Ratcheting Strain Measurement of a Steel Pipe Elbow under In-plane Cyclic Loading

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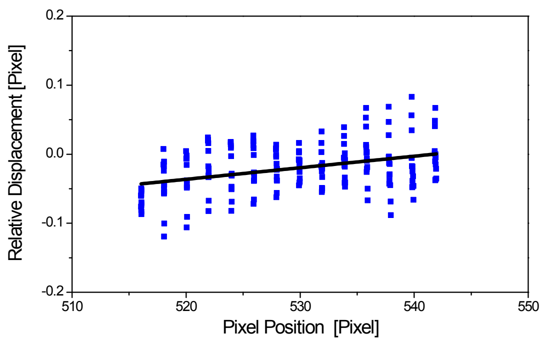
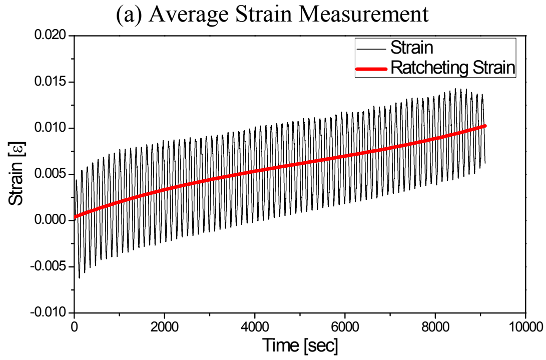
1. Introduction

Currently, the limit state of the piping design standard is plastic collapse, and the actual pipe failure is leakage due to penetration crack [1]. However, actual pipe failure cannot be applied to the analysis of seismic fragility because it is difficult to quantify. Therefore, this study proposes method of measuring ratcheting strain [2], which is required for evaluating the quantitative failure criteria of piping by using an image signal. Generally, strain is an important factor in evaluating structure integrity. It is primarily measured using contact type methods such as an electric resistance strain gage. However, an electric resistance strain gage is sensitive to the external environment. Moreover, it cannot be relocated or reused, and it has a limited measurement range. Therefore, measuring a large strain is difficult. Therefore, a method for measuring the strain from a remote distance, without attaching any sensor, is required. In this study, the ratcheting strain was measured efficiently by using the image signal.

2. Ratcheting Strain Measurement Using Image Signal



(a) Average Strain Measurement

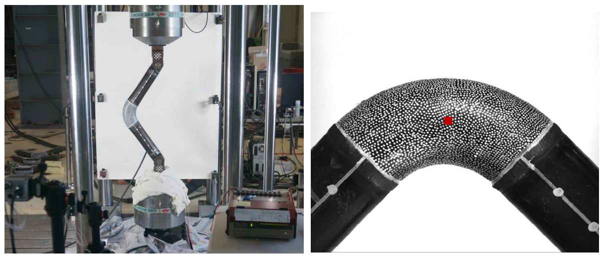


(b). Ratcheting Strain Measurement

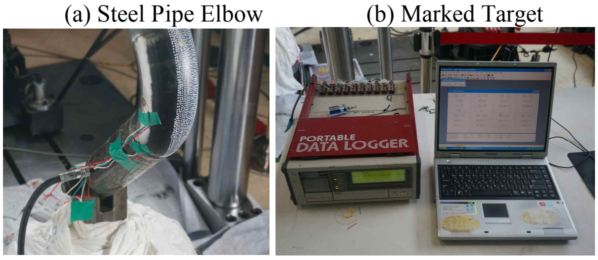
Fig. 1. Ratcheting Strain Measurement Using Image Signal

When conducting the in-plane cyclic loading test on the steel pipe elbow, considering the component characteristics, the strain in hoop direction was measured by using the average strain [3], as shown in Fig. 1 (a). The axial displacement along the axis direction was plotted for each image based on the pixel, and the linear function was used to calculate the slope. This slope is the strain. The ratcheting strain was calculated by using the curve fitting algorithm, as shown in Fig. 1 (b).

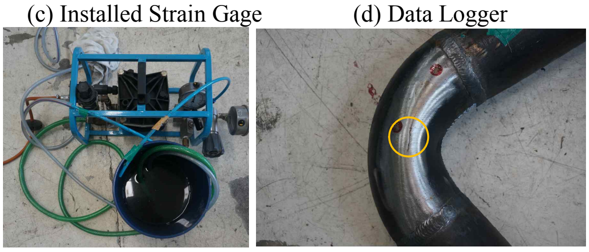
3. In-plane Cyclic Loading Test Using Steel Pipe Elbow



(a) Steel Pipe Elbow (b) Marked Target



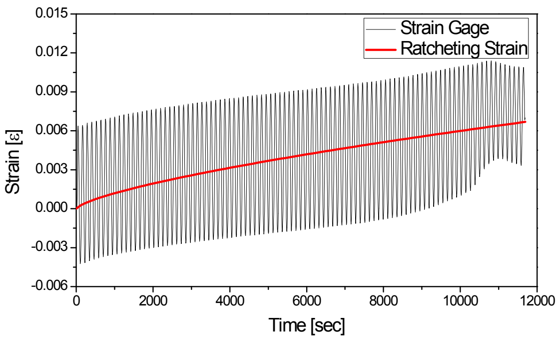
(c) Installed Strain Gage (d) Data Logger



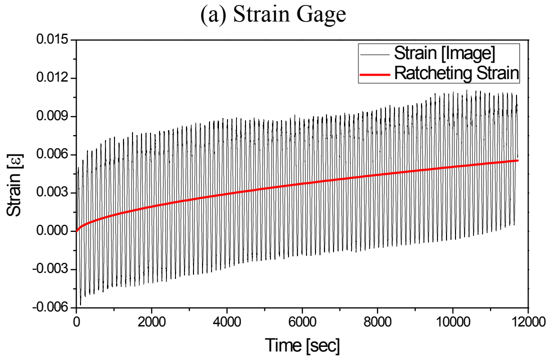
(e) Air Pump (f) Elbow with Crack

Fig. 2. Experimental Setup

The setup location of the sensor is shown in Fig. 2. An SA-106 3-inch SCH40 specimen of ASME B36.10M was manufactured. To enable the plastic behavior at the bend of the specimen, a direct pipe with sufficient length over 3D (270 mm) was welded to the elbow. To represent the pin connection on both ends of the specimen, a fixture was manufactured and welded to the specimen. The fixture was connected to the UTM (Universal Testing Machine). Fig. 2 (a) shows the steel pipe elbow installed on the UTM. Fig. 2 (b) represents a randomly marked target, which was installed to measure the ratcheting strain of the steel pipe elbow. At the red square region of the elbow, control points were used to estimate the ratcheting strain. Fig. 2 (c) shows the strain gage installed on the center of the symmetric side of the steel pipe elbow as installing the strain gage on the location where the image measurement system is installed can disturb the image analysis. Figure 2 (d) shows the data logger for storing strain response. Fig. 2 (e) refers to the air pump used for the internal pressurization of the steel pipe elbow up to a pressure of 3 MPa. Fig. 2 (f) shows the elbow affected by a through crack formed at the crown. By using image signal, the ratcheting strain measured from the strain gage was compared with the strain. During the in-plane cyclic test, the image measurement system was used to acquire 2448 × 2048 pixel images at 2 frames per second. The strain response was measured at a speed of 0.25 Hz, respectively.



(a) Strain Gage

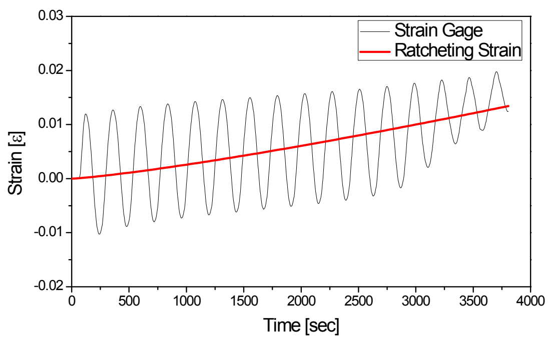


(b) Image Signal

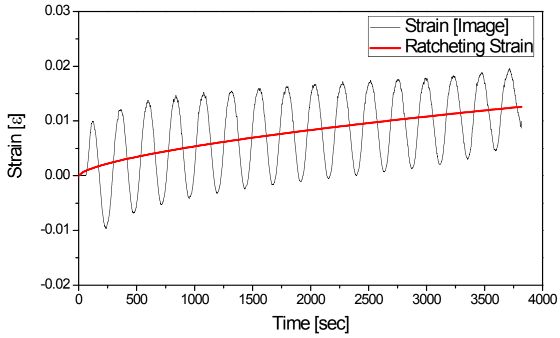
Fig. 3 Ratcheting Strain Measurement in ±20 Load Case

Table I: Max. Ratcheting Strain

Load Case	Strain Gage	Image	Difference (%)
±20	0.0067	0.0061	8.955
±40	0.0134	0.0126	5.970



(a) Strain Gage



(b) Image Signal

Fig. 3 Ratcheting Strain Measurement in ±40 Load Case

Figs. 3 and 4 compare the strain measured in the hoop direction using the image signal and the response measured by the strain gage. In the figure, the black line shows the strain and the red line shows the ratcheting strain. In Table I, the error rate is within 10%, which indicates that the error is somewhat large. However, this is seemingly due to the local problem of installing the strain gage symmetrically.

4. Conclusions

The ratcheting strain of the steel pipe elbow was measured using the image signal. The accumulative strain is expected to be of use when estimating the failure criteria. In addition, by using the image signal, the ratcheting strain at a remote distance can be measured without the installation of a conventional sensor. Therefore, the ratcheting strain is expected to become major factors for defining the failure criteria of the piping system.

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REFERENCES

[1] B.G. Jeon, S.W. Kim, H.S. Choi, D.U. Park, N.S. Kim, A failure estimation method of steel pipe elbows under in-plane cyclic loading, Nuclear Engineering and Technology, Vol.49, p.245, 2017.
[2] S.K. Gupta, S. Goyal, V. Bhasin, K.K. Vaze, A.K. Ghosh, H.S. Kushwaha, Ratcheting-Fatigue Failure of Pressurized Elbows made of Carbon Steel, International Conference on Structural Mechanics in Reactor Technology (SMiRT 20), August 9-14, 2009, Espoo, Finland.
[3] S.W. Kim, H.S. Choi, B.G. Jeon, D.G. Hahm, M.G. Kim, Strain and deformation angle for a steel pipe elbow using image measurement system under in-plane cyclic loading, Nuclear Engineering and Technology, Vol.50, p.190, 2018.