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Mechanical Behavior of Cantilevered Cylindrical Shell in Opening under Lateral Load

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ABSTRACT

In the study, the mechanical behavior of cantilevered cylindrical shell is reviewed considering parameters such as the opening condition and the geometry of the structure. The dimensions of experimental model are as follows; the wall thickness 4cm, the outer diameter 100cm and the height 120cm, which are 1/45 of the prototype. The asymmetrical lateral loads are applied. The mechanical behaviors of the structure under various opening conditions, especially the stress concentration in the region of the opening, are studied. Finally, the experimental results are compared with the analytical results of GTSTRUDL, which is commercial computer program for structural analysis.

1. INTRODUCTION

Generally, shell means structure with three-dimensional curvature of which thickness is considerably smaller than other two sides in length. Shell is very effective structure to resist external load with in-plane force.

Shapes of shell structure are various. Cantilevered cylindrical shell, one of those is used in many fields. Because cantilevered cylindrical shell is very excellent in transmitting load and doesn't have the character of direction by axial force.

Loads applicable to cantilevered cylindrical shell without spherical dome are dead load, live load, thermal load, seismic load, and internal pressure load. When asymmetrical loads, which is seismic load and wind load, are applied to cantilevered cylindrical shell, bending, axial force, in-plane shear force will behave compositely.

Therefore, in this paper we experiment the case that static horizontal load which is simply changed from asymmetrical load is applied to the top of models. Experimental models are made with nuclear power plant in Canada in 1984.

The structural behavior of reinforced concrete cantilevered cylindrical shell appears differently depending on the ratio of reinforcing bar, the thickness, the ratio of radius, the ratio of shape. But it is very difficult to apply these various parameters to experiment. In this paper, we will study mechanical behavior with opening of model and without opening and different experimental parameters remain constant.

The experiment of model with opening on the side of tension is focused on mechanical behavior of the circumference of opening and is understood on the direction of deployment of crack, the flow of force. Finally, we compare two different models.

2. OUTLINE OF EXPERIMENTS

2.1 Specimen

The experimental model is a structure composed of a cylindrical wall and two thick rectangular slabs, one at the top and the other at the bottom of the cylinder. Particulars of the specimens are given in Table 1. Vertical and horizontal bars were arranged with 6.0mm, and 5.0mm in the part of cylinder wall. The ratio of reinforcing bar was designed with 0.8% in order to occur bending failure. Sufficient rigidity was prepared in two thick rectangular slabs not to be destroyed during load.

This experimentation, in case that cylindrical shell is subjected to horizontal load, is to understand mechanical behavior of structure according to with and without opening. Therefore, having opening or not is parameter of experiment. Four specimens will be used.

The position of opening is one third height of cylindrical shell where is the most weak part structurally. The size of opening was designed with square having 20cm ×20 cm

2.2 Materials

The results of tests on concrete cylinders are given in Table 1. The results of tensile tests of reinforcing bars are indicated in Table 2.

2.3 Loading Method.

The method of horizontal loading is shown in Fig. 2. The base slab is fixed on the floor. The specimens were subjected to lateral load applied to top of cylinder through steel loading frame. The method of controlling load is displacement control. Load keeps constant velocity in the elastic range. After yield, load is applied according to condition of deformation.

3. RESULTS OF EXPERIMENT

3.1 Load-Displacement Relation

Fig. 3 is comparison of load-displacement curve according to having opening or not. This figure is shown with similar behaviors till occurrence of first crack. After occurrence of crack, displacement of models without opening is smaller than with opening. And both cases don't exist the range of yielding. Sudden failure, which has inclination of brittleness, is shown after losing rigidity.

3.2 Failure Process

Final crack formations of models are represented by Fig. 4. In this test, the part subjected to membrane stress by bending moment act as flange, the part subjected to shear force act as web.

When load of model CS-N2 pass over 3.5ton, diagonal crack of mid-web kept going toward upper level. Flexural crack progressed toward the side of compression. After all, These models might lose their function as a structure by the failure of flexural crack.

In case models of CS-O1, CS-O2, even if lateral flexural crack happen, the failure can't be led by. Therefore, the failure must be progressed by flexural and shear stress in the circumference of opening. Compared with the failure mode of two models, flexural failure was shown in CS-N2. Flexural and shear failure was shown in CS-O1, CS-O2. This means that failure of model was changed by stresses focused on the circumference of opening.

3.3 Stress of Reinforcing Bar

Compared with stress of vertical reinforcing bar in each model, CS-N2 was shown that tensile reinforcing bar is yielded first, yield was moved to web step by step. In case of models such as CS-01, CS-02, in the initial time of load, strain of reinforcing bars placed in flange of bottom of cylindrical wall is larger than strain of reinforcing bars in web. But in ultimate load, strain of reinforcing bar placed in web was increased considerately.

Compared with stresses of horizontal reinforcing bars in cylindrical wall, in the web of model CS-N2, Strain of reinforcing bars in the middle is larger than strain of reinforcing bars in the bottom. In the flange of model CS-O1, CS-O2, strain of reinforcing bar in the bottom is larger than strain of reinforcing bar in the middle.

3.4 Stress in the Circumference of Opening

Fig. 7 is the result of comparing experimental data with Finite element method. Both results are identical comparatively.

4. CONCLUSION

In this study, when cantilevered cylindrical shell is subjected to static lateral load in the top of model, mechanical behavior of structure with opening and without opening on the side of tension was studied.

The results are follows.

1. In case that opening is located in the side of tension, reinforced concrete cantilevered cylindrical shell shows brittle behavior in ultimate load.
2. In case that opening is located in the side of tension, displacement of average 15% is increased by the decrease of flexural rigidity compared with no opening.
3. Failure mode of experimental model is changed by the convergence of stress in the circumference of opening. Model without opening occurs flexural failure. Model with opening on the side of tension occurred shear failure and flexural failure.
4. The reinforcement in the bottom of opening where stress is concentrated is required.

From above results, opening result in the decrease of rigidity of cylindrical shell. It is the weakest part against of failure.

5. REFERENCES

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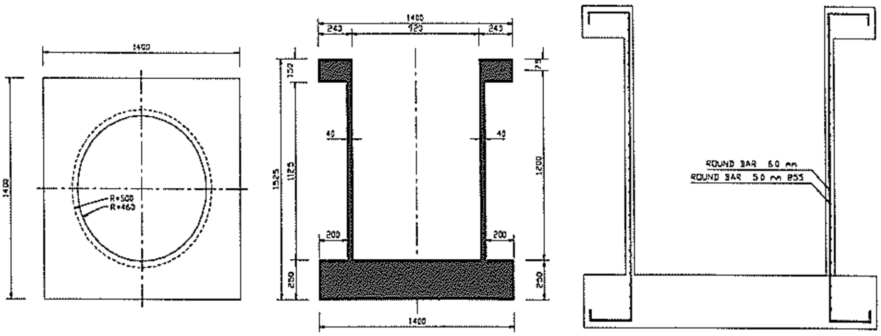


Fig. 1 Outline of specimen

Table 1 Measured properties of reinforcement

	Normal sectional area (cm^2)	Ultimate strength (kg/cm^2)	Yield stress (kg/cm^2)	Young's modulus ($10^6 kg/cm^2$)
ϕ5.0	0.20	6450.0	5250.0	2.66
ϕ6.0	0.28	6896.8	6100.0	2.16

Table 2 Measured properties of reinforcement

Compressive strength (kg/cm^2)	Tensile strength (kg/cm^2)	Young's modules ($10^5 kg/cm^2$)
351.3	32.8	2.64

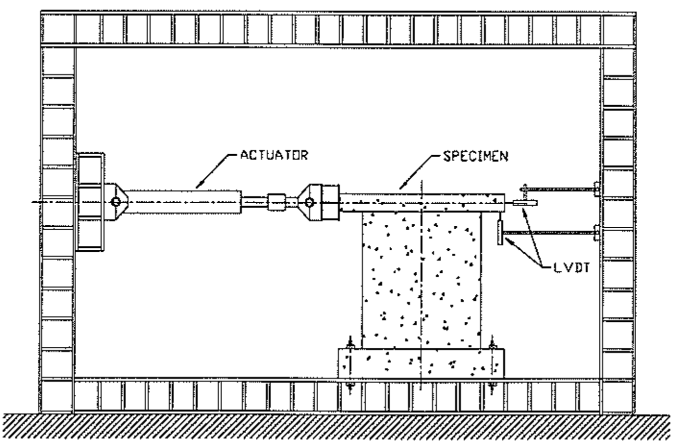


Fig. 2 Experimental setup and instrumentation

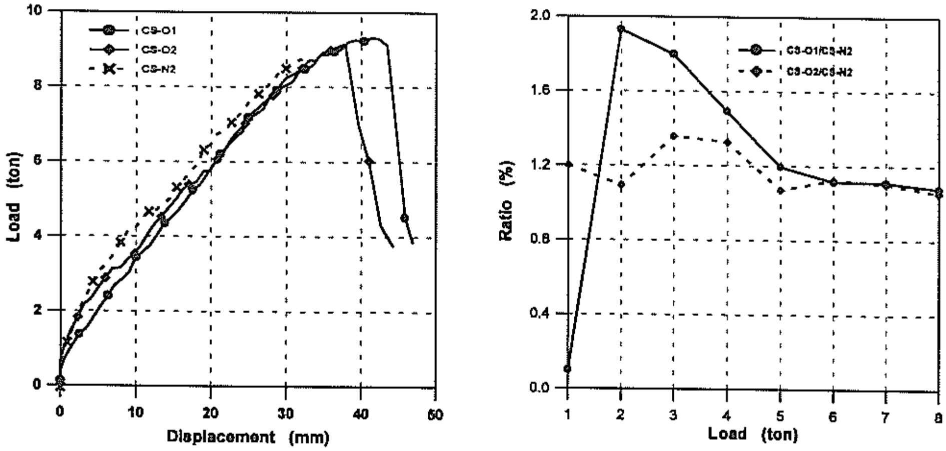
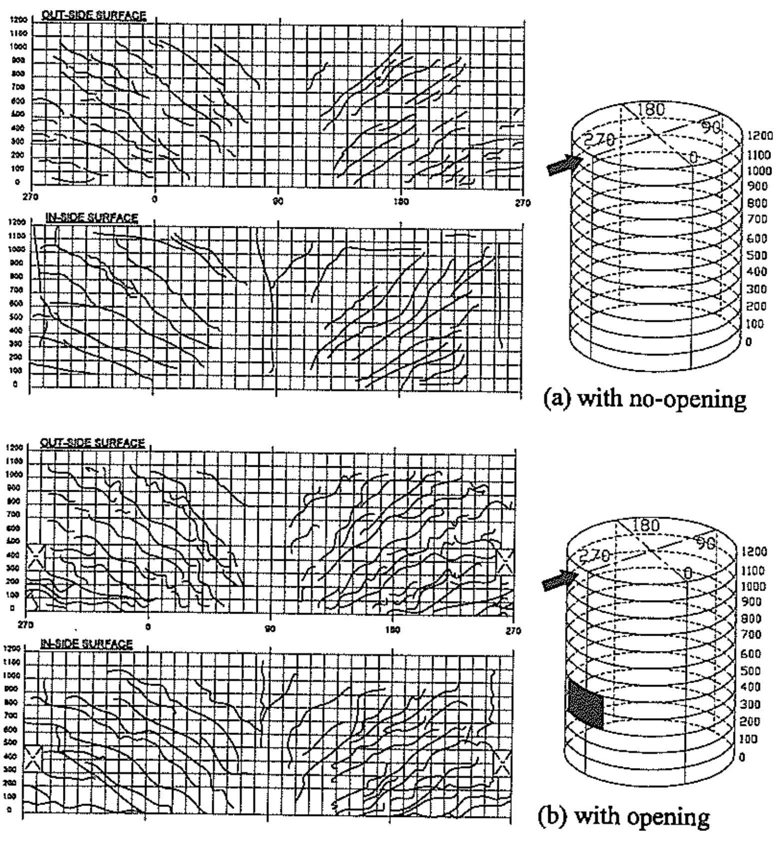


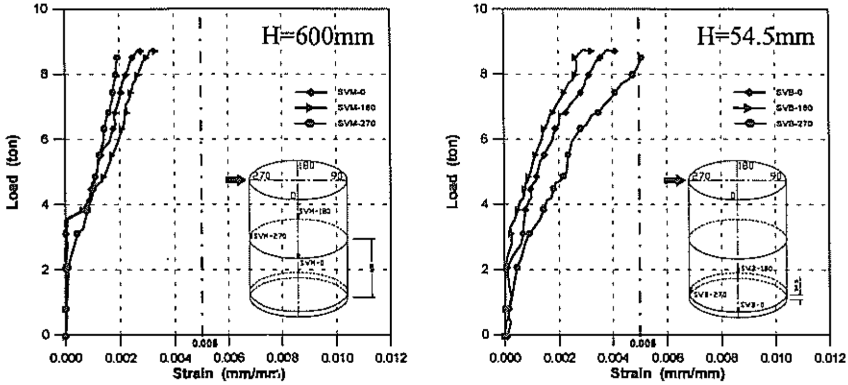
Fig. 3 Horizontal load-displacement relationship



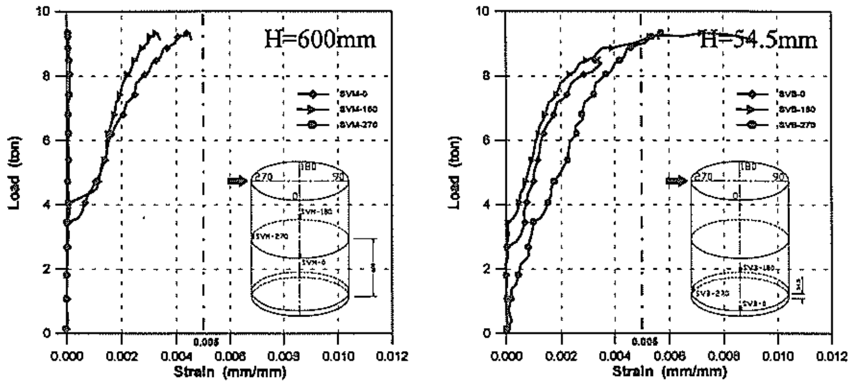
(a) with no-opening

(b) with opening

Fig. 4 Crack pattern and failure mode

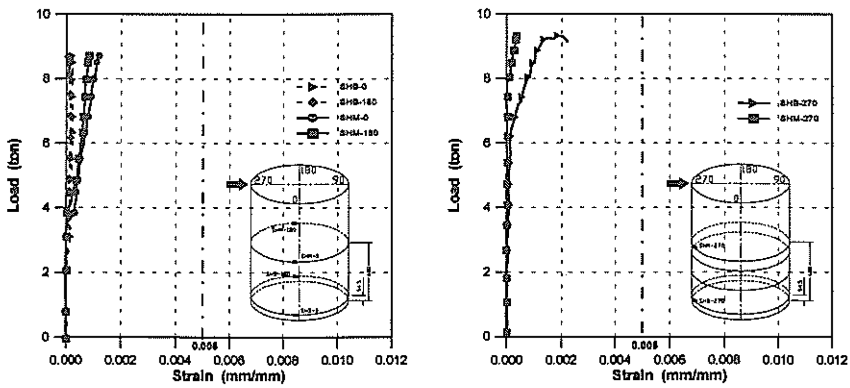


(a) CS-N2



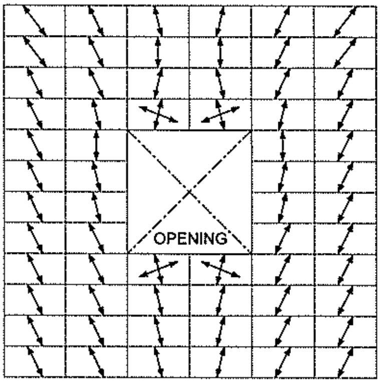
(b) CS-O1

Fig. 5 Load-strain relationship of vertical reinforcements

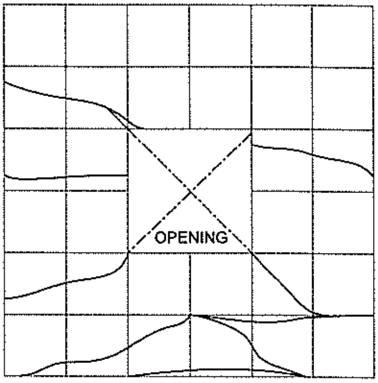


(a) CS-N2 (b) CS-O1

Fig. 6 Load-strain relationship of horizontal reinforcements

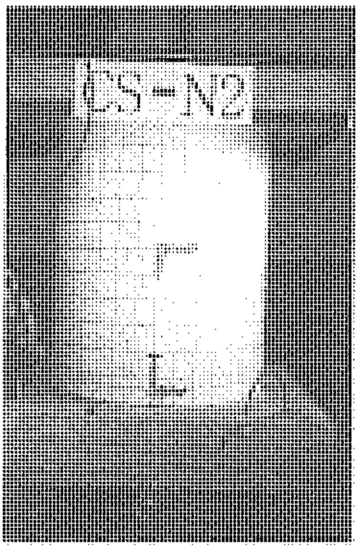


(a) Principal stress (F.E.M Analysis)

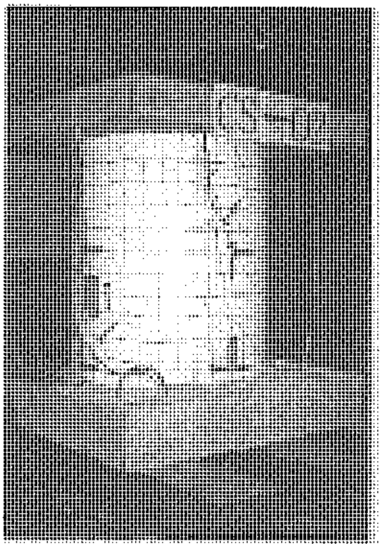


(b) Crack pattern around opening

Fig. 7 Stress around opening



(a) with no-opening



(b) with opening

Fig. 8 Final collapse