EARTHQUAKE RECORDING FOR SSI STUDY BY BRI

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ABSTRACT

The Building Research Institute (BRI) had been in charge of the strong motion recordings in buildings since 1955. The other classes of structures such as bridges, dams, port facilities were instrumented by different organizations. The BRI is currently maintaining 77 recording sites nationwide. The recording system was introduced in the previous workshop. [Okawa, et. al. 1998] As was mentioned in the proceedings of the workshop, several recorded motions from our earthquake recording system have been used for seismic design of buildings in Japan. In this paper, some additional notes on our recording system will be given. In nationwide strong motion observation, the BRI currently maintains 47 recording sites that include the new base-isolated Kushiro Governmental Collective Office building. The former recording site in Kushiro was abolished due to the movement of the Japan Meteorological Agency (JMA) office to the newly built office. The Hachinohe city hall building was replaced with base-isolated one. The instruments were more densely installed in the building than before. In October 6, 2000, a large earthquake named as 2000 Tottori-ken-Seibu earthquake occurred in the western part of Japan. The JMA measured intensity of 6+ was observed between Tottori and Shimane prefectures. A BRI strong motion seismograph captured the motion at the basement of the Yonago city hall. There was no instrument in surrounding ground. However, K-net seismometer maintained by the National Research Institute of Earth Science and Disaster Prevention, the Science and Technology Agency (STA) and Seismic Intensity seismometer maintained by the JMA recorded the motion at the nearby ground. With the aid of these densely instrumented recording system, we can estimate the free field motion on the surrounding ground. We have earthquake recording system in surface ground of Sendai area in the northern part of Japan focusing on the effect of surface geology on seismic motions. Although we had obtained only records with relatively small amplitudes, we recognized that the amplification characteristics are varied depending on site-specific nature of the recording sites. Looking back the BRI strong motion recording, there were very few examples that include simultaneous recording system in both building and ground. The simultaneous recording is crucial for quantitative investigation of the SSI effects to buildings. With these in background, we had started other earthquake recording systems after the Kobe earthquake. One is the strong motion seismograph array network deployed around the greater Tokyo metropolitan area. The other is the dense instrumentation in BRI campus. Some recorded motion with those systems will be introduced in this paper. The ground motion records with the instruments in BRI campus will be presented elsewhere.

KEYWORDS

Earthquake Recording, Free Field, Tottori-ken-Seibu Earthquake, Nationwide Strong Motion Observation, Dense Seismometer Array Observation

1. INTRODUCTION

Strong motion recordings were started with seismometers installed in structures. The Building Research Institute (BRI) published many epoch-making records such as the Kawagishi-cho apartment, during 1964 Niigata earthquake, recording the tilting of the apartment building due to soil liquefaction. We believe this was the first recording of liquefaction phenomenon in the world. After that, we had also obtained large earthquake record in the campus of Tohoku university, during 1978 Miyagiken-oki earthquake. The earthquake was recorded at the 1st and 9th floor of the building in the campus. The amplitude in the first floor was large enough at the time. Attention was drawn from many researchers that the 9th floor accelerogram showed amplitude more than 1G. We had also large amplitude records during 1993 Kushiro-oki earthquake, and 1994 Hokkaido Toho-oki earthquake and 1994 Sanriku Haruka-oki earthquake. Unfortunately, we had not installed seismometers in Kobe. Because Kobe had long been believed to be earthquake-free area by residents. We had instead obtained record in Osaka several tens km away from Kobe.

BRI seismometers had generally been installed in the buildings with some exceptions since its beginning. Considering the large amplitude recorded by the free field sites, we came up to bear idea in mind that the free field ground motion is not identical to the input motion to the structure. Here, we should define what is the input motion. That is the motion to be used for the analysis of superstructure with the assumption of fixed-base model. It might be appropriate to call it effective input motion to structure. With the terminology, it is said that we should seek for the effective motion or how to distinguish or evaluate effective motion from recorded ones.

Recently we set up two kinds of earthquake recording systems. One is a system with 2 to 4 three-component sensors in one site installing in first or basement floor, top floor and nearby free filed. We installed seismometers at 19 sites around greater Tokyo metropolitan area. It is not easy; however, to find places for free field, since there are few free grounds with little influence of buildings, especially in Tokyo. The other is the dense instrumentation to building and surrounding ground including deep boreholes. We set up this system in newly constructed 8-story steel reinforced concrete (SRC) building next to the main building in our institute campus 4 years ago. Totally 66 channels record the event when certain level of motion is exceeded. We believe the recording system of this kind will be very directly utilized for evaluating the SSI phenomena.

2. BRI EARTHQUAKE RECORDING ACTIVITIES

2.1 Nationwide Strong Motion Observation in Buildings

BRI has installed strong-motion instruments in major cities throughout Japan since 1955. There are now 47 observation sites in operation mostly using the digital strong-motion instruments. The observation sites are shown in Fig.1. The recordings are mainly conducted in buildings, and the recording spot is usually placed both on the top and in the foundations of the building. We are increasing the free field recording spot. However, the objective spots had long been limited within the building. The recording sites are listed in the Table 1. There are very few sites that facilitate the free field instrumentation. Most of the recording sites are connected to BRI via public telephone line in order to reduce maintenance work and to retrieve data directly and promptly.

We had also large amplitude records during 1993 Kushiro-oki earthquake, 1994 Hokkaido Toho-oki earthquake and 1994 Sanriku Haruka-oki earthquake. During the 1993 Kushiro-oki (Off Kushiro) Earthquake, 711 gal was recorded as the peak acceleration on the ground surface at Kushiro Local Meteorological Observatory. Whereas, JMA seismometer installed in the same observatory recorded 920 gal. After this earthquake, BRI installed additional seismometer under the ground of the site. In 1994 Hokkaido Toho-oki earthquake, simultaneous recordings in surface and underground were obtained. In the 1994 Sanriku-haruka-oki (Far off Sanriku) earthquake, a large acceleration amplitude record was obtained in the building next to the severely damaged old Hachinohe municipal office building. The maximum acceleration recorded at the basement was more than 400 cm/s/s.

After 1995 Hyogo-ken-Nanbu (Kobe) earthquake, considerable number of strong motion seismometers were installed nationwide. Its good example is the Kyoshin-Net (K-Net) by National Research Institute of Earth Science and Disaster Prevention, Science and Technology Agency (NIED). In addition, beside the recording system mainly for research purposes, the Japan Meteorological Agency (JMA) and many local governments also deployed wide coverage of strong motion seismograph installation nationwide as well as the STA. These instruments were installed to provide seismic intensities of areas immediately after the large earthquake.

In October 6, 2000, a large earthquake named Tottori-ken-Seibu earthquake occurred in the border of Shimane and Tottori prefectures in the western part of Japan. The damage was minor, in spite of large recorded acceleration amplitudes. Figures 2 and 3 shows the scatters of maximum acceleration and velocity amplitudes announced by the K-net and KiKnet maintained by NIED. The figure does not include the recorded motion in the structures.

The BRI maintains the seismometer in Yonago city hall building only in the basement. Looking around the area, Both NIED and JMA maintain the recording system on the ground. Those spots are not very close each other. However, we can estimate the free field motion at the city hall, using the published surface soil data.

The estimation is not the intention of this paper. The comparison indicates that the record from the city hall basement record show smaller amplitude than the free filed motion in two sites.

2.2 Strong-Motion Instrument Network in the Metropolitan Area

The BRI has established nineteen new recording sites placed radially in the Tokyo metropolitan area. This project aims partly to investigate the characteristics of the seismic motion affecting the whole Kanto Plain through observation records. The system immediately collects information on the seismic intensity at the time of an earthquake occurrence. The site location is shown in Fig. 7. We had tried to install seismometers both in the buildings and free field. However, it is very difficult to find free field point near the building especially densely populated Tokyo area. The recording sites in the suburbs have both, and therefore comparative data for SSI problem will be available.

The recording sites are summarized in Table 2. The example record from one site is shown in Fig. 8. It is the records of the Misato city hall. This building is installed with three seismometers, one on the top floor, one on the first floor and one in the nearby free field. The response spectra with 5% damping are also shown in Fig. 10. Fortunately, this system has not captured the large event yet to date.

The array is designed for obtaining the data with respect to the propagation of seismic waves in deeper subsurface structure. For the purpose, velocity type seismometers are deployed in some sites.

2.3 Dense seismometer array earthquake recording in various soil conditions of Sendai

We also installed seismographs in grounds. Eleven recording stations are deployed around Sendai area, Japan as shown in Fig. 11. The location and geology of observation sites are listed in Table 1. The recording stations were selected so that typical surface soil conditions of urban areas in Japan are contained. Sendai was severely damaged during the 1978 Miyagiken-oki earthquake. There is result of damage investigation. The damage distribution had clear correlation with the soil conditions. Therefore, we will get the difference of strong motion characteristics when large earthquake database is completed. Each station has three seismographs with three component sensors. They are installed from surface to so-called engineering bedrock. These records have provided data to evaluate the effect of surface geology on seismic motions. Unfortunately, earthquake data that are large enough to examine the effect of nonlinear behavior of soils are still very few in number.

This recording system had been operated as the cooperative research between BRI and the Association for Promotion of Building Research that represents the 16 private construction companies and a union of structural design firms. The cooperative work had finished in 1999. The strong motion records collected during the cooperative period were published as the general report including data CD-ROM from the association.

The earthquake recording is still ongoing. BRI maintains 6 recording sites. Tohoku University took over the maintenance of the five recording sites from the association.

3. CONCLUSIONS

The earthquake recording system currently maintained by BRI is introduced with some newly obtained data. The nationwide strong motion recording operated by Science and Technology Agency are mainly set up for ground behavior and does not assume some specific structures. The behavior of each structural system, such as building, bridge, dam, and port facilities is investigated by the organization with specific research objectives. A coordination may be necessary between such organizations with general and specific purposes for the efficient utilization of strong motion recording systems. In addition, the accumulation of the recorded motions with various classes of buildings including behavior not only for superstructure but also foundation and pile foundation as well as ground is our next issue to establish the advanced structural design schemes in the future.

4. REFERENCES

1) Building Research Institute, "Report on the Damage by 1978 Off-Miyagi Prefecture Earthquake" (in Japanese), Research Report of BRI, No.86, pp.75-81, 1978.
2) T. Kashima et al., “Strong-Motion Observation Program in the Metropolitan Area”, (in Japanese) Proceedings of the AIJ Annual Meeting, Vol.B-2, pp.275-276, Kinki, 1997
3) T. Kashima et al., “Earthquake Motion Observation in and around 8-Story SRC Building”, (in Japanese) Proceedings of the AIJ Annual Meeting, Vol.B-2, pp.213-214, Kyushu, 1998
4) I. Okawa et al., “Dense Array Observation and Analysis of Strong Ground Motions at Sites with Different Geological Conditions in Sendai”, BRI Research Paper 139, 1994

5) I. Okawa, et al., “Dense Instrumentation in BRI Building and Surrounding Ground”, Proceedings UJNR Workshop on Soil-Structure Interaction, Menlo Park, California, September 22-23, 1998
6) Building Research Institute, Japan Association for Building Research Promotion. “General Report of Sendai Dense Array Strong Motion Observation”, December 1999.

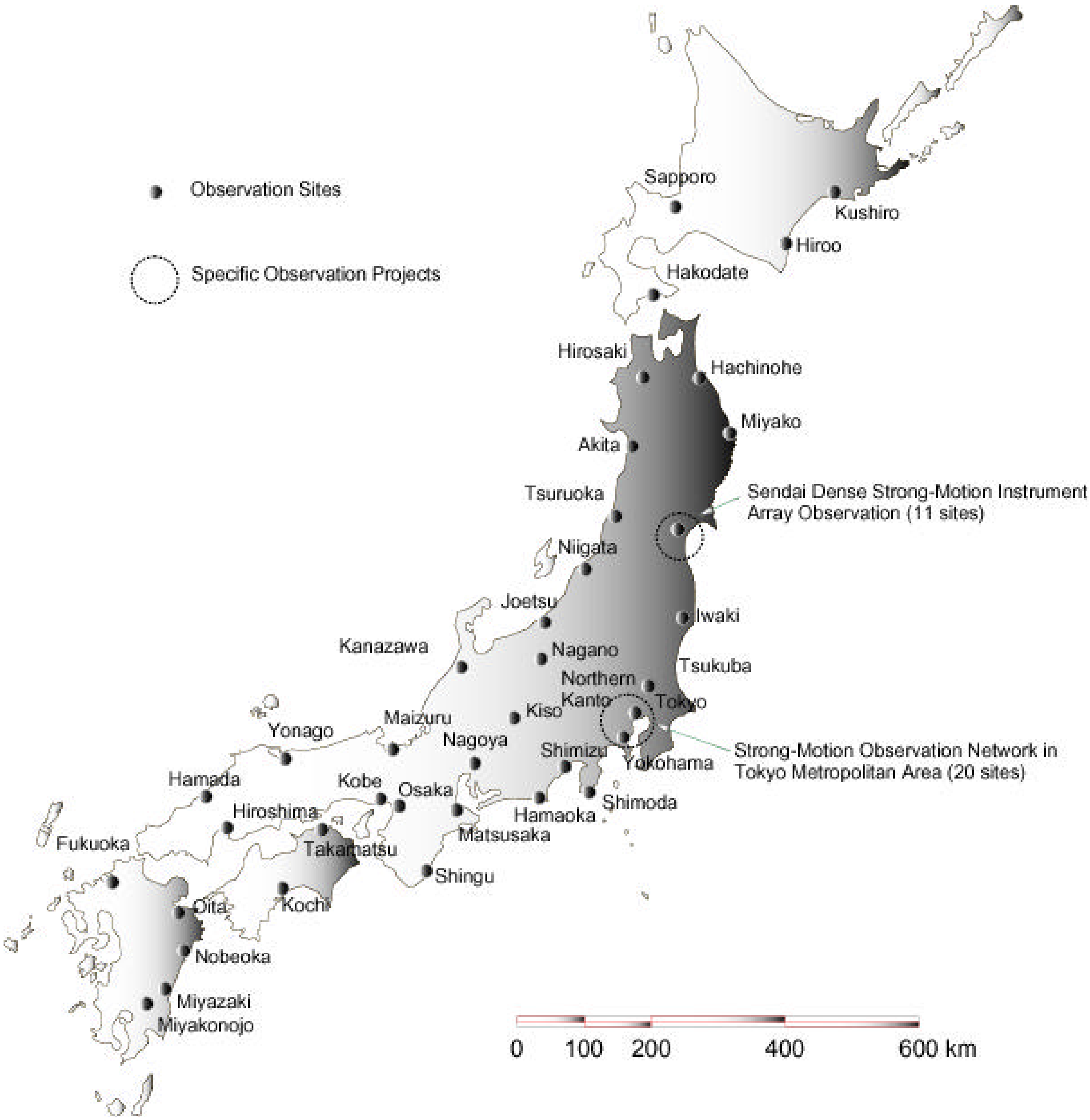


Figure 1 Locations of Strong Motion Observation Network of Building Research Institute

Table 1 Recording Sites of BRI Nationwide Strong Motion Observatio

Code	Name	Instrument	Structure	SensorPlaces
KGC	Kushiro Government Collective	SMAC-MDU	RC(BI)/B1F+9F+P1F	GL, G10, G34, B1F, 01F, 09I
HRO	Hiroo Town Office	SMAC-MD	RC/2F	01F
HKU	Hokkaido University	SMAC-MD		GL
HKD	Hakodate Development and Construction Department, Hokkaido Development Bureau	SMAC-MD		GL
HCN	Hachinohe City Hall	SMAC-MD	RC/B1F+6F+P1F	B1F, 06F
HCN2	Annex, Hachinohe City Hall	SMAC-MDU	SRC(BI)/B1F+10F+P1F	GL, G30, G105, 10F, 01F, PI
ATG	Atago Junior High School, Miyako	SMAC-MD	RC/2F	01F
AKT	Akita Prefectural Office	SMAC-MD	RC/B1F+6F+P3F	08F, B1F
THU	Tohoku University	SMAC-MD	SRC/9F	01F, 09F
SND	Sendai Government Collective Office	SMAC-MD	S/B2F+15F+P2F	B2F, 15F, G40
IWK	Iwaki City Hall	SMAC-MD	SRC/B1F+8F+P1F	B1F, 09F
MNM	Minamisuna Apartment #3	SMAC-MD	SRC?/14F+P3F	15F, 01F
CGC	Central Government Collective	SMAC-MD	S/B3F+20F+P1F	01F, 20B, 19C
OTM	Otemachi Government Collective Office #3	SMAC-MD	SRC+S/B3F+15F+P2	16F, B3F
BRI	Building Research Institute	SMAC-MD	RC/1F	01F
NIG	Niigata City Hall	SMAC-MD	RC/B1F+6F+P2F	B1F, 07F
JET	Joetsu Social Education Office	SMAC-MD	RC/2F	01F
NGN	Nagano Prefectural Office	KSG	?/B1F+10F+P2F	B1F
ISK	Ishikawa Prefectural Office	SMAC-MD	RC?/B2F+4F+P1F	05F, B2F
KSO	Kiso Office, Nagano Prefecture	KSG	RC/B1F+5F+P2F	B1F
SMS	Shimoda Office, Shizuoka Prefecture	SMAC-MD		GL
SMK	Shimoda-kita High School	SMAC-MD	RC/4F	01F
HMO	Hamaoka Nuclear Power Plant	SMAC-MD		GL
MTS	Matsusaka Office, Mie Prefecture	SMAC-MD	RC/6F+P1F	07F, 01F
SNG	Shingu City Hall	KSG	RC/B1F+4F+P1F	B1F
MIZ	Maizuru City Hall	KSG	RC/4F+P2F	01F, 05F
OSK	Osaka Government Collective Office	SMAC-MD	S/B3F+15F+P3F	18F, B3F
YNG	Yonago City Hall	SMAC-MD	RC/B1F+5F+P1F	B1F
HRS	Hiroshima Government Collective Office #2	SMAC-MD	SRC/B1+11F+P2F	B1F, 11F
HMD	Hamada Office, Shimane Prefecture	SMAC-MD	RC/3F+B1F	01F
KCK	Kouchi Work Office, Shikoku Regional Construction Bureau	KSG	RC/4F	01F, 04F
MYZ	Miyazaki Prefectural Office	SMAC-MD	SRC/B1F+9F+P1F	01F, 09F
OIT	Oita City Hall	SMAC-MD	SRC?/B2F+9F+P1F	01F, 09F
NBO	Nobeoka Office, Miyazaki Prefecture	KSG	RC/3F+P1F	01F, 04F
MYK	Miyakonojo Office, Miyazaki	KSG	RC/B1F+3F+P2	B1F
YKH	Yokohama Government Collective Office #2	SMAC-MD	S/B3F+22F+P2F	23F, B2F
HRH	Hirosaki Legal Affairs Office	SMAC-MDU	RC/3F	01F
TRO	Tsuruoka Government Collective Offic	SMAC-MDU	RC/4F+B1F	01F, 04F
SMZ	Shimizu Government Collective Office	SMAC-MDU	SRC/6F	01F, 06F
NGY	Nagoya Government Collective Office	SMAC-MDU	SRC/11F+B2F	GL, B2F, 12F
TKM	Takamatsu Regional Taxation Bureau	SMAC-MDU	SRC/8F+B1F	GL, B1F, 09F
FKO	Fukuoka Government Collective Offic	SMAC-MDU	SRC/10+B1	GL, B1F, 10F
NMW	National Museum of Western Art	SMAC-MDU	RC(BI)/B1F+3F	GL, PITE, PITW, 01FE, 01F
SGS	Sengen Shrine	SMAC-MDU		GL
KYM	Kiyomuzuyama Park	SMAC-MD2		01F
KSG	Koshigaya Branch, Urawa Legal Affairs Bureau	SMAC-MDU		1F, 1F[V]
ANX	Annex, Building Research Institute	AJE-8200	SRC/8F+B1F	A01, A14, A43, A89, N14, B C01, BFE, BFN, BFS, 1FE, 2FE, 2FW, 5FE, 5FW, 8FE, 8 8FS, MBC, M5C, M8C, M8E

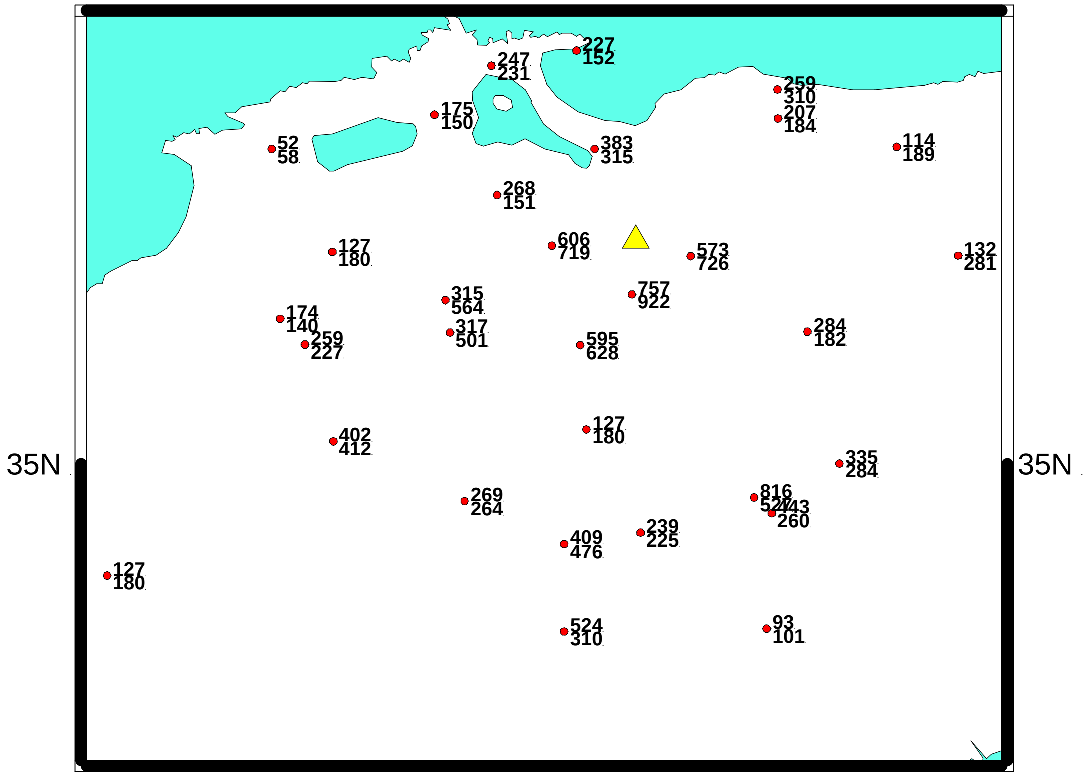


Figure 2 Horizontal Peak Acceleration for 2000.10.6 Tottori-ken-Seibu Earthquake (after K-net, KiKnet, NIED, STA)

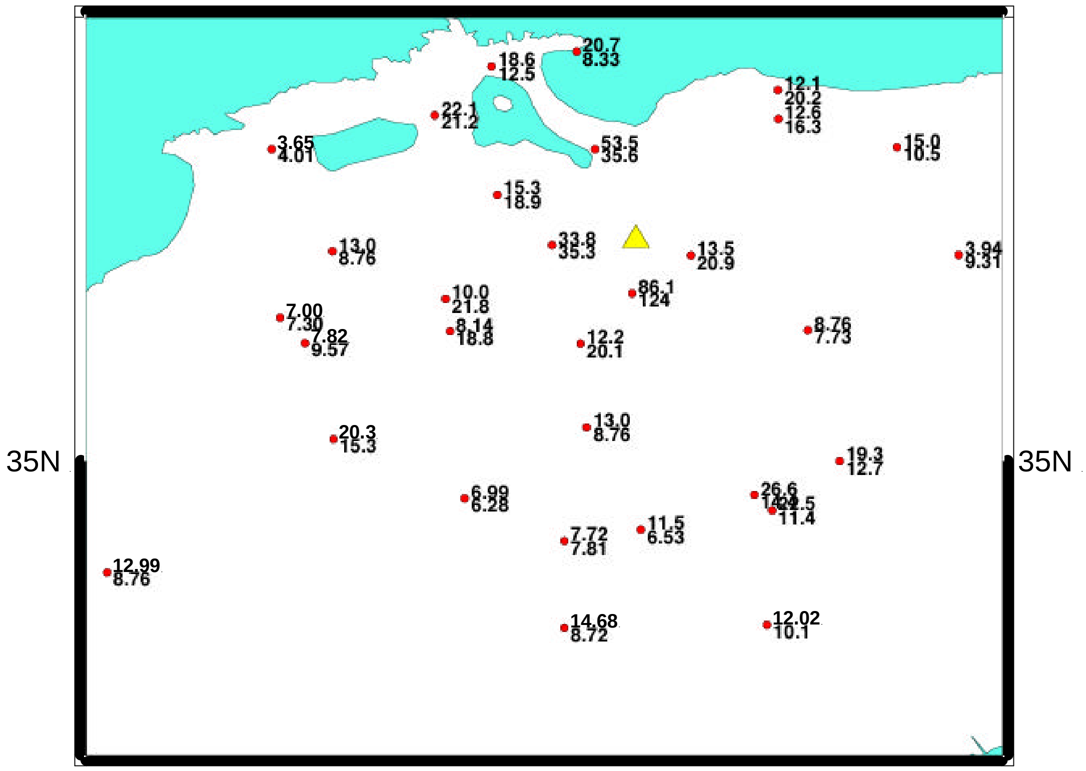


Figure 3 Horizontal Peak Velocity for 2000.10.6 Tottori-ken-Seibu Earthquake (after K-net, KiKnet, NIED, STA)

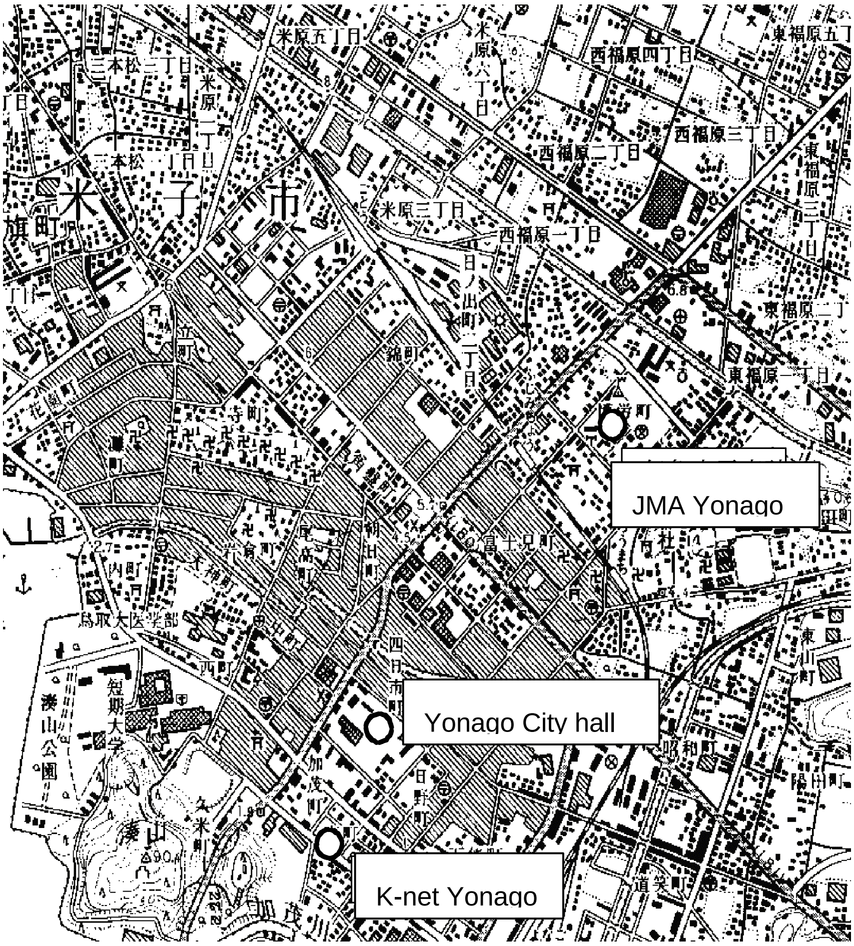
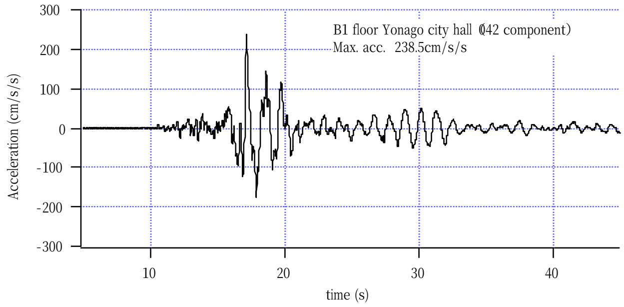


Figure 4 Three Strong Motion Observation Sites in Yonago city

Photo 1 Yonago city hall building



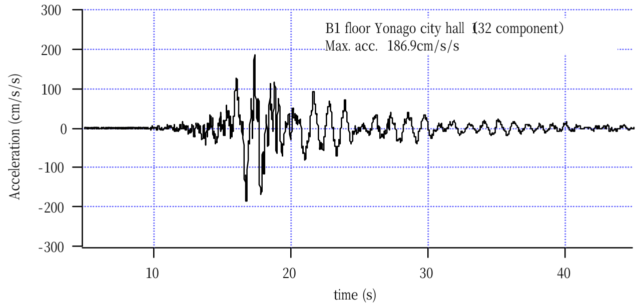


Figure 5 Recorded motion at the basement of Yonago city hall

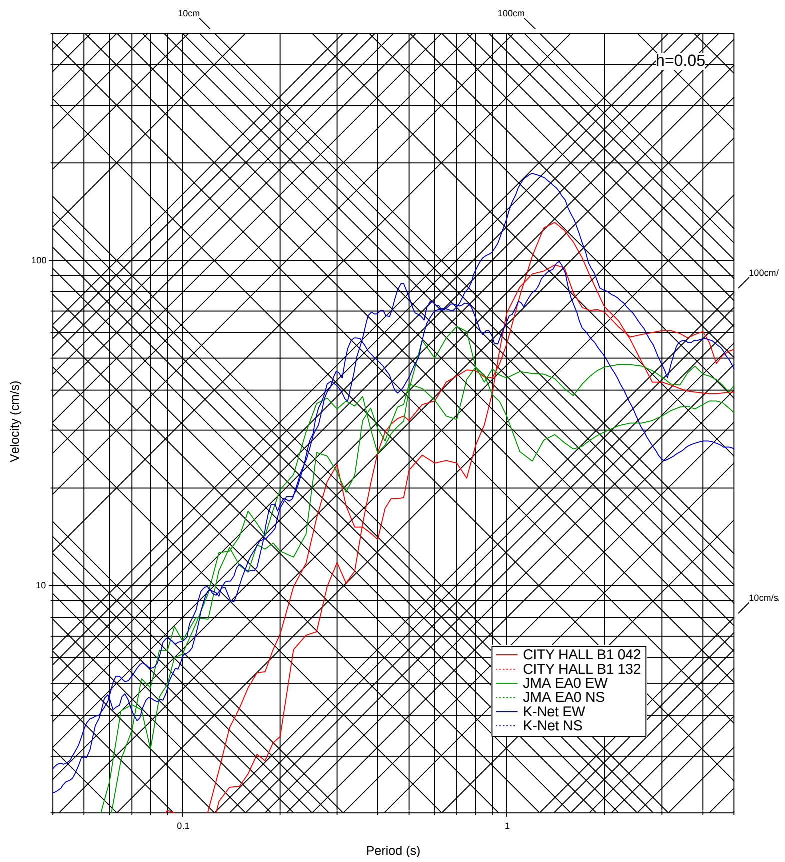


Figure 6 Comparison of Acceleration response spectra for three recording sites

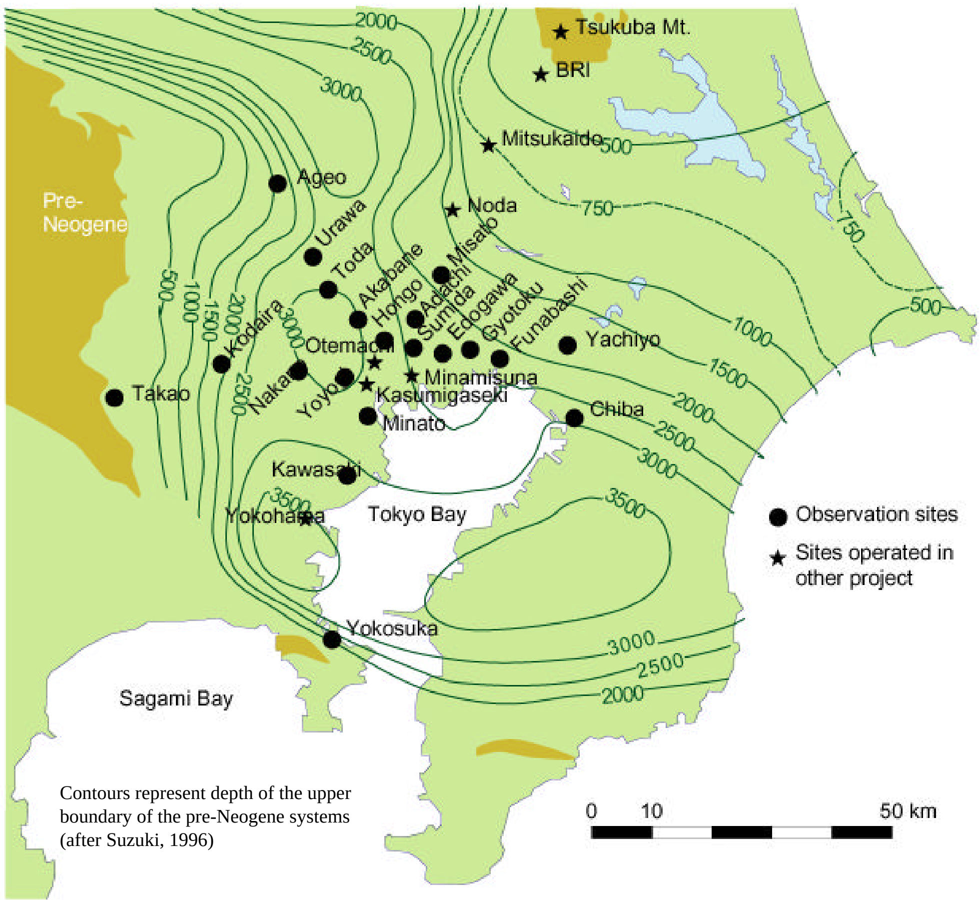


Figure 7 Strong Motion Instrument Network in Tokyo Metropolitan Area

Table 2 Recording Sites of BRI Tokyo Metropolitan Network

Code	Name	Instrument	Structure	SensorPlaces
SMD	Sumida Ward Office	KSG	B2F+19F+P1F	P1F, B1F, 08F
EDG	Edogawa Ward Office	KSG	B1F+5F+P1F	05F, 01F
ICK	Gyotoku Library, Ichikawa City	KSG	6F+P1F	01F, 02F, 05F
FNB	Educational Center, Funabashi City	KSG	8F+P1F	01F, 08F, GL
YCY	Yachiyo City Hall	KSG	B1F+6F+P2F	B1F, P1F, GL
CHB	Chiba Government Collective Office #2	KSG	B1F+8F+P1F	B1F, 08F, GL
ADC	Adachi Government Collective Office	KSG	B1F+5F	01F, 04F
MST	Misato City Hall	KSG	B1F+7F	01F, 07F, GL
UTK	University of Tokyo	KSG	9F	07F, 07F, 01F, GL
AKB	Akabane Hall, Kita Ward	KSG	B2F+7F	B1F, 06F
TDS	Toda City Hall	KSG	B1F+8F+P2F	B1F, 08F, GL
AGO	Ageo City Hall	KSG	B1F+7F	07F, 07F, B1F
YYG	National Olympics Memorial Youth Center	KSG	4F	B1F, 04F, GL
NKN	Nakano Branch, Tokyo Legal Affairs Bureau	KSG	5F+P1F	P1F, 01F
KDI	Construction College, Ministrry of Contsruction	KSG		01F
TKO	Takao Natural Museum	KSG	3F	GL
TUF	Tokyo University of Fisheries	KSG	7F+P1F	01F, 07F, GL
KWS	Bureau	KSG	7F	01F, 02F, 07F

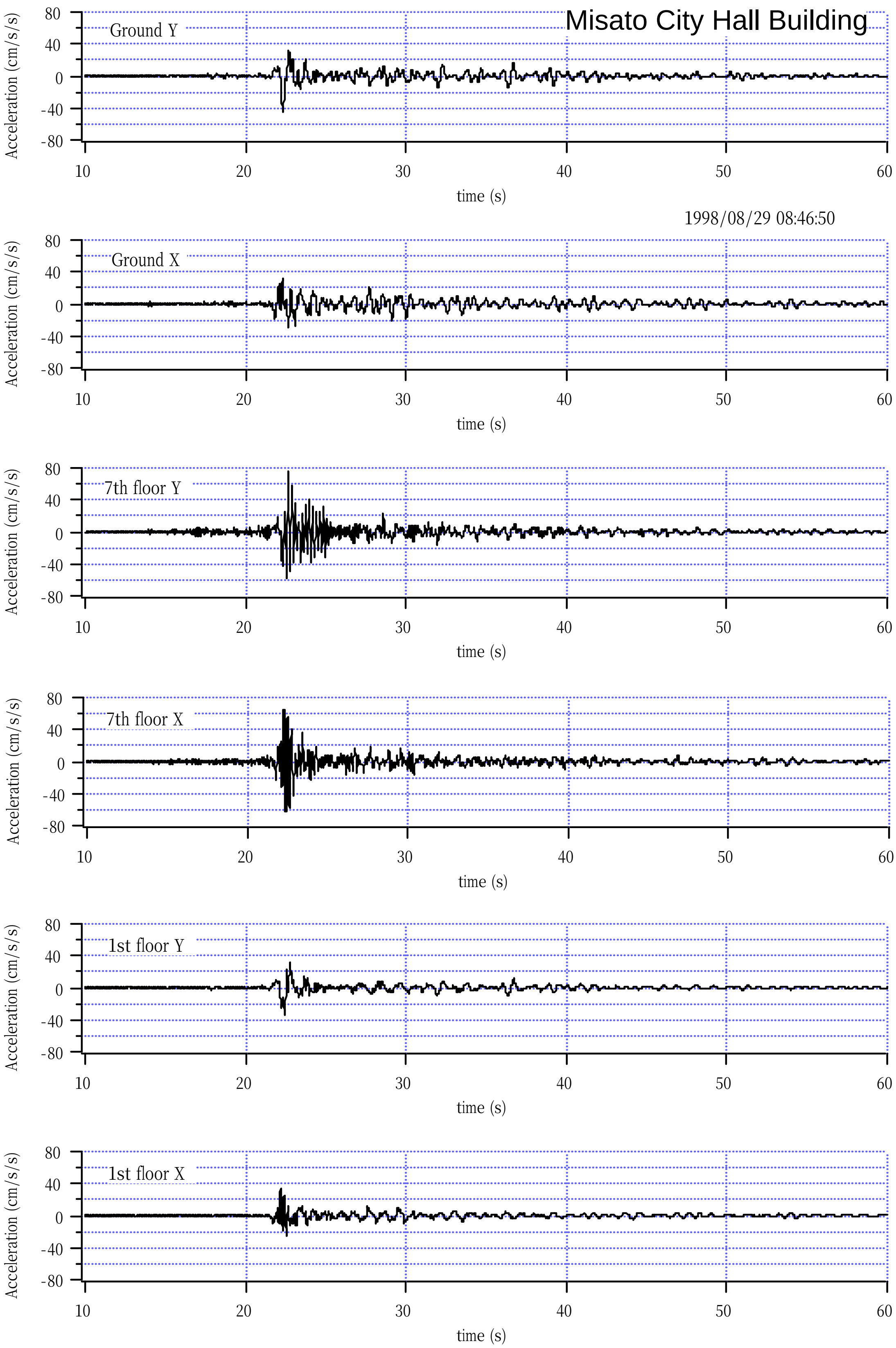
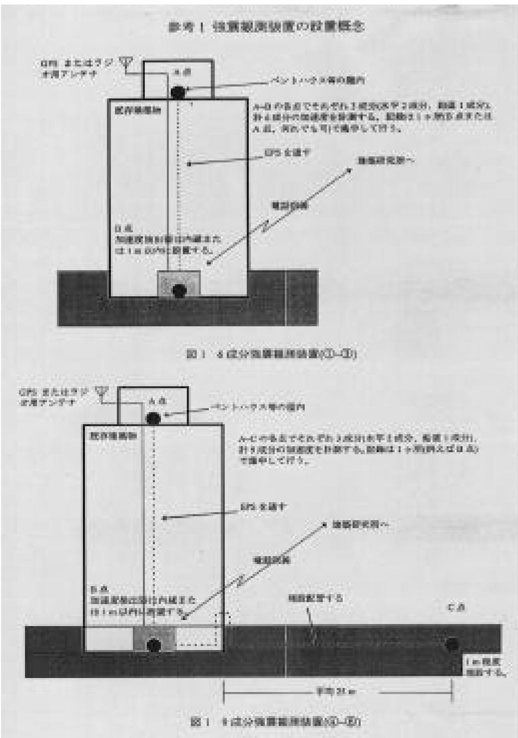


Figure 8 Recorded motion for Misato city hall



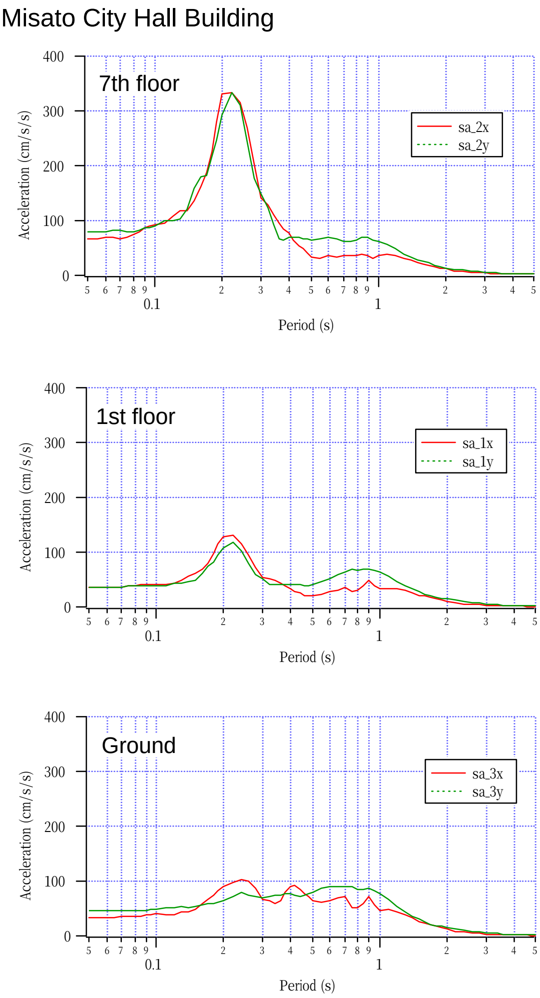


Figure 9 Installation of Seismometers

Figure 10 Response spectra for recorded horizontal motions

Photo 2 Misato city hall building

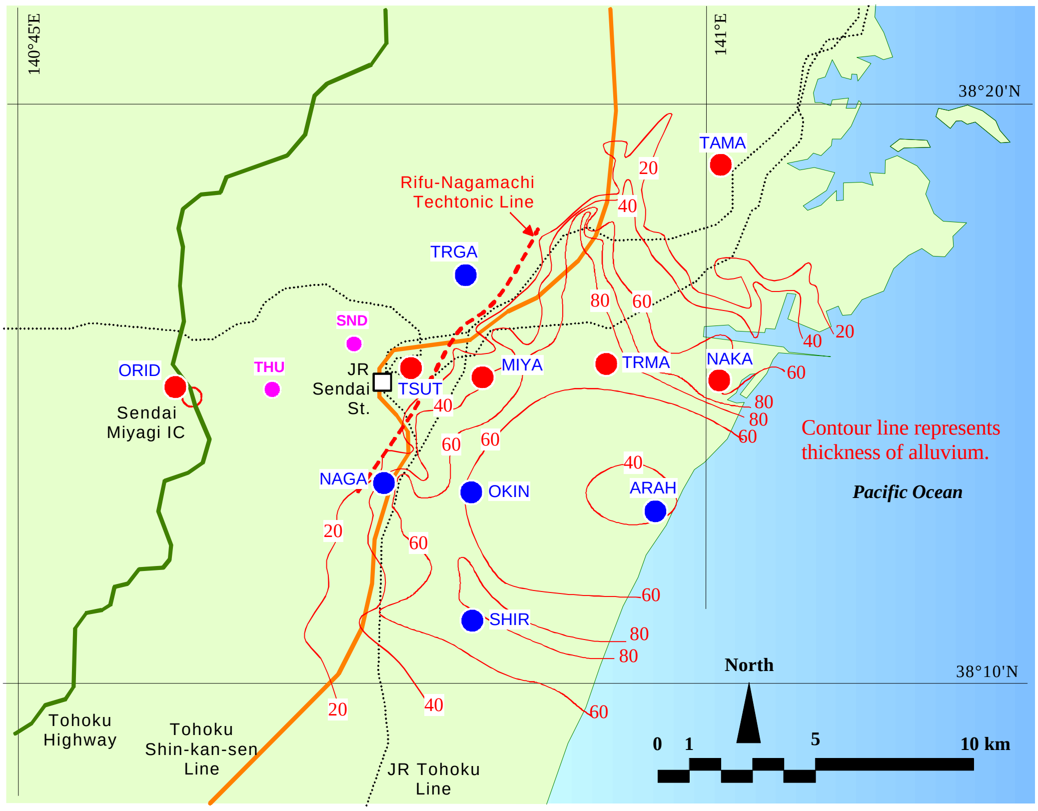


Figure 11 Recording sites of Sendai dense seismometer arrays

Table 3 Various parameters of recording sites

Site name	Abr.	Lat.	Lon.	Soil	Installed	Depth (m)		
Miyagino	MIYA	38-15'24"N	140-55'16"E	2	1984	1	22	54
Nakano	NAKA	38-15'14"N	141-00'26"E	3	1985	1	30	61
Tamagawa	TAMA	38-19'03"N	141-00'34"E	1	1986	2	11	33
Oridate	ORID	38-15'26"N	140-48'39"E	1*	1987	1	57	76
Tsutsujigaoka	TSUT	38-15'30"N	140-53'36"E	2	1988	1	36	59
Okino	OKIN	38-13'26"N	140-55'05"E	3	1988	1	17	62
Tsurumaki	TRMA	38-15'38"N	140-58'15"E	3	1988	1	25	79
Tsurugaya	TRGA	38-17'16"N	140-54'53"E	2	1988	2	37	62
Shiromaru	SHIR	38-11'29"N	140-54'53"E	2	1988	1	20	76
Nagamachi	NAGA	38-13'45"N	140-53'01"E	2	1989	1	29	81
Arahama	ARAH	38-13'11"N	140-59'00"E	3	1989	1	31	76

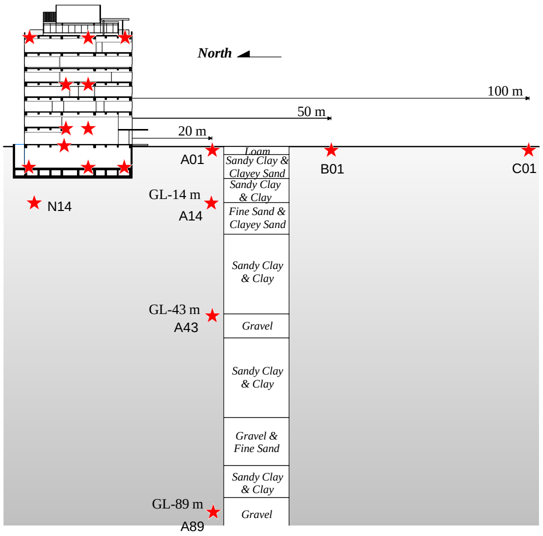


Figure 12 Cross-sectional configuration of recording points for dense instrument array in the Building Research Institute Campus, Tsukuba