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OBSERVATION OF EARTHQUAKE MOTIONS BY DENSE INSTRUMENT ARRAYS AT SOFT GROUND

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SUMMARY

Very soft alluvial clay layers exist commonly in coastal area in Japan. The stability of port structures such as quaywalls is significantly dependent on the dynamic behavior of the layers during earthquakes.

Coping with this circumstances, the Port and Harbour Research Institute (PHRI) has been observing earthquake motions propagating through the soft layers at several sites around Tokyo bay area.

This paper presents an outline of the instrument arrays and some preliminary analyses of the records from the arrays.

INTRODUCTION

It is generally recognized that earthquake motions propagating through soft surface layers are fairly amplified and the stability of the structures on such ground are significantly dependent of the fact. As the large-scale and new type of structures have been proposed in port area, the earthquake resistant design procedures reflecting the characteristics of ground motions and the behaviors of surface layers during earthquakes become very important in recent years.

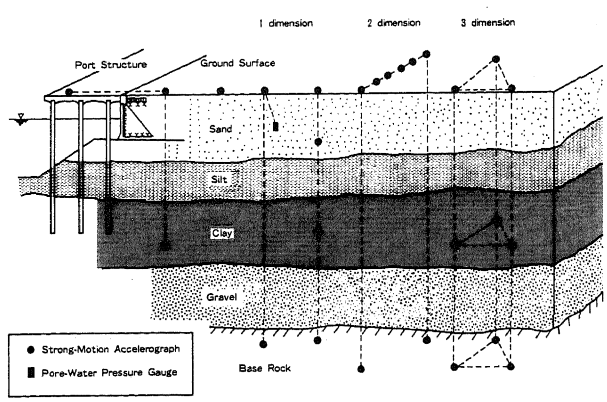


Fig.1 Dense instrument arrays of PHRI

In order to solve this problem, PHRI has installed strong-motion accelerometers on and in the surface layers at several stations around Tokyo bay area and has been observing the behavior of the layers during earthquakes.

ARRAYS

The PHRI has been conducting the following three types of dense instrument array systems.

(1) Vertical Instrument Arrays

In order to make clear the amplification characteristics of surface layers, accelerometers have been vertically deployed on and in the ground, as shown in Fig.1. This one dimensional vertical arrays have been established since 1967. Observations are still continued at 3 stations in Fig.2.

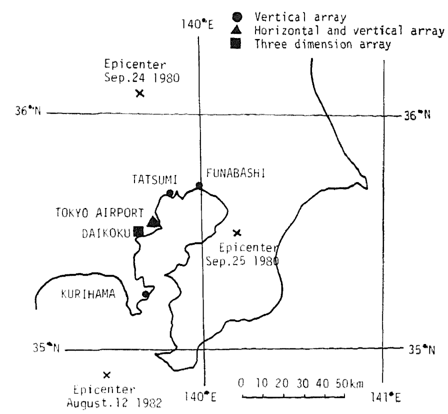


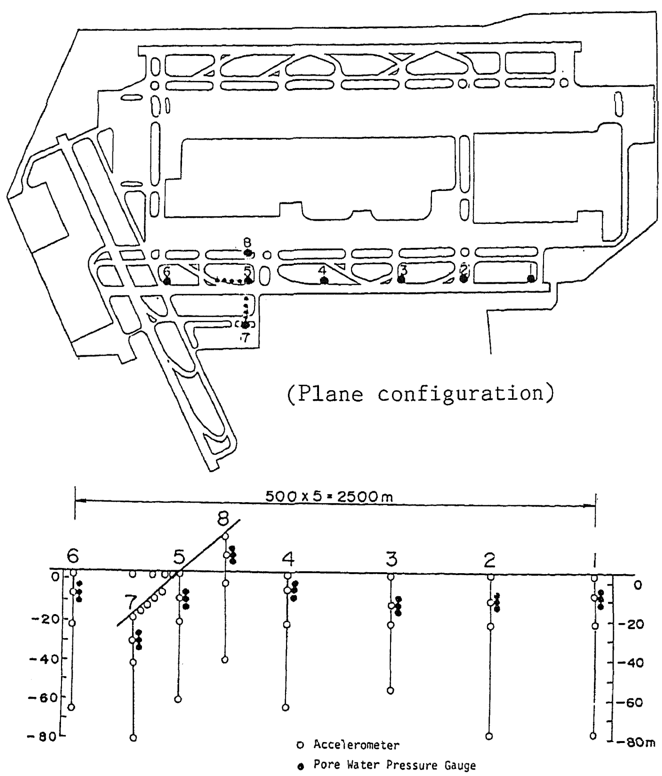
Fig.2 Stations of instrument arrays and epicenters of earthquakes

(2) Horizontal and Vertical Arrays

An aseismisity of long extending structures such as tunnels and pipe-lines is dependent not only on accelerations but also on deformations of ground along the structures during earthquakes.

For investigating the deformations of grounds, the horizontal and vertical array, as shown in Fig.1, has been established in Tokyo airport at Haneda in 1974. The array consisted of six sets of accelerometers on the ground in every 500 m along the runway of 2500 m and of two sets of accelerometers in the bedrock.

In 1988 the array has been replaced with the larger system, as shown in Fig.3. The new array has cross-shaped configuration and consists of 16 accelerometers on the ground, 23 in the ground and 8 in the base rock. 30 pore water pressure gauges are installed in the sandy layers.



(Vertical configuration)

Fig.3 Horizontal and vertical array in Haneda airport

(3) Three dimensional Array

In order to investigate the behavior of soft ground more accurately, accelerometers has been distributed on and in the ground, as shown in Fig.1.

This three dimensional system has been equipped at Daikoku island in Yokohama port and the observation has been started since 1980. As shown in Fig.4, plane configuration of the array is a triangle-shaped and 9 accelerometers have been deployed in three different levels of ground.

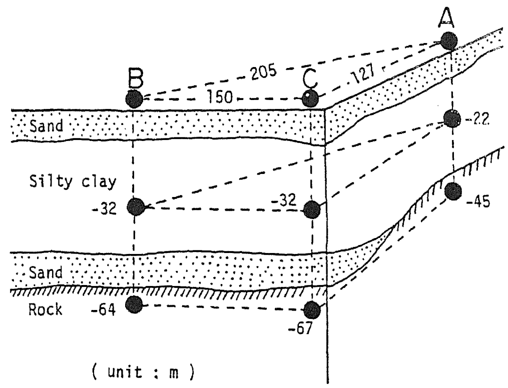


Fig.4 Three dimensional array in Yokohama port

OBSERVATION RESULTS

Observed results by the vertical arrays and the two dimensional array were already reported.[1)2)] The some results by the three dimensional array at Daikoku in Yokohama port are briefly introduced.[3)]

(1) Earthquakes and Max. Accelerations

Three earthquakes with magnitude about 6 happened in this district, as shown in Fig.2, and relatively large accelerations have been observed by the array. The earthquake data and the maximum accelerations at Daikoku station are listed in Table 1. Maximum base rock accelerations at stations around Tokyo bay are also listed in Table 2.

Table 1 Max. accelerations observed at Daikoku station in Yokohama port

Date and time		04:10 Sep.24,1980			02:54 Sep.25,1980			13:33 August.12 1982		
Epicenter region		SE IBARAGI prif.			Central CHIBA prif.			Near OSHIMA		
Latitude		36.1°N			35.5°N			34.9°N		
Longitude		139.7°E			140.2°E			139.6°E		
Depth		60 km			70 km			40 km		
Magnitude		6.0			6.1			5.8		
Epicentral distance		71 km			47 km			85 km		
Station		DAIKOKU			DAIKOKU			DAIKOKU		
		A	B	C	A	B	C	A	B	C
Ground surface	NS	13.5	13.3	13.9	49.0	45.9	--	15.8	17.3	25.1
	EW	14.7	15.8	13.9	41.9	29.6	--	18.4	23.9	21.5
	UD	9.5	9.6	10.5	36.6	28.6	--	13.5	12.3	12.5
Intermediate	NS	11.9	14.2	13.7	37.4	70.0	--	13.4	26.9	19.5
	EW	15.1	13.6	15.3	33.7	28.4	--	20.1	21.2	19.0
	UD	9.0	6.8	8.5	19.5	12.8	--	9.7	8.8	9.6
Base rock	NS	6.9	7.3	6.3	30.5	33.5	--	10.8	8.6	13.0
	EW	6.7	7.1	6.5	19.8	20.5	--	10.7	9.7	9.3
	UD	5.0	4.6	3.7	10.6	8.4	--	4.9	4.5	5.5

Table 2 Max. base rock accelerations in earthquake of Sept. 25, 1980

Accelerograph Site		FUNABASHI	TATSUMI	TOKYO AIRPORT		DAIKOKU		KURIHAMA
				A	E	A	B	
Hypocentral Distance		85 km	89 km	90 km		94 km		98 km
Maximum Base Acceleration	NS	44 Gal	20 Gal	85 Gal	115 Gal	31 Gal	34 Gal	13 Gal
	EW	47 Gal	17 Gal	83 Gal	82 Gal	20 Gal	20 Gal	16 Gal
	UD	16 Gal	3 Gal	14 Gal	35 Gal	11 Gal	9 Gal	---

(2) Accelerations and Strains in Ground

As shown in Table 2, large accelerations were observed during the earthquake of Sept. 25, 1980. Accelerations of over 200 gals at ground surface in Tokyo airport were recorded and it is reported that about 100 window-panes of the airplane hanger were broken. As an example, acceleration time histories of NS components at B-point in Daikoku station were reproduced in Fig.5. Observed records show some amplification of soft surface ground.

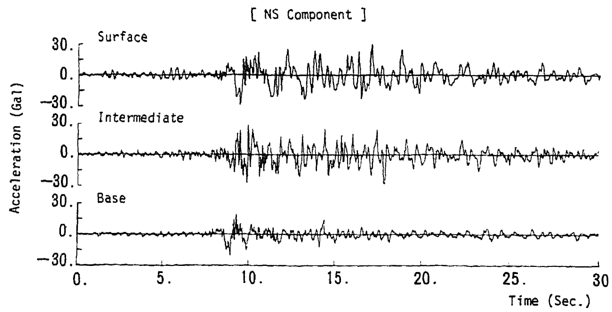


Fig.5 Acceleration time histories of B-point at Daikoku station (Earthquake of Sept. 25, 1980)

Ground strains induced by the earthquakes were estimated from displacements of ground motions, in which displacements were calculated by the double integration of observed accelerations.[4] Fig.6 shows ground strains during earthquake of Sept. 24, 1980. In these cases, maximum values of axial strain and shearing strains are not so large and strains in ground surface are more than 4 times of those in bedrock.

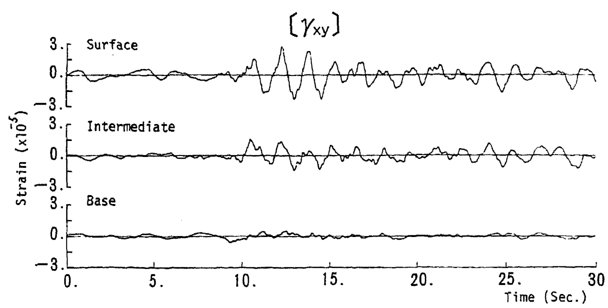


Fig.6 Ground strains at Daikoku station (Earthquake of Sept. 24, 1980)

Acceleration time histories at each level were calculated by the multi-reflection model of shear waves for observed baserock accelerations. The Fourier spectra of calculated accelerations were also compared with those of observed. As shown in Figs.7 and 8, they mostly agree in low frequency range, but some difference occurs in high frequency range.

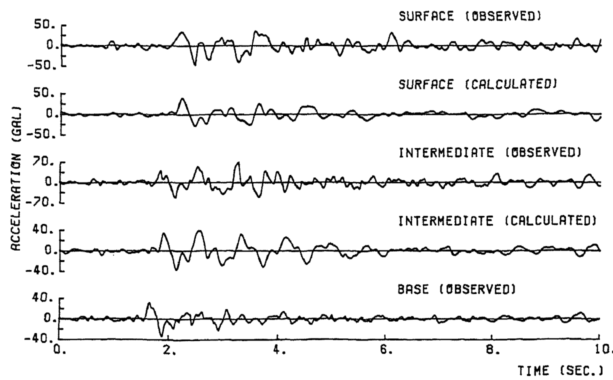


Fig.7 Acceleration time histories observed and calculated (Earthquake of Sept. 25, 1980)

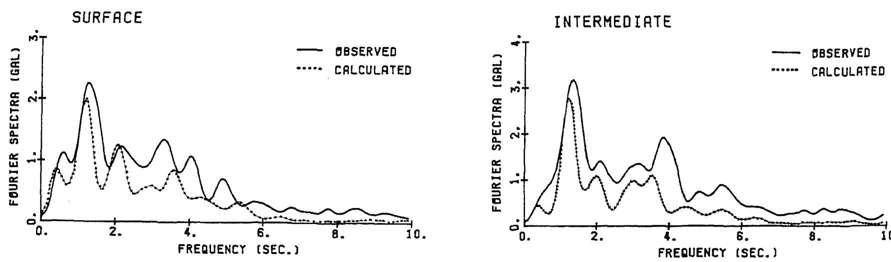


Fig.8 Fourier spectra observed and calculated (Earthquake of Sept. 25, 1980)

(3) Base Rock Motions

It is considered that a large scale instrument array is formed by each station along the Tokyo bay. The acceleration time histories of the base rock motion in the large array are obtained as shown in Fig.9. According to these data, the base rock accelerations do not always decrease with increase of the epicentral distance.

If the wave components with maximum amplitude are supposed as shear waves, the velocity through the bedrock around Tokyo bay area can be roughly estimated from the epicentral distance and the arrival time of the waves. According to Fig.9, shear wave velocity is estimated as about 4 km/s.

Fig.10 shows the hodographs which are obtained from displacements of base rock at each station. In this figure it is shown that displacements occur predominantly in east-west direction at almost all stations. This fact may give information on the source characteristics of the earthquake or structures of the crust in this region.

CONCLUDING REMARKS

Dense instrument arrays of the Port and Harbour Research Institute has successively been established for investigating the dynamic behaviour of the soft surface layers in the coastal area during earthquakes. As the records obtained will be significantly useful to improve the earthquake resistant design procedures, the consolidation of the observation networks and the collection of the records will be continued hereafter.

REFERENCES

1) Tsuchida,H., Noda,S., Iai,S. and Kurata,E. "Observation of Earthquake Response of Ground with Horizontal and Vertical Seismometer Arrays (2nd Report)," Proc. of 7th WCEE, (1980).
2) Tsuchida,H., Iai,S. and Kurata,E. "Analysis of Earthquake Ground Motions Observed with Two Dimensional Seismometer Array (1st Report) -North Tokyo Bay Earthquake of June 4,1977-," Report of PHRI, Vol.22, No.2, (1983), (in Japanese).
3) Noda,S., Kurata,E., Iai,S. and Tsuchida,H. "Observation of Earthquake Motions by Instrument Arrays in Port Area and Preliminary Analyses," Proc. of 6th Japan Earthquake Engineering Symposium,(1982).
4) Iai,S., Kurata,E. and Tsuchida,H. "Digitization and Correction of Strong-Motion Accelerograms," Technical Note of PHRI, No.286, (1978), (in Japanese).

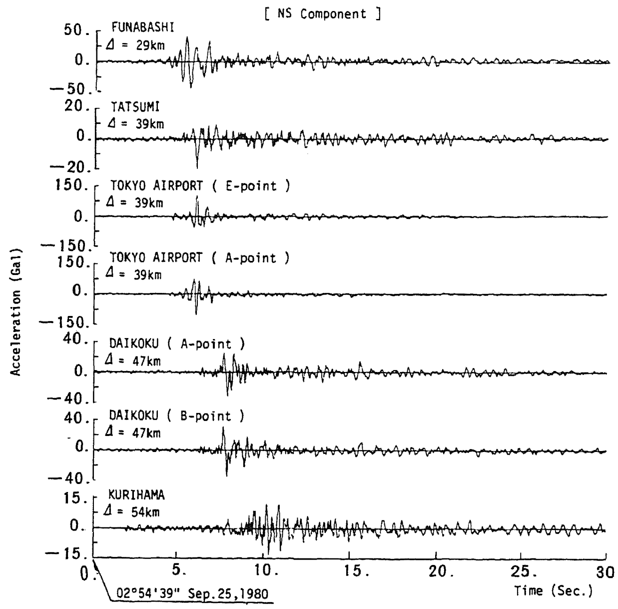


Fig.9 Acceleration time histories of base rock at each station (Earthquake of Sept. 25, 1980)

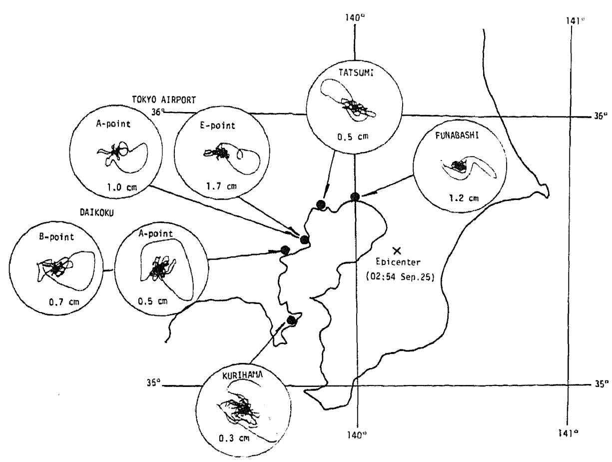


Fig.10 Hodographs of displacement at base rock (Earthquake of Sept. 25,1980)