ELASTO-PLASTIC BENDING BEHAVIOR OF STEEL SHORT CYLINDERS UNDER AXIAL FORCE FLUCTUATION

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1. Introduction

During the Hyogo-ken Nanbu earthquake, destructive damage is occurred in many steel structures. Extensive research has been carried out to understand the ductility and ultimate strength of short cylinders since this earthquake,. In these researches, the bending behavior of the structure under constant axial force is studied and practical formulae to estimate the ultimate strain are proposed. However, the axial force fluctuates together with the bending moment during earthquakes in some structures, such as portal frame bridge piers and arches subjected to in-plane excitation.

The influence of the axial force fluctuation on the ductility and the moment capacity of steel cylinders is studied in this research based on the results of the numerical analyses of the parametric steel short cylinder models.

2. Studied Models

The structural parameters of the short cylinder models used in the numerical analysis are listed in **Table 1**.The radius–thickness ratio parameter (R_t), which is given by

$$R_t = \sqrt{3(1-\nu^2)} \cdot \frac{\sigma_y}{E} \cdot \frac{r}{t} \tag{1}$$

where, E=Young`s modulus, $\upsilon$=Poisson`s ratio, σ_y=yield stress, r= radius of the cylinder and t= thickness of the cylinder, is set as the main parameter. The length of the cylinders (L) is set to the critical length that gives a minimum ultimate strength. A typical finite element mesh which is shown in **Figure 1** is employed to analyze the cylinders by using the general purpose finite element analysis software “Marc”. Because of symmetry about the midsurface in the longitudinal direction, only the upper half of a cylinder is modeled and a simply supported boundary condition is assumed for the lower boundary of the model. The upper boundary nodes are linked to the node situated at the diaphragm center by a constraint condition which defines a plane motion under bending with the diaphragm center node. The cylinders are made of mild steel (SS400) and a tri-linear stress-strain relationship is adopted to account for the material nonlinearity. Initial imperfections, i.e. the residual stresses and the initial geometrical deflection, are taken into account.

Table 1: Analyzed Models

MODEL	D (mm)	t (mm)	L (mm)	D/t	R_t	L/D
1	1062	20	173.6	53.1	0.050	0.164
2	1328	20	199.2	66.4	0.063	0.150
3	1988	20	252.6	99.4	0.094	0.127
4	2656	20	292.2	132.8	0.125	0.110
5	3980	20	350.2	199.0	0.188	0.088
6	5308	20	398.0	265.4	0.250	0.075
7	6636	20	411.4	331.8	0.313	0.065
8	7962	20	420.0	398.1	0.375	0.053
9	10616	20	407.0	530.8	0.500	0.038

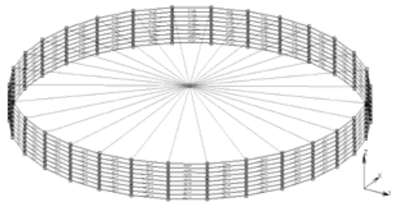

Figure 1: Finite Element Model

3. Methodology

A series of elosto-plastic large displacement analysis of the generated models subjected to bending moment with constant or fluctuating axial force is conducted. The axial force is considered to increase linearly with the bending moment since the relationship between axial force and bending moment is linear during the earthquake excitations in members of portal frames and arches. This is simulated by an eccentrically applied displacement load (P_δ) with respect to the upper diaphragm center node (See **Figure 2**) which leads to axial force increments together with the bending

Keywords: Short cylinders, axial force fluctuation, large displacement analysis
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moment in a linear pattern. The initial axial force is applied concentrically and kept constant throughout the analysis. The variation of the bending moment and axial force with respect to the rotation of such procedure is shown in **Figure 3**. The initial axial force (P_i) is assumed as 20% of the squash load (P_y) and different fluctuation amounts are studied by changing the final axial force (P_f) which is modified by adjusting the eccentricity (e) of the applied load. For the constant axial force case, analyses are conducted by applying the final axial force of the fluctuating case to the upper diaphragm center node as a fixed value. The results of the two cases are compared to evaluate the influence of the axial force fluctuation.

4. Results and Discussions

The bending behavior under constant and fluctuating axial force is compared in **Figure 4** for Model 4 when the fluctuation is from P_i=0.2P_y to P_f=0.6P_y. It can be seen that the ultimate strength is the same for both cases. On the other hand, the ductility is significantly higher in the post-peak region for the fluctuating axial force case. In **Figure 5**, the strains at the outmost edge of the compressive side corresponding to the 95%, 90% and 80% of the ultimate strength after the peak load is shown for all of the models. It is seen that the ductility is higher in fluctuating axial force case for all of the models almost in the same amount although the ratio is much higher for the models with the R_t-value of 0.06-0.10. The increase in the ductility is more apparent when further post-peak behavior is considered. The analysis results are compared with the formulation proposed by Gao *et al.*[1] which gives the ultimate strain for the 95% of the ultimate strength after the peak load by considering the axial force as a constant value. The comparison is given in **Figure 6**. It can be seen that the ductility is fairly increased when the axial force fluctuation is considered and further improvement can be achieved by employing further post-peak behavior as the limit state. Modification of the current formula by certain correction function in order to consider the influence of the axial force fluctuation may be possible based on the figure.

5. Conclusions

It is found that the ductility corresponding to the post-peak behavior increases when the axial force fluctuation is considered although the moment capacity is not changed. Establishing some formulation that considers this finding may lead to the more rational design of steel pipe sections.

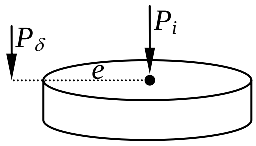

Figure 2: Loading method for axial force fluctuation

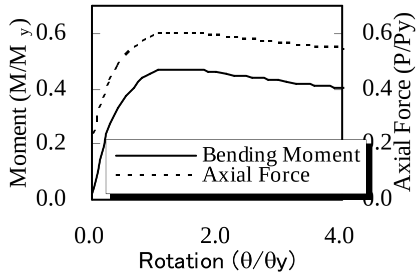

Figure 3: Axial Force Fluctuation (Model 4)

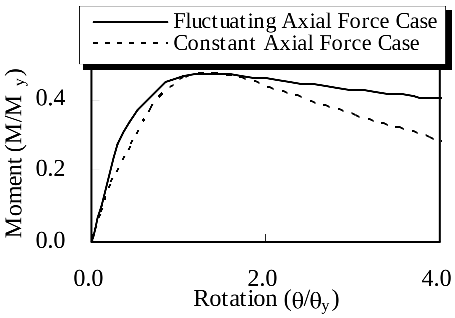

Figure 4: Bending Behavior (Model 4)

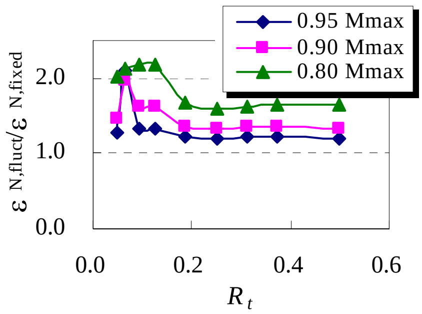

Figure 5: Post-Peak Ductility

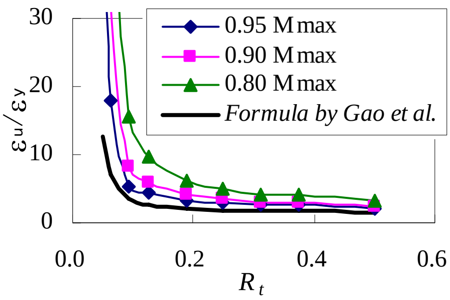

Figure 6: Comparison with a prior formulation

In the future work, correction functions will be developed that will modify the existing formula by considering the fluctuation effect after clarifying influence of all factors involved in the axial force fluctuation.

Reference

1) Gao S., Usami T., Ge H., "Ductility of steel short cylinders in compression and bending", *Journal of Engineering Mechanics*, (ASCE), 124(2), 176-186, 1998.