STRONG GROUND MOTIONS OF THE 1997 NORTHWESTERN KAGO-SHIMA PREFECTURE EARTHQUAKE AND SEISMIC HAZARD OF THE REGION

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SUMMARY

The earthquake of M 6.5 occurred in the northwestern part of Kagoshima prefecture in Japan on March 26 in 1997. After about 50 days, another earthquake of M 6.3 whose source region was adjoining occurred on May 13. Some reinforced concrete school buildings and a lot of wooden houses suffered severe damage. This region is in low seismicity in Japan and there was no record of historical seismic disaster. Many strong ground motions were recorded by the new type seismographs that were settled in high density by the JMA and the NIED after the 1995 Hyogoken-Nanbu Earthquake. Two source regions were under the Mt. Shibi, and so the nearest seismographs were at seven stations in three cities and a town that surround the source regions in different directions and were about 10 km apart from the epicenters. The high peak ground accelerations such as 728 cm/s^2 in Izumi or 902 cm/s^2 in Miyanojyo were observed. These motions with the high peak ground accelerations were observed at the stations that were at right angles to the faults and their response spectra show that they contain predominant high frequencies. The seismic hazard analyses by the statistical method and by the probabilistic method show that the return period of these peak ground accelerations in the region is estimated as 3500 years or 1100 years.

INTRODUCTION

It is very difficult to predict the maximum ground motion and to make a plan to prevent seismic disaster especially in low seismic region. Even in such a region, extremely strong ground motion may occur though the return period is very long. Even if severe ground motion occurred in the region, the strong ground motion near source region would not be recorded up to the present by the unequally distribution of seismographs. The number and the scale of aftershocks usually decrease with time. However, the same scale earthquake occurs rarely in almost the same place. The earthquake occurred in the northwestern part of Kagoshima prefecture in Japan in 1997 is such an earthquake. Fortunately a lot of strong ground motions near source region were obtained in this earthquake by the new type seismographs that were settled in high density after the 1995 Hyogoken-Nanbu Earthquake. The intensities and the response spectra of the observed ground motions are somewhat different from the past remarkable strong motions, for instance, El Centro 1940 and Taft 1952.

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EARTHQUAKES AND STRUCTURAL DAMAGE

The earthquake of M 6.5 occurred in the northwestern part of Kagoshima prefecture in Japan on March 26 in 1997. The source region was under the Mt. Shibi (1067m high) and almost all damage of buildings occurred in cities and towns around the mountain. Several reinforced concrete buildings, especially school buildings, and many wooden houses suffered damage. After a lot of aftershocks followed, in which the largest one was M 5.5 on April 3, the earthquake of M 6.3 occurred in almost the same region on May 13. Two events are considered as different earthquakes though faults and aftershock regions were adjoining. By the latter earthquake, a lot of buildings were furthermore damaged which had been damaged by the former earthquake and continuous aftershocks. Though several school buildings had been out of use, some of them were collapsed. Damage of houses was not so serious; e.g. the roof tiles of traditional wooden houses slipped off by vibration. Figure 1 shows the location of epicenters, aftershock regions and the remarkable collapsed school buildings. Table 1 shows the information of earthquakes. Table 2 shows the list of structural damage.

Table 1: Information of main shocks and the largest aftershock

Date and time of event	Location of epicenter	Magnitude	Depth
March 26, 1997, 17:31	31 58' N , 130 22' E	6.5	12 km
April 4, 1997, 4:44	31 59' N , 130 19' E	5.5	9 km
May 13, 1997, 14:38	31 57' N , 130 18' E	6.3	9 km

Table 2: List of structural damage

	March 26	April 3 ~ April 9	May 13	Total
Complete collapse	4	0	4	8
Half collapse	22	11	29	62
Slightly damage	2,184	200	4,944	7,328

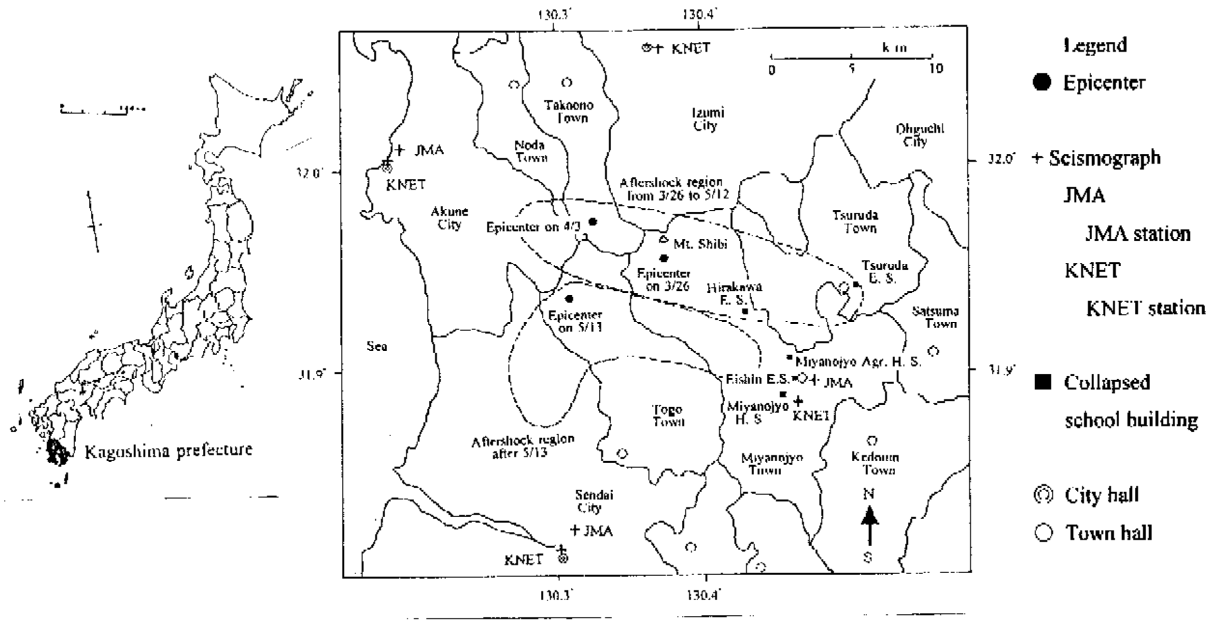


Figure 1: Location of epicenters, aftershock regions, collapsed school buildings and seismographs

STRONG GROUND MOTIONS

New type strong-motion seismographs were settled in Japan after the 1995 Hougoken-Nanbu earthquake; about one thousand K-NET95 strong-motion seismograph with the natural frequency of 450 Hz by NIED (the National Research Institute for Earth Science and Disaster Prevention) [Kinoshita et al., 1997] and about six hundreds Type 95 Intensity meter by JMA (Japan Meteorological Agency). This earthquake was the first damaged earthquake that strong motions were recorded by these seismographs. Though there were no seismographs in the source regions, seven observatory stations in three cities and a town surround the source regions and were about 10 km apart from the epicenters. The locations of these stations are shown in Figure 1. KNET stands for Kyoshin (strong motion in Japanese) NET station by NIED and JMA stands for JMA station. Two seismographs were settled in Miyanojyo town located southeast from the source regions, Sendai city located south and Akune city located northwest. A seismograph was settled in Izumi city located north.

The high PGAs (peak ground accelerations) were observed by this earthquake as shown in Tables 3 and 4. The PGAs on March 26 were 727 cm/s^2 in Izumi and 663 cm/s^2 in Miyanojyo. The PGAs on May 13 were 902 cm/s^2 in Miyanojyo and 728 cm/s^2 in Izumi. Figure 2 shows the orbits of horizontal ground accelerations and the estimated faults that were not observed on the ground. The fault on March 26 was the right-lateral fault. It is obvious that ground motions at stations that are at right angles to the fault are larger than those at stations on the extension of the fault. The severe structural damage occurred, however, on the east extension of the fault. The fault on May 13 consists of two parts which are mutually perpendicular and one is parallel to the fault on March 26. The major structural damage concentrated from the east to the south of the fault.

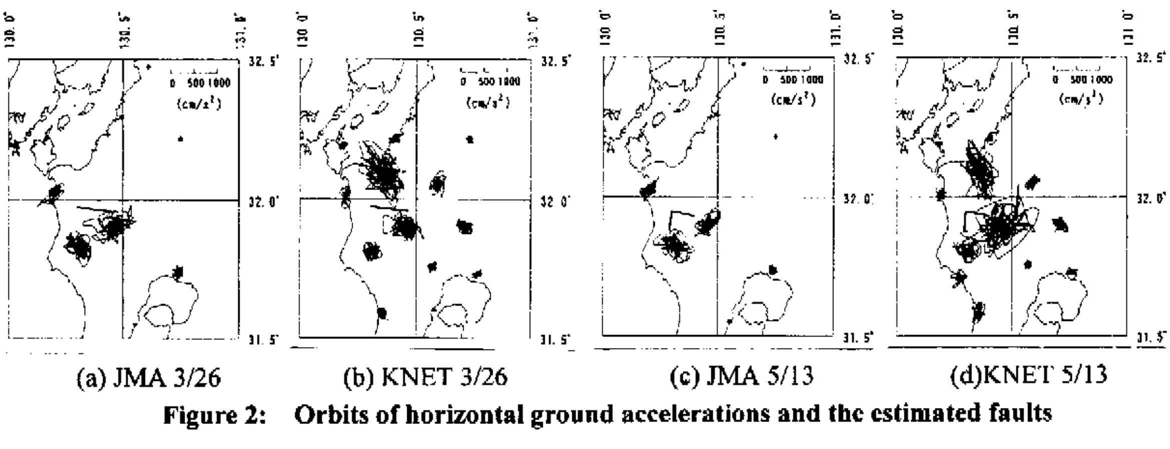
The attenuation curves of the PGA by the KNET stations are shown in Figure 3. Kanai's relation [Kanai,1966] with the predominant soil period of 0.6 s and Fukushima's relation [Fukushima, 1996] are shown in the figure. The observed values are almost the same level to the relations in the hypocentral distance from 30 km to 100 km, but those are larger than the relations in short hypocentral distance below 30 km. This may depend on the characteristics of new seismograph as described later.

Table 3: Peak ground accelerations at KNET stations (unit:cm/s^2)

Date	Time	M	Miyanojyo			Sendai			Akune			Izumi		
			NS	EW	UD	NS	EW	UD	NS	EW	UD	NS	EW	UD
3/26	17:31	6.5	434	498	146	211	224	111	293	431	96	727	542	246
4/03	4:33	5.5				124	179	50	98	112	70			
5/13	14:38	6.3	902	901	288	300	318	149	156	125	100	728	443	189

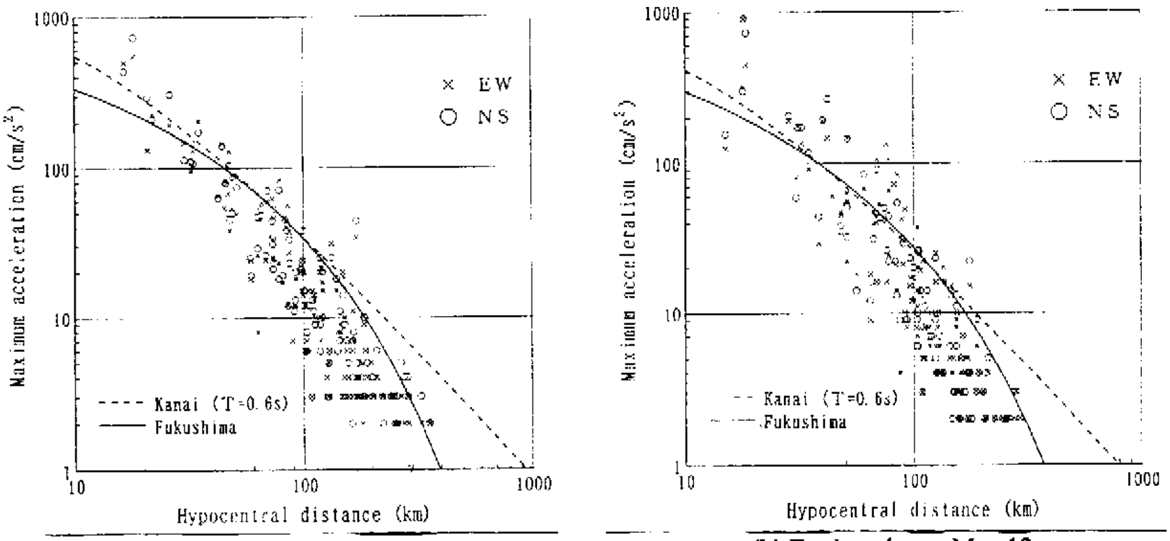
Table 4: Peak ground accelerations at JMA stations (unit:cm/s^2)

Date	Time	M	Miyanojyo			Sendai			Akune		
			NS	EW	UD	NS	EW	UD	NS	EW	UD
3/26	17:31	6.5	491	663	393	435	364	128	305	397	131
4/03	4:33	5.5	280	223	170	233	296	82	194	382	94
5/13	14:38	6.3	354	298	321	413	470	189	299	214	173



(a) JMA 3/26 (b) KNET 3/26 (c) JMA 5/13 (d)KNET 5/13

Figure 2: Orbits of horizontal ground accelerations and the estimated faults



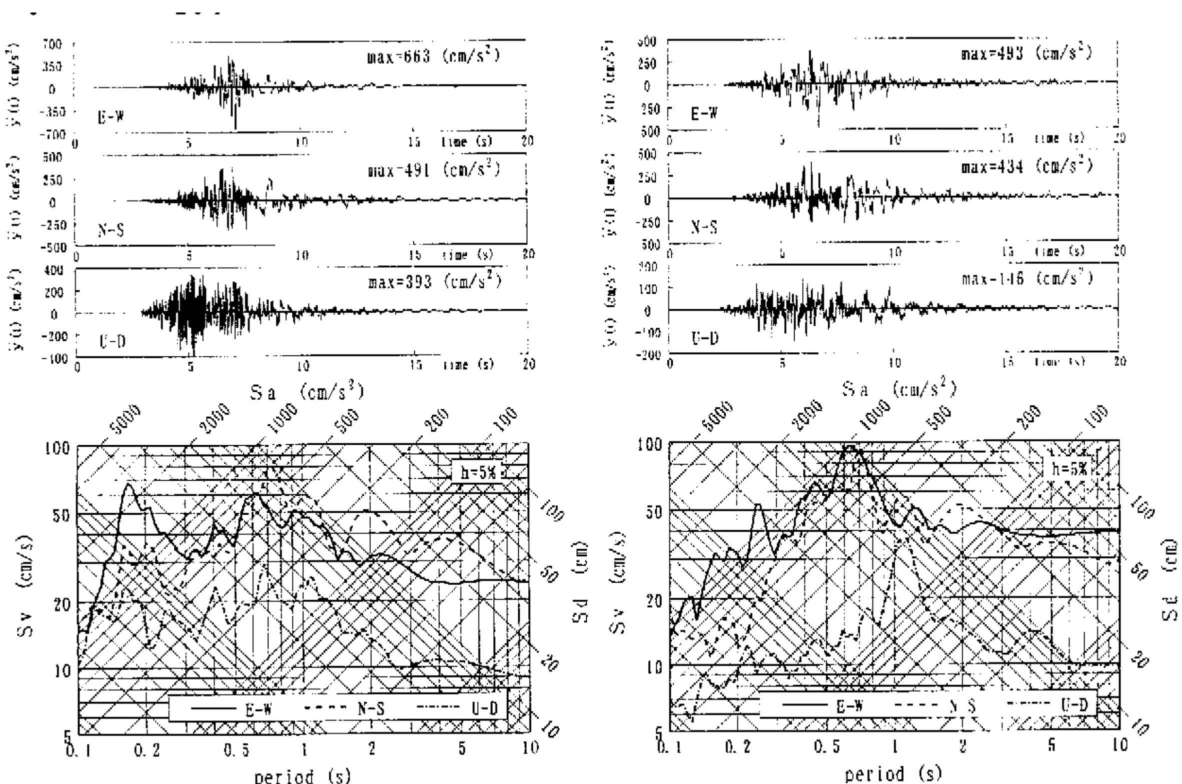
(a) Earthquake on March 26

(b) Earthquake on May 13

Figure 3: Attenuation curves obseved by the KNET stations

CHARACTERISTICS OF THE GROUND MOTIONS

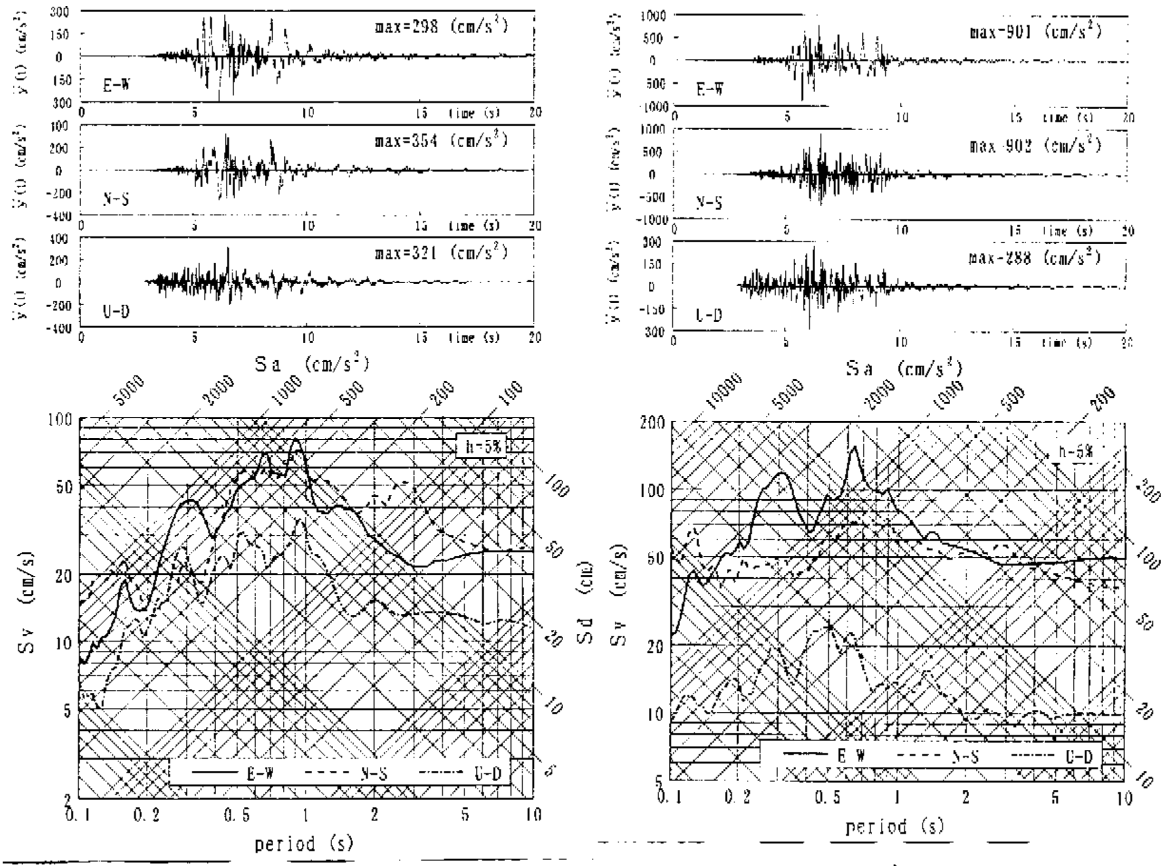
The severe structural damage occurred in Miyanojyo town that was near the east extension of the fault. Two stations in the town are about 500 m apart each other. The JMA station is on the level ground in a small basin and the KNET station is on the cut ground in the slope of a hill. The PGA at JMA on March 26 is larger than that at KNET because JMA station is north and closer to the fault. However it is contrary on May 13. This shows that ground motion is strongly depend on the location to the fault. The ground motion and the response spectra for the damping ratio of h=5% on March 26 and May 13 are shown in Figures 4 and 5, respectively. It is recognized that the periods lower than 0.3 s in the strong motion at JMA on March 26 and in the strong motion at KNET on May 13 are strongly predominant. This is the main cause of the high PGA.



(a) JMA station

(b) KNET station

Figure 4: The ground motions and response spectra in Miyanojyo on March 26



(a) JMA station (b) KNET station

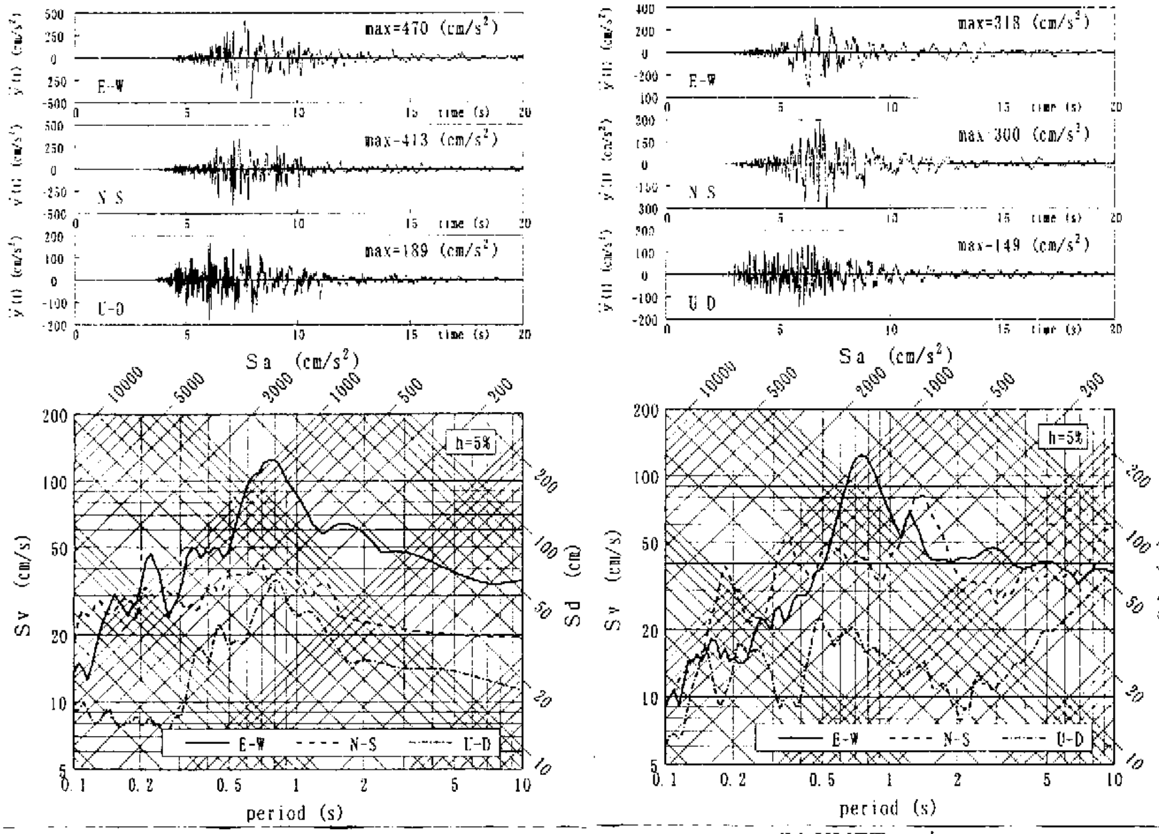
Figure 5: The ground motions and response spectra in Miyanojyo on May 13

Sendai city is located to the south of the source regions and two seismographs are about 500 m apart each other on the soft ground close to the Sendai river. The structural damage on May 13 was more severe because the fault was closer to the city. The ground motions and the response spectra for h=5% on May 13 are shown in Figure 6. It is recognized that the period of 0.75 s in EW component is predominant, but PGAs of two horizontal direction are almost the same level. The periods below 0.3 s are not predominant. This is the effect of the location to the fault and the soft ground condition.

Akune city is located to the northwest of the source regions. KNET station is on the soft ground close to the sea and JMA station is on the firm ground in the slope of a hill. Both stations are about 1.5 km apart each other. The structural damage was not severe though the city was on the extension of the fault on March 26. The ground motions and the response spectra on March 26 are shown in Figure 7. The period of 1.3 s in NS direction at KNET is strongly predominant and this period is obviously recognized in the ground motion. This is the effect of the liquefaction because it is observed on the ground of reclaimed land near the station. The predominant period of 0.2 s at JMA is related to the soil characteristics because it is observed in the micro-tremors too.

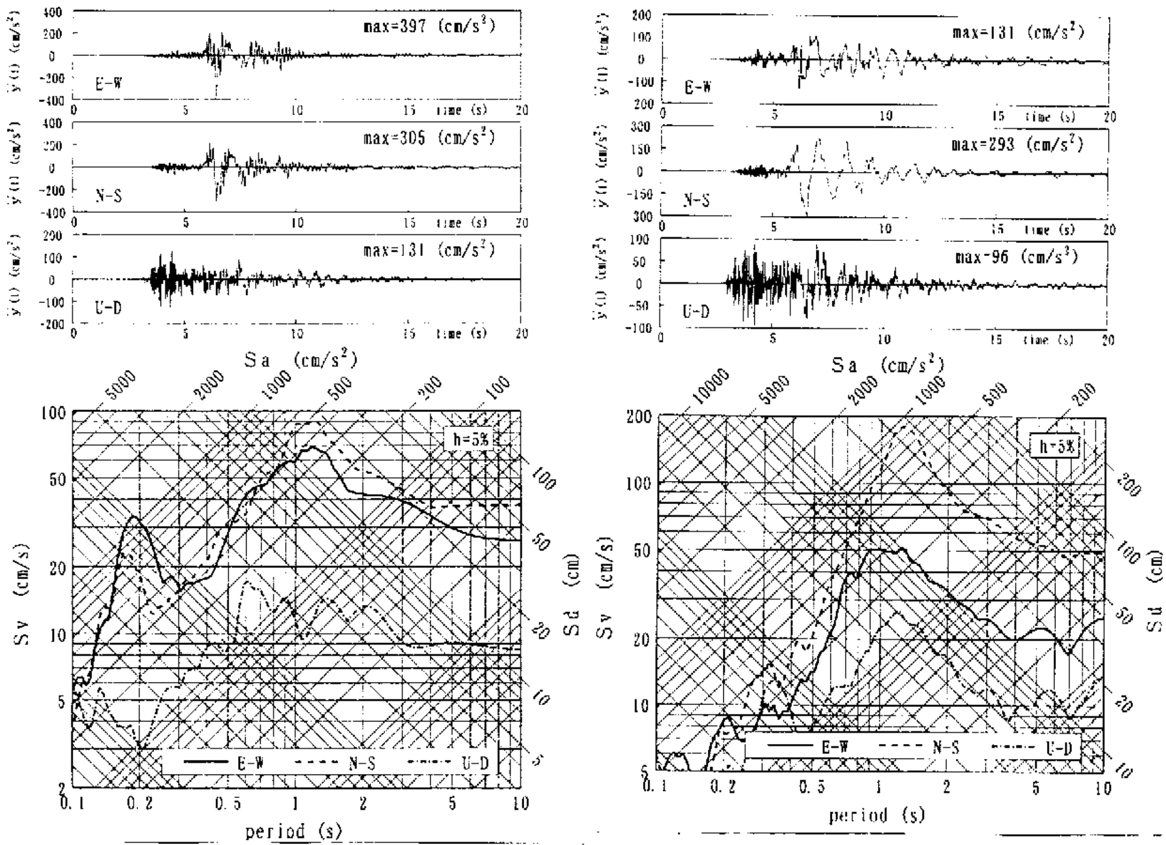
Izumi city is located to the north of the source regions and KNET station is on the very firm ground. The ground motions and the response spectra on March 26 are shown in Figure 8. The structural damage in the city was not serious though high PGAs were recorded. For instance, a poor-designed one story warehouse adjoined to the KNET station suffered no damage. In these ground motions, periods below 0.5 s are extremely predominant. This is the cause of the high PGA and slightly structural damage .

As a result, the peak ground motion depends on the location and distance to a fault and ground conditions. If soil is firm and the hypocentral distance is short, PGA is very high even though the magnitude of earthquake is lower than 7. High frequencies over 3 Hz are predominant in such a severe strong motion.



(a) JMA station (b) KNET station

Figure 6: The ground motions and response spectra in Sendai on May 13



(a) JMA station (b) KNET station

Figure 7: The ground motions and response spectra in Akune on March 26

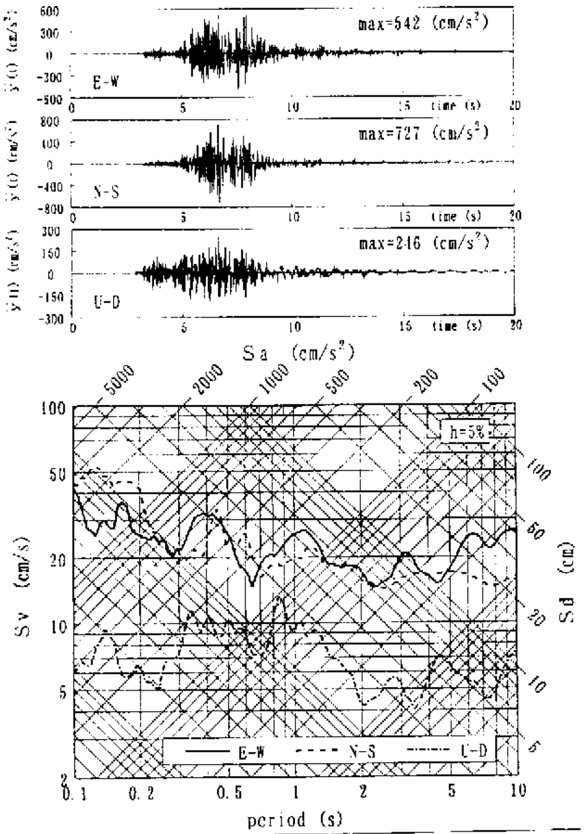


Figure 8: The ground motions and response spectra at Izumi on March 26

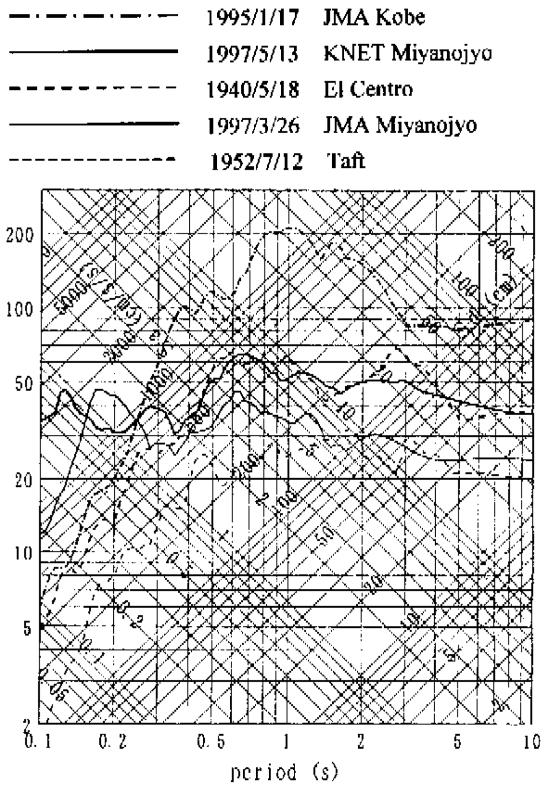


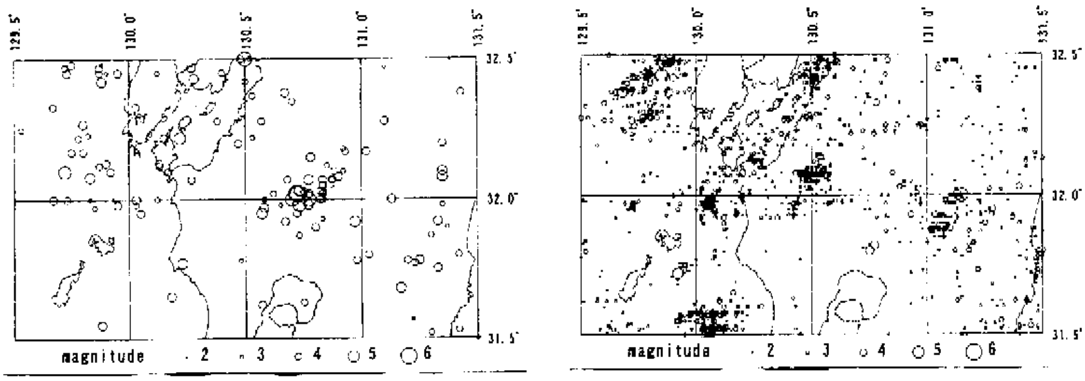
Figure 9: Comparison of response spectra (h=5%)

To compare with past remarkable ground motions, Figure 9 shows the response spectra for h=5% of Miyanojyo 3/26, Miyanojyo 5/13, El Centro 1940, Taft 1952 and JMA Kobe 1995. The level of response spectrum of Miyanojyo 3/26 is almost the same to Taft 1952 over the period of 0.5 s, but is larger below 0.5 s. The level of response spectrum of Miyanojyo 5/13 is almost the same to El Centro 1940 over the period of 0.5 s, but is larger below 0.5 s. This difference may depend on the natural periods of new seismographs that are smaller than those of the past strong-motion seismographs.

SEISMIC HAZARD

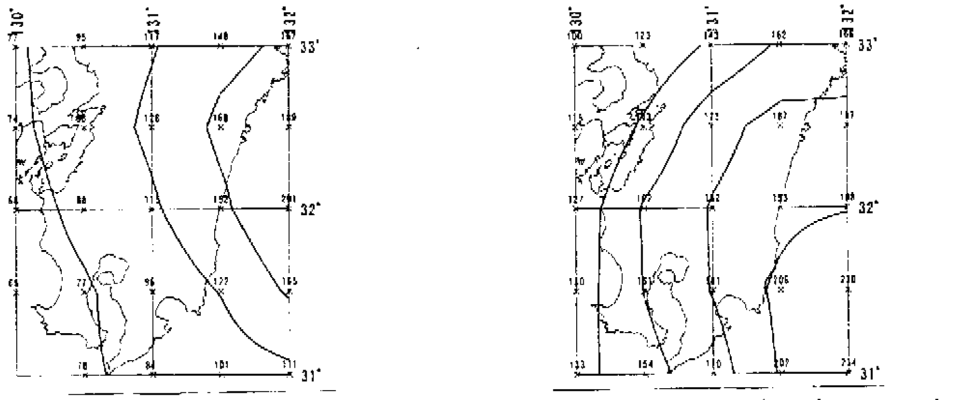
There were no historical records of the earthquake disaster near the source region. Figure 10 shows the earthquake epicenters for two periods; (a) is from 400 to 1990 and (b) is from 1926 to 1996. In 1968, an earthquake swam that contains several earthquakes of JMA intensity 5 occurred about 40 km east. In 1994, the earthquake of M 5.7 occurred northeast and after this event micro earthquakes gradually moved to the source region in 1997.

Figure 11 shows the two seismic hazards of the south Kyushyu. Figure (a) is made by the statistical method that fits the order statistics derived from the earthquake catalogs to the second extreme value distribution [AIJ, 1993] and figure (b) is made by the probabilistic method that uses the areal source regions based on the seismotectonics [Matsumura, 1996]. Return period values for 100 years are estimated as 88 cm/s^2 and 162 cm/s^2, respectively. Return period values for 500 years are estimated as 210 cm/s^2 by the statistical method and 390 cm/s^2 by the probabilistic method. If 900 cm/s^2 is assumed as the value of mean plus one standard deviation and the coefficient of variation is 0.5, the mean return period value is about 600 cm/s^2. The corresponding return periods are 3500 years by the statistical method and 1100 years by the probabilistic method.



(a) Earthquakes from 400 to 1990 (b)Earthquakes from 1926 to June 1996

Figure 10: location of earthquakes



(a) analysis base on the earthquake catalog (b) analysis based on the seismotectonics

Figure 11: return period values for 100 years in acceleration (cm/s^2)

CONCLUSIONS

Following conclusions are derived from the information of source region, structural damage and the analysis of strong ground motions of the 1997 northwestern Kagoshima prefecture earthquake.

1) Another earthquake with the same magnitude occurred in the adjoining source region after about 50 days.
2) Many buildings that had bean damaged by the former earthquake suffered severe damage by the latter earthquake. We must pay attention to this for prevention of seismic disaster and repair of damaged buildings.
3) Intensities and spectra of strong motions are strongly depend on the location of a fault and site conditions.
4) High strong motions over 900 cm/s^2 were recorded though the magnitudes of earthquakes were 6.5 or 6.3.
5) Those high strong motions contain predominant high frequencies.
6) The return period corresponded to PGA=600 cm/s^2 in this region is estimated as 1100 years and 3500 years by two seismic hazard analyses.

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