GENERAL REVIEW OF RECENT FIVE DAMAGING EARTHQUAKES IN JAPAN

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ABSTRACT

This paper summarizes five large earthquakes which hit Japan within the last two years. The Kushiro-Oki Earthquake on January 15, 1993, the Hokkaido-Nansei-Oki Earthquake on July 12, 1993, the Hokkaido-Toho-Oki Earthquake on October 4, 1994, and the Sanriku-Haruka-Oki Earthquake on December 28, 1994, occurred in the offshore of northern Japan, and finally the Great Hanshin Earthquake on January 17, 1995, jolted central western Japan and brought the most serious damage in the last 70 years. Seismological aspects, strong motion records, geotechnical aspects, performance of buildings, bridges and lifeline systems, and social impacts of these earthquakes are presented and lessons learned from the disasters are given.

INTRODUCTION

In the last two years, five large earthquakes occurred consecutively in Japan. The Kushiro-Oki Earthquake of magnitude (M) 7.8 on January 15, 1993, the Hokkaido-Nansei-Oki Earthquake of M=7.8 on July 12, 1993, the Hokkaido-Toho-Oki Earthquake of M=8.1 on October 4, 1994, and the Sanriku-Haruka-Oki Earthquake of M=7.5 of December 28, 1994, seriously affected Hokkaido (the northern major island) and Tohoku (the northern part of the main island: Honshu) regions of Japan. The Hokkaido-Nansei-Oki Earthquake was the most devastating among the four events due to tsunamis, which killed over two hundred people.

On January 17, 1995, only three weeks after the Sanriku-Haruka-Oki event, the Great Hanshin (also called Hanshin-Awaji or Hyogoken-Nanbu) Earthquake of M=7.2 hit the southern part of Hyogo Prefecture and the northern part of Osaka Prefecture. Death toll from the earthquake rose over five thousand, the largest in Japan since the 1923 Great Kanto Earthquake, which killed about 140 thousand people mostly by associated fires. The Great Hanshin Earthquake was really a big shock to various societies in Japan. Together with restoration and reconstruction works, numerous projects related to earthquake disaster mitigation have started throughout Japan.

This paper aims to introduce the various aspects of these five events to outside Japan since English literature on them are rather limited except for the Great Hanshin Earthquake. Seismological aspects, strong motion records, geotechnical aspects, structural damage, fires, performance of lifelines, and social impacts due to these events are reviewed and lessons learned from the disasters are provided.

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SEISMOLOGICAL ASPECTS

Japan is located in a part of the Pan-Pacific volcanic zone, i.e., the eastern edge of the Eurasian plate, and its geological structure is very complicated. The Pacific coast of Japan is compressed by the Pacific plate in the east and by the Philippine plate in the south. The Pacific plate subducts both the North-American plate and the Philippine plate which in turn subducts the Eurasian plate.

More than 1,500 active faults are reported in and around Japan. Active faults are breaks in the earth's crust along which movement has occurred during the Quaternary (from about 1 or 2 million years ago to present) and along which future movement is expected. Roughly speaking, the land area of Japan comprises only 0.2% of the world but the earthquakes that occurred in and around Japan comprise 6 to 7 % of the world's total.

Due to the stress conditions, the fault type of earthquakes occurring in each region of Japan can be generally expected. In Hokkaido, since the Pacific plate subducts the North-American plate, earthquakes are of the dip-slip type in the east-west direction. In the Tohoku area, earthquakes of the reverse dip-slip type occur in the southwest-northeast direction in the subduction zone between the Pacific plate and the North-American plate. In central and southwestern Japan, where the North American and the Eurasian plates collide, earthquakes of both strike-slip and reverse dip-slip types occur due to compression in the east-west direction. These earthquakes may also be attributed to the northwest compression due to the subduction of the Philippine plate. In Kyushu (southwestern major island), normal dip-slip earthquakes occur because of the tensile stress conditions of the area.

Figure 1 shows the locations of focal regions of the five earthquakes. Table 1 summarizes basic information and damage statistics of the five earthquakes. Figure 2 shows the fault types of these five earthquakes. Except for the Sanriku-Haruka-Oki Earthquake, which was an ordinary interplate earthquake, the types of the earthquakes were rather uncommon. The Kushiro-Oki and Hokkaido-Toho-Oki Earthquakes were intraplate earthquakes in subduction zones while the Great Hanshin Earthquake was right-lateral strike-slip type earthquake. The mechanisms of the earthquakes occurring around the boundary between the North-American and Eurasian plates are not clear because the age of the boundary is young and it is not yet clear which plate is subducting.

Among these earthquakes, the Great Hanshin and the Hokkaido Nansei-Oki Earthquakes caused the severest damage as shown in Table 1. During the Great Hanshin Earthquake, over 190,000 buildings and houses collapsed or were severely damaged, killing more than 5,500 people. Killer tsunamis, which hit the southwestern coast of Hokkaido before tsunami warnings reached the people after the Hokkaido-Nansei-Oki Earthquake, were the main cause of the earthquake's death toll of 230. Okushiri Island, located almost right above the focal region, was the hardest hit area. Tsunami warnings were issued five minutes after the earthquake occurred, probably the best time possible by the technology at that time. However, the onrush of the tsunamis was too fast for the residents in Okushiri Island and the southwestern parts of Hokkaido. According to damage observations and accounts of survivors, wave heights of the tsunamis in many parts of Okushiri Island were between 5 and 10 meters. But they were even greater at several sites, the highest being estimated over 30 meters.

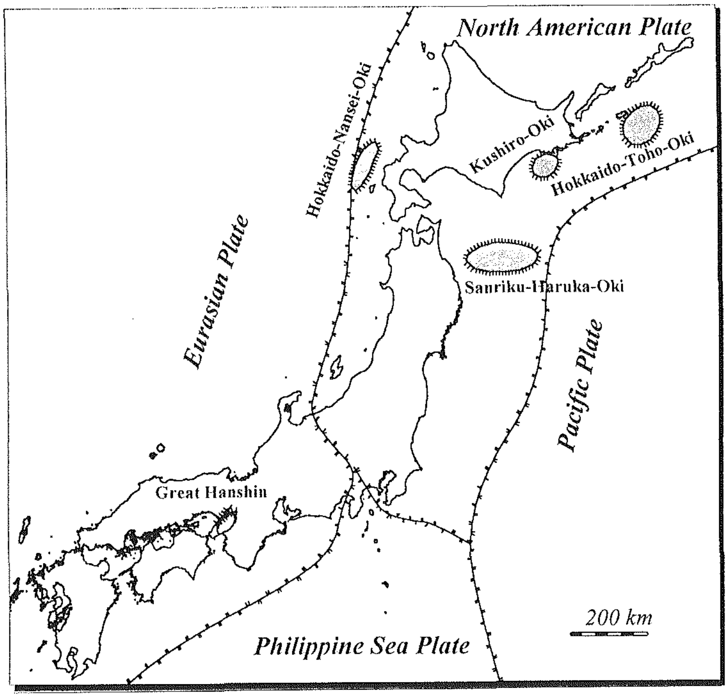


Figure 1 Tectonic environment of Japan and focal regions of the 5 earthquakes

Table 1 Summary of the five recent earthquakes in Japan

Earthquake	Kushiro-Oki	Hokkaido-Nansei-Oki	Hokkaido-Toho-Oki	Sanriku-Haruka-Oki	Great Hanshin-Awaji
Date	Jan. 15, 1993	July 12, 1993	Oct. 4, 1994	Dec. 28, 1994	Jan. 17, 1995
Time	20:06	22:17	22:23	21:19	5:46
JMA Magnitude	7.8	7.8	8.1	7.5	7.2
Depth (km)	110	34	30	≈ 0	14
Epicenter	42° 51'N 144° 23'E	42° 47'N 139° 12'E	43° 22'N 147° 40'E	40° 27'N 143° 43'E	34° 36.4'N 135° 02.6'
Death + missing	2	231	0 in Japan	3	5,504
Heavily injured	116	66	32	66	1,812
Lightly injured	850	239	405	721	39,689*1
Collapsed buildings	60	1,144	61	72	100,827
Heavily damaged	298	528	348	429	90,114
Lightly damaged	5,311	3,464	7,095	9,021	147,260
Monetary loss of infrastructures (billion yen)	94.1	158.3	54.9	16.1	3,300

* 1 Including people whose injury extent under survey.

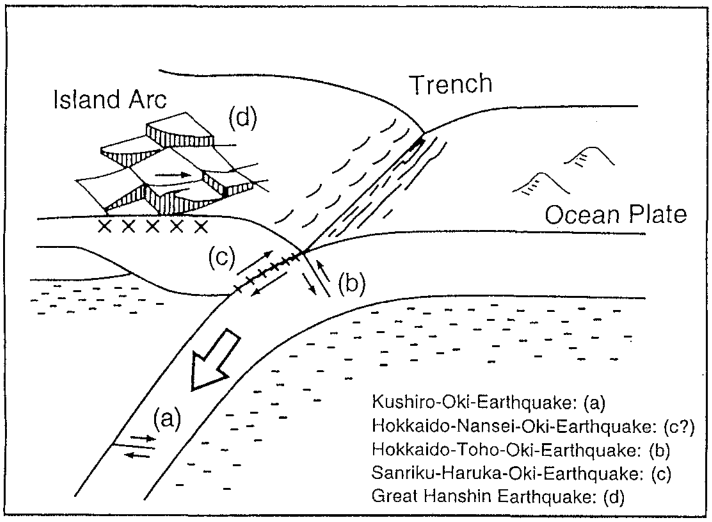


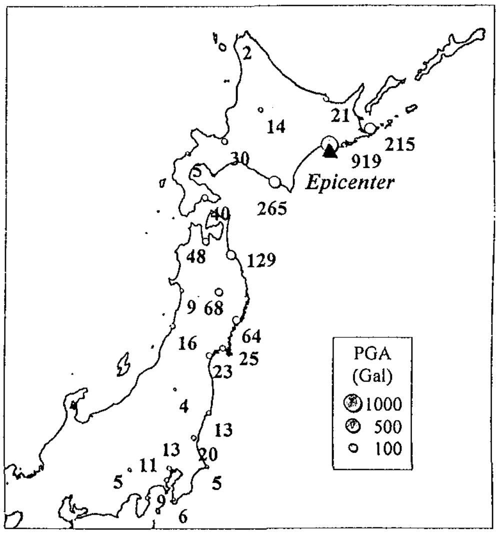
Figure 2 Fault type of the 5 earthquakes (after Prof. M. Kikuchi [1])

STRONG MOTION RECORDS

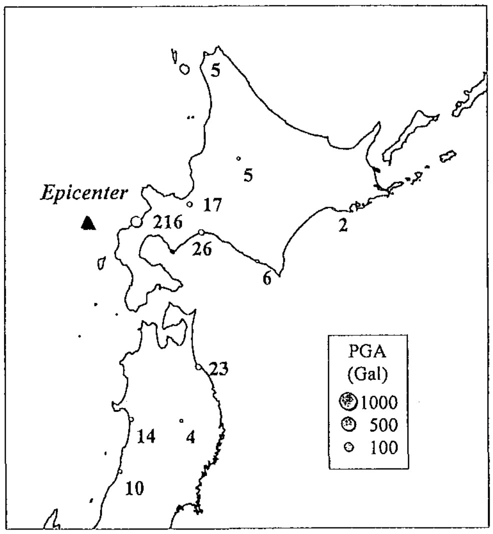
A large number of strong motion records were obtained from the five earthquakes. Figure 3 shows the peak ground accelerations (the larger of two horizontal components) recorded by the accelerograph network of the Japan Meteorological Agency (JMA) for the four earthquakes in northern Japan. The network consists of 76 recording stations throughout Japan and uses the new JMA-87 type accelerometers, which do not require instrumental corrections. Attenuation relationships for peak ground acceleration and peak ground velocity were developed by Molas and Yamazaki [2] using 2,166 pairs of horizontal components recorded by the JMA-87 type accelerometers from 387 events at 76 stations. Many other earthquake records by several organizations also exist for the five major events.

In the Kushiro-Oki Earthquake, a peak ground acceleration of over 0.9g was recorded [3] at the JMA Kushiro Station as shown in Figure 4. This record is a bit controversial. In the same site, another accelerometer of the Building Research Institute of the Ministry of Construction recorded about 20 % lower acceleration. From the statistical analysis [2], JMA Kushiro was found to have the largest station coefficient among the 76 JMA stations, which means that the recorded acceleration at the JMA Kushiro Station is much larger than that estimated from the magnitude and distance. The topography of the station, located at the edge of tableland, may be responsible for this unique soil response. It was surprising that although the focus of the Kushiro-Oki Earthquake was deep (110 km) and out of the range of ordinary attenuation formulas, the recorded ground motion was very large.

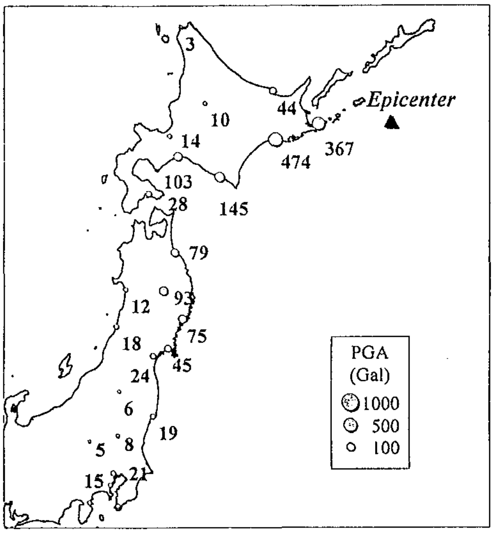
In the Hokkaido-Nansei-Oki Earthquake, no near-source record was obtained [4] since the focal region was located in the sea. The source-site distance at Suttsu, where the largest acceleration was recorded (Figure 4), was about 70 km. Peak ground accelerations recorded by the Hokkaido-Nansei-Oki and Kushiro-Oki events, both having magnitude of 7.8, were compared for the same slant distance to the faults. The Kushiro-Oki event shows higher acceleration than the



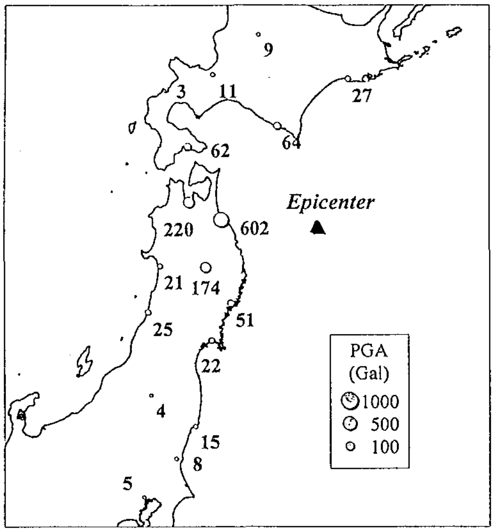
(a) 1993 Kushiro-Oki Earthquake



(b) 1993 Hokkaido-Nansei-Oki Earthquake



(c) 1994 Hokkaido-Toho-Oki Earthquake



(d) 1994 Sanriku-Haruka-Oki Earthquake

Figure 3 Peak ground accelerations recorded by JMA 87-type accelerograph network for 4 major earthquakes

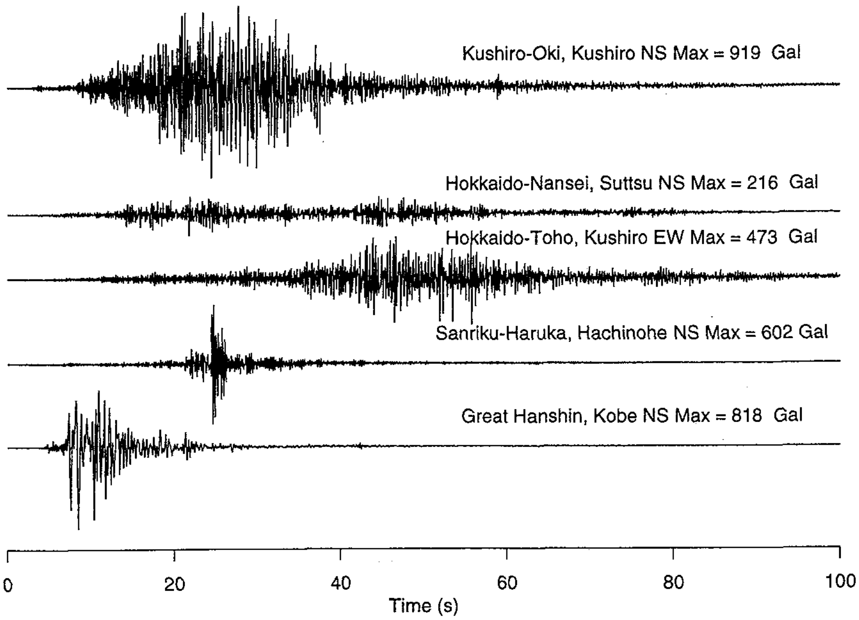


Figure 4 Ground acceleration records by the JMA 87-type accelerograph for the five major earthquakes. The largest horizontal component was selected for each event.

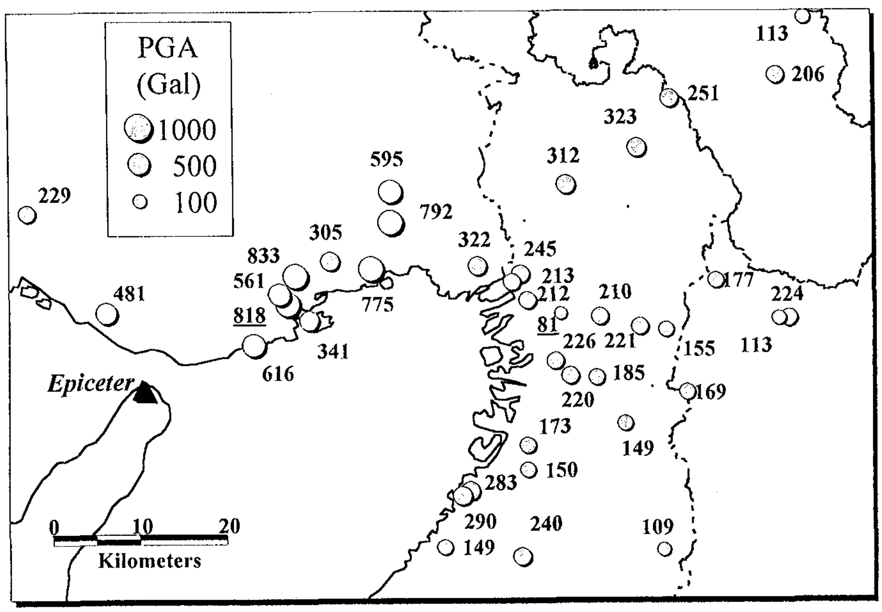


Figure 5 Peak ground accelerations recorded by several accelerograph networks for the Great Hanshin Earthquakes (JMA Kobe : 818 cm/s^2 and JMA Osaka : 81 cm/s^2)

Hokkaido-Nansei-Oki event for the same distance, indicating the effect of source depth to the attenuation relation. In the aftershock observation of the Hokkaido-Nansei-Oki event, a very large ground acceleration (1.55g) was recorded in Otobe Town by the Earthquake Research Institute, the University of Tokyo. Although the magnitude of the aftershock was 6.5, the focus was close to the recording site. Local site effects of the recording station seem to be responsible for this large acceleration.

In the Hokkaido-Toho-Oki Earthquake, whose epicenter is located at about 200 km offshore of Hokkaido, strong ground motions were also recorded: 0.48g in Kushiro and 0.37g in Nemuro [5]. The acceleration recorded at the JMA Kushiro Station was again the largest, although the JMA Nemuro Station is much closer to the epicenter.

Local site effects may be responsible for this phenomenon. Since the magnitude is very large (M=8.1), the tremor was clearly felt even in Tokyo, over 1,000 km away from the epicenter.

In the Sanriku-Haruka-Oki Earthquake, a peak ground acceleration of over 0.6g was recorded in the JMA Hachinohe Station [6]. The duration of the strong motion looks much shorter than those of the three large magnitude events.

In the Great Hanshin Earthquake, many strong motion records [7] were obtained as shown in Figure 5. Among others, the acceleration obtained at the JMA Kobe Station is a good near source record, which is quite rare in Japan since most earthquakes occur in the sea. The acceleration obtained at Kobe Port Island is also very interesting: an occurrence of liquefaction can be clearly observed [8]. These strong motion records are quite valuable to explain structural damage in the Great Hanshin Earthquake as well as to grasp the nature of earthquake ground motion.

GEOTECHNICAL ASPECTS

Since most of the land areas in Japan is mountainous, landslides and rockfalls often follow strong ground shaking. In the Hokkaido-Nansei-Oki Earthquake [9], a large landslide occurred in Okushiri Island (Photo 1). A two-story wood-frame hotel and an 800 kl oil tank were crushed and buried by massive amounts of soil. The hotel was located just below a steep cliff with a height of about 100 m. Twenty-four people were killed by this landslide. Many other landslides and rockfalls occurred along the coast of Okushiri Island and the southern Hokkaido Peninsula. Fortunately, however, these areas were not populated. Damage to roads and rock sheds was reported.

In the Great Hanshin Earthquake, the number of landslides was rather small in spite of the intense shaking probably because of the dry season. One large landslide occurred in Nigawa, Nishinomiya and killed 34 people (Photo 2). The existence of ground water flow is considered as one of the causes of the landslide.

Many embankment failures of roads and railways occurred in the Kushiro-Oki, Hokkaido-Nansei-Oki, Hokkaido-Toho-Oki and Sanriku-Haruka-Oki Earthquakes. Many similar scenes, in which cars and trucks were involved and overturned, were observed in those failures. Most of the failures occurred at fills on soft ground. It was also shocking that a house slid down a slope for about 10 m in the Kushiro-Oki Earthquake (Photo 3). In the earthquake, damage to houses and buried pipes was concentrated at hilly sloping grounds of Kushiro.

Extensive liquefaction occurred in all five earthquakes. Liquefaction developed in a very similar manner and in almost the same places in the Kushiro-Oki and Hokkaido-Toho-Oki events

[10]. Settlements and cracks of pavement developed in Kushiro Fishery Port twice within two years. In the Kushiro Industrial Port, liquefaction occurred only in the backyard, outside of the ground improvement zone. Manholes of sewage lines floated up in the same manner in the two earthquakes due to liquefaction (Photo 4).

Liquefaction was observed along the coast lines of Hokkaido Peninsula in Hokkaido-Nansei-Oki Earthquake. In Oshamanbe, a town developed on an old riverbed and 100 km from the epicenter, liquefaction occurred throughout the town. Numerous breaks of gas and water pipes and settlements of building foundations were observed. The Port of Hakodate, the largest port in the southern Hokkaido, was severely affected by liquefaction (Photo 5). Large ground fissures and settlement disrupted paved areas and quay walls moved seaward.

In the Great Hanshin Earthquake, extensive liquefaction occurred in Kobe and its vicinity. The Port of Kobe, the largest container facilities in Japan, had severe damage in its container piers and gantry cranes (Photo 6). Two major man-made islands in Kobe, Port Island and Rokko Island, were covered by sand and mud water. However, buildings with pile foundation to firm layers performed well and no significant damage was reported. Liquefaction affected many industrial facilities located on reclaimed land or natural soft deposits along the Osaka Bay. About 2 kilometers of the banks of Yodo River were also destroyed due to liquefaction.

BUILDINGS

The numbers of collapsed and damage buildings by the five earthquakes are summarized in Table 1. The number is by far the largest for the Great Hanshin event: more than 100 thousand buildings and houses totally collapsed. This number is the third largest in the history of Japan: next to the 1923 Great Kanto Earthquake (M=7.9) and the 1891 Mino-Owari Earthquake (M=8.1). In the Great Kanto Earthquake, wide spread fires in Tokyo and Yokohama were the main cause of building damage and human casualties. The Mino-Owari Earthquake occurred in much less populated area and Japan was not so modernized at that time. After the 1948 Fukui Earthquake (M=7.1), no earthquake caused such devastating damage. Hence, the Great Hanshin Earthquake was really a big one to Japan.

In the Great Hanshin Earthquake[11], traditional wood-framed houses were most severely affected (Photo 7). The collapsed houses were concentrated in a narrow band area of approximately 1 km wide and about 20 km long (Kobe, Ashiya, and Nishinomiya Cities). The area lies between the mountain range and the coast line. The thickness of alluvial deposits are not so large in this area. No surface fault was found in the main land. Hence, the cause of the damage concentration was due to strong shaking related to the soil condition.

The performance of engineered buildings in the strong shaking area was also bad in the Great Hanshin Earthquake. Both reinforced concrete buildings and steel buildings suffered severely (Photo 8). The damage ratio of buildings was dependent on the construction age, which corresponds to their adopted design code. The seismic provisions of the Japanese building code were revised twice, in 1971 and 1981. The strength of buildings against lateral forces was increased by the revisions. New buildings following the new code performed much better than those designed by the old codes. Mid-story collapse, which was quite rare in Japan, occurred to many medium height (about 10 story) buildings (Photo 9). It was also shocking that many steel buildings had damage in their structural members.

Photo 1 A large landslide buried a hotel in Okushiri Island in the Hokkaido-Nansei-Oki EQ.

Photo 2 A landslide occurred in Nishinomiya and killed 34 people in the Great Hanshin EQ.

Photo 3 A house slid down a slope in the Kushiro-Oki EQ.

Photo 4 Manholes of a sewage line floated out of the ground due to liquefaction in the Kushiro-Oki EQ.

Photo 5 Settlement of pavement with cracks were observed in Hakodate Port in the Hokkaido-Nansei-Oki EQ.

Photo 6 Extensive liquefaction occurred throughout Port Island in the Great Hanshin EQ.

Photo 7 Many wood-frame houses with heavy roof totally collapsed in the Great Hanshin EQ.

Photo 8 An example of very badly damaged buildings in the Great Hanshin EQ.

Photo 9 The old building of Kobe City Hall collapsed at a mid-story in the Great Hanshin EQ.

Photo 10 Houses in the Aonae District of Okushiri Island were destroyed by tsunamis in the Hokkaido-Nansei-Oki EQ.

Photo 11 The first story of a pachinco parlor in Hachinohe collapsed in the Sanriku-Haruka-Oki EQ.

Photo 12 A shear crack developed in a reinforced concrete column of a high school building in the Sanriku-Haruka-Oki EQ.

Over one thousand houses and buildings collapsed in the 1993 Hokkaido-Nansei-Oki mostly due to tsunamis (Photo 10). Only a few engineered structures were located in the region of strong shaking of the event.

In the 1993 Kushiro-Oki earthquake, damage to buildings was only minor although the recorded acceleration at the JMA Kushiro Station was quite large. From questionnaire surveys to the residents and damage observations, it is known that the ground motion in the central part of Kushiro City was much smaller than that around the JMA Station. In the 1994 Hokkaido-Toho-Oki Earthquake, Kushiro City was again attacked by strong shaking. But, again, structural damage was quite minor.

In the 1994 Sanriku-Haruka-Oki Earthquake, several reinforced concrete buildings in Hachinohe was severely damaged. A "pachinco parlor" (Japanese game center) collapsed in the downtown of Hachinohe and killed two people (Photo 11). Some other old reinforce concrete buildings were severely damaged. A high school building which had minor damage in the 1968 Tokachi-Oki Earthquake was totally damaged and demolished later (Photo 12). Except for few cases, however, the overall performance of buildings and houses were good in the earthquake.

Actually, before the Great Hanshin Earthquake, we thought that engineered buildings in Japan would withstand strong earthquakes, as demonstrated especially in the Kushiro-Oki, the Hokkaido-Toho-Oki, and the Sanriku-Haruka-Oki events. However, it was an illusion. In these earthquakes, the shaking was not strong enough. It was realized that if strong motion exceeds a certain level, damage suddenly starts to occur.

Regional difference in the structure of wood-frame houses should not be neglected. Houses in Hokkaido are generally strong to seismic motion since they are prepared for snow load and uplift from frozen soil. Roof tiles, which are common to Japanese houses, and roof mud under tiles, which is unique to old houses in western Japan, are not used in Hokkaido. These facts may partially explain the differences in performance of traditional houses in the Great Hanshin and in the northern earthquakes.

BRIDGES

Until the Great Hanshin Earthquake occurred, bridges in Japan have performed well during earthquakes. Totally collapsed bridges were very few: only 4 road bridges in the last 40 years, three in 1964 Niigata Earthquake due to liquefaction and one in 1978 Miyagiken-Oki Earthquake.

Performance of bridges was also good in the four recent earthquakes in northern Japan. In the Kushiro-Oki Earthquake, 64 road bridges and 9 railway bridges were damaged, but none of them was fatal. Restoration works took a few days to several months. Damage occurred mostly at the joints of the super-structure and sub-structure, e.g. shoes, base mortar of shoes, and anchorage bolts. Ground settlements in the backfill of abutments were also seen at many bridges.

Minor to moderate damages were also reported in the Hokkaido-Nansei-Oki and Hokkaido-Toho-Oki Earthquakes. Again none of them was fatal.

In the Great Hanshin Earthquake, however, a large number of highway bridges (Photo 13, 14) and railway bridges (Photo 15, 16) collapsed, by far larger than all the number of damaged bridges in the history of Japan. For example, the damage ratio of reinforced concrete piers in Hanshin Expressway's Kobe Line was about 50%, 512 piers out of 1012 piers were suffered from severe to minor damage. The damage ratio of shoes was even higher (64%). It is obvious that earthquake ground motion exceeded the design lateral force. Since the damage was so tremendous and unexpected, review of seismic design codes has started in several organizations.

FIRES

Fires broke out in all the five earthquakes. However, fires spread only in the 1993 Hokkaido-Nansei-Oki and the 1994 Great Hanshin Earthquakes. Due to the fire which broke out in Aonae district of Okushiri Island (Photo 17), 108 houses and 79 other buildings were burned down (5.1 ha). The fire could not be extinguished because of the debris brought by tsunamis and the shortage of water due to pipe breaks.

After the Great Hanshin Earthquake, a total of 175 fires occurred within 10 days in Kobe (Photo 18). About half of them started within few hours after the earthquake. Many fires occurred even a few days after. For 44 fires, electricity was estimated as the cause of fire. The total area burned down by the fires was about 70 ha (0.7 km^2). Compared with the 1923 Great Kanto Earthquake (34 km^2 in Tokyo and 9.9 km^2 in Yokohama), however, the area was much smaller.

Major reasons for the spread of fire in the Great Hanshin Earthquake were shortage of water, too many simultaneous fires, and traffic jams. Densely built-up low-rise areas, which caught fires in Kobe, also exist in all the major cities in Japan. Countermeasures for fires after earthquakes were highlighted by the earthquake although it have been the most important task since the 1923 Great Kanto Earthquake.

LIFELINES

Lifeline systems were also affected by the five damaging earthquakes, especially by the Great Hanshin Earthquake. Power outage occurred in the five earthquakes. In the Kushiro-Oki Earthquake, about 57,000 customers lost power but restoration was completed within 24 hours. The causes of power outage were damage to substations (Photo 19) and distribution lines. Damage extents and restoration processes were more or less similar in the Hokkaido-Toho-Oki and the Sanriku-Haruka-Oki events. Power supply was restored to all the customers within one day by using alternate lines or bypassing damaged equipment.

In the Great Hanshin Earthquake, however, structural damage to the power system was by far more severe than the other events. Minor to severe damage occurred in 5 thermal power stations, 17 substations, 23 transmission lines, and several hundred distribution lines (Photo 20). About 2.6 million customers, mostly in Hyogo Prefecture, lost power as shown in Figure 6. Within a few hours, the number of customers without power was reduced to less than 1 million. However, full restoration took about 6 days. The figure compares the power restoration curve of the Great Hanshin Earthquake with those (2 power utilities in the Southern California) of the 1993 Northridge Earthquake. It is noticed that in spite of severe damage to the power systems, the restoration was rather prompt in the two earthquakes.

Gas delivery systems were most seriously affected among all the lifelines in the 1993 Kushiro-Oki Earthquake and the 1995 Great Hanshin Earthquake. In the Kushiro-Oki Earthquake, gas supply was stopped for 9,300 customers and full restoration took 22 days (Figure 7). In the Great Hanshin Earthquake, gas supply was stopped for 860 thousand customers of Osaka Gas, the sec-

Photo 13 A 500 meter section of the Hanshin Expressway rolled over completely in the Great Hanshin EQ.

Photo 14 A collapsed section of the Hanshin Expressway in the Great Hanshin EQ. A bus could escape from falling down.

Photo 15 A collapsed bridge of the Hanshin Railway Line in the Great Hanshin EQ.

Photo 16 A Sanyo Shinkansen (bullet train) bridge overpassing another railway line collapsed in the Great Hanshin EQ.

Photo 17 Houses and buildings were burned down in the Aonae District in the Hokkaido-Nansei-Oki EQ.

Photo 18 Raging fires in Kobe in the Great Hanshin EQ. Fire fighting was almost impossible because of the lack of water.

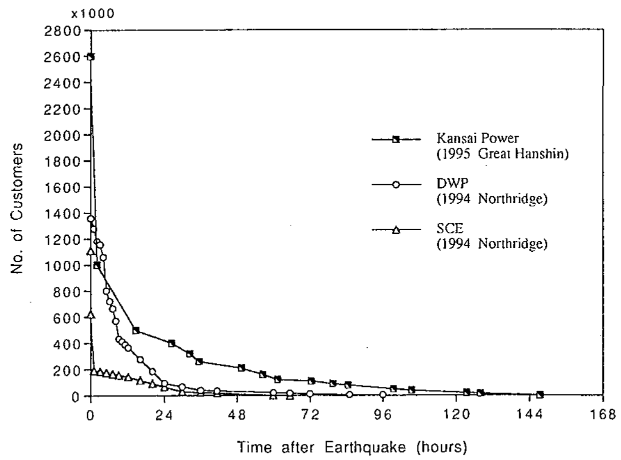


Figure 6 Restoration of power outage after earthquakes

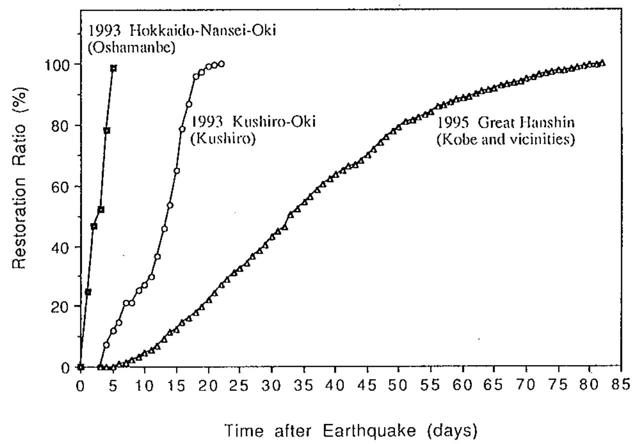


Figure 7 Restoration of gas supply after earthquakes

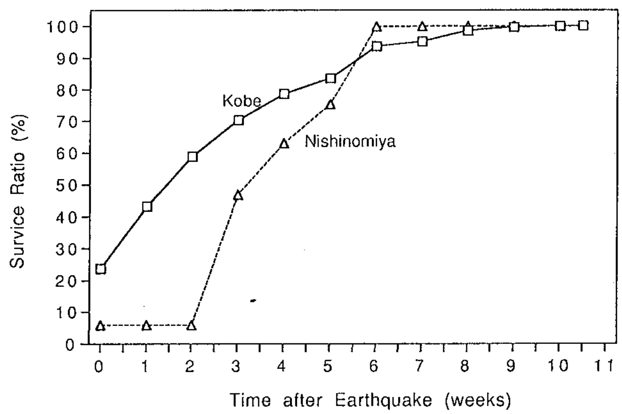


Figure 8 Service ratio of water systems after the Great Hanshin Earthquake

ond largest gas utility having about 5.7 million customers. In spite of nation-wide aid by other gas utilities, full restoration took 85 days due to numerous pipe breaks (over 26 thousand in total) and other difficulties, e.g., debris blocking roads, traffic jams, water from broken water mains.

Water systems were affected more or less in all the five earthquakes, but again, by far larger in the Great Hanshin Earthquake. In the Kushiro-Oki Earthquake, a few hundred houses on tableland of Kushiro lost water due to pipe breaks. Many breaks in water distribution lines were also reported in the Hokkaido-Nansei-Oki, Hokkaido-Toho-Oki, and Sanriku-Haruka-Oki events. Tank trucks of water departments and Self-Defense-Force brought water to the residents.

In Kobe, almost all the homes lost water shortly after the Great Hanshin Earthquake. Kobe and its vicinities depend mostly on Yodo River in Osaka for their water. Raw water pipes from the river to filtration plants were broken in many places and some filtration plants were also damaged. Together with numerous breaks in distribution lines (13,785) and service pipes (50,828), full restoration took 73 days in Kobe (Photo 21). Figure 8 compares the ratios of water customers in service in Kobe and Nishinomiya after the earthquake. A total of 432 water delivery trucks were engaged during the period in Kobe. Only 50 trucks were belong to Kobe and the others were from many other cities and the Self Defense Force (Photo 22).

Telecommunication systems were always affected by the five earthquake disasters. Few structural damages, e.g., broken poles and disrupted underground cables, were reported in the four northern earthquakes. In general, the physical effects were small because earthquake countermeasures of telecommunication systems are well established. In the Great Hanshin Earthquake, however, structural damage to telecommunication systems was large, mostly on lines and buried ducts.

The biggest problem for telecommunication systems after earthquakes is overload of traffic. Too many calls to and from affected areas cause jams in the telecommunication system. For cities like Kushiro and Hachinohe with population of about 200 thousand, overload continued for one day. The trouble was rather minor since the population was not so large and people could get information by TV or radio. But after the Great Hanshin Earthquake, the overload of telephone traffic continued for several days since more than two million people lived in the affected area and the people outside were watching TV showing devastating scenes. The telephone traffic jams made the emergency operations more difficult. To cope with heavy traffic demands and to compensate disrupted lines, the Nippon Telegraph and Telephone (NTT) installed several temporary service centers in the affected area (Photo 23).

SOCIAL IMPACTS

The five earthquake more or less affected the lives of residents and local economy. Functional loss of infrastructures damaged by the earthquakes, e.g. roads, railways, ports, might be most significant effects for the Kushiro-Oki and the Hokkaido-Toho-Oki Earthquakes. But restoration was completed mostly in a few months. However, restoration of Okushiri Island from the Hokkaido-Nansei-Oki Earthquake is still underway after two years. Mental care was highlighted first in Japan after the disaster in Okushiri. Mental care became a more common practice after the Great Hanshin Earthquake.

Social impacts by the Great Hanshin Earthquake are too large, hence it is difficult to summa-

Photo 19 Batteries torn down from the supporting ceramic columns in Kushiro Substation in the Kushiro-Oki EQ.

Photo 20 Electric poles were torn down along the street in the Great Hanshin EQ. About 10 thousand poles were damaged.

Photo 21 Construction work of water lines in Kobe after the Great Hanshin EQ.

Photo 22 Lines of people waiting for water delivery trucks in Kobe after the Great Hanshin EQ.

Photo 23 People are calling from the temporary telephones setup by NTT after the Great Hanshin EQ.

Photo 24 Temporary apartments for refugees in Ashiya after the Great Hanshin EQ.

rize here. The damaged railways have been almost restored after 6 months. Reconstruction of collapsed highway bridges needs two years. Many damaged factories started operation recently. Some offices in the central Kobe moved to Osaka. Moreover, many difficult problems arose, e.g., how to rebuild totally destroyed districts taking into account many different opinions. People who lost their homes and had been in refugee camps have moved to temporary houses provided by local jurisdictions (Photo 24). But reconstruction of new houses may take a long time. For some people, it may not be possible. We need a few years till we can talk about the social impacts from the Great Hanshin Earthquake.

CONCLUDING REMARKS

A general review of five damaging earthquakes which occurred in Japan in the last two years was given in this paper. The authors initially aimed to provide English literature on the four earthquakes which occurred in northern Japan: the 1993 Kushiro-Oki Earthquake, the 1993 Hokkaido-Nansei-Oki Earthquake, the 1994 Hokkaido-Toho-Oki Earthquake and the 1994 Sanriku-Haruka-Oki Earthquake. However, the Great Hanshin Earthquake occurred on January 17, 1995, and its damage and human loss were incomparably larger than the four previous events. Hence more description was provided for the Great Hanshin Earthquake than the others. Seismologists said that both the eastern and western halves of Japan entered an active period of seismic activities. We must be prepared for more earthquakes coming in the near future. Various lessons learned from those earthquakes should be considered seriously in promoting countermeasures for earthquake disasters.

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