Development of Low-reaction Type of Steel Pipe for Crossing Fault

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ABSTRACT

In response of pipe damages caused by fault offset, the authors had developed the normal type of SPF, as a countermeasure of water supply pipelines for crossing fault. However, in case of reverse fault in flexure layer, the compression force mainly works on the pipe in the axial direction, and the reaction force at wave-shaped pipe section is huge, and the strain at the sleeve pipe section is huge as well. Therefore, the low-reaction type of SPF has been developed, in order to have the capacity of normal type, to absorb the deformation of axial compression direction and to reduce the reaction force of the wave-shaped pipe section. The optimum shape of the wave-shaped pipe section has been determined by FE analysis, to put a value into the 2 variables; the height and the width. As the result, the low-reaction type could reduce the maximum reaction force by one third of the normal type. The axial compression test and the split-basin test have been carried out, in order to verify the deformation performance of the low-reaction type. Moreover, this paper introduces the case study to verify the low-reaction type on FE analysis.

INTRODUCTION

Recently, pipe damages, caused by fault displacement, had been occurred as one of earthquake damages. Water steel pipes, of which the diameter are 2,200mm and 2,000mm, had been damaged by Kocaeli earthquake of 1999 in Turkey and Chi-chi earthquake of 1999 in Taiwan. Therefore, the authors had developed steel pipe for crossing fault (hereinafter SPF) as a countermeasure of water supply pipelines for crossing fault (Hasegawa, 2009). The normal type of SPF has a structure to absorb bending deformation in case of reverse fault. However, in case of reverse fault in flexure layer, it is necessary to absorb bending and axial compression deformation, and to reduce the reaction force on axial compression deformation. Therefore, the low-reaction type of SPF has been newly developed.

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PIPE IN FLEXURE

Flexure

Flexure is a phenomenon that fault slips down and surface ground bends.

There are 2 types of flexures. 1st one is the case that the fault lies in the ground, as shown in the left side of Figure 1. 2nd one is the case that soil accumulates after the fault appeared on the ground surface, and the ground lifts up when the fault raises again, as shown in the right side of Figure 1.

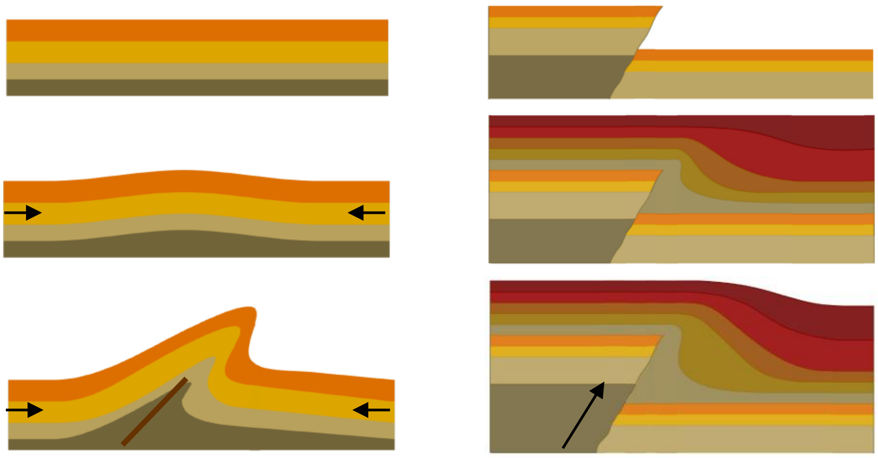


Figure 1 Flexure

Required Performance of Pipe in Flexure

In case of reverse fault in flexure layer, the fault plane does not reach to the ground surface because of a soft ground, although the fault displacement occurs.

If the pipeline is installed in the reverse fault of flexure layer, the compression force mainly works on the pipe in the axial direction. As it can be assumed that the fault plane newly appears in the flexure layer, it is necessary to absorb the bending deformation as well.

Moreover, the reaction force at wave-shaped pipe section (hereinafter WAVE) is huge, and the effect of the strain at the sleeve pipe section on the both sides of WAVE is huge as well, in case the axial compression deformation occurs.

Therefore, low-reaction type of SPF has been developed, in order to have the capacity of normal type of SPF, to absorb the deformation of axial compression direction and to reduce the reaction force of WAVE.

DEVELOPMENT OF LOW-REACTION TYPE OF SPF

Concept of Low-reaction Type of SPF

The WAVE, SPF has, is designed and manufactured, in order to be easy to deform. The optimum shape of the WAVE has been determined by FE analysis, to put a value into the 2 variables; the height and width of the WAVE, in order to absorb the axial compression deformation and to reduce the reaction force of WAVE in the axial direction. And, the allowable angle has been determined as 8 degrees, in order to absorb the bending deformation.

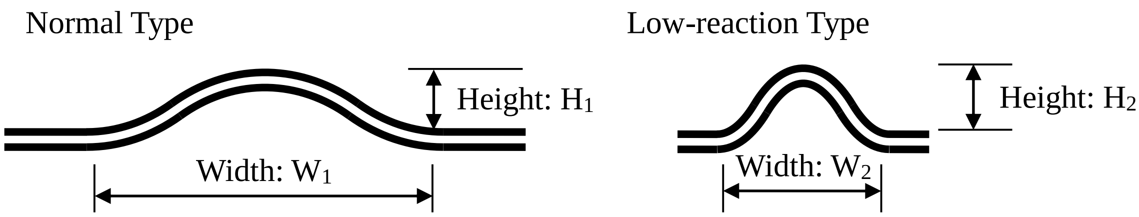


Figure 2 Reformed shape of Wave-shaped Pipe Section

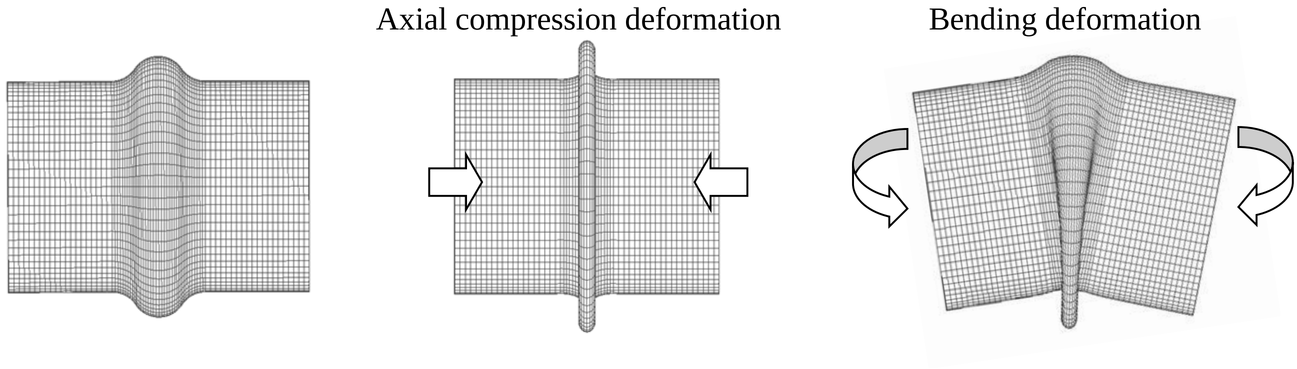


Figure 3 Deformation of Low-reaction Type of SPF

Compared with the reaction forces on the normal type and low-reaction type by FE analysis, the low-reaction type of SPF could reduce the maximum reaction force by one third of the normal type, as shown in Figure 3.

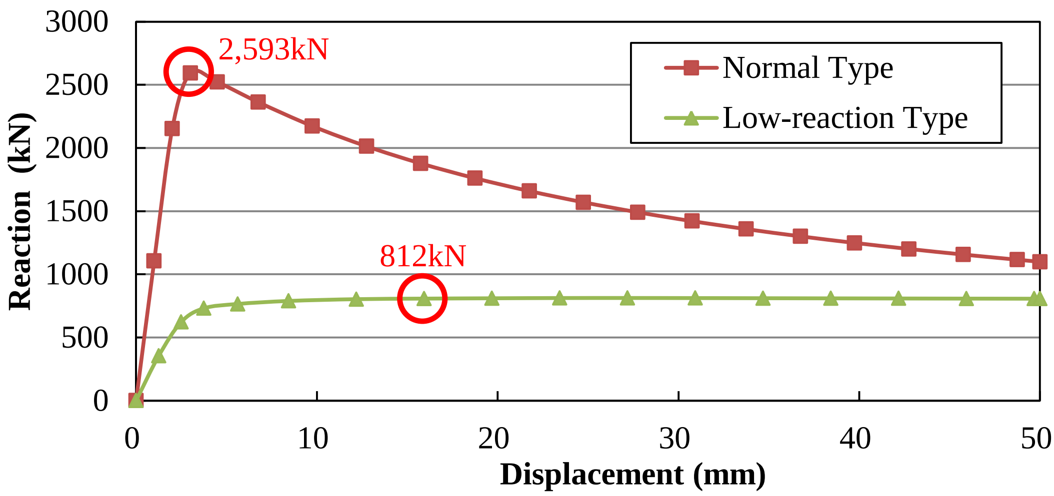


Figure 3 Comparison of Reaction by Displacement

Experiments

The axial compression test and the split-basin test have been carried out, in order to verify the deformation performance of the low-reaction type of SPF. In each experiment, there are 3 test pipes, of which the diameter is 100mm.

Axial Compression Test

The axial compression test has been carried out, by using the structural testing machine, as shown in Figure 4. In this experiment, 2 WAVEs were installed in the test pipe, in order to confirm the coupled deformation of the 2 WAVEs, as shown in Figure 5.

Figure 4 Structurral Testing Machine

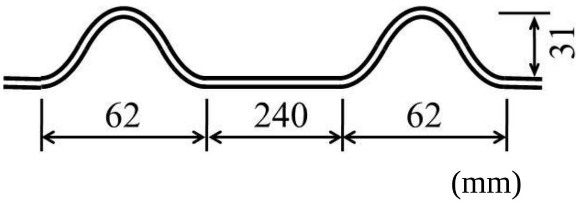
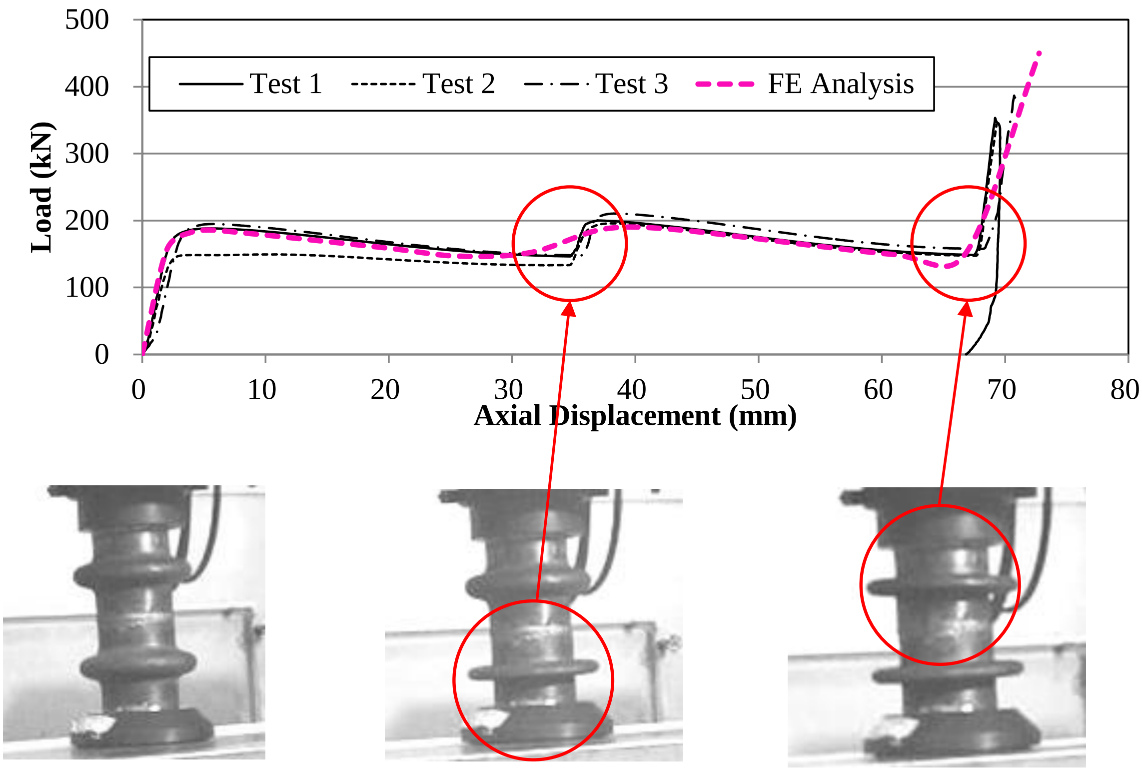


Figure 5 Shape of Test SPF

The load by the axial displacement is shown in Figure 6 in case of 3 test results and FE analsis result. One of test results was diferent from any other results at the maximum load, because the edge of the test pipe was not cut accurately. However, the results of 3 tests and FE anlysis have the same tendencies, especially at the 1st and 2nd points to contact the inner pipe walls. Therefore, it could be found that these results have highly-repeatable.



Initial State　Contact (Lower Wave)　Contact (Upper Wave)

Figure 6 Results of Axial Compression Test

Split-basin Test

The split-basin test has been carried out, in order to confirm the performance of SPF under the buried condition. The dimension of the basin is 1.0m as the width, 1.0m as the depth and 5.0m as the length. As shown in Figure 7, the partition plate was set as the fault plane in the split basin, and the load was forcibly applied to the left side of split basin by using the hydraulic actuator, as the displacement of reverse fault. The fault angle was assumed as 80 degrees.

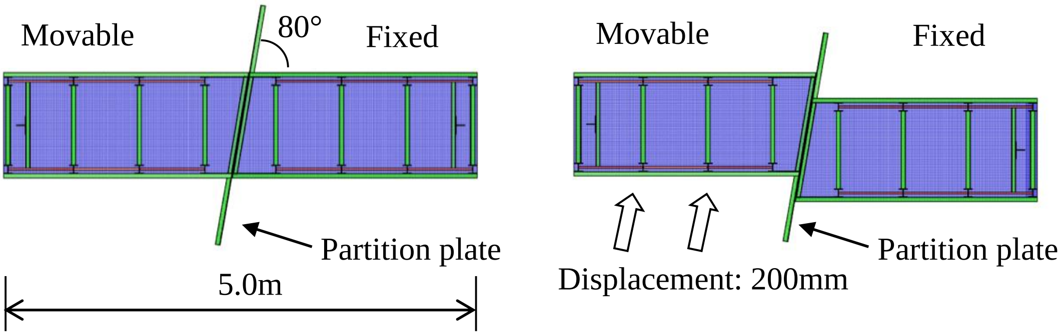


Figure 7 Plan of Split-basin Test

The diameter of the test pipe was 100mm (O.D.114.3mm, thickness 2.3mm, length 6m), in the assumption of one tenth model of 1000mm. As shown in Figure 8, the distance between 2 WAVEs was 600mm across the fault plane, according to FE analysis result. The test pipe was fixed in rotation direction and free in axial direction. Moreover, the amount of displacement was set as 200mm, as the result, the inner pipe wall contact angle was 18.5 degrees.

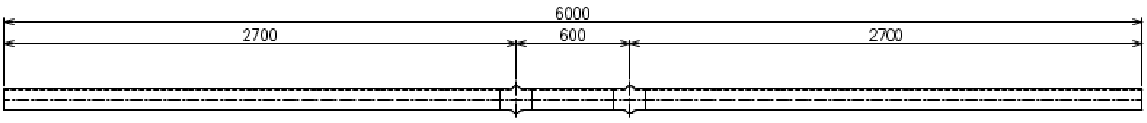


Figure 8 Pipe of Split-basin Test (100mm)

The test pipe after deformation is shown in Figure 10. The deformation of SPF appeared only at the WAVEs, which absorb the fault offset as bending deformation. The adequate result has been obtained about the installation position of the WAVEs, because the deformation concentrated only on the WAVEs and the WAVEs were deformed equally on both sides.

Figure 9 Overview of Split-basin

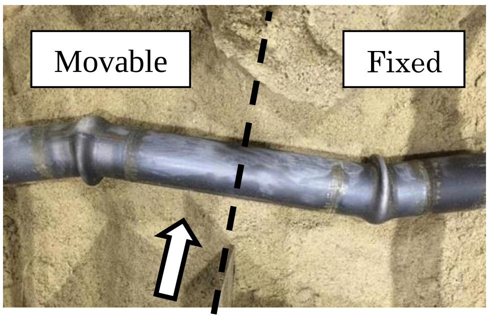


Figure 10 Test Pipe after Deformation

The result of FE analysis under same condition as the split-basin test is shown in Figure11. The adequate result also has been obtained that the deformation in FE analysis was closely similar with the deformation in the split-basin test, as shown in Figure 10.

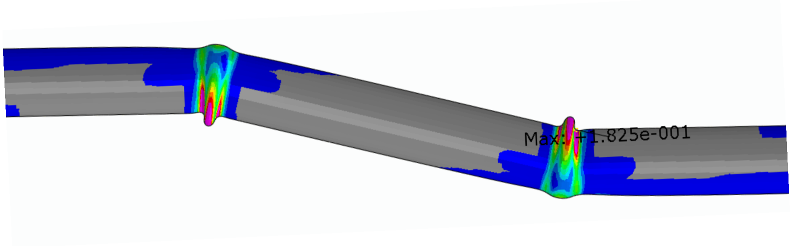


Figure 11 Result of FE Analysis in case of Spilt-basin Test

CASE STUDY

The low-reaction type of SPF was verified by FE analyses in 2 cases; deformation in flexure layer and deformation at fault crossing points. The status of inner pipe wall contact, water flow cross-section area and strain in sleeve pipe section were inspected in the above 2 cases.

Specification of SPF

The affected area (flexure zone) of upper layer, caused by fault offset, was calculated, by using the ground deformation analysis, in case the amount of fault offset is 3.6m. As the result, the length of flexure zone was assumed as 200m, as shown in Figure 11.

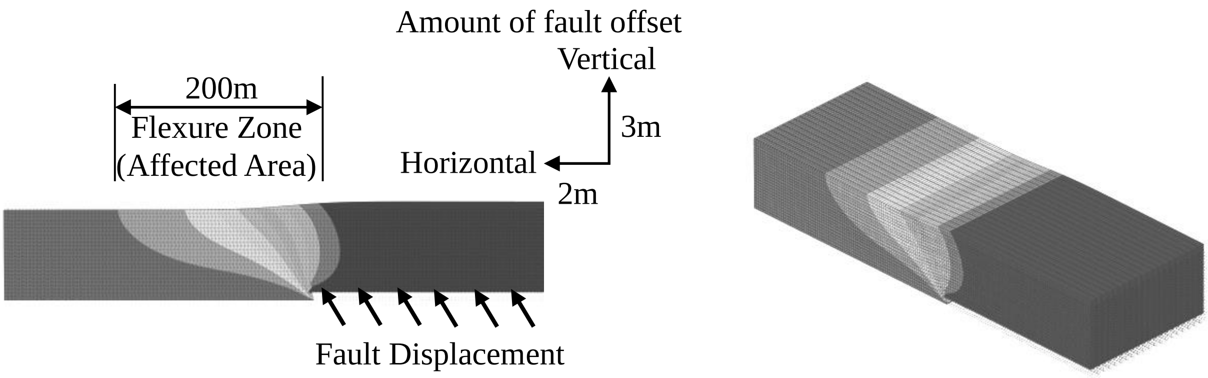


Figure 11 Distribution of Fault Displacement (Ground Deformation Analysis)

The straight pipe, of which the diameter is 2,000mm, was modeled on the FE analysis, and the pipe got the fault offset, of which the amount is 3.6m (Vertical:3m, Horizontal:2m). As the result, the plastic hinges occurred at the positions 6m-apart from fault plane, as shown in Figure 12. Therefore, the distance between plastic hinges was set as 12.0m as the installation positions of each WAVE.

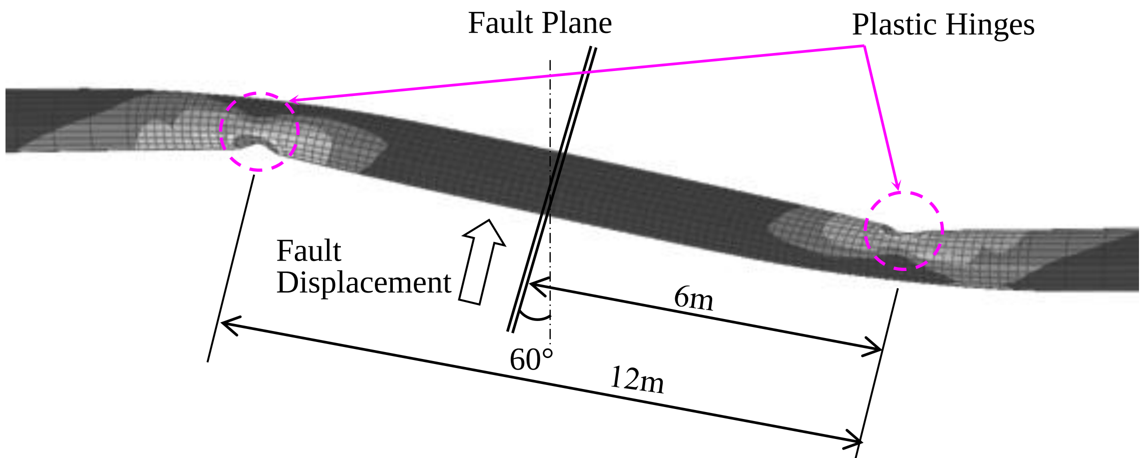


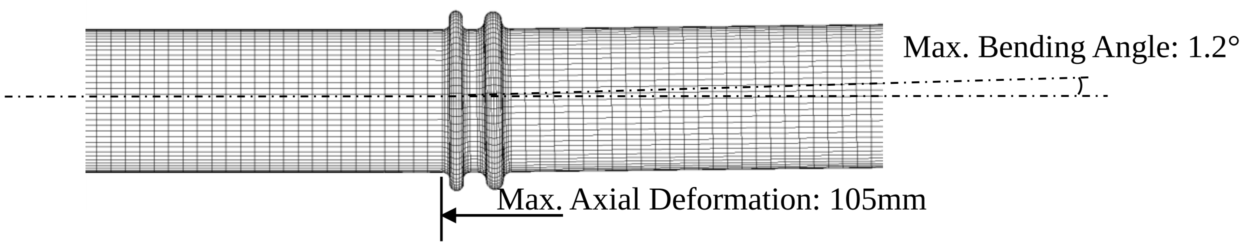
Figure 12 Distance between Plastic Hinges

In addition, the required number of the WAVE was set as 2 WAVEs per a SPF on each plastic hinge, from the results of axial compresstion displacement and bending displacement.

Verification by FE Analysis

Deformation in flexure layer

The analysis result in flexure layer is shown in Figure 13. 2 WAVEs were deformed one by one, not at the same time, as shown in Figure 13. The maximum bending angle was 1.2 degrees within 16 degrees as an allowable bending angle, and the maximum axial deformation was 105mm within 570mm as an allowable axial deformation. Moreover, the maximum strain in the sleeve pipe section occurred just by 0.03%, and it could be found that the WAVEs absorb the deformation in flexure layer.



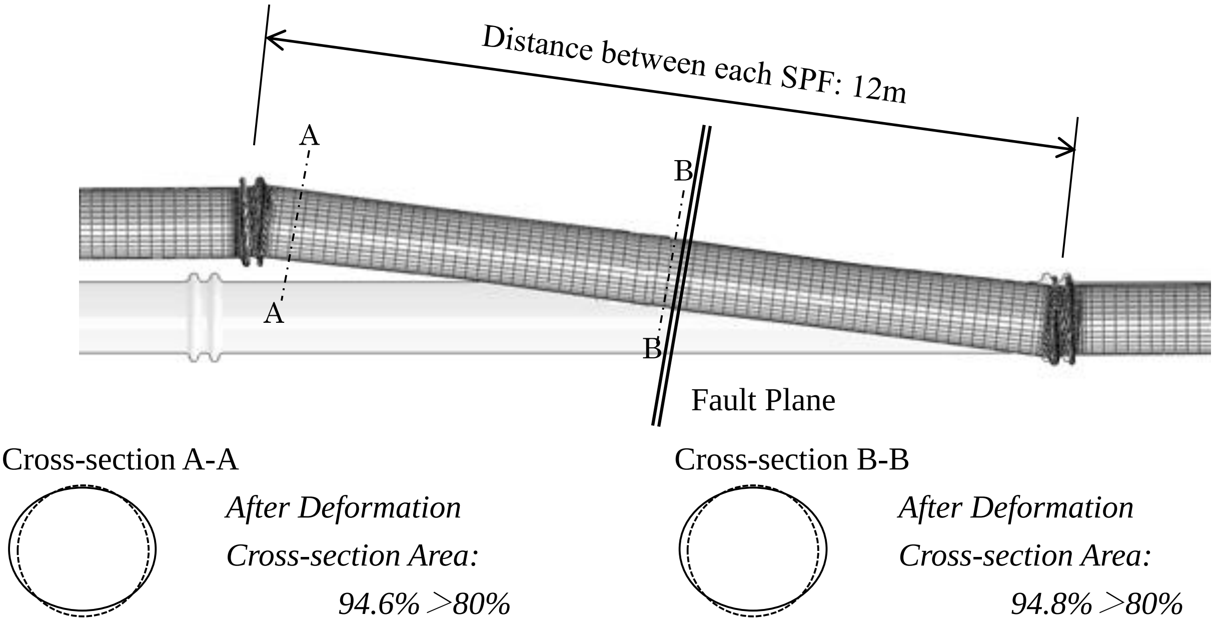
Max. Bending Angle	θ:	1.2°	$<$	$\theta_{a2} = 16°$
Axial Deformation	δ:	105mm	$<$	$\delta_a = 570mm$
Max. Strain at Sleeve Pipe Section	ε:	0.03%	$<$	$\varepsilon_a = 5\%$

Figure 13 Max. Axial Deformation

Deformation at fault crossing points

The analysis result at fault crossing points is shown in Figure 14. As shown in Figure 14, the WAVEs could absorb the fault offset as bending deformation. The bending angle was 14.5 degrees within 16 degrees as an allowable bending angle, and the maximum strain in the sleeve pipe section was 1.64% within 5% as an allowable strain.

The cross-section areas of A-A and B-B are shown in Figure 14, at the moment the amount of fault offset is 3.6m. The cross-section area of A-A and B-B were 94.6% and 94.8% of the area before deformation, even though the area became flattened due to bending deformation.



Bending Angle θ: *14.5°* $< \theta_{a2} = 16°$

Strain at Sleeve Pipe Section ε: *1.64%* $< \varepsilon_a = 5\%$

Figure 14 Cross-section area before and after fault offset

CONCLUSION

This paper introduces the low-reaction type of SPF corresponding to the deformation in flexure layer, though the experiment results and the case study based on FE analysis. We hope that it will be helpful to those who are engaged in the countermeasure of the pipe for crossing faults.

REFERNCE

N.Hasegawa, Development of High Seismic Performance Pipe for Crossing Active Fault, the 6th Taiwan-US-Japan Workshop on Water System Seismic Practices, 2009