derive suggestions from unscathed structures. What happened, in any case, was that exceptionally large motion occurred in areas along a number of extremely localised lines. Large seismic motion occurred in other areas too, of course, but it seems that one must consider the seismic motion in other areas to be one of a different order from the one occurring in these localised strips.

There is a danger, therefore, that one may reach completely wrong conclusions, unless, in conducting our analysis, we bear in mind the fact there are limits on our ability to draw general conclusions from structures that remained relatively free of damage. It is extremely risky, in other words, to treat the whole of the disaster area as having been subjected to the same kind of seismic forces, and care must be taken over this point especially in statistical analysis. Just because there were structures that remained undamaged or received only minor damage, one must not jump to any rash conclusions and say that there is no need for any major revision of the seismic design standards.

6) How often will earthquakes of such a scale occur? Is there no likelihood of even larger earthquakes?

Seismologists and civil engineers, including myself, had thought that the level of seismic motion which is believed to have occurred during the Great Kanto Earthquake was about the largest that was ever likely to occur. It has been proved, however, that there are earthquakes capable of causing damage far in excess of that previously expected. It may be that seismic motion of the level observed this time actually occurred in localised pockets during the Great Kanto Earthquake and the Fukui Earthquake of 1948, for example. If so, even though it may be once in several thousand years that such an earthquake will occur at a given point, in Japan as a whole one must be prepared for its recurrence at a fairly high frequency. There are also doubts as to whether one can say that the earthquake this time was of the largest order possible. It would seem more appropriate to say that even greater earthquakes, though of extreme rarity, can occur.

Cases of mistakes in construction and defective work have been identihed in the wake of the earthquake, and I myself have seen indications of such defective work at a large number of points during our field survey. This is something I had always pointed out, and it is something which we engineers must humbly acknowledge and reflect upon regardless of whether or not they were the main causes of the disaster. There have been statements to the effect that "one cannot say that there were no mistakes and defects, but they were not the main causes of structural failure." Such arrogant statements not only fail to convince but generate mistrust towards us engineers among the public. We must first make a sincere acknowledgement of our past failure and a statement of our resolve to rectify the situation; only then can we proceed to an objective discussion as to whether or not defective work was the cause of failure in each case.

It has been said that the collapse of the Shinkansen viaduct was caused by defective work on concrete joints in its columns. Conclusions drawn from an examination of the failure conditions and simple numerical calculations do not point to defective work on column joints as the cause of the shear failure, and there are in fact cases of shear failure which have occurred at points away from joints. My colleague, who is the proponent of this opinion, has for some time been a vocal critic of defects in concrete work, and it seems that he was led by his cherished opinion into a premature attribution of the failure to defective work when defects were discovered on concrete columns this time. Whatever the truth of the matter here, truth must be sought in all cases through accurate, objective and scientific analysis.

One will not, of course, be able to say that there were no cases where failure was caused by defective work. Neither will it be the case, however, that such fatal damage would not have occurred had the construction work been carried out as it should have been. If defective work were the main cause of the damage, this would make things very easy for us, as it would mean that there was nothing wrong with the design. If we were to believe this, however, we would be risking the recurrence of a major disaster. One must not be led to the wrong conclusions by subjective judgements.

What I would ask of the public is not to force academics and experts to provide hasty conclusions and proposals for what should be done while various problems remain unsolved. Academics and experts, for their part, should not make any rash proposals for "standards for structures capable of comfortably withstanding earthquakes on the level of the Great Hanshin Earthquake." For the present, the best we can do is to draw up provisional standards for the emergency restoration work, which must be revised later in the light of more thorough and accurate discussions.

Finally, I would like to touch on a basic problem relating to our future actions.

There is no doubt that the our recent bitter experience will lead to a major revision in the evaluation of the effects of "earthquakes of the largest class" in various design standards. As mentioned earlier, there are those who claim that the present standards are basically adequate and that there is no need for a major revision, but this is unlikely to be so.

The next question one will ask is whether, if the standards are revised, that will be adequate for preventing similar disasters in future. The answer, unfortunately, is negative. The application of the new standards will require a vast amount of time and money, and it will be impossible in practice to reinforce and construct all structures to a level where they will be able to withstand an earthquake on par with the Great Hanshin Earthquake. (There are those who are of the opinion that there will be no major increase in the costs. It would be good if this were true, but this is very unlikely.) There are also those who say that it would be impractical to draw up standards ensuring that structures will be able to withstand abnormal earthquakes which might occur once in a thousand years. As I have mentioned earlier, however, an earthquake of this level may occur fairly frequently in the whole of Japan, and this leaves us with no choice but to draw up standards for structures capable of withstanding an earthquake of the same scale as the Great Hanshin Earthquake and to do the best we can to satisfy these standards. Just because we are told what must be done to achieve safety, it does not mean that we can immediately turn this into reality. The unfortunate truth is that we are forced as a result to remain at a lower level than that which is desirable. I have made this point again and again over the past decade, but my lone voice seems on the whole to have fallen on deaf ears.

Be that as it may be, the whole society must accept this fact in a cool light. As a major prerequisite for this, academics and experts must be honest in telling the truth, and the whole society must then discuss what is to be done. The prevailing opinion in the past was that one can leave design standards and other such matters to academics and experts. This in fact was the mistake. Not only academics and experts, but no one, in fact, can guarantee absolute safety. Despite this truth, academics and experts claimed that they could guarantee safety and the public were led to believe this lie.

Our recent experience has shown us the grave truth that there is no such thing as absolute safety. We cannot but stand dumbfounded when we perceive how low the highest limits of the social activities of man (as a fruit of our scientific knowledge, financial resources and social and political actions) are in comparison with the workings of nature which far exceed human comprehension. But, at the same time, we must not give up. We have no choice but to carry on with our work of reducing the risks of disasters through whether realistic actions we can take.

Field Survey Report on Coastal and Harbor Facilities

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1. SURVEY AREA AND FACILITIES INVESTIGATED

The areas listed below, and also shown in Figure 1, represent the scope of our investigation.

① Left bank of the Yodo river
② Amagasaki port, Amagasaki lock
③ Nishinomiya Yacht Harbor
④ Reclaimed area of Minami Ashiyahama
⑤ East No.4 zone
⑥ Rokko Island
⑦ Maya Wharf
⑧ Jetties Nos. 5 to 8
⑨ Port Island
⑩ Hyogo Port
⑪ Nagata Port
⑫ Suma beach

Two methods were used in the investigation: onshore approach and visual observations from offshore sites. The team also visited the Hyogo Prefectural Office (Harbor Division, Fishing Port Division, and Business Agency) and Kobe City Hall (Harbor Bureau) to collect pertinent information.

2. DAMAGE AND ITS MAIN CAUSES

The damage done to major harbor facilities, such as Port Island and Rokko Island, has already been covered by the First and Second Investigations of the Japan Society of Civil Engineers. This report details the damage in areas not covered in the previous reports.

Damage in the area around the mouth of the Yodo river

The geological feature of the Yodo river mouth is the existence of loose alluvial sand over an underlying layer of loose alluvial clay. This means the ground is susceptible to liquefaction caused by even comparatively minor earthquakes. Thus, many structures were damaged in the Great Hanshin Earthquake.

Typical examples of the damage are the collapse of the left bank levee of the Yodo river (see the Second Group Report) and damage to the Amagasaki lock, which was constructed in 1957. Regarding the Yodo river levee, when liquefaction occurred around Amagasaki lock, dark black alluvial sand spouted from the ground, as shown in Photo 1, and a nearby revetment structure subsided, as shown in Photo 2. This type of damage, subsidence of revetments, has caused serious problems for low-lying land near the mouths of rivers. Immediate countermeasures must be taken to rectify the damage.

The new lock, which had been constructed beside the old lock, was not damaged. A lifting crane at the thermal power plant in Amagasaki port collapsed due to the movement of soil during the earthquake (Photo 3).

Damage to reclaimed area off Nishinomiya and Ashiya

High quality soil consisting of decomposed granite was used to reclaim the area off the Nishinomiya and Ashiya coast. Below the reclaimed layer, there lies a loose alluvial clay layer. This clay layer lies on an alluvial sand layer, under which a strata of diluvial sand and diluvial clay exist alternately. These landfill sites suffered great damage due to liquefaction caused by the earthquake. This liquefaction was probably caused as a result of large seismic motion, unlike the previously mentioned case where there was weak alluvial sand present.

The description regarding the damage to these reclaimed areas and their coastal dikes have already been covered in the First and Second Group Reports, where it is explained that the effect of landfill liquefaction combined with lateral movement of coastal dikes caused serious damage to the foundations of bridge structures, especially those standing near revetments.

Various types of revetment structure had been used at the reclamation sites. At the site off Minami Ashiya coast, three main types were in use, as shown in Fig. 2. With all of these designs, ground subsidence or lateral movement was observed (for example, the Type B coastal dike shown in Photos 4 and 5).

The Wangan (longshore) Route of the Hanshin Expressway passes across the north of the reclaimed site off Minami Ashiya coast. Foundations of large elevated bridges standing near coastal dikes toward the eastern and western shores of this reclaimed island were damaged by the effect of lateral movement. This damage caused problems related to connections between girders forming bridge superstructures and the bridge foundations (Photos 6 & 7).

Damage to coastal dikes at the Second Reclamation Zone on Port Island

Further reclamation from the sea is presently under way at the Second Reclamation Zone of Port Island. The fill level toward the southern end of this zone is low. The structure of the coastal dike is illustrated in Fig. 3. Here, the coastal dike also suffered damage. The ground moved laterally and the caisson revetment which had yet to be filled subsided at the southwestern corner (Photo 8). The breakwater situated nearby also subsided (Photo 9). Such deformation of the coastal dike is assumed to be brought about as a result from loss of bearing capacity by replacement sand fill at the bottom of the caisson. This requires further investigation.

Damage at Hyogo Port and Nagata Port

Coastal dikes at these ports at the western end of the Kobe Port area were also damaged. The geological feature of this area shows ample natural deposits of sediment. These natural deposits of sediment are supposed to be carried by river flow and the tidal current, and accumulated at that area. Given this structure, liquefaction might be expected in medium-size earthquakes, as with the ground at the mouth of the Yodo river. Breakwaters at these two ports either tilted over or subsided, as was the case at Port Island, and an immediate investigation is necessary to determine how to replace the sand fill below the caisson (Photo 10).

Small oil tanks standing in the area also suffered damage, including tilting over, due to ground liquefaction (Photo 11). The concrete riverbed of some nearby river channels was also damaged as a result of lateral movement caused by ground liquefaction (Photo 12).

3. RECOVERY

It is now about one month since the January 17 earthquake. Some emergency repairs have already been carried out at major port facilities on Port Island and Rokko Island, including the construction of a temporary berth for the unloading of emergency materials. Recovery work, however, is very slow at other port facilities.

Hyogo Prefecture and Kobe City are working on repairs according to the following schedule:

- Temporary repairs to be completed by the end of March, but full recovery will take until after April.
- Six container terminals (PC-2, 4, 7 and RC-2, 4, 7) will be repaired by the end of April 1995.
- Two public terminals will also be usable by the end of June 1995.
- One third of the container terminals at the Kobe Port will be repaired within this year.
- The number of temporary operational berths within the Kobe Port area will gradually increase, with full recovery of all berths scheduled within two years.

4. SUGGESTIONS AND RECOMMENDATIONS

We suggest that earthquake resistant design has to be investigated by carrying out a comparative study of various structures, using this as the basis for selecting structures for heavy caissons, piers, etc. in planning and implementing coastal and harbor facilities and quay recovery schemes.

The January 17 earthquake caused serious damage to coastal structures and harbor facilities. Various factors are responsible for the severity of the damage, including liquefaction of reclaimed areas, lateral movement of coastal dikes, loss of bearing strength by sand fill, and dynamic deformation of soft alluvial clay layers. Careful and thorough investigations must be carried out to determine the mechanisms of revetment structure damage before planning recovery measures.

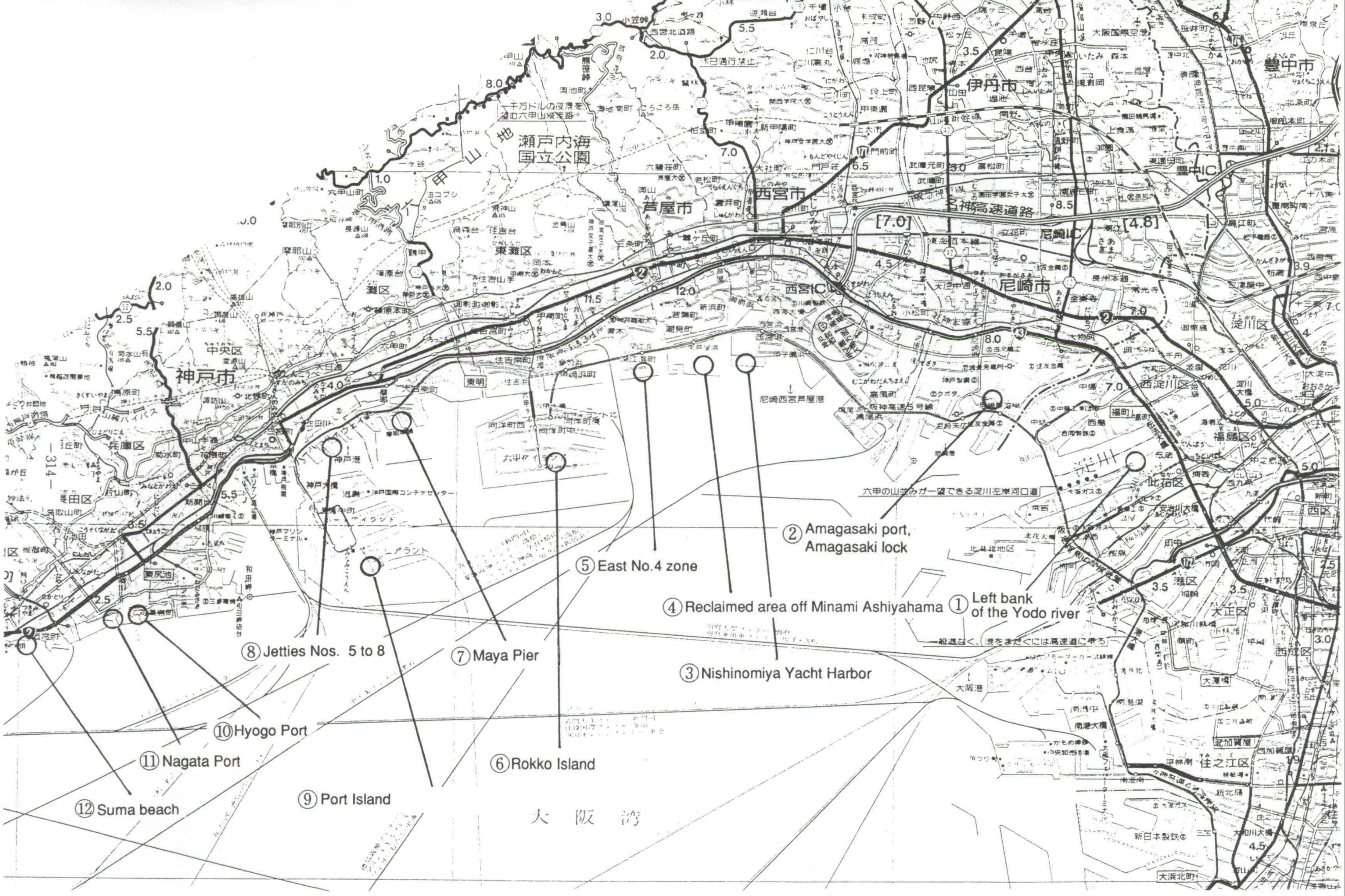

Fig. 1 Facilities covered by the investigation

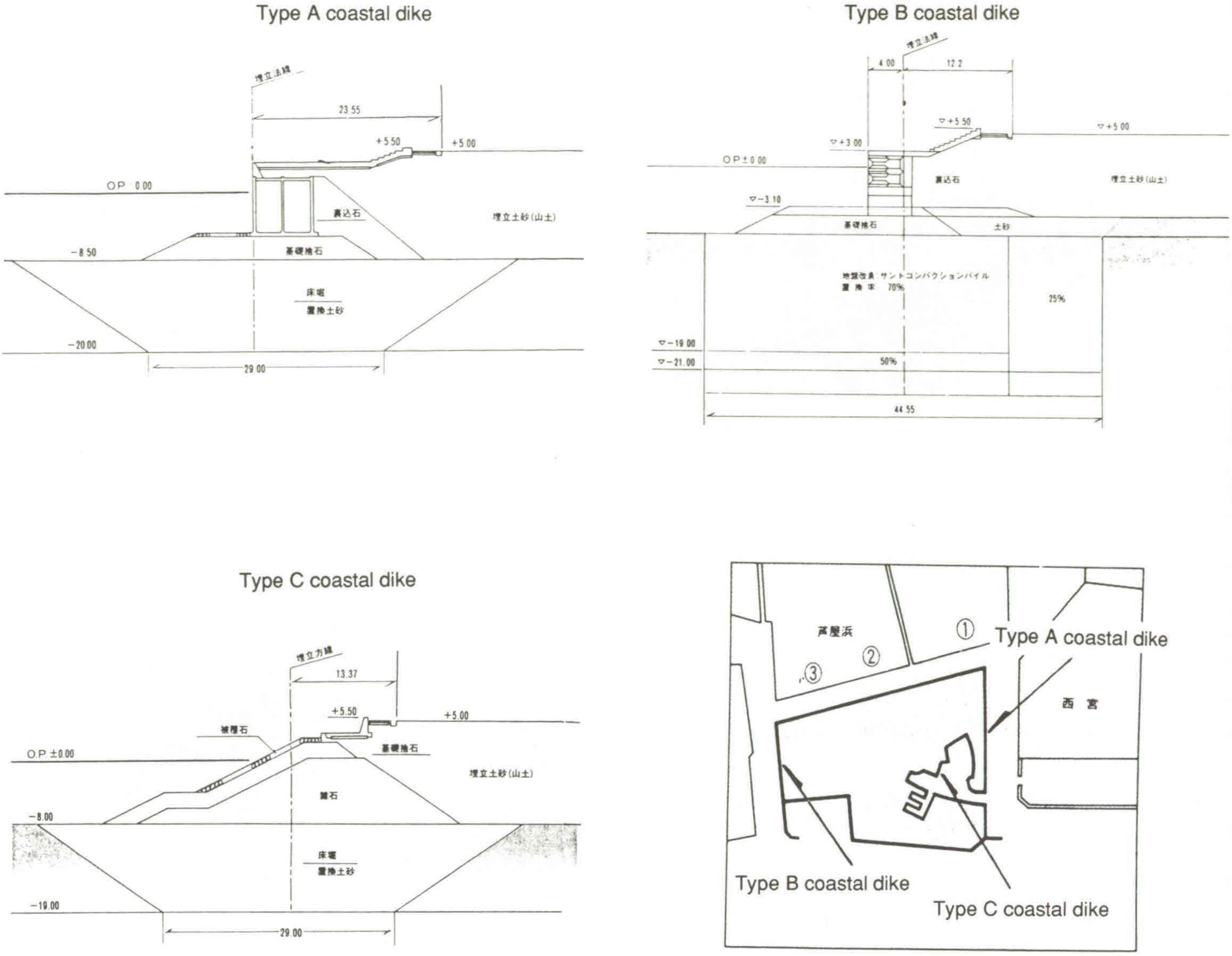

Fig. 2 Coastal dikes used in reclamation off Minami Ashiya coast

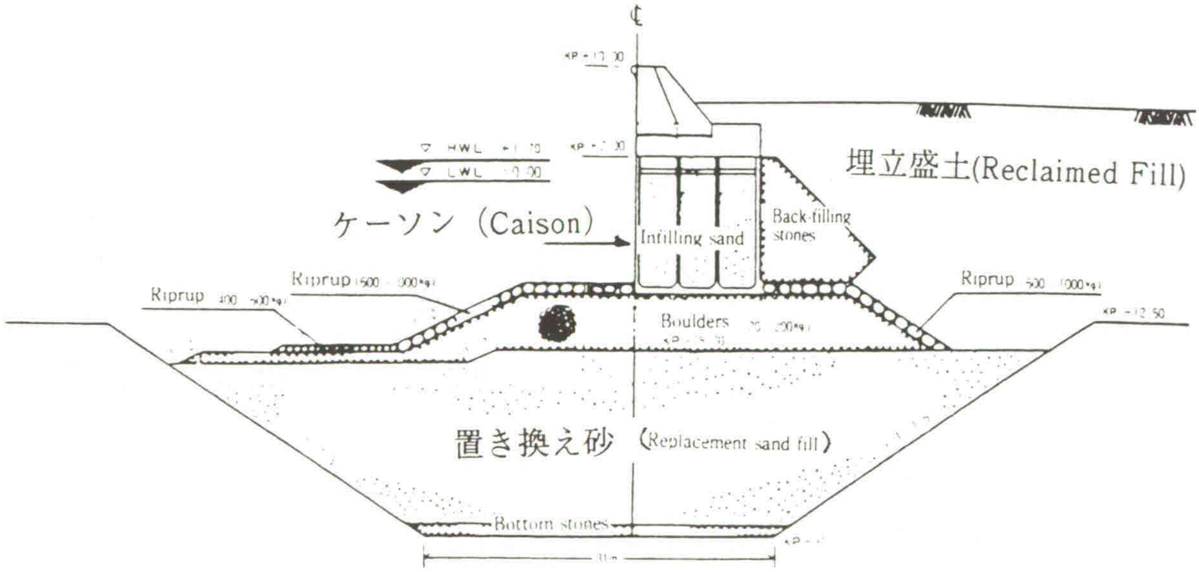

Fig. 3 Typical coastal dikes on Port Island

Photo 1 Liquefaction occurred around the Amagasaki Lock

Photo 2 Damage to the Amagasaki Lock

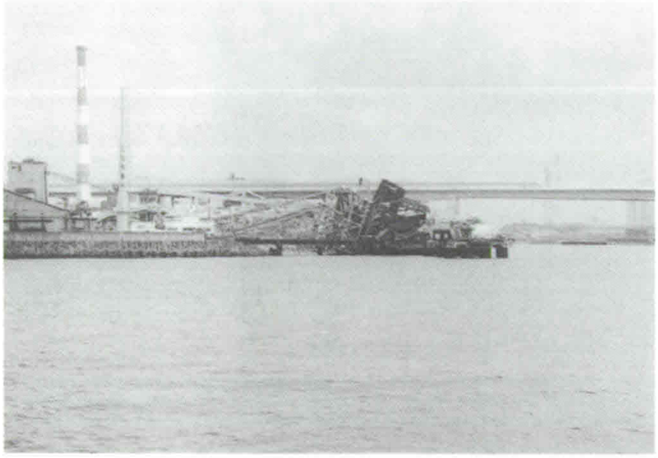

Photo 3 Overturned lifting crane at the Amagasaki Port

Photo 4 Subsidence of revetments at the site off Minami Ashiya coast

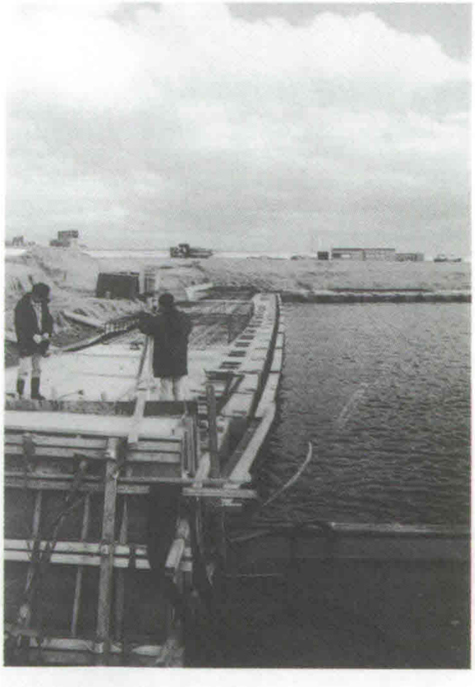

Photo 5 Lateral movement of coastal dike at the site off Minami Ashiya coast

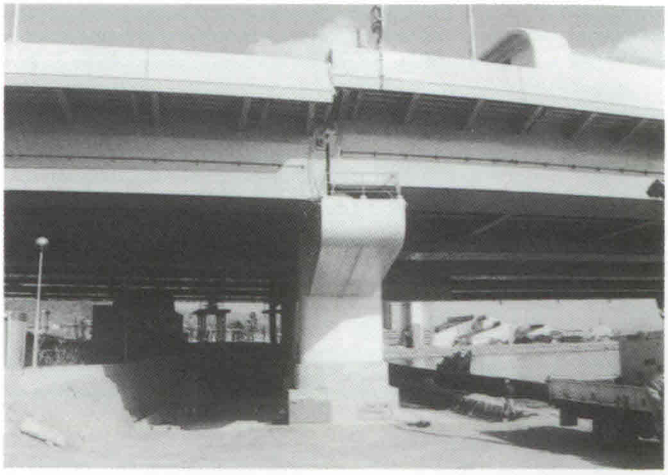

Photo 6 Lateral movement of the foundation of the Hanshin Expressway Wangan Route

Photo 7 Lateral movement of the foundation of the Hanshin Expressway Wangan Route

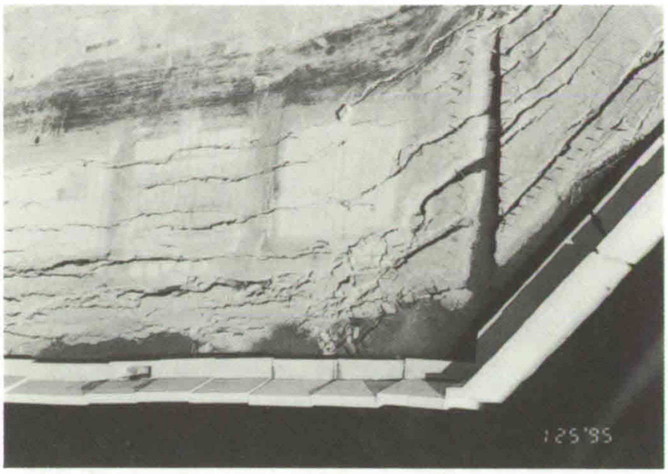

Photo 8 Damage to coastal dikes at the second reclamation zone on Port Island

Photo 9 Subsidence of the Port Island Breakwater

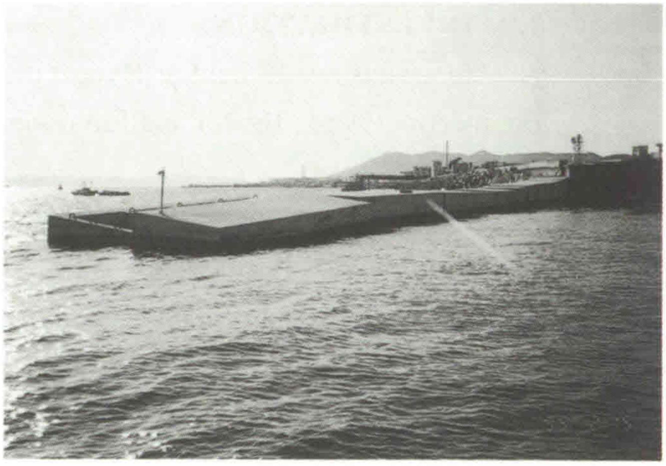

Photo 10 Tilting and subsidence of the Nagata Port Breakwater

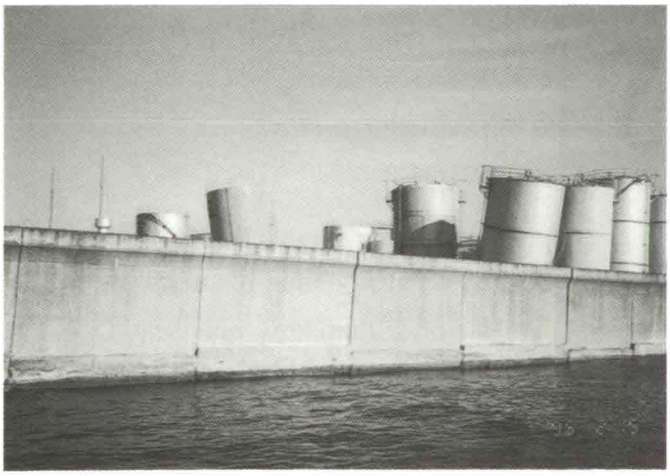

Photo 11 Tilting of small oil tanks in the Nagata Port

Photo 12 Damage to the concrete riverbed near Nagata Port

Sewage Group Investigation Report

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1. INVESTIGATIONS

Interviews were held at Hyogo prefectural offices (Sewage Works Div. of Civil Engineering Dept., Health and Environment Dept., and Nishinomiya Civil Engineering Office)

Site investigations were carried out at the Higashinada Sewage Treatment Plant and sewage-related facilities on Port Island, in Kobe City, at damaged areas and a temporary debris storage site in Nishinomiya City, and at sewage-related facilities, such as manholes, in the area between Sannomiya and Hyogo

2. DAMAGE

The damage caused by the January 17 earthquake has already been reported by the Second and Third Investigation Teams of the Japan Society of Civil Engineers and by the Ministry of Construction and other governmental organizations. This report, therefore, only gives an outline.

2-1 Sewage treatment plants

Of the 43 sewage treatment plants in the disaster area, eight were reported to have suffered damage (Ministry of Construction report). Kobe City's Higashinada plant was the worst hit of these. Other plants reported only relatively minor damage, including water leaks, pump room flooding, partial damage to piping within the plant, including discharge ports, damage to sludge collectors, and damage to sewage purifiers.

At the Higashinada plant, retaining walls bordering the adjacent canal and the sea moved considerably and suffered subsidence. This had a serious effect on the facility, damaging water intake culverts within the plant, pipework connecting the initial sedimentation tank, expansion joints in the treatment plant, the structure of the dewatering plant and an administration office building, and an underground corridor, to name the major points. As a result of these damages, the plant was completely disabled (Photo 1).

In the previous investigations, damage to the foundation piles was not investigated, but it is considered essential to look into this so as to determine where excessive stress was imposed.

2-2 Pumping facilities

There were no reports of serious damage to pumping stations, but there were reported instances of power generation and other functions being disabled due to lack of a prime and/or coating water; water would be needed to prime pumps during power outages and as cooling water for power generators of its own. Some pump stations are reported to have used water highly treated by tertiary treatment, to operate pumps as a makeshift measure.

2-3 Sewer pipes

No major damage to catchment basin sewer mains was reported, and the only problems were local and minor, such as sand sinking or of pipes cracking. Most of the sewer mains measure over 1 m in diameter and they are buried 5 or 8 m below ground.

There is a huge installed length of sewers less than 800 mm in diameter (about 3,000 km in Kobe alone), so only the pipes in an area south of the uptown mains were investigated. Thus, since the investigation did not cover the entire network, we cannot offer a definitive conclusion. Nevertheless, our limited investigation indicates there was little major damage to these smaller sewer pipes. The damage that was reported included displacement of manhole risers, cracking of culvert pipes, level differences, damage due to damaged civil engineering structures, and influxes of sand due to liquefaction .

A large volume of sea water was entrained in the Higashinada treatment plant, but where and how much has not been clearly established. Other plants were not fully investigated, so there is no knowing whether there is any cracking or how much damage was done because there was no flow in sewer pipes due to shutdown of water supply.

This means there is no telling whether there is a danger of sewage seeping into the ground or and, conversely, inflows of underground water into sewers.

Known local damage to sewer pipes includes destruction of connections from household piping to sewer inlets, displacement of link sewers (connecting the inlet to the sewer main), cracking, and changes in gradient (Photo 2). The city authorities concerned are working all out to obtain an overall picture of this damage.

At Port Island, an artificial island consisting of reclaimed land off Kobe, manholes now project above the ground surface where the ground around them subsided (Photo 2). Our survey indicates that such damage is not very widespread, however. In any case, it is extremely difficult to gain a full understanding of the damage to sewer pipes since they are all underground.

2-4 Storm drains

When rain falls in an urban area, the water collects as runoff and flows into roadside drains. Separate storm drains dominate in most of Kobe, although the sewer system takes runoff in some areas. Mountains rise up steeply just north of the damaged area, and storm water from the southern slopes runs directly down through the city and drains into the sea. There are about 350 discharge points along the coast in Kobe. The total length of storm drain pipework is shorter than the sewer length (being about 500 km, about one seventh the length of sewer pipes). There are also many open culverts. Covered storm drains suffered similar kinds of damage to sewer pipes, while the earlier report says open culverts were dammed by fallen debris or sand from collapsed buildings and in many places destroyed as retaining walls collapsed (Photo 3).

Since the discharge pipes open onto the sea, some suffered damage related to the collapse of revetments (Photo 3). Although some of these damaged discharges have been repaired temporarily, immediate repairs are required so that the storm drain system is able to handle possible downpours.

3. PROGRESS OF RECOVERY WORK

3-1 Sewage plants

Sewage treatment plants, other than the Higashinada plant, have returned to normal levels of treatment after the completion of makeshift repairs, although the amount of sewage arriving is still low because water supplies have yet to be restored in many places.

The Higashinada Treatment Plant is unable to resume treatment because of delays in repairing the headrace. Work is continuing, and the aim is now to resume operations by the end of April, but it will be some time before complete recovery is possible.

Sewage continues to be pumped by the pumping plant within the facility (Uosaki Pump Plant) and thus is being discharged into the Uosaki Canal by storm water pumps. The inflow (throughput) before the earthquake was 160,000 m^3 a day, but at the time of the investigation team's visit, the daily inflow reading was 80,000 m^3. This reduced flow is due to still unrestored water supplies in the area served by the plant. Since the concentration of chlorine ions in the influent is very high, it is likely that a large amount of sea water is finding its way into the sewage. Discharge from the Fukae Pump Plant, in the fourth zone close to the Uosuki Pumping Station, was 3,000 to 5,000 m^3 before the earthquake, but had increased to 15,000 m^3 on the day of the investigation. This wastewater also has a high concentration of chlorine ions, attesting to a sea water influx. This demonstrates that sea water is entering the sewer system through holes and cracks.

This effluent is currently being discharged into the Uosaki Canal by storm water pumps. Since this presents a hazard as regards water quality deterioration of the Seto Inland Sea, the canal (40 m wide, 300 m long, 3 m deep) has been dammed and now serves as a sedimentation tank in which the wastewater is treated for final discharge. This situation, however, cannot be regarded as desirable and immediate measures should be taken to improve matters.

3-2 Sewer pipes

Emergency measures were taken to recover capacity where sewage facilities had been blocked or severely damaged. These included the installation of temporary pipework and the temporary use of underground multi-purpose conduits as bypass routes (Photo 4).

A comprehensive inspection of sewer pipes was carried out between January 22 and February 10. Assistance was given by personnel from other large cities and the Association of Sewage Maintenance (headed by president Kei Toyama).

In Kobe, this inspection covered the urban area south of the uptown mains (Photo 5). To be more specific, it included Higashinada Ward to the east and part of Nagata Ward and Tarumi Ward to the west, and these areas were covered by joint teams headed by Tokyo and Hiroshima Cities, respectively. The Kobe City government led a team which covered the central area of Chuo Ward including Sannomiya, Hyogo Ward, Port Island, Kita Ward, and Nishi Ward.

The total length of sewer pipes in the areas covered by these joint teams totals around 1,000 km. Inspectors opened all manholes, made careful visual inspections, entered the manholes, and checked for internal damage visually. About 60 km of sewer pipes judged to have been damaged were filmed using a TV camera lowered into the pipe. These films are now being analyzed and compiled to offer basic data for use in future repair planning (Photo 5). As of February 10, a total of about 600 video cassettes, each of 1 hour 50 minutes, had been filled.

Full understanding of damage has to await detailed analysis of these video cassettes. Roughly speaking, though, underground structures suffered minor damage as compared with those above ground, and in most cases they are almost free of serious damage.

The investigation so far has been confined to the urban plain only, and mountainous districts or the northern part of Kobe City have yet to be surveyed. Further investigations are strongly recommended.

3-3 Storm drains

Temporary measures have been taken to make damaged storm water drains serviceable; earth deposits have been removed and the beds of open culverts and their revetments have been repaired. As a result, the drains can now at least carry storm water away.

The period between the earthquake and the time of the investigation is one of low rainfall. Fortunately, therefore, there has been no torrential rain. The wet season is expected to begin before repair work is completed, however. Immediate contingency measures are needed to cope with this situation. While the rainfall adopted for design purposes in Kobe is 50 mm/hr., observations show that it sometimes actually exceeds 70 mm/hr (a maximum of 75.6 mm/hr was recorded during torrential rain on July 9, 1967). It is not too early to take proactive measures.

3-4 Flush toilets

Shelters and evacuation centers have been set up in schools and public facilities in areas damaged by the earthquake. Evacuees have had a hard time, since the use of flush toilets has been limited as a result of problems with the water supply. Makeshift toilets have been set up at some evacuation centers, but they failed to satisfactorily meet the needs of refugees; they took too long to set up and anyway they were inadequate in number. There have also been reports of handicapped and aged people finding problems because of the need to carry in water for flushing toilets. Measures to swiftly cope with these problems need to be developed.

4. RECOMMENDATIONS

Our investigation of the damage caused by the January 17 earthquake observed only some of the recovery efforts being made. This experience, albeit limited, allows us to make the recommendations outlined below.

4-1 Securing of water supplies

Shortages of non-potable water, such as for flushing toilets, cooling, or pump priming, are a problem that has not been addressed in studies of past disasters. In the case of this disaster, in which many "lifeline" functions including water and power were destroyed, the damage is spread over a large area and it is to be expected that repairs will take considerable time. The shortage of non-potable water therefore poses a serious threat to the recovery effort in the damaged area. Typical problems are reported to be inability to operate pumps or emergency generators due to lack of cooling water or difficulties in priming pumps immediately after the earthquake. Emergency use of treated sewage water for such purposes solved the problem in some cases. The lesson to be learnt here is the need to keep "backup" supplies of water within sewage facilities for use when needed.

The inability to use flush toilets because of lack of water supplies was a common problem. This emphasizes the need to prepare ways of making use of fire fighting water or swimming pool water in case of emergency.

4-2 Anticipated rainfall

With this destructive earthquake occurring in January, which is a time of low rainfall on the Pacific coast of Japan, there has been no flooding due to heavy rain. The immediate establishment of means of response to torrential downpours during the coming wet season is strongly recommended, now that it is clear full recovery will be a slow process. To be specific, the first emergency step will be to remove blockages from the drainage system. It will also be necessary to bring in small submersible pumps from all over the country for deployment in locations where heavy rainfall might be expected to cause damage, thus minimizing further disruption for evacuees and other victims of the earthquake.

4-3 Cooperation among municipalities

The cities and towns of the disaster area need to cooperate with one another in their response to damaged sewage facilities. Clearly, such cooperation is crucial in all efforts at recovery from this type of emergency. We recommend that the municipalities concerned be prepared for the immediate deployment of mobile emergency equipment and personnel through emergency planning and regular training. Such preparations allowed large cities throughout the country to send reinforcements as soon as the earthquake occurred, offering help with remediation efforts in the damaged areas, including inspection and evaluation of sewer pipes and the damage they suffered.

4-4 Decentralization of information

The offices of Kobe City Sewer Bureau collapsed in the January 17 earthquake. This disastrous situation prevented the immediate retrieval of valuable data on the sewer pipe network. Fortunately, backup data were held by consultant firms and could be used to help minimize disruption. However, the roundabout means by which the information was obtained did cause certain delays in repair work. Such bad luck might occur only once a century, but still there is a possibility of something similar happening again in the future. In anticipation of this, it is clearly desirable to decentralize important information, such as by keeping maps in several different locations and improving the backup system.

4-5 Correlation with revetment damage

Many revetments constructed on reclaimed land are reported to have suffered serious damage in the earthquake. Related damage to sewage facilities has also been reported. Structures are often built as close as possible to revetments to ensure effective use of land, since reclaimed land is still costly. This, however, resulted in aggravated damage to these structures. In building new treatment plants, it is necessary to incorporate certain proactive measures in the design, including the provision of open space, walkways, or landscaped areas around the facility, thus minimizing damage caused by failing revetments.

4-6 Ground condition at sewage plants

Given the physical characteristics of sewage systems, treatment plants need to be located as far downstream as possible. In a country like Japan that is stretched for land, these plants are most likely to be located on reclaimed land off the coast. In the case of Port Island, the land was expected to subside and continue sinking into the future, so appropriate countermeasures were taken from the outset. Ground subsidence is unavoidable on this type of landfill site, so countermeasures to subsidence are incorporated into the design of sewage treatment plants. Pile foundations are a typical way to ensure that damage is avoided — with its pile foundations, the Port Island sewage plant escaped damage almost completely, despite serious damage to the surrounding area.

Sewage treatment was thus resumed at a very early stage following the earthquake (although one report says the use of flush toilets was prohibited in some high-rise apartments due to damage to sewer connections). This demonstrates that proper strengthening and improvement of the ground effectively minimizes earthquake damage.

Generally speaking, sewer pipes and sewage treatment facilities do not have to be constructed in a great hurry. They are built one by one as an area develops and the need arises for sewage systems. This means that ground improvement methods may vary depending on where and when a facility is constructed. In some cases, ground improvement was only implemented around the major plant facilities, or where the foundations were not uniform in quality or strength. The result is a varying seismic load on different parts of the plant which gives rise to excessive loading on head races and the conduits linking separate facilities. This makes them very susceptible to damage. This is demonstrated by the damage at Higashinada Treatment Plant, where connecting conduits and the joints between conduits and the primary sedimentation tank were damaged, blocking the flow of sewage.

In future, the design and construction of sewage treatment plants must include ground improvement planning for the entire plant site.

A sewage plant used to be constructed in several stages. When a new section is added, the pre-existing part of the plant and the new section are connected with piping. This type of connection is one of the most vulnerable parts of a plant, according to the investigation. Damage may be reduced by introducing flexible joints or expansion joints.

Expansion joints were used in connections to main sewers at some high-rise apartment buildings on Port Island, and these escaped serious damage. On the other hand, where the joints were fixed, flush toilets became unusable.

4-7 Connecting sewers and connecting pipes

A sewage system only serves its purpose when connected to each household. Slight inconsistencies in the construction of the private and public parts of the system resulted in reduced effectiveness. The wastewater drain from each house is connected to the sewer pipe via a connecting sewer and house outlet; the connecting sewer is installed for each household by officially designated contractors. It is recommended that the administration develop closer daily contact with these contractors. Since the effect of damage to these connecting sewers is particularly influential in the case of large apartment buildings and condominiums, retroactive measures, such as the use of flexible pipes, are required.

It is impossible for the administration to keep tabs on all drains within the compounds of private houses, but the question of whether the management of large groups of such drains, as in the case of a condominium, should be left to individuals (or developers) needs to be discussed. The Water Works Law now stipulates that the administration must take responsibility for distribution (reservoir) tanks in the compounds of apartment buildings and condominiums. The same idea needs to be discussed as regards the sewage system.

4-8 Improvements to joints

Many types of joint are to be found in sewage systems. Many of the designs are reported to have been damaged in the earthquake. Yet there are other joints that survived because of their suitability. We strongly recommend a discussion of which joint types are preferable and how they should be used to ensure safety.

Some treatment plants use expansion joints. In other cases, expansion joints have been eliminated; boxes are directly connected via fixed connections or boxes small enough to not require expansion joints have been used. Such measures are intended to minimize the number of expansion joints to minimize damage. As a whole it seems wise to use expansion joints as little as possible.

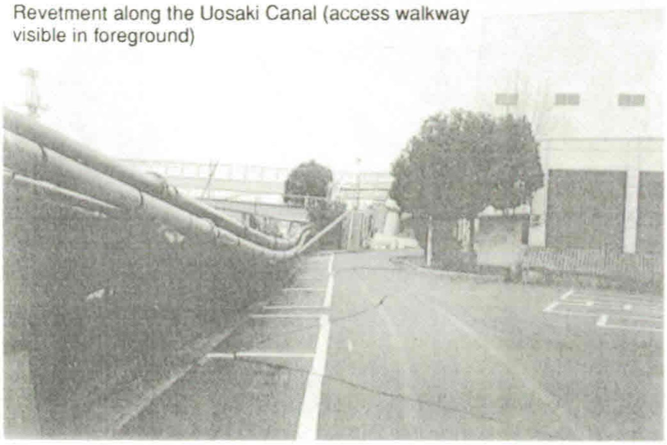
4-9 Underground multipurpose tunnels

Once a sewer pipe has been damaged, locating the damage and then checking the severity and extent of the damage is a very time-consuming process. In the case of an earthquake as devastating as this one, the damage is very wide-ranging, making inspection work extremely difficult. In fact, this applies not only to the sewage system, but also to water, gas, and electricity supplies where their conduits are buried in the ground. There is a need to increase the use of underground multipurpose tunnels large enough to walk in, as found in Europe and America, for large-diameter mains.

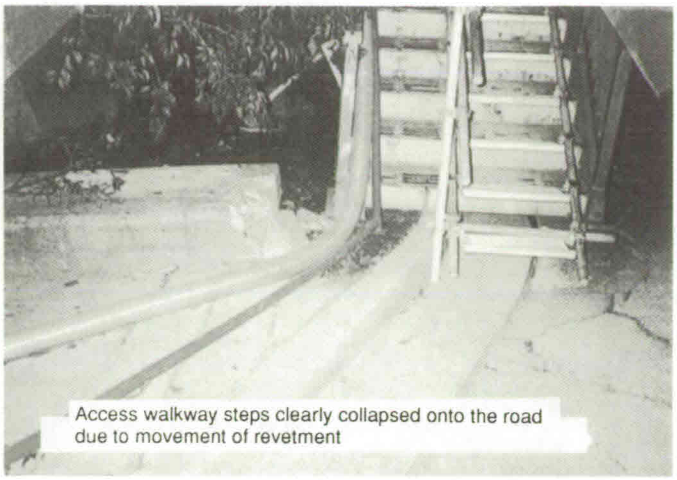
If all the utilities could get together and construct common tunnels and put them under central control, remarkably quick recovery would be possible in such a case as this earthquake. Such common underground conduits will be an indispensable part of our highly populated cities of the future.

4-10 Monitoring system

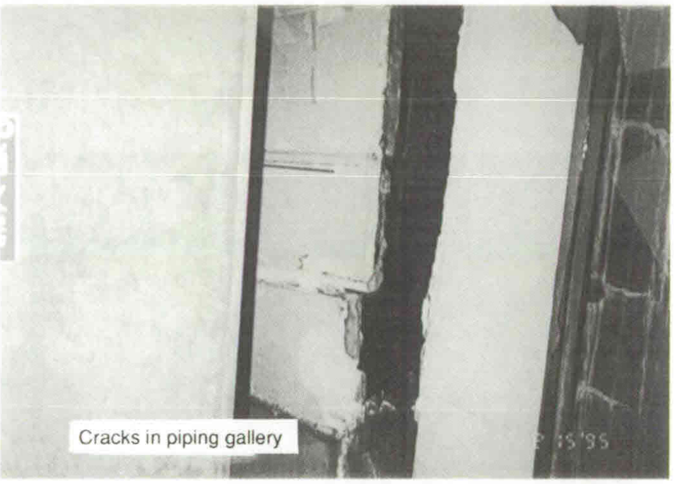
It is necessary to develop a monitoring and inspection system for checking underground sewer pipes. At present, emergency measures are being taken through the united efforts of municipalities all over the country. Further improvements are necessary, however, to redouble the reliability of sewer pipes in the future.



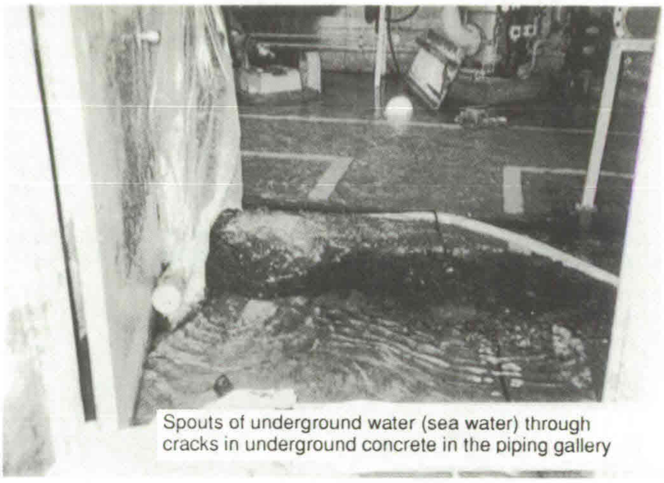
Revetment along the Uosaki Canal (access walkway visible in foreground)



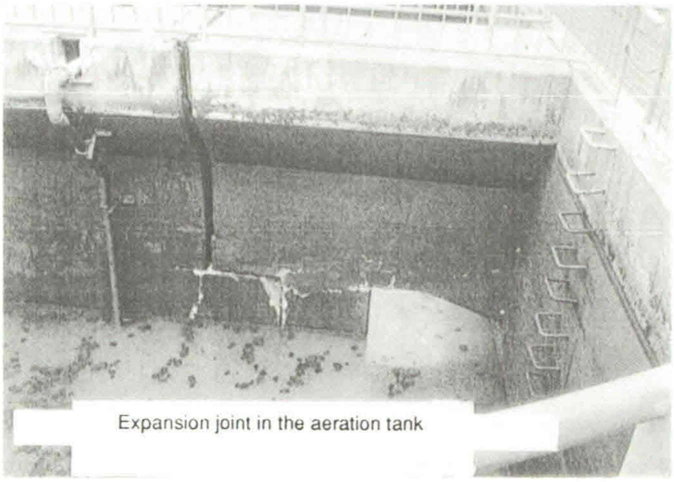
Access walkway steps clearly collapsed onto the road due to movement of revetment



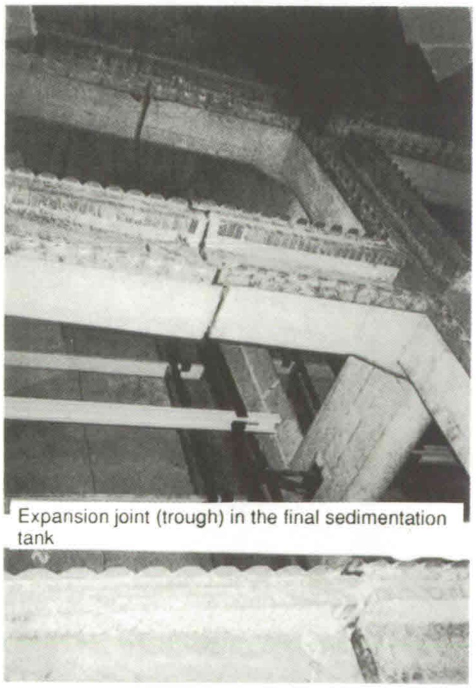
Cracks in piping gallery



Spouts of underground water (sea water) through cracks in underground concrete in the piping gallery



Expansion joint in the aeration tank

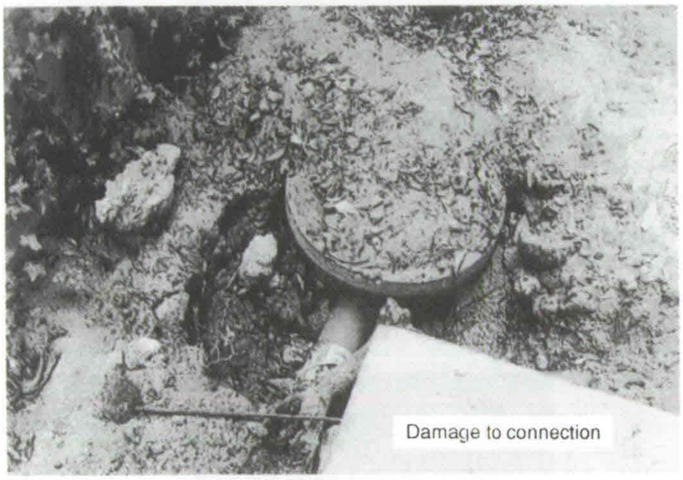


Expansion joint (trough) in the final sedimentation tank

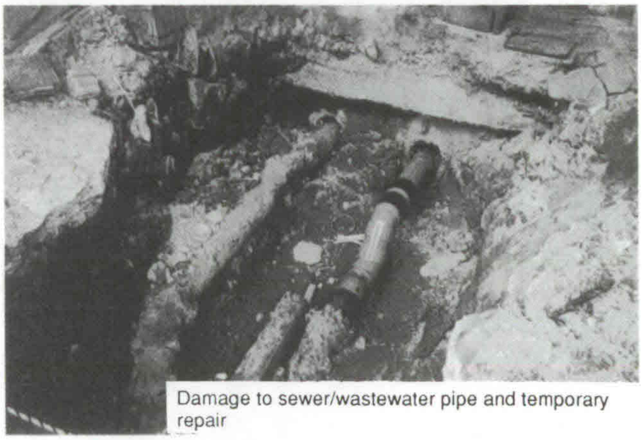
Photo 1 Damage to Higashinada Sewage Treatment Plant

Manhole protruding above surface due to subsidence of surrounding ground

Damage to manhole (Port Island)



Damage to connection

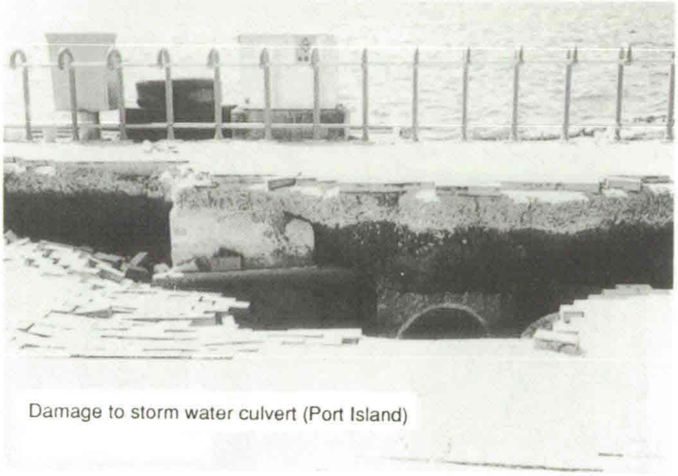


Damage to sewer/wastewater pipe and temporary repair

Photo 2: Damage to Manholes and Connecting Sewers

Drainage culvert displaced laterally but without major damage, despite significant lateral movement of the revetment

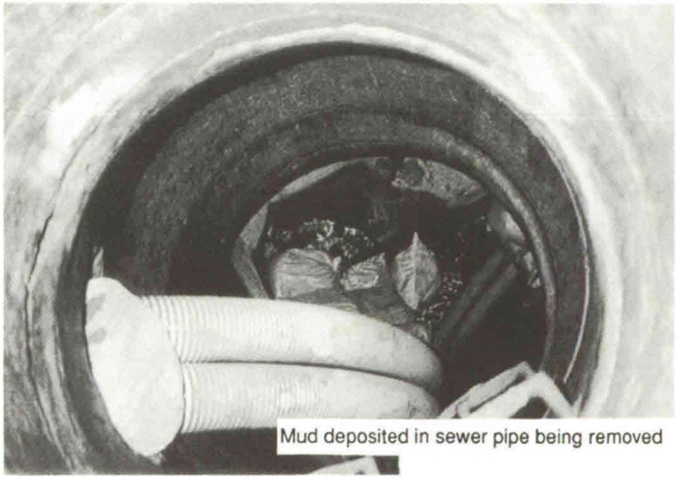
Damage to culvert on road side (Shimoyamate street)



Damage to storm water culvert (Port Island)

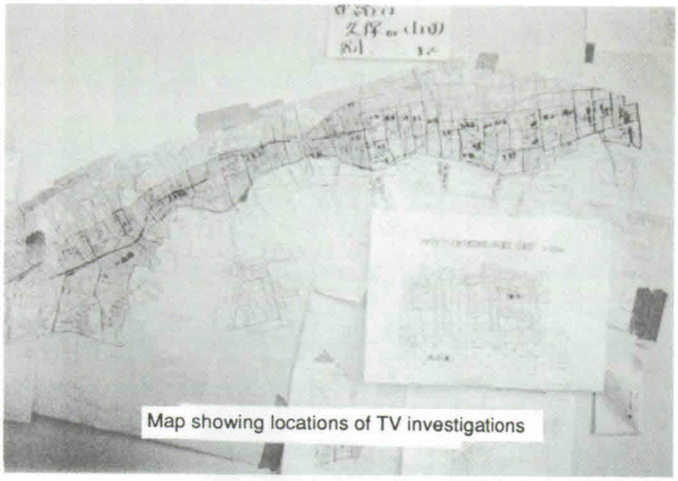
Photo 3: Damage to Storm Drains

Temporary pipes circumventing cave-in

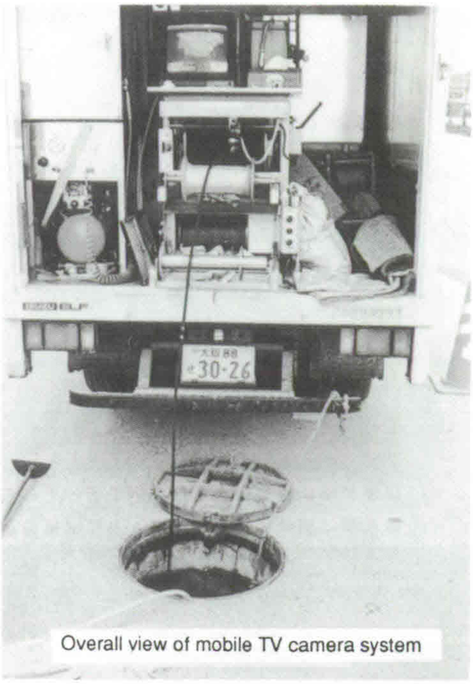


Mud deposited in sewer pipe being removed

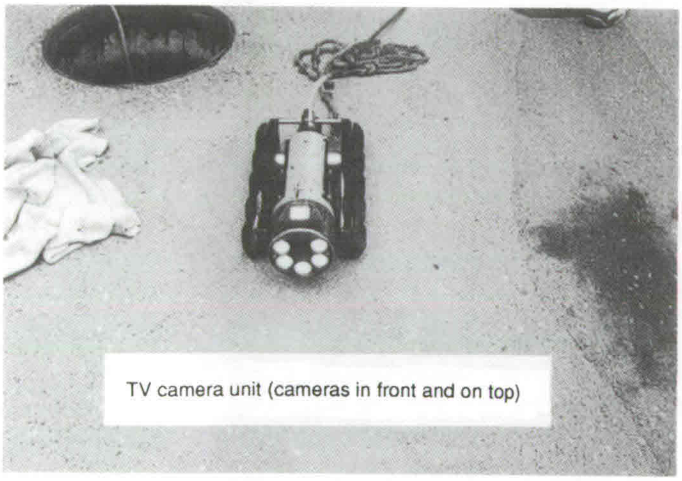
Photo 4: Emergency Repairs



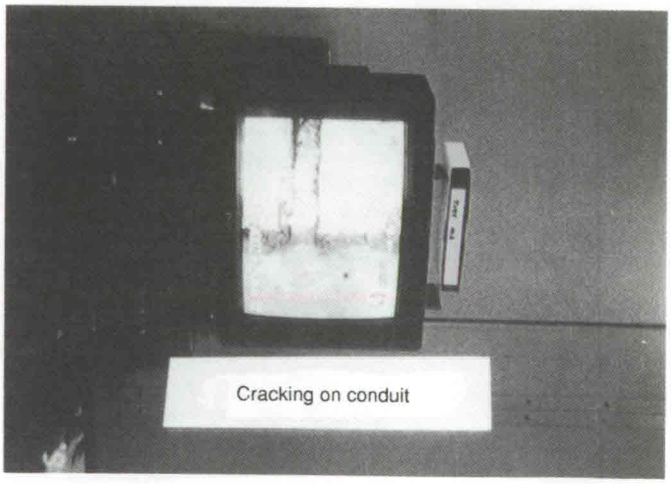
Map showing locations of TV investigations



Overall view of mobile TV camera system



TV camera unit (cameras in front and on top)



Cracking on conduit

Photo 5: TV Camera Investigation of Sewer Piping

Addendum

Treatment and Disposal of Debris

The main objective of our investigation was to look into the damage done to the sewage system, one of the critical "lifeline" facilities, and to report on progress with recovery work and the problems remaining to be solved. During this work, we came across the problem of treatment and disposal of debris, which remains unaddressed. The investigation team is keenly aware of the immediate need to deal with this issue.

The treatment and disposal of debris is ordinarily a normal waste disposal problem. However, after this earthquake, there seemed to be no coordinated action as regards the handling of the debris disposal problem. The main reason for this is the unprecedented amount of rubble produced by this devastating earthquake. Yet recovery will be a long and laborious process unless the huge heaps of debris can be properly treated and disposed of. This requires attention now.

The handling of debris is normally the responsibility of the individual municipalities. The cities of Kobe, Nishinomiya, Ashiya, and Amagasaki all have their own plans for handling debris, but in this case the problem has not been fully dealt with because of shortages of labor, difficulties in maintaining disposal sites, and a failure to establish transportation methods. These problems are now holding back other recovery work.

With pressure growing, the government has now moved. The Regional Planning Section of the Water Supply and Environmental Sanitation Department at the Ministry of Health and Welfare took the initiative in gathering the Ministry of Transport (Ports and Harbors Division), the Ministry of Construction (Economic Affairs Bureau), the Ground Self-Defense Force (Chubu District Army Headquarters), Hyogo Prefecture (Health and Environmental Division, Civil Engineering Division, and Urban Housing Division), and Hyogo Prefectural Police Department Traffic Control Division and persuading them to set up a committee to promote the disposal of disaster-related debris. Other committee members include the local municipalities of Kobe, Amagasaki, Nishinomiya, Itami, Takarazuka, Kawanishi, Akashi, Sumoto, Miki, Ashiya, and Hokudan and certain private corporations and organizations — JR Nishi Nihon, Hankyu Corp., Hanshin Electric Railway Co., Sanyo Electric Railway Co., Kobe Electric Railway Co., Kobe Express Railway, and the Osaka Bay Wide-Area Coastal Environment Improvement Center. These committee members exchange information and centrally control the unified treatment and disposal of waste.

The estimated amount of debris produced by the earthquake, as of February 8, was 6.5 million m^3 (7.8 million tons) from collapsed houses and structures and 3 million m^3 (5 million tons) from public facilities such as railways. An updated estimate based on recent surveys indicates that the actual amount may be almost double this first estimate.

Final disposal sites include landfills (reclamation sites) of the Osaka Port Wide-area Coastal Environmental Improvement Center (Phoenix Plan) — one (4 million m^3) off Amagasaki City and another (11 million m^3) off Izumi Ohtsu City — Kobe's Fusehata landfill (8 million m^3), Tanga landfill (7 million m^3), the Hokko landfill in Osaka (2 million m^3), Sakai Izumi Hokko landfill (0.4 million m^3), and a landfill operated by the Business Agency (1.2 million m^3). The debris can thus be theoretically handled by these landfills. Since direct transport of debris from its source to these sites is difficult, it is being temporarily stored at dumping sites set up in each city for later transport to these final landfills.

Regarding these temporary dumping sites, Kobe has one at Uosaki beach in Higashinada Ward and three others with a total area of 17.6 ha. Amagasaki has one at Marushima with an area of 6.3 ha. Nishinomiya has the 8.0 ha Koshien beach site. Ashiya has 6.0 ha at Minami Ashiya beach. Itami City has 3.0 ha at the former Shikibo Industrial Site, as well as two other sites totaling 4.0 ha including one within the Osaka quarry site. Kawanishi has four sites covering 1.2 ha, including the Kamo 6-chome public disposal site. On Awaji Island, the Business Agency plans to set up a 17.0 ha landfill site at Sano. On the day of our investigation, debris was being transported to each of these temporary dumping sites. Debris from public areas and railways, which is basically handled by each administrative body, is to be stored at a 3.0 ha site to be set up on a reclaimed land off Koshien, before being directly transported by sea to final disposal sites.

Roads in the disaster area are operating at reduced capacity due to the collapse of structures and heavy usage by construction and emergency vehicles. As a result, the transportation of debris is already behind schedule. No systematic treatment and disposal plans have been proposed by the authorities, so citizens wanting to get rid of their debris are trying to grab disposal companies faster than others. This is worsening the confusion. Since many temporary sites are situated right on the coast, vehicles carrying debris have to cross the busy main Highways 2 or 43 to get there. This naturally causes traffic snarl-ups when they are held up at lights, and makes the traffic situation even more serious. Worse, since there are no well-planned systems for receiving the debris at temporary sites, trucks often line up for kilometers waiting for their turn to discharge.

Many problems exist. There is a shortage of vehicles for removing debris. There are no effective transportation routes, so vehicles get stuck in congestion. As a result, each truck is said to be able to make only 1 or 1.5 rounds per day. With this low efficiency, it is no wonder that complete removal of debris is now expected to take a tremendous period of time, having a negative effect on the overall prospects for recovery.

The debris includes wood, clay walling, concrete fragments, plastic, and all other materials. It is impossible to classify all the debris by material. At many final landfill sites, combustible waste must be incinerated. With the huge overload of debris, "open incineration" is being practiced in some cities, especially in the case of wooden waste. Yet since open incineration produces smoke — resulting in air pollution — it really should not happen.

The government has recently decided that the costs incurred by individuals in removing debris from collapsed houses will be covered by subsidy, so the great confusion of the early days has died down. Still, it will be a long time before all the debris is cleared from the streets.

Suggestions and Recommendations:

1. Development of a debris treatment and disposal plan: there is a great need for coordinated debris treatment and disposal plans covering the entire Hanshin region and proper implementation of such plans. We suggest that the selected temporary sites should be brought into new urban plans by turning them into plazas, public open spaces, etc.
2. More temporary disposal facilities: reports on a major flood in Nagasaki clearly demonstrate that setting up plenty of temporary disposal sites around the city promoted rapid rebuilding. In the Hanshin region, it is important to set up such temporary sites in locations where access does not entail crossing main arteries.
3. Securing of transport routes: special bus lanes are often seen on main streets. Likewise, it is important to set up lanes for use by debris removal vehicles, at least at certain times of the day, to promote the efficient removal of debris.
4. Debris certification: when Nishinomiya set up temporary debris disposal sites and opened them to the public, trucks from outside the damaged area flooded in and dumped heaps of "non-disaster" debris. In response, the city imposed a certification system on debris. Though it may appear exaggerated, we suggest that a system of recording slips, consisting of 4 to 5 sheets, be implemented so that a record is kept of the origin of the debris, the company transporting it, its destination, etc.

Progress in the Recovery of Lifelines and Restoration Strategy

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1. GAS

1.1 Progress of recovery

(1) Emergency response and progress with recovery

Osaka Gas supplies a total of 5.7 million customers in eight large blocks which are divided up into 55 smaller blocks. Gas supplies were completely halted in five of the larger blocks between 11:30 on the morning of January 17, 1995, six hours after the earthquake, and the evening of the same day. This affected 856,000 customers. Of these, 295,000 had their gas supply returned by February 17. Figure 1.1 *1 shows how gas supplies were returned over time. The rate of recovery compares favorably with the return of gas supplies by Kushiro Gas following the Kushiro-oki Earthquake, especially considering the severity of the January 17 earthquake. Still, it is taking longer to return gas supplies to normal than was the case for power and telephone; this is part of the intrinsic nature of the gas supply system — once stopped, it takes a long time to restore.

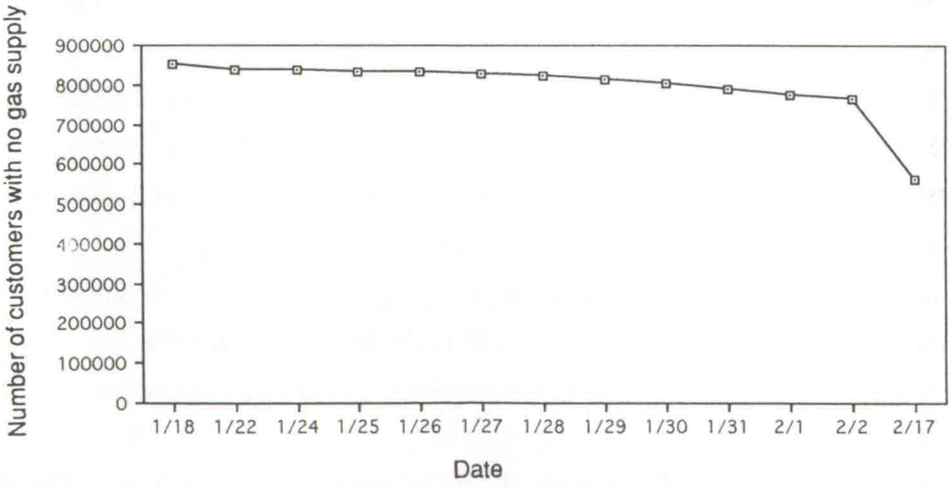


Fig. 1.1 Recovery of gas supplies

There are other reasons, as follows:

- Low-pressure gas pipes filled with water leaking from the water and sewage systems, as well as liquefied sand and soil. Removal of this type of foreign material is very labor-intensive.
- The efficiency of recovery work is low because of debris from collapsed structures and poor traffic conditions.

On the reclaimed land of Port Island, where liquefaction was commonplace, influxes of mud were reported, but pipes themselves suffered only slight damages. This is because of the use of expansion joints and the double-tube method, which demonstrated their effectiveness in the face of ground subsidence up to around 50 cm.

(2) Recovery strategy

The smaller service blocks were further divided into sub-blocks for the purpose of repair, and the work began with sub-blocks which had suffered less damage in terms of leaks, earthquake damage, roads, taking into account the availability of the necessary equipment and materials. Work began on the east side of the cut-off area, proceeding gradually west, then north, and lastly reaching the north, east, and west areas around the center of Kobe. Critical facilities such as hospitals, crematoriums, and garbage treatment plants had first priority. In some cases, temporary medium-pressure pipes were set up to supply gas. A recovery team consisting of about 6,000 employees of the Osaka Gas group and about 1,800 specialists from the Japan Gas Association and other gas companies started work on January 18. Inspection of the high-pressure main supply pipes was followed by inspection of medium-pressure and low-pressure distribution pipes and the implementation of repairs to these pipes. As it turned out, the gas manufacturing plants and high-pressure mains had suffered no damage. Repairs to Type-A and Type-B medium-pressure distribution pipes were completed on January 31 and February 8, respectively. Low-pressure pipes to customers, which mainly suffered damage at screw joints, are now in the process of being repaired.

Given the huge area of damage, and the fact that it was concentrated in the center of Kobe where damage to buildings and roads was serious, recovery has faced huge difficulties. The incidence of damage was very high, and the damage was of many types. It has been necessary to inspect each and every customers' premises, entailing digging up pipes in almost every case. Osaka Gas has been helped by more than 500 reinforcements from gas companies all over the country, and efforts have been redoubled since February 1; a work force of some 8300 specialists is now at work. The progress of recovery by administrative zone is shown in Table 1.1.

Table 1.1: Progress with gas recovery (as of Feb. 16)

Municipality	No. of customers	No. of customers with no gas supply	Rate of repair (%)
Kawanishi City	41,300	39,500	100.0
Itami City	61,100	2,100	100.0
Amagasaki City	206,800	3,650	100.0
Takarazuka City	75,700	69,100	73.2
Nishinomiya City	172,500	170,400	38.9
Ashiya City	37,600	37,600	5.6
Inagawa Town	5,200	5,200	100.0
Kobe City	626,750	493,050	18.6
Akashi City	66,900	24,200	89.3
Osaka City	1,308,800	61,500	100.0
Toyonaka City	161,500	500	100.0
Ikeda City	38,200	50	100.0
Toyono Town	5,900	5,900	100.0
Total	2,808,250	912,750	34.4

Alongside the repair work, Osaka Gas also supplied emergency equipment, comprising sets consisting of one portable gas cooker and three cylinders, to cities and towns affected by interrupted gas supplies on January 22. A total of 118,000 cookers and 551,500 gas cylinders were supplied (see Table 1.2).

Table 1.2: No. of portable gas cookers loaned by Osaka Gas (as of Feb. 2)

	Cookers	Cylinders
Itami City	1,500	4,500
Ashiya City	9,000	33,000
Akashi City	9,000	33,000
Takarazuka City	9,500	34,000
Kawanishi City	10,000	30,000
Nishinomiya City	21,000	78,000
Amagasaki City	2,000	9,000
Kobe City	54,000	324,000
Toyonaka City	1,000	3,000
Toyono Town	1,000	3,000
Total	118,000	551,500

Loans from Hyogo Prefecture Propane Gas Association are listed in Table 1.3. Kobe at first rejected these supplies for fear of fire at damaged private homes and evacuation centers, but accepted half on January 28 and then all by January 30. Calls for proper handling of gas were made by Osaka Gas through the mass media; flyers were also distributed to the public.

Table 1.3 No. of propane gas units loaned by Hyogo Prefecture Propane Gas Association (as of Feb. 2)

Cassette cookers	400 units (200 for Kobe and 200 for Awaji)
Gas heaters	50 units

1.2 Problems with gas facilities

It is inherent to the gas supply system that once it is stopped, recovery takes a long time. One way to improve things would be to reduce the incidence of leaks by replacing existing pipes and joints with earthquake-resistant ones, introducing microchip-controlled gas meters (meters equipped with microchips designed to stop the flow when a certain seismic intensity is exceeded) to every consumer, and introducing remote-controlled cut-off valves at the block level. Unlike the water supply system, which can easily be returned to its condition before the earthquake, there is much more work entailed in recovering gas supplies, since damaged parts have to be replaced with earthquake-resistant joints and PE pipes.

Since the January 17 earthquake occurred under an urban area, the damage to various "lifeline" functions is much more inter-related (traffic jams, inflows of water from water and sewer pipes) than in earthquakes such as the Kushiro-oki Earthquake. It is now clear that it will take longer than originally estimated to make a full recovery. This situation has led to realization of the need to develop systems which support coordinated activity among the municipalities concerned and the various lifeline utilities. This earthquake was tremendously strong and destroyed buildings over a wide area. We have no clear blueprint for how to go about recovery. This lack of a vision posed a question for those involved in getting gas supplies working again: should they return the system to what it was before? They have been left on their own as regards this question. We hope, however, that the knowledge and experience gained from this first major earthquake to hit a highly urban area will be reflected in future earthquake response strategies for gas supply facilities.

2. TELECOMMUNICATIONS

2.1 Progress with recovery

NTT's Kobe branch sent out 1,000 of its own employees together with 3,000 from other branches to undertake recovery work immediately after the earthquake. The recovery team checked all lines in telephone tunnels on January 18 to gain an overall picture of the damage. Tunnel joints which had been seriously damaged and were leaking water were repaired using resin mortar. Cracks likely to allow water in were also repaired with resin. As of today, full recovery of damaged lines is scheduled to be completed by the end of April.

There was some visible damage such as cracks on the surface above buried communications cables and cables breaking into manholes. This damage is being thoroughly checked using cameras and pressure measurements. All cables are scheduled for checking by the end of April, while repairs may take up to 3 to 5 years.

Figure 2.1 shows progress in the recovery of severed telephone connections. NTT called in the staff of its disaster response section at 8:30 on the morning of January 17, and the inspection and repair of communications lines began immediately. Exchanges were brought back on line with the help of mobile electricity generators on January 18, and the number of severed connections had decreased to 85,000, about one third the initial number, on January 19. The team of some 7,000 workers, including 4,000 sent by other telecommunications companies, continued work until all failed connections had been restored on January 31; this is aside from the 38,000 lines which were almost impossible to repair because of total or partial collapse of structures. The equipment used during the disaster included 11 mobile generators, 6 satellite communications vehicles with radio equipment, and 12 mobile satellite communications systems. NTT set up 2,255 toll-free public phones in 727 evacuation centers in Kobe, Amagasaki, Akashi, Nishinomiya, Sumoto, Ashiya, Itami, Kakogawa, Takarazuka, Kawanishi, and Miki. The telecommunications company also set up 361 fax machines at 319 locations at evacuation centers for audibly handicapped people. Special services were also offered, including, for example, waived basic charges in the damaged area, a free service giving names of the dead, use of teleconferencing systems for city halls in Hyogo Prefecture, and the donation of 30,000 telephones for use in temporary housing. Line congestion, a problem often faced when an earthquake occurs, was severe following this earthquake, so call controls were imposed until January 22. Congestion peaked on the January 17, when 50 times the normal number of calls were recorded.

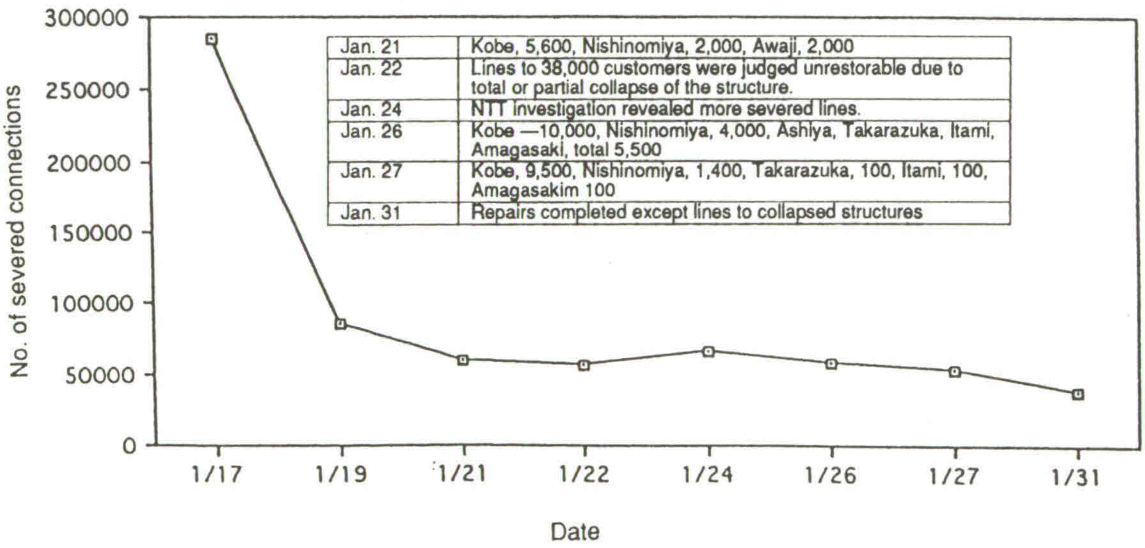
2.2 Problems with telecommunications facilities

Telephone tunnels and underground cables demonstrated excellent earthquake resistance, and most kept functioning following the devastating earthquake. There are great advantages in extending such earthquake-resistant systems, in the form of medium-diameter conduits, as near as possible to actual telephone subscribers.

Once underground cables are damaged, repair takes much more time than in the case of overhead cabling. Emergency procedures to cope with such damage are needed. Although most underground cables fortunately suffered only minor damage on this occasion, it is worth considering plans for backup tunnels to be on the safe side in future.

Work is needed on a method of detecting damage in manholes, since this would increase recovery speed. In the case of telephone tunnels, there is demand for a method of repairing damage to joints and walls that does not reduce the usable cross section.

This earthquake revealed that unprecedented congestion of the communications system occurs when an earthquake hits a large city. We cannot emphasize too strongly the urgent need to develop systems that can overcome such line congestion. It is also clear that measures need to be developed to cope with damage to "top-heavy" structures, such as steel towers or antennas, and other structures housing key telecommunications installations. Since damage to these facilities has a great effect on telephone users, full consideration is needed.



Jan. 21	Kobe, 5,600, Nishinomiya, 2,000, Awaji, 2,000
Jan. 22	Lines to 38,000 customers were judged unrestorable due to total or partial collapse of the structure.
Jan. 24	NTT investigation revealed more severed lines.
Jan. 26	Kobe —10,000, Nishinomiya, 4,000, Ashiya, Takarazuka, Itami, Amagasaki, total 5,500
Jan. 27	Kobe, 9,500, Nishinomiya, 1,400, Takarazuka, 100, Itami, 100, Amagasakim 100
Jan. 31	Repairs completed except lines to collapsed structures

Fig. 2.1 Recovery of severed connections

Damage to Mountain Slopes and Embankments in Residential Areas

Takashi Okimura, Associate Professor, Kobe University, Mountain Disaster Prevention Engineering

1. DAMAGE TO MOUNTAIN SLOPES

1.1 Damage distribution

Aerial photos taken by Asia Aerial Survey Co., Ltd. on January 20, 1995 at a scale of 1/8,000 and 1/4,000 were used to prepare a map of damage distribution. This was then used to check the extent and severity of landslides caused by the January 17 earthquake. The base map used was a topographical map to a scale of 1/10,000.

The landslides seen in the photos are, with a few exceptions, rather minor in scale. Many are cases where steep cliffs collapsed, a type of damage often seen after torrential rainfall. As a result, it was difficult to be sure which damage the January earthquake was responsible for. It may be that many landslides attributable to the devastating earthquake have been overlooked, but nevertheless the author presents here an analysis of certain characteristics of the earthquake-induced landslides using the distribution maps prepared so far. This chapter deals with landslides on natural mountain slopes, while the next considers artificial embankments built in the development of new residential land.

1.2 Characteristics of collapse

The observed earthquake-induced collapse has the following six major characteristics: (1) small-scale collapse is dominant; (2) steep slopes are particularly susceptible; (3) the volume of collapse and amount of erosion are small; (4) collapse occurs on planar (linear) slopes and some ridges; (6) collapse mostly originates at sharp turning points (knickpoint); (6) some collapses occurred on exposed cliffs. This matches the characteristics reported in other earthquakes, including a report on the earthquake in Oita Prefecture in 1975 and a survey of earthquakes on Izu Oshima Island1).

Another characteristic to note is the loosening of unstable masses of ground. Photo 1 shows large rocks that hit Dobashi station of the Rokko Cable Car. Many slopes have big cracks, some of which led to collapse and some of which did not. Photo 2 shows the slope to the east of the site shown in Photo 1. This is a ridge-shaped slope, and a hiking trail followed the ridge. Steep sections were provided with concrete steps, and two of these points slid by about 1m, as shown in Photo 2. The concrete steps were destroyed.

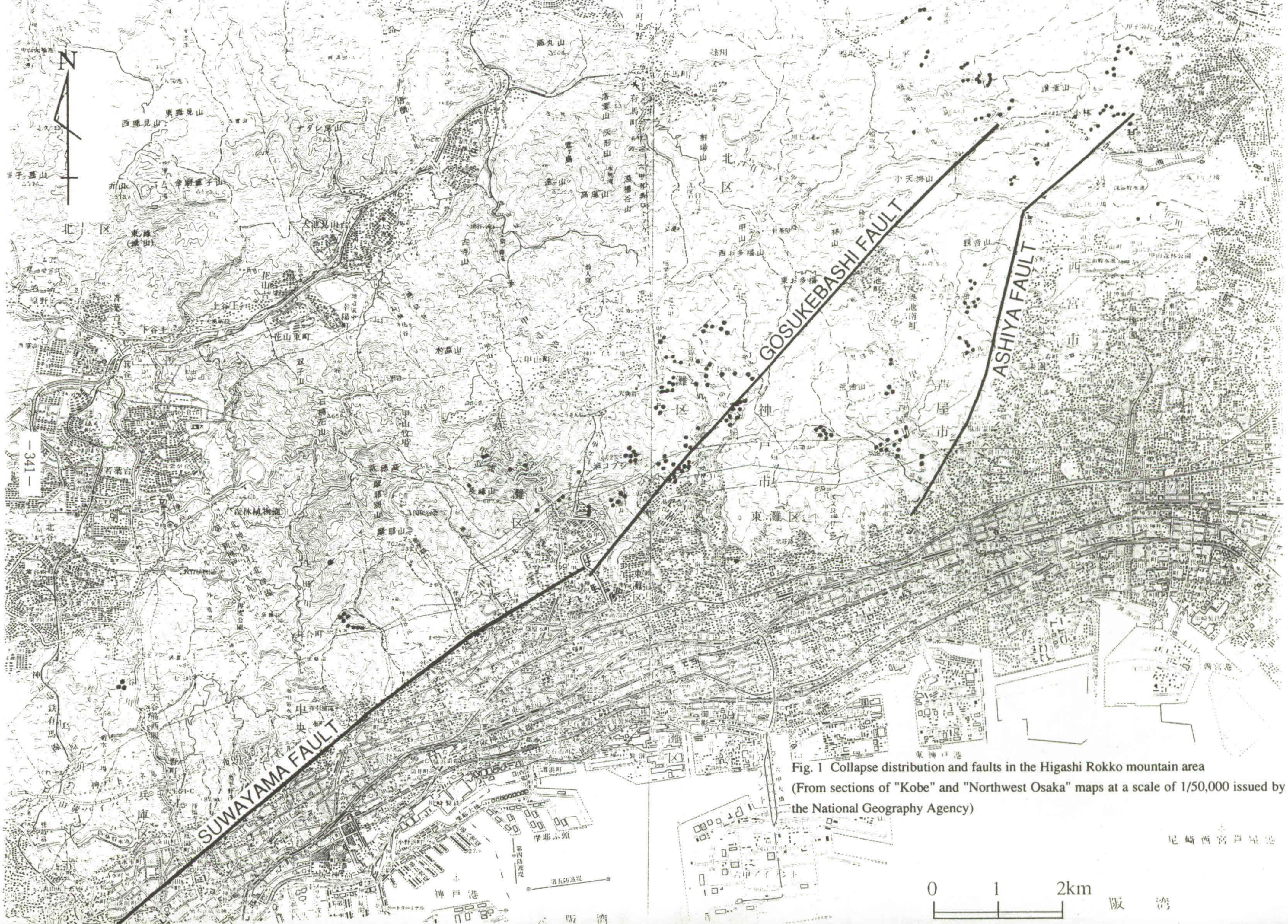


Fig. 1 Collapse distribution and faults in the Higashi Rokko mountain area
(From sections of "Kobe" and "Northwest Osaka" maps at a scale of 1/50,000 issued by the National Geography Agency)

Photo 1 Rockfalls at Dobashi station, Rokko Cable Way

Photo 2 Damaged slope in the Tsurukabuto area, Nada Ward

1.3 Characteristics of collapse locations

A collapse distribution map to a scale of 1/50,000 was prepared from the 1/10,000-scale maps. This reduced map shows no details of each collapse — each location is simply marked with a red circle. The marks therefore do not reflect the magnitude of the collapse. Figure 1 is a map of the collapse distribution in the eastern Rokko area. The map also shows the rough positions of the Suwayama Fault, the Gosukebashi Fault, and the Ashiya Fault[2]. It follows from the map that landslides occurred along lines parallel with these faults. This leads to a number of possible conclusions: (1) the movement of faults appears to be responsible for landslides; (2) although the whole mountain range was subject to the same seismic shock, only steep slopes with the topographic features of a fault line collapsed; or (3) both of the these effects caused the collapse of mountain slopes. However, the exact cause of the landslides is not yet known. Further study and analysis is needed on the basis of these earthquake distribution maps.

The 1/10,000-scale collapse distribution maps were used to analyze the direction of collapse. Figure 2 shows the direction of movement of the collapses observed in the aerial photos. An overwhelming number of collapses occurred in the NW to SE direction. This indicates a perpendicular relationship with the faults under the Omote Rokko mountains, which mostly run in the NE to SW direction. This analysis, however, only covered slopes where landslides actually occurred; to confirm the result, it is necessary to obtain the orientation of slopes over the entire area.

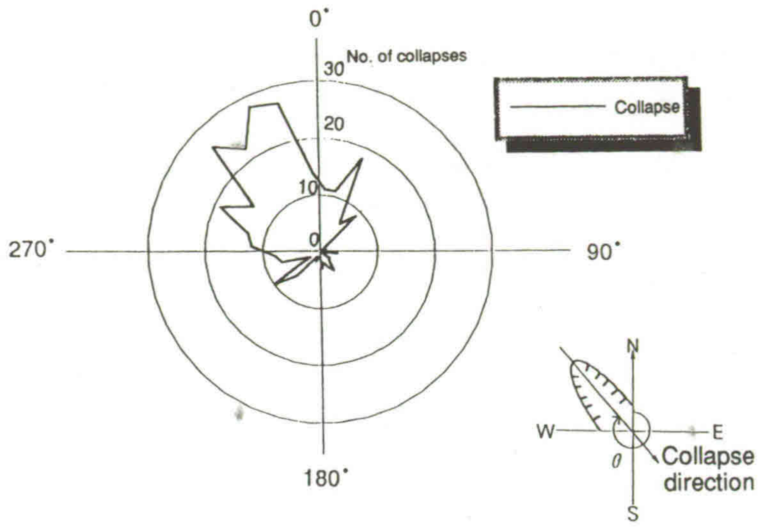


Fig. 2 Directions of collapse

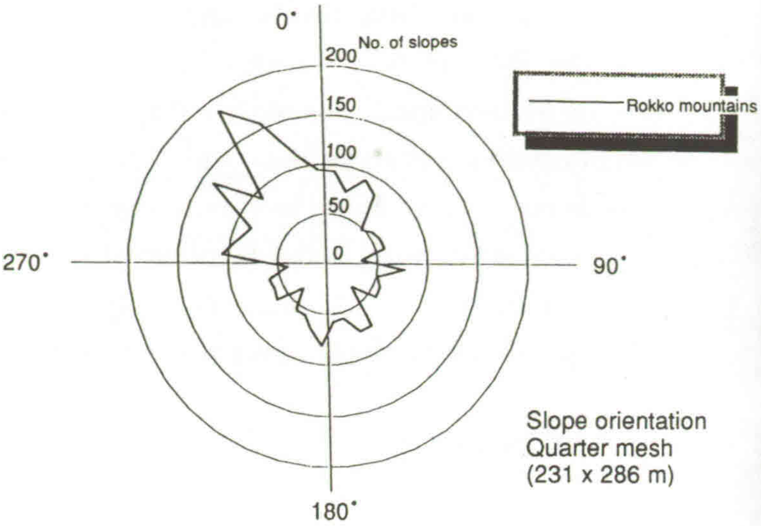


Fig. 3 Slope orientation in the Rokko mountains

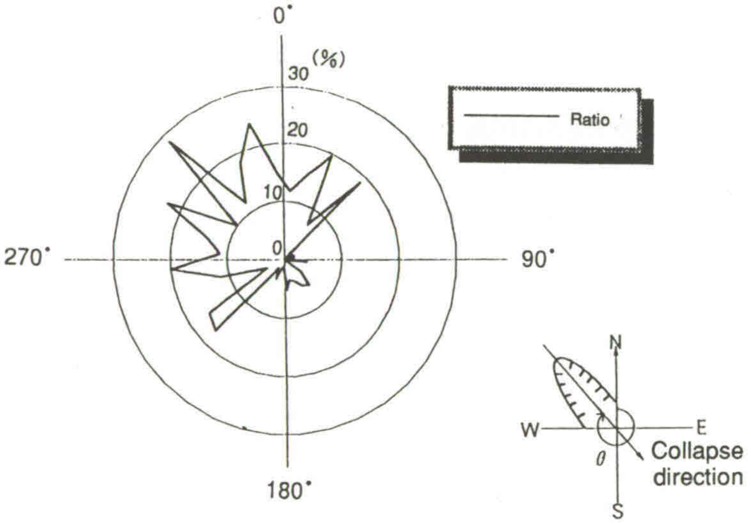


Fig. 4 Occurrence of collapses in each direction

The author checked the distribution of slope orientation in the Rokko area using a one-quarter mesh of a numerical map published by the National Geographic Agency. A quarter mesh in the Rokko area equals a square of 231 x 286 m. Figure 3 show the distribution of slope orientation based on this mesh. Since the long, narrow Rokko range itself has a NE to SW direction, this figure shows there are more slopes with NW to SE orientation than with NE to SW orientation. There is thus a greater bias in slope orientation than in the direction of slope collapse. Thus, it is still debatable whether this discussion of direction is valid. The appearance of collapses in each direction in Fig. 2 and Fig. 3 is shown in Fig. 4. This shows that there are many cases of collapse with NW to SE direction. The ratio of collapses with NE to SW direction, normal to the NW to SE direction, was also a maximum. The former is assumed to indicate that collapse occurred at many steep slopes, such as a surface of the end of a triangle, along faults with NE-SW direction or many landslides occurred at the peaks of valleys lying in the direction normal to those faults. The latter probably suggest that two peaks of collapse with NE-SW direction are collapse of the walls of valleys normal to the faults.

1.4 Summary

The characteristics of collapse observed in this investigation are almost the same as those noted conventionally. That is, the January 17 earthquake caused the small-scale collapse of steep slopes, ridges — especially narrow ones — with sudden turn points as the origin. Exposed cliffs and unstable rock masses were potential dangers. The location of the points of collapse is thought to be deeply related to existing faults.

2. EMBANKMENTS IN RESIDENTIAL AREAS

2.1 Field survey

In order to obtain the distribution of damage to embankments in the residential developments dotted along the foot of the Omote Rokko mountains from Higashinada Ward to Hyogo Ward in Kobe, field surveys were conducted at 12 points during the fourth investigation. The survey looked for evidence of bulging, cracking, and collapse of retaining walls, damage to the pavement, damage to drainage ditches, house collapse, and the distribution of such damage. Field comments were noted on residential maps or 1/2500-scale national maps.

2.2 Investigation results

Damage to embankments in these housing developments can be roughly categorized into two types: local damage and linearly distributed damage. Local damage includes cracking and collapse of retaining walls and damage to pavements. Linear damage is of three types: (1) damage limited to an area where only local deformation is observed (specifically, the damage consists of collapse and cracking of retaining walls, destruction of pavements, and house collapse); (2) damage distributed in zones and attributable to faults (the local damage appears in a zonal distribution); (3) damage attributable to mass movement of the ground (specifically, local damage is extensive and consists of collapsed embankments and cliffs or considerably deformed pavements.

Photos 3, 4, 5, and 6 show a stone retaining wall which collapsed, vertical cracking on a stone retaining wall, bulging of a two-stage retaining wall, and an overturned concrete retaining wall due to collapse of a road, respectively.

Photo 3 Collapse of stone retaining wall

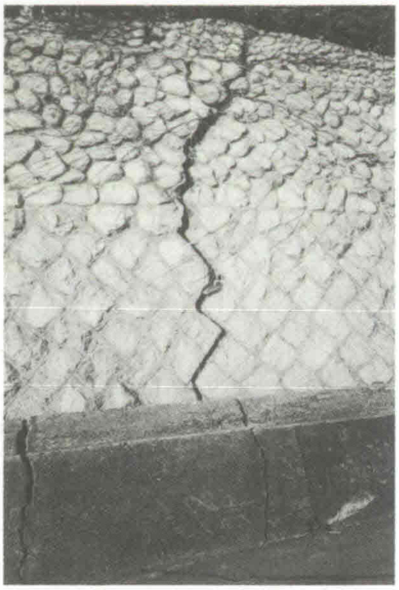


Photo 4 Vertical crack in stone retaining wall

Photo 5 Bulging of two-stage retaining wall

Photo 6 Overturned concrete retaining wall

3. SUGGESTIONS AND RECOMMENDATIONS FOR RECOVERY

(1) According to the latest observations, movement of both natural slopes and artificial embankments has stopped. Reinforcement of damaged sections, however, is necessary, since seasonal rains and typhoons are approaching.

(2) Slope stabilization cannot be completed in a hurry, so temporary work is required on those slopes which show indications of further movement. In the case of other slopes, it is important that nearby residents keep a close watch on their behavior.

(3) It is necessary to measure the displacement of slopes threatening to cause more damage, and to introduce a warning system to prevent further destruction.

(4) It is important to prevent rainwater from seeping into the ground through cracks. In residential areas, many downpipes taking water from roofs into the ground were damaged below ground by the earthquake. This needs a lot of attention.

(5) There is a need to study the shape of deformed or slipped faces formed in the earthquake. This is important to understanding the mechanism of deformation and collapse. There is thus a requirement to carry out various investigations, including borehole surveys, on some of these slopes.

(6) Many older retaining walls were seen to be badly damaged. Measures to protect these old retaining walls are also important. The old retaining walls need to be addressed on the basis of not only hardware but also software.

(7) Since the bedrock and fill have different dynamic response characteristics, deformation or destruction often occurred where they meet. A method of integrating bedrock and fill needs to be developed.

(8) It is necessary to immediately develop a method of diagnosing the safety of stone and concrete retaining walls in residential areas that have visible cracks, and to prepare a set of draft standards for repair methods.

The author intends to focus his study on the damaged slopes to clarify the mechanism of collapse. Thanks are due to Rokko Sediment Control Office, Kinki Construction Bureau, and the Ministry of Construction for some of the aerial photos used in this study.

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1) Yasue, A., and Nakano, K.: Hazard Evaluation of Steep Slope in Earthquakes, Civil Engineering Technology, p.34, Aug. 1978

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January 17, 1996

Dear Colleagues :

Enclosed please find a copy of "Preliminary Report on The Great Hanshin Earthquake" from the Japan Society of Civil Engineers. This report includes preliminary findings from field investigations by teams dispatched by JSCE immediately following the earthquake. This report was completed in Japanese in March, 1995. A number of copies translated into English have already been distributed, and we would like to take this opportunity to distribute additional copies to provide information that we consider valuable.

The Japan Society of Civil Engineers has been continuing efforts to accumulate information on the damage to infrastructures caused by the Great Hanshin Earthquake, to analyze the failure mechanism of these infrastructures, to investigate the cause of the damage, and to propose possible improvements to the design code. The results of such studies will be made available as soon as they are completed. The distribution of this preliminary report is only the first step in our endeavors.

The results of studies by committees or members will be disseminated through reports or technical papers. For your interest, the enclosed report includes information on English periodicals published by the Japan Society of Civil Engineers. They are supposed to act as a means to transfer to researchers and engineers abroad Japanese information on Civil Engineering including that on the Great Hanshin Earthquake.

We would appreciate it if you could return the inserted questionnaire on English Periodicals by the Japan Society of Civil Engineers. Your answers will be used to help us provide further useful information in the future. We appreciate your cooperation in advance.

We would be delighted to receive any comments or suggestions related to our continuous efforts to learn important lessons from the severe damage in Kobe and to do our best to avoid such a sorrowful tragedy again.

Yours faithfully,

小坂忠

Tadashi Kosaka
President
Japan Society of Civil Engineers

土木学会

JAPAN SOCIETY OF CIVIL ENGINEERS
(DOBOKU-GAKKAI)
Mubanchi, Yotsuya 1-chome, Shinjuku-ku, Tokyo, 160 JAPAN
TELEPHONE : (3) 3355-3441 FACSIMILE : ~~(3) 3355-3446~~ (3) 5379-2769 CABLE ADDRESS : JSCEDOBOKU TOKYO

Your Ref. **Our Ref.**

January 25, 1995

To subscribers of the Journal of Hydroscience
and Hydraulic Enginering, JSCE

Dear Colleagues:

The Committee on Hydraulics of the Japan Society of Civil Engineers has published semiannually the Journal of Hydroscience and Hydraulic Engineering since 1983. The journal has contributed to communication of Japanese activities on hydraulics and related fields to foreign researchers. Many contributions have also been made from other countries.

I would be very much obliged if you could advise us how to improve the Journal of Hydroscience and Hydraulic Engineering by filling in the questionnaire enclosed herein. I would also very much appreciate if you could continue reading the journal and recommend it to other researchers.

Sincerely yours,

Syunsuke Ikeda

Syunsuke Ikeda
Editor, JHHE

SI/sk

English Periodicals by the Japan Society of Civil Engineers

The Japan Society of Civil Engineers (JSCE) is responsible to introduce our academic accomplishments and engineering activities in Japan to the world. We also devote ourselves to exchange academic information regarding innovation in civil engineering internationally.

To achieve this role, we are currently publishing the following official English journals periodically.

Structural Engineering/Earthquake Engineering *biannual*

Covering subjects: mechanics of materials, structural mechanics and engineering, earthquake engineering, structural dynamics and vibration control, reliability and risk analysis, wind engineering, aesthetics of structures, computational mechanics, optimal design, fatigue and maintenance of structures.

Journal of Hydroscience and Hydraulic Engineering *biannual*

Covering subjects: hydraulics, hydrology, river-engineering, sanitary engineering, coastal engineering and new fields to be developed in the science of water engineering.

Coastal Engineering in Japan *biannual*

Covering subjects: offshore and nearshore waves and currents; coastal sediment transport and geomorphology; coastal, harbor and offshore structures; coastal zone development; environmental problems; technical reports on coastal construction work and on field measurements.

Concrete Library International *biannual*

Covering subjects: materials, concrete structures and pavements; selected technical papers published in Japan, recommendations for design and construction practices prepared by the Concrete Committee of JSCE.

Journal of Global Environment Engineering *annual*

Covering subjects: Physical aspects of global environmental problems (climatic change, see level rise, destruction of the ozone layer, acid precipitation, international water disputes, marine pollution, transboundary movement of hazardous wastes, desertification, species extinction, and conservation of historical and cultural inheritances); **Socio-economic aspects of global environmental problems** (environmental issues in developing countries, injurious impacts of global environmental change on developing countries and minority groups, double standard, deportation of environment-disruptive industries to developing countries, response strategies in developed countries, depletion of natural and energy resources, and civil engineering technologies in developing countries.

All these journals are open to original contributions by researchers and engineers from abroad.

Subscription

Subscription Prices per Volume (including surface mail postage)

Structural Engineering/Earthquake Engineering	US$ 30.00		
Journal of Hydroscience and Hydraulic Engineering	US$ 64.00		
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Concrete Libraty International	US$ 50.00		
Journal of Global Environmental Engineering	3,000 JY (JSCE members)	6,000 JY (non-members)	extra 1,000 JY for Airmail

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- ☐ Concrete Library International
- ☐ Journal of Global Environmental Engineering

Questionnaire on
English Periodicals by the Japan Society of Civil Engineers

The Japan Society of Civil Engineers (JSCE) would like to know your opinions and requests about our activities on publishing English periodical journals.

Please answer the questions below and send by Fax or mail to:

Committee of Journals
The Japan Society of Civil Engineers
Yotsuya 1, Shinjuku-ku, Tokyo 160, Japan
Fax : +81-3-5379-0125

1. Please introduce yourself as much as possible. But we will not at all disclose your answers on this questionnaire in such a way that one can specify you.

Name/Title ______________________ Position ______________

Department ____

Institution ____

Address ____

____

Post/Zip code __________________ Country ________________

Telephone ______________________ Fax ____________________

E-mail __________________________

2. Please express your position on which your answers below are made.

☐ As a (possible) reader ☐ As an official position such as Librarian or Department Chairman

3. These are the English journals currently published by JSCE. Please fill the cells with "x" :

	I am a subscriber or reader of :	I am planning to subscribe :
Structural Engineering/Earthquake Engineering		
Journal of Hydroscience and Hydraulic Engineering		
Coastal Engineering in Japan		
Concrete Library International		
Journal of Global Environmental Engineering		

4. What fields or topics do you expect to read in case JSCE publishes new English journals ?

Planning and management of infrastructures	
Management and engineering in construction	
Geotechnical engineering	
Reports and news of on-going/future projects	
Prevention of natural disasters	
Forums and letters to/from JSCE members and readers	
Activities and events of JSCE	

If anything else, ____

5. What is your convenient way of payment ?

☐ Credit Card ☐ Cheque to JSCE ☐ Bank Transfer If anything else, ______________

6. Thank you very much for your cooperation. If you have any more messages to us, please write here.

English Periodicals
by the Japan Society of Civil Engineers

- Structural Engineering/Earthquake Engineering
- Journal of Hydroscience and Hydraulic Engineering
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- Concrete Library International
- Journal of Global Environment Engineering

Japan Society of Civil Engineers
Yotsuya 1, Shinjuku-ku, Tokyo 160, Japan
Fax : +81-3-5379-0125

Courtesy by Asia Air Survey Company