Study on Behavior of Ductile Iron Pipelines with Earthquake Resistant Joint Buried across a Fault

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Abstract. This study is focusing on behavior of ductile iron pipelines with the earthquake resistant joint buried across a fault being used widely for water pipelines in Japan. It is necessary to design a pipeline carefully in case of crossing a fault, because the partially large displacement occurs on the pipelines when a fault moves by an earthquake. However, there are few studies on behavior of ductile iron pipelines.

We analyzed the behavior of pipelines near a fault by large displacement analysis method, and we confirmed that the earthquake resistant joint nearest to a fault began to move when a fault began to move, then the joints next in line began to move when the joints movement reached their capacity.

In this study, we investigated the behavior of ductile iron pipeline installed into a sand container which moved like a fault for verification of pipeline behavior analysis. As a result, we confirmed that pipeline showed the behavior like the analysis result and we verified the validity.

Keywords. ductile iron pipe, earthquake, earthquake resistant joint, fault, pipeline behavior

1. Introduction

In a fault caused by inland earthquake, the magnitude of slippage may be as much as several meters, and structures existing near ground surface may suffer a great deal of localized damage, if a large crack appears near the ground surface. Because of this possibility, the pipelines across a fault must be designed carefully. However, very few researches study how ductile iron pipelines distributed across a fault behaves in response to fault movements; a design method has not been established.

This paper reports on these.

(1) Simulation analysis of behavior of ductile iron pipelines buried across a fault
(2) Verification of analysis results with experiment
(3) Assessment of the safety of pipeline

2. Simulation analysis of pipeline behavior

2.1 Analysis method

In displacement analysis for buried pipelines, a behavior analysis method is generally used in which pipes are expressed as beams laid on an elastic floor, and their joints and the interactions with the ground as springs (Fig.1). In the conventional method, the directions of springs that link pipe and ground are fixed. So, when the ground displacement in the fault reaches several meters, drastic errors in analysis may result. Therefore, in this study, we employed large-displacement analysis method which the directions of the springs can change depending on the movements of pipe and ground. The method used in this study is shown in Fig.2.

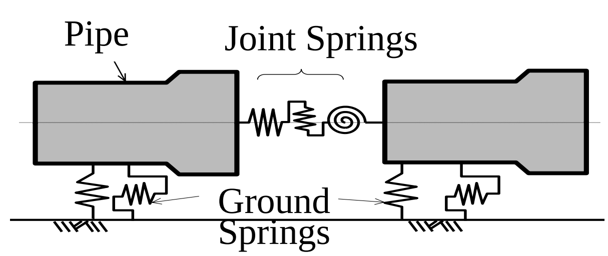


Fig. 1 Outline of analysis model

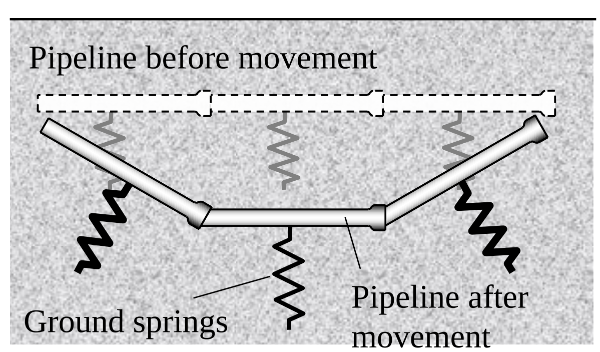


Fig. 2 Large-displacement analysis method

2.2 Analysis model

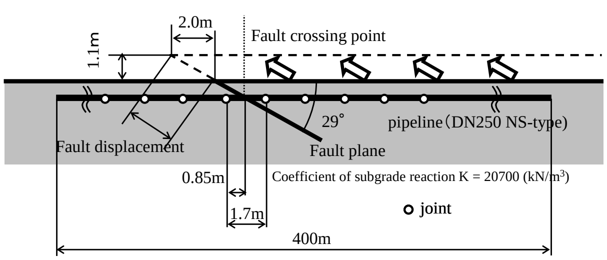
The analysis model is shown in Fig.3. A reverse fault model, in which horizontal displacement was 2.0 m, vertical displacement was 1.1m and inclination was 29 degrees, was set up with reference to the result of a survey by Kataoka et al. of the Nojima fault, which underwent in the Kobe Earthquake.

In this study, the length of each pipe was set at 1.7 meters, a value smaller than the regular pipe length 5m, so that the behavior of multiple pipes in this displacement range could be analyzed.

The pipeline was modeled as an assembly of beams connected with joint springs and ground springs. Considering the properties of the elements in this model, these springs were assumed to be non-linear springs.

The properties of the joint springs were determined based on results of experimental studies. For instance, the rotation spring of joint becomes resistant to further deflection when its deflection angle reaches 5.3 degrees, the limit value of deflection (Fig.4).

The ground spring property was based on friction between pipe and ground and the reactive force from the ground. For instance, the relationship between friction in a direction orthogonal to the axis and displacement in that direction were set up as bilinear relationships (Fig.5).



Fault type	Reverse fault
Amount of fault displacement	2.3m
Pipeline	DN250 NS-type ductile iron pipe
Pipeline length	400m
Burial depth	0.6m
Ground condition	Coefficient of subgrade reaction K=20700(kN/m3)

Fig. 3 Analysis model and conditions

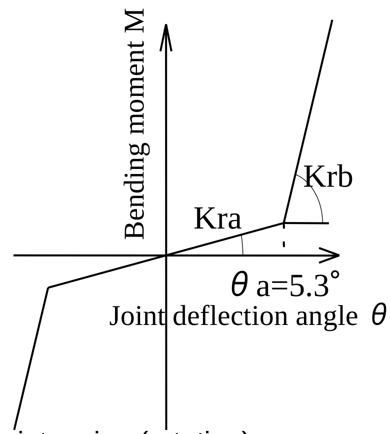


Fig. 4 Joint spring (rotation)

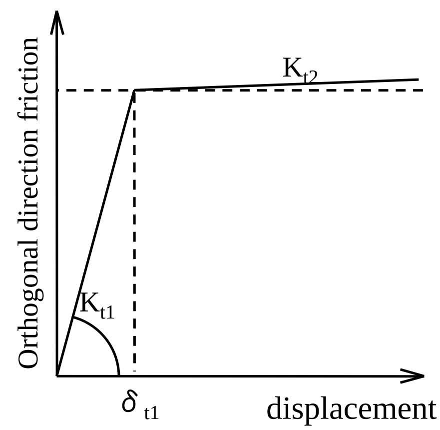
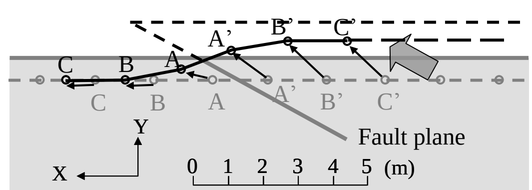


Fig. 5 Ground spring (orthogonal direction)

2.3 Analysis result

(1)Pipeline behavior

Results for analysis of pipeline behavior near the fault are shown in Fig.6. The pipeline could follow fault displacement because of deflections in the joints A, B, A' and B'. The displacement in the Y-direction at joints B' and C' was almost the same as the 1.1 m displacement of the ground, indicating that they moved together with the ground.



		Joint						Ground
		C	B	A	A'	B'	C'	
Displacement (m)	X	0.82	0.87	0.95	1.10	1.17	1.23	2.00
	Y	0.00	0.00	0.32	0.86	1.13	1.10	1.10

Fig. 6 Analysis result of pipeline behavior

(2)Joint contraction/expansion

Shown in Fig.7 is the analysis result for the contractions/expansions of the joints. Since the ground was displaced in such a way that the pipe had to contract in its axial direction, only contracting movements took place in the joints. In 37 joints centering on the fault, contraction was approximately 50 mm, the limit contraction value for each. The total contraction for the pipeline was 1.96 m, a value almost equal to the 2.0 m displacement of the ground in the axial direction, showing that the ground displacement was almost entirely absorbed by the joint contractions. The contractions of individual joints relative to the fault displacements (in the axial direction) are shown in Fig.8. Also shown is the movement of the pipe: when the fault displacement was still small, joint A, closest to the fault, contracted first. When the contraction in joint A reached its limit value, joint B began to contract; then, joint C, joint D and so on, one after another, following the movement of the joints closer to the fault.

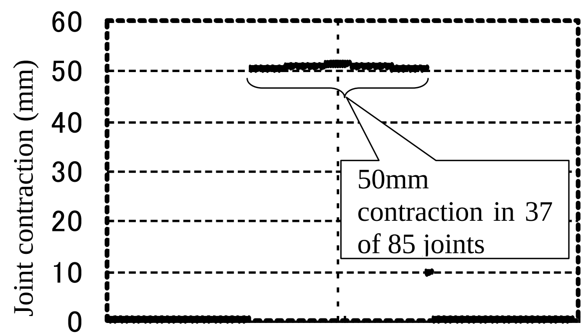


Fig. 7 Joint contraction

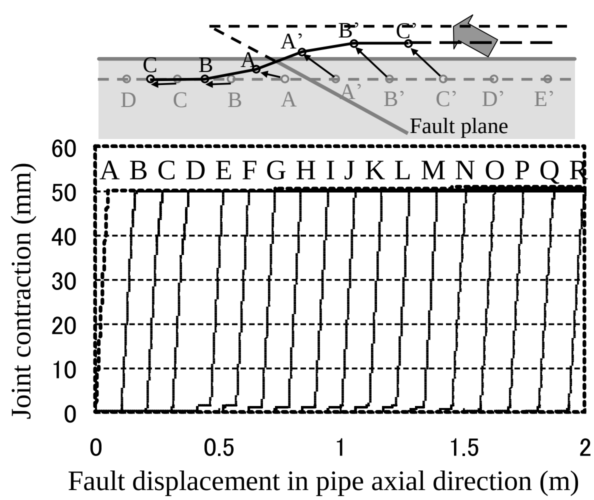


Fig. 8 Joint contraction

(3)Joint deflection angle

The results of joint deflection angle analysis are shown in Fig.9. Plus or minus sign in front of deflection angles on the Y-axis indicates the direction of deflection. This graph shows that deflections were generated in 4 joints straddling the fault. Shown in Fig.10 are the deflections angles in Joints A, B and C relative to fault displacement orthogonal to the pipeline axis. Deflection was also first generated in joint A, the closest joint to the fault, when the fault began to move. When this deflection reached its limit value, joint B began to be deflected.

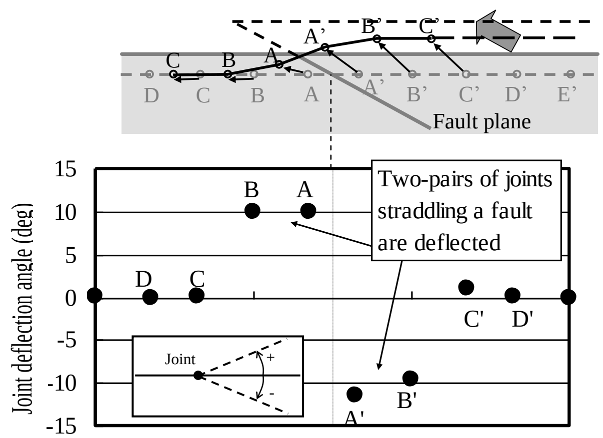


Fig. 9 Joint deflection angle

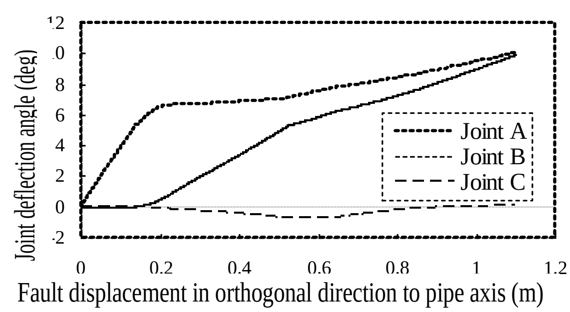


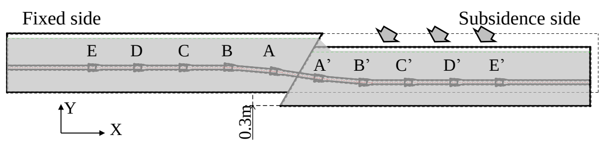
Fig. 10 Joint deflection angle relative to fault displacement

3. Verification experiment

3.1 Experiment method

The validity of the analysis results of the pipeline behavior simulation was checked with a verification experiment in which actual pipes were used.

As shown in Fig.11, we distributed DN75 NS-type ductile iron pipes in a sand container that was divided into two portions and filled with sand. One portion was then dropped 300 mm in the direction of 60 degrees to simulate a fault movement, and various measurements were taken on the pipeline.



Pipes	DN75 NS-type
Pipe length	1m
Number of joint	10
Fault type	Reverse fault
Soil compacting	15 N-value
Fault displacement	-0.17m (X-direction) -0.30m (Y-direction)

Fig. 11 Experiment method and conditions

3.2 Experiment result

The setup of the experiment is shown in photo.1. Photo.2 shows the fault crossing part from the side and indicate fault.

The experiment results of contractions of joint A and B relative to the fault displacements (in the axial direction) are shown in Fig.12. The analysis results are shown in this graph in addition, too. The pipelines moved following by the ground displacement, and it was confirmed that the experiment results were almost the same as the analysis results.

We show the result of a measurement of pipeline behavior in fig.13. Like the analysis results, it was revealed that the pipeline followed fault displacement in the experiment results, too. However, in the joint A and A', the closest joints to the fault, it turns out that the pipeline displacement magnitude in an experiment is smaller than analysis.

Therefore I analyzed joint behavior in detail. The joint deflection angle of joint A, A', B and B' is shown in fig.14. With the container of the subsidence side, deflection angle of joint B' neighboring joint A' which was the closest to the fault was bigger. And we confirmed a tendency unlike the analysis result. In other words, it is estimated that the pipeline behavior of the fixed side is different from the subsidence side.

Photo 1 Setup of the experiment

Photo 2 Fault part side

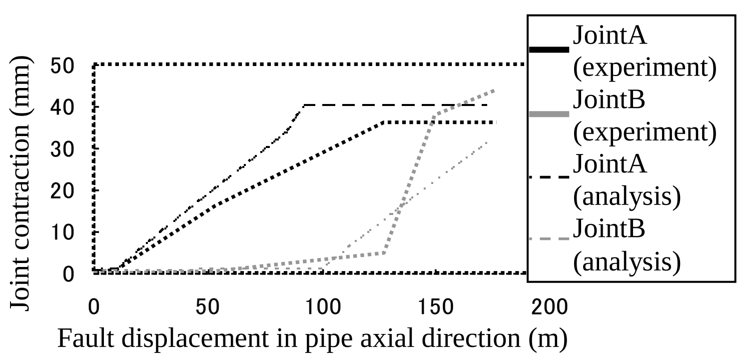


Fig. 12 Joint contractions

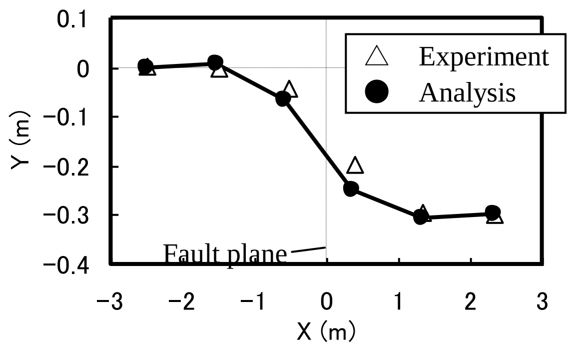


Fig. 13 Pipeline behavior

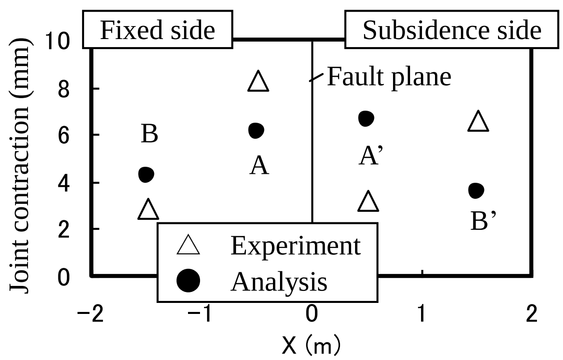


Fig. 14 Joint deflection angle

3.3 Verification of ground spring

In our analysis, we set the same ground condition in the fixed side and the subsidence side. We confirmed whether this was proper by an experiment.

As shown in Fig. 15, as for the pipeline in the fixed side container, the ground reaction force acts from the upper part, as for the pipeline in the subsidence side container, it acts from the lower part. Therefore, as shown in Fig. 16, we installed DN75 ductile iron pipe in a sand container, and measured the ground reaction force when the pipe was displaced to above and down.

The result is shown in Fig. 17. It turned out that the ground reaction force when the pipe moved downward was bigger than when it moved upward.

From this experimental result, as shown in Fig. 17, we modeled ground spring and analyzed again.

Joint deflection angle is shown in Fig.18. The analysis result which re-modeled the ground spring was approaching by the experimental result.

We show the result of a measurement of pipeline behavior in fig.19 and the result of a measurement of deflection of joint A, B and C in fig.20.

(1)Only the joints near the fault behaved with fault movement.

(2)When the fault began to move, the joints straddling the fault moved first. By the experiment result, the behavior of pipeline across a fault showed like the analysis result.

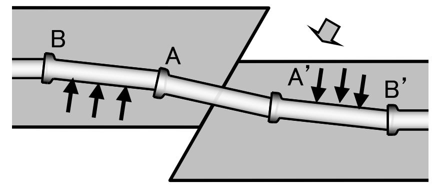


Fig. 15 Direction of ground reaction force

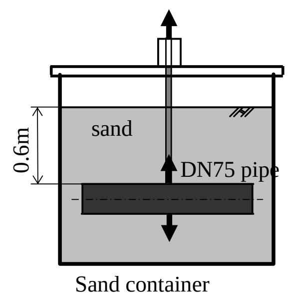


Fig. 16 Measurement method of ground reaction force

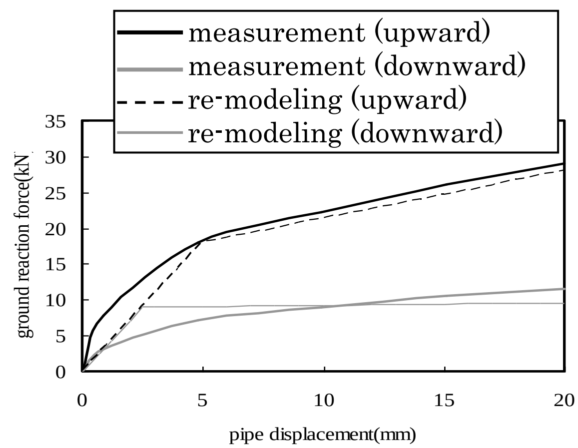


Fig. 17 Measurement result of ground reaction force

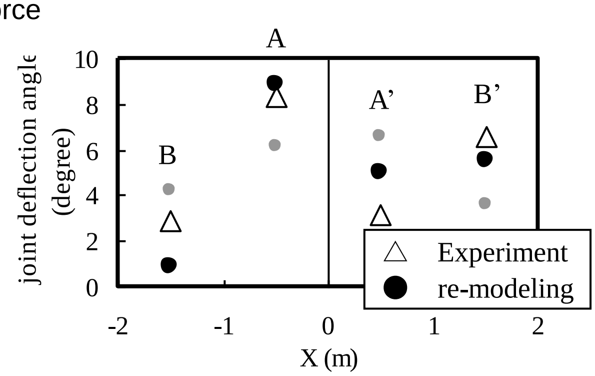


Fig. 18 Joint deflection angle

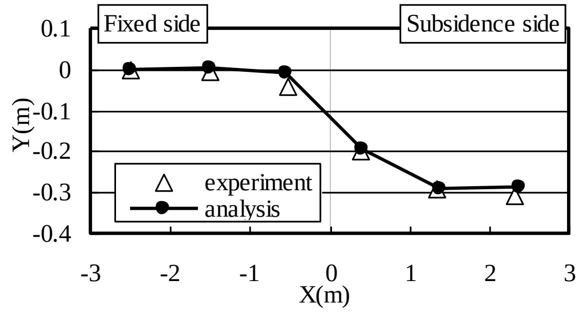


Fig. 19 Pipeline behavior

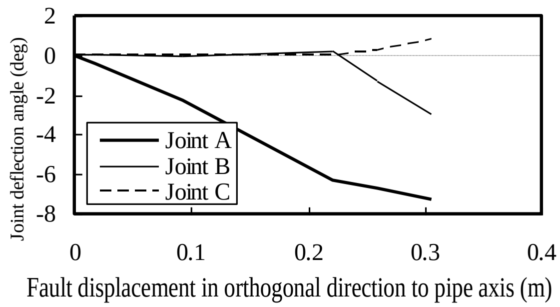


Fig. 20 Joint deflection angle relative to fault displacement

4. Conclusions

We carried out a detailed pipeline behavior simulation and a verification experiment simulating distributed pipeline buried across a fault comprising ductile iron pipe with earthquake-resistant joints. As a result, the following conclusions were drawn.

When the fault began to move, the joints straddling the fault moved first. When the deflection angles in these joints reached their maximums, the joints next in line began to move.

We intend to continue the simulation analysis under various conditions of fault and pipeline and ground, in order to establish a design method for ductile iron pipelines buried across a fault.

References

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