Cumulative Damage Indices in a Carbon Steel Pipe Elbow under Cyclic Loading

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Abstract

In this study, the in-plane cyclic loading test was conducted on a test specimen composed of a 3-inch pipe elbow and 3-inch straight pipes, which are mainly used in the piping of nuclear power plants, through displacement control. The test was conducted using constant amplitudes of various sizes until leakage, which is the limit state of the test specimen, occurred. From the test results, the limit state in which leakage occurred in the test specimen was quantitatively expressed using the damage indices based on the force–displacement and moment–deformation angle relationships. Park and Ang's damage index and Banon's damage index, which can express cumulative damage, were used.

Low Cycle Fatigue Test

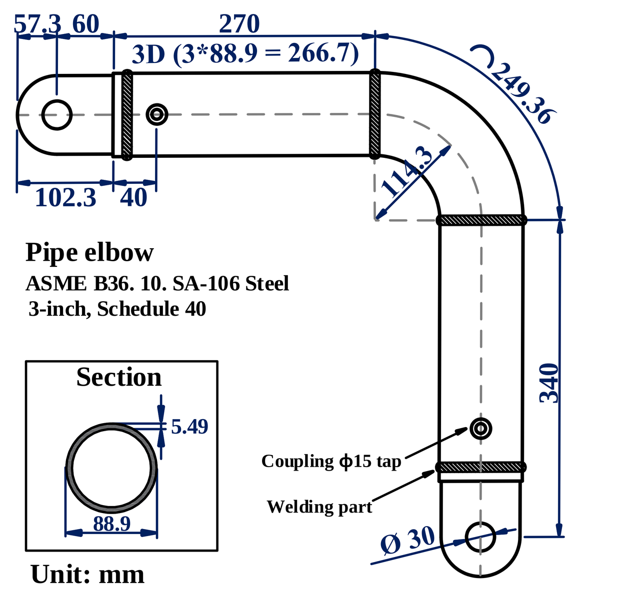
❖ Experimental Setup

Pipe : ASME B36. 10, SA-106 STEEL 3-inch SCH. 40(STD), THK.=5.5mm

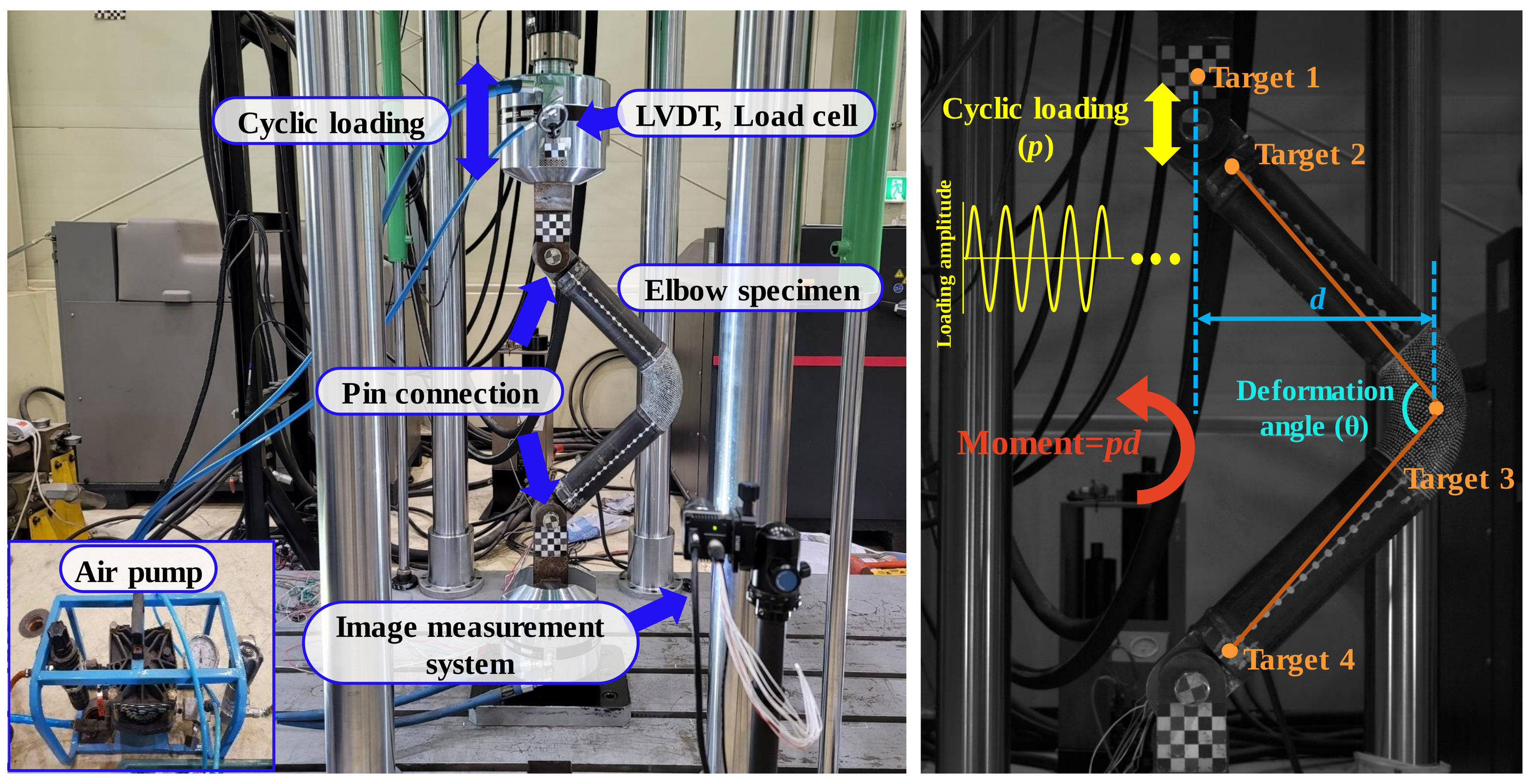
Elbow : ASME A234 WPB STEEL 3-inch SCH. 40(STD), THK.=5.5mm

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

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

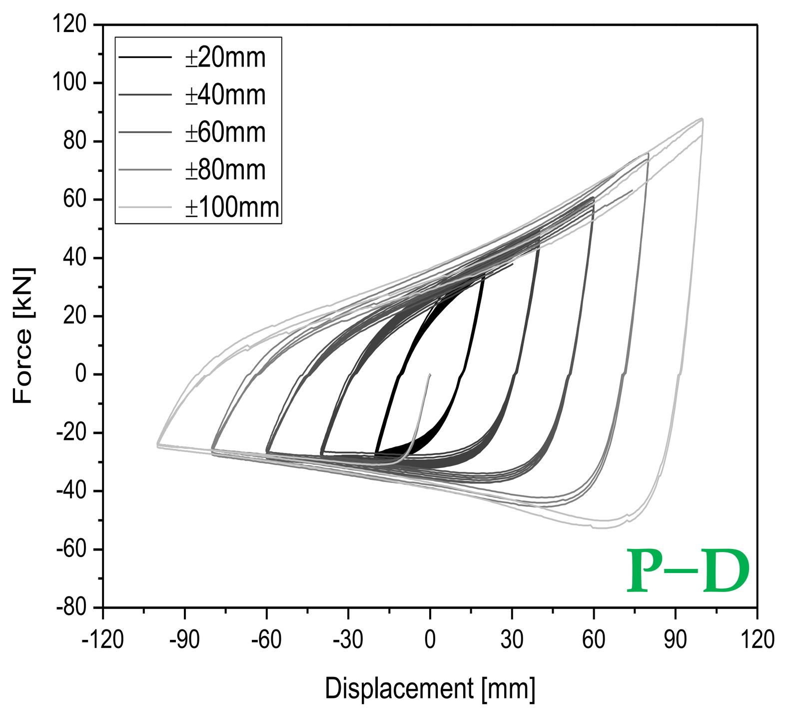


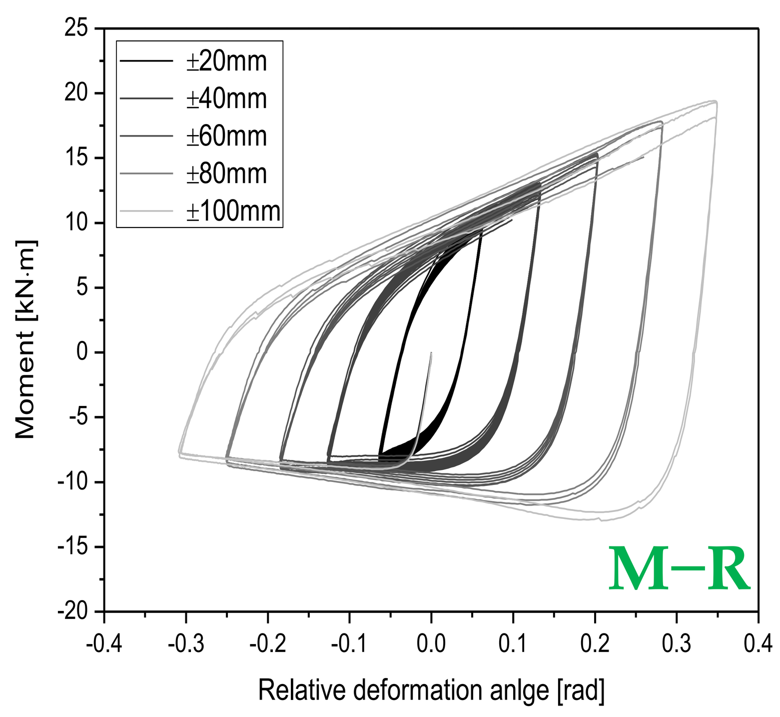
❖ Measurement position



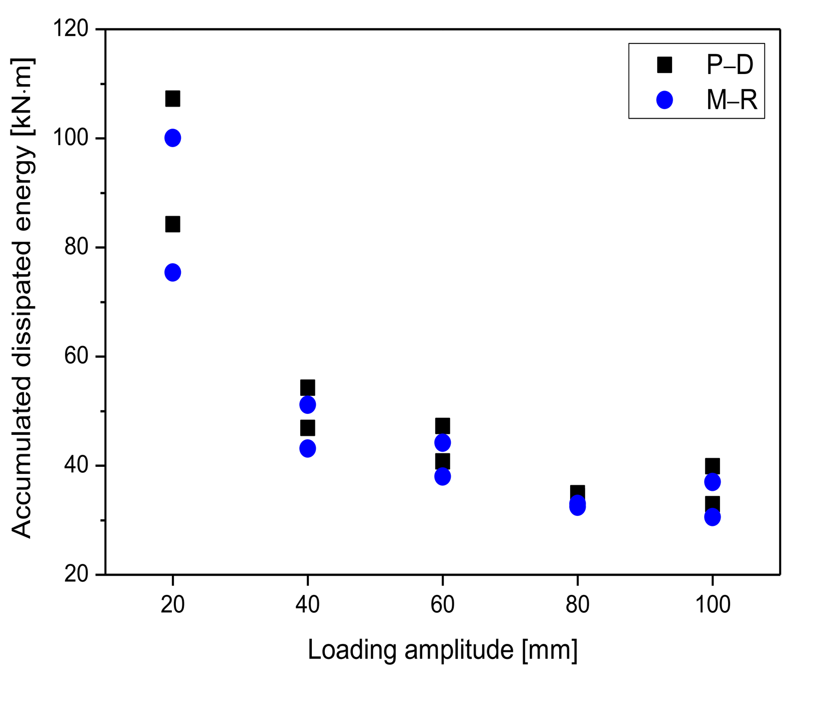
❖ Energy

Hysteresis loop





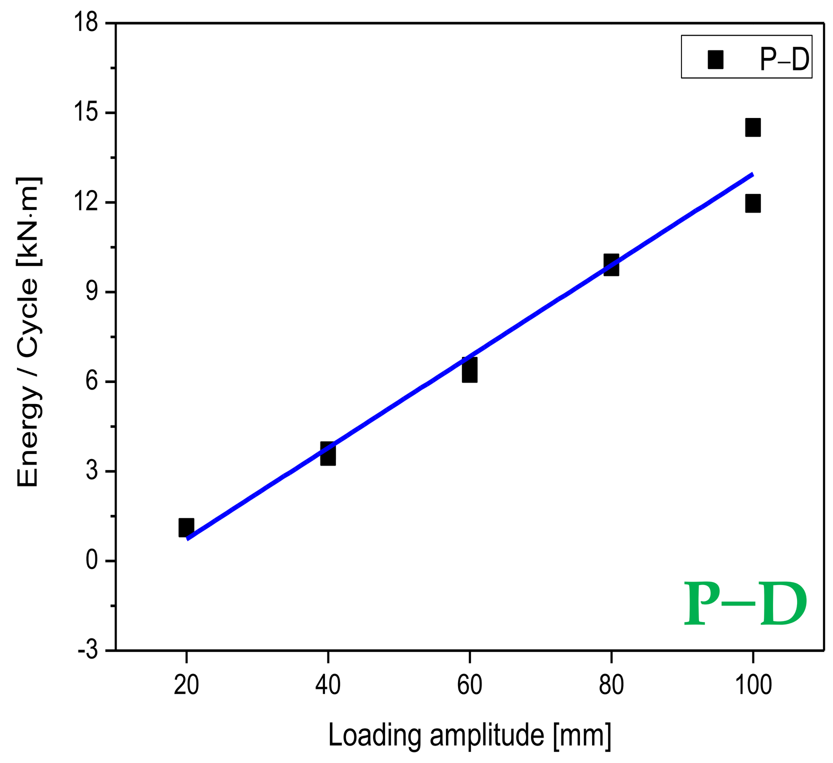
Comparison of statistical data for damage index



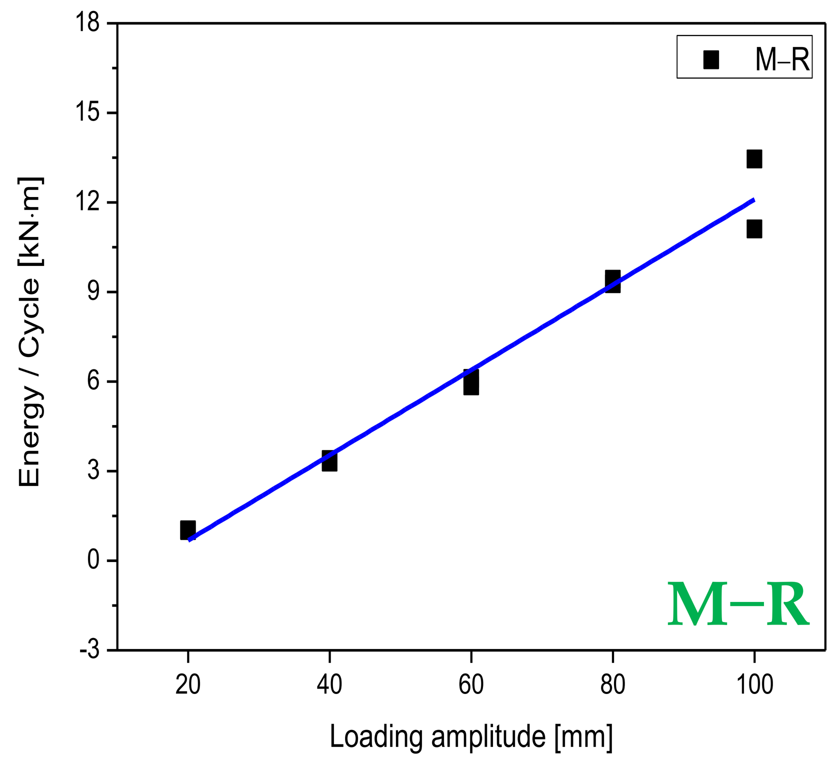
Loading amplitude (mm)	Accumulated dissipated energy		
	P–D	M–R	Difference (%)
±20	84.23	75.41	11.69
	107.27	100.08	7.18
±40	46.91	43.13	8.76
	54.26	51.16	6.06
±60	47.23	44.20	6.86
	40.76	38.02	7.22
±80	34.44	32.45	6.15
	34.91	32.97	5.90
±100	39.87	36.98	7.81
	32.90	30.54	7.76

Energy for each cycle

$(P-D)\ y = 0.15x - 2.32, R^2 = 0.98$



$(M-R)\ y = 0.14x - 2.17, R^2 = 0.98$



Limit State Assessment

❖Damage index

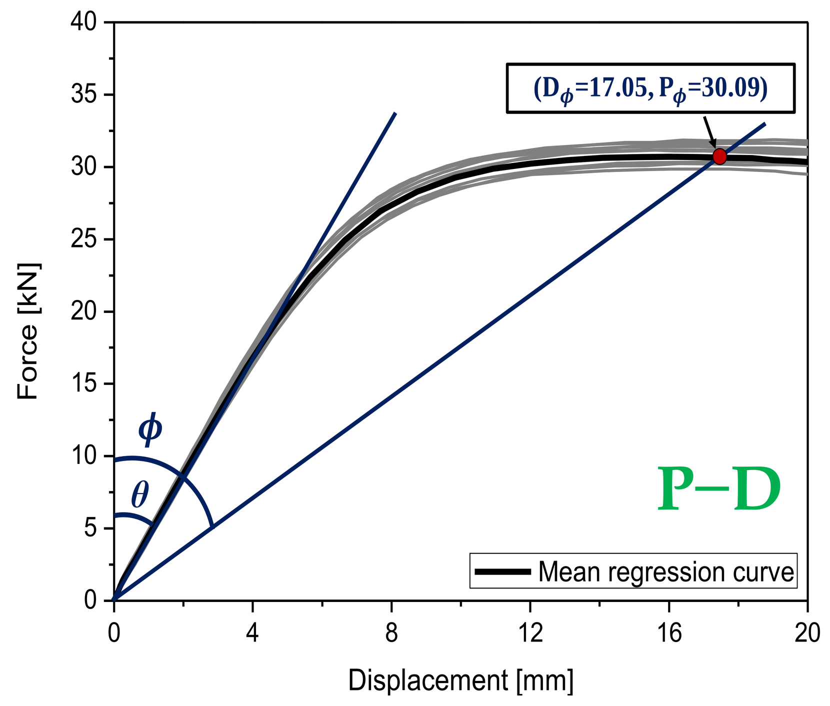
Park and Ang

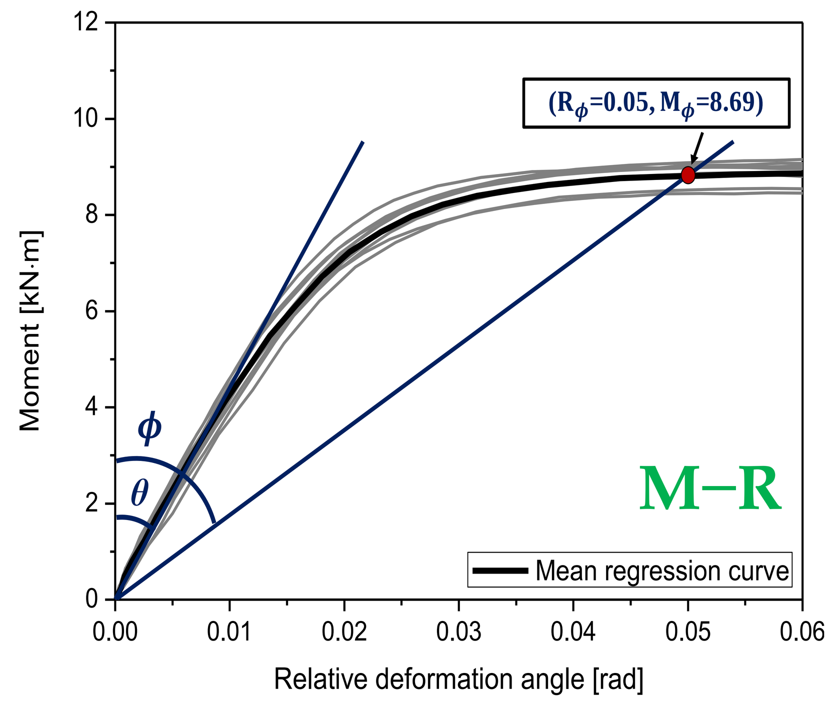
$$D_{P-D} = max\left(\frac{D_i}{D_y}\right) + b\sum_{i=1}^{N}\left(\frac{E_i}{F_y D_y}\right) \qquad D_{M-R} = max\left(\frac{\theta_i}{\theta_y}\right) + b\sum_{i=1}^{N}\left(\frac{E_i}{M_y \theta_y}\right)$$

Bannon

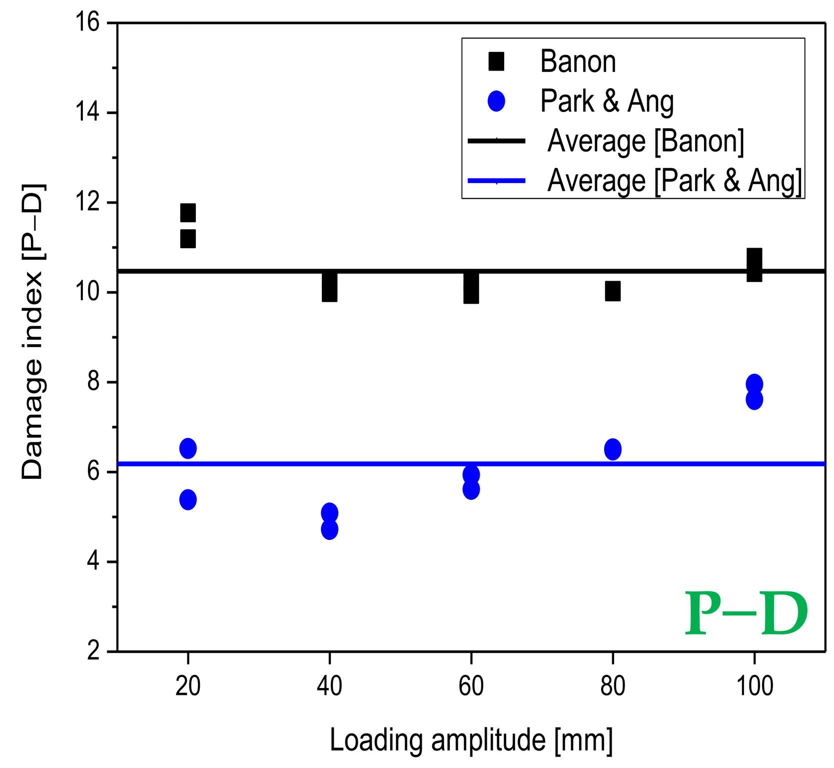
$$D_{P-D} = \sqrt{\left(max\left(\frac{D_i}{D_y} - 1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(\frac{E_i}{F_y D_y}\right)^d\right)^2} \qquad D_{M-R} = \sqrt{\left(max\left(\frac{\theta_i}{\theta_y} - 1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(\frac{E_i}{M_y \theta_y}\right)^d\right)^2}$$

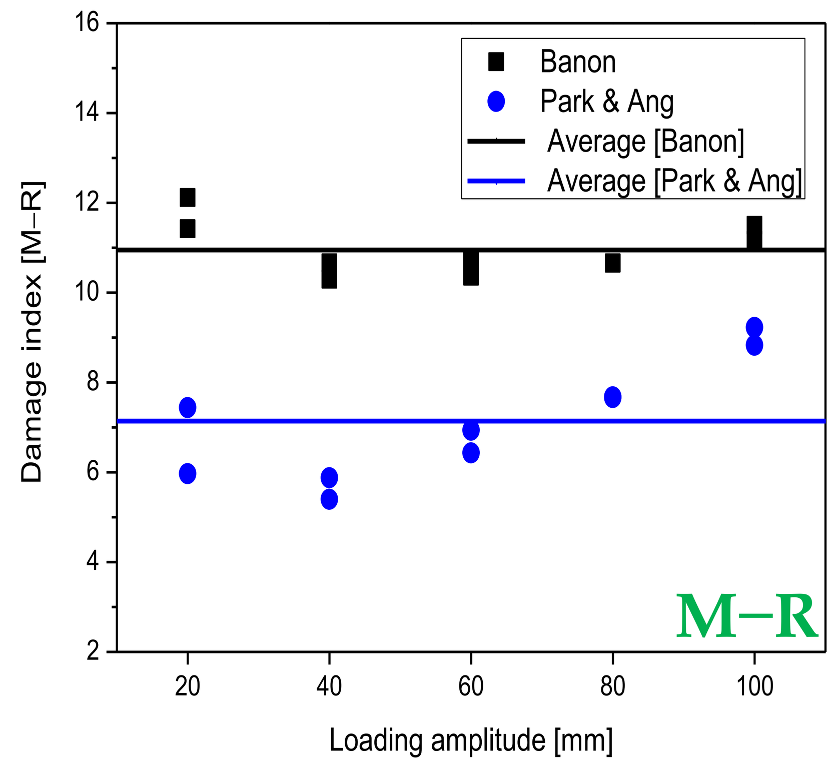
❖Yield point





❖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	6.18	7.14	10.47	10.95
Standard deviation	0.99	1.20	0.57	0.55

Conclusions

In this study, the failure mode of the test specimen was defined as the leakage caused by through-wall cracks. In the limit state, damage indices must be distributed with a small standard deviation from the average value. Therefore, it was found that the use of Banon's damage index is more appropriate to use than Park and Ang's damage index to express the limit state of the test specimen.