

EFFECTS OF LOCAL SITE CONDITIONS ON DAMAGE TO BUILDINGS DURING AN EARTHQUAKE

by

Junichi Shibuya^I, Hideki Kimura^{II} and Toshio Shiga^{III}

SUMMARY

For the purpose of studying the effects of local site conditions on earthquake damage to buildings, a prediction of ground motions on alluvial deposits in Sendai during the Miyagi-ken-oki earthquake of June 12, 1978 is made by means of the dynamic analyses of alluvial layer models. Correlations of the maximum accelerations, response spectra and spectrum intensities of the predicted ground motions with the soil conditions are discussed. Dynamic characteristics of the predicted ground motions on the alluvial deposits are considered to interpret the patterns of damage distribution of buildings in the city in the event of the earthquake.

INTRODUCTION

The Miyagi-ken-oki earthquake of June 12, 1978 caused severe architectural and structural damage to buildings in Sendai city located in the north-east of Japan (1,2). About thirty reinforced concrete buildings, most of which were 3- to 4-storied office and school buildings, suffered heavy structural damage, and five of them were collapsed. More than thirty steel frame buildings, most of which were 2- to 3-storied warehouses and office buildings, suffered heavy structural damage, and five of them were collapsed. More than four thousands of wooden dwellings suffered heavy damage, and about seven hundreds of them were totally collapsed. Steel framed reinforced concrete buildings, which were high rised apartment and office buildings of 8 to 18 stories, suffered relatively minor structural damage.

The distribution of the damaged buildings was not uniform, but was concentrated in localized areas in the city. In the central part of the city on a diluvial upland, the damage was relatively minor. On the other hand, in the eastern and southern part of the city on alluviums (alluvial fan and flood plain), severe damage to buildings was observed. All of the collapsed reinforced concrete and steel frame buildings were on the alluviums. Also could be seen the difference in the distribution of the damaged buildings depending on a type of construction materials.

Several records of strong ground motion have been obtained in the center of the city during the earthquake, whereas no records have been available on the alluvial deposits where the damage was significant.

The objectives of the paper are as follows :

- 1) to predict ground motions on the alluviums from response analyses of sub-soil models using the accelerograms recorded in the center of the city.
- 2) to discuss the relationship between the dynamic characteristics of the predicted ground motions and the soil conditions.
- 3) to discuss the correlation of the patterns of the predicted ground motions

I Research Assistant, Faculty of Engineering, Tohoku University, Japan

II Graduate Student, ditto

III Professor, ditto

on the various subsoil deposits with the observed patterns of the damage distribution of buildings in the event of the earthquake.

DISTRIBUTION OF DAMAGED BUILDINGS AND SOIL CONDITIONS

Fig. 1 shows the distribution of earthquake damage to buildings in the Sendai area. Heavily damaged reinforced concrete and steel frame buildings were plotted in the figure. Shaded parts of the figure indicate zones where collapsed wooden dwellings were concentrated. Fig. 2 shows the geological map in the Sendai area. Damaged reinforced concrete buildings were concentrated in Oroshimachi and Nigatake located on an alluvial fan. Damaged steel frame buildings were distributed in Ogimachi and along the Sendai bypass located on an alluvium of flood plain. It is noticed that the areas where damaged reinforced concrete buildings were concentrated did not overlap with the areas where damaged steel frame buildings were concentrated. Collapsed wooden dwellings were distributed in Nagamachi, Rokugo, Arai and other areas on alluviums, and also in Midorigaoka, Nankodai, Kuromatsu and other areas on the slopes of hills which were newly developed for residential areas. The damage to wooden dwellings on the slopes of hills were mainly caused by landslides and ground failures.

Fig. 3 shows typical boring logs of subsoil deposits at the center of the city, the alluvial fan near Oroshimachi and the alluvium of flood plain near the bypass. The subsoil deposit at the center of the city, where damage to buildings was relatively minor, is composed of a surface gravel layer of a 4 to 7 m thickness and a lower bedrock layer. The subsoil deposit of the alluvial fan is composed of a soft surface layer of silt and clay of a 3 to 5 m thickness and a lower gravel layer. The depth to the bedrock is estimated to be about 30 m. The subsoil deposit of the flood plain is composed of a soft surface layer of silt and clay with organic matters of a 15 to 20 m thickness and a lower gravel layer. The depth to the bedrock is estimated to be about 50 to 60 m. The bedrock which lies under the diluvial and alluvial deposits consists of the Pliocene formations.

The strong ground motions have been obtained at the basements of three buildings in the center of the city during the earthquake. The maximum accelerations of the motions range from 250 to 430 gal in the north-south component and 150 to 240 gal in the east-west component.

DYNAMIC CHARACTERISTICS OF ALLUVIUM MODELS

In the following analyses of the alluvial deposits, the bedrock of the Pliocene is assumed to be common to the diluvial and alluvial areas. Therefore, the ground motions recorded at the basements of the buildings, which are founded in or on the bedrock layer, can be considered to represent approximately the incident motions at the lower bedrock of the alluvium.

Two kinds of models of the alluvial deposits are analysed to predict surface ground motions in the alluvial areas. Fig. 4 shows geological formations and values of parameters of the alluvium models. The alluvium model I which corresponds to the subsoil deposit of the alluvial fan near Oroshimachi has a 30 m depth to the bedrock with a soft surface layer of a 3 m thickness. The alluvium model II which corresponds to the subsoil deposit of the flood plain near the bypass has a 60 m depth to the bedrock with a

soft surface layer of a 15 m thickness.

Nonlinear properties of the soil layers are taken into account in the determination of the values of soil parameters. Initial values of shear wave velocity and the damping of soil, assumed from the measurement tests of the site (3), are modified to be compatible with the strains in the layers calculated from the response analyses of the models subjected to incident seismic waves. The maximum strains calculated are about 0.2 to 1.0 percent in the soft layers, 0.05 to 0.08 percent in the gravel layers and 0.02 percent in the bedrock. The initial values of the shear wave velocity are modified by multiplying the coefficients of 0.5 to 0.7 for the soft layers, 0.8 for the gravel layers and 0.9 for the bedrock, each depending on the effective strain which is assumed to be 70 percent of the maximum strain developed in the layer. Modified values of the damping are 0.15 for the soft layers, 0.10 for the gravel layers and 0.05 for the bedrock (4).

Fig. 5 shows the frequency response functions at the surface of the alluvium models. The ordinate of the figure indicates the amplification of the surface motions to the double amplitude of the incident motions at the bedrock. The alluvium model I has the predominant periods in the short period range, 0.2 and 0.5 sec. The amplifications of the both peaks are about 2. The alluvium model II has the predominant period in the relatively long period range, 1.3 sec. The amplification of the peak is about 3.

PREDICTED GROUND MOTIONS

Ground motions on the alluviums are predicted from the response analyses of the two alluvium models to the incident motions at the bedrock. Six accelerograms observed at the basements of the three buildings are used as the input motions to the bedrock of the alluvium models. The calculations are based on the method of Fourier transforms and inverse-transforms.

Fig. 6 shows the examples of the observed motions in the center of the city and the predicted motions on the alluviums. In the motions of the alluvium model I, the short period components and the maximum acceleration are amplified compared with the observed motions. In the motions of the alluvium model II, the short period components are suppressed and the long period components are amplified.

The maximum accelerations of the observed motions on the bedrock in the center of the city and the predicted motions on the alluvium models are shown in Table 1. The maximum accelerations on the alluvium model I are 450 to 580 gal in the north-south direction, and 210 to 440 gal in the east-west direction. The maximum accelerations on the alluvium model II are 370 to 590 gal in the north-south direction, and 180 to 250 gal in the east-west direction. Ratios of the maximum accelerations on the alluviums to those on the bedrock are 1.4 to 1.9 for the model I, and 1.0 to 1.5 for the model II.

RESPONSE SPECTRA

Fig. 7 shows the comparisons of acceleration response spectra of the predicted ground motions on the alluvium models with those of the observed ground motions in the center of the city. In the case of alluvium model I,

the spectral accelerations in the short period range show larger values than those on the bedrock. Particularly, in the period range from 0.2 to 0.4 sec, the spectral accelerations exceed 1000 gal. In the case of alluvium model II, although the spectral accelerations in the short period range are nearly same as those on the bedrock, the spectral accelerations in the period range longer than 0.8 sec. are twice as large as those on the bedrock.

Spectrum intensities, defined as the areas of velocity response spectra in the period range from 0.1 to 2.5 sec, of the observed and the predicted ground motions are shown in Table 1. The spectrum intensities of the predicted ground motions on the alluvium model I are about 1.3 times and those on the alluvium model II are 2.0 times as large as those on the bedrock in the center of the city.

CONCLUSIONS

Ground motions on alluvial deposits in Sendai during the 1978 Miyagi-ken-oki earthquake are predicted from the dynamic analyses of the two kinds of alluvium models. The maximum accelerations, response spectra and spectrum intensities of the predicted ground motions are discussed in relation to the soil conditions of the models.

The spectral acceleration of the ground motions on the alluvium model I shows an extremely large value in the short period range from 0.2 to 0.4 sec and decreases with the increasing period. These characteristics of the ground motions are likely to cause severe damage to a low rise reinforced concrete building, which has a small capacity of plastic deformation of the structure to lateral forces in spite of its relatively high lateral strength. On the other hand, although the spectral acceleration of the ground motions on the alluvium model II shows a nearly same value in the short period range as that on the bedrock in the center of the city, it increases with the increasing period and reaches at its peak at the period of 1.0 sec. These characteristics of the motions are likely to cause severe damage to a low rise steel frame building with a low lateral strength even if it has a large capacity of plastic deformation. It is considered that the above tendencies of the ground motions of the alluvium models interpret the actual damage distribution of the reinforced concrete and steel frame buildings in Sendai in the event of the Miyagi-ken-oki earthquake.

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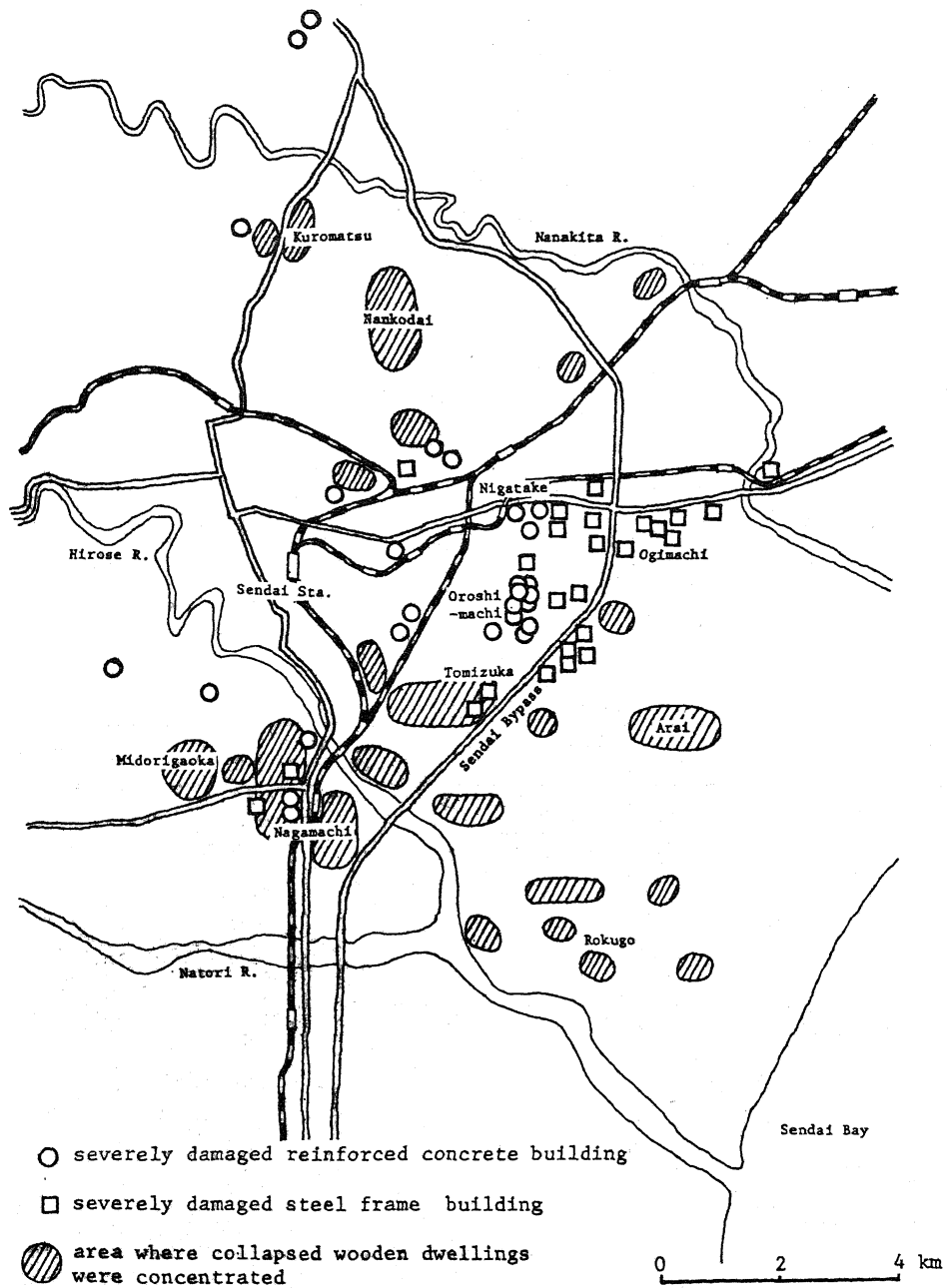


Fig. 1 Distribution of Damaged Buildings in Sendai

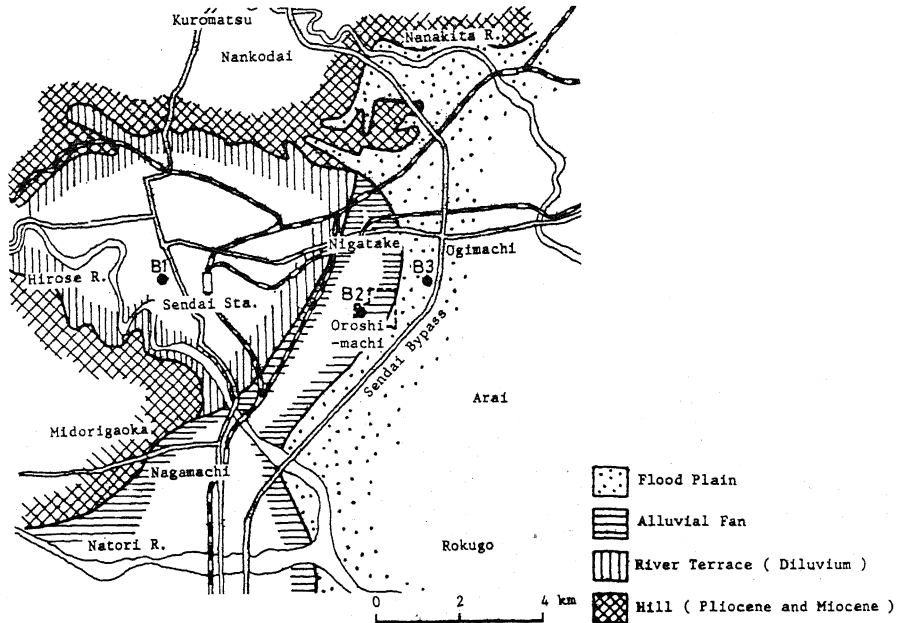


Fig. 2 Geological Map in Sendai Area

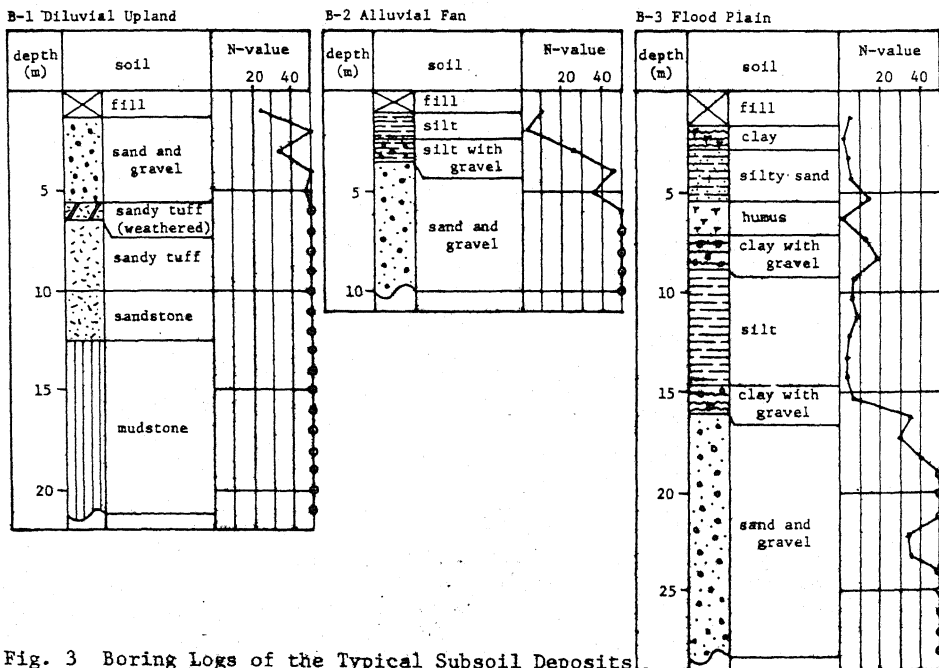


Fig. 3 Boring Logs of the Typical Subsoil Deposits

Alluvium Model I

	1 2	soil	H(m)	$\rho(t/m^3)$	Initial values		Modified values	
					$V_S(m/s)$	h	$V_S(m/s)$	h
	3	1. fill, silt	3	1.4	100	0.05	70	0.15
	4	2. gravel	4	1.9	200	0.02	160	0.10
	23	3. gravel	23	1.9	300	0.02	240	0.10
	4	4. rock		2.0	600	0.02	540	0.05

Alluvium Model II

	1 2 3 4 5 6	soil	H(m)	$\rho(t/m^3)$	Initial values		Modified values	
					$V_S(m/s)$	h	$V_S(m/s)$	h
	7	1. fill, silt	7	1.4	100	0.05	70	0.15
	2	2. gravel	2	1.9	200	0.02	140	0.15
	6	3. sandy silt	6	1.4	100	0.05	50	0.15
	10	4. clay with gravel	10	1.9	200	0.02	120	0.15
	35	5. gravel	35	1.9	300	0.02	240	0.10
		6. rock		2.0	600	0.02	540	0.05

H ; thickness of a layer
 ρ ; weight of unit volume
 V_S ; shear wave velocity
h ; fraction of the critical damping

Fig. 4 Two Alluvium Models and the Values of Parameters

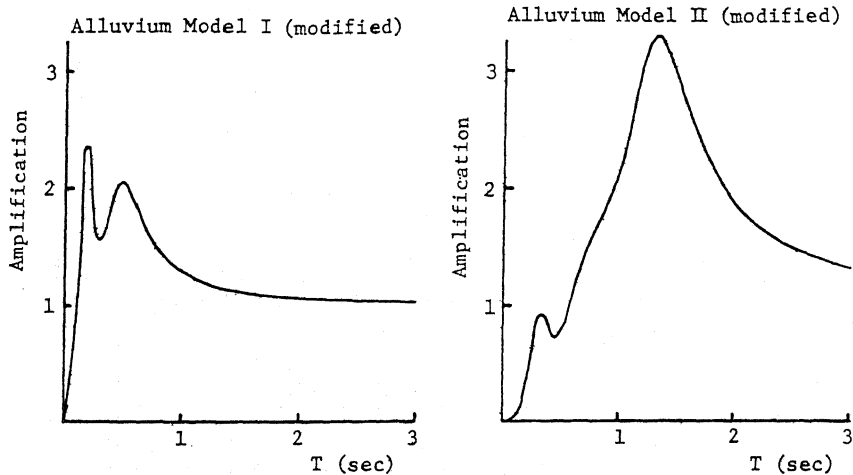


Fig. 5 Frequency Response Functions of Surface Motions of the Models

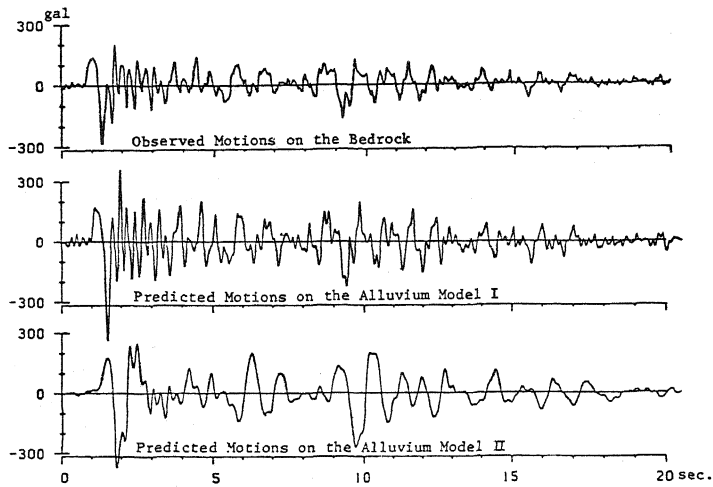


Fig. 6 Examples of the Observed and Predicted Ground Motions

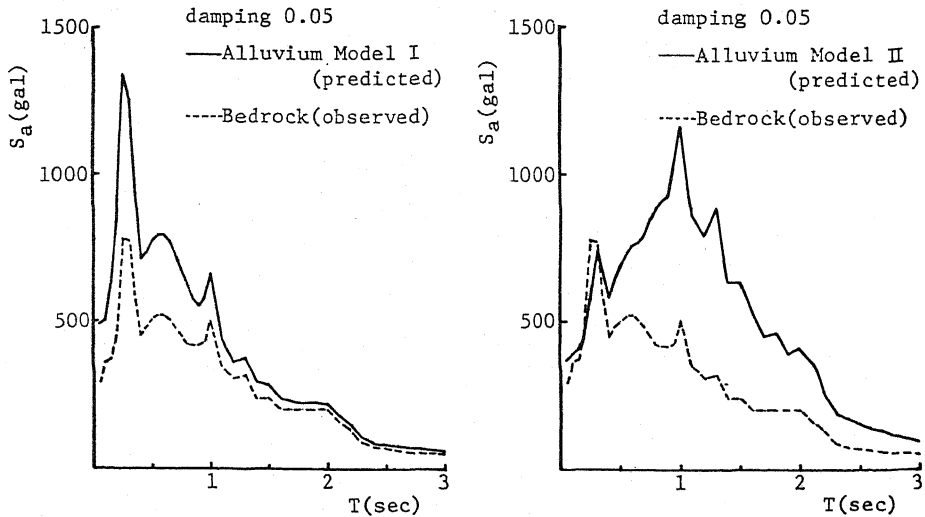


Fig. 7 Comparisons of Acceleration Response Spectra

Table 1 Maximum Accelerations and Spectrum Intensities

Input Motions*	Maximum Accelerations (gal)			Spectrum Intensities (cm)		
	Bedrock (observed)	Alluvium I (predicted)	Alluvium II (predicted)	Bedrock (observed)	Alluvium I (predicted)	Alluvium II (predicted)
A	NS	294	487	118	148	251
	EW	145	210	84	106	172
B	NS	250	449	107	135	230
	EW	240	395	96	124	170
C	NS	432	583	164	204	348
	EW	232	438	98	127	192

* Motions recorded at the basements of the three buildings