A CASE STUDY - MICROTREMOR MEASUREMENTS AND EARTHQUAKE OBSERVATIONS FOR THE PURPOSE OF COMPARISON BETWEEN THE DAMAGE OBSERVED AND THE DAMAGE ESTIMATED

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SUMMARY

In order to establish a suitable method of damage estimation, the damage to structures due to the 1978 Miyagiken-oki Earthquake are estimated and compared with the damage observed. The estimation is made by using the current soil dynamics and response analysis techniques based on the results of microtremor measurements and earthquake observations as well as boring and seismic prospecting data. Relatively good agreement is obtained for the estimated and the observed damage to wooden houses and some remarks are made on the relation between earthquake input and the resulting damage estimation for reinforced concrete buildings.

INTRODUCTION

The damage to various structures during the 1978 Miyagiken-oki Earthquake differed from place to place in the Sendai district due to changes in ground conditions (Figs. 1 and 2). A study group has been organized in order to verify the method of damage estimation by making comparisons between the damage observed and that estimated using the various input motions at various places of differnet ground conditions. This paper presents the results of investigations which have been carried out as a part of the study group's work for the purpose of estimating the main shock inputs to various locations in the Sendai district.

It has been recognized that differences in earthquake input motions into structures are mainly due to differences in the dynamic characteristics of ground strata on which the structures stand, especially those of surface soil layers. The depths of the soil layers to be considered range in an order of 100 to 1,000 meters depending on the natural periods of the structure under consideration and the contrast in rigidity of two adjacent soil layers. In this study, a soil layer having a shear wave velocity of 1,500 m/s is chosen as so-called bedrock.

MICROTREMOR MEASUREMENTS, EARTHQUAKE OBSERVATIONS AND OTHER DATA

Microtremor measurements were taken twice at 238 points in the Sendai district as shown in Fig. 2; for 8 days in 1978 for the first time, and for 12 days in 1981 for the second time during the night in the urban area where traffic is busy and during the daytime in the suburban and rural areas. The

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distance between two adjacent points ranged from 1 to 2 km. The instruments used were composed of a set of transducers with natural period of pendulum 1.0 sec, integrating amplifiers, an eight-channel data recorder, and a pen oscillograph for monitor purposes. As the overall characteristics of instruments the magnification factor is constant in the range of 0.1 to 1.0 sec. and decreases over 1.0 sec, and the maximum magnification factor is 500,000.

The records of 82-sec duration taken from the relatively stable part were used for this analysis. Fourier spectra of displacement records were calculated using FFT after making AD conversion at an interval of 0.02 sec, and then those of velocity were also obtained by simply multipling each ordinate value by the corresponding angular frequency. Fig. 3 shows the Fourier spsctra and the original wave forms at 13 measuring points extending about 15 km along the seashore in the eastern part of Sendai. The dotted lines in the spectra connect the peak values at each point.

Earthquake observations were made at two sites in the Sendai district using a set of accelerometers; at the Izumi High School campus representing the hilly tertiary terrain area and at the Shichigo Primary School campus representing the alluvial plain area. Earthquake records have been obtained since 1981 for several seismic events with the maximum acceleration at the ground surface ranging from several to several ten gals. Simultaneous observations have been carried out at several sites in this district by other members of the same study group including the sites where the main shock of the 1978 Miyagiken-oki Earthquake was recorded. All these records were analyzed to supplement the dynamic model derived from the micritremor investigation and to establish the main shock input during the 1978 event at specific points.

Boring data on 319 points in the Sendai district were collected and analyzed to set up a dynamic model of the soil layer. The data of seismic prospecting and earthquake observations at 11 points including those from the study group mentioned above were also used for establishing a suitable dynamic model of the soil layer at some specific points. The results of shear wave velocity investigations by Kobayashi and others (Ref. 1) were taken to set up the bedrock in this study.

PROCEDURE AND RESULTS OF DYNAMIC MODELLING OF SOIL LAYERS

The dynamic model of soil layers to be used to estimate the earthquake input motion was determined by the following procedure: i) The soil profile along 13 NS and 12 EW lines was drawn using boring data which enable classification into upper, lower, lowermost and bedrock layers (Fig. 4). ii) The distribution of shear wave velocity (Vs) was determined for each layer using the N-value of the standard penetration test and the formula governing the Vs-N relationship (Ref. 2). iii) Modification of Vs-values was made at 11 points where the Vs-values were determined by seismic prospecting data or from earthquake observation records. iv) The density (ρ) and the attenuation factor (Q) were also determined from the boring data and Vs-values, and using these values the transfer functions were calculated for various kinds of soil layers. Modification of Vs-values was done by comparing the transfer functions with the microtremor spectra so that the predominant periods in the spectra coincide with those in the transfer functions (Fig. 5). v) The dynamic model thus obtained was transferred to that at 500 m mesh points by a suitable interpolation technique. Fig. 6 shows some examples of such dynamic models.

ESTIMATION OF INPUT GROUND MOTION

Using the dynamic models of various types of ground at each mesh point the ground motion during the 1978 Miyagiken-oki Earthquake was estimated assuming one-dimensional,vertical shear wave propagation in the surface layers. In this study, the main part of 10 sec of the strong motion accelerogram taken at a Tohoku University building was used as a standard motion. The procedure to determine the ground motion at each mesh point is as follow: The wave form of Tohoku University record in the NS componnent was transformed to the spectrum form in the frequency domain. Using the transfer function at Tohoku University site the base motion of the Tohoku University building was reduced to the seismic incident wave at the upper bounds of bedrock assuming the wave propagated in accordance with one-dimentional theory. To the seismic incident wave thus obtained the responded surface ground motion at each mesh point was calculated again by the same propagation theory using the dynamic model obtained above. The time history wave form of surface ground motions was obtained by means of the inverse Fourier Analysis.

After grouping 800 mesh points into 41 points each of which represents about 20 mesh points having similar soil conditions, the response analysis at 41 points was made for corresponding ground motion. The acceleration spectra for these 41 points were calculated and again the grouping was made so as to reduce the number from 41 to 13. The results are shown in Fig. 8. As is seen in this figure, the difference in the spectrum value ranges from 1.0 to 2.0. The spectral intensity defined by Housner as well as that modified for the integral range from 0.1-2.5 sec to 0.1-0.8 and 0.1-1.5 sec. The results are shown in Table 1. The maximum accelerations are also shown in this Table. The difference in intensities and maximum accelerations ranges also 1.0-2.0.

COMPARISON OF DAMAGE TO STRUCTURES

Using the earthquake input motion estimated above, the damage to wooden houses and reinforced concrete buildings was estimated and compared with that observed during the earthquake. Since the wooden house is most common and almost uniformly distributed in this district, the damage estimation can be dealt with as a statistical quantity. On the other hand, although there is considerable number of reinforced concrete buildings in this district, it is a rather difficult to deal with their damage estimation statistically. Therefore, the damage estimation for reinforced concrete buildings is made only at a specific place where three school buildings of similar construction and of different damage are located within a several hundred-meter distance.

Wooden Houses

The damage to wooden houses was first estimated by the use of a simple microzoning system in which the whole district was divided into four microzones from the surface geological viewpoint as shown in Fig. 7. The damage ratios, which are the ratio between total-collapsed houses plus one half of half-collapsed houses and total houses, were estimated to be 0.5, 1, 2, and 5% for I, II, III, and IV respectively. Fig. 9 shows the comparisons between estimated and observed damage ratios. It is seen that the damage ratios observed are scattered in the same microzone suggesting scattering of earthquake input motion even in the same surface geology zone, and the need for a more reasonable and solid method to estimate the input motion is recognized.

The damage to wooden houses was also estimated by using a response analysis technique, in which the earthquake inputs at various points are taken from the results shown in the previous section and a suitable dynamic model of wooden houses having the restoring force characteristics of degrading trilinear type. According to the damage criteria for calculated displacement responses of wooden houses, the damage ratios were analyzed of the locations having various soil conditions. The results are compared with those observed as shown in Fig. 10 indicating different marks for different microzones. It is seen from this figure that nearly linear relationship is obtained between analyzed and observed values although analyzed values are somewhat higher than observed values for microzones II and IV. The results may be improved by using more realistic data of wooden houses.

Reinforced Concrete Buildings

Three school buildings having a similar reinforced concrete structure are located on the hilly tertiary terrain in the northern suburbs of Sendai. During the 1978 Miyagiken-oki Earthquake, the three story Izumi High School building was heavily damaged in the longitudinal direction and the four story Shogen-Nishi Primary School building suffered visible shear cracks on the columns also in the longitudinal direction, while four story Shogen-Chuo Primary School building did not suffer any structural damage. The Izumi and Shogen-Nishi buildings are resting on a hard soil layer directly, while the Shogen-Chuo building is on the reclaimed soft soil and is supported by concrete piles of about 10 meters long.

In order to clarify the relation between input ground motion and structural damage, earthquake response analyses are made using two kinds of input ground motions derived from the dynamic models of soil layers shown in Table 2.

The fundamental natural periods and seismic capacities (base shear coefficient) of buildings used in this analysis are shown in Table 3 (Ref. 5). The results of analyses shown in Table 3 and Fig. 11 indicate that the base shear coefficients resulted from non-linear response analyses did not differ very much for those three buildings, although for linear analyses those of Izumi and Shogen-Nishi are higher than those of Shogen-Chuo by 1.2 to 2.0 times. Judging from the fact that the seismic capacity of Izumi and Shogen-Chuo, the main reason of difference in damage among these three school buildings is probably due to the difference in the seismic capacity. The difference in linear response values may be an additional effect on the damage, and further, the difference in the dissipation damping, presuming to be 0.02 for Izumi and Shogen-Nishi and 0.05 for Shogen-Chuo, may have played another part of producing the difference in the damage.

CONCLUDING REMARKS

Considering the frequency range of 0.5-10 c/s, the seismic input motion at various ground conditions during the 1978 Miyagiken-oki earthquake was derived using a current soil dynamics technique based on the microtremor measurements and earthquake observations as well as boring and seismic prospecting data. Then the damage estimation was made for wooden houses in the Sendai district and for reinforced concrete buildings in the northern suburbs of Sendai and the results are compared with those observed. The results of comparison indicate that the input ground motion for wooden houses is reasonable and the damage estimation using current soil dynamics and response analysis techniques gives effective and solid method which is much better than the traditional microzoning method based on the classification of surface geology. For damage estimation of reinforced concrete buildings the relation between input ground motion and resulting damage is clarified as a special example through dynamic characteristics of building structures. Although the current analytical techniques based on the various data show satisfactory results, further investigation is needed, for instance, on the effect of plastic deformation of soil, on the wave propagation theory other than one-dimentional vertical one which are not taken into consideration in this study.

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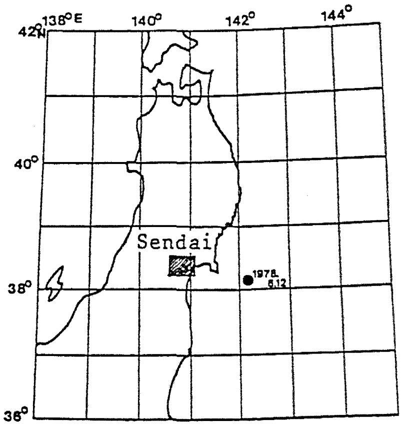


Fig. 1 Epicenter of the 1978 Miyagiken-oki earthquake and location of study area

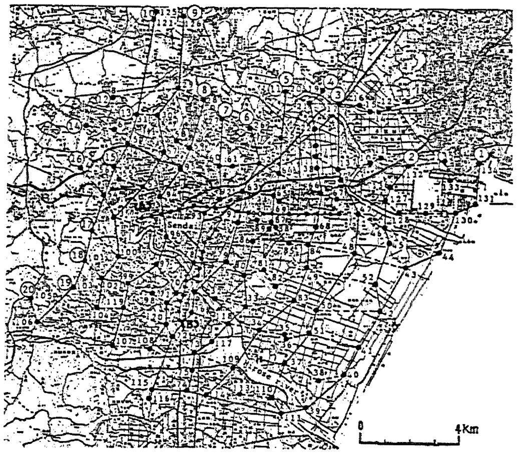


Fig. 2 Locations of the measurement points of microtremors

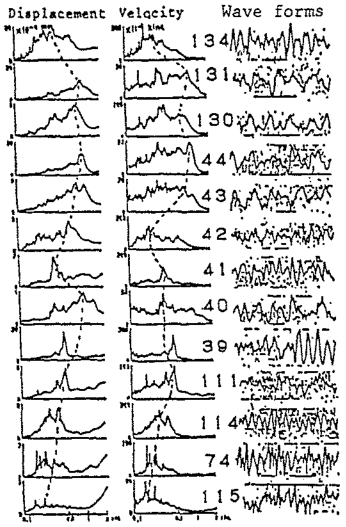
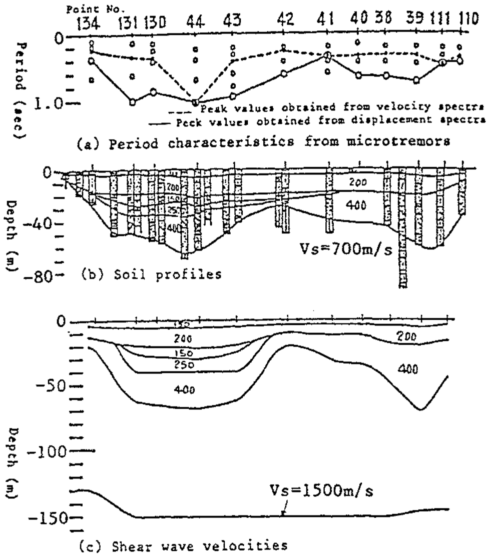


Fig. 3 Fourier spectra and wave forms of microtremors



(a) Period characteristics from microtremors

(b) Soil profiles

(c) Shear wave velocities

Fig. 4 Microtremors, soil profiles and shear wave velocities

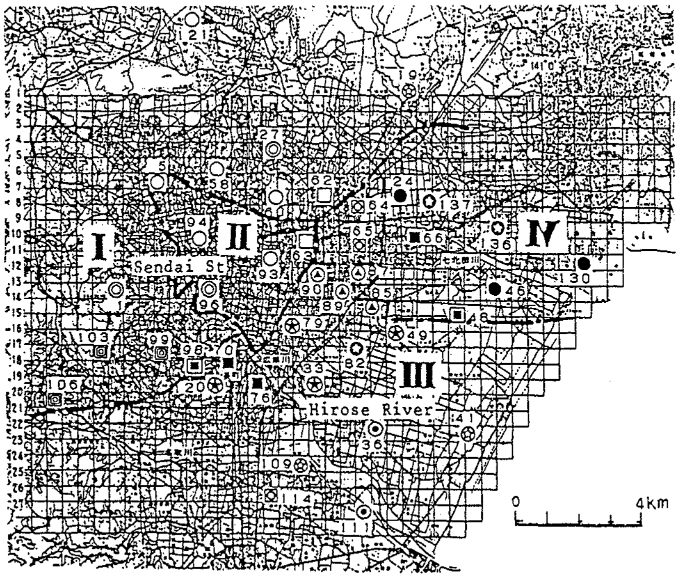


Fig. 7 Locations of response analyses and microzoning from the surface geological viewpoint

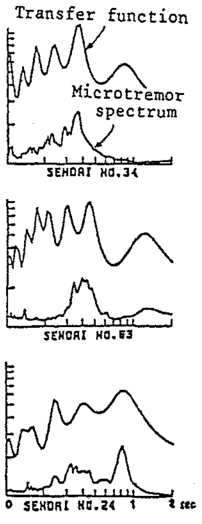


Fig. 5 Comparison of the transfer function to the microtremor spectra

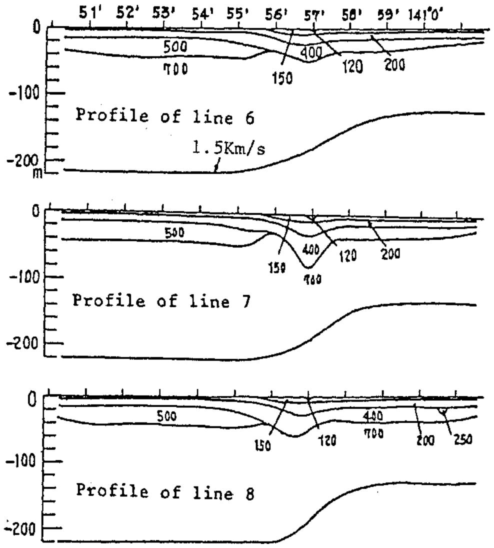


Fig. 6 Dynamic models of soil layers

Table 1 Maximum acceleration and spectrum intensity (NS component)

No.	Amax. (Gal)	SI h=5% T=0.1-0.8	SI h=5% T=0.1-1.5	SI h=5% T=0.1-2.5	MARK
1 96 27	255 233 250	29 26 28	108 100 104	202 192 195	◎
121 94 93 60 58 5	197 206 206 208 197 205	23 23 24 24 23 24	84 89 89 87 86 89	164 180 182 179 177 181	○
19 41 109	280 257 260	34 35 32	106 101 100	192 183 183	⊛
79 49 33 120	301 299 289 282	35 36 37 37	117 117 112 109	213 210 200 195	✪
63 62	229 212	26 25	92 90	186 183	□
65 64 114	301 287 274	32 30 38	102 99 102	199 194 183	⊡
66 70 76	410 393 393	45 46 46	145 146 155	252 253 267	■
106 103 99	193 201 238	26 26 31	77 78 86	148 150 160	⧈
36 111	328 335	43 47	119 121	209 210	⊙
136 137 82	357 346 339	49 45 43	135 129 127	231 224 223	⍟
85 87 89 90	310 287 291 276	37 34 35 34	120 115 117 115	218 212 215 213	◬
48 98	343 343	46 47	136 128	235 221	▣
24 46 130	328 392 324	37 42 26	161 159 152	284 274 275	●

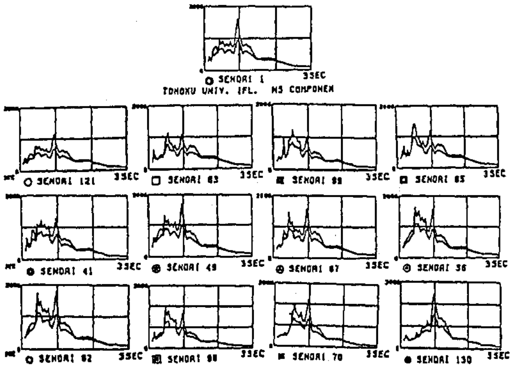


Fig. 8 Acceleration response spectra (h=2%,5%)

Table 2 Dynamic models of soil layers

Model	H(m)	Vs(m/s)	ρ(t/m3)	Q	Location
THK	23	300	1.9	20	Tohoku Univ.
	157	700	2.0	20	
	---	1500	2.3	100	
IZM	4	200	1.7	40	Izumi High School
	16	300	1.9	50	
	160	700	2.0	50	Shogen-Nishi Primary School
	---	1500	2.3	100	
SYG	6	160	1.7	30	
	10	300	1.9	50	Shogen-Chuo Primary School
	160	700	2.0	50	
	---	1500	2.3	100	

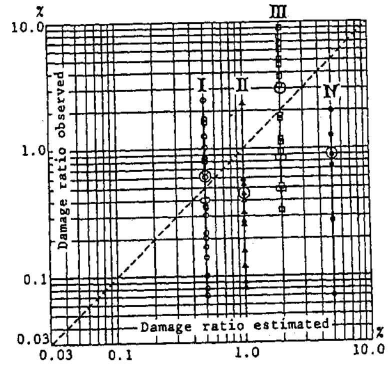


Fig. 9 Comparision between estimated and observed damage ratio

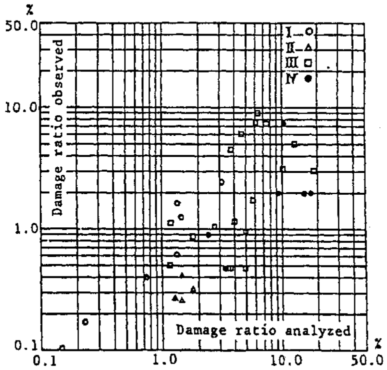
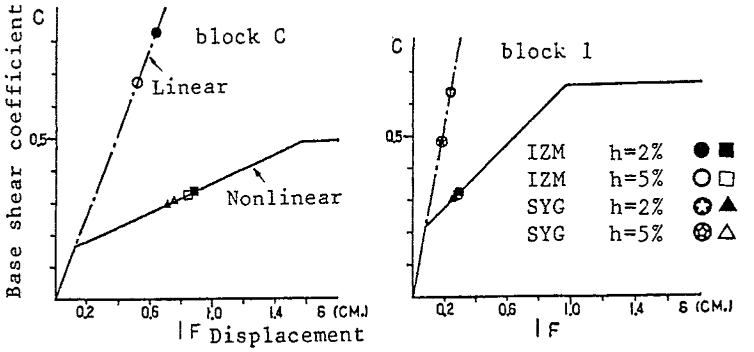


Fig. 10 Comparision between analyzed and observed damage ratio

Table 3 The seismic capacity of structures and the results of seismic response analyses at the 1st story in longitudinal direction

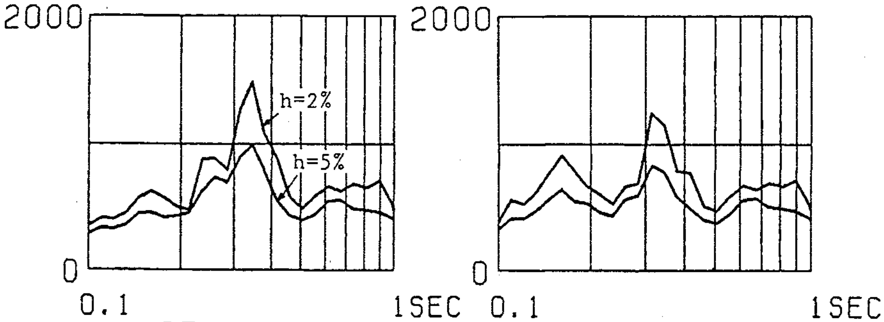
Item				Izumi High School			Shogen-Nishi Primary School		Shogen-Chuo Primary School	
Block				A	B	C	1	2	1	2
1st-mode period (sec)				0.235	0.230	0.245	0.247	0.238	0.203	0.228
Base shear coefficient	Seismic capacity			0.559	0.570	0.489	0.493	0.496	0.653	0.597
	Response	Input	Damping	Results of response analyses						
	Linear	IZM*	h=2%	0.868	0.756	0.827	0.750	0.838	0.636	0.568
			h=5%	0.605	0.542	0.671	0.640	0.611	0.481	0.408
	Nonlinear	IZM*	h=2%	0.343	0.339	0.336	0.314	0.315	0.309	0.309
			h=5%	0.290	0.323	0.327	0.293	0.300	0.301	0.284

* IZM for Izumi and Shogen-Nishi, SYG for Shogen-Chuo



(a) Izumi High School (b) Shogen-Chuo Primary School

Fig. 11 Results of seismic response analyses



(a) IZM (b) SYG

Fig. 12 Acceleration response spectra (h=2%,5%)