# DISINTEGRATION OF ACCELEROGRAMS INTO SURFACE AND BODY WAVES

by

Kenzo TOKI I)

## SYNOPSIS

The phase velocity dispersion curves for frequency range from 0.2 to 2 Hz are detected from strong-motion earthquake records which were obtained during the San Fernando earthquake Feb.9, 1971. The resulting dispersion curves indicate that the phase velocity is greatly dependent on frequency, especially in the frequency range from 0.3 to 1 Hz. Making use of the dispersion curves, time traces of strain at the ground surface are computed for a few kind of strain components being attributed to both of surface and body waves. The maximum strain amplitude incorpolated with surface waves are comparable with strain amplitude which is estimated under the assumption of vertically incident SH wave in a near-surface ground.

## INTTRODUCTION

The seismic waves with period from 1 to 10 sec is getting important in the response analysis of large scale structures such as high-rise building, long-spanned bridge and so on. However there is a pausity of information on the wave transmission properties of such period range because those period is not so dominant in accelerograms recorded during the past strong-motion earthquakes. Although the velocity time trace may provide useful informations for wave properties of this frequency range, accelerograms are still important in the structural response analysis to the ground shaking and a number of studies 1)-3) have investigated the existence of surface wave components in some earthquake records which were taken by accelerographs.

Two different methods have been frequently used for seismic response analysis of near-surface ground; one is the multiple reflection method of vertically incident SH wave and the other is the lumped mass method which can be adopted to nonlinear behavior of soils. Both methods, however, assume the vertical incidence of SH wave or horizontal shaking by the prescribed acceleration and therefore only one component is considered when the methods are applied to the inference of strain. Taking into account the surface wave component of seismic records it is of interest to investigate the strain incorpolated with surface waves, in relation to the seismic response of ground and/or submerged structures.

## STRONG-MOTION ACCELEROGRAMS

The pahse velocity can be determined from the travel time of waves between two different stations if a common time signal is marked on both records. In order to apply the method to accelerograms recorded by usual accelerogragh networks, it is necessary that two stations have the same epicentral azimuth and the distance is less than about 10 km because the damping is noticeable for high frequency components which is predominating in accelerograms.

From the strong-motion accelerograms4) recorded during the San Fernando earthquake, Feb.9, 1971, two sets of recording stations are selected for the analyses. Location of those stations is shown in Fig.1. The distance between

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I) Prof., Disaster Prevention Res. Inst., Kyoto Univ., Kyoto, Japan.

HW and WS sites and VO and VT sites are 3.2 km and 4.5 km respectively and they have almost the same epicentral azimuth. Table 1 summarize the location, structural type and soil condition of these recording stations.

Two horizontal components of source accelerograms are converted into the transversal(TRNS) and longitudinal(LNGT) component with respect to the epicentral azimuth. Fig.2 shows the Fourier spectra at HW and WS sites and Fig.3 illustrates a cross spectrum of both records. As seen in Fig.2, there is little correlation for frequency range higher than about 2 Hz and this result implies that high frequency components of the range are not necessarily attributed to surface waves traveling along the ground surface but are associated with body waves which are transmitted through the base rock and magnified in surface layeres. Figs.4 and 5 show the shear velocity distribution with depth at HW and VO sites. Geology at VT site is close to that of VO site and the geology to the base rock at WS site is not available.

## PHASE VELOCITY DETECTION

Although the phase velocity can be estimated from the travel time between two stations if a common signal is marked on recordings at both stations, such a simultaneous triggering device is not provided in usual accelerogragh networks and the origin of time axis is not corresponded each other. As seen in Fig.2, however, since waces with period of about 4 to 5 sec are contained in both records and the phase velocity of this frequency range is considered to be close to that of a base rock, the travel time can be estimated from the distance between two stations and therefore we can adjust the origin of time axis of both records. Moreover in some cases we can find a corresponding phase on both of velocity curves integrated from accelerograms. Fig.6 is an examle of the case, in which the arrows on both velocity curves are considered to be the same phase.

The sums and differences method[5)] is used in the study to detect the phase velocity from accelerograms. Now consider the Fourier transform $H_+(\omega,\tau)$ and $H_-(\omega,\tau)$ of accelerograms $f_a(t)$ and $f_b(t)$ , which defined by

$$H_+(\omega,\tau) = \int\{ f_a(t+\tau)+ f_b(t) \}\exp(-i\omega t)dt \qquad (1)$$

$$H_-(\omega,\tau) = \int\{ f_a(t+\tau)- f_b(t) \}\exp(-i\omega t)dt \qquad (2)$$

in which $\tau$ represents the phase delay time and $f_a(t)$ is the record at the nearer site to the epicenter. $H_+(\omega,\tau)$ takes the maximum value and $H_-(\omega,\tau)$ the minimum value when two records are in phase for a given frequency. Then defining the function $G(\omega,\tau)$

$$G(\omega,\tau) = \log\{ H_-(\omega,\tau)/H_+(\omega,\tau) \} \qquad (3)$$

this function takes large negative value when two records are in phase and positive value when out of phase by $\pi$ for a wave with circular frequency $\omega$. Appling the method to the records at HW and WS sites yields the result shown in Fig.7 for TRNS component and Fig.8 for LNGT component. Since the positive and negative values of $G(\omega,\tau)$ compose the peaks and troughs on the chart as shown in Figs.7 and 8, plotting of the train of successive deep trough defines the travel time-frequency relationship, which is marked by shade on the chart.

Appling the method to the other set of accelerograms recorded at VO and VT sites, the phase dispersion curves are determined as shown in Fig.9, which are converted from the travel time between the stations. It is noticeable in this figure that the phase velocity varies remarkably from the base rock velocity level for period around 3 to 4 sec to the level of 1.0 to 1.5 km/sec for the higher frequency component than about 1.0 Hz. Fig.10 illustrates TRNS component of record at HW site, out put from low pass filter with cut off frequency 0.5 Hz and that from high pass filter with same cut off frequency. This figure indicates that the high frequency components beyond 2 Hz is predominated in the first 8 to 10 sec, which is accompanied with high acceleration amplitude. Q value of surface ground in Los Angels area6) is reported to be about 20 to 50. Therefore, for example, a wave with period 0.5 sec decreases its amplitude from 0.05 to 1.0 while it travels between two sites HW and WS. Moreover frequency contents of 2 to 4 Hz is predominant accelerogragh records in the near epicentral region and its duration time is 8 to 10 seconds. Considering these facts, it is obvious that the first 10 sec of records is caused by response of near-surface ground to the shaking of body waves traveling through the base rock and, consequently, waves with longer period beyond about 2 sec seems to be surface waves.

In order to verify the result above obtained, a method proposed by Sutton7) is adopted. A result is shown in Fig.11 in which the first two acceleration time traces are longitudinal and vertical components of records at HW site and the third is the multiplication of both components. The fourth and fifth curves are filtered traces of the third trace with cut off frequency 1.0 and 0.5 Hz respectively. If the longitudinal and vertical components are associated with body wave, the trace of multiplication of both components keeps the same sign with respect to the base line depending on the sense of original recordings. If Rayleigh wave is contained in records, the resulting time trace oscilates around the base line. From the results illustrated herein, it is concluded that the first 6 to 8 sec is mainly due to body waves and Rayleigh-type component exhibit the corresponding predominant phases in the remaining portion of records.

## STRAIN COMPONENTS

It is usually interpreted that the strain in near surface ground is chiefly caused by multiple reflection of vertically incident SH waves in parallel soil layers. However, as discussed above, the surface wave components are evidently contained in acceleration time traces and therefore some consideration should be paid not only on the strain by SH waves but also on the strain induced by surface waves in a near surface soil layer. Moreover since the seismic behavior of such structures as submerged tubular structure is almost governed by the relative displacement of adjacent soil, strain in subsurface ground becomes important factor for the aseismic design for this kind of structures. From this point of view, the inference of stress and strain induced by wave transmission along the ground surface is an area of research deverving more attention.

The velocity trace and phase velocity characteristics are necessary to obtain the time trace of strain. The velocity time trace is easily computed by integration of accelerogram and however, the dispersion curve giving the phase velocity have been obtained only for the frequency range below 2 Hz. Then, for comparative purpose, three curves T1,T2 and T3 are assumed for frequency range higher than 2 Hz as shown in Fig.12. Three case are compared in Fig.13 to show the small effect of the variation of the dispersion curves in higher frequency range. Appling the method to the other components and another recordings treated herein, the almost same results are obtained and this implies that the dispersion characteristics of frequency range below about 2 Hz is the most important for inference of strain induced by waves traveling along the ground surface.

Strain developed by surface wave components are compared with strain induced by vertically incident SH wave and the result is summarized in Table 2. Strain levels listed in Table 2 represents the maximum amplitude reached in every strain time traces and those values of surface waves denote the strain amplitude at the ground surface. Although the phase velocity of surface wave is almost ten times of that incorpolated with SH wave, the strain level is comparable and the strain level by surface wave components may increase significantly in case of lower phase velocity and nonlinear behavior of soils.

## CONCLUSION

The phase velocity of waves traveling along the ground surface is detected from accelerograms of the San Fernando earthquake, Feb.9, 1971 for the frequency range of 0.2 to 2 Hz, which is greatly depending on the frequency, especially in the period range from 4 to 1 sec. The existence of surface wave components in accelerograms is confirmed by a few different method and strain components developed by this kind of wave are compared with strain induced by vertically incident SH wave. Strain level computed under the assumption of vertically incident SH wave and that of surface wave are comparable. Considering the vector space composed by these strain components, strain levels actually reached in near surface ground during earthquakes seems to be higher than that caused by SH wave only.

## REFERENCES

1) Shima, E.: Seismic Surface Waves Detected by the Strong Motion Acceleration Seismogragh, Proc. Third Japan Earthq. Eng. Symp., 1970, pp.277-284.

2) Bolt, B.A.: San Fernando Rupture Mechanism and Pacoima Strong-Motion Record, Bull. Seis. Soc. Am., Vol.62, No.4, 1972, pp.1053-1061.

3) Hanks, T.C.: Strong Ground Motion of the San Fernando, California, Earthquake: Ground Displacement, Bull. Seis. Soc. Am., Vol.65, No.1, 1975, pp.193-225.

4) Hudson, D.E., A.G. Brady and M.D. Trifunac: Strong-Motion Earthquake Accelerograms, Vol.II, Part D, E, I and J, Earthq. Eng. Res. Lab., Caltec, 1971.

5) Bloch, S. and A.L. Hales: New Techniques for the Determination of Surface Wave Phase Velocities, Bull. Seis. Soc. Am., Vol.58, 1968, pp.921-1034.

6) Lastrico, R.M., C.M. Duke and Y. Ohta: Effwcts of Site and Propagation Path on Recorded Strong Earthquake Motions, Bull. Seis. Soc. Am., Vol.62, No.4, 1962, pp.933-954.

7) Sutton, G.H. and P.W. Pomeroy: Analog Analysis of Seismograms Recorded on Magnetic Tape, J. Geophys. Res. Vol.68, 1963, pp2791-2815.

8) Toki, K. and S. Cherry: Inference of Underground Seismic Motions from Surface Accelerogragh Records, Proc. Fifth World Conf. on Earthq. Eng., 1973, pp.745-754.

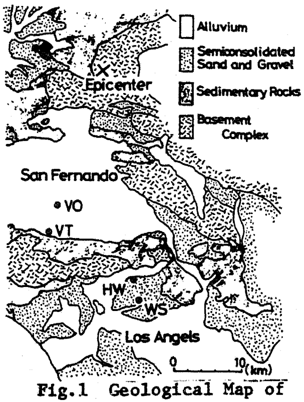

Fig.1 Geological Map of Epicentral Region and Recording Stations.

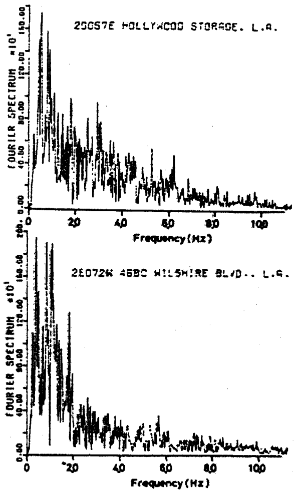

Fig.2 Fourier Spectra of Accelerograms at HW and WS site (TRNS comp.)

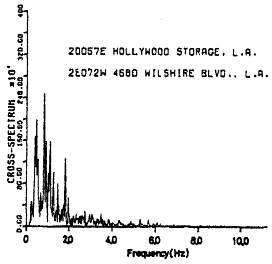

Fig.3 Cross-spectrum of Accelerograms at HW and WS site (TRNS comp.)

Table 1 Data of Recording Stations.

| Station | Location | Geology | Ref.No. |
|---|---|---|---|
| HW -- Hollywood Storage | Basement of 14-story Bldg. | Alluvium | D057 |
| WS -- 4680 Wilshire Blvd. | Basement of 7-story Bldg. | Alluvium | E072 |
| VO -- 15107 Vanowen St. | Basement of 7-story Bldg. | Alluvium | J145 |
| VT -- 15910 Ventura Blvd. | Basement of 17-story Bldg. | Alluvium | I137 |

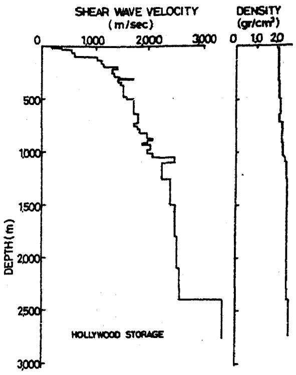

Fig.4 Subsurface Model at HW site.

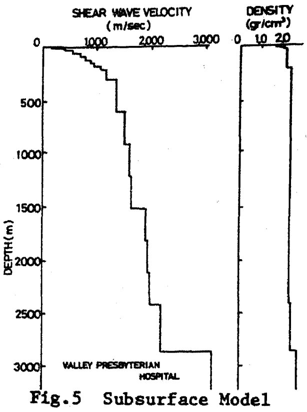

Fig.5 Subsurface Model at VO site.

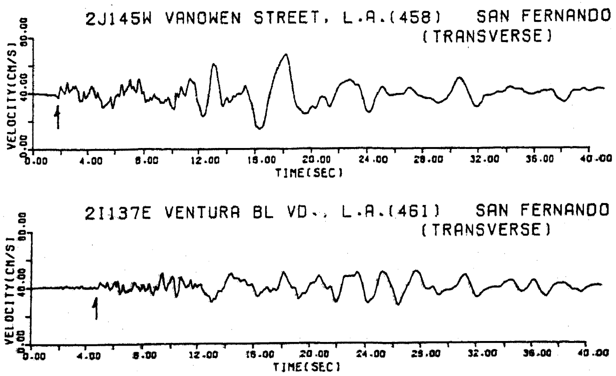

Fig.6 Velocity Curves Converted from Accelerograms at VO and VT sites.

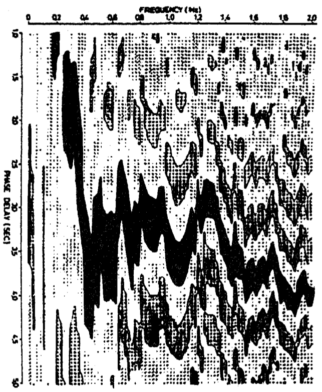

Fig.7 Phase Delay Time vs. Frequency Chart ( HW-WS site, TRNS comp.)

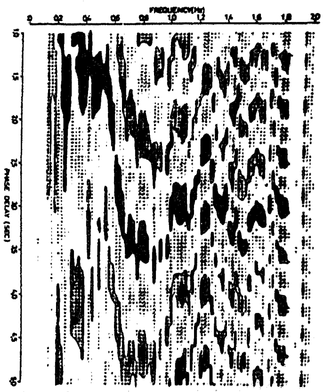

Fig.8 Phase Delay Time vs. Frequency Chart ( HW-WS site, LNGT comp.)

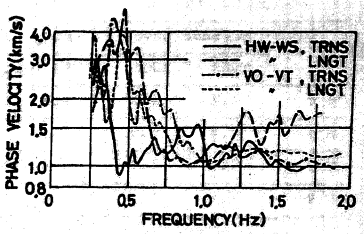

Fig.9 Dispersion Curve

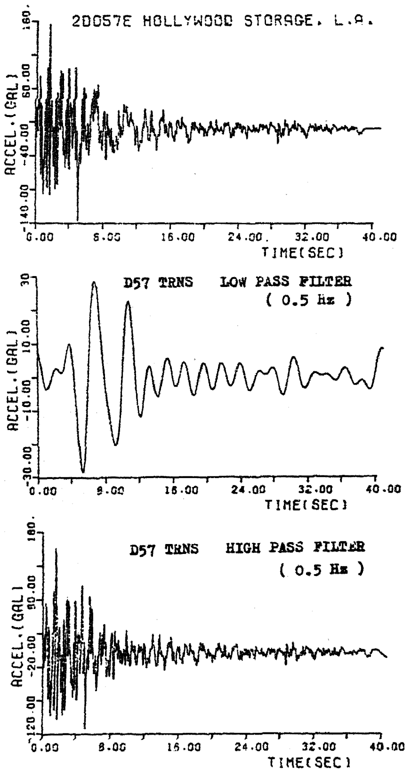

Fig.10 Filtering of Accelerogram

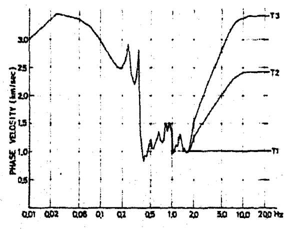

Fig.12 Dispersion Curves

Table 2 Comparison of Maximum Strain Level

( $\times 10^{-4}$ )

| | Surface Wave | | Body Wave |
|---|---|---|---|
| | TRNS | LNGT | SH (depth) |
| H W | 1.2 | 1.0 | 3.9 (10m) |
| W S | 1.4 | 0.9 | —— |
| V O | 1.3 | 1.9 | 1.4 (60m) |
| V T | 0.7 | 1.4 | 2.4 (10m) |

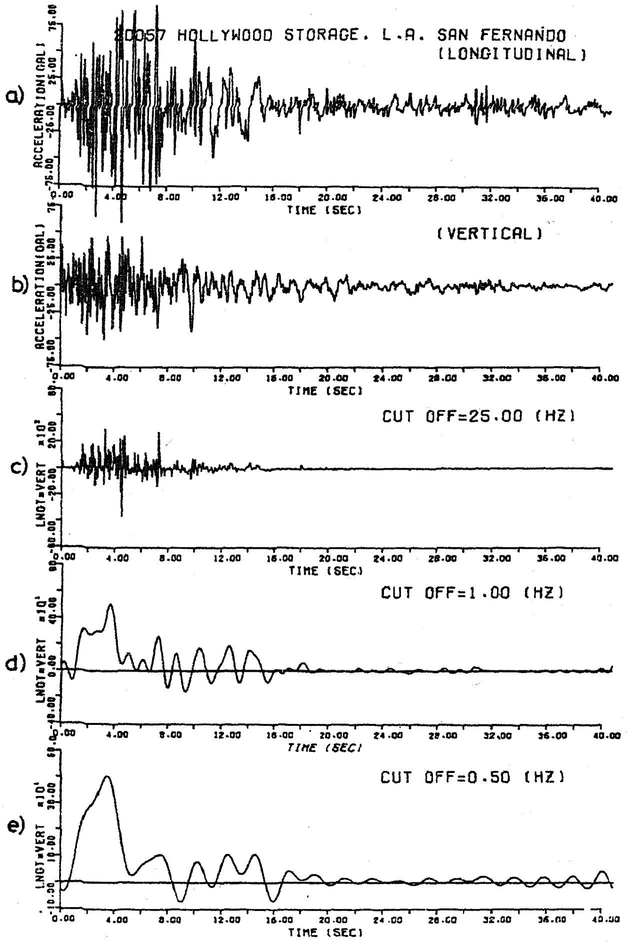

Fig.11 Detection of Rayleigh Wave

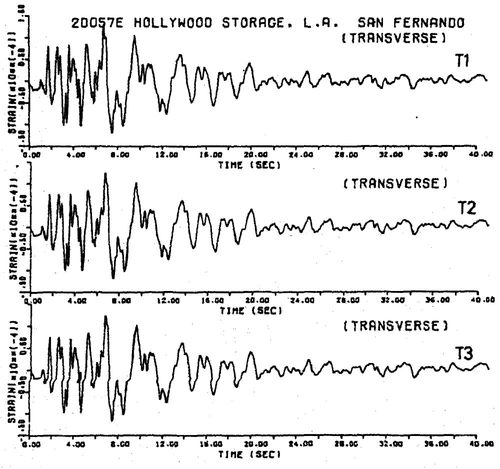

Fig.13 Influence of Dispersion Characteristics on Strain Curve