SEISMIC DAMAGE PREDICTION OF BURIED PIPELINES IN DUE CONSIDERATION OF JOINT MECHANISM

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SUMMARY

The present paper develops a new methodology for damage estimate of buried pipelines with mechanical joints. The methodology includes the following procedures; seismic response analysis of buried gas pipelines with various kinds of joint due to wave propagations, response analysis of the pipelines due to large ground deformations such as faulting and subsidence, determination of damage propabilities with the aids of experimental data. The methodology is applied to an actual urban lifelines under seismic loadings. Damage predicted results teach that joints with high reliability for seismic loadings are very important factor to raise safety levels of urban lifelines.

INTRODUCTION

A damage rate (pipe break numbers per unit length of buried pipelines of a certain pipe material), which is determined by damage data of past severe earthquakes, has been habituating for predicting total damage numbers of buried pipelines in urban lifeline systems. However, these damage rate can not be always related with mechanical strength of various kinds of joints. New damage predicting methodology have to be established in due consideration of joint mechanisms of recent gas or water buried pipelines. The methodology also has a necessity to include considerations for ground failure such as faulting, liquefaction and subsidence as well as considering for wave propagation.

Present paper proposed a new methodology for predicting pipeline damages in urban area and the methodology was applied to an actual pipeline networks subjected to given earthquakes.

ANALYSIS ON SEISMIC STRENGTH OF JOINTED PIPELINES

The present paper analyses aseismic strength of ductile iron gas pipelines with mechanical joints.

Joint and Its Characteristics

Joint dimensions and configurations of five types of gas joints employed for conducting analysis are listed in Table 1 and Fig.1. Fig.2 is test results on joint resisting forces related with extraction or compression joint displacements for five types of joints (Ref.1). The tests were carried out for

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joint parts in the air paying no regard to inner gas pressures. A-type joint is constituted of jute and lead coaking to prevent gas leakage and has the longest history for usage. This joint type belongs to fixed type joints not to be allowed for extraction and rotation. B and C-type joints are tightened mechanically with bolts and nuts having jute, lead and rubber materials to prevent gas leakage. C-type joint has a projection part to have a function preventing pull out of joints, whereas B-type joint has not such functions. D-type joint is a kind of seismic resistant joints and lock ring, protection ring and rubber ring are used for preventing gas leakage. E-type joint has the same capability for joint extraction as D-type joint, but the more margin is allowed for joint compression by shearing the lock ring than D-type joint. E-type joint has the highest reliability for seismic loadings.

Ground Strain by Wave Propagation and Joint Response

Seismic response analyses were conducted for buried gas distribution pipelines with the joints mentioned above. In the present section, wave propagation is considered as seismic loadings.

Analytical Model: Straight buried pipelines of 95.5 m length jointed with 19 segmented ductile cast iron pipes were analysed. Both ends of the pipelines were connected with T-shaped pipelines. Ground deformations caused by P-wave propagating towards the direction of the pipeline axis were employed for seismic inputs as shown in Fig.4(a). The ground deformation gave tension and compression ground strains preferable to investigate responses of the pipelines with different joint characteristics between extraction and compression. 14 cases of numerical computations were carried out for different displacement amplitudes (0.2-10.0 cm) and constant wave frequency 1 Hz and wave velocity 191 m/sec.

Analytical Procedures and Examination of Propriety for Models: ERAUL (Earthquake Response Analysis of Underground Lifelines) computer program developed by author (Ref.2) were used for numerical computations. The program is able to introduce non-linear characteristics of joint and ground resisting forces based on a quasi-static analysis. Fig.3 gives good simulated joint behaviors compared with given ones for E-type joint. Several cases of numerical computations were done prior to compute 14 cases, to examine the effect of boundary conditions at both ends of the pipelines, input wave frequency and input wave length on the pipeline responses. Figs.4(a) and 4(b) show simulated response displacements of joints for 95.5 m of wave length and 10 cm of amplitude, and 47.75 m of wave length and 5 cm of amplitude respectively which give the same ground strain 3290 μ. The maximum joint displacement is 1.48 cm for Fig.4(a) and 1.34 cm for Fig.4(b). More computational results showed that input seismic waves with the same maximum strains calculated by various combinations of wave lengths and amplitudes may simulate nearly the same response values of joint displacements.

Ground Strain and Maximum Joint Displacement: Maximum joint displacements and maximum joint compression stresses related with maximum ground strains for 5 types of joint are plotted in Figs.5 and 6. Fig.5 shows that the maximum joint displacement is proportional to the maximum ground strain with an equivalent proportional constant of unit pipe length (400-500 cm) for any kinds of joints. This fact suggests that the maximum joint displacement can be predicative by multiplying unit pipe length with the maximum ground strain during earthquakes. Differences of the joint types do not give any differences for the amount of maximum joint displacements because deformations of the pipeline are restriced due to input forced ground deformations. However, the compressional pipe stresses are much different among 5 types of joint as shown in Fig.6.

Ground Failure and Joint Extraction: Fundamental analyses were conducted to investigate behaviors of the buried pipelines subjected to ground failures such as faulting and subsidence. The buried pipeline was forced to subject longitudinal or transversal displacements or forces within limitted pipe segments due to relative permanent ground deformations as shown in Fig.7. Fig.8 is an analytical model for simulating actual permanent ground deformations with longitudinal motions of the jointed buried pipeline. Input ground deformations of 2-20 cm were imposed to the buried pipelines with 5 types of joint mentioned in the previous section. ERAUL computer program was also employed in this case. Figs.9 and 10 indicate distributions of joint extractions along the longitudinal direction of the pipeline for A and E-type of joint under each seismic loading Δ. As shown in Fig.9, A-type joint (fixed joint) can mobilize only the first joint to resist the external ground deformation. Δ=8 cm is the maximum ground deformation to be able to bear for pipelines with A-type joint under allowable joint extraction of 60 mm. On the other hand, E-type joint (aseismic joint) can resist against more than 16 cm of the ground deformation mobilizing the joint functions up to the forth joint as shown in Fig.10. Fig.11 shows relationships between the forced ground deformation and the maximum joint extractions for 5 types of joint. The maximum resisting ground deformations were 7 cm for A and B-type joints, 9 cm for C-type joint and 20 cm for D and E-type joints in due consideration of 60 mm allowable joint extraction. D and E-type joints with aseismic proofness are considered to be efficient for larger ground deformations.

SEISMIC RELIABILITY OF JOINTS

Fig.12 is a figure to explain general idea of the relations between joint reliability and experimental test data about joint function. In the figure, data on leakage (●), structural damage (△) and perfect pulling out of joint (□) are assumed to be given by push and pull tests for various joints with inner gas pressures. Functional damages of the joint start from joint extraction b and structural damages are within a range between c and d as shown in Fig.12. Damage probability function (III) can be expected for the joint reliability in due consideration of functional and structural damages. However, the damage probability function (II) is obtained corresponding to the joint displacement b-c when the failure of the joint is specified as conditions of initial stage of structural damages. Values of joint displacement b, c and d are uncertain variables by experiments. Then, desirable damage probability function (I) for actual usage can be obtained for the joint extraction a with some factor of safety against b. Fig.13 shows the desirable damage probability functions for 5 types of joint for usage in the following analysis, which are determined by insufficient experimental data as well as by engineering judgements (Ref.1).

DAMAGE PREDICTION OF GAS DISTRIBUTION NETWORKS IN URBAN AREA

Damage numbers of joints of gas distribution pipelines in 1 km square meshes in urban area shown in Fig.14 were predicted with the aid of the analytical results in the previous sections. 3 past earthquakes caused damages in the area were assumed to be seismic inputs to the gas distribution pipelines. EA and EB earthquakes were near field earthquakes having a several kilometer epicentral distance with earthquake magnitude of 6.4 for EA and 6.8 for EB, and EC earthquake was a far-field earthquake having a few ten kil meter epicentral distance with the magnitude of 7.5. Epicenters of EA and EB earthquakes were in the vicinity of southern part of the city with soft groun conditions and northern part with hard ground respectively.

Ground Strain for Given Earthquakes

Maximum ground strains could be predicative for given earthquake-magnitude and epicentral distances by the methodology proposed by author (Ref. 3). Estimated ground strains were not more than 800 μ in the southern part of the city and less than 500 μ in the northern part of the city for EA earthquake. High values of ground strains 700-1000 μ were estimated for EB earthquake because of overlapping earthquake epicentral area and soft ground conditions. EC earthquake gave highest values of ground strains over 1000 μ among 3 earthquakes because of the largest earthquake-magnitude inspite of the longest epicentral distance.

Ground Permanent Displacements for Given Earthquakes

There exists several reclaimed areas in the city where buried pipelines are thought to be easy to break due to ground distortions as known by damage investigated data in the past severe earthquakes. Relative ground displacements of reclaimed grounds against to unreclaimed grounds were estimated by using the procedure proposed by Newmark (Ref.4). Estimated results at six reclaimed areas in the city revealed that the maximum relative ground displacements were 0.9-2.4 cm for EA earthquake, 2.6-4.6 cm for EB earthquake and 1.9-4.9 cm for EC earthquake.

Pipeline Laying Characteristics

Gas distribution buried pipelines with A, B and C-type joints have a major portions in the northern part of the city where gas supply has a long history. On the countrary, a large number of pipelines with D and E-type aseismic joints are buried in the southern part in the city. Then, it can be said that pipelines of D and E-type joints with high seismic reliabilities are buried in weak grounds of the southern part in the city whereas A, B and C-type joints with low seismic reliabilities in hard ground of the northern part in the city.

Prediction of Joint Break Numbers in Each Mesh

Following procedure is established to predict numbers of joint breaks in each mesh subjected to wave propagation and ground distortion for the given earthquakes in due consideration of differences of the joint mechanism.

(a) Average ground strains and permanent ground displacements in each mesh are calculated for given earthquakes.
(b) Maximum joint extractions corresponding to the ground strains and displacements are known by Figs.5 and 11.
(c) Joint damage probabilities are determined by Fig.13 for 5 different types of joint associated with the maximum joint extractions.
(d) Damage numbers in each mesh are the sum for damage numbers of each type of joint which can be calculated by multiplying total joint

numbers by damage probability and damage occurrence probability. The damage occurrence probability is specified by taking account that the maximum joint extraction does not occur at once at joints within a half distance of the wave length.

Figs.14 and 15 show reliability levels of each mesh for EA and EC earthquakes. As shown in Fig.14, there exists many meshes with high reliability for EA earthquake because of less pipeline laying length and usage of aseismic D and E-type joints inspite of large ground strains in the southern part of the city. Main causes of decrease in reliability levels in the mesh are A-type joint with high damage probability and large ground relative displacements in reclaimed grounds. For example, ratio of joint damage probability by wave propagations is 0.001 compared with that by permanent ground deformations for A-type joint. In Fig.15, there exists many meshes with low reliability including meshes where many A-type joints are buried and ground are reclaimed. Damage predicted results show that joints with high reliability for seismic loadings are very important factor to raise up safety levels of urban lifelines.

REFERENCES

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(3) Goto,H., Kameda,H., Takada,S. and Sugito,M. "Earthquake Motion Estimation for Buried Lifelines," 2nd Specialty Conf. of TCLEE, Aug. 1981, pp.321-334.

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Table 1 Dimensions of joints

	A-Type	B-Type	C-Type	D-Type	E-Type
Radius (mm)	169	169	169	169	169
Thick-ness (mm)	9.5	9.0	10.9	8.5	8.5
Flange (mm)	307	297.6	297.6	287.0	275.0
Young's Modulus (kg/cm^2) x10^6	1.0	1.7	1.0	1.7	1.7
Length (cm)	400	500	500	500	500

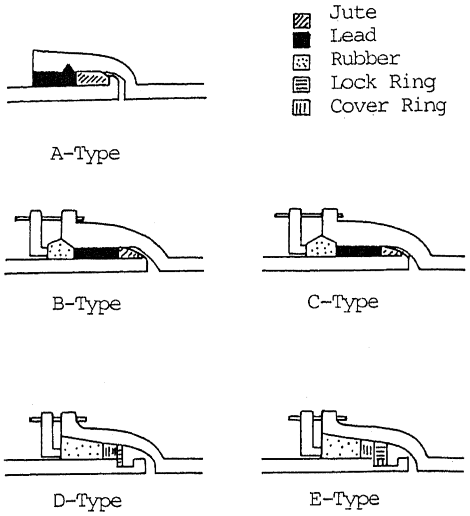

Fig.1 Joint types

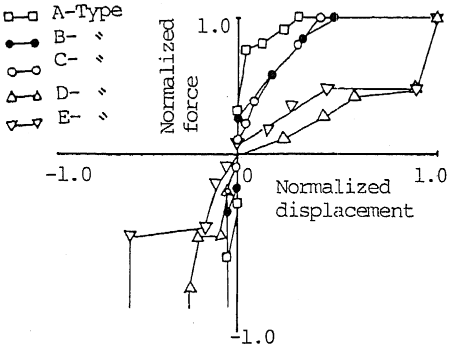

Fig.2 Joint characteristics

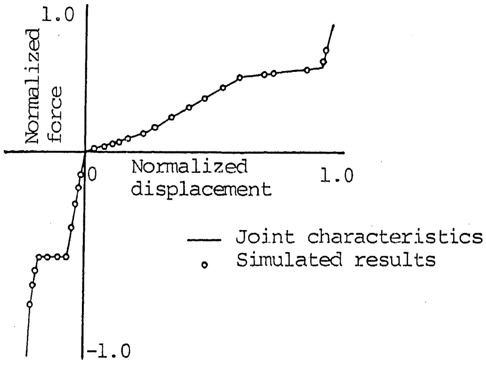

Fig.3 Simulated results of joint characteristics

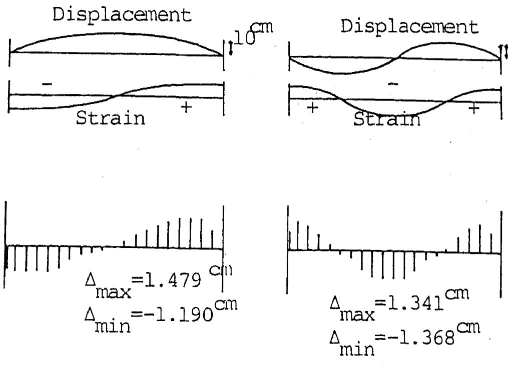

Fig.4 Effects of input-wave-length

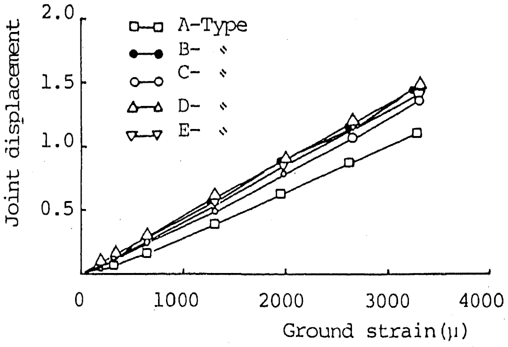

Fig.5 Ground strain and joint displacement

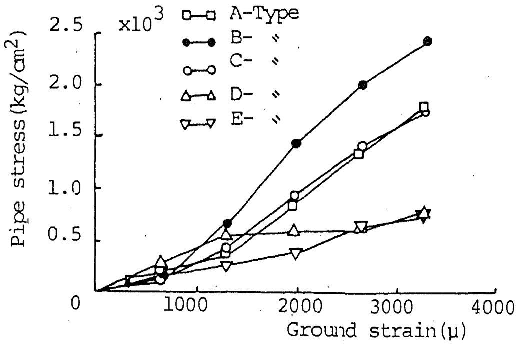

Fig.6 Ground strain and pipe stress

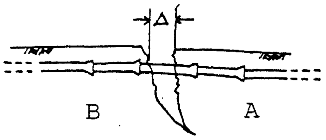

Fig.7 Ground fissure and pipeline

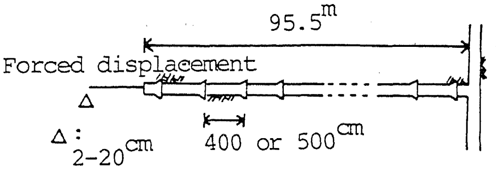

Fig.8 Analytical model for ground distorsion

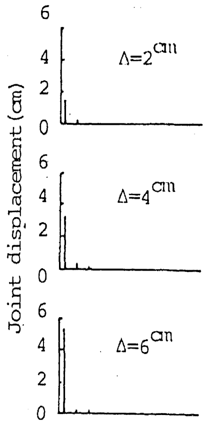

Fig.9 Joint behavior of A-Type

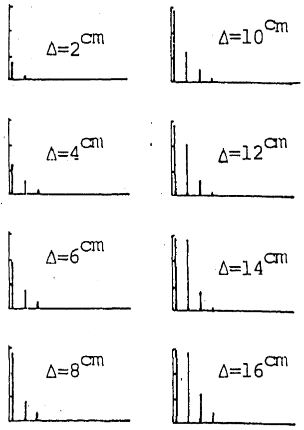

Fig.10 Joint behavior of E-Type

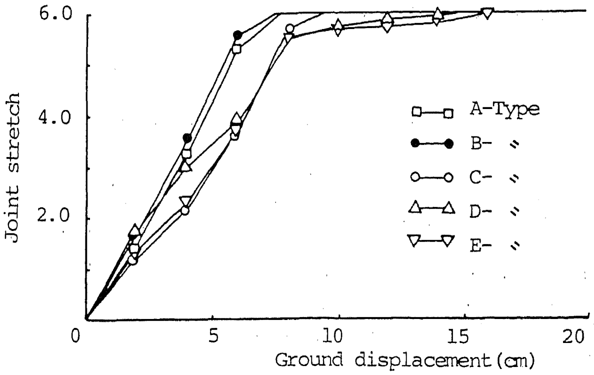

Fig.11 Ground displacement and joint stretch

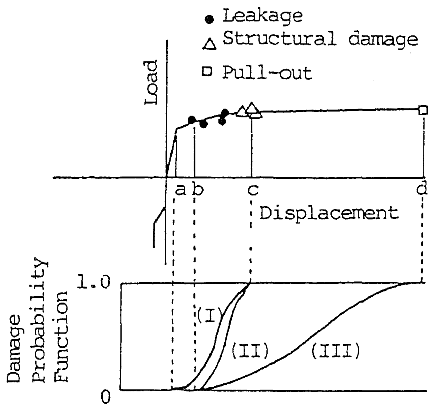

Fig.12 Generalized sketch for joint reliability

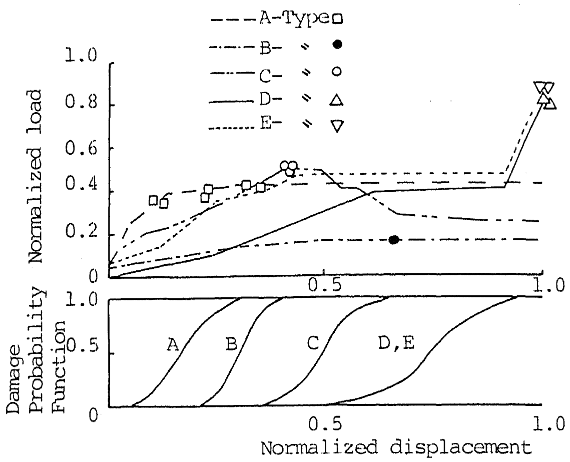

Fig.13 Damage probability function of each joint

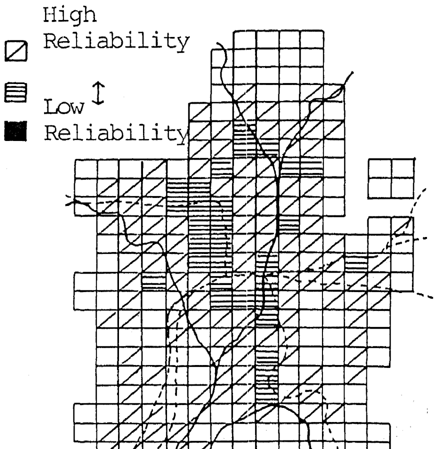

Fig.14 Reliability of low pressure gas pipelines in each mesh (EA earthquake)

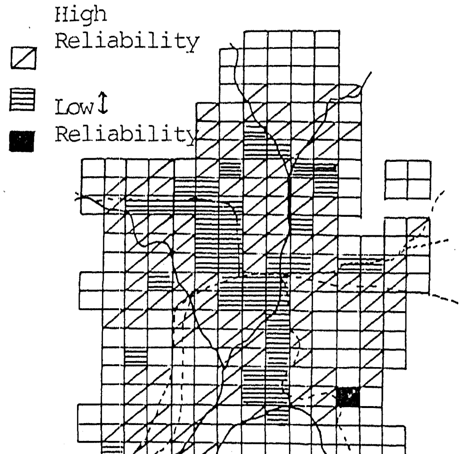

Fig.15 Reliability of low pressure gas pipelines in each mesh (EC earthquake)