Analytical method for seismic performance of gas distribution pipelines renovated by the hose lining method

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Background

- Earthquakes in Japan

In the past, damage to low pressure gas pipelines was caused by major earthquakes in Japan.

The Southern Hyogo Prefecture Earthquake (1995)

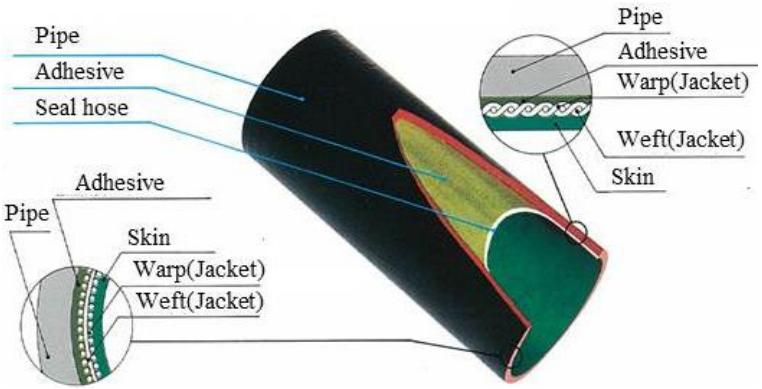
Tohoku Region Pacific Coast Earthquake (2011)

City gas companies in Japan have been taking measures to protect their pipelines against large earthquakes.

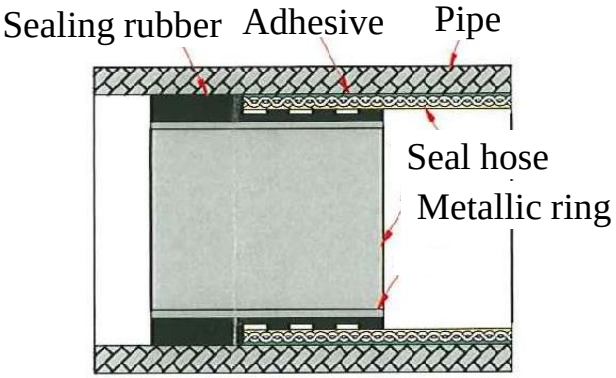
Background

Hose lining method

This method can renovate and rehabilitate distribution pipelines without excavation.



<The end part>



A distribution pipeline in which the hose lining method had been applied had no leakage in past earthquakes.

However…

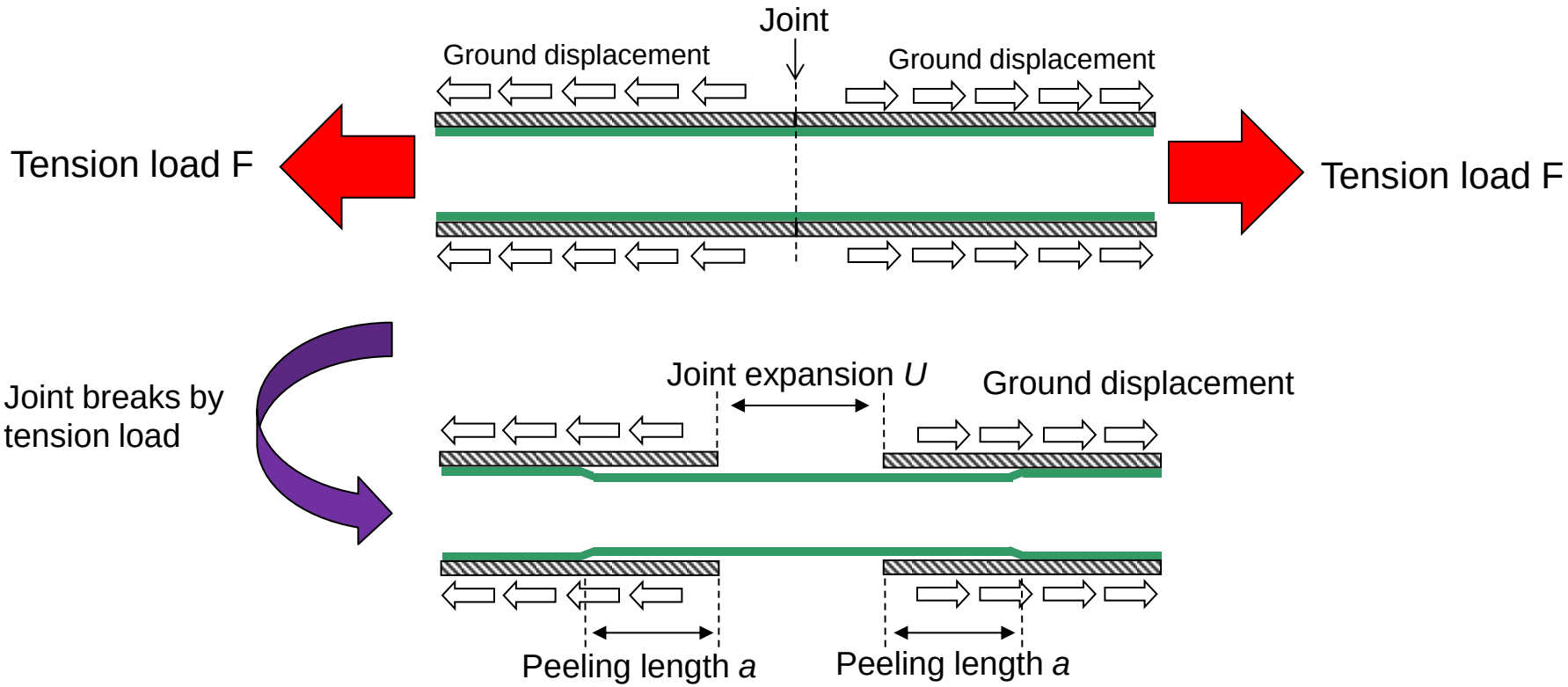
The leakage limit of this method against earthquakes has been hardly clarified.

Objective

- To establish the evaluation method for leakage limit of hose-lined pipe against earthquakes

1. Leakage mode of the hose-lined method

- The deformation behavior of seal hose when a joint breaks due to ground displacement



The seal hose peels off from the inner pipe as a function of joint expansion.

1. Leakage mode of the hose-lined method

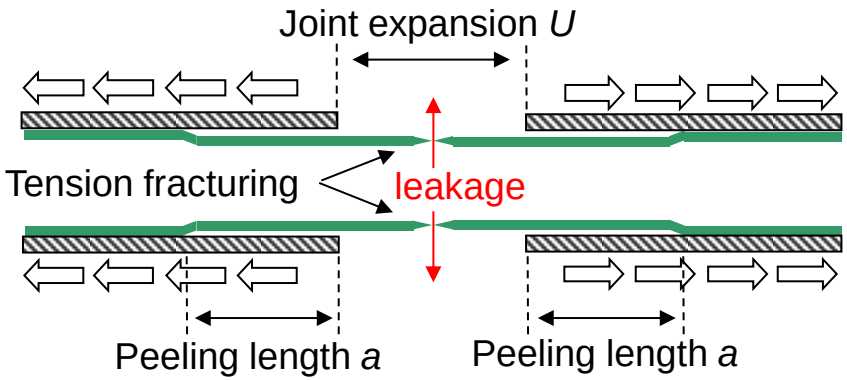
- The leakage of a hose-lined pipe due to earthquakes follows two modes

<Mode A>

The seal hose breaks when the tension load generated on the seal hose exceeds the fracture load of the seal hose.

$$F_{cr} > F$$

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

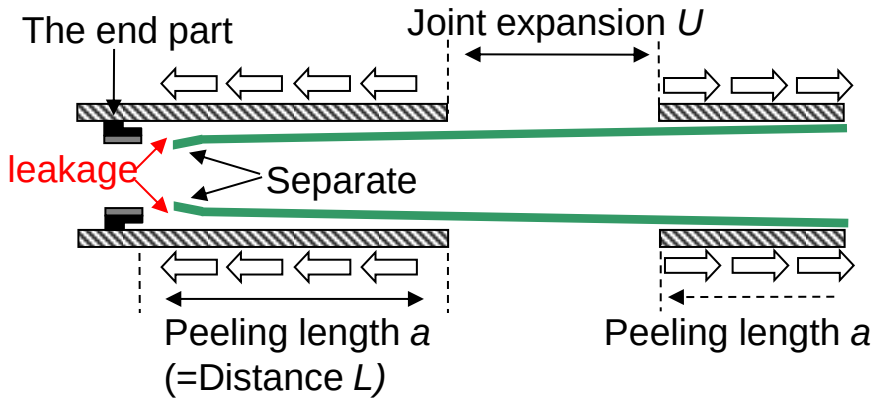


<Mode B>

The peeling of the seal hose reaches the metallic ring with sealing rubber, and the seal hose separates from the end part.

$$L > a$$

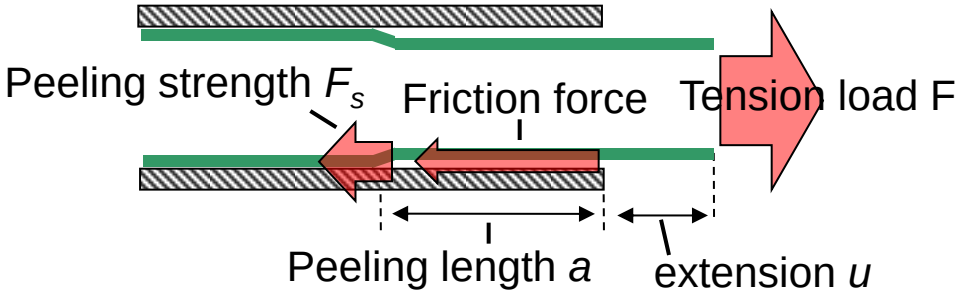
L: the distance between the end part and the adjacent joint



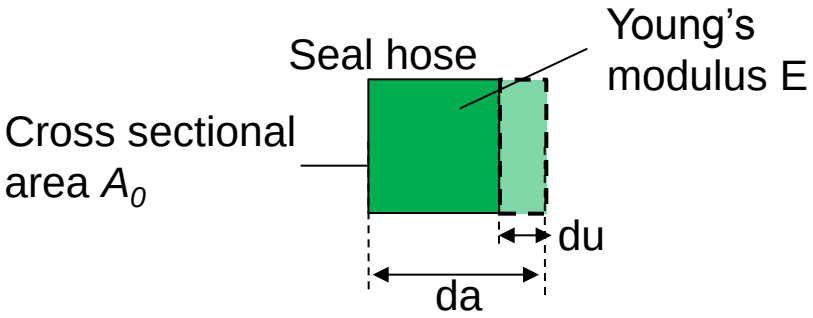
⇒ It is necessary to associate U with a and F for evaluation

2. The existing evaluation method for the deformation behavior of a hose-lined pipe*

◆ The equilibrium of force in the whole of a system



◆ The equilibrium of force in a minute fraction



Tension load F= Peeling strength + Friction force

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

$$F = EA_0 (du/da)$$

At $a = 0, u = 0$

$$a = \frac{-F_s + \sqrt{F_s^2 + \pi (D - 2t_1) p\mu EA_0 U}}{p\mu}$$

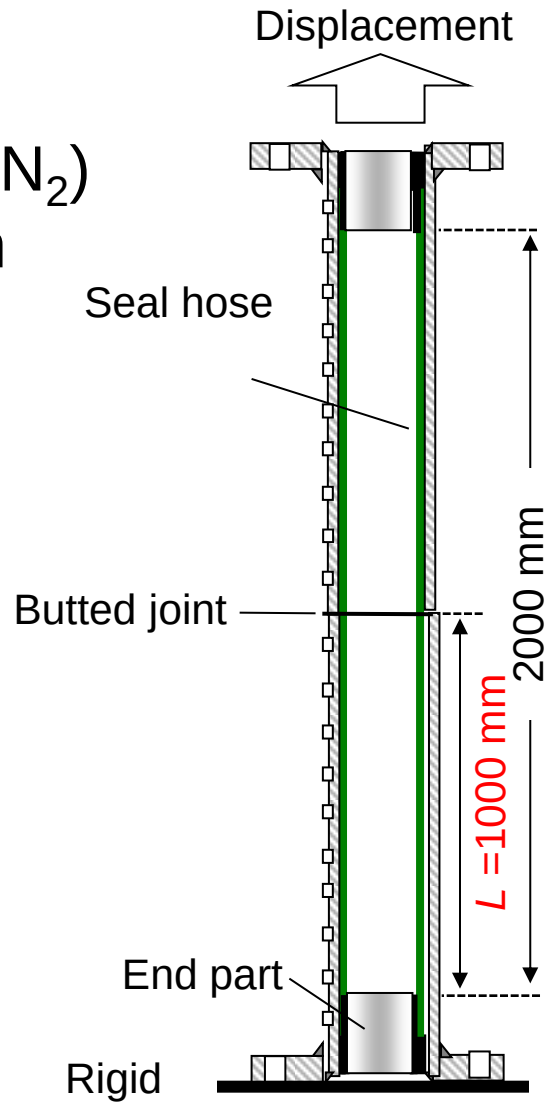
U: twice the value of u

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

3. The validity of existing method

- Full-scale tensile tests

Number of test specimen :3
Inner pressure :0.3MPa (N_2)
Pipe Diameter :165.2mm
Distance *L* :1000mm

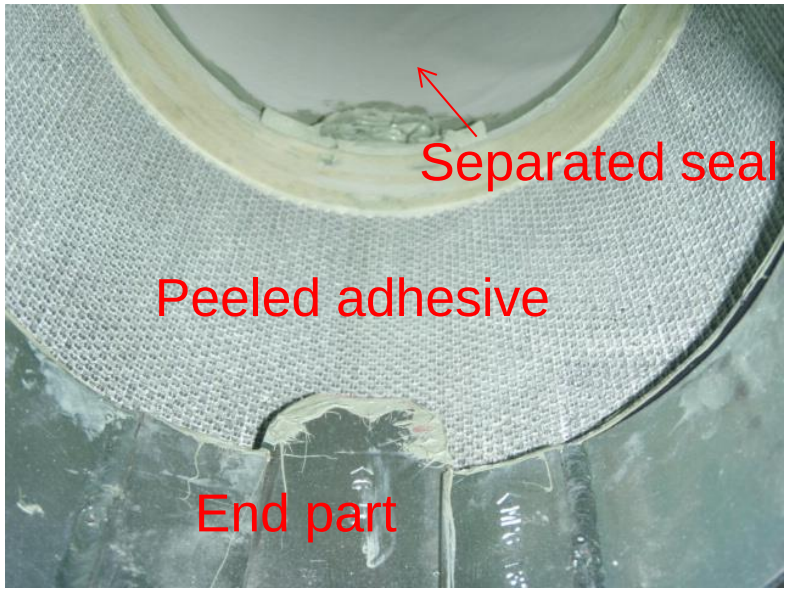


3. The validity of existing method

Test results

Test No.	Leakage mode	Joint expansion at leakage(mm)
1	B (Separation from end part)	213.8
2	B (Separation from end part)	215.8
3	B (Separation from end part)	209.3

Peeling of seal hose



Separation of seal hose from end part

3. The validity of existing method

Test results

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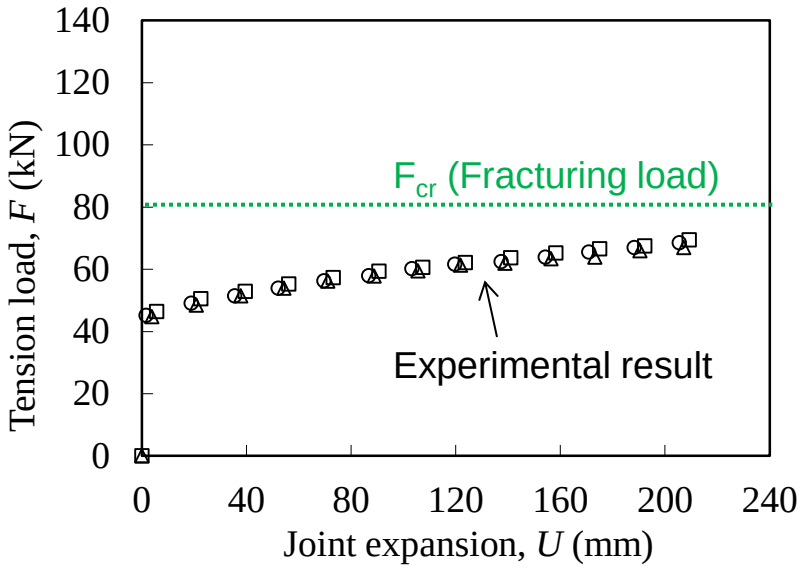
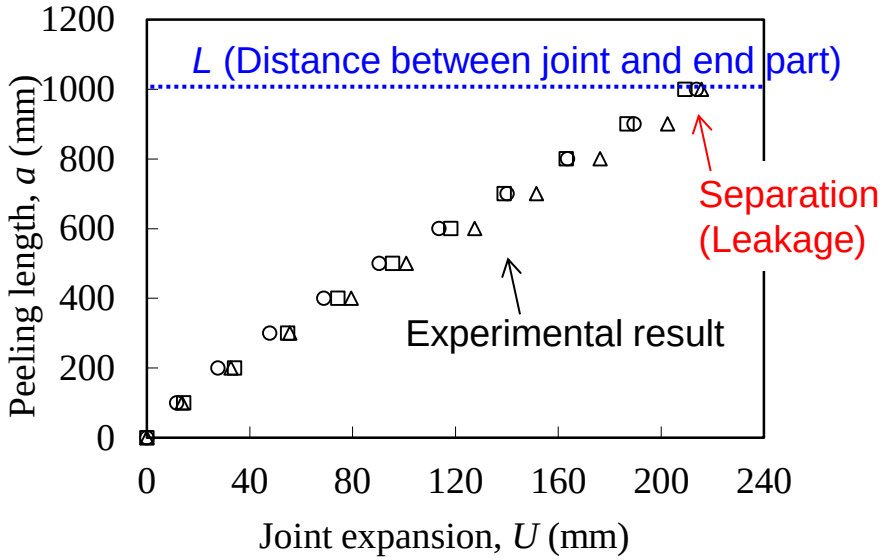


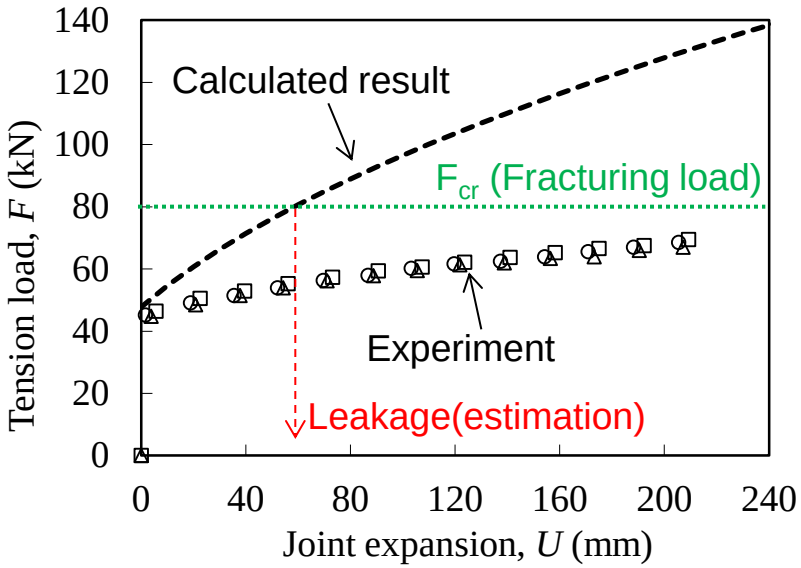
Mode A : F_{cr} vs F



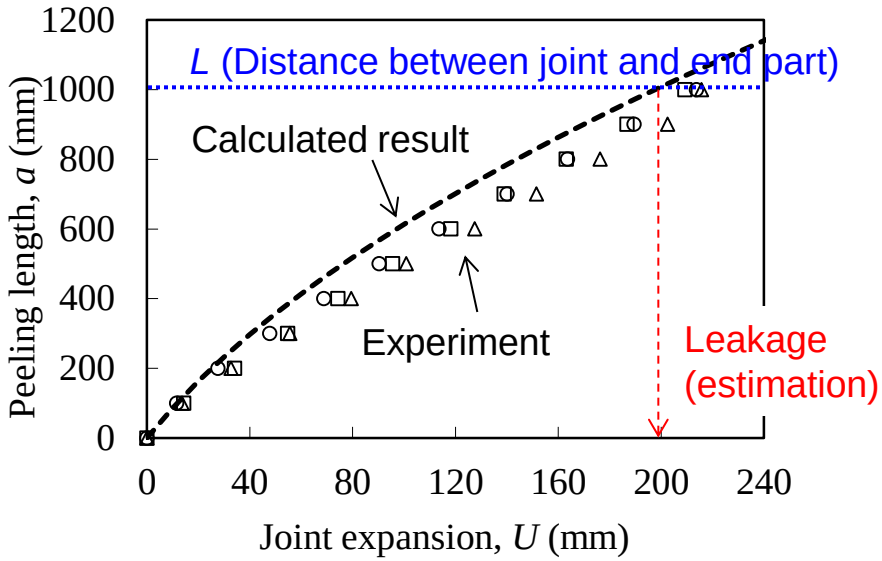
Mode B : L vs a

3. The validity of existing method

Estimation of leakage limit by existing method



Mode A : F_{cr} vs F



Mode B : L vs a

	Leakage mode	Joint expansion at leakage (mm)
Test No.1~3	B (Separation from end part)	209.3~215.8
Existing method	A (Fracturing of seal hose)	58.6

The existing method was insufficient to evaluate the leakage limit of the hose-lined pipe.

4. The new evaluation method for lined pipe

- It is considered that the tension load was overestimated due to the following factors

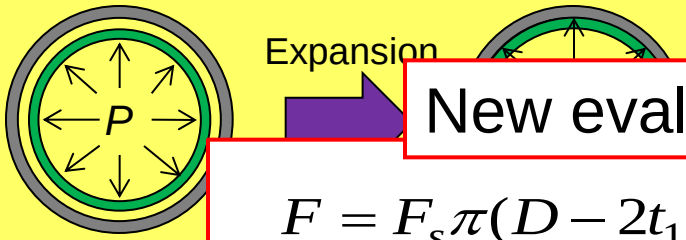
A) Decreasing of pressure acting on the peeling boundary

B) Decreasing of Cross-sectional area of the seal hose

C) Influence of specimen size on axial Young's modulus *E*

D) Influence of vertical pressure on dynamic friction coefficient μ

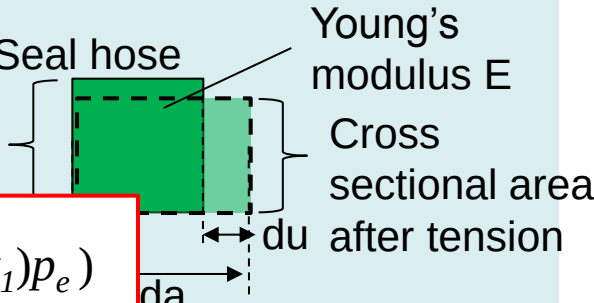
A) Decreasing of pressure acting on the peeling boundary



$p_e = p -$

p_e :the actu

B) Decreasing of Cross-sectional area of the seal hose



$\frac{1}{du/da}\frac{du}{da}$

t $a = 0, u = 0$

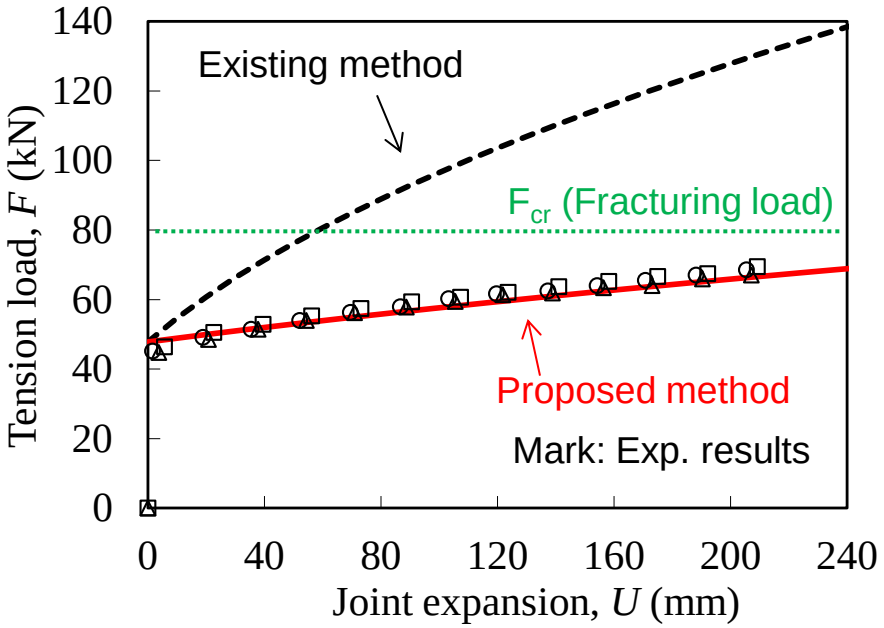
New evaluation formula

$$F = F_s\pi(D-2t_1) + P\mu a \quad (P : p(D\text{-}2t_1)p_e)$$

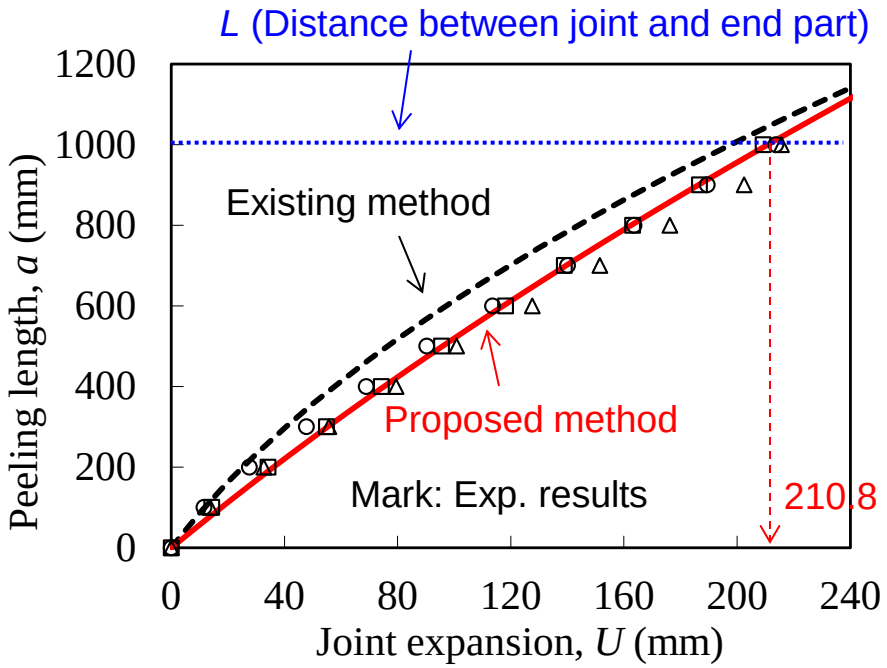
$$U = \frac{2EA_0}{P\mu}\ln\left(\frac{EA_0 - F_s\pi(D-2t_1)}{EA_0 - F_s\pi(D-2t_1) - P\mu a}\right) - 2a$$

4. The new evaluation method for lined pipe

The validity of proposed method



Mode A : F_{cr} vs F



Mode B : L vs a

	Leakage mode	Joint expansion at leakage (mm)
Test No.1~3	B (Separation from end part)	209.3~215.8
Proposed method	B (Separation from end part)	210.8

Conclusion remarks

- A new evaluation method for the leakage limit (fracture of seal hose, separation of seal hose from the end part) of a hose-lined pipe was established.
- The validity of the proposed method was demonstrated by full-scale tensile tests of hose-lined pipe.

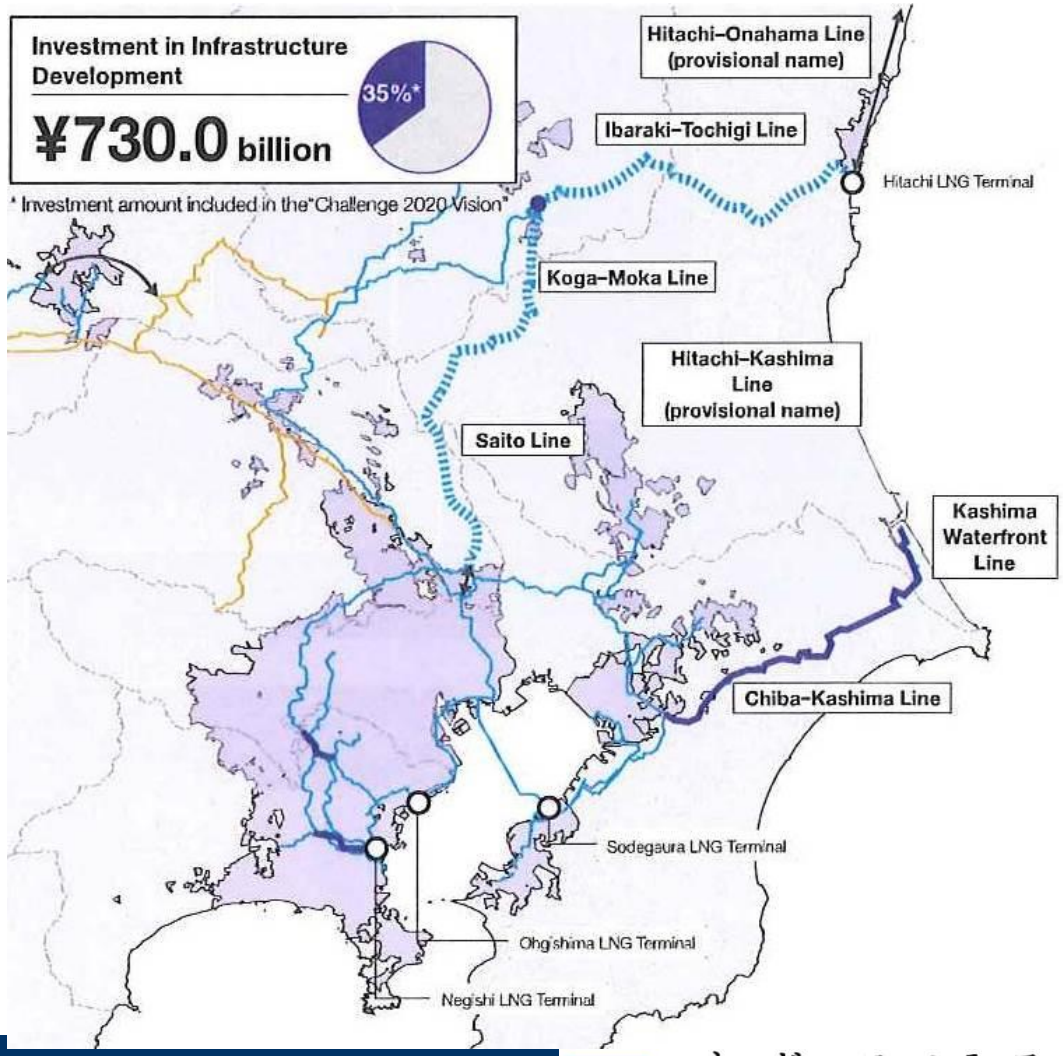
Thank you for your kind attention.

Follwing, reference page

Background

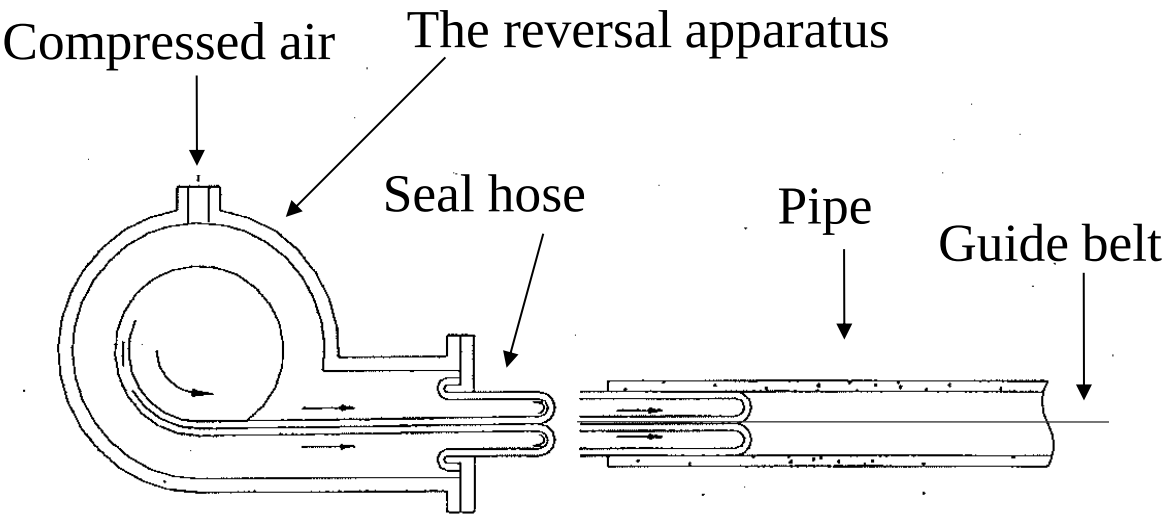
Pipeline network in Tokyo Gas

Entire Length : about 54000km
Steel pipe : 24000km
High pressure line : 800km
Middle pressure line : 23400km



Hose lining method

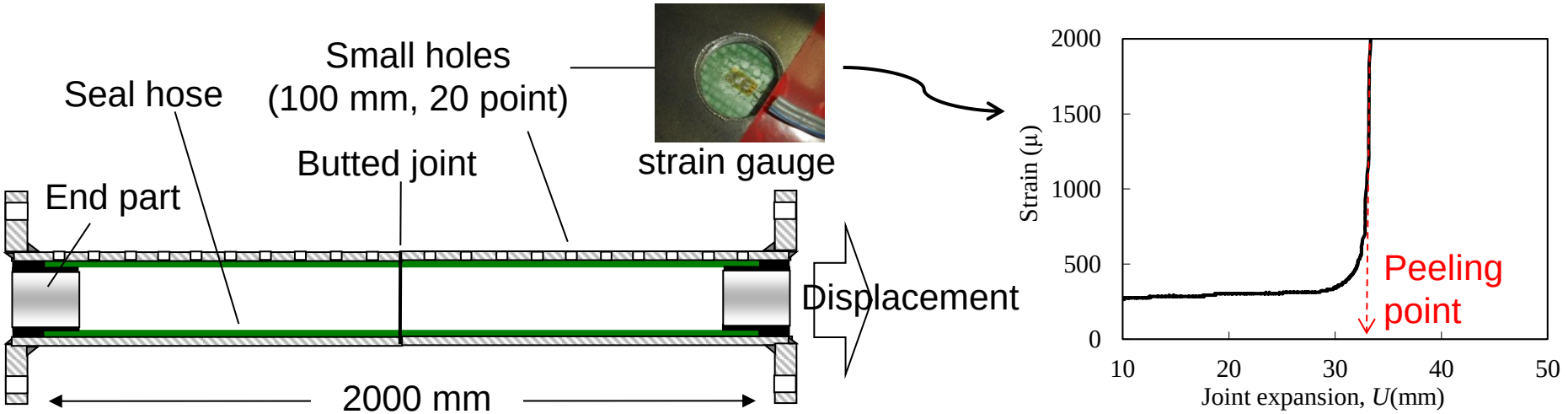
- Seal hose is inserted into the in-ground pipe, air pressure is used to inflate or draw out the hose down the length of the pipe, with simultaneous inversion.
- A guide belt contained within the hose helps to control the reversal as well as the speed of the continuous process.
- The reversal of the seal hose is performed in a manner similar to turning socks inside out.



3. Full-scale tensile tests of the hose-lined pipe

Experimental condition

Number of test specimen : 3
Inner pressure : 0.3MPa (N_2)
Displacement rate : 10mm/min
Measurement : applied load, joint expansion, strain



4. The new evaluation method for lined pipe

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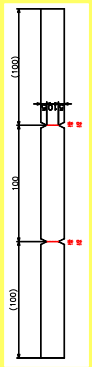
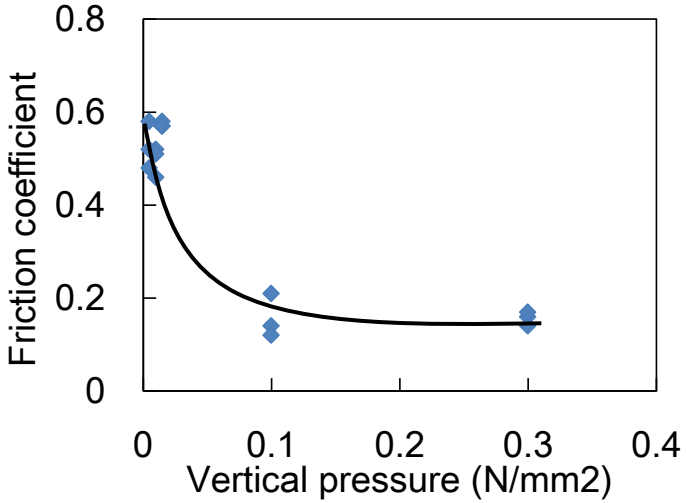
A) Decreasing of pressure acting on the peeling boundary
B) Decreasing of Cross-sectional area of the seal hose
C) Influence of specimen size on axial Young's modulus *E*
D) Influence of vertical pressure on dynamic friction coefficient μ

C) Influence of specimen size on axial Young's modulus *E*



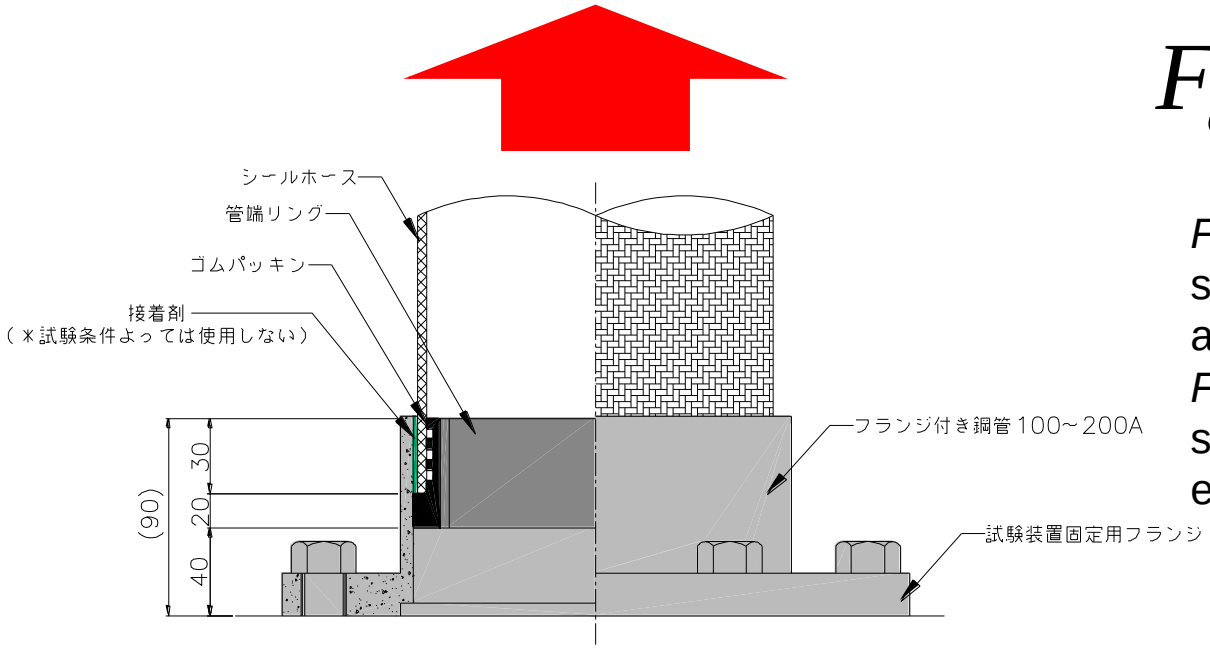
Test No.	1	2	3	Ave.
Specimen tests	1023	1073	1051	1049
Full-size tests	717	658	825	733

D) Influence of vertical pressure on dynamic friction coefficient μ



Strength of the end part

■ Tensile test for the end part



$$F_{edge} = F_a + F_{ring}$$

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

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

5. Seismic performance of distribution pipeline with applied hose lining

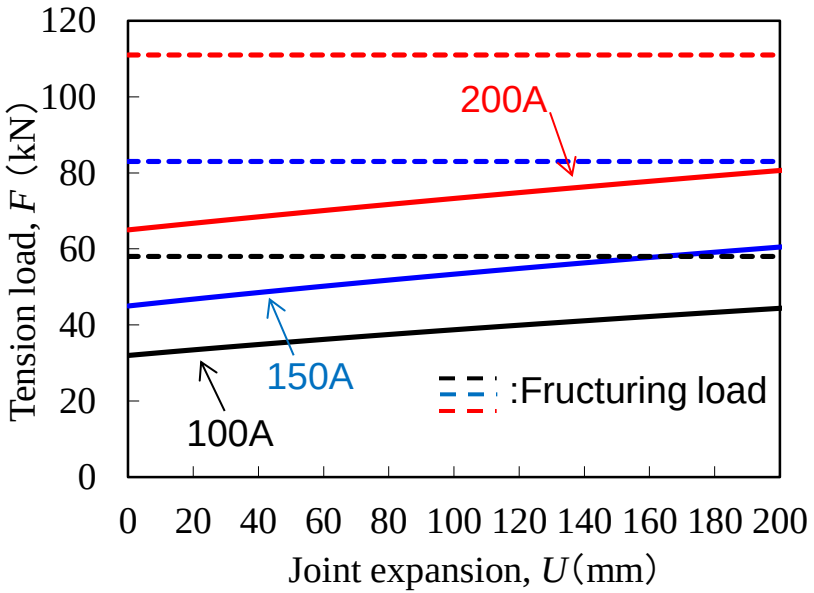
The evaluation for both mode A and B

It is necessary that the generated tension load dose not exceed the fracturing load

$$F_{cr} > F$$

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

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



The tension fracture does not generate when the ground displacement is assumed as 70mm .

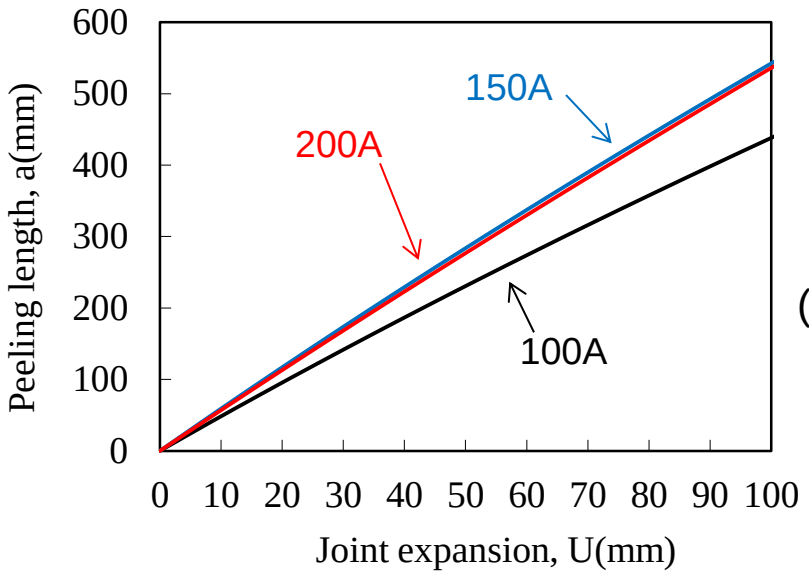
5. Seismic performance of distribution pipeline with applied hose lining

■ The separation of the seal hose from the end part (Mode B)

The leakage by separating of the seal hose from the end part would not occur, if the peeling of the seal hose does not reach the end parts.

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

$$L > a$$



L:the distance between the end part and the adjacent joint

Requirement *L*
(when the ground displacement is assumed as 70mm)

Pipe Diameter	100A	150A	200A
Requirement *L*	320	400	400