Limit State Assessment of a 3-Inch Carbon Steel Pipe Tee of Nuclear Power Plant

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Abstract

To assess the seismic performance of a piping system, the relative displacement repeated by seismic motions must be considered. In this study, in-plane cyclic loading tests were conducted under various constant amplitudes using test specimens composed of SCH 40 3-inch pipes and a tee in the piping system of a nuclear power plant. Additionally, an attempt was made to quantitatively express the failure criteria using a damage index based on the dissipated energy that used the force–displacement and moment–deformation angle relationships. The failure mode was defined as the leakage caused by a through-wall crack, and the failure criteria were compared and analyzed using the damage index of Park and Ang and that of Banon. Additionally, the method of defining the yield point required to calculate the damage index was examined. It was confirmed that the failure criteria of the SCH 40 3-inch carbon steel pipe tee can be effectively expressed using the damage index.

Keywords : *Failure criteria, Carbon steel pipe tee, Yield point, Damage index*

Low Cycle Fatigue Test

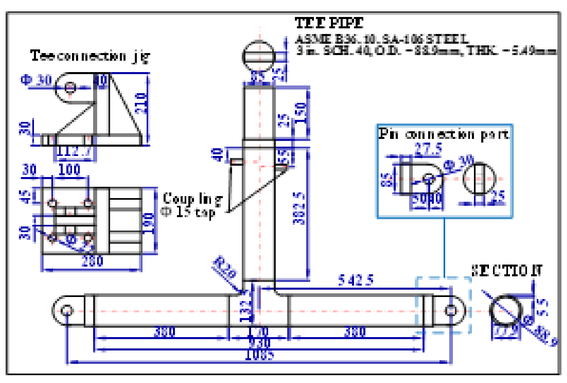
❖ Experimental Setup

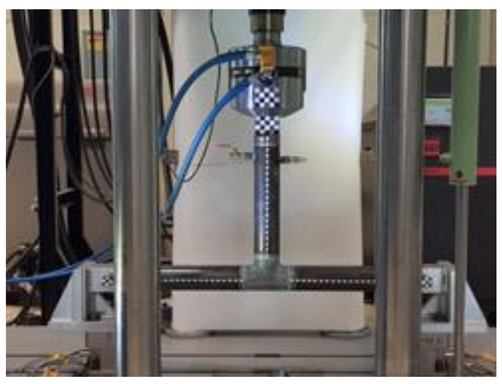
Pipe : ASME B36. 10, SA-106 STEEL 3-inch SCH. 40(STD), THK.=5.49mm

Tee : A234 Gr. WPB STEEL 3-inch SCH. 40(STD), THK.=5.49mm

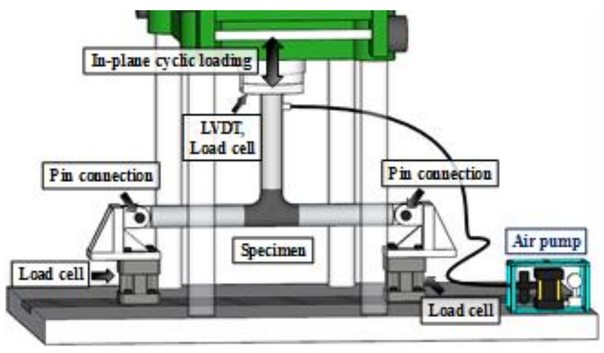
Sampling Rate UTM : 1Hz, Image Measurement System : 2Hz (5472 X 3468 pixels)

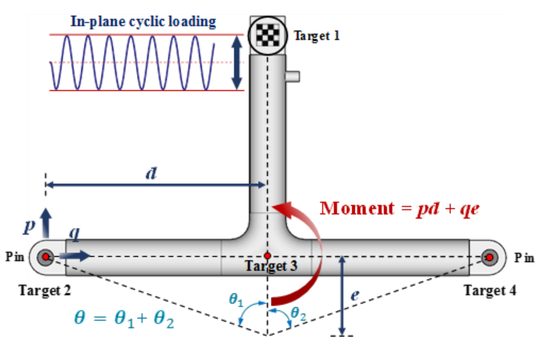
Load Case : ±10mm, ±20mm, ±40mm, ±60mm, ±80mm



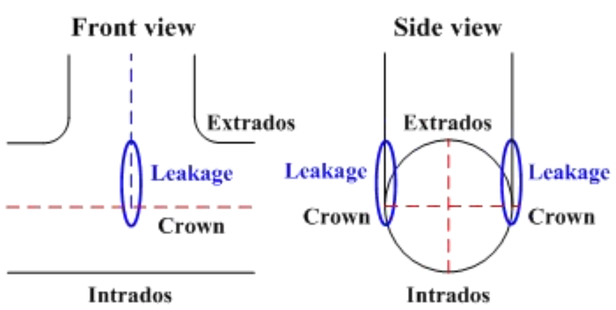


❖ Measurement position

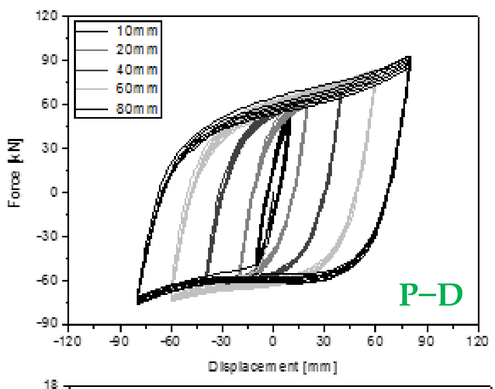


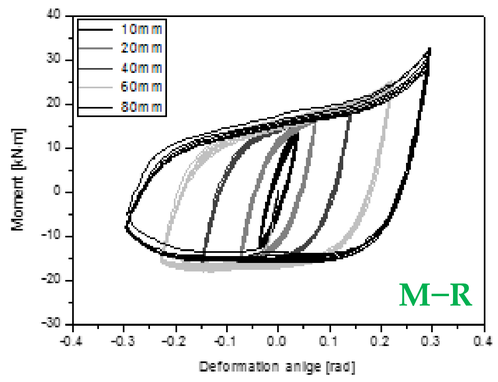


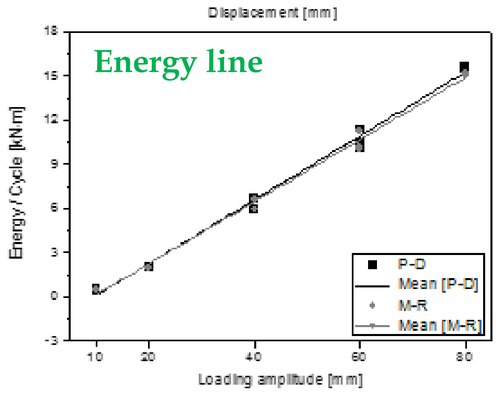
❖ Failure mode (Leakage)



❖ Energy







Energy for each cycle

$(P-D)\ y = 0.22x - 2.07,\ R^2 = 0.99$

$(M-R)\ y = 0.21x - 1.97,\ R^2 = 0.99$

Limit State Assessment

❖Damage index

Park and Ang

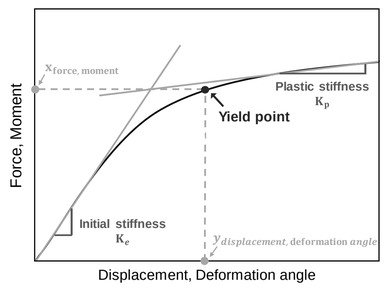
$$D_{P-D} = max\left(\frac{D_i}{D_y}\right) + b\sum_{i=1}^{N}\left(\frac{E_i}{F_y D_y}\right) \qquad D_{M-R} = max\left(\frac{\theta_i}{\theta_y}\right) + b\sum_{i=1}^{N}\left(\frac{E_i}{M_y \theta_y}\right)$$

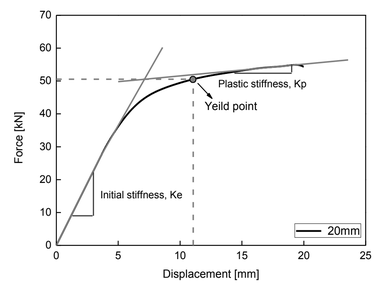
Bannon

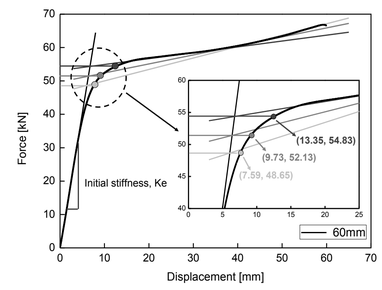
$$D_{P-D} = \sqrt{\left(max\left(\frac{D_i}{D_y} - 1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(\frac{E_i}{F_y D_y}\right)^d\right)^2} \qquad D_{M-R} = \sqrt{\left(max\left(\frac{\theta_i}{\theta_y} - 1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(\frac{E_i}{M_y \theta_y}\right)^d\right)^2}$$

❖Yield point

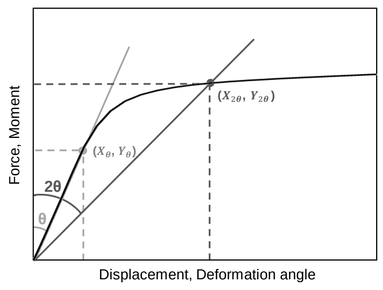
Tangent intersection method

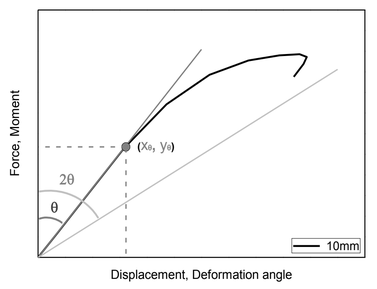


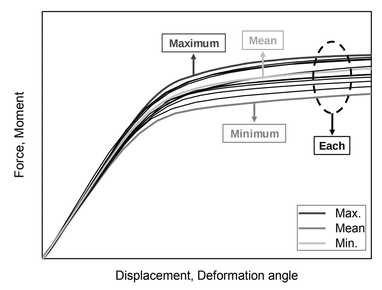




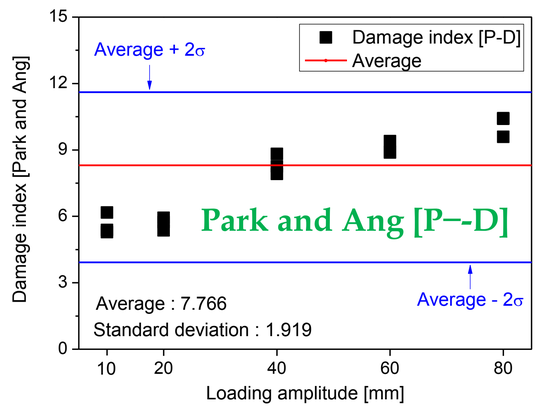
Twice-elastic slope method

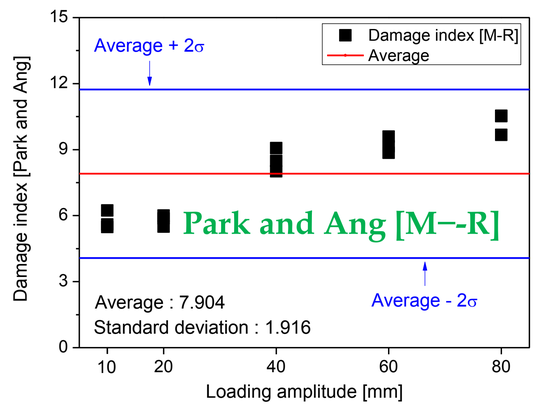


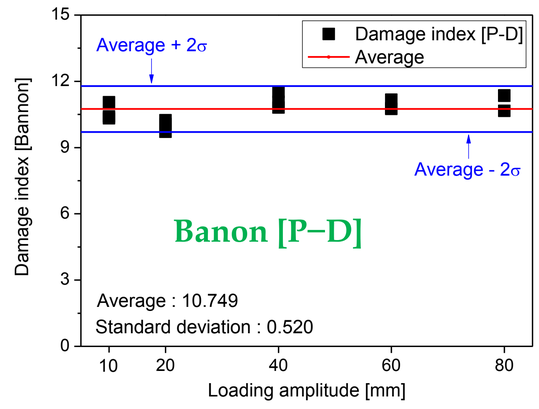


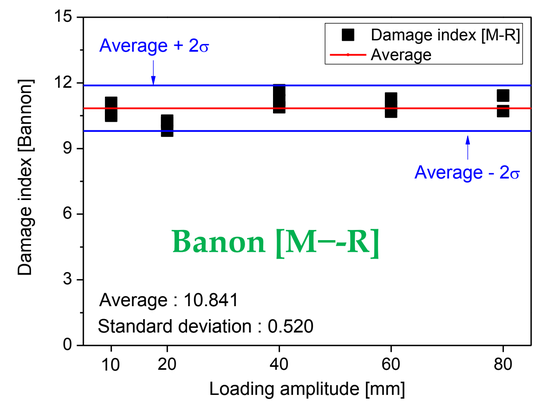


❖Comparison of damage index









Comparison of statistical data for damage index

Statistics	Damage Index			
	Park and Ang		Bannon	
	P–D	M–R	P–D	M–R
Average	8.30	8.44	10.79	10.87
Standard deviation	1.90	1.90	0.54	0.53
Variation	3.61	3.62	0.29	0.29

Conclusions

The damage index of Banon was calculated for all loading amplitudes using the yield point of the mean regression curve. There was a maximum difference of 2.52% between the damage indices of Banon for the P–D and M–R relationships, and all the damage indices were within ±2σ. The standard deviation for the damage indices calculated using the P–D and M–R relationships was less than 0.6. This indicates that the damage index of Banon is suitable for quantifying the failure criteria for the SCH 40 3-inch carbon steel pipe tee. Therefore, the method of calculating the damage index proposed in this study can be used to calculate the quantitative failure criteria that can express the leakage of nuclear power plant piping systems.