# (18) ESTIMATION OF SEISMIC-INDUCED GROUND STRAINS BY DENSE SEISMOMETER ARRAY OBSERVATION


BY

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## ABSTRACT

Using the earthquake ground motion records obtained by a very densely located seismometer network, it has been attempted to find a rational solution for calculation and analysis of ground strains. Two of the best records so far obtained by the network have been analyzed in detail. Time histories as well as frequency properties of ground strains have been evaluated and the results were compared with the directly measured strains in the ground and the strains produced in a steel pipe and in the joints of a ductile-iron-cast buried pipe.


## INTRODUCTION

During the recent investigations it has been revealed that the seismic- induced ground strain is the most important contributing factor in seismic behavior of the buried linear structures such as pipes and tunnels. But up to the present time, the observational data on the seismic soil strain has been limited and fragmentary and the quantitative information on the properties of engineering importance is extremely lacking. With a very densely located seismometer array network, which has been operating since April, 1982, it became practically possible to obtain the characteristics of soil strains during the occurrences of earthquakes in a comprehensive and reliable manner.

The system is composed of 36 three-component accelerometers which are capable of simultaneous recording of 108 components of ground motions on and in the ground. A complementary system, which includes the direct measurements of relative ground displacements as well as the observation of strains in a buried steel pipe and relative motions in the joints of a ductile-cast-iron pipe, was completed and began operation in December, 1982. The best records so far obtained by this system have been analyzed and compared with the calculated strains obtained through the array network.

## GENERAL LAYOUT OF ARRAY NETWORK

### The Site

The system is located in the Chiba Experiment Station of the Institute of Industrial Science of the University of Tokyo. The topographical and geological conditions of the site are generally uniform and indicate a relatively simple subsoil structure. A typical soil profile is shown in Fig. 1.

### The Array

The general layout of the network as well as the newly developed strain measurement system is shown in Fig. 2. The latter system includes three directly measuring instruments of relative displacement (G1, G2, G3) and a steel as well as a ductile-cast-iron buried pipes, both of 150 mm in diameter and each with some 120 m in length.

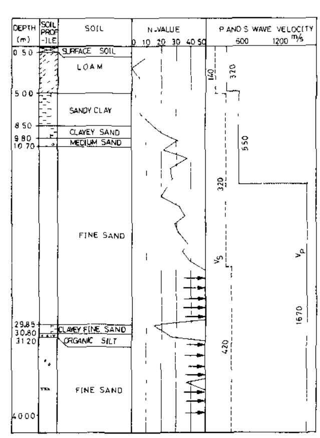


Fig. 1 Typical Soil Profile at CO

Figure 3 shows the general configuration of the array network. There is a large triangular network


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CO-P5-P6 with the three sides having approximately 110 m in length. Around point CO eight points are located, four of which are only 5 m from CO, and the remainings are 15 m from CO.

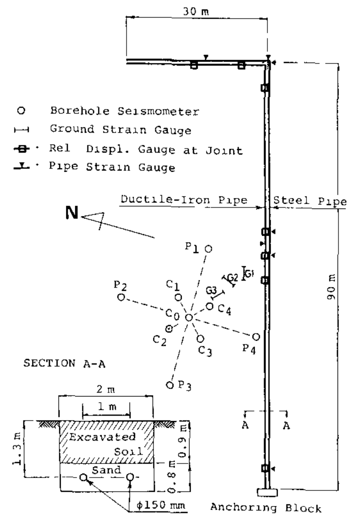


Fig. 2 Layout of the Observation System

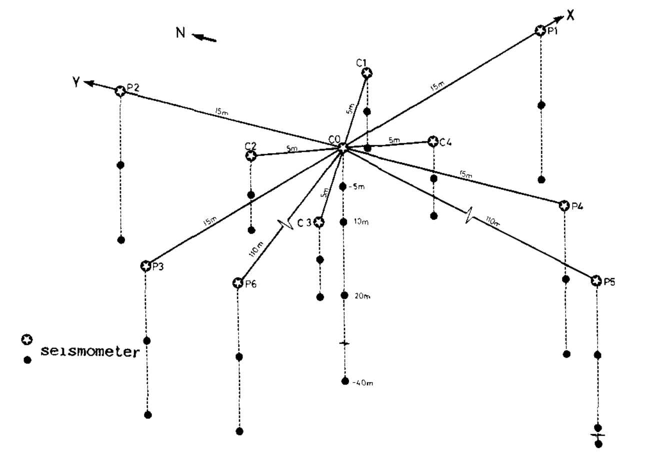


Fig. 3 General Configuration of Seismometer Array at Chiba

## The Instrumentation

The piezo-electric type acceleration transducer is used for the array observation. It is expected that the seismometers have a practically flat sensitivity in the frequency range between 0.1 Hz and 30 Hz. The output sensitivity of the transducer and amplifier system is 5 V per 1000 cm/s$^2$ and the output impedance is 10 Ω.

The signal from the seismometers are digitized by AD-converter at time interval of 0.01 s and are recorded by two 64-channel digital recorders. The recording system has a 3 s pre-event memory, therefore it is practically possible to obtain the initial part of the ground motion which is important in these analyses.

## CALCULATION OF SEISMIC-INDUCED GROUND STRAIN

For the calculation of seismic-induced ground strain, Finite Element Method in three dimensional space has been employed. A tetrahedron element with an assumed linear shape function constitutes the basic element. Fast Fourier Transformation has been applied throughout the analyses. In the present study all the integration for the calculation of velocities and displacements have been performed in Frequency Domain.

Two of the best records so far obtained successfully have been analyzed in detail. The first one was induced by the earthquake of July 23 ,1982, which occurred under the sea off Ibaraki Prefecture. The second one was obtained during the earthquake of February 27, 1983, which occurred in the southern part of Ibaraki Prefecture. The characteristics of two events are summarized in Table 1.

Table 1. List of Earthquakes

| Date | Magnitude | Focal Depth Km | Epicentral Dis. Km | Max Acc. at Array Site |
|---|---|---|---|---|
| July 23,1982 | 7.0 | 10 | 180 | 38 Gal |
| Feb. 27,1983 | 6.0 | 70 | 40 | 70 Gal |

Only the results of the latter event are discussed in this paper.

As it can be seen in Fig. 3, it is possible to choose numerous tetrahedron elements for the calculation of ground strains. This is one of the advantages of this system which makes it possible to evaluate the effect of spacing between seismometers, the effect of different regions as well as different depth ,etc. on the calculated strains. At present, to study the effect of spacing between seismometers on calculated strains, strains in three elements have been evaluated and analyzed. The largest one has the vertices at points P1(-1m),P3(-1m),P5(-1m), and P5(-40m), the intermediate one at points P1(-1m),P3(-1m), P4(-1m), and C0(-40m). Finally the smallest element is composed of points C0(-1m), C3(-1m), C4(-1m), and C0(-5m).

To verify the accuracy of calculated strains, they were evaluated in the G1, G2, and G3 directions. Surprisingly the calculated time histories as well as Fourier spectra of strains showed quite reasonable similarity with those of directly measured. The order of strains in the largest element shows good agreement with the actual ones. But the order becomes somewhat higher in smaller elements especially in the element with the sides of only 5 m. Although this effect can be greatly removed by elaborate application of filtering process, more investigations are clearly needed. To interpret this problem, two main reasons were speculated.

1. During the preliminary observations it was found that some of the seismometers seem to be out of the preset directions. This trouble has been discussed (Ref. 1) and the effect of out-of-preset- direction of seismometers on the calculated strains was studied (Ref. 2). Although this problem has been greatly recovered but existence of slight incorrect direction of seismometers has rather significant effect on the calculated strains over the short spans of only 5 m.

2. Since in the calculation of strains relative values are involved, a slight difference between characteristics of individual seismometers has a great influence on the accuracy of the calculated strains, especially for very short spans. Also the existing integration methods for the calculation of ground displacements are known to be sensitive to various assumptions and parameters involved. This factor is also emphasized over shorter spans.

It is interesting to notice that for smaller elements the higher frequency contents and for larger elements the longer period contents show the best agreement with the real strains. The calculated strain time histories of strong motion part, in G1 direction, for the event of Feb. 27, 1983, have been enlarged and shown in Fig. 4. The time histories of directly measured ground strain, steel pipe strain, and relative motions in a joint of ductile-cast-iron pipe are shown in Fig. 5. It is interesting to note that the steel pipe experiences exactly the same strain as the surrounding soil. Although the relative motions in joints of ductile pipe also show similar characteristics compared with those of surrounding soil but their magnitudes are significantly different. The detailed analysis of the new system is still under way.

The predominant frequency content of ground strains for this particular event was found to be approximately about 1 Hz, with the maximum value of $9.5*10^{-5}$ .

## CONCLUSIONS

In the present study an attempt was made to calculate the seismic-induced ground strains by using the acceleration time histories obtained in a very densely located seismometer array network. The components of strains were calculated in a rather large, intermediate and small tetrahedron elements. Using these values the ground strain time histories in specified directions were obtained and compared with the directly recorded ones. It was found that the calculated strains in the element with the side of approximately 100 m showed the best agreement with the actual ground strains, while agreement was poorer for the smallest element. The reasons were briefly mentioned.

The observed strains in the joints of ductile-cast-iron and steel pipes generally showed very similar characteristics compared with those of the surrounding ground but for ductile pipe the magnitude of strain was smaller.

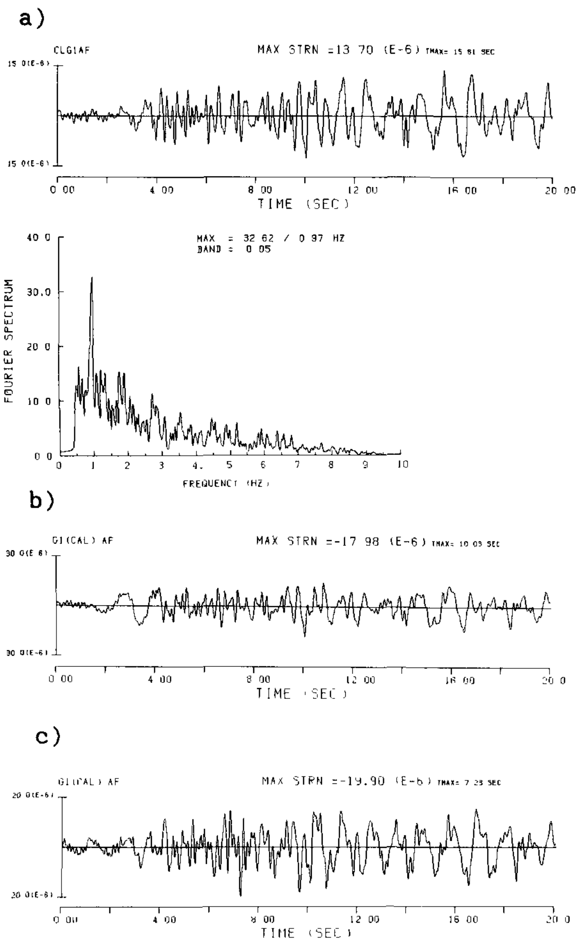


Fig. 4 Calculated strain Time Histories in Elements
a) P1(-1m)P3(-1m)P5(-1m)P5(-40m)
b) P1(-1m)P3(-1m)P4(-1m)C0(-40m)
c) C0(-1m)C3(-1m)C4(-1m)C0(-5m)

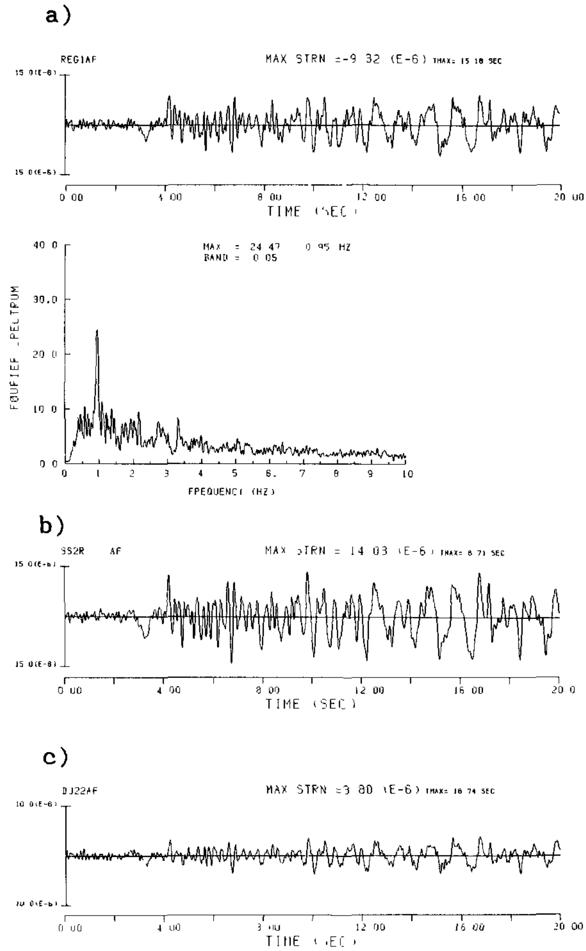


Fig. 5 Measured Strains in
a) Ground
b) Steel Pipe
c) Joint of a Ductile Pipe

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