Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Behavior of R/C Cylindrical Panel Subjected to Combined Axial and Shear Loadings

Takashi HARA*

*Tokuyama College of Technology
Gakuendai, Shunan 745-8585, JAPAN
t-hara@tokuyama.ac.jp

Abstract

Reinforced concrete (R/C) cylindrical panels have been applied to the roof or the underground structures. Also, in constructing a high rise building, an R/C wall is often used to improve the lateral rigidity of the building comparing with beam column systems under wind or seismic loading. In this paper, the behavior of R/C cylindrical shell under combined axial and lateral shear loadings is analyzed numerically. R/C cylindrical shells are often adopted for the core wall system. R/C cylindrical panels are fixed at both hoop edges and are subjected to a lateral shear displacement after axial compressive load is applied in the meridional direction. In numerical analyses, the behavior of R/C cylindrical shell panel is analyzed under several combinations of axial and lateral loadings. The panels are modeled by use of the shell elements.

Keywords: R/C panel, cylindrical shell, axial loading, lateral shear, combined loading, FEM procedure, shell element

1. Introduction

Reinforced concrete (R/C) cylindrical shell panels have been applied to the roof or the underground structures because of their high strength characteristics under a lateral loading. R/C cylindrical shell panels also show the large load bearing capacities under an axial compression. These are used for the stacks or the cooling tower structures. In constructing a high rise building, an R/C cylindrical shell wall is often used to improve the lateral rigidity of the building comparing with beam column systems under wind or seismic loading. These wall core systems enable us to obtain a large opening space in the floor and high shear capacity under seismic loadings. However, the wall core systems are usually composed of flat R/C panels. Therefore, stress concentrations are arisen around the junction of these panels. Especially, R/C panel is prone to show the cracking around the junctions of these structures.

In this paper, the behavior of R/C cylindrical shell under combined axial and lateral shear loadings is analyzed numerically. R/C cylindrical panels are adopted for the core wall system. R/C cylindrical panels are fixed at both hoop edges and are subjected to a lateral displacement after axial compression is applied in the meridional direction.

In numerical analyses, the behavior of R/C cylindrical panels is analyzed under several combinations of axial and lateral loadings. The panels are modeled by use of the shell elements. The lateral load is controlled by displacement increment. Also the stress distributions and crack propagations are examined. The ultimate load is obtained from the peak loading on the load deflection curve.

FEM schemes are used on the basis of the degenerate shell formulation. The numerical parameters are obtained from the experimental results and the numerical models are constructed based on the experimental specimens. Load deflection characteristics and the ultimate strength are computed under several combinations of loadings.

2. Numerical Procedure

2.1. Specimen

R/C cylindrical panel has the cylindrical shape with 960mm x 960mm plan and has 688.75mm radius and 10mm thickness (see Figure1). ϕ0.75mm stainless wires are used as the reinforcements and are placed in the middle of the shell thickness in both meridional and hoop direction. They are placed in equi-distance of 5mm. The specimen is made by use of the steel mold to avoid the geometric imperfections. The micro concrete with aggregate size 2.5mm is used. The material properties are shown in Table 1 and 2 defined from the material tests.

Specimens are assumed to be fixed on hoop edges. Also, both meridional edges are free.

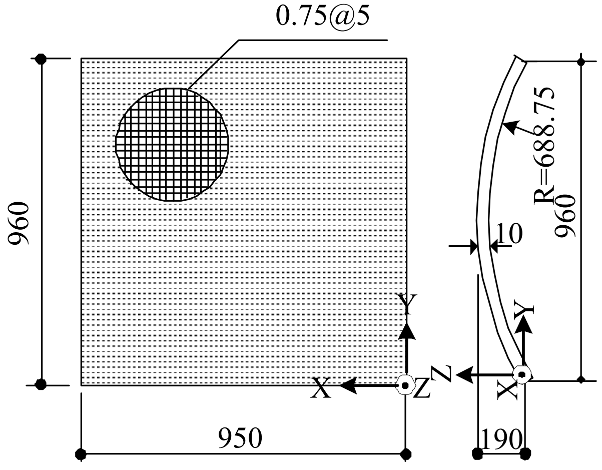


Figure1 Geometric dimensions of R/C cylindrical shell (unit:mm)

Table 1 Material properties of concrete

Compressive Strength (MPa)	38.2
Tensile Strength(MPa)	3.8
Young's Modulus(GPa)	23.6
Poisson's Ratio	0.20

Table 2 Material properties of steel

Yield Stress(MPa)	235
Tensile Stress(MPa)	449
Young's Modulus(GPa)	206
Tangential Modulus(GPa)	21

The specimens are subjected to the axial compression in the hoop direction. Then the lateral shear loading due to the lateral displacement is applied in Y direction as shown in Figure 1.

2.2. Numerical model

In numerical analyses, the finite element procedure is applied. Figure 2 shows the FE mesh of this analysis. The full model is adopted. The model is divided into 32 elements in meridional and hoop directions, respectively. Each element is divided into 8 concrete layers and 2 steel layers based on the layered approach (Hara [1], Hinton *et al*. [2]).

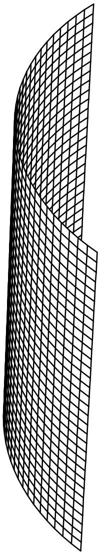


Figure 2 FE Mesh

Boundary conditions are free along both meridional edges and are fixed on both hoop edges. In numerical model, the axial diaplacements and the lateral Y displacement (see Figure 1) on hoop edges represent the same quantities in each direction, respectively.

2.3. Finite element

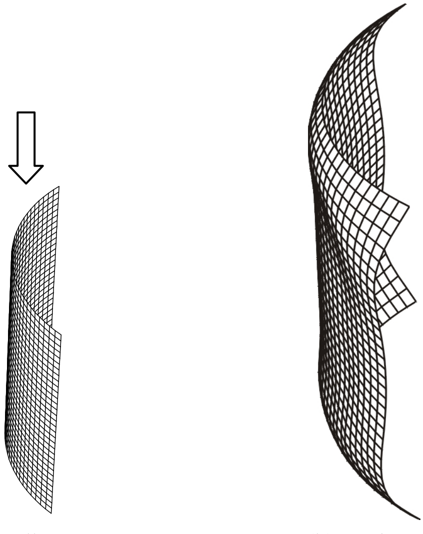
In numerical analysis, the degenerate shell element is adopted and the geometric and material nonlinearlities are taken into account. 9 nodes Heterosis element is used and 2×2 reduced integration is performed to avoid the numerical problems.

The numerical simulation is performed under the displacement incremental scheme. The yield condition of concrete is defined as the Dracker-Prager type, which is assumed that concrete yields when the equivalent stress based on mean stress and second deviatoric stress invariants reaches uniaxial compressive strength (Hinton *et al.* [2]). The crushing condition is contorolled by strains. The ultimate compressive strain of concrete is assumed as 0.003 by Kupfer's experiment (Kupfer *et al.* [3]). Also, after cracking of concrete, the tension stiffenig parameters accounting for the tensile strength of concrete are introduced. The material nonlinearlities of steel are assumed to be bilinear stress-strain relation for the reinforcement.

3. Numerical Results

3.1. R/C cylindrical panel under compression

R/C cylindrical panel under uniaxial compression in meridional direction is investigated (see Figure 3).



(a) Loading (b) Deformation

Figure 3 Deformation under axial compression

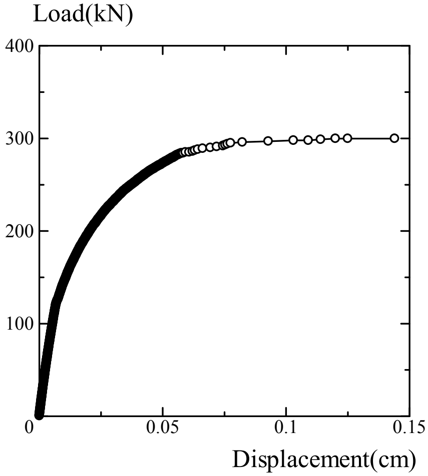
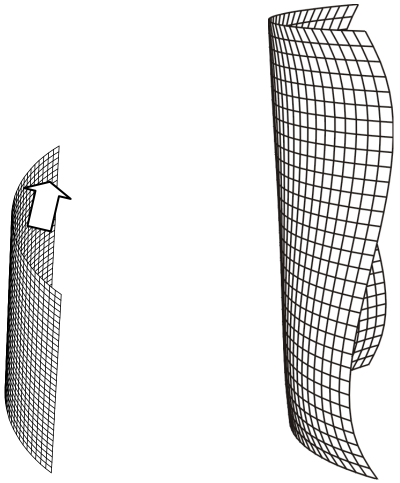


Figure 4 Load-displacement relation under compression

Figure 3 shows the deformation pattern under the maximum compressive load. R/C cylindrical shell shows the large deformation around the supporting and loading edges. Especially, a larger deformation is arisen near the free edges.

Figure 4 shows the load-displacement relation of R/C cylindrical shell under an axial compression. The target point of displacement is the free edge around the upper supporting point. The maximum loading capacity is 306kN. From the load-displacement relation, R/C cylindrical panel shows ductile failure pattern.



(a) Loading (b) Deformation

Figure 5 Deformation under lateral shear

3.2. R/C cylindrical panel under laetral shear load

Figure 5 shows the deformation patterns of R/C cylindrical panel under lateral shear load along the hoop direction (see Figure 5). The loading direction is represented as the arrow in the figure. The loading status is the shear along the supporting edges.

R/C cylindrical shell deforms inward at the right top and left bottom due to the shear deformation. Also the shell deforms outward at the left top and right bottom. Figure 6 shows the load-deflection relation at the top of R/C cylindrical panel. The maximum load is 10.9kN. The load-displacement relation represents the brittle failure due to shear.

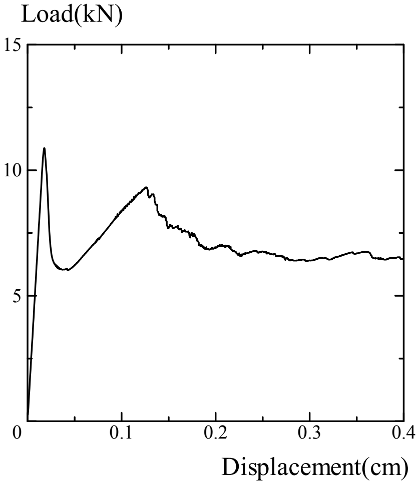


Figure 6 Load-displacement relation under lateral shear

3.3. R/C cylindrical panel under combined axial compressive and lateral load

If R/C cylindrical panel is used for the core wall, the panel is subjected to combined axial compression and lateral shear. Figure 7 shows the load deflection behavior of R/C cylindrical panel. In Figure 7, the square mark represent the load-deflection behavior of R/C cylindrical panel subjected to the lateral shear load without any axially compressed load. The triangular, the reverse triangular and + marks repreent the load-deformation behavior under 0.1P, 0.2P and 0.5P of axially compressed load, respectively. Here, P is the maximum ultimate compressive load of 306kN (see Figure 4). In each loading condition, the maximum shear load is 31.16kN, 39.40kN and 5.32kN, respectively.

From Figure 7, the maximum ultimate strength under combined axial and lateral shear loading conbination is obtained depending on the axial loading level. Figure 8 represents the relation between the axial compressive preload and the ultimate lateral shear load. In the range of small compressive load, the larger the axial compressive preload is, the larger the ultimate lateral strength is. However, when the preload exceeds 0.2P the maximum lateral shear load decreases with increasing the preloading.

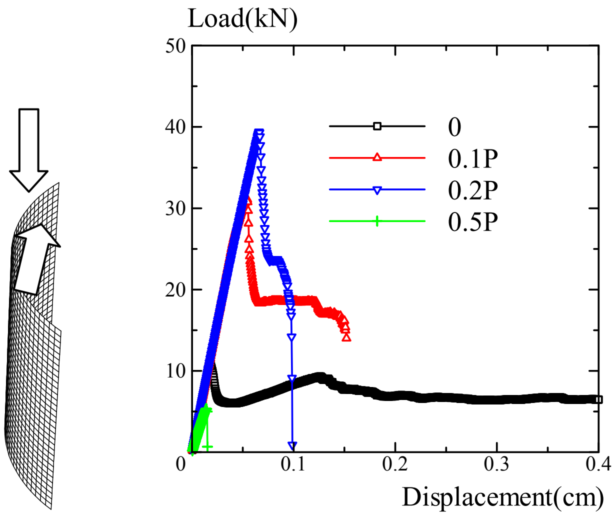


Figure 7 Load-displacement relation under lateral shear with preloading

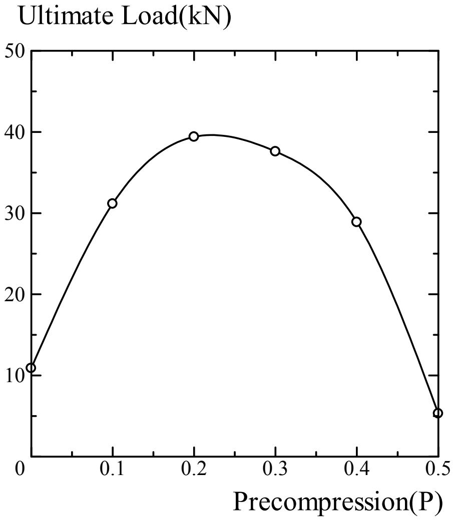
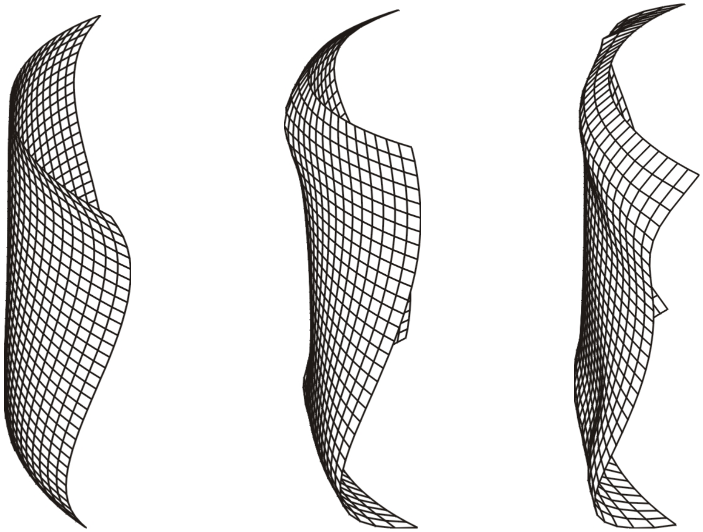


Figure 8 Preloading and the ultimate lateral shear loading

Consequently, the largest ultimate strength 39.4kN is obtained when the 20% of the ultimate axiall compressive loading is applied to R/C cylindrical shell.

Figure 9 shows the deformation pattern under lateral shear with several axial preloading.



(a) 0P (b) 0.2P (c) 0.5P

Figure 9 Deformation patterns

In the case without compressive load (0P), R/C cylindrical shell deforms mainly in the loading direction. However, R/C cylindrical shell deforms with combined axial and the lateral shear deformations when the axial compression 0.2P is applied. Then, R/C cylindrical shell deforms as both axial and lateral shear deformations as well as the local deformation combined with cracks and the crushing when R/C shell is subjected to 0.5P compressive load.

4. Conclusions

In this paper, the behavior of R/C cylindrical shell is analyzed numerically under several combinations of axial compressive and lateral shear loads. The boundary condition is that both hoop edges are fixed and both meridional edges are free. From the numerical investigation, the following conclusions are obtained.

1. R/C cylindrical shell represents the ductile failure when the axially compressed load is applied in meridional direction.
2. R/C cylindrical shell represents the brittle failure when the lateral shear load is applied parallel to the hoop direction.
3. R/C cylindrical panel shows the maximum ultimate strength under combined axial and lateral shear load when the 20% of axial compressive load is applied.
4. The deformation of R/C cylindrical panel shows the different patterns depending on the axial preloading.

In this paper, only the numerical analyses are represented and the load bearing behavior and the deformation characteristics are discussed. However, both the deformation and the ultimate strength of R/C cylindrical panel are strongly influenced by the initial geometric imperfections and the inaccurate reinforcing placements. Therefore, the experimental investigations will be required.

References

[1] Hara, T., Numerical and experimental evaluation of R/C shell. Proceedings of *International Conference on Advances in Structural Engineering and Mechanics*, 2008, 133-144.

[2] Hinton, E. and Owen, D.J.R., *Finite element software for plates and shells*, Prineridge Press, Swansea, UK. 1984

[3] Kupfer, H. and Hilsdorf, K.H., Behavior of concrete under biaxial stress, *ACI Journal* 66(8) , 1969, 656-666.