Seismic Performance of Gas Distribution Pipelines Renovated by Hose Lining Method

Y. Seko, M. Masaki, T. Sakanoue & H. Motohashi
Tokyo Gas Co., Ltd., Japan

SUMMARY:
In this study, the new theoretical formula for the deformation behavior of hose-lined pipe was proposed based on the previous approach proposed by Sato. We then clarified appropriate test methods for measuring the strength properties of seal hose necessary to evaluate the deformation behavior by the new formula. The validity of the new theoretical formula was demonstrated by conducting full-scale tensile tests of a hose-lined pipe. In addition, the tensile property of the metallic ring with sealing rubber was evaluated. Based on these results, we proposed a new evaluation method for the seismic performance for hose-lined pipes including the metallic ring with sealing rubber.

Keywords: hose lining method, seismic performance, buried pipelines, theoretical formula

1. INTRODUCTION

Buried pipelines in seismically active regions may suffer damages from ground deformation due to large earthquakes. In the past, damage to low-pressure gas distribution pipelines was caused by major earthquakes, such as the Southern Hyogo prefecture earthquake in 1995, the Niigataken Chuetsu-oki earthquake in 2007, the 2011 earthquake off the Pacific coast of Tohoku. As a result, city gas companies in Japan have been taking measures to protect their pipelines against large earthquakes.

Two procedures are recommended for mitigating earthquake damage to distribution pipelines: the upgrading of pipe materials and the use of earthquake-proof joints. The implementation of these procedures for newly constructed distribution pipelines is not very difficult, but it is not efficient for existing distribution pipelines. One of the efficient procedures for improving existing distribution pipelines is the hose lining method, cooperatively developed by the Ashimori Industry Co., Ltd., and the Tokyo Gas Co., Ltd., which can renovate and rehabilitate distribution pipelines without excavation. This method can prevent leakage through the use of a seal hose that stretches when a welded joint breaks. A distribution pipeline in which the hose lining method had been applied had no leakage in the Southern Hyogo prefecture earthquake in 1995, which demonstrated that this method was a useful measure against damage from large earthquakes. However, quantitative evaluation of the seismic performance of this method has been limited to date. In addition, the seismic performance of the metallic ring with sealing rubber used to fasten seal hoses on a pipe has never been evaluated.

The evaluation method of the deformation behavior for the hose-lined pipe (vide infra) was suggested by Sato. However, the validity of this method was not quite confirmed. In addition, this method had not been taken into account of the properties of the metallic ring with sealing rubber that fastens the seal hoses. In this study, full-scale tensile tests of a hose-lined pipe were conducted to confirm the validity of the proposed evaluation method and to identify deficiencies of this method. In addition, the strength properties of the metallic ring with sealing rubber were evaluated. Based on these results, we proposed a method to evaluate the seismic performance of the hose-lined pipe including the metallic ring with sealing rubber.

2. OUTLINE OF THE HOSE LINING METHOD

The components used in the hose lining method consist of a seal hose, an adhesive, and a metallic ring with sealing rubber (termed "the end part"). The cross section of a hose-lined pipe is shown in Fig. 2.1, and a schematic diagram of the end part is shown in Fig. 2.2. The seal hose is a cylindrical seamless jacket coated by a polyester elastomer to prevent gas leakage. The adhesive, having the function of bonding between the seal hose and the pipe, is a two-component epoxy resin. The end part consists of the metallic ring and sealing rubber, and functions to fasten the edge of the seal hose to the pipe.

Generally, the method involves the attachment of the inside-out seal hose at the open end of a reversal apparatus. After insertion into the in-ground pipe, air pressure is used to inflate or draw out the hose down the length of the pipe, with simultaneous inversion. A guide belt contained within the hose helps to control the reversal as well as the speed of the continuous process. The reversal of the seal hose is performed in a manner similar to turning socks inside out, as shown in Fig. 2.3.

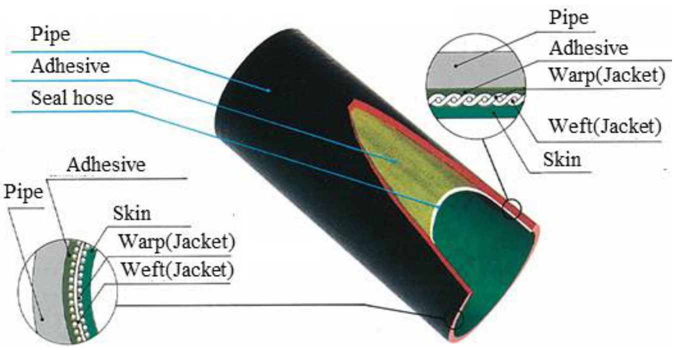

Figure 2.1 Cross section of a hose-lined pipe

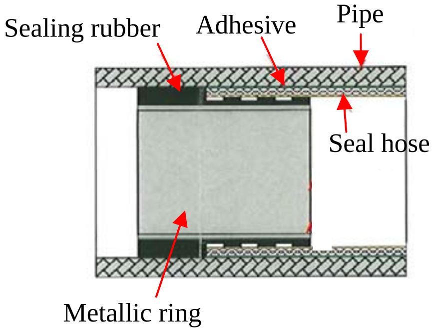

Figure 2.2 Schematic diagram of the end part

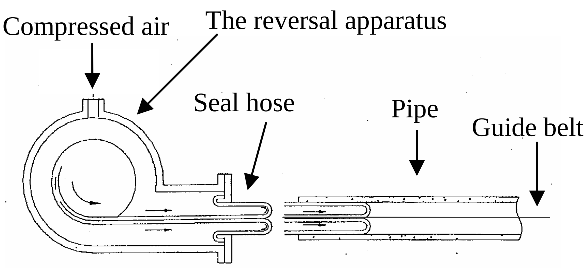

Figure 2.3 Schematic diagram of hose-lining apparatus

3. LEAKAGE MODE OF THE HOSE-LINED PIPE

In order to assess the integrity against seismic ground motion, it is necessary to clarify the leakage mode of the hose-lined pipe. When a joint breaks due to tension displacement along the axis by seismic ground motion, the seal hose peels off from the inner pipe as a function of joint expansion. As the joint expansion increases, the peeling length of the seal hose increases and the tension load generated on the seal hose increases simultaneously. Therefore, the leakage of a hose-lined pipe due to earthquakes follows two modes:

(1) The seal hose is broken because the tension load generated on the seal hose exceeds the fracture load of the seal hose. (Fig. 3.1)

(2) The peeling of the seal hose reaches the metallic ring with sealing rubber, and the seal hose separates from the end part. (Fig. 3.2)

To assess the above leakage modes, it is necessary to clarify the relationship between joint expansion, the peeling length of the seal hose, and the tension load generated on the seal hose.

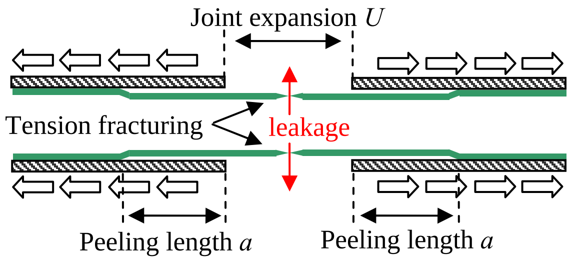

Figure 3.1 The leakage mode caused by fracturing of the seal hose

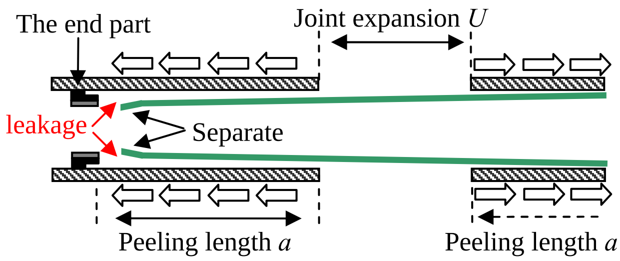

Figure 3.2 The leakage mode caused by separating of the seal hose from the end part

4. THE EXISTING EVALUATION METHOD FOR THE DEFORMATION BEHAVIOR OF A HOSE-LINED PIPE

The evaluation method for the deformation behavior of the hose-lined pipe was suggested by Sato. It can be described as follows.

Frictional stress acts on the peeling boundary surface due to inner pressure. In addition, the peel strength acts on the top of the peeling. Thus, the tension load F generated on the seal hose is expressed by the following equation:

$$F = F_s \pi (D - 2t_1) + p\pi (D - 2t_1)\mu a \tag{4.1}$$

F_s : the peel strength per unit length
p : the inner pressure
D : the diameter of the pipe
t_1 : the thickness of the pipe
μ : the dynamic friction coefficient of the peeling boundary surface
a : the peeling length of the seal hose

Additionally, the following equation is obtained based on the equilibrium of force in a minute fraction:

$$F = EA_0 \left(du/da \right) \tag{4.2}$$

E : the axial Young's modulus of the seal hose
A_0 : the cross-sectional area of the seal hose
u : the elongation of the seal hose

The boundary condition to solve Eqn. 4.2 is given by

$$\text{At} \quad a = 0,\, u = 0 \tag{4.3}$$

Neglecting the pipe extension and that of the seal hose bonded to the pipe wall, the peeling length of the seal hose a is expressed as follows, from Eqn. 4.1 – 4.3:

$$a = \frac{-F_s + \sqrt{F_s^2 + \pi(D - 2t_1)p\mu E A_0 U}}{p\mu} \tag{4.4}$$

U : twice the value of u

If the mechanical strength properties of the seal hose, E, μ and F_s, are measured in small-scale tests, the relationship between F, a, and U can be calculated from Eqn. 4.1 – 4.4.

5. VALIDITY OF THE EXISTING METHOD

To confirm the validity of the existing method, full-scale tensile tests of the hose-lined pipe were conducted. Fig. 5.1 shows the test specimen. Two steel pipes of length 1000 mm were butted and lined with a seal hose. There were 10 small holes in each side to measure the peeling length of the seal hose via a strain gauge. The test specimen was tensioned at 10 mm/min along the axial direction under 0.3 MPa inner pressure. Total of three experiments were conducted under the same conditions.

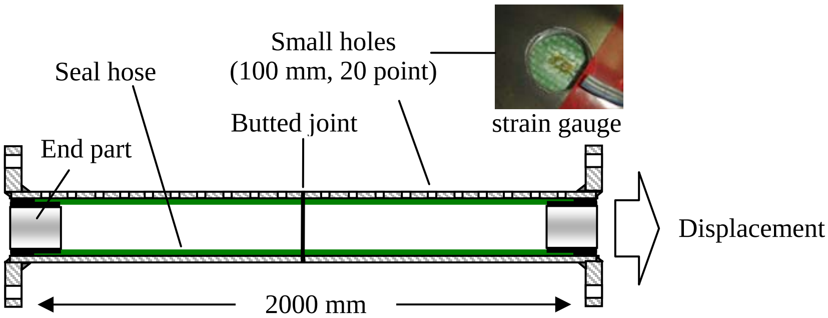

Figure 5.1 Test Specimen

Experimental test results versus those calculated by the existing method are shown in Fig. 5.2 and 5.3. Input data for the calculation are shown in Table 5.1. The relationship between the peeling length of the seal hose and the joint expansion calculated by the previous evaluation method was approximately in agreement with the test results. However, the relationship between the tension load and joint expansion was different, revealing that the previous evaluation method overestimated the tensile load F. Therefore, the existing method was insufficient to evaluate the deformation behavior of the hose-lined pipe.

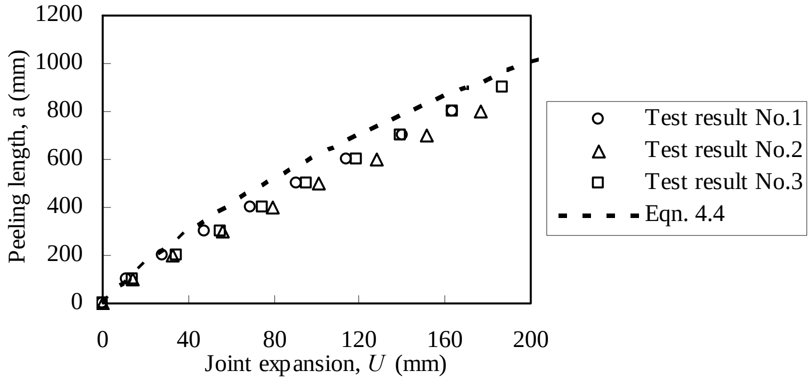

Figure 5.2 The relationship between the joint expansion and the peeling length

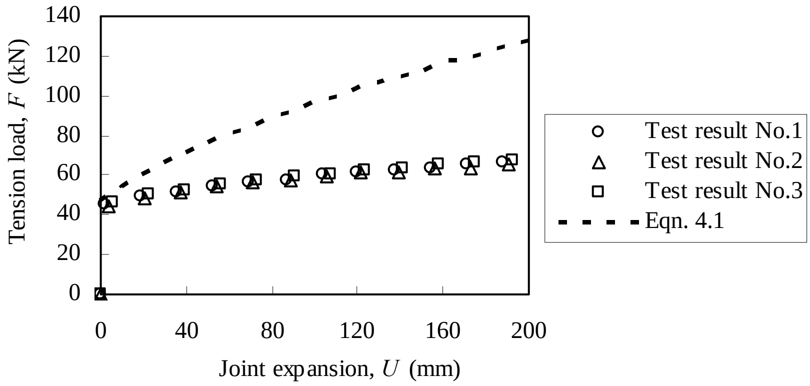

Figure 5.3 The relationship between the joint expansion and the tension load

Table 5.1. Input data for calculation

Peelings Strength *Fs* (N/mm)	Young Modulus *E* (N/mm^2)	Friction Coefficient μ	Inner pressure *p* (N/mm^2)	Pipe diameter *D* (mm)	Pipe thickness t_1 (mm)	Thickness of seal hose t_2 (mm)
308	1049	0.53	0.3	165.2	4.5	1.7

6. VALIDITY OF THE NEW EVALUATION METHOD

The result calculated by the existing evaluation method was different from the test results. It is considered that the tension load was overestimated due to the following factors:

(1) Expansion of the seal hose by inner pressure
(2) Cross-sectional area variation of the seal hose
(3) Influence of specimen size on axial Young's modulus *E*
(4) Influence of vertical pressure on dynamic friction coefficient μ

The abovementioned factors will be examined next.

6.1. Expansion of The Seal Hose by Inner Pressure

The outer diameter of the seal hose is smaller than the inner diameter of the pipe, so the inner pressure actually causing the friction force in the peeled area is smaller than the inner pressure of the test specimen. Therefore, the actual inner pressure p_e is expressed by following equation:

$$p_e = p - p' \tag{6.1}$$

p' : the inner pressure required to expand the seal hose

The hoop stress of the seal hose caused by the inner pressure p' is expressed by following equation:

$$\sigma_c = \frac{D - 2(t_1 + t_2)}{2t_2} p' \tag{6.2}$$

Meanwhile, σ_c is expressed as follows, based on Hook's law:

$$\sigma_c = E_c \cdot \varepsilon_c \tag{6.3}$$

E_c : the circumferential Young's modulus of the seal hose
ε_c : the circumferential strain of the seal hose

The circumferential strain is given by

$$\varepsilon_c = \frac{(D-2t_1)-D_s}{D_s} \tag{6.4}$$

D_s : the outer diameter of the seal hose

After eliminating σ_c, ε_c, and p', the actual inner pressure p_e is given by

$$p_e = p - \frac{2t_2 E_c}{D_s} \cdot \frac{(D-2t_1)-D_s}{D-2(t_1+t_2)} \tag{6.5}$$

6.2. The Evaluation Formula Considering The Cross-Sectional Area Variation of The Seal Hose

To consider the cross-sectional area variation, Eqn. 4.2 is expressed by following equation:

$$F = EA_0 \frac{1}{1+du/da} \frac{du}{da} \tag{6.6}$$

The boundary condition to solve Eqn. 6.6 is given by

$$\text{At} \quad a=0, u=0 \tag{6.7}$$

From Eqn. 4.1, 6.6, and 6.7, the evaluation formulas of the deformation behavior of the seal hose are obtained as follows:

$$F = F_s \pi (D-2t_1) + P\mu a \tag{6.8}$$

$$U = \frac{2EA_0}{P\mu} \ln\left(\frac{EA_0 - F_s \pi (D-2t_1)}{EA_0 - F_s \pi (D-2t_1) - P\mu a} \right) - 2a \tag{6.9}$$

P : $\pi(D\text{-}2t_1)p_e$

6.3. Influence of Specimen Size on Axial Young's Modulus *E*

It is generally accepted that the axial Young's modulus of fabric is influenced by specimen size. Therefore, axial Young's modulus was measured using a test specimen with a size similar to that in the full-scale test. Test results are shown in Table 6.1. The axial Young's modulus *E* was lower than those obtained from small scale specimen shown in Table 5.1. Therefore, it was revealed that the test specimen size in the axial Young's modulus measurement test should be similar to that in the full-scale test.

Table 6.1. Test results for Young's modulus and fracturing load

Test No.	1	2	3	Ave.
Young's modulus *E* (N/mm^2)	717	658	825	733
Fracturing load F_{cr} (kN)	86.0	80.0	98.0	88.0

6.4. Influence of Vertical Pressure on The Dynamic Friction Coefficient μ

Generally, the friction coefficient of a polymer material is influenced by vertical pressure. Therefore, the dynamic friction coefficient was measured under vertical pressure as in the full-scale test. Test results are shown in Table 6.2 and are lower than those previously obtained (Table 5.1). Therefore, the vertical pressure in the dynamic friction coefficient measurement test should be similar condition to that in the full-scale test.

Table 6.2. Test results for the dynamic friction coefficient

Test No.		1	2	3	Ave.
Vertical pressure (N/mm^2)	0.1	0.21	0.14	0.12	0.15
	0.3	0.14	0.16	0.17	0.16

6.5. The Validity of The Proposed Evaluation Method

Comparisons between the experimental test results and the results calculated by the new evaluation method are shown in Fig. 6.1 and 6.2. Both the peeling length and the tension load calculated by the new evaluation method were in good agreement with the test results. Therefore, the new method is adequate for seal hose evaluation. From these results, the deformation behavior of the seal hose as a determinant of the leakage mode shown in Fig. 3.2 can be evaluated with the new method.

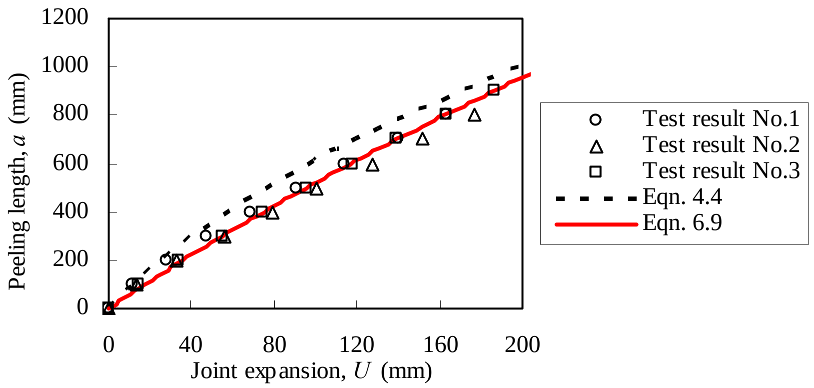

Figure 6.1 The relationship between the joint expansion and the peeling length

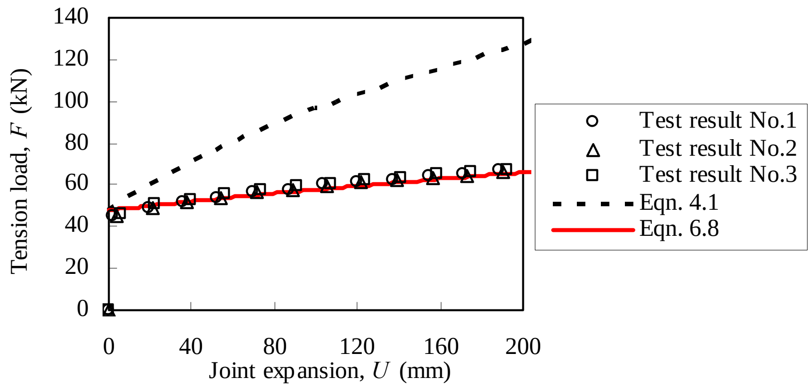

Figure 6.2 The relationship between the joint expansion and the tension load

7. SEISMIC PERFORMANCE OF DISTRIBUTION PIPELINE WITH APPLIED HOSE LINING

7.1. Calculated Method of Joint Expansion

The joint expansion *U* can be calculated using finite element method (FEM) analysis. A sine wave ground displacement acts on the buried pipeline during an earthquake, as shown in Fig. 7.1, according to "Recommended Practice for Earthquake-Resistant Design of High Pressure Gas Pipeline". A schematic diagram of the finite element model is shown in Fig. 7.2. The finite element model, with a length of half the wavelength, was built from a one-dimensional pipe element. The soil-pipe interaction was expressed by discretized spring elements. Applying the sine wave displacement to the nodes of the spring elements, the joint expansion U can be calculated by the displacement of the free edge.

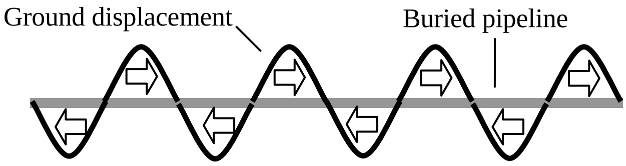

Figure 7.1 Ground displacement acting on buried pipeline

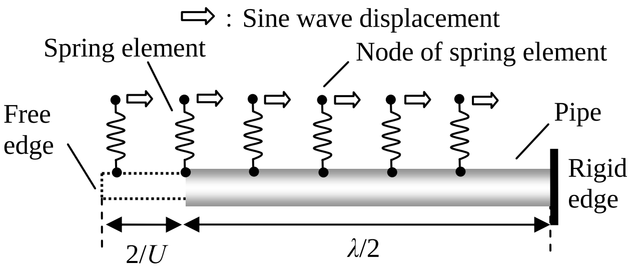

Figure 7.2 FEM analytical model

7.2. The New Evaluation Method Applied to The Tension Fracture of The Seal Hose

The condition under which the seal hose does not fracture is expressed by following equation:

$$F_{cr} > F \tag{7.1}$$

F_{cr} : the fracturing load of the seal hose

If the tension load F is calculated from Eqn. 6.8 and the joint expansion U is obtained by the FEM described in section 7.1, the potential of leakage caused by fracturing of the seal hose as shown in Fig. 3.1 can be evaluated using Eqn. 7.1.

7.3. The New Evaluation Method Applied to The Separation of The Seal Hose from The End Part

Tensile tests were conducted to evaluate the separation of the seal hose from the end part. In the end part, the seal hose was fixed by the bonding load caused by the adhesive and the expanding load of the metal ring. Therefore, the separation load of the seal hose from the end part F_{edge} is expressed by the following equation:

$$F_{edge} = F_a + F_{ring} \tag{7.2}$$

F_a : the bonding load of the seal hose caused by the adhesive in the end part
F_{ring} : the resistance load of the seal hose generated by expansion of the metal ring

F_{edge} was measured using a test specimen with adhesive and F_{ring} was measured using a test specimen without adhesive. Test results are shown in Table 7.1. The resistance loads of the seal hoses generated by expansion of the metal rings F_{ring} were much smaller than the bonding loads of the seal hoses by the adhesive in the end part F_a in all test specimens. In other words, the separation of the seal hose is highly dependent on the bonding load of the seal hose by the adhesive in the end parts.

From the above results, the leakage by separating of the seal hose from the end part as shown in Fig. 3.2 would not occur, if the peeling of the seal hose does not reach the end parts. In other words, the condition to prevent separation of the seal hose from the end parts is expressed by the following equation:

$$L > a \tag{7.3}$$

L : the distance between the end part and the adjacent joint
a : the peeling length of the seal hose calculated using Eqn. 6.9

Table 7.1. Test results for the end part

Pipe diameter (mm)	114.3	165.2	216.3
Separation load of seal hose F_{edge} (kN)	33.2	55.0	69.1
Bonding load by adhesive F_b (kN)	31.1	51.5	64.8
Resistance load generated by the metal ring F_{ring} (kN)	2.1	3.5	4.3

7.4. The New Evaluation Procedure for Seismic Performance

The proposed evaluation procedure applied to seismic performance for the hose-lined pipe is shown in Fig.7.3. Firstly, the tension load of the seal hose F and the peeling length of the seal hose a are calculated by using Eqn. 6.8 and 6.9 for a given joint expansion U obtained from the FEM described in section 7.1. If the tension load F is lower than the fracturing load of seal hose F_{cr}, the hose-lined pipe has no seismic performance because the leakage would occur as shown in Fig. 3.1. If F is bigger than F_{cr}, the another leakage mode shown in Fig. 3.2 should be then checked. If the L, which is the distance between the end parts and the adjacent joint is bigger than the peeling length a, the hose-lined pipe would have sufficient seismic performance.

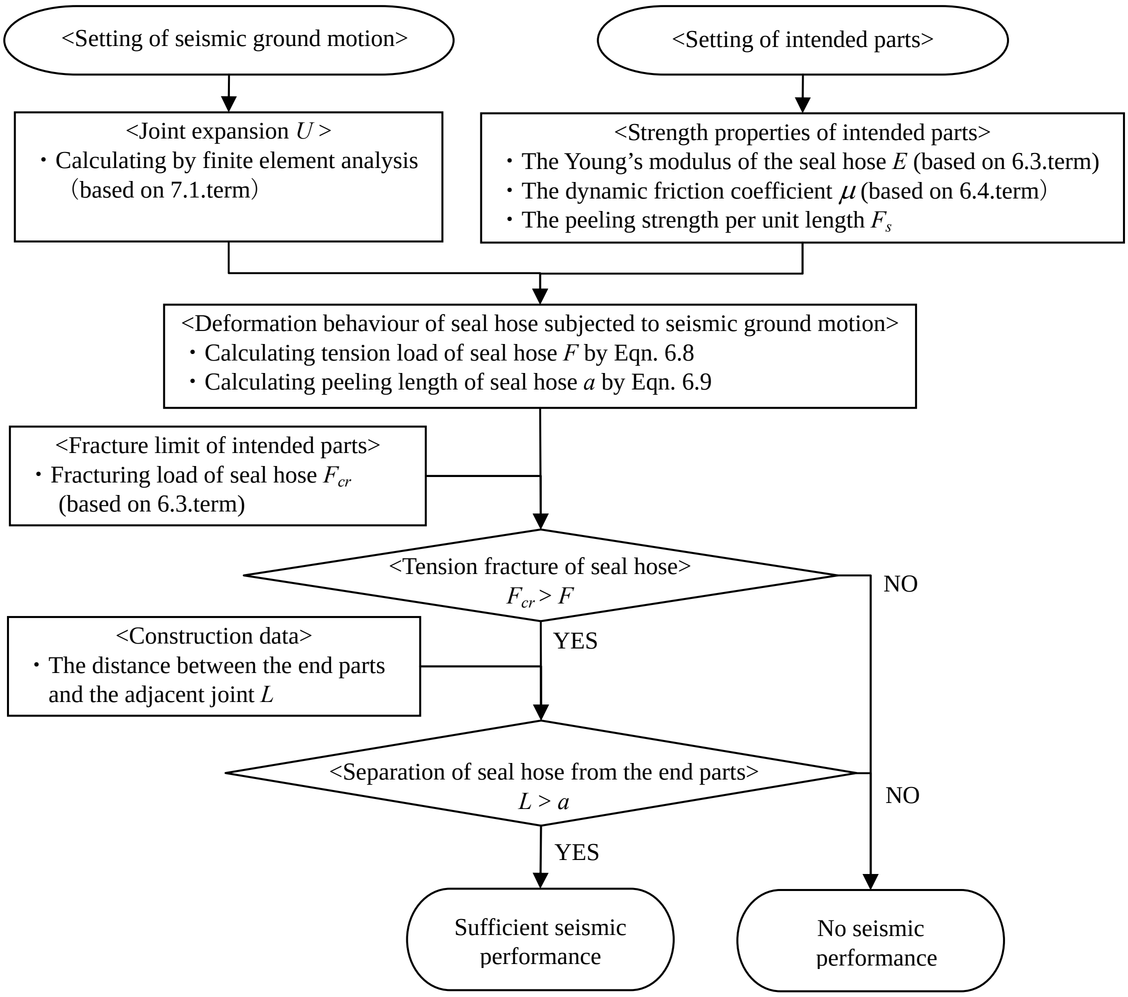

Figure 7.3 Evaluation procedure for seismic performance of hose-lined pipe

8. CONCLUSION

In this study, a new evaluation method for the seismic performance of a hose-lined pipe including the end part was established based on the existing evaluation method. Using the new method, the seismic performance of the hose-lined pipe including the end part can be evaluated using only theoretical calculations and the strength properties of the intended parts, without conducting full-scale tensile tests.

AKCNOWLEDGEMENT

The authors wish to thank Mr. Ueda and Mr. Yamamura of Ashimori Industry for their technical assistance in the experiments.

REFERENCES

Sato, T. (1985). Earthquake damage to buried pipes and their renovation by hose lining. *Journal of Pressure Vessel Technology* **98**, 125-131.

Seshimo, M. (2007). Renovation of underground existing pressure pipeline. *Journal of Japan Tappi* **62**, 46-52.

L.E, Nielsen. (1976), Mechanical properties of polymers and composites, Kagakudoujin.

Japan Gas Association. (2000), Recommended Practice for Earthquake-Resistant Design of High Pressure Gas Pipeline, Japan Gas Association.