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Structural Behaviors of Reinforced Concrete Dome with Shell System under Various Loading Conditions

Khine Zar Aung, Khin Aye Mon, Khin Thanda Htun

Department of Civil Engineering, Yangon Technological University, Yangon, Myanmar

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ABSTRACT

There are many different systems constructing dome structure. Among them, the shell system is the most popular in reinforcement concrete structure in these days. Therefore, it is necessary to know the structural behaviours of it. The objectives of this journal is to study the structural behaviours of the reinforced concrete dome structure with shell system under gravity loading and lateral loading in cyclone wind categories and various seismic zones. Seismic loads are considered from zone 1 to zone 4 based on UBC (1997).Wind loads are considered from I to V category as cyclone categories. Structural elements of RC dome structure are designed according to Building Code of American Concrete Institute (ACI 318-99). With these member forces obtained from the SAP 2000 analysis, the design for all structural members will be performed according to ACI 318-99. The members of dome structure are designed as an intermediate moment resisting frame. The design of the shell beams is verified by using hand calculations with the output forces under the gravity loading and lateral loading obtained from the SAP2000 analysis. Equivalent static analysis procedure is used in this study. Based on the comparison of analysis results, it can be observed where the maximum deflection occurs along the meridian direction under seismic and wind loading conditions. Then, the axial force of dome structure is significant than any other forces in shell system. From the study of analysis results of both systems, it has been noticed that the bottom ring in shell system is essential to control the forces from the shell area.

KEYWORDS: *shell system, structural behaviour, seismic loads, wind loads*

I. INTRODUCTION

A dome is a self-supporting structural element of architecture that resembles the hollow upper half of a sphere. Dome is one of the most efficient shapes in the world since it covers the maximum volume with the minimum surface area. Dome structure can be constructed by different structural systems. Among them, thin shells with ring beam as structural elements occupy a leadership position in engineering. Shell structures support applied external forces efficiently by virtue of their geometrical form, as a result, shells are much stronger and stiffer than other structural forms [1]. It is light, strong and supported.

II. MODELLING OF REINFORCED CONCRETE DOME STRUCTURE

The proposed reinforced concrete dome structure is 150 feet in diameter and 40 feet in height. The thickness of RC dome is used 6 inches for shell system as shown in Fig. 1. There are four entrances because it is used as sport center. The shell structural systems constructing in RC dome structure are considered in this study. This dome structure is designed to withstand gravity loads, cyclone-level wind loads [2] and seismic loads from design threats.

The wind loads and seismic loads based on UBC-97 [3] are assigned to the SAP 2000 model. Wind loads are considered as cyclone category which intensities are 55.9mph, 77.675 mph, 102 mph, 139.2 mph, 173.4 mph. With these member forces obtained from the SAP 2000 analysis, the design for all structural members will be performed according to ACI 318-99 [4]. The members of dome structure are designed as an intermediate moment resisting frame. The design of the shell beams is verified by using hand calculations with the output forces under the gravity loading and lateral loading obtained from the SAP2000 analysis.

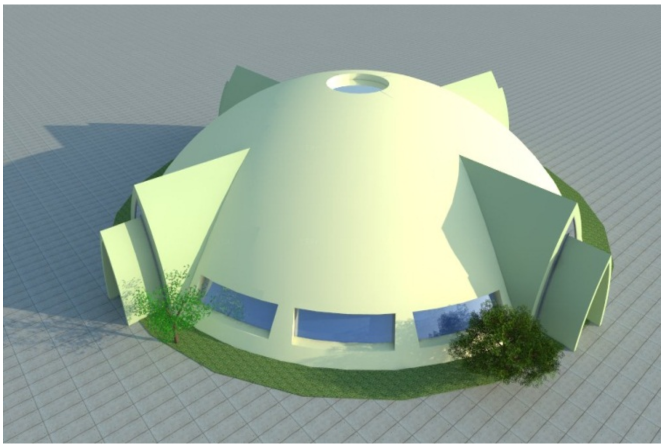

Fig. 1 Architectural Model of Proposed Dome Structure

A. Material properties

Analysis property data,
Weight per unit volume = 150 pcf
Modulus of elasticity = 3605 ksi
Poisson's ratio = 0 for shell system [4]
Design property data,
Concrete strength (fc') = 4,000 psi
Reinforced yield stress (fy) = 60,000 psi
Shear reinforcing yield stress (fys) = 60,000 psi Data for dead load

B. Data for gravity load which are used in structural analysis are as follows:

Superimposed dead load = 20 psf (Ceiling is considered as superimposed dead loads)
For dome with 1/8 ≤ rise /span ≤3/8, Roof live load = minimum 16psf (used 20psf).

C. Data for wind load Data for wind load which are used in structural analysis are as follow:

Exposure type = C
Effective height for wind load = 34 feet
Different wind velocities on model = 55.9mph, 77.675mph, 102mph, 139.2mph, 173.4mph
For slope 2:12 ≤ 4:7.5≤ 9:12,
Windward coefficient C_q= 1.4 for outward due to partially enclosed structure
Windward coefficient C_q = 0.3 for inward due to partially enclosed structure
Leeward coefficient = 1.2
Important factor, I_w = 1.0

D. Data for earthquake load

Data for earthquake load which are used in structural analysis are as follow:
Seismic Zone =1, 2A, 2B, 3 and 4 2B
Zone Factor, Z = 0.075, 0.15,0.2,0.3 and 0.4
Structural System = Shell system
Soil Type = S_D
Importance Factor, I = 1
Response Modification Factor, R = 5.5
Seismic Response Coefficient, C_a and C_v are varied according to the seismic zone and soil profile type.

E. Load Combinations

Design codes applied are ACI 318-99 and UBC-97.There are 26 numbers of load combinations which are accepted in CQHP (Committee for Quality Control of High-Rise Building Construction Project).

1. 1.4 DL
2. 1.4 DL + 1.7 LL
3. 1.05 DL+1.275 LL+1.275WX
4. 1.05 DL+1.275 LL-1.275 WX
5. 1.05 DL+1.275 LL+1.275 WY
6. 1.05 DL+1.275 LL-1.275 WY
7. 0.9 DL+1.3WX
8. 0.9 DL-1.3WX
9. 0.9 DL+1.3WY
10. 0.9 DL-1.3WY
11. 0.9 DL+1.02EQX
12. 0.9 DL-1.02EQX
13. 0.9 DL+1.02EQY
14. 0.9 DL-1.02EQY
15. 1.05 DL+1.28LL+EQX
16. 1.05 DL+1.28LL-EQX
17. 1.05 DL+1.28LL+EQY
18. 1.05 DL+1.28LL-EQY
19. 1.16 DL+1.28LL+EQX
20. 1.16 DL+1.28LL-EQX
21. 1.16 DL+1.28LL+EQY
22. 1.16 DL+1.28LL-EQ
23. 0.79 DL+1.02EQX
24. 0.79 DL-1.02EQX
25. 0.79 DL+1.02EQY
26. 0.79DL-1.02EQY

where,
D.L = dead load
L.L = live load
WX = wind load in x direction
WY = wind load in y direction
EQX = earthquake load in x direction
EQY = earthquake load in y direction

III. SHELL BEHAVIORS AND DESIGN CONSIDERATIONS

While shell system of RC dome structure is analyzed under gravity loading and lateral loading, membrane actions are more effected in any other forces in dome structure. Shell areas are designed under the membrane forces along the meridian and circumferential directions. In the design of shell area for dome structure, the reinforcement is placed due to F_{11} along circumferential direction and F_{22} along the meridian direction. Shear is checked in designed area. The shear is under the concrete nominal shear. So, it is no need to provide shear reinforcement. In design of shell area for RC dome structure, tensile force can be directly resisted by steel and compressive force can be resisted by steel and concrete.

Table1. Provided Steel Areas for Each Portion.

	Provided Steel area for circumferential plane	Provided Steel area for meridian plane per feet
Top portion	No.5 bar @ 6" c/c spacing in both layer	No.5 bar @ 8" c/c spacing in both layer
Area between openings	No.7 bar @ 6" c/c spacing in both layers	No.5 bar @ 6" c/c spacing in both layers
Entrance dome at upper level	No.7 bar @ 6" c/c spacing in both layers	No.7 bar @ 6" c/c spacing in both layers
Tension ring at plinth level	6no.9 bars	B 24x24
Compression ring at top	3no.5 bars	B10x14

Edge beams stiffen the shell edges and act together with the shell in carrying the load of the supporting system. Beam size 24" x24" is used for the edge beam in plinth level. Edge beams carry the longitudinal tensile force. 6No.9 bars are provided for maximum tensile force P_{max}=308 kips.

IV. ANALYSIS RESULTS AND DISCUSSIONS

The gravity loading due to dead load and live load and lateral loading due to wind or earthquake are the major factors that cause different displacements and forces in reinforced concrete dome structure with shell system. There are seven critical points on this structure depending on structural configuration as shown in Fig. 2.

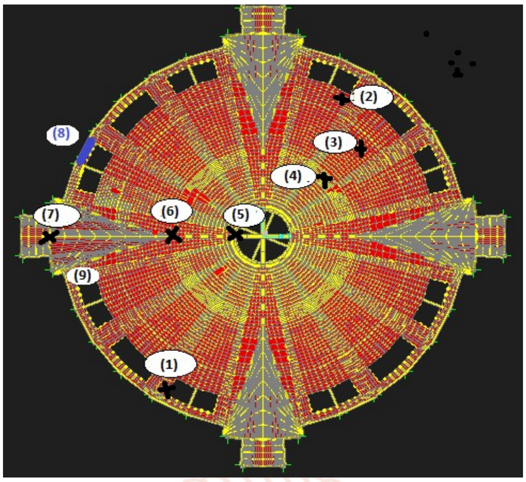

Fig.2 The Critical Points of the Plan View of Reinforced Concrete Dome Structure with Shell System

A. Maximum Displacements in Shell System

Fig. 3 shows the maximum displacement in X, Y and Z directions of point 1 which is in middle portion (2) above window under twelve critical load combinations. The displacements of X, Y, and Z direction are gradually increased according to the wind speed and the seismic zone. The maximum displacement at that point in shell system is 0.26 inches in Z direction which is under wind load combination 4 (1.05DL+1.275LL-1.275WX).

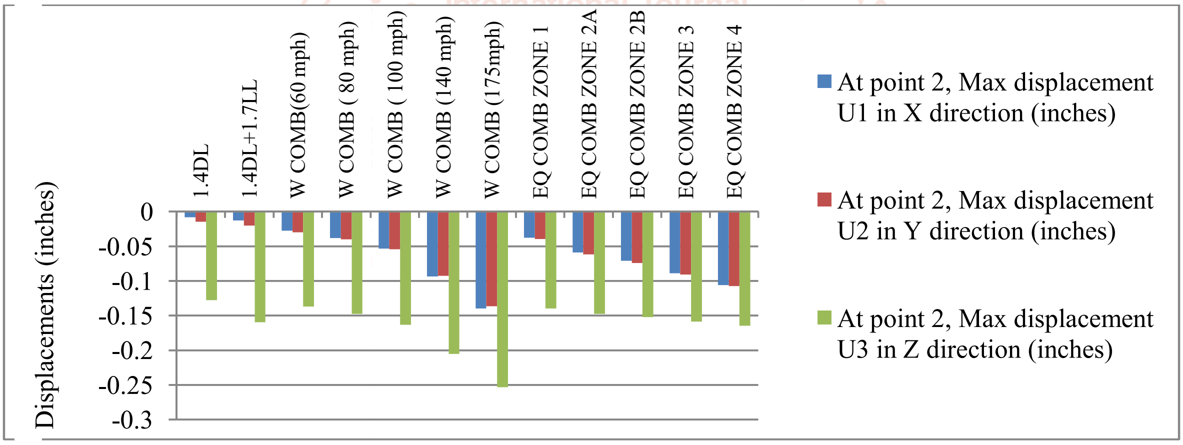

Fig.3 Maximum Displacements at the Point of Middle Portion (2) above Window in Shell System of Dome

B. Maximum Membrane Forces of the Shell Area of Bottom Portion

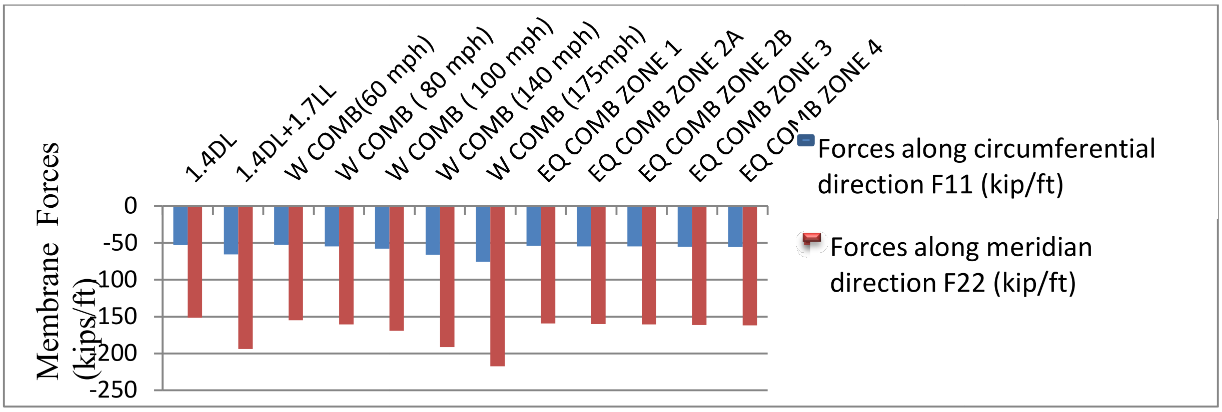

Fig. 4 Maximum membrane forces along the circumferential direction F11 and the meridian direction F22 in the critical area of bottom

The Figure 4 shows maximum membrane forces along the circumferential direction F11 and the meridian direction F22 in the critical area of bottom portion of RC dome with shell system. In critical wind loading combination, maximum membrane forces along the circumferential direction F11 and the meridian direction F22 in the critical area of bottom portion are gradually increased according to the wind speed and that of under seismic load combinations are also gradually increased as the seismic zone is high. The maximum membrane force along the meridian direction F22 in the critical area of bottom portion under maximum wind loading is more than that under gravity loading and maximum seismic loading combination by 1.12 times and 1.34 times.

C. Maximum Forces of Critical Ring Beams in Shell System

Fig. 5 shows the critical axial force, major shear, minor shear, major bending moment, and torsional moment of the critical bottom ring beam (8) in shell system under twelve critical load combinations. Among them, the axial force and bending moment are the significant forces under all critical loading. The maximum axial force in the critical bottom ring beam I in shell system is 200.4 kips which is under wind load combination4 (1.05DL+1.275LL-1.275WX).

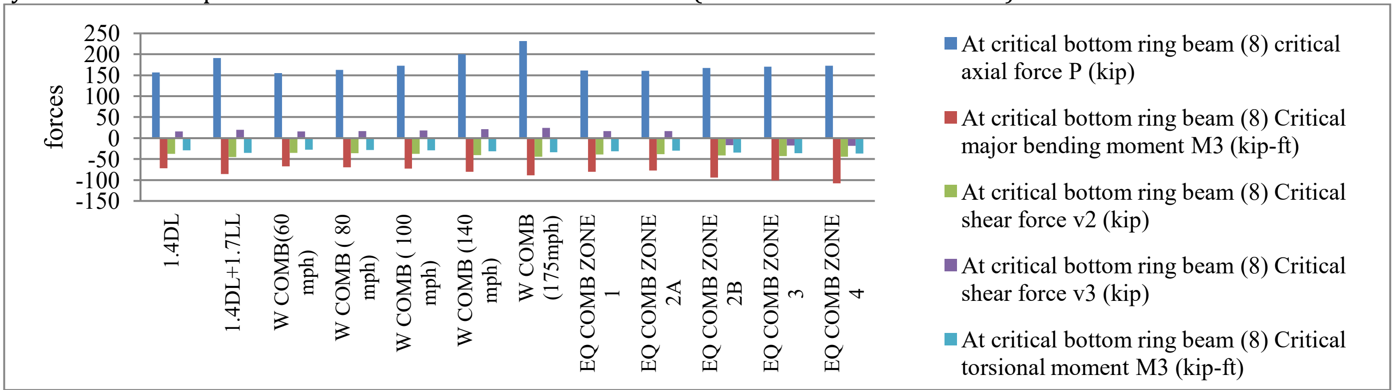

Fig.5 Critical Forces of Critical Bottom Ring Beam (8) in Shell System

D. Critical Reactions of the Shell System

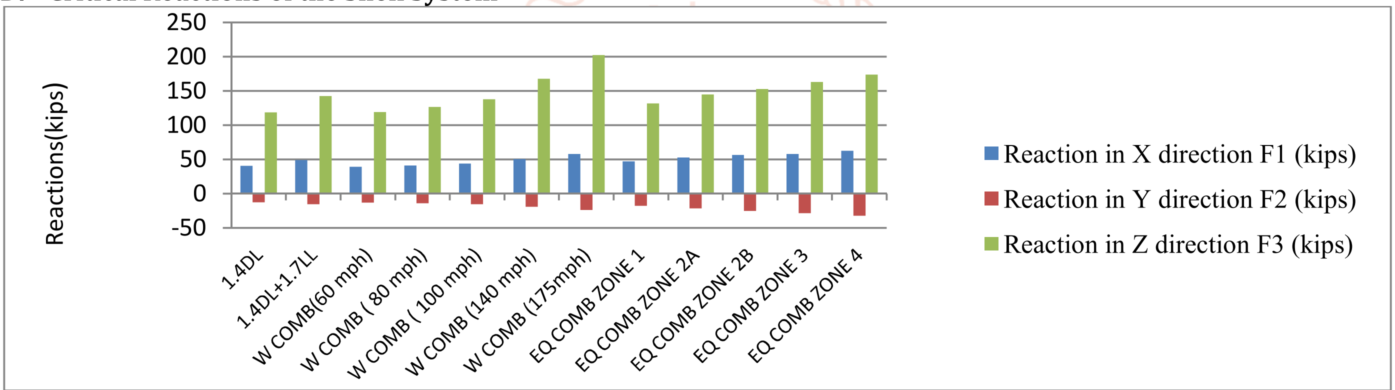

Fig.6 Maximum Reactions F1 in X Direction, F2 in Y Direction, and F3 in Z Direction at Critical Point (9) at the Base of Y Beam in Shell System

Fig. 6 shows the reactions F1 in X direction, F2 in Y direction, and F3 in Z direction at the critical point (9) at the base of Y beam in shell system under twelve critical load combinations. The reactions of X, Y, and Z direction are gradually increased according to wind speed and seismic zone. The maximum reactions in shell system is 207 kips in Z direction which is under wind load combination 4 (1.05DL+1.275LL-1.275WX).

V. CONCLUSION

From the above study, it can be concluded as the following.

1. From the study of analysis results of shell system in RC dome, the maximum displacement occurs in Z direction in the middle portion of dome under wind load combination.
2. The membrane forces are also the maximum under wind load combination in both meridian and circumferential directions.
3. From the analysis result of critical bottom ring beam, the axial forces are 230 kips in shell system. Therefore, the bottom ring in shell system of dome structure is essential to control the forces from the shell area.
4. The critical reaction in Z direction is control any other reactions in shell system. The maximum reaction in this system of dome is 207 kips which is also under wind the combination.

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