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Investigation of Cracks Found in the Circumferential Direction on Jacking Pipes

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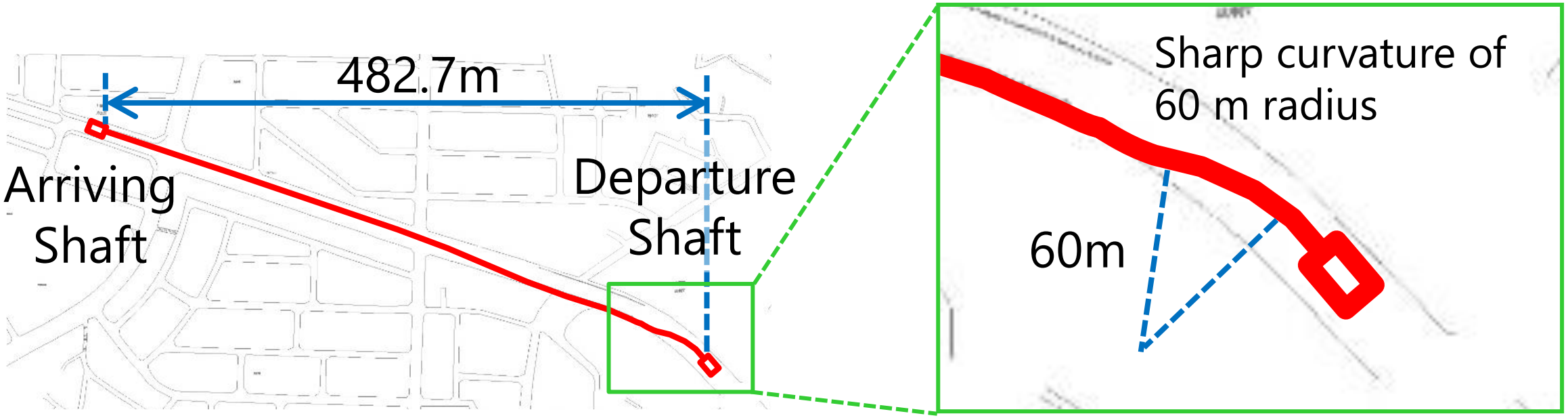
TOPICS

1. Project Overview
2. Trouble Overview
3. Investigation of Cracks on Jacking Pipes in This Project
4. Future Subject
5. Conclusion

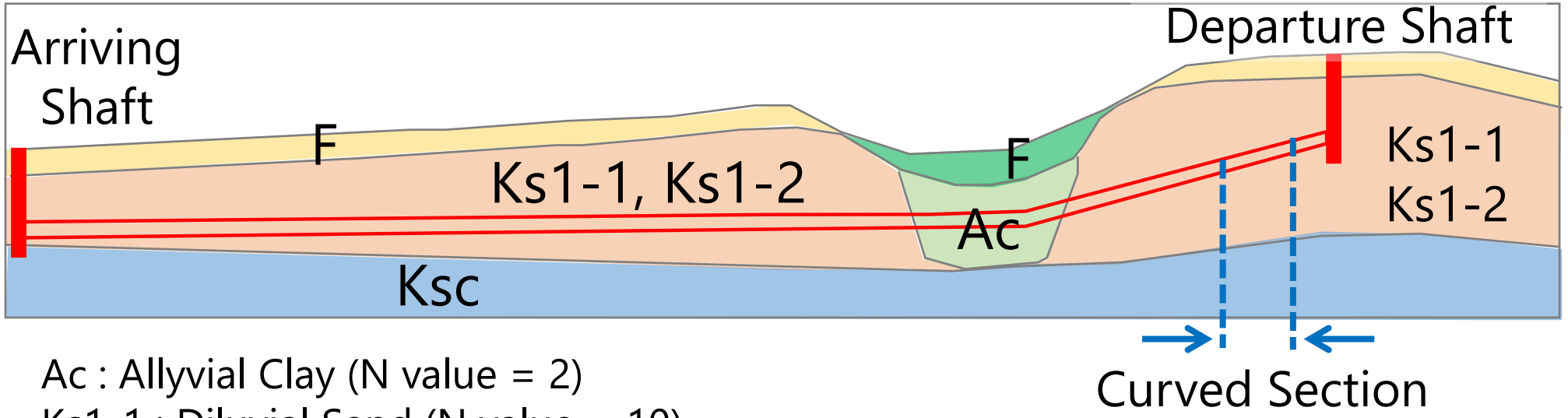
1. PROJECT OVERVIEW

- Construction project by pipejacking method for electric power cable accommodation
- Tunnel lengths was 482.7 m including sharp curvature of 60 m radius
- Inner diameter of the pipes was 900 mm



1. PROJECT OVERVIEW

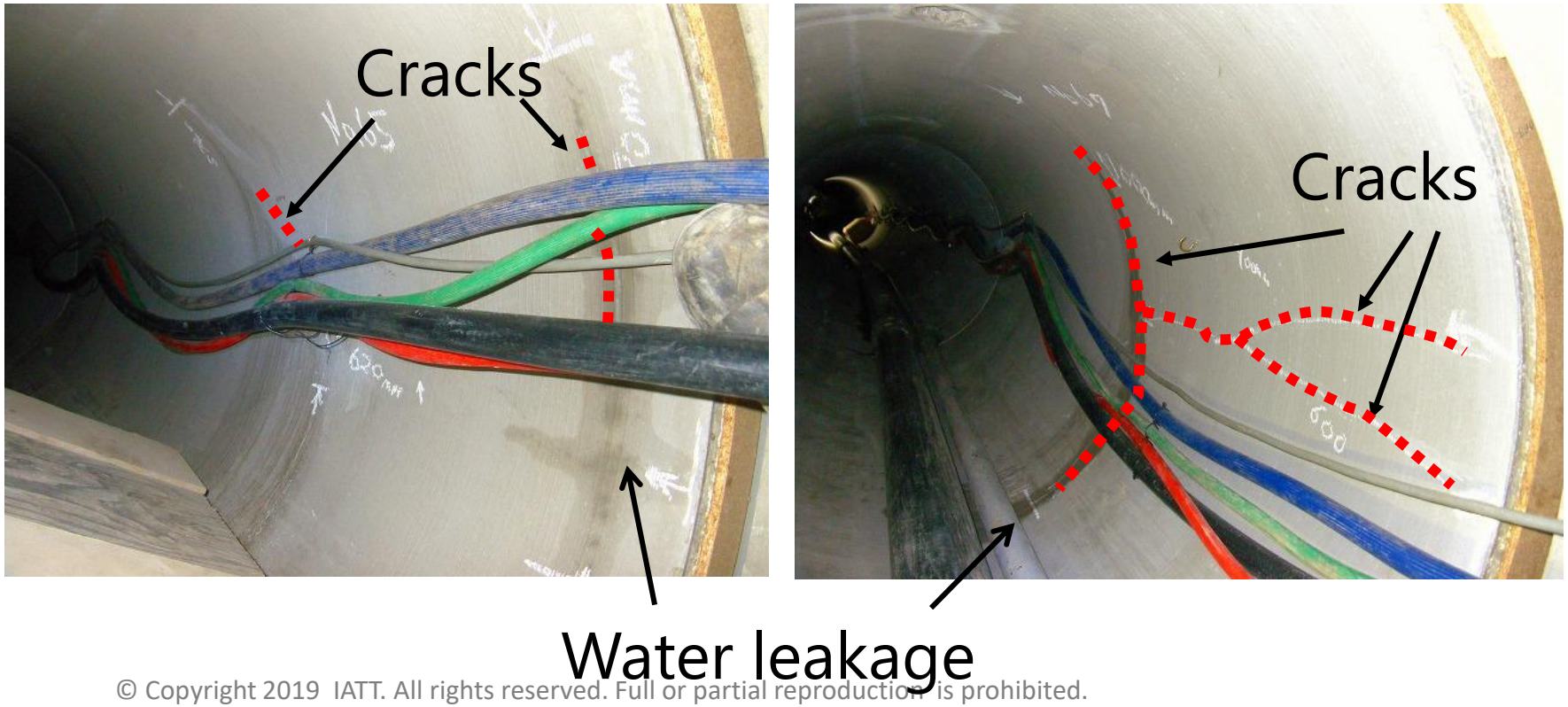
- The tunnel was mainly buried in diluvial sand including curved section
- Ground cover was between 4.2 m to 10.2 m
- All pipes were standard pipes including curved section (pipe length = 2.43 m)



Ac : Allyvial Clay (N value = 2)
Ks1-1 : Diluvial Sand (N value = 10)
Ks1-2 : Diluvial Sand (N value = 30)

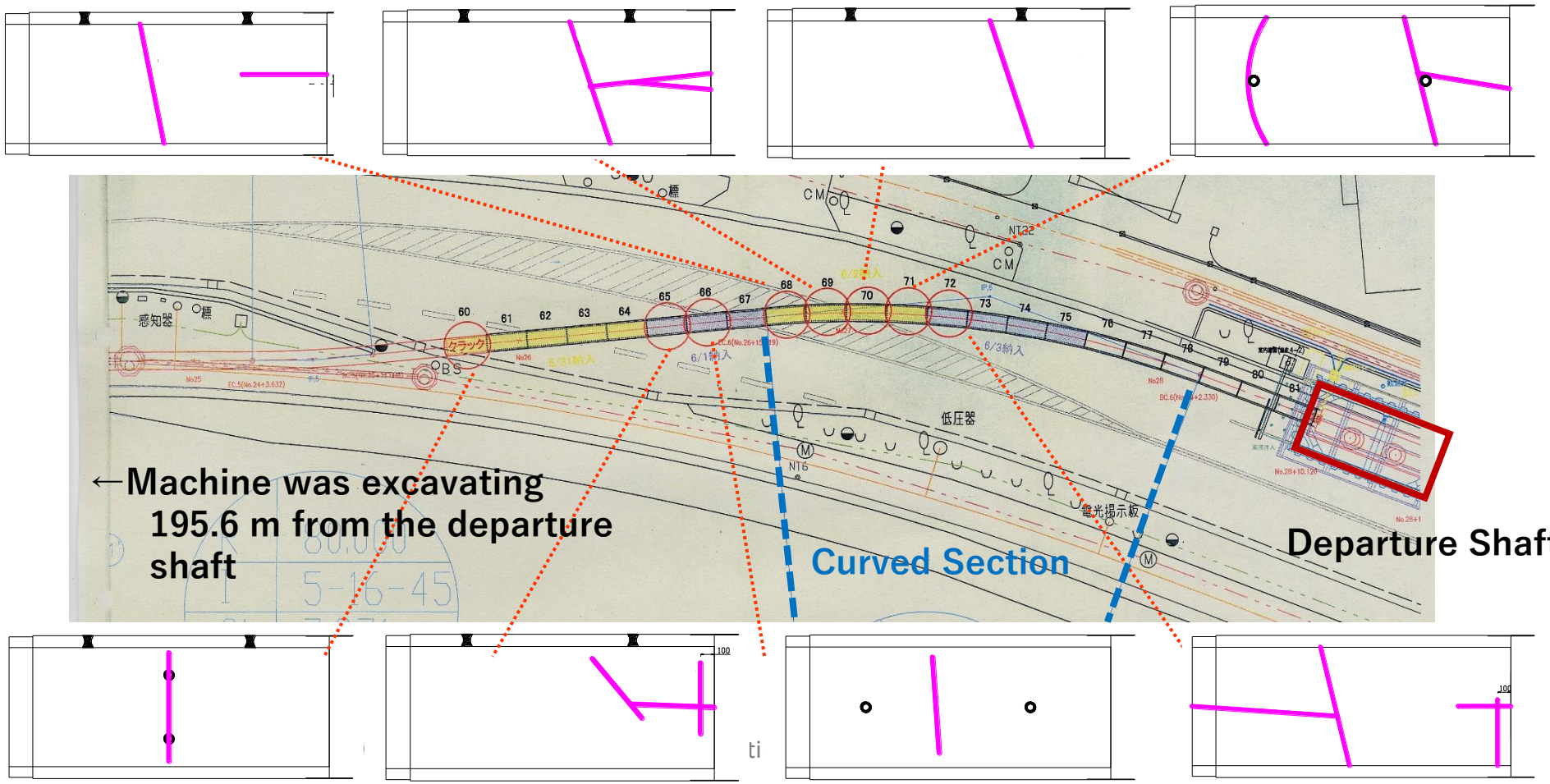
2. TROUBLE OVERVIEW

Cracks involved water leakage were found in a total of 8 pipes around curves section when drilling 195.6 m from the departure shaft.



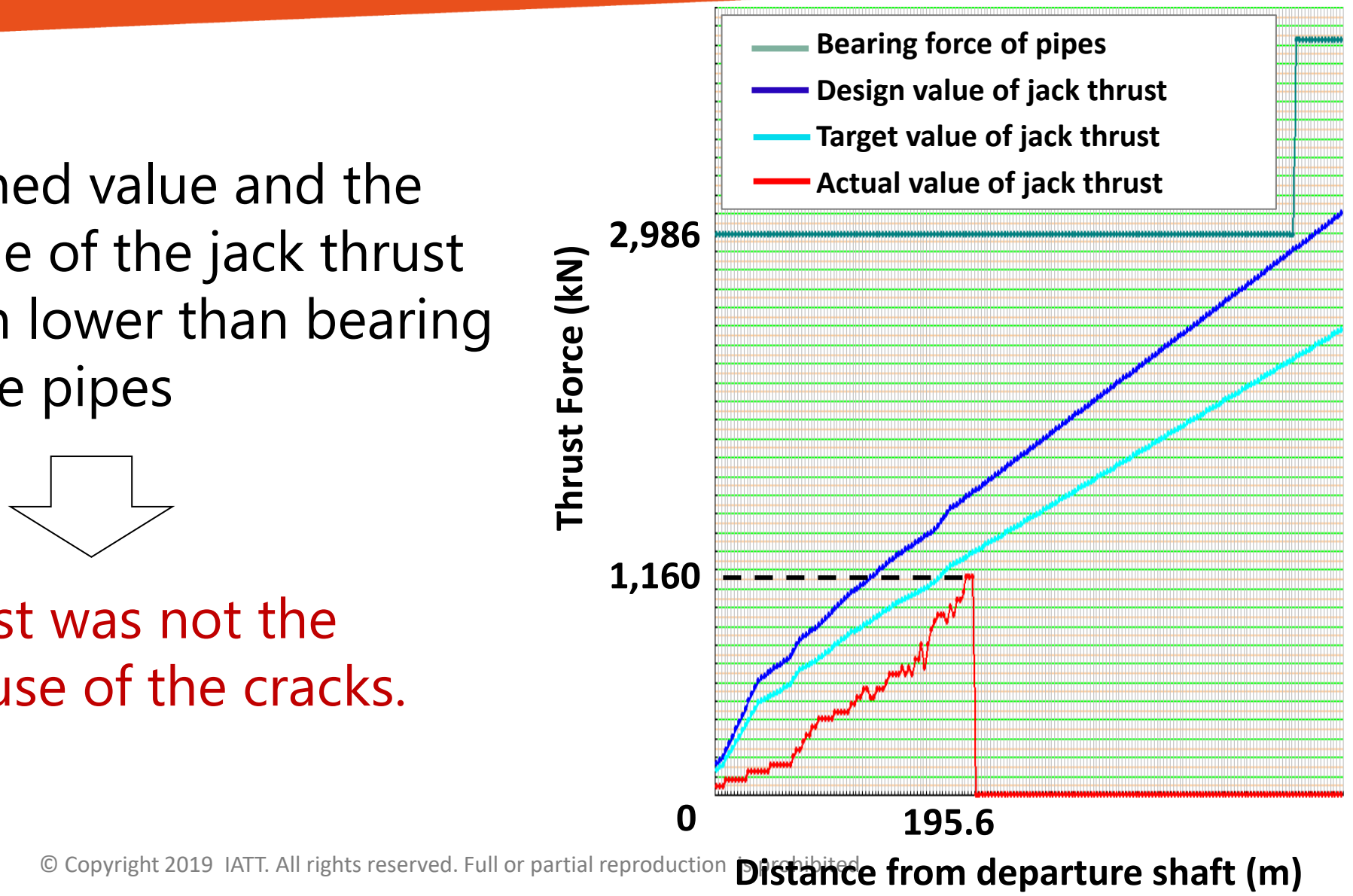
2. TROUBLE OVERVIEW

Cracks were mostly found in circumferential direction, external side of curve, around curved section.



2. TROUBLE OVERVIEW

The designed value and the actual value of the jack thrust were much lower than bearing force of the pipes

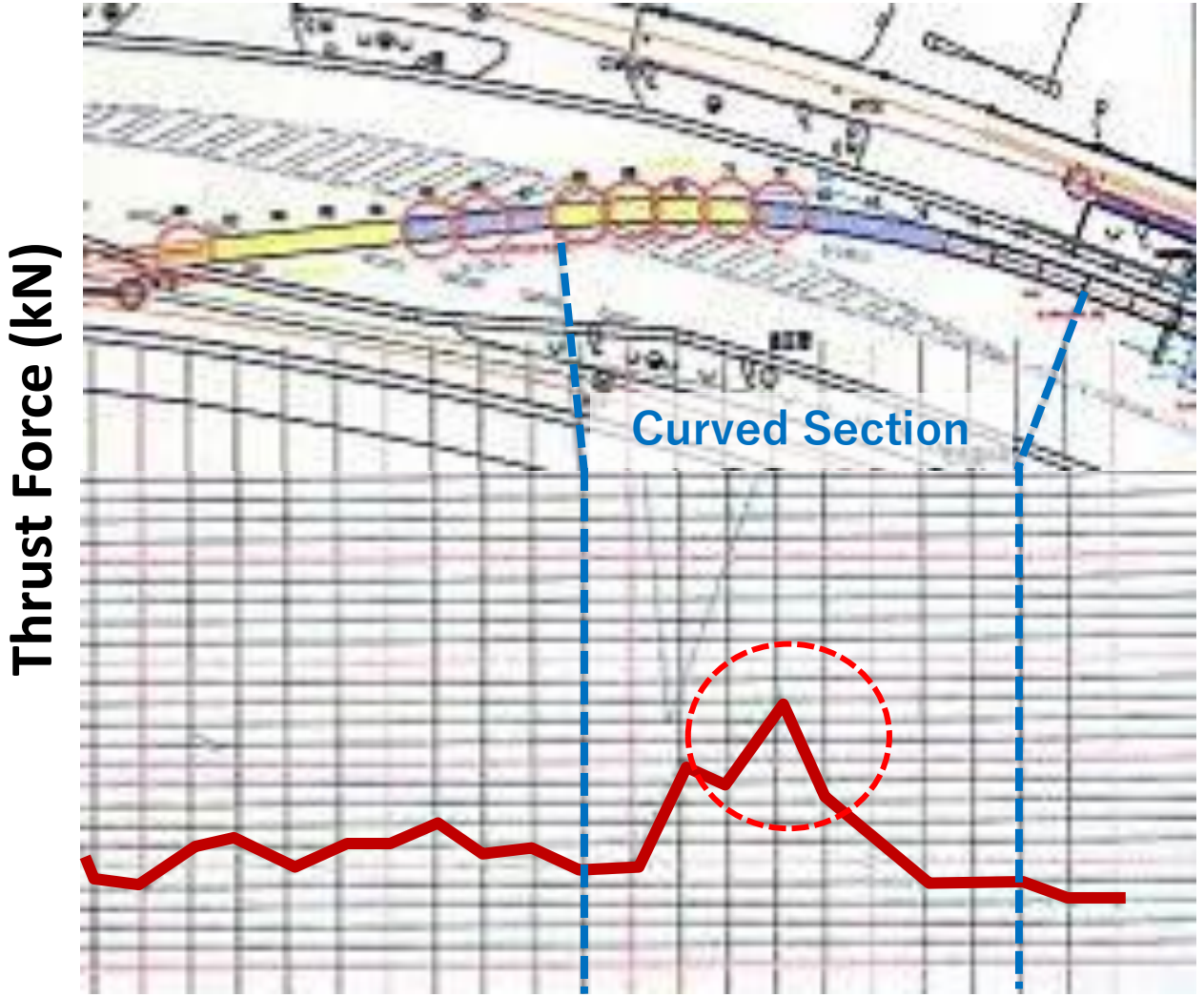


Jack thrust was not the direct cause of the cracks.

2. TROUBLE OVERVIEW

The torque value went up for a temporary period of time when the pipejacking machine was drilling through the curved section.

The ground might have been harder soil than predicted



Torque value of the pipejacking machine

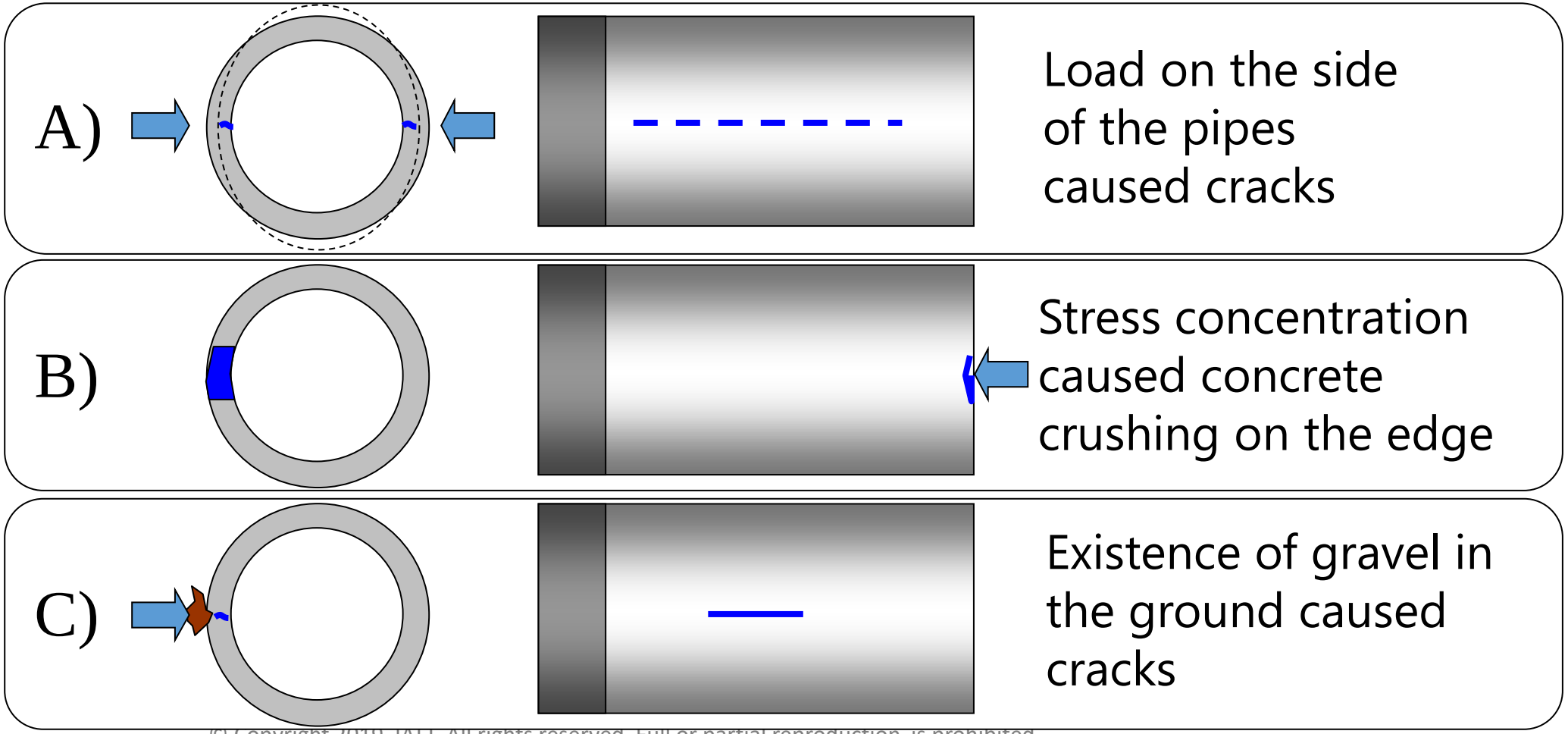
3. INVESTIGATION OF CRACKS ON JACKING PIPES IN THIS PROJECT

In order to investigate the causes of these cracks, the following procedure was taken:

1. Find similar cases in the past
2. Clarify the characteristics of these projects
3. Interview the pipe manufacturers and contractors
4. List up the possible causes of cracks
5. Narrow down the causes of cracks by testings
6. Determine the cause of cracks

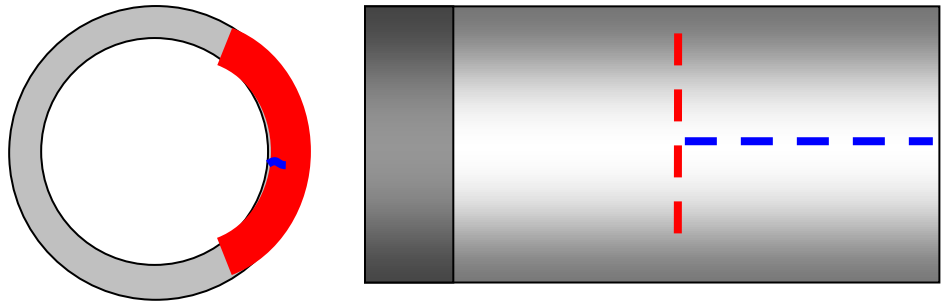
3-1. FIND SIMILAR CASES IN THE PAST

Common reasons of cracks during construction

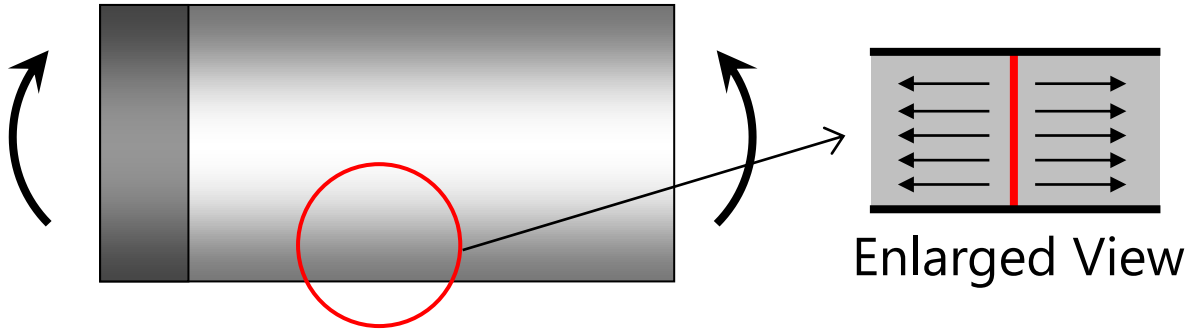


3-2. CLARIFY THE CHARACTERISTICS OF THESE PROJECTS

Assumed reasons of cracks for this project



Cracks in the longitudinal direction were assumed to occur by the reason A.
Cracks in the circumferential direction were assumed to occur by the different reasons.



From the standpoint of crack appearance, tensile stress due to bending was seemed to be the cause of cracks.

3-3. INTERVIEW THE PIPE MANUFACTURES AND CONTRACTORS

From the contractors

- Cracks in circumferential direction were rarely found in the past, but the causes were still dissolved.
- Experientially, half-length pipes are recommended when constructing tunnels including sharp curvature in order not to produce too much stress on the pipes. Basically, half-length pipes were recommended in the case of sharp curvature which radius was less than 75 to 80 times inner diameter.

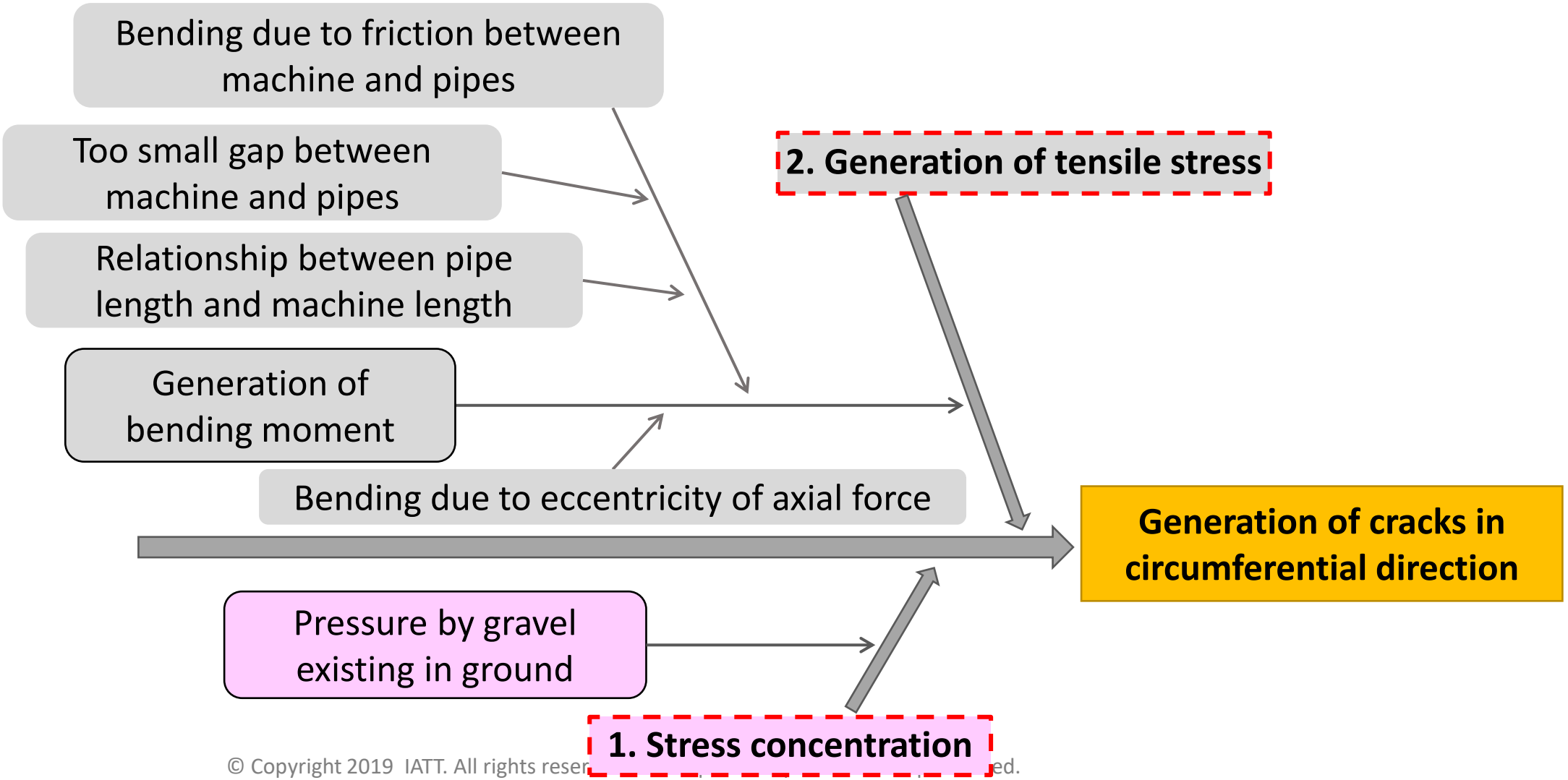
3-3. INTERVIEW THE PIPE MANUFACTURES AND CONTRACTORS

From the pipe manufacturers

- Cracks in circumferential direction had never occurred in the past when using standard pipes.
- However, when using large pipes which inner diameter was 4 m, the circumferential cracks occurred due to too much bending moment.

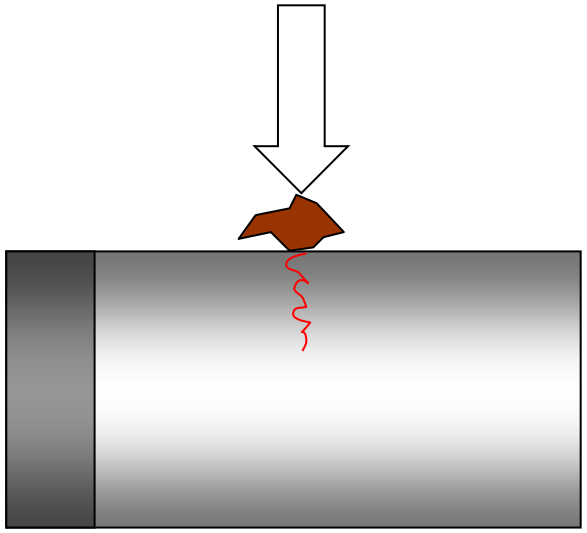
Both did not provide direct information for analyzing factor of circumferential cracks.

3-4. LIST UP THE POSSIBLE CAUSES OF CRACKS



3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

Possibility of stress concentration



Stress concentration

due to existence of gravel

From surplus soil, it was confirmed that gravel was included in the ground.

However, this was not be an option any more by the reasons described as follows:

1. No cracks occurred between the cracks and the jacking machine.

2. No cracks occurred after use of half-length pipe as a countermeasure of cracks.

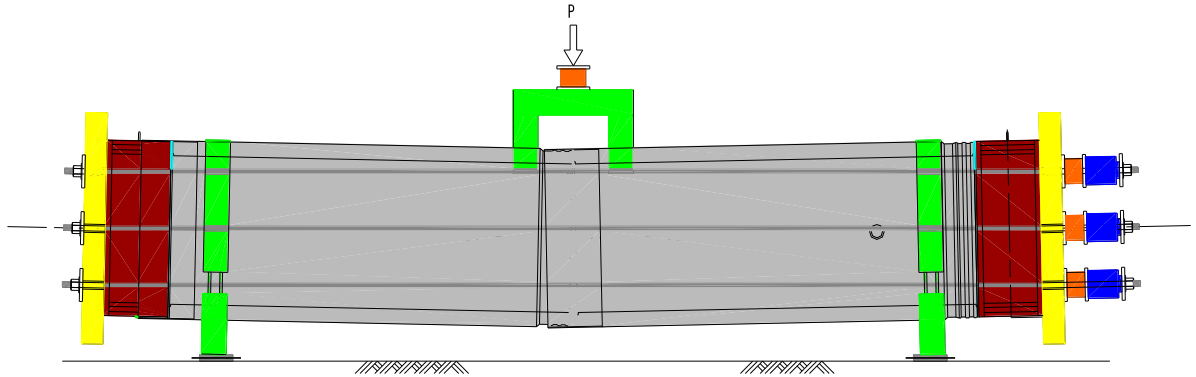
3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

Possibility of tensile stress due to earth pressure

In order to obtain cracking moment and cracking load of actual pipes, a full-scale-model experiment was conducted using the same pipe as used at the site.

In addition to obtain cracking moment, rotational spring stiffness of the joints was also measured in the experiments so as to utilize in numerical analysis.

Experiments to obtain cracking load and moment

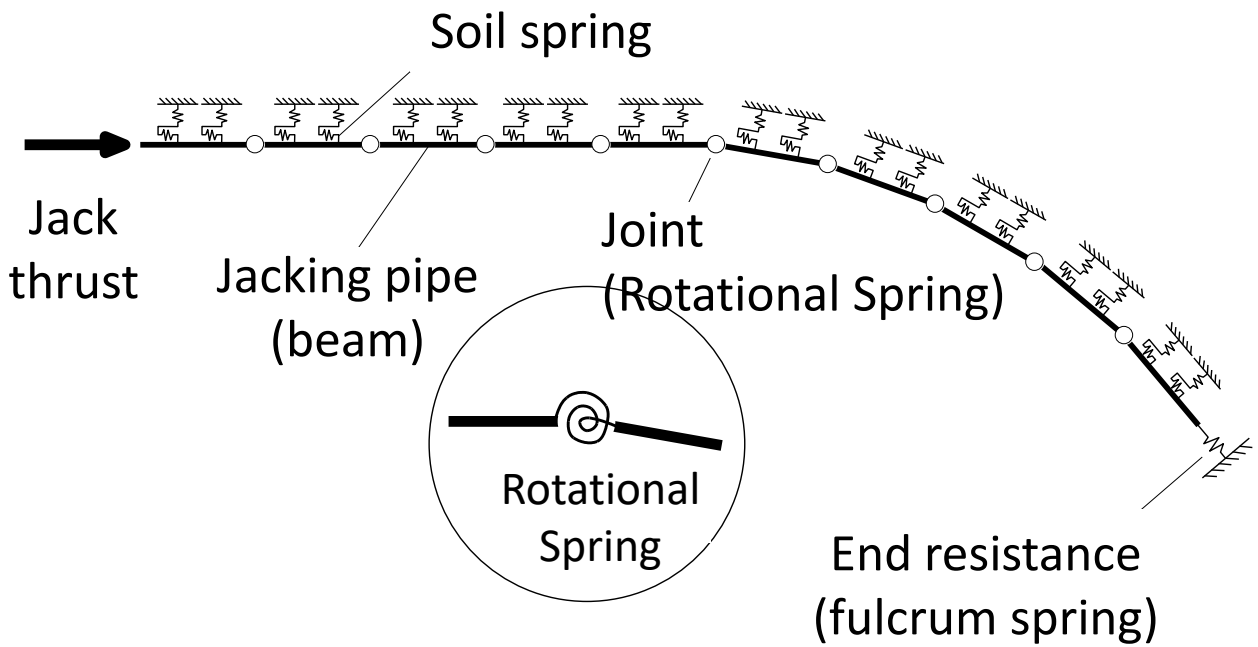


Experiments to obtain rotational spring stiffness

3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

Possibility of tensile stress due to earth pressure

From the data obtained by the experiments, numerical analysis using beam-spring model was conducted in order to presume the actual load that was applying to the pipes.

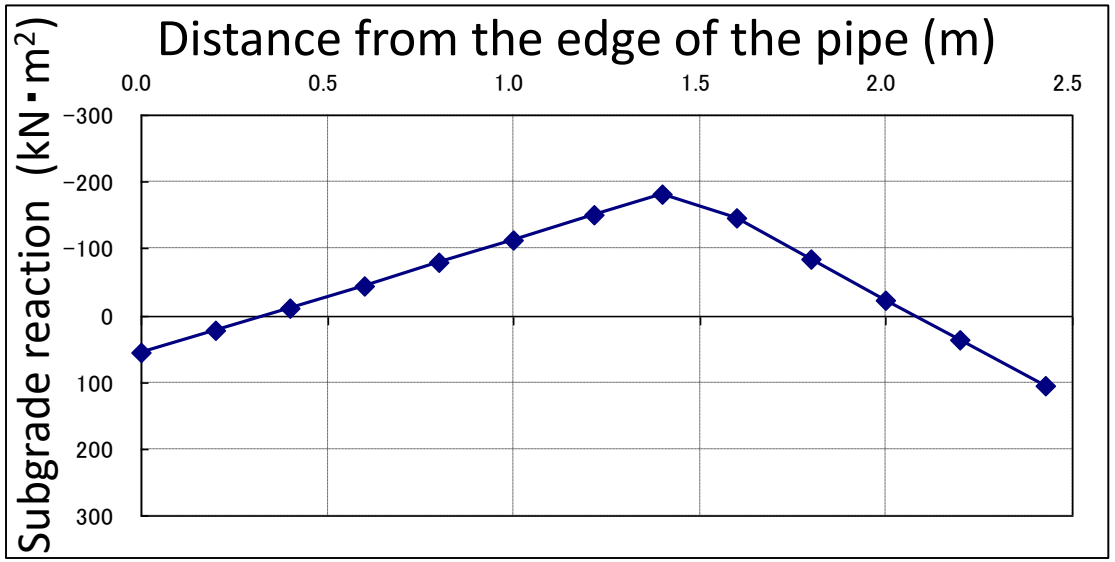


Beam-Spring Model

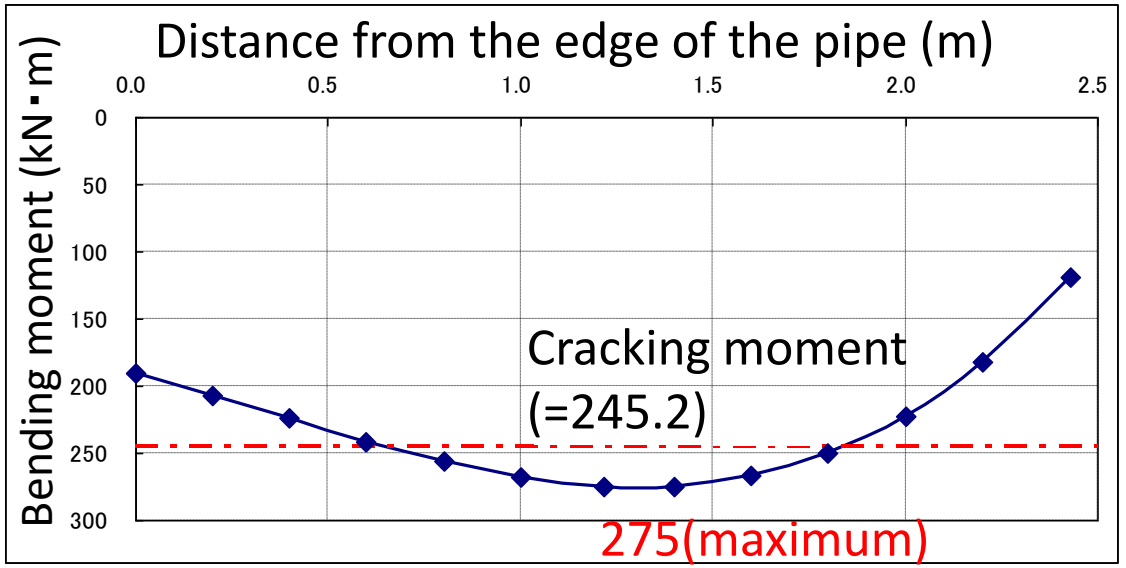
3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

The maximum bending moment was 275 kN・m in the middle of the jacking pipe.

It indicates that generated bending moment was larger than cracking moment of the pipe.

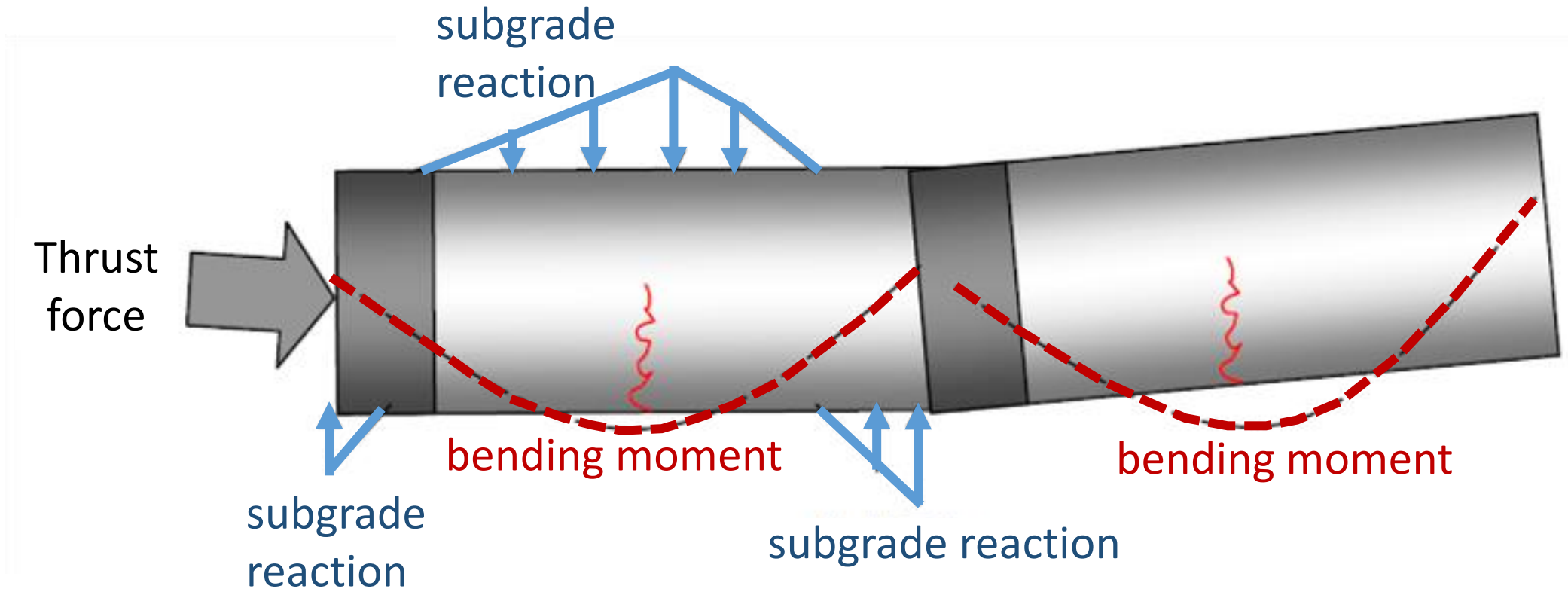


Distribution of subgrade reaction to the pipe in curved section



Bending moment acting on the pipe in curved section

3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS



The image how bending moment was generated by subgrade reaction

3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

The maximum bending moment (=275 kN・m, by numerical analysis) was larger than cracking moment (=245.2 kN・m, by full-scale-model experiments), but the actual cracks differ to the axial force.

The stress on the pipe was calculated as below.

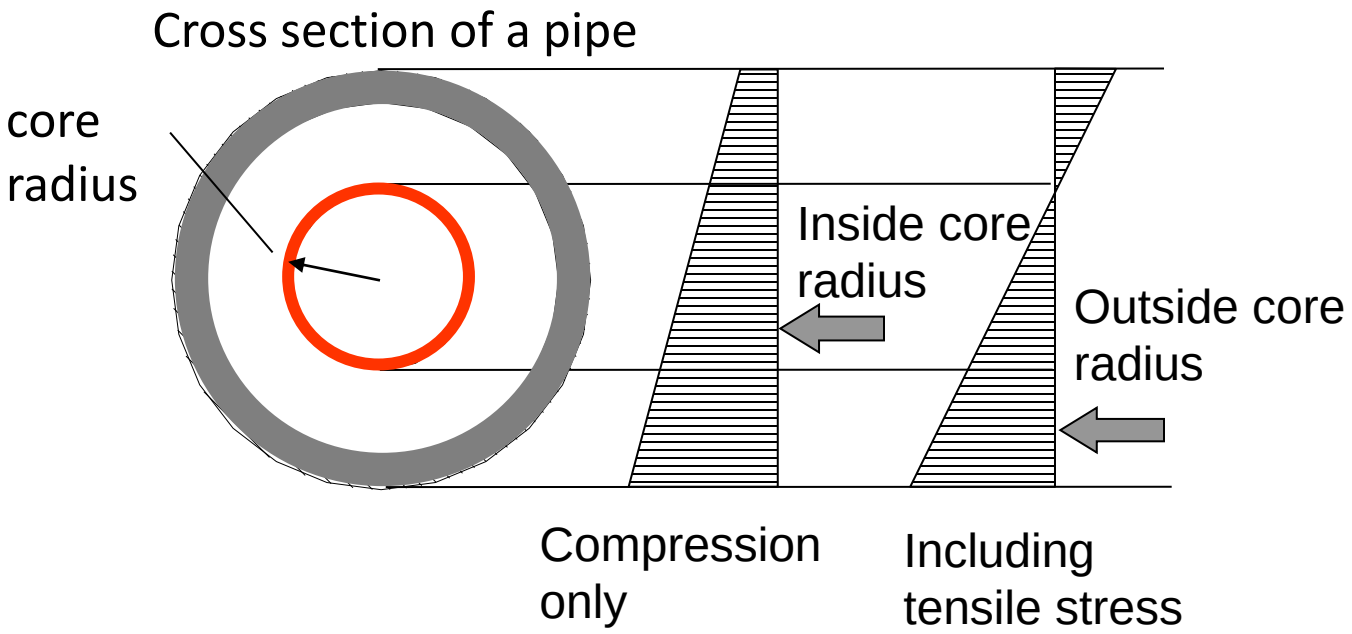
$$\sigma = -\frac{M}{I}y + \frac{P}{A} = -0.266[N/mm^2]$$ ＜ 5.24 (N/mm^2) Maximum tensile strength

M : Maximum bending moment (=275 kN・m)
P : Axial force (=1128kN)

Given that tensile strength was 5.24 N/mm^2 by the tests in average, the calculated tensile stress was lower than tensile strength as an effect of the compressive load.
Since tensile stress was lower than tensile strength, **cracking should not be occurred.**

3-5. NARROW DOWN THE CAUSES OF CRACKS BY TESTINGS

The possibility of generation of bending moment by the eccentricity of axial force during construction of sharp curvature was examined.



Generally, when axial force acts to the section with eccentricity, tensile stress may be generated.

Taking into account the eccentricity of axial force, the stress on the pipe can be calculated by the following equation.

$$\sigma = -\frac{M}{I}y - \frac{eP}{I} + \frac{P}{A} = -5.54[N/mm^2]$$ > 5.24 (N/mm²) Maximum tensile strength

3-5. DETERMINE THE CAUSES OF CRACKS

Cracks found in circumferential direction occurred due to generation of bending tensile stress.

The factors of bending moment are considered to be:

1. Subgrade reaction
2. Eccentric axial force

These 2 factors produced bending moment all together to the pipes.

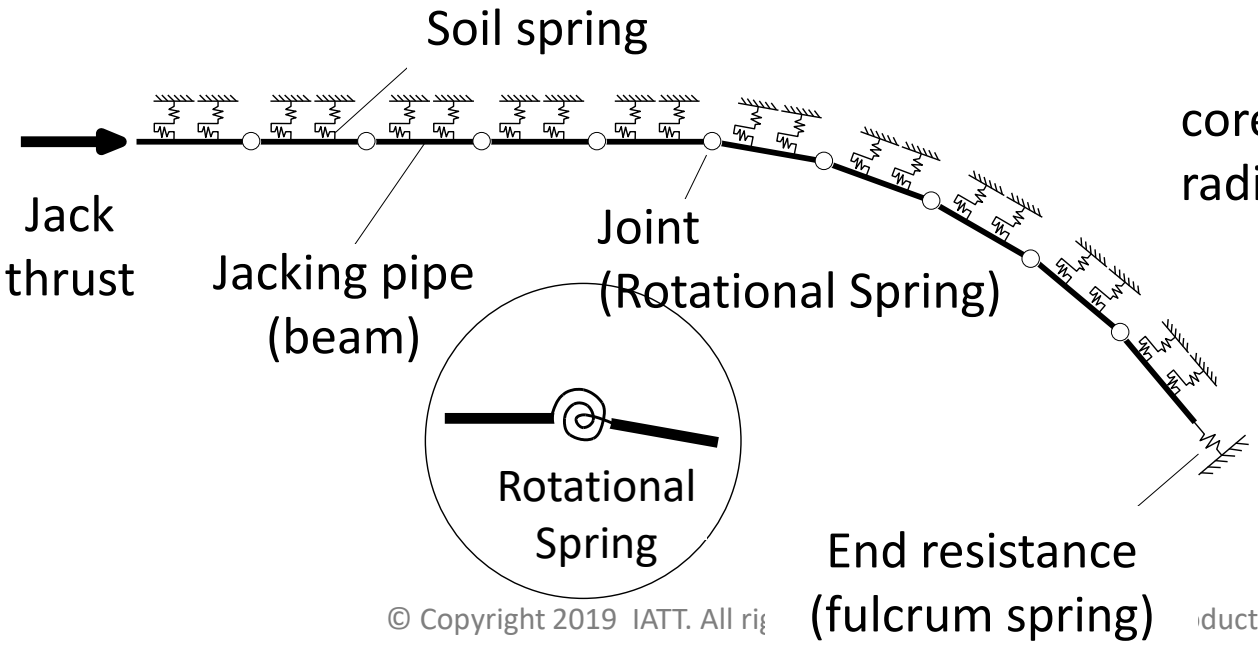
As a result, cracks in circumferential direction appeared on the pipes.

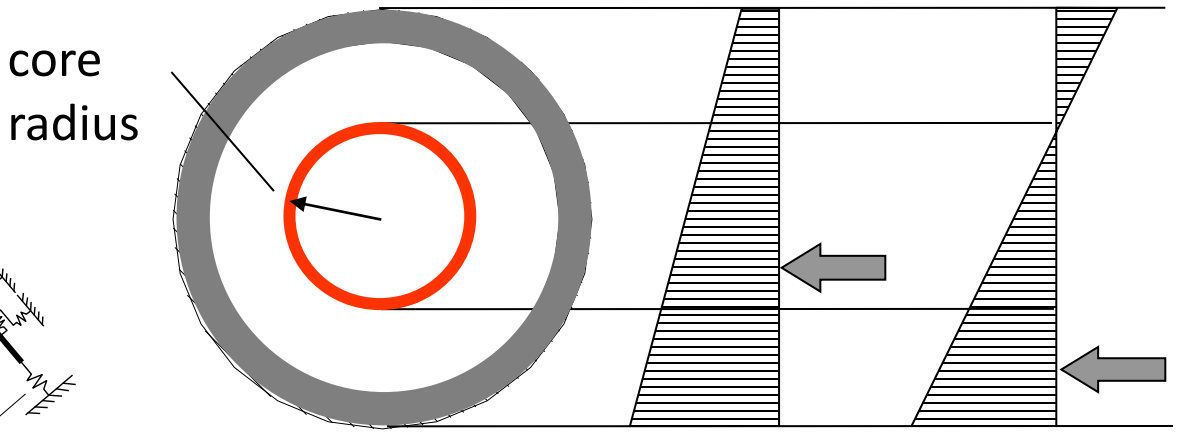
4. FUTURE SUBJECT

In order to avoid the same kind of trouble in the future, further study should be conducted as follows when using standard pipes in curved section:

1. Numerical analysis using beam spring model to calculate bending moment acting on pipes

1. Calculation of bending moment considering eccentricity of axial direction





5. CONCLUSION

- This report described the situation that cracks in circumferential direction occurred during construction of tunnel by pipejacking method.
- The investigation from various points of view has conducted and ended up that the direct cause of cracks was generation of bending tensile stress.
- Bending tensile stress was generated not only by the subgrade reaction, but also by the eccentric axial force.
- In order to avoid the same situation happening in the future, when constructing a tunnel including sharp curvature, numerical analysis and calculation considering eccentricity of axial direction should be conducted.