RECOMMENDED PRACTICES FOR EARTHQUAKE-RESISTANT DESIGN OF GAS PIPELINES

CONTENTS

(Contents I and II are based on the "Recommended Practices for Earthquake-Resistant Design of Gas Pipelines" Published in March, 1985, by the Japan Gas Association)

JAPAN GAS ASSOCIATION

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I. HIGH-PRESSURE GAS PIPELINE

1. Basic Concept of Earthquake-Resistant Design

A Recommended Practice for Earthquake-Resistant Design of High-Pressure Gas Pipelines is based on greatly improved concepts with regard to the evaluation of seismic motions and interaction (slippage) between the ground and the gas pipeline. Features of the Recommended Practice (Standards) are as follows.

(1) The design method consists of strain design. Strains during an earthquake are allowed to be in excess of the elastic limit by evaluating fatigue damage in plastic region.

(2) The design method for bends and tees is very important because seismic forces concentrate in them, while smaller strains in a straight pipeline are due to the slippage between the pipe and the ground.

(3) The standards consider the seismic waves apparently propagating along the ground surface and the strain in ground with inclined base rock.

Table 1 shows the flow diagram of the earthquake resistant design based on the above concept.

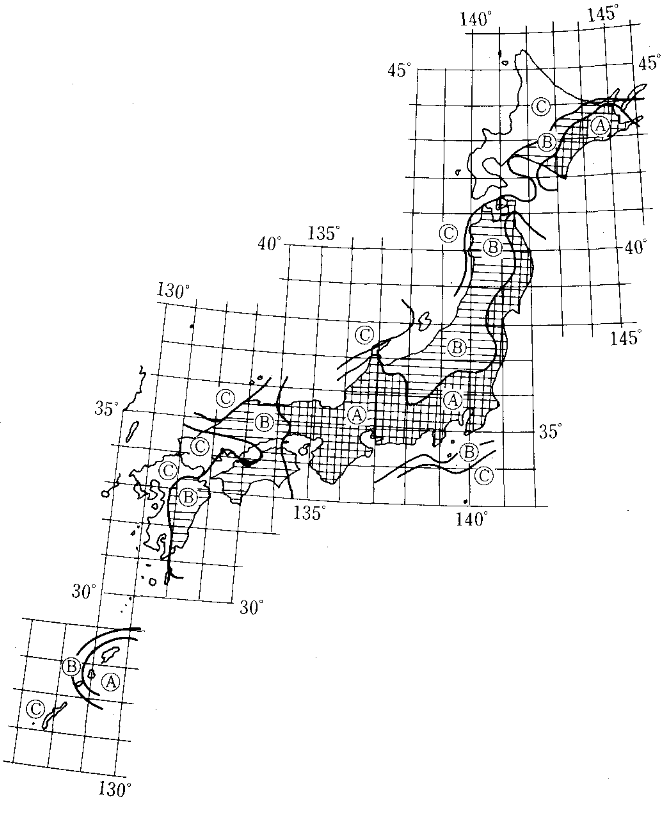


Fig. 1 Zone coefficient

Table 1 Flow Diagram of Earthquake-Resistant Design

Seismic Motions for Design

(1) Horizontal seismic intensity at Base Rock

$K_{oh}=0.15 \cdot \nu_1 \cdot \nu_2$

ν_1 : Coefficient of Importance

	Pipeline Buried under Public Road in Urban Area	Others
ν_1	1.0	0.8

ν_2 : Seismic Zone Coefficient

(2) Natural Period of Surface Layer

$T=\dfrac{4 \cdot H}{V_S}$, $V_S=\dfrac{\Sigma V_{Sj} \cdot H_j}{H}$

H : Thickness of Surface Layer (m)

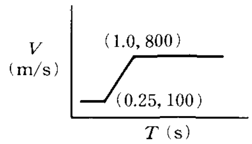
V_S : Shear Wave Velocity in Surface Layer (m/s)

- Elastic wave Survey $\times C$ — Sand 0.6, Clay 0.85
- Estimate from N Value — Sand $62N^{0.021}$, Clay $122N^{0.078}$

(3) Apparent Wavelength of Seismic Motion

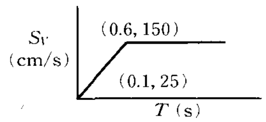
$L=V \cdot T$

V : Apparent Propagation Velocity of Seismic Motion



(4) Displacement Amplitude of the Surface Layer

$U_h=\dfrac{2}{w^2} T \cdot S_V \cdot K_{oh} \cdot \cos\dfrac{\pi z}{2H}$



S_V : Velocity Response Spectrum per Unit Seismic Intensity at Base Rock (cm/s)

z : Depth of Pipeline (m)

(5) Strain in Ground with Uniform Surface Layer

$\varepsilon_{G1}=\dfrac{2w \cdot U_h}{L}$

$\varepsilon_{G1}=\dfrac{3 \cdot S_V \cdot K_{oh}}{\pi \cdot V} \cdot \cos\dfrac{wz}{2H}$

(6) Strain in Ground with Inclined Base Rock

$\varepsilon_{G2}=\sqrt{\varepsilon_{G1}{}^2+\varepsilon_{G3}{}^2}$

$\varepsilon_{G3}=x \cdot \dfrac{K_{oh}}{V_S} \cdot \tan\theta \cdot \cos\dfrac{wz}{2H}$

x : $T<0.3s$ $x=405 \cdot T$

$T \geqq 0.3s$ $x=122$

θ : Inclination of Base Rock (deg.)

(7) Design of Straight Pipe

(7)′ Strain Transfer Cofficient

$\alpha_1=q \dfrac{1}{1+\left(\dfrac{2\pi}{\lambda_1 \cdot L}\right)^2}=q \cdot \alpha_0$

q : Coefficient Considering Slippage between Pipe and Ground

$\lambda_1=\sqrt{\dfrac{K1}{E \cdot A}}$ $K1$: Ground Spring Constant in Axial Direction

(7)″
1. Strain in Straight Pipe
   - Uniform Ground $\varepsilon_{P1}=\alpha \cdot \varepsilon_{G1}$
   - Inclined Base Rock $\varepsilon_{P3}=\alpha \cdot \varepsilon_{G2}$
2. Strain in Joint (welded) of Straight Pipe
   - Uniform Ground $\varepsilon_{P2}=i_P \cdot \alpha \cdot \varepsilon_{G1}$
   - Inclined Base Rock $\varepsilon_{P4}=i_P \cdot \alpha \cdot \varepsilon_{G2}$
   - i_P : Stress Index

(8) Design of Bend and Tee

(8)′ Displacement Transfer Coefficient

$\alpha^*=q^* \cdot \alpha_0$

q^* : Coefficient Considering Slippage between Pipe and Ground

Relative Displacement of Pipe and Ground

$\Delta=(1-\alpha^*) \cdot U_h$

(8)″ Strain in Bend and Tee

Bend $\varepsilon_B=\beta_B \cdot \Delta$

Tee $\varepsilon_T=\beta_T \cdot \Delta$

β : Coefficient of Conversion

(9) Allowable Pipe Strain

(9)′ Allowable Strain in Straight Pipe

(i) 1.0% or

(ii) $35\, t/D_m$ (%) (Buckling Strain Obtaind by Actual Measurement with Safety Factor of 1.25 taken into Consideration), Whichever is Smaller

(9)″ Allowable Strain in Joint of Straight Pipe, Bend and Tee

1.0%

2. Seismic Motion for Design

2.1 Horizontal Seismic Intensity at Base Rock

The horizontal seismic intensity to be considered for design is given by Equation (1).

$$K_{oh} = 0.15\nu_1 \cdot \nu_2 \qquad \cdots\cdot(1)$$

In Equation (1), 0.15 is the basic input at base rock. Here, ν_1 is a coefficient of importance and ν_2 is the seismic zone coefficient shown in Figure 1.

2.2 Natural Period of Surface Layer

Equation (2) gives the natural period of the surface layer.

$$T = \frac{4H}{V_s} \qquad \cdots\cdot(2)$$

H in Equation (2) represents the thickness of the surface layer. V_s shows the shear wave velocity in the surface layer. Determination of the base rock face depends on an N value not less than 50 or a measured shear wave velocity of 300 m/sec or more.

2.3 Apparent Wavelength of Seismic Motion

Apparent wavelength of seismic motion is given by

$$L = V \cdot T \qquad \cdots\cdot(3)$$

V in Equation (3) is the apparent propagation velocity of seismic motion. Figure 2 shows the relationship between the natural period and the apparent propagation velocity.

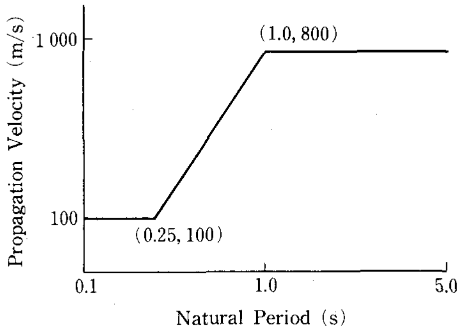


Fig. 2 Apparent propagation velocity of seismic motion

2.4 Displacement Amplitude of Surface Layer

Equation (4) gives the displacement amplitude of the surface layer.

$$U_h = \frac{2}{\pi z} T \cdot S_v \cdot K_{oh} \cdot \cos\frac{\pi z}{2H} \qquad \cdots\cdot(4)$$

where

S_v: velocity response spectrum per unit seismic intensity

z: depth of pipeline

S_v is given by Figure 3.

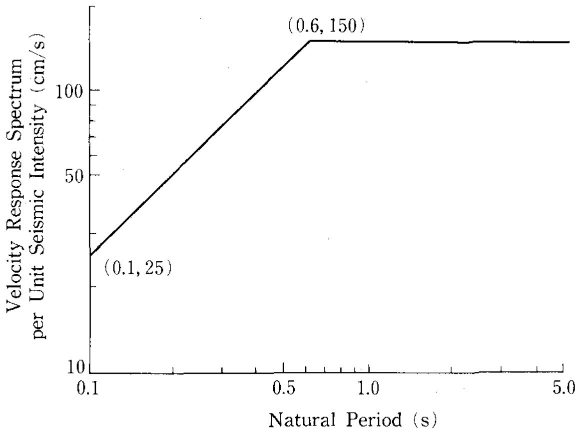


Fig. 3 Velocity response spectrum per unit seismic intensity

2.5 Strain in Ground with Uniform Surface Layer

The strain in the ground with a uniform surface layer is given by Equation (5).

$$\epsilon_{G1} = 2\pi \cdot U_h / L \qquad \cdots\cdots(5)$$

2.6 Strain in Ground with Inclined Base Rock

The strain in the ground with inclined base rock is given by Equation (6).

$$\left.\begin{aligned} \epsilon_{G2} &= \epsilon_{G1}{}^2 + \epsilon_{G3}{}^2 \\ \epsilon_{G3} &= \kappa \cdot \frac{K_{oh}}{V_s} \tan\theta \cdot \cos\frac{\pi z}{2H} \end{aligned}\right\} \qquad \cdots\cdots(6)$$

where

ϵ_{G3}: strain in ground occurring by differences in displacements of two points

θ: inclination of base rock

κ: coefficient related to the natural period of ground surface

3. Design for a Straight Pipe

3.1 Strain in a Straight Pipe

The strain in a straight pipe is given by Equation (7)

$$\epsilon_{P1} = \alpha \cdot \epsilon_{G1} \qquad \cdots\cdots(7)$$

3.2 Strain in a Pipe Welded Joint

The strain in a pipe welded joint is given by Equation (8).

$$\epsilon_{P2}=i_p\cdot\alpha\cdot\epsilon_{G1} \quad \ldots.(8)$$

Where

i_p: stress index ($i_p=2.0$)

4. Design of Bend and Tee

4.1 Strain in a bend

The strains in bends (ϵ_B) are given by Equation (9).

$$\epsilon_B=\beta_B\cdot\Delta \quad \ldots.(9)$$

where

Δ: relative displacement between the pipe and the ground

β_B: coefficient of conversion for bend

$$\beta_B=\frac{2\cdot i_B\cdot A\cdot\bar{\lambda}^2\cdot D\cdot|(5+R\cdot\bar{\lambda})\cdot b_1|+4\cdot\bar{\lambda}^3\cdot I\cdot|5\cdot(1+b_2)-b_1|}{10\cdot A+5\cdot L\cdot I\cdot\bar{\lambda}^3\cdot(1+b_2)+10\cdot A\cdot b_3}$$

$$b_1=-\frac{1+2\cdot R\cdot\bar{\lambda}+(\pi-2)\cdot n\cdot R^2\cdot\bar{\lambda}^2}{(1+R\cdot\bar{\lambda})\cdot\{2+\pi\cdot n\cdot R\cdot\bar{\lambda}+(4-\pi)\cdot n\cdot R^2\cdot\bar{\lambda}\}}$$

$$b_2=\frac{1-2\cdot n\cdot R^2\cdot\bar{\lambda}^2-(4-\pi)\cdot n\cdot R^3\cdot\bar{\lambda}^3}{(1+R\cdot\bar{\lambda})\{2+\pi\cdot n\cdot R\cdot\bar{\lambda}+(4-\pi)\cdot n\cdot R^2\cdot\bar{\lambda}^2\}}$$

$$b_3=n\cdot R^3\cdot\bar{\lambda}^3\cdot\left\{\frac{\pi}{2}+\frac{\pi\cdot I}{2\cdot n\cdot A\cdot R^2}+\left(1-\frac{I}{n\cdot A\cdot R^2}\right)\cdot b_1+\left(\frac{2}{R\cdot\bar{\lambda}}+\frac{\pi}{2}+\frac{\pi\cdot I}{2\cdot n\cdot A\cdot R^2}\right)\cdot b_2\right\}$$

where

β_B: Coefficient of conversion of bend

i_B: Stress index for bending load on bend

n: Flexibility factor of bend

A: Sectional area of pipe

R: Radius of curvature of bend

I: Second moment of area of pipe

D: Outside diameter of pipe

L: Apparent wavelength of seismic motions

$\bar{\lambda}$: $\sqrt[4]{\dfrac{K_2}{4E\cdot I}}$

K_2: Ground spring constant in the transverse direction to the axis per unit pipe length

E: Young's modulus of pipe

The relative displacement between the pipe and the ground is given by Equation (10).

$$\Delta=(1-\alpha^*)\cdot U_h \quad \ldots.(10)$$

where

α^*: displacement transfer coefficient

$$\alpha^* = q^* \cdot \alpha_0$$

$$q^* = \sin\left(\frac{2\pi}{L} \cdot l^*\right) - \frac{2\pi}{L} l^* \cos\left(\frac{2\pi}{L} \cdot l^*\right) + \frac{\pi^2}{8}\left\{1 - \left(\frac{4l^*}{L}\right)^2\right\} \frac{1}{S_J}$$

(Adopt $q^* = 1$, when slippage judging value $S_J < 1$)

4.2 Strain in a tee

The strains in tees (ϵ_T) are given by Equation (11) and (12).

$$\epsilon_{T1} = \beta_{T1} \cdot \Delta_2 \quad \text{....(11)}$$

$$\epsilon_{T2} = \beta_{T2} \cdot \Delta_1 \quad \text{....(12)}$$

where

Δ_1: relative displacement between the main pipe and the ground

Δ_2: relative displacement between the branch pipe and the gound

β_{T1}: coefficient of conversion for branch when seismic waves input in parallel to main pipe

β_{T2}: coefficient of conversion for main pipe when seismic waves input in parallel to branch

$$\beta_{T1} = i_T \frac{4 \cdot \bar{\lambda}_1^2 \cdot D_{1T} \cdot A_2 \cdot (C-1)}{4 \cdot A_2 + L \cdot I_1 \cdot \bar{\lambda}_1^3 \cdot C} \cdot \left(\frac{I_1}{I_{1T}}\right)$$

$$C = \frac{1 + 4(\bar{\lambda}_1/\bar{\lambda}_2)^3 (D_2/D_1)}{1 + 2(\bar{\lambda}_1/\bar{\lambda}_2)^3 (D_2/D_1)}$$

where

i_T: Stress index

$$\beta_{T2} = i_T \cdot \frac{\bar{\lambda}_2^2 \cdot D_{2T} \cdot A_1}{A_1 + 2 \cdot L \cdot I_2 \cdot \bar{\lambda}_2^3} \left(\frac{I_2}{I_{2T}}\right)$$

Note: Subscripts with sectional area A, second moment of area I, outside diameter D, and λ are:

Subscription 1....Straight pipe in branch part

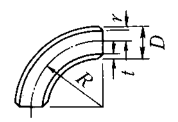
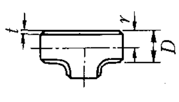
2....Straight pipe in main part

1_T....Tee in branch part

2_T....Tee in main part

4.3 Stress index and flexibility factor

Stress index and flexibility factor of bends and tees are shown in the below table.

Type	Stress index		Flexibility factor	Illustration Unit: cm
Bend (Butt weld elbow)	i_B	The larger one of $\frac{1.95}{\left(\frac{t \cdot R}{r^2}\right)^{2/3}}$ or 1.5.	$\frac{1.65}{\left(\frac{t \cdot R}{r^2}\right)}$	
Tee (Butt weld tee)	i_T	The larger one of $0.67\left(\frac{r}{t}\right)^{2/3}$ or 2.0.		

where

t: Wall thickness

R: Radius of curvature

r: Mean radius of pipe

D: Outside diameter of pipe

5. Allowable Strain

Seismic strains in straight pipeline are uniform tensile or compressive strains in the entire area. The allowable strain in a straight pipeline is smaller value of 1% or the allowable strain due to buckling given by Equation (13).

$$\epsilon = \frac{4}{3} \cdot \frac{t}{D_m} n \qquad \ldots .(13)$$

where

ϵ: buckling strain

n: 0.11

t: pipe wall thickness (cm)

D_m: mean diameter of pipe $(=D-t)$ (cm)

The allowable buckling strain is given by $35(t/D_m)$ (%) using Equation (13) with a safety factor of 1.25.

II. MEDIUM -AND LOW-PRESSURE GAS PIPELINES

1.1 Basic Policy on Earthquake-Resistant Design

1.1.1 General Principles

Earthquake-resistant design for medium- and low-pressure pipelines is aimed at achieving greater pipeline flexibility and thereby reducing gas pipe leakage or breakage.

1.1.2 Quantitative Flexibility Evaluation Method for Pipelines

Aseismic strength is judged by calculating the capability of the pipeline to absorb the stipulated ground displacement. If the value exceeds the design ground displacement determined by ground and other conditions, the pipeline is judged to be earthquake-resistant.

1.2 Earthquake-Resistant Design Procedure

The procedure is shown in Fig. 1. Evaluation of earthquake resistance is based on the following items.

1. Selection of burying conditions
2. Calculation of design ground displacement
3. Calculation of pipeline ground displacement absorption
4. Selection of ground displacement input
5. Selection of standard strain and standard displacement
6. Evaluation of earthquake resistance

1.3 Design Ground Displacement

The design ground displacement for evaluating pipeline flexibility is determined by the following formula.

1) Horizontal displacement (in axial direction of pipe): $U=\alpha_1\alpha_2U_0$

2) Vertical displacement (prependicular to pipe axis): $V=1/2U$

In the formula, α_1 is determined by the seismic zone factor in Table 1 of which the division of area is the same as that shown in Fig. 1 in Chapter I.

Table 2 shows that α_2 is a factor representing the combination of pipeline type and ground condition.

U_0 is determined as 5.0 (cm) in standard design ground displacement.

The ground condition type in Table 2 is based on "1.4 Definition of Ground Condition."

Table 1 Seismic Zone Factors (α_1)

Division of Area	SA	A	B	C
α_1	1.0	0.8	0.6	0.4

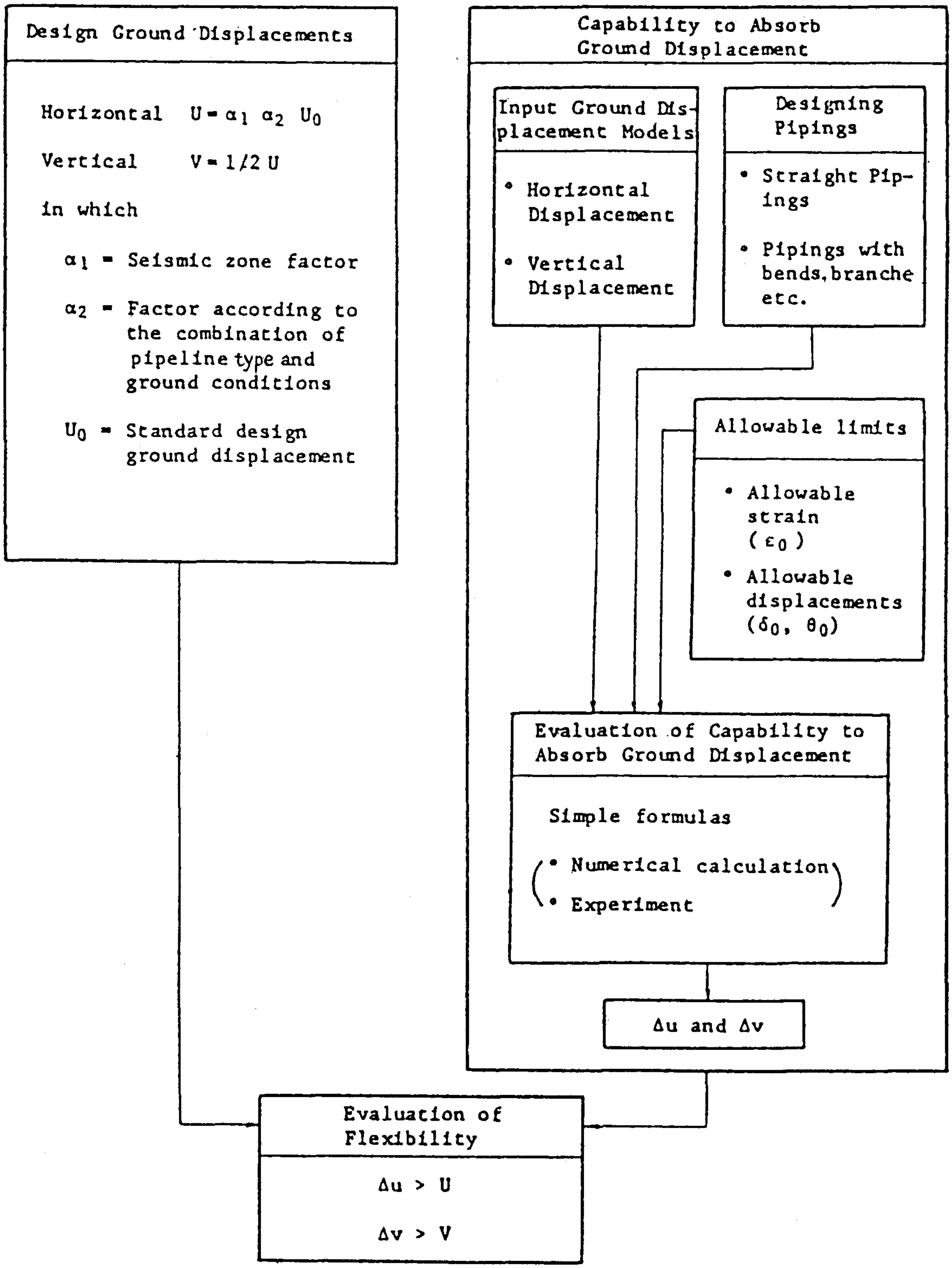


Fig. 1 Flow Diagram of Earthquake-Resistant Design of Medium- and Low-Pressure Pipelines

Table 2 **Factors according to the combination of the kind of pipeline and ground conditions (α_2)**

Classification of pipeline \ Ground conditions	I	II	III
Medium pressure *A* ($3 \leqq P < 10$ kgf/cm²)	0.9	1.3	1.8
Medium pressure *B* ($1 \leqq P < 3$ kgf/cm²)	0.7	1.0	1.4
Low pressure (main) ($P < 1$ kgf/cm²)	0.5	0.7	1.0
Low pressure (service) ($P < 1$ kgf/cm²)	0.7	1.0	1.0

1.4 Ground Condition

Ground conditions are determined by the state of the ground in the general area where piping is installed and by the piping installation's geographic location.

I. Area formed by any of the following ground types or areas where the three are found in combination.

(1) Soil layer dating back to the Triassic Era or earlier (hereinafter called "rock layer")

(2) Diluvium layer

(3) Alluvium layer less than 10 m thick or layer in which soft layer is less than 5 m thick

* Provided there exists a rock layer or firm diluvium layer ($N>50$, seismic wave velocity of more than 300 m/sec.)

II. Area formed chiefly by alluvium layer of more than 10 m or soft layer of more than 5 m.

IIIa. Mixture of soil layer equivalent to Condition I and a layer equivalent to Condition II, or area in which the two types are mixed

IIIb. Border area between soil layer and sturdy structure built upon foundation equivalent to Condition II and other locations where displacement is evidently discontinuous

1.5 Pipeline Capability to Absorb Ground Displacement

1.5.1 Capability of Straight Piping to Absorb Ground Displacement in Axial Direction (Δu)

The capability of a straight pipe to absorb ground displacement in the axial direction

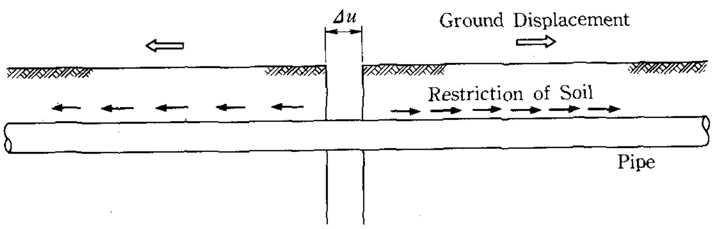


Fig. 2 Ground Displacement Input for Ground Conditions I, II, and IIIa

(Δu) under ground conditions I, II, and IIIa, as shown in Fig. 2 is a ground displacement that can be absorbed by the pipe at a displacement input that focuses on one point on the ground surface.

i) A Pipeline with continuous restraint force from projection in axial direction

[a] Reduced elastic modulus model (for polyethylene pipe, etc.)

$$\Delta u=\frac{A\bar{E}\epsilon_0^2}{\pi D\tau} \quad [\mathrm{mm}]$$

where, A: Area of cross-section (mm²)

D: Pipe diameter

$\bar{E}$: Reduced elastic modulus (N/mm²)

τ: Restraint force of ground per unit surface of pipe (N/mm²)

ϵ_0: Allowable strain (specified in 1.6)

[b] Elastoplastic calculation model (welded steel pipe)

$$\Delta u=\frac{AE\{\epsilon_y^2+\lambda(\epsilon_0^2-\epsilon_y^2)\}}{\pi D\tau}$$

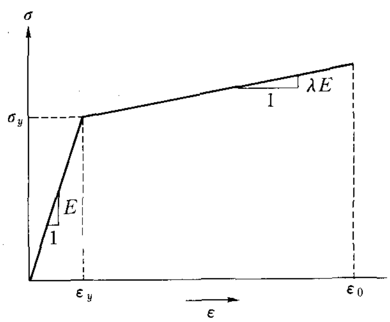


Fig. 3 Bilinear Elastoplastic Model of Steel Material

ϵ_y: Yield strain of pipe

ϵ_0: Allowable strain of pipe

E: Elastic modulus (N/mm²)

λE: Tangent modulus of pipe

ii) Piping showing localized reduction in tensile stress on cross-section (such as steel pipe with screwed joint)

$$\Delta u=\frac{F^2}{\pi D\tau AE}$$

where, F_0: Allowable tensile strength of screwed joint portion

iii) Piping with mechanical joint

$$\Delta u=\delta_0+2(\delta_1+\delta_2+\cdots\cdots+\delta_n)$$

Where, δ_0 is the maximum displacement of joint in the center of ground displacement, at which leakage or serious damage of joint is expected. $\delta_1, \delta_2, \ldots, \delta_n$ represents allowable displacement (slipout) in joints adjoining the joint in the center, calculated taking into account the reduction in load due to the ground restraint force between the joints.

The capability of a straight pipeline fixed at one end in Ground Condition IIIb to absorb axial ground displacement is ground displacement that can be absorbed when the input of ground displacement that concentrates at the border of a structure and ground is added, as shown in Fig. 4

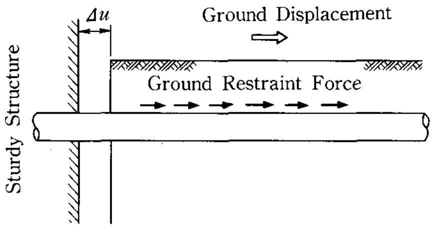


Fig. 4 Ground Displacement Input on Piping Fixed at One End in Ground Condition IIIb

1.5.2 Capability of a Straight Piping to Absorb Ground Displacement in Direction Transverse to Axis

The capability of straight piping to absorb ground displacement in the direction transverse to its axis (Δv) in Ground Condition I, II, or IIIa is ground displacement that the piping can absorb when transverse displacement concentrates on one point on the ground, as shown in Fig. 5.

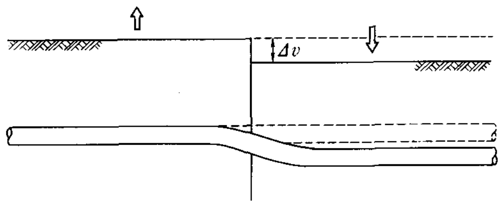


Fig. 5 Ground Displacement Input in Transverse Direction Under Ground Condition I, II, or IIIa

i) A pipeline with homogeneous rigidity along its axis (steel pipe with welded joint or polyethylene pipe)

$$\Delta v = \frac{2\sqrt{2}\, e^{\pi/4}}{D} \sqrt{\frac{4\bar{E}I}{kD}}\, \epsilon_0$$

Where, $\bar{E}$: Reduced elastic modulus (N/mm^2)

I: Moment of inertia of cross-section (mm^4)

k: Reduced coefficient of subgrade reaction (N/mm^3)

ii) Piping with localized drop in strength against bending moment (steel pipe with screwed joint)

$$\Delta v=\frac{\sqrt{2}\,e^{\pi/4}}{EI}\sqrt{\frac{4EI}{kD}}M_0$$

Where, M_0: Moment at the location of localized drop in strength (N·mm)
E: Elastic modulus (N/mm²)

The capability to absorb ground displacement when the pipe is fixed to structures under Ground Condition IIIb, as in Fig. 6, is displacement that the pipe can absorb when displacement concentrates at the border of the structure and ground.

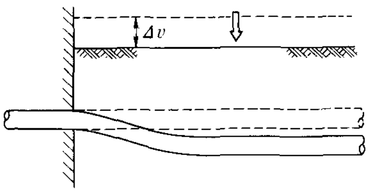
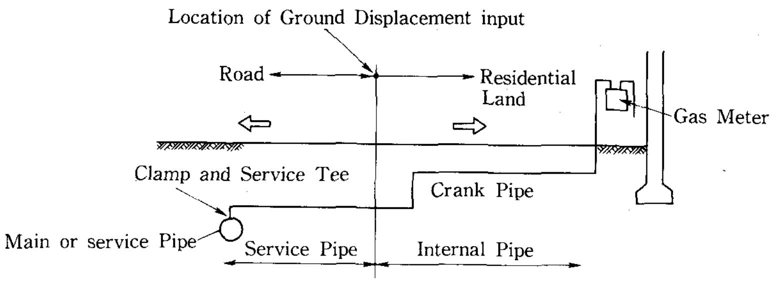


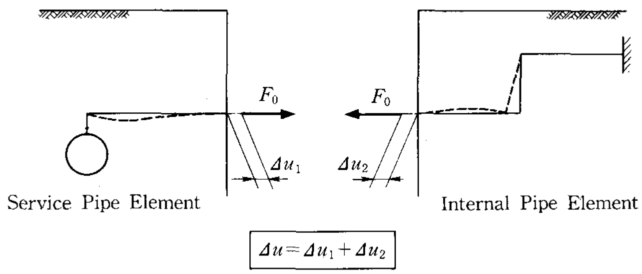
Fig. 6 Ground Displacement Input in Transverse Direction for Piping Fixed at One End Under Ground Condition IIIb

1.5.3 Capability of 3-D Piping to Absorb Ground Displacement (Δu)

The capability of a 3-D piping system comprised of low-pressure service and internal pipes under Ground Condition I, II, or IIIa is ground displacement that the piping can absorb at the displacement shown in Fig. 7.



a) Location of Ground Displacement Input



b) Division of Service Pipe and Internal Pipe Elements and Displacement of Each Element

Fig. 7 Ground Displacement Input for Sercive and Internal Pipe System and Calculation of Ground Displacement Absorption Capability (Sample)

The absorption capability of a 3-D piping system buried under Ground Condition IIIb and fixed at one end to a structure is ground displacement that can be absorbed when the ground displacement shown in Fig. 4 is applied.

1.6 Allowable Strain and Allowable Displacement

1.6.1 Allowable Strain in Pipe Material (ε_0) and Elastic Modulus ($\bar{E}$)

The allowable strain (ϵ_0) that is set over the plastic limit and the reduced elastic modulus ($\bar{E}$) applied when calculating the material's ability to absorb ground displacement, which depend upon the material, are shown below.

1) Steel pipe: Allowable strain....$\epsilon_0 = 3$ [%]
   Reduced elastic modulus....$\bar{E} = 3.0 \times 10^4$ [N/mm²]
2) Ductile cast-iron pipe: Allowable strain....$\epsilon_0 = 2$ [%]
   Reduced elastic modulus....$\bar{E} = 3.0 \times 10^4$ [N/mm²]
3) Polyethylene pipe: Allowable strain....$\epsilon_0 = 20$ [%]
   Reduced elastic modulus....$\bar{E} = 3.0 \times 10^2$ [N/mm²]

When, however, reduced elastic modulus is inapplicable for steel or ductile cast-iron pipe, Young's modulus that is within the range of elasticity is applied.

Steel pipe: 2.1×10^5 [N/mm²]
Ductile cast-iron pipe: 1.6×10^5 [N/mm²]

Coefficient λ used to determine the tangent modulus (λE) used to calculate elasticity of steel pipe is founded upon the following: $\lambda = 7.1 \times 10^{-3}$

1.6.2 Allowable Displacement for Mechanical Joints and Expansion Fittings

Standard displacement for expansion joints such as mechanical and flexible joints for connecting pipes in ways other than welding is the official value specified under JIS or other equivalent standards. If no nominal value is found, it is determined as the displacement that removes airtightness or inflicts serious damage or deformation upon a major part of the joint.

III. APPENDIX

Earthquake Countermeasures for Gas Distribution Systems—the Status Quo

1. Improvement of Earthquake Resistance of Pipelines

Improving the earthquake resistance of pipelines is essential to: (1) prevent disaster caused by gas leakage; (2) minimize the suspension of supply of gas; and (3) minimize the restoration works thus enabling fast restoration of supply of gas to the customers.

The Recommended Practices for Earthquake-Resistant Design of Gas Pipelines described in the preceding Chapters are aimed at the improvement of the earthquake resistance of newly constructed pipelines.

Retrofitting techniques have been developed and are being applied to the old pipelines. There are several kinds of retrofitting techniques which are recommended by the Japan Gas Association and officially approved by the government authorities as safe and reliable techniques for use in the gas industries. Lining the pipelines from inside with polymer tubes is typical of these techniques.

2. Block System of Pipeline Networks

Damage susceptibility of pipelines depends on: (1) the distance from the origin of earthquake (the shorter the distance is, the more intense the earthquake ground motion is, in general); and (2) the ground conditions (damage is apt to be concentrated to the areas with very soft grounds, in general). Therefore, the degree of concentration of damage varies greatly from an area to another.

To isolate heavily damaged areas from less damaged areas, the block system of pipeline networks are in effect in major gas industries in Japan. This system is aimed at minimizing the number of suspended customers, as a result, maximizing the efficiency of restoration activities.

The block system takes a hierarchical structure; large blocks cover wide areas and the blocking valves are remotely operated at the control center; these blocks are divided into medium size networks which are not connected mutually; the medium sized blocks are equipped with block-valves by which the blocks can be divided further into small blocks (valves are operated manually).

3. Customer Shut-off System

Installation of automatic shut-off system for individual customers is going on at every gas industry in Japan.

At Tokyo Gas Company, for example, about 70% of total customers are equipped with this system as of the end of 1991, and it is expected to reach 100% within several years.

This system is called "Maikonmehta", which means an intelligent gas meter installed with a micro-computer chip, and can shut off the supply of gas triggered by a simple acceleration transducer placed in, or around, the gas meter. The triggering value of acceleration is set at 200 cm/s^2 which corresponds to an upper range of JMA Intensity Scale of V (JMA Intensity V corresponds approximately to the acceleration ranging between 80 and 250 cm/s^2).

In the event of Tokyo Bay Earthquake which took place in the early morning of February 2, 1992 (M=5.9), the JMA Intensity in the central part of Tokyo was V, and some 100,000 Maikonmehtas were shut off. As a result, no gas leakage in the households, therefore, no fire caused by gas leakage was reported.

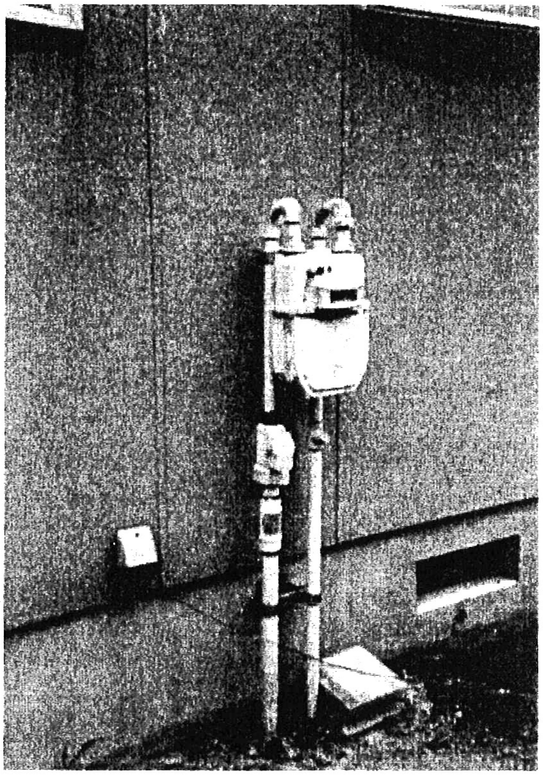


Photo Maikomehta (Intelligent Gas Meter)

Photo: Maikomehta (Intelligent Gas Meter)