TS-21 IWASAKI / 1

STRONG GROUND MOTION DURING THE KOBE EARTHQUAKE OF JAN.17,1995

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Paper No. 2149. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3
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ABSTRACT

This paper describes the characteristics of the strong ground motion during the Kobe earthquake. The attenuation of the horizontal maximum accelerations were compared with the experimental equations and were found to correspond well each other. The directivity of the intensity of the acceleration was discussed and the stronger vertical acceleration than horizontal one was also found in filled ground. The difference of the amplification between small and strong ground motion was presented. The structural damage in the epicentral region was compared with the strong motion amplitude of the observed records.

KEY WORDS

Kobe earthquake, strong ground motion, directivity, amplification, epicentral region, housing damage

1995 KOBE EARTHQUAKE

Just one year after of the North ridge earthquake near Los Angeles, California, a magnitude 7.2 earthquake hit the Kobe area at 5:46'51.9" in the early morning of January 17, 1995. MA(Japanese Meteorological Agency) named the earthquake "Hyogoken-Nambu Earthquake". The damage caused by the earthquake was so devastated and have destroyed the illusion of Japan as the most advanced region in the world prepared against earthquakes. These two earthquakes are as follows,

Table-1 Northridge and Kobe Earthquake

	Northridge Earthquake	Kobe Earthquake
Date	4:30 January 17, 1994	5:46 January 17,1995
Magnitude	M_L=6.7	M_L=7.2
Moment	1.2x10^{26}dyne-cm Mw=6.7	2.5x10^{26}dyne-cm Mw=6.9
Depth	18km	14km
Fault Type	Reversed	Strike-slip with reversed comp.
Strike/Dip	N123^{o}E	N53^{o}E/85^{o}N
rake	105^o	165^o
Fault Length	16km	30-45km
Averaged Slip on Fault	1.6m	2.5m
Death	61	6,500(as of Jan.,1996)
evacuated	414,000 families	320,000 peoples
Damaged Houses	14,000	159,000
Maximum Acc.	1.82g(Tarzana)	0.86g(Kobe, JMA)

The aftershock distribution shown in Fig.1 corresponds well to the existing active fault called as Nojima Fault along the north-western side of the Awaji island and Suwayama Fault along the southern edge of the Rokko mountain. The length of the after shock area is about 60km and the depth ranges shallower than 15-20km in the nearly vertical plane.

THE STRONG MOTION CHARACTERISTICS

The distribution of the maximum horizontal acceleration recorded during the earthquake was shown in Fig.2. There is a tendency that the stronger acceleration was found along the fault towards the ENE direction. The attenuation of the maximum acceleration from the fault is shown in Fig.3 for the points within a angle from-30 to +30 degrees along from the fault line in the east direction(Forward Zone). Fig.4 shows that the same plots for the other points (Side and Backward Zone). Two solid lines of the experimental attenuation relation are shown int he same figure. One is by Joyner and Boore(1981) and another is by Fukushima(1994), which are found to correspond well to the observed attenuation tendency. It is seen that the amplitude in the forward zone is about twice larger than the other zones. This is an effect of directivity which is caused by the energy concentration towards the rupture propagates(so called Doppler's effect).

Figs. 5 shows velocity wave form variation from Kobe to Osaka region observed at several sites in the area. KOBE, KBU, and KMO are sites within the energy released zone. The waves are rather very simple and ends within about 10 seconds. AMA, FKS, ABN, MRG, and YAE are in the Osaka plain of very thick soil layers. The durations of the strong motions become 5 to 6 times longer than the former sites.
The depth of the base rock in the Osaka Basin is shown in Fig.6. The depth to base rock in Osaka area is about 1,500m from the surface and the typical velocity structure in the area is shown in Fig.7(Iwasaki, 1995). The soil deposits, which is mainly composed of quaternary sediment, show the shear wave velocity of 200-1,000m/sec. with 600-700m/sec. as an averaged velocity.

VERTICAL MOTION

It is recognized that the vertical motion is comparatively larger than the past records. Usually vertical motion is caused by the P-wave motion or surface wave of Rayleigh type ground motion. However, the ground motion at very near site to the fault of dip movement may prevail vertical motion by vertically polarized S-waves(SV-waves). Generally, the fault movement causes shear wave. If the fault moves horizontally the particle motion of shear wave is horizontal, which is called SH-wave(horizontally polarized shear wave). If the fault is reverse of normal fault, the motion is called SV-wave(vertically polarized). In general, the actual fault movement contains both strike and dip components, and associates SH and SV waves.
Since the maximum vertical motion at Kobe-JMA station comes at the same time of the S-wave motion, this vertical motion is known as caused by SV-wave.

Table-2 Vertical and Horizontal Acceleration

	Max.Horizontal	Max.Vertical Max.	Ratio
Kobe JMA	818.0gal	332.2gal	0.41
Kobe Port Island	341.2	555.9	1.63

The vertical motion at Kobe Port Island is very large compared to the maximum horizontal component.
This is due to large amplification ratio given by surface layer structure. The top surface of filled land is usually low P-wave velocity of the order of 0.4-0.7m/sec. due to unsaturated condition. On the other hand, the completely saturated layer shows 1.6-2.0km/sec. of P-wave velocity. If the ratio of P-wave of top surface to the base layer becomes large, the P-wave motion is also amplified like shear wave amplification.
The failure mode of some structures could not be understood without considering vertical tension stress, which may be due to the amplified high frequency compression/tension wave by P-wave.

NONLINEAR RESPONSE

There is vertical array data at Kobe Port Island. The maximum acceleration value at the depth G.L.-83.5m is

Table-3 The Change of Maximum Ground Motion at Port Island

	NS		EW		UD	
GL-0.0m	340.6gal	89.8kine	284.2	51.0	555.6	62.0
-16.5m	564.7	76.1	543.5	52.6	786.6	42.1
-32.5m	543.4	64.5	461.4	76.13	200.0	52.6
-83.5m	678.6	66.6	302.6	29.5	186.6	28.6

678.6gal and is decreased to 50% of 340.6gal at the ground surface.
This is due to softening of the soils and it is expected that the maximum ground motion at the deep soft and /or filled ground decreased compared to those on the hard ground condition.

THE SITE AMPLIFICATION IN OSAKA BASIN FOR WEAK MOTIONS

The committee of Earthquake Observation and Research in Kansai Area (CEORKA) had started in April, 1994 just eight months before the Kobe earthquake. There are several small events earthquakes which were recorded by the CEORKA network.

Typical examples of the records are shown in Figs.8, 9 and 10. Figs.8 and 9 show the ground motion by rather weak motion caused by a very deep shock of M=7.6 from more than 1,000 km of the epicentral distance(Fig.8) and a medium distant earthquake(Δ=70km) of M=5.2(Fig.9). Fig.10 shows strong ground motion caused by Kobe earthquake, 1995.

The spectral ratio to the rock site of KBU(Kobe University) is shown in Fig.11 for weak motions including the above two motions. In general, the spectral ratio of the surface motion in the Osaka basin to the KBU is about five in the range of 0.2-2Hz. The amplification ratio becomes less than unity above a frequency larger than 3Hz. The spectral ratio of the strong motion during the Kobe earthquake was also computed and compared with the averaged ratios for weak motions in Fig.12.
It is seem that there is a significant difference in the spectral ratio between the strong and weak motions. The dotted line is the strong motion and the real line is the weak motion. In the most site, the spectra for strong motion was amplified for the longer period of about greater than 10sec. and deamplified in the period of 1second. These deamplification may be due to nonlinear soil characteristics.

STRONG GROUND MOTION NEAR THE SOURCE REGION

The change of the maximum horizontal acceleration with the distance from the fault was shown in Fig.3 and 4. As shown in the figure, the attenuation of the maximum acceleration was more or less constant within 10km from the fault and sharply decays with the distance in the longer distance region than 10km. This is mainly because the energy release source was about 14km in depth from the surface and the attenuation with distance of wave travel was about the same for the region. The maximum recorded accelerations in the horizontal directions varies from 200-800gal, which are further grouped into ground conditions.

The accelerations of soil ground surface were amplified by a factor of two to three. On the other hand, the filled ground, if liquefied, the acceleration was deamplified and stayed within the same intensity level as in rock. For the maximum velocity and displacement, the filled ground showed very large response during the earthquake. This is because the liquefaction gave a strong effects on high frequency components.

Table-4 Maximum ground motion in the near-source region(within 6km from the fault)

ground	max.acc (gal)	max.vel. (kine)	max.disp (cm)
rock			
Kobe Univ.	300	55	15
hard soil ground			
JMA Kobe	818	84	18
Port Is.(in-layer)	679	59	22
soft soil ground			
Takatori 666	138	42	
Takarazuka	694	80	27
filled			
Port Island	341	81	34

The accelerations of soil ground surface were amplified by a factor of two to three. On the other hand, the filled ground, if liquefied, the acceleration was deamplified and stayed within the same intensity level as in rock. For the maximum velocity and displacement, the filled ground showed very large response during the earthquake. This is because the liquefaction gave a strong effects on high frequency components.

THE STRUCTURAL DAMAGES IN NEAR SOURCE REGION

Most of the severe damaged zones of Intensity VII are distributed in the near source region within the corner distance.
The housing damages in Nishinomiya region were shown in Fig.13.
The damage ratio is defined as
damage ratio=(Nc+0.5*Nh)/Nt
where
Nc; number of completely damaged house,
Nh; number of half damaged house,
Nt; total number of houses in the area.

The plotted data were taken from the Nishinomiya region, where distribution of houses are found on various ground condition and provides number of damage ratios with longer distance from the fault. The damaged ratio are grouped into ground conditions of lower plain soft ground, terrace and hard soil ground, and rock ground. The damage ratios differs greatly due to ground conditions. On the same ground condition, it decreases with distance within the epicentral region.

The maximum damage ratio is about 70% for soft ground and 40% for hard ground condition within 4-5km from the fault. The maximum acceleration does not differ much between the soft and hard ground conditions. Table-5 shows the maximum ground motions for different ground conditions within 5-6km from the earthquake fault. The maximum velocity in the soft ground ranges in 80-140kine, while those in the hard ground ranges in 60-85kine. The average damage ratio for rock ground region is about 15% and the maximum velocity is 55kine. The damage ratio for filled ground is scattered and found between hard and soft ground. The maximum velocity for filled ground is 80kine.
The damage ratio may be correlated with the maximum velocity as follows,

Table-5 Damage Ratio vs Maximum Velocity in Near Source Region

Damage ratio	Maximum Acceleration	Maximum Velocity	Ground
70%	660-690gal	110kine	soft ground
40%	800gal	80kine	hard ground
15%	300gal	50kine	rock

CONCLUSION

The several lessons learnt from Kobe earthquake are as follows,
1.The strong earthquake motions were recorded at various sites including the epicentral regions and the attenuation with a distance from the fault was found relatively good comparison with the experimental relations relations in average with two times larger accelerations in the rupture propagation direction.
2.The vertical acceleration was stronger than horizontal one notified specially in the filled land, where horizontal motion was deamplified due to nonlinear effects and the vertical motion was amplified due to strong velocity contrast in the upper unsaturated layer and small damping characteristics for longitudinal waves under strong motion.
3.The site amplification was found different for small and large ground motions, which may be caused by nonlinear effects.
4.The strong ground motion was rather constant at sites within 5 to 10km from the fault under the same ground condition. The damage distribution were different for various ground conditions and decreases with distance away from the fault. The damage ratio of housing may be related with the maximum velocity on the ground surface.

Earthquake records used in the paper were provided by CEORK. Application form for the digital data is obtained through Fax correspondence to CEORKA at +81-6-536-1739.

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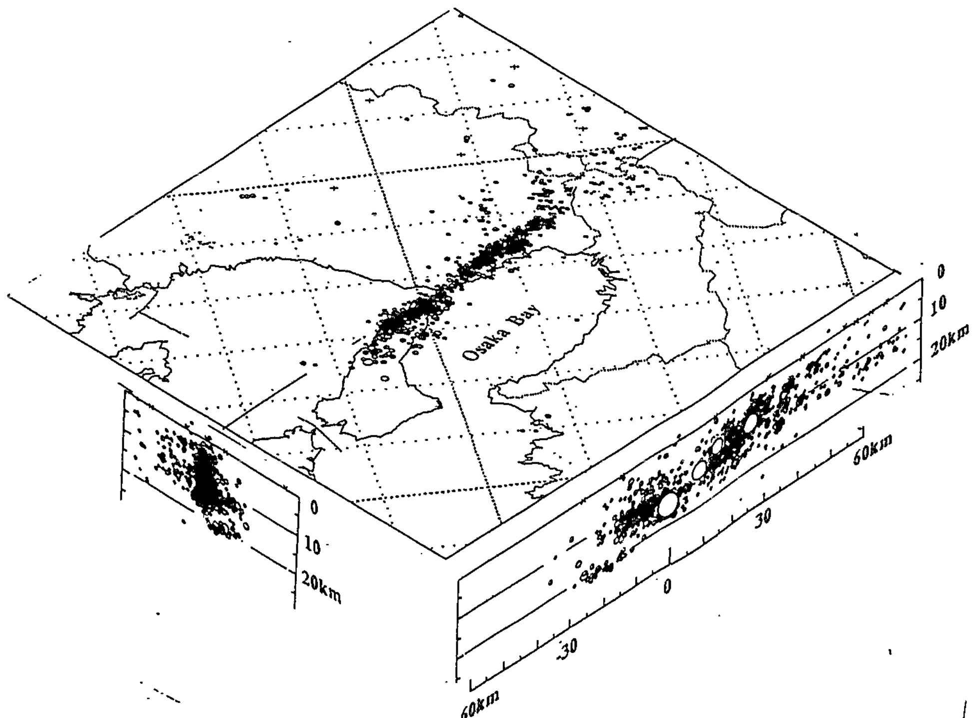

Fig.1 After Shock Distribution of the Kobe Earthquake of 1995

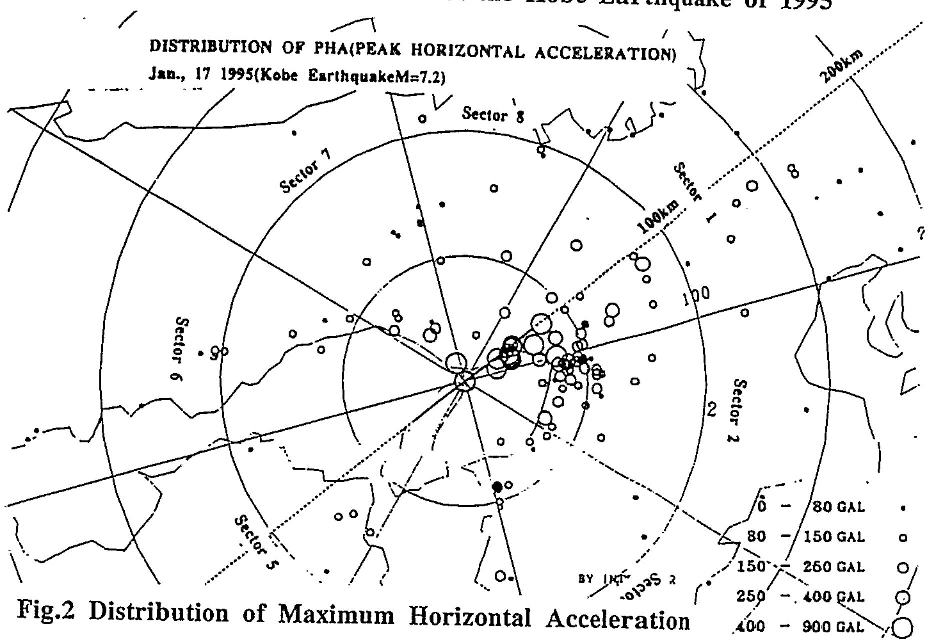

Fig.2 Distribution of Maximum Horizontal Acceleration

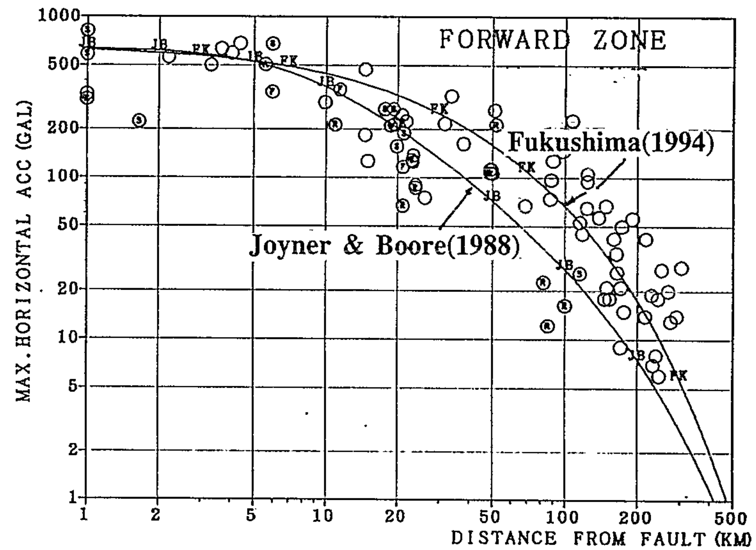

Fig.3 The Attenuation of Max. Horizontal Acceleration in Forward Zone(Sector 1 in Fig.2)

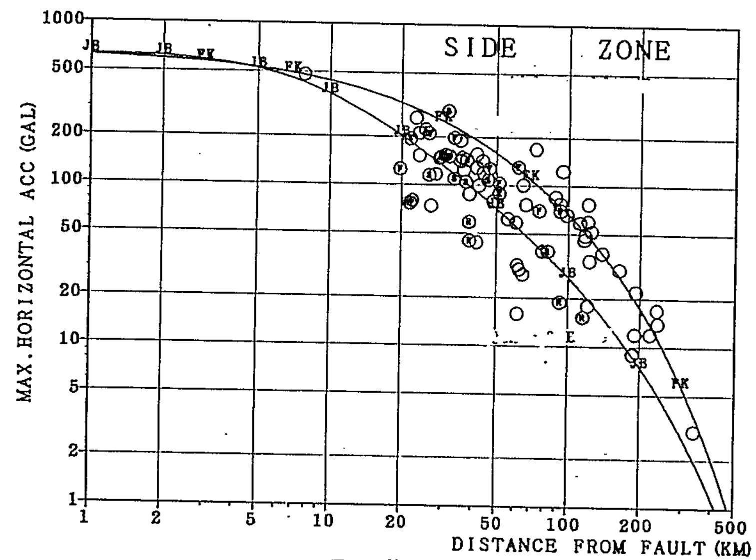

Fig.4 The Attenuation of Max. Horizontal Acceleration in Side and Backward Zone(Sector 2+3+7+8 in Fig.2)

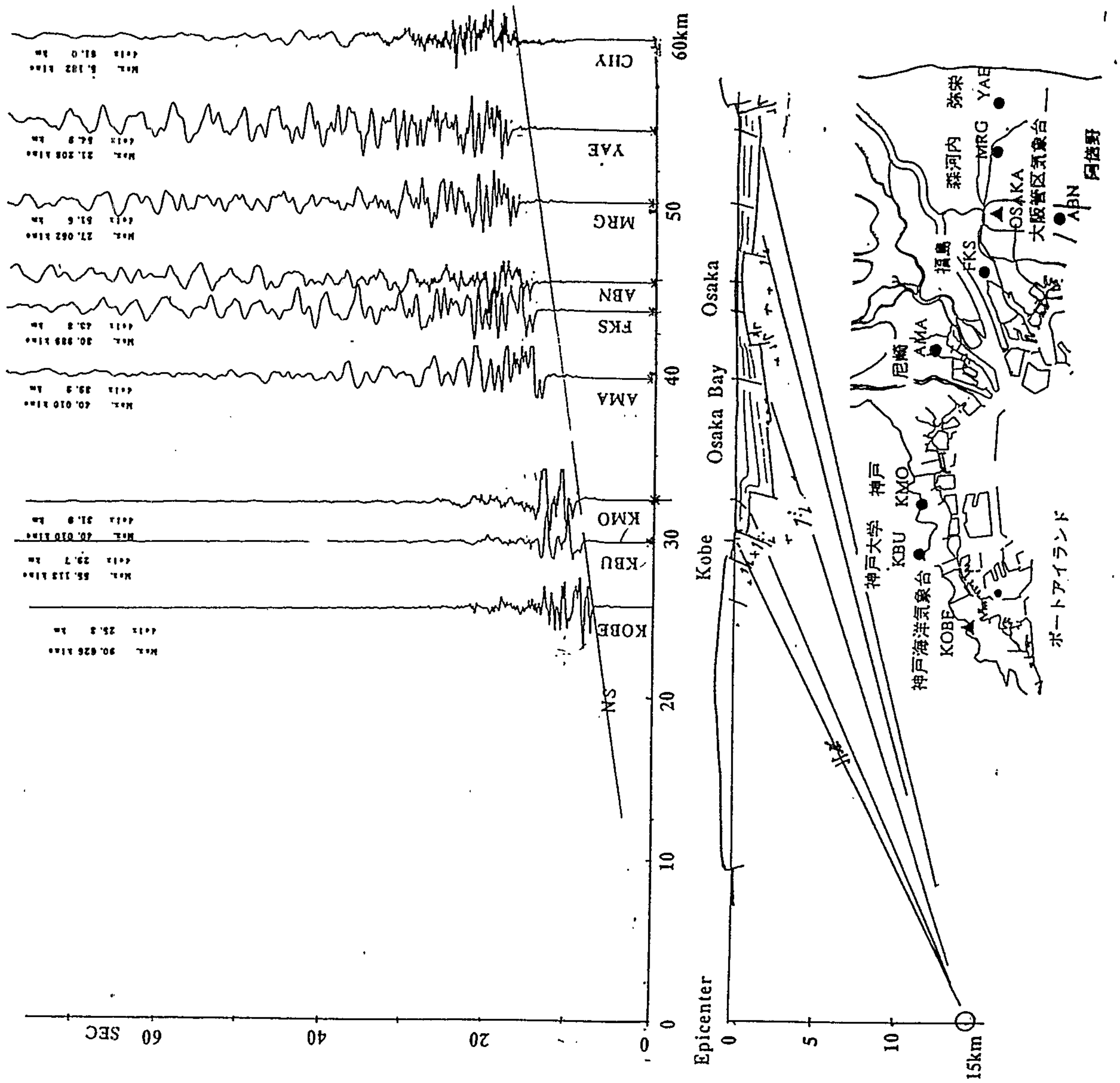

Fig.5 Variation of Ground Motion(NS) during Kobe Earthquake from Kobe to Osaka Region by CEORKA

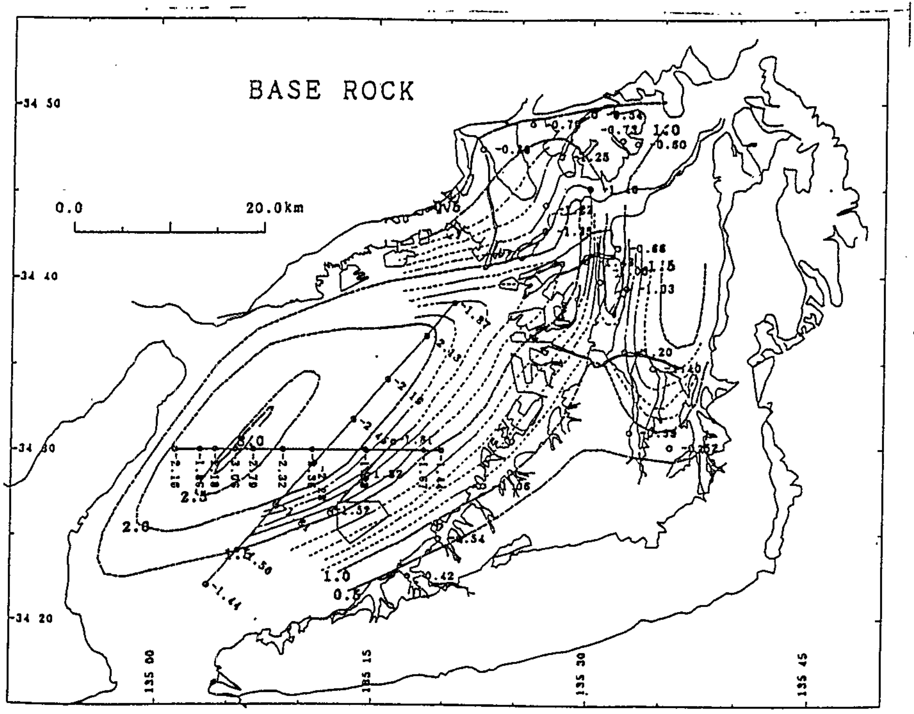

Fig.6 Depth of Base Rock in Osaka Basin

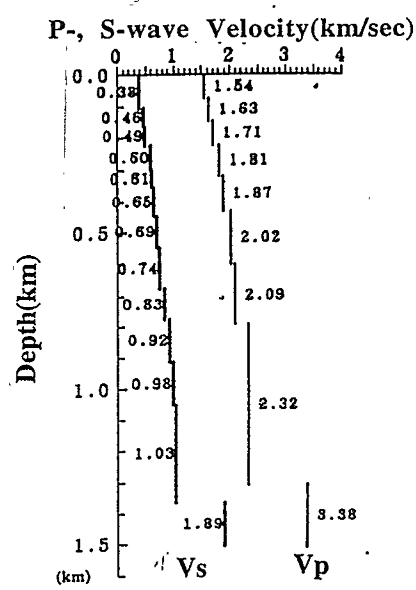

Fig.7 Typical P-and S-Velocity Structure of the Osaka Basin

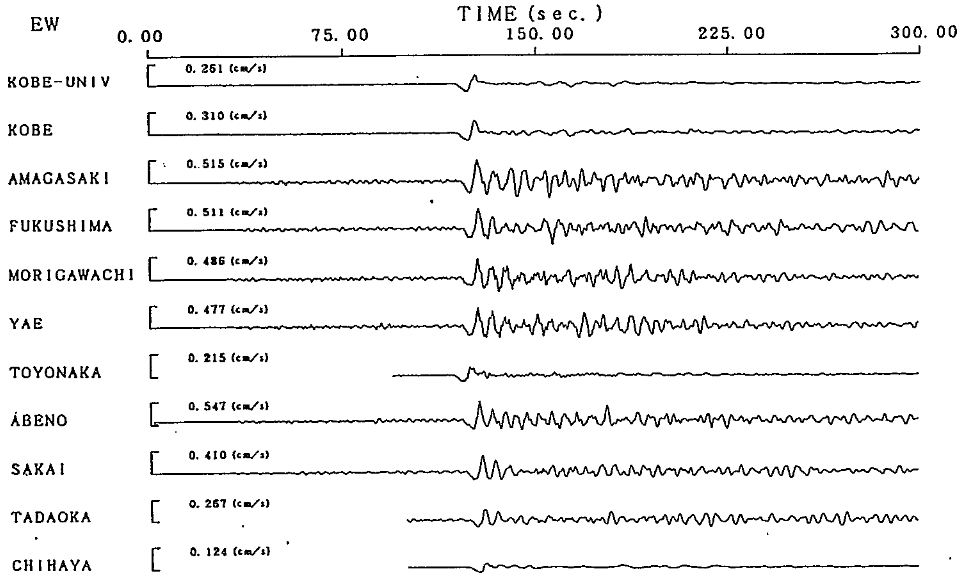

Fig.8 Ground Motion(EW) with Short Period by Weak Motion (Maximum Velocity 0.1--0.5kine)

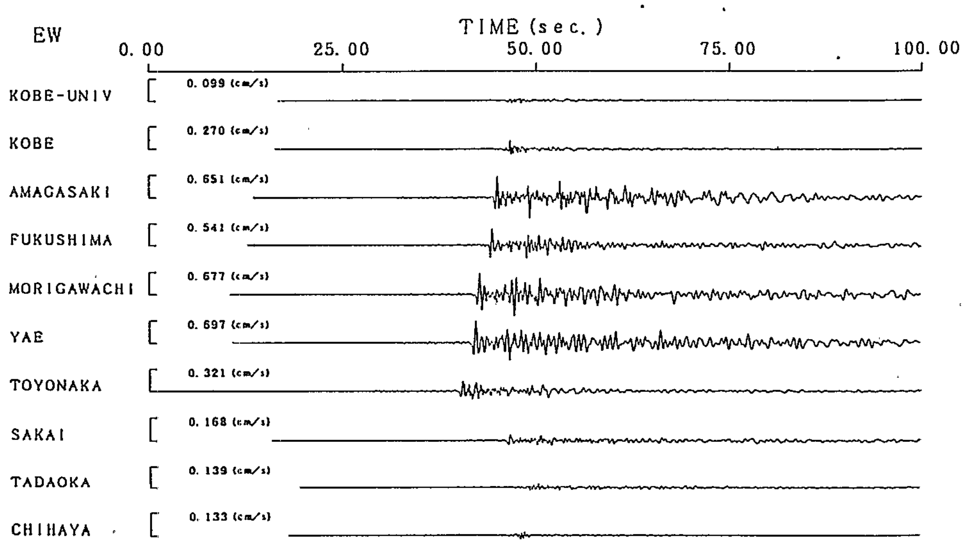

Fig.9 Ground Motion(EW) with Long Period by Weak Motion (Maximum Velocity 0.1--0.5kine)

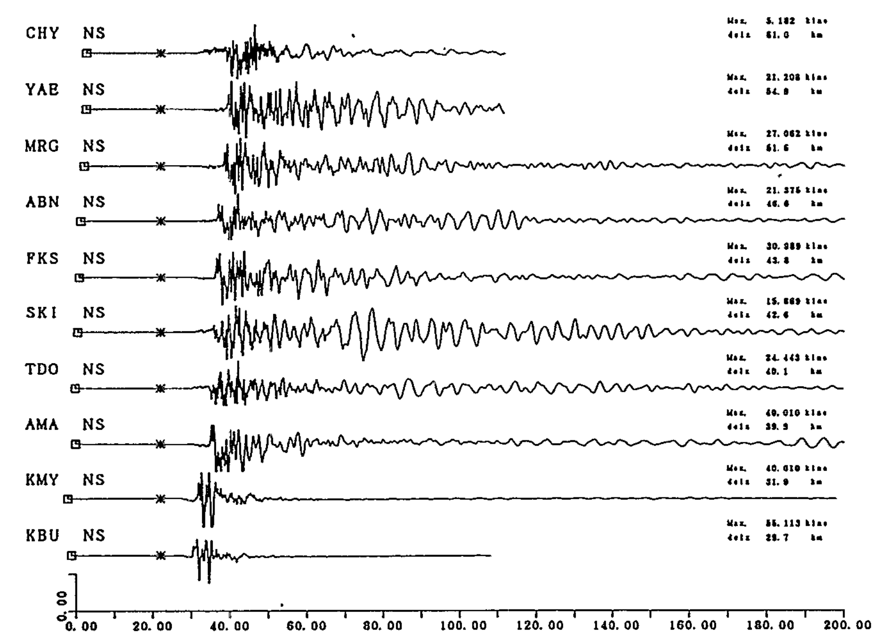

Fig.10 Ground Motion(NS) during Kobe Earthquake, 1995

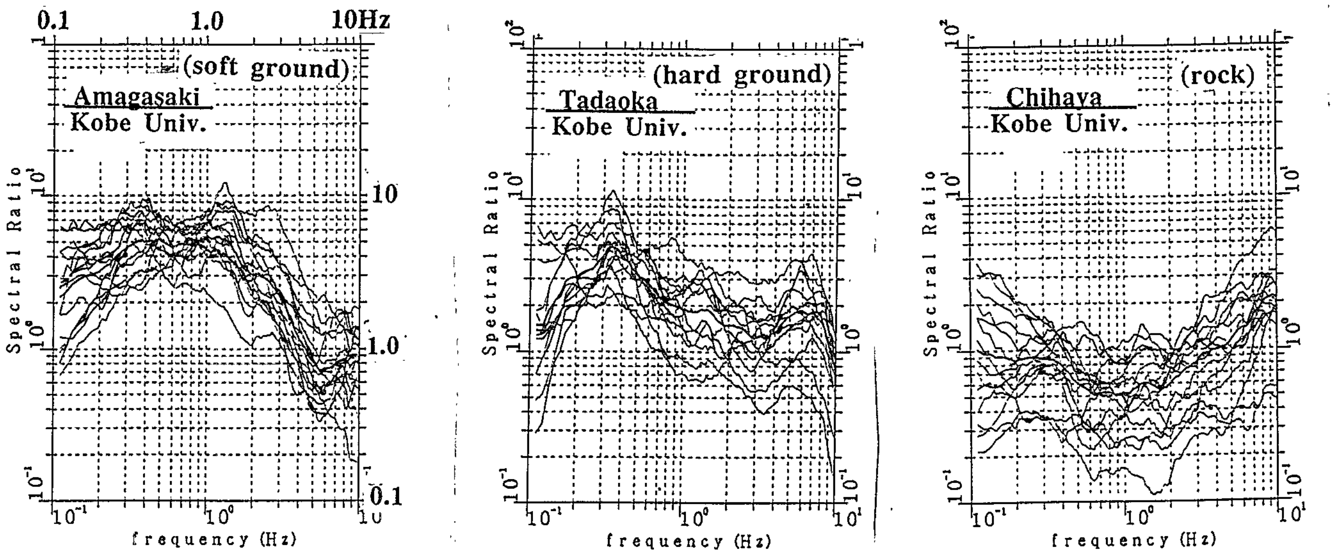

Fig.11 Spectral Ratio of Weak Motion in Different Sites to Kobe Univ.

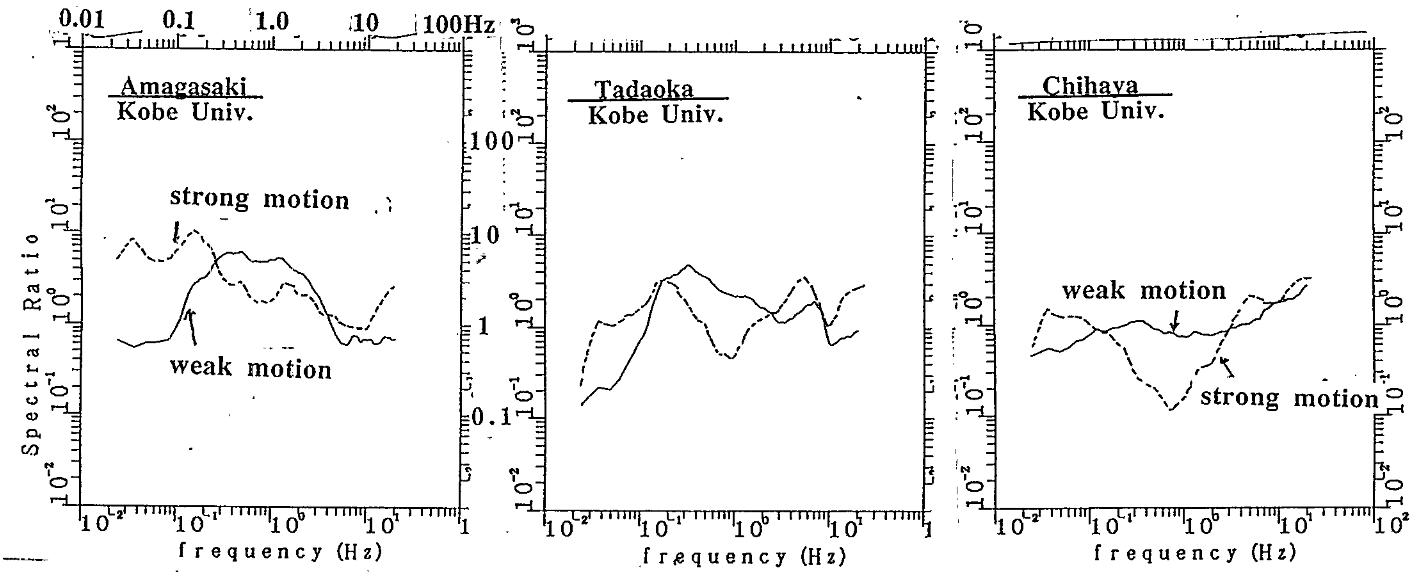

Fig.12 Comparison of Spectral Ratio of Weak and Strong Motion to Kobe Univ.

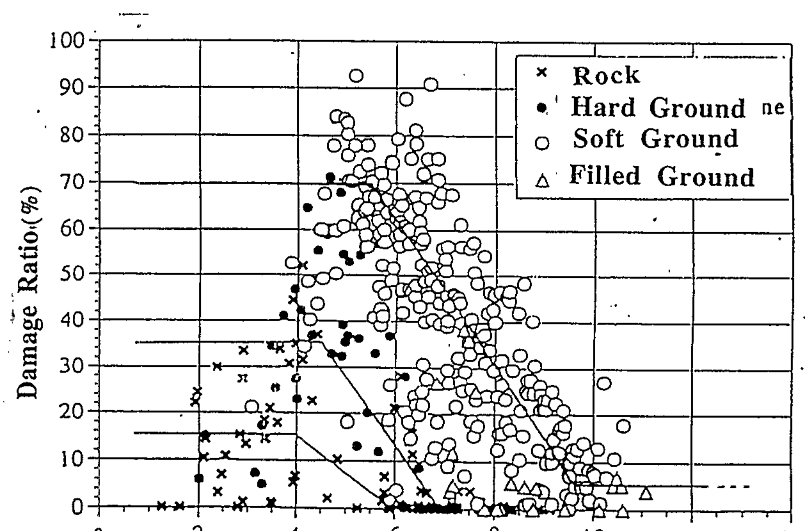

Fig.13 Attenuation of Damage Ratio of Houses with Distance from the Fault