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A DETAILED SURVEY ON THE DAMAGE OF BUILDINGS DURING THE HYOGOKEN NANBU (KOBE) EARTHQUAKE WITH REFERENCES TO AFTERSHOCK DATA AND GEOLOGY

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ABSTRACT

It is a fact that the severe damage concentrated in the narrow band in Kobe during the Hyogoken Nanbu earthquake of January 17, 1995. We operated the temporal aftershock observation soon after the earthquake along the line that crossed the "earthquake damage belt" of the JMA seismic intensity scale of 7, and carried out a detailed survey of damage on the several types of buildings including the observation points. It was our objective to make the reason for the damage belt clear. In this paper, we show the damage ratio of buildings, aftershock data, geotechnical data, and one-dimensional amplifications in Nagata-ku, west Kobe. The method of Fourier spectral ratios was applied for estimating the relative severity of ground motion. Assuming the geology of the survey area to be a horizontally layered, simple model, we calculated the amplifications for obtaining the fundamental characteristics. We compared those with the damage and discussed the reasons of damage concentration in Nagata-ku.

KEYWORDS

Hyogoken Nanbu Earthquake, Earthquake Damage Belt, Detailed Damage Survey, Aftershock Array Observation, Spectral Ratio, West Kobe, Geotechnical Data, Geology, Amplification Characteristics

INTRODUCTION

The Hyogoken Nanbu (Kobe) earthquake (M_{JMA} 7.2) of January 17, 1995, brought a great number of human losses, 5,500, and severe damage of structures and lifeline systems. The damage was concentrated in downtown Kobe, and the extreme of collapsed buildings was distributed in a narrow band, about 500*m* in width, between the mountains and seashore. Although the surface strike slip with dip slip was very clear at the west of Awaji Island, no clear surface scarp was visible on the Kobe side, where many active faults run along the Rokko Mountains. However, the "earthquake damage belt" of the JMA seismic intensity scale of 7, was recognized on the Kobe side from the west to the east between the Rokko Mountains and the seashore and in the Hanshin district (between Kobe and Osaka), as shown in Fig. 1 (JMA, 1995).

We operated the temporal aftershock array observation soon after the earthquake. The observation consisted of six points crossing the "earthquake damage belt" of the JMA seismic intensity scale of 7, in Nagata-ku, west Kobe, and four points being additionally installed in other areas. This was part of join strong ground motion observations near the source region (Join strong ground motion observation group, 1995).

Our objective was to make clear the reasons for damage concentration in the narrow band in Kobe. Therefore, we carried out a detailed damage survey on the several types of buildings in Nagata-ku, where the aftershock observation points and the worst damaged area were included. The damage ratio, more than 80% to wooden buildings, was found in a part of the survey area. We examined the relationships among the damage of buildings, the spectral characteristics of the aftershock ground motion, and geological data. In order to estimate the fundamental amplification characteristics, we calculated the amplifications of ground motion due to the surface geology of Nagata-ku, assuming a horizontally layered soil model and, compared them with the spectral ratio of the aftershock ground motion.

AFTERSHOCK ARRAY OBSERVATION

We operated the temporal aftershock array observation on January 19, 1995, in Western Kobe. Seismographic instruments of acceleration type were set up at Tarumi-ku, Suma-ku, and Nagata-ku. In particular, our observation put emphasis in Nagata-ku, from the view points of the worst damaged area and of being included in the "earthquake damage belt." Respectively, from the north in Nagata-ku, the observation points were Hayashiyama-machi (Kobe Women's Junior College, symbolized by KWC), Ikedatani-machi (Nagata High School, NGH), Ikedakami-machi (Tokiwa Girls' High School, TWH), Kawanishi-dori (Office Building, NGT), Mano-cho (Shiriike Primary School, SIP), Futaba-cho (Shinyo Primary School, SYP), and Minamikomae-machi (Kobe Sewage Disposal Plant, KMG). These points are shown in Fig. 2, with large, black circles. KWC was located on a relatively hard rock.

DAMAGE SURVEY of BUILDINGS

Many researchers carried out damage surveys of the whole Kobe area (AIJ, 1995). In order to make clear the reasons for damage concentration in a narrow band in Kobe, it was necessary to carry out more detailed damage survey for all buildings. We chose the part of the area in Nagata-ku, circled in Fig. 1, and enclosed by

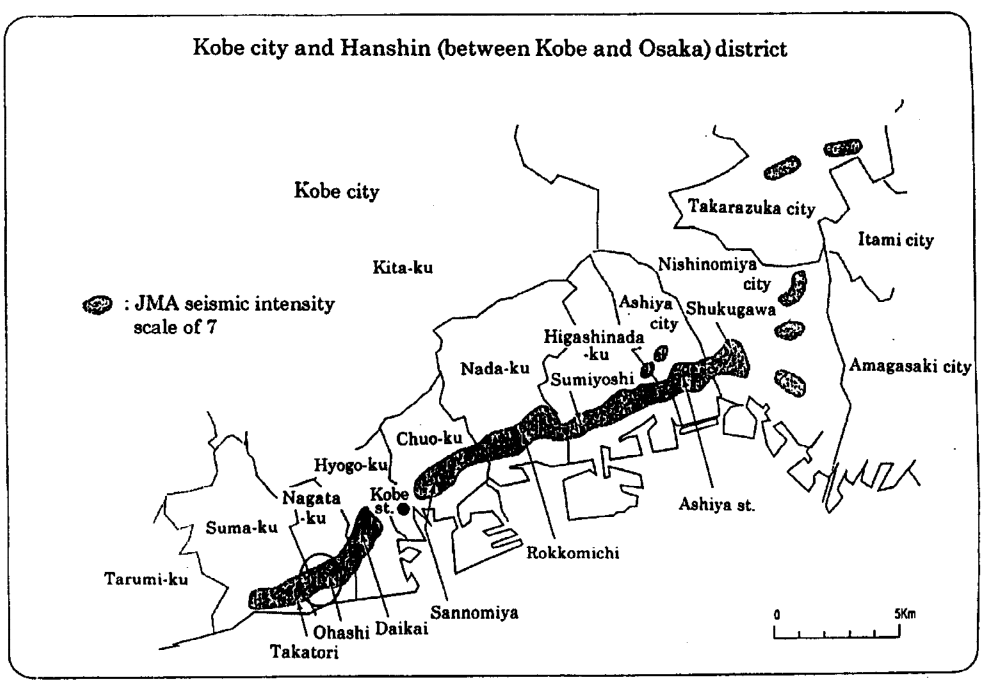

Fig. 1. Distribution of the JMA seismic intensity scale of 7, on the Kobe side (JMA, 1995), the Hyogoken Nanbu earthquake (1995).

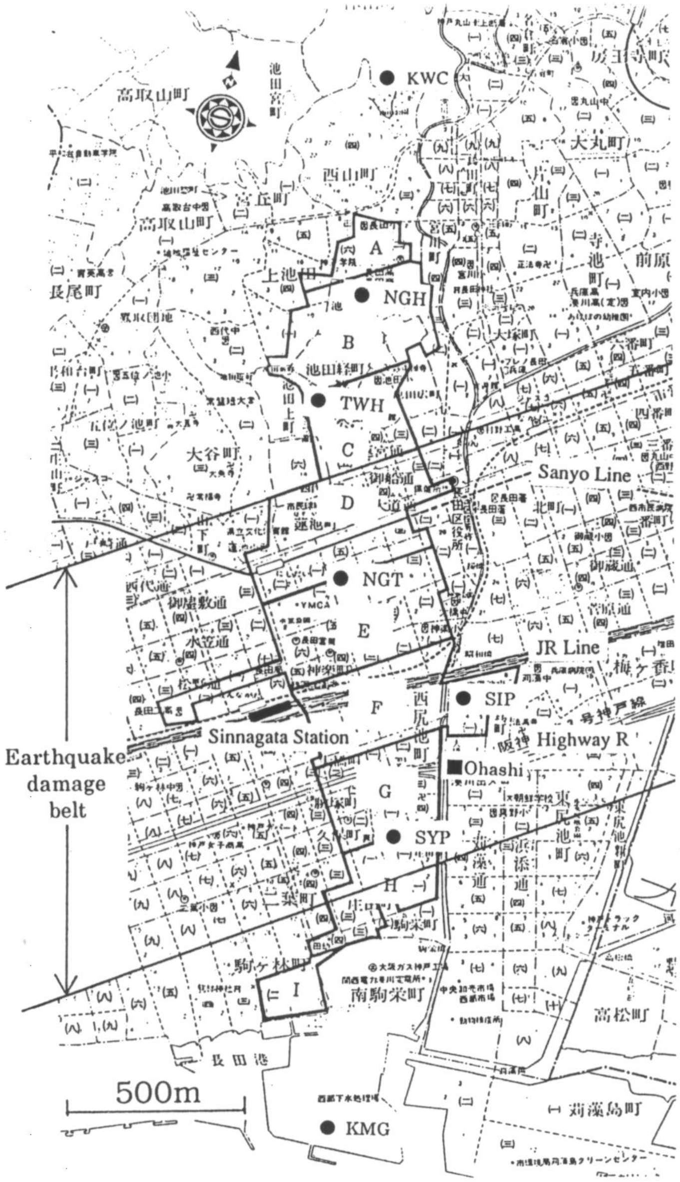

Fig. 2. Aftershock observation points (●) and the building damage survey area in Nagata-ku.

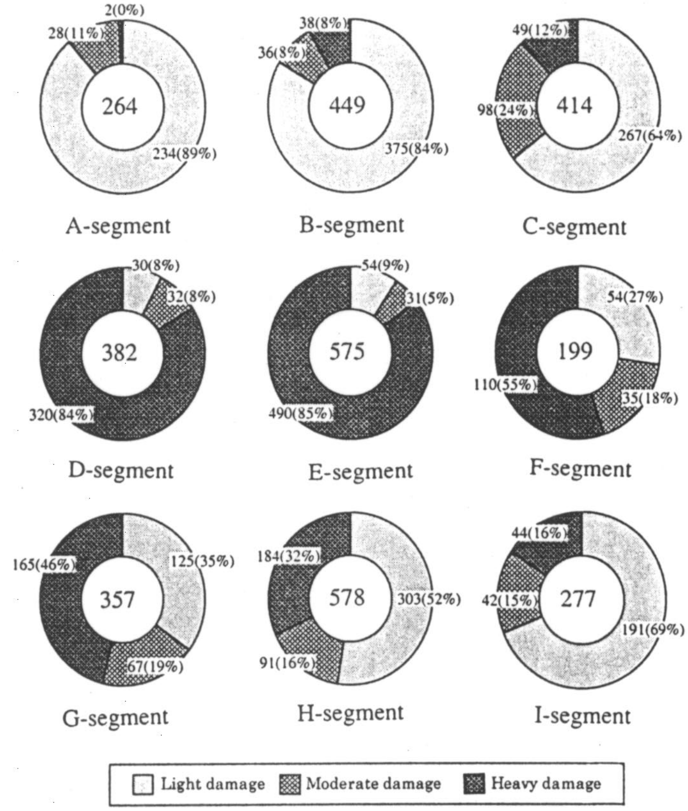

Fig. 3. Damage number and ratio of wooden buildings of three levels in each segment (A-I).

the thick solid line in Fig. 2, and started a detailed damage survey from February 15, 1995. The breadths of the north-south and the east-west were, respectively, about 2.0*km*, and about 500*m*. This surveyed area, of course, enclosed the above six observation points and crossed the earthquake damage belt, drew down referring to (JMA, 1995). We divided this area into nine segments in our work and each segment was lettered from the north by A through I (Fig. 2).

Damage Classification

First, we classified the buildings into three structural kinds: wooden buildings (lettered by W), reinforced concrete buildings (RC) including steel encased reinforced concrete buildings, and steel construction buildings (S). All buildings in segments A through I, were surveyed except buildings that had already been removed or burned. Next, we classified the damage into the following three levels on the basis of external appearance of the buildings (AIJ, 1995):

(1) Heavy Damage : Collapse or near total destruction of a building
(2) Moderate Damage : Permanent deformation on a structural member of a building
(3) Light Damage : No damage or slight damage to a building

Results

The total number of buildings in each damage level is shown in Table 1. The percentage given in parentheses in this table represents the proportion of each type of building inflicted with each damage level. In the

Table 1 Number (the average damage ratio) of damaged buildings in the entire segments

Kind of buildings	Damage level			Total
	Heavy damage	Moderate damage	Light damage	
W	1,402 (40%)	460 (13%)	1,633 (47%)	3,495
RC	27 (11%)	12 (5%)	200 (84%)	239
S	66 (16%)	31 (8%)	314 (76%)	411

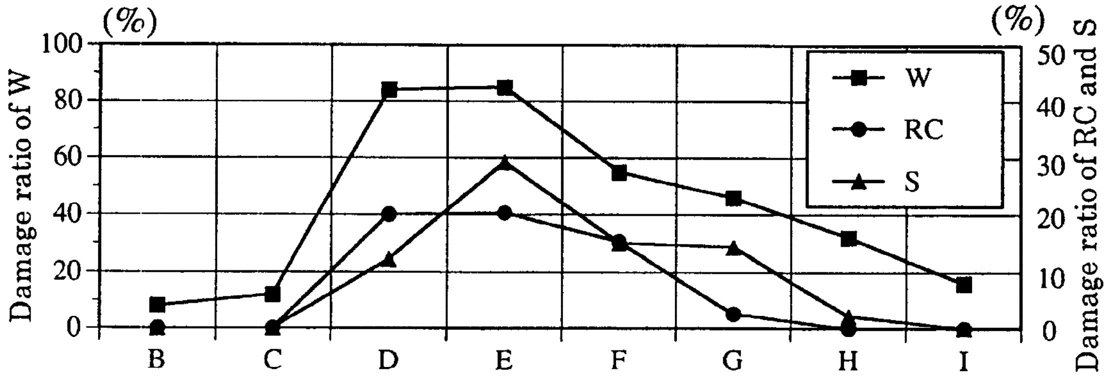

Fig. 4. Damage ratios of the W, RC, and S buildings in each segment (B-I).

surveyed area, it was found that the average heavy damage ratios of the W, RC, and S, were, respectively 40%, 11%, and 16%, and that the average light damage ratios were, respectively, 47%, 84%, and 76%. The damage to reinforced concrete and steel buildings was not so heavy. In addition, no severe damage in the A segment was visible. The heavy damage ratio of the W of each segment is shown in Fig. 4, together with the RC and the S buildings. The state of damage of each type of building is described in the following detail:

Wooden Buildings (W) The numbers of the W with heavy damage, moderate damage, and light damage were, respectively, 1,402 (40%), 460 (13%), and 1,633 (47%) among 3,495. Almost all of the W in the D and the E segments, located between the Sanyo Electric Railway Line and the JR Line, were severely damaged. The heavy damage ratios for their segment were, respectively, 84% and 85%, and these percentages were extremely high. The ratios for the F and the G segments, located to the south of the E segment, were low and 55% and 46%, respectively. The other mountainside B and C segments were lower than the others and under 20%.

Reinforced Concrete Buildings (RC) The numbers of the RC with heavy damage, moderate damage and light damage were, respectively, 27 (11%), 12 (5%), and 200 (84%) among 239. The severe damage was concentrated between the D and the F segments. The RC of the E segment between the Sanyo Line and the JR Line were severely damaged as the W. Many buildings had damage on the first floor and the others, damage on the second floor. These severely damaged buildings had been constructed with the use of the old criteria of earthquake resistant design.

Steel Buildings (S) The number of the S buildings that suffered severe damage, moderate damage, and light damage were, respectively 66 (16%), 31 (8%), and 314 (76%) among 411. Almost all of the S in the surveyed area were 2-5 story buildings and 2-3 story buildings, mainly constructed using the lattice columns and girders. The severe damage was concentrated between the D segment and the G segment. The S in the E segment, between the Sanyo Line and the JR Line, were also severely damaged as the W and the RC.

Though we have not yet got much information about the construction time and the structural style at this point, one of the reasons why severe damage was caused is that many old wooden residential buildings were densely packed, and that the earthquake was larger than had ever been experienced or predicted.

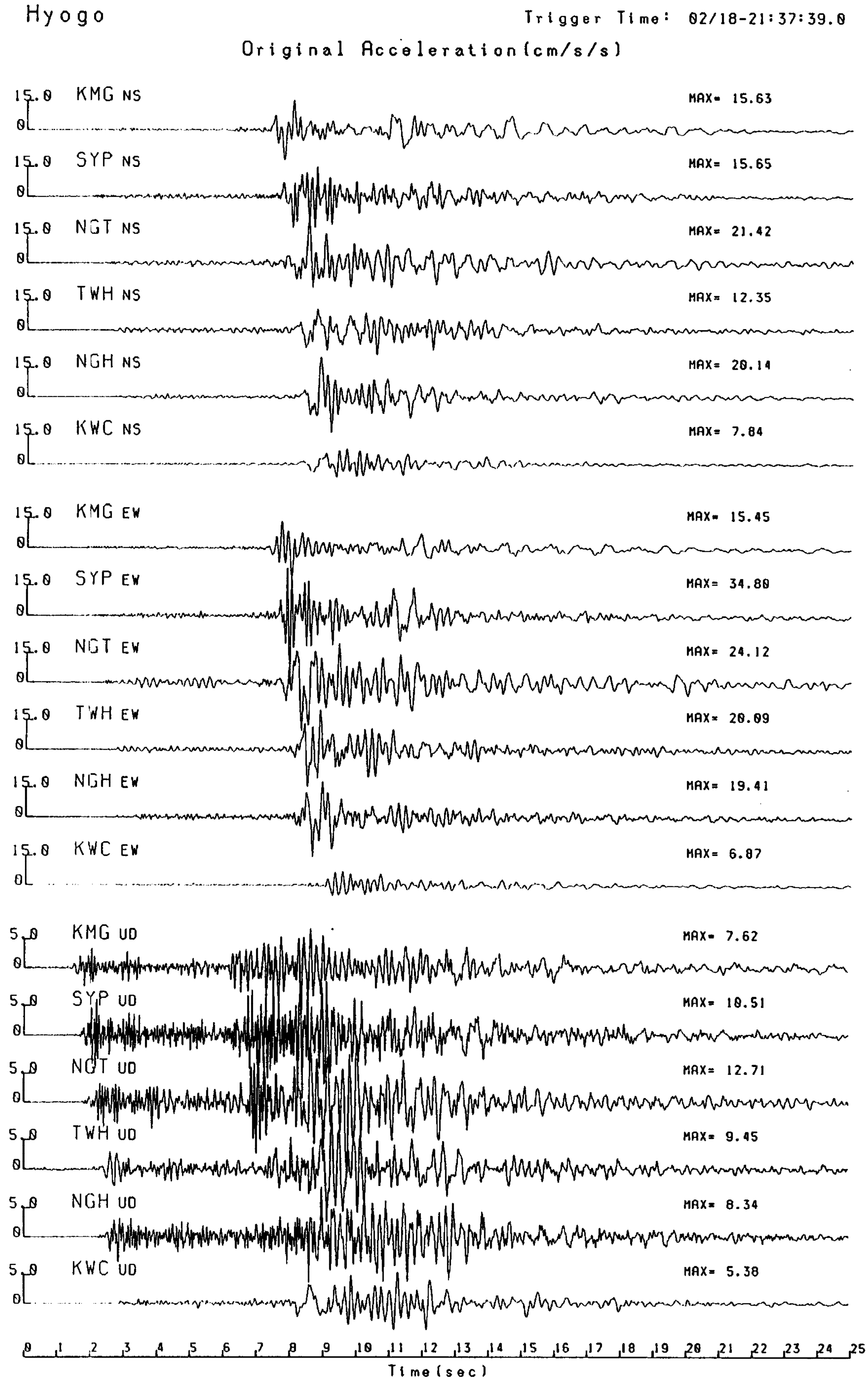

Fig. 5. Accelerograms of NS, EW, and UD components of the aftershock (M_{JMA} 4.9) on February 18th, 1995.

Figure 5, shows the strong motion accelerograms from the largest aftershock (MJMA 4.9) on February 18, 1995, recorded at the six array observation points in Nagata-ku. In this figure, NS, EW, and UD components are shown. The largest accelerations for the NS and UD components (respectively, 21.42 and 12.71 cm/sec^2) were recorded at NGT, and that for the EW component (34.80 cm/sec^2), at SYP. These two observation points were in the severely damaged area during the mainshock.

Figure 6, shows the spectral amplitudes of average horizontal acceleration of each observation point. The spectral peaks were found in the frequency band between 1.0 and 2.5 *Hz* and around 4.0 *Hz*. Particularly, the amplitude of NGT is larger than the others in the band. At the same time, the one of KWC is significantly small in the whole frequency band.

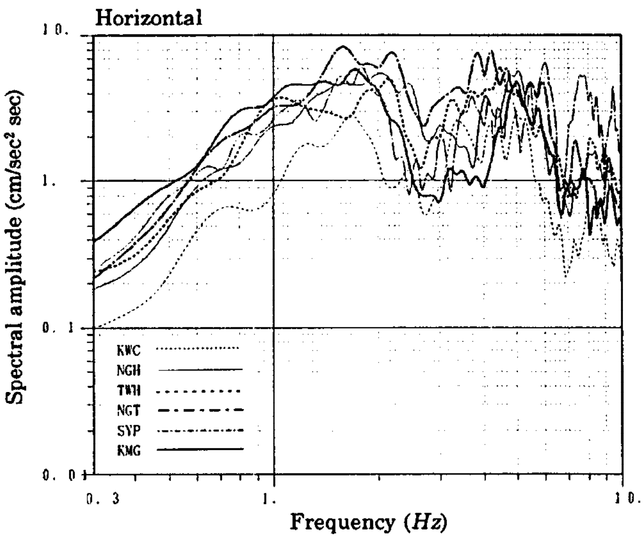

Fig. 6. Average horizontal spectral amplitudes at the 6 array observation points from the aftershock (MJMA 4.9), Feb. 18, 1995.

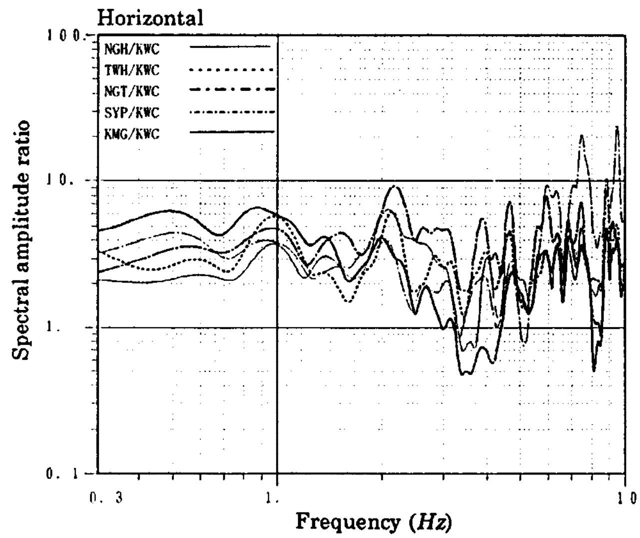

Fig. 7. Spectral ratios of average horizontal acceleration of each observation point to the one of KWC, Feb. 18,1995.

Figure 7, shows the spectral ratios of the average horizontal acceleration of each observation point to that of KWC. The thick solid line (KMG/KWC) is higher than the other lines except the dotted line (TWH/KWC) when the frequency band is less than 0.6*Hz*. Note that the KGM site lies on reclaimed land. The thick dot-dash-line (NGT/KWC) is quite high in the wide band of 0.6-6.0*Hz*. This would be the key to explain the severe damage to the W, RC, and S in the D segment area. The thick dot-dash-line (SYP/KWC) shows some large peaks in the band of over 6.0*Hz*, but it is smaller than the thick dot-dash-line (NGT/KWC) at 1.5-6*Hz*. The thin solid line (NGH/KWC) is lower than the other lines nearly throughout the entire frequency band.

As mentioned above, we found that the peak values of the aftershock accelerogram, the spectral amplitude, and the average spectral ratio at NGT, where many buildings were severely damaged, were larger than those at the other observation points.

GEOTECHNICAL CONDITIONS and GEOLOGY

Figure 8, illustrates the geological cross-section, from north to south (ICT, 1989), of the surveyed area in Nagata-ku. The northern part of the surveyed area was located to the north of the Egeyama fault and lay on a diluvial formation known as the "Osaka Group Layer." The alluvial deposits get thicker in the south (with proximity to the seashore). At Kawanishi-dori (NGT), where the damage to the wooden buildings was extremely severe, the thickness of the alluvial deposits was about 10*m* of clay. At its southern edge, the thickness of the deposits was about 20*m*.

We estimated the fundamental amplification characteristics at NGT, by assuming a one-dimensional 18 layered soil model (Kawase, 1995). We chose the soil damping to be $0.06/\omega$ (ω is the circular frequency), where the shear wave velocities are lower than 300*m/sec*. The properties of soil model are shown in Table 2, of which the shear wave velocities were based on the geological borehole data at NGT as follows (AIJ, 1985):

$$Vs = 84.0 \times (N^{0.31}) \tag{1}$$

where, N is the N value of the standard penetration test.

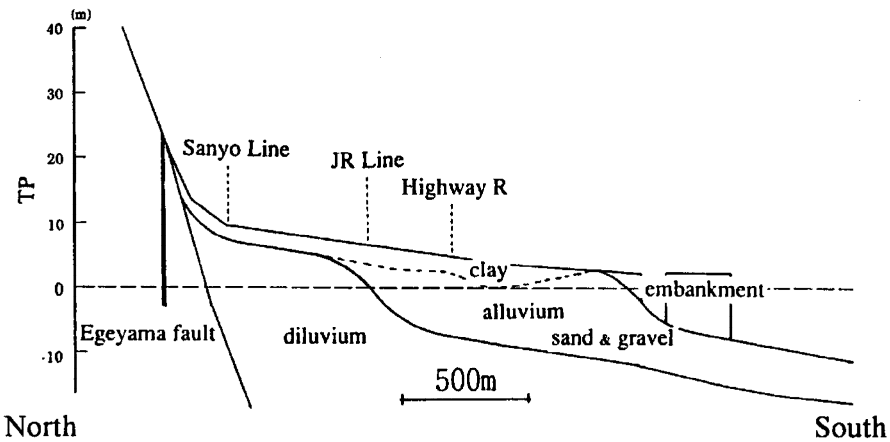

Fig. 8. Illustration of geological cross-section in Nagata-ku.

Table 2 Properties of ground model

Thickness (m)	Soil type	Density (t/m^3)	S-wave vel. (m/s)
2.05	silt	1.60	104.1
3.20	sand, silt	1.60	138.3
0.45	clay	1.70	118.1
4.65	silt	1.60	171.5
0.75	sand	1.70	171.5
0.30	humus	1.60	166.0
1.45	sand, silt	1.60	181.5
1.10	clay	1.70	198.4
0.65	sand, gravel	1.90	282.4
0.95	clay	1.70	194.5
0.45	sand	1.70	273.4
0.40	sand, gravel	1.90	277.1
2.75	sand, gravel	1.90	282.5
35.00	diluvium 1	1.95	450.0
140.00	diluvium 2	1.95	550.0
200.00	diluvium 3	2.00	650.0
600.00	diluvium 4	2.20	1000.0
∞	bedrock	2.50	2500.0

diluvium 1: upper part of Osaka Group Layer
diluvium 2: middle part of Osaka Group Layer
diluvium 3: lower part of Osaka Group Layer
diluvium 4: lowermost pert of Osaka Group Layer

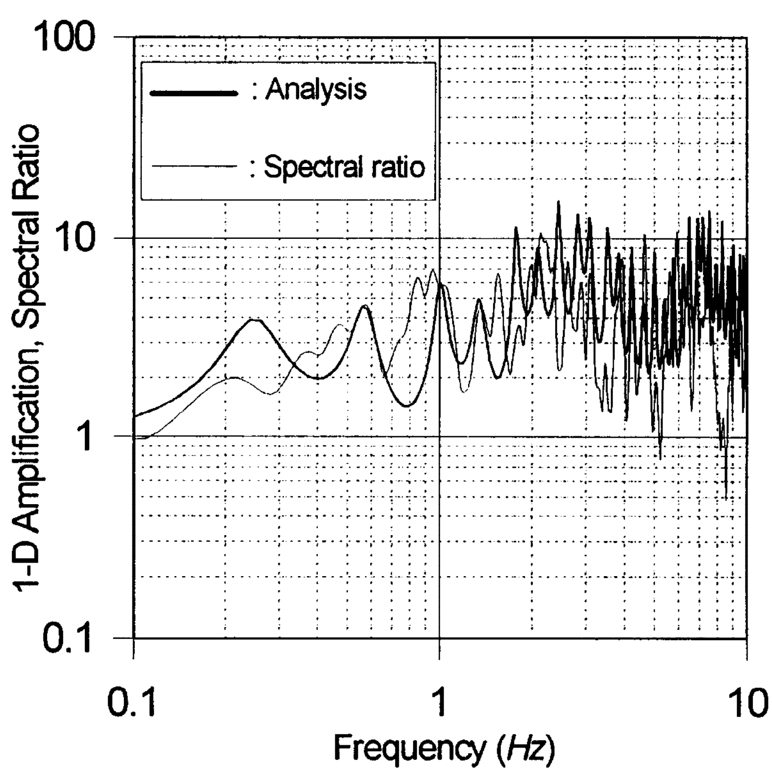

Fig. 9. Comparison of the analytical amplification for the 1-dimensional model with the spectral ratio at NGT.

Figure 9, shows the amplification for the one-dimensional soil model by a thick solid line and the spectral ratio (NGT/KWC) by a thin solid line. From both lines, we can find a similarity in the whole frequency band. Therefore, it is possible to explain the spectral ratio using the one-dimensional soil model and to take the rough, geological structure for this area. However, it is obvious that we need to get the more detailed geological information. It is reasonable to say that the peaks at around 1.0 *Hz* and the lower frequency would be due to the deep soil structure, and that the ground of KWC is regarded as a hard rock -- like a bedrock.

CONCLUSIONS

We operated the temporal aftershock array observation and carried out a detailed damage survey on the several types of buildings after the Hyogoken Nanbu earthquake (Jan. 17, 1995) crossing the "earthquake damage belt" in west Kobe. In order to make clear the reasons for damage concentration in a narrow band in Kobe, we studied the spectral characteristics of aftershock ground motion (Feb. 18, 1995) and examined geotechnical data in Nagata-ku, west Kobe. We also calculated the one-dimensional amplification and compared it with the corresponding spectral ratio. As a result, we summarized as follows:

1) The ground motions at sediment sites obtained from aftershock were significantly larger than those at the rock site; The spectral ratios of the sediment sites to the rock one were large as much as 5-10 times in a wide frequency band (0.2-10 *Hz*). This will be a fundamental reason that the high contrast of damaged and no-damaged areas was found during mainshock.

2) The spectral ratios, NGT/KWC and SYP/KWC, which related to the most severely damaged sites, were larger than those at the other sites in the frequency band of 2-5 *Hz*. This might suggest that the ground motion during mainshock contributed to the severe damage of wooden buildings. However, we also have to convince on the effect of nonlinear behavior of soil during mainshock, and on the quality of the buildings, that is, the construction time and/or the style of buildings. These are the future concern of us.

(3) The spectral ratio was closely similar to the one-dimensional amplification obtained by assuming the geology of Nagata-ku to a horizontally layered soil model. Therefore, it is possible to explain the spectral ratio by the amplification characteristics and to know the rough soil structure of this area using the one-dimensional model. We also need to get the accurate information of the deep soil structure.

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REFERENCES

Earthquake Motion and Ground Condition (1985). Architectural Institute of Japan (in Japanese)

Study on geological survey of Kobe city (1989.3). *Institute of Construction Technology* (in Japanese)

General earthquake and volcano condition (1995.2). *Japan Metological Agency*

Kawase H. (1995). Effect of sedimentary basins on strong motion -In Mexico city and in Kobe city-. *The 23rd Simp. of Earthquake Ground Motion.* Architectural Institute of Japan pp. 83-91

Preliminary Reconnaissance Report of the 1995 Hyogo-ken Nanbu Earthquake (1995.3). Architectural Institute of Japan