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Dense strong motion accelerometer array at site with different topographic and geographic conditions

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ABSTRACT: This research study describes an on-going earthquake recording system in Sendai, Japan. This system includes eleven observation sites and a control station. A number of records with intermediate amplitude levels have been obtained to date. Utilizing these records, we investigated effects of surface soil layers using peak accelerations and response spectra.

1 INTRODUCTION

A multi-site earthquake observation project in Sendai introduced by Kitagawa et al. (1988) is continued. The observation sites in Sendai include variety of soil conditions commonly found in urban areas in Japan. The purpose of this observation is mainly to obtain the basic data for evaluating the design earthquake motions for buildings, especially data on site responses, i.e., variations of ground motions in a limited region.

Although the seismic activity around Sendai was not so high for these years, a number of earthquake records have been obtained. The completed observation system and the earthquake records obtained so far are introduced. Some analytical results on the properties of the records are also shown in this paper. Average characteristics for typical sites were examined through the response spectral analysis and effects of the surface layers were discussed.

2 ARRAY CONFIGURATION

Sendai, a metropolis in the northern part of Japan, has a wide variety of topography and geology, and there are many types and scales of structures. The Sendai area suffered severe damage from the 1978 Off Miyagi Pref. Earthquake (Magnitude 7.4). After the earthquake, various studies were performed to examine the earthquake damage. In term of geological conditions of the surface layers, the Sendai district is generally classified into three areas, i.e. the hilly Tertiary terrain in the eastern and northern side, the terrace area in the central part, and the alluvia plain in the coast side.

The installation of accelerometers and recording systems was started in 1984, and was finally completed in 1989 as listed in Table 1. Eleven observation sites scatter with distances of 3 to 4 kilometers as shown in Fig.1. In the figure, a contour line of the depth of alluvium which was reported by Miyagi prefecture is also shown. There is a fault called Rifu-Nagamachi tectonic line geologically dividing the city into two zones. The west side of the fault is a hilly zone and the east side of the fault features its thick alluvial soil layer.

Table 1 List of observation sites

Code	Location	Depth			Vs*
MIYA	Miyagino primary school	01	22	54	680
NAKA	Nakano primary school	01	30	61	720
TAMA	Tamagawa secondary school	02	11	33	1400
ORID	Oridate primary school	01	57	76	1050
TSUT	Tsutsujigaoka primary school	01	36	59	950
TRMA	Tsurumaki primary school	01	25	79	660
OKIN	Okino primary school	01	17	62	820
TRGA	Tsurugaya primary school	02	37	62	1000
SHIR	Shiromaru primary school	01	20	76	830
NAGA	Nagamachi primary school	01	29	81	700
ARAH	Arahama primary school	01	31	76	950

* Shear wave velocity of the deepest layer in m/sec

3 GEOLOGICAL CONDITIONS OF SITES

Outline of geological conditions at observation sites are as follows;

Miyagino (MIYA) site: This site is classified as lowland, close to the border between the hill. The Tertiary Pliocene layer is found at 26 meters below the surface. The degree of compaction of the Tertiary layer is lower at the upper layer, which changes to sand. The compaction for the lower layers is high. The sand gravel layer, found at the upper part of the Tertiary, contains clay, and is fairly firm.

Nakano (NAKA) site: This site lies on the basin of the Nanakitagawa river. The Tertiary layer is found approximately 58 meters below the surface. Thick alluvial layer lies above the layer. This site belongs to the soft soil category. The Tertiary pelite or tuff deposit is fairly firm but fragile against a light hammer blow. The upper layer is rather loose, but the lower is fairly firm.

Tamagawa (TAMA) site: This site is on the Tertiary rock formation except for the thin fill layer on the surface. The rock consists mainly of tuff and sand. The upper portion of the rock is loose, the lower is extremely firm.

Oridate (ORID) site: This site consists mainly of relatively soft pelite or tuff. The lower part of the layer is andesite with upper part of andesite being weathered and fragile. The layer at more than 70 meters below the surface is fairy firm.

Okino (OKIN) site: This site is on the basin of the Natorigawa river. The Tertiary layer is found at approximately 50 meters below the surface. It consists mainly of sandstone, relatively firm but fragile. The upper alluvial part has layers of clay and sand at the uppermost, the remaining part is mostly sand gravel. The sand gravel layer contains clay and is fairly firm.

Tsutsujigaoka (TSUT) site: Up to 5 meters below the surface is a loose layer consisting of a diluvial sand-gravel, a clay, and a fill. The Tertiary deposits are below the layer. The upper part of the layer consists of a firm sandstone layer, and a mostly firm sand-gravel-like layer. The deeper we go, the firmer the soil becomes, but it is very fragile.

Shiromaru (SHIR) site: This site, along with Okino site, is on the basin of the Natorigawa river. The Tertiary layer is found at approximately 50 meters below the surface. The upper part of the layer is getting weathered, and has a non-consolidated portion. On the other hand, the lower part is fairly firm and a sand-gravel layer is found as well. The alluvial layers consist mostly sand-gravel layers, except for the surface layer approximately a 3 meter thickness, which also contai clay fines, and is a fairly consolidated layer. T diameters of some of the gravels are large.

Tsurumaki (TRMA) site: This site is on the basin the Nanakitagawa river. Due to the erosion of the riv bed, the Tertiary layer lies at the depth of valley-shap soil structure. Consequently, the depth of the Tertia layer extends as much as 80 meters. The layer sandstone. The consolidation is low and the layer fragile. The alluvial deposit contains surface laye partly thin sand or clay layers. Most of the layers of t deposit are sand gravel which are fairly firm.

Tsurugaya (TRGA) site: A Tertiary layer is fou below the surface fill. The layer contains sand and tı sand-stone. The consolidation is fairly high near t surface.

Nagamachi (NAGA) site: This site is on the basin the Natorigawa river, and also close to the Rif Nagamachi tectonic line. The Tertiary layer is found the depth of approximately 57 meters below the surfa The layer consists mainly of sandstone. T consolidation of the upper part of the layer is low. T upper part of the alluvial deposit contains loo composite layers of clay, sand, and gravel, up to t depth of approximately 30 meters from the surface. T lower part of the deposit consists of sand grav containing clay and is fairly firm.

Arahama (ARAH) site: This site is between t Nanakitagawa and Natorigawa rivers. Although this s is classified as a hill, the Tertiary layer is found a relatively shallow depth. The depth of the layer approximately 35 meters below the surface, and consi

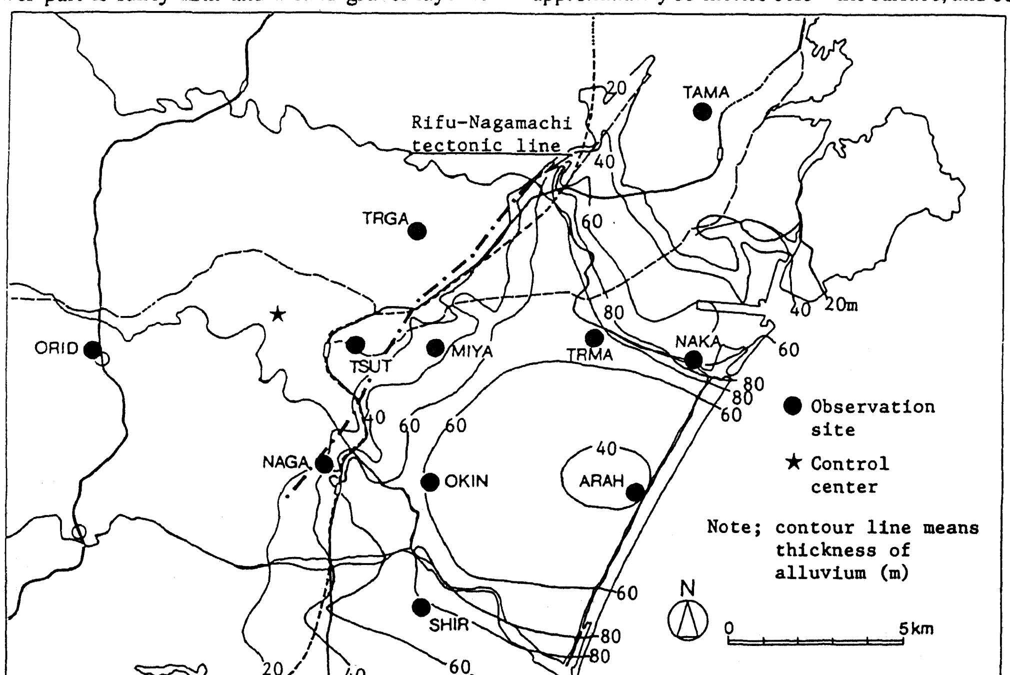

Figure 1 Layout of observation sites and a control station, and thickness of alluvium

of sandstone and pelite. The consolidation is relatively low. The upper alluvial deposit consists of layers of sand and silt, and make a formation of a loose soil deposit. A sand gravel layer is found, with a thickness of 4 meters, at the interface above the Tertiary layer.

In this study, three typical sites are selected for discussion. Therefore distribution of shear wave velocities are shown in Fig.2.

4 OBSERVATION SYSTEM

Each site has three-component accelerometers at three depths underground, i.e., one on the ground surface, one on the layer with shear wave velocity of greater than 700 m/sec and the other in-between. Accelerograms are recorded on half-inch magnetic tape after converting with 16-bit A-D converter. The recording system widely covers frequency range of 0.05 to 30 Hz, and the overall dynamic range reaches 96 dB.

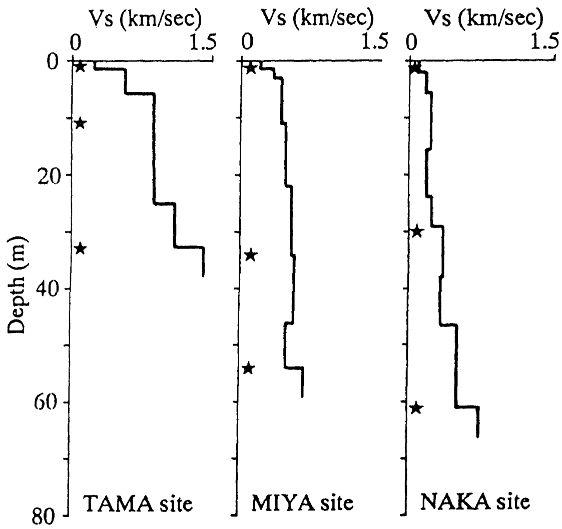

Figure 2 Distribution of shear wave velocities
★: installed accelerometers

A control station is connected with each observation site via the exclusive telephone line, and is managing status of observation instruments. When an earthquake occurs, the recording system of each site starts by own triggering logic, and informs it to the control station. The control station commands all sites to start when two or more sites feel the earthquake. Building Research Institute in Tsukuba has a set of personal computer, that is connected with the control station via the public telephone line, for monitoring the observation system. The block diagram of the observation system is shown in Fig.3.

Table 2 Instrumental Specifications

Accelerometer	triaxial velocity feedback type
Amplitude range	1 g
Frequency range	0.05 - 30 Hz
Overall dynamic range	96 dB
A/D converter	16 bits
Low pass filter	phase linear type, 30 Hz
Sampling frequency	100 or 200 Hz (selectable)
Recording medium	half inch 9 track magnetic tape
Start trigger level	0.5 gals (controllable)
Stop trigger level	0.05 kines (controllable)
Pre-event memory	6 seconds
Clock accuracy	5 milli-seconds
Backup battery	30 minutes after power failure

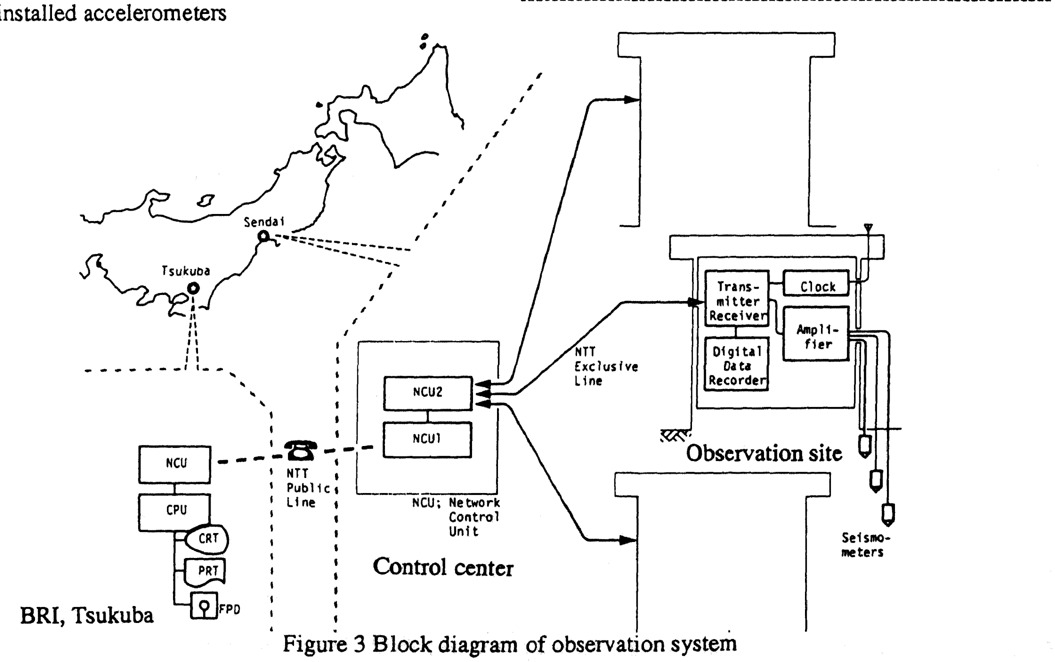

Figure 3 Block diagram of observation system

5 OBSERVED EARTHQUAKES

We have never obtained an accelerogram as large as the one for the 1978 Off Miyagi Pref. Earthquake since the observation project began in 1984. However, a vast amount valuable data has been accumulated year by year. Table 3 shows 24 earthquakes used in this study, and these epicenters are plotted in Fig.4. It is shown that most of the earthquakes occurred in the distances of 100 to 200 km and larger earthquakes occurred mostly off the sea coast. As an example, accelerograms on the ground surface at three sites for the earthquake #8724 are shown in Fig.5. The maximum acceleration in these 8 years is 108 gals which was observed on the ground surface at NAKA site for the earthquake #8724.

Table 3 Observed eathquakes

No.	Date	Epicenter	H*	M**
8603	86/06/24	SE off Boso Peninsula	73	6.5
8608	86/10/14	E off Fukushima Pref.	53	5.7
8609	86/10/21	E off Miyagi Pref.	55	4.6
8613	86/11/03	Kinkazan Region	68	4.4
8615	86/12/01	Kinkazan Region	51	6.0
8701	87/01/09	Northern Iwaki Pref.	72	6.6
8702	87/01/14	Hidaka Mountains Region	119	7.0
8704	87/01/21	E off Miyagi Pref.	50	5.5
8708	87/02/06	E off Fukushima Pref.	30	6.4
8709	87/02/06	E off Fukushima Pref.	35	6.7
8713	87/02/28	E off Fukushima Pref.	31	5.6
8714	87/02/28	E off Fukushima Pref.	79	4.9
8715	87/03/01	E off Fukushima Pref.	54	4.6
8717	87/03/10	E off Fukushima Pref.	29	5.6
8719	87/04/07	E off Fukushima Pref.	44	6.6
8721	87/04/17	E off Fukushima Pref.	45	6.1
8722	87/04/20	E off Fukushima Pref.	45	4.9
8724	87/04/23	E off Fukushima Pref.	47	6.5
8728	87/04/30	E off Fukushima Pref.	50	5.0
8734	87/05/12	Kinkazan Region	50	5.7
8735	87/05/26	E off Miyagi Pref.	22	5.6
8739	87/09/24	E off Ibaraki Pref.	41	5.8
8740	87/10/04	E off Fukushima Pref.	42	5.8
8804	88/01/26	E off Fukushima Pref.	34	5.6

* Focal depth in km.
** Magnitude by Japan Meteorological Agency

6 CHARACTERISTICS OF TYPICAL SITES

Ground conditions are classified into three types according to the surface geology and the predominant ground period in the Japan building standard regulation. To investigate site effects, we selected three sites, TAMA, MIYA and NAKA, which are typical of three

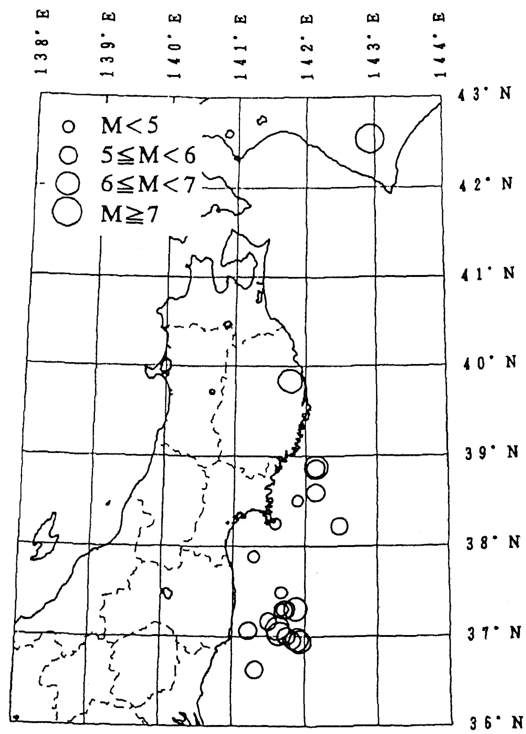

Figure 4 Epicenters of observed earthquakes

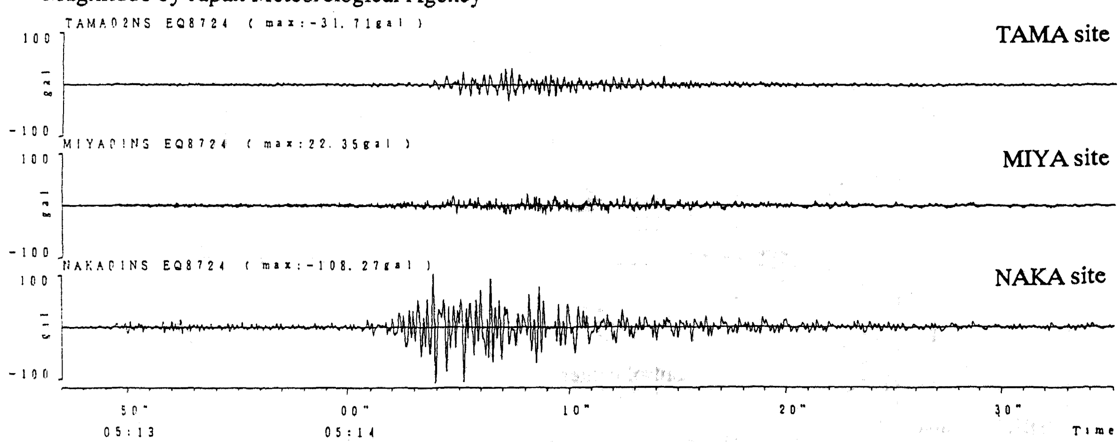

Figure 5 Accelerograms on the ground surface for the earthquake #8724 (NS component)

ground conditions in the regulation.

Ratios of horizontal peak accelerations observed on the surface to ones on the deepest layer for three sites are shown in Fig.6. Peak accelerations on the soft surface layers at NAKA site becomes 3 to 5 times compared with ones on the layer with shear wave velocity of 720 m/sec, and ratios generally decreases according as an absolute amplitude increases. However, the differences between peak accelerations on the surface and on the bedrock are slight at MIYA and TAMA site. For TAMA sites, peak acceleration ratios are distributed within 1 to 1.5.

Figure 7 also shows peak acceleration ratios at three site for the vertical components. Although the ratios are smaller as compared with horizontal components, the similar situation can be recognized.

Figure 8 shows velocity response spectra with 5% damping for the accelerograms shown in Fig.5. A velocity response spectrum on the surface at NAKA site has a similar shape with one at TAMA site, and is larger 2 to 5 times. However the response spectrum for MIYA site has a distinguished peak at period of 2 seconds.

Differences of horizontal response spectra due to the depth at each site are shown in Figs. 9, 10 and 11. For NAKA site, It is clear that the large magnifications are produced by shallow deposits. The effect of surface layers with thickness of 30 meters is especially remarkable. For TAMA site, the three response spectra at three depths agree with each other. It is means that magnification effects of surface layers, which consist of tuff and sand rock, at TAMA site are quite small in this period range. Differences of three velocity response spectra for MIYA site are also not so large in the period of lower than 2 seconds. However remarkable rising of the spectrum on the surface can be observed at period of 4 to 5 seconds. One of the possible causes is the influence of surface waves, but the detailed examination is on-going.

Ratios of velocity response spectra on the ground surface to ones on the deepest layer are shown in Fig.12. The effects of surface layers become clear. The first natural period of surface layers at NAKA site is approximately 1 second and the amplitude is magnified 5 times. For MIYA site, an apparent peak is recognized at 0.5 seconds. In the long period range, large ratios can be observed as mentioned above. For Although magnification effects of surface layers are not apparent at TAMA site, a small peak can be recognized near 0.1 seconds in period.

7 CONCLUSIONS

The array observation system in Sendai has recorded a number of earthquake motions reflecting the soil conditions of each site. The influence of soil conditions on surface ground motions was investigated through the response spectral analysis of the records from the typical observation sites, and the notable magnification of soft surface layers are pointed up. The amplitudes of acceleration on the soft surface layers become 3 to 5 times compared with ones on the hard rock. Such

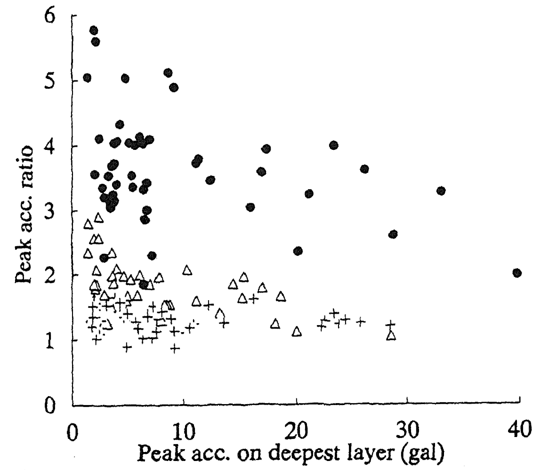

Figure 6 Horizontal peak acceleration ratios on surface to deepest layer

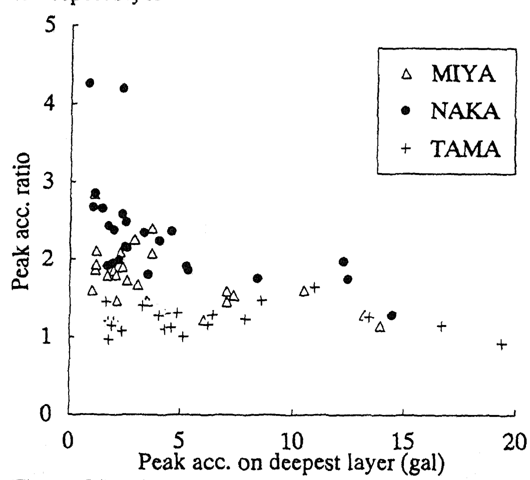

Figure 7 Vertical peak acceleration ratios on surface to deepest layer

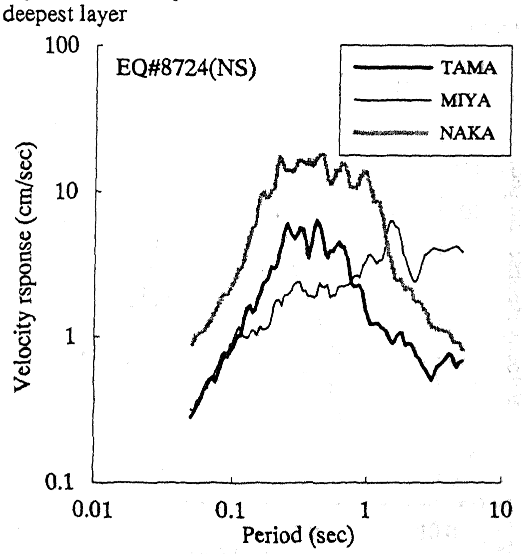

Figure 8 Response spectra on surface for eq. #8724

magnifications are produced by very shallow layers. For other observation sites, valuable records are being accumulated. Our observed data and study results will contribute to the generalization of site effects of seismic design in the future.

8 ACKNOWLEDGMENT

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REFERENCES

Building Research Institute 1978, *Report on the Damage by 1978 Off-Miyagi Prefecture Earthquake* (in Japanese), Rept. of BRI

Kitagawa, Y., I. Okawa and T. Kashima 1988. Dense Strong Motion Earthquake Seismometer Array at Sites with Different Topographic and Geologic Conditions in Sendai: *Proc. 9th WCEE*: 215-220, Vol.II: Japan

Miyagi Prefecture 1985, *Seismic Geological Map of Miyagi Prefecture* (in Japanese)

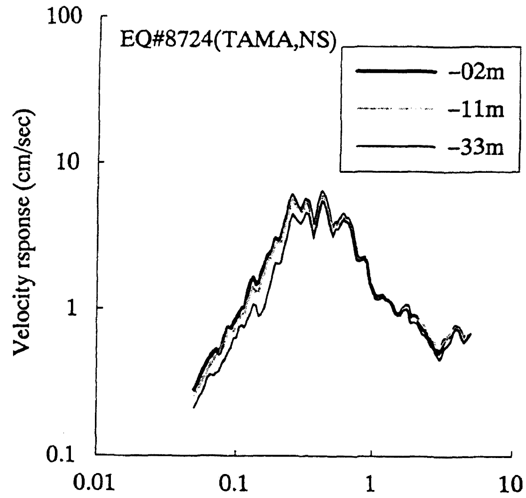

Figure 9 Response spectra at TAMA site

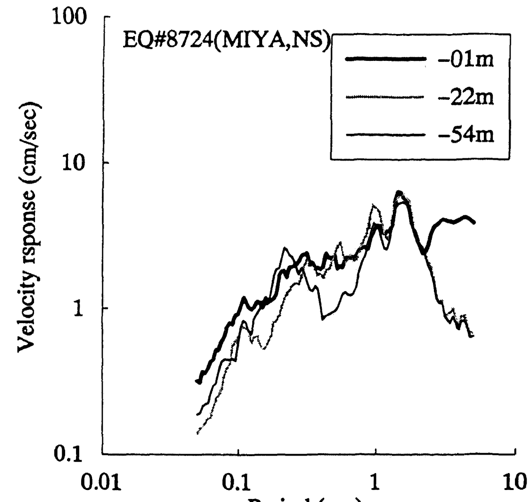

Figure 10 Response spectra at MIYA site

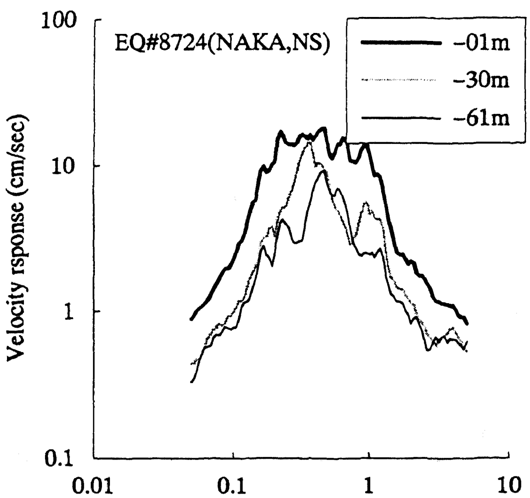

Figure 11 Response spectra at NAKA site

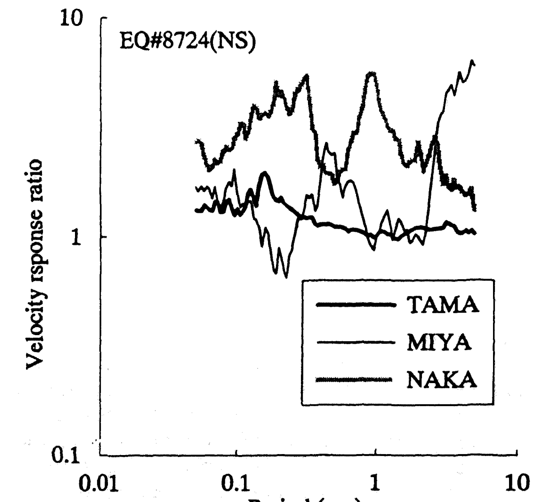

Figure 12 Response spectral ratios (surface/deepest)