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STRUCTURAL BEHAVIOR OF R/C SHELL CONSIDERING THE POSITION OF EDGE BEAM

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Reinforced Concrete (R/C) shell has been constructed to cover large public spaces and large industrial buildings. RC shell is originally a continuous structure and shows the large load bearing capacity. To apply these structures to such purpose, the structure is cut at any particular portion and loses their continuum properties. Therefore, edge beams must be placed to avoid the stress concentration and a local failure. In this paper, R/C cylindrical shell with edge beam on meridional free edges was analyzed by use of FEM. RC shell had 960 x 960 mm plan and the thickness was 10 mm. The radius and the depth of the shell were 688 mm and 190 mm, respectively. As the edge beam, three kinds of rectangular beams, which had 2 cm width and 4 cm depth, were arranged. One was connected to the shell at the gravity center of the beam and the others were connected at the bottom or the top of the beam. From the numerical analyses, the deformation and the stress distribution of the shell mentioned above were analyzed precisely. The shell connected with the gravity center of the beam showed the smooth deformation and the stress distributions.

Keywords: FEM, Beam arrangement, Stiffening, Cutting-edge, Deformation, Crack.

1 INTRODUCTION

Reinforced Concrete (R/C) shell has been constructed to cover large public spaces and large industrial buildings. R/C shell is originally a continuous structure and shows the large load bearing capacity. To apply these structures to such purpose, the structure is cut at any particular portion and loses their continuum properties. Therefore, edge beams must be placed to avoid the stress concentration and a local failure. Figure 1 shows the cylindrical shell with edge beams (Aloss 2015).

IASS recommendation and ACI building code recommends to place edge beam at free edges and the intersection of shells (IASS 1979, ACI 2012). However, the required dimensions and the details of connection method between shell and edge beam are not clearly recommended.

In this paper, R/C cylindrical shell with edge beam on meridional free edges was analyzed by use of FEM. R/C shell had 960 x 960 mm plan and the thickness was 10 mm. The radius and the depth of the shell were 688 mm and 190 mm, respectively. RC shell was supported only at the four corners and was subjected to the self weight.

As the edge beam, three kinds of rectangular beams, which had 2cm width and 4cm depth, were arranged. One was connected to the shell at the gravity center of the beam and the others were connected at the bottom or the top of the beam. In the numerical analyses, the deformation and the stress distribution of the shell mentioned above were analyzed precisely.

Figure 1. Nencki AG (Heinz Isler 1956 in Aloss 2015).

2 NUMERICAL MODEL

2.1 Model Geometry

Figure 2 shows R/C shell model (Hara 2010). The width and length of cylindrical shell are 960 mm and 960 mm, respectively. The thickness of the shell is 10 mm. Radius of the cylinder is 688 mm. In the middle of the thickness of the shell, reinforcement mesh (diameter 0.75 mm) with 5 mm openings is arranged. On both the meridional edges, edge beams, which are 20 mm width and 40 mm depth, are attached. The stiffened R/C shell is supported at four corners as shown in Figure 3.

Three kinds of arrangements of the edge beam were considered. Figure 4 shows the arrangement of the edge beam. In Type C, the edge beam at the gravity center is connected to the cylindrical shell. In Type U and Type B, the edge beam is connected at the top or at the bottom to the cylindrical shell. Two ϕ 3 mm reinforcements were arranged on both top and bottom parts of the edge beam. The cover of the micro-concrete was 5 mm.

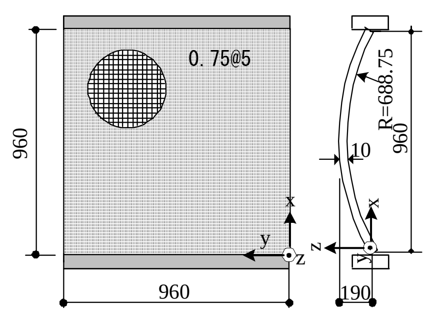


Figure 2. Geometric dimensions of R/C cylindrical shell (mm).

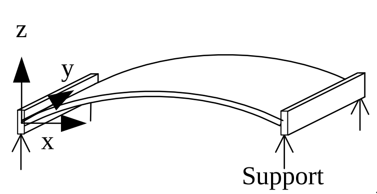
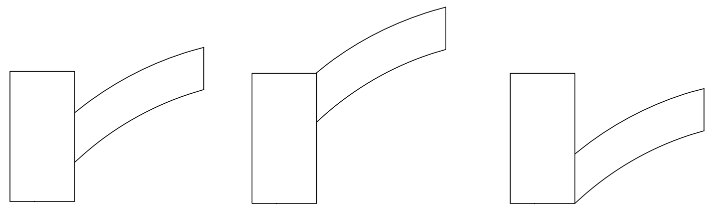


Figure 3. Supporting of R/C cylindrical shell.



(a)Type C (b)Type U (c)Type B

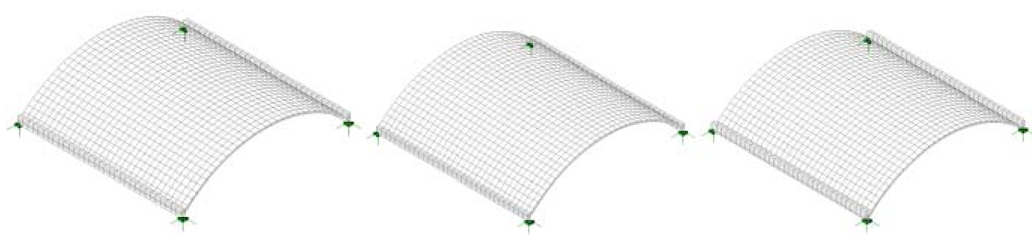
Figure 4. Connection of edge beam.

2.2 Material Properties

The model was assumed to construct by the mild steel and the micro concrete. Both the material parameters are shown in Table 1. Material properties were obtained by the material tests.

Table 1. Material properties of concrete and steel.

Concrete		Steel	
Compressive Strength (MPa)	38.2	Yield Stress(MPa)	235
Tensile Strength(MPa)	3.8	Tensile Stress(MPa)	449
Young's Modulus(GPa)	23.6	Young's Modulus(GPa)	206
Poisson's Ratio	0.20	Tangential Modulus(GPa)	21



(a) Type C (b) Type U (c) Type B

Figure 5. Numerical model.

2.3 Numerical Model

Figure 5 shows the numerical models. Type C denotes the model with edge beams connected at the gravity center. Type U and Type B show the model with edge beams connected at the beam top and the beam bottom, respectively. Each model was divided into solid elements with 20 nodes.

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 I_1 but also on the second deviatoric stress invariant J_2 (Hinton and Owen 1984; Hinton 1988). The yield condition of tri-axial compressive concrete is expressed by Drucker Prager criterion (Hara 2004; Hara and Hadi 2005; Hinton and Owen 1984; Hinton 1988).

$$f(I_1, J_2) = \sqrt{\beta(3J_2) + \alpha I_1} = \sigma_0 \tag{1}$$

where α and β are the constants. Also σ_0 is the equivalent stress.

Parameters adopted in the criterion are defined by Kupfer's (1969) experiment. It is assumed that the initial yield begins when the equivalent stress exceeds $0.3f_c$ (f_c: compressive strength of concrete) (Hinton 1988). 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.

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

$$\sigma = f_t' \exp\left(-\frac{\varepsilon - \varepsilon_t'}{\gamma}\right), \quad \gamma = \frac{G_f - 0.5 f_t' \varepsilon_{cr} \ell_c}{f_t \ell_c} \tag{2}$$

where f_t' is maximum tensile strength of concrete, γ is the tension stiffing parameter, ε_t' is crack strain, G_f is the fracture energy of concrete, ℓ_c is the cubic root of volume in Gaussian point, and ε_{cr} is the strain in crack. γ =0.1 is adopted in this paper due to the characteristics of normal concrete.

The reinforcing bars are considered as steel sheet. 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 (Hinton 1988).

3 NUMERICAL RESULTS

Figure 6 shows the load – displacement relation for each connecting method between edge beam and R/C shell. The loading condition is the self weight. Factor (k) at the ordinate denotes the magnification factor of self weight. The legend "No rib" means the numerical result of R/C shell without edge beams.

The edge beam improves 2.5 to 4 times the load carrying capacity of R/C shell under self weight. R/C shell of Type C shows the large stiffness and ultimate strength. R/C shell of Type B shows larger stiffness than that of Type U. However, the ultimate strength of R/C shell with Type U shows the larger ultimate strength.

Figure 7 shows the deformation patterns of R/C shell with edge beams. Total deformation patterns are almost the same. The deformation of the edge beam of Type U shows the larger deformation than that of Type B.

Figure 8 shows the crack pattern of R/C shell with several types of edge beams. Type C and Type U show almost the same crack patterns. However, in case of Type B, cracks concentrate in the middle of the edge beams and propagate to R/C shell.

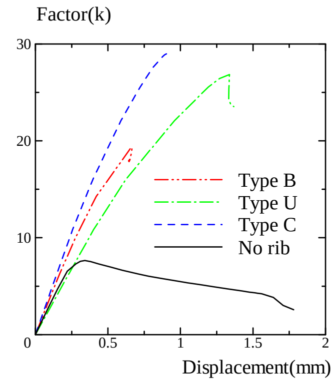
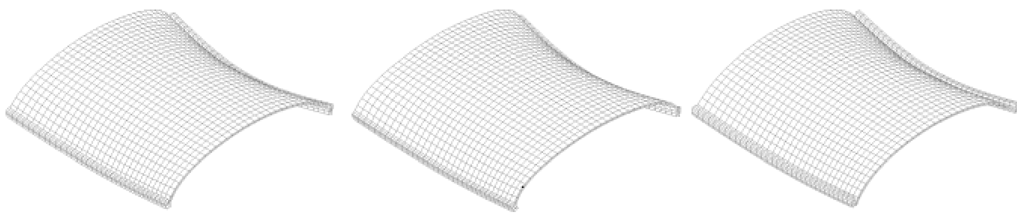
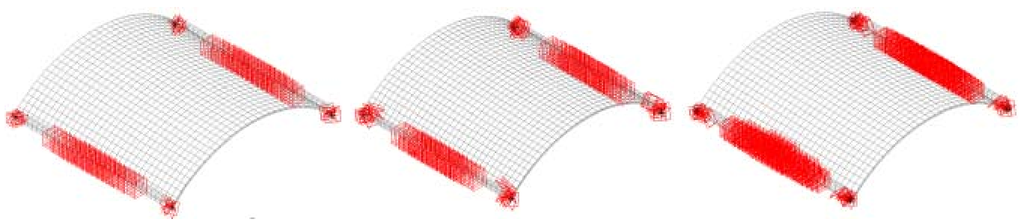


Figure 6. Load-Displacement relation.



(a) Type C (b) Type U (c) Type B

Figure 7. Deformation of the shell.



(a) Type C (b) Type U (c) Type B

Figure 8. Cracks on the shell.

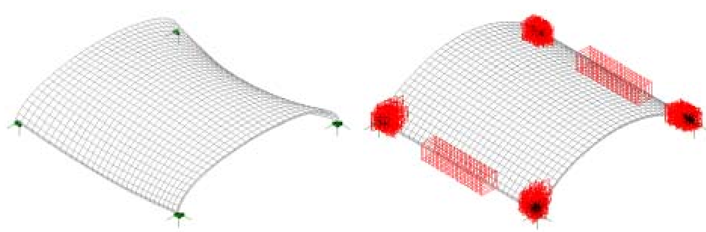


Figure 9. Deformation and crack pattern of R/C shell without edge beam.

Figure 9 shows the deformation and crack patterns of R/C shell without edge beam. Deformation show flat and the cracks concentrate at four corners. The failure begins at corners. R/C shell could not show large ultimate strength due to such failure.

4 CONCLUSIONS

In this paper, R/C cylindrical shell with edge beam on meridional free edges was analyzed by use of FEM. In numerical analysis, the different arrangements of the edge beam were considered. From the numerical results, following conclusions are obtained.

(1) The arrangement of the edge beam influences the strength of R/C shell with edge beam. Edge beam connected at the beam top is better than that connected at the beam bottom. Edge beam connected at the gravity center shows the better performance.

(2) At all cases, the edge beams on the meridional edge improve 2.5 to 4 times the strength of R/C shell without edge beam.

(3) The edge beam plays an important role to avoid R/C shell failure itself. It works to prevent the failure of the supporting corners. Also, it prevents the crack propagation from the edge to inner portion of R/C shell.

Acknowledgments

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