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DETECTION OF APPARENT WAVE VELOCITY IN NEAR SURFACE GROUND WITH IRREGULAR PROFILE BY AN ARRAY OBSERVATION

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SUMMARY

It is known that seismic waves do not propagate in a straight line from the epicenter to the observation site. In near surface complex geological structures some irregular features are detected from the records even in the high frequency range, a range that is important from an engineering point of view. This paper describes some considerations on the seismic wave path and on the apparent wave velocity in such a structure.

INTRODUCTION

The first approximation concerns the strain induced in the pipe. Deformation of buried pipe is governed by the relative motion of the surrounding ground at different arbitrary points of the pipeline. The motion of the ground surrounding the pipe is very similar to that of the free field.

The second approximation concerns the propagating direction of the apparent wave. The wave propagates in a straight line from the epicenter to the observation point.

Therefore, the axial strain ε is calculated from the following equation:

$$\varepsilon = \frac{v}{c}$$

in which, v is the particle velocity produced by the wave traveling along the pipe's axis and c is the apparent wave velocity. v is easily determined from ground motion records; whearas, c is determined neither from a record obtained at one observation site nor from records taken at sites that are not synchronized. Therefore a common time signal must be marked on all records in order to determine the wave velocity from seismograms obtained at different sites.

ARRAY OBSERVATION NETWORK

The observation site is near the Edo River in northern Tokyo. The farther from the river the point is, the thicker the surface soft layer becomes. The array observation network consists of four independent data recorders and seven accelerographs. Four data recorders are connected with NTT telephone system and receive the common time signal every other second to keep the four independent records synchronized. The data sampling rate is 200 Hz. A buffer memory is prepared to obtain a three-second delay. Each recorder is connected with two accelerographs, one locates 2 meters below the surface and one at the interface between alluvial and dilluvial layers. The accelerograph is a three-component servo type with a frequency range of 0.1 to 30 Hz and a dynamic range of 0.1 to 1000 gal. When one of the data recorders registers an earthquake, the master station receives the trigger signal from the recorder and sends the trigger signal to the other recorders.

Observation started in 1980 and over 100 waves have been recorded.

DETECTION OF APPARENT WAVE VELOCITY

The apparent wave velocity is usually calculated as the ratio of propagating distance and time delay between two observation points. Propagating distance is given as the orthogonal projection of two observation distances in the azimuthal direction. Time delay is given as the peak time of cross-correlation. Since seismic waves are usually supposed to propagate in a straight line, the wave should reach the observation point nearer the epicenter earlier.

Fig.2 shows the relationship between apparent wave velocity and azimuthal direction. The data are plotted in polar cordinates; the arm length means the apparent wave velocity and the angle means the azimuthal direction. Black dots mean that the apparent wave velocity is negative and therefore they are plotted in the opposite direction to the azimuthal direction. They reveal that the seismic wave reached the distant point from the epicenter earlier and that the apparent wave propageted in the reverse direction of what was expected. It is remarkable that the apparent wave velocities are all negative when the epicenter is in the thicker surface side, i.e. the left side of the sub line in Fig.2.

SEISMIC WAVE PATH

An incident angle decreases when the wave propagates from a solid medium to a soft medium. The depth of the typical seismic center ranges from one to several tens of kilometers and in cases involving multiple layers, the deeper layer is usually harder. Therefore, the incident angle becomes small when the seismic wave reaches the ground surface.

Table 1 shows the incident angles at the dilluvial layer of the observation site calculated from the depth and the distance of the seismic center and the shear wave velocity of the ground on the path of eight seismic waves (5 having epicenters in the thinner surface side and 3 in the thicker surface side).

Fig.3 shows the seismic wave propagation after the seismic waves reached the dilluvial layer for seismic waves having the epicenter in both the thinner surface side and the thicker surface side. It takes less time for a wave to travel through a solid layer. Therefore, the wave reaches the surface layer earlier where the solid layer is thicker. The wave reaches the distant point earlier, when the epicenter is in the thicker surface side. Fig.3 reveals the apparent wave always travels from the thinner soft layer point to the thicker soft layer point on the surface ground and has no relationship to the azimuthal direction.

CALCULATION OF APPARENT WAVE VELOCITY

It is important which is adopted to calculate the apparent wave velocity as the propagating distance, orthogonal projection in the azimuthal direction or simple distance between 2 observation points. Based on our hypothesis, adoption of the orthogonal projection in the azimuthal direction is unappropriate. The apparent wave velocity, for example, may reach 2000m/s based on our hypothesis, while the same observation data would give a velocity of 100m/s via the conventional method as shown in Fig.4.

Fig.5 shows the comparison of the apparent wave velocity when the wave is considered to travel along the azimuthal direction and when it is considered to travel from the thinner soft layer point to the thicker soft layer point.

CONCLUSIONS

In near surface complex geological structures, the apparent wave propagating direction does not always coincide with the azimuthal direction, and seismic waves reach the surface earlier where the near surface soft layer is thinner. Consequently, it is highly risky to evaluate the apparent wave velocity without considering its propagating direction.

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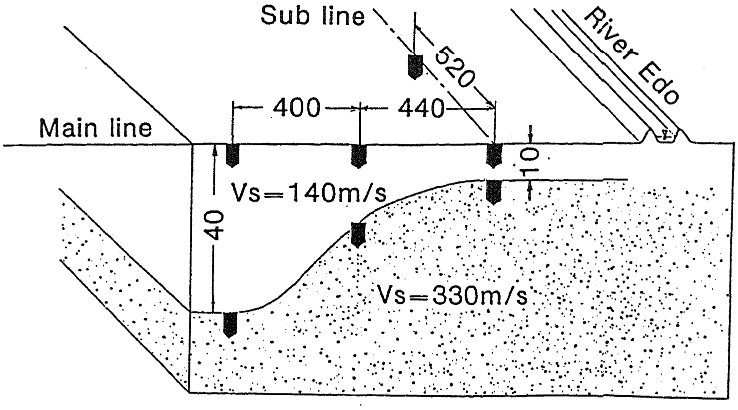


Fig. 1 Near Surface Ground Profile and Array Observation Network

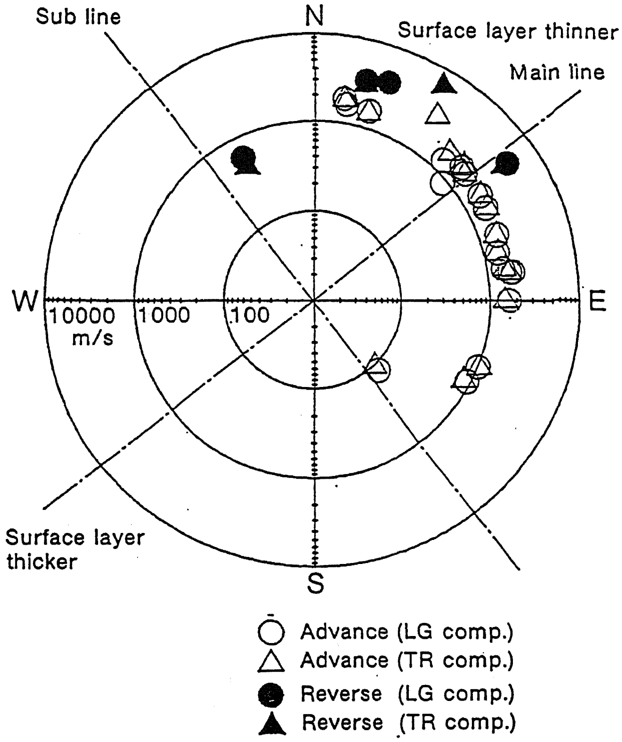
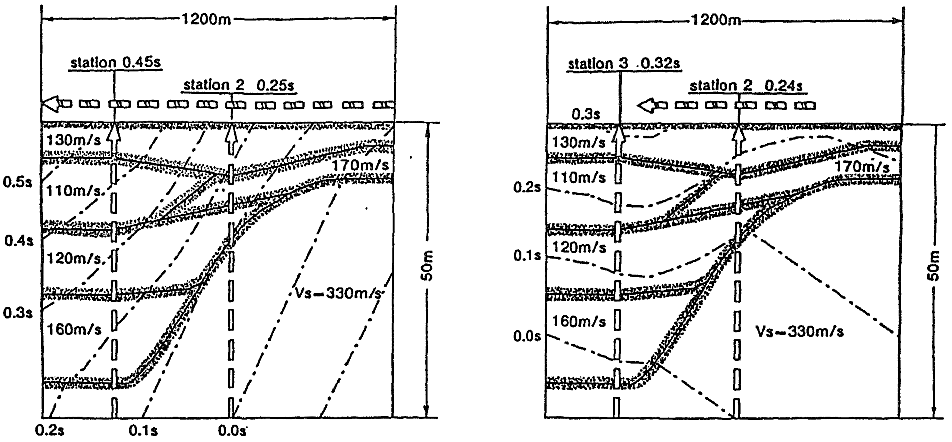


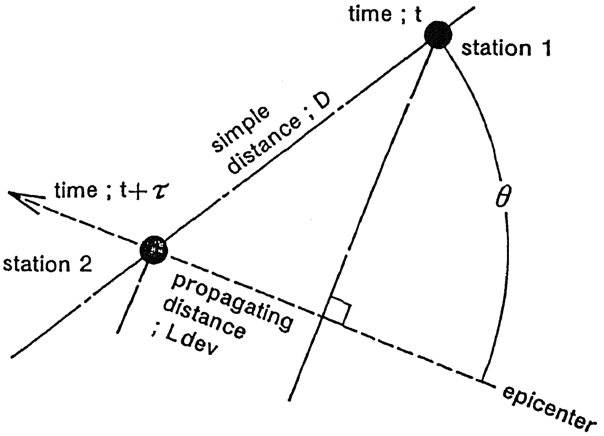
Fig. 2 Relationship between Apparent Wave Velocity and Azimuthal Direction



(a) Epicenter is in the thinner soft layer side.

(b) Epicenter is in the thicker soft layer side.

Fig. 3 Seismic Wave Propagation after the Seismic Wave Reaches the Dilluvial Layer

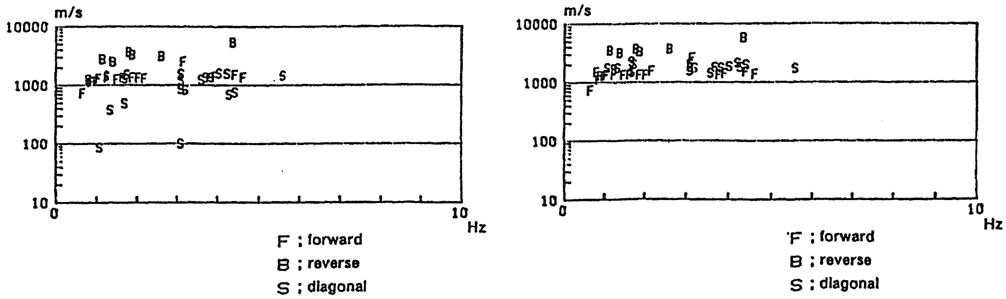


$$L\,dev = D \times \cos\theta$$

$$C = \frac{L\,dev}{\tau}$$

C ; apparent wave velocity
L dev ; propagating distance
τ ; time delay
D ; distance along the direction from thinner soft layer to thicker soft layer
θ ; angle between the azimuthal direction and the direction from thinner soft layer to thicker soft layer

Fig. 4 Calculation of Apparent Wave Velocity



(a) traveling along the azimuthal direction

(b) traveling from thinner soft layer to thicker soft layer

Fig. 5 Comparison of Apparent Wave Velocities by Conventional Theory and by Our Hypothesis

Table 1 Calculated Incident Angle at the Dilluvial Layer and Extracted Time Delay

Quake No.	Date	Origin			Azimuthal Direction	Incident Angle	Extracted Time Delay (sec)
		Northern Latitude	Eastern Longitude	Depth (km)			
60	Aug.24,'82	36° 22′	141° 29′	30	20°	6.2°	0.235
57	Aug.14,'82	36° 29′	141° 13′	40	28°	6.1°	0.230
58	Aug.16,'82	36° 30′	141° 3′	30	32°	6.2°	0.235
21	Feb.22,'81	36° 27′	140° 41′	50	40°	5.6°	0.235
17	Jan.27,'81	38° 14′	143° 3′	42	42°	5.6°	0.235
74	Jan.27,'83	35° 46′	139° 38′	57	215°	-4.5°	-0.085
23	Mar. 6,'81	32° 12′	138° 17′	360	251°	-5.3°	-0.085
56	Aug.12,'82	34° 53′	139° 34′	30	257°	-6.1°	-0.100