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Dynamic Characteristics and Damage to Structures of the Earthquake at the Western Part of Nagano Prefecture in 1984

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Abstract

The Earthquake at the Western Part of Nagano Prefecture on September 14, 1984 with magnitude 6.8 on Richter scale occurred near Otaki Village in Kiso District (137.5°E, 35.8°N). The earthquake caused the debris avalanches and the slope failures in a large scale.

The present paper deals with dynamic characteristics of this earthquake and the damage to structures due to ground motion itself. Through the investigation of tombstone overturn and measurements of aftershocks and microtremors, the authors estimate the dynamic characteristics of mainshock and study the correlation between the damage to structures and characteristics of the ground motion.

1. Introduction

The Earthquake at the Western Part of Nagano Prefecture on September 14, 1984 occurred in Otaki village. The focus of the earthquake was estimated to be about 2km below the ground surface near Mt. Ontake. The epicenter of the mainshock was located at Matsukoshi area in the village. The earthquake triggered a large slope failure in the southern slope of Mt. Ontake. The slope failure blocked the flow of a river and swept away a number of houses and other structures. Japan Meteorological Agency estimated the earthquake intensity in the village at the

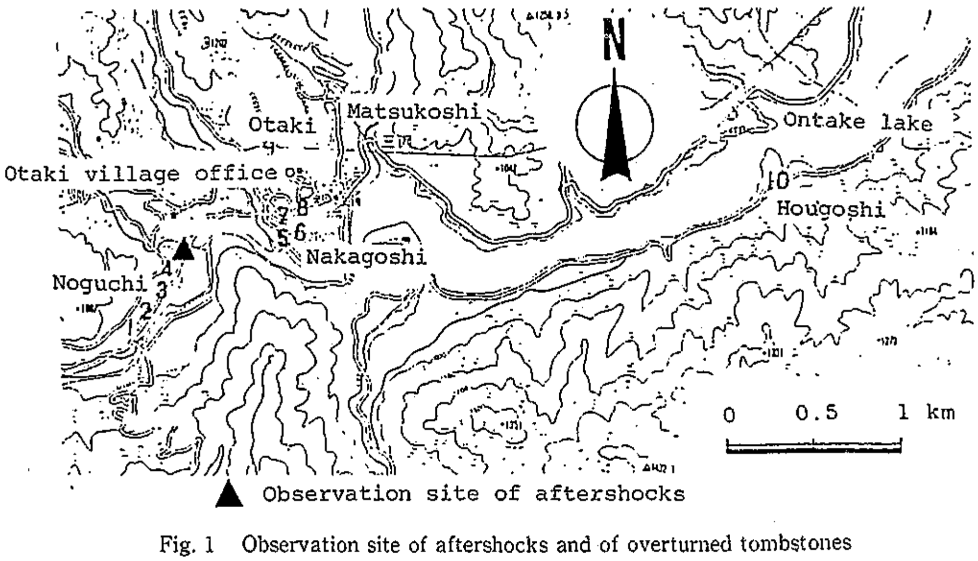

Fig. 1 Observation site of aftershocks and of overturned tombstones

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six on JMA intensity.

The present paper describes an outline of damage to structures and of the dynamic characteristics of ground motion and discusses the correlation between the characteristics of the ground motion and the damage. The investigation was conducted as follows: first, we investigated the damage to the wooden houses and lifeline structures in the village. Second, the ratio of height to length of the basement of overturned tombstone was measured. Third, the dynamic characteristics of mainshock was estimated based on analyses of aftershocks by our accelerometer (AKASHI V401BS type) as there was no seismograph installed in the village. Finally, the dynamic characteristics of surface ground were estimated by using the results of microtremor measurement at the observation site.

2. Estimation of the Frequency Characteristics and the Scale of Mainshock

2-1 An outline of the mainshock recorded at each meteorological observatory

The intensities of the mainshock were IV in Koufu, Iida and other areas, III in Matsumoto, Nagano and other areas in Chubu Region by the Meteorological Agency[1]. Aftershocks frequently occurred after the mainshock. A quake which occurred at 7:14 a.m. on September 15 had magnitude 6.4 on the Richter scale, and a quake which occurred at 7:39 a.m. on the same day was 5.6 on the same scale. Landslides and damage occurred repeatedly due to these aftershocks in the village.

The outline of the mainshock at each meteorological observatory, which is located near the epicenter, is listed in Table 1[1]. The maximum acceleration amplitudes at all sites were not obtained because the accelerograph exceeded its capacity. Table 1 suggests that the further the epicenter distance is, the later the starting time of the mainshock is and the longer the P-S time is.

Table 1 The outline of mainshock at each observatory

Observatory	JMA intensity scale	Starting time of mainshock	P-S (seconds)
Iida	IV	8:48′57.3″a.m.	8.2
Matsumoto	III	8:49′02.8″a.m.	8.8
Nagano	III	8:49′08.5″a.m.	14.1
Koufu	IV	8:49′05.3″a.m.	12.7

(Data source is Report on the Earthquake at the Western Part of Nagano Prefecture in 1984, 1984[1])

The Earthquake at the Western Part of Nagano Prefecture in 1984 consisted mainly of vertical component. However as structural damage is related to horizontal component of the ground motion as mentioned in 2-2, we investigated the relationship between the horizontal component of the ground motion and the dynamic characteristics of the ground.

2-2 The characteristics of aftershocks and microtremors

An aftershock observation was performed off the central of the aftershock regions from 10:00 a.m. to 5:00 p.m. on September 20, by the Disaster Prevention Engineering Laboratory,

Kanazawa University. The purpose of this observation is to study following items:
1) estimation of the characteristic of the mainshock at Otaki village, where the mainshock was not recorded.
2) evaluation of the dynamic properties of surface ground based on the field data of the aftershocks and the microtremors.

First we described the characteristics of the aftershocks. The observed site was located in one of the most active regions in Otaki village, which is called Noguchi area. The pick-up was installed in the direction of E-W component. In order to observe the aftershocks, the servo-type accelerometer (AKASHI, V401-BS type, a natural period of 490Hz) and data recorder (TEAC, R-81) were used. The noise included in signal was lower than 0.15Hz and it was cut off by a high pass filter in the digital computer (MELCOM 70)[2]. The data interval time was 0.02 second in this analyses. Nine aftershock records were obtained.

The starting time of the observed aftershocks are presented in Table 2. The aftershock No. 5 has the maximum acceleration among the data, and this quake occurred at 1:39 p.m.. The magnitude of the quake was 3.6 by Japan Meteorological Agency. Fig. 2 indicates the time history of these aftershocks. It was found that the ground was vibrated at high frequency from this figure. The duration time of these aftershocks is short. From the above mentioned observation, it seems that the ground motion due to the mainshock has the high predominant

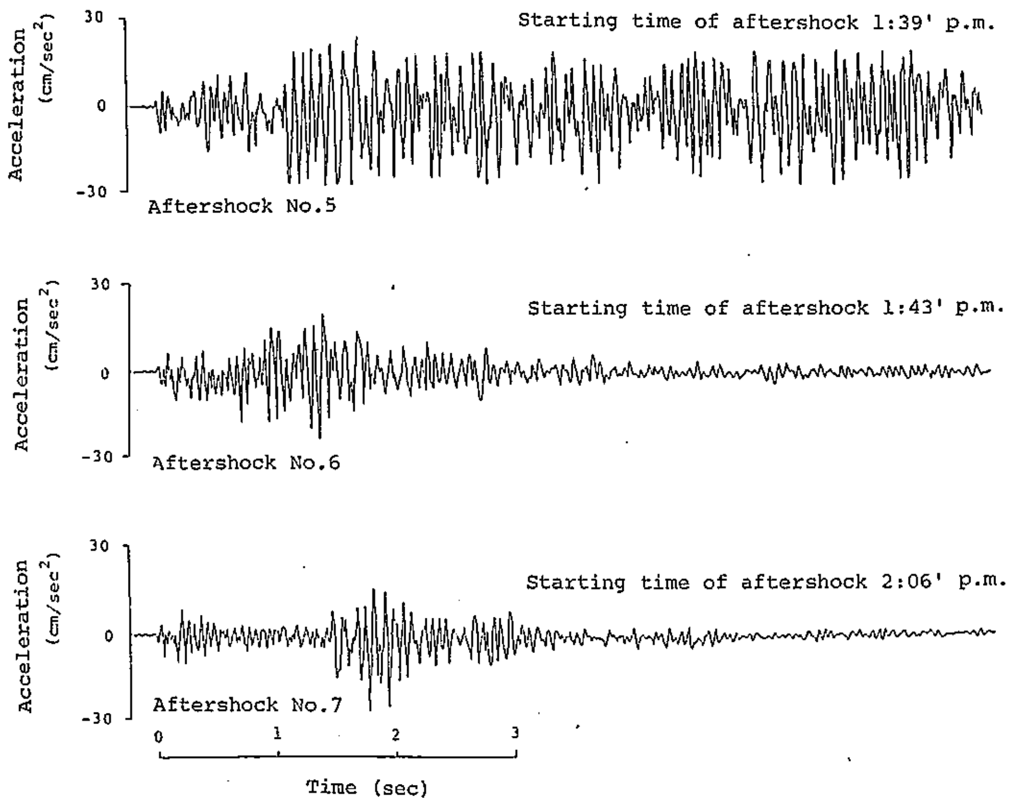

Fig. 2 Time history of aftershocks

Table 2 Starting time of aftershocks

Aftershock No.	Starting time
1	11:33′a.m.
2	0:08′p.m.
3	0:22′p.m.
4	0:42′p.m.
5	1:39′p.m.
6	1:43′p.m.
7	2:06′p.m.
8	2:46′p.m.
9	3:47′p.m.

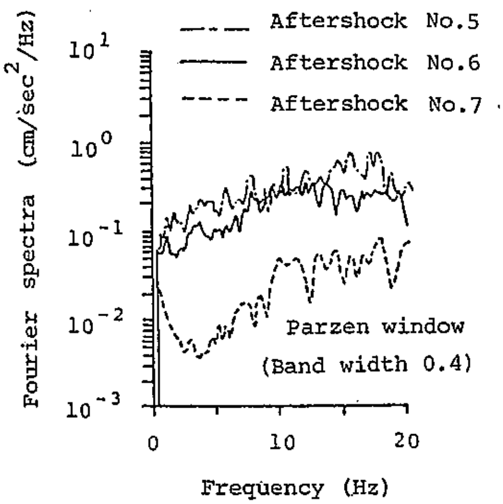

Fig.3　Fourier spectra of aftershocks

frequency and the short duration time.

The fourier spectra of the aftershock records are shown in Fig. 3. The curves were smoothed in the frequency domain by using Parzen window, the band width of which was 0.4Hz. The predominant frequencies of these curves are about 10 to 20Hz and the shapes of the spectra are almost the same. The acceleration response spectra for a damping ratio of 0.05 of the aftershocks were calculated as shown in Fig. 4. This figure indicates that the natural periods of the maximum acceleration responses for the Nos. 5, 6 and 7 of the aftershocks are 0.09, 0.06 and 0.09 second, respectively.

Next we described the dynamic properties of surface ground based on analyses of mi-

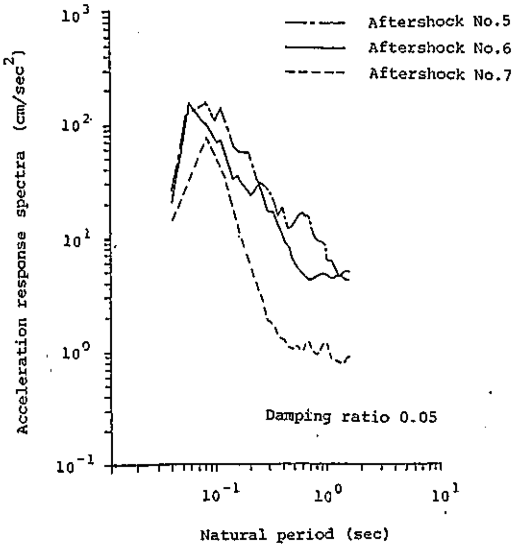

Fig. 4　Acceleration response spectra of aftershocks

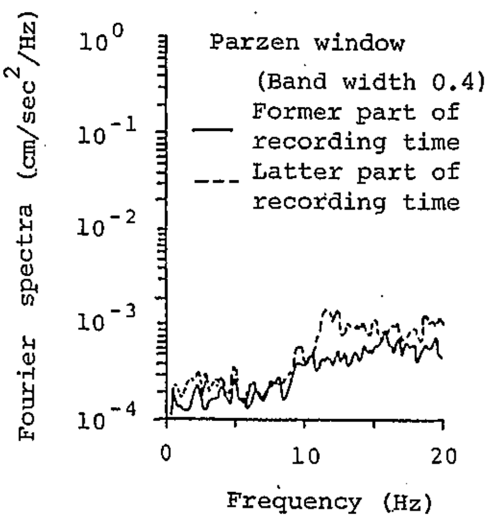

Fig. 5　Fourier spectra of microtremor records

crotremors. The observation system of the microtremor measurment was same as that of the aftershock measurement. The signal were increased 500 times by the amplifier (TOYODA AA -3004 type) which was used between the pick-up and the data recoder[4].

An example of fourier spectra in this measurment is shown in Fig. 5. In order to confirm the non-stationarity of the microtremor wave used in the analyses, analytical time duration was divided into two parts: one is the former part of the time history, and the other is the latter. Solid and segmented lines in Fig. 5 are the fourier spectra of the former and latter parts, respectively. Sampling time is about 20 seconds. The time interval is 0.02 second, and the number of data is 1024. It is clearly seen in Fig. 5 that the natural frequency of surface ground is about 10 to 20Hz, and that the former frequency is not much different from the latter.

Similarly, the acceleration response spectra of microtremor wave are also shown in Fig. 6.

In order to compare the fourier spectra of the aftershocks with that of the microtremor measurement, the results of those are drawn in Fig. 7. The results of acceleration response spectra are also drawn in Fig. 8. It was concluded as follows: it was considered that the mainshock in

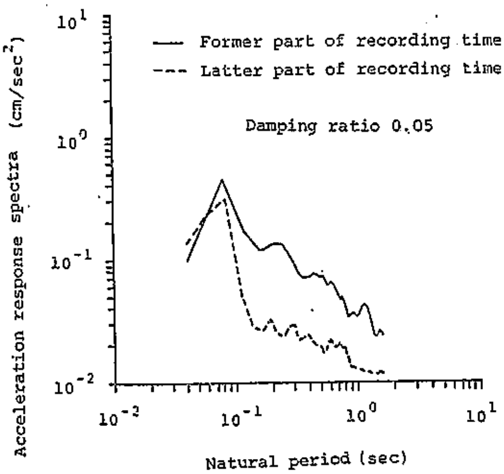

Fig. 6 Accelaration response spectra of microtremor records

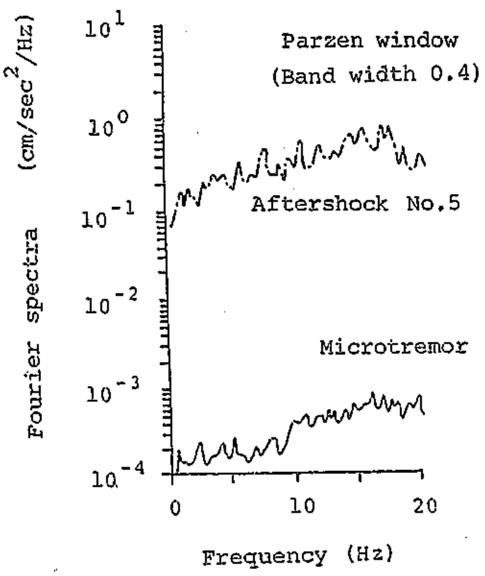

Fig. 7 Comparison between the fourier spectra of microtremor and aftershocks

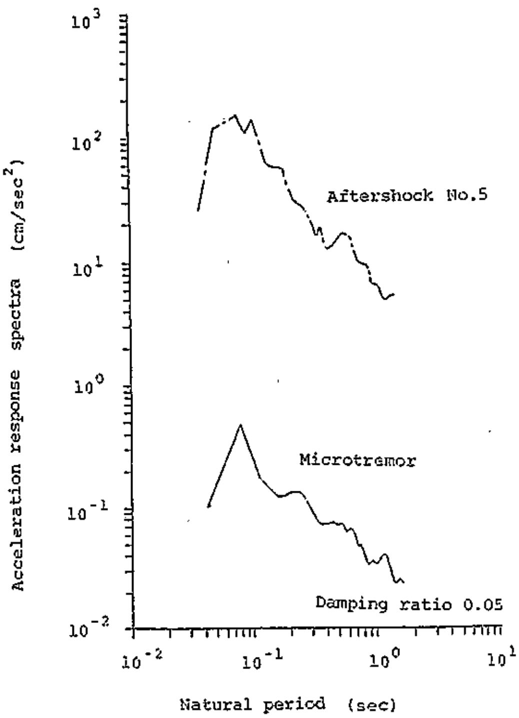

Fig. 8 Comparison between the acceleration response spectra of microtremor and aftershocks

Otaki village is high predominant frequency: 10 to 20Hz. The analyses of microtremor measurement suggest that the high frequency components in the spectra of the aftershoks reflect not only the characteristics of the aftershocks themselves, but also the characteristics of the surface ground. This means that the surface ground in Otaki village is rigid and good.

2-3 Observation of overturned tombstones in Otaki village

Fig. 1 shows observation sites of overturned tombstones. The purpose of this observation is to study the distribution of ground motion intensity. Observation of overturned tombstons was performed by the simplest method as below[5].

1) The overturned tombstones whose foundation stone moved, rotated and/or jumped were avoided.
2) In selection of non-overturned tombstones, we checked whether or not the tombstones were restored after overturn by the earthquake.
3) The ratios of width(B) and height(H) of tombstones were calculated based on the data of the overturned tombstones and the non-overturned tombstones.

A view of the overturned tombstones near Otaki office is shown in Photo. 1. The results of overturned tombstones are listed in Table 3. Estimated horizontal acceleration using the overturned tombstones (α(gals)) can be derived from

$$\alpha = (B/H) \cdot 980$$

The real applying acceleration to the overturned tombstones is lower than the estimated horizontal

Photo. 1 A view of overturned tombstones near Otaki village office

Table 3 Results of observing the overturned tombstones

Site No.	(A)	(B)	(A)/(B)	Estimated acceleration (gal)	Overturned Width(B) (cm)	Overturned Height(H) (cm)	Overturned B/H×980 (gal)	Non-overturned Width(B) (cm)	Non-overturned Height(H) (cm)	Non-overturned B/H×980 (gal)
1	7	9	78	400～460	23.4	51.4	455	30.5	74.0	404
2	6	7	86	400～420	25.5	60.7	412	25.0	61.0	401
3	12	15	80	400	30.5	74.8	400	30.4	74.6	399
4	27	29	93	400～430	31.5	76.5	404	31.0	71.3	426
5	2	2	100	380	27.8	71.0	384	—	—	—
6	12	12	100	440	23.2	51.2	444	—	—	—
7	8	8	100	360	26.0	71.5	356	—	—	—
8	22	22	100	350	24.5	68.7	351	—	—	—
9	47	50	94	350～400	31.0	86.5	351	24.2	60.5	392
10	4	5	80	400～420	31.5	76.0	406	26.0	61.5	414

(A): Number of overturned tombstones
(B): Number of tombstones

acceleration in this equation, because we neglect the effect of the vertical component of the earthquake on the tombstones.

In Table 3, the ratios of overturned tombstones at the regions from Noguchi to Hougoshi in Otaki village are very high : 80~100%. The estimated horizontal acceleration is about 400gals. The estimated acceleration is high and it corresponds to the six on JMA intensity scale. Similarly we estimated that earthquake intensities in most areas were the six on JMA intensity scale, and that in some areas they were the seven on the same scale. These estimated values do fit those estimated by Japan Meteorological agency. However, it is considered that the vertical component of the ground motion dominates the horizontal component, because there are many overturned tombstones due to the saltation and rotation. Therefore exact estimation of the horizontal acceleration of earthquake that occurred in the shallow ground and on the land such as this shock is not made perfectly only by investigation of overturned tombstone.

3. Damage to Structures

3-1 Buildings

Table 4 indicates the actual condition of the damage to buildings. The total number of damaged buildings in Otaki village is 427. It means that all of the buildings in Otaki village was damaged. All of the razed houses were swept by the slope failure. And no house is completely destroyed by ground shaking itself. Based on the field investigation in Noguchi, Uejima and Nakagoshi areas in this village, the features of the damage to the buildings due to ground motion is summarized as below.

(1) Slide and fall of the roofing tiles.

(2) Separation and fall of the earthen wall of the storehouse.

(3) Permanent deformation between the ground sill and foundation of the houses due to landslide

Table 4 Number of damaged houses (in Nagano Prefecture, 1984. 10. 13, in Gifu Prefecture, 1984. 10.2)

City, town and village	Number of damaged houses		
	Totally destroyed houses	Partially destroyed houses	Partially damaged houses
Nagano Prefecture			
Otaki Village	14	73	340
Kiso Fukushima Town			30
Uematsu Town			1
Nagiso Town			12
Tarukawa Village			1
Kiso Village			5
Kaida Village			4
Hiyoshi Village			7
Mitake Village			84
Ohkuwa Village			34
Gifu Prefecture			48
Total	14	73	666

of up-fill ground.
As to the foregoing items (1) and (2), they are very similar to the damage to the buildings near to the epicenter subjected to the 1974 Izuhanto-oki Earthquake ($M=6.9$, focal depth is about 10km) and the 1975 Oitaken-chubu Earthquake ($M=6.4$, focal depth is about 0km). Their foci were located on the land and they were very shallow earthquakes. It is also the common feature of these three earthquakes that the totally destroyed wooden houses due to ground shaking is little. They could be explained as follows. As a high frequency domain of 10 to 20Hz predominates in the sites near the epicenters of these very shallow earthquakes as mentioned above, rigid structures such as storehouses are more severely damaged due to the resonanse than flexible structures such as wooden houses. The short duration period of mainshock prevented the wooden houses from totally destroying. It is also one reason of slight damage to the houses that the zinc-roofing houses are much more than the tile-roofing ones, that is, there are very little number of top-heavy houses. Item (3) indicates the characteristic of the earthquake damage in mountanious districts.

As shown above, the damage to the building due to earthquake was relatively slight and was limited to the small area. Most of the damages were caused by the debris flow. The furnitures, however, were severely damaged due to large ground acceleration.

3-2 Lifelines

3-2-1 Bridges

Three bridges, Shin-omata, Kuzo-taka and Korigase bridge, were swept by the large slope failure. As Shin-omata bridge connected between the center of this village and the other villages, fall of this bridge had great effects over a wide range of restoration operation.

The damage to the bridges due to the ground motion itself, however, was slight as same as the buildings. In Matsubara bridge, the soil behind the bridge abutment settled abut 15cm, some parts of the reinforced concrete piers were ripped in the direction perpendicular to the axis of the bridge by the ground motion (See Photo. 2) and the break of the anchor-bolt at the fixed bearing was caused (See Photo. 3). It is conceivable that the ground motion in this direction could be predominant. Other bridges suffered slight damage.

As mentioned above, it is interesting to note that fall of the bridge had great effects over a wide range of restoration operation, particularly in these mountanious areas.

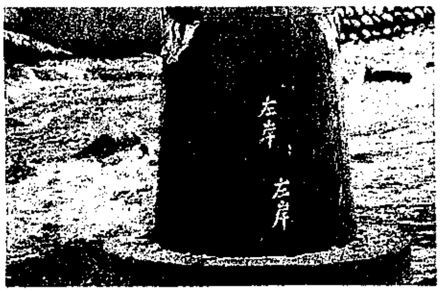

Photo. 2 Damage to reinforced concrete pier of Matsubara bridge

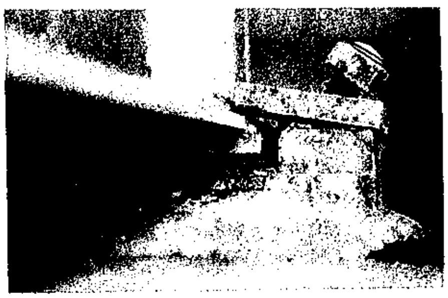
Photo. 3 Break of anchor-bolt of Matsubara bridge

3-2-2 Water supply systems

The overall damage has been estimated at 208 million yen, mainly in Otaki village. The particular modes of the damage to the pipelines were sweeping of the pipelines due to the large slope failure, the breaks and the cracks of the pipe body of the asbestos cement pipes and the pull-out and looseness at the joints of the polyvinyl chloride pipes. This section briefly describes the restorations of the water supply systems in Otaki village, that followed the damage inflicted by this earthquake. The emergency water supply operation employing polyvinyl containers immediately following the earthquake was conducted because of suspension of water supply and muddy water in many houses. Fig. 9 shows the network of the water supply system in Otaki village. This system had two main sources of water supply. One of them, however, did not work due to the slope failure in Matsukoshi area. The headrace pipes, whose length is about 3km from the source to the distributing reservior, consist of the asbestos cement pipes and polyvinyl chloride pipes with 75mm and 100mm diameter. About twenty damage was found and was repaired. As to the distributing pipes, above ground piping employing vinyl pipes with 50mm diameter was made as emergency restoration since it was discovered that the asbestos cement pipes were completely destroyed.

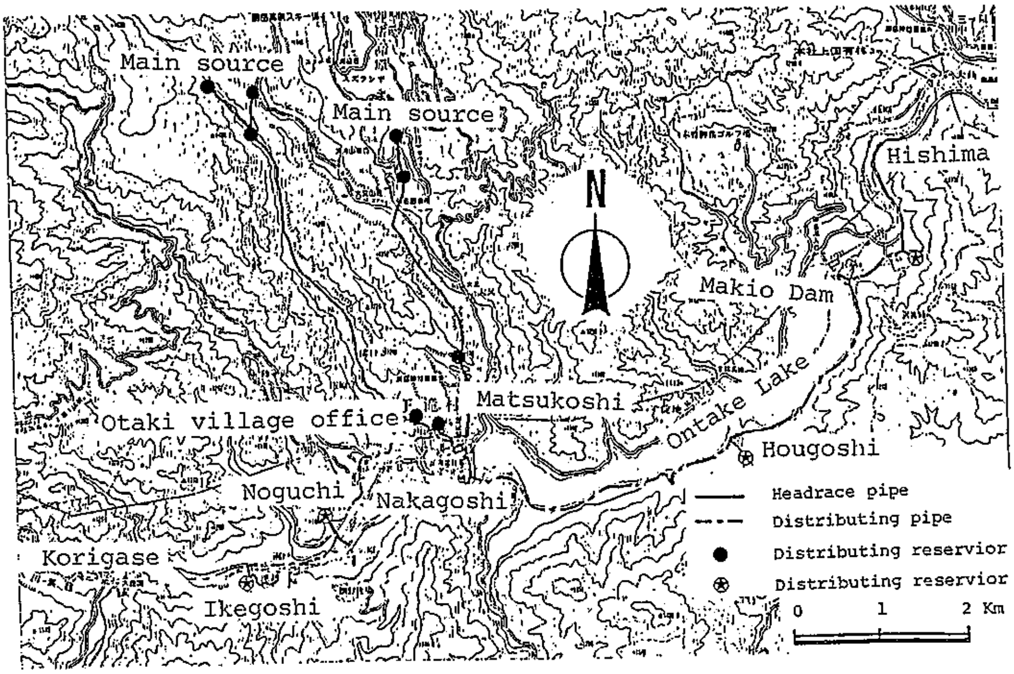

Fig. 9 Network of the water supply system in Otaki village

A total of about 16 days was required for temporary recover of the water supply systems. Even then, the supplied water is not good for drink in spite of chlorination because of the supplied water was muddy. The water supply using the water wagon was continued for several days.

3-2-3 Electric power systems and telephone systems

Estimated 501 customers of power services were affected by the power outages caused by seismic damage to power system facilities. About 90% of the damage facilities, however, was restored on that day and the remains were repaired next day.

On the other hand, a total of about 20 days was required for completely restoration of the telephone service. As the emergency operation, specially public telephones were installed and the communication satellite "SAKURA" was utilized. The cross talk of the walkie-talkie affected the restoration operation of the earthquake damage and research for missing.

4. Concluding Remarks

The present paper discussed the dynamic characteristics of the ground motion based on the investigation of the tombstone overturn and measurement of microtremors and aftershocks, and the correlation between the damage to the structures due to the Earthquake at the Western Part of Nagano Prefecture in 1984.

Findings in the present study can be summarised as follows:

1) It seems that the duration of the mainshock is short and that the predominant frequency is high; 10 to 20Hz.
2) The results of overturned tombstones suggest that the estimated horizontal acceleration is about 400gals near the epicenter.
3) The damage to the wooden houses seems comparatively slight; mainly fall of the roofing tiles and permanent deformation between the ground sill and foundation. It can be explained in terms of the high predominant frequency and short duration time of the mainshock.
4) The damage to bridges due to the ground motion itself was light as same as the buildings.
5) As for the lifeline systems, electric service was recovered on that day, the recovery of telephone service and water supply service, however, needed 20 days and 16 days, respectively. It is interesting to note that the cross talk of the walkie-talkie affected the restoration operation of the earthquake damage and research for missing.

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