(51) COMPARISON OF GROUND AND PIPE STRAINS DURING EARTHQUAKES

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SUMMARY: A study on the correlation between ground strain and pipe strain is carried out based on earthquake observation at the Chiba Experiment Station. A comparative analysis is performed in both the time and the frequency domains. Unreasonable peaks in the low frequency range are detected in the ground strain records. The characteristics of the cumulative power of strains are studied. More than 90% of the strain total power is found to be contributed by the frequency range between 0.1 and 6.5 Hz. The relative motion between pipe and soil is found to be negligible for the earthquakes considered in the analysis.

INTRODUCTION

The seismic behavior of the buried linear structures such as pipes and tunnels is strongly influenced by the relative displacement of the surrounding soil. Simplified procedures for the analysis of strains due to the wave propagation effects were first developed by Newmark [1] and have since been used and/or extended by a number of researchers. It is assumed in this analysis procedure that the pipeline and soil tend to move together, that is, the inertia terms are small and may be neglected.

In this report, a comparison study is conducted between pipe strains and the strains in the adjacent soil medium. The study employs the data obtained at the Chiba Experiment Station of the Institute of Industrial Science, University of Tokyo. A detailed comparative analysis is performed to investigate the correlation between ground and pipe strains, assess the accuracy of the recorded strains, and identify the ill-effect of instrumental errors and of long-period noise.

STRAIN MEASUREMENT SYSTEM IN THE CHIBA STATION

The Chiba Experiment Station is located 30 Km east of Tokyo. The topographical and geological conditions of the site are generally simple with the ground surface being almost flat. The top soil layer is loam with thickness of 4-5 m resting on a 4-meter-thick clayey layer. The clayey layer is underlain by a sand layer. The groundwater table was found to be lower than GL -5 m.

The strain measurement system installed at the site consists of buried pipes of two different materials and three ground strain transducers as presented in Fig. 1. A welded steel pipe and a ductile-cast-iron pipe of diameter 150 mm are buried at GL -1.3 m. Twenty-nine strain gauges are attached to these pipes to measure the strain in the steel pipe, and both the strain and the relative displacement over the joints in the ductile-cast iron pipe. The relative displacements of ground are directly measured at GL -1.3 m by means of three displacement transducers (G1 - G3).

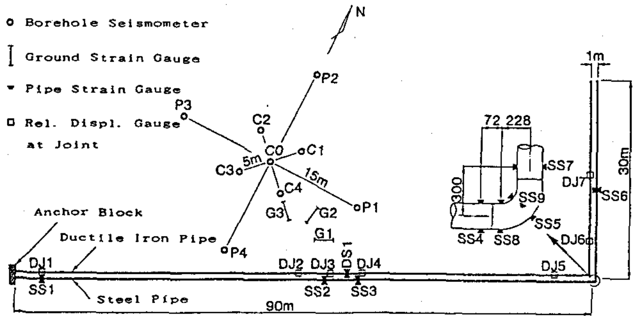


Fig. 1 Strain Measurement System at Chiba Site.

The ground strain transducers measure the changes in distance during earthquakes between two points that are 3 m apart. Details of the transducer are shown in Fig. 2.

More than 160 earthquakes have been recorded since 1982. Based on 27 major events whose peak acceleration is greater than 20 cm/sec^2, a strong motion database [2] has recently been created. This database was employed in the present study. Out of this 27 major events, the four strongest records were selected for the analysis of the strains. The main features of these events are summarized in Table 1.

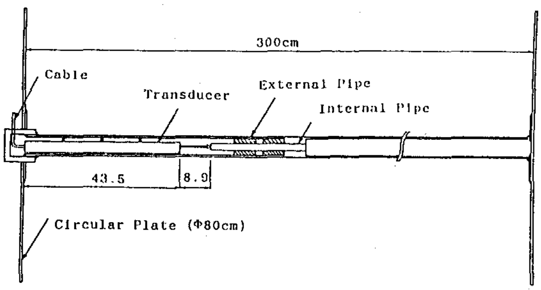


Fig. 2 Details of ground strain transducer.

Table 1 Events selected for the analysis

Event Code IEQK	Date	Max. Accel. at C001 (cm/s^2)	Epicent. Distance (km)	JMA Magnitude	Focal Depth (Km)	Max. Pipe Strain (x 10E-06)
8307	83.02.27	55.7	45	6.0	72	15.7
8519	85.10.04	82.2	131	6.1	78	18.2
8722	87.12.17	327.1	105	6.7	58	55.6
8816	88.03.18	59.8	28	6.0	96	18.3

CORRELATION BETWEEN GROUND AND PIPE STRAINS

The ground strains measured by the transducer G1 and the pipe strains recorded at the strain gauge SS2 (see Fig. 1) are utilized to investigate the correlation between pipe and ground strains. The separation distance between the pipe and the transducer is approximately 5 m.

The power spectra of the ground and pipe strains recorded during the events 8722 and 8307 are shown in Fig. 3. The general characteristics are seen to be basically the same although some reduction is observed in the amplitudes of the spectra corresponding to the ground strain. Note that the power of the frequencies higher than around 6.5 Hz is very small. Important differences were found in the low range of frequencies, especially for the weaker motions. While the amplitudes of the power spectra of the pipe strain diminish as the frequencies get lower, sharp peaks were observed for the ground strains. Since these peaks are not present in the case of the pipe strains and their effect is much more noticeable for the weaker motions, they are likely to be the result of long-period noise.

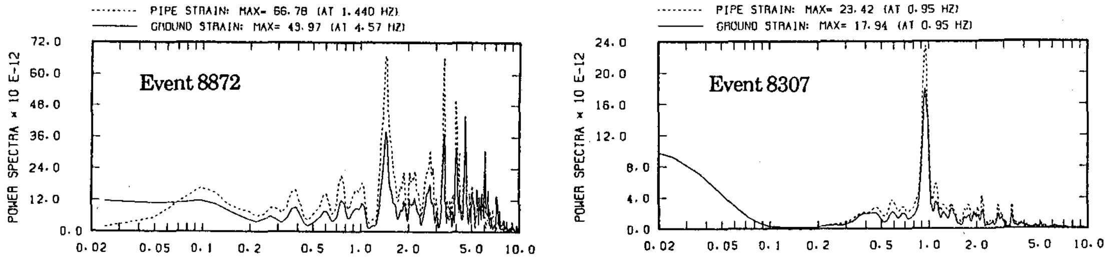


Fig. 3 Comparison of the power spectra of ground and pipe strains for Events 8722 and 8307

A comparative analysis in frequency domain was carried out with the aid of the coherence function, the phase delay, and the Fourier spectrum ratio. When estimating the spectra for a pair of records, a smoothing technique is employed with the Parzen window of bandwidth = 0.30 Hz. Figure 4 shows the results obtained for the four selected events.

A very high degree of correlation was found for frequencies up to approximately 6.5 Hz. The coherence function dropped drastically for frequencies higher than 6.5 Hz. Similar characteristics were observed for the phase and the spectral ratio. This is something to be expected due to the very small power corresponding to the frequencies higher than 6.5 Hz that makes impractical the comparison of ground strains and pipe strains for high frequencies.

A good agreement in coherence, phase and spectrum ratio is found for the event 8722 even for the low frequencies. On the contrary, a complete lack of correlation can be observed for the weaker motions with the coherence dropping down to the zero-level, and amplifications of the spectral amplitudes well above 3.

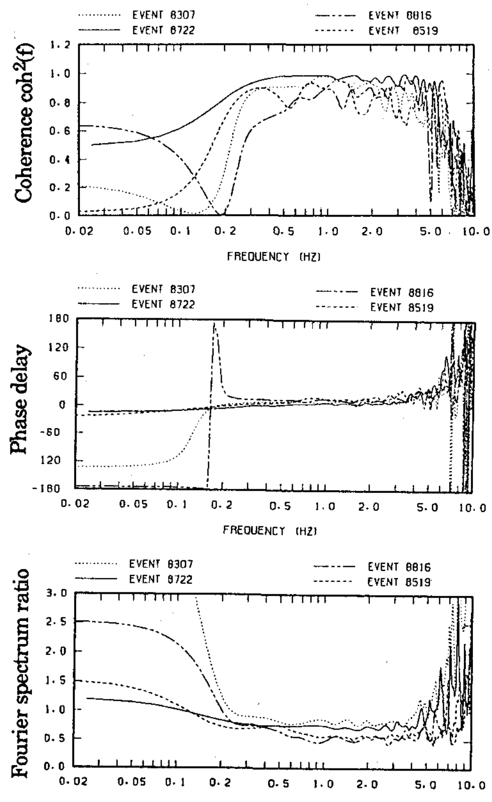


Fig. 4 Correlation between pipe and ground strains for four ground motions.

These observations lead to two important conclusions. First, the level of coherence between pipe and ground strains depends very much on the strength of the motion. The coherence diminishes with weaker signal strength. Secondly, the differences occur mainly in the range of frequencies corresponding to the long-period contents of the ground strain

Studies were performed in terms of the cumulative power. Figure 5 shows the cumulative power of strains expressed as percentage that has been evaluated for the four events under consideration. Results are presented for both the pipe strains and the ground strains

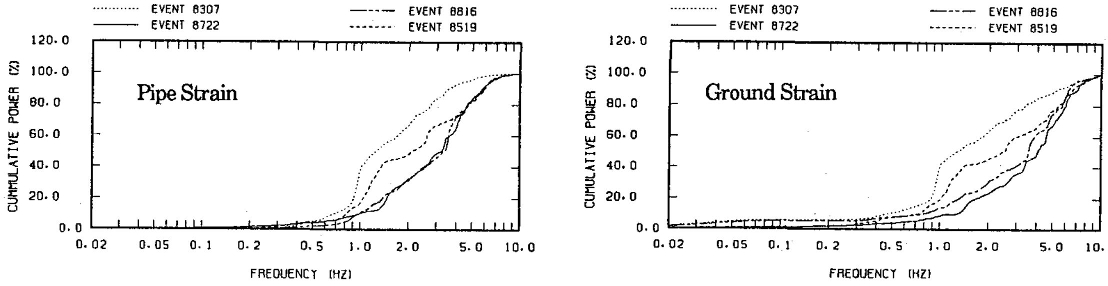
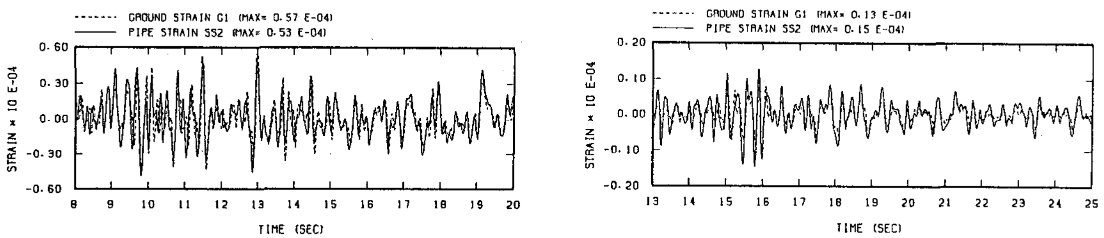


Fig. 5 Cumulative power of pipe and ground strains for four events

The power contributed by the frequencies up to 6.5 Hz was found to account always for more than 90-95 % of the total power. It is clear then that the power contributed by the higher frequencies is minimal and could be neglected for practical purposes.

It was also found that the contribution of the low range of frequencies, namely those lower than about 0.1 Hz, to the total power is quite small, less than about 3 %. Hence, it can be said that more than 90% of the total power of the strain comes from the frequency range between 0.1 and 6.5 Hz. Additionally, it is within this range where the high level of coherence was found between the ground and pipe strains (see Fig. 4). This provides supporting evidence to the claim that pipe and ground strains can be considered to be the same for practical purposes.

The ground strain records of the weaker events were low-cut filtered in order to eliminate the ill-effect of the long-period contents. The filter has a cut-off frequency of 0.10 Hz. The coincidence of the pipe strains and the "corrected" ground strains is shown in Fig. 6 for the events 8722 and 8816.



a) Event 8722　　　　b) Event 8816

Fig. 6 Comparison of ground and pipe strains for events 8722 and 8816.

CONCLUSIONS

The recorded ground strain included unreasonable peaks in the low range of frequencies (f < 0.1 Hz). Their effect was more noticeable for the weaker events due to the high noise-signal ratio.The ill-effect of the long-period contents was satisfactorily removed by low-cut filtering the records using a cut-off frequency of 0.1 Hz. It was found that more than 90% of the total power of the strains comes from the frequency range between 0.1 and 6.5 Hz. It is within this range where the high coherence between pipe and soil strains was observed.The contribution to the total power from frequencies higher than 6.5 Hz and lower than 0.1 Hz is minimal and their effect may be neglected for practical purposes. The results showed that, for the selected motions, the pipe strains are practically the same as those of the surrounding soil and the relative motion between pipe and soil during an earthquake is negligible.

REFERENCES

1. Newmark, N., "Problems in Wave Propagation in Soil and Rock," Proc. Inter. Symp. on Wave Propagation and Dynamic Properties of Earth Materials, Albuquerque, N.M., 1967.
2. Katayama, T., Yamazaki, F., Nagata, S., Lu, L. and Turker, T., "A Strong Motion Database for the Chiba Seismometer Array and its Engineering Analysis," Earthquake eng. struct. dyn., 19, 1089-1106, 1990.