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. Since this earthquake, extensive research has been carried out to understand the ductility and ultimate strength of short cylinders. 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 short steel cylinder models.

2. Studied Models

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

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

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

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 models are generated by giving variations to it between 0.05 and 0.5. The length of the cylinders (L) is set to the critical length that gives a minimum ultimate strength. It is computed by the equation,

$$\frac{L}{D} = \frac{0.585}{R_t^{0.08}} - 0.580 \qquad (2)$$

where, D=diameter of cylinder. 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”. A type of four-node doubly curved shell element included in Marc element library is adopted. 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 in 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 stress-strain relationship given in Figure 2 is adopted to account for the material nonlinearity. Initial imperfections, i.e. the residual stresses and the initial geometrical deflection, are taken into account.

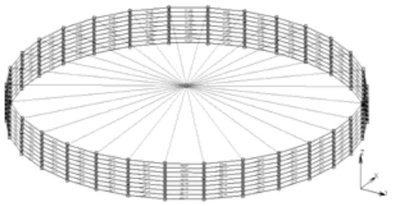

Figure 1: Finite Element Model

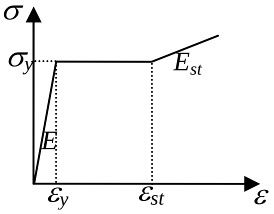

Figure 2: Material model

3. Methodology

A series of elasto-plastic large displacement analysis of the generated models subjected to bending moment with constant or fluctuating axial force is conducted. The fluctuation pattern of the axial force is considered as an increasing pattern from an initial value to the final axial force in a linear relationship with the bending moment since the relationship between axial force and bending moment is linear during the earthquake excitations of 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 3) which leads to axial force increments together with the bending 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 4. It is seen that the axial force starts from its initial value (P_i) which is considered as the 20% of the squash load (P_y) of the member and increase until the final value. The final axial force (P_f) can be modified by adjusting the eccentricity (e) of the applied load. As it is seen in the figure the bending moment and the axial force reach their ultimate values at the same instant. For the constant axial force case the ultimate axial force of the fluctuating case is applied to the upper diaphragm center node as a constant value and linear rotation increments are applied to the same node to account for the bending behavior. The results of these two cases are compared to evaluate the influence of the axial force fluctuation on the bending behavior.

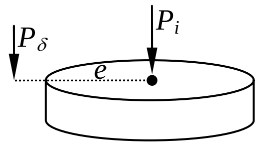

Figure 3: Loading method for axial force fluctuation

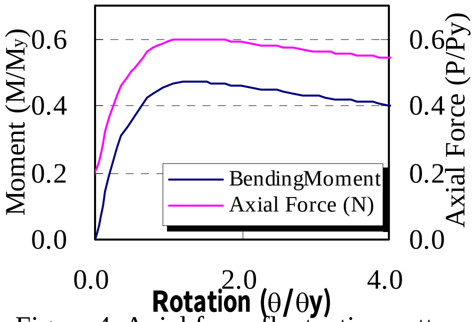

Figure 4: Axial force fluctuation pattern (Model 3)

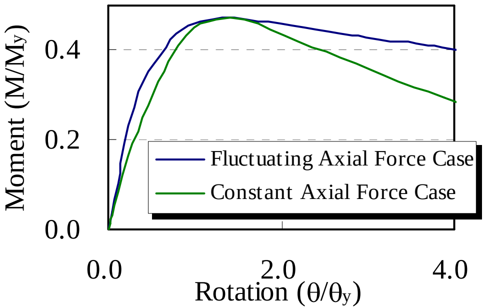

Figure 5: Bending behavior（Model 3）

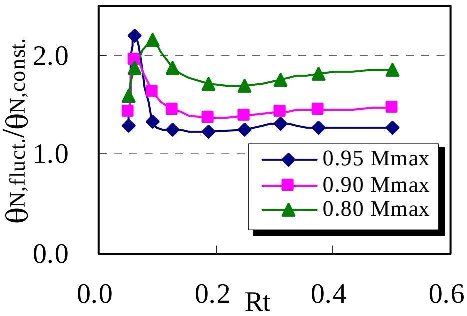

Figure 6: Ductility capacity comparison

4. Results

The bending behavior under constant and fluctuating axial force is illustrated in Figure 5 for Model 3. The axial force fluctuates from P_i=0.2P_y until P_f=0.6P_y in the fluctuating axial force case. The axial force is 0.6P_y for the constant axial force case. It can be seen that the ultimate strength is the same for both cases suggesting that the axial force fluctuation dot not affect the maximum moment capacity. But it can be seen that the ductility is significantly higher in the post-peak behavior for the fluctuating axial force case. In Figure 6 the post-peak rotation values of constant and fluctuating axial force cases are compared for the 95%, 90% and 80% of the maximum moment capacity 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.

5. Conclusions

It is found that the ductility corresponding to the post-peak behavior increases when the axial force fluctuation is considered. Although the maximum moment capacity is found to be the same as the constant axial force case, the moment capacity after the ultimate load is observed to drop more slowly. As there are some design practices allowing the post-peak behavior up to the 95%, 90% or even the 80% of the maximum moment capacity, consideration of the axial force fluctuation could lead to more rational design of steel members with pipe sections.

In the future work, after studying the influence of different fluctuation patterns, design formulae for the ultimate strength and ductility considering the axial force fluctuation will be developed.