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OBSERVATION ON BEHAVIORS OF BURIED PIPELINES AND GROUND STRAIN DURING EARTHQUAKES

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SUMMARY

We have been observing the dynamic behavior of pipelines and ground movement during earthquake at three sites since 1975. Pipelines are stressed by ground strain, but the pipe stress is eliminated by the sliding movement at pipe joint. Ground strain is generated by the relative displacement of the ground which is produced by the apparent propagation of seismic wave. It is presumed that the ground strain was to arise owing to the propagation velocity of Rayleigh waves taking the ground down to about 400 m depth in consideration at our observation stations.

INTRODUCTION

As one of the researches on the seismatic behavior of buried pipelines, we have observing of the behaviors of the pipelines actually used, ground strain and so on during earthquakes in Hachinohe and Aomori cities and others. This report is to describe on the behaviors of the expansion - contraction at joints in the straight part of ductile iron pipelines and 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 report, the results of analysis of the records obtained in Kansen and Shimonaga observation stations being carried out in Hachinohe City are shown.

OBSERVATION EQUIPMENT AND PIPING

In both observation stations, seismometers, ground strain-meters which directly measure the relative displacement in the ground, expansion-contraction at joint, pipe strain gauges and so on are installed, and the number of measuring points is 53 in the Kansen and 42 in the Shimonaga, further uninteruptible power equipments are installed. The arrangement of sensors is shown in Figs. 1 and 2. The pipelines as the object of observation are the S-type ductile iron pipes shown in Fig. 3, and in these pipelines, the joints can move freely in tension, compression, bending and so on, and have the performance of preventing separation using lock rings. The pipe diameter is 1500 mm in the Kansen and 1000 mm in the Shimonaga, and the pipe length is 6 m in both observation stations.

The soil properties and PS logging values in the Kansen and Shimonaga are shown in Figs. 4 and 5. From these figures, the soil of the Kansen is a sandy loam stratum, and there is a sandstone stratum which is considered to be the bearing stratum (basement rock) at this point around 20 m from the ground surface. Besides, this place is the ground of stratifying structure. The soil of the Shimonaga 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 rocks is about 40 m.

Now, when the predominant period was determined by $T = 4H/Vs$, it became 0.43 sec in the Kansen and 1.31 sec in the Shimonaga, and almost agreed with the measured values in the records of strong motion earthquakes.

The records as the object of analysis were those for about 12 years since May, 1975, and those in which the behavior of pipelines has been definitely obtained were taken up as the object. Those were 61 data in the Kansen, and 21 data in the Shimonaga.

ON BEHAVIOR OF PIPELINES

In Fig. 6-1,2, the wave forms recorded in the Kansen and Shimonaga during Miyagiken-Oki Earthquake (Japanese seismic intensity IV in Hachinohe) in 1978, which was the largest earthquake since the beginning of observation, are shown. Besides, the maximum ground acceleration in pipe axis direction in these records was 138 gal in the Kansen and 125 gal in the Shimonaga.

In order to observe the relationship among ground strain, the pipe strain and the expansion - contraction at joints, in Fig. 7, respective values read at the same time from the above recorded waveforms are shown. oreover, the line of $e = \varepsilon \cdot \ell$ in the figure shows the relation when it was assumed that all the ground strain (ε) is relieved by the expansion - contraction at joints (e). ℓ is the length of pipes.

In Fig. 8, the relation of ground strain (ε) to the value ($\varepsilon_j + \varepsilon_p$) which is the sum of the value ($\varepsilon_j = e/\ell$) by converting the expansion - contraction at joints (e) to strain and the pipe strain (ε_p) in the above earthquake in the Kansen is shown.

From the above figures, the following facts are known.

(1) By the fact that the waveforms of ground strain, the pipe strain and the expansion - contraction at joints behaved in the same phase, a force was exerted on pipelines by ground strain.

(2) It is presumed that ground strain (ε) is in the following realtion with the expansion - contraction at joints (e) and the pipe strain (ε_p) in Kansen.

$$\varepsilon = \varepsilon_j + \varepsilon_p = e/\ell + \varepsilon_p \qquad .... (1)$$

(3) When ground strain became large, the expansion - contraction at joints became large in proportion. The pipe strain arising during earthquakes was very small as compared with the expansion - contraction at joints. Their rigidity is very high as compared with that of ground, and it is considered that the calculation of the expansion - contraction at joints during earthquakes in the ductile iron pipelines of 6 m length may be carried out by Equation (2), considering $\varepsilon_p \ll e/\ell$ in Equation (1). Where, e is the expansion - contraction at joints, ε is ground strain, and ℓ is the length of pipes.

$$e = \varepsilon \cdot \ell \qquad .... (2)$$

(4) On the other hand, even though ground strain became large, the pipe strain did not become larger than a certain value. It was about 4×10^{-6} in the Kansen and 6×10^{-6} in the Shimonaga. When those are converted to stress ($\sigma = \varepsilon p \cdot E$, $E = 1.6 \times 10^{6}$ kgf/cm^2), 6.4 kgf/cm^2 and 9.6 kgf/cm^2 respectively are obtained, which are very small as compared with the tensile strength of ductile iron pipes (not lower than 4200 kgf/cm^2).

The fact that the pipe strain was constant seems to show that ground and pipe bodies slip, accordingly hereinafter, the results of its investigation are shown.

The backfilling for the pipelines in the Kansen and Shimonaga was carried out with pit sand as shown in Fig. 9. Now for example, when it was assumed that slip occurred in the state shown in Fig. 10, the strain arising in pipe bodies is expressed by Equation (3).

$$\varepsilon p = \frac{\pi \cdot D \cdot f \cdot \ell}{2 A_0 \cdot E} \qquad \text{.......... (3)}$$

where, D: outside diameter of pipes, A_0: actual cross-sectional area of pipes, E: Young's rate, ℓ : length of pipes, and f: friction force per unit area between ground and pipe bodies. When f was determined by using Equation (3), f = 0.038 kgf/cm^2 in the Kansen and f = 0.041 kgf/cm^2 in the Shimonaga resulted from it.

Now, when it was assumed that f can be expressed by the shearing strength of soil, it is expressed by Equation (4).

$$f = C + K \cdot \sigma v \cdot \tan \phi$$
$$\sigma v = \gamma \cdot h \qquad \text{.......... (4)}$$

where, C: cohesion, K: coefficient of earth pressure at rest, σv: vertical effective stress, ϕ: angle of internal friction, γ: weight per unit volume of earth, and h: depth of pipe center from the ground surface. In both Kansen and Shimonaga, backfilling was carried out with sand, therefore, when C = 0, ϕ = 35° and $\gamma = 1.7 \times 10^{-3}$ kgf/cm^3, K = 0.3 were assumed, and f was determined, in the Kansen (h = 2.25 m) f = 0.080 kgf/cm^2, and in the Shimonaga (h = 2.00 m) f = 0.071 kgf/cm^2 were obtained. As compared with the values determined by Equation (3), those were as large as 2.1 times in the Kansen and 1.7 times in the Shimonaga, but when the stress in pipe bodies ($\sigma = \varepsilon p \cdot E$) during earthquakes in the ductile cast iron pipelines of about 6 m length is calculated, it is considered that it will do to use Equation (3) and give f with the shearing strength of earth in Equation (4).

ABOUT GROUND STRAIN

In Fig. 11, the relation between maximum ground velocity amplitude (v) and maximum ground strain (ε) in the Kansen and Shimonaga is shown. The regression equation and its correlation coefficient (r) when the maximum ground velocity amplitude is not lower than 1 cm/sec become Equation (5).

Kansen $\varepsilon = 5.24\ v^{1.00} (\times 10^{-6})$ (r = 0.930)
Shimonaga $\varepsilon = 6.80\ v^{1.35} (\times 10^{-6})$ (r = 0.945) .... (5)

Besides, a part of the above records was already reported by Nakamura, Katayama and Kubo.[2)]

According to the results of analyzing the recorded waveforms of the

Miyagiken-Oki Earthquake in 1978 and others in Shimonaga, which were analyzed separately, the result that ground strain is caused by the Rayleigh waves including higher order modes taking the deep strata of about 400 m into account has been obtained.[1]

Now, when it was assumed that the ground distortion in both observation stations occurs by the propagation of earthquake waves in Equation (6), and the propagation velocity (V) of earthquake waves was determined, it became V = 1908 m/s in the Kansen, and V = 924 m/s in the Shimonaga. As for the records as the object of analysis, those of the maximum ground velocity amplitude being 1 cm/sec or higher were adopted.

$$\varepsilon = v/V \qquad \text{..........} \quad (6)$$

In Fig. 12-1,2, the models of ground in the Kansen and shimonaga, in which estimation was made down to the deep parts, are shown. The theoretical dispersion curves of the phase velocity of Rayleigh waves and Love waves (basic mode) according to these models are shown in Fig. 13 . Besides, in the figure, the propagation velocity of the above earthquake waves at the predominant period is shown by plots. From this figure, it is known that the propagation velocity determined by Equation (6) is close to that of Rayleigh waves in both Kansen and Shimonaga.

From the above facts, though considerably daring, it is presumed that the ground strain in the Kansen and Shimonaga observation stations was to arise owing to the propagation velocity of Rayleigh waves taking the ground down to about 400 m depth in consideration.

CONCLUSIONS

Above, the results of analyzing the records of observing the behaviors of buried ductile iron pipelines and ground strain during of earthquakes were described.

Hereafter, the authors intend to promote the accumulation of the records for Japanese seismic intensity of IV and more in these observation stations, and to carry out the analysis of the records obtained in other observation stations in Aomori City and others.

These observation stations have been operated by the cooperation of the Water Supply Division of Hachinohe City, and we express their deep sense of gratitude using the space of this paper.

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2) M. Nakamura, T. Katayama, K. Kubo: Quantitative study on observed seismic strains in underground structures. Proceedings of Japan Society of Civil Engineers, No. 320, April 1982.

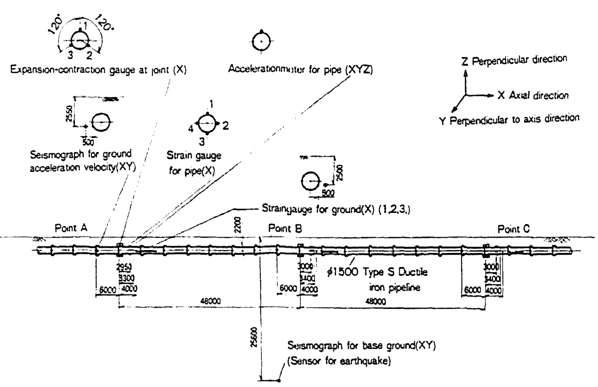

Fig. 1 Kansen observation station

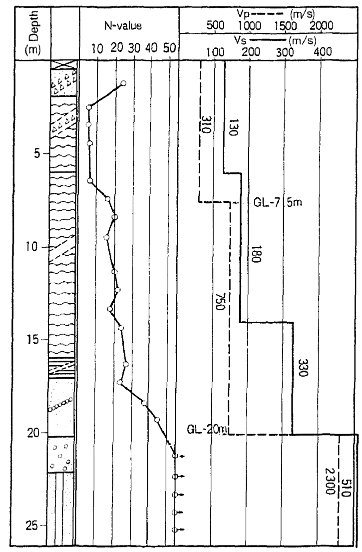

Fig.4 Soil condition, PS logging (Kansen)

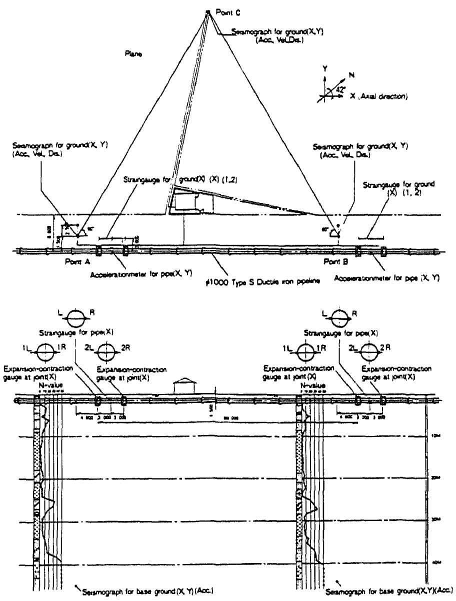

Fig.2 Shimonaga observation station

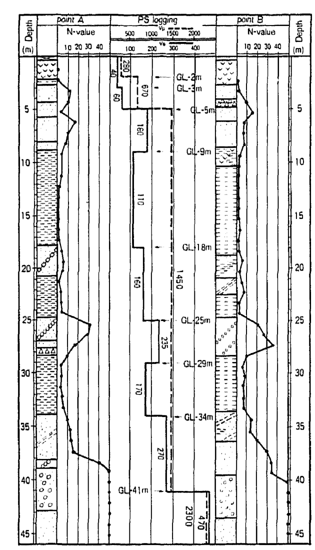

Fig.5 Soil condition, PS logging (Shimonaga)

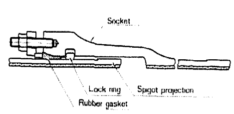

Fig.3 S-type ductile iron pipe

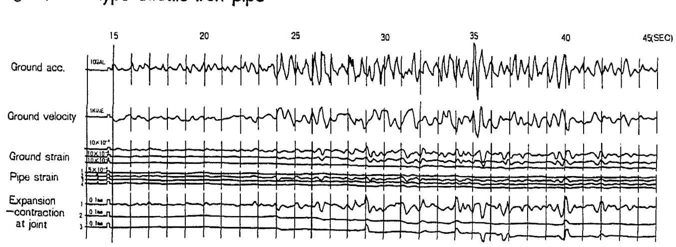

Fig.6-1 Recorded waves (Kansen, point A, Miyagi-ken-oki Earthquake, June 12, 1978)

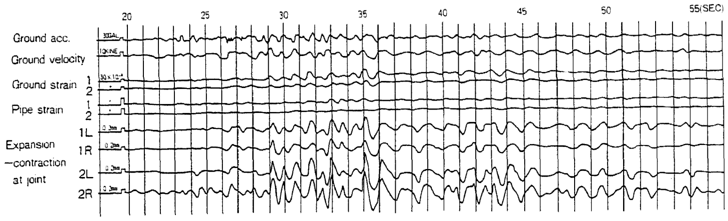

Fig.6-2 Recorded waves (Shimonaga, point A, Miyagi-ken-oki Earthquake, June 12, 1978)

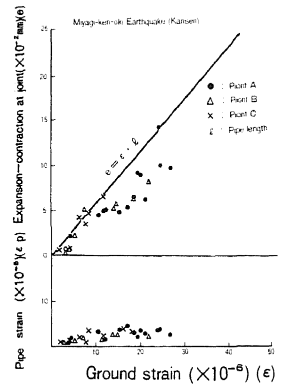

Fig.7 Relationship between ground strain and pipe strain, and expansion —contraction at joint (Kansen)

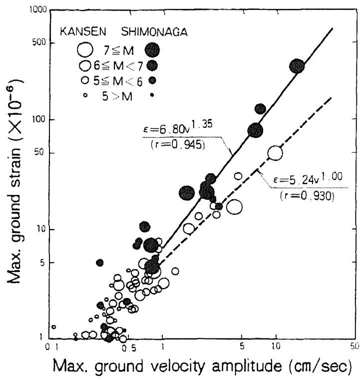

Fig.11 Relationship between Max. ground strain and Max. ground velocity amplitude (Kansen, Shimonaga)

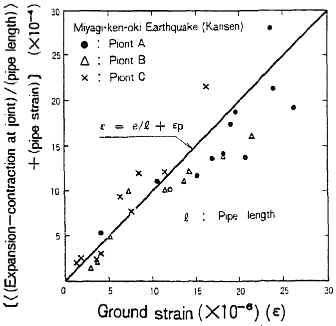

Fig.8 Relationship between ground strain and pipe strain, and expansion —contraction at joint (Kansen)

Vp (m/sec)	Vs (m/sec)	ρ (gf/cm³)	H (m)	Depth (m)
				0
310	130	1.4	6	6
310	180	1.4	1.5	7.5
750	180	1.8	6.5	14
750	330	1.9	6	20
2300	510	2.1	6	26
3000	1300	2.1	174	200
5000	2800	2.6	∞	

Fig.12-1 Ground model (Kansen)

Vp (m/sec)	Vs (m/sec)	ρ (gf/cm³)	H (m)	Depth (m)
				0
280	40	1.35	2	2
670	40	1.35	1	3
670	60	1.30	2	5
1450	180	1.65	4	9
1450	110	1.45	9	18
1450	160	1.60	7	25
1450	235	1.90	4	29
1450	170	1.55	5	34
1450	270	1.80	7	41
2300	470	2.10	159	200
5000	2800	260	∞	

Fig.12-2 Ground model (Shimonaga)

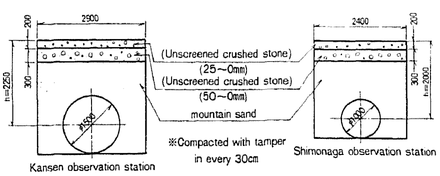

Fig.9 Backfilling condition of pipeline

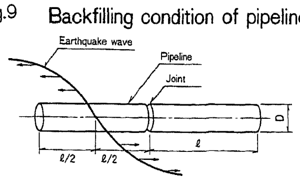

Fig.10 Slip condition model of ground and pipeline (example)

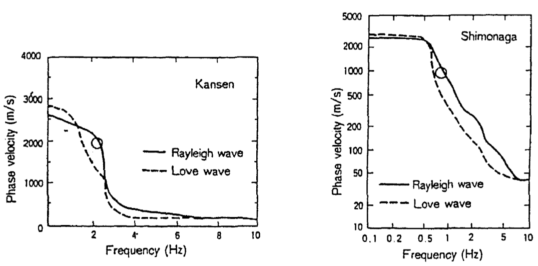

Fig.13 Thoretical distributed curve of Rayleigh wave, Love wave (Kansen, Shimonaga)