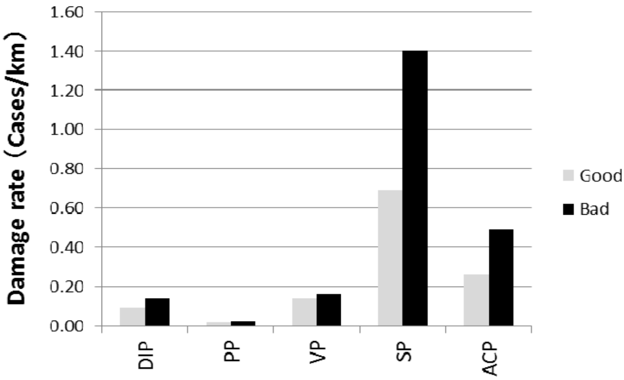

Figure 6. Comparison of damage rate of each pipe type in micro topography classification category.

Table 4. Piping length in each level of JMA seismic intensity, categories of micro topography classification and pipe type.

Unit :m

Category	JMA SI	CIP	DIP(ERJ)	DIP	PE(Fusion)	PP	VP	SP	SUS	ACP	other	Sum
Good	less than 4		1,499	1,232	12	4,860	10,915	180	75	52	0	18,825
	4					435	445	0			0	881
	5-		1,076	10,020	409	4,949	17,681	892	34	35	0	35,095
	5+	627	4,767	45,326	9,500	23,730	115,270	3,116	132	4,726	41	207,235
	6-	404	14,017	90,504	9,083	63,873	265,575	5,561	306	10,929	1,118	461,380
	6+	930	11,337	82,438	5,687	57,004	357,647	2,667	92	14,935	275	533,009
	7		900	21,545	613	10,029	79,164	682		15,743	53	128,730
Sum of Good		1,961	33,596	251,064	25,304	164,880	846,696	13,098	639	46,420	1,487	1,385,154
Bad	less than 4	536	842	17,739	1,572	13,663	54,481	2,831	560	3,985	14	96,223
	5-			113		200	587	30	10		0	940
	5+		1,905	14,022	2,576	16,908	42,309	1,255	331	562	101	79,967
	6-	4,344	20,551	87,439	16,536	68,613	288,032	7,157	778	10,648	176	504,358
	6+	15,863	44,501	329,648	13,155	142,744	839,706	15,029	1,545	34,686	592	1,437,468
	7	4,499	1,974	38,234	1,614	28,999	154,013	1,582	140	23,753	333	255,139
Sum of Bad		25,241	69,773	487,195	35,453	271,127	1,379,127	27,884	3,364	73,632	1,215	2,374,096
Sum		27,202	103,369	738,259	60,757	436,007	2,225,824	40,982	4,004	120,052	2,702	3,759,250

ERJ：Earthquake Resistant Joint

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A Study on Behavior of Ductile Iron Earthquake Resistant Pipeline in the Deformed Road at the 2011 Great East Japan Earthquake

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ABSTRACT

A number of water pipelines were damaged in the 2011 Great East Japan Earthquake. After the earthquake, we measured behaviors of the earthquake resistant ductile iron pipeline (hereafter, ERDIP) located in a collapsed road embankment by removing soils around the pipes, and investigated their correlation with road subsidence and lateral spread of the embankment. This paper describes the results of this on site investigation and analysis.

OUTLINE AT THE GREAT EAST JAPAN EARTHQUAKE

The earthquake of magnitude 9.0 occurred in the Pacific Ocean coast on March 11, 2011. This magnitude 9.0 was the greatest recorded in Japan. Over 40m high tsunami assaulted the coast of East Japan in this earthquake. This earthquake caused unprecedented damage to a building, water service, electricity, gasoline, roads, etc. As for water service, about 2.2 million households were cutoff from water supply, at the maximum.

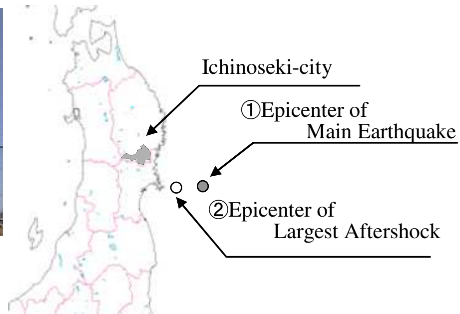
The damage of the water pipeline was less than those observed in the past large earthquakes in Japan, such as the 1995 Great Hanshin Earthquake. However, pipeline damages occurred in the areas of liquefied ground, soft ground, developed land, banking, and interfacing with structures. Under such conditions, although the earthquake resistant ductile iron pipeline (ERDIP) joints were not damaged, even though there were over 1,857 km of ERDIP installed in the seismically damaged area.

THE SUMMARY OF THE PIPELINE TO INVESTIGATE

Ichinoseki-city where we investigated the behavior of ERDIP (DN150mm), had been struck twice by earthquakes measuring a lower 6 on the JMA scale on March 11, 2011 and April 7, 2011, and suffered great damages to waterworks facility such as a collapsed of distributing reservoir (Photo 1). Figure 1 shows the two earthquake epicenters and the outline of seismic intensity at Ichinoseki-city.

The pipeline was built in an embankment having a length over 1.8km along the national road bypass. The pipeline was confirmed to have no leakage under the hydraulic test (0.74MPa) after the main shock and several aftershocks.

Photo 1. Collapse of a distributing reservoir.



	Outbreak time	Scale (magnitude)	Maximum acceleration (gal)	JMA scale
①	2011/3/11 14:46	9.0	1225.8	lower 6
②	2011/4/7 23:32	7.1	870.8	lower 6

Figure 1. Ichinoseki-city and Earthquakes position.

DAMAGE OF ROAD EMBANKMENT

Figure 2 shows the ground elevations of the road embankment before and after the earthquake event. This road embankment has a 5% gradient.

As described below, the road embankment was damaged during the earthquake from surface cracks, subsidence, and lateral spreading of the embankment for over approximately 300m. There was a box-culvert, and a Takizawa-bridge in the damaged embankment.

(1) A-B section in Figure 2. Regarding the road embankment, transverse cracking has been generated in the surface of earth fill beside the upper part of box culvert (Photo 2).

Additionally, longitudinal cracking has been generated at a location about 30 m downstream of the box culvert, accompanied by ground subsidence of 0.7 m and lateral spread in the face of slope (Photo 3). On the other hand, it was found that cracking of curbstone occurred next to the Takizawa bridge (point B in Figure 2) (Photo 4), and the ground surface was compressed.

(2) C-D section in Figure 2. Regarding the road embankment, the ground has subsided in the area about 1400 m distant from the work starting point (hereafter, observation point, OP.1400m). Conversely, the ground has up heaved in the area about OP.1460 m. Thus, the ground has exhibited displacement behaviors in the direction to restore the original flatness. Additionally, lateral displacement with a transverse cracking of 0.5 ~ 1.0 m in width had also been generated at OP.1420 ~ 1480 m (Photo 5).

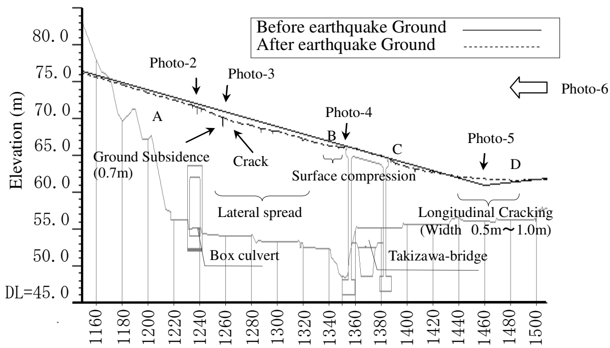


Figure 2. Ground elevation.

Photo 2. Transverse cracking OP. 1230m.

Photo 3. Longitudinal cracking OP. 1260m.

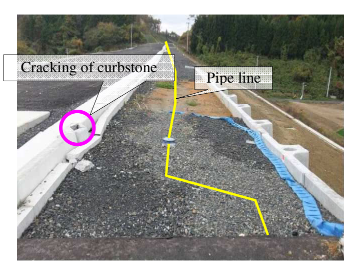


Photo 4. Compression of ground OP. 1350m.

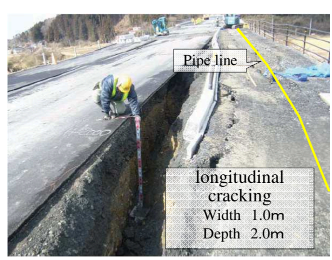


Photo 5. Longitudinal cracking OP. 1460m.

METHOD OF PIPELINE BEHAVIOR MEASUREMENT

We excavated the pipe along the deformed road embankment section to investigate the pipeline behavior. Photo 6 shows the view of the upstream area observed from point about OP.1500 m. The following three measurements were obtained for the pipeline behavior.

(1) Expansion/contraction of joint. The displacement of each joint was obtained from Equation 1 with the measurement of the distance between the white line on the spigot and the socket end.

$$l = a - 80^{\aleph} \tag{1}$$

l :Amount of expansion contraction of joints (mm)
a :End face the socket~White line indication on spigot (mm)
ℵ The distance between the white lines (=80 mm)

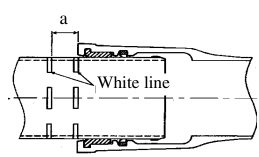


Figure 3. Measurement of ERDIP joint.

(2) Deflection angle of joint. The deflection angle in horizontal direction was calculated from the difference of right and left expansion amounts of each joint as shown in Equation 2.

$$\theta = \tan\left(\frac{l - l'}{D_2}\right) \tag{2}$$

θ = Deflection angle of joint in horizontal direction (degrees)
$l - l'$ = Difference of the amount of expansion/contraction Joints on each side (mm)
D_2 = Diameter of pipe (=0.169m)

(3) Elevation of pipe (elevation of the top of the spigot pipe). The Elevation of each pipe segment was obtained from leveling measurements taken on the top of pipe socket.

(4) Length of pipe. The length of each pipe was obtained from the as-built drawings for this work. Photo 7 shows the example of joint measurement situation. We found out that the expansion amount of the joint was approximately 50 mm.

Photo 6. OP. 1500m.

Photo 7. Survey situation OP. 1230m.

RESULTS OF MEASUREMENT

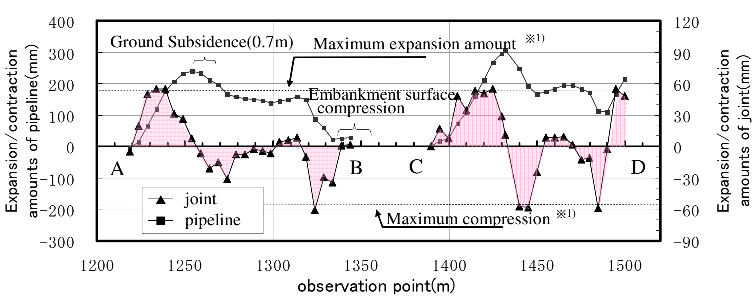
Figure 4, Figure 5 and Figure 7 show the measurement results of pipeline behavior. The measurement results revealed that the pipeline laid under the road embankment had absorbed the large ground displacement by ERDIP joint.

(1) Longitudinal displacement of joint and pipeline. Figure 4 shows the expansion/contraction amounts of joint and pipeline, respectively. The pipeline expansion amount was obtained by Equation. 3 based on the joint expansion amount.

Three consecutive joints near the point OP.1230 m had reached the maximum expansion amount (Figure 4). Additionally, although the road embankment ground has shown subsidence up to 0.7 m near the area about OP.1260 m, the pipeline has also expanded to follow the displacement of road embankment.

On the other hand, while the compression of the road embankment surface took place near the area about OP.1350 m, the result shows that the pipeline contracted to follow such displacement. Therefore, in the A-B section, localized expansion of joint was generated in the upper part of slope, and localized contraction of joint was generated in the lower part of slope.

Moreover, in the C-D section, longitudinal cracking of 0.5 m or more occurred near the area about OP.1420 m ～1480 m. The joint located near the crack corresponding to this also shows regionally the maximum amount of expansion.



※1) Maximum amount of expansion/contraction(±54mm)

Figure 4. Expansion/contraction amounts of pipeline and joint.

$$\lambda_i = \sum_{k-1}^{i} l_k \tag{3}$$

l_i :Amount of expansion/contraction of the ith pipeline from the reference point (mm)

l_k :Amount of expansion/contraction of the kth joint from the reference point (mm)

(2) Horizontal displacement of pipeline and embankment. Figure 5 shows the displacement of pipeline and embankment in horizontal direction. The displacement of pipeline was obtained by Equation 4, which calculates the amount of displacement in horizontal direction with reference to the original location. The displacement amount shown in Figure 5 is corrected as the displacement for points A and D where the ground displacement are small and for points B and C where pipelines are connected to structures and displacements are assumed to be zero.

Moreover, Figure 6 shows the embankment before and after earthquake. In Figure 5, the horizontal displacement of embankment indicates the combined displacement of top of slope. At any observation point, the displacement of pipeline is larger than that of top of slope. Even at the observation point around OP.1440m where the displacement of embankment was maximum at 1.7m, it was found that the ERDIP had followed.

$$\delta = L_1 \cdot \sin(\theta_1) + L_2 \cdot \sin(\theta_1 + \theta_2) + L_3 \cdot \sin(\theta_1 + \theta_2 + \theta_3) + \cdots \tag{4}$$

δ : Displacement of pipeline in horizontal direction (m)

l_i : Length of i-th pipe (m)

θ_i : Horizontal deflection angle of i-th joint (degrees)

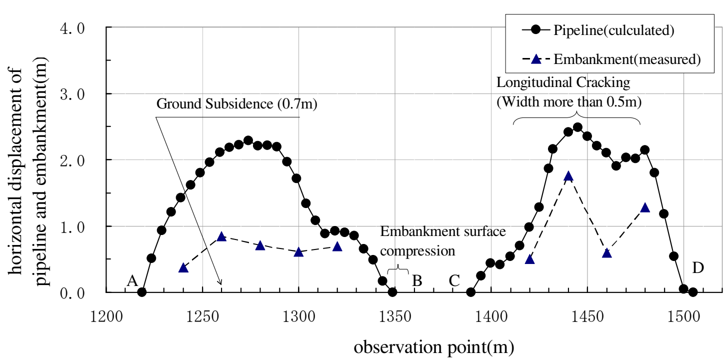


Figure 5. Horizontal displacement of pipeline and embankment.

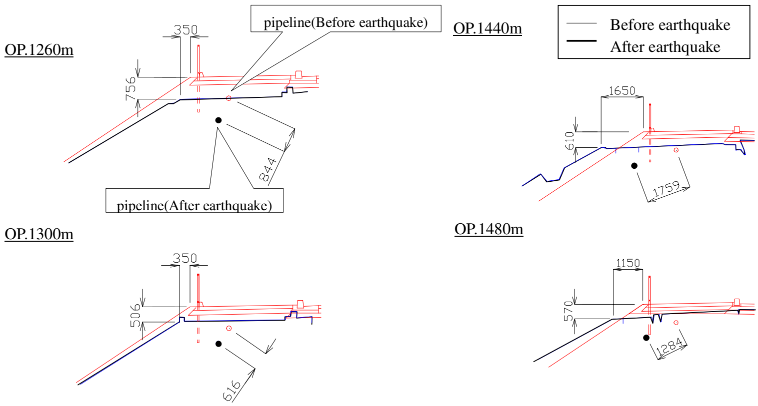


Figure 6. Cross section of embankment before and after earthquake.

(3) Elevation amount of pipeline and ground. Figure 7 shows the vertical displacement of pipeline and ground after the earthquake. The vertical displacement of pipeline coincides with the ground displacement where subsidence and upheaval occurred after the earthquake, with the exception of some sections. Therefore, it is understood that the pipeline followed the ground deformation of road embankment. Especially in the A-B section, the pipeline displacement was practically the same as that of the ground. In the C-D section there is some difference between them. We considered that the difference was caused by the fact that not only ground subsidence, but also longitudinal cracking occured.

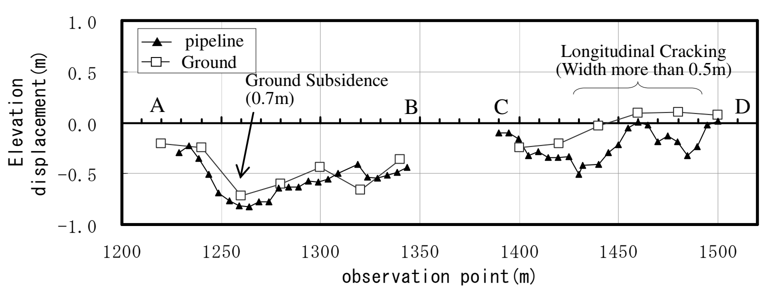


Figure 7. Vertical displacement after earthquake.

CONCLUSION

The results of this study are summarized as follows.

(1) The ERDIP can absorb the large embankment deformations (crack, subsidence, etc.) through joint expansion/contraction and deflection, without damage at the event of big earthquakes.

(2) Some pipeline joints were recorded at the maximum expansion / contraction amount. Therefore, we understood that the ground was significantly deformed locally.

(3) Even after absorbing the local ground strain, residual expansion rate of the pipeline is much less than 1%. This shows once again how well the ERDIP can respond strong earthquakes.

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

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ABSTRACT

This study is focusing on behavior of ductile iron pipelines with earthquake resistant joint buried across a fault 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. Although there are some researches on behavior of steel pipelines which cross a fault, there are few studies of ductile iron pipelines.

In this study, we investigated the behavior of pipeline buried across a fault by simulation analysis and verification experiment. As a result, we clarified that the earthquake resistant joint nearest to a fault began to move when a fault began to move, and then the joints in line began to move when the expansion, contraction and deflection angle in the joint nearest to a fault reached its capacity.

In addition, we confirmed that we could evaluate the safety of pipeline against the fault movement by deflection angle in each joint. As a result, using colors with large bending performance than straight pipe sockets of shortening the pipe length was effective to increase the safety of pipeline near a fault.

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