Estimation of the Damage Index for a Nuclear Power Plant Piping System

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Abstract

In general, the crossover piping system is composed of straight pipes and fittings such as elbows and tees. It was found that the failure mode of the crossover piping system under seismic loads is low-cycle fatigue failure accompanied by ratcheting, and that elements that fail due to the concentration of nonlinear behavior are fittings. This study aimed to quantitatively define the failure criteria for the pipe elbow, which is an element vulnerable to seismic loads in the crossover piping system of a base-isolated nuclear power plant, using Banon's damage index. The limit state of the pipe elbow was quantitatively expressed using the damage index based on the force–displacement (P–D) relationship, and the damage index based on the moment–relative deformation angle (M–R) relationship.

Low Cycle Fatigue Test

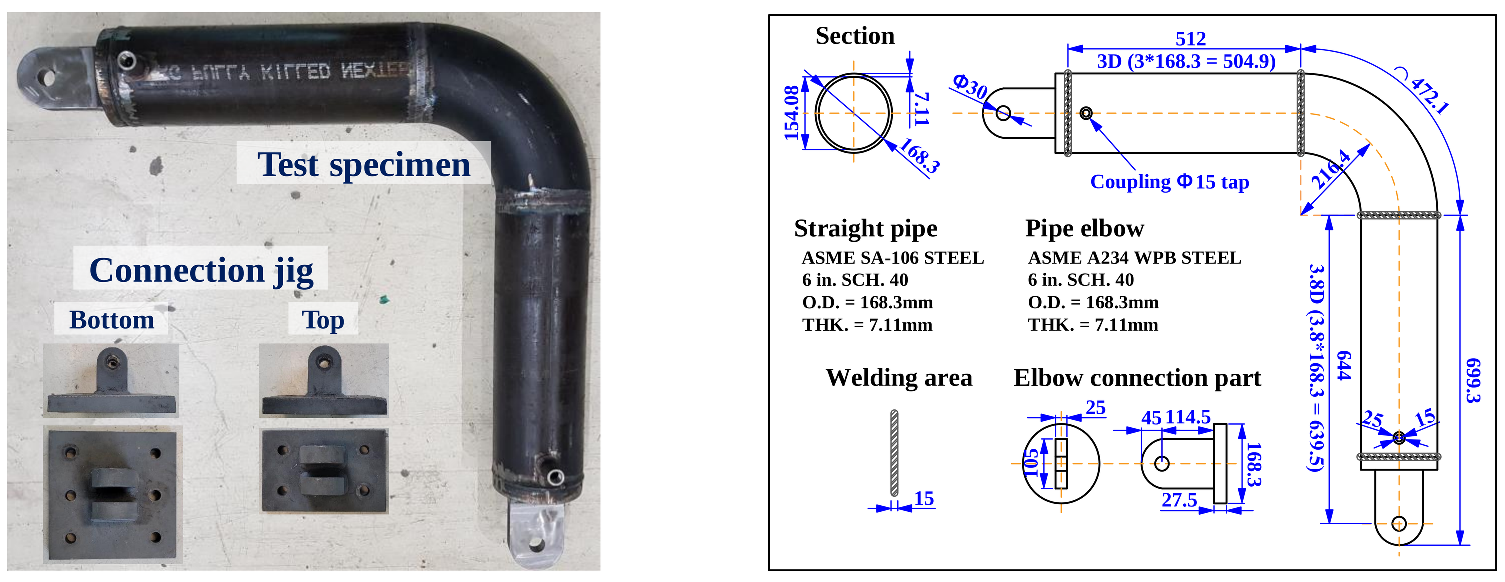
❖ Experimental Setup

Pipe : ASME B36. 10, SA-106 STEEL 6-inch SCH. 40(STD), THK.=7.11mm

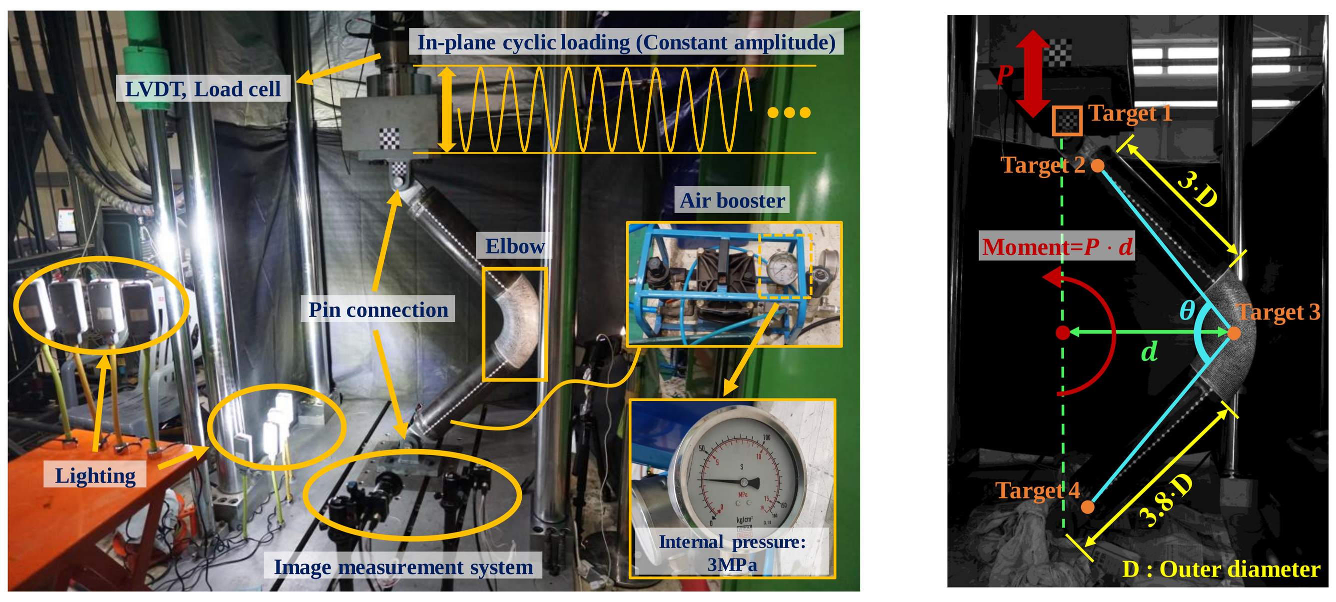
Elbow : ASME A234 WPB STEEL 6-inch SCH. 40(STD), THK.=7.11mm

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

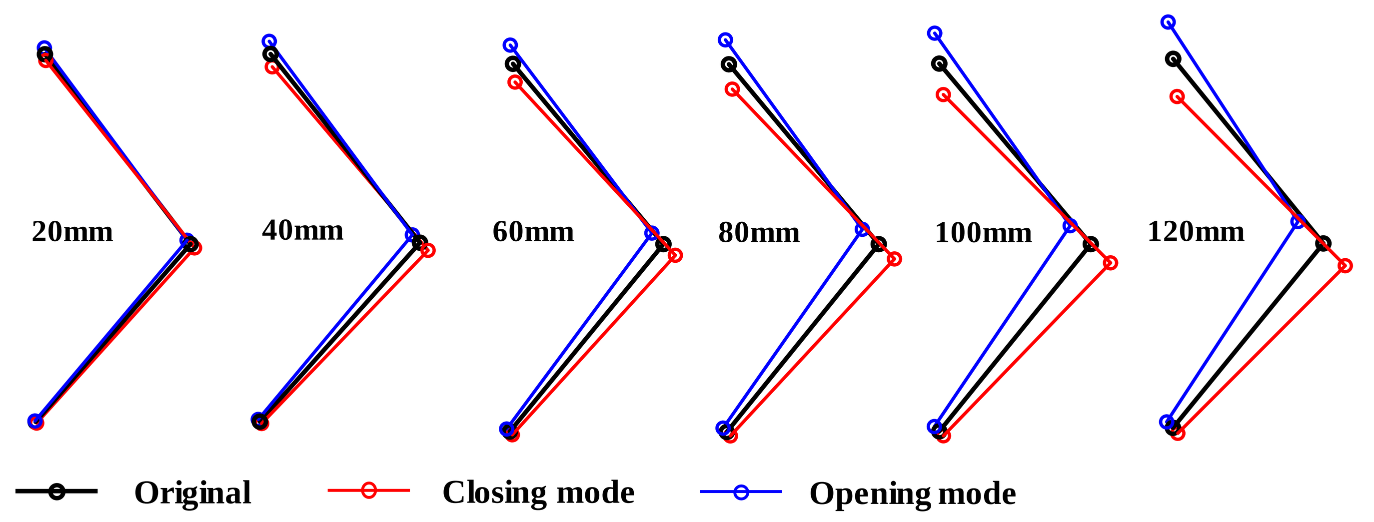
Load Case : ±20mm, ±40mm, ±60mm, ±80mm, ±100mm , ±120mm



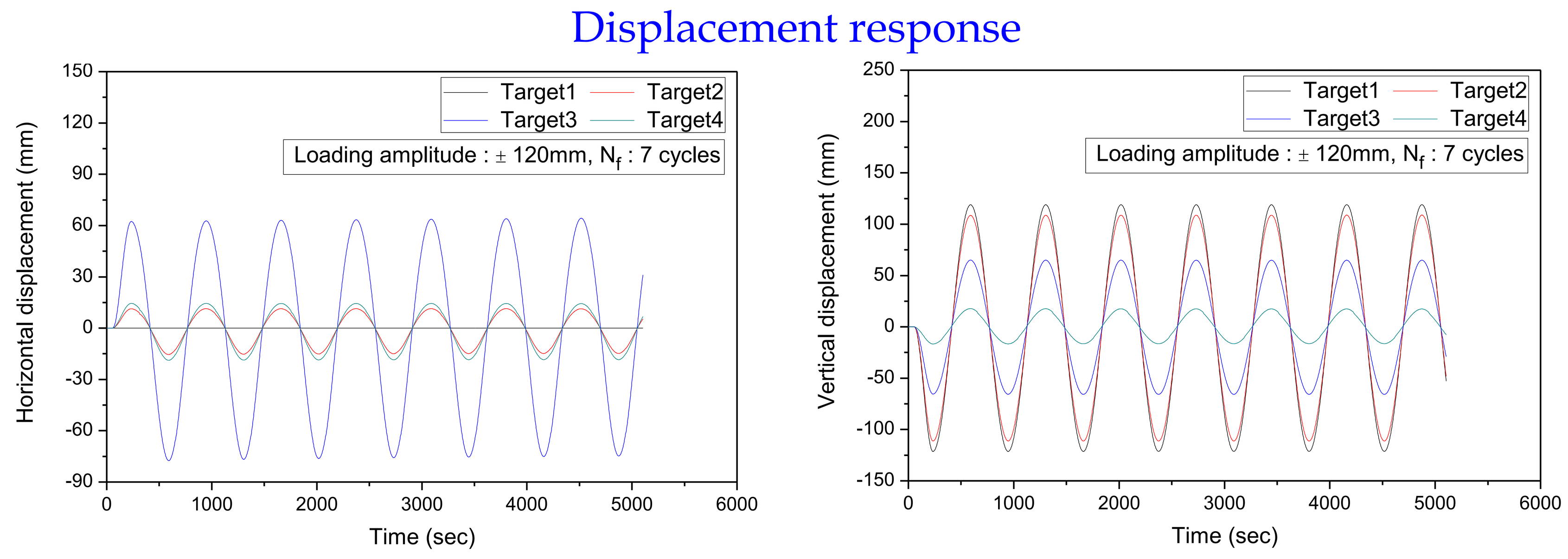
❖ Measurement position



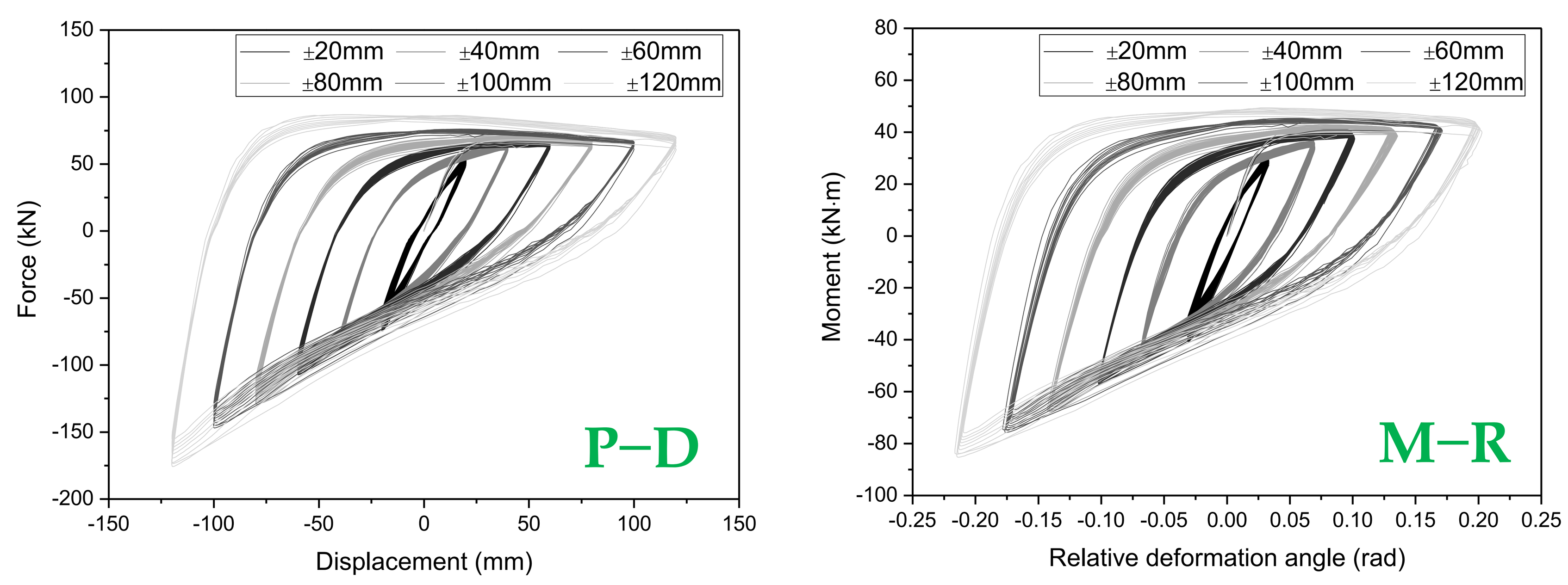
❖ Deformed shape



Displacement response



❖Hysteresis loop



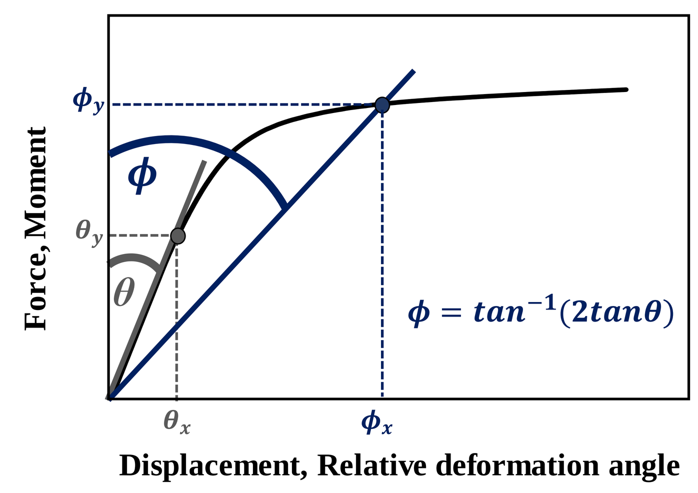
Limit State Assessment

❖ Bannon damage index

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

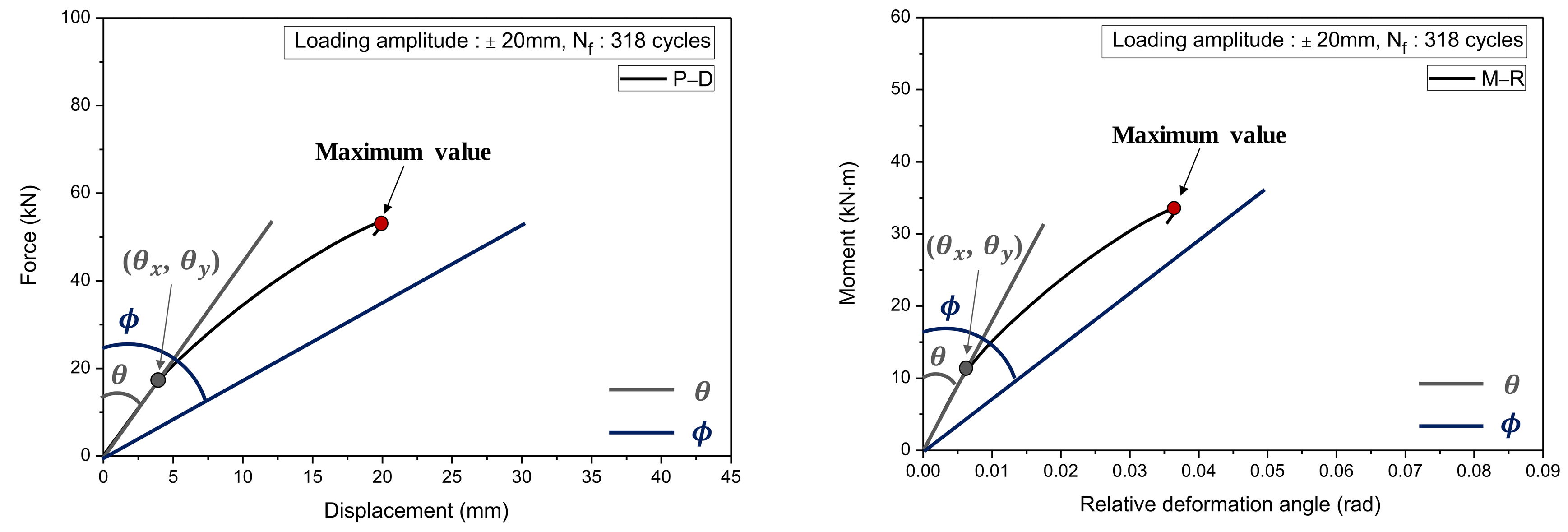
$$D_{M-R} = \sqrt{\left(max\left(\frac{\theta_i}{\theta_y}-1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(\frac{E_i}{M_y \theta_y}\right)^d\right)^2}$$

❖ TES method

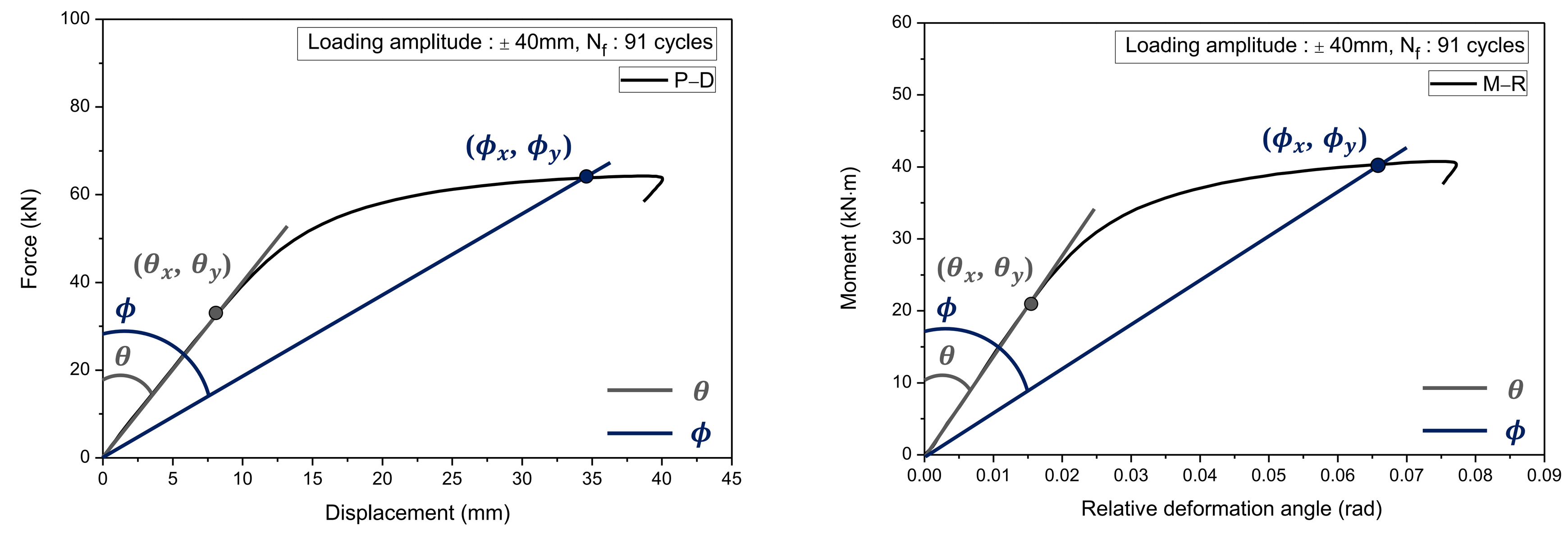


❖Yield point calculation using TES method

P–D and M–R relationships at a loading amplitude of ±20 mm.

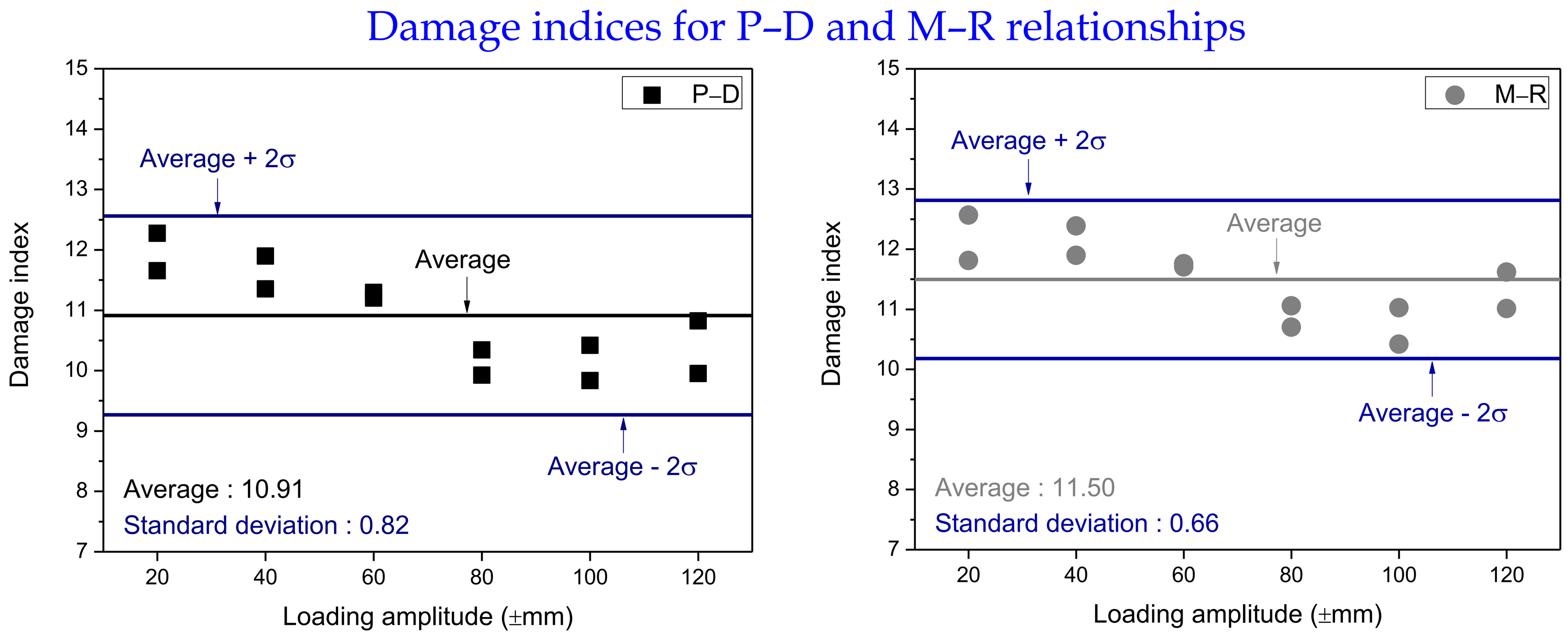


P–D and M–R relationships at a loading amplitude of ±40 mm.

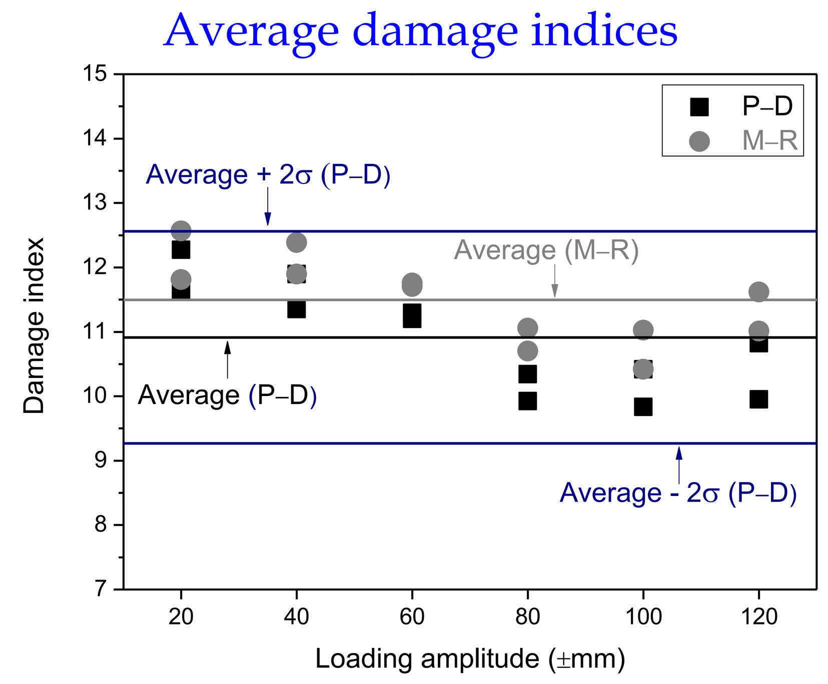


❖Comparison of damage index

Damage indices for P–D and M–R relationships



Average damage indices



Statistical information

Statistical data	Damage index	
	P–D	M–R
Maximum	12.28	12.57
Minimum	9.83	10.42
Variance	0.68	0.43
S.D.	0.82	0.66

Conclusions

In this study, The failure criteria for the SCH40 6-inch carbon steel pipe elbow were quantitatively expressed using the damage indices that can consider the combination of ductility and energy dissipation. There was an approximately 5% difference between the average values of the damage indices calculated using the P–D and M–R relationships. In addition, all the damage indices for each loading amplitude were confirmed to have been located between ±2σ (the standard deviation) of the average line. Moreover, the standard deviations for the damage indices calculated using the P–D and M–R relationships were found to be less than 0.8. This confirmed that the damage indices calculated using the P–D and M–R relationships can quantitatively express the failure criteria for the limit state of the 6-inch carbon steel pipe elbow.