CS 4 - 3〔I〕 GROUND STRAINS DUE TO PROPAGATING SEISMIC WAVES

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INTRODUCTION: Array observation systems are extremely useful in the study of stress and strain induced by wave transmission along the ground surface.[1,2] In this paper, the ground strains caused by travelling seismic waves are investigated using the data obtained at the Chiba Experiment Station of the Institute of Industrial Science, University of Tokyo. The axial and shear ground strains induced by the seismic waves are evaluated using the wave propagation theory and compared with the strains measured directly.

STRAINS FROM WAVE PROPAGATION THEORY: Generally, earthquake motions are the results of stress waves propagating through the ground. It is commonly assumed[3] that the displacement field $\rho(x,t)$ can be written as a travelling wave: $\rho(x,t) = f(x-ct)$ where c is the phase velocity, x is the position, and t is the time. After finding the various derivatives of the displacement ρ with respect to x and t, the following expressions can be derived:

$$\varepsilon = -\frac{V}{c} \quad (1); \qquad \text{curvature} = \frac{a}{c^2} \quad (2); \qquad \gamma = -\frac{V_t}{c_r} - \frac{V_r}{c_t} \quad (3)$$

where ε is the axial ground strain, V is the particle velocity, a is the acceleration in a direction perpendicular to the direction of propagation, γ is the shear ground strain, V_r and V_t are the particle velocities in the radial and transverse directions, respectively, and c_r and c_t are the speeds of propagation of waves travelling in radial and transverse directions, respectively. The validity of these expressions is investigated by using the records obtained at the Chiba Experiment Station. The characteristics of the array have been already described.[1] A database comprising the 27 stronger motions recorded so far was employed to identify the records that are dominated by surface wave motion. The correlation between pipe strains and the peak values of the ground motions was investigated. Two groups of motions could be clearly distinguished. In one group, comprising 25 out of the 27 events, the strain was found to be linearly proportional to the peak acceleration. These are events caused almost exclusively by body waves. The second group, which includes two events, corresponds to the motions induced mainly by surface waves. One of the motions of the second group, the Naganoken-Seibu earthquake (Mg=6.8) of September 14, 1984 (event 8414) was selected for the analysis. Figure 1 shows the time trace and the nonstationary spectra for this event. The power is found to concentrate at the low frequency range ($f < 1.0$ Hz). The arrival of a train of waves of the surface type can be seen clearly at about 130 s from the starting time. The dominant period of the surface wave is found to be 4 to 5 s. The initial part of the motion, assumed to be caused by body waves, shows the power concentrated at much higher frequencies. The motions due to P waves can be identified at the very beginning and the arrival of S-waves is seen at about 25s.

METHODOLOGY: The frequency-wavenumber spectrum was used to estimate the apparent wave velocity. The time window between 130 and 200s was adopted. The level of noise was found to be dominant for frequencies higher than 1.0 Hz. The estimation was carried out in the frequency range between 0.15 and 0.30 Hz at 0.012 Hz intervals and smoothing was performed over near-neighbor frequencies using a frequency window of 0.098 Hz. The values estimated for apparent wave velocity and azimuthal angle were 0.98 km/s and 259 degrees clockwise from north, respectively. The azimuthal angle was found to be close to the direction of the epicenter. These values along with the ground velocity obtained from the integration of the acceleration records were employed to evaluate the axial and shear ground strains using equations 1 and 3. The time traces of the evaluated strains and the observed ground strains are presented in Fig. 2. There is a good coincidence both in strain amplitude and phase. A comparative analysis is also carried out in frequency domain using the coherence function, the phase delay function and the Fourier spectrum ratio. Results are presented in Fig. 3. A good correlation is found at the low frequency range. Any agreement can hardly be found for frequencies higher than 0.5 Hz. It can be concluded then that ground strains induced by motions with dominating surface waves can be estimated with reasonable accuracy by assuming wave propagation effects only. Strains induced by body waves may show a much more complex behavior and may be strongly affected by other factors such as local geology and the propagation path from the epicentral region.

CONCLUSIONS: The accuracy of the estimation of seismic ground strains by applying the wave propagation theory was investigated using data obtained at the Chiba site. A motion dominated by surface waves was selected for the analysis. Good agreement between estimated and observed strains was obtained both in amplitude and phase. The highest correlation was achieved at the low frequency range. Almost no agreement could be observed for frequencies higher than 0.5 Hz.

REFERENCES:

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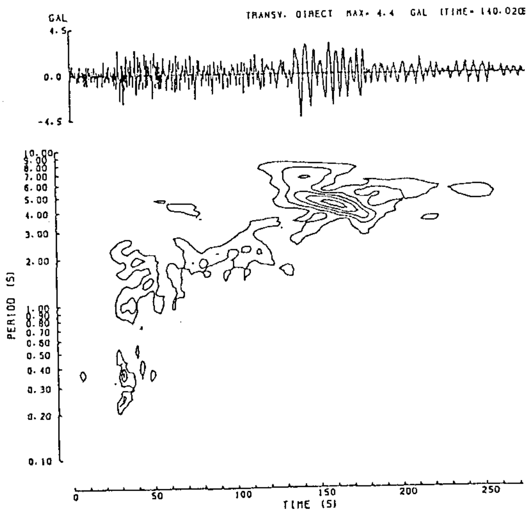
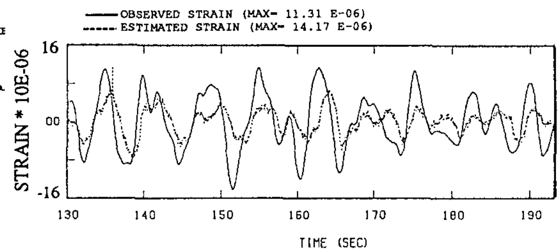
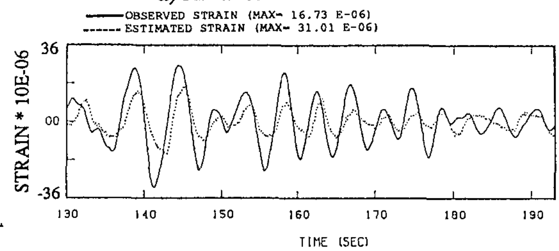


Fig. 1 Nonstationary spectra for event 8414

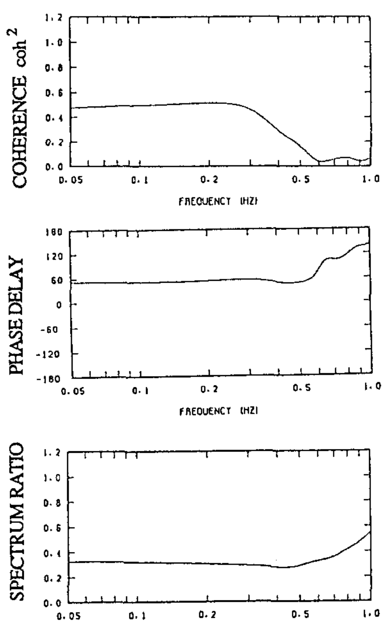


a) Axial strain



b) Shear strain

Fig. 2 Comparison of estimated and observed strains



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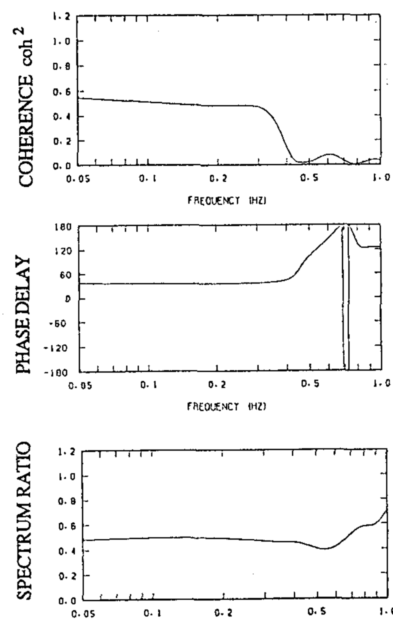

b) Shear strain

Fig. 3 Comparison of estimated and observed strains in frequency domain