ENGINEERING PROPERTIES OF GROUND MOTION OBTAINED FROM DENSE SEISMOGRAPH ARRAY DATA (Part 1: Ground Strain)

by

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ABSTRACT

As a part of the results of a series of researches performed on the evaluation of engineering properties of earthquake ground motion by using dense seismograph array data, analysis of ground strain is presented in this paper. Ground acceleration records obtained by 36 three-component seismometers installed on and in the ground with horizontal spacings varying from 5 m up to 150 m were used for this study.

Effects of several factors such as spacing between seismometers, depth, and different regions considered on the evaluated ground strain were discussed. Good agreement was found between evaluated and directly observed ground strains. Further studies on some other engineering properties of ground motion are under way.

INTRODUCTION

For better and more comprehensive understanding of some engineering properties of earthquake ground motion, a very dense seismograph array network has been installed in the Chiba Experiment Station of the Institute of Industrial Science, the University of Tokyo. The array network that simultaneously records 108 components of ground acceleration was completed in April, 1982.

Using the ground motion records obtained by this system, it has become practicably possible to evaluate the characteristics of soil strain during the occurrences of earthquakes in a comprehensive and reliable manner. The

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array network was expanded since then by installing a complementary system including direct measurement of relative ground displacements as well as observation of strains in a buried steel and ductile-cast-iron pipes, both of 150 mm in diameter and some 120 m in length. Among a total of 59 earthquakes so far recorded, four events are analyzed and the results are discussed hereafter.

LAYOUT OF THE ARRAY NETWORK

The topographical and geological conditions of the site are generally simple with the ground surface being almost flat. The superficial layer is loam with a thickness of 4-5 m resting on a 4-meter-thick clayey layer. The clayey layer is underlain by a hard sand layer.

The general layout of the array network and the complementary system is shown in Fig. 1. The latter system includes the direct measurement of ground strains in three different directions and strains in a steel as well as a ductile-cast-iron buried pipe. It is capable of simultaneously recording 26 strain components. Figure 2 shows the spatial configuration of the array network with a total number of 36 three-component accelerometers.

The piezo-electric type acceleration transducer is used for the array observation with a practically flat sensitivity in the frequency range between 0.1 Hz and 30 Hz. The signals are directly digitized by AD-coverter with time interval of 1/200 s. The recording system has a 1.5 s pre-event memory, which makes it possible to obtain the initial part of the ground motion often needed in analysis. The overall system is explained in detail elsewhere (Refs. 1 and 2).

ANALYSIS PROCEDURE

The ground strains are calculated by employing a finite element method. A tetrahedron with an assumed linear shape function constitutes the basic element. All the integrations for calculation of velocities and displacements are performed in frequency domain.

The flexibility of the array network in choosing many different combinations of tetrahedron elements makes it possible to evaluate the effect of different factors such as seismometer spacing, depth, different regions, etc. on the calculated ground strains.

RESULTS

Four of the best records so far obtained by the array network were analyzed in detail. These four events seem to have substantially different characteristics which greatly affect the engineering properties of ground motions. In the present study these effects on the characteristics of ground strain are discussed.

The characteristics of four events are summarized in Table 1.

Table 1 List of Earthquakes

Event No.	Date	Magnitude	Focal Depth (km)	Epicentral Dis.(km)	Max Acc*	Max Strain**
Event No.1	1983.2.27	6.0	72	35	70	11
Event No.2	1984.1.1	7.3	388	374	35	7
Enent No.3	1984.3.6	7.9	452	705	30	10
Event No.4	1984.9.14	6.8	2	232	5	19

* gal ** ($x10^{-6}$)

For each event ground strains were evaluated in many different elements with the lengths of sides ranging from 5 m to approximately 140 m. It was observed that the size of chosen element and the range of band pass filter have vital influence on the accuracy of calculated strains.

EVENT NO. 1

This event occurred in the southern part of Ibaraki Prefecture on February 27, 1983, some 35 km distant from the site. Its magnitude was 6.0 and the total recorded length was 182 s. The event was the strongest so far recorded by the array network and the strong shaking continued for about 12 s. Ground accelerations at different points about 150 m apart show slight differences only for higher frequency components.

Figure 3 shows the accelerations in borehole CO (see Fig. 2) at the depths of 1 m, 20 m, and 40 m, respectively. It is interesting to notice that the effect of amplification of superficial layer is exhibited mostly in higher frequency components, generally higher the 3.5 Hz, while velocity and displacement do not show significant changes with depth (Ref. 5).

It was found for this event that the characteristics of strains in ground and in the buried steel pipe are very similar for both high and low frequency components. However, the higher frequency componets were found to be greatly suppressed in the relative displacement of joints of ductile pipe. Directly observed strains in ground, in the steel pipe and in one of the ductile-pipe joints are shown in Fig. 4. Components of about 1 Hz dominate in the initial part and lower frequency components are dominant in the latter part.

To illustrate the effectiveness of the proposed method, (Refs. 3, 4, and 5) ground strains were evaluated by using many different elements. Figure 5 shows samples of evaluated strains in 4 elements. To examine the accuracy of calculated strains they are compared with the directly observed strain in steel pipe. In Fig. 5, there are shown from the top to the bottom observed strain in steel pipe, strains evaluated in four elements with the sides of about 5 m, 20 m, 40 m and 140 m, respectively. Although agreement is poor for the element with the sides of only 5 m, it becomes better as the size of element increases. Very good agreement is achieved in the element with the sides of about 40 m. For still larger element with the sides of about 140 m, good agreement is found, for lower frequency components but higher frequency contents are mostly suppressed in the calculated strain. It is seen from Figs. 3 and 5 that the amplitude of ground acceleration decreases very rapidly with time, but that very good similarity still exists between the observed ground strain and the strains evaluated by the elements of 40-meter-side and larger.

The effect of different regions on the calculated ground strains is shown in Fig. 6. These strains were calculated in two adjacent elements of almost the same size. The similarity between them is obvious.

To investigate the effect of depth on the ground strains, three elements were chosen in such a way that for each element three of the vertices were located at the same depth, namely 1 m, 10 m and 20 m. The strains in a typical element are shown in Fig. 7. The strains do not show significant changes with depth, but the higher frequency components are suppressed in deeper layers.

EVENT NO. 2

This event was a deep and distant earthquake with a focal depth of about 388 km and an epicentral distance of about 370 km. High frequency components are dominant in acceleration time histories as clearly observed in Fig. 8, and low frequency components are not significant. On the contrary to Event No. 1, accelerations at different points within the network are not similar (see Fig. 8). With such a difference in a small region, it is interesting to study the reliability of using only one recorded time history for engineering design purposes as is usually done in practice. Studies on this topic is at present under way. The amplifying effect of superficial layer is more significant in this event than in Event No. 1 as exhibited in Fig. 9, which shows the acceleration time histories at depths of 1 m, 20 m and 40 m.

The observed strain in steel pipe and the evaluated strains in elements with sides of 40 m and 140 m are shown in Fig. 10. The strain level for this event was smaller than that for Event No. 1, and evaluated strains in the element with the sides of 5 m did not agree well with the observed ground strain. Agreement is better for larger elements with sides of 40 m and 140 m, especially for low frequency components. Higher frequency components are eliminated in larger element as in the previouse case. Strains in deeper layers show almost the same trend as those of the previous event did.

EVENT NO. 3

This earthquake with magnitude 7.9 had a focal depth of 452 km and an epicentral distance of 705 km. The characteristics of ground motion and ground strain are basically similar to those mentioned for Event No. 1. Acceleration, velocity and displacement in the same direction as those of the pipe are shown in Fig. 11. The observed steel pipe strain and the evaluated ground strains in two elements with sides of 40 m and 140 m are shown in Fig. 12.

It is important to note that, although with the lapse of time the acceleration amplitude shows dramatic decrease, the strain level does not decrease significantly. It should be noted, however, longer period components become dominant with the lapse of time. As it can be seen in Fig. 12, agreement between observed and evaluated strains is extremely good even in the latter part of the event in which the amplitude of acceleration is less than 4 gal.

EVENT NO. 4

This shallow earthquake with magnitude 6.8 and epicentral distance of about 230 km showed very different characteristics in comparison with the previous ones. Long period components with T=2 s or longer were dominantly observed with maximum acceleration, velocity, and displacement of about 5 gal, 1.5 kine and 0.9 cm, respectively. The effect of superficial layer is shown in Fig. 13. The time histories for depths of 20 m and 40 m are almost the same.

It was found that ground strain is very small in the initial part of the record. However, in the latter part (after about 100 s) the strain level becomes large with dominant period T 5 s. Although the amplitude of recorded acceleration is very small and the noise-signal ratio seems to have been high, the calculated ground strain shows relatively good agreement with the directly observed strain. For small-amplitude records like this, band pass filtering has an important effect on the accuracy of calculated strains. Figure 14 shows the latter part of the time histories for the directly observed strains in ground and steel pipe and the evaluated strain in an element with the sides of about 120 m. The differences in the magnitude of strain amplitudes may be attributed to the effect of filtering.

CONCLUSIONS

In this paper some characteristics of ground strain during earthquakes were presented based on the results of array observation. It was shown that the ground strain evaluated by the proposed method is in good agreement with the directly observed ones. It was also concluded that

1. The superficial layer mostly amplifies the higher frequency components of ground accelerations.

2. The accuracy of evaluated strain mainly depends on the size of chosen element. In the present study strains evaluated in elements with sides of about 40 m or more show good agreement with the directly observed ones, while accuracy becomes poorer for smaller elements. For larger elements with the sides of about 120 m,

higher frequency components are eliminated.

3. Band pass filtering process is very important specially for small events with higher noise-signal ratio. More accurate filtering process may be needed for small-amplitude records.

4. Variation of strain level at different depths (0 to 20 m) was not significant except for higher frequency components.

5. For ground motions containing very low frequency components, ground strains may be large even though the maximum acceleration is of the order of several gals.

ACKNOWLEDGEMENTS

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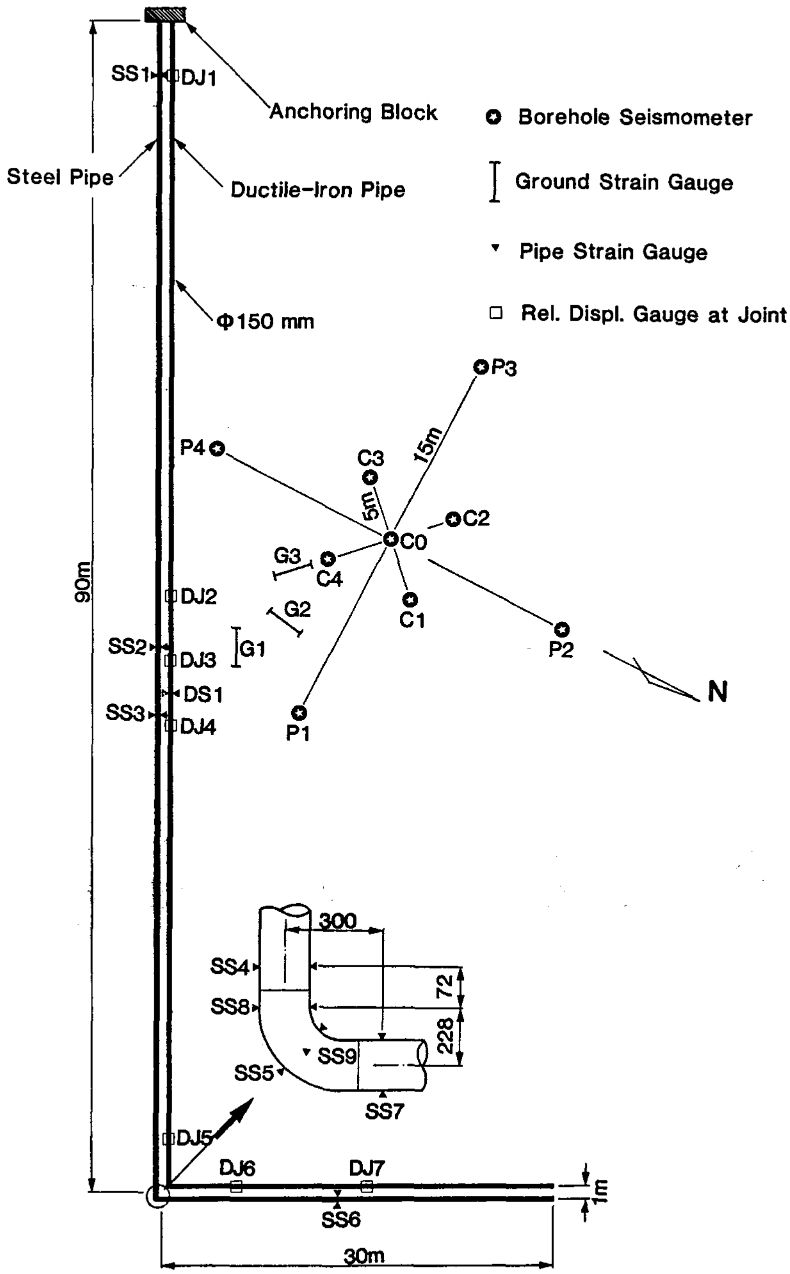

Fig. 1 Layout of Observation System

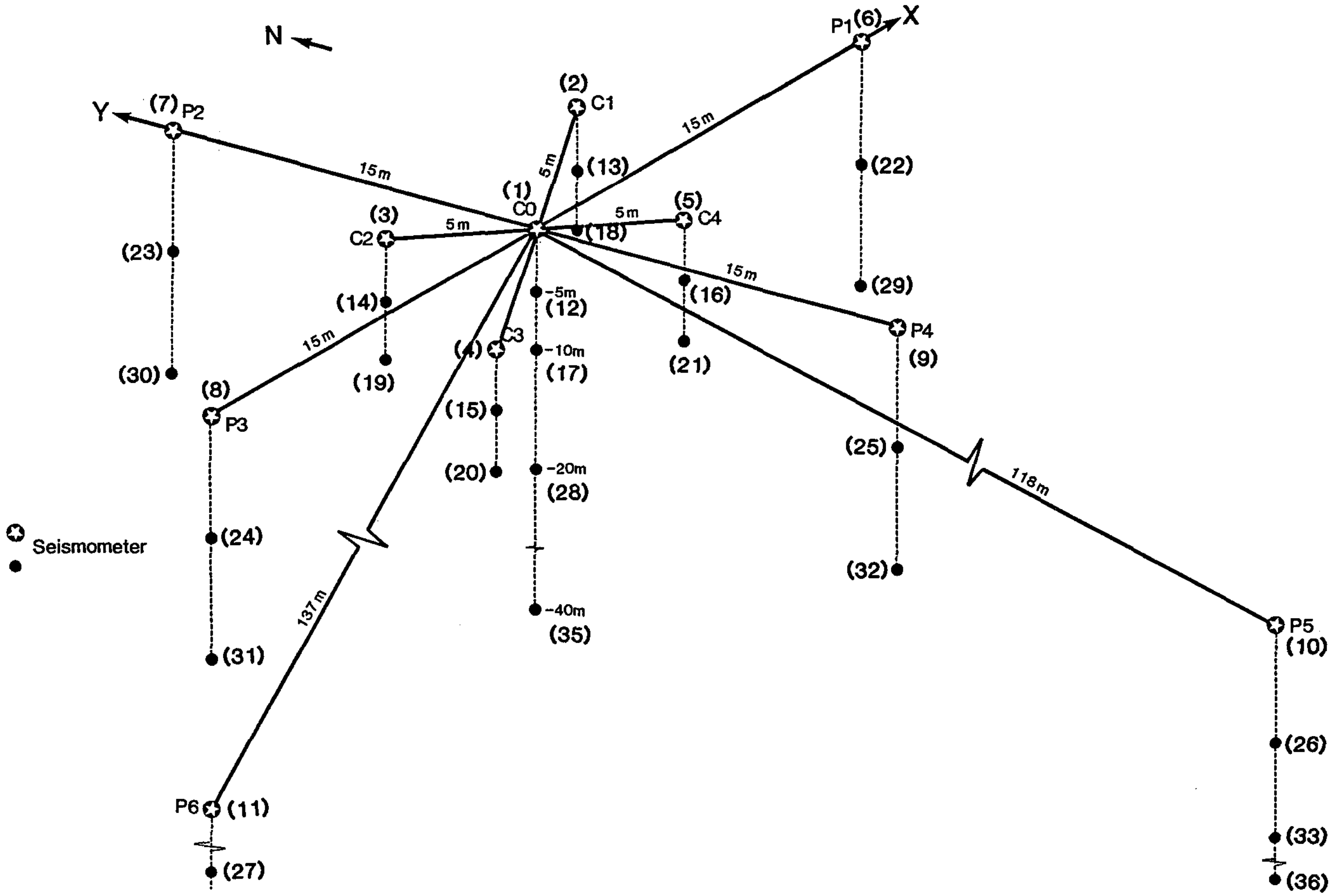

Fig. 2 Spatial Configuration of Seismograph Array

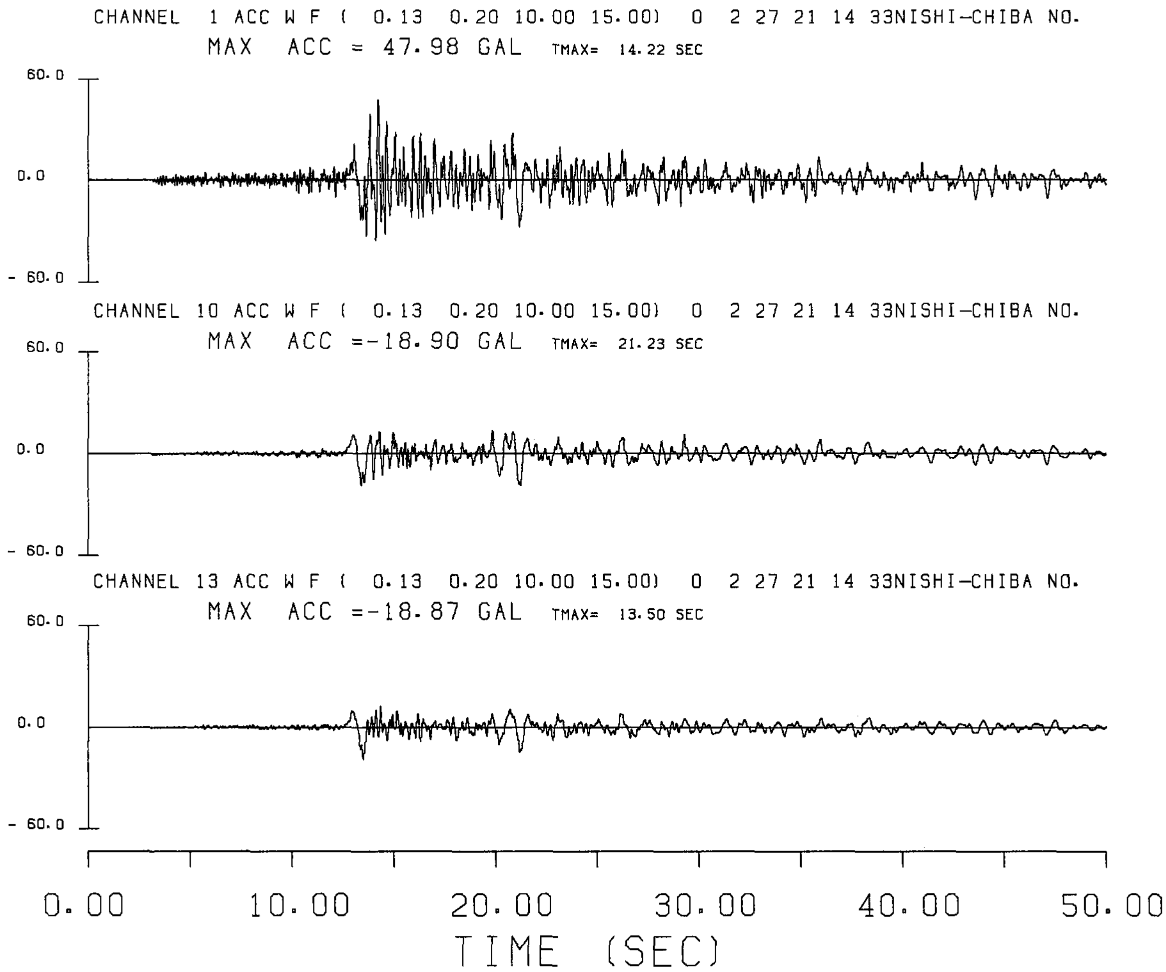

Fig. 3 Ground Acceleration at the Depths 1 m, 20 m and 40 m

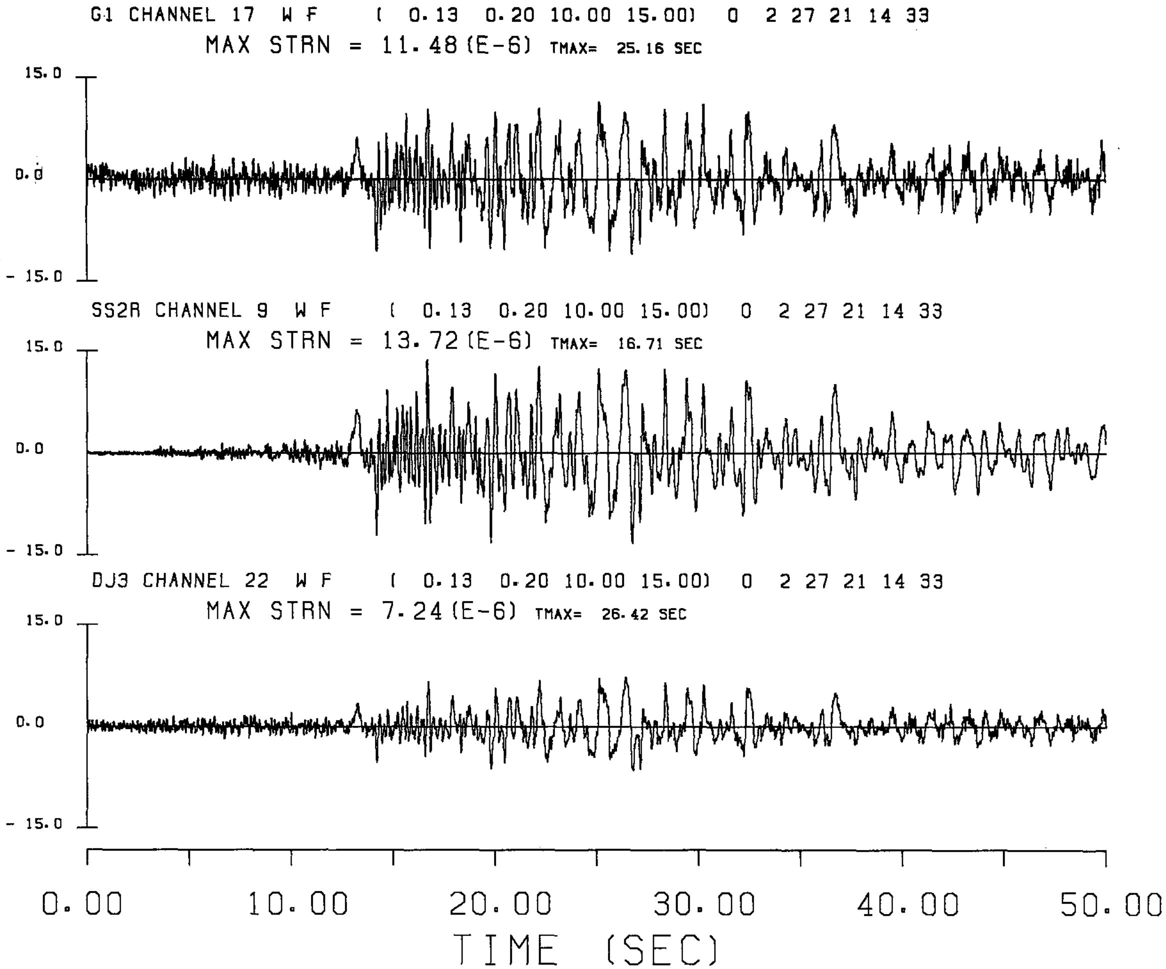

Fig. 4 Observed Strains in Ground, Steel Pipe and Joints of Ductile Pipe

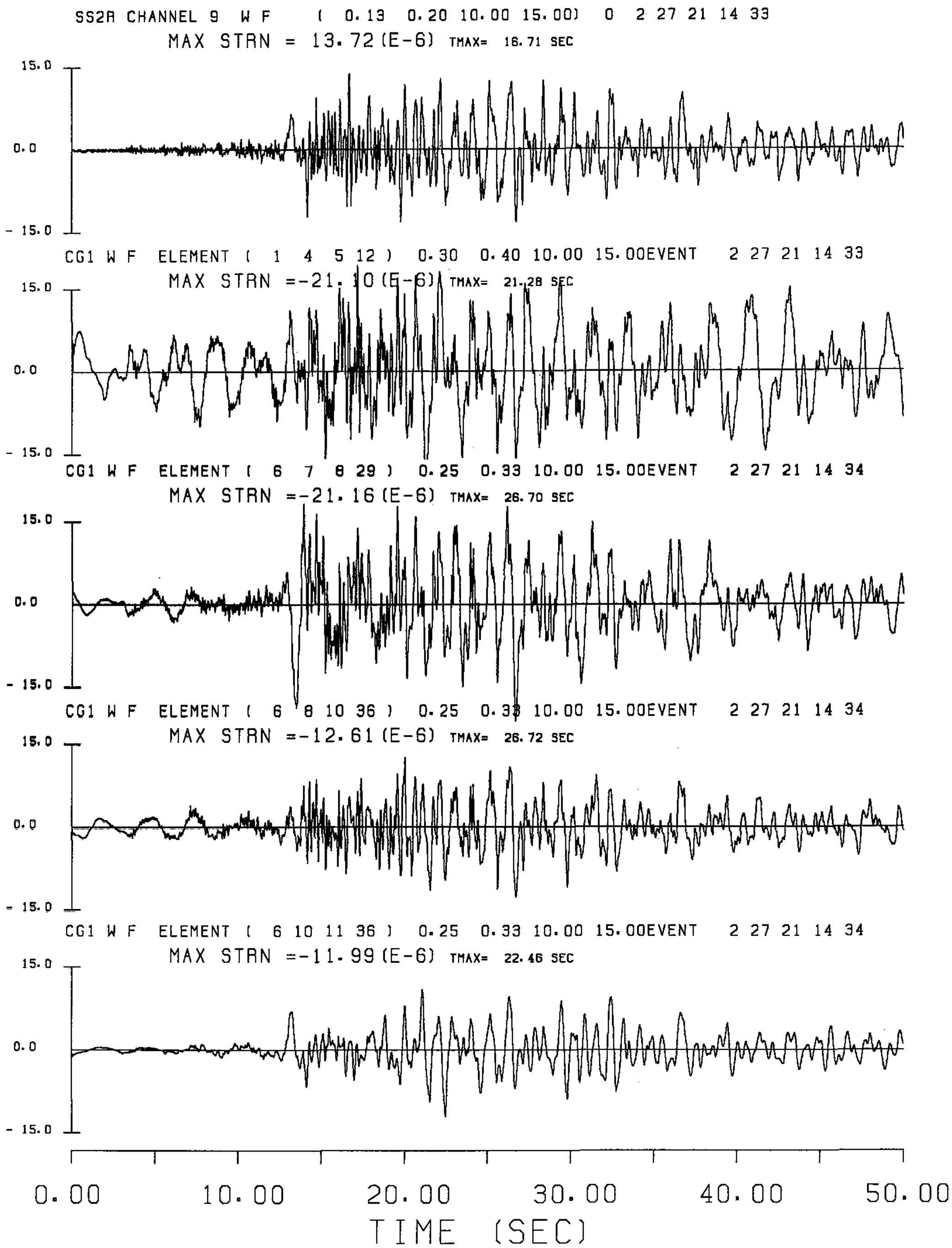

Fig. 5 Observed Strain in Pipe and Evaluated Strains in Four Elements

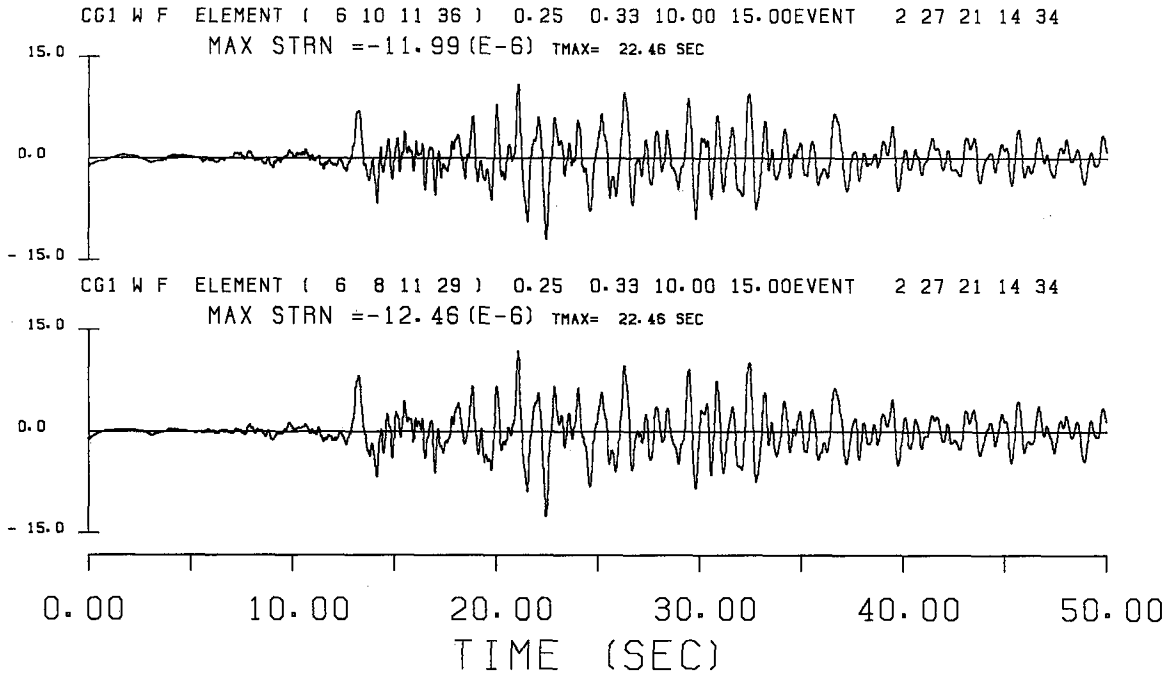

Fig. 6 Evaluated Strains in Two Different Regions

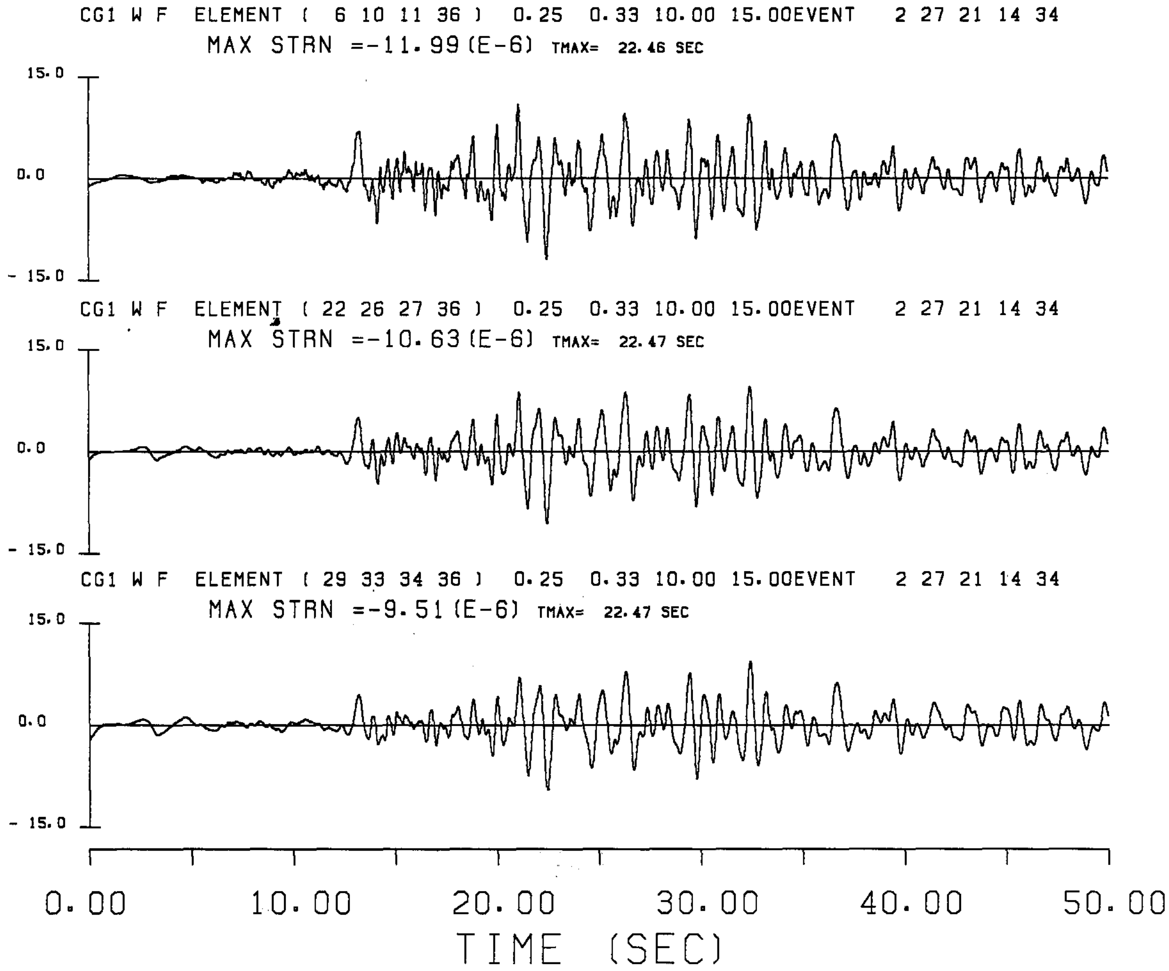

Fig. 7 Evaluated Strains at Depths 1 m, 10 m and 20 m

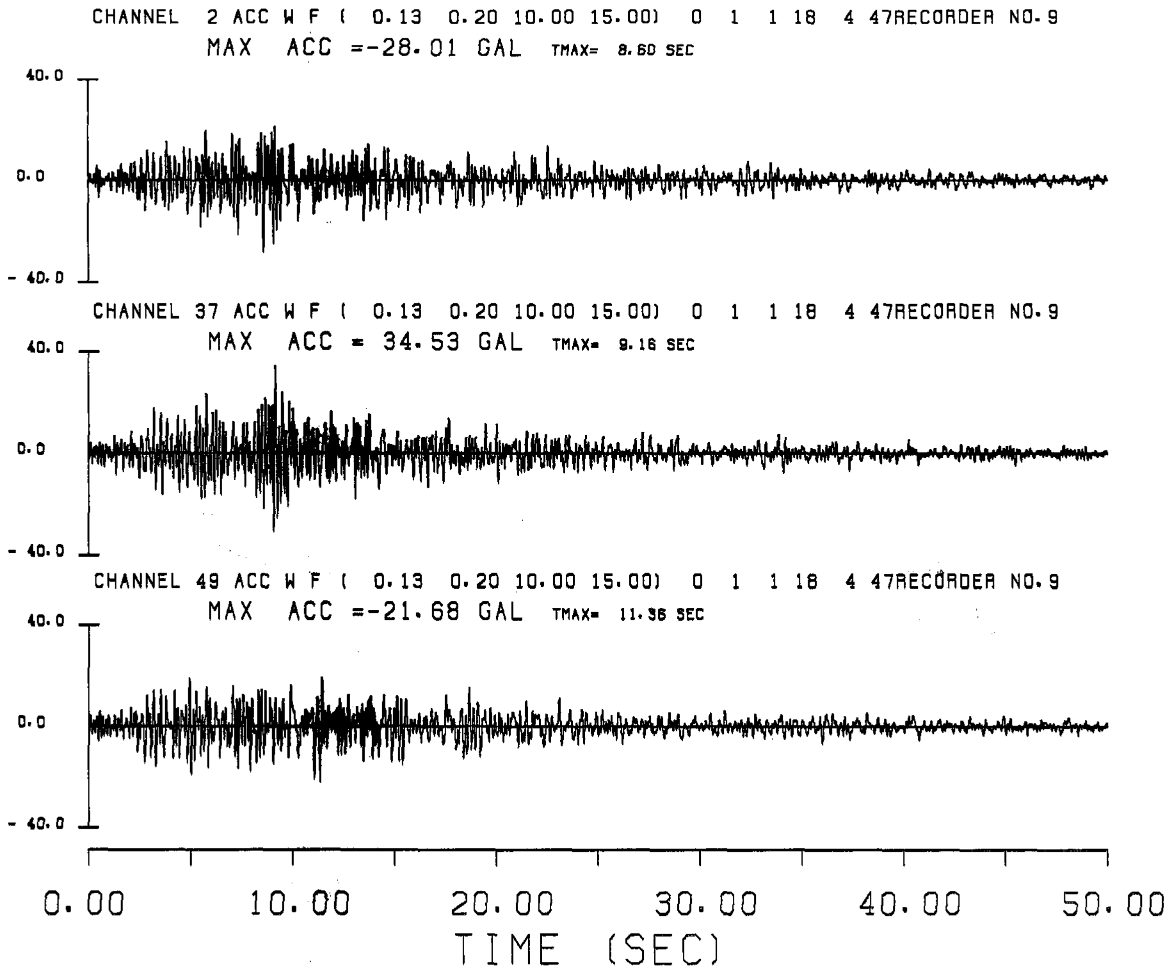

Fig. 8 Ground Acceleratons at Points P101, P501 and P601

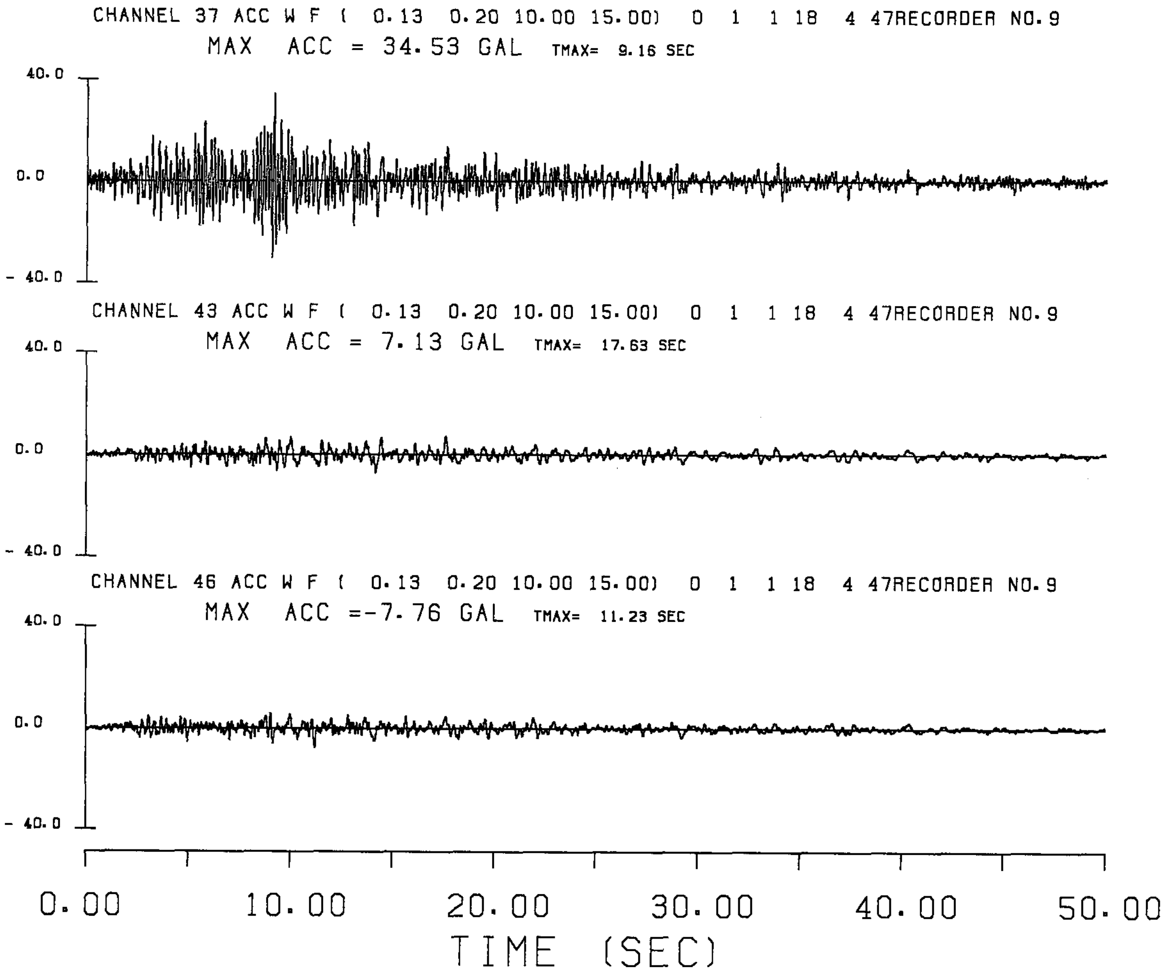

Fig. 9 Ground Accelerations at Depths 1 m, 20 m, and 40 m

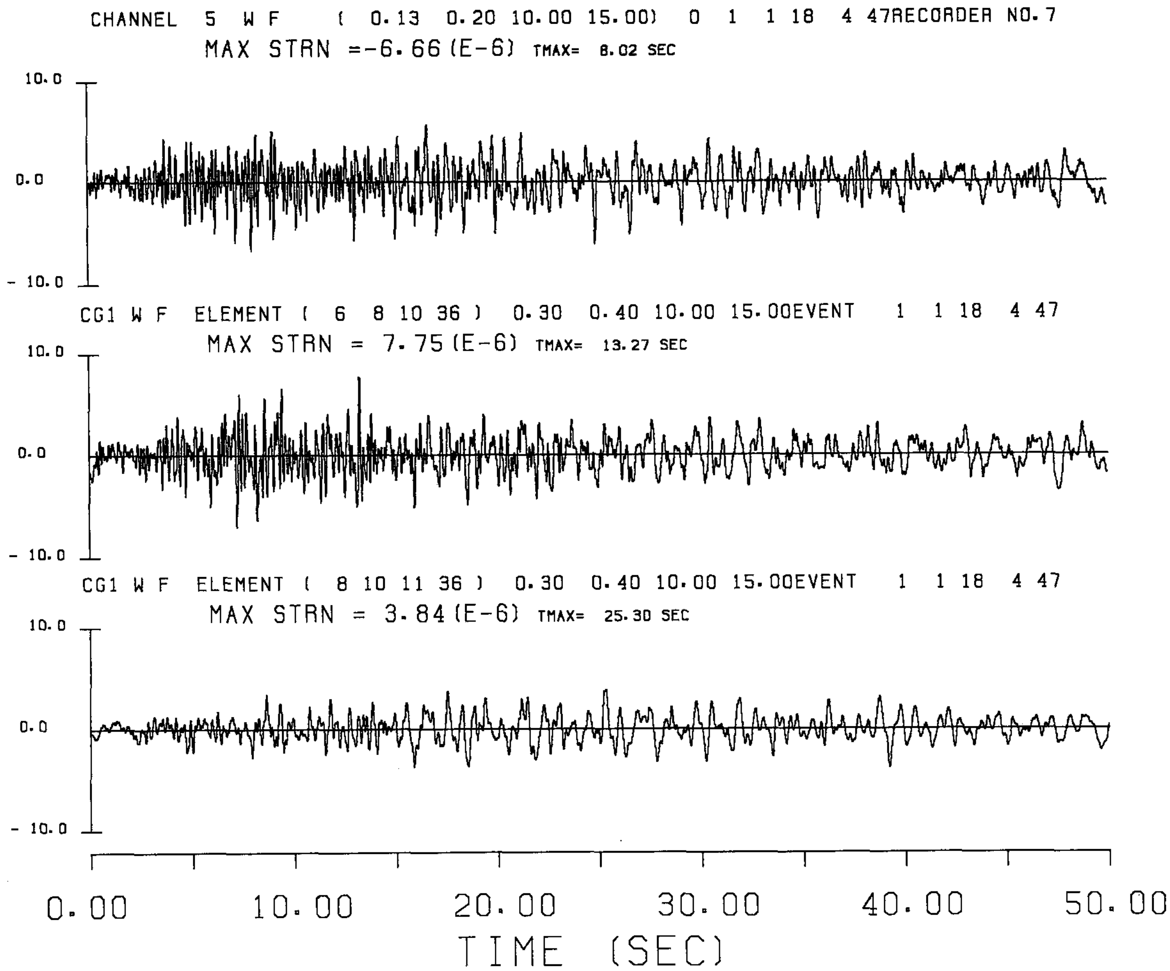

Fig. 10 Observed Strain in Pipe and Evaluated Strains in Two Elements

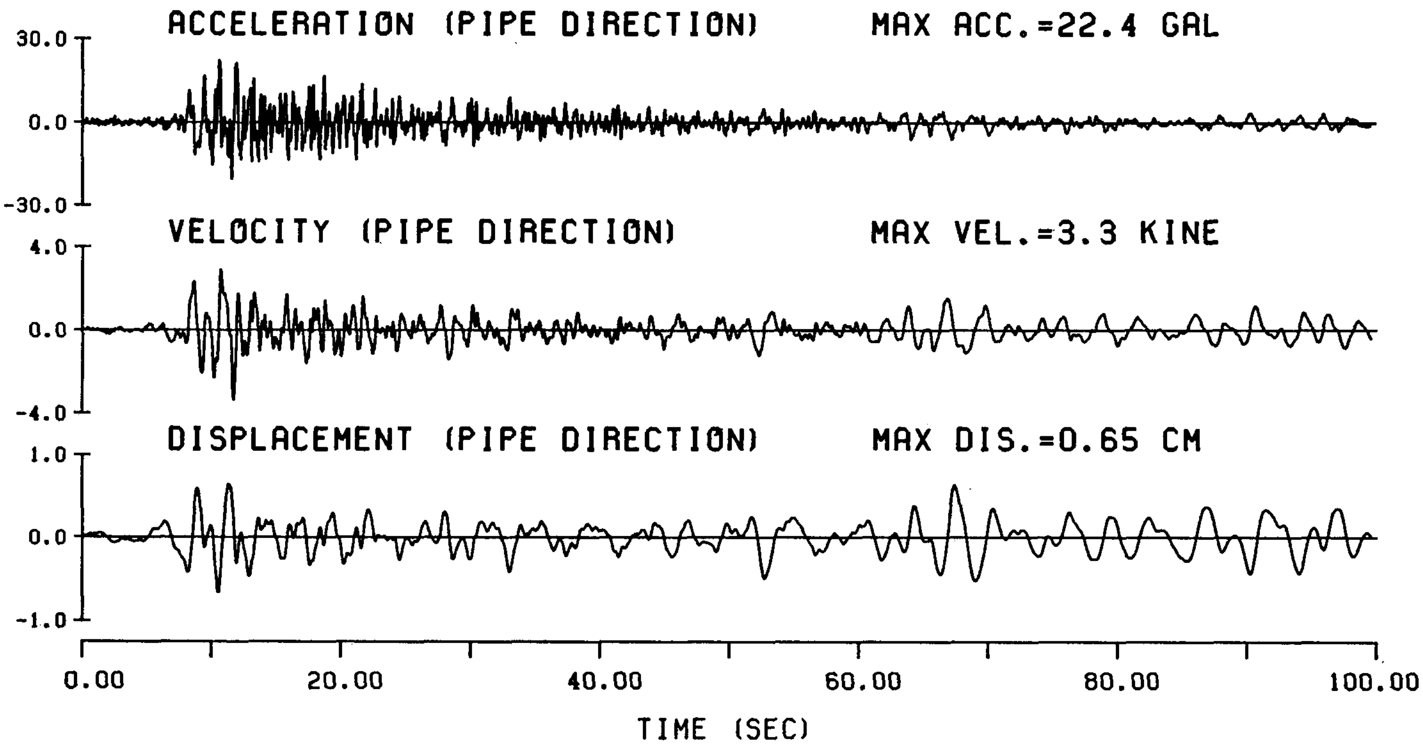

Fig. 11 Acceleration, Velocity and Displacement Time Histories

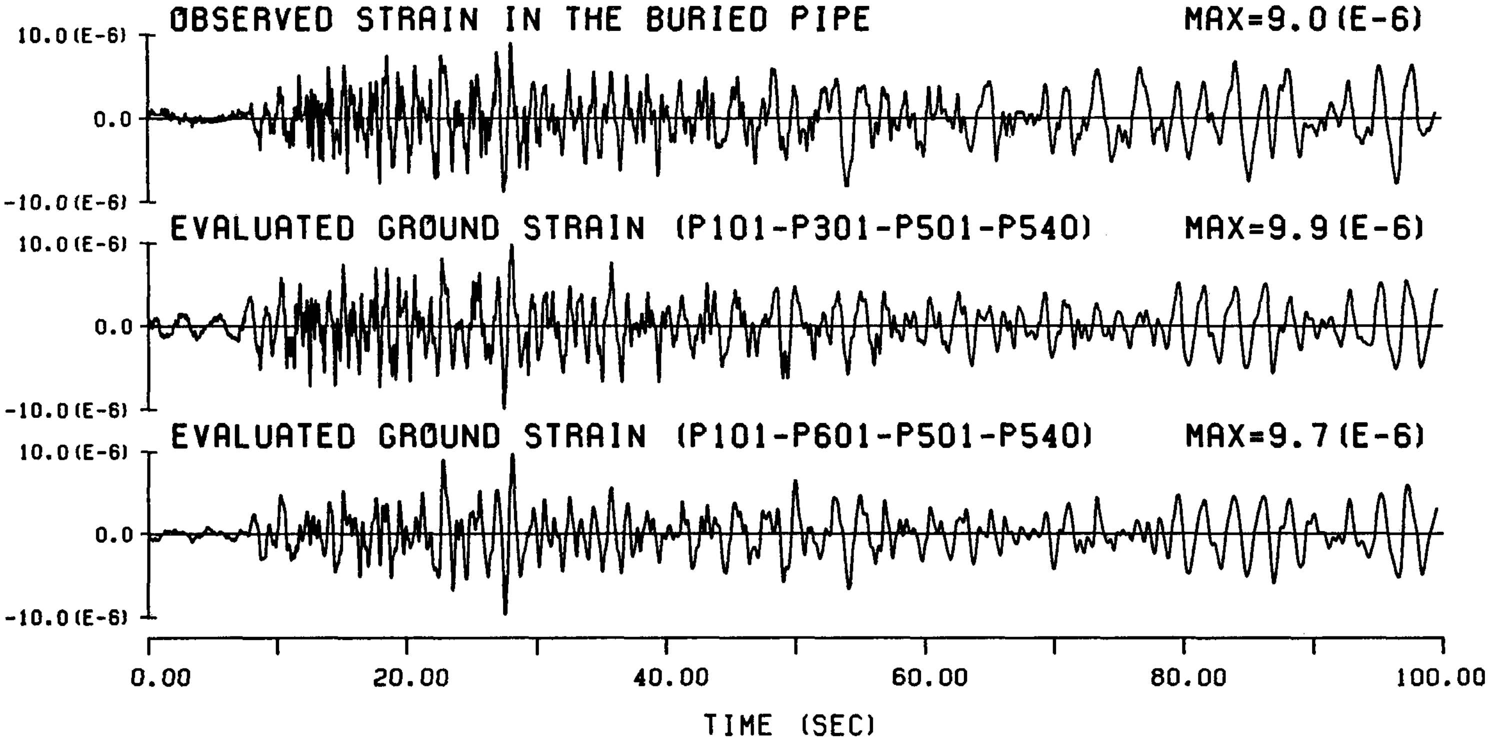

Fig. 12 Observed Strain in Pipe and Evaluated Ground Strains in Two Elements

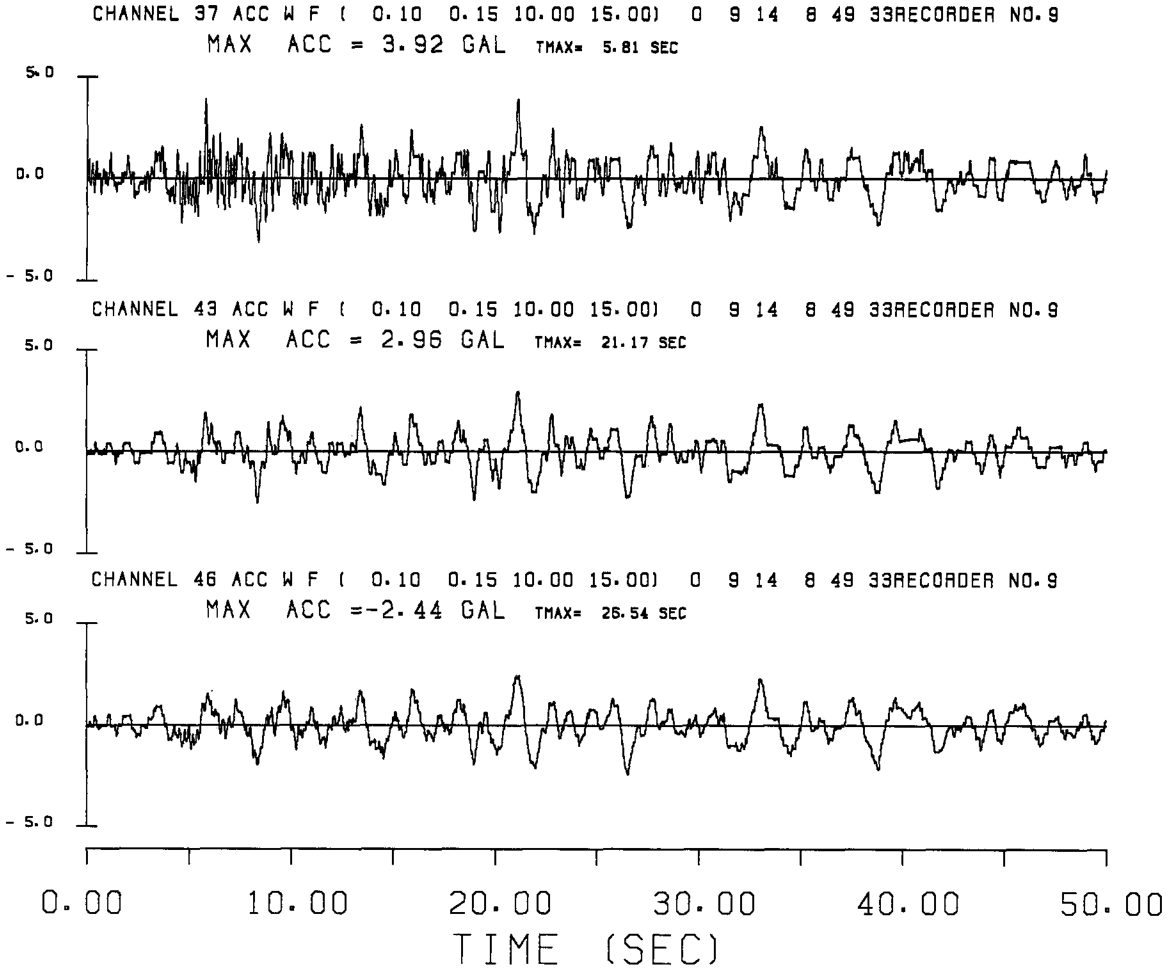

Fig. 13 Ground Acceleration at Depths 1 m, 20 m and 40 m

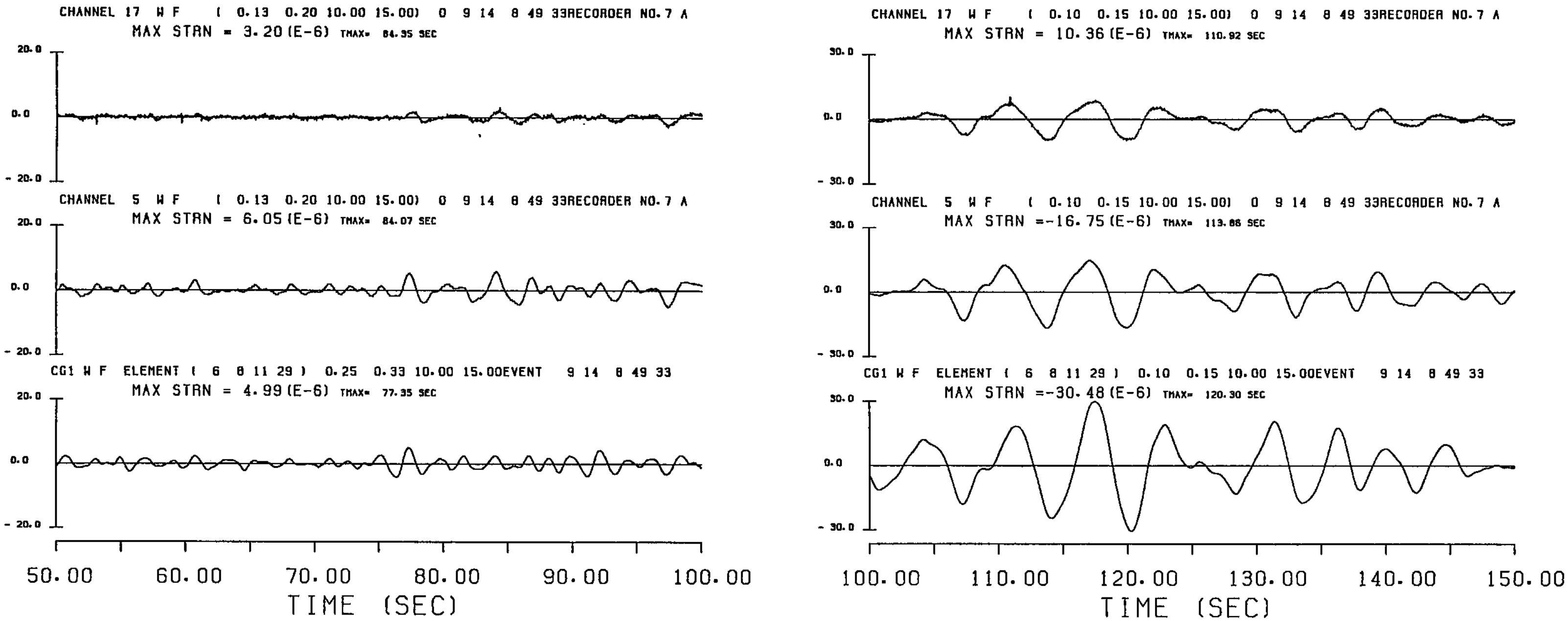

Fig. 14 Observed Strains in Ground and Pipe and an Evaluated Strain in Element P101P301P601P120