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IMPROVEMENT OF REINFORCEMENT METHOD OF R/C CYLINDRICAL SHELL WITH OPENING

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Reinforced concrete (R/C) chimney with a hole is prone to decrease the strength. Therefore, the particular reinforcements have been placed around the hole. Both meridional and hoop reinforcements have been placed additionally equivalent to the loss amount of reinforcements at the hole and the diagonal reinforcements have been placed to prevent the corner failures as well. Diagonal reinforcements in the shell were curved shape. It is the laborious work to place them. In this analysis, the improved reinforcement method was proposed instead of placing the conventional diagonal reinforcements. In the proposed methods, only the hoop and the meridional reinforcements were arranged around the corners instead of diagonal reinforcements. FEM analyses were done to evaluate the proposed reinforcing method. Numerical model was the cylindrical panel with a rectangular opening. From the numerical analyses, it was concluded that the R/C panel with proposed reinforcement method showed the same behavior as that with conventional reinforcement method.

Keywords: R/C Shell, Chimney, Inlet hole, Crack, FEM.

1 INTRODUCTION

A reinforced concrete (R/C) cylindrical chimney has a large opening at the lower portion to take in a flue-gas. The region around the hole is prone to decrease the strength. Therefore, particular reinforcements have been supplied around the hole. Figure 1 shows the Tupras stack collapsed under Kocaeli earthquake in 1999 (Huang *et al.* 2004). The dotted line denotes the collapsed part, and the chimney had a rectangular hole at the lower part. It was concluded that the cause of collapse was introduced by the wide opening and a lack of reinforcement around the corners.

Figure 1. Collapse of Tupras chimney (Photo by P.L. Gould 2004).

To improve the panel strength with hole, many researchers have been studied (e.g. Doh *et al.* 2006). In the same manner, the design code of the chimney with hole was recommended (ACI Committee 307 2008). The thickness of the concrete around the hole is increased and the meridional and hoop reinforcements were placed equivalent to the loss amount of reinforcements at the hole. In addition, the diagonal reinforcements were placed to prevent corner failures. However, when placing diagonal reinforcements in the shell, the reinforcing bars have a curved shape (Figure 2). Sami stated the difficulties to place them and the requirement of improving these works. (Sami *et al.* 2016).

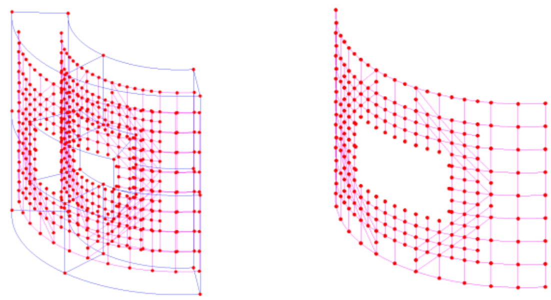


Figure 2. Current reinforcement around the Hole.

In this paper, the improved reinforcement method was proposed instead of placing the conventional diagonal reinforcements. In the proposed methods, only the hoop and the meridional reinforcements were arranged around the corners. The reinforcements equivalent to the diagonal reinforcements were placed at the same region. FEM analyses were done to evaluate the proposed reinforcing method. In numerical analyses, four types of model were examined. One model was R/C panel without hole and three models were R/C panels with hole. Specimens were cylindrical panel supported on hoop edges and were free along the meridional edges. The stiffness, the ultimate strength and the crack propagations were compared among these models.

2 NUMERICAL MODEL

Figure 3 shows the configuration of the numerical model. The model is a cylindrical panel. The radius and the opening angle are 693.75mm and 83.08º, respectively. The height and the thickness are 900mm and 40mm, respectively. The shell has the rectangular (264mm x 240mm) opening in the middle of the shell panel. The reinforcements are placed in both hoop and meridional directions. The reinforcement ratio is 0.35% in each inner and outer surface (ACI-ASCE Committee 334 2017). The concrete cover is 5mm. The reinforcing methods adopted in this paper are shown in Figure 4. Figure 4(a) shows the panel without hole. Figure 4(b) shows the panel with hole and without reinforcing around the hole edges. In Figure 4(c), the panel with hole has conventional reinforcements (ACI Committee 307 2008). Finally, in Figure 4(d), diagonal reinforcements are replaced to meridional and hoop reinforcements with the same reinforcement ratio as shown in Figure 4(c). The material properties adopted in these analyses are shown in Table 1.

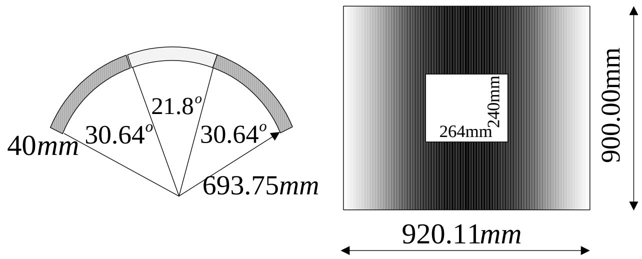
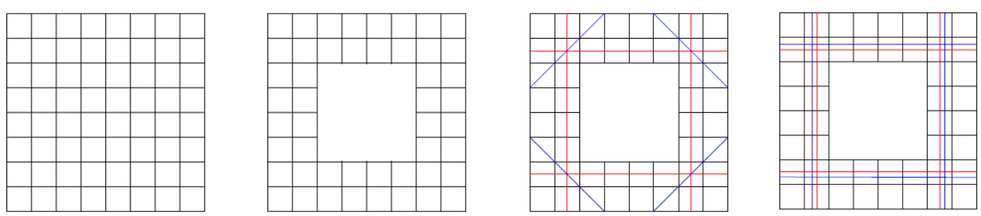


Figure 3. Configuration of R/C panel.

Table 1. Material properties.

CONCRETE			STEEL		
Elastic Modulus	E_c	22.3GPa	Elastic Modulus	E_s	208GPa
Poisson's ratio	ν	0.20	Hardening Parameter	H'	0.01
Compressive Strength	f_c'	34.4MPa	Yield Strength	f_y	235MPa
Tensile strength	f_t	3.44MPa	Tensile Strength	f_b	402MPa



(a)Without hole. (b)With hole. (c) With hole+m+h+d. (d)With hole+2m+2h.

Figure 4. Reinforcing patterns.

3 NUMERICAL ANALYSIS

3.1 Numerical Method

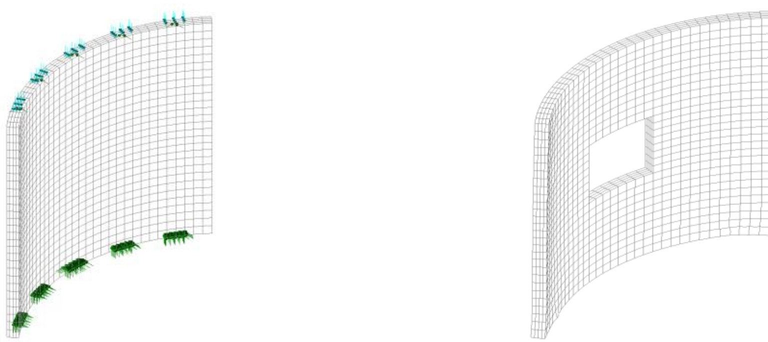
In numerical analysis, Finite Element Method was applied. The concrete and the reinforcements were represented by twenty nodes hexahedral element and the thin surface model, respectively. The inelastic behavior of concrete possesses the recoverable strain components and irrecoverable strain components. Under tri-axial stress state, the yield function depends not only on the mean normal stress but also on the second deviatoric stress invariant (Hinton 1988). The yield condition of tri-axial compressive concrete is expressed by Drucker Prager criterion (Hinton 1988 and Hara 2017). Parameters adopted in this criterion were defined by the Kupfer's experiment (Kupfer and Hilsdorf 1969). It is assumed that the initial yield begins when the equivalent stress exceeds 0.3f'_c (f'_c: compressive strength of concrete). Also, the crushing condition of concrete is described as a strain control phenomenon and the crushing condition is defined as like as the yield function (Hinton 1988 and Hara 2017).

The response of concrete in tension is modeled as a linear-elastic brittle material; maximum tensile stress criteria are employed. After cracking, to evaluate the stiffness of concrete, the stress reduction normal to the crack plane is assumed as an exponential degradation curve.

The reinforcing bars are considered as steel sheets. The bilinear idealization is adopted in order to model the elasto-plastic stress strain relationship and both the tensile and the compressive states are governed by the same relationship.

3.2 Numerical Model

Figure 5 shows the numerical model. R/C panels are supported on hoop edges and are free on meridional edges. Supporting points are equally placed five portions on the hoop edges. In the case of the chimney, the structure is subjected to wind load. If the shell thickness is small comparing with the shell diameter, the out of plane bending is quite important. However, in this numerical model, the axial tensile and the compressive loads are applied to the meridional direction of R/C panel. The model is divided into 32 elements in hoop direction and 28 elements in meridional direction, respectively. Also, the R/C panel is divided into four elements through the thickness.



(a) R/C panel without hole. (b) R/C panel with hole.

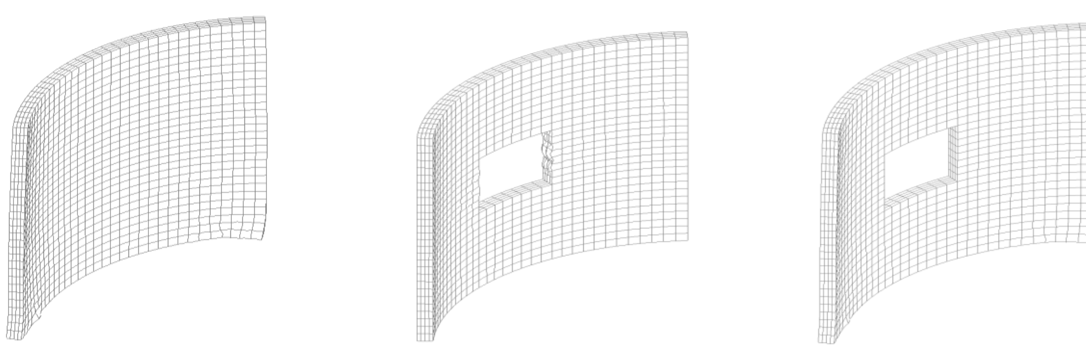
Figure 5. Numerical model.

4 NUMERICAL RESULTS

4.1 R/C Cylindrical Panel in Compression

There is the possibility of the buckling of R/C cylindrical panel under compression. Figure 6 shows the numerical results of the eigenvalue analysis.

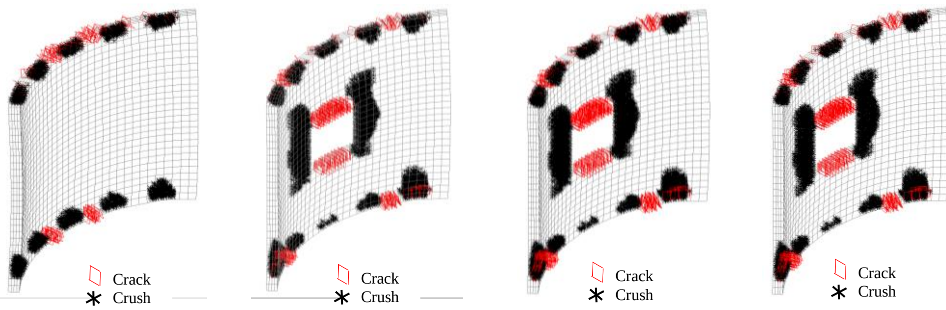
In the case of the R/C panel without hole, the local deformation arises at the end of the bottom hoop. However, in the case of the panel with hole and without reinforcement, the edge around the hole shows the buckling (see Figure 6(b)). It is important to reinforce the opening edge. When the reinforcing steels are placed around the hole (see Figure 4(c) (d)) the buckling mode is the same as that of the R/C panel without hole (see Figure 6(c)).



(a)Panel without hole. (b)Panel with hole (no reinf.). (c) Panel with hole (with reinf.).

Figure 6. Buckling mode.

Figure 7 shows the cracks and the crushing points depending on the reinforcing method under compressive load 140kN. Marks (*) show the crushing point and the rectangles show the cracking of the concrete. These are represented at each Gaussian integration point. At the loading points and supporting points, the crushing is detected and the portion between loading points shows the cracking. Also, upper and lower edges of the hole show the cracking. There are few differences between the results for each reinforcing method.

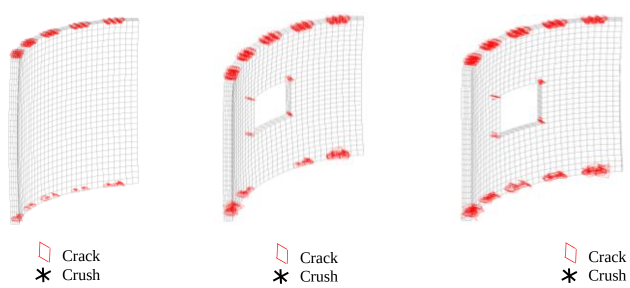


(a)Without hole. (b)With hole. (c)With hole+m+h+d. (d)With hole+2m+2h.

Figure 7. Cracks and crush in compression.

4.2 R/C Cylindrical Panel in Tension

Figure 8 shows the cracks when the tensile force is applied. In all cases, the element around the hoop edges shows the cracks. In the case of R/C panel with hole, tensile cracks appear at the hole corners. It is important to prevent the tensile crack propagation around the corners using the diagonal reinforcement.



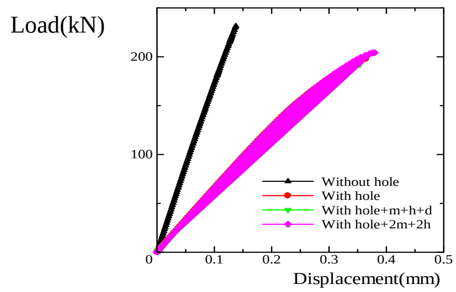
(a)Panel without hole. (b)Panel with hole (no reinf.). (c) Panel with hole (with reinf.).

Figure 8. Cracks in tension.

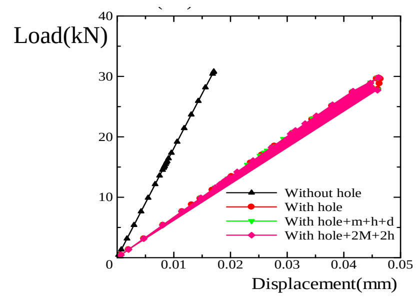
4.3 Load Deflection Curve

Figure 9 shows the load deflection relation of R/C panel in compression (a) and in tension (b). The abscissa and the ordinate show the displacement at the top center of the opening and the total applied load, respectively. Each mark shows the numerical results depending on the reinforcing method (see Figure 4).

In the case of the panel without hole, the stable load bearing behavior is shown up to failure. The stiffness of the panel with hole under the compressive force decreases gradually and the panel fails. The ultimate strength of R/C panel is almost the same between R/C panel with and without hole. In case of the R/C panel with hole, the models adopted in this analysis show the same ultimate strength. However, replacing of diagonal reinforcements with meridional and hoop reinforcements shows the larger strength.



(a) Under compression.



(b) Under tension.

Figure 9. Load deflection relation.

5 CONCLUSIONS

The deformation and the strength of R/C panel with hole was investigated by replacing the diagonal reinforcement with both meridional and hoop reinforcements. From the numerical analyses following conclusions are obtained.

(i) R/C cylindrical panel with hole degraded the stiffness under compressive load
(ii) The stiffened R/C panel with hole and R/C panel without hole show the same strength.
(iii) The ultimate strength of R/C panel with proposed reinforcements and a hole showed the same or the larger ultimate strength than that with conventionally reinforced R/C panel and hole.

The proposed reinforcement method was effective under the loading and the supporting conditions shown in this analysis. It is required to investigate the behavior of R/C panel with hole under other conditions combining with the experimental analyses.

Acknowledgements

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