第 I 部門　Setting the Fiber Model for Estimating the Allowable Displacement of Steel Bridge Piers Based on Cyclic Loading Experiments

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1. Foreword

The 1995 Hyogo-ken Nanbu Earthquake promoted widespread research efforts consisting of both experimental and analytical studies for the purpose of understanding the performance of steel bridge piers under seismic loads. The 1996 revised seismic design specification stipulated that ductility design method be used and performance be estimated on a nonlinear dynamic analysis using a hysteretic restoring force model. The fiber model uses a stress-strain hysteretic restoring force model[1] and therefore can consider changing axial forces within a rigid frame. For this reason the fiber model is considered more accurate.

Fig.1 A rectangular specimen

2. Nature of Research

In this research, the fiber model is used for analysis of single rectangular specimens of approxiamately 1/3 scale[2] under pushover and cyclic loading pattern. Strain (on the compression face) and curvature (at base) are considered as parameters for expressing the allowable displacement of each pier.

3. Analysis Results

Seventeen rectangular piers were analysed for allowable strain and allowable curvature. Allowable strain (ε_a) is defined as strain when the pier has been deflected to the displacement of maximum load as defined by an experimental cyclic loading test. Results of allowable strain to yield ($\varepsilon_a/\varepsilon_y$) were graphed against width thickness to flange ratio R_F and a strong negative correlation was found (Fig.2). The strain results shows that pushover analysis yields lower results than compared to a cyclic analysis. Allowable curvature (ϕ_a) is defined as the difference of compression and tension face allowable strain per unit width. Similarly, a strong correlation was found with curvature (ϕ_a/ϕ_y) against R_F (Fig.3). Curvature results show that pushover and cyclic loading patterns yield almost identical results. In comparison, strain is affected by pushover or cyclic loading pattern while curvature is hardly affected at all.

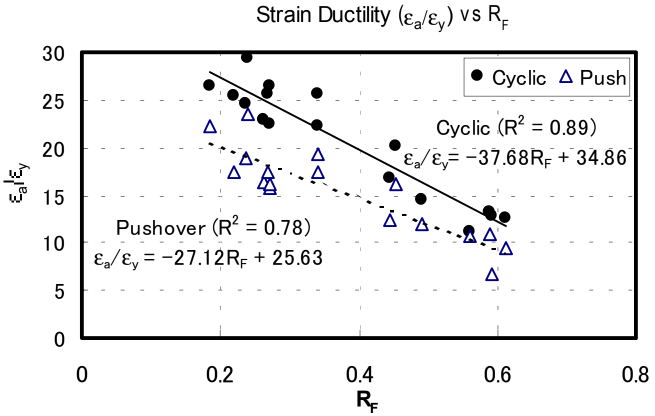

Fig. 2　Results for strain ductility

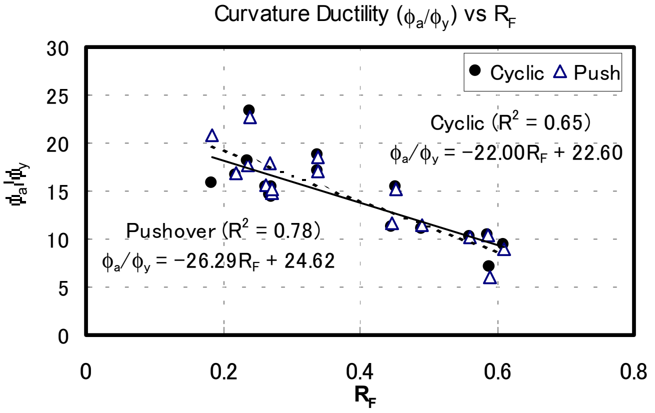

Fig. 3　Results for Curvature Ductility

$$R_F = \frac{b}{t}\sqrt{\frac{\sigma_{yM}}{E}\,\frac{12(1-\upsilon^2)}{\pi^2 k_F}} \qquad \textbf{(Eq. 1)}$$

b = flange width　　t = flange plate thickness
υ = Poisson’s ratio (=0.3)　E = Young’s modulus
σ_{yM} = material lower yield stress
k_F = buckling coefficient of a stiffened plate.

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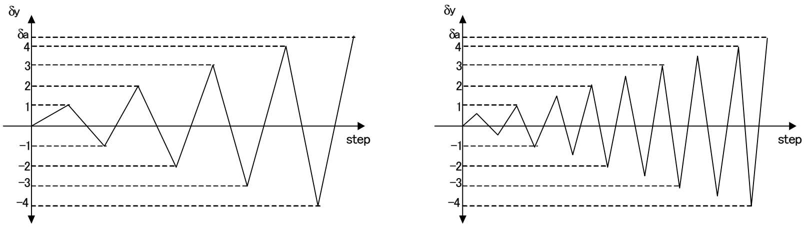
5.Cycle Influence Study

During an earthquake the loading pattern may take any form. Hence, an investigation into the influence that the cyclic loading pattern exhibits on strain and curvature results was conducted. The cyclic analysis pattern was doubled and is as shown in Fig. 4. Results showed an increase in strain producing a larger ratio of allowable strain to yield strain ($\varepsilon_a/\varepsilon_y$). This is indicative of the influence of the axial force for which with increasing cycles causes the strain to shift towards compression, thus increasing strain for increasing cycles as shown in Fig. 5 with a strain versus load step graph. However no change in curvature occured since the strain difference remained relatively unchanged. This indicates that curvature (ϕ_a/ϕ_y) has an advantage over strain ($\varepsilon_a/\varepsilon_y$) since in the range of allowable displacement the cyclic pattern makes no influence to the results.



(a) Standard Cyclic Loading Pattern (b) Double Step Cyclic Loading Pattern

Fig 4. Cyclic patterns

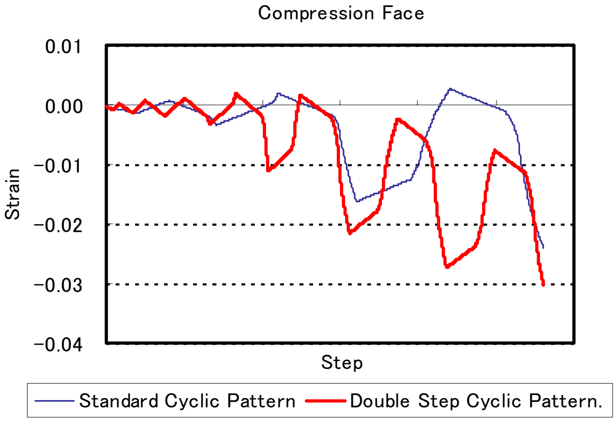


Fig. 5 Double step cyclic pattern for cyclic

6. Axial Force Influence Study

Omitting the axial force causes strain to decrease leading to a lower strain result ($\varepsilon_a/\varepsilon_y$) (Fig. 6). However, the strain difference between compression and tension faces remains unchanged thus causing no effect on curvature. This counterbalance effect shows that in the results of curvature, omitting the axial force yields no effect on the curvature of the pier. Furthermore, omitting the axial force causes strain results of pushover and cyclic anaylses to merge together (Fig. 7). With axial force applied, strain values diverge towards the compression side, thus giving a higher value of strain on the compression face than the tension face. However, omitting the axial force, the strain values do not diverge but oscillate symmetrically to the zero axis. This indicates that in the case of no axial force, strain is independent of cyclic pattern.

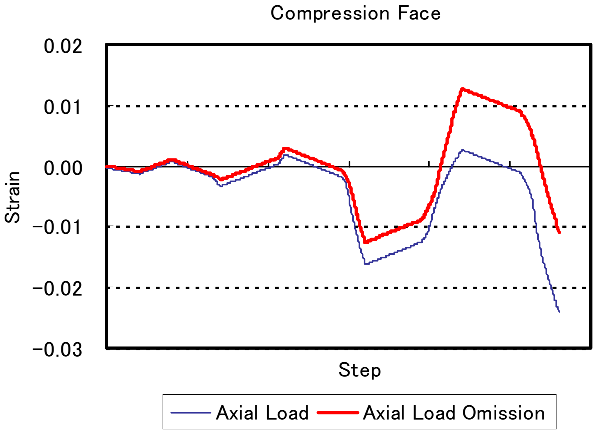


Fig. 6 Axial force omission for cyclic

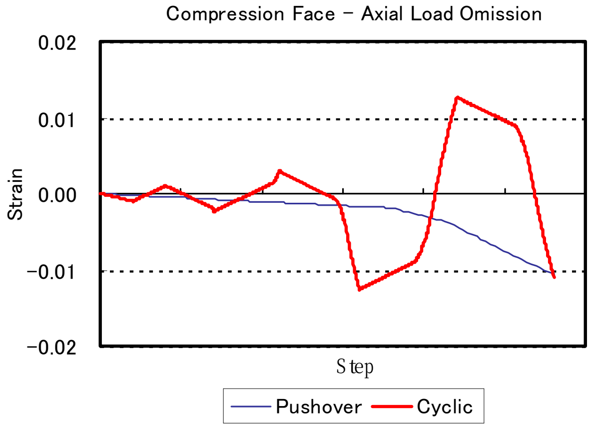


Fig. 7 Axial Load omission for cyclic and pushover

7. References

1) Nakasu, K., Ono, K., Nishikawa, K., & Nonaka, T, 2000. Research related to the Setting of Restoring Force Model using the Fiber Model for Steel Bridge Piers based on Experimental Results. Japan Society of Civil Engineers, 55th Annual Academic Meeting, I-A143, August.

2) Public Works Research Institute of the Ministry of Construction and five organisations: Ultimate Limit State Design Method of Highway Bridges Piers under Seismic Loading, Cooperative Research Reports.