Estimation Formula of Pipe Strain due to Fault Dislocation Based on Elasticity Theory

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INTRODUCTION

Linear structures such as buried pipeline and tunnel crossing seismic fault are generally difficult to setback from the fault. There are no relevant specifications about how to avoid the damage caused by the fault movement. Ground strain near the ground surface caused by fault movement is a common phenomenon that can lead to pipeline failure, causing significant economic and environmental consequences. The authors tried to make clear the pipe strain by the fault movement when the fault displacement does not appear the ground surface based on the elasticity theory of dislocation. General information on the location at maximum pipe strain under the several conditions between the crossing angle between pipe and fault, fault depth and rake angle were made clear (Pan and Kuwata, 2022). Here, in order to understand amount of maximum pipe strain under the several fault parameters, we tried to calculate maximum pipe strain with several fault parameters based on the elasticity theory of dislocation and we attempted proposing the estimation formula of pipe strain by the regression analysis.

CALCULATON OF PIPE STRAIN BY FAULT DISLOCATION

According to the elasticity theory of dislocation by Okada[1)], **Fig.1** shows a schematic diagram of this model[2)]. Okada introduced the surface displacement based on the fault displacement. Pan and Kuwata (2022) calculated the pipe strain when the pipeline cross over the projection of fault plane. In this calculation, the pipe strain can be obtained the axial strain on the pipe axial and bending strain along the pipe axis with give pipe diameter under the assumption that the slip between the pipe and soil interaction does not occur. The changes of various parameters of the fault are shown in **Table 1**. They can be arbitrarily combined into one case. For example, when L = 40 km, W = 20 km, δ = 90 deg., θ = 90 deg., $\mu_0 = \lambda_0$ = 32 GPa, e = 2 m, use the elasticity theory of dislocation to calculate the surface deformation on the XY plane. The locations at maximum pipe strain varies by the fault parameters and intersection angle between fault and pipeline. **Fig.2** shows the relative position of the pipeline on the surface. The position of the intersection point and the included angle of pipeline crossing the fault will change to calculate

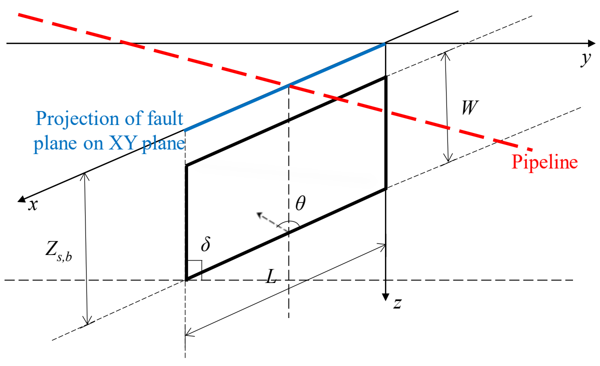

Fig. 1 Calculation model.

Table 1 Fault parameters

Length of fault, L (km)		40		30	20
Width of fault, W (km)		20		15	10
Dip angle of fault, δ (deg.)		90	80	70	60
Rake angle, θ (deg.)	Strike-slip fault	0			
	Reverse fault	90			
Lame constant, λ_0 (GPa)		32			
Lame constant, μ_0 (GPa)		32			
Element dislocation, e (m)		1.5		2	2.5

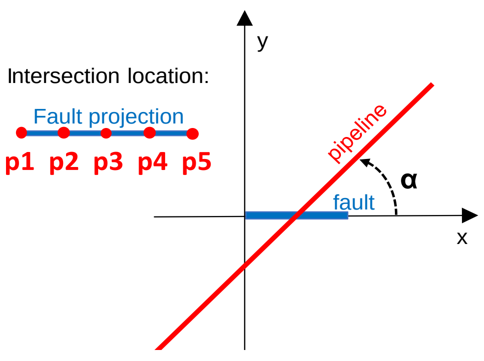

Fig. 2 Position and direction of pipe.

Key words: buried pipe, fault crossing, elasticity theory of dislocation, deformation, regression analysis
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the maximum pipe strain. The included angle between fault projection and pipeline ranges 0 degrees to 180 degrees, with intervals of 15 degrees. The all position in **Fig.2** can be calculated to get and output the maximum value of pipe strain ε (10^{-3}) in the one case of fault parameter set. In total of 864 cases, we calculated each maximum pipe strain.

REGRESSION ANALYSIS OF PIPE STRAIN

In order to estimate the maximum pipe strain easily, the estimation formula of maximum pipe strain is proposed based on the calculation results by the use of regression analysis. The objective valuable is set to be the calculated maximum pipe strain and the explanatory variables are set to be the fault parameters such as shown in **Table1**. We tried to model the linear estimation formula and the exponential estimation formula. The exponential estimation formula can get better regression result. Here, a new variable, distance from the upper end of the fault to the surface *Ds*, is introduced:

$$D_s = Z_{s,b} - W \sin\delta \tag{1}$$

When the rake angle is 0 degree, it is strike-slip fault, after performing a linear regression analysis, the relationship between various parameters and maximum pipe strain caused by faults is as follows:

$$\varepsilon = 0.03\, L^{0.34} D_s^{-1.38} U^{0.92} \tag{2}$$

Where pipe strain ε is in terms of 10^{-3}, coefficient of determination R^2 is 0.96.

When the rake angle is 90 degrees, it is reverse fault, the exponential regression analysis shows:

$$\varepsilon = 0.11 L^{0.11} D_s^{-1.25} U^{1.00} \tag{3}$$

Where pipe strain ε is also in terms of 10^{-3}, coefficient of determination R^2 is 0.98.

Table 2 Exponential regression results

(a) Reverse fault

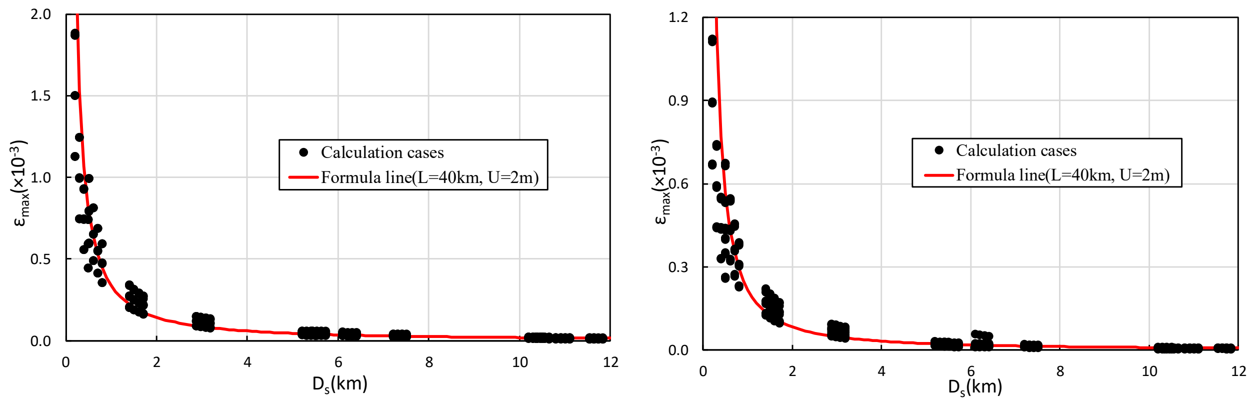
	Coefficients	P-value
intercept	-2.18	2.98E-53
lnL (km)	0.11	1.86E-03
lnU (m)	1.00	4.33E-68
$\ln D_s$ (km)	-1.25	0.00E+00

(b) Strike-slip fault

	Coefficients	P-value
intercept	-3.43	4.67E-57
lnL (km)	0.34	1.85E-10
lnU (m)	0.92	1.47E-32
$\ln D_s$ (km)	-1.39	7.1E-308

The results of using exponential regression are shown in **Table 2**. According to **Table 2**, the p-values of the regression results are very small. Although a small p-value cannot guarantee that the impact of this parameter on the dependent variable has practical significance or practical application value, it at least indicates that the impact of this parameter on the dependent variable is significant and there is a significant correlation.

Fig.3 shows the fitting of the estimation formula. As can be seen from the figure, the red line basically passes through all the points of the calculated data, so the exponential regression results are relatively reliable.



a) Reverse fault **b)** Strike-slip fault

Fig. 3 Diagram of estimation formula and calculation cases.

REFERENCES

1) Okada, Y.: Surface deformation due to inclined shear and tensile faults in a half space, Bulletin of the Seismological Society of America, Vol. 75, No. 4, pp. 1135-1154, 1985.

2) Y. Pan, Y. Kuwata: Deformation risk of buried pipeline due to fault based on elasticity theory of dislocation, Journal of Japan Society of Civil Engineers, Ser. A1(Structural Engineering & Earthquake Engineer) Vol. 78, No.4, pp. I_117-I_126, 2022.

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