-List of Contents-

Seismology and Ground Motion Features of 1995 South Hyogo Great Earthquake

1. Introduction

On Jan. 17, 1995 at 5:46 a.m., a big earthquake with M=7.2 hit west part of Japan in which the highest intensity and most severe damage was concentrated in the southern part of Hyogo prefecture. Damage intensity in Kobe City and north of Awaji Island is announced by Japan Meteorological Agency as VII in the Japanese scale (approximately equal to MM=XI) which is the highest one ever experienced in Japan. The epicenter situation and the distribution of intensities are depicted in Fig. 1.

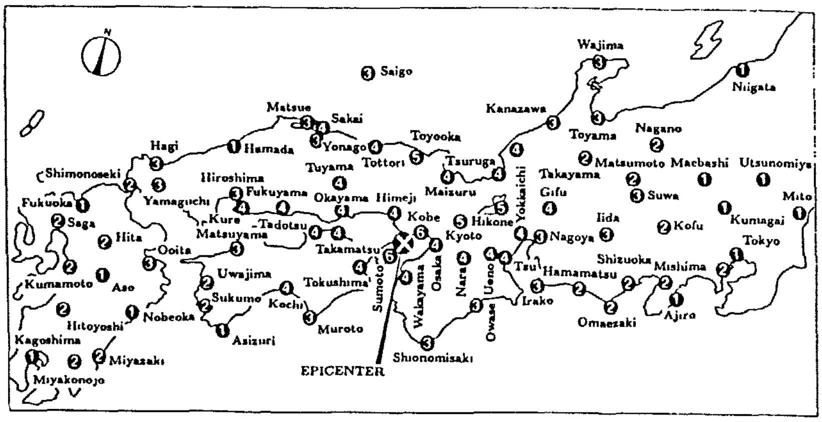


Fig 1. Distribution of Intensity and location of epicenter

The quake made more than 5,472 casualties, 26,804 injuries, 83,536 destroyed houses, 68,761 severely damaged houses and more than 300,000 people went to the emergency shelters. More than 258 fires burned about 671,253 m^2 of the populated areas. Several bridges fell down and the transportation system suffered severe damage. For the first time several underground tunnels were severely damaged. Damage on lifeline caused interruption of gas and water to more than 800,000 houses. Electricity and telecommunication were cut off due to the damage to their facilities. The total damage is estimated between 95 to 140 billion U.S. dollars.

The areas with intensity 7 which have sustained the most severe damage are shown in Fig. 2.

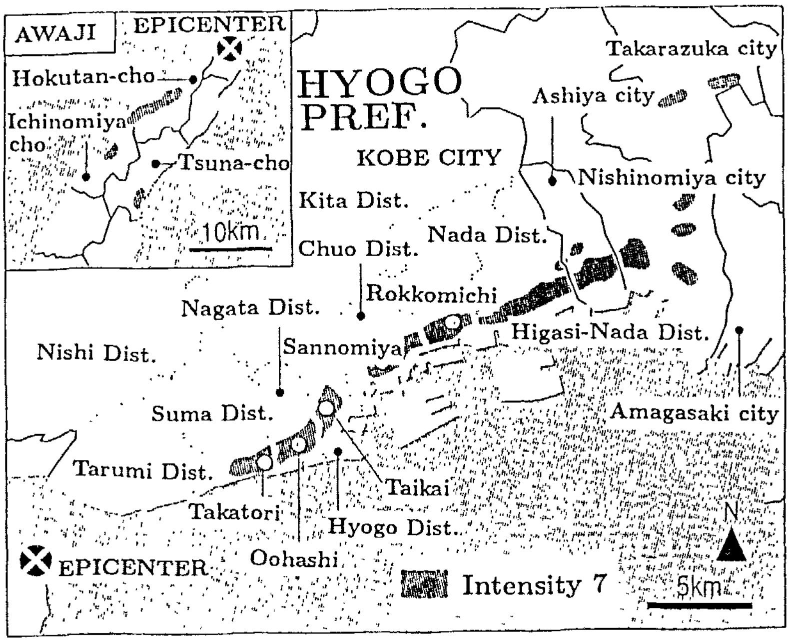


Fig. 2 - Areas with intensity of 7

It should be noted that after more damage investigation, 3 days after the quake the JMA upgrade the intensity of the above areas from 6 to 7. According to the JMA scale of intensity, 7 degree of intensity is the case that more than 30% of Japanese style wood houses be destroyed. An approximate relation between the intensities and ground acceleration are summarized in Table 1.

Table 1 - Approximate relation between Intensities and ground acceleration

Intensity (JMA Scale)	Acceleration (gal)
7	More than 400
6	250 - 400
5	80 - 250
4	25 - 80
3	8 - 25
2	2.5 - 8
1	0.8 - 2.5

JMA : Japan Meteorological Agency
Gal= Gravity acceleration / 980

2. Fault mechanism

According to the Japan Meteorological Agency the magnitude of earthquake was 7.2 in Richter scale and its epicenter was in 34.6° north and 135.0° east in the northern tip of Awaji Island with a focal depth of 14 km. According to the results of the recorded in 24 observation center, the fracture which triggered the earthquake was happened inside the Nojima Fault. Also investigation in the sea bed by the Ocean observatory Center shows that the cracks occurred in Nojima Fault. This fault forms a part of a group of faults known as the "Rokko Fault", which extends from Awaji Island through Kobe City to the foot of Mount Rokko. A schematic map of the faults in this area are depicted in Fig. 3.

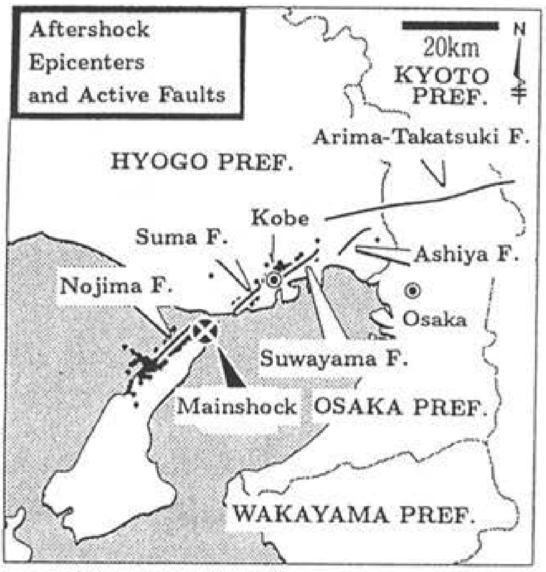


Fig. 3 - The main active faults and aftershocks epicenters in the quake-hit area

The movement mechanism of fault that it has strike-slip type with right-lateral movement. The direction of movement is from the south-west to the north-east. The maximum horizontal and vertical displacements which were observed in the ground surface are about 1.8 m and 1.3 m, respectively. The Photo 1 shows the Nojima Fault movement.

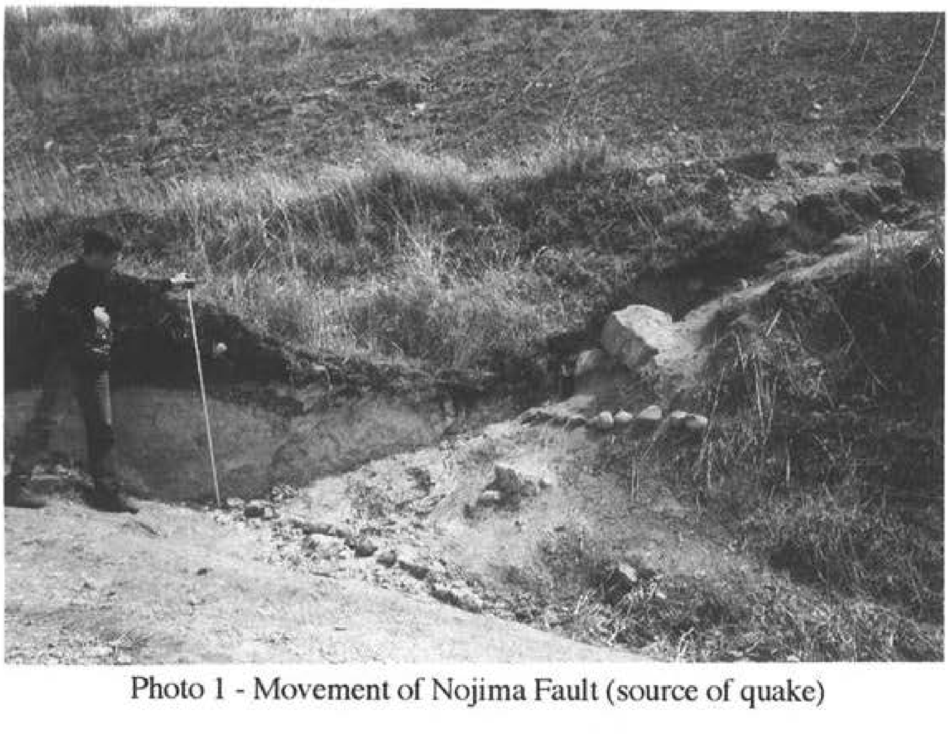


Photo 1 - Movement of Nojima Fault (source of quake)

The movement of the fault can be explained by the Tectonic characteristic of west Japan. The main reason for the big earthquakes in west part of Japan are the tectonic activities of the Eurasian, the Paciffic, the North America and the Phillipin plates. The collision between these plates in the central part of Honshu (Japan main island) is the main source of strain accumulation in the crust of western part of Japan. During the past 100 years, the big earthquakes with magnitude more than 7 (such as Nobi, Tottori and Fukui earthquakes) had a strike-slip type of movement and can be explained by this mechanism.

From the historical point of view on Nov. 26, 1916 there was a M=6.1 earthquake which hit Hanshin area but from the another fault and with a light damage. The last activity of Nojima Fault before the South Hyogo Earthquake has been recorded about 1000 years ago.

3. Ground Motion

The strong ground motion have been recorded in so many places by several organizations. The main of these organizations are Committee of Earthquake Observation and Research in Kansai Area (CORKA), Osaka Gas and Japan Railways(JR). The records of CORKA are the maxim horizontal (N-S and E-W) and vertical component of acceleration. The ones from Osaka Gas are the vector combination of horizontal acceleration. The JR results are obtained after high cut filtration at 5 Hz. The important ones of all records of maximum accelerations mainly recorded by the above mentioned organizations are summarized in Table 2. Approximate location of the observatory stations are shown in Fig. 4.

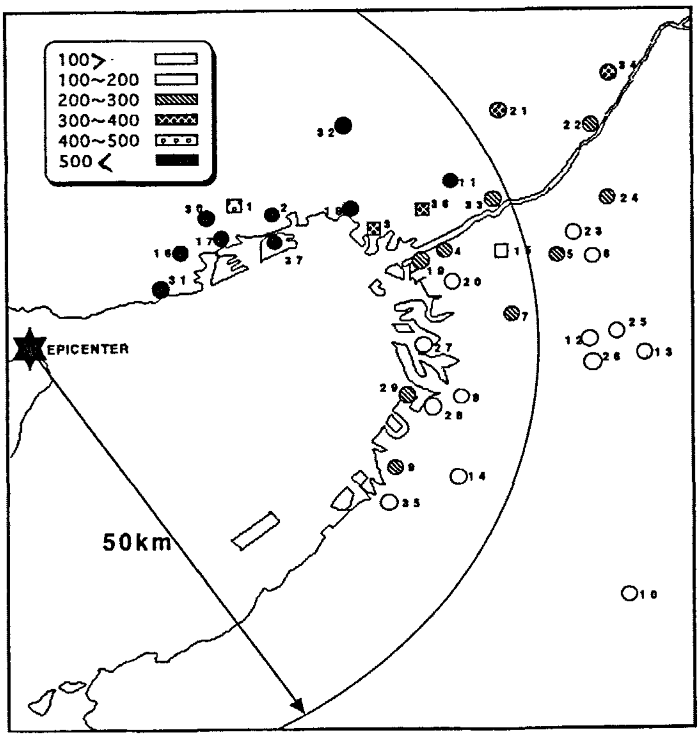


Fig. 4 - Location of Observatory stations

Table 2 - Maximum acceleration recorded by some observatory stations

Organization	Location	Maximum Accelerations N-S	E-W	U-D	Remarks	NO.+
++ CORKA	Kobe University	269.8	305.3	446.5?	Bed rock	1
	Kobe Motoyama	421.0?	774.9?	379.3?		2
	Amagasaki	271.4?	321.5?	327.9?		3
	Fukushima	180.0	211.5	194.8		4
	Morigawachi	210.1	123.3	158.8		5
	Yae	154.7	14.9	127.1		6
	Abeno	217.4	226.4	136.2		7
	Sakai	150.2	124.7	100.3		8
	Takaoda	290.4	190.1	136.5		9
	Chihoya	90.6	108.6	73.6	Bed rock	10
Kansai Electricity	Soken	299	507	205	Groun Level	11
		294	320	199	GL-97.0 m	
	Yao	148	139	82	Groun Level	12
	Shigi Power Transformer Station	22	20	11	GL-22.0 m	13
		25	20	10	Groun Level	
	South Osaka	144	145	93	Groun Level	14
B.R.I *	Osaka Daisan Godochoshya	90.2	82.5	108.8	-3 th Floor	15
		412.3	316.3	209.4	18 th Floor	
K.O.O.S**	Kobe (central ward)	818	617	332		16
Osaka Gas	Kobe Chuo Fukiae	833				17
	Nishinomiya Imazu	792				18
	Osaka Konohana	266				19
	Osaka Iwasaki	185				20
	Osaka Suitashi	312				21
	OsakaTakatuki	251				22
	Higashi Osaka	177				23
	Osaka Shityo Nawate	224				24
	Osaka Yao	169				25
	Osaka Fujidera	149				26
	Sakai	173				27
	Sakai	178				28
	Sakai	240				29
Japan Railways (JR)	Shinkobe	561				30
	Takatori	616				31
	Takarazuka	601				32
	Shinosaka	245				33
	Osaka Shintakatuki	323				34
	Higashikishiwada	149				35
Ministry of Construction	JR Amagasaki	300	273	307		36
	Amagasaki	475				
Takeda Eng. Office	Rokko Island	319		507		37

? : Out of scale

+ : Number of location in Fig. 4.

++ : Committee of Earthquake Observation and Research in Kansai Area

* : Building Research Institute

** : Kobe Ocean Observatory Station

The time histories of the ground accelerations which have been recorded by Kobe Ocean Observatory Station are shown in Fig. 5.

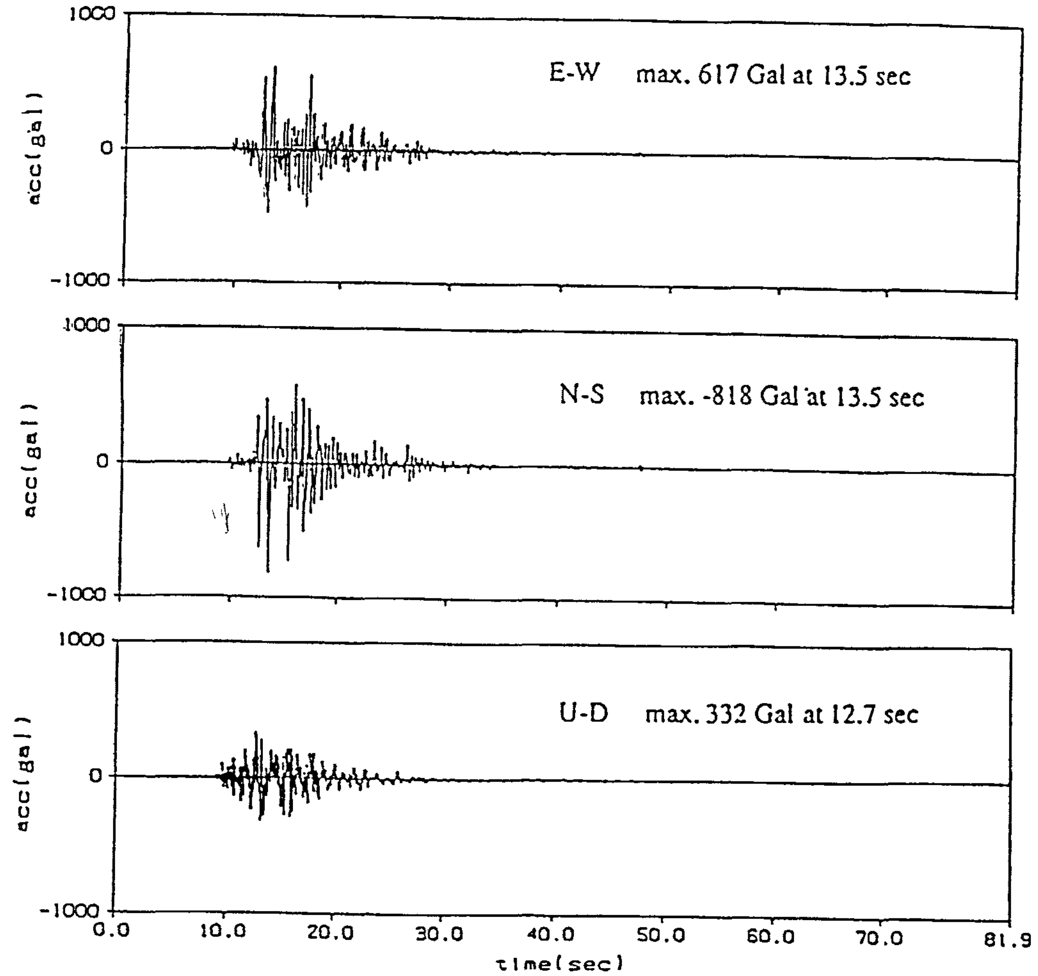


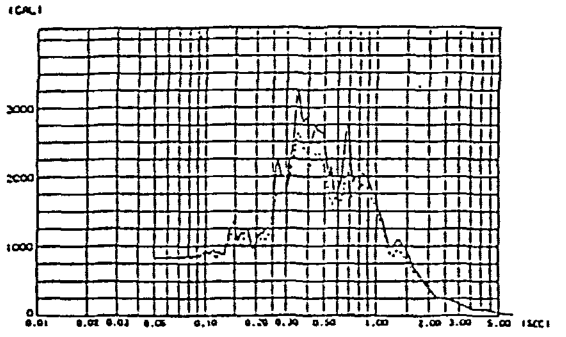
Fig. 5 - The Accelerations time-history recorded by Kobe Ocean Observatory Station

The maximum accelerations are :

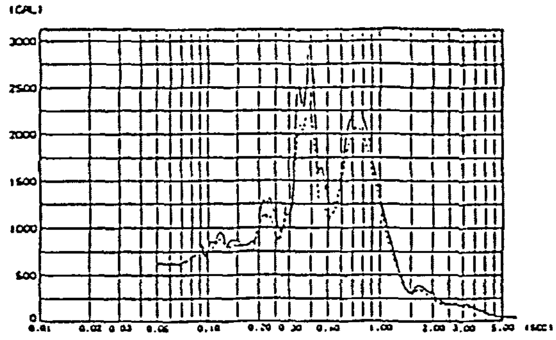
- North-South direction 818 gal
- East-West direction 617 gal
- Up-Down 332 gal

Comparing to the other earthquakes in Japan such big amount of accelerations have not been experienced. The maximum ones of Kanto Big Earthquake in 1923, were something between 300 t0 400 gals which is half of South Hyogo Earthquake. The response spectra of the above mentioned accelerations are show in Fig. 6. The bolded lines show the results for damping ratio of 3% while the dotted ones show those for 5%.

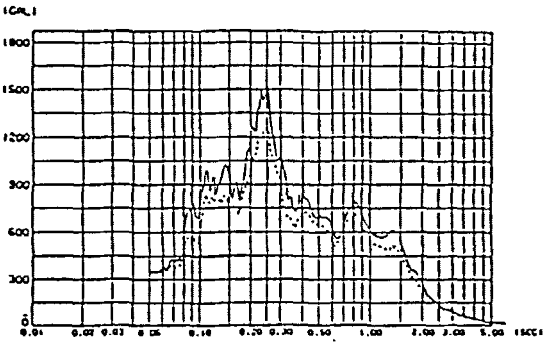
To have a general view about the site effect and ground amplification, accelerations time-histories which are recorded by two stations in Port Island (reclaimed land) at ground level and 83 m under the ground level, are show in Fig. 7 and 8, respectively.



North-South



East-West



Up-Down

Fig. 6. Response spectra for the accelerations recorded by Kobe Ocean Observatory Station

There is not so much maximum vertical in the underground one, while at the ground level the vertical one is 1.6 of the maximum horizontal acceleration. From the bottom to the top (ground level) the maximum horizontal has been increased 0.3 time and the vertical one by 1.9 .

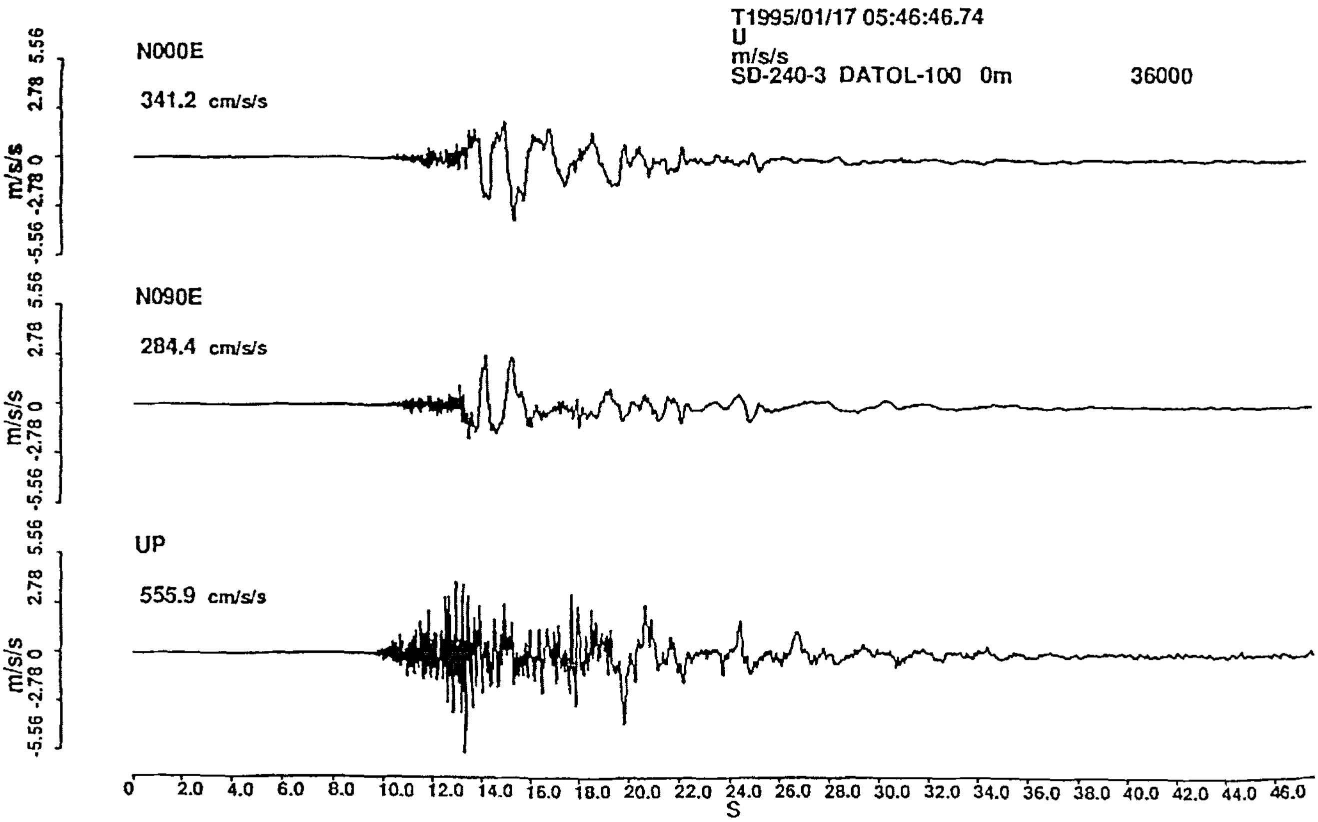


Fig. 7 - Acceleration time-histories recorded in Port Island Ground level

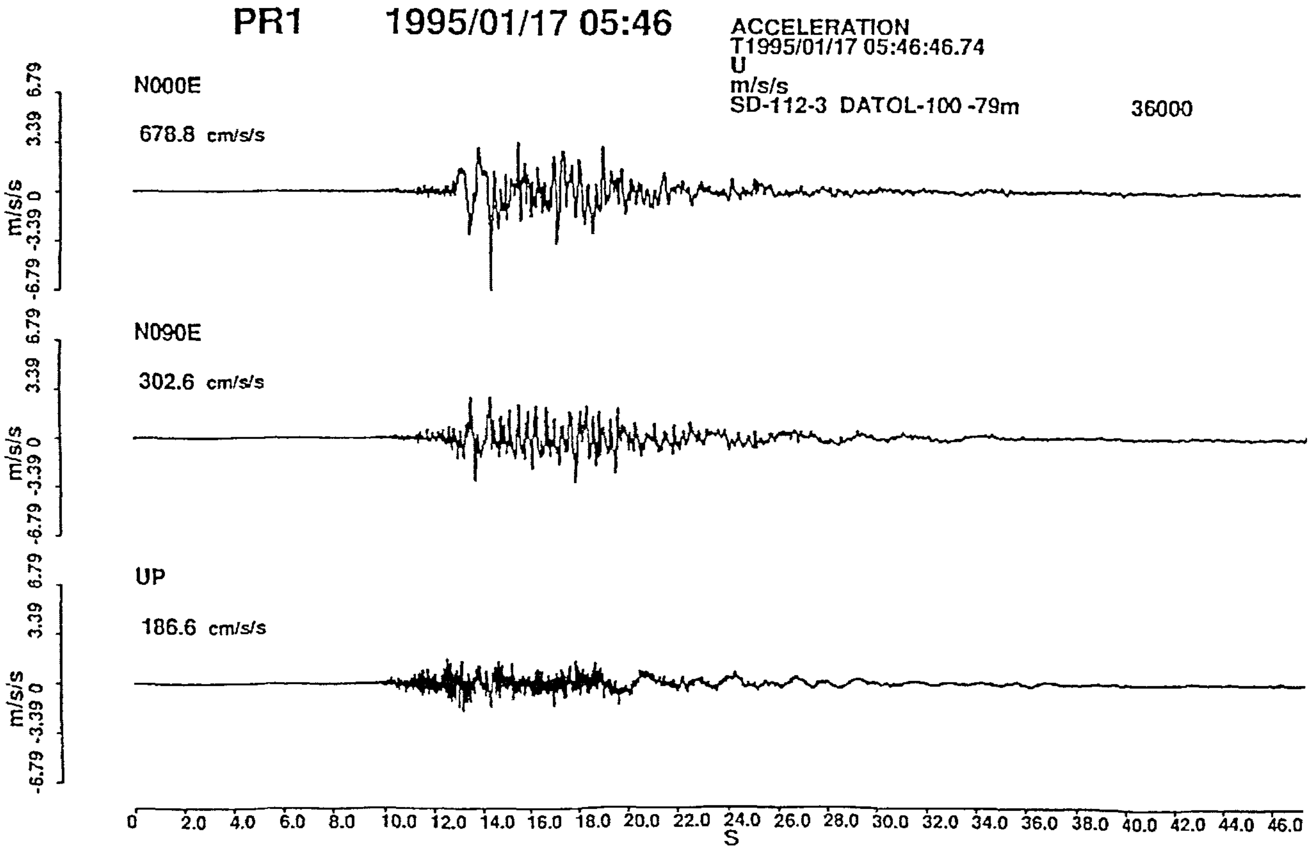


Fig. 8 - Acceleration time-histories recorded in Port Island 83 m under ground

In general the maximum horizontal acceleration of the South Hyogo Earthquake is between 600-800 and the maximum vertical one between 300-400 gal which is 50% of maximum horizontal acceleration.

4. Concluding remarks

The main seismological points which can be concluded as the important lessons and remarks of this earthquake may be explained as followings:

1- This is the first experience of high accelerations in Japan which may affect the Japanese standards for seismic design of structures.

2- The activity of a fault after a long time is an important lesson to consider the potential of such a faults in seismic zonation for more accurate estimating the degree of intensity.

3- High level of vertical shock followed by big horizontal shock is one of the most important feature which caused a large number properties to be damaged.

Acknowledgments

The authors would like to express their best appreciation to those persons in related organizations for their kind assistance. They also thank the those students and staffs of Civil Engineering Department of Kobe University who helped the authors with their best.

(by Shiro Takada and Nemat Hassani)

Liquefaction and Damages to Harbour Facilities

Hashin Earthquake has given catastrophic damages to the coastal area of Kobe and Hashin area where many near-shore reclaimed lands with modern harbour facilities are built. Kobe port has functioned as a number one international freight handling port in Japan, and it handled nearly 70% of the international trade cargo of its country. For two months after the quake, all container berths (35 berths in total) were out of operation and only one container berth in Maya Wharf is back in operation on March 20th. The area map of Kobe port is shown in Fig. 1. There are two major reclaimed lands in Kobe port, namely Port Island and Rokko Island. These islands are built to serve as a modern container port along the perimeter of island as well as a new city with residential and commercial areas in the central part of island. The quake has destroyed almost entire structures constructed near the shore-line of the islands, while there was an extensive liquefaction of ground in almost entire part of the islands. This report summarizes mainly the ground damages caused by the earthquake to these islands and these damages are typical of other reclaimed lands along the shore in Kobe and Hanshin area.

1. Construction of Port and Rokko Islands

The 1st stage of Port Island which has an area of 436 ha was completed in 1981 and, in the south, there is a second stage of Port Island with an area of 390 ha that is originally planned to be completed in 1996. The Rokko Island with an area of 580 ha was completed in 1992. These islands are built by placing granular materials on the top of soft clay at seabed and a typical ground profile of seabed is shown in Fig.2. As shown in Fig.2, a layer of soft marine clay, 10 to 15 m in thickness, covers the seabed, and then a very thick layer of sand and gravel underlies the soft clay layer. Below the layer of sand and gravel, a thick layer of stiff marine clay is found.

The water depth in Kobe port varies from 10 to 15m approximately, and the fill level of island was 4 to 5 m above the sea level. Thus the fill height of these islands range around 15 to 20 m. The shore-line of island is protected by a line of concrete caisson and these caissons are placed on the top of sand and gravel fills that replaced the superficial soft marine clay layer after the clay being dredging. The earthquake caused an extensive liquefaction of granular fill of these islands and large lateral movements of concrete caisson towards the sea.

2. Example of Earthquake Damages

Figs. 3 and 4 show typical example of the earthquake damages to the islands, and these are the failure of south end shore-line of Rokko Island and the liquefaction at container yard at west shore of Port Island, respectively. As to the failure of shore-line, tilting and a large horizontal movement of concrete caisson was a typical of failure mode and the granular fill behind caisson settled and moved horizontally over a wide area. The movements of these shore-line are surveyed by using a satellite and the measurements at Port Island are shown in Fig. 5. The figure shows that the shore-line moved 2 to 3 m horizontally and settled over 1m in average. The possible cause of sea-wall failure seems to be the combination of ground liquefaction behind caisson, the lateral movement of caisson due to the seismic force, and possible liquefaction of the granular fill below caisson. Because of such movements of shore-line, huge cargo cranes in container yard are heavily damage, and more importantly many bridge foundations and facilities connecting the reclaimed land and main-land have been damaged. For example, an elevated track for new un-manned train connecting Rokko Island and main-land has fallen more than 20 m as the pier foundation at Rokko Island side tilted and moved horizontally.

3. Liquefaction of Reclaimed Land

Although the liquefaction of reclaimed land occurred extensively, there were only few damages at the central part of the two islands. The settlement due to liquefaction ranged from 0.3 to 0.1 m in central parts of the islands. Moreover, precautions for foundation design are exercised as these islands are built on the top of soft compressive marine clay, and high rise buildings are built on long piles penetrated into lower sand and gravel layers and ground improvement schemes such as sand drain are extensively applied. Because of these foundation schemes, there were almost no damage to the structures, except of the damages to utility facilities.

It is also to be noted that different granular fill materials are used for the reclamations and the difference of fill material has resulted in different degrees of liquefaction. In Port Island, granular soil of decomposed granite is used while in Rokko Island crushed material of mud stone is used. Extensive liquefaction was found in Port Island while less liquefaction in Rokko Island. Also it was found that the areas installed with displacement type of sand drain showed less extent of ground liquefaction. This indicates that the reclaimed fill is also compacted in some degree by the installation of displacement type of sand drain.

The seismic motion of reclaimed land was monitored at Port Island. The location of seismic measurement is at north west part of the island and the ground profile at measurement point is shown in the bore-hole log of p187 in Fig.2. The measurement is taken at four different depths from the surface, namely at -83, -32, -16m and the ground surface. Figure 6 shows the seismic records of north to south directions taken at these four depths. It shows that the large seismic record started after 13 seconds from the start of measurement. The strong seismic motion only lasted for a period of 10 to 15 seconds. The figure shows that the seismic responses of ground at lower three levels are similar while that of surface show a more smooth response. Since the horizontal motion of ground is transmitted through shear wave through the ground, the time differences among the seismic records at these four levels should indicate the seismic velocities between the measuring points. The correspondences among the seismic records at early times of measurement are noted as shown in Fig.6, and based on these time differences the seismic velocities are estimated as follows; about 30 m/s between 0 to -16m, 85 m/s for -16 to -32m, and 250 m/s for -32 to -83m. Although it is difficult to define the shear velocity of material which may be exhibiting non-linear deformation, it is clear that the shear velocity of reclaimed fill, that is 30 m/s between 0 to -16m, is too low for a compacted fill. It is therefore very likely that liquefaction of reclaimed fill has taken place at such early times (about 2 seconds from the start) of seismic motion.

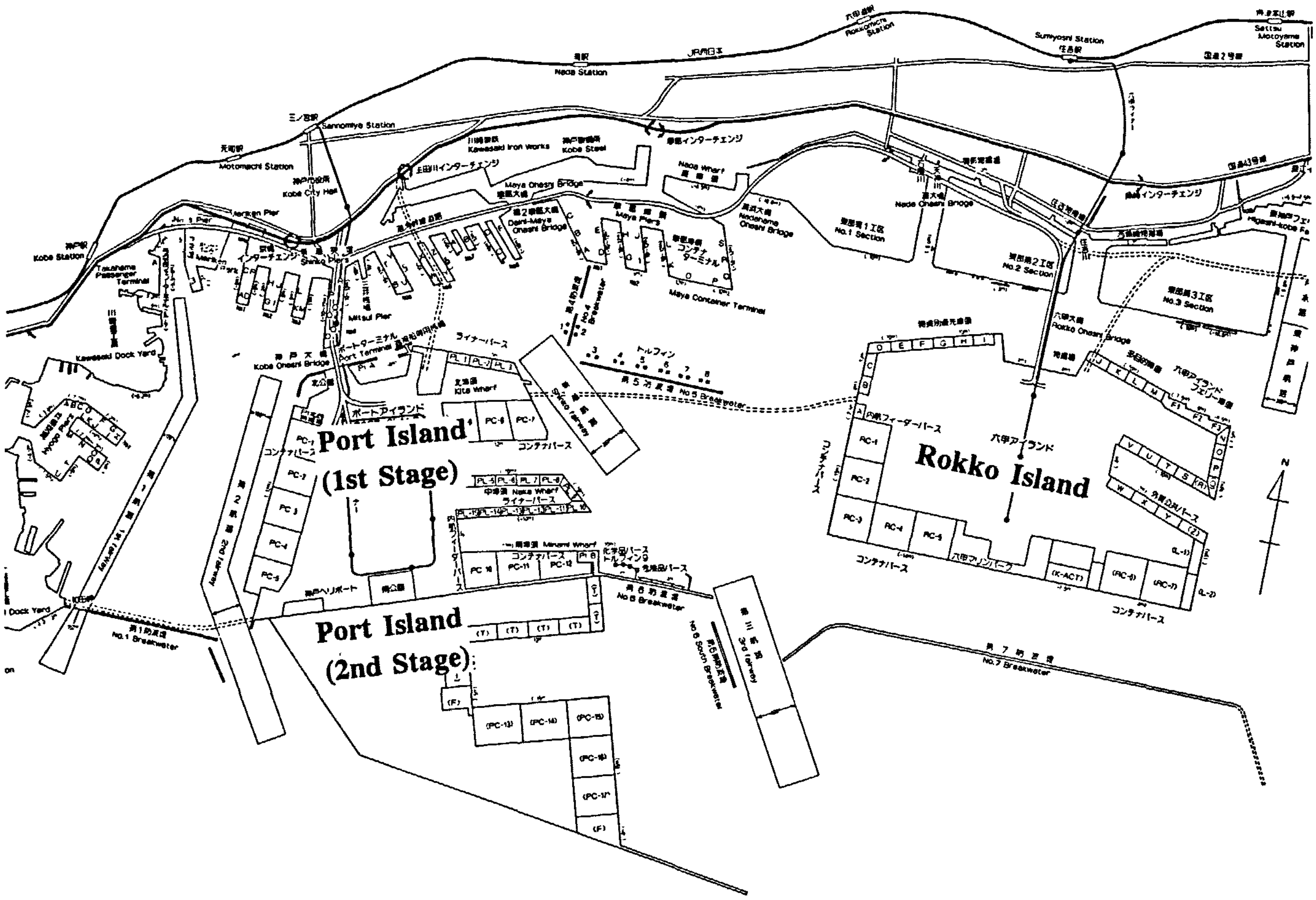


Figure 1 Area Map of Kobe Port

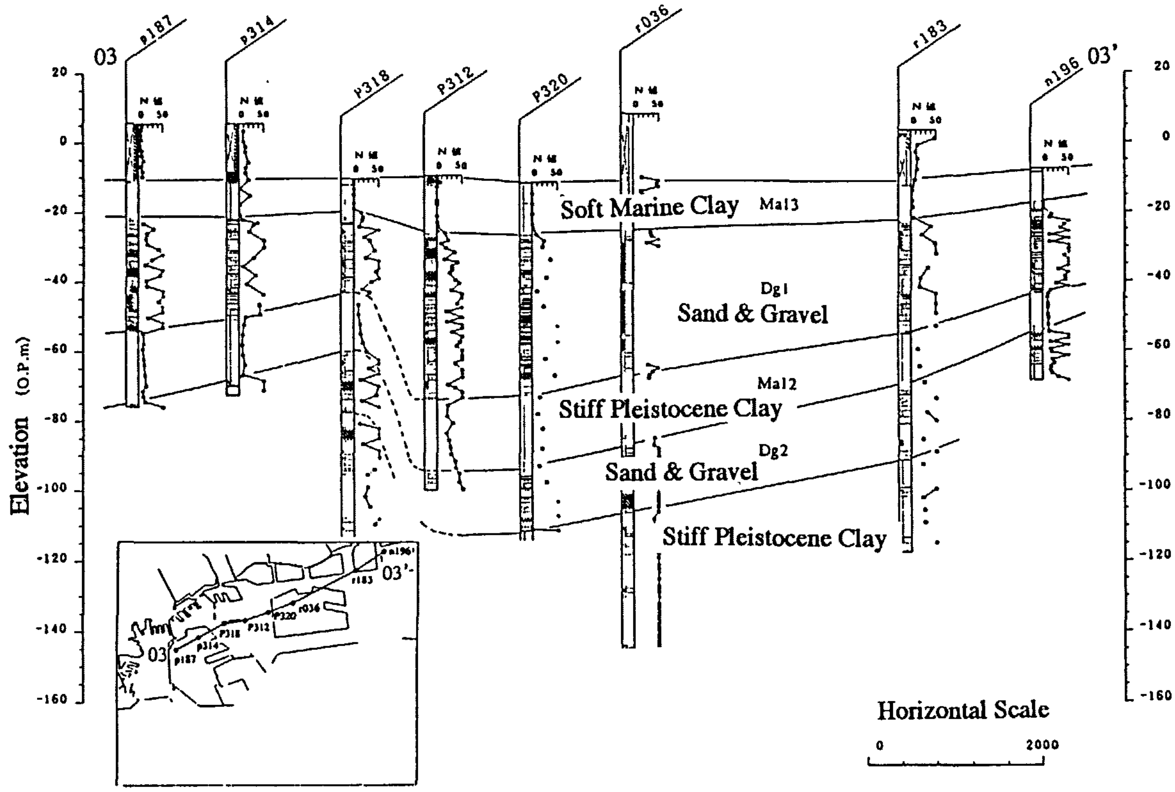


Figure 2 Geological Section of Seabed along Kobe Port

Figure 3 Damages of Seawall along South End of Rokko Island

Figure 4 Liquefaction of Container Yard at West of Port Island

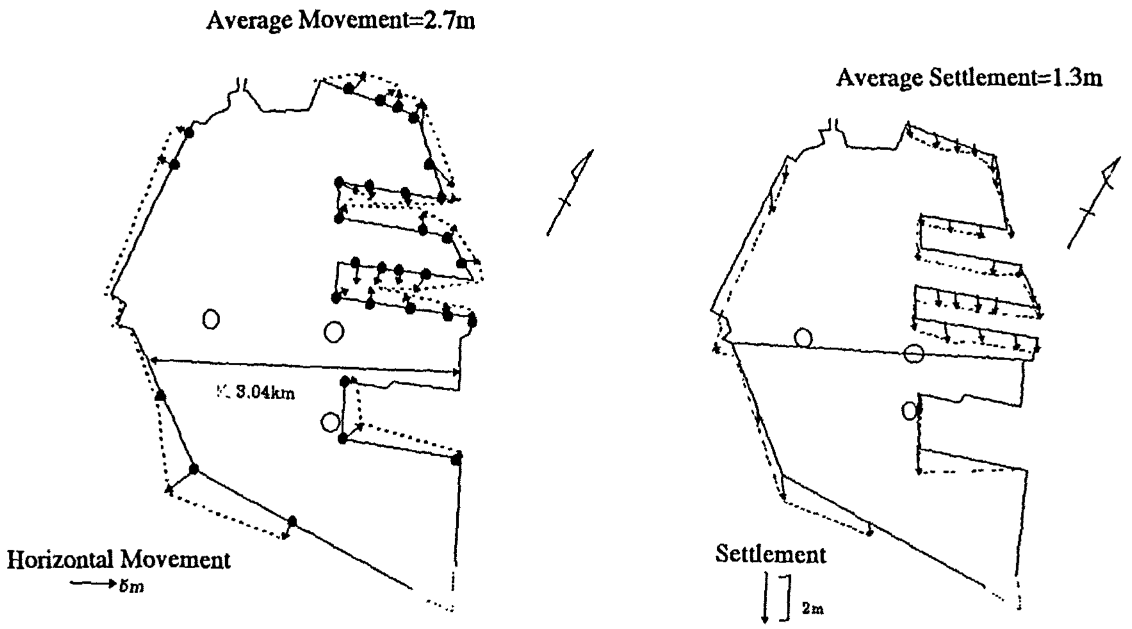


Figure 5 Settlement and Horizontal Movements of Shore-line of Port Island

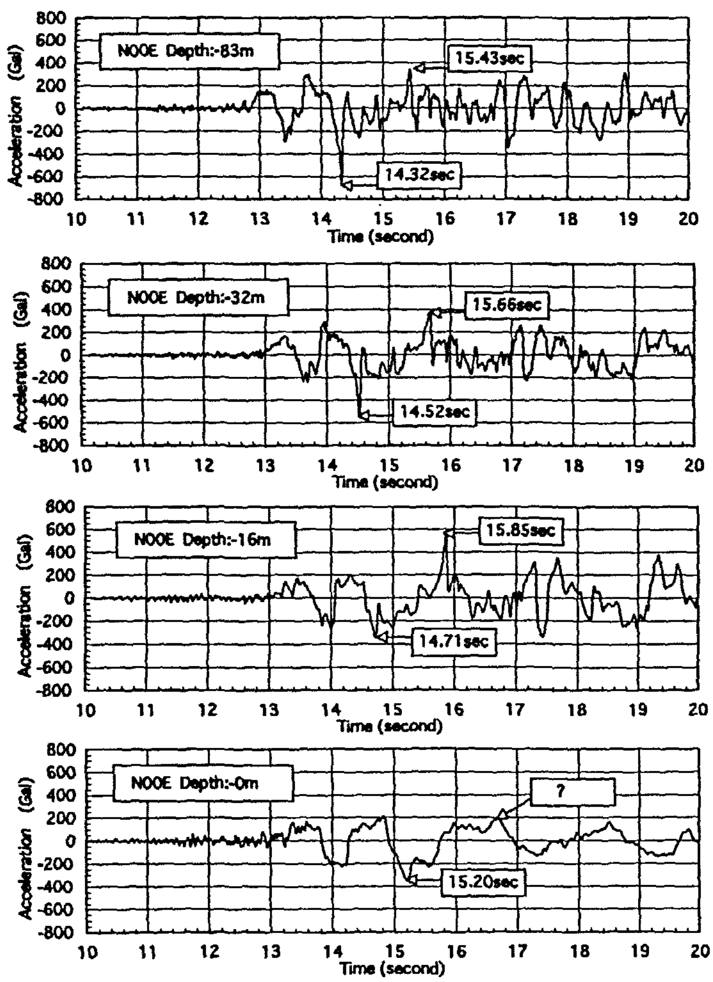


Figure 6 Seismic Records at Different Depths at Port-Island

(by Yasuo Tanaka)

Mountain Slope Failures Caused by the Great Hanshin Earthquake

1. Introduction

In order to get the distribution of mountain slope failures caused by the Great Hanshin Earthquake, failure distribution figure was made by using aerial photographs. The scales of the aerial photographs are 1 to 8,000 and 1 to 4,000 which were taken on January 20, 1995. Topography maps of scale 1 to 10,000 were used as base maps.

2. Characteristics of mountain slope failures

Figure 1 shows a part of the failure distribution figure which was reduced to a scale of 1 to 10,000. The area of this map is Gosuke and Momiji valley situated at the upper region of the Sumiyoshi river. It can be seen from this figure that the characteristics of mountain slope failures

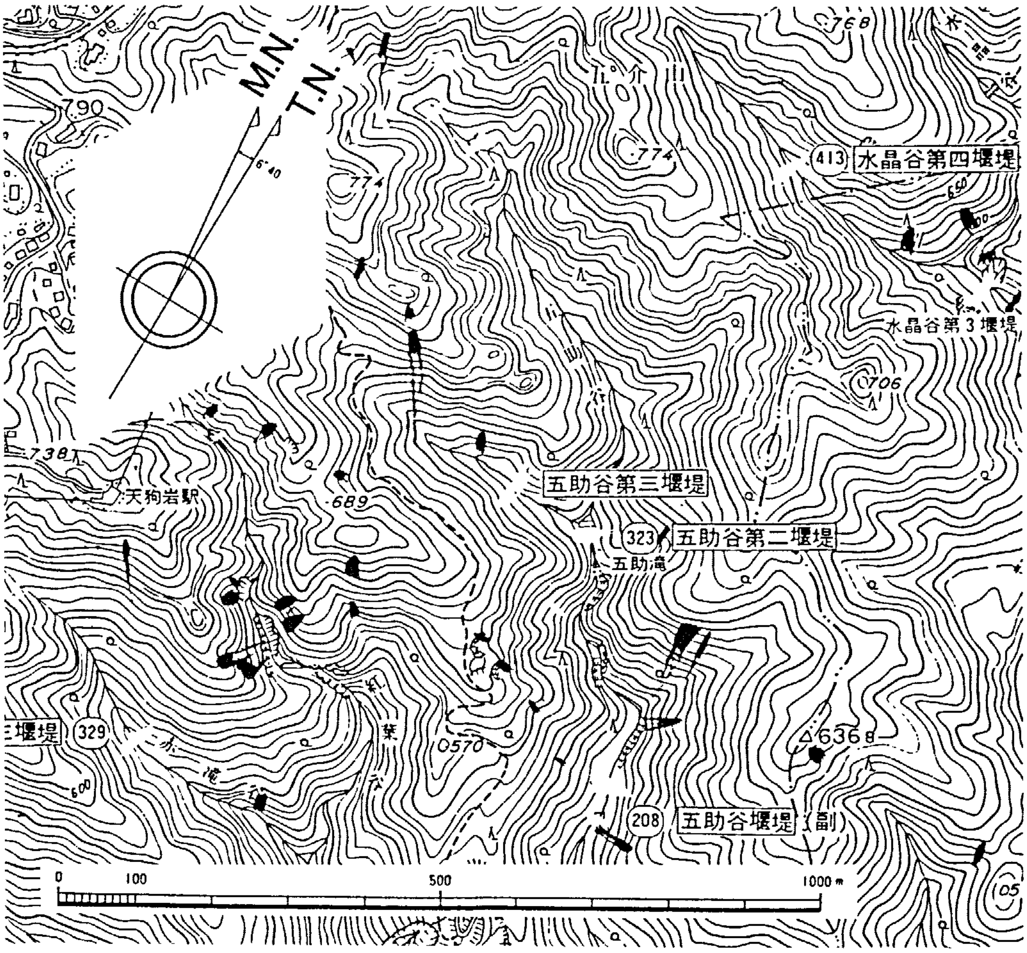


Figure 1 Part of the failure distribution

obtained from the distribution map are: 1) as a whole, there are many cases of small area failures, 2) the failures are mainly on very steep slopes, 3) flowed and eroded areas are very small, 4) the failures appeared on planar and/or crest slopes, 5) failures often appear at knick points downwards from gentle to steep gradient, 6) some failures appeared at outcrop, 7) unstable rock mass failed and rolled along the slopes. (Refer to Photographs 13.1 and 13.2 on the Japanese language report) and 8) big cracks developed along the mountain slopes which have not yet failed. (Refer to Photograph 13.3 on the Japanese language report).

3. Distribution of mountain slope failures

Figure 2 shows the distribution of mountain slope failures at the eastern part of Rokko mountains. It seems that as a whole, these failures are distributed along two belts. In this figure, the big faults named as Suwayama, Gosukebashi and Ashiya faults are shown. These failures occurred parallel to these faults. The reasons for these mountain slope failures distribution are thought to be: 1) shear movement of these faults by big earthquake, 2) these failures appeared from steep slopes which are usually seen along faults even if there are no shear movements, and 3) both 1) and 2). In future, the causes of failure distribution will be studied by using equi-acceleration maps.

4. Aspect of mountain slope failures

Figure 3 shows the aspect of mountain slope failures caused by the earthquake. The failures occurred along the orientation from NW to SE direction. Many faults developed in Rokko mountains perpendicular to this direction as seen in Figure 2. In order to get the aspect distribution of Rokko mountains, we used the digital map whose mesh spacing is 231 by 286 m. The results are shown in Figure 4. From this figure, it can be seen that there are more slopes that formed with the crest along the NE to SW direction compared to the opposite orientation. The ratio of the mountain slope failures to their orientation is obtained by dividing the number of failures (Figure 3) to the number of slopes (Figure 4) respective to the orientation. The results are shown in Figure 5. There are many failures along the orientation from the NW to SE direction. In addition, some failures appeared along both the NE to SW and SW to NE orientations. It may be implied that the failures along the former orientation appeared on the terminal facets and the failures along the later orientations appeared on the side walls of the small valley which developed perpendicular to the direction of the main faults.

5. Conclusion

The characteristics of the mountain slope failures are similar to those reported elsewhere. For example, the failures appeared on steep slopes, on the ridges especially steep ridges, at the knick points downwards from gentle to steep gradient, at the outcrops, and failures caused by the rolling down of unstable rock mass. The scales of these failures are small. The distribution and orientation of the mountain slope failures have a close relationship to the developed faults in Rokko mountains.

Fig.2 Distribution of the mountain slope failure at Eastern Rokko area

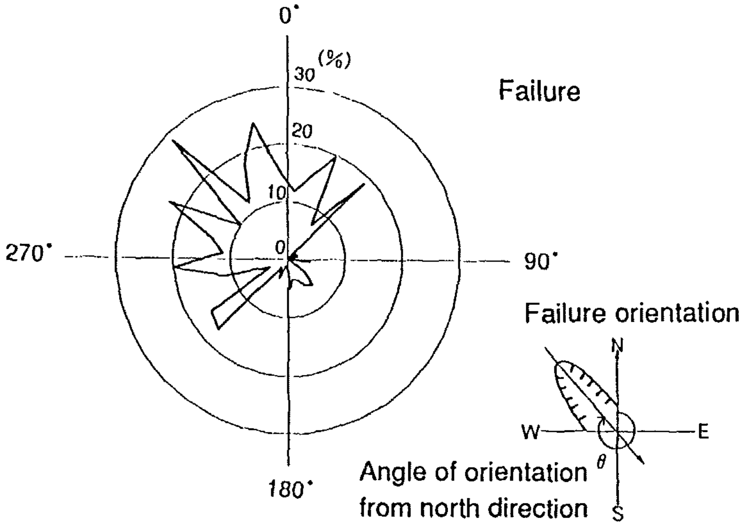


Fig.3 Orientation of the failure

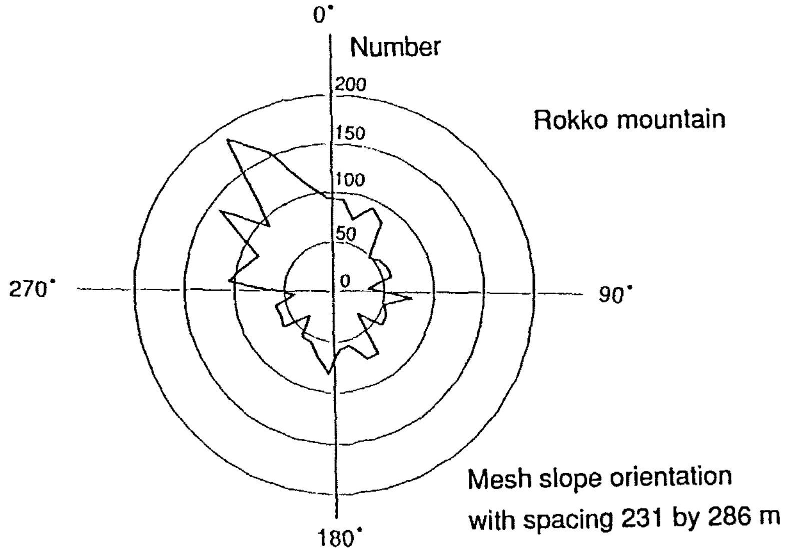


Fig. 4 Orientation of the Rokko mountain slopes

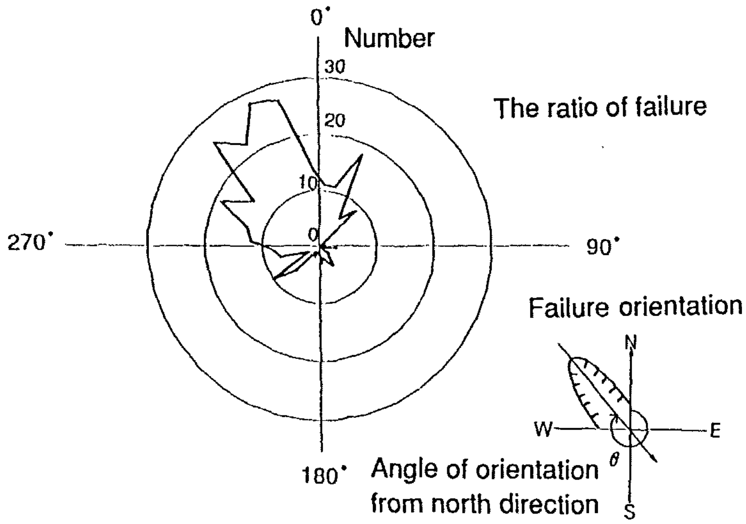


Fig. 5 The ratio of the mountain slope failures respective to the orientation

(by Takashi Okimura and Teng Hye Koid)

DAMAGE TO BRIDGES ON HIGHWAYS AND RAILROADS CAUSED BY THE GREAT HANSHIN EARTHQUAKE OF JANUARY 17, 1995

ABSTRACT

This report is made on basis of a site survey on almost all bridge structures located in the quake-affected area. By the inspection of damaged or collapsed bridges is clear that **a large number were designed long time ago.** Another important factor to be considered is that **almost all of collapsed structures had not been retrofitted** to increase their resistant capacity against large earthquakes. Finally, **this earthquake showed more than ever, the effect of vertical acceleration** on the failure mechanism of collapsed structures.

1. INTRODUCTION

For stricken areas on which earthquake damage have been arosen, traffic roads network which are usually linked by bridge structures are required as passage for refugee and emergency transport of relief goods, restoration works, etc. Is just on the aftermath of an earthquake when the roads (Highways and Railways) can be properly defined as "lifelines". However, immediately after the "**Great Hanshin Earthquake of Jan. 17,1995**" , the road networks were badly damaged so they have fallen into the situation of not fulfill their function anymore. It is needless to say that it was one of the factors that make damage scale immensurable. Investigation of the causes should be made methodologically and exhaustively in order to cope with the reparation and retrofitting works on a large number of existing bridges of the affected highway and railroad systems .

As result of our site survey on major spots, a description of damaged bridges is presented in the following in order to grasp the damage situation and phenomena. Fig. 2.1 shows the spatial distribution of major damages to bridges on Highways and Railways.

The traffic on the Hanshin Expressway was totally interrupted in Kobe Area and will remain paralized for at least one year and a half which is the estimated time for complete the full reparation works. By the way, all train services in the ravaged area were interrupted and gradually reopened according the advance on repairing of damaged structures, reparing works range from two to six months. **The lessons from this earthquake prompt a necessary revision of the current standards for bridges design.** By this way, available **guidelines for bridge retrofitting should be up-graded and put on practice in the nationwide.**

2. DAMAGE TO BRIDGES ON HIGHWAYS

2.1 PRINCIPAL DAMAGES TO BRIDGES ON THE HANSHIN EXPRESSWAY

On the Hanshin Expressway - Kobe line, 47 collapsed bridge piers have been accounted, 82 piers were severely damaged, 471 piers were partially damaged. A summary of the major damaged spots is presented in the following.

1. Neighborhood of Nishinomiya City, Imazu-Kusugawa Town :

Pier N. Shin 166-167

- Brige type : Super-structure : Simple steel plate girder.
  Sub-structure : T -Type RC bents composed by piers of circular section.
  Foundation : RC basement.
- damage situation : The bridge fall at both, east and westbounds by the collapse of the piers.
- Picture 2.1.1

2. Neighborhood of Nishinomiya City, Kurakake Town :

Pier N. Shin 39-40

- Bridge Type : Super-structure : Simple steel box girder.
  Sub-structure : T-Type RC bents composed by piers of circular cross section.
  Foundation : RC basement.
- Damage situation : The bridge fall at the eastbound due to the failure of bearing supports.
- Picture 2.1.2

3. Neighborhood of Nishinomiya City, Koroen (Nishinomiya exit bound) :

Pier N. Shin 51,52 and 53

- Bridge type : Super-structure : Unknown
  Sub-structure : Steel box frame + T-Type RC bents with piers of circular section.
- Damage situation : Whole buckling of steel columns.
- Picture 2.1.3

4. Neighborhood of Nishinomiya City, Kawanishi Town :

Pier N. Shin 67

- Bridge type : Super-structure : Simple steel box girder.
  Sub-structure :T-type RC bents composed by piers of rectangular cross section.
  Foundation : RC basement .
- Damage situation : Collapse of piers and displacement of girder at bearing supports.

5. Neighborhood of Ashiya City, Uchide-Town

- Bridge type : Super-structure : Simple steel box girder.
  Sub-structure : Steel frame composed by steel box-cross sectional columns.
  Foundation : RC basement.
- Damage situation : buckling at the base of the piers.

6. Neighborhood of Ashiya City : Uchide Town / Ashiya Eastbound entrance lamp-way.

- Bridge type : Super-structure : Two-spans continuous steel girder.
  Sub-structure : Bents composed by RC piers of circular cross section.
  Foundation : RC basement.
- Damage situation : Breaking of restraining devices at bearing supports due to the heavy damage at the base of the attached piers.

7. Kobe City, Higashi-Nada Ward, Fukae Honmachi

- Bridge type : Super-structure : Three spans continuous steel box girder.
  Sub-structure : RC Bents composed by piers of circular cross section.
  Foundation : RC basement.
- Damage situation : Buckling of main girder by settlementof support caused by a diagonal breakage along the pier.
- Picture 2.1.4

8. Neighborhood of Kobe City, Higashi-Nada Ward, Uozaki Honmachi

- Bridge type : Super-structure : Piltz bridge
  Sub-structure : Bents composed by RC piers of circular cross section.
  Foundation : RC basement.
- Damage situation : Bridge collapse by breakage of welded joints of main reinforcing bars
- Pictures 2.1.5 and 2.1.8

9. Kobe city, Higashi-Nada Ward, Mikage Honmachi / Hamanaka crossing

- Bridge type : Super-structure : Three continuous spans steel box girder.
  Sub-structure : T-type RC bents composed by columns of circular cross section.
  Foundation : RC basement.
- Damage situation : - Buckling of the main girder by settlement of support.
  - Diagonal breakage in the central part of the pier (Tractional failure mode).

10. Kobe City Higasi-Nada Ward, Mikage Tsuka Town / Tomei crossing

- Bridge type : Super-structure : Continuous steel box girder.
  Sub-structure : T-type RC bents composed by piers of rectangular cross section.
  Foundation : RC basement.
- Damage situation : - Buckling of the main girder by settlement of supports.
  - Diagonal cracks in the central part of the pier (Tractional failure mode).
- Picture 2.1.7

11. Kobe City, Chuo Ward, Wakihama Town

Pier N. shin 352-353

- Bridge type : Super-structure : Simple steel plate girder bridge.
  Sub-structure : ∏ type bents composed by columns of rectangular cross section.
  Foundation : RC basement.
- Damage situation : Buckling of pier accompanied with collapse of contiguous building.
- Picture 2.1.8

12. Kobe City, Chuo Ward, Isogami Street / Ikutagawa entrance and exit lamp ways

- Bridge type : Super-structure : Simple steel plate girder.
  Sub-structure : Steel box frame with columns of circular cross section.
- Damage situation : Lateral displacement of the girder outside off its ends.
- Picture 2.1.9

13. Kobe City, Chuo Ward, Kaigan Street / To the north of the Meriken Park

Pier N. Shin 455

- Bridge type : Super-structure : Two- span curved continuous steel girders.
  Sub-structure : Steel columns.
  Foundation : RC basement.
- Damage situation : Girder crush atop the pier . Bearing pressure.
- Picture 2.1.10

14. Kobe City, Chuo Ward, Benten-cho / South of JR Kobe station

Pier N. Shin 475-478

- Bridge type : Super-structure : Continuous steel curved girder.
  Sub-structure : Single RC piers.
- Damage situation : Breakage of pier and girder collapse by collapse of bearing supports.

15. Kobe City, Hyogo Ward, Ashihara-dori

Pier N. Shin Upper- down 580-588

- Bridge type : Super-structure : Three spans continuous steel box girder.
  Sub-structure : T-type steel bents composed by columns of circular cross section.
- Damage situation : Tumbled columns at the north side of the bridge

16. Kobe City, Nagata Ku, Sugawara-dori

Pier N. Shin 588-591

- Bridge type : Super-structure : Three spans continuous steel girder.
  Sub-structure : Steel frame.
- Damage situation : Buckling and settlement of the intermediate bearing support.

17. Kobe City, Nishi-Ikejiri-cho / Minatogawa entrance and exit ways

Pier N. Shin 606-611

- Bridge type : Super-structure : Simple steel girder.
  Sub-structure : T-type steel bents and T-type RC bents, in both cases with piers of circular cross section, finally, steel frames.
- Damage situation : Bridge fall and decoupling of girders of adjacent spans, breakage of restrainer devices at bearing supports at both west-bound and east bounds due to the shear failure at the middle part of the piers.
- Picture 2.1.11

18. Kobe City, Suma Ku, Ikuhira-cho / At JR line Overcrossing

Pier N. Shin 687-670

- Bridge type : Super-structure : Three span continuous curved steel box girder.
  Sub-structure : T-type RC bents with piers of eliptical cross section.
  Foundation : RC basement.
- Damage situation : Total collapse of the pier N. Shin 688. Buckling of main girder and shear failure at the bearing supports.

- Picture 2.1.12

19. Damage to bridges on Hanshin Expressway Route 5 - Wangan line

1. Nishinomiya-ko-bridge (Koshien shore-Nishinomiya shore) bridge approach

. Nishinomiya-ko Ohashi bridge:

- Bridge type : Steel basket handled type Nielsen-Rose.girder.
- Damage situation : Fall of girder accompanied by severe shear failure at bearing support.

. Bridge approach:

Super-structure: Three main steel box girders.
Sub-structure : Steel frame.

- Picture 2.1.13

2. Nishinomiya-ko Ohashi bridge (Nishinomiya City, Koshien shore)

- Bridge type : Super-structure : Steel basket handled type Nielsen-Rose girder.
  Sub-structure : Steel frame.
  Foundation : On Neumatic caissons.
- Damage situation : Moderate shear failure at piers and supports.
- Picture 2.1.14

3. Higashi-Kobe bridge (Kobe City, Higashi-Nada ku)

- Bridge type : Steel cable stayed bridge on neumatic caissons.
- Damage situation : Separation between the bridge approach and the superstructure.

2.2 PRINCIPAL DAMAGES TO BRIDGES ALONG THE MEISHIN EXPRESSWAY

Severe damages did occur along the Meishin Expressway such as those in the Nishinomiya, Amagazaki and Toyonaka cities. In the following, an overview of the damage situation is presented.

1. Bridge-Overhead in the neighbourhood of Imazu - Akebono-cho and Nishinomiya City (Neighbourhood of the fly-over crossing of HanshinRailway main line)

- Bridge type : Four spans RC continuous frame bridge.
- Damage situation : Relative movement of the girder atop the pier (20 cm. approx.)

2. Nishinomiya City, Tsumon-IIda-cho: Fly-over bridge on Route 2

- Bridge type
  Super-structure : Three continuous spans, steel girder.
  Sub-structure : RC framed bents
  Foundation : RC basement
- Damage situation : Shear-compressive failure of intermediate suppotrt at north side and buckling of main girder.
- Picture 2.2.1

3. Bridge Overhead at Yamate-Kansen crossing (In the neighbourhood of Nishinomiya City, Takamatsu-cho, Kawaragi-nishi)

- Bridge type :
  Super-structure : Three-continuous RC span structure, skewed 50 degrees approx.
  Sub-structure : RC piers of wall type at the ends, RC rocker columns as intermediate supports.
  Foundation : Hollow basement foundation.
- Damage situation :
  - Slide an fall of girder on the eastbound at free support.
  - Buckling of RC piers at the fixed support.
  - Tilting of rocker columns.

4. Mukogawa bridge - At the border between Nishinomiya City and Amagazaki City

- Bridge type
  Super-structure : Three-continuous spans, composite steel plate girder with three bearing supports atop each pier.
  Sub-structure : RC Oval type piers
- Damage situation : Breakage of bridge fall protection equipment.
  Fall of bearing supports toward the northside bridge bed.
  Concrete cracking and exposed reinforcement at piers.
- Pictures 2.2.2 and 2.2.3

5. Several places in the Neighbourhood of Amagazaki City, Minami Mukonoso.

- Bridge type : Super-structure : Five RC continuous spans structure.
  Sub-structure : RC wall type piers
  Foundation : RC basement
- Damage situation : Collapse and buckling of RC piers and settlement of superstructure.

6. Several places in the neighbourhood of Amagazaki City, Suido-cho

- Bridge type : Super-structure : Five RC continuous spans structure.
  Sub-structure : RC wall type piers
  Foundation : RC basement
- Damage situation : Collapse and buckling of RC piers and settlement of superstructure.
- Pictures 2.2.4 and 2.2.5

7. Several places in the neighbourhood of Amagazaki City, Tachibana-cho

- Bridge type : Super-structure : Five RC continuous spans structure.
  Sub-structure : RC wall type piers
  Foundation : RC basement.
- Damage situation : Collapse and buckling of RC piers and settlement of superstructure.
- Picture 2.2.6

8. Several places in the Neighbourhood of Amagazaki City, Onishi-cho

- Bridge type : Super-structure : Five RC continuous spans structure
  Sub-structure : RC wall type piers
  Foundation : RC basement
- Damage situation : Collapse and buckling of RC piers and settlement of superstructure.

9. Several places in the neighbourhood of Amagazaki City, Wakaoji

- Bridge type : Super-structure : RC continuous spans structure
  Sub-structure : Bents composed by multiple RC rectangular columns at the ends, and single RC rectangular piers as intermediate supports.
  Foundation : RC basement
- Damage situation :
  - Collapse of stoppers at the roll-bearing supports.
  - Collapse and buckling of RC piers and settlement of superstructure.
- Pictures 2.2.7 and 2.2.8

10. Neighbourhood of Toyonaka Gateway

Collapse of toll booth.

2.3 PRINCIPAL DAMAGES TO BRIDGES ON THE CHUGOKU HIGHWAY

On Chugoku Highway, damages were extended over a wide range as in Takarazuka City, Itami City, Kawanishi City, Ikeda City and Toyonaka City.

1. Takarazuka City, Kiyoshikojin (Kojingawa pier)

- Bridge type : Super-structure : Four spans continuous composite plate girder
  Sub-structure : RC wall type piers
  Foundation : RC basement.
- Damage situation : Separation of the superstructure from its bearing supports.

2. Neighbourhood of the west side at Takarazuka gateway.

- Bridge type : Super-structure : RC continuous structure.
  Sub-structure : RC wall type piers
  Foundation : RC basement
- Damage situation : Buckling and tilting of piers.

3. Several places in the neighbourhood of Itami city, Aramaki and Ogino

- Bridge type : Super-structure : RC continuous structure.
  Sub-structure : RC bents composed by multiple columns of rectangular cross section.
  Foundation : RC basement.
- Damage situation : Shear (diagonal) cracks and spalling of cover concrete at piers.

- Pictures 2.3.1 - 2.3.3

4. Neighbourhood of Toyonaka City, Shibahara-cho

- Bridge type : Super-structure : Three spans simple steel composite girder
  Sub-structure : single RC piers
  Foundation : RC basement
- Damage situation : Cracking and partial spalling of cover concrete at piers.

2.4 DAMAGES TO THE KOBE HAMATE BY-PASS ON ROUTE 2 - KOBE LINE

1. Kobe City, Chuo-Ward, Hamabe-dori

Piers N. Hamate 1-3

- Bridge type : Super-structure : Simple steel plate girder.
  Sub-structure : Single RC piers of circular cross section.
  Foundation : RC basement.
- Damage situation : The girder crushed at one of its ends due to the breakage of a bearing support.

- Picture 2.4.1

2. Kobe City, Chuo-Ward, Hamabe-dori

Piers N. Hamate 7-9

- Bridge type :
  Super-structure : Two-lanes, Simple steel plate girder
  Sub-structure : Single RC piers of rectangular cross section and also bents composed by multiple columns
  Foundation : RC basement.
- Damage situation : Relative displacement of the girder at some of its bearing supports
- Picture 2.4.2

3. Kobe-City, Chuo-Ward, Kanohana-dori

Piers N. Hamate 2-3 Umi

- Bridge type :
  Super-structure : Continuous steel box girder
  Sub-structure : bents composed by multiple RC circular columns.
  Foundation : RC basement.
- Damage situation : Buckling at the bottom of piers.
- Picture 2.4.3

4. Neighbourhood of Kobe City, Chuo-Ward, Shinko-cho

Piers N. Hamate 36-41

- Bridge type :
  Super-structure : Three spans continuous steel box girder.
  Sub-structure : Two level contiguous bents composed by multiple rectangular columns.
  Foundation : Steel basement.
- Damage situation :
  - Buckling at the bottom of piers at several places.
  - Relative displacement between girder and piers at several places.
- Picture 2.4.4

5. Kobe City, Chuo Hatoba-machi, Shinko-cho

Piers N. 48-49

- Bridge type :
  Super-structure : Three continuous span steel box girder + Three continuos span plate girder.
  Sub-structure : Two level contiguous bents composed by multiple RC rectangular columns + Two contiguous bents composed by single RC , circular piers.
  Foundation : RC basement.
- Damage situation :
  - Buckling at the bottom of piers , besides that, exposed reinforcement and spalling of cover concrete at several piers.
  - Relative displacement of bearing supports that caused partial crushing atop some piers.

2.5 PRINCIPAL DAMAGES ON NATIONAL ROUTES

1. Route 171

- Damage situation : Fall of the Overhead bridge at the south-side of Mondo-Yakujin Station on Hankyu Line and other places.

2. Tennoji-gawa Overhead bridge on Route 176 (West-bound) in Itami City - Aramaki.

- Bridge type : Super-structure : 10 continuous spans structure
  Sub-structure : T -type Rectangular piers
  Foundation : RC basement.
- Damage situation : Shear cracks at piers and buckling.
- Picture 2.5.1

3. Kohama Pedestrian Overpass on Route 176 (Takarazuka City Kozuki-cho, Kohama 4-chome)

- Bridge type : Super-structure : Three continuous span + Two simple supported span non-composite plate girders.
  Sub-structure : T-type rectangular piers and steel piles.
- Damage situation : - 10-20 cm of relative displacement between the two-simple supported span bridge and all its bearing supports.
  - About 20 cm of Settlement at fill (two places).

4. Teshi-gawa Bridge on Route 176 (Takarazuka City - Yamamoto)

- Bridge type : Super-structure : RC hollow slab.
  Sub-structure : Abutments at bridge's approach and ovaled RC piers
  Foundation : RC basement.
- Damage situation : Relative displacement of the girder respect to its supports.

5. Juso Ohashi Bridge (On Route 176)

- Damage situation : shear cracks at piers

6. Aioi Bridge on Route 250 (Kakogawa City, Ogami-cho)

- Bridge type : Super-structure : 24 spans, gerber composite plate girder.
  Sub-structure : Ovaled RC piers
  Foundation : RC basement
- Damage situation : breakage of bearing supports atop two piers.

7. Iwaya Pedestrian Overpass on Route 43 (Kobe City, Nada-Ward, Miyako-dori)

- Bridge type : Super-structure : Simple supported PC girder + Simple supported steel box girder.

Sub-structure : Single rectangular steel piers + Single rectangular RC columns.

- Damage situation : Steel piers crushed at one place while RC piers buckled at several places, it caused the fall of bridge girders at several places.
- Picture 7.5.2

2.6 PRINCIPAL DAMAGES ON PREFECTURAL ROADS

1. Meigetsu Overpass at Amagasaki-Ikeda Line (Amagasaki City , Nishi-Nagasu, Overhead Bridge on JR Tokaido Line)

- Bridge type : Super-structure : 12 spans-simple supported PC non-composite plate with T beams.
  Sub-structure : Inverted T-type abutments.
  Foundation : PC piles.
- Damage situation : Shear cracks at all piers.

2. Amatsu Overpass on Itami-Toyonaka Line (Itami City - Amatsu, Overhead bridge on JR Fukuchiyama Line

- Bridge type : Super-structure : 11 spans-simple supported non-composite plate girder with T beams.
  Sub-structure : Inverted T-type abutments.
  Foundation : Cast-in-place piles.
- Damage situation : Shear cracks and spalling of cover concrete all piers and exposure of main steel reinforcement on several piers.
- Picture 2.6.1

3. Kuwazu Bridge on Itami-Toyonaka Line (Itami City, Higashi-Kuwazu, Inagawa)

- Bridge type : Super-structure : Nine-spans RC gerber T-type girder.
  Sub-structure : Wall type RC piers.
  Foundation : Cast-in-place piles.
- Damage situation : Shear cracks in all piers, also, main reinforcement exposed in several piers.

4. Kukuchi Overpass on Takada-Kukuchi Line (Amagasaki City - Kukuchi , Overhead bridge on JR Fukuchiyama line.

- Bridge type : Super-structure : 14 spans, Post-tensed PC-T girder.
  Sub-structure : Framed type bents
  Foundation : Cast-in-place piles.
- Damage situation : Six piers were severe cracked

5. Shin-Myojin Bridge on Fukura-Ei-Iwaya line (Ichinomiya-cho, Myojin Yamada river.

- Bridge type : Super-structure : Single spans plate girder + steel slab.
  Sub-structure : Inverted T-type abutments.

Foundation : Precast piles.
- Damage situation : brekage of restrainer devices at bearing supports.

6. **Shin-Murotsu bridge on Fukura-Ei-Iwaya line (Hokudan-cho Murotsu, Murotsu river)**

- Bridge type : Super-structure : Two-spans simple supported RC structure.
  Sub-structure : Gravity-type abutments.
  Foundation : Spread foundation.
- Damage situation : Several cracks on the Girder's surface.

7. **Hamade bridge on Fukura-Ei-Iwaya line (Ichinomiya-cho Momogawa, Hamade river**

- Bridge type : Super-structure : RC Single span simple supported RC structure, RC T-type beams.
  Sub-structure : Gravity-type abutment.
  Foundation : Spread foundation.
- Damage situation : Cracks on several parts of the girder.

8. **Nojima Bridge on Fukura-Ei-Iwaya Line (Kita-Hokudan-cho Nojima, Nojima river**

- Bridge type : Super-structure : Two-spans simple supported RC structure.
  Sub-structure : Ovaled piers at intermediate supports and gravity-type abutments.
  Foundation : Spread foundation.
- Damage situation : Several cracks on girder's surface

9. **Nishinomiya Ohashi Bridge at Nishinomiya Shore**

- Bridge type : Super-structure : Six-spans continuous steel box girder + RC slab.
  Sub-structure : RC piers of square cross section.
- Damage situation : Several cracks on piers.

- Pictures 2.6.2 and 2.6.3

2.7 PRINCIPAL DAMAGES TO BRIDGES ON CITY ROADS,ETC.

1. **Kobe Harbour Highway (Daini-Maya Ohashi Bridge)**

Piers N. 68 - 71
- Bridge type : Super-structure : Three spans-continuous steel box girder.
  Sub-structure : Composed by single tall circular RC piers.
  Foundation : RC basement.
- Damage situation : Extensive cracking and tilting at the center span's pier (west-side). Also, relative displacement at supports located at ends of the girder.
- Picture 2.7.1

2. **Kobe Harbour Highway**

Piers N. 74-75

- Bridge type : Super-structure : Two-spans + Three spans Continuous steel box girder.
  Sub-structure : Pier N. 74 (Rectangular single RC pier)
  Pier N.75 (Two-column framed steel bent)
- Damage situation : Extensive cracking and chunks at the lower part of the RC pier.
  Cracks and buckling at bent's upper corners on the south-side of the bridge.
  Failure and collapse of bearing supports, it caused a relative displacement at one end of the girder.

- Pictures 2.7.2 and 2.7.3

3. Kobe Harbour Highway

Piers N.83-87

- Bridge type : Super-structure : Two-level simple supported steel plate girder.
  Sub-structure : RC rectangular single piers.
- Damage situation : Collapse of a single pier.

4. Kobe Harbour Highway (Nishinada Ohashi Bridge)

- Bridge type : Super-structure : Three continuous span RC framed structure.
  Sub-structure : Steel bents of V -type
- Damage situation : Collapse of one bearing support, it caused a relative displacement of the concurrent spans.Besides that, extensive cracking on piers at both middle and lower parts, also breakage of bearing supports' anchor devices.

5. Kobe Ohashi Bridge

- Bridge type : Super-structure : Balanced arch.
  Foundation : Concrete caisson.
- Damage situation : Lateral displacement and settlement at one end of the bridge.

3. DAMAGE TO BRIDGES ON RAILROADS

Railroad networks are the lifelines which constitute the basis of the mass-transportation and have a great influence in the economic activities such as the case of the Hanshin area. Railroads and roads constitute together the main ways of transportation for people as well as for goods, so they play a vital role in any kind of activity and progress in any comunity. Railroads as well as roads were seriously damaged by the effects of the Great Hanshin Earthquake of Jan.17,1995 (See Fig. 3.1). As result of that, the economical activity was completely paralized in the quake aftermath, remarkable damages occurred at some overhead bridges on routes of the bullet-train (shinkansen), such bridge structures were seismically designed by taking into account the effects of Great Kanto Earthquake that ravaged the Kanto area in 1923. So, the collapse of several overhead bridges during the Great Hanshin Earthquake put the Japanese current standards for bridge design in the imperious necessity to be re-examined.

In the following, a description of our site survey's results is presented. It pretends to grasp the damage situation on principal damaged spots.
At first, the damage situation according to the Ministry of Transports' Railroad Bureau is presented (See 3.1), after that, the damage situation according our survey will be presented(See 3.2 to 3.7).

1. OUTLINE OF DAMAGES TO BRIDGES ON RAILWAYS (By Ministry of Transportation)

1. JR TOKAIDO SHINKANSEN (BULLET TRAIN)

- **Kyoto - Shin-Osaka :**
  Collapse of an Overhead caused by the severe damage to seven piers.
- **Shin-Osaka station :**
  Relative displacement of a girder on an overhead bridge respect to its bearing supports.

2. JR SANYO SHINKANSEN

- **Shin-Osaka - Shin-Kobe :**
  - Fall of an overhead bridge at nine places.
  - Shear failure of 13 bridge piers.
  - Lateral displacement of the girder at 6 places.
  - The Rokko sub-station collapsed.
- **Shin-Kobe station :**
  - Lateral displacement of a plataform at one place.
- **Shin-Kobe - Nishi-Akashi :**
  - Fall of an overhead bridge at one place.
  - Relative displacement of girders at 5 places.
- **Nishi-Akashi - Himeji :**
  - Fall of girder at one place.
  - Collapse of 36 overhead piers.
  - relative movement of the girder at 8 places.
- **Tunnel part :** - Partial collapse at Rokko, Kobe, Suma and Takatsukayama.

3. JR TOKAIDO LINE

- **Ashiya station :**
  - Sinkage of station building on a bridge.
  - Collapse of steel platform.
- **Sannomiya-Kobe :**
  - Partial collapse of an overhead bridge.

4. JR SANYO LINE

- **Kobe - Hyogo :** - Partial collapse of an overhead bridge.
- **Hyogo - Takatori :** - Tilting of a retention wall.
- **Shin-Nagata station :** - Partial collapse of the station building on the south-side.
- **Suma station :** - Rotation of a girder.
- **Akashi - Nishi-Akashi :**
  - Relative movement of the Akashi-gawa bridge.

5. JR FUKUCHIYAMA LINE

- **Nakayamadera station :**
  - Collapse of a steel platform.

6. HANKYU KOBE LINE

- **Nishinomiya Kitaguchi - Shukugawa :**
  - Fall of an overhead bridge in a length of 200 m. approx.
- **Shukugawa station :** - Collapse of a steel platform.
- **Shukugawa - Ashiyagawa :**
  - Destruction of rail-tracks caused by the collapse of a building.
- **Sannomiya station :** - Collapse of station building.

7. HANKYU ITAMI LINE

- **Itami station :** - Destruction of station building.

8. HANKYU IMAZU LINE

- **Nishinomiya Kitaguchi - Mondo-Yakujin :**
  - Fall of an Overcrossing on Route 171.
- **Mondo-Yakujin - Kotoen :**
  - Out-side fall of a bridge supporting wall at a Shinkansen overhead.

9. HANKYU TAKARAZUKA LINE

- **Nakatsu - Juso :** - Collapse of an overcrossing.
- **Juso - Mikuni :** - Collapse of an overcrossing.

10. HANSHIN MAIN LINE

- **Ogi - Mikage :** - Bridge collapse in a length of 2 Km approx.
  - Fall of bridge girder at 8 places.

- **Nishi-Nada station and 9 stations more :**
  - Several types of failures on several bridge components.
- **Ogi - Uozaki :** - Collapse of protection wall in a length of 1.2 Km approx.
  - Collapse of fill in a length of 0.8 Km approx.

11. KOBE DENTETSU - ARIMA LINE

- **Minatogawa - Nagata :**
  - Collapse of face of slope in a length of 62 meters.
  - Collapse of retaining wall in a length of 106 meters.
  - Several cracks in the Higashiyama Tunnel.

- **Yama no Machi - Minodani :**
  - Settlement of the back-side of the bridge-bed.

- **Minodani station :** - Settlement of a line platform.
- **Arima-guchi - Arima-Onsen :**
  - Collapse of face of slope.

12. KOBE DENTETSU - AWABU LINE

- **Kawaike Signal station - Kizu :**
  - Settlement at the back side of the bridge bed.
- **Kizu - Kihata :** - ditto.

13. KOBE DENTETSU - SANDA LINE

- **Shintetsu-Dojyo - Yokoyaka :**
  - Settlement at the back side of the bridge bed.
- **Yokoyama - Sanda-Honmachi :**
  - ditto.

14. KOBE MUNICIPAL SUBWAY - YAMATE LINE

- **Sannomiya - Shin-Kobe :**
  - Cracks along the tunnel.
- **Sannomiya Station - Kamisawa Station :**
  - Severe damage on 70 tunnel center columns.
- **Shin-Nagata - Kamisawa :**
  - Severe damage on 100 tunnel center columns.

15. KOBE KOSOKU TETSUDO TOZAI LINE

- **Sannomiya - Hanakuma :**
  - Fall of several girders due to relative displacement of them.
- **Daikai Station :**
  - Severe damage along 120 m of railway.
- **Daikai - Kosoku - Nagata :**
  - Severe damage at 230 tunnel center columns (530 m.)
  - Movement of retention wall along 334 meters.
- **Kosoku-Nagata station :**
  - Collapse of 7 tunnel center columns.

16. KOBE SHINKOTSU - ROKKO ISLAND LINE

- **Whole line :** - Several station structures and girders severely damaged.
- **Sannomiya - Nada Koen :**
  - Fall of girder.
- **Port-Terminal - Nada-Koen :**
  - Relative movement of girder.

17. KOBE SHINKOTSU - ROKKO ISLAND LINE

- **Whole line :** - Several station structures and girders severely damaged.
- **Sumiyoshi station :**
  - Fall of girder.

. **Island - Kitaguchi station :**
- Girder fall on the northern lanes.

18. SANYO DENTETSU - MAIN LINE

. **Itadayo Station and two other stations :**
- Severe damage of station building and rotation of platforms.

. **Sumaura-Koen station and other 8 stations :**
- Rotation of platform.

. **Nishi-Maiko - Okuradani :**
- Collapse of proteccion wall.

. **Sumadera - Suma:**
- Landslide.

19. OSAKA MUNICIPAL SUBWAY

. **Routes 1-7 :** - Rotation of tunnel and water leaks.

. **Nanko Port Town Line :**
- Rotation of columns and railroads tracks.

3.2 PRINCIPAL DAMAGES TO BRIDGES ON THE JR SHINKANSEN LINE

1. Neighbourhood of Itami-City, Noma

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed bents
  Foundation : RC piles.
- Damage situation : - Complete collapse on the whole 8 constituent bents.
  - Complete sinkage of girder in the north direction.
- Picture 3.2.1

2. Neighbourhood of Amagasaki City , Mukonosato interchange

- Bridge type Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed bents.
  Foundation : RC piles.
- Damage situation : - Bridge collapse on the whole 8 constituent bents.
  - Sinkage of girder to the north.
- Picture 3.2.2

3. Mukogawa bridge at the border between Nishinomiya and Amagasaki cities

- Bridge type : Super-structure : RC continuous girder.
  Sub-structure : RC continuous framed structure with piers of T- type and elliptical cross section.
  Foundation : RC piles.
- Damage situation : Concrete chunks and exposure of steel reinforcement mainly at piers.
- Pictures 3.2.3 and 3.2.4

4. Neighbourhood of Nishinomiya City, Shoraiso 3-chome

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed bents.
  Foundation : RC piles.
- Damage situation : - Collapse of hinges and bearing supports and severe damage on the whole 8 constituent bents.
  - Girder singake to the east.
- Pictures 3.2.5 and 3.2.6

5. Neighbourhood of Nishinomiya City, Shoraiso 1 chome

- Bridge type : Super-structure : RC simple girder.
  Sub-structure : RC continuous framed bents.
  Foundation : RC piles.
- Damage situation : Girder fall by collapse of two bents at the east side.

6. Nishinomiya City, Matsuraiso : Overcrossing on Hankyu Imazu Line

- Bridge type : Super-structure : RC simple girder.
  Sub-structure : RC continuous framed bents.
  Foundation : RC piles.
- Damage situation : Girder fall by collapse of two bents on the east side.
- Picture 3.2.7

7. Nishinomiya City - Kotoen, Neighbourhood of Rokko Tunnel

- Bridge type : Super-structure : RC simple girder.
  Sub-structure : RC continuous framed bents
  Foundation : RC piles.
- Damage situation : Girder fall by collapse of two bents on the east side.
- Pictures 3.2.8 and 3.2.9

8. Kobe City, Nishi-Ku, Ikawadani-cho, Minami-beppu: Ikawa bridge

- Bridge type : Super-structure : RC slab.
  Sub-structure : RC framed bents, in some cases composed by columns of rectangular cross section and in others composed by circular columns.
  Foundation : RC piles.
- Damage situation : Girder fall on both up and down lines caused by the collapse of a bridge bent.
- Picture 3.2.10

9. Kobe City, Nishi-Ku, Iwadani-cho, Jyunwa - Tamatsu-cho, Shinkata

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed bents.
  Foundation : RC piles.
- Damage situation : Severe damage atop of piers on both up and down lines (30 % of the total amount of columns).

10. Akashi City, Toba

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed structure
  Foundation : RC piles.
- Damage situation : Collapse at the middle part of the columns on both up and down lines.
- Picture 3.2.11

11. Akashi City, Fujie

- Bridge type : Super-structure : RC continuous rigid frame
  Sub-structure : RC continuous framed structure.
  Foundation : RC piles.
- Damage situation : Ditto (3.2.11)
- Picture 3.2.12

12. Akashi City, Fujie

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed structure.
  Foundation : RC piles.
- Damage situation : Severe damage atop columns.

13. Akashi City, Eijima

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed structure.
  Foundation : RC piles.
- Damage situation : Severe damage atop piers.

3.3 PRINCIPAL DAMAGES TO BRIDGES ON JR ORDINARY LINES

. Kobe City, Nada-Ward, Kawahara-dori, 2-chome

- Bridge type : Super-structure : PC slab.
  Sub-structure : ∏ type bents + continuous framed bents.
  Foundation : RC footing.
- Damage situation : Girder fall by collapse of framed bents on the up and down lines.
- Picture 3.3.1

2. Neighbourhood of Kobe City, Hihara-cho, 4-chome

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed structure.
  Foundation : RC footing.
- Damage situation : Severe damage at the middle part of columns on both up and down lines.
- Picture 3.3.2

3. Neighbourhood of Kobe City, Nada-Ward, Nagate-cho - Rokko-michi station

- Bridge type : Super-structure : RC continuous rigid frame.
  Sub-structure : RC continuous framed structure.
  Foundation : RC footing.
- Damage situation : Severe damage at the middle part of the columns on both up and down lines.
- Picture 3.3.3

4. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-cho, Gunke

- Bridge type : Super-structure : RC simple girder.
  Sub-structure : RC continuous framed structure.
  Foundation : RC footing.
- Damage situation : Girder fall by the collapse atop of columns on both up and down lines.

- Picture 3.3.4

3.4 PRINCIPAL DAMAGES TO BRIDGES ON THE HANSHIN MAIN LINE

1. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-Honmachi, 2-chome

- Damage situation : Train fall caused by collapse of protection.
- Picture 3.4.1

2. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-Tsukamachi,2-chome.

- Damage situation : Fill collapse
- Picture 3.4.2

3. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-Tsukamachi, 2-chome

- Damage situation : Fall of RC bridge.

4. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-Tsukamachi, 2-chome

- Damage situation : Fall of Steel girder bridge.

5. Neighbourhood of Kobe City, Higashinada-Ward, Mikage-Tsukamachi, 4-chome

- Damage situation : Fall of RC bridge

- Picture 3.4.3

6. Ishiyagawa Marshaling Yard in the neighbourhood of Kobe City, Higashinada-Ward, Tsuka-cho, 4-chome

- Damage situation : Collapse of RC bridge pier
- Picture 3.4.4

7. Neighbourhood of Kobe City, Nada-Ward, 2-chome

- Damage situation : Slip-down of girder caused by the fall of a RC bridge column
- Picture 3.4.5

8. Shinzaike station

- Damage situation : Ditto (3.4.7)
- Picture 3.4.6

9. Neighbourhood of Kobe-City, Oishi-higashi-cho, 3-chome

- Damage situation : Ditto (3.4.7)
- Picture 3.4.7

10. Neighbourhood of Kobe City, Oishi-higashi-cho, 3-chome

- Damage situation : Ditto (3.4.7)

11. Neighbourhood of Kobe City, Oishi-higashi-cho, 5-chome

- Damage situation : Slip down of steel girder caused by the collapse of a RC column.
- Picture 3.4.8

12. Oishi station

- Damage situation : Collapse of RC bridge pier and sinkage of railroad track
- Picture 3.4.9

13. Neighbourhood of Kobe City, Nada-Ward, Funadera-dori, 4-chome

- Damage situation : Ditto (3.4.7)
- Picture 3.4.10

14. Nishinada station

- Damage situation : Tilting of column and sinkage of girder (Steel bridge).

- Picture 3.4.11

3.5 PRINCIPAL DAMAGES TO BRIDGES ON HANKYU LINE

1. Neighbourhood of Nishinomiya City, Ogi-cho - Kobe Line

- Damage situation : Fall of girder caused by the collapse of a RC bridge column.

2. Neighbourhood of Nishinomiya Kitaguchi, Murokawa-cho - Kobe Line

- Damage situation : Ditto (3.5.1)
- Picture 3.5.1

3. Neighbourhood of Nishinomiya City, Nishida-cho - Kobe Line

- Damage situation : Ditto (3.5.1)

4. Neighbourhood of Nishinomiya City, Wakamatsu-cho - Kobe Line

- Damage situation : Ditto (3.5.1)
- Picture 3.5.2

5. Neighbourhood of Nishinomiya City, Tonoyama-cho - Kobe Line

- Damage situation : Fall down of an apartment house on railroad track.
- Picture 3.5.3

6. Neighbourhood of Ashiya City, Higashiyama-cho - Kobe Line

- Damage situation : Settlement of surrounding ground foundation

7. Neighbourhood of Kobe City, Nishioka-Honmachi 4,8 and 9-chome

- Damage situation : Sinkage of surrounding ground foundation just out a protection wall.

8. Neighbourhood of Kobe City, Nada-Ward, Harada-dori 5-chome

- Damage situation : Several shear cracks on RC arch bridge.

9. Neighbourhood of Sannomiya station - Kobe Line

- Damage situation : - Steel girder sinkage by tilting of steel column
  - Severe damage at station building caused by the collapse of a RC column.

10. Itami station - Itami Line

- Damage situation : Station building collapsed completely.

- Pictures 3.5.4 and 3.5.5

3.6 PRINCIPAL DAMAGES TO BRIDGES ON THE KOBE NEW TRANSIT PORT ISLAND LINE

The Kobe-New-Transit Port Island Line was built in 1977-1980 with a total length of 6.4 kilometers and 9 stations. Station building on whole stations as well as bridges at 5 places were damaged. A Summary of this is as following.

1. Neighbourhood of Kobe City, Chuo-Ward, Miyuki-dori, 6-chome (Crossing at north corner of Sogo Department store car parking and outh side of a Movie theater)

- Bridge type : Super-structure : Steel box girder.
  Sub-structure : RC circular piers.
  Foundation : RC basement.
- Damage situation : Slip down of firder caused by the collapse of a pier.
- Picture 3.6.1

2. Kobe City, Chuo-Ward, Yawata-dori, 3 and 7-chome

- Bridge type : Super-structure : Steel box girder
  Sub-structure : RC circular piers.
  Foundation : RC basement.
- Damage situation : Collapse of 4 piers.

3. Kobe City, Chuo-Ku, Isobe-dori, 5-chome (South side of Boeki Center Station)

- Bridge type : Super-structure : Steel box girder
  Sub-structure : RC circular piers
  Foundation : RC basement.
- Damage situation : Breakage of anchorage devices at bearing supports, it caused the girder to be hung in the air.

4. Pier N. 4 (North side of Port Terminal station)

- Bridge type : Super-structure : Steel box girder.
  Sub-structure : RC circular columns
- Damage situation : Tilting of 5 piers footings to the west caused by liquefaction.

5. Bridge approach at the Port Pier Oohashi on the Port Island side

- Bridge type : Super-structure : Steel box girder.
  Sub-structure : Rectangular steel columns
- Damage situation : Dislocation of restrainer devices at girder supports to south side.

3.7 PRINCIPAL DAMAGES TO BRIDGES ON THE KOBE NEW TRANSIT ROKKO ISLAND LINE

The Rokko Island Line was built in 1972-1990 with a total length of 4.5 kilometers and 6 stations. It is different from the Port Island Line and is composed mainly by steel bridges which were severe damaged by the effects of the Great Hanshin Earthquake. The principal damages are summarized as following.

1. East-west junction railroad tracks toward the N.2 track of Sumiyoshi station

- Damage situation : Severe damage inside the station and fall of the N.2 railroad track girder and pedestrian deck.

2. Overhead bridge on east-side of Sumiyoshi station

- Bridge type : Super-structure : Two steel box girders.
  Sub-structure : Framed Steel bents .
- Damage situation : - Tilting of 5 columns toward the north-side (toward JR railroad).
  - Collapse of superstructure facilities.

3. Sumiyoshi-River, Ugan Line (Neighbourhood of Sumiyoshi-higashi-cho 1 and 2-chome)

- Bridge type : Super-structure : Steel box girder.
  Sub-structure : Steel single columns.
- Damage situation : - Partial buckling and rotation on about half of the number of columns, 23 columns approx.
  - Buckling and breakage in the conection between columns and girders.

4. Rokko Ohashi Bridge on Rokko Island side

- Bridge type : Super-structure : Steel box girder.
  Sub-structure : Steel single columns.
- Damage situation : Fall of girder to one side.
- Pictures 3.7.1 and 3.7.2

3.8 CONCLUSIONS

- As result of our site survey on damages to bridge structures on highways and railways is possible to conclude that **the scale of damage is of serious concern**. The data gathered during the presented survey may help to understand the situation of principal damages to bridges.
- The **lack of enough adhesion, bearing interaction and friction at bond between concrete and steel reinforcement (anchorage)** during the strong shaking are founded to be the principal causes that initiated the failure and collapse of many bridge piers.
- The **shear reinforcement and anchorage of steel bars was deficient** in almost all collapsed bridges.
- Both, **continuous and simply supported girders of many spans (RC, PC or steel) were severely damaged.** By the other hand, Most of the damaged structures were supported on older RC piles, pedestal piles and caissons. However the damage to foundation structures was relative small.
- In order to investigate the causes of damage it **is necessary to elucidate the collapse mechanism associated with the type of structure, seismological and geological conditions of the site as well as the the damage distribution in the overall ravaged area.**

AKNOWLEDGMENTS

Finally, We have to express our simpathy for all quake victims and their relatives . We have had wholehearted cooperation by the Hyogo Prefecture and Kobe City Authorities to whom we aknowledge sincerely. The authors are also grateful to Prof. Ayaho Miyamoto as well as Hidee Kobayashi and T. Li who are research staff members at the Earthquake Engineering Laboratory of the Faculty of Civil Engineering - Kobe University.

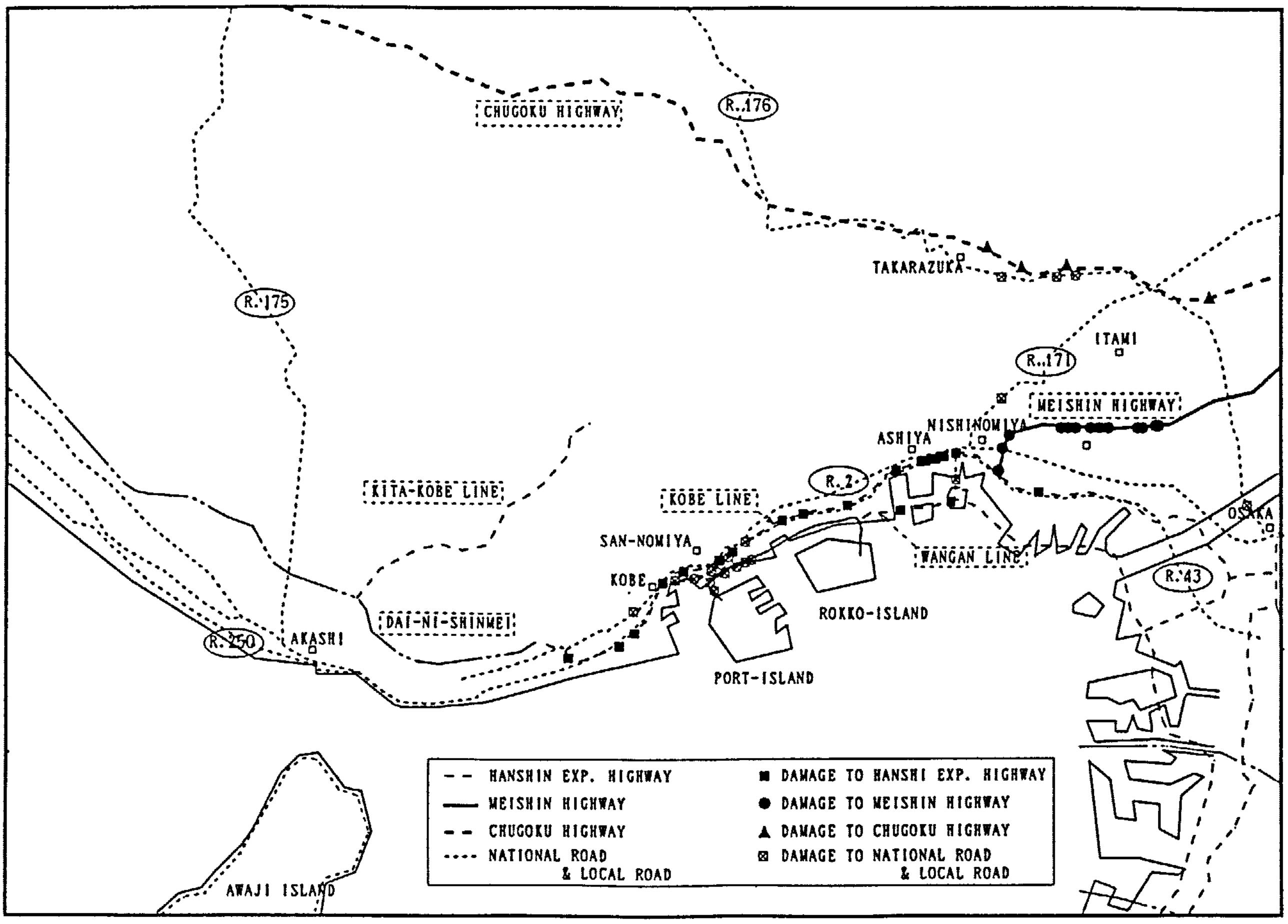


FIG. 2.1 DAMAGES TO HIGHWAYS NETWORK

Photo 2.1.1 **HANSHIN EXPRESSWAY**
(Nishinomiya City - Kusugawa-cho)

Photo 2.1.2 **HANSHIN EXPRESSWAY**
(Nishinomiya City - Kurakake-cho)

Photo 2.1.3 **HANSHIN EXPRESSWAY**
(Nishinomiya City - Koroen)

Photo 2.1.4 **HANSHIN EXPRESSWAY**
(Higashinada-Ward - Fukae-Honmachi)

Photo 2.1.5 **HANSHIN EXPRESSWAY**
(Higashinada-Ward - Uozaki-Honmachi)

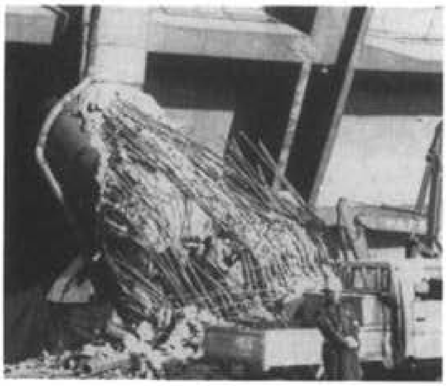


Photo 2.1.6 **HANSHIN EXPRESSWAY**
(Higashinada-Ward - Uozaki-Honmachi)

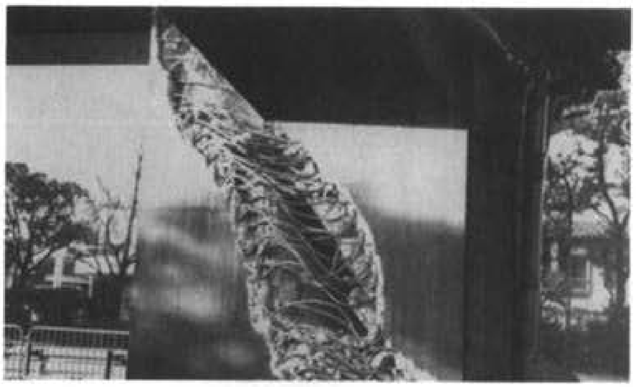


Photo 2.1.7 **HANSHIN EXPRESSWAY**
(Higashinada-Ward - Mikage-Tsuka-cho)

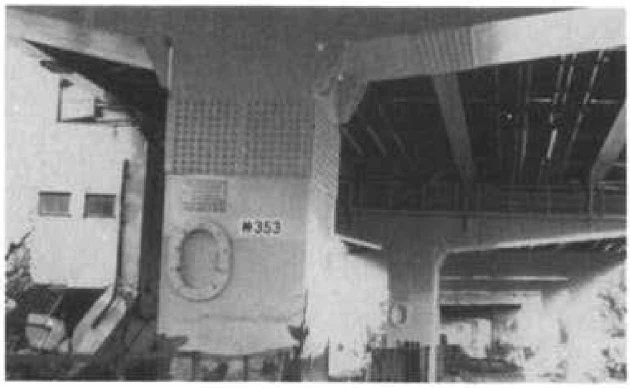


Photo 2.1.8 **HANSHIN EXPRESSWAY**
(Chuo-Ward - Wakihama-cho)

Photo 2.1.9 HANSHIN EXPRESSWAY
(Chuo-Ward - Isogami-dori/ Ikutagawa Gateway)

Photo 2.1.10 HANSHIN EXPRESSWAY
(Meriken Park north side)

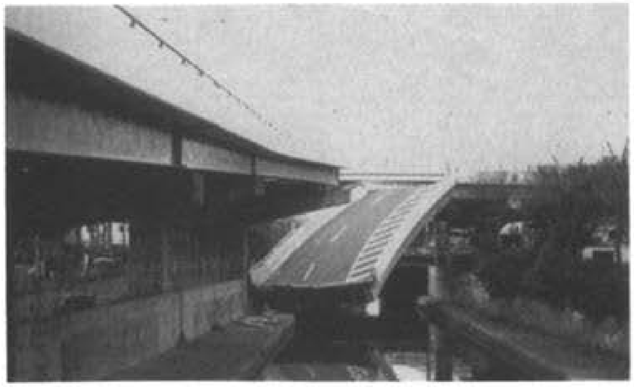


Photo 2.1.11 HANSHIN EXPRESSWAY
(Minatogawa gate-way)

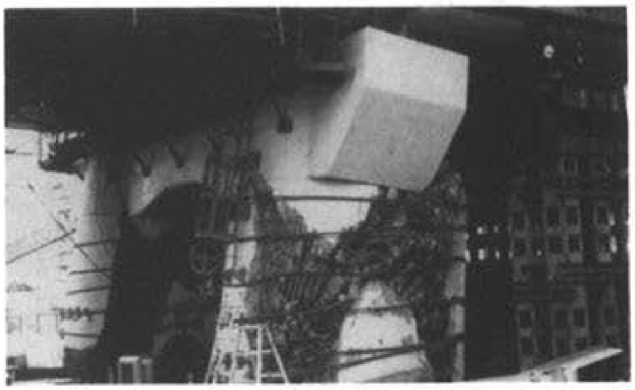


Photo 2.1.12 HANSHIN EXPRESSWAY
(Suma-Ward - Ikuhira-cho /JR crossover bridge)

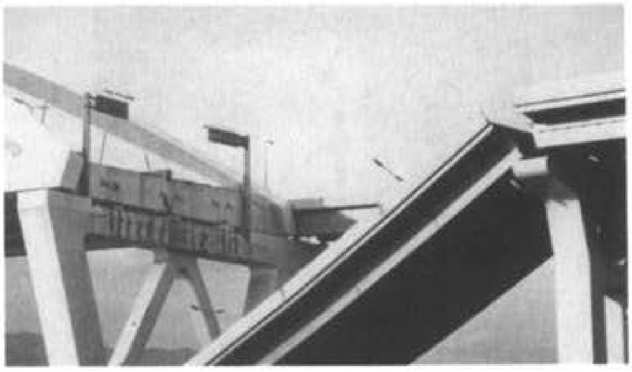


Photo 2.1.13 HANSHIN EXPRESSWAY
(Wangan Line)

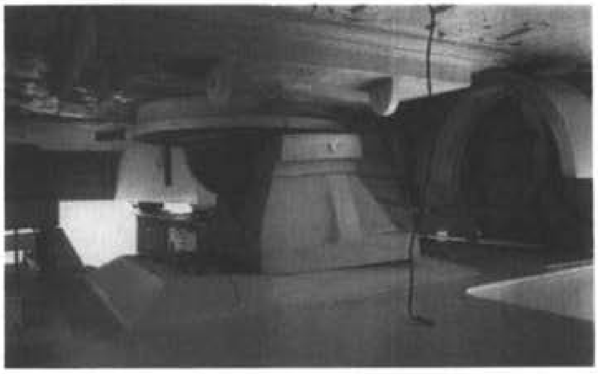


Photo 2.1.14 HANSHIN EXPRESSWAY
(Nishinomiya-ko Ohashi Bridge)

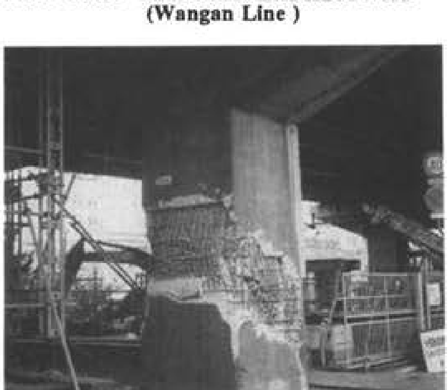


Photo 2.2.1 MEISHIN HIGHWAY
(Nishinomiya City - Tsumon-iida-cho)

Photo 2.2.2 MEISHIN HIGHWAY
(Mukogawa Bridge)

Photo 2.2.3 **MEISHIN HIGHWAY**
(Mukogawa Bridge)

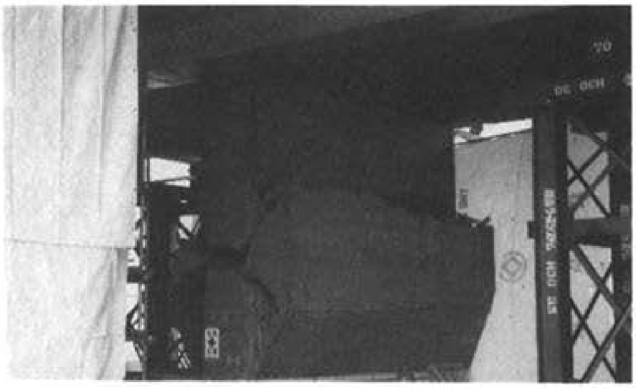


Photo 2.2.4 **MEISHIN HIGHWAY**
(Amagasaki City - Suido-cho)

Photo 2.2.5 **MEISHIN HIGHWAY**
(Amagasaki City - Suido-cho)

Photo 2.2.6 **MEISHIN HIGHWAY**
(Amagasaki City - Tachibana-cho)

Photo 2.2.7 **MEISHIN HIGHWAY**
(Amagasaki City - Jakuoji-cho)

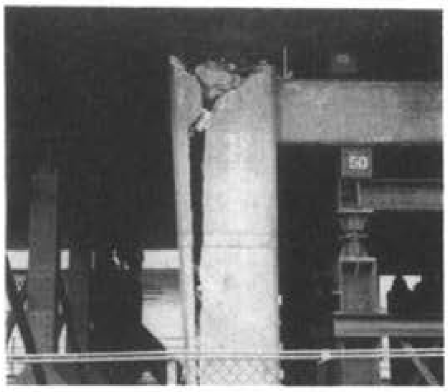


Photo 2.2.8 **MEISHIN HIGHWAY**
(Amagasaki City - Jakuoji-cho

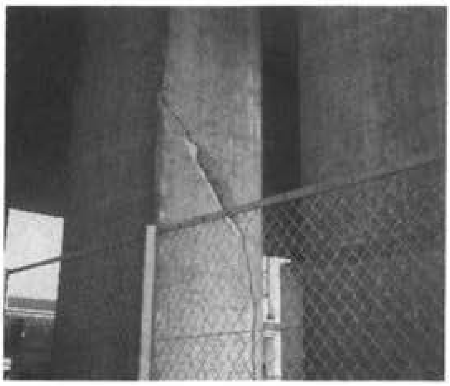


Photo 2.3.1 **CHUGOKU HIGHWAY**
(Itami City - Hagino)

Photo 2.3.2 **CHUGOKU HIGHWAY**
(Itami City - Hagino)

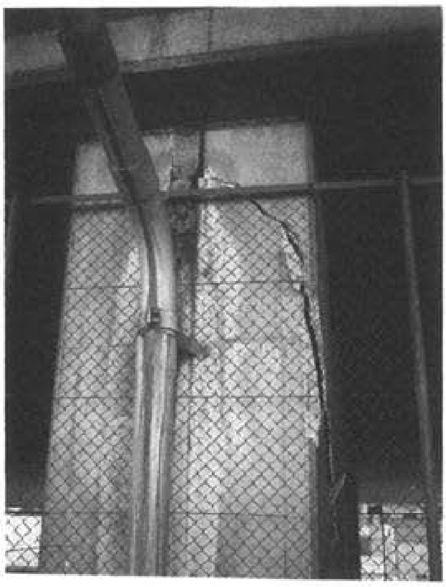


Photo 2.3.3 CHUGOKU HIGHWAY
(Itami City - Hagino)

Photo 2.4.1 ROUTE 2 - HAMATE BY-PASS
(Chuo-Ward - Hamabe-dori)

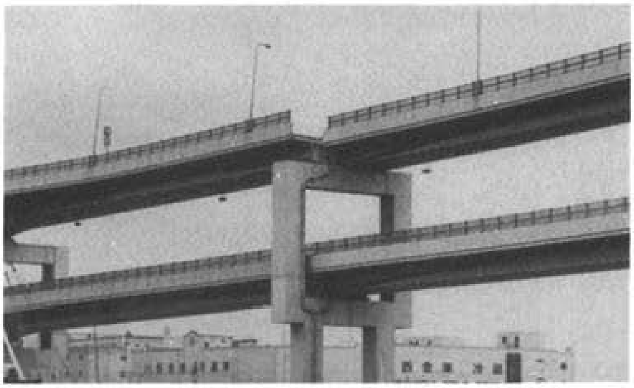


Photo 2.4.2 ROUTE 2 - HAMATE BY-PASS
(Chuo-Ward - Hamabe-dori)

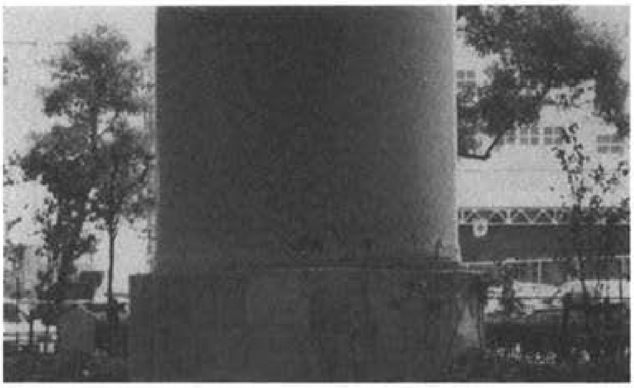


Photo 2.4.3 ROUTE 2 - HAMATE BY-PASS
(Chuo-Ward - Onohama-dori)

Photo 2.4.4 ROUTE 2 - HAMATE BY-PASS
(Chuo-Ward - Shinko-cho)

Photo 2.5.1 ROUTE 176
(Itami City - Aramaki, Tennoji-gawa Bridge)

Photo 2.5.2 ROUTE 43
(Iwaya, Nada-Ward - Miyako-dori)

Photo 2.6.1 ITAMI TOYONAKA ROUTE
(Itami City - Amatsu)

Photo 2.6.2 NISHINOMIYA OHASHI BRIDGE
(Nishinomiya-Hama)

Photo 2.6.3 NISHINOMIYA OHASHI BRIDGE
(Nishinomiya-Hama)

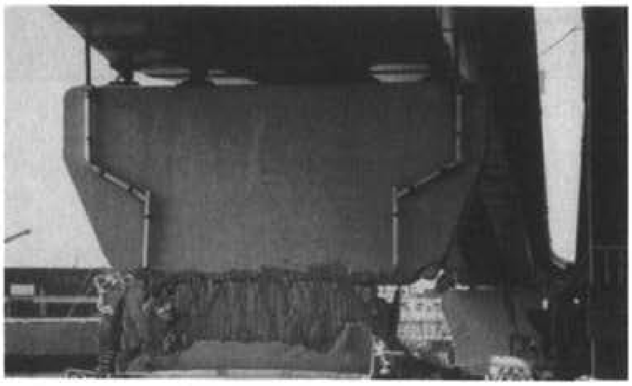


Photo 2.7.1 DAINI MAYA OHASHI BRIDGE

Photo 2.7.2 KOBE HARBOUR HIGHWAY

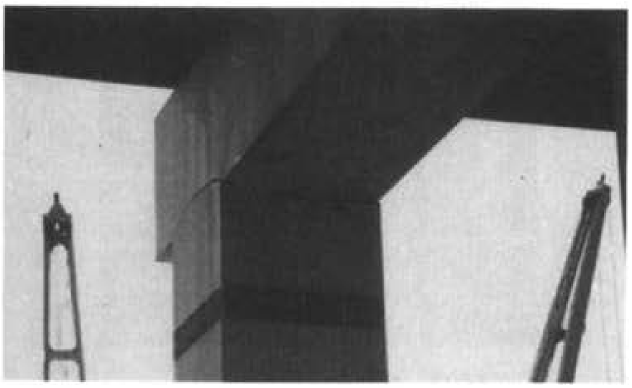


Photo 2.7.3 KOBE HARBOUR HIGHWAY

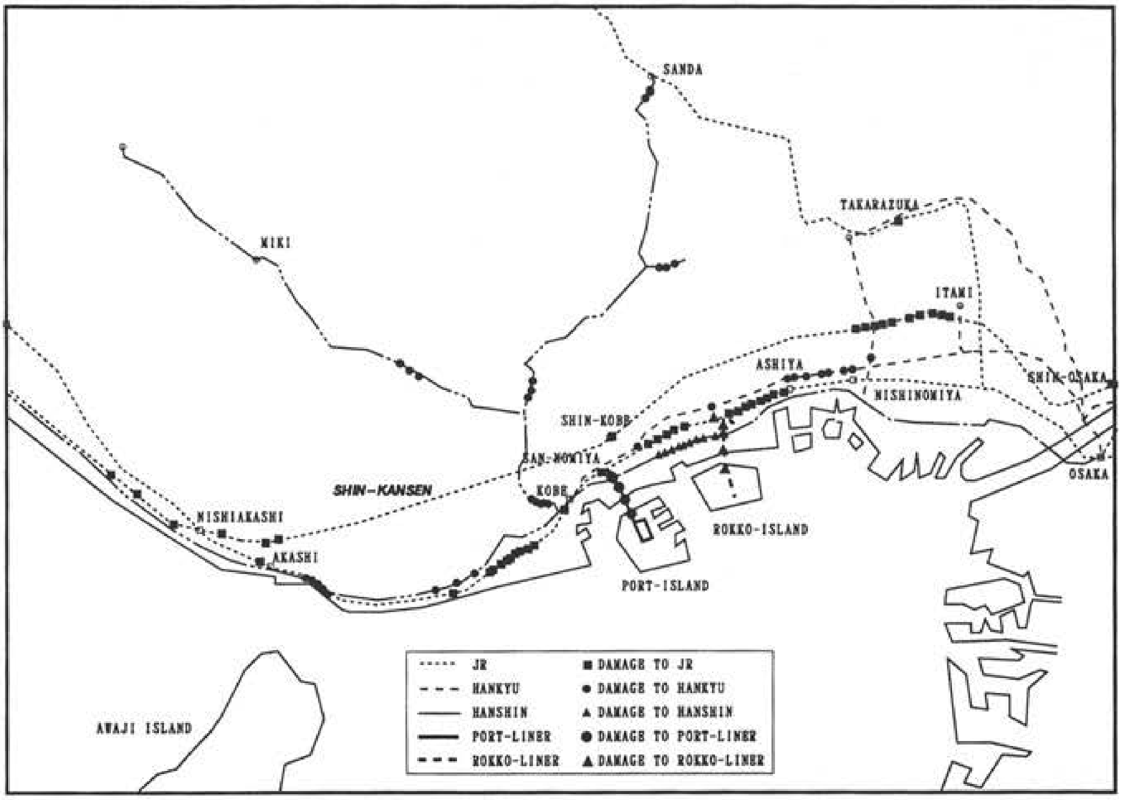


FIG. 3.1 DAMAGES TO RAILROADS NETWORK

Photo 3.2.1 JR SHINKANSEN (Itami City - Noma)

Photo 3.2.2 JR SHINKANSEN (Amagasaki City - Mukonosato)

Photo 3.2.3 JR SHINKANSEN (Mukogawa Bridge)

Photo 3.2.4 JR SHINKANSEN (Mukogawa Bridge)

Photo 3.2.5 JR SHINKANSEN
(Nishimomiya City)

Photo 3.2.6 JR SHINKANSEN
(Nishinomiya City)

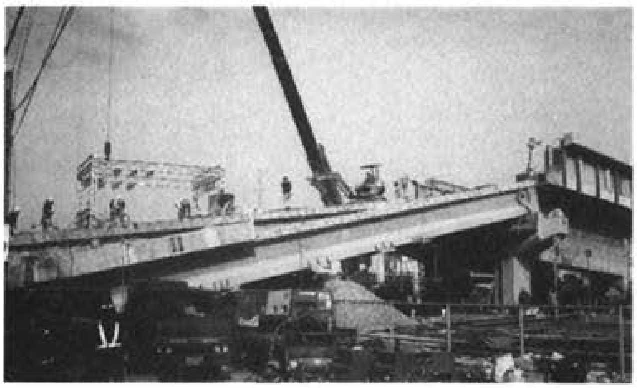


Photo 3.2.7 JR SHINKANSEN
(Hankyu Imazu Line crossover)

Photo 3.2.8 JR SHINKANSEN
(Near Rokko Tunnel)

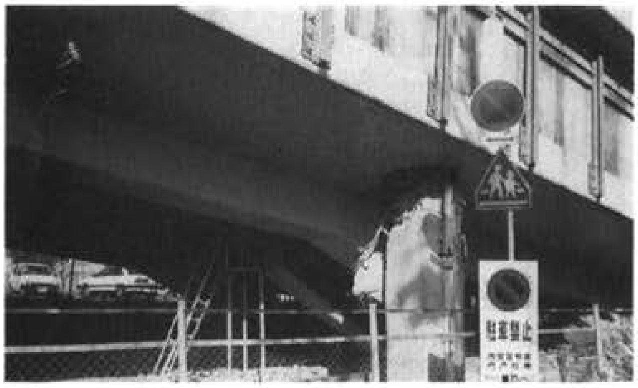


Photo 3.2.9 JR SHINKANSEN
(Near Rokko Tunnel)

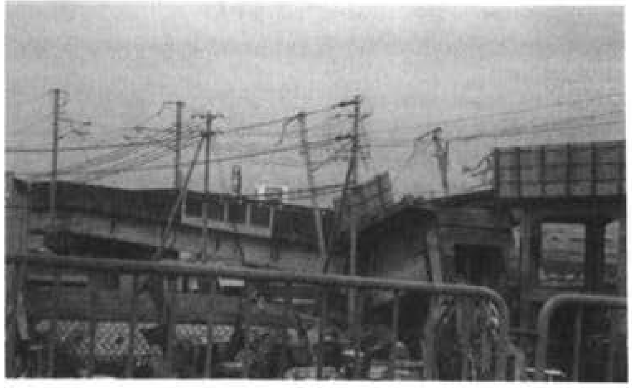


Photo 3.2.10 JR SHINKANSEN
(Nishi-Ward, Ikawadani-cho, Minami-beppu)

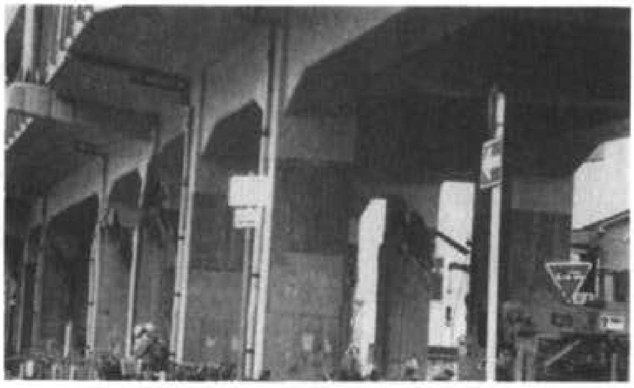


Photo 3.2.11 JR SHINKANSEN
(Akashi City - Toba)

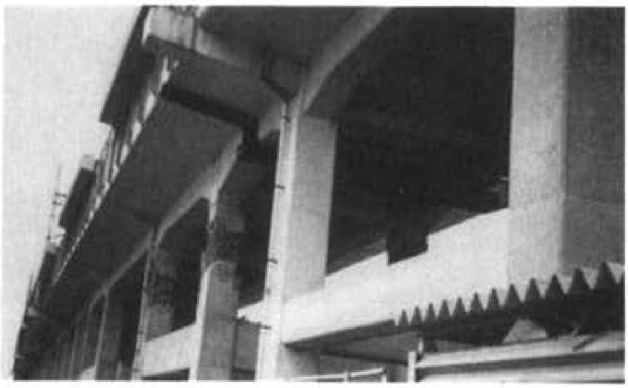


Photo 3.2.12 JR SHINKANSEN
(Akashi City - Fujie)

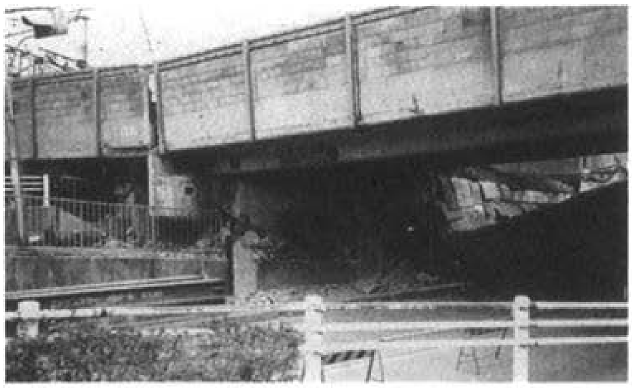


Photo 3.3.1 JR TOKAIDO LINE
(Nada-Ward - Kawahara-dori 2-chome)

Photo 3.3.2 JR TOKAIDO LINE
(Hihara-cho 4-chome)

Photo 3.3.3 JR TOKAIDO LINE
(Rokko-michi station)

Photo 3.3.4 JR TOKAIDO LINE
(Higashinada-Ward - Mikage-cho, Gunke)

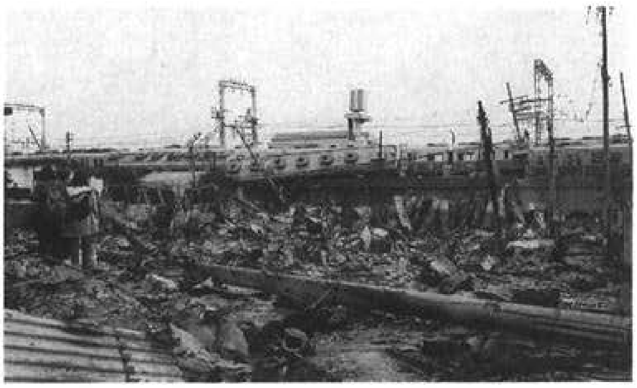


Photo 3.4.1 HANSHIN LINE
(Higashi-Nada-Ward - Mikage-Honmachi 2-chome)

Photo 3.4.2 HANSHIN LINE
(Higashi-Nada-Ward - Mikage- tsuka-cho 2-chome)

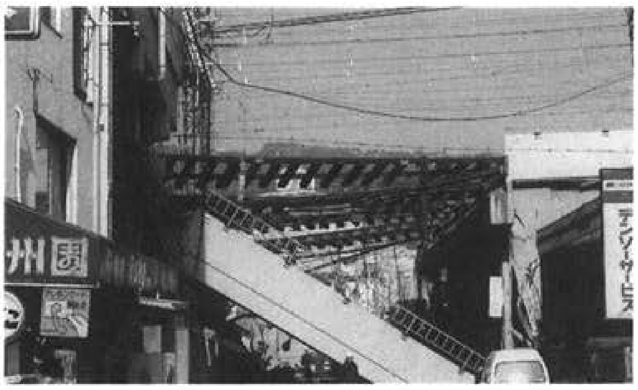


Photo 3.4.3 HANSHIN LINE
(Higashi-Nada-Ward - Mikage-tsuka-cho 4-chome)

Photo 3.4.4 HANSHIN LINE
(Ishiyagawa Marshaling Yard)

Photo 3.4.5 HANSHIN LINE (Nada-Ward - Hamada-cho 2-chome)

Photo 3.4.6 HANSHIN LINE (Shinzaike station)

Photo 3.4.7 HANSHIN LINE (Nada-Ward - Oishi-Higashi-cho 3-chome)

Photo 3.4.8 HANSHIN LINE (Nada-Ward - Oishi-Higashi-cho 5-chome)

Photo 3.4.9 HANSHIN LINE (Oishi station)

Photo 3.4.10 HANSHIN LINE (Nada-Ward - Funadera-dori 4-chome)

Photo 3.4.11 HANSHIN LINE (Nishi-Nada station)

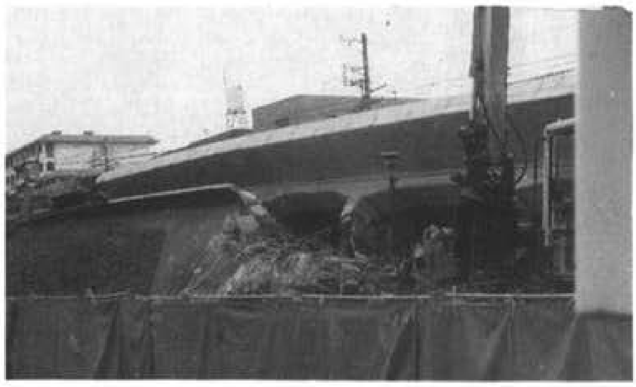


Photo 3.5.1 HANKYU LINE (Nishinomiya City - Murokawa-cho)

Photo 3.5.2 **HANKYU LINE**
(Nishinomiya City - Wakamatsu-cho)

Photo 3.5.3 **HANKYU LINE**
(Nishinomiya City - Tonoyama-cho)

Photo 3.5.4 **HANKYU LINE**
(Itami station)

Photo 3.5.5 **HANKYU LINE**
(Itami Station)

Photo 3.6.1
PORT LINER
(Chuo-Ward - Miyuki-dori 6-chome)

Photo 3.7.1 **ROKKO LINER**
(Rokko Ohashi)

Photo 3.7.2 **ROKKO LINER**
(Rokko Ohashi)

(by Shiro Takada, Hidenori Morikawa and Freddy R.Duran Cardenas)

DAMAGE TO LARGE-SCALE UNDERGROUND LIFELINES DURING THE 1995 SOUTH HYOGO PREFECTURE EARTHQUAKE

This report summarizes the damage situation of large-scale underground lifelines due to the 1995 South Hyogo Prefecture Earthquake which occurred in the Hanshin area, Japan, on January 17, 1995 at 5:46 a.m. (local time) and of a magnitude 7.2 on the Richter scale and 7 on the Japanese Meteorological Agency Scale (corresponding to XI~XII on the MMI).

Owing to the limited available information, it is not possible to include all the large-scale underground lifelines in this report. However, damage to the following lifelines are reported :-

1. South Hyogo Prefecture Common Ducts:
   a. Amagasaki City Common Duct at National Road Number 2.
   b. Nishinomiya City Common Duct at National Road Number 2.
   c. Kobe City Common Duct at National Road Number 2.
   d. Amagasaki City Common Duct at National Road Number 43.
   e. Takarazuka City Common Duct at National Road Number 176.
   f. Kobe City Port Terminal Common Duct.
2. South Kansai Electric Company Shield Tunnel.
3. Osaka South Port Immersed Tunnel.
4. Daikai Station Subway Tunnel.

Figure 1 shows a map of the Hanshin area, location of the epicenter, Nojima fault which triggered the earthquake, and the location of the above lifelines. Nojima fault sides slides against each other by a maximum of about 1.8m horizontally and 1.3m vertically, thus generating a double shock: in the horizontal and vertical directions. The vertical shock of this earthquake was remarkable, and in some locations exceeds the horizontal one. It should be noted that most of the active faults in the Hanshin area are almost parallel to Nojima fault and the line joining the upper tip of Awaji Island to Nishinomiya City. These faults are approximately extend in the shaded area of Figure 1.

Table 1 shows the PGA (peak ground acceleration) at the nearest station to the location of the above lifelines. (HL.PGA: Maximum horizontal acceleration for which the exact horizontal orientation is not yet available, NS: North-South, EW: East-West, UD: Up-Down, LG: Longitudinal, TR: Transverse.)

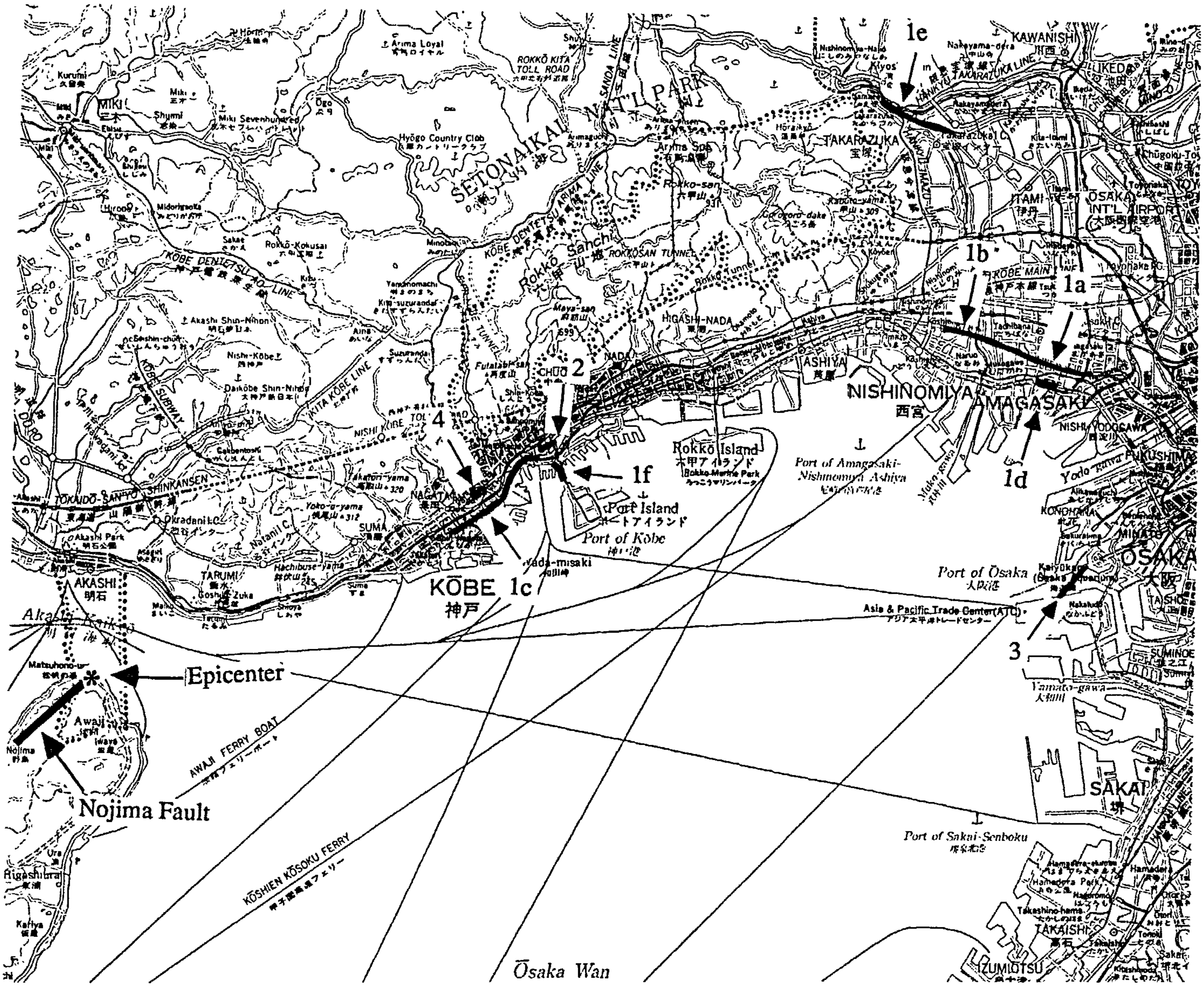


Figure 1 : Map of the Hanshin Area and Locations of the Underground Lifelines

Table 1 : Peak Ground Acceleration at the Nearest Station to Lifelines

Lifeline	Nearest Station	PGA (gal)
1a. Amagasaki City Road No.2 1b. Nishinomiya City Road No.2 1d. Amagasaki City Road No.43	Amagasaki Overpass	LG=310 TR=274 UD=336
1c. Kobe City Road No.2 1f. Kobe City Port Terminal 2. Kansai Electric Company	Kobe Marine Meteorological Observation	NS=818 EW=617 UD=332
1e. Takarazuka City Road No.176	JR Takarazuka	HL.PGA=601
3. Osaka South Port Tunnel	Fukushima	NS=180 EW=211.5 UD=194.8
4. Daikai Station Subway Tunnel	JR Takatori	HL.PGA=616

1. SOUTH HYOGO PREFECTURE COMMON DUCTS

The available information and damage situation (reported in Ref.1) of South Hyogo Prefecture common ducts are given in Table 2. All these ducts are reinforced concrete box-sections with rubber joints between duct block segments. The dimensions W&H are the internal ones. The completed part of the Kobe City Common Duct at Road No.2 is located starting from the right side shown in Figure 1. A sketch of the cross sections of the Takarazuka City duct and Kobe City Port Terminal duct are shown in Figures 2 and 3 (E: Electricity, G: Gas, T: Telecommunication, S: Sewage, W: Waterworks).

Table 2 : Damage Situation of South Hyogo Prefecture Common Ducts

Items \ Common Duct	Amagasaki City at National Road No.2	Nishinomiya City at National Road No.2	Kobe City at National Road No.2	Amagasaki City at National Road No.43
Period of Construction	1977 - 1993	1977 - 1990	1987 - present	1962 - 1963
Length	L = 5,525m	L = 515m	L = 5,860m among which 854m utilities were completed.	L = 1,021m
Cross Sectional Dimensions (m) W : Width H : Height	W = 3.1 to 5.7 H = 2.2 to 4.0	W = 3.65 H = 2.25	W = 3.1 to 3.95 H = 3.85 to 4.35	W = 3.7 H = 2.1
Utilities	Telecommunication, Gas, Electricity.	Telecommunication, Gas.	Telecommunication, Gas, Electricity, Sewage.	Telecommunication, Gas, Waterworks.
Damage Situation	- Almost no damage. - Leakage of water occurred in an interconnection chamber at Yodo river. - In another location leakage of water occurred at a section joining the main body of the duct to an inter-connection chamber. - In a third location, fine cracks occurred, but without leakage of water.	- Almost no damage. - In one location, fine cracks occurred, but without leakage of water.	- Almost no damage. - In one location, fine cracks occurred, but without leakage of water (Photo 1). - In another location, and for a 16m length in the axial direction of the duct, steel bars were expo-sed from concrete at the upper haunches (Photo 2). Leakage of water occurred at this location (Photo 3).	- Almost no damage. - In one location, fine cracks occurred, but without leakage of water.

Table 2 : Damage Situation of South Hyogo Prefecture Common Ducts (continued)

Items \ Common Duct	Takarazuka City at National Road No.176	Kobe City Port Terminal
Period of Construction	1985 - present	1972
Length	L = 860m at north side. L = 1,100m at south side.	L = 845m
Cross Sectional Dimensions (m) W : Width H : Height	W = 1.7 to 3.3 H = 2.05 to 2.35	W = 3.0 H = 4.75
Utilities	Telecommunication, Sewage, Waterworks Gas, Electricity.	Telecommunication, Electricity, Gas, Waterworks.
Damage Situation	- Damage to rubber joints due to unequal vertical displacements of the duct blocks facing each other at joints (Photo 4). - Remarkable cracks in the main body of the duct in one location on the north side and two locations on the south side (Photo 5). - Separation and damage of the concrete walking sheets. It was remarkable in two locations on the north side and two locations on the south side (Photo 6). - Leakage of water was remarkable at locations of the damaged joints, cracks in the main body, and in a large number of interconnection chambers entrance (Photo 4). - Moreover, the utilities inside the duct was badly damaged. Some of the utilities and equipments were submerged under the water, and the shelfs carrying the telecommunication cables failed.	- In 12 main locations, sea water had entered through the cracks. As a result, the electric equipments and the concrete supports of the sewage pipe were submerged under the water (Photos 7&8).

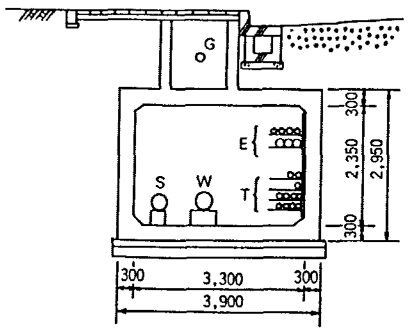


Figure 2 : Cross Section of Takarazuka City Common Duct (units: mm)

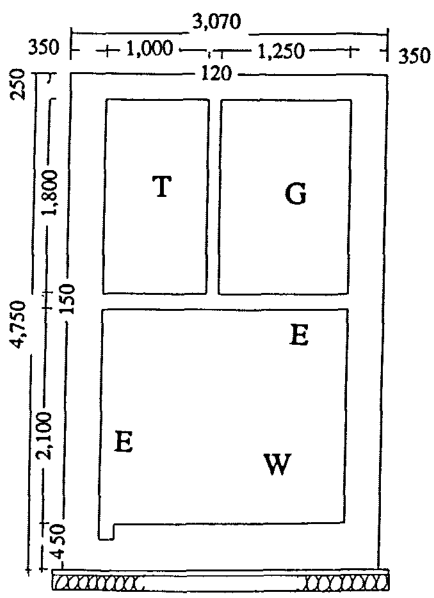


Figure 3 : Cross Section of Kobe City Port Terminal Common Duct (units: mm)

Photo 1 : Cracks in the Upper Slab

Photo 2 : Steel Bars Exposed from the Concrete Upper Haunch

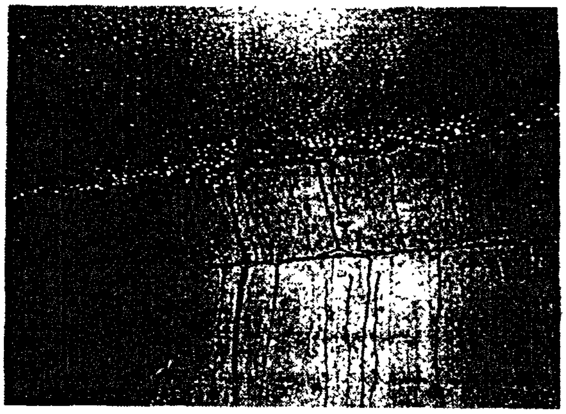


Photo 3 : Leakage of Water

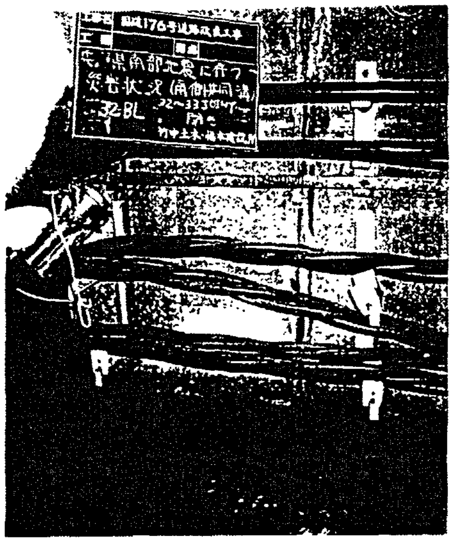


Photo 4 : Damage to Rubber Joints and Leakage of Water

Photo 5 : Cracks in the Main Body

Photo 6 : Separation and Damage of Concrete Walking Sheets

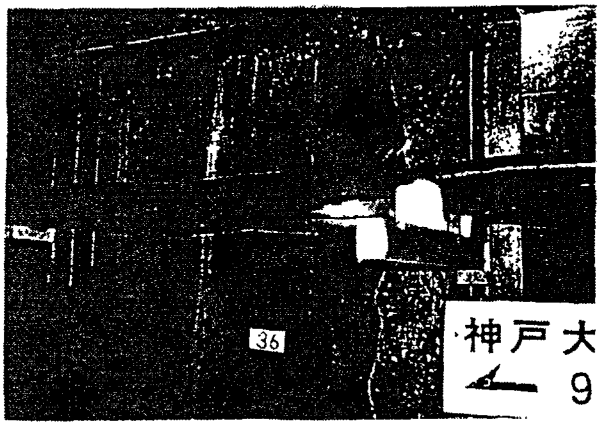


Photo 7 : Damage to Rubber Joint and Leakage of Water

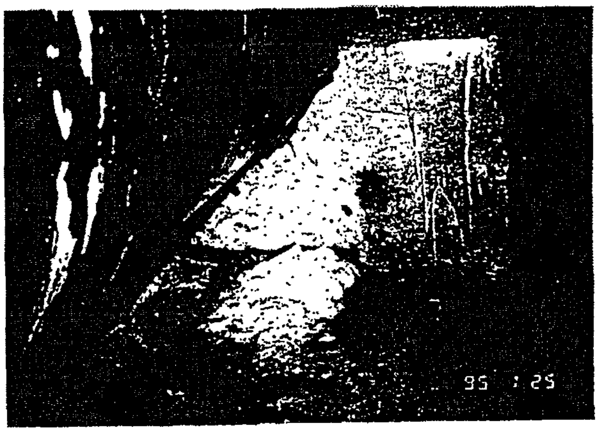


Photo 8 : Part of the Concrete Supports of the Sewage Pipe are Submerged under Water

Discussion of Damage Situation

I- It seems that Amagasaki and Nishinomiya Cities Common Ducts sustained almost no damage, perhaps because the peak ground acceleration and the peak ground velocity were not so high at these locations.

II- Kobe City Common Duct at Road No.2 sustained slight damage, although it is located at the hard-hit area and the peak ground acceleration and the peak ground velocity were very high. The duct is almost parallel to Nojima fault and one expects that during the earthquake it was subjected to a very high level of reversal axial forces from the horizontal shock, and high combined bending moments from the vertical and horizontal shocks. Also, the soil had liquefied thus increasing the differential settlements between duct block segments. It seems that the rubber joints perform well in absorbing these forces and settlements.

Another segment of Kobe City Common Duct at Road No.2 is reported in Ref.2. The segment is located near JR Kobe Station, Chuo Ward. The area surrounding this location is close to the sea, and liquefaction had occurred in many locations at the waterfront (at Meriken Park). Moreover, investigation shows that the ground had settled about 10cm in the area. The duct is a reinforced concrete box section of internal width 2.0m and internal height 2.2m. The duct is provided by rubber joints of 20 to 30mm width to connect between block segments. The duct is almost parallel to Nojima fault. The peak ground acceleration and velocity were very high at this location. During the earthquake, the duct was subjected to a high axial compressive forces from the horizontal shock and differential settlements from liquefaction and the vertical shock. It seems that the rubber joints perform well in absorbing these forces and settlements. Generally, the reported damage can be summarized as follows :

1. At the position of the rubber joints, cracks occurred at the edge of the duct block segments.
2. At many locations, remarkable bumps occurred due to the high compressive stresses resulting from the impact of the duct block segments facing each other.
3. In one location, separation occurred.

4. At the upper haunch corner, horizontal cracks of 1mm width occurred.
5. Under the upper haunch by 20 to 30cm, a horizontal crack of 1mm width extended for about 10m on the side walls.
6. Above the lower haunch by 20 to 30cm, a horizontal crack of 1mm width extended for about 10m on the side walls.
7. In many locations, the shell material on the side walls had crushed. All the locations have a similar appearance and same crushing level. However, this does not extend on the whole block. The crush of the shell material was due to the compressive forces resulting from the impact of the duct block segments facing each other. In one location, a hole of 50mm dimensions occurred inside the shell material.
8. At one location (the neighborhood of Benten Chuo crossing point), where there is a change in the elevation of the duct (inclination), separation occurred (beside the rubber joint whose width is 25mm) in the interior surface of the upper concrete slab. The separation shape is a part of a circle. Its width is 90cm and extends for 60cm, and the steel bars were exposed. However, the block segments and the rubber joint are nearly smooth without shear deformations. Such status can be considered due to the strong compression forces in the longitudinal direction acting on this part.
9. Leakage of water was not reported.

III- On the contrary, Kobe City Port Terminal Common Duct sustained moderate damage. The duct is almost perpendicular to Nojima fault and one expects that during the earthquake it was subjected mainly to a combined bending moments from the horizontal and vertical shocks. Also, it was constructed before the achieved progress in earthquake-resistance design and technology of flexible joints, and probably designed according to the old code. Moreover, the soil conditions under the duct is a layer of 15m composed of almost fine sand which had liquefied, thus increasing the differential settlements between duct block segments.

IV- As for Takarazuka City Common Duct which sustained a moderate damage, the information about soil conditions at the site or the peak ground vertical acceleration are still not available. However, it seems that the duct was subjected to a very large differential settlements resulting from a single or combined action of liquefaction and the vertical shock.

2. A SHIELD TUNNEL OF KANSAI ELECTRIC COMPANY

The tunnel is located in downtown Sannomiya, Chuo Ward, Kobe City. The R.C. tunnel is of circular cross section of 4.0m internal diameter and 931m length. The segment length is 1.0m. A second lining is provided to the tunnel invert only for operation purposes. The surrounding ground at the site is diluvium coarse sand or gravel of 20 to 50mm diameter. The tunnel is almost parallel to Nojima fault. The peak ground acceleration and velocity were very high at this location. During the earthquake, the tunnel was subjected to a high axial compressive forces from the horizontal shock and differential settlements from the vertical shock. It seems that the bolts connecting tunnel segments perform well in absorbing these forces and deformations. Generally, the reported damage can be summarized as follows :

1. For an interval of about 100m of the tunnel, cracks surrounded the corners of all the segments.
2. Separation does not occur but the interior side is pushed about 2 to 3mm. This occurred at a 45 degrees from the tunnel crown in both sides.
3. There are two curved divisions in the tunnel alignment of 20m radius. At this curved parts, steel segments of 25 to 35cm length are used to join the last R.C. segment of the straight part of the tunnel. In this segment, separation occurred at 45 degrees from the tunnel crown in both sides and extended for the next 4 to 5 rings. However, no separation or cracks due to the destructive compression observed in the ring invert, and no damage occurred to the connecting bolts.

An interesting point was also reported that there was no cracks at 45 degrees from the tunnel crown (or invert). It is well known that the maximum bending moments are at these locations when analyzing the cross sectional direction under horizontal ground displacements. This assure that the tunnel was mainly subjected to axial forces rather than bending moments.

3. OSAKA SOUTH PORT IMMERSED TUNNEL

The Osaka South Port immersed tunnel is a combined 4 lane roadway and 2 track railway. The construction started at 1991 and will end by 1997. The total immersed part is 1025m. The structural system is a composite steel shell. The cross sectional dimensions is shown in Figure 4.

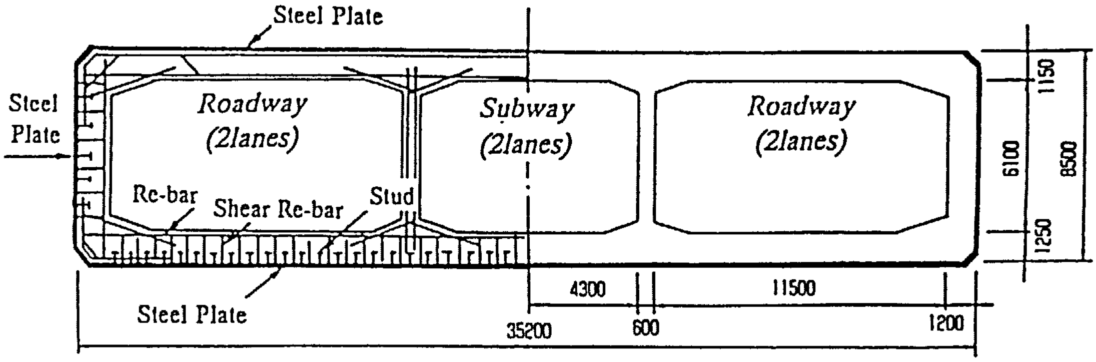


Figure 4 : Steel-Concrete Composite Cross Section of Osaka South Port Immersed Tunnel (units: mm)

For all the elements of the tunnel, flexible joints are adopted to reduce the sectional forces due to earthquakes, to cope with the nonuniform settlement between the ventilation shaft and the tunnel element, and to absorb the movement of the element due to temperature variations. The flexible joint have reliable water proof properties for expansion and rotation due to settlement. The joint consists of a Gina-type rubber gasket against leakage and to resist compressive force, Ω-shaped rubber gasket as a secondary water tightness, PC connecting cable and coupler to resist tensile force, and horizontal and vertical shearing keys to resist horizontal and vertical displacements. A sketch for the flexible joint is shown in Figure 5.

The construction progress at the time of earthquake occurrence was as follows : 6 immersed tunnel elements were already sunk into the sea, starting from the position of the Minato Ward ventilation shaft which is still under construction. Among these elements, the first three elements were already covered and surrounded by a layer of crushed stone. The damage situation could be summarized as follows :

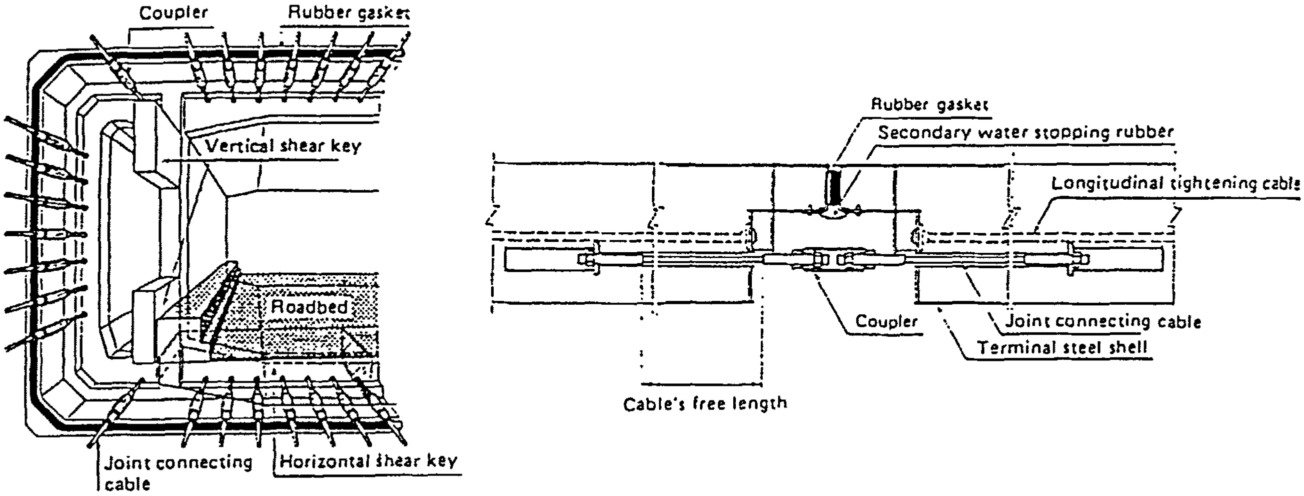


Figure 5 : Flexible Joint of Osaka South Port Immersed Tunnel (units: mm)

1. There was a 10mm differential settlement at the flexible joints connecting the tunnel element number 1 with the ventilation shaft. However, it is somewhat complicated to estimate the future settlement of the shaft, or the extension of the PC connecting cable and coupler of the shaft side. Moreover, the Ω-shaped rubber gasket was barely twisted. Also, very few fine cracks occurred at the neighborhood of the corner part of the horizontal shear key. Therefore, the 72 main flexible joints at this location prove their effectiveness as an earthquake absorbing device.
2. Cracks occurred at the neighborhood of the horizontal shear key of tunnel elements number 2 and 3 as shown in Photo 9. In the vertical neighborhood of the cracks, a 20mm horizontal dislocation of a part of the vertical shear key.
3. A 15 to 20mm horizontal dislocation of a part of the vertical shear key of tunnel elements number 3 and 4 as shown in Photo 10.
4. During the earthquake, water come out from the blast-tank, but there was no damage. Inside the tank (3m width), the height of water was 5m, about 0.7m from them come out due to earthquake vibrations.
5. No damage or leakage of water through the temporary bulk head located at the end of element number 6.
6. Floating of any of the six elements due to the earthquake vertical shock did not occur.

Photo 9 : Cracks in a Horizontal Shear Key

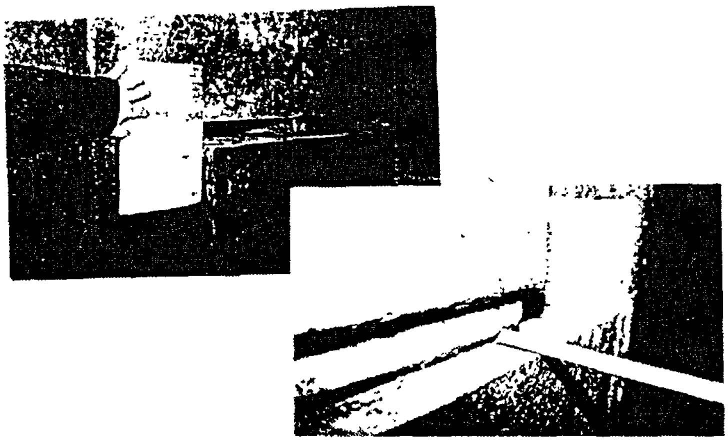


Photo 10 : Dislocation of a Vertical Shear Key

It seems that the tunnel sustained slight damage, because the peak ground acceleration and the peak ground velocity were not so high at this location. Also, the tunnel and the flexible joints were designed and constructed based on the state-of-the-art earthquake-resistance design and technology in Japan. However, it is complicated to expect the damage of the tunnel under the maximum credible earthquake.

4. DAIKAI STATION SUBWAY TUNNEL

One of the worst damage of the large-scale underground lifelines was the collapse of Daikai Station of Kobe Municipal Subway in Kobe City, Hyogo-Ward, and under the Daikai street. The station was opened in 1968. 30 R.C. columns of the station's 35 columns supporting the platform failed as shown in Photo 11, resulting in the collapse of the roof, the underground tunnel, and the street above. About 95m by 28m area of the asphalt road above the station settled with a maximum of 3m as shown in Photo 12. Soil profile in the site is 8.5m diluvium sand layer followed by 9.0m alluvium clay layer. The bed rock is estimated at 17.5m under the ground surface. The water level is at 8.7m under the ground surface. The original R.C. box-section at the position of the maximum ground settlement (3m) and the failure shape of the underground tunnel is shown in Figure 6.

Photo 11 : Failure of the Concrete Columns

Photo 12 : Settlement of Daikai Street

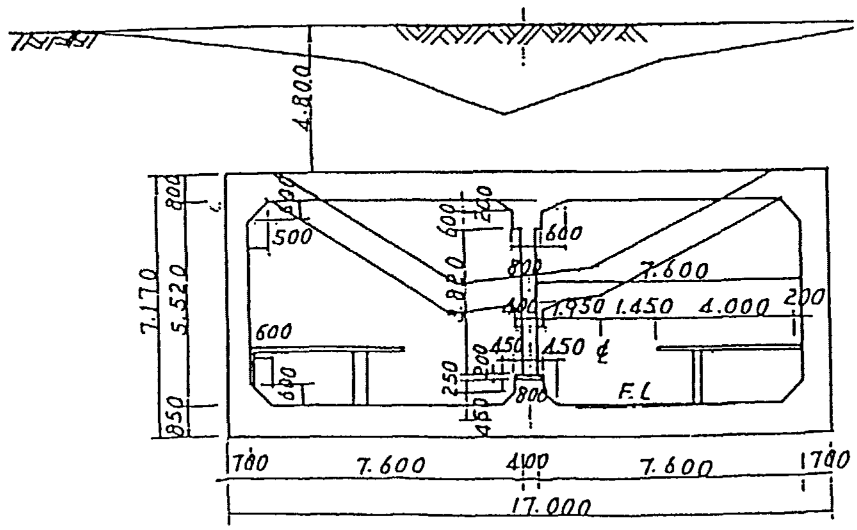


Figure 6 : Cross Section and the Failure Shape of the Tunnel (units: mm)

It is difficult now to assure the exact reason for the collapse of the station without further field investigation and computer analysis. However, the reason may be one or a combination of the following factors:

1. The station was designed and constructed before 1968 according to the old codes, before the recent development in earthquake-resistant design regulations, quality of concrete and reinforcing steel, and construction technology in Japan.

2. The Hanshin area was coded to have an JMA Intensity Level 5 on the Japanese scale of 8 levels (0~7). This value corresponds to a ground acceleration between 80 and 250 gal. However, the Hyogo earthquake magnitude was 7 on the Japanese scale and the ground acceleration at the site was 616 gal (about 2.46 times).

3. The station is located close to the epicenter (about 15km). During the earthquake, it was subjected to high ground accelerations in its longitudinal direction and moderate vertical accelerations, due to the rupture of Nojima fault. Referring to Photo 11, the longitudinal direction of the station seems to be stiff enough to resist the longitudinal accelerations as the columns, upper slab and foundation forms a stiff structure. On the other hand, the transverse direction failed due to a single or combined effect of the vertical acceleration and liquefaction which probably occurred.

4. A combined effect in the transverse direction of the vertical acceleration which decreased the apparent weight of the station, and in the meantime the horizontal acceleration (due to Nojima fault horizontal offset) was acting. This might led to the columns or the underground tunnel collapse.

5. The area of the location of the Daikai Station is estimated as an old river basin and having trace of overflooding.

CONCLUDING REMARK

For the above lifelines of Kobe City being subjected to the maximum credible earthquake in their lifetime, these lifelines (except Daikai Station Tunnel) perform well during the earthquake without a serious damage, as the sustained damage could be maintained. On the other hand, for lifelines in Amagasaki, Nishinomiya, Takarazuka, and Osaka Cities being subjected to a moderate to strong earthquake, these lifelines also perform well with a slight to medium damage that can be easily maintained. However, Takarazuka and Kobe's Port Terminal Common Ducts required more field investigation and computer analysis. Finally, the predominant importance of flexible joints is assured in this earthquake.

REFERENCES

1. Report of The Lifeline Research Society by Hyogo Prefectural Government.
2. Report of The Sub-Committee of Earthquake Resistant Design of Tunnels in JSCE.

ACKNOWLEDGMENTS

The authors would like to express their best gratitude to The Lifeline Research Society of Hyogo Prefectural Government and to The Sub-Committee of Earthquake Resistant Design of Tunnels in JSCE, for supplying information about the damage situation for these lifelines.

(by Shiro Takada and M. Abdel-Aziz)

Lifelines Performance and damage during Jan. 17, 1995 South Hyogo Great Earthquake

1. Introduction

In this report the main points about performance of lifelines including gas, water, waste water, electricity and telecommunication systems are presented. Damage types to these systems facilities and faunctionalities are summarized. The main problems during the urgent damage investigation and restoration are explained. The countermeasure against earthquake in current restoration activities and the outlines of the future plan have been also discussed. Some remarks as the lessons from this earthquake are concluded at the end.

2. Gas system

Gas cut off: The main gas supplier for the quake-hit area is Osaka Gas Co. L.t.d. which with about 49,000 km of pipelines supplies gas for 5.7 millions of households. Among these, 5 millions are equipped with automatic control system. Due to the earthquake gas was cut off to more than 860,000 households. Except 164,000 ones which are due to the destruction or burning of houses, the others that are about 90% will be restored by the end of March, 1995. The total damage to gas system is estimated about $ 1.9 billions, which 1.75 billions of it is due to the damage of gas network facilities. It should be noted that one of the reasons for gas cut off was shut down for preventing of entrance of water or waste water in the gas pipes in those areas which water pipes or waste water pipes were near to the gas pipes. There was such a countermeasure also in liquefied zones to prevent inflow of sand or water into the pipes.

Damage: There was not damage to the gas holders and big pressure pipes and facilities. Damage to the B type of medium pressure pipes was more than A type (Table 1). Restoration of former one took one weak more than the other and was finished by March 8, 1995 .

Table 1 - Pipes in gas system

Name		Pressure(kg/cm2)	Diameter (mm)		
			800 - 400	300 - 100	80 - 50
High Pressure		> 10	Steel pipe (Welded)	-	-
Medium Pressure	A	3 - 8	Steel pipe (Welded)	-	-
	B	1 - 3	Steel pipe (Welded)	Steel (Welded) Ductile pipe (Mech. joint)	-
Low Pressure		0.02	-		Steel (Mechanical joint) Poly-ethylene (resin)

The main part of damage was concentrated in low pressure supply pipes and in screw joints and its restoration was very troublesome and took a lot of time. A large number (about 70%) of these joints had been replaced by the earthquake resistant ones before the quake (Table 2).
The supply pipes for the buildings were severely damaged due to the non uniform settlement of surrounding ground and buildings specially near the sea and two man-made islands. The main damage of internal pipes of buildings were in connections in walls and specially those of water heaters.

Table 2 - Damage to middle pressure gas pipes

Location	Damage Total
Manhole	59
Governer	12
Steel pipes welding	14
D.C.I.P Joints (GM II)	3
Others	8
Total	96

Restoration: There were 9700 persons doing the restoration activities from which 6000 persons were from Osaka Gas and the others from other gas companies in Japan. Restoration progress until the March 14, 1995 are depicted in Table 3 .

Table 3 - Gas restoration until the March 14, 1995

Name of place		Householdes required restoration	Restoration Ratio (%)
Takarazuka		66,900	99.4
Nishinomiya		155,100	90.3
Ashiya		30,300	65.7
Kobe		353,850	76.5
Wards of Kobe	Higashinada*	53,800	49.2
	Nada	36,600	69.7
	Chuo	49,400	76.3
	Hyogo	43,200	85.4
	Nagata*	41,100	48.1
	Suma	18,700	71.9
	Tarumi	86,700	99.9
	Nishi	12,300	100.0
	Kita	12,050	100.0
Others		86,750	100.0
Total		692,900	84.3

* Too many houses destroyed in this area

Procedures of restoration are summarized in followings:
1- Determining the restoration block (area) and shutting gas down in pipes (first day).
2- Leakage control and repairment (second and third days).
3- Check of gas pipes and meters of buildings, repairing them and opening the valves (forth day).
The restoration time became more than that was estimated at first. The main reasons for long time of restoration are as followings:
1- Time necessary for decision making about gas shut down in different areas.
2- Checking for and removing water and sand in gas pipes.
3- Damage to the roads, streets and houses which made it very difficult to access the damaged parts.
4- Necessity of checking the gas pipe system of buildings.

Countermeasures: Performance of gas pipes in man-made islands which were aseismic designed by using flexible joints and double pipe method in man-made islands showed that these countermeasures have been effective against liquefaction and ground subsidence.
The main aseismic countermeasures of Osaka Gas during the restoration are:
1- Replacing damaged joints by aseismic designed mechanical joints.
2- Replacing a number of damaged pipes by Poly-ethylene ones.
3- Replacing damaged gas meters by maiconmeters.
For the future plan of countermeasure against earthquake two important points should be considered.
1- Long period of restoration showed that the physical countermeasures (such as aseismic design of pipes and joints) merely are not enough, and it is necessary to have a complete and comprehensive plan for damage restoration in the emergency cases (after earthquake).
2- Any kind of interaction (functional, structural, elector-chemical) between the lifelines which are installed beside each other should be considered in countermeasure plan.

3. Water system

Water cut off: One of the main water supplier companies in quake-hit area is Hanshin Water Corporation which can supply more than 726,274 m^3/day for about 2,470,888 population in Hanshin area. Kobe city water bureau supplies about 200,000 m^3/d from its water resources, 619,000 m^3/d from the above mentioned company and 16,000 m^3/d from Hyogo province. Due to the earthquake there were serious damage to water system functionally and water was cut off to a large area. There was not enough water for fire fighting, neither for hospitals nor for temporary shelters. Due to the lack of electricity, water could not be treated in Treatment Plants so it was necessary to cut it off.

Damage: More than 4 reservoirs (treatment and distribution) in Kobe city (such as Nunobiki, Uegahara, Karasuhara, Motoyama, ...) suffered from the quake, which the most severe damage occurred in Uegahara facilities. Several other ones were damaged in other cities hit by the quake. The main damage monitored in reservoirs are as followings:
1- Damage to pumps, generators, and electric facilities.
2- Damage to access roads and bridges.
3- Partial damage of buildings

4- Damage to the joint parts of pipes (transmission and distribution) specially those between pipes and storages.

Damage states in Transmission pipes are summarized in Table 4 .

Table 4 - Damage to the transmission lines

Name	Diamater (mm)	Material	damaged locations	Remarks
Hanshin water Corporation	1500	-	5	
	1200	-	2	
	2100	Steel	-	Flexible joint
Hyogo provience	700	DCIP	1	
Kobe city	1200	-	Too many	
	500	-	Too many	
	500	PC		Water leakage through joint
	300	HP		Cracks in pipe body
Ashiya	200-700	-	22	
Itami	500	CIP		Joint separation
	1000	PC	2	
	400	-	1	
Takarazuka	-	-	8	

Some information about the distribution pipes in Kobe are shown in Table 5.

Table 5 - Distribution pipes in water system of Kobe city

Pipe Material	Joint Type	Length (km)	Percent of Total	Remarks
Ductile Cast Pipe	Earthquake resistant Joint (S, SII)	237.3	6.0	For over ϕ400 mm (trunk main) Below ϕ300 mm in reclaimed land and lanslide,..
	Mechanical joint (K)	3,180.2	80.2	For ϕ300 mm (submain)
	Titon joint (T)			For ϕ75-200 mm (distribution pipe)
Steel Pipe	Welded joint	103.3	2.6	High pressure pipe
Cast Iron Pipe	Mechanicl joint (A)	308.9	7.8	Replacement in progress
	Leaded joint	7.0	0.2	
Poly-Vinyle Chloride Pipe	TS joint	126.4	3.1	Replacement in progress
Asbestos Cement Pipe	-	0	0	Replacement completed in 1987
Total	-	3,963.1	100	

A large number of distribution (main) and supply pipes were damaged due to the quake. In Kobe city 1,422 locations of main and 10,135 ones of supply pipes have been damaged. More than 40,474 of private pipes of buildings have been damaged in this city. The damage of distribution pipes in Kobe are summarized in Table 6 . There are also 73 damaged locations in main pipes of Hanshin Water Corporation. A steel pipe with 700 mm diameter passing through Rokko Big Bridge, and a steel pipe with 600 mm diameter passing through Kobe Big Bridge (in Port Island) buckled and failed by shear in welding. Another ductile cast iron pipe with 900 mm diameter damaged in joint part. Main pipes damaged in Akashi and Amagasaki cities in 85 and 130 locations respectively.

The main damage modes in main and supply pipes were :

1- Separation and leakage of joints.

2- Pipe buckling and deformation due to the permanent ground movement.

3- Cracks in pipes body.

One of the weak points, which sustained so many damage was the connection between the main pipes buried under the streets (near the pavements) and the supply pipes of buildings. Usually the supply pipes pass under the small channel of rainfall an then come up and then inter the building. The joints and specially the valves in these parts sustained so many damage which is supposed to be due to non flexibility against the ground shaking and movement in these parts.

Table 6 - Damage to the main distribution pipes in Kobe

Diameter (mm)	Length (m)	Damaged Locations	Damage percent Location/km	Damage state		
				A	B	C
50	63,143	15	0.24	6	9	0
75	165,051	40	0.24	7	30	3
100	790,329	197	0.25	43	127	27
150	1,455,137	301	0.21	55	206	40
200	744,689	138	0.19	23	104	11
250	39,706	6	0.15	3	3	0
300	386,606	139	0.36	20	96	23
350	18,195	5	0.27	0	4	1
400	79,700	30	0.38	4	17	9
450	3,082	0	0.00	0	0	0
500	88,450	24	0.27	2	7	15
560	45,244	13	0.29	2	3	8
700	46,857	24	0.51	1	7	16
800	10,284	9	0.88	3	5	1
900	26,131	21	0.80	1	6	14
1000	498	2	0.02	0	0	2
Total	3,963,062	964	0.24	170	624	170

A= Deformation and crack of pipes
B= Joints pull apart
C= Valves damage

Due to failure of sixth floor of building number 2 of Kobe municipality it was not possible to access to the map of main pipes and other necessary document in Kobe. One of the other buildings of Kobe water bureau was partially burnt in west of the city. However, an emergency shut valve system has been developed in Kobe Water Bureau in recent years as a countermeasure during earthquake which could save 400,000 ton waters in 18 reservoir tanks and supplied drinking water just after the quake.

Restoration: After more than two months of earthquake occurrence restoration activities were continued. The main reasons for such a long restoration period are as follows:

1- There was not enough water pressure to find the leakage parts as soon as possible.

2- Damage to roads and streets which made it difficult to reach to damaged area quickly.

3- Large number of damaged houses which made it difficult to find the damaged places.

4- Removing the damaged structures and restoration activities of other facilities (buried pipelines) caused damage to the water pipes which were not damaged during earthquake.

5- Damage to the main office building of Kobe Water Bureau.

6- During the restoration, people were using purified water. Because after repairment of a pipe, it was wash out (inside the pipe) by the flow of water and then the quality was controlled, which needed much more time.

The common method for repairment of damaged parts of pipes was cutting that part and then inserting the replace segment between the two cut parts using two joints (dressing) at the ends.

Countermeasure: The outlines of countermeasures are depicted in Fig. 1.

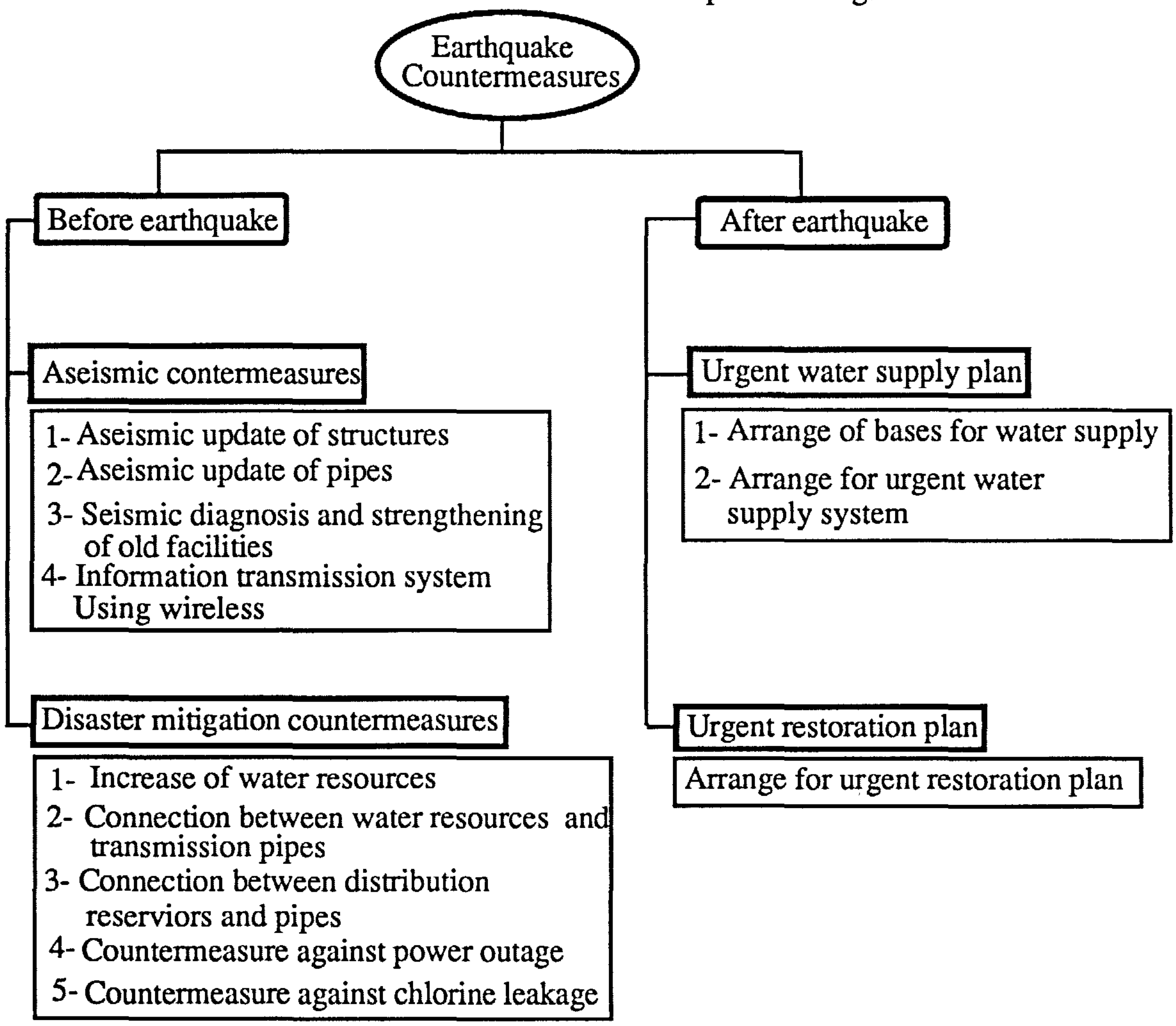


Fig.1 - Outlines of earthquake countermeasures in Kobe city

Three other important points for the future countermeasures are:
1- Using more flexible joints such as S and SII in stead of mechanical joints, in spite of these types of joints are about 30% more expensive.
2- Using Plastic pipes for replacement of damaged ones.
3- Setting more reservior tanks with emergency shut valve system.

4. Waste water system

General view: More than 16,029 ha of Kobe city are handled by Kobe waste water bureau with more than 3,315 km and 484 km (60% open channels)pipes for gathering waste water and rainfall, respectively. The waste water system mainly is the tributary method, but in some parts the combined method also is used.
There are 7 treatment plans with about 737,415 m3/day and 23 pump station. There is also one sludge center with 600 tons capacity per day.

Damage: Three Treatment Plants in Higashinada, Chubu (Central part) and Seibu (west part) were damaged, which the first one is very severe but the two others were urgently restored in the first day of quake. The preliminary restoration Higashinada plants will be completed by the end of February of 1995, but its final restoration takes about 2 or 3 years. One of the main damage in Treatment Plants was severe damage of intake pipes. The concrete piles under the administration office in Higashinada buckled in liquefied area. It should be noted that the main office of Kobe waste water bureau was in the 5th floor of the building number 2 of the Kobe municipality which its 6th floor (main office of Kobe water bureau) collapsed completely. From the 15 waste water pumps and 11 rainfall pumps, 5 and 1 were damaged respectively. Damage to the facilities of other cities are summarized in Table 7 .

Table 7 - Numbers of damaged locations of waste water system

City name	Treatmant Plant	Pump station	Pipe
Amagasaki	3	6	30
Akashi	3	6	5
Nishinomiya	3	11	50
Ashiya	1	2	75
Itami	-	-	3
Takarazuka	-	-	64
Kawanishi	-	-	9
Total	10	21	236

The main waste water pipe of Hyogo province was buried with 5-8 m depth and did not suffered any damage from the quake. From 32 of waste water trunk line with 83,900 m length, among 23 of them (length about 67,100 m) about 4,273 m of conduits were partially damaged, while there was not any damage to 5 of them with 12,900 m length.

About 10 percent of pipes were China pipes which severely damaged. More than 20% are PVC pipes which there was not damage to them. Approximately 70% of the pipes are concrete pipes which the main damage in them are as follows:

1- Damage of joint parts specially between man-holes and pipes.

2- Uplift of manholes in liquefied areas (such as Port Island).

3- Flow of sand and soil inside the pipes (due to the big fracture in pipes or joints).

4- Pipe body failure.

5- Damage to private (houses) pipes.

Damage to pipes of waste water system of Kobe city are summarized in Table 8. Total damage to waste water system of this city is estimated more than $350 millions.

Table 8 - Damage to the pipes of Kobe waste water system

Damage state	Wastewater	Rainfall	Total
Damage to man-holes	672	138	810
Damage of road surface	314	58	372
Pipe damage and breakage	76	57	133
Water flooding	0	0	0
Flow of sand into pipes	41	4	45
Others	44	10	54
Total	1147	267	1414

Restoration: More than 30 restoration teams, each of them composed of 5-6 persons have restored about 4000 locations by March 10, 1995. The main steps in inspection and restoration are as follows:

1- Preliminary inspection from the man-holes.

2- Using Tele-Camera inside the pipes to monitor the damage states (about 37 cameras)

3- Technicians getting inside those parts with pipe section deformation or pounding of waste water.

There was not any effect from damage of the pipes and facilities on public health. In one place waste water flew out from the damaged pipes which immediately were controlled and repaired. The complete restoration of pipes takes about 2 years.

Countermeasure: The outlines of countermeasures for earthquake in future are as follows:

1- Deep buried tunnels (shield tunnel) for transmission

2- Connecting between Treatment Plants in liquefied areas (Higashinada) with other Plants.

3- Liquefaction countermeasures (Table 9)

Table 9 - Countermeasures against liquefaction

Name of Treatment Plant	Outline of liquefaction contermeasures
Higashinada	Construction with pile foundation
Port Island	Sand drain method, Sand compation method
Seibu	Vibro composer method
Tarumi	Ground improvement and Construction with pile foundation

5. Electricity System

Electricity cut off: Power is supplied through steam, water and nuclear power plants and transmitted by 500 and 275 kv high pressure lines to the Transformer Substations and then distributed by low pressure lines to the consumers. Most of the transmission lines are aerial, however recently the underground lines have been increased because of highly impacted areas and to have a more beautiful view of the city. There was a big damage to this system which caused electricity shortage up to 2836000 kw in a large area from Hyogo to Kyoto prefectures.

Damage: From 112 damaged transmission lines, 96 were underground ones. Totally 660 distribution line damaged which the damage ratio for both the aerial and buried lines was almost the same.
Due to the non-uniform settlement between the buildings and pavement, the large ducts shifted, the joint apartheid and the ends of cables were damaged. Due to this phenomena it was not possible to supply emergency power to the areas which were covered by 64 damaged lines.
Damage to the electric facilities are summarized in Table 10.

Table 10 - Number of damage in electric system

Facilities		Unit	Number of damage		
			A	B	Total
Power plants		Location	5	4	9
Transformer Substation		Location	17	30	47
Transmisson	Aerial	Line	11	12	23
	Buried	Line	3	92	95
Distribution		Line	649	-	649
Telecommunication		Line	-	76	76

A= Severe damage to main facilities
B= Damage to other facilities including light damage to mains

Among the power plants there was not damage to the water and nuclear ones, while the steam power plants were damaged in 10 places. However damage to these plants were not in the important parts (boilers, turbines and oil tanks). The maximum accelerations in some stations are shown in Table 11. The big amounts of acceleration specially vertical one (such as Shin Kobe and Amagasaki) caused damage to Power Plants and Transformer Substations in 10 and 50 places respectively.

Table 11 - Maximum accelerations in some PGP and PTS

Location	Maximum accelerations (gal)	
	Horizontal	Vertical
West Kyoto (PTS)	130	84
Shinkobe (PTS)	547	478
Amagasaki (3th PGP)	279	331
Danto (PGP)	126	199
Akaho (PGP)	104	122

PGP=Power Generation Plant
PTS=Power Transformer Substation

In the areas with damage intensity of 7 (MM=XI), 14 of 29 Transform Substations (about 50 %) were damaged, which most of them were constructed before 1965. There were 7 , constructed after 1975 which didn't suffered any damage from the quake (Table 12).

Table 12 - Damage in Transformation Substations considering the construction time

State	Befor 1955	1955-1965	1965-1975	After 1985	Total
Damaged	7	7	-	-	14
Non damaged	3	5	4	3	15
Damage Ratio	0.70	0.58	0.00	0.00	0.48

Restoration: The main outlines of restoration plan after quake were as followings:

1- less than 5 days after the quake

-Urgent power supply for the emergency places such as hospitals, shelters and the organizations whose activities has priority in restoration.

2- About two months after the quake

- Increasing the urgent electricity and control of its safety.
- Supplying electricity for temporary houses and the construction sites.

3- From 6 months to one year after the quake

- Replacing the preliminary restoration by the permanent one.

4- Several years

- Revival of pervious plans by using the new facilities which will be designed by the most update seismic design standard

Immediately after the quake, retrofitting and restoration operation started and the other power suppliers in other parts of Japan supplied the necessary amount of electricity for the quake-hit area and dispatched their technicians to the area. There were 3300 persons for restoration which this number increased to 6000 from Jan. 23, 1995.

The most important points during restoration which should be noted are as follows:

1- The aerial lines were restored more quicker than underground ones and were used for supplying the emergency power to the area. While finding the damaged locations in underground cables needed more time and their restoration also took much more time comparing to the aerial ones.

2- Due to damage of roads and streets supplying the necessary equipment and parts for damaged locations was very difficult and caused restoration time to become more long.

3- Helicopter was very helpful in the daytime while in the night it was difficult to use it.

4- The experiences of Miagioki Earthquake was used for aseismic countermeasure in quick restoration in this earthquake.

Countermeasure: The outlines of countermeasures against earthquake can be summarized as in Table 13.

Table 13 - Aseismic design outlines for electric facilities

Facilities	Aseismic design idea
Power Trasformation Facilities	Basically aseismic design of facilities should be done for intensity 6 (in Japanese scale) and based on the experiences from Kanto Big Earthquake
Steel Towers Electric poles	Condition 63 of techneical standard for design of electric facilities against wind pressure should be modified for the load due to an earthquake with intensity of 6.
Buried facilities	The common ducts with cables inside should be designed for intensity 6 so that even in the case of damage to the ducts, there will not be any damage to the cables functionality

6. Telecommunication system

Cut off: There are about 1,443,000 lines in quake-hit area which more than 285,000 of them (122,000 lines in Kobe) were cut due to damage to the cables and facilities. The main causes of interruption of these lines are :

1- Power outage of switching system

2- Buildings damage

3- Cables damage and cut

Damage: Between central and Nagata wards of Kobe, some parts of NTT cables and facilities are located inside the underground tunnels. One of the tunnels has been constructed by open-trench method and the other one is a shield tunnel. There was not any damage to the shield one, while the other one suffered damage in joints and walls. Totally there is about 360 km underground tunnel composed of about 4000 spans in Kobe city. The results of damage investigation in more than 1000 of these spans (in the south of national route No. 43) showed that in 20 to 30 percent of them most of damage are in man-hole parts. It should be noted that in spite of damage to the tunnels, there was not damage to cables and their functionality continued safely. The main damage to the NTT tunnels are summarized in Table 14.

Other damage to NTT facilities are mainly as follows:

1- Damage to the cables due to the ground settlement around the buildings.

2- Deformation of those cable which were supported by the long-span bridges due to the compression.

3- Damage of 3 buildings of NTT (specially Minato Buildings) which were repaired and strengthened.

4- Buckling of NTT tower in central ward of Kobe.

Table 14 - Outlines of damage in NTT Tunnels

Location	Damage state
Near Minato building (Kaigandori, centeral ward)	Slip off of the expansion joints in 2 places (h=7 cm, v=7 cm) , (h=8 cm , v=15 cm)
Near Kobe branch (Kaigandori, centeral ward)	Damage to the slab and the wall of the special section Damage to the neighboring hunch part
Near Minatogawa building (Hyogo ward)	Cracks in the slab and the walls of the special section Buckling of the steel cords in middle of the tunnel
Kamizawadori 4 chome (Hyogo ward)	Slip off of the expansion joints in 1 place (h=4 cm, v=13 cm) Flow of sand inside the tunnel due to liquefaction
Kamizawadori 7 chome (Hyogo ward)	Cracks in on the wall of the special section

h=horizontal v=vertical

Restoration: There were 4000 persons (1000 from Kobe branch of NTT and 3000 from other places) doing the preliminary restoration, while it is estimated that the complete restoration needs 3-5 years.

Countermeasure: The main points for aseismic countermeasure plan for future can be summarized as follows:

1- Well functional performance of those cables and facilities which were installed in underground ducts.

2- Finding and repairing damage of buried structures is time-consuming, so it is necessary to find some suitable method for predicting the damage locations.

3- The related buildings specially those with important facilities or top-heavy ones should be more reliable and safe.

7. Damage to collocation lifelines

One of the important problems which recently have been experienced during the earthquakes in big cities is the damage to the lifelines which have been collocated in one place. The main cause of damage to the buried lifelines in such a cases is the large ground displacements. This phenomena was reported in some locations in Kobe during the quake.

There was a large ground displacement (maximum settlement in the Main of street about 3 meters) in Daikaidori Station of Kobe subway which caused a severe damage to the subway tunnel, station and several buried pipelines of lifeline systems which were installed above the tunnels, underground. The main gas pipes, water and 3 of waste water and rainfall pipes were severely damaged. They were restored by new by passes.

The other case of collocation of buried pipelines was in Sannomiya area (downtown of Kobe) near the Boeki station of Port liner. There was a collection of different lifelines including gas, water, waste water and cable ducts. In this place there was also a severe damage to the main gas and main water pipes due to the horizontal ground displacement permanently. Gas pipe was steel with 40 cm diameter and water pipe was ductile cast iron pipe with 90 cm diameter and 18 mm thickness.

8. Concluding remarks

Considering the common points of performance and damage of lifeline systems during the south Hyogo earthquake in Jan. 17, 1995, some remarks can be concluded as the most important lessons from this earthquake concerning the lifeline earthquake engineering, as followings:

1- The main cause of damage to the above ground lines and facilities was damage of structures (such as buildings, bridges, towers, poles,...) due the severe ground shaking.

2- The main causes of damage to the underground lines were liquefaction and ground movements.

3- The weakest points of lifelines networks were man-holes, joints and specially those connection facilities between the main and the supply lines (between the street and building).

4- Those under ground lines which were buried relatively deeply did not sustain any damage or severe damage from neither from ground shaking nor from ground movement.

5- Damage to the large number of buildings, transportation system, administration office buildings and the functional interaction between the lifelines were the main causes of long time period of restoration.

6- Updating the seismic structural design of lifeline facilities for intensity 6 as a countermeasure plan before the earthquake is necessary. While for post earthquake countermeasure a sophisticated and comprehensive plan is much more necessary.

7- Redundancy in the lifeline systems specially for those facilities which are in the areas with the high damage risk is supposed to be the main factor in restoration and countermeasure plans.

Acknowledgments

The authors would like to express their best appreciation to those persons in Osaka Gas, Kobe Water Bureau, Kobe Waste Water Bureau, NTT and other organizations for their kind assistance. They also thank the those students and staffs of Civil Engineering Department of Kobe University who helped the authors with their best.

(by Shiro Takada and Nemat Hassani)

Outline of the Geographical Information System (GIS) Database and Internet Information

1. GIS Database

One of the aims of the scientific investigation is that disaster information from the Hyogo-ken Nanbu Earthquake can be accurately recorded in detail. As explained in paragraph 4 of the Japanese text, investigation was carried out with housing maps. These results are arranged on the National basic topography maps on the scale of 1 to 2500. The investigation results was input into GIS and a database was created to apply these results for more effective research.

In Japan, GIS is applied to the management of districts, regions, national land, disasters, environment, resources, etc. and to civil engineering construction management.

The characteristic of GIS is that geographical position data can be used just like non-spatial data. For this, GIS consists of software, hardware and its procedures. The acquisition, management, operation, analysis, modelling, expression of spatial data and the solution to the problem of the handling of a lot of spatial data can be supported.

GIS is mainly used in Engineering Work Station (EWS) base. Personal computer base, pc ARC/INFO was introduced to the Reclamation Engineering Research Institute in Kobe University a few years ago and was used to promote the location analysis of housing development. Besides the cost of the software being high, it was felt that the ability of the personal computer was not sufficient to use software made for EWS. In choosing between the EWS's GIS or the personal computer base's GIS, it was decided that the personal computer base's GIS be adopted. The reason for this is the high cost of the software and hardware of the EWS's GIS and for the sake of the many researchers who may want to use the earthquake data.

The system adopted is called GEOSIS. This system has many features, including it can be operated on personal computer, raster (including color raster)/vector data can be combined, it has menu type screen, it is possible to customize the database design or other systems. By applying the "customize" feature to this research, the earthquake database system as shown in Figure 16.1.1 in the Japanese language report was designed. The regions studied consist of 7 cities and 5 towns. The base map has a scale of 1 to 2500, on which the various data were input as vector data. An example is shown in the frontispiece photograph 63. The geographical information was input as raster data into the National basic topography map of scale 1 to 2500. The method of vectoring investigated data was adopted. Besides that, aerial photographs were applied onto the base map. Moreover, site photographs taken during the investigation were also input as data. A list of the existing maps used are shown in Table 16.1.1 in the Japanese language report, while the input data and the data to be input are shown in Table 16.1.2 in the Japanese language report. The conditions and distribution of the damaged buildings of the 1st to the 3rd investigation results are shown in the frontispiece photographs 9 to 21. Frontispiece photographs 9 to 14 show the distribution of damaged buildings on the topographical maps, 15 to 21 show that on the geological maps while 22 shows that on geomorphological map (red dots : total damaged, yellow dots : half damaged and green dots : partly damaged). Figures 4.5 to 4.10 in the Japanese language report show the distribution of damaged buildings on land use maps while Figures 4.11 to 4.14 in the Japanese language report show that on land condition maps.

The flow for creating the database is shown in Figure 16.1.2 in the Japanese language report. The constituents of the adopted equipment and their interactions are shown in Figure 16.1.3 and Table 16.1.3 in the Japanese language report.

Sufficient ability has been shown for the possibility of the required overlay, buffering, re-classification, analysis, synthesis, statistical treatment and image treatment of the input data. This research attempts to derive the relationship between the distribution of damaged buildings to geological, land condition, land use and geomorphological maps, and plans to study the causes of the failures. In future, 3-dimensional ground conditions models will be constructed by using data from bore-holes and the distribution of damaged buildings, utility lifelines, railway lines, roads, tunnels, underground structures, river structures, port facilities, shore protection structures and sewerage facilities, liquefaction of reclaimed land, and mountain failures will be studied.

2. Internet Information

(1) Kobe University Campus Network

The information network, KHAN (Kobe Hyper Active Network) was completed in October 1994 at Kobe University. This is based on the idea of multi-media input visual field campus high speed network, that is, anybody at anytime from anywhere can use the high speed multi-equipment computer and communication sets in the campus and apply it freely to research and education (network computing environment). Based on this, highly specialized post-graduate education and research can be carried out. With this, intelligent campus can then be realized.

(2) Kobe University's World Wide Web (WWW) Server and Earthquake Information

As the nucleus for the despatch of information on internet by using KHAN, it was possible to collect and exchange Kobe University's information and other agencies information and synthesis them by combining them together. These are carried out on Kobe University WWW's establishment. The 1st page of Kobe University WWW's home page, in Japanese and English, is shown in Photographs 16.2.1 and 16.2.2 (in the Japanese language report) respectively. Due to the power failure immediately after the Hyogo-ken Nanbu Earthquake, Kobe University Synthetic Information Management Center's equipment was interrupted and network communication was not possible temporarily. It was restored the following day (January 18). To enable this network be used for the exchange of earthquake information, a core group of people including Information Network Application Committee Chairman, Associate Professor Kunisada Ebina, Research Associate Kazuyuki Taruma of the Synthetic Information Management Center, Associate Professor Kazuhiro Otsuki of the Faculty of International Culture and Research Associate Toshiharu Samura of the Faculty of Science and Technology placed earthquake information page into Kobe University's home page. Kobe University's information on students casualties, the damage suffered by the university, lectures & other schedules after the earthquake, entrance examination for the new academic year, volunteering activities, etc. were placed on this page. Moreover, similar to Kobe University, immediately after the earthquake, Kobe city (Kobe City Foreign Language University support), other universities, agencies, companies, etc. started to offer earthquake information on WWW and had information link up. Kobe city's WWW home page was mirrored on the server outside the city by resolving the complexities in information transmission and reducing the load on the network through the efforts of related agencies such as NTT and NEC. Other than this WWW's information offer, to promote the effective flow of information among the information sponsors within and outside Kobe University, a private mailing list on internet (quake-vg@kobe-u.ac.jp) was established. The 2nd step of the WWW information offer is to increase these general information and information on the development of the earthquake investigation conducted by Kobe University and other related information, and to link them up it was concluded that it is necessary to set up a scientific information page. Professor Takeshi Nakajima, Associate Professor Yuji Ikeda and Research Associate Shigeo Hosokawa of the Mechanical Engineering Department, Faculty of Engineering, prepared the support organization, proposed the idea of establishing KRISS (Kobe Research Information Service System), and volunteered to set up the entire work, for the sake of linking up the development and collection of earthquake scientific data. The Hyogo-ken Nanbu Earthquake Scientific Investigation Team of the Civil Engineering Branch, Faculty of Engineering, Kobe University, established the Hyogo-ken Nanbu Earthquake Information Center and carried out information perusal and copy services, immediately after the earthquake, to make public the important information concerning the scientific investigation and its results. Together with that and especially, as a mean to offer information to foreign countries, both Ebina and Taruma investigated the use of internet on WWW which can display effects and offered consultations. From the consultations with the 3 persons mentioned above, the earthquake scientific information page was established on February 3rd. Within this page, the Faculty of Engineering Earthquake Information Center's page was inserted. After that, on the earthquake scientific information page were added 5 other pages in order, namely, Kyoto University's Disaster Prevention Research Institute page, Space Development Project group page, Ministry of Construction's National Land Geography Institute page, Railway Technical Research Institute page, and Fire Outbreak Causes page.

3. The composition of the Internet earthquake scientific information support organization

Even though the Faculty of Engineering Earthquake Information page was inserted into the Kobe University's WWW home page, the actual information collecting, processing and maintenance management need a lot of effort and the establishment of a support organization is very important. Thus, an organization as below was set up.

* Associate Professor Kunisada Ebina and Research Associate Kazuyuki Taruma : responsible for the supervision of WWW, network and earthquake information and response to any enquiries on the earthquake information.

* Professor Takeshi Nakajima, Associate Professor Yuji Ikeda, Research Associate Shigeo Hosokawa and Mr. Naoki Yamada (graduate student) : volunteered to be responsible for earthquake related scientific information support service (KRISS : Kobe Research Information support service). Also responsible for the registration and making public earthquake related scientific information and the windows on the exchange of opinion and information and support information collection.

* Associate Professor Mayumi Morimoto of the Faculty of International Culture : volunteered to be responsible for translating the earthquake scientific information into English.

* Professor Shiro Takada and Research Associate Hidenori Morikawa of Kobe University Faculty of Engineering Earthquake Information Center : responsible for the arrangement of accumulated scientific information for inserting into Internet.

4. Outline on the method to access to earthquake scientific information and its contents

In the beginning, access into Kobe University's WWW home page (address : www.kobe-u.ac.jp), after that from the menu, access into Kobe University earthquake information page is possible. But because of the heavy network load to Kobe area, the access may take some time. In that case, it may be better to access from the prepared mirror sight from outside Kobe.

After access into Kobe University's WWW home page has been gained, Photographs 16.2.1 (in Japanese) and 16.2.2 (in English) in the Japanese language report will appear on the screen. Here, choose (mouse click) Hanshin-Awaji Great Earthquake (Hyogo-ken Nanbu Earthquake) Scientific Information and scientific information's menu as shown in Photographs 16.2.3 (in

Japanese) and 16.2.4 (in English) in the Japanese language report, which contain 7 items, namely, (1) KRISS (Kobe Research Information support Service), (2) Kobe University Faculty of Engineering Earthquake Information Center, (3) Kyoto University's Disaster Prevention Research Institute, (4) Space Development Project Team, (5) Ministry of Construction's National Land Geography Institute, (6) Railway Technical Research Institute and (7) Fire Outbreak Causes will appear on the screen. Next, click (2) Kobe University Faculty of Engineering Earthquake Information Center and you will arrive at Kobe University Faculty of Engineering Earthquake Information Center as shown in Photographs 16.2.5 (in Japanese) and 16.2.6 (in English) in the Japanese language report. Here, at present stage, the First Quick Report on the Hyogo-ken Nanbu Earthquake by the Hyogo-ken Nanbu Earthquake Research Group, Department of Architecture and Civil Engineering, Faculty of Engineering, Kobe University and the maps of the damaged buildings in Kobe city (plotted on geological/faults, land use and geographical maps) is inserted as shown in Photographs 16.2.7 (in Japanese) and 16.2.8 (in English) in the Japanese language report. In the earthquake research report, frontispiece photographs and each chapter together with their appendices can be selected and important information can be read or printed. For example, Photographs 16.2.9 and 16.2.10 in the Japanese language report are examples of the gravure photographs while Photographs 16.2.11 and 16.2.12 in the Japanese language report are examples of the text. In this way, important text, figures and photographs can be called out and viewed. Meanwhile, the damaged buildings are plotted on the geological/fault, land use and geographical maps of:- 1) the entire region of Kobe city, 2) the enlargement of the eastern part of Kobe city, 3) the enlargement of the central region of Kobe city, 4) the enlargement of the western part of Kobe city (red dots : total damaged, yellow dots : half damaged and green dots : partly damaged) and these are inserted in the item on the maps of damaged buildings. For example, Photographs 16.2.13 and 16.2.14 in the Japanese language report show the distribution of the damaged buildings plotted on the geological/fault, geographical maps of the central region of Kobe city.

5. Earthquake Scientific Information Access Situation

Through the above details, composition and contents, the Internet information offer on the earthquake investigation results was started. The earthquake scientific information page was set up and the announcement on the insertion of the information was made on February 3, and by the 4th week of February, the First Quick Report and the map on the distribution of damaged buildings were inserted. Up to March 9, the access to this information is shown in Table 16.2.1 in the Japanese language report. Immediately after the announcement on the insertion, the number of domestic access increases rapidly. It dropped once, but after the report and the maps have been inserted, it increases again, showing a very sensitive response. Up to March 9, the number of domestic access recorded is 1489 while the access from foreign countries, though it shows an increase after the insertion of the report, is only about 6% of the domestic access.

6. Conclusion

In this earthquake, civil engineering structures and buildings suffered enormous damaged while computer equipments and networking systems suffered very little functional damage. Even though there was a disruption of electricity supply, it was quickly restored. Thus, it appears that communication of information through network can be very effective. These include the various types of information from information concerning safety, welfare, & aid to scientific information. Moreover, information developed from various places can be combined and managed systematically. Even though this process involves trial and error, but it can result in the smooth operation of information management network by information seeker, in other words, approaching information super-highway. This paper introduced the trial of Internet information offer of earthquake research results, and the degree of reaction to the offer from the data on the number of direct access. At the national level, though combination and management of information using the earthquake investigation results have been done, its effectiveness could not be measured concretely. But domestically, network popularization ratio cannot be said to be high and the effective means of its usage (i.e. anybody at anytime from anywhere can use the system simply) cannot really be said. Therefore, we propose that a national project be established to enable universities and research agencies promote the popularization and arrangement of domestic networks, the arrangement and connection of domestic networks to overseas networks and the establishment of such a network.

(by Takashi Okimura, Hidenori Morikawa and Teng Hye Koid)

第２次、第３次調査および資料の整理に協力していただいた方々

〇神戸大学大学院自然科学研究科助手

李　騰雁

〇神戸大学大学院自然科学研究科博士後期課程院生

白川和靖、大久保高志、河合琢也

〇神戸大学大学院工学研究科院生

鄭　勝仁、牛田智樹、久保勝俊、坂井逸作、渡辺佳秀

〇神戸大学大学院自然科学研究科博士前期課程院生

尾崎竜三、榎本真浩、北山　篤、中川正樹、中西　誉、浅田昌蔵、門田克史
河井克之、山口　充、宮本岳人、西川　亨、恒藤博文、鳥居宣之、原田　貴
遠山直樹、能勢正義、坂本　格、川端　稔、伊藤達平

〇神戸大学工学部土木工学科学生

松本正人、嘉嶋崇志、前田俊宏、中島健司、松本隆史、片山憲一、井上　卓
鈴木弘俊、繁本　護、芦田　渉、伊井政司、落合　修、西野日出樹

〇その他

住友金属工業、三菱重工業、大成建設、フジタ、鹿島建設、阪急電鉄、オオバ、佐藤工業、銭高組、コープラン、ＮＨＫ、日本コンピュータグラフィック、富士通、セイコー電子工業、栗本鉄工所、片山ストラテック

（順不同）