RESPONSE CHARACTERISTICS OF SOIL AND STRUCTURES OBTAINED FROM OBSERVATION NETWORKS

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SUMMARY

After the 1995 Hyogoken-Nanbu Earthquake, observation network has been developed in and surrounding Kyoto City, Japan. Total 132 channels at ten observation places distributed at each wards and additional seven places such as the campus of Disaster Prevention Research Institute, Kyoto University (DPRI), rock site along Uji River close to DPRI and so on. are measured simultaneously, covered by the response of building structures as well as deep soil. Network in Hikone, Shiga was also arranged at the building of the University of Shiga Prefecture (USP) and -100m, -30m and surface layer close to the building. Additional observation place was set in 1998, at the surface of hard soil, 3km west from USP.

Five records obtained from Kyoto network are used for clarification of the effect of ground motion on the response of 7-story building and the site effect due to near field earthquakes and far field earthquakes. Some records obtained from Shiga network are also used for analysis of soil characteristics in Shiga area. Those data can be used in damage estimation of that region. Response of building structure subjected to the far field earthquake is predominant in first mode, while response due to near field is predominant in higher mode. Transfer function of surface strata in each site changes corresponding to the characteristics of soil strata. All most all observation sites at hard layer behave similarly due to far field earthquake.

INTRODUCTION

It already passed four and a half years since Hyogoken-Nanbu Earthquake occurred in 1995. Many earthquake records were obtained in and around Kobe City [1)], but there is few systematic network before the earthquake. After the earthquake, Japan Meteorological Agency 2 distributed a thousand of seismic intensity meters around our country[)]. Professor Kikuchi supports risk assessment in Yokohama and organized seismic networks with 100 stations [3)]. Those networks are mostly composed of system measured at surface soil.

One of the observation networks explained here is composed of 3-dimensional array distributed in each ward of Kyoto city by the effort of Disaster Prevention Research Institute (DPRI), Kyoto University, where is 15 km far from Kyoto city. This observation network is used for quick emergency responses by Disaster Prevention Bureau of Kyoto (DPB) as well as for fundamental research on the amplification of soil condition, responses of building structures, development of new method for prediction and mitigation of seismic risk and so on. The other network is spread at a building of the University of Shiga Prefecture (USP) and deep soil near the building, and surrounding Lake Biwa. Figure 1 shows the map including Kyoto and Shiga Prefectures as well as epicenters of the earthquakes analysed in this paper. Here, those observation networks are introduced and some of the analytical results of obtained data are presented.

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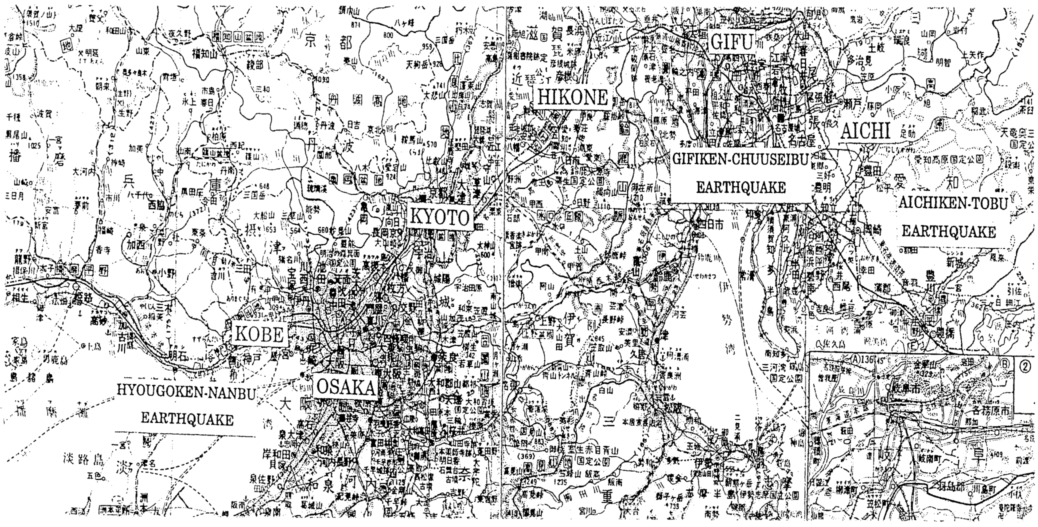
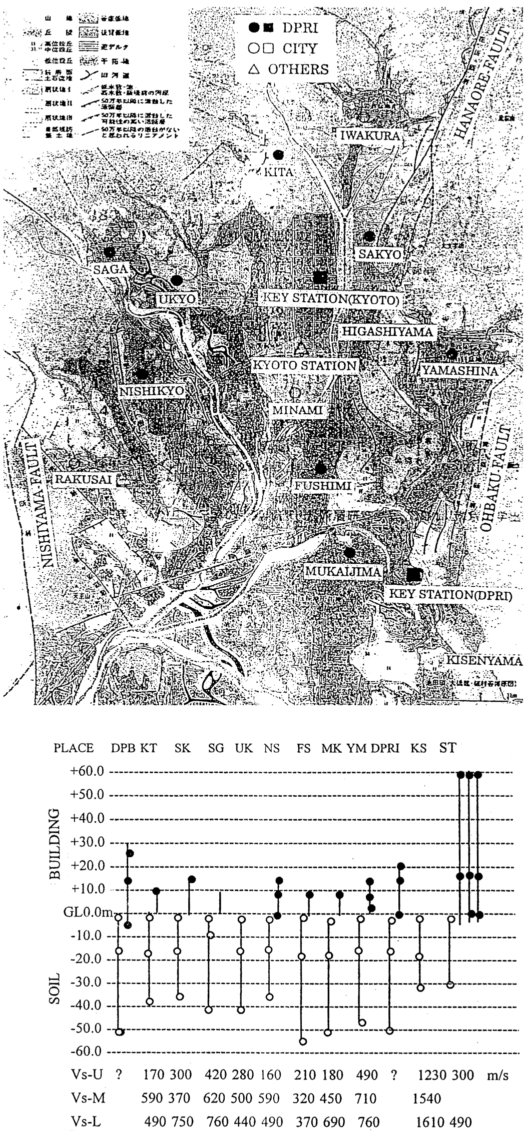


Fig.1 Map of Kansai area including Kyoto and Shiga Prefectures



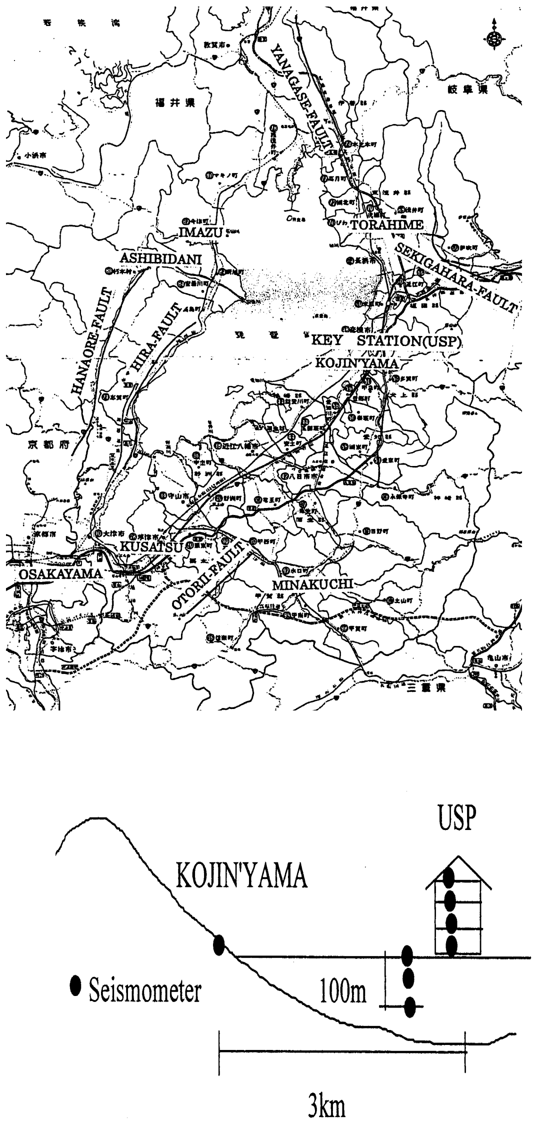


Fig. 2 Observation network and vertical array in Kyoto

Fig. 3 Observation network in Shiga

OBSERVATION NETWORKS

Network in Kyoto City   Observation network has been developed in and around Kyoto city. Total 132 channels at ten observation points were distributed at each wards named Kita (KT), Sakyo (SK), Yamashina (YS), Ukyo (UK), Nishikyo (NK), Saga (SG), Fushimi (FS), Mukaijima (MK) from the north point of the city and at the building of Disaster Prevention Bureau (DPB) of Kyoto city, which are covered not only by the responses of building structures but by the surface soil, -50m and -30m soil responses, and Kisen'yama (KS), rock site along Uji River, where is a referential point of this network. Additional four points (Iwakura (IK), Higashiyama (HG), Minami (MN), Rakusai (RK)) measured on the surface soil cooperated with Kyoto city municipal office and two points, Uji campus of Kyoto Univ. (DPRI), Kyoto station (ST), measured at the building and under ground are also under recording simultaneously. Those data are transmitted to key stations of Disaster Prevention Research Institute, Kyoto University (DPRI) and Disaster Prevention Bureau of Kyoto Municipal Office (DPB). Figure 2 shows the observation points in Kyoto as well as areas of some active faults along skirts of mountain. Hanaore-Fault in northeastern part, Nishiyama-Fault in western part and Obaku-Fault in southeastern part are estimated to be dangerous for Kyoto. Vertical array of this network and shear velocity of those points are also shown in Fig.2. Soil condition of Kyoto basin is formed by hard soil in northern region and soft in southern region.

Dynamic characteristics of surface soil at each observation point are shown later [4].

Network in Shiga Prefecture   Shiga Prefecture is located to the adjacent prefecture from Kyoto. Network in Shiga Prefecture has been also arranged at each story of the 3-story school building and at -100m, -30m and surface soil layer near the building of the University of Shiga Prefecture (USP) from 1994 [5], where soil condition is very soft and friction piles were used for the foundation of the building. Additional place measuring at rock site, skirt of MT. Kojin'yama, where was 3 km far from the campus was prepared in 1998, measured data of which was automatically sent to the USP. Other six observation places (Torahime, Imazu, Ashibidani, Osakayama, Kusatsu, Minakuchi) in Shiga Prefecture around Lake Biwa are under recording by the effort of Disaster Prevention Bureau of Shiga Prefecture (DPBS) and Prof. Matsunami, DPRI, Kyoto Univ. [6]. Those data are available for us to use the prediction and mitigation of earthquake risk in Shiga Prefecture.

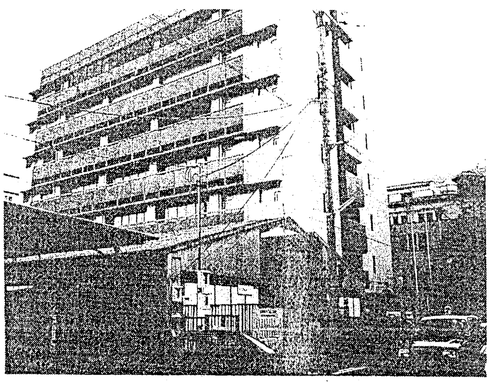
Figure 3 shows the observation points in Shiga as well as some active faults around Lake Biwa. In Shiga Prefecture, Hanaore-Fault in western part, Yanagase-Fault in northern part and Sekigahara-Fault in eastern part are careful for earthquake disaster. Section of the building measured in the Univ. of Shiga Pref. and schematic observation system including Mt. Kojin'yama site are shown in this figure.

We are now planning to systemize those two networks for earthquake risk analysis in Kyoto and Shiga.

CHARACTERISTICS OF BUILDING OBSERVED

Dynamic characteristics of typical buildings of those observation points are briefly explained in this section [7].

Building of the Disaster Prevention Bureau in Kyoto   Figure 4 shows bird-eye-view of DPB building. This building is located at the center of Kyoto city and is 8-story steel composite structure, designed by larger value



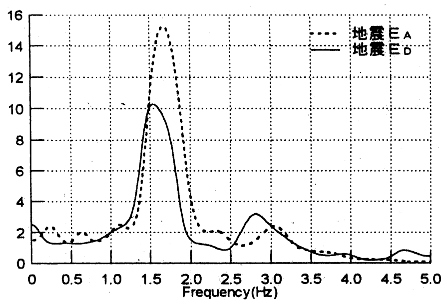


Fig. 4 Bird-eye-view and transfer function of Disaster Prevention Bureau in Kyoto

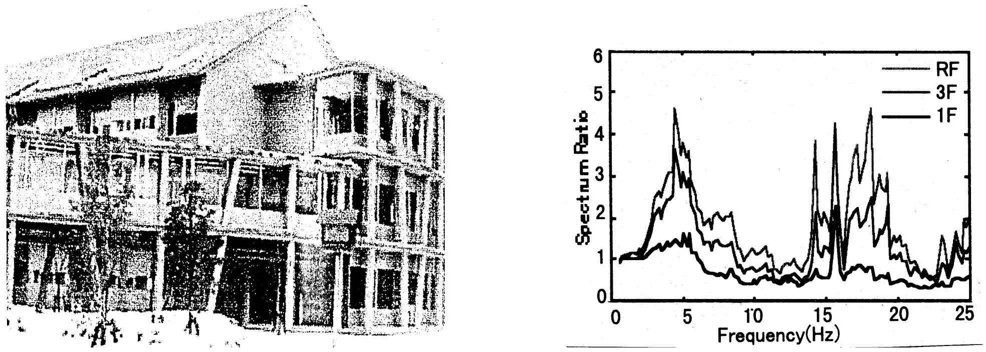


Fig. 5 Bird-eye-view and transfer function of the Univ. of Shiga Prefecture

of base shear coefficient than ordinary buildings because of use in emergency. Fundamental frequency of this building is 1.51 Hz. in NS- and 1.41 Hz. in EW- component estimated from transfer function of observed data as shown in the right side of Fig.4. Predominant frequency of surface layer observed is about 6 Hz. Comparing the predominant frequencies of surface layer observed with other observation points in Kyoto [4)], soil condition of DPB is estimated to be rather hard.

Building of the University of Shiga Prefecture Figure 5 shows 3-story reinforced concrete building in our campus (USP), where accelerometers are set at each floor. From the micro-tremor measurement of this building, fundamental frequency of this building is estimated to be 4.9 Hz in long direction and 3.8 Hz in short direction. Predominant frequency of surface soil is lower than the frequency of upper structure because of soft soil [8)].

Other buildings measured Buildings in each ward are used for the fire station and mostly 2- or 3-story reinforced concrete structures, fundamental frequency of which is approximately similar to that of USP. New building of Kyoto Station with height of 60m, width of 400m was constructed in 1996 after the Hyogoken-Nanbu Earthquake. We have 24 channel of accelerometer on some floor and in deep soil. Fundamental periods of this building are 1.09, 0.88 sec. in NS and 0.88 sec. in EW related to the wings of different use [9)]. Building of key station, DPRI, in Uji is 5-story steel structure was constructed for the purpose of dynamic test of full size building. The dynamic characteristics of the structure are precisely measured and analysed [10)].

SOIL CONDITION AT OBSERVATION AREAS

Movement of faults formed soil condition at observation area in Kyoto basin. Northern half of Kyoto City is layered by mountain, hill and terrace (KT, SK, SG). Katsura River from northwest and Kamo River from northeast flow into the central area and go through Osaka Bay connected with Uji River and Kizu River in southern part of the city. Therefore, soil profile is more and more soft in south area of the city (FS, MK). Uji campus of Kyoto Univ. (DPRI) is on the riverbed of Uji River and Kisen'yama station is rock site. Shear velocities of soil layer at each observation point are shown in Fig.2.

Shiga Prefecture is also surrounded by mountains and biggest lake Biwa in Japan is located on the center of the Prefecture. Alluvium strata spreads along Biwa Lake with depth of mostly less than 15m, especially deep in south-eastern area such as USP, Hikone, where many rivers pour into the Lake [5, 11)]. There are three points in Hikone, measured. Depth of alluvium at the site of USP is very deep more than 25m. While the site measured by AMJ named Hikone is about the depth of 9m, where is 2 km far from USP. Ground motions at those two places are quite different as shown bellow.

EARTHQUAKE RESPONSE OF SOIL AND STRUCTURES

From May 1996 to Jan. 1998, 15 earthquake records were obtained at DPB and other places in Kyoto. From those records, four earthquakes (EA: 1996.7.18 M=4.0, EB: 1996.5.29 M=3.8, EC: 1997.2.24 M=3.4, ED: 1997.3.16 M=5.6) are analysed here, in which EA, EB, EC earthquakes occurred around Kyoto City and ED earthquake occurred about 90 km far from Kyoto in eastern Aichi Prefecture. Figure 6 shows Fourier spectrum of surface soil at DPB subjected to EA, EB, EC and ED. Predominant frequency of far field earthquake ED is very sharp about 1-1.5 Hz and lower than that of near field earthquake about 4 -10 Hz. Figure 7 shows Fourier spectrum of deep soil at DPB subjected to earthquake EA and earthquake ED. Spectrum of near field earthquake is flat in wide range. However, spectral ratio of surface to deep soil, that is, transfer function of surface soil subjected to near field earthquake is quite similar to far field earthquake as shown in the right side of the figure,

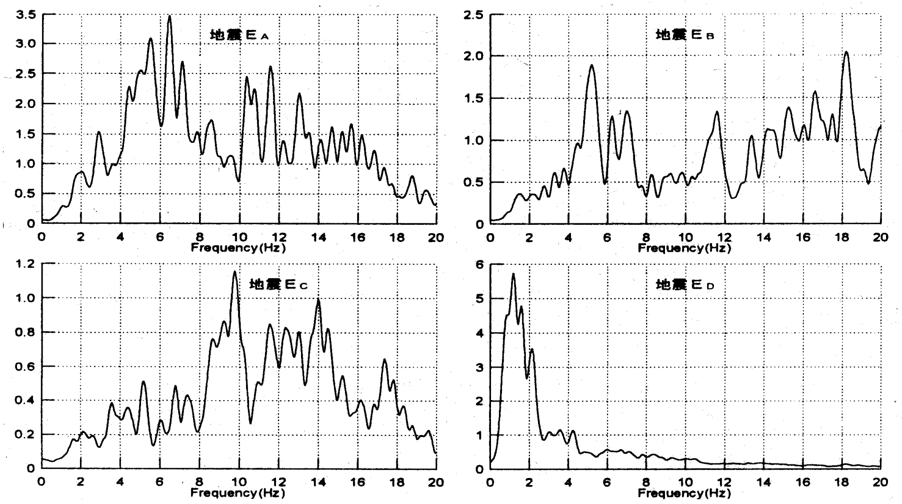


Fig. 6 Fourier spectra of surface soil at DPB due to near field- (EA, EB, EC) and far field- (ED) earthquake

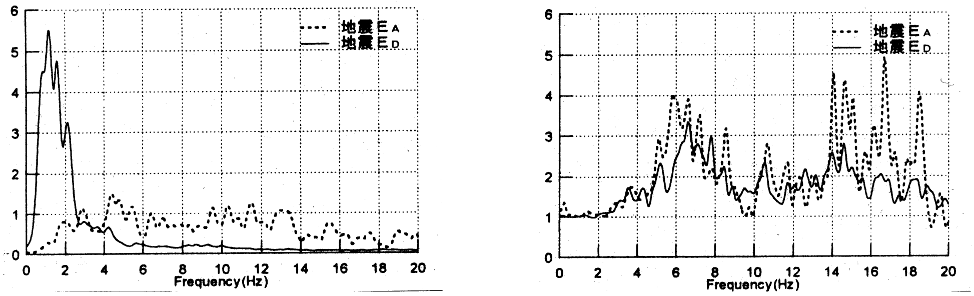


Fig. 7 Spectrum of deep and Spectral ratio of surface to deep soil at DPB due to EA and ED earthquake

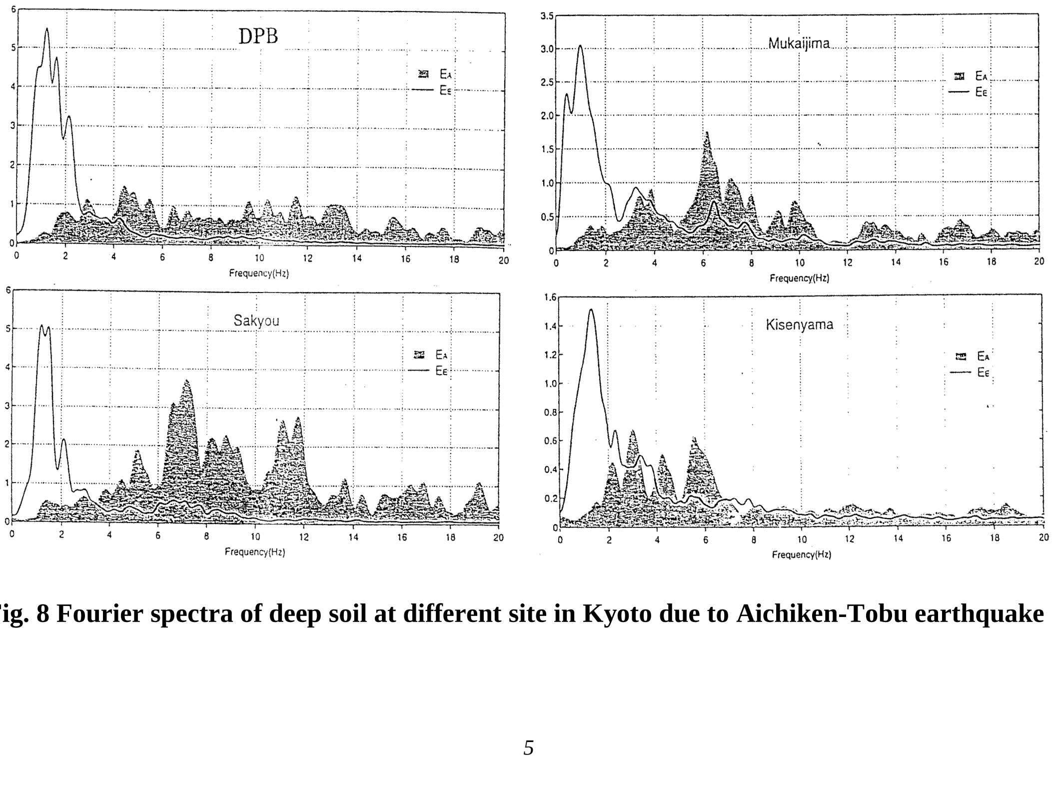


Fig. 8 Fourier spectra of deep soil at different site in Kyoto due to Aichiken-Tobu earthquake

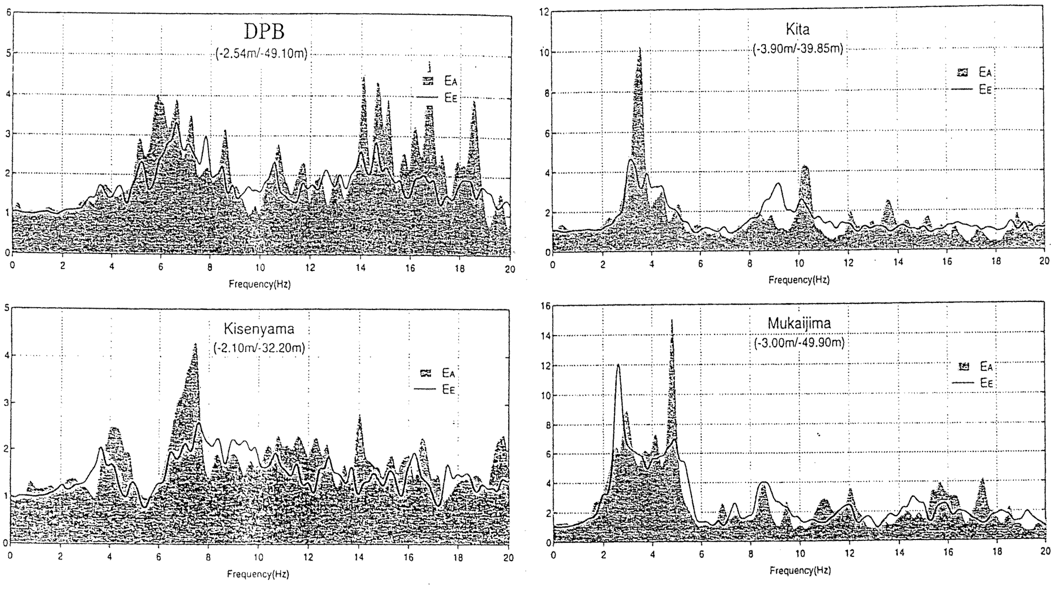


Fig. 9 Transfer function of surface to deep soil at different due to Aichiken-Tobu earthquake

predominant frequency of which is 5-6 Hz and likes that of hard soil of Kisen'yama (KS) site as shown in Fig. 9. Fundamental frequency of this building (DPB) is about 1.6-1.7 Hz as shown in former section and higher mode response is amplified by near field earthquake [4)]. Frequency characteristics of deep soil at other sites in Kyoto subjected to Aichiken -Tobu Earthquake (ED) are quite similar to each other because of similar distance and similar direction from epicenter as shown in solid line of Fig. 8 and spectrum due to near field earthquake depends on the peculiar soil condition as shown in black area of Fig. 8. Therefore, responses of surface soil depend on the transfer function of surface soil and characteristics of input motion. Figure 9 shows spectral ratio of surface to deep soil in different sites in Kyoto due to Earthquake EA and ED. Predominant frequency at Mukaijima (MK) is smaller than that of DPB because of soft layer.

Following results are obtained from the record of Gifuken-Chuseibu Earthquake (M=5.6) occurred in April 22, 1998. The University of Shiga Prefecture is 40 km far from the epicenter and Kyoto city is about 80 km from there. Seismic intensity in Gifu Prefecture and Eigenji close to USP was IV in JMA Scale. Maximum accelerations of deep soil, surface soil and top of building at different sites subjected to the earthquake are compared in Table 1. Acceleration responses at deep soil of USP are smaller than that at Sakyo (SK), Mukaijima (MK) and Yamashina (YM) in Kyoto, in spite of close distance from the epicenter but larger than at Kisen'yama (KS). It may be estimated that responses at deep soil of MK and YM are amplified by underneath soil condition.

There are six records after 1997 at the sites of USP, Hikone 2km south-east from USP and Kojin'yama (KOJ) 3km west from USP. Three sites are very close comparing the epicentral distance. Earthquakes were occurred at Aichiken-Tobu (97.3.16 M=5.6), Enshu-nada (97.5.24 M=5.6), Gifu-Chuseibu (98.4.22 M=5.2), Kyoto-Nanbu (99.2.12 M=4.0), Mieken-Chubu (99.2.18 M=3.9) and Shigaken-Hokubu (99.3.16 M=5.1), respectively. Epicenter of Shigaken-Hokubu Earthquake is close to Hikone. Kyoto-Nanbu Quake is 40 km west from Hikone and others are about 50-70 km east from Hikone. Table 2 shows maximum acceleration at surface soil of three points. Maximum value at USP is rather smaller than Hikone, inspite of deep alluvium. Fourier spectra of acceleration of surface soil recorded at Hikone (HKN), USP and Kojin'yama (KOJ) are shown subjected to Gifu-Chuseibu Earthquake (98.4.22 M=5.2) in upper part and Shigaken-Hokubu Earthquake (99.3.16 M=5.1) in lower part of Fig.10. Low frequency is predominant in three point subjected to far field earthquake and power of high frequency more than 2 Hz is larger in Hikone than in USP. That means soil condition at Hikone is rather stiff comparing to that in USP.

Figures 11 and 12 show spectra of deep soil and transfer function of surface soil to deep soil at USP, Mukaijima (MK) and Kisen'yama (KS) subjected to Gifuken-Chuseibu Earthquake. Spectrum at deep soil of USP is quite similar to response at Kisen'yama, which mostly depends on the source mechanism and on the pass profile. Dynamic characteristics of surface soil depend on the regional condition of soil profile and geology. It must be necessary to analyse more data obtained by those networks in near future to make clear the effects of source mechanism and amplification at each site on the responses of surface soil.

CONCLUSIONS

Observation networks in Kyoto and Shiga were introduced and results of responses of buildings as well as soil structures are discussed. Following remarks were obtained from this research:

1) Three dimensional strong motion observation networks in Kyoto and Shiga are effective to estimate the responses of surface ground and deep soil as well as building structures in wide area. The results obtained by those networks can be used not only for investigation on the ground motion in different soil condition and for seismic risk assessment in urban region but also for emergency response by Disaster Prevention Bureau as real time information.

2) Responses of buildings depend on the frequency characteristics of input motion and transfer function of building structures. We must investigate the reason of different amplification on similar distance from epicenter in detail, if it depends on the dynamic characteristics of surface layer or not.

3) Near field earthquake sometime magnify the higher mode response for high-rise buildings. In order to estimate the earthquake damage in urban region, it is necessary to predict the responses of different types of building structures not only due to far field earthquakes but due to near field earthquakes.

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Table 1 Maximum acceleration at Shiga and Kyoto due to Gifu Earthquake

PLACE	DIR	USP	SK	YM	MK	KS
ROOF	NS	20.2	28.9	53.8	48.5	-
	EW	19.2	22.3	30.1	46.9	-
SURFACE SOIL	NS	10.9	11.1	13.5	16.9	4.8
	EW	14.9	11.9	14.6	15.8	3.6
DEEP SOIL	NS	4.9	5.7	8.7	7.1	2.6
	EW	4.9	9.4	8.0	7.2	2.6

USP: Univ. of Shiga Prefecture, SK: Sakyo, YM: Yamashina, MK: Mukaijima, KS: Kisen'yama

Table 2 Maximum acceleration around USP due to six earthquakes

PLACE	DIR	97.3.16	97.5.24	98.4.22	99.2.18	99.2.18	99.3.16
USP	NS	16	3	11	2	2	20
	EW	13	3	15	2	2	22
HIKONE	NS	24	2	67	3	9	29
	EW	26	2	41	3	10	58
KOJ	NS	–	–	–	–	3	20
	EW	–	–	–	–	4	24

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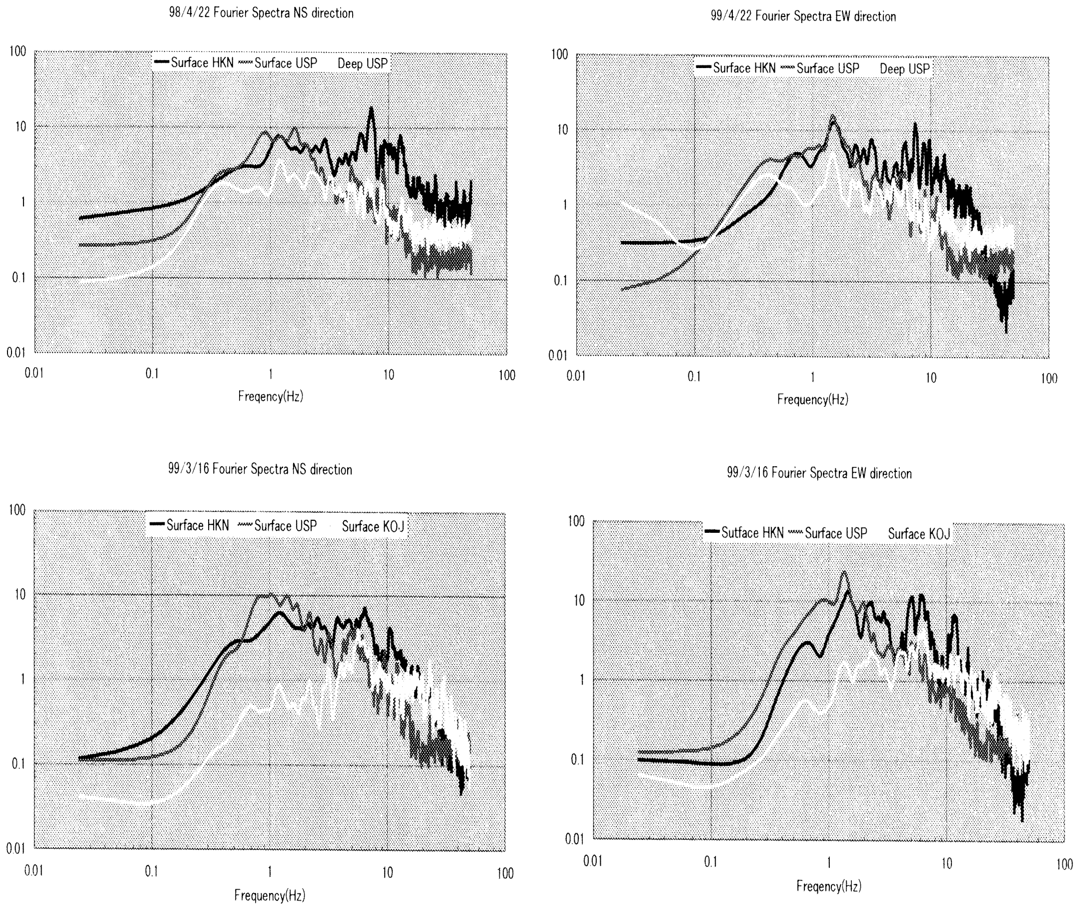

Fig. 10 Fourier Spectra of acceleration of surface soil recorded at Hikone, USP and Kojin'yama subjected to Gifu-Chuseibu Earthquake (98.4.22 M=5.2) and Shigaken-Hokubu Earthquake (99.3.16 M=5.1)

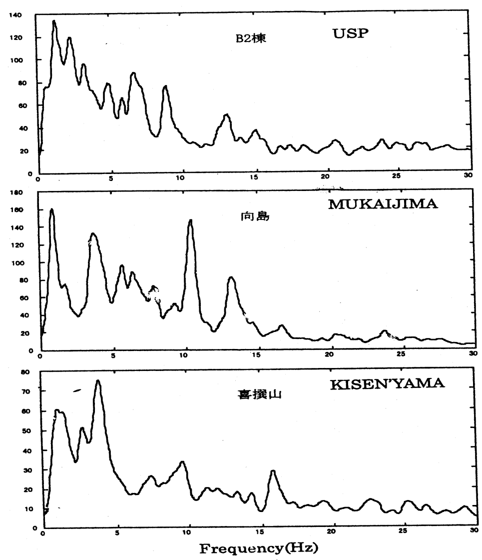

Fig. 11 Fourier spectra of deep soil in Kyoto and Shiga due to Gifuken-Chuseibu earthquake

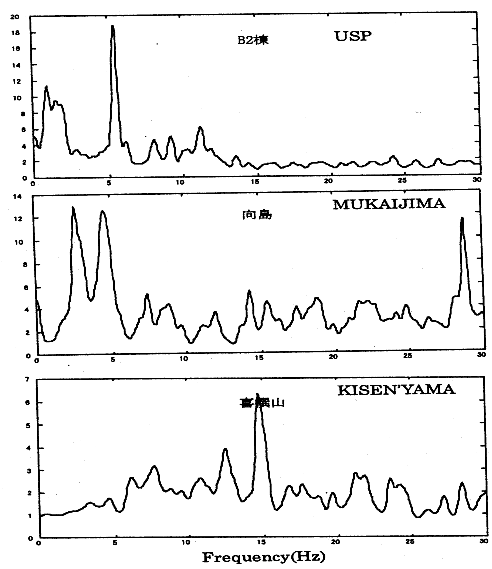

Fig. 12 Transfer function of surface to deep soil in Kyoto and Shiga due to Gifuken-Chuseibu earthquake