OBSERVATION OF EARTHQUAKE RESPONSE OF GROUND WITH HORIZONTAL AND VERTICAL SEISMOMETER ARRAYS

by

Hajime Tsuchida[I], Eiichi Kurata[II], and Satoshi Hayashi[III]

SYNOPSIS

A horizontal seismometer array having six observation points along a straight line of 2500 meter length have been established. Downhole seismometer arrays also have been established at two points. Records of three earthquake events are selected and analyzed, while 32 earthquake events had been recorded as of June 1976. Correlations among the ground motions at the observation points are studied. The relative displacements among the observation points on the ground surface are also studied, and stresses in a buried pipeline due to the relative displacements are estimated.

INTRODUCTION

Importance of earthquake response analysis of ground over an area has been recognized and investigated by researchers and also by practicing engineers. This is very important especially for extending structures such as pipelines and subaqueous tunnels. They are extending for considerable distance; and stresses in such structures due to earthquake ground motions depend largely upon relative displacements of the ground along a route, rather than accelerations at locations of the structures in the ground. For that reason, the earthquake response analysis of the ground along a route or over an area is important.

Basic data on which the earthquake response analysis should be based are simultaneous recording of earthquake ground motions at several points on a line or points distributed in an area. The strong motion earthquake instruments currently being operated in the world, however, are installed to record ground motions at points separately. Only a few observations of earthquake ground motions with seismometers arranged along lines have been carried out to obtain basic data in this field (1,2).

The authors established a horizontal and two vertical seismometer arrays for simultaneous recording of ground motions at eight points distributed in a vertical plane in a ground. The observation started in April 1974, and as of June 1976, 32 earthquake events had been recorded. In this paper some results of observation and analyses on three earthquakes out of 32 will be presented, although the observation and also the analysis are being continued.

SEISMOMETER ARRAYS

The horizontal seismometer array has been established in the Tokyo International Airport parallel to the C-runway, as being shown in Fig. 1.

I Chief, Earthquake Resistant Structures Laboratory, Structures Division, Port and Harbour Research Institute, Ministry of Transport

II Member, Earthquake Resistant Structures Laboratory, Structures Division, Port and Harbour Research Institute, Ministry of Transport

III Head, Structures Division, Port and Harbour Research Institute, Ministry of Transport

The soil profile beneath the array is shown in Fig. 2; the profile was constructed by engineering geologists based on the two borings made for installation of the downhole seismometers and 69 borings which had been made for planning and construction of the facilities in the airport.

The seismometers to observe ground surface motions are installed at six observation points, the points A through F in Fig. 1. The distance between adjacent points is 500 meters and total length of the observation line is 2500 meters. Each point is equipped with transducers to observe longitudinal and transverse components of ground accelerations. At the points A and E the vertical seismometer arrays are installed; the lower seismometers are at depths 67.2 meters and 49.6 meters below the ground surface respectively. The downhole seismometers have three transducers to observe longitudinal, transverse, and vertical components of ground accelerations.

All the seismometers are of moving coil type and output from them are recorded with four electro magnetic oscillographes. Frequency ranges of the seismometers for sensitivity decrement within 10% are 0.1 to 35 Hz for the seismometers on the ground surface and 0.5 to 50 Hz for the downhole seismometers. The oscillograms were digitized for analysis with a computer on-line digitizer at an equal time interval of 0.01 second.

OBSERVATION RESULTS

Parameters of the three earthquakes of which records are designated as TIA-3, TIA-6, and TIA-9 are listed in Table 1 together with maximum accelerations at the points, and others. The locations of the epicenters are in directions of approximately S40°W, N53°E, and N14°E from the observation site, for the earthquakes TIA-3, 6, and 9, respectively. The observation line is directed in N27°W and the point F is located at the north end of the observation line. As an example of the records the acceleration time histories of earthquake TIA-3 at the observation points A and E are shown in Fig. 3. The figure shows acceleration time histories at the ground surfaces and the downhole seismometer locations.

DISPLACEMENTS

Displacements of the earthquake ground motions were calculated from the observed acceleration time histories. For the calculation, operation of a seismograph which has a pemdulum with natural period 6.0 seconds and damped at 55% of critical to the observed ground accelerations was simulated with an analog computer. The seismograph considered here has the same characteristics to those of the seismograph being used in the network of the Japan Meteorological Agency. Filtering was applied to the input to and the output from the simulated seismograph to eliminate components with periods longer than 10 seconds. This procedure was compared with the procedure developed at the California Institute of Technology for processing the strong motion accelerograms in the United States (3). The displacements calculated by both procedures agreed very well, when the differnce of the frequency ranges of the integrations between both procedures are taken into account.

The calculated displacements for the earthquake TIA-3 are shown in Fig. 4. It is seen from the figure that the displacement time histories at all the observation points are very similar each other. The similarity of wave froms of the earthquake TIA-6 was also as good as the earthquake TIA-3 among the observation points. However, the earthquake TIA-9 did not show the good similarity as the other earthquakes did. The maximum ground displacements at the observation points are listed in Table 1.

From the ground displacement time histories the relative displacements of the two points adjacent each other were calculated, and the results are listed in Table 1.

WAVE PROPAGATION

The cross correlation functions between the time histories of the ground displacements at the points were calculated, and the time-shift for maximum correlation between the points A and F were obtained as 0.19, 0.17, and 0.44 second for the earthquakes TIA-3, 6, and 9 respectively. They are averages of the time-shifts of longitudinal and transverse components; however the difference of time-shifts between both components were less than 0.03 second, as far as the three earthquake records are concerned.

If it is assumed that the waves propagated from the epicenters straightly along the ground surface, the velocities of the wave propagations are estimated as 5.3, 2.6, and 4.4 km/sec for the earthquakes TIA-3, 6, and 9, respectively. It will be noted, however, that regardless of the locations of the epicenters the cross correlation analysis implied that the waves always had arrived at the point F earlier than at the point A.

STRESSES IN BURIED PIPELINE

It was considered that a pipe had beed existed at shallow depth in the ground along the observation line, and the stresses in the pipe due to the earthquake ground motions were estimated. In the estimation the followings were assumed. First, the pipe was made of steel and its diameter was 1000 millimeters. Secondly, the pipe deformations were identical with the ground deformations derived from the recorded ground motions; in other words, the rigidity of the pipe was neglected.

Table 1 includes the stresses due to the longitudinal deformations of the pipe and the stresses due to the horizontal bending deformations. They are maximum values along the observation line. It is seen that the stresses due to bending deformations are considerably smaller than those due to longitudinal deformations.

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Record designation	TIA-3		TIA-6		TIA-9	
Date	May 9, 1974		July 8, 1974		August 4, 1974	
Time	08:33		14:15		03:17	
Hypocenter						
Latitude	33.6°N		36.4°N		36.0°N	
Longitude	138.8°E		141.2°E		139.9°E	
Depth	10 km		40 km		50 km	
Magnitude	6.9		6.3		5.8	
Epicentral distance	140 km		161 km		54 km	
(Component)	Long.	Tran.	Long.	Tran.	Long.	Tran.
Maximum acceleration in gals						
Point A	15.0	9.1	6.4	6.1	20.0	24.6
B	14.0	9.8	11.4	8.8	47.0	35.8
C	16.3	12.8	9.6	7.5	36.6	31.0
D	21.7	11.2	11.7	9.1	29.3	22.5
E	23.2	19.2	10.7	11.4	51.8	32.4
F	18.5	13.0	11.7	11.9	40.9	34.7
A(-67.2m)	5.8	4.3	3.8	3.0	10.1	8.4
E(-49.6m)	10.1	5.6	5.5	4.4	23.1	13.8
Maximum displacement in cm						
Point A	1.34	0.91	0.52	0.63	0.40	0.38
B	1.48	0.76	0.50	0.63	0.42	0.87
C	1.83	0.85	0.54	0.69	0.63	0.52
D	2.14	0.81	0.81	0.79	0.46	0.39
E	1.96	1.36	0.49	0.83	0.46	0.58
F	1.92	0.94	0.51	0.66	0.58	0.55
A(-67.2m)	0.72	0.51	0.37	0.25	0.16	0.18
E(-49.6m)	1.48	0.64	0.42	0.57	0.30	0.25
Maximum relative displacement in cm						
Point A & B	0.50	0.59	0.16	0.16	0.39	0.31
B & C	0.37	0.64	0.19	0.13	0.22	0.87
C & D	0.71	0.61	0.13	0.25	0.51	0.34
D & E	0.74	0.53	0.32	0.21	0.34	0.27
E & F	0.64	0.64	0.68	0.24	0.23	0.26
Maximum stresses in a buried pipe (Dia. 1000 mm) in kg/cm sq.						
Stress due to axial deformation	31		29		21	
Stress due to bending deformation	0.06		0.02		0.07	

Table 1 Earthquakes, maximum accelerations, maximum displacements, maximum relative displacements, and maximum stresses

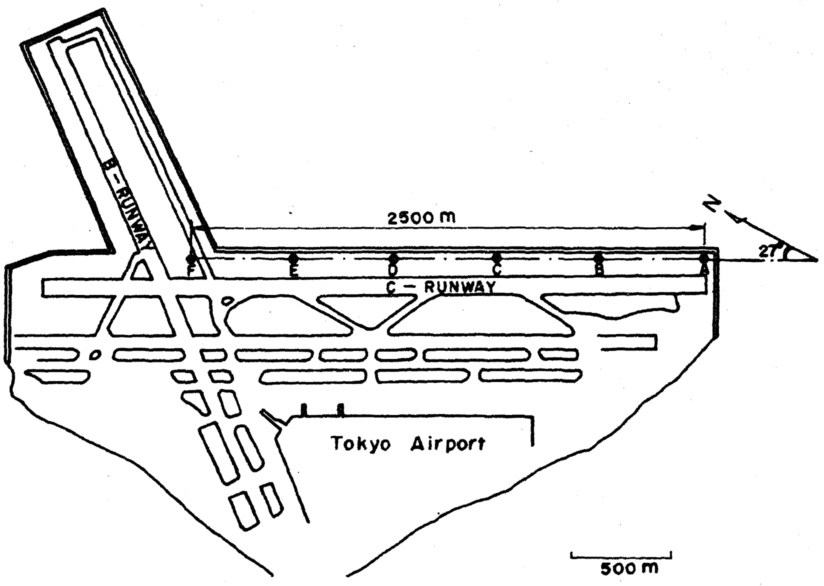
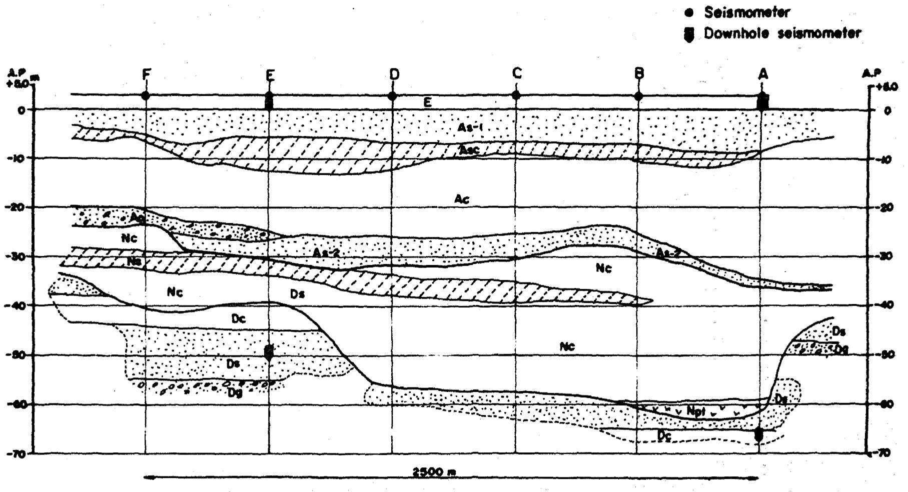


Fig. 1 Plan of seismometer array site



Key (Fill) E:Fill, (Alluvial deposit) A_{s-1}:Sand, A_{sc}:Silty sand
A_c:Silty clay, A_{s-2}:Sand, A_g:Sandy gravel, (Diluvial Deposit)
N_c:Silty clay, N_s:Silty Sand, N_{pt}:Peat, D_s:Sand,
D_g:Sandy gravel, D_c:Silt.

Fig. 2 Soil profile at seismometer array site

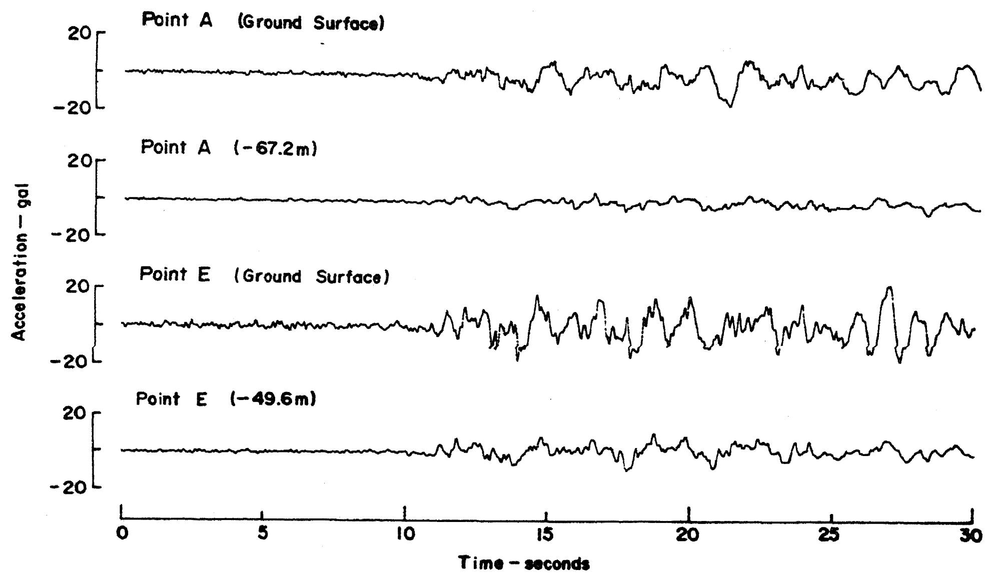


Fig. 3 Observed ground acceleration time histories
(TIA-3, Longitudinal component)

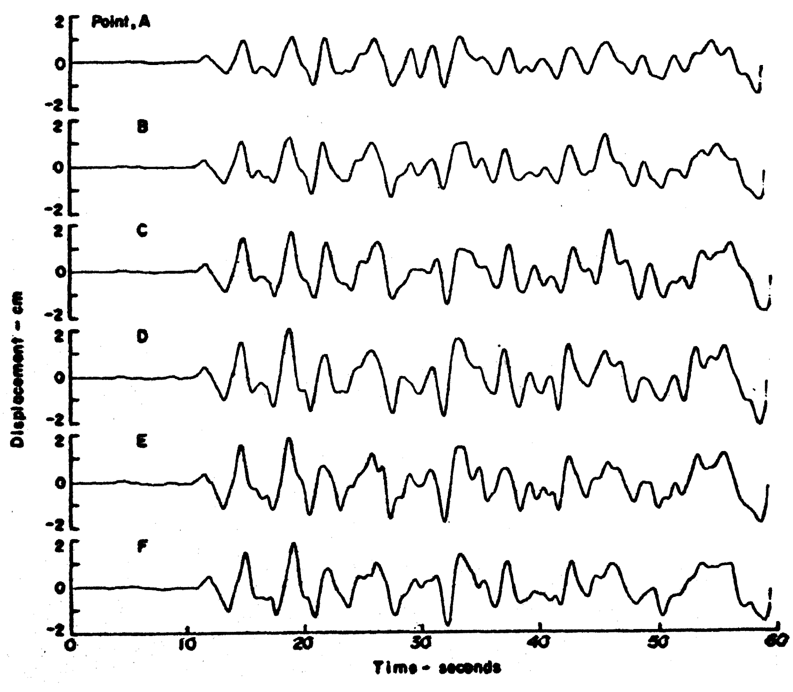


Fig. 4 Ground displacement time histories
(TIA-3, Longitudinal component)

DISCUSSION

H.M. Chaudhury (India)

It is seen that earthquake motion is reported from three different quakes but recorded at the same location. The azimuth of the epicentres presumably are different. How could the longitudinal and transverse components be recorded ? Were these separated by a special technique ?

S.K. Guha (India)

In Fig. 3 of your paper, large decays of ground acceleration are shown but in rocky ground in Koyna earthquake area we do not find such rapid decays in acceleration with depths even up to 600m when the accelerographs are situated in an under ground power house. Can you please explain ?

Author's Closure

With regard to the question of Mr. Chaudhury, we wish to state that the longitudinal and transverse components in the paper mean those with the observation line which is an imaginaty line connecting the observation points A and F in Fig. 1. Therefore, the ground motions of those components are the outs themselves from the transducers.

It will be noted, however, that the ground motions of the longitudinal and transverse components with the directions of epicenters are also available. The ground motion records of all the components had been digitized at the equal time interval simultaneously, and ground motions in any direction can be calculated from the digitized data.

With regard to the question of Mr. Guha, we wish to state that the authors consider the large decay of acceleration depend on the subsoil conditions at the sites. The lower seismometers are located at nearly surface of the diluvial layers, and the subsoils between the ground surface seismometers and the lower ones are alluvial deposits of which shear wave velocities range from 130 to 500 m/sec. The velocities are remarkably smaller than those of rocks.

Similar decay of acceleration is also reported by H.Arai and others in the paper "Underground Earthquake Motions in Ports and Harbours of Japan" presented at the same Conference.