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Observation on behaviors of buried pipelines and ground strain during earthquakes

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ABSTRACT : We have been observing the dynamic behavior of pipelines in diameter of 1000mm and ground movement during earthquake since 1975. Pipelines are stressed by ground strain, but the pipe stress is releasing by the expansion-contraction at pipe joint. We proposed the calculation formula for the expansion-contraction at joints and pipe body stress. And we obtained the relation between ground strain and ground velocity amplitude.

1 INTRODUCTION

As one of the researches on the seismic behavior of buried pipelines, we have been observing of the behaviors of the pipelines actually used and ground strain during earthquakes in Hachinohe and Aomori cities in Japan. This paper is to describe on the behaviors of the expansion-contraction at joints in the straight part of ductile iron pipelines, the pipe strain and the results of analysis of ground strain which is considered to control the behavior of such underground structures as pipelines, tunnels and tanks.
In this paper, the results of analysis of the records obtained on Shimonaga observation station in Hachinohe City are shown.

2 OBSERVATION EQUIPMENT AND PIPING

In observation stations, seismometers, ground strain-meters which directly measure the relative displacement in the ground, expansion-contraction at joint and pipe strain gauges are installed, and the number of measuring points is 42 in the Shimonaga, further uninteruptible power equipments are installed. The arrangement of sensors is shown in Fig.1. The pipelines are ductile iron pipes of S-type joint shown in Fig.2. The joints can move freely in tension, compression and bending and have the performance of preventing separation using lock rings. The pipe diameter is 1000 mm, and the pipe length is 6 m.

The PS logging values is shown in Fig. 3. The soil consists of a humic soil stratum, a soft sand stratum and a silt stratum, and is the typical soft ground zone of stratifying structure, where the depth of basement is about 40 m.
When the predominant period was determined by T=4H/Vs, it became 1.31 sec in the Shimonaga, and almost agreed with the measured values in the records during earthquakes.

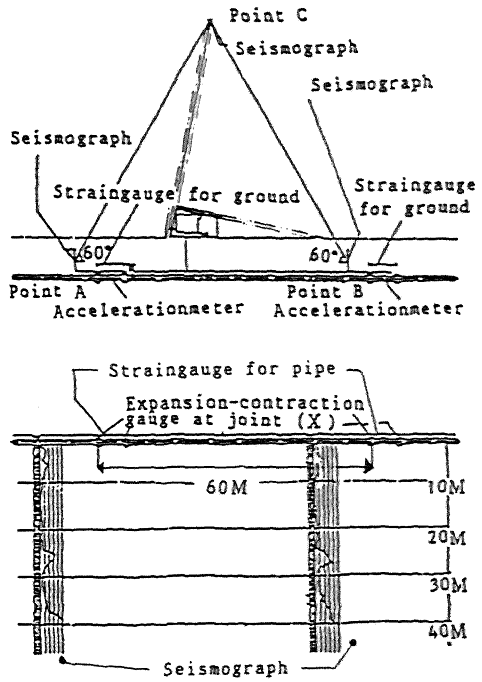

Figure 1. Shimonaga observation station

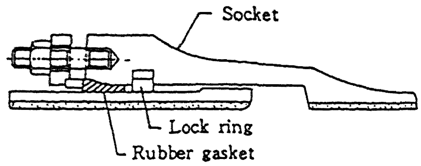

Figure 2.Ductile iron pipe of S-type joint

Vp (m/sec)	Vs (m/sec)	ρ (gf/cm³)	H (m)	depth (m)
280	40	1.35	2	0
670	40	1.35	1	2
670	60	1.30	2	3
1,450	180	1.65	4	5
1,450	110	1.45	9	9
1,450	160	1.60	7	18
1,450	235	1.90	4	25
1,450	170	1.55	5	29
1,450	270	1.80	7	34
2,300	470	2.10	∞	41

Figure 3. PS logging (Shimonaga)

3 ON BEHAVIORS OF PIPELINE

Figs.4 and 5 show recorded waveforms of earthquake with largest and characteristic motion after the start of observation in 1975. Maximum acceleration of ground of observation point of both earthquake are nearly the same. Table 1 shows two earthquake record. Record No.1 shows earthquake of medium-long epicentral distance of 271km, and Record No.2 shows recorded waveform of short epicentral distance of 80km.

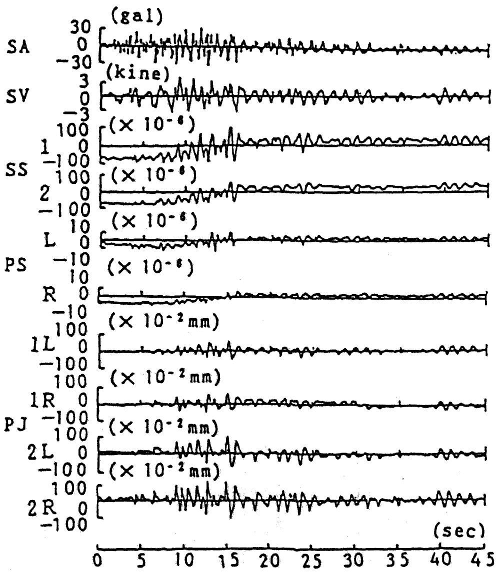

Figure 4. Recorded waves (No.1, Point-A, Miyagiken-oki, 1978.6.12)

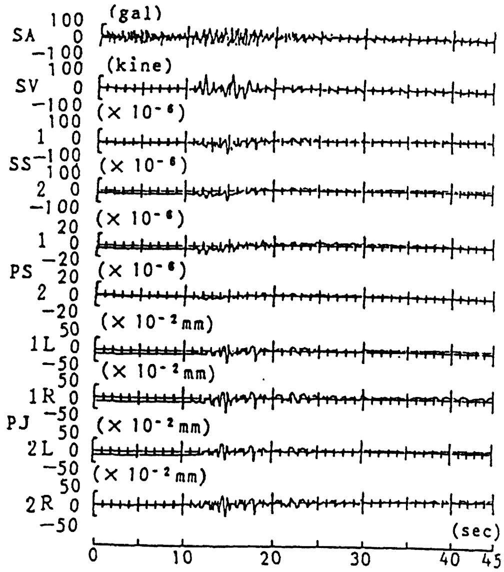

Figure 5. Recorded waves (No.2, Point-A, Iwateken-tubu, 1987.1.9)

Index of Fig. 4 and 5 show following content

SA : ground acceleration
SV : ground velocity amplitude
SS : ground strain, PS : pipe strain
PJ : expantion-contraction at joint

Table. 1 Analyzed earthquake records

Record	No.1	No.2
Location	Miyagiken-oki	Iwateken-tubu
Date	1978.6.12 17:14	1987.1.9 15:14
Epicenter	142° 10′ E 38° 09′ N	141° 47′ E 39° 51′ N
Magnitude	7.4	6.6
Depth (km)	40	71
Max.Acc(X) (gal)	125	142
Epicentral distance (km)	271	80

Figs.6 and 7 show Fourier spectra the velocity amplitude and expansion-contraction at joint of recorded waveform of both earthquake. Fig.8 shows the result of reading of relation of ground strain, pipe strain and the amount of expansion-contraction at joint at the same time. Further, in Fig.8 shows the relation which is expressed by following equation.

$$e = \varepsilon \cdot \ell \qquad (1)$$

Where e shows expansion-contraction at joint, ε shows ground strain and ℓ shows the length of pipe (= 6m).

From these figures, followings facts are known.

1. In periodic characteristic of ground, difference was hardly found between medium-long distance earthquake and short distance earthquake, and they are nearly the same.

2. Ground strain, pipe strain and amount of expansion-contraction at joint are in the same phase, and pipeline is controlled clearly by ground strain.

3. Amount of expansion-contraction becomes larger as ground strain becomes larger. Equation (1) expresses the case when ground strain is releasing by expansion-contraction at joint, and amount of expansion-contraction at joint is supposed to be possible to express by equation (1).

4. Pipe strain does not go larger than certain fined value, and the value itself is as small as 10×10^{-6}. It correspond to $16kgf/cm^2$ when converted to stress ($\sigma = \varepsilon \cdot E$, $E = 1.6\times10^6 kgf/cm^2$).
Standard tensile strength of ductile iron pipe is higher than $4200kgf/cm^2$.

The fact that strain of pipe shows constant value, is supposed to be the presence of sliding between ground and pipe. Based on this fact, strain of pipe (εp) is supposed to be expressed by following equation.

$$\varepsilon p = \frac{\pi \cdot D \cdot f \cdot \ell}{2 A_0 \cdot E} \qquad (2)$$

Where, D : outside diameter of pipes,
A_0: actual cross-sectional area of pipes,
E : Young's rate, ℓ : length of pipe, and
f : friction force per unit area between ground and pipe.
The relations of equations (1) and (2) are possible to obtain the same result from record No.1.

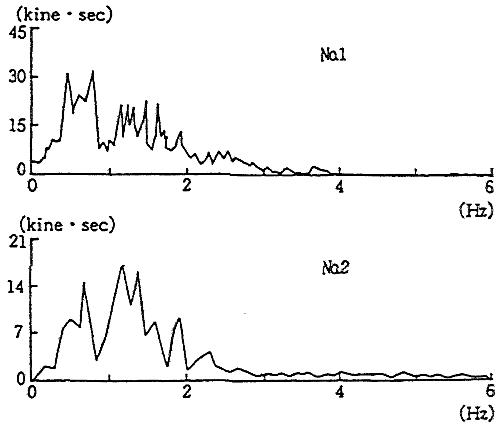

Figure 6. Fourie spectra of ground velocity amplitude

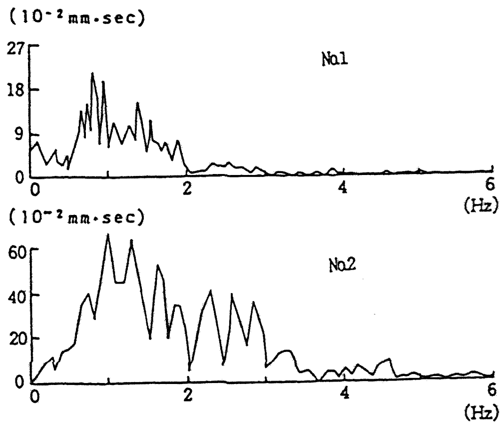

Figure 7. Fourie spectra of expansion-contraction at joint

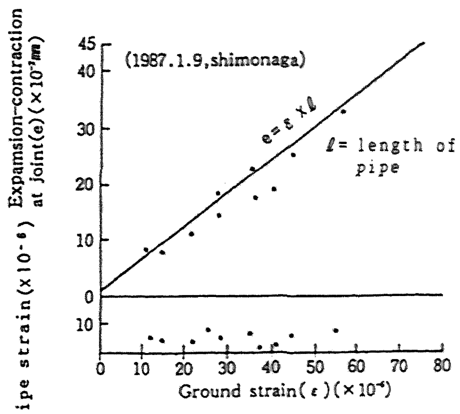

Figure 8. Relationship between ground strain, pipe strain and expansion-contraction at joint

4 GROUND STRAIN

Fig.9 shows the relation between maximum ground strain and maximum ground velocity amplitude in record which were obtained in past about 15 years. Maximum ground strain is obtained by dividing maximum amount of expansion-contraction at joint by pipe length (ℓ), by applying equation (1). Fig.9 shows values of Records No.1 and No.2 in Table 1. In spite of nearly the almost same degree of ground velocity amplitude, maximum ground strain of Record No.2 shows value as small as about 1/4 of No.1. Records, except Record No.2, are corresponding almost to medium-long distance earthquake. Following expression shows relation between maximum ground strain and maximum ground velocity amplitude, except Record No.2.

$$\varepsilon = 7.66v^{1.26} \quad (r = 0.937) \qquad (3)$$

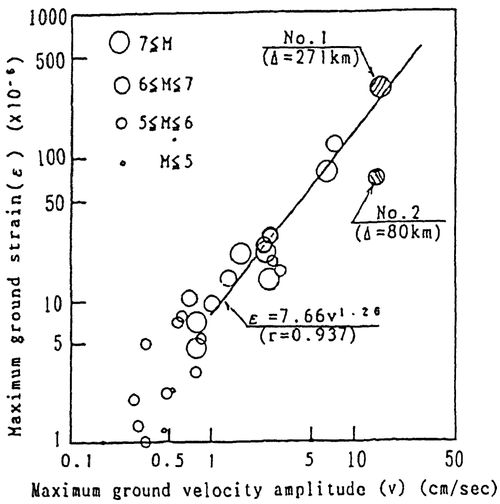

Figure 9. Relationship between maximum ground strain and maximum ground velocity amplitude

Generally it is known that ground strain (ε) is possible to express by following equation, based on the analyses of earthquake records in the past.

$$\varepsilon = v / V \qquad (4)$$

Where v is ground velocity amplitude, and V is propagation velocity of earthquake wave.

Following shows the results of analyses on propagation velocity of earthquake wave in Records No.1 and No.2. Fig.10 show waveforms of ground velocity amplitude Point A, B and C on distance of 60m which was shown in Fig.1 of Records No.1 and No.2. Fig.11 show results of analyses of propagation velocity (V) of earthquake wave in the direction of pipeline's axis (A→B) which were obtained by cross-correlation method concerning these waveforms. From these analyses, V=667m/s for Record No.1, and V=3000m/s for Record No.2 were obtained, namely, Record No.2 shows propagation velocity about 4 times larger compared to No.1. The principal cause that the ground strain of Record No.2 was smaller compared to No.1, is supposed to be attributable to the difference of propagation velocity of earthquake wave.

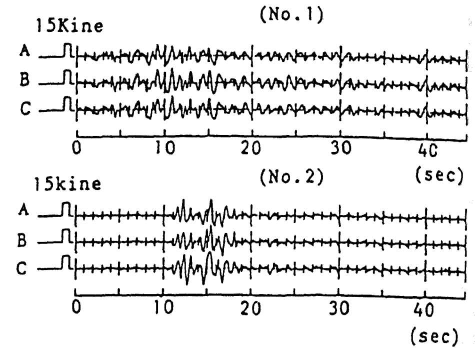

Figure 10. Ground velocity amplitude at point A, B and C in the records No.1 and No.2 (X-direction)

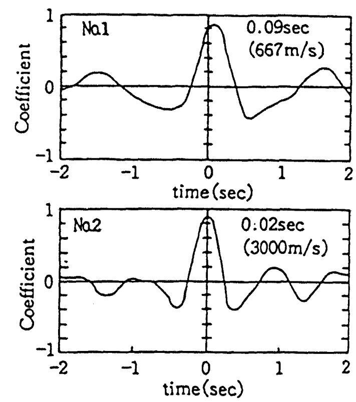

Figure 11. Analysis of propagatin velocity (Cross-correlation method, point A→B)

In addition, the relation between epicentral distance, magnitude and maximum ground strain was shown in Fig.12. From this relation, ground strain is found to become larger, when magnitude is larger when epicentral distances are the same. Regression formula of M ≧ 7 can be expressed as follows. Where Δ is epicentral distance (km).

$$\varepsilon = 3.88\times 10^{5}\Delta^{-1.84} \quad (r = 0.685) \qquad (5)$$

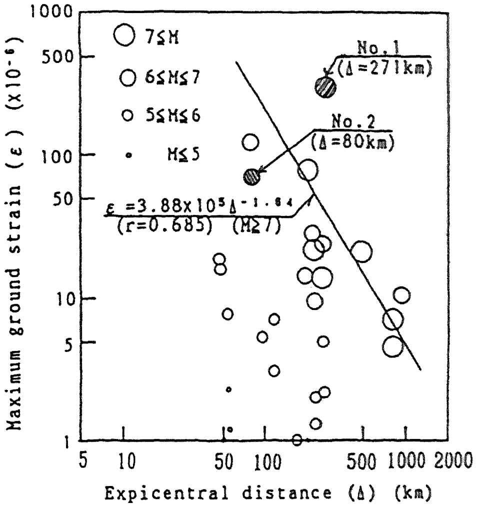

Figure 12. Relationship between expicentral distance, magnitude and maximum ground strain

5 CONCLUSION

1. We could obtain clearly the dynamic behaviors of buried pipelines during earthquakes.
Pipelines are stressed by ground strain, but the pipe stress is releasing by the expansion-contraction at joint.
2. We proposed the calculation formula for the expansion-contraction at joints and pipe body stress.
3. We obtained the relation between maximum ground strain and maximum ground velocity amplitude.

This observation station has been operated by the cooperation of the Water Supply Division of Hachinohe City, and we express their deep acknowledgement using the space of this paper.

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