EARTHQUAKE OBSERVATION OF AN UNDERGROUND PIPELINE AND SEISMIC RESPONSE ANALYSIS

H.Oishi (I)
K.Sekiguchi (II)
Presenting Author: K.Sekiguchi

SUMMARY

This paper describes the effectiveness of two seismic response analysis methods (surface waves method , body waves method) for underground pipelines, based on the measured data on Izuhanto-Tohooki Earthquake. It is made clear that the seismic waves contain both surface and body waves by evolutionary spectra analysis and phase velocity analysis. On this basis the observed waves are separated into surface and body waves. Calculated strain time histories for pipelines by using the separated waves and the raw waves are compared with the observed strains.

THE EARTHQUAKE OBSERBATION

We have continued earthquake observation on an underground water pipeline (o:1800mm x t:19mm) since 1977. The observation site is located in Kawasaki City. Fig.1 shows the measurement instrument array. Eight sets of acceleration seismographs (3 components each) are used. Four sets are installed on the pipeline at the points 1,2,3 and 4. Four sets are installed on the ground at the points 5,6,7 and 8. In order to compare the ground and pipe motions, acceleration seismographs 3,7 and 4,8 are set very closely. In the two cross sections of the pipeline at the points 9 and 10, eight strain meters are installed, four strain meters in each section.

IZUHANTO-TOHOOKI EARTHQUAKE

More than twenty earthquakes have been observed since the instruments installation. In this paper, the Izuhanto-Tohooki Earthquake (June 29,1980) is dealed with for an example. Its magnitude is 6.7 and the focal depth is 10 km. The epicentral distance from the observation site is approximately 86 km.

Type of seismic waves

Fig.1 shows accelerograms obserbed at the points 5,6 and 7. During the time interval of 0-35 sec, relatively high frequency waves are amplified between the points 5 and 7. After 40 sec, relatively lower frequency waves are predominant, which are not amplified between the points 5 and 7.

Fig.3 shows particle orbits of the ground at the points 5,6 and 7. The direction of the epicenter is shown in the figure. It is clear that the motion is dominant in the transverse direction and the particle orbits at three points are almost the same. This implies that the Love wave is predominant.

It is common that wave trains form characteristic clusters depending on the type of waves. This is observed clearly on the evolutionary spectra. For example, when the wave trains are surface waves, they appear dispersively

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(I),(II) Research Engineer,Technical Research Center,Nippon Kokan K.K., Japan on the evolutionary spectra.

The evolutionary power spectra(Ref.1) of the observed earthquake motion are shown in Fig.4 and Fig.5. In Fig.4(transverse component), the clusters in the evolutionary power spectra may be separated to four groupes, A,B,C and D. The clusters A and B are strongly amplified between the points 5 and 7. They exhibit no dispersion as the locations of their peaks on the time axis do not vary with frequency. On the other hand, the clusters C and D for the points 5 and 7 have almost same intensities. They also exhibit a dispersive nature, with the peak value locations on the time axis varying with frequency. This implies that this part of the wave is Love wave. In Fig.5(radial component), the clusters are separated into two groups E and F. The clusters E and F are similar to the clusters A and B. There is no evidence of dispersive clusters which would imply the Rayleigh waves.

Surface waves propagate in the horizontal direction. On the other hand, body waves propagate in the vertical direction near the ground surface. Phase velocities of the seismic waves will be useful information for identifying surface and body waves.

Table 1 shows the phase velocities of the observed ground motion which were obtained by cross correlation method. The ground motion time histories are separated into three time ranges. The interval of 0-10 sec corresponds to clusters A and E, 10-40 sec corresponds to clusters B,C and F, and 40-80 sec corresponds to cluster D.

Based on the evolutionary spectra analysis and phase velocity, the type of seismic waves is estimated as follows.

Clustes A and E ---- These exhibit no dispersive natures, and the vertical phase velocities are nearly equel to that obtained by the seismic prospecting. Therefore, they are estimated to be S waves. Apparent phase velocities in the horizontal direction are more than 3000 m/sec.

Clusters B and F ---- These exhibit no dispersive natures, and the vertical phase velocities are nearly equel to that obtained by the seismic prospecting. So they are estimated to be S waves. But they do not seem to propagate in horizontal direction apparently, because the cross-correlation coefficients for records measured at 200 m separation are much smaller than those of the clusters A and E.

Cluster C ---- It exhibits the dispersive nature. Because cluster B has a much higher intensity than cluster C, we could not obtain the horizontal phase velocity of the cluster C from the cross correlation method. Judging from the relation between the axial strain waves and the ground velocity waves, they are estimated to be higher mode Love waves. (See also the last part of the next chapter)

Cluster D ---- It exhibits clear dispersive nature, and the horizontal phase velocity of the predominant harmonic component is 1730 m/sec. As is shown in Fig.6, the phase velocity is almost the same to the theoretical value. So it is estimated to be the fundamental mode Love waves.

Separation of Body and Surface Waves(Ref.2)

Because the frequency ranges of surface waves(the clusters A,B,E,F) and body waves(the clusters C,D) are very different, we can easily separate body and surface waves as follows; 0 - 0.3 Hz : surface waves , 0.3- (10) Hz : body waves. The separated waves are shown in Fig.7.

RELATION BETWEEN THE PIPE STRAIN AND THE GROUND MOTION

Fig.8 shows the relation between the pipeline and the ground motion. First, we examine the motion of the pipeline and the surrounding ground. In Fig.8, the pipe velocity and the ground velocity are very similar to each other. The pipe acceleration is a little larger than the ground acceleration in the time interval of 0-10 sec, where predominant frequencies are relatively high(1-2 Hz). But they are very similar after 20 sec. From this, it can be concluded that the pipeline and the surrounding ground move in the same manner except for relatively high frequencies.

Next, the relation between the ground motion and the pipe strain is examined. In Fig.8, the axial strain is similar to the ground velocity in the interval of 0-10 sec and after 40 sec. Therefore, it is estimated that the axial strain was caused by the horizontally propagating waves(the clusters A, D, E). In the interval of 10-40 sec, the axial strain of around 1 Hz is estimated to have been caused by irregular ground motion by the clusters B and F(body waves which do not propagate apparently in the horizontal direction). At relatively lower frequencies, on the other hand, axial strain and ground velocity are similar. Therefore, the axial strain in this region may be caused by the horizontally propagating waves(the cluster C).

Now the phase velocity for cluster C is estimated. In Fig.8, the ratio of the ground velocity to the pipe strain for the interval of 10-40 sec (cluster C) is nearly equel to that for 40-80 sec (cluster D : the phase velocity is 1730 m/sec). This implies that the phase velocity of the cluster C is almost equel to that of the cluster D.

EFFECTIVENESS OF SEISMIC RESPONSE ANALYSIS METHOD OF UNDERGROUND PIPELINE

Various seismic response analysis methods of underground pipelines have so far been proposed. Herein the following two seismic response analysis methods are examined regarding its effectiveness.

Method I --- Surface wave method which one of the authors has already proposed(Ref.3). This method is mostly based on Ref.4.
Method II -- Multiple lumped mass method which deals with body waves(Ref.5)

Observed and Calculated Strains from Unseparated Records

Separation of recorded motions into surface and body waves is not so easy in many cases. This often makes one perform the analysis under the assumption that the entire ground motion is either surface waves or body waves. Fig.9 shows the calculated strains by using the original observed ground motions.

In method I all the input motion have been treated to be fundamental mode Love and Rayleigh waves. The calculated strain of around 1Hz is 3 times the observed one. This is a consequence of using the dispersion curve in Fig.6 for all frequency ranges. In Method II, all the input waves have been treated as body waves. The calculated strain is very different from the observed one.

Obseved and Calculated Strains from Separated Records

The seismic response analysis has been performed by using the separated waves(Fig.6). Fig.10 shows the calculated strains. In Case 1 the axial strain has been calculated from method I by using separated surface waves. As the 0-0.2 Hz waves correspond to cluster D, they are treated as the fundamental mode Love wave. Similarly the 0.2-0.3 Hz waves are treated as the second mode Love wave, as they correspond to cluster C. The calculated strain gives a good agreement with low-frequency components of the observed strain, say 0-0.3 Hz.

In Case 2 and Case 3, the axial strains have been calculated from Method II by using separated body waves. The calculated strains are similar to the observed strain in the sense that they have similar predominant frequencies and the maximum strains are in the same order of magnitude. However, in the phase characteristic they do not give a good agreement. In Case 4 and Case 5 the calculated strains have been obtained by superposing those from Method I and Method II. The superposed strains give a good agreement with the observed strain.

From the foregoing discussion, it may be concluded that seismic response analysis of underground pipelines should be performed by using surface and body waves separately for the input ground motion.

CONCLUSIONS

The results may be summarized as following conclusions.

1. By evolutionary spectra and phase velocity, the types of the seismic waves observed in Izuhanto-Tohooki Earthquake were estimated. The observed waves were separated to surface and body waves.
2. Not only horizontally propagating waves but also irregular ground motions seem to cause axial strain of the underground pipeline.
3. When the ground motion contains both surface and body waves, the calculated pipe strain by the conbining Method I and Method II gives a good agreement with the observed strain.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. Nishizuka and the designing staffs of Kanagawa Kennai Koiki Suido Kigyodan for their cooperation in the arduous earthquake observation and Dr. Kameda and Mr. Sugito of Kyoto University for many advices about the evolutionary spectra and the separation of the seismic waves.

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Table 1 Phase Velocity of Seismic Waves

	direction	time range (sec)	coefficient of correlation	time delay (sec)	phase velocity (m/sec)
transverse component	horizontal	0 - 10	0.72	0.05	3460
		10 - 40	0.54	-	-
		40 - 80	0.80	0.10	1730
	vertical	0 - 10	0.61	0.28	168
		10 - 40	0.51	0.26	181
		40 - 80	0.86	0.01	4700
radial component	horizontal	0 - 10	0.85	0.04	4325
		10 - 40	0.57	-	-
		40 - 80	0.76	0.11	1573
	vertical	0 - 10	0.69	0.28	168
		10 - 40	0.50	0.27	174
		40 - 80	0.79	0.02	2350

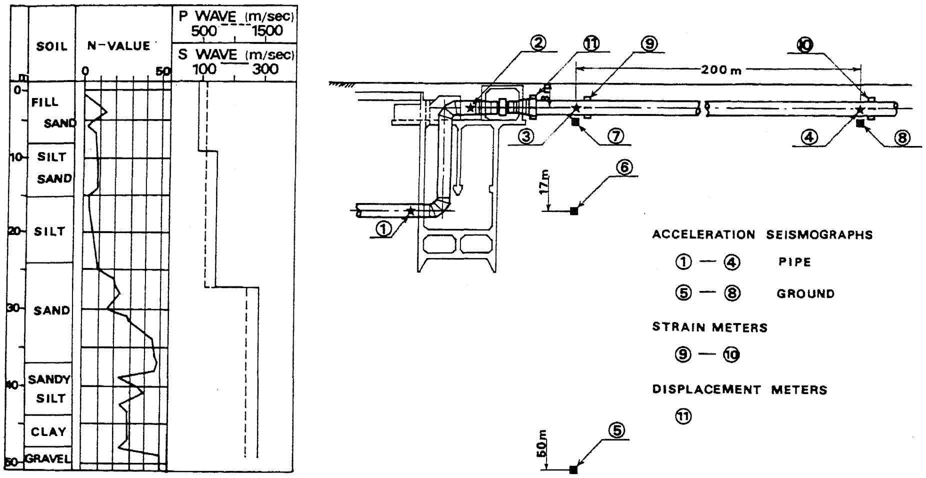


Fig.1 Soil Profile and Measurement Instrumentation

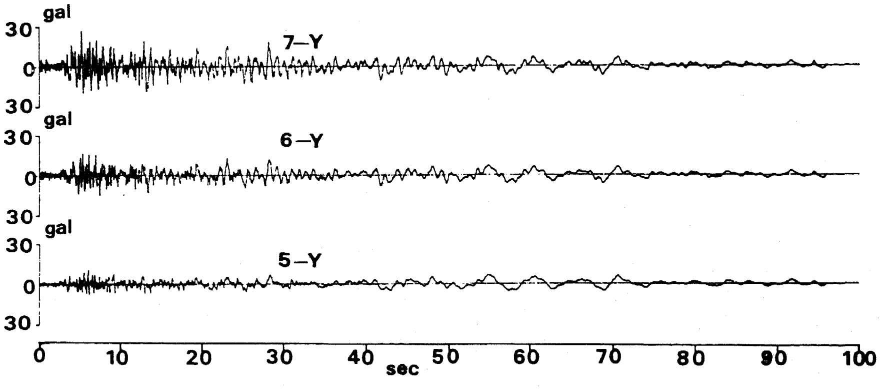
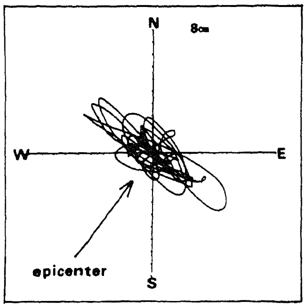
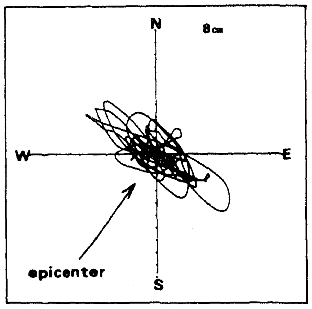


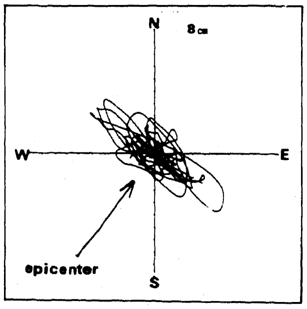
Fig.2 Observed Accelerograms during the Izuhanto-Tohooki Earthquake of June 29, 1980



(a) ⑤ (GL- 50m)

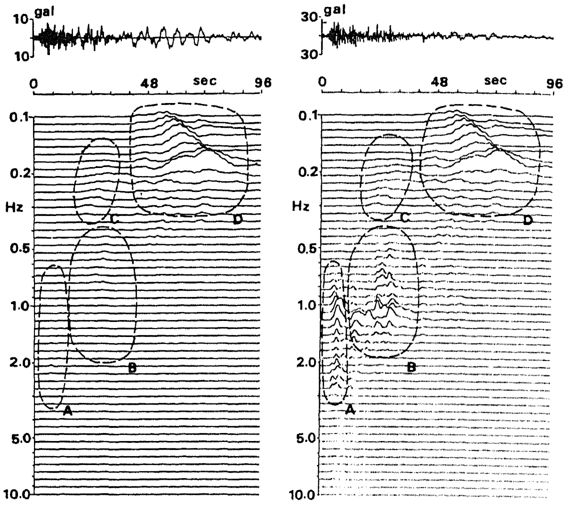


(b) ⑥ (GL-17m)



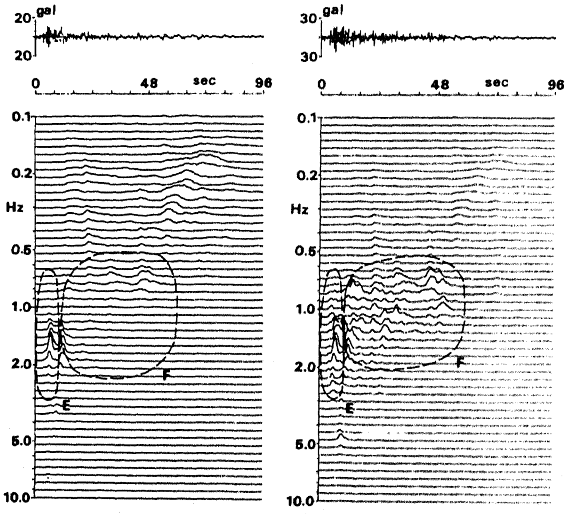
(c) ⑦ (GL-3m)

Fig.3 Particle Orbits



(a) observation point⑤ (GL-50m) (b) observation point⑦ (GL-3m)

Fig.4 Evolutionary Spectra
(transverse component)



(a) observation point⑤ (GL-50m) (b) observation point⑦ (GL-3m)

Fig.5 Evolutionary Spectra
(radial component)

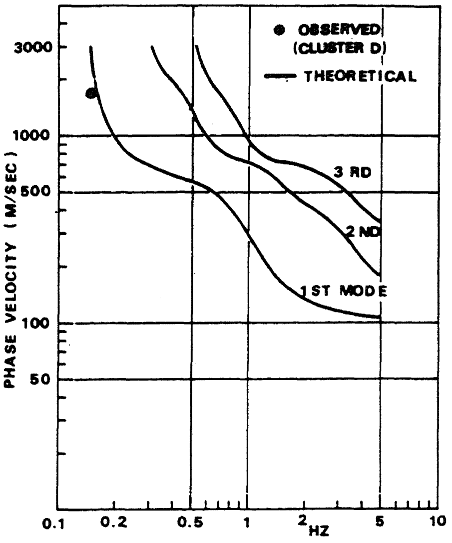


Fig.6 Theoretical Dispersion Curve and Observed Phase Velocity

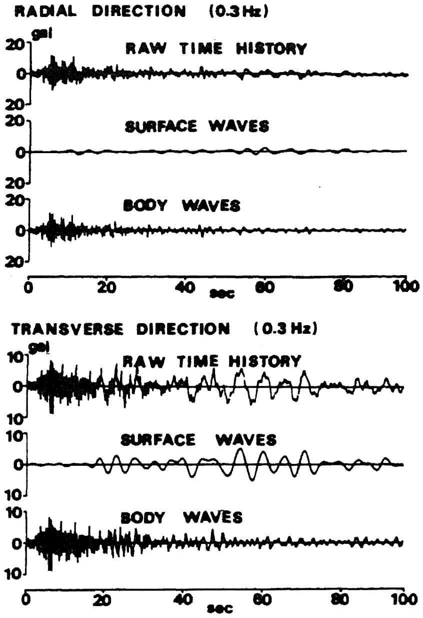


Fig.7 Separated Surface and Body Waves

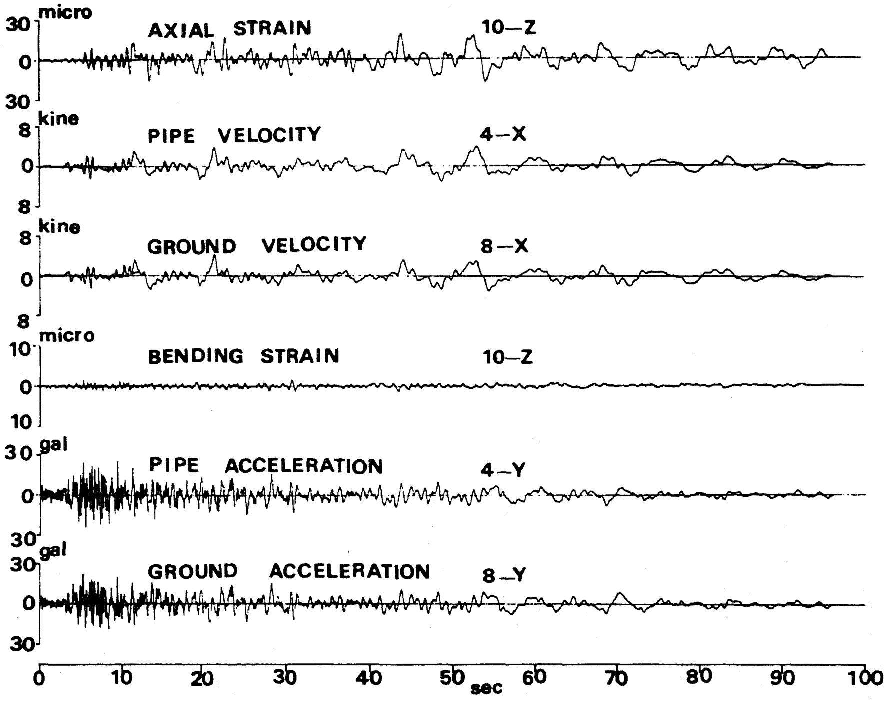


Fig.8 Relation between Pipe Strain and Ground Motion

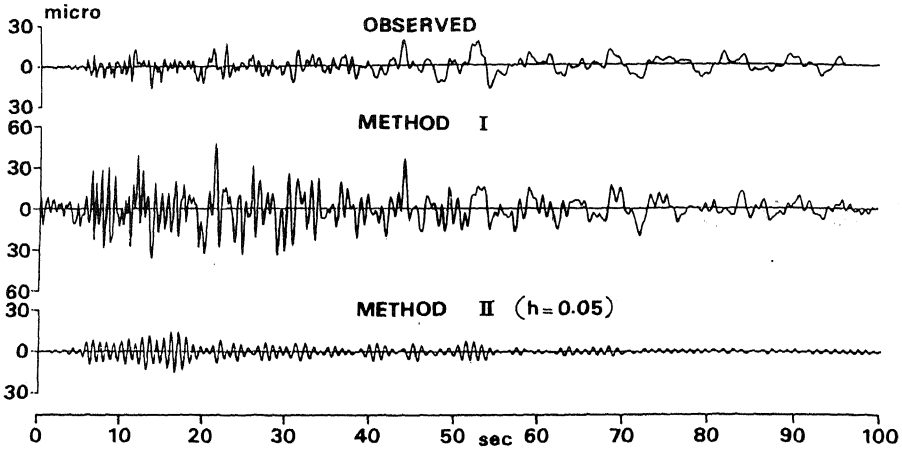


Fig.9 Observed and Calculated Axial Strain
(input waves: raw waves)

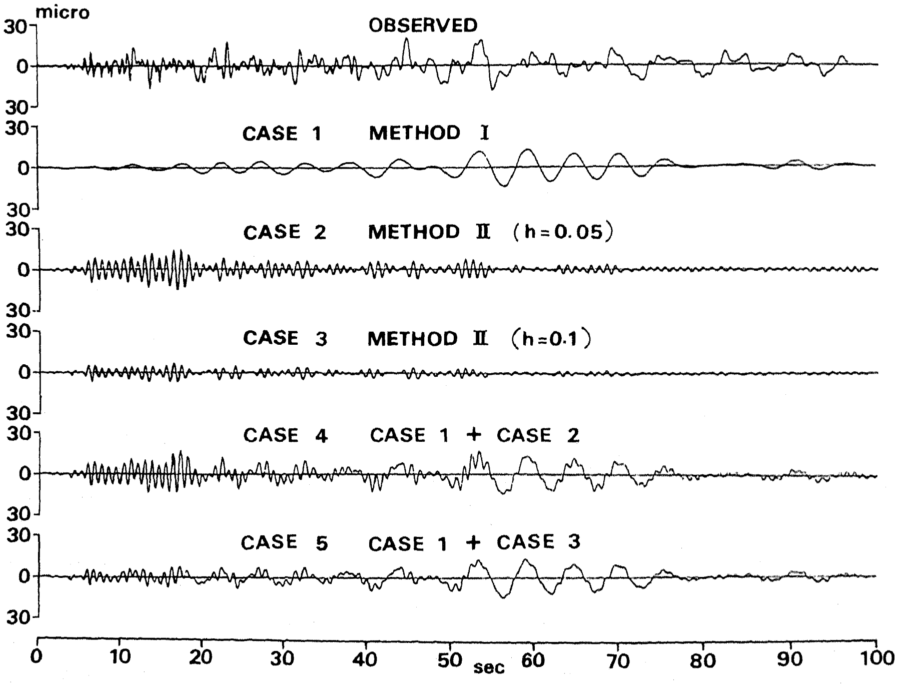


Fig.10 Observed and Calculated Axial Strain
(input waves: separated surface and body waves)