EARTHQUAKE OBSERVATION ALONG MEASURING LINES ON THE SURFACE OF ALLUVIAL SOFT GROUND

by

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SYNOPSIS

Two kinds of earthquake observations were carried out to grasp planar behavior of alluvial ground during earthquakes. One was observation by several seismographs installed on orthogonal measuring lines 500 m and 200 m in length established on the ground surface of filled land. The other was by a measuring line inside a steel shield tunnel in alluvial ground and a measurement point at the ground surface. The paper describes the propagation of earthquake motions in the depth direction and directions along the ground surface based on correlations of the records taken at the various measurement points.

I. INTRODUCTION

When carrying out earthquake-resistant design of long underground structures, large-sized structures and long bridges, a necessity arises for behavior of ground during earthquake to be observed simultaneously on the lines, in the area, including in the depth direction. In case of alluvial ground a considerable amount of earthquake observation has been done at points deep underground, but there are extremely few cases where linear or planar measurements have been made for this purpose extending over a certain range either at the surface or underground[1)2)3)].

During 1966∿1968, the authors made two kinds of earthquake observations for this purpose at Koto-ku, Tokyo. One consisted of observations on a single straight line or two orthogonal straight lines at the surface of soft alluvial ground about 60 m in thickness. Separate observations in the depth direction were also carried out at this site. The other consisted of observations at a distance of about 1.5 km from the first site where a shield tunnel was utilized. A part of the earthquake records and analyses are described.

II. EARTHQUAKE OBSERVATION (A)

II-1. Ground Conditions and Outline of Observations

The observation site is in a reclaimed lot at the downstream right bank of the Ara River Diversion Channel. The geological profile, as shown in Fig. 2, shows a top layer of fill (Layer A) of about N=5 under which there is a Layer B consisting of alternations of fine sand and silt averaging about N=15. Underlying this is an almost uniform silt layer (Layer C) averaging about N=3 and 30 m in thickness followed further by Layer D, alternations again of fine sand and silt, to reach the so-called Tokyo Sand-Gravel Layer (Layer E) of N=50 and higher which is well compacted, and a fairly uniform stratified ground structure is presented.

A 500-m measuring line pointing approximately north-south runs parallel to and about 85 m from the boring line in Fig. 2, while perpendicular to this is a 200-m line (Fig. 1). The seismographs are electro-

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magnetic accelerometers having 0.5-sec natural periods of displacement seismometers with 1.0-sec periods. The black dots on the measuring lines in Fig. 1 are seismograph locations which were changed according to the observation stage. At the first stage, displacement seismometers were installed at the 5 points of E, N, W, C and S. At the second stage, displacement seismometers were installed at 25-m intervals between N and S, while at the third stage, accelerometers were installed at the 6 points of 1, 2, ..., 6 which were 100 m apart. All records were taken on a single roll of recording paper driven at a speed of approximately 10 cm/sec.

II-2. Earthquake Records and Analyses

Four earthquakes were recorded between January and July 1968 of which the following are shown in Figs. 3 and 4: earthquake symbol Eq 1, time 2045 hr 23 Jan. 1968, location 140°9'E 35°44'N, depth 80 km, epicentral distance 30 km, recorded for displacement, and earthquake symbol Eq 2, time 1945 hr 1 July 1968, location 139°26'E 35°59'N, depth 50 km, magnitude 6.1, epicentral distance 52 km, recorded for acceleration. These data are according to Japan Meteorological Agency announcements. The first letters of the symbols in the records of Fig. 3 correspond to the measurement points in Fig. 1 and the EW and NS following indicate measurement directions. The numbers in the records of Fig. 4 correspond to the measurement point numbers 1 to 6 of Fig. 1 while all measurements were in the NS direction.

Predominant frequencies determined from peak values of power spectra of the records in Fig. 4 are as given in Table 1. The predominant frequency of No. 6 is slightly small, but it may be considered that predominant frequency scatter according to measurement point is insignificant. Predominant frequencies in the 4 earthquakes are 0.68∿0.71 Hz, 0.94∿1.19 Hz, 1.9∿2.2 Hz and 2.4∿2.6 Hz, and scatter in frequencies according to measurement location in any single earthquake is small. In all of the records, it is seen that the powers of low predominant frequencies are prominent. According to acceleration waveforms recorded at depths of 3, 15, 27, 39 and 50 m, it is seen that vibrations of low predominant frequencies in earthquakes not of small scale are amplified at the surface layer to become predominant. From this, it is surmised that these predominant frequencies are mainly related to Layer D and above.

Since the earthquake waveforms were geometrically similar for each earthquake and each direction as seen in Figs. 3 and 4, the time lags of the records were computed from the cross-correlations of the records for the various measurement points for the same earthquakes and the same directions. The correlations with records of other measurement points taking N-EW and N-NS as bases in case of earthquake Eq 1 are shown in Fig. 5. From this figure it can be seen there is high coherency not only for predominant frequency of approximately 0.7 Hz, but also for 2∿3 Hz. Time lags obtained for basic waveforms from cross-correlograms are indicated in Table 2. The location of each measurement point was projected in the direction in which the earthquake wave was thought to have travelled and the above time lags collated against the respective locations are shown in Fig. 6. Except for measurement point W, they are seen to be aligned on a straight line. In this case, the propagation velocity at the ground surface is 2.9 km/sec. Similar time lag computations for earthquake Eq 2 and projections in the focal direction are shown in Fig. 7. The propagation velocity at the ground surface in this case was 2.6 km/sec. With the two other earthquakes the time lags were small and also scattered so that velocities could not be computed.

III. EARTHQUAKE OBSERVATION (B)

III-1. Ground Conditions and Outline of Observation

Earthquake observations were made from 1966 to 1968 on a measuring line inside a shield tunnel and at the ground surface at a site about 1.5 km from the beforementioned place (Fig. 8). The surface layer for about 10 m at this site is sandy silt under which there is a silty clay layer. Deeper parts are thought to be little different from the ground conditions at the first site. The ground water level is at a depth of about 1 m.

The seismographs were accelerometers of natural period of 3 Hz and displacement seismometers of 1 Hz with measurements made at 3 points in the shield at 14-m intervals on the tunnel axis and 1 point at the ground surface. All records were taken on a single roll of recording paper driven at a speed of approximately 10 cm/sec.

III-2. Earthquake Records and Analyses

Seventeen earthquakes were recorded and the records shown in Fig. 9 are those of Eq 2 described in II-2. The first letters G and S of the symbols in the records respectively indicate ground surface and inside the tunnel, while the following letters A and P denote measurement directions (both horizontal), the direction of the tunnel axis and the direction perpendicular to this respectively. The third letter in case of the tunnel indicates measurement location, while the last letters A and D respectively indicate whether the records are on acceleration or displacement.

The acceleration records for the ground surface and tunnel in Fig. 9 were used for calculating the cross-correlation of the two to obtain the velocity of earthquake motion travelling from inside the ground to the surface, which is shown in Fig. 10. That maximum values seen at the left side of the longitudinal axis at GP-A and SPC-A indicate there are wave motions heading from inside the ground toward the surface, while similarly, the maximum values at the right side indicate wave motions in the opposite direction. Similar characteristics are seen for GA-A and SAC-A, but peaks are normally nct distinct compared with the former. These trends are seen with almost all earthquakes and are thought to indicate the state of propagation of earthquake motion in the depth direction. Obtaining the propagation velocity of earthquake waves at the part between the tunnel and the ground surface from the time lag between the two maximum values assuming that the wave motions travel vertically from the ground surface, it is 140 m/sec.

Next, that the axial direction displacement waveforms at the measurement points inside the shield are almost in complete agreement regardless of location is seen with all earthquakes, and this is thought to be due to the rigidity of the tunnel against axial direction deformation and the characteristics of the earthquake waveforms along the tunnel axis.

IV. SUMMARY

The foregoing is on the results of studies on the behavior during earthquake of alluvial ground having approximately uniform structure based on earthquake observation records without considering factors making earthquake motions complicated such as earthquake scale, earthquake-inducing mechanism, relative locations of measurement points and hypocenter, and in addition, topography and macroscopically-viewed geological structure. As a result, it was learned that there is a low-order predominant frequency due to the vibration characteristics of the surface ground which appears, and that these vibrations travel the ground surface at fairly high velocities. These velocities were between 2.6 to 2.9 km/sec in the observations.

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Fig.1 Locations of Seismometers

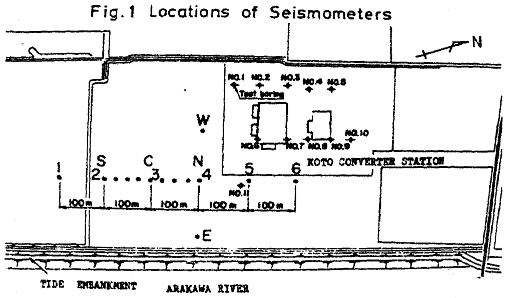

Fig.2 Geological Profile

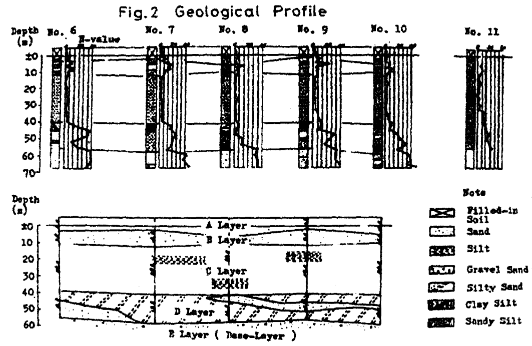

Fig.6

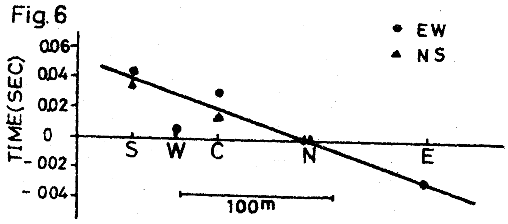

Table 1

LOCATION AND DIRECTION OF SEISMOMETER	PREDOMINANT FREQUENCY (Hz)			
1 - NS	0.85			
2 - NS	0.85		2.37	3.25
3 - NS	0.85		2.43	
4 - NS	0.82	1.18	2.62	
5 - NS	0.81		2.48	
6 - NS	0.78		2.39	

Fig. 7

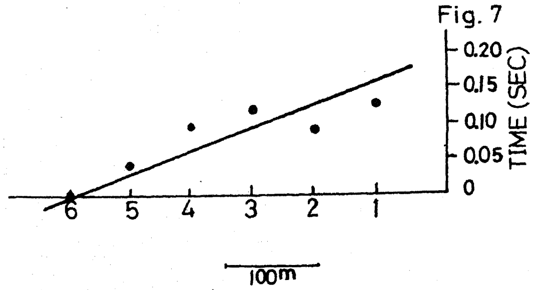

Table - 2

Direction	Points	Time lag(sec)
EW	N ~ E	- 0.0273
EW	N ~ W	0.0057
EW	N ~ C	0.0304
EW	N ~ S	0.0438
NS	N ~ C	0.0133
NS	N ~ S	0.0342

Fig.3 Displacement Records of Earthquake, Jan., 23, 1968

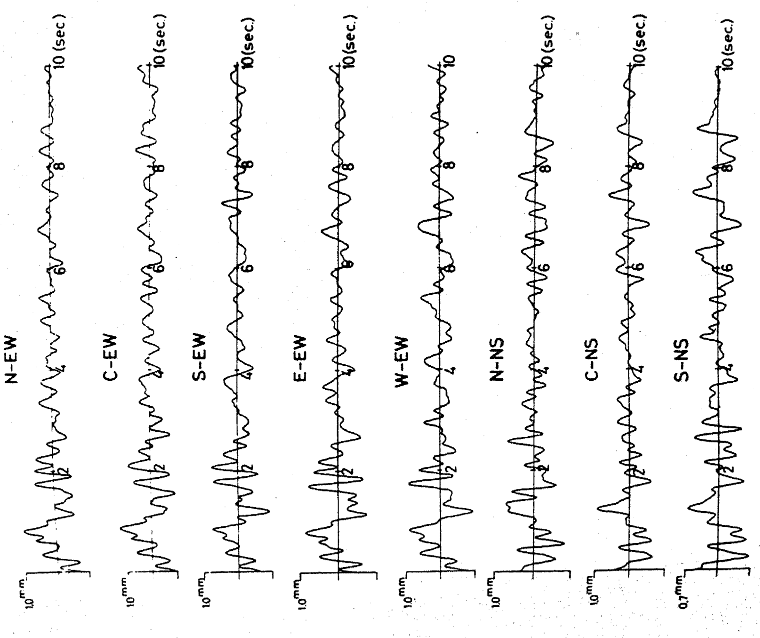

Fig.4 Acceleration Records of Earthquake, Jul., 1, 1968

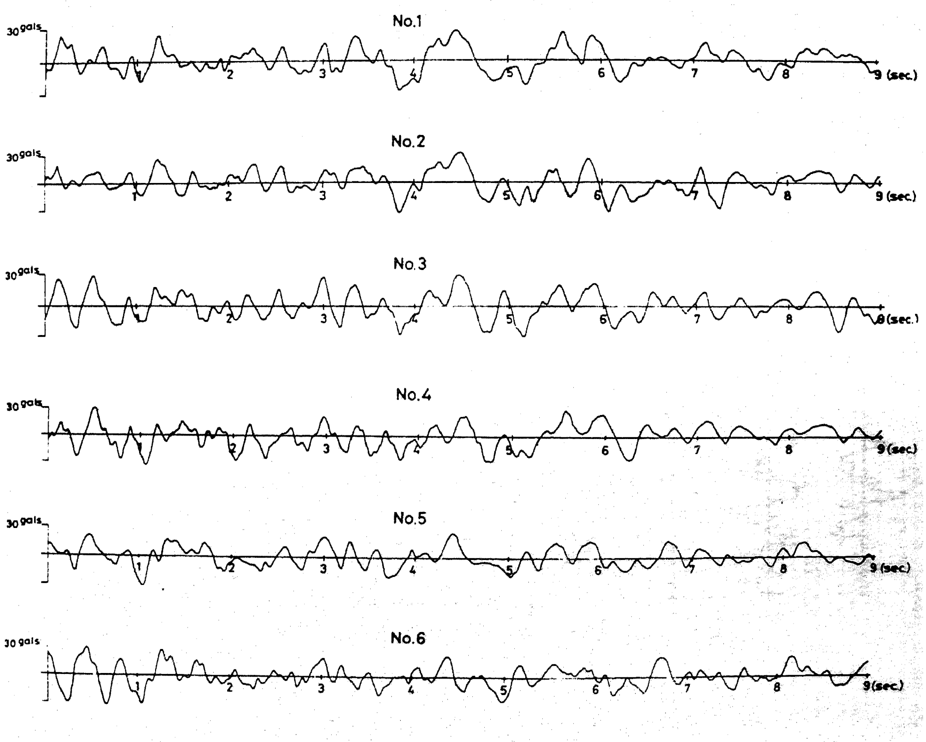

Fig.9 Earthquake Records (July 1, 1968)

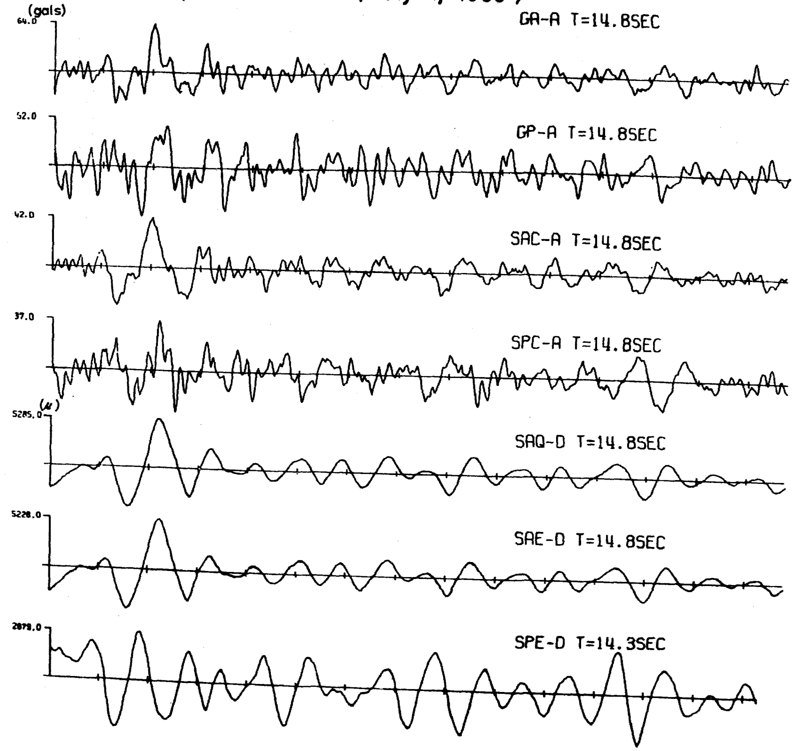

Fig.10
Cross – Correlations of Acceleration Records of Earthquake, July, 1, 1968 (EQ-2)

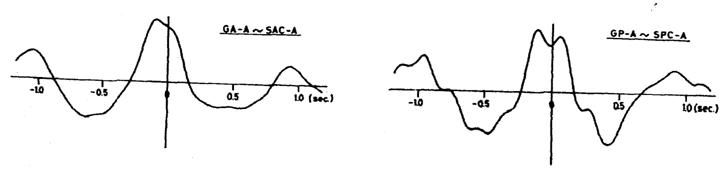

Fig.5 Cross-Correlations of Displacement Records of Earthquake, Jan., 23, 1968

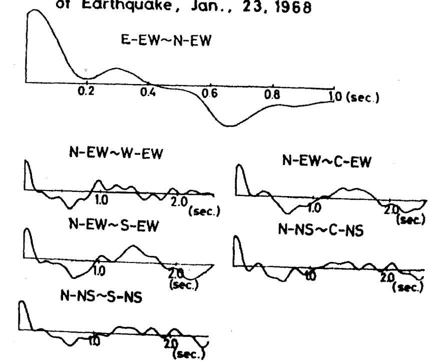

Fig.8 Geological Condition and Locations of Seismometer.