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Elephant-Foot Buckling of Cylindrical Shells under Compression and Repetitive Bending

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1. INTRODUCTION

Many kinds of severe structural damages were caused by Hanshin-Awaji Great Earthquake[1]. The most typical damage observed on the steel bridge piers is a local buckling of thin plate/shell elements. Although a local buckling of steel bridge piers has been simulated in the laboratory testing before, further experimental and analytical works are being carried out to understand the behavior of thin-walled steel bridge piers and to develop new earthquake-resistant bridge piers as well as the rational retrofit method of existing bridge piers. In this study, the mechanism of an elephant-foot buckling of cylindrical shells is focused and assessed based on the numerical analysis.

2. ANALYTICAL PROCEDURE

The elasto-plastic finite displacement analysis[2], which is based on a 9-node degenerated shell element with shear and membrane strain interpolations, is made to evaluate the strength and the ductility of a cantilever cylinder column subjected to the compression and the horizontal load as shown in Fig.1. The factors relating to the strength and the ductility such as radius to thickness ratio, axial compressive force ratio, initial imperfections etc. are studied. Table 1 summarizes the 24 analytical cases.

3. RESULTS AND DISCUSSIONS

In this study, the strength and the ductility are defined at the peak of load-displacement curves. The relation of strength and the ductility to R/t, H/R, Fz/Py are summarized in Figs.2, 3 and 4 respectively. It can be seen that with the increase of R/t, H/R as well as Fz/Py, the strength and the ductility decrease significantly.

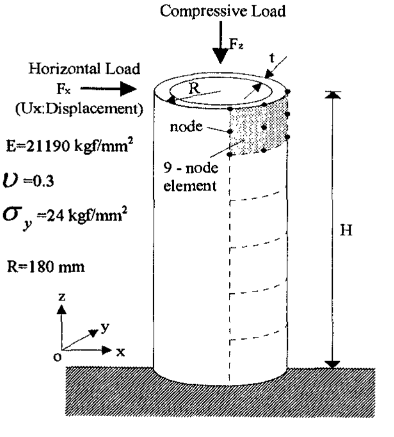


Fig. 1 A Cantilever Cylinder Column

Table 1 List of Analytical Cases

CASE	R/t	t (mm)	H/R	H (mm)	Fz/Py	Cr (%)	Kreds	Elements
1-1	25	7.2	2.07	373	0	0.2	1	8x6
1-2	25	7.2	2.07	373	0.2	0.2	1	8x6
1-3	25	7.2	2.07	373	0.4	0.2	1	8x6
2-1	37.5	4.8	2.07	373	0	0.2	1	8x6
2-2	37.5	4.8	2.07	373	0.2	0.2	1	8x6
2-3	37.5	4.8	2.07	373	0.4	0.2	1	8x6
3-1	50	3.6	2.07	373	0	0.2	1	8x6
3-2	50	3.6	2.07	373	0.2	0.2	1	8x6
3-3	50	3.6	2.07	373	0.4	0.2	1	8x6
4-1	37.5	4.8	4	720	0	0.2	1	10x8
4-2	37.5	4.8	4	720	0.2	0.2	1	10x8
4-3	37.5	4.8	4	720	0.4	0.2	1	10x8
5-1	37.5	4.8	10	1800	0	0.2	1	8x12
5-2	37.5	4.8	10	1800	0.2	0.2	1	8x12
6-1	37.5	4.8	2.07	373	0	0	1	8x6
6-2	37.5	4.8	2.07	373	0.2	0	1	8x6
6-3	37.5	4.8	2.07	373	0.4	0	1	8x6
7-1	37.5	4.8	2.07	373	0	1	1	8x6
7-2	37.5	4.8	2.07	373	0.2	1	1	8x6
7-3	37.5	4.8	2.07	373	0.4	1	1	8x6
8-1	37.5	4.8	2.07	373	0	0.2	0	8x6
8-2	37.5	4.8	2.07	373	0.2	0.2	0	8x6
8-3	37.5	4.8	2.07	373	0.4	0.2	0	8x6
9	37.5	4.8	4	720	0.2	0.2	1	8x12

Note: (1) Kreds=1: Residual stresses are considered.
(2) Kreds=0: Residual stresses are not considered.

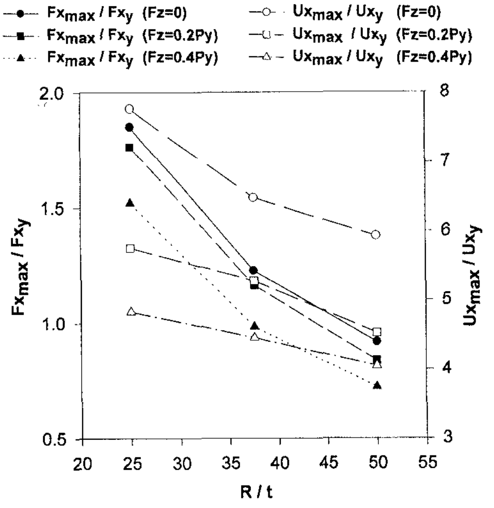


Fig. 2 Effect of Radius to Thickness Ratio
(H/R=2.07, R=180mm)

The horizontal load and displacement curve under Fz=0.2Py and a repetitive bending is shown in Fig.5 (R/t=37.5, R=180mm). The buckling modes are shown in Fig.6, in which the elephant-foot buckling can be clearly seen when the horizontal displacement is reversed to the original position. However, the unsymmetric buckling shape is observed in the case of Fz=0 as shown in Fig.7.

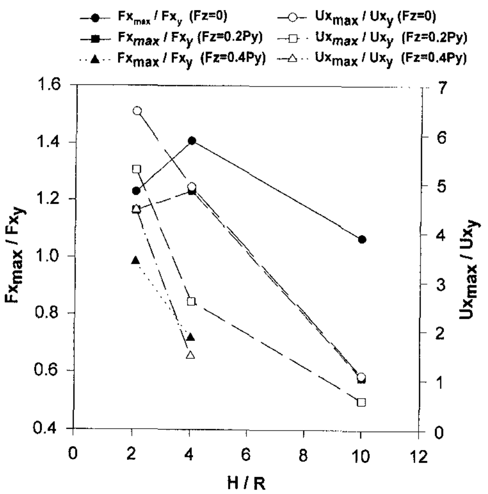


Fig. 3 Effect of Height to Radius Ratio (R/T=37.5, R=180mm)

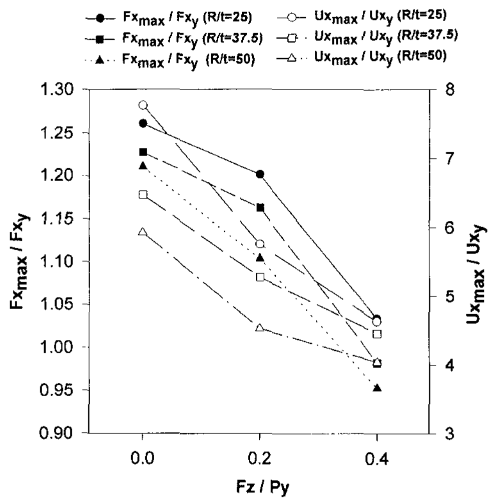


Fig. 4 Effect of Axial Compressive Force Ratio (H/R=2.07, R=180mm)

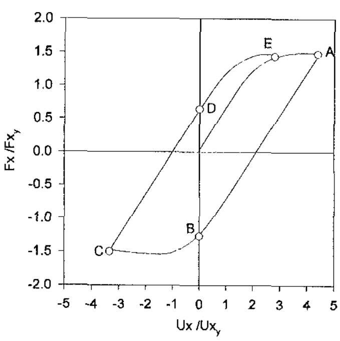
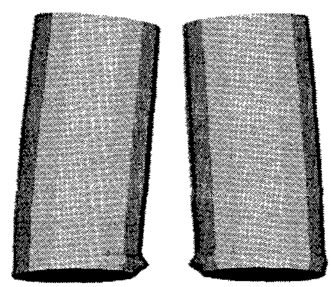


Fig.5 Horizontal Load and Displ. Curve (F_z=0.2P_y, H/R=4, R/T=37.5, R=180mm)



(a) at Point A (b) at Point B

Fig. 6 Elephant-Foot Buckling of Cylindrical Shells

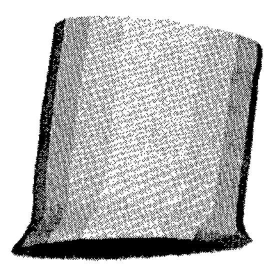


Fig. 7 Severe Local Deformation in Tension Side(F_z=0)

4. CONCLUSIONS

Based on the parametric analysis varying R/t, H/R and Fz/Py, the following conclusions are obtained:

(1) Since the ratio of R/t and H/R can affect the strength and ductility of cylindrical shells, those must be limited by certain range for assuring the structures in good performance against strong earthquakes.

(2) The compressive loads can also affect the strength and should be limited to be small.

(3) The elephant-foot buckling of cylindrical column observed on the bridge piers by Hanshin-Awaji Great Earthquake is simulated numerically and it is concluded that this buckling is caused by excessive bending at base of column due to horizontal load and a compressive force is effectively contributed.

REFERENCES 1) E. Watanabe, Y. Maekawa, K. Sugiura and Y. Kitane, "Damages and Seismic Performance of Steel Bridge," Journal of JSCE, Vol. 80, July, 1995, pp. 54-62, (in Japanese). 2) E. Watanabe, K. Sugiura, T. Utsunomiya and M. Ohta, "Rational Design of Stiffened Plated Structures Considering Strength and Ductility," Proceedings of the Fifth International Symposium on Plasticity and its Current Application, July, 1995, pp. 487-490.