Seismic Design for Gas Pipelines (2004)
(By Japan Gas Association)

1. Recommended Practice for Earthquake-Resistant Design of Gas Pipelines (2004)

1.1 Introduction

The first edition of "Recommended Practice for Earthquake-Resistant Design of Gas Pipelines" was established as the recommended practice for earthquake-resistant design of gas pipelines in March 1982, after the Miyagiken-Oki Earthquake (June 1978).

The Hyogoken-Nanbu Earthquake occurred in January 1995. Since the earthquake far exceeded conventional theory, the Central Disaster Prevention Council reviewed its Basic Plan for Disaster Prevention and the Japan Society of Civil Engineers presented a proposal.

The Japan Gas Association revised the Recommended practice for earthquake-resistant design of High-Pressures Gas Pipeline in 2000, mainly for the purpose of introducing the design method of high pressure pipelines to the seismic motion of Level 2, which corresponds to the shocks generated by the Hyogoken-Nanbu Earthquake in the Kobe District.

The presently used Recommended Practice for Earthquake-Resistant Design of Gas Pipelines has not been revised in the medium- and low-pressure gas pipelines section, since it has been confirmed that the recommendations therein are reasonable for earthquake-resistant design, judging from the results of investigation of the Hyogoken-Nanbu Earthquake.

1.2 High-Pressure Gas Pipelines

1.2.1 Foundamental Principles of Earthquake-Resistant Design

(1) Basic Concept of Earthquake-Resistant Design

For the earthquake-resistant design, two levels of seismic motions are assumed to secure the earthquake-resistant performance specified for the respective levels of seismic motions in principle.

(Description)

(a) The Basic Plan for Disaster Prevention of the Central Disaster Prevention Council was reviewed based on the Hyogoken-Nanbu Earthquake which occurred on January 17, 1995, and it now stipulates that the earthquake-resistant design of structures, facilities, etc. to be constructed in the future shall not suffer any serious loss of function even should general seismic motions with a probability of occurring once or twice within the service life of the pipeline occur, and shall not have any serious influence on human life even should a higher level of seismic motions of low probability occur, due to an inland type earthquake or trench type huge earthquake.

(b) For the earthquake-resistant design of gas equipment, two levels of seismic motions are assumed, and considering the influence of structures, facilities, etc. on human life, the influence on relief activities and on the prevention of secondary disasters, and the influence on economic activities, gas equipment must have earthquake-resistant performance suitable for its respective kinds and degree of importance.

(c) Based on the above basic concept, earthquake-resistant design is performed to secure the earthquake-resistant performance required for the two levels of seismic motions, as described in the following chapter.

(2) Seismic Motions to be Assumed for Design, and Earthquake-Resistant Performance

> The seismic motions to be assumed for design, and the earthquake-resistant performance required of them are shown in Table 1.2.1.

Table 1.2.1 Seismic Motions and Earthquake-Resistant Performance

Seismic Motions to be Assumed for Design		Earthquake-Resistant Performance
Seismic motions of level 1	General seismic motions with a probability of occurring once or twice during the service life of gas pipeline are assumed.	Operation can be resumed immediately without any repair.
Seismic motions of level 2	Very strong seismic motions due to an inland type earthquake or trench type earthquake likely to occur at a low probability rate during the service life of gas pipeline are assumed.	The pipeline does not leak, though deformed.

(Description)

(a) Seismic Motions of Level 1, and Earthquake-Resistant. Performance against Them

[Seismic Motions]

Seismic motions specified in the previous Recommended Practices for Earthquake-resistant design of High Pressure Gas Pipelines (March 1982).

[Earthquake-Resistant Performance]

The earthquake-resistant performance required for the seismic motions of level 1 is such that "Operation can be resumed immediately without any repair." based on the Report of the Committee for Preventing Seismically Caused Gas Disasters.

(b) Seismic Motions of Level 2, and Earthquake-Resistant Performance against Them

[Seismic Motions]

A proposal concerning the seismic standard, etc. of the Japan Society of Civil Engineers presents concrete images as "seismic motion near the hypocenter fault of an earthquake caused by any internal strain of a plate of magnitude 7 class (hereinafter called an inland type earthquake)" and "seismic motion in the hypocenter region by a large-scale inter-plate earthquake occurring near land (hereinafter called a trench type earthquake)", and the present "Recommended Practices" assumes the seismic motions of these two earthquake types, inland type earthquake and trench type earthquake.

Further, even if there is no active fault found in the existing documents, there is a possibility that an inland type earthquake may occur. Thus, it was decided to adopt a concept that a lower limit level is set when seismic motions are assumed.

[Earthquake-Resistant Performance]

The earthquake-resistant performance required for the seismic motions of level 2 is such that "the pipeline does not leak, though deformed." based on the Report of the Committee for Preventing Seismically Caused Gas Disasters

(3) Evaluation of Earthquake-Resistance

> Since seismic motions repetitively forcibly displace the pipeline, the fatigue damage at a very low frequency caused by them is evaluated for earthquake-resistant design.
>
> When the ground of the planned pipeline is likely to be greatly deformed by liquefaction, etc., it must be examined adequately.

(Description)

The method for evaluating earthquake-resistance was decided, considering that seismic motions have the following characteristics:

a) the loads are short-term ones, and

b) since the strains (or relative displacements) caused in the ground by seismic motions are repetitively applied to the pipeline, the loads are periodically displacement-controlled, and also in reference to the concepts of existing standards (ASME Sec. III, etc.) which specify these loads.

1.2.2 Earthquake-Resistant Design against Seismic Motions of Level 1

> The earthquake-resistant design against seismic motions of level 1 is performed according to the Recommended Practices for Earthquake-resistant design of High Pressure Gas Pipelines (Japan Gas Association, March 1982)*. However, for the "apparent propagation velocity of seismic motion*, the value stated in "Apparent wavelength of seismic motion" is used, and for the "ground spring constants in the axial direction of the pipe and in the transverse direction of the pipe", the values stated in "Confining force of ground" are used.

(Description)

For earthquake-resistant design against seismic motions of level 1, Recommended Practices for Earthquake-Resistant Design of High Pressure Gas Pipelines* (Japan Gas Association, March 1982) is applied.

However, the following portions among the latest results of research concerning the earthquake-resistant design, especially among the findings obtained after the 1995 Hyogoken-Nanbu Earthquake inclusive should also be applied, in view of their nature, to the earthquake-resistant design against seismic motions of level 1. So, for the following values stated in the 1982 Recommended Practices, those stated in the present Recommended Practices are used.

(1) "Apparent propagation velocity of seismic motion" in "Design seismic motion"

(2) "Ground spring constants in the axial direction of the pipe and in the transverse direction of the pipe" in "Earthquake-resistant design of straight pipe in uniform ground", "Earthquake-resistant design of straight pipe in roughly varying Ground" and "Earthquake-resistant design for bend and tee".

1.2.3 Earthquake-Resistant Design against Seismic Motions of Level 2

(1) Entire Flow of Earthquake-Resistant Design

(a) The procedure for setting the design seismic motion is shown in Fig. 1.2.1.

(b) The earthquake-resistant design flow based on the set design seismic motion is shown in Fig. 1.2.2.

(2) Setting of Design Seismic Motion

[A] Procedure and Method for Setting Design Seismic Motion I, II and III

> The design seismic motion is set as follows based on "[B] Investigation of active fault" and "[C] Judgment as to existence of active fault".
>
> 1) When it has been concluded that the existence of any active fault is positive:
>
> - The seismic motion obtained by multiplying the design seismic motion I stated in "[D] Design seismic motion I" by the seismic zone coefficient stated in "[G] Seismic zone coefficient" is used as the design seismic motion.
> - Alternatively if fault analysis can be performed, the seismic motion calculated according to the fault analysis stated in "[F] Design seismic motion III" is used as the design seismic motion. However, if the calculated design seismic motion is smaller than the seismic motion obtained according to the procedure of 2), the seismic motion of 2) is used as the design seismic motion.
>
> 2) When it has been concluded that the existence of any active fault is negative:
>
> - The seismic motion obtained by multiplying the design seismic motion II stated in "[E] Design seismic motion II" by the seismic

zone coefficient stated in "[G] Seismic zone coefficient" is used as the design seismic motion.

3) When it has been concluded that the existence of any active fault is unknown:

- The seismic motion obtained by multiplying the design seismic motion I stated in "[D] Design seismic motion I" by the seismic zone coefficient stated in "[G] Seismic zone coefficient" is used as the design seismic motion.

(Description)

(1) The seismic motion of level 2 to be applied for design is set using any of the three kinds of seismic motion described below based on the conclusion as to whether the existence of any active fault is positive or negative.

Design seismic motion I: Seismic motion decided for the inland type earthquake based on the observation records of Hyogoken-Nanbu Earthquake

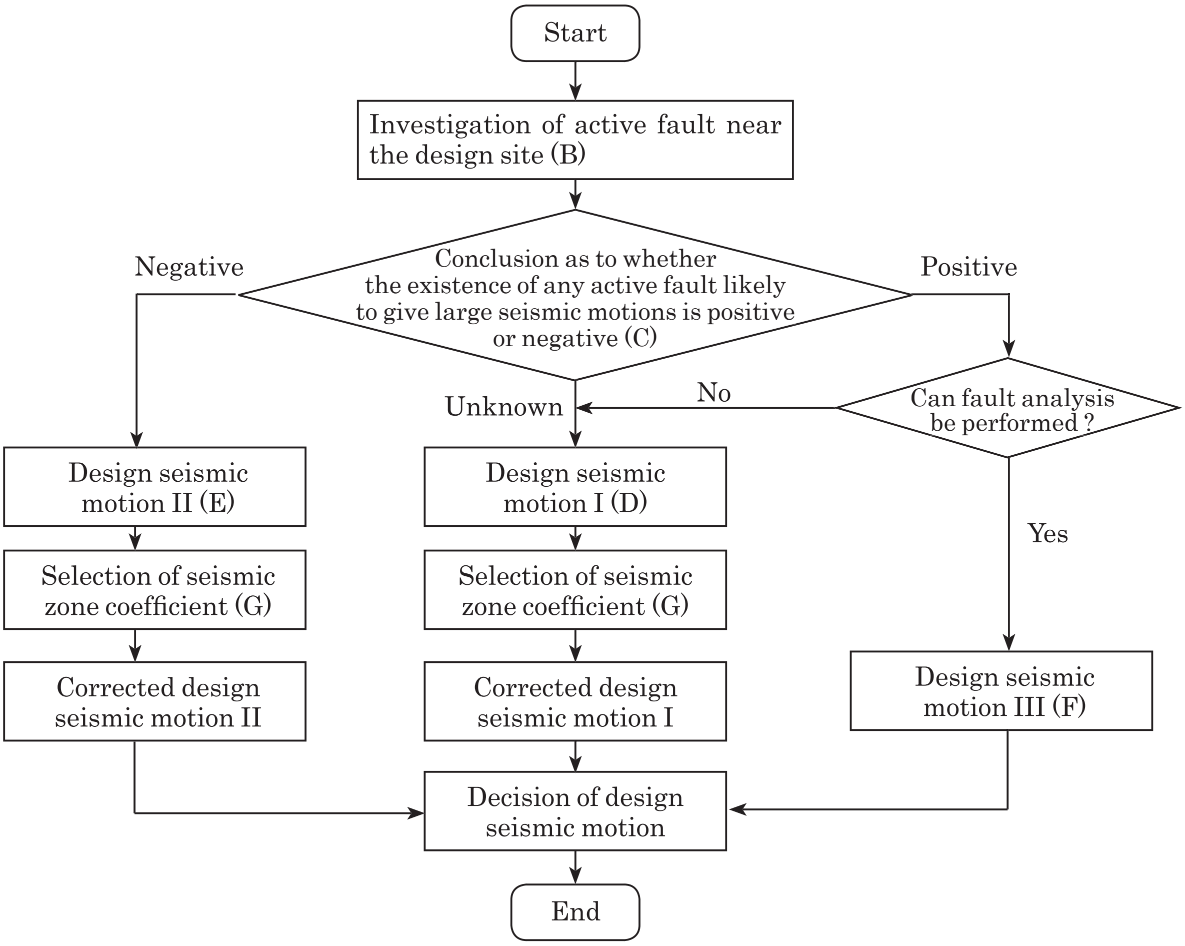
Design seismic motion II: Seismic motion decided for the trench type earthquake based on past earthquake observation records

Design seismic motion III: Seismic motion analytically decided for the inland type earthquake by modeling the hypocenter fault and using the hypocenter parameter and the information on the ground and physical properties of propagation routes

(2) If it is concluded that the existence of any active fault likely to greatly affect the planned pipeline is positive, it can be considered to analytically calculate the seismic motion by modeling the hypocenter fault and using the fault parameter and the information on the ground and physical properties of propagation routes (this method is called fault analysis). However, presently the data necessary for analysis and the analytical method are not sufficiently established. Therefore, the design seismic motion is set by using the design seismic motion I decided based on the observation records of Hyogoken-Nanbu Earthquake, one of the recent largest inland type earthquakes, or by fault analysis.

(3) When it has been concluded that the existence of any active fault is negative, it is required to take only the trench type earthquake into consideration, and the design seismic motion is set using the design seismic motion II for the trench type earth quake.

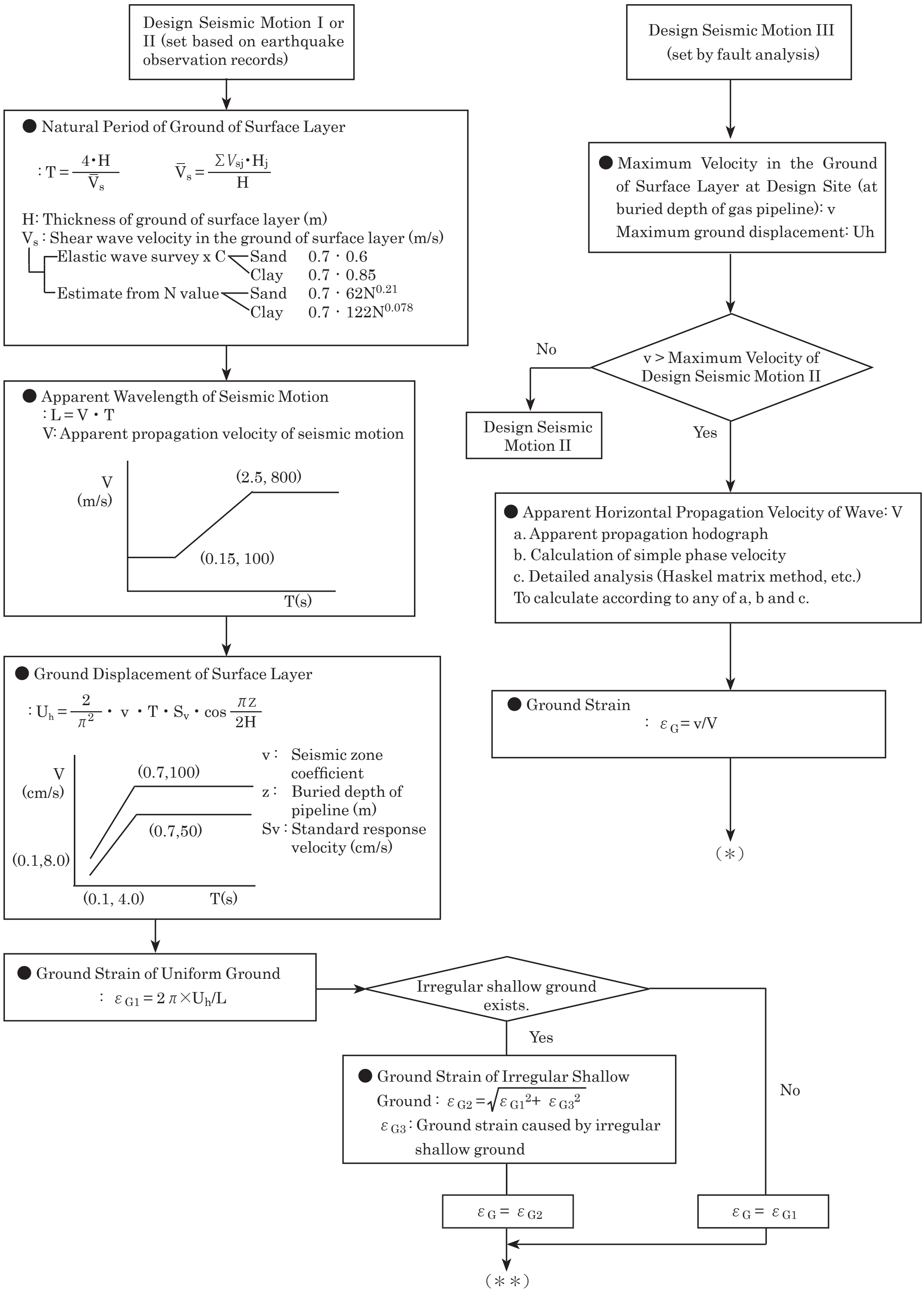
(4) When it has been concluded that the existence of any active fault is unknown, the design seismic motion is set using the above-mentioned design seismic motion I, from the viewpoint of obtaining conservative results for design, since it cannot be concluded that there is no active fault.

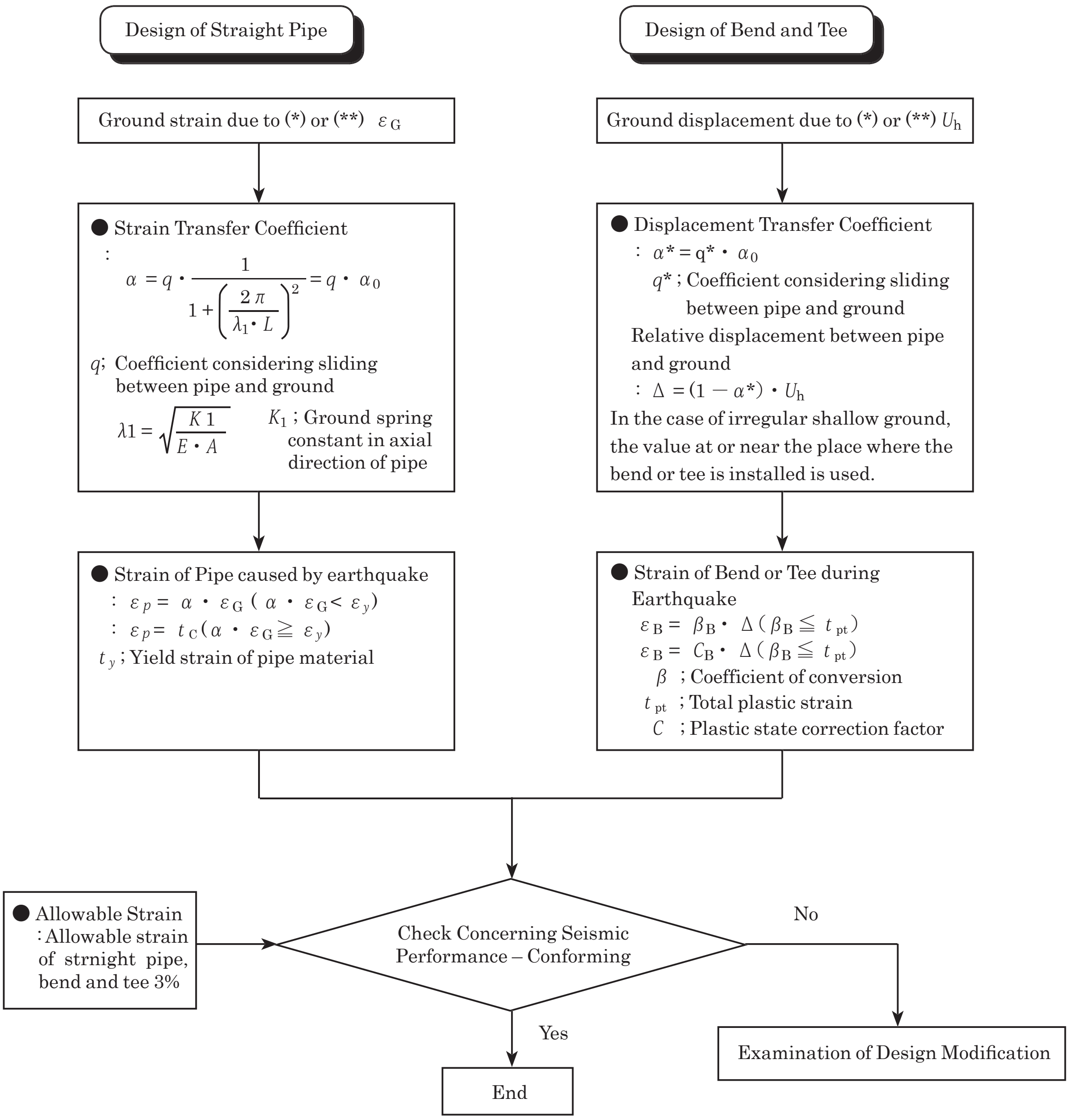


*1) If the design seismic motion III is smaller than the corrected design seismic motion II, the corrected design seismic motion II is used as the design seismic motion.

Fig. 1.2.1 Design Seismic Motion Setting Flow

Fig. 1.2.2 Earthquake-Resistant Design Flow for High Pressure Gas Pipelines against Seismic Motions of Level 2




Design of Straight Pipe
Design of Bend and Tee
Ground strain due to (*) or (**) ε_G
Ground displacement due to (*) or (**) U_h
● Strain Transfer Coefficient
: $\alpha = q \cdot \dfrac{1}{1+\left(\dfrac{2\pi}{\lambda_1 \cdot L}\right)^2} = q \cdot \alpha_0$
q; Coefficient considering sliding between pipe and ground
$\lambda 1 = \sqrt{\dfrac{K1}{E \cdot A}}$
K_1 ; Ground spring constant in axial direction of pipe
● Displacement Transfer Coefficient
: $\alpha^* = q^* \cdot \alpha_0$
q^* ; Coefficient considering sliding between pipe and ground
Relative displacement between pipe and ground
: $\Delta = (1 - \alpha^*) \cdot U_h$
In the case of irregular shallow ground, the value at or near the place where the bend or tee is installed is used.
● Strain of Pipe caused by earthquake
: $\varepsilon_p = \alpha \cdot \varepsilon_G \ (\alpha \cdot \varepsilon_G < \varepsilon_y)$
: $\varepsilon_p = t_C (\alpha \cdot \varepsilon_G \geqq \varepsilon_y)$
t_y ; Yield strain of pipe material
● Strain of Bend or Tee during Earthquake
$\varepsilon_B = \beta_B \cdot \Delta (\beta_B \leqq t_{pt})$
$\varepsilon_B = C_B \cdot \Delta (\beta_B \leqq t_{pt})$
β ; Coefficient of conversion
t_{pt} ; Total plastic strain
C ; Plastic state correction factor
● Allowable Strain
: Allowable strain of strnight pipe, bend and tee 3%
Check Concerning Seismic Performance – Conforming
No
Yes
End
Examination of Design Modification

2. Recommended Practice for Design of Gas Transmission Pipelines in Areas Subject to Liquefaction (2001)

2.1 Introduction

After the 1995 Hyogoken-nanbu (Kobe) Earthquake, the Japan Gas Association, launched studies to establish the Recommended Practice for Design of Gas Transmission Pipelines in Areas Subject to Liquefaction.

The studies of the magnitude of liquefaction-induced ground displacements, restraint forces exerted upon pipelines, simplified and useful deformation formulas for evaluating large-scale pipeline deformations caused by liquefaction-induced ground displacements and critical pipe deformations capable of satisfying the seismic performance criterion of "no leakage of gas", the Recommended Practice for Design of Gas Transmission Pipelines in Areas Subject to Liquefaction was established. This section describes the fundamental principles of the Recommended Practice.

2.2 Fundamental Principles of the Design

2.2.1 Seismic Performance

The seismic performance criterion set in the Recommended Practice is "no leakage of gas". Although pipeline deformation is permissible, gas leaks must not occur.

2.2.2 Liquefaction Effects to be Considered

The effects of the following liquefaction-induced ground displacements shall be considered:

1) horizontal displacements in sloping ground areas,
2) horizontal displacements in areas behind quay walls,
3) settlements in areas in which pipelines are provided with rigid supports such as abutments.

2.2.3 Design Seismic Motion and Design Ground Displacements

Level 2 design seismic motion shall be used to identify the presence and severity of liquefaction. While the probability of an occurrence is small, the intensity of such an event is very high. Design ground displacements are set to be large enough when they are compared with those obtained by case studies in previous earthquakes.

2.2.4 Pipe Deformation Mode

Four pipe deformation modes shall be considered in the design, as follows:

1) straight pipe - uniaxial compression,
2) straight pipe - bending,
3) pipe bend - in-plane bending in the closing direction,
4) Pipe bend - in-plane bending in the opening direction.

Figure 2.1 shows these four deformation modes.

2.2.5 Load and Resistance Factor Design

For the seismic performance criterion, Equation (1) must be satisfied for any of the considered deformation modes.

$$S_d \leq R_d \tag{1}$$

where S_d: Design pipeline deformation evaluated by pipeline deformation analysis,
R_d: Design critical deformation. Beyond this critical deformation, gas leaks.

The Load and Resistance Factor Design was adopted to ensure appropriate safety margins and to facilitate the incorporation of future study and understanding into the Recommended Practice. In this design methodology, a safety margin is assigned to each individual design component in the form of a partial safety factor, as is shown in Equation (2) and Equation (3). Figure 2.2 shows the design flow diagram.

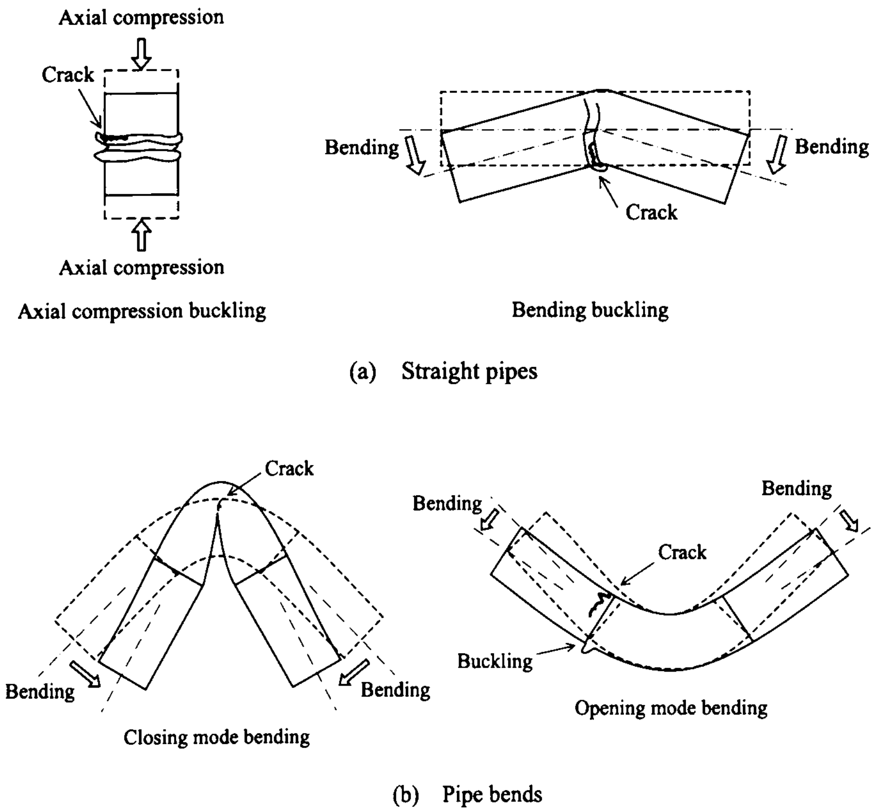


Figure 2.1 The deformation modes for straight pipes and pipe bends

$$S_d = \gamma_\alpha \cdot S(\gamma_\delta \cdot \delta, L, \gamma_K \cdot K) \tag{2}$$

$$R_d = R\,(\varepsilon_u / \gamma_m) / \gamma_b \tag{3}$$

where $S(*)$: Function used to evaluate design pipeline deformation.

δ: Liquefaction-induced ground displacement.

L: Length of the area in which liquefaction-induced ground displacements occur.

K: Restraint force exerted upon pipelines due to liquefaction-induced ground displacements.

$R(*)$: Function used to evaluate design critical pipe deformation.

ε_u: Critical pipe strain. Beyond this critical strain, gas leaks occur.

γ_* : Partial safety factor.

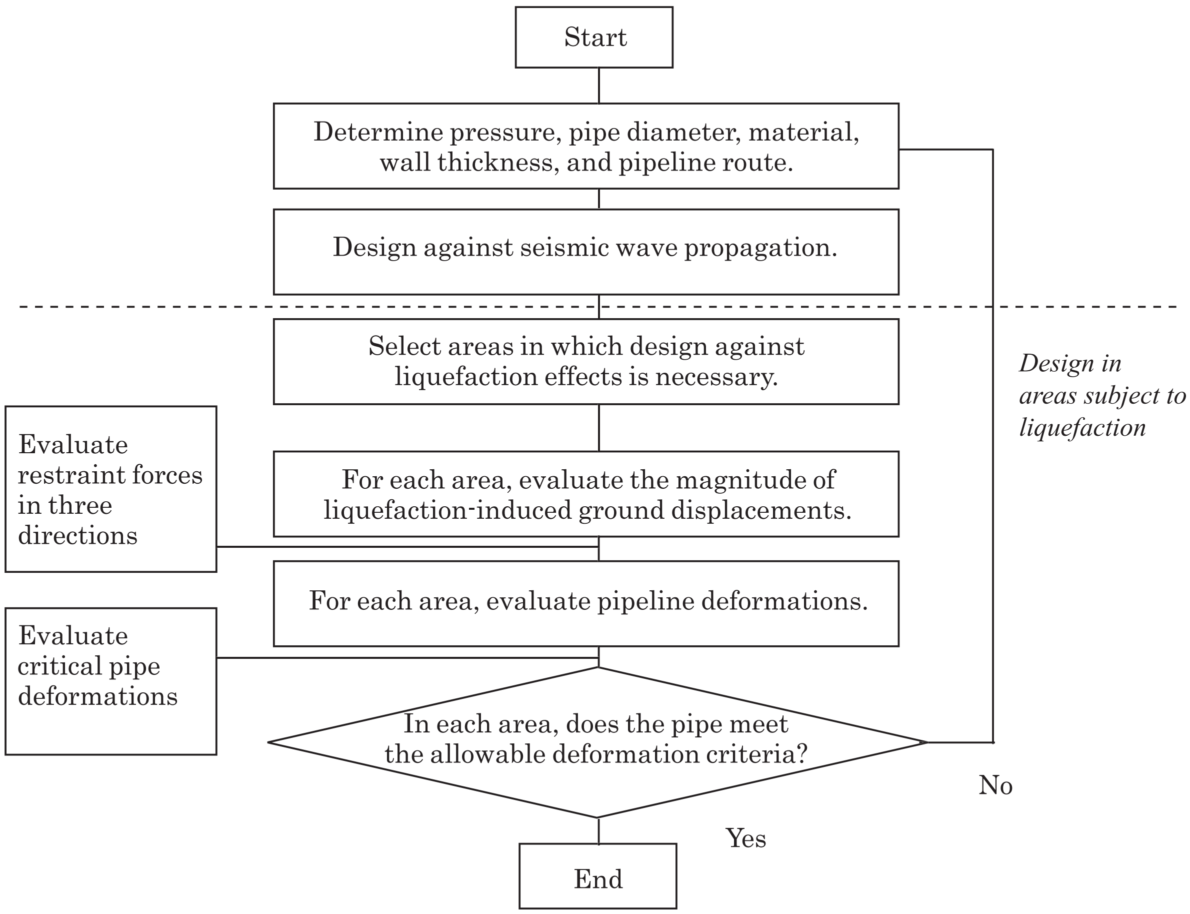


Figure 2.2 Design flow diagram