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OBSERVATION OF SEISMIC GROUND MOTION AND BURIED PIPE STRAIN IN A VERY DENSE SEISMOMETER ARRAY

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SUMMARY

A dense seismograph array network, located in the Chiba Experiment Station of the Institute of Industrial Science, the University of Tokyo, began operating in April, 1982. The array network was expanded, since then, by installing some additinal seismometers and a complementary system including direct measurement of relative ground displacement as well as observation of strain in buried pipes. Noting the observation results of buried pipes during earthquakes, the relation between ground accelerations and pipe strains, the distribution of the axial and bending strains of pipes, and the relation between pipe strains and types of propagation wave are discussed in this paper.

INTRODUCTION

The dynamic responses of underground structures, such as buried pipelines, submerged tunnels, embedded tanks and rock tunnels, during earthquakes are greatly influenced by the behavior of the surrounding soil. By reflecting the above-mentioned finding, the response-displacement method is widely used in Japan for the earthquake resistant design of these structures. However, the distribution of ground displacement during an earthquake, namely the seismic strain in the ground, has not been well understood today. In most cases it is difficult to directly measure the strains in the ground caused by an earthquake. However, past studies have conclusively shown that the strains produced in pipelines during an earthquake are almost the same as those of the surrounding ground. In fact, it is always more practical to estimate the approximate soil strains in the surrounding ground from the measured pipe strains.

Observation of earthquake ground motions began in the Chiba Experiment Station of the Institute of Industrial Science, the University of Tokyo, in April, 1982, by using a very densely located three-dimensional seismometer array. Since December, 1982, the system was expanded with a complementary system including measurements of relative displacements in ground, strains of the buried steel pipe and those of the ductile iron pipe, each 150 mm in diameter and about 120 m in length. Moreover in January, 1985, an additional 8 seismometers were installed to further expand the array network (Refs. 1,2).

A total of 144 earthquakes have been recorded since Decmber, 1982. The strongest event, so far recorded by the network, had a maximum acceleration of 326 cm/s^2 and occurred in the Chibaken-Toho-Oki Earthquake of December 17, 1987. The maximum buried pipe strain, 54x10^{-6}, was obtained also by the same earthquake

(Ref. 3).

The purpose of this paper is to study the relation between the maximum ground accelerations and the maximum buried pipe strains for all types of earthquake records, and the distribution of the axial and bending strain in the buried pipeline. Moreover, by using the typical earthquake events, the relations between buried pipe strain and wave types or wave propagation direction were investigated in detail (Ref. 4).

OBSERVATION SYSTEM

The observation system of earthquake ground motions and ground strains consists of the very densely located array network, the direct measurements of the relative displacements of ground, and the strain measurements of buried pipes (Fig.1).

The array network is composed of 44 three-component accelerometers which are capable of simultaneous recording of 132 components of accelerations on and in the ground. The seismometers are installed in the site covering a region of 300 m in plane and 40 m in depth. A seismometer made up by three piezo-electric type acceleration transducers and three amplifiers in a cylindrical casing has a practically flat sensitivity in the frequency range between 0.1 Hz and 30 Hz.

The ground strains are measured by using three devices, each of which detects the uni-axial relative displacement between two points 3 m apart. As each of the device is buried in the ground in a different direction, the arbitrary components of ground strain on a plane are possible to be obtained.

One steel pipe and one ductile-iron pipe, both 120 m in length and 150 mm in diameter, are buried, and the strains of both pipes and the relative displacements at the joints of ductile-iron pipe are measured. It is possible to obtain axial and bending pipe strains, because the strain gages are installed on both sides of pipes.

The total of 164 components, 132 for ground motions, 3 for relative displacements in ground and 29 for pipe strains and relative displacements at pipe joints, are converted simultaneously into digital values by using 12 bit A/D

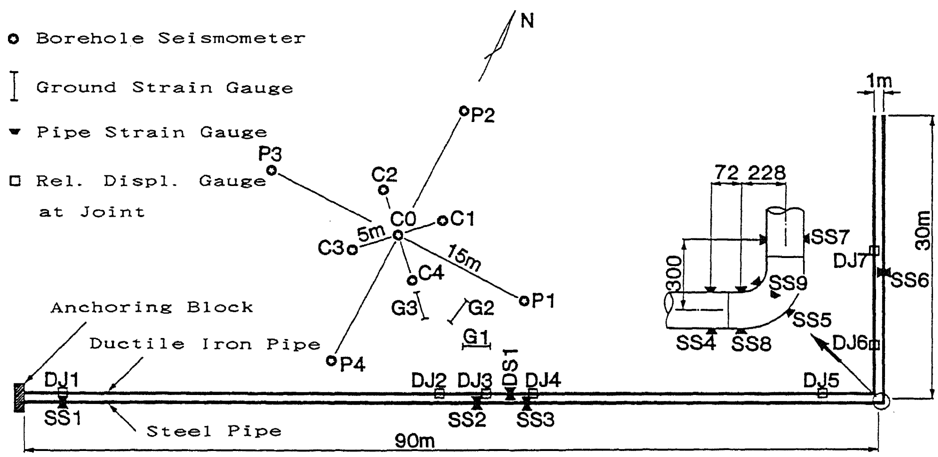

Fig. 1 General Layout of Observation System

converters, and these values are recorded on magnetic digital tapes.

The surface of the observation site is almost flat, and the ground property is also almost the same in the region of the site. 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 velocities of the S wave, measured at the point C0 in the site, are 140 m/s in loam, 320 m/s in clayey and upper sand layer, and 420 m/s in lower sand layer.

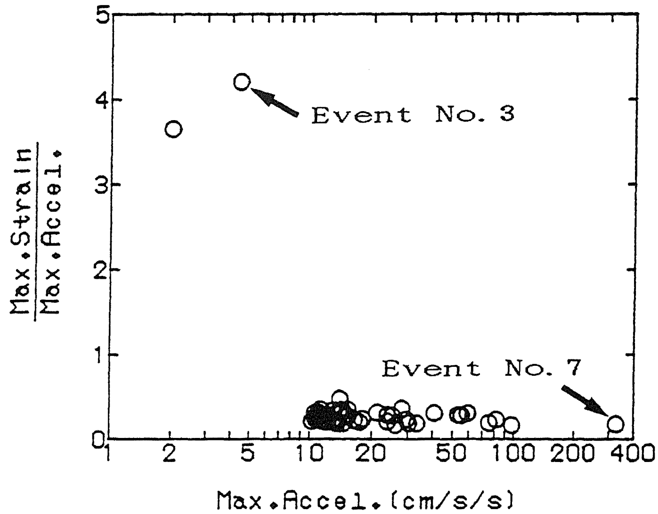

Fig. 2 Relation between the Maximum Values of Ground Acceleration and Pipe Strain

RECORDS AND CONSIDERATIONS

About 5 years have passed, since the start of earthquake observations concerning the ground strains and the behaviors of buried pipes. Upto March, 1988, a total of 144 earthquakes had been recorded at the observation center. Out of these recorded earthquakes 45 had either acceleration exceeding 10 cm/s^2 or pipe strain exceeding 5x10^{-6}. Table 1 lists 10 earthquakes, from among the recorded ones, which generated pipe strain exceeding 10x10^{-6}. The strongest event was the Chibaken-Toho-Oki Earthquake of December 17, 1987, and it recorded a ground acceleration of 326 cm/s^2 and a pipe strain of 54x10^{-6} (Event No.7 in Table 1 and Fig. 3).

Figure 2 shows the relation between the maximum values of the horizontal ground acceleration and pipe strain for 45 of the abovementioned records. Except for two events including Event No.3, it will be noted that the maximum pipe

Table 1 List of Earthquakes

Event No.	Date	Epicenter	Mag.	Focal Depth	D*	I**	Max. Amp.*** Accel.	Strain
1	Feb. 27, 1983	N 35° 56′, E 140° 9′	6.0	72km	35km	3	55.5	15.5
2	Mar. 6, 1984	N 29° 20′, E 139° 12′	7.9	452km	705km	4	28.1	10.1
3	Sept. 14, 1984	N 35° 49′, E 137° 34′	6.8	2km	232km	2	4.4	18.5
4	Oct. 4, 1985	N 35° 52′, E 140° 10′	6.1	78km	28km	4	82.0	18.8
5	Nov. 6, 1985	N 35° 21′, E 140° 14′	5.0	63km	32km	3	75.6	14.4
6	June 24, 1986	N 34° 49′, E 140° 43′	6.5	73km	105km	4	53.5	15.2
7	Dec. 17, 1987	N 35° 21′, E 140° 29′	6.7	58km	46km	5	326.1	54.2
8	Jan. 5, 1988	N 35° 24′, E 140° 28′	4.3	43km	41km	2	40.9	12.5
9	Jan. 16, 1988	N 35° 22′, E 140° 27′	5.2	53km	42km	3	97.9	15.9
10	March 18, 1988	N 35° 40′, E 139° 39′	6.0	99km	42km	4	59.6	18.1

* ; Epicentral Distance
** ; JMA Intensity at Chiba
*** ; Acceleration in cm/s/s and Strain in 10^{-6}

strains are almost proportional to the maximum ground accelerations. Therefore, they can be classified into two groups, namely, the group with proportional relation (named as Group-1) and the group, including Event No. 3, (named as Group-2). The ratios of the maximum pipe strain to the maximum ground acceleration are about 0.15 to 0.3 for Group-1, and about 4 for Group-2. The earthquakes belonging to Group-2 generate larger pipe strain through a lower acceleration level. Event No.3, belonging to Group-2, is called as the Nagonoken-Seibu Earthquake.

Figure 3 shows recorded time histories of the ground accelerations and pipe strains during Event No.3 and No.7 (described in Table 1). Event No.7 is the largest earthquake, belonging to Group-1 with a proportional relation. Seeing the waveforms of Event No.7, it is seen that both the ground acceleration and the pipe strain became larger in the portion, where the propagation is supposed to be by body wave. Even though the maximum acceleration of Event No.3 was only about 1.5 % to that of Event No.7, the pipe strain of Event No.3 grow up to a level of almost 34 % to that of Event No.7 at the time of arrival of the surface wave in the later half of the record.

Figure 4 shows the waveforms of axial and bending pipe strains for Event No.7 in Group-1 and Event No.3 in Group-2, respectively. The axial strains were generated in all the positions except in neighbourhood of the pipe corner. It is seen that the magnitudes and the shape of waveforms are almost similar at the three measuring points (SS1A, SS2A and SS3A) on the pipe 90 m in straight length. It is observed that for Event No.3, the axial strains in the central position of straight lines with 90 m and 30 m length (SS2A and SS6A), have opposite phases to each other. However, for Event No.7, such tendency does not exist. On the other hand, notable bending strains are found to occur only in the neighbourhood of the bending position of a pipe for the two groups. These bending strains show a reversed wave in the neighbourhood of the bending point, with a zero at the bending point itself.

Figure 5 shows the comparison of the pipe strain (dashed line) to ground acceleration, velocity and displacement (solid line). Here, the shapes of waveforms are compared by holding the maxima of those amplitudes to be constant. It is found that the pipe strain has good agreement only with the ground

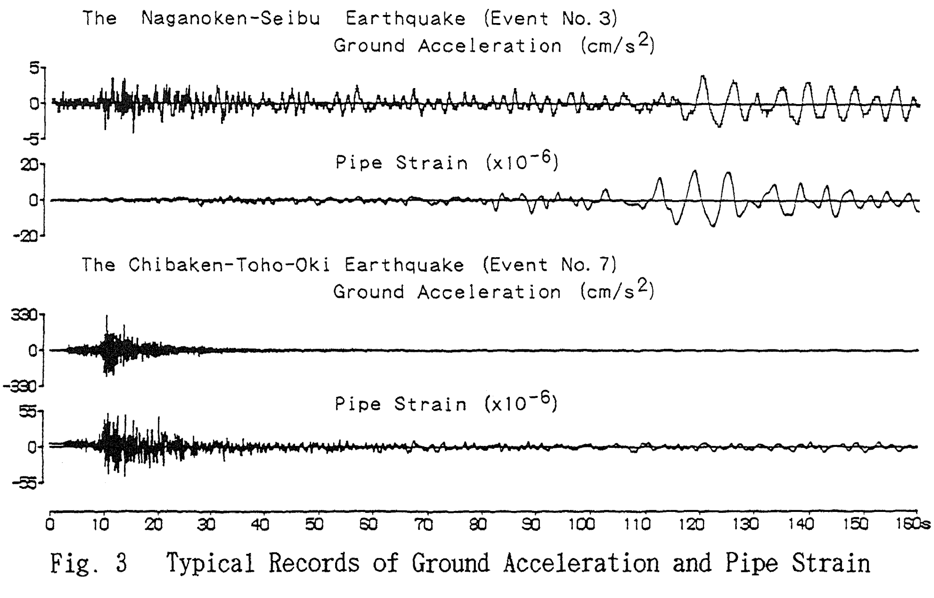

Fig. 3 Typical Records of Ground Acceleration and Pipe Strain

velocity, during Event No.3. It should be mentioned that pipe strain is caused by propagation of a wave in a plane.

Using the results of the array observation of ground motions, it is concluded that the quake of Event No.3 was caused by the Love Wave which arrived from the West. Hence, it was possible to explain the resemblance of the waveforms to the axial strains in the buried pipes of the two directions, and the agreement of strain waveform and ground velocity waveform. Moreover, the amplitude of strain coincided with the ratio of ground velocity to propagation velocity (Ref. 5).

On the other hand, in the Group-1, which is represented by Event No.7, the maximum values of the pipe strain were nearly proportional to the maximum horizontal accelerations of ground. The waveform of the pipe strain in the part where body wave propagation is presumed has no resemblance to the ground velocity, and in addition, the axial strains of the buried pipe of 90 m and 30 m straight length showed a different shape. An estimation of the propagating direction and velocity of the earthquake wave from the results of the array observations was attempted, but a clear propagation property such as the case of Event No.3 could not be recognized. Consequently, the behavior of the Group-1

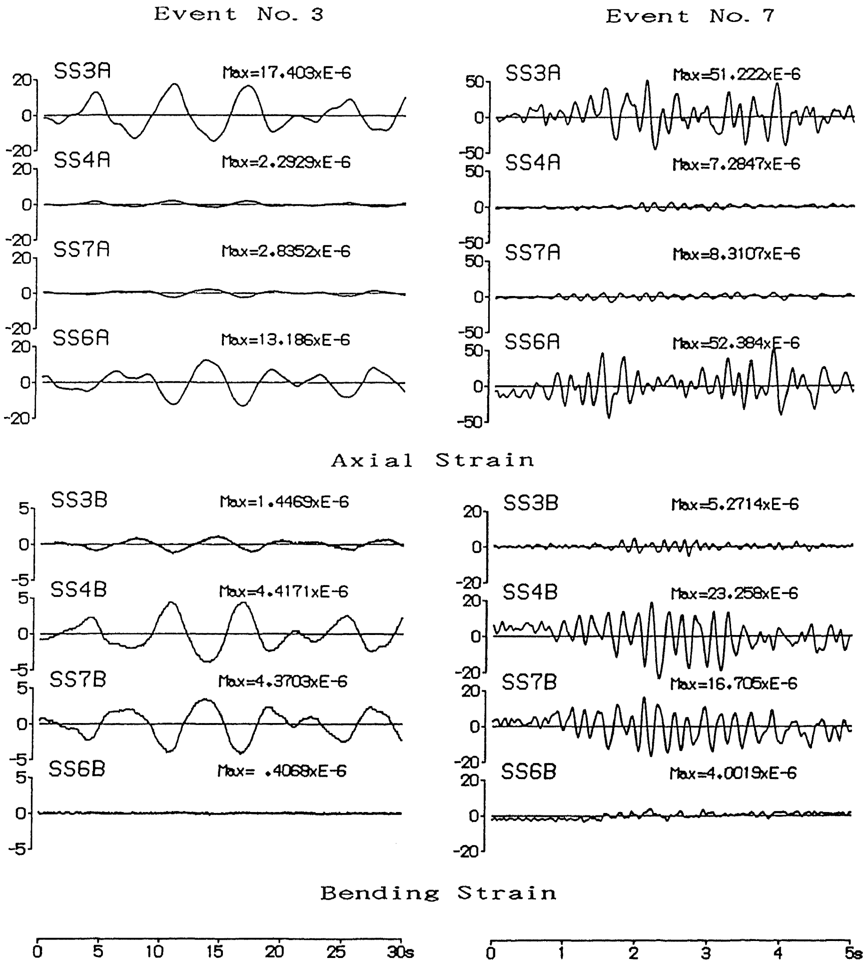

Fig. 4 Records of Axial and Bending Strain ($x10^{-6}$)

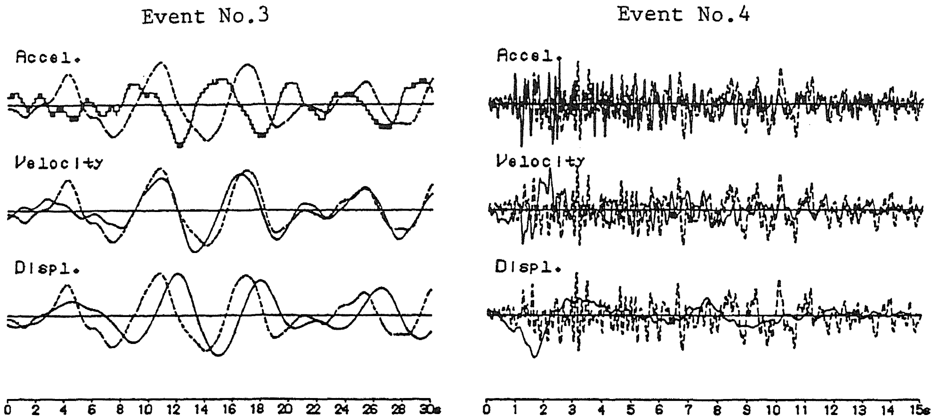

Fig. 5 Comparison of Pipe Strain (Dashed Line) to Ground Acceleration, Velocity and Displacement

cannot be explained by simple wave propagation in a horizontal direction. As the buried pipes showed a similar behavior for all of the earthquakes which occurred in various directions for this observation area, it is considered that the body wave, which reflects the ground structure of the wide region including this area, is the cause.

CONCLUSIONS

In the present study, the relation between the seismic ground motion and the buried pipe strain in a very dense seismometer array was discussed. The results can be summarized as follows :

(1) The buried pipe strain caused by the body waves is strongly correlated with maximum ground acceleration.
(2) The buried pipe strain caused by the surface waves, which is obtained by the Naganoken-Seibu Earthquake, is different from the buried pipe strains caused by body waves.
(3) The buried pipe strain caused by the surface waves is strongly correlated with the ground velocity.
(4) For the same level of the acceleration, the buried pipe strain by the surface waves is greater than that by the body waves.

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