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(Citation)
神戸大学都市安全研究センター研究報告. 特別報告, 1:2-18

(Issue Date)
1998-07

(Resource Type)
departmental bulletin paper

(Version)
Version of Record

(JaLCDOI)
https://doi.org/10.24546/00044711

(URL)
https://hdl.handle.net/20.500.14094/00044711

Damages and disasters caused by the Create Hanshin Earthquake, Japan 1995

Takashi Okimura 1)

Abstract: On 17 January 1995, a big earthquake, registering magnitude 7.2 on the Richter scale hit the western part of Japan, claiming 6,394 lives, injuring at least 40,071 people, and destroying properties and infrastructures, causing an estimated damage of between 95 to 140 billion U. S. dollars. This paper gives a detailed description of the disaster and attempts to provide a scientific explanation to the disaster.

Key words: earthquake, fault, liquefaction, slope failures, bulding damage, damage of transportation system, lifeline

1. Introduction

On 17 January 1995 at 5:46 a.m., a big earthquake, registering magnitude 7.2 on the Richter scale hit the western part of Japan. The epicenter of the quake appeared at the northern tip of Awaji Island, an island in Osaka bay, off the coast of Kobe city. The highest intensity and the most severely damaged areas were concentrated on the southern part of Hyogo prefecture. The location of the epicenter and the distribution of the intensities, as originally announced by the Meteorological Agency (MA) are shown in Figure 1. After further investigations, the quake intensity for part of Kobe and northern Awaji Island were later revised to 7, the maximum, on the Japanese scale. The intensity levels used by MA and its approximate relation to ground accelerations are shown in Table I. The areas with intensity 7 which suffered the most severe damage are shown in Figure 2. The quake claimed 6,394 lives and caused injuries to more than 40,000 people. The number of buildings destroyed was 247,486, affecting 444,900 households, while the number of buildings burnt down was 7,119, affecting 7,453 households, causing more than 316,000 people to take refuge at 1,153 temporary shelters. About 176 outbreaks of fire burned up approximately 641,000 m2 of the populated areas. Many bridges and tunnels along the transportation systems suffered severe damage, causing massive disruptions. Damages to the utility lines caused interruption of gas and water supplies to mare than 1,270,000 households. Electricity and telecommunication lines were cut of due to damages to their facilities. The total damage was estimated to be between 95 to 140 billion U. S. dollars.

2. Seismology

The epicenter of the quake was at 34.6N and 135E with a focal depth of 14 km. According to data recorded in 24 observatories, the fracture which triggered the earthquake occurred at Nojima fault. This fault is part of a group of faults known as "Rokko Fault" which stretches from Awaji island through Kobe city to the foot of Mount Rokko. The faults in this area are shown in Figure 3. The movement mechanism of the fault is the strike-slip type with lateral movement, from south-west to north-east. The compression in the east to west direction caused shear to occur in the south-west to north-east direction. The maximum horizontal and vertical displacements observed on the ground, as shown in Photo. 1, are about 1. 8 and 1. 3m, respectively.

The movement of the fault can be explained by the tectonic characteristics of west Japan. The main reason for the occurrence of big earthquakes in the western part of Japan is the tectonic activities of the Eurasian, the Pacific, the North America and the Philippine 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 west Japan. During the past 100 years, the big earthquakes with magnitude more than 7 on the Richter scale, such as the Nobi (1891), Tottori (1943) and Fukui (1948) earthquakes, had a strike-slip type of movement and can be explained by the above.

3. Ground Motion

Strong ground motions were recorded in many places by various organizations, such as the Committee Earthquake Observation and Research in Kansai area (CEORKA), Osaka Gas Co. and Japan Railway (JR) Co. CEORKA recorded the maximum horizontal and vertical component of the acceleration, Osaka Gas Co. recorded the vector combination of the accelerations while JR records were made after high cut filtration at 5 Hz. The data recorded by these organizations are summarized in Table II while the approximate location of the observatories and their recorded data are shown in Figure 4. The time history of the ground accelerations recorded by Kobe Maritime Meteorological Observatory (KMMO) is shown in Figure 5. The maximum accelerations in the north-south, east-west and up-down directions are 818, 617 and 332 gal respectively. Accelerations as big as these acting together at the same time had not been experienced before in other earthquakes in Japan, for example, the maximum accelerations of the 1923 Great Kanto earthquake were between 300-400 gal, which was only half of the accelerations recorded in this earthquake. Even though the maximum horizontal acceleration recorded during the Kushiro earthquake (1993) was 919 gal, but its vertical acceleration was small compared to this quake.

The response spectra of the above mentioned accelerations are shown in Figure 6. The bold lines show the results for damping ratio of 3% while the dotted lines show those for 5%. From Figure 6, the period in the north-south, east-west and up-down directions were 0.35-0.40, 0.70-0.80 and 0.25 s respectively. These periods caused small frequencies. The velocity in the north-south, east-west and up-down directions were 55.1 cms-1, 31.0 cms-1 and 33. 2 cms-1, respectively.

Acceleration time history recorded by 2 stations in Port Island (reclaimed land) at ground level and at 79 m below ground level which was set at Pleistocene series are shown in Figures 7 and 8, respectively. The horizontal acceleration in the north-south direction at the ground level is 341.2 gal which is about 0.5 times that recorded underground while the vertical acceleration is 555.9 gal which is about 3 times that recorded underground.

In general, the maximum horizontal and vertical accelerations of this earthquake were between 600-800 gal and between 300-400 gal, respectively. This shows that the vertical acceleration was about 50% of the horizontal acceleration.

4. Liquefaction and Damages to Harbor Facilities

The earthquake caused catastrophical damages to the coastal area of Hanshin region (which encompasses six cities, including Osaka and Kobe), especially Kobe area, where modern port and harbor facilities were constructed on reclaimed land near the shore. Kobe port was the number one international freight handling port in Japan, handling close to 70% of the international cargoes of Japan. The area map of Kobe port is shown in Figure 9. There are two major man-made islands in Kobe port, namely Port Island and Rokko Island whose areas are 436 and 580 ha respectively. These islands were built to serve as a modern container port along their perimeters as well as a new city with residential and commercial areas in the central part of the islands. They were constructed by placing sandy materials on soft clay at seabed and a typical ground profile of seabed is shown in Figure 10. The perimeter of the islands are protected by a long stretch of breakwater system, which consists of a large concrete caisson, 10-14 m wide. The foundation of the caisson consists of sand and cobble fill which were placed after completely excavating the soft clay from the seabed. The water depth in Kobe port varies from 10-15 m.

The quake destroyed the structures constructed along the shore-line of these islands with extensive liquefaction and large lateral movements of breakwater structures. These damages are typical of other damages suffered on reclaimed land. Typical examples are shown in Photos 2 and 3. Due to the liquefaction, ground settlements occurred and they were estimated to be between 5-60 cm in depth in Port island. Tilting and large horizontal movement of the concrete caisson accompanied by settlement and horizontal movement of the granular fill behind the caisson were typical failure modes. The movements of the shore-line were surveyed by using satellites and the measurements at Port Island are shown in Figure 11. The figure shows that the shore-line moved 2-3 m horizontally and settled on the average by about 1 m.

The possible cause of the sea-wall failure seems to be the combination of ground liquefaction behind the caisson, the lateral movement of the caisson due to the seismic force and liquefaction of the sandy fill behind the caisson. Due to the large movements of the shore-line, huge cargo cranes in container yards and port facilities sustained severe damages, and more importantly, many foundations of bridges and facilities connecting the man-made islands to the mainland were also damaged. For example, a section of the elevated track for the new automated train line connecting Rokko Island to the mainland fell more than 20 m because its pier foundation tilted and moved horizontally.

Although there were ground settlements at the center of the islands, most of the structures there did not suffer severe damages, probably because the settlements were quite uniform and small, compared to those at the edges and, moreover, these structures were built on long piles which extended to the lower bearing stratum of stiff sand.

5. Mountain Slope Failures

In order to get the distribution of mountain slope failures in Rokko mountains, failure distribution figure was made by using aerial photographs. The scales of the aerial photographs are 1 to 8000 and 1 to 4000 which were taken 3 days after the quake. Topography maps of scale 1 to 10000 were used as base maps. Figure 12 shows a part of the failure distribution which was reduced to a scale of 1 to 10000. The area of this map is Gosuke and Momiji valley, situated at the upper region of the Sumiyoshi river in Kobe. From this figure, it can be seen that (1) as a whole, there were many cases of small area failures, (2) the failures were mainly on very steep slopes, (3) flowed and eroded areas were very small, (4) the failures appeared on planar and/or crest slopes, (5) failures often appeared at knick points downwards from gentle to steep gradients, (6) some failures appeared at outcrop, (7) unstable rock mass failed and rolled along the slopes, as shown by example in Photo 4, and (8) big cracks developed along the mountain slopes which have not failed yet.

Figure 13 shows the distribution of mountain slope failures at the eastern part of Rokko mountains, which is composed of granite. As a whole, these failures were distributed along two belts. The big faults, namely, Suwayama, Gosukebashi and Ashiya faults are shown in this figure. The failures occurred parallel to these faults. The reasons for this failure distribution are thought to be: (1) shear movement of these faults by the quake, (2) these failures would have appeared on steep slopes which are usually seen along faults even if there were to be no shear movements, or (3) both (1) and (2). In the near future, the causes of this failure distribution will be studied by using equi-acceleration maps.

Figure 14 shows the aspect of the mountain slope failures caused by the quake. The failures occurred along the NW to SE direction. There are many faults in Rokko mountains which are perpendicular to this orientation as can be seen in Figure 13. Digital maps of mesh spacing 231 by 286 m were used to obtain the aspect distribution. The results are shown in Figure 15. From this figure, it can be seen that there are more slopes whose crest are along the NE to SW direction compared to the opposite direction. The ratio of mountain slope failures to their orientation is obtained by dividing the number of failures (Figure 14) to the number of slopes (Figure 15) respective to the orientation. The results are shown in Figure 16. There were many failures along the NW to SE direction and some failures along the NE to SW direction. It may be implied that the failures along the former direction appeared on the terminal facets while the failures along the latter direction appeared on the side walls of the small valley which developed perpendicular to the direction of the main faults.

6. Damage to Buildings

More than 247,000 buildings were destroyed by this quake, out of which 7,119 were burned down. The majority of the collapsed buildings were old timber houses which were located parallel to the fault line and most probably, were founded on weak ground. Some of the taller buildings in downtown Sannomiya, Kobe had shear failures in their intermediate floors. More than 2,900 out of 8,863 commercial premises in Kobe city suffered heavy damages. According to a survey carried out by the board of education, about two thirds of the schools or 223 schools sustained damages, out of which about 30 schools either collapsed or were unstable while 38 other schools were severely damaged with cracks in walls and fissures on the ground. Part of the distribution of the damages suffered by buildings is shown in Figure 17.

(1) TIMBER STRUCTURES

The failure modes of timber structures were: (1) tilting, (2) collapse of the first floor and (3) total collapse. The main reasons for these are: (1) aging of the materials, (2) there were no structural elements such as bracing to resist the lateral force, (3) poor connections between vertical and horizontal elements, (4) nonrigid floor and roof, (5) relatively heavy materials on the roof, and (6) impact forces from neighboring collapsed buildings. Examples of collapsed timber structures are shown in Photos 5 and 6.

(2) REINFORCED CONCRETE (RC) BUILDINGS

A large number of private residential reinforced concrete buildings overturned or collapsed at the first floor while the taller public housing, business and commercial buildings failed at one of their intermediate floors. The possible causes for these are: (1) interaction between the different modes of vibration causing maximum stresses and strains in one of the intermediate floors, (2) effect of construction methods on the shear resistance of the columns, (3) lack of shear and/or internal walls or having many wide openings in walls especially in external walls, and (4) combined effects of the vertical and horizontal vibrations on the shear resistance of the floors.

Some of the other factors that contribute to the damages are: (1) aging of materials, (2) poor quality of concrete, (3) lack of bond between concrete and reinforcing bars because of the use of smooth surface bars, and (4) the distance between stirrups and their arrangement were not appropriate. Examples of collapsed reinforced concrete buildings are shown in Photos 7,8 and 9.

7. Damage to the Transportation System (Including Bridges, Roads and Railways)

(1) HIGHWAY NETWORK

There are four routes between Kobe and Osaka, namely, (i) Hanshin expressway, Kobe route, (ii) Hanshin expressway, Wangan route, which runs along the shore line, (iii) national route number 43 and (iv) national route number 2. Several sections of the Hanshin expressway, Kobe route (opened in 1970) are elevated on piers. Of the 1,172 piers under the 32.7 km long expressway, 611 piers were damaged, out of which 150 piers were beyond repair and need to be replaced. Highway columns made of steel suffered less damage than those made of reinforced concrete. Most of the columns that remain intact were made of steel. Of the damaged columns, only 100 were steel columns and these are at the hardest hit areas. It is believed that the steel columns performed better than the reinforced columns and this could possibly be due to the ability of the material to absorb the energy generated by the quake. The difference in the resilience of the steel reinforcement and the concrete in the reinforced concrete may be a factor that caused damages.

The columns in the 635 m section of the Hanshin expressway, Kobe route which collapsed had only half the number of links required under the current anti-quake standards. Each of these columns are cylindrical in shape with a diameter of 3 m, having 180 vertical steel reinforcement of 35 mm diameter. Hoops of 16 mm diameter were put transversely at 20-30 cm intervals. Studies have shown that hoops can help the column to withstand severe transverse force and are effective in preventing the collapse of columns under severe earthquake. Under the new standards, hoops should be installed at 10-15 cm interval, especially in the lower part of the columns.

One section of the Hanshin expressway, Wangan route fell, while 30 piers cracked and damages were spotted at 440 locations along the route. All the damaged piers can be repaired. The collapsed section fell because of ground liquefaction which caused the foundation to settle as well as move laterally. Thus, the connection bolts ruptured and the bridge fell. This 52 m long by 27 m wide bridge was designed to withstand a horizontal earthquake acceleration of 0.2 g.

Two of the bridges along national route 43 completely collapsed. There were not much damage along national route 2. One of the bridges along Meishin expressway which connect Kobe to Nagoya collapsed. The longest suspension bridge in the world linking Kobe City and Awaji Island which was under construction was also affected by the quake. Both the piers on the northern part as well as on Awaji Island moved 20 and 30 cm, respectively. Examples of collapsed highway are shown in Photos 10 and 11. The distribution of the damage to the highway network is shown in Figure 18.

(2) RAILWAY NETWORK

Eight railway systems in the quake stricken area were severely damaged, namely:

1. Sanyo Shinkansen (super express train) railway line,
2. Hankyu line linking Sannomiya (Kobe city center) to Kyoto,
3. Japan Railways (JR) line linking Sannomiya to Osaka and to east Japan,
4. Hanshin line linking Sannomiya to Osaka,
5. Port liner linking Port Island to Sannomiya,
6. Rokko liner linking Rokko Island to Sumiyoshi, a town in Kobe city,
7. Kobe city subway system,
8. Kobe railway line linking west Kobe to Sanda, a city north of Kobe.

The elevated Sanyo Shinkansen tracks were constructed to withstand lateral movements greater than those recorded in this quake, but it was not constructed to withstand such high vertical movements. Nine elevated sections collapsed. The collapsed sections looked as though they had been smashed by some downward pressure. Seismic records in that particular area indicated that vertical movements were greater than lateral movements. Two tunnels along this Shinkansen line were severely damaged. The Rokko tunnel between Shin-Osaka and Shin-Kobe stations which is about 16.5 km long had cracks in about 8 km of its length. Among the 1,800 viaduct supports of the east end of Rokko tunnel, 400 had been damaged, out of which 100 had collapsed. Tunnels constructed by the open-cut method were badly affected by the quake.

A number of elevated sections of the JR, Hanshin and Hankyu lines collapsed. Some of their stations were completely destroyed. 15 trains were derailed. One of the badly damaged Kobe city subway station's tunnel and 30 out of its 35 reinforced concrete columns collapsed. As explained in Section 4, the Port liner and Rokko liner both suffered severe damages with tilted, settled or collapsed columns, failed connections and/or joints, displacements of girders, etc. Examples of the damages sustained by the railway network are shown in Photos 12-15. The distribution of the damages is shown in Figure 19.

8. Damages to Utilities (Lifeline)

(1) GAS SUPPLY

Gas pipelines were severely damaged by the quake due to the ground movements. More than 860,000 households had their gas supply cut off due to the quake. The supply was cut off to prevent the entrance of water, waste water, sand or dirt into the pipelines. The total damage to the gas supply system is estimated to be approximately 1.9 billion U.S. dollars. Many of the joints along the pipelines were damaged especially those screw joints whose flexibility was only less than 3 cm. The damaged joints were replaced by mechanical joints while the damaged pipes were replaced by polyethylene pipes. It took 100 days to restore gas supply to all the households affected.

(2) WATER SUPPLY

The damages to the water pipelines caused 1.36 million people in 9 cities and 5 towns to experience water shortages, out of which 930,000 households had their water supply cut off. Due to the distribution of water supply, many outbreaks of fire could not be fought. Thus, the fire continued to spread and burn up even more areas. Reservoirs and dams were not badly damaged, except for some access bridges and roads. Some of the treatment plants sustained damages on their distribution system, joint parts, equipments, and water tanks. The number of damaged locations along the 7,685 km long distribution pipe lines was reported to be more than 5,000. The main damage modes were: (1) separation and leakage of joints, (2) buckling and deformation of pipes due to ground movement and (3) cracks in pipe. The number of damages to joints was much more than the number of damages to the pipe. The damaged pipes were being replaced by plastic ones. More flexible joints instead of mechanical joints should be used while more reservoir tanks should be equipped with emergency shut off system.

(3) WASTE WATER SYSTEM

The waste water system suffered damages at more than 1,410 locations. Some of the damages were uplift or settlement of manholes, inflow of soil and sand, damaged joint parts especially between man-holes and pipes, damaged facilities such as aeration plants and pumping systems. Some treatment plants were so severely damaged that three of them had their capacities reduced to 0.20 and 50%.

The waste water treatment plants in the man-made island were shut down because of broken pipe lines as well as movement of plants caused by liquefaction.

(4) ELECTRICITY SUPPLY

Electricity is supplied through steam, hydroelectric and nuclear power plants and transmitted by 500 and 275 kV lines to the transformer substations, transformed and then distributed to the consumes. On the day of the earthquake, one million households were without electricity. Electricity supply was quickly restored and the number of households without electricity was quickly reduced to 360,000 on the next day, and it was fully restored within one week after the quake. Hydro electric and nuclear power plants did not suffer any damage while thermoelectric power plants suffer relatively light damages like ground settlements and boiler damages. Some transformer stations, transmission and distribution lines had damages in about 540 locations. Damages to gas pipelines and electricity cables caused more than 350 outbreaks of fire, some of which burned up large areas.

(5) TELECOMMUNICATION SYSTEM

Of the 1,440,000 telephone lines in the quake striken area, 285,000 lines were disrupted. The main causes of the disruption were: (1) power cut to switching system, (2) damages to buildings and facilities and (3) damages to cables. These were quickly restored the following day after the quake. But telephone calls were difficult to make because of the increase in the number of calls. On the day of the quake, the number of calls increased to 50 times of the usual number during peak period.

9. Conclusions

Some of the important points that can be concluded from the investigation into this earthquake are:

1. The earthquake intensity was much higher than would normally be expected.
2. According to aerial photographs, most of the damaged areas were located in the direction of and parallel to the activated fault from the north of Awaji island to Hanshin area.
3. Most of the buildings and bridges which collapsed were designed based on the old codes of practice.
4. One of the weak points of a structure is the joint. Many structures and/or utility lines failed at the joints thus causing damages and/or collapse.
5. Ground lateral movements and liquefaction, especially at reclaimed lands caused extensive damages to port and harbor facilities, structures carrying utilities, railway lines, bridges and roads.
6. Mountain slope failures occurred at steep slopes, on ridges, at knick points, at unstable rock mass. The distribution and orientation of these failures have a close relationship to the faults in Rokko mountain.

Acknowledgments

The authors would like to thank the Reconnaissance Team on the Great Hanshin Earthquake, Department of Civil Engineering, Faculty of Engineering, Kobe University, Japan for their kind assistance.

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Authors: 1) Takashi Okimura, Professor, Research Center for Urban Safety and Security, Kobe University

Table I Earthquake intensities and ground acceleration

Intensity	Description	Acceleration (gal)
0	Not felt by people but strong enough to be recorded on seismometer	<0.8
1	Felt only by people remaining still or people sensitive to quakes	0.8–2.5
2	Felt by most people. Slight tremors of doors or shoji (sliding paper screen) can be seen	2.5–8
3	Houses are jolted. Doors and shoji screens rattle. Objects hanging from ceilings swing much. Liquids in containers pitch and roll	8–25
4	Houses are jolted strongly. Unstable objects, such as vase, topple. Liquids spill out of containers. Felt also by people walking. Many people go out of their houses	25–80
5	Walls get cracked. Tombstones fall down. Chimneys and stone fences are damaged	80–250
6	Less than 30% of houses collapse. Landslides occur. Cracks appear in the ground. Most people cannot stand	250–400
7	30% of houses or more collapse. Landslides occur, the ground cracks or faults are caused by the earthquake	>400

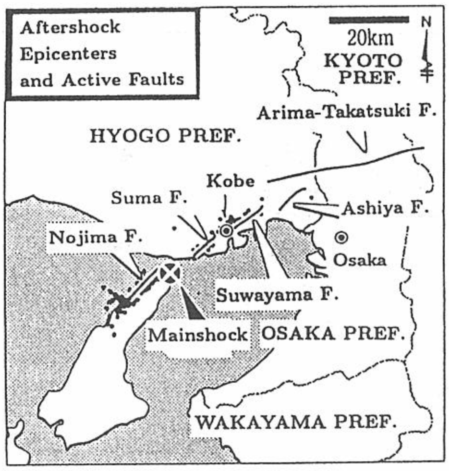
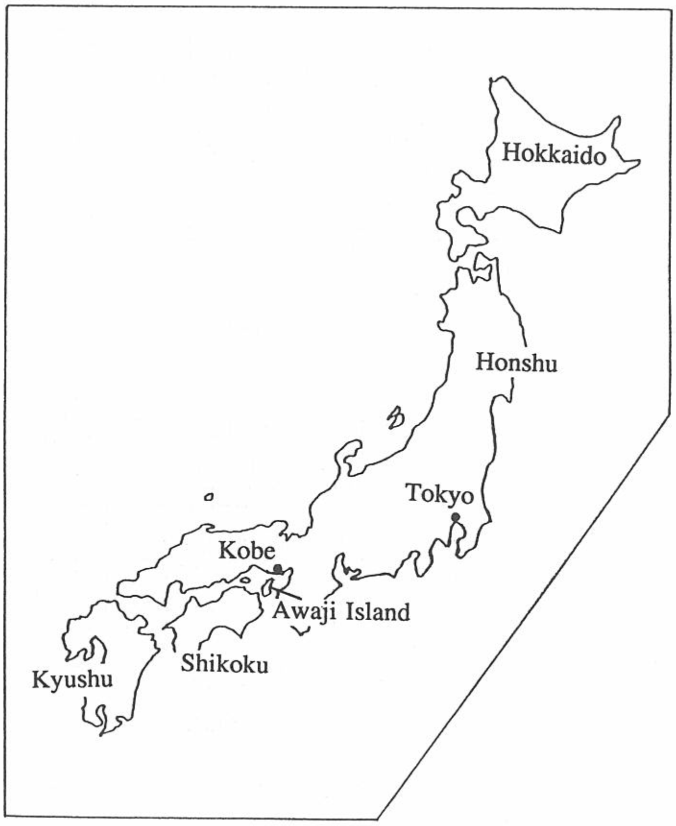


Figure 3 The main active faults in the a [1]. hit area[1]



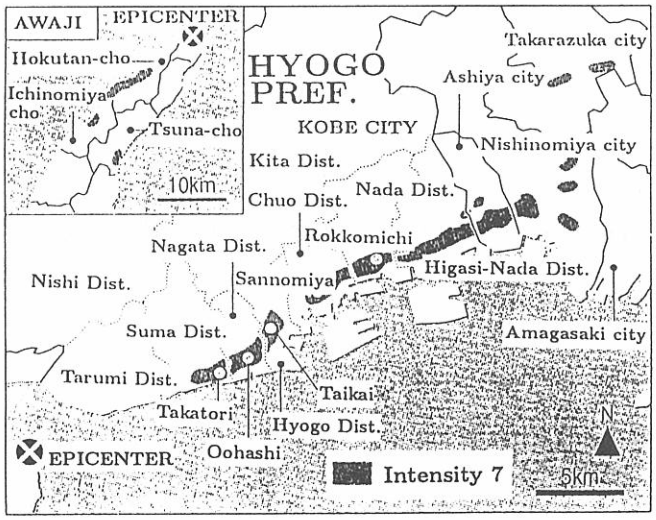


Figure 2 Areas with intensity [1]

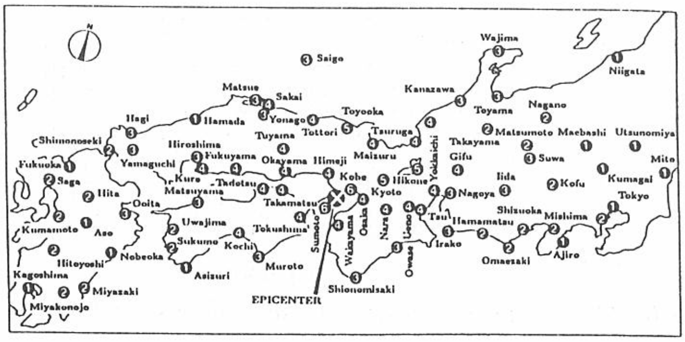


Figure 1 Location of epicenter and distribution of intensity [1]

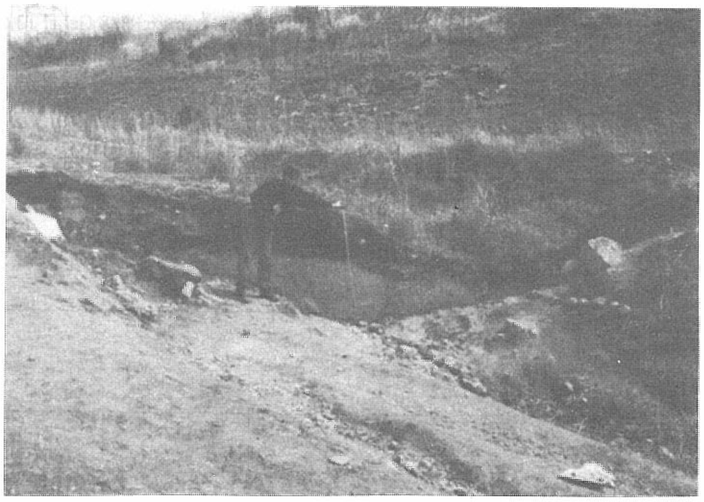


Photo 1 Movement of Nojima fault (source of quake)

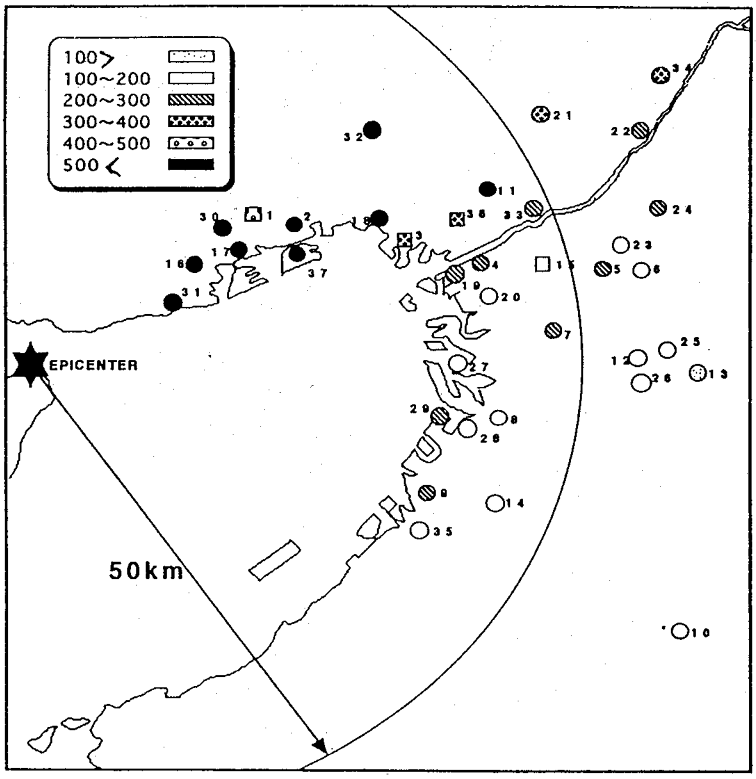


Figure 4 Location of the observatories and their accelerations (in gal)
(Numbers on this map correspond to the location numbers in Table II.)

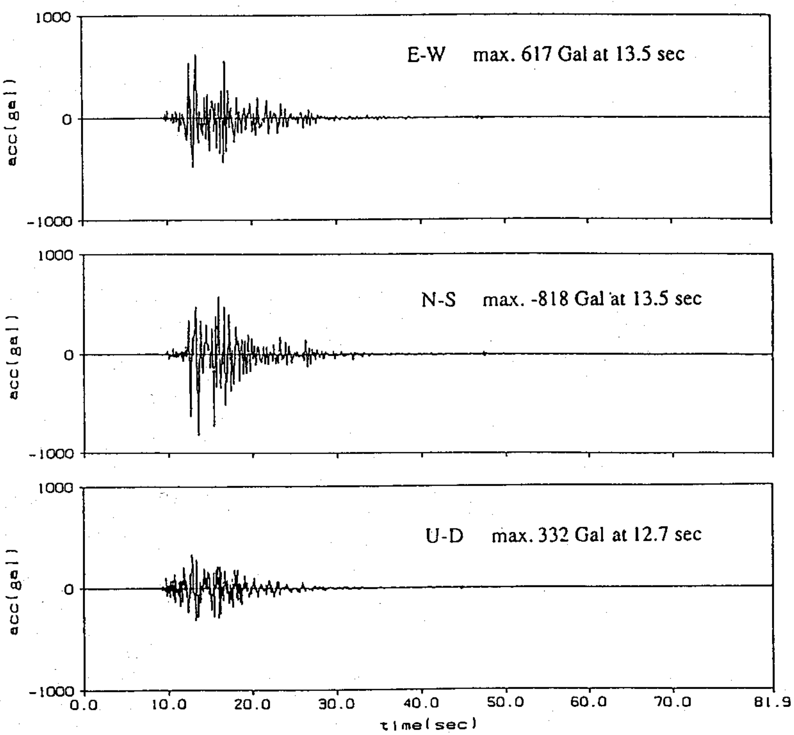


Figure 5 Time history of ground acceleration as measured by KMMO at Kobe city centre

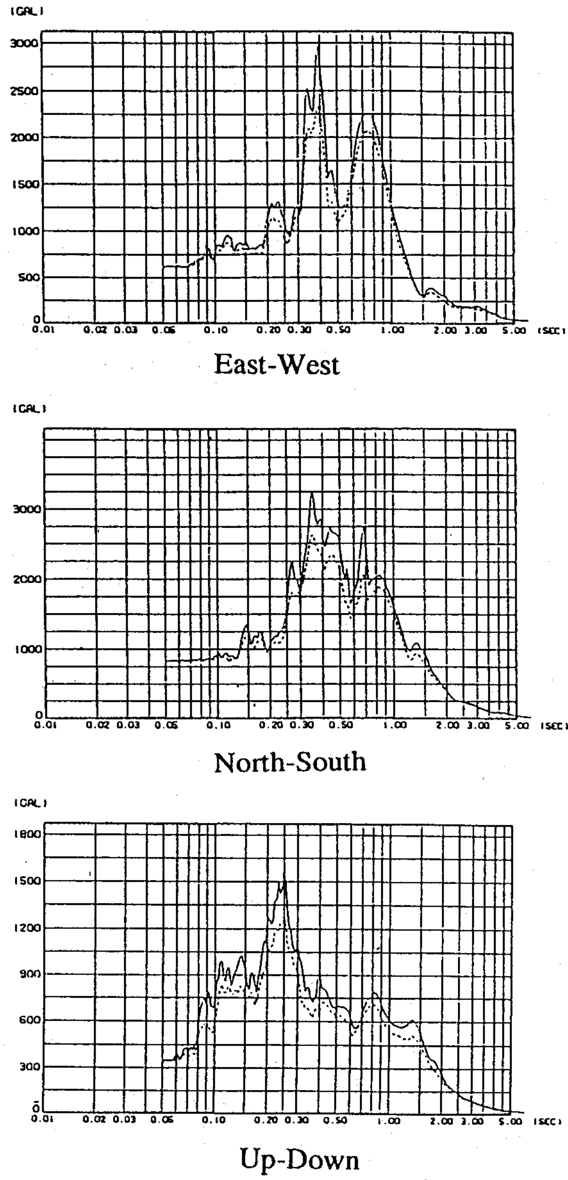


Figure 6 Response spectra of the accelerations

Table II Maximum acceleration (in gal) recorded by some observatory stations

Organization	Location	Maximum accelerations N–S	E–W	U–D	Remarks	No.[c]
CEORKA[d]	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	Soken	299	507	205	Ground level	11
Electricity Co.		294	320	199	GL-97m	
	Yao	148	139	82	Ground level	12
	Shigi Power Transformer	22	20	11	GL-22m	13
	Station	25	20	10	Ground level	
	South Osaka	144	145	93	Ground level	14
BRI[a]	Osaka Daisan	90.2	82.5	108.8	−3rd floor	15
	Godochosha	412.3	316.3	209.4	18th floor	
KOMS[b]	Kobe city center	818	617	332		16
Osaka Gas	Kobe Chuo Fukiae		833			17
	Nishinomiya Imazu		792			18
	Osaka Konohana		266			19
	Osaka Iwasaki		185			20
	Osaka Suita		312			21
	Osaka Takatsuki		251			22
	Higashi Osaka		177			23
	Osaka Shijyo Nawate		224			24
	Osaka Yao		169		25	
	Osaka Fujidera		149			26
	Sakai		173			27
	Sakai		178			28
	Sakai		240			29
Japan Railways	Shinkobe		561			30
	Takatori		616			31
	Takarazuka		601			32
	Shinosaka		245			33
	Osaka Shintakatsuki		323			34
	Higashi Kishiwada		149			35
Ministry of	JR Amagasaki	300	273	307		36
Construction	Amagasaki		475			
Takeda Office	Rokko Island	319	507		37	

?, Out of scale; [a] Building Research Institute; [b] Kobe Maritime Meteorological Observatory; [c] Number of location in Figure 4; [d] Committee of Earthquake Observation and Research in Kansai Area.

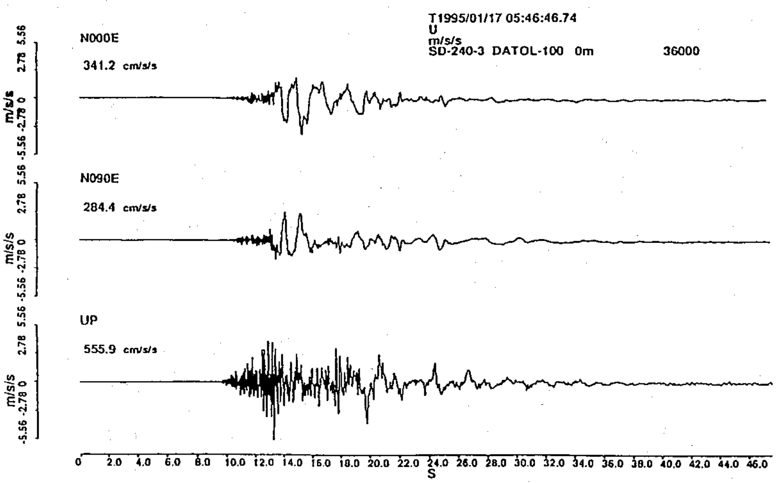


Figure 7 Acceleration time history as recorded in Port island at ground level

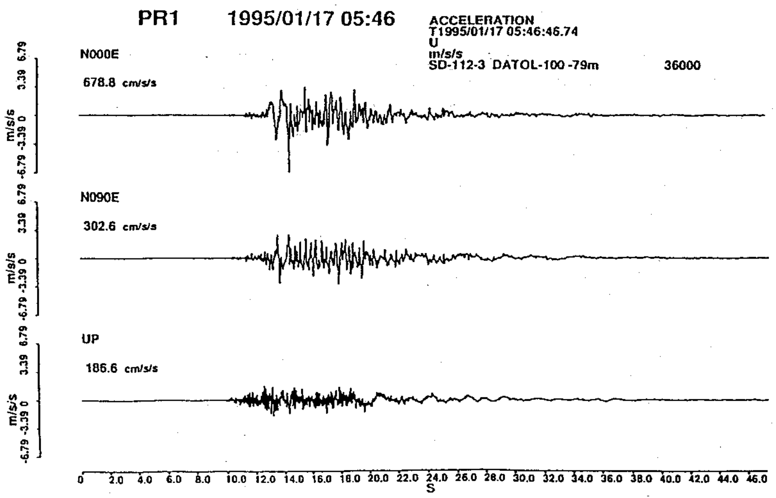


Figure 8 Acceleration time history as recorded in Port island 79 m underground

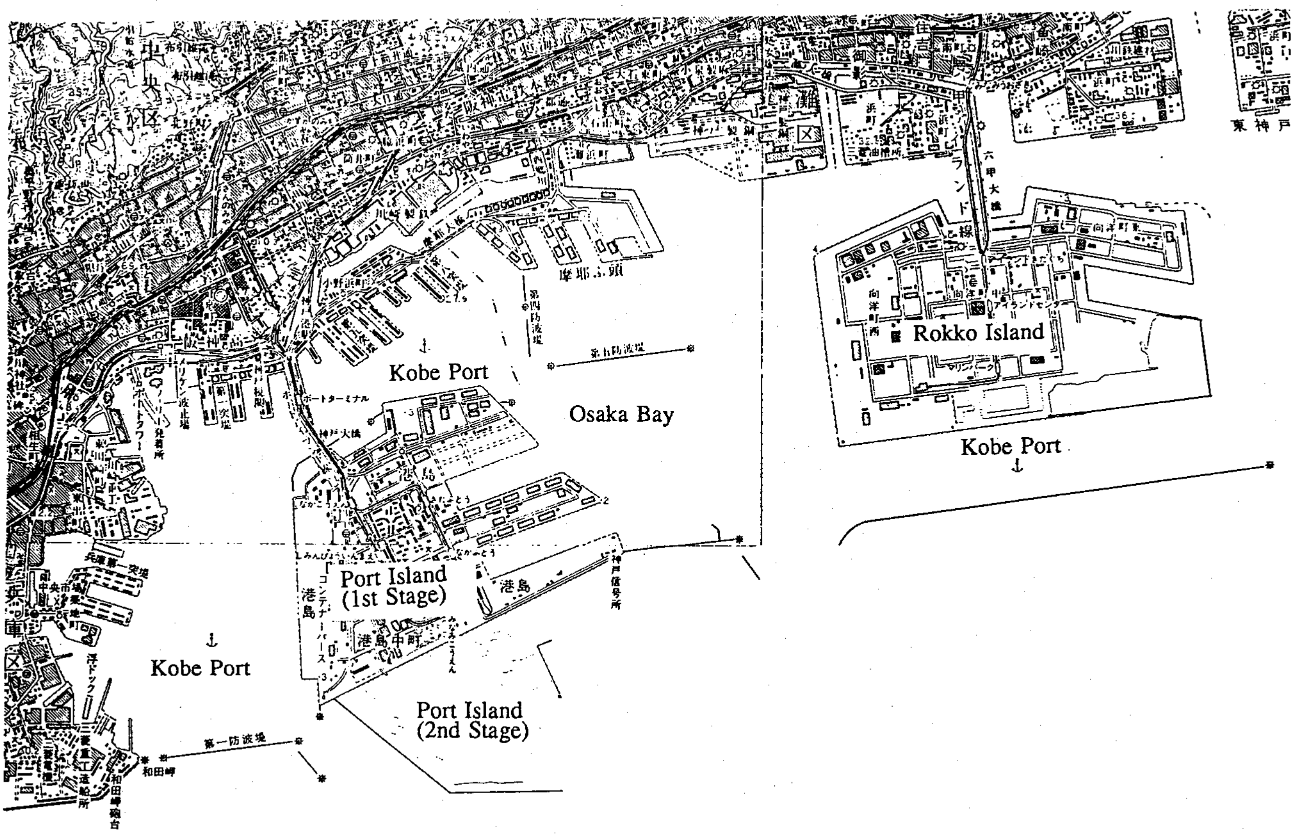


Figure 9 Area map of Kobe port

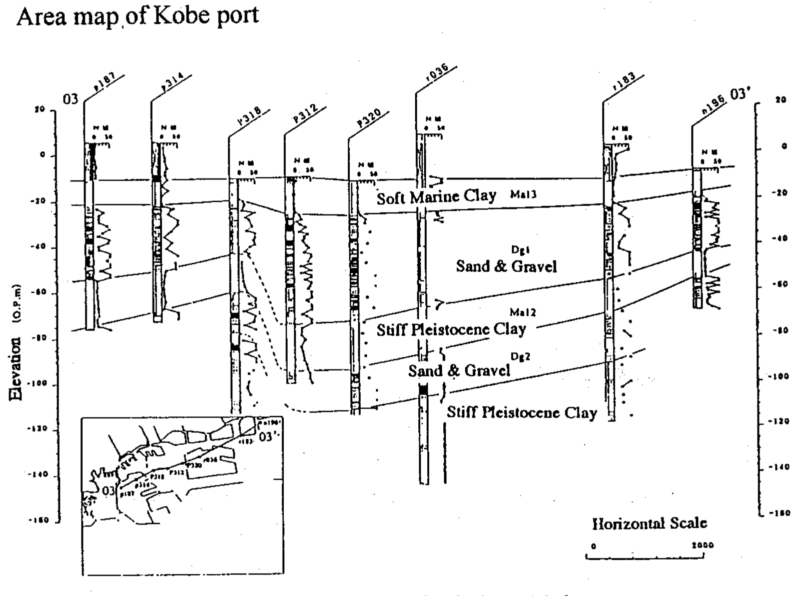


Figure 10 Geological section of seabed along Kobe port

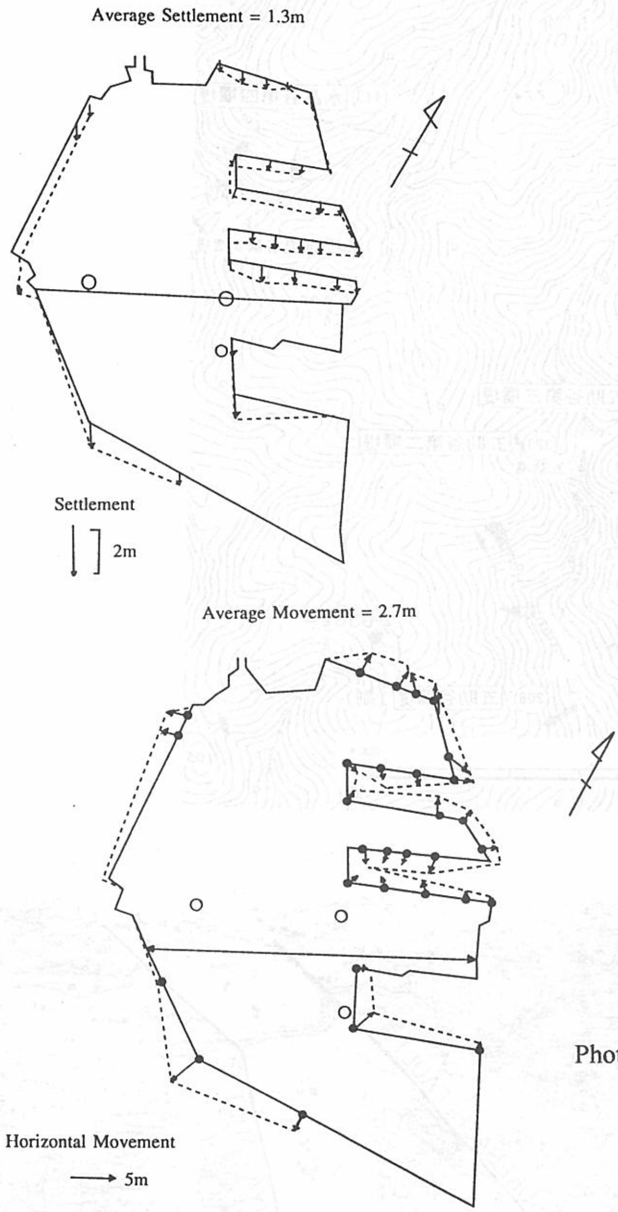


Figure 11 Settlement and horizontal movement of Port Island's shore line

Photo 2 Damages to the seawall along south end of Rokko Island

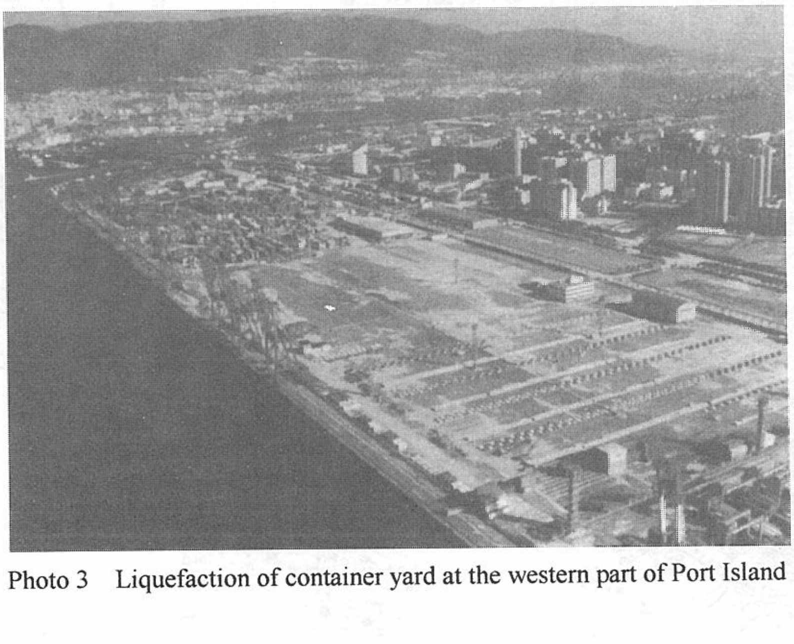


Photo 3 Liquefaction of container yard at the western part of Port Island

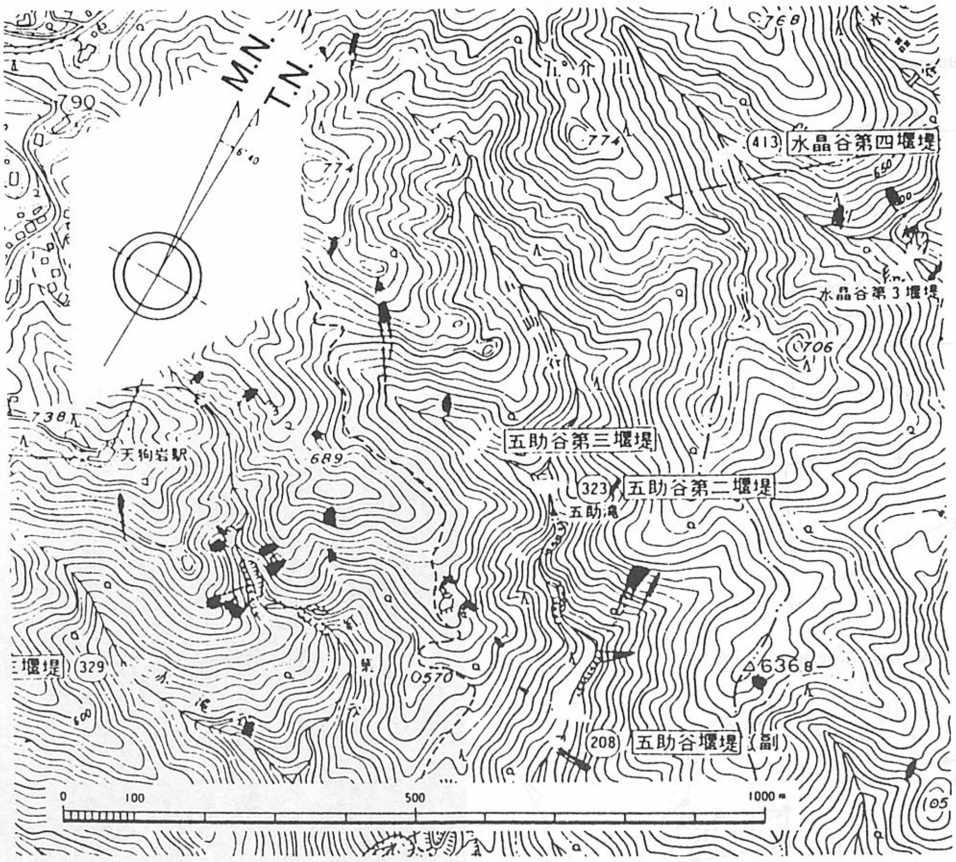


Figure 12 Part of the failure distribution

Figure 13 Distribution of the mountain slope failures at the eastern part of the Rokko mountains

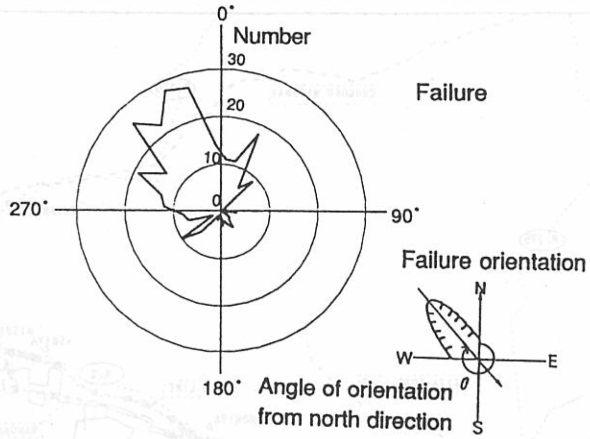


Figure 14　Orientation of the failures

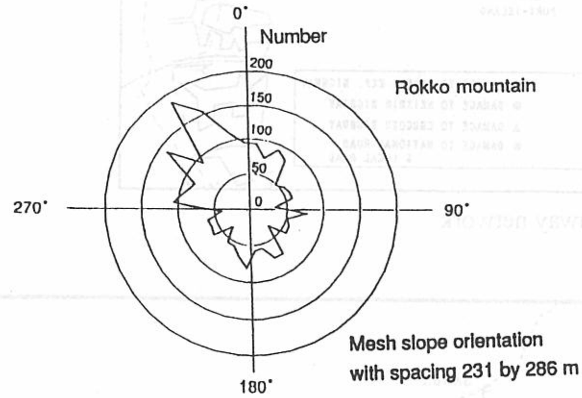


Figure 15　Rokko mountain slopes' orientation

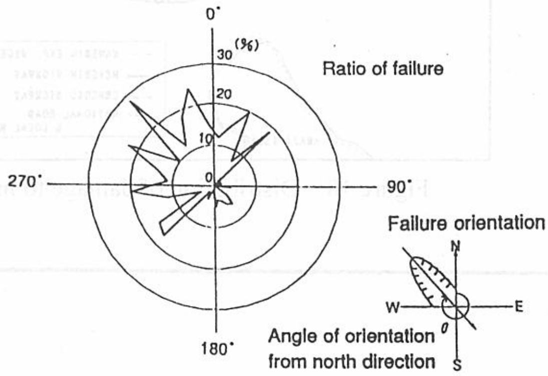


Figure 16　Ratio of failures

Figure 17　Part of the distribution of the damages sustained by buildings

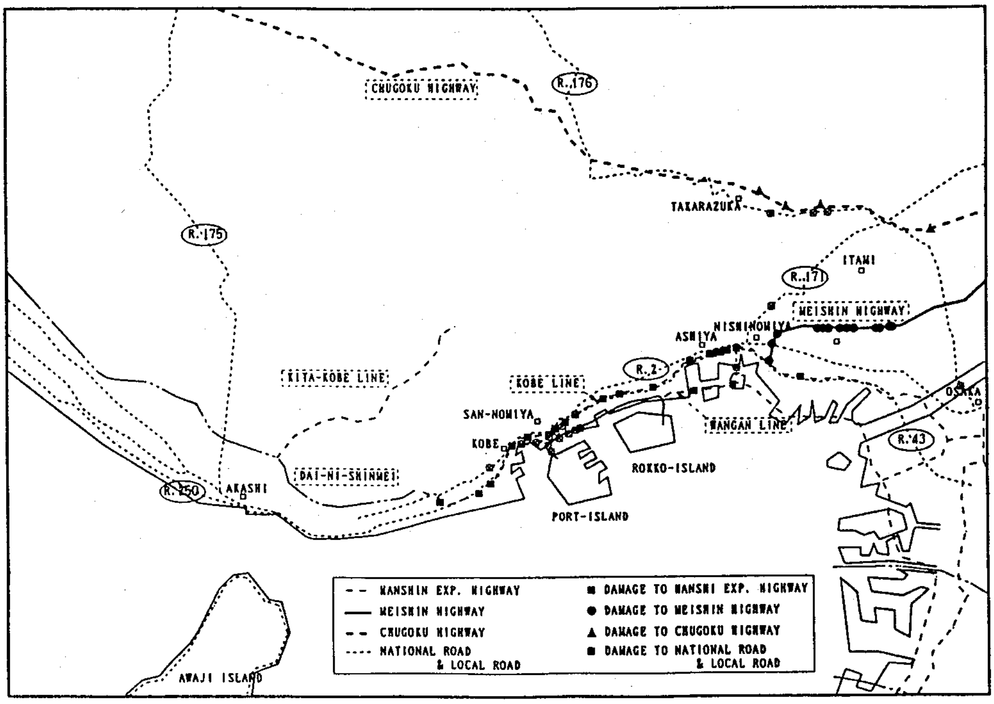


Figure 18 Distribution of damage to highway network

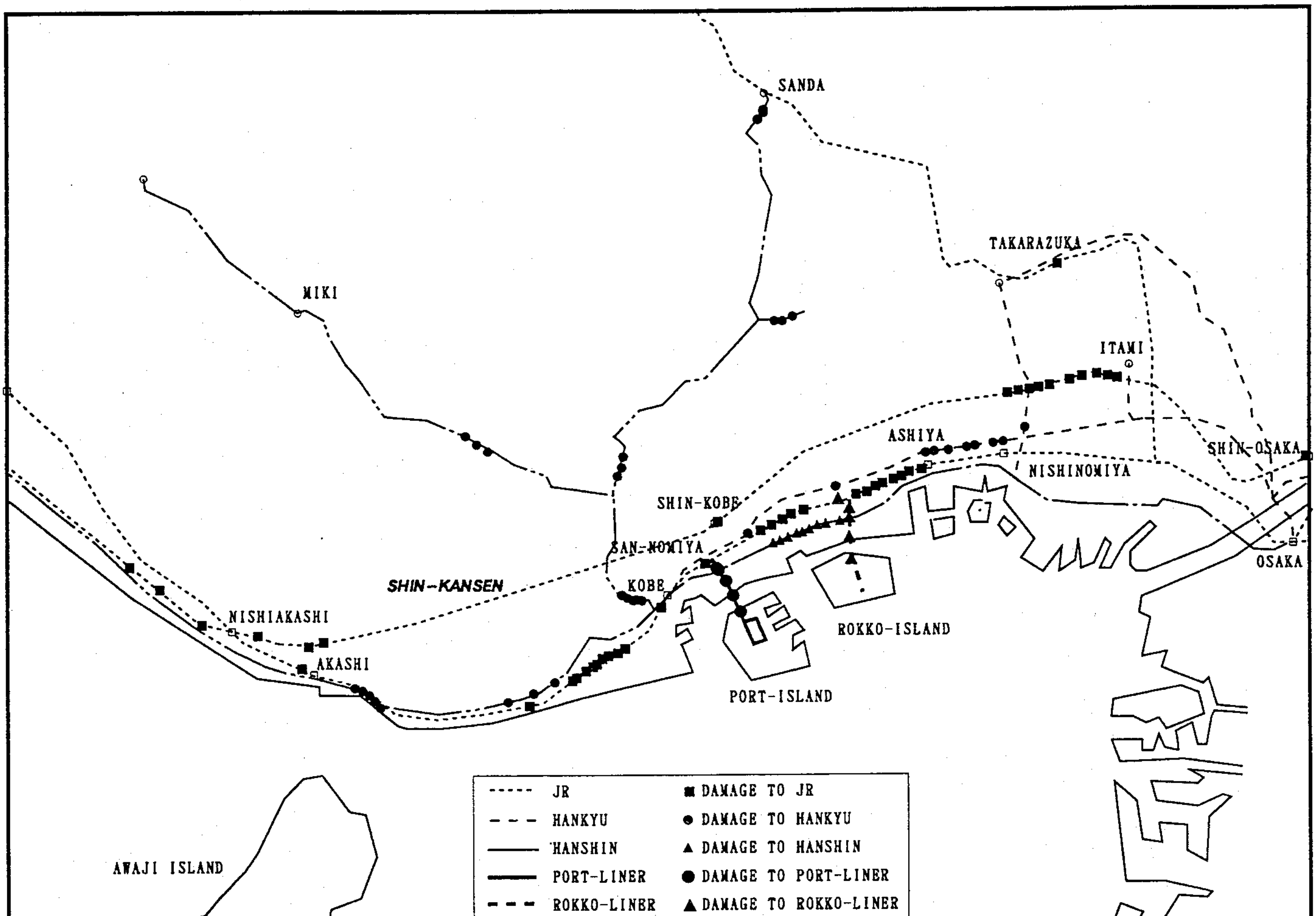


Figure 19 Distribution of damage to railway network

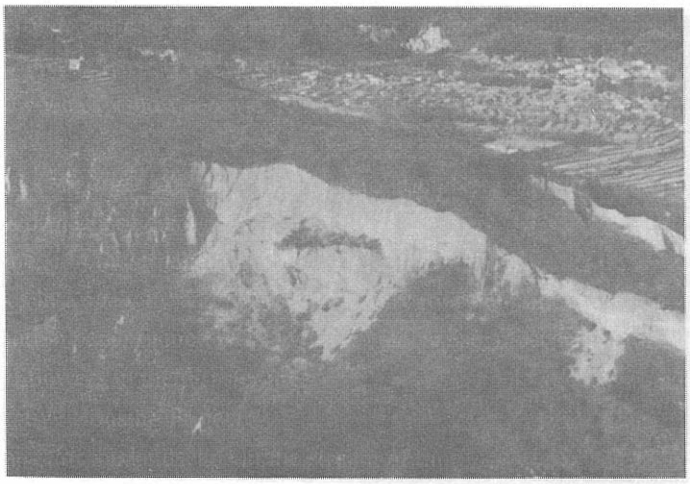


Photo 4 Mountain slope failure

Photo 5 Collapse of timber houses with heavy roof tiles

Photo 6 Total collapse of a timber house in Kobe

Photo 7 Collapse of the 6th floor of one of Kobe city hall buildings

Photo 8 Collapse of the 5th floor of Sannomiya traffic center building

Photo 9 Collapse of a tall RC building onto the road below in Kobe

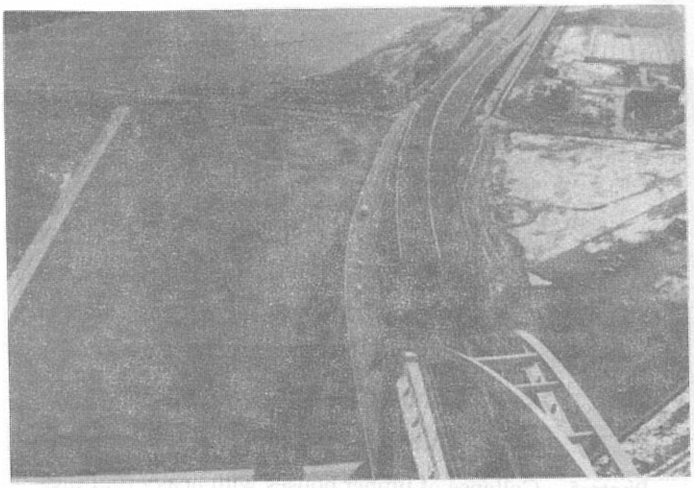


Photo 10 Collapse of a part of Hanshin expressway, Wangan route due to liquefaction and lateral movement

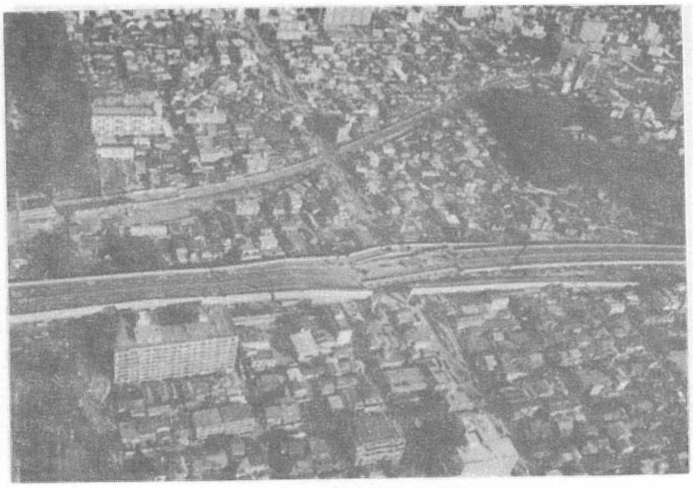


Photo 11 Collapse of a part of Hanshin expressway, Kobe route due to column failure

Photo 12 Shinkansen line at Itami

Photo 13 Shinkansen Line (Nishinomiya)

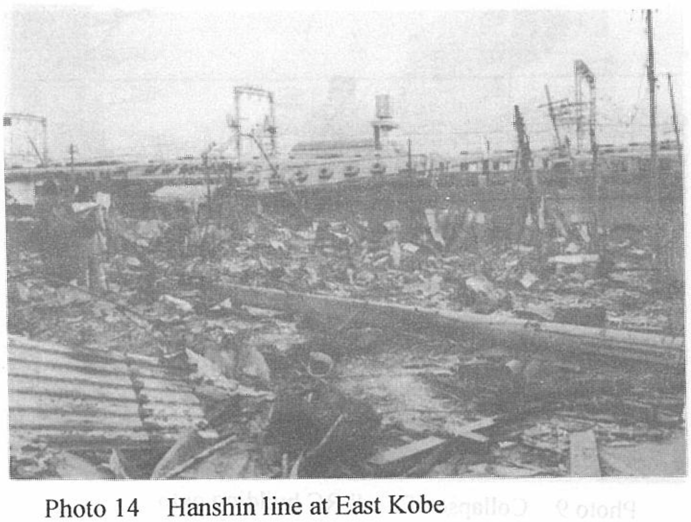


Photo 14 Hanshin line at East Kobe

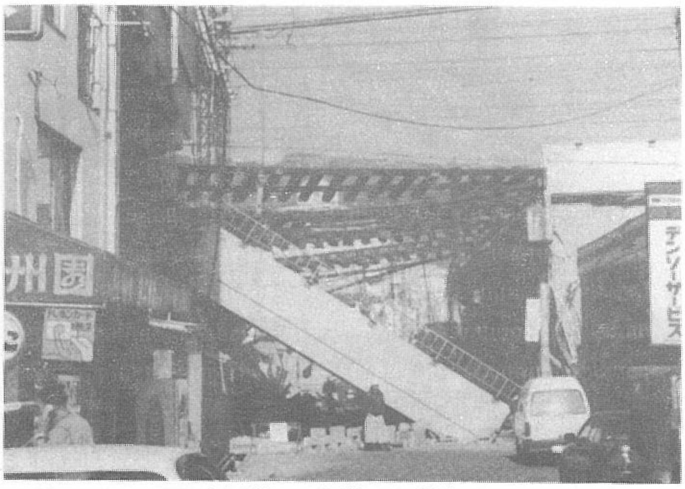


Photo 15 Hanshin line at Mikage, Kobe