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EARTHQUAKE RESISTANCE EVALUATION OF SERVICE JUNCTIONS IN A SMALL-DIAMETER STEEL PIPELINE

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SUMMARY

Small-diameter gas pipelines (3 inch or less) are connected with mechanical joints, which have earthquake-resistant properties. In this paper, the earthquake resistance of newly developed welded small-diameter pipes, especially service junctions with mechanical joints, are evaluated. Present analysis clarified the effects of external forces acting on the conventional junction materials.

INTRODUCTION

For small-diameter gas pipelines, mechanical joints (SGM joints) are generally used because they are flexible and capable of absorbing ground movement during differential settlement and/or seismic movement. On the other hand, recent technological developments have facilitated commercialization of welded joints using simple welding devices. It is expected that such joining techniques without the use of joints will be combined with trenchless pipe-laying techniques to improve pipeline construction efficiency. It is, however, necessary to use mechanical or screw joints for service junctions on customers' premises and not welded joints. This report describes the earthquake resistance evaluation of service junctions in a small-diameter pipeline. An earthquake response simulation of lead-in service junctions was made with an earthquake input and the soil properties prescribed in "Recommended Standards for Earthquake Resistant Design of Gas Pipelines" (Ref. 1) (to be called "the Recommended Standards") as the parameters, and the results were analyzed. Since service pipes are of three-dimensional configuration, the analysis was made using ERAUL III (Earthquake Response Analysis of Underground Lifelines III), a three-dimensional nonlinear program for analysis of pipeline response to earthquakes.

METHOD OF ANALYSIS AND MODEL

Outline of Method The method of analysis employed in the present study is based on the theory of a beam on an elastic foundation and the modified transfer matrix method just as ERAUL II developed by Takada et al. (Ref. 2). Where the present method differs from ERAUL II is that the condition of force equilibrium

at the tee and the condition of displacement compatibility have been introduced into the discussion. Figure 1 shows the forces at the tee and the direction of displacement. Equations (1) give the relation between the mechanical quantities of the i-th and (i+1)-th elements and those of the k-th element of the service pipe in terms of displacement U and force Q (generalized coordinate system).
The transfer process in the direction indicated by → from the main pipe to the service pipe at the tee is given by the following equations.
By substituting Eqs. (2) in Eqs. (1) and rearranging, α, β and γ at the left end of the (i+1)-th element of the main pipe is given by (3)
Further, by using the transfer quantities, in both directions, of the (i+i)-th element of the main pipe to find the coefficients α, β and γ for the i-th element and k-th element of the main pipe and the service pipe, respectively, the transfer process in the direction indicated by ← at the tee can be expressed as follows.

$$\left.\begin{array}{ll} Q_{i+1}^{L} = Q_i^R + Q_k^R & U_{i+1}^{L} = U_i^R + U_k^R \end{array}\right\} \quad (1)$$

$$\left.\begin{array}{ll} \vec{\alpha}_i^R \cdot U_i^R + \vec{\beta}_i^R \cdot Q_i^R = \vec{\gamma}_i^R & \vec{\alpha}_k^R \cdot U_k^R + \vec{\beta}_k^R \cdot Q_k^R = \vec{\gamma}_k^R \end{array}\right\} \quad (2)$$

$$\left.\begin{array}{ll} \vec{\alpha}_{i+1}^{L} = \vec{\beta}_i^{R-1} \cdot \vec{\alpha}_i^R + \vec{\beta}_k^{R-1} \cdot \vec{\alpha}_k^R & \vec{\beta}_{i+1}^{L} = E \\ \vec{\gamma}_{i+1}^{L} = \vec{\beta}_i^{R-1} \cdot \vec{\gamma}_i^R + \vec{\beta}_k^{R-1} \cdot \vec{\gamma}_k^R & \end{array}\right\} \quad (3)$$

$$\left.\begin{array}{ll} \overleftarrow{\alpha}_i^R = \overleftarrow{\beta}_{i+1}^{L\ -1} \cdot \overleftarrow{\alpha}_{i+1}^{L} - \vec{\beta}_k^{R-1} \cdot \vec{\alpha}_k^R & \overleftarrow{\beta}_i^R = E \\ \overleftarrow{\gamma}_i^R = \overleftarrow{\beta}_{i+1}^{L\ -1} \cdot \overleftarrow{\gamma}_{i+1}^{L} - \vec{\beta}_k^{R-1} \cdot \vec{\gamma}_k^R & \end{array}\right\} \quad (4)$$

$$\left.\begin{array}{ll} \overleftarrow{\alpha}_k^R = \overleftarrow{\beta}_{i+1}^{L\ -1} \cdot \overleftarrow{\alpha}_{i+1}^{L} - \vec{\beta}_i^{R-1} \cdot \vec{\alpha}_i^R & \overleftarrow{\beta}_k^R = E \\ \overleftarrow{\gamma}_k^R = \overleftarrow{\beta}_{i+1}^{L\ -1} \cdot \overleftarrow{\gamma}_{i+1}^{L} - \vec{\beta}_i^{R-1} \cdot \vec{\gamma}_i^R & \end{array}\right\} \quad (5)$$

A program for analyzing the response of a three-dimensional tee to an earthquake has been developed by the introduction of the coefficients α, β and γ into the computational process given by ERAUL II.

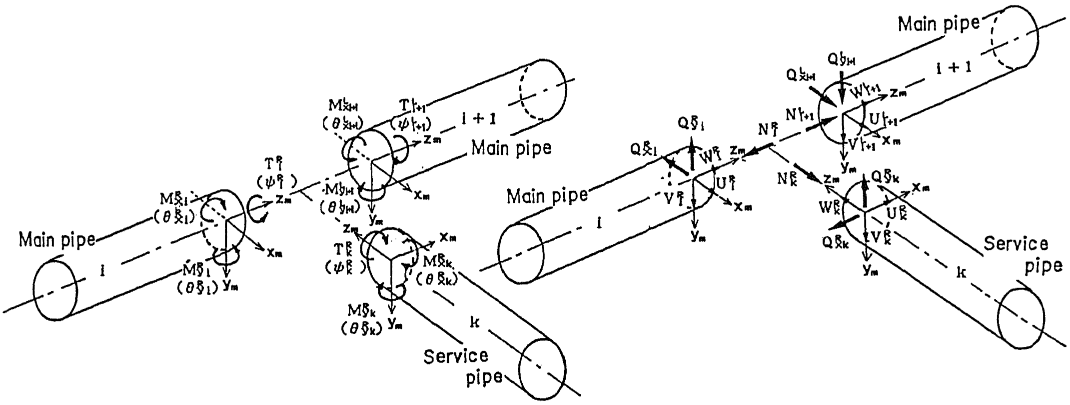


Fig. 1 Coordinate System and Direction of Displacement and Force

Ground Characteristics The ground spring constant used in the analysis was as shown in Fig. 2. It was completely elastoplastic in the axial direction (spring constant per unit area k_1, critical shearing force Z_{cr}) and elastic in the transverse direction (spring constant per unit area k_2). The values of k_1, k_2 and Z_{cr} were as shown in the Recommended Standards:

$k_1 = 0.6$ kgf/cm^3

$k_2 = \pi k_1 = 1.9$ kgf/cm^3

$Z_{cr} = 0.1$ kgf/cm^2

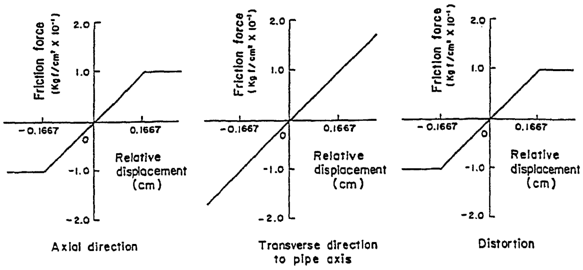


Fig. 2 Ground Spring Constant

Earthquake Input and Ground Movement Input A seismic wave enters buried pipes in the axial direction and is considered to be a longitudinally propagating wave with displacement in the direction of propagation (a sine wave with wavelength L and amplitude U_h). The seismic wave used for input was as indicated in the Recommended Standards. L and U_h values were obtained from the following equations:

$$L = V \cdot T \qquad U_h = \frac{2}{\pi^2} \cdot T \cdot S_v \cdot K_{oh} \cdot \cos \frac{\pi \cdot z}{2H}$$

where

K_{oh}: Designed horizontal seismic intensity
T : Natural period of surface ground layer
H : Thickness of surface ground layer
V : Apparent propagation velocity of seismic wave
L : Apparent wavelength of seismic wave along ground surface
S_v : Response velocity per unit seismic intensity
U_h : Displacement amplitude of surface ground layer
τ_{cr}: Critical shear stress between pipe and soil
Δ : Relative displacement between soil and pipe
z : Buried depth of pipeline

Figures 3 and 4 indicate the relationship between T and V, and T and Sv, respectively. Figure 5 plots the relationship between T and U_h. Since the relative displacement between the pipe and soil due to sliding of the straight portion of pipe concentrates at the junction, the pipe strain is maximum at the junction when relative displacement Δ is maximum. In this analysis, therefore, the natural period T of soil where Δ is maximum for the pipeline was used as a representative value (Fig. 6).

$L = 148.6$ m $\quad \Delta\,\max = 1.98$ cm $\quad T = 0.51$ sec.

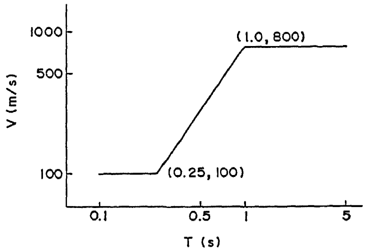


Fig. 3
Apparent Propagation
Velocity of Seismic Wave

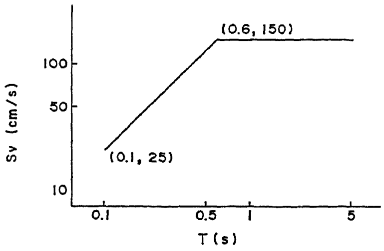


Fig. 4
Velocity Response Spectrum per Unit Seismic
Intensity at Base Rock

A ground movement input (settlement and/or fissure) was assumed near a junction (30 cm) for response analysis. The relative displacement at the junction was as shown in the recommended Standards with U for horizontal (axial) direction and U' for vertical direction.

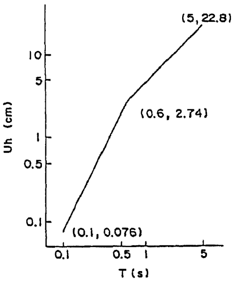


Fig. 5
Displacement Amplitude of the Surface Layer

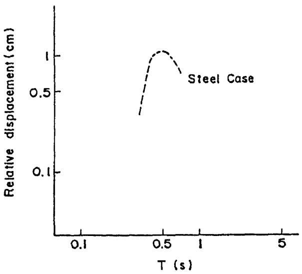


Fig. 6
Relative Displacement

U = 5 cm U' = 2.5 cm

Pipe Model for Analysis The pipe model for analysis was as shown in Fig. 7 and was composed of 185.8 m of straight main pipes on one side of junction and 2.5 m of a service pipe. When connecting the main pipes with mechanical joints (to be called SGM) or screw joints, the interval between the joints was set at 4 m. In practice, a junction is constructed as shown in Fig. 7. It consists of a service clamp and a service tee screw-jointed to the clamp, and an SGM joint.

Analysis was made of the eight cases shown in Table 1. Analysis was also made (in two cases out of eight) of the junction of a welded small-diameter pipe connected with a GMII-jointed larger-diameter pipeline (junction B in Fig. 7). Figures 8 and 9 indicate input points, etc.

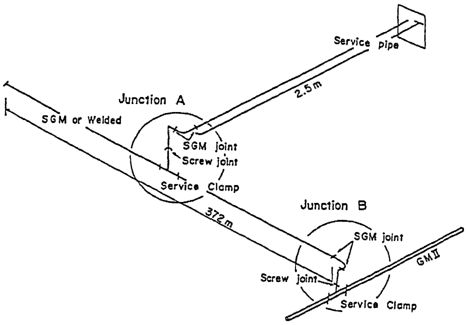


Fig. 7 Calculation Model

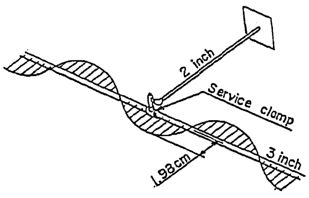
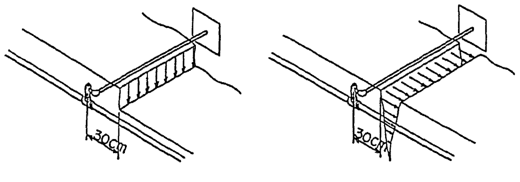


Fig. 8 Seismic Wave



Settlement Fissure

Fig. 9

Table 1

	Case	Input	Joint of Main pipe	Joint of Service pipe
A	1	Seismic wave	SGM joint	SGM joint
	2	Seismic wave	Welded joint	SGM joint
	3	Settlement	Welded joint	SGM joint
	4	Settlement	Welded joint	P E
	5	Fissure	Welded joint	SGM joint
	6	Fissure	Welded joint	P E
B	7	Settlement	Mechanical joint (GMII)	Welded joint
	8	Fissure	Mechanical joint (GMII)	Welded joint

Table 2 summarizes the dimensions of a main pipe and a service pipe.

Table 2 Dimension of Pipes

		Diameter (cm)	Thickness (cm)	Cross section area (cm^2)	Geometrical moment of inertia I (cm^4)	Elastic modulus E(kg/cm^2)	Shear modulus G(kg/cm^2)
Main pipe	SGM·Welded	8.91	0.42	11.2	101.2	2.1×10^6	8.1×10^5
	GM II	32.28	0.85	83.93	10371	1.6×10^6	6.2×10^5
Service pipe	SGM·Welded	6.05	0.38	6.77	27.32	2.1×10^6	8.1×10^5
	PE	6.05	0.38	6.77	27.31	3.0×10^3	1.2×10^3

Figure 10 shows an example of the mechanical properties of various joints (SGM, screw and service clamp). These figures provide the experimental data.

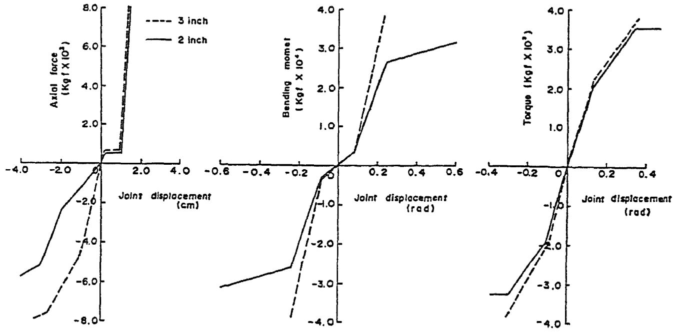


Fig. 10 Characteristic of SGM Joint

RESULTS OF ANALYSIS

Results of analysis for cases 1 to 8 are summarized in Table 3. As an example, Fig. 11 depicts the junction behavior in case 5. Moment distributions are plotted in Fig. 12.

From these results, the following conclusions can be drawn.

Junction A from a small-diameter pipeline

i) For seismic wave input (Cases 1 and 2)

When main pipes are SGM-jointed, the junction materials are not subjected to great force. This is because SGM-jointed pipes follow the wave input owing to the effective flexibility of the joint. Welded pipes are subjected to force at junctions because welded joints do not absorb seismic input; however, the effects of seismic input are less than 20% of the strength of the joint, thus allowing continuous use of the current junction materials.

ii) For settlement input (Cases 3 and 4)

When main pipes are welded, a significant bending moment is applied on the service tee screw at the junction. The moment, however, is only about 2° in terms of joint bending angle even when the settlement input is close to the junction, posing no serious problems. When the service pipe is a polyethylene pipe, the effects of the seismic input are less than those for a steel pipe.

iii) For fissure input (Cases 5 and 6)

In cases 5 and 6, where the main pipes are of welded type, the bending moment at the service tee is approximately half the maximum allowable value. As in the case of settlement input, the values for polyethylene pipes are smaller than those for steel pipes.

Junction B from a larger-diameter pipeline

i) For settlement input (Case 7)

In case 7, where welded pipes branch from larger-diameter (6 inches or more) main pipes connected with GM II (mechanical) joints, the force applied onto the junction materials is not very great.

ii) For fissure input (Case 8)

In case 8, where welded pipes is connected to larger-diameter GM II-jointed main pipes, a rotational behavior (13°) occurs at the service tee in the counterclockwise direction. This is due to the absorption of movement mainly by the junction and the closeness of the seismic input to the junction.

Through these analyses involving severe input conditions, it has been possible to analyze the response of welded small-diameter pipes with mechanical joints to external forces. It maybe concluded that welded joints have no problems for use in place of flexible SGM-joints. Further studies will be made to obtain higher seismic reliability and practical use of these newly developed systems.

Table 3 Results of Analysis

Moment · Torque : kg·cm
Axial force : kg

	CASE NO'	Input	Junction / MAIN(service)	Service clamp			Service tee (Screw side)			Elbow (Tee side)		
				Moment	Axial force	Torque	Moment	Axial force	Torque	Moment	Axial force	Torque
A	1	Seismic wave	S G M (SGM)	200	20	13	80	1	-4	20	10	3
	2		Welded (SGM)	5,200	510	640	2,040	10	-50	800	300	80
	3	Settlement	Welded (SGM)	18,600	230	400	17,100 2.0°	1,200	-600	4,600	160	-1,600 4.8°
	4		Welded (PE)	14,900	190	680	13,500 0.9°	1,000	-390	3,600	120	-1,820
	5	Fissure	Welded (SGM)	24,100	2,400 0.1mm	3,400 0.4°	9,300 0.6°	40	290	4,300	1,400 -10.7mm	-440
	6		Welded (PE)	15,300	1,700	2,500	5,600	15	520	3,300	710 -10.3mm	-260
B	7	Settlement	G M II (Welded)	5,100	10	500	5,300	290	-70	1,500	10	-720
	8	Fissure	G M II (Welded)	31,200	1,000	11,400	7,800	15	-3,400 13°	9,510	1,700 4mm	6
	Critical value *1			30,000 (370,000	3,000 15,000	10,000 *2 50,000)	20,000 5°	7,500	-3,050	27,000	5,000	2,000

* 1 Critical value of joint performance (from experimental data)

* 2 ( ) is value of GM II service clamp

Upper : Moment , force

Lower : Behavior of joint (selected)

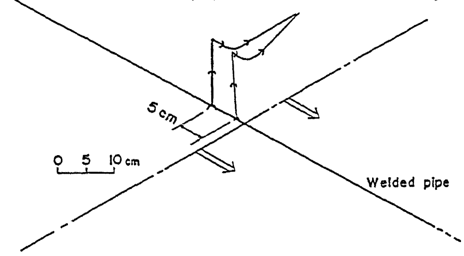


Fig. 11 Case 5 Behavior (Fissure)

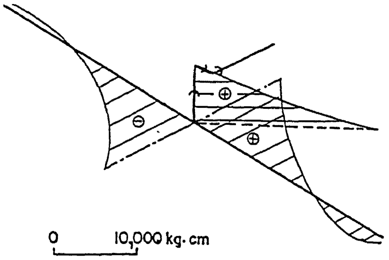


Fig. 12 Case 5 X-Bending Moment (Fissure) (Local coordinate: Ref. Fig. 1)

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