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Systematical structural analysis of monolithic domes

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Abstract

Monolithic dome structures were built in the 1970s in Europe and America. These dome structures share common benefits of being cost efficient, earth-friendly, extremely durable, and easily maintained. Monolithic shells are easily constructed and are extremely cost-effective. Monolithic domes respond efficiently to any climate, even to extremely cold or hot temperatures. In terms of utility savings, monolithic domes can cut electricity consumption by up to one-third, thereby saving 60–70% of total energy costs. Moreover, monolithic structures provide the highest survivability rates from destructions. The interior of monolithic domes have perfect, concave shapes to ensure that sound travels through the dome and perfectly collected at different vocal points. These dome structures are utilized for domestic use because the scale allows the focal points to be positioned across daily life activities, thereby affecting the sonic comfort of the internal space.

This study examines the various acoustic treatments and parametric configurations of monolithic dome sizes. A geometric relationship of acoustic treatment and dome radius is established to provide architects guidelines on the correct selection of absorption needed to maintain the acoustic comfort of these special spaces. In this study we cannot take the particular research paper for comparison of results. The location of structure for terrain category I calculated and so the wind speed varies according to terrain and this results in different value of load calculation for different terrain category.

Keyword: Monolithic Dome; STAAD PRO V8i; IS 456; IS 875; IS 1893

1. Introduction

Monolithic Dome is thin wall reinforced concrete shell structure. The structure provides safe shelter for the people in the area with hurricanes and earthquakes. This technique is an effective alternative to conventional methods. A Monolithic Dome is a structure cast in a one-piece form. A curve rotated about a central axis to form a surface, creates a Dome. Monolithic domes are not only unique and eye catching, but studies have shown them to be exponentially energy efficient. They use 50% less energy than traditionally built structure of similar size. Domes are designated as tornado shelters. Three brothers David, Barry and Randy built and patented the first monolithic dome in 1975. The construction of monolithic dome with proper earth sheltering will withstand bomb blast more effectively. Sizes: very small 2.5 m-very large 80m diameter domes.

Today, monolithic domes are used in a variety of residential, commercial and industrial projects. Because of the strength, durability and economics, they are used to store large amounts of various commodities in the cement, fertilizer, agricultural, power and mining industries. Due to their structural integrity, they are used as the containment buildings at some nuclear power plants. Forms have been made using nearly every common structural material including air pressure supported fabric.

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Figure 1 Monolithic Domes

Aim

The main Aim of this project is to study, analysis and design of Monolithic Concrete Dome by using Staad pro V8i with substructure for an auditorium and to design the structural elements of a dome structure such as shell structure, ring beam, column and footing.

Figure 1 Energy Saving Monolithic Domes

Objectives

- The main objective of this project is to study analysis and design of Monolithic Concrete Dome using STADD Pro v8i with substructure of an auditorium.
- To study the design of structural elements of a dome structure such as shell structure, ring beam, column and footing.
- To analyze the structural elements of domes for carrying the various load like dead load, live load, wind load and seismic load.
- To study the stress developed on structural elements of monolithic domes for an auditorium.
- To design the structure according to Indian standards codal provisions.(RCC structure. • IS 456-200 • IS 1893-2002/2005 • IS 875-1987)
- Comparison between Flat roof and Dome roof.

2. Problem statement

- The demand of monolithic domes is increased in variety of residential, commercial and industrial projects.
- The main need of this study is to improvise new dimensions of domes to analyse the behaviour of dome like strength variation and durability. Monolithic domes will helps in studying load analysis.
- All the study will implement on Staad-pro v8 is software to calculate the load of structure and implementing the correct sizes of columns, beams.

3. Future scope

- Monolithic domes are energy efficient housing options for example a monolithic dome for a living space, having ceiling and walls with earth-friendly, efficient, extremely durable and easily maintained.
- Domes are ideally suited for structures where open spaces are required. They are open span and therefore no columns intrude on or interrupt valuable space.

- Most importantly, a monolithic dome consumes 50% less energy for cooling and heating than a same-size, conventionally constructed building.
- The spherical sections of the dome offer minimum surface area for the contained volume, because of this there is less surface for transfer of heat with the outside air.

4. Materials used for monolithic dome

Monolithic dome structure is composed of three main material

- Air form kits,
- polyurethane foam
- Steel & concrete.

Figure 3 Air form kits, Polyurethane foam and Reinforcing Steel

5. Construction of monolithic dome

Monolithic dome is a rounded building structure typically made of concrete and rigid steelrods. It consists of an outer airtight form, polyurethane foam insulation and reinforced concrete.The building process of monolithic domes entailed:-

- Lay down the foundation of the dome, usually made of reinforced concrete.
- An air form or fabric is inflated over the foundation.
- Poly urethane foam is then added to the inside of the form.
- Special clips are affixed to the foam interior, and rebar is installed.
- Finally concrete ispoured over the air form, rebar, and foam supporters and dome like shape emerges.

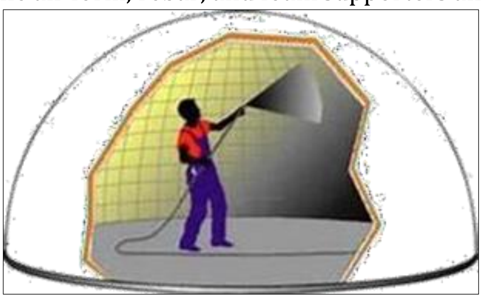

Figure 4 Application of shortcrete

6. Stresses acting on monolithic dome structure

- Meridional thrust (T) along the direction meridian.
  Compressive only and increase toward the base. Thrust produced is directly proportional to the weight of its materials.
- Hoop stress along latitudes.
  Compression at top and tension at the base with transition at an angle 51.8 degree from the top

7. Methodology and analysis

- The project study will describe two stages.
- The primary data will take from a Literature survey targeted by web searches and review of e books, manuals, codes and journal papers.
- After review the problem statement is defined and the selected dome models are taken up for detail study and analysis purposes.
- This project execution follows the flow chart given below
- Start – Calculation of Dome load – Calculation of stress acting on dome – Design of Ring beam – Design of Column – Check for Serviceability – Results.

Table 1 Terrain Category

Model	Dome Size	Terrain Category		
		Terrain 1	Terrain 2	Terrain 3
Dome 1	10m X 5m	39m/s	44 m/s	NA
Dome 2	15m X 7m	39m/s	44 m/s	NA
Dome 3	20m X12m	39 m/s	44 m/s	50 m/s

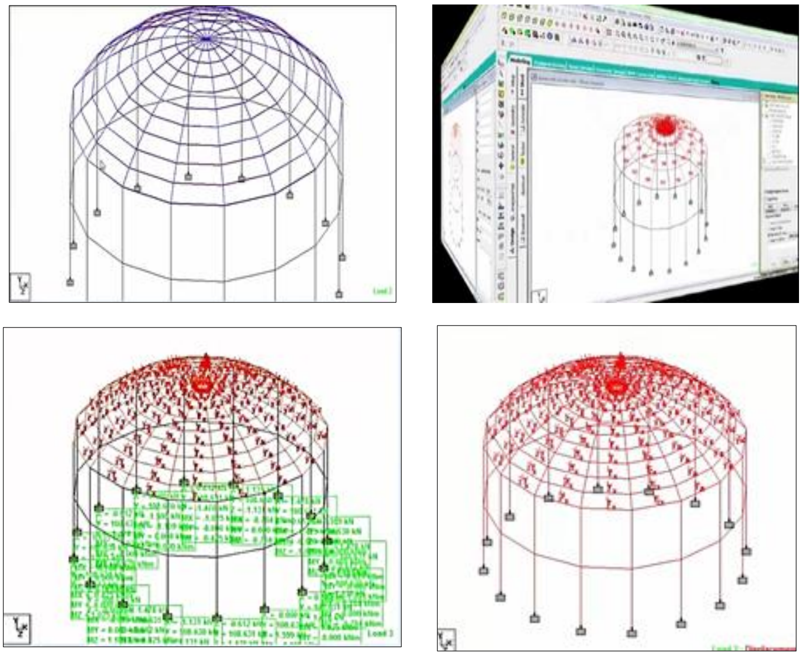

Figure 5 Design of Dome

7.1. Manual calculation

- Meridional thrust (Tu) = 255.73KN (C)
- Meridional thrust (τvt) = 1.022mpa (C)
- Hoop force = 141.41KN (T)
- Hoop stress (τht) = 0.565mpa (T)
- Hoop tension in ring beam = 556.66KN
- Area of steel reinforcement in each element of dome = 700mm^2
- Spacing along both lateral and transverse diameter of bar used = 16mm
- Total area of each ring beam section = 2416mm^2 spacing of bar in ring beam = 150mm c/c
  - o Diameter of bar used in ring beam is 8mm and 21 nos.

- Composite area of ring beam = 133000 mm^2 - Size of ring beam adopted = 350mm x 400mm
- Shear reinforcement in ring beam = Area of each section = 101mm^2 - Spacing of stirrups = 200mm
- Diameter of bar = 8mm and 2 legged stirrups.

Table 2 Reinforcement summary of Dome Slab

Portion	Main steel	Distribution steel
Meridian	#16mm @290mm c/c	#16mm @290mm c/c
Hoop	#16mm @290mm c/c	#16mm @290mm c/c

Table 3 Reinforcement summary of Ring Beam

Portion	Main steel	Shear reinforcement
Ring beam	21nos #8mm @150mm c/c	8mm-2 legged @200mm c/c

Table 4 Comparison between Manual and Staadpro Stresses

Description	Stress as per manual design (N/mm2)	Stresses as per Staadpro v8i design (N/mm2)
Max stress	1.022 (C)	1.27 (C)
Min stress	0.565 (T)	0.394 (T)

8. Comparison between flat and dome roofs

Table 5 Comparison between flat and dome roofs

Feature	Flat Roofs	Dome Roofs
Seismic stability	Vulnerable to Transverse loads.	More effective against transverse loads
Deformation	To obtain the same deformation, the column section of a flat roof structure had to be raised by 40mm to obtain the same value as that of a G+4 storied frame dome roof structure	30%, 34.5% and 35%, respectively were the average percentage reduction in the average percentage reduction in deformation, maximum bending moment and maximum shear force.
Resistance to Explosion	This type of roof is the most compatible against explosion.	The roof because of it being aerodynamic will operate well against explosion, also with regard to its higher area of vertical plane obtains a remarkable force.
Materials usually used	PVC Membrane , TPO Membrane, EPDM, Rubber Membrane, Modified Bitumen, Rolled roofing	Shingles, metal and even glass. However, for a dome roof that will require less maintenance, metal is suggested
Future Expansion	Future expansion of the living space an easy option, since patios, gardens or even penthouse rooms can be added	The unique structure and area consumption makes further expansion a difficult option.
Expenses	Less expensive than other popular roof styles.	Both expensive and time-consuming to construct, prefabricated options on the market, can translate to substantial savings.

9. Conclusion

- Through this Report, we have dealt with the brief history of Domes and have highlighted some of the recent innovations and focus on using it for modern housing.
- The advantage of using them over Flat roofs has also been done through the paper indicating the superiority of dome structures. Two popular types namely Geodesic and Monolithic domes have been discussed.
- Both Monolithic and Geodesic domes have advantages particularly for energy-efficient and disaster resistant housing. Thorough this paper we have attempted to bring out the relevance of carrying out further research and investigation in the use of suitable dome structures for popular constructions like housing.
- In Monolithic Dome method we can use the industrial waste fly ash to replace 15-20% of cement used in construction which also helps to save the environment and cost of construction.
- We can use composite hallow circular columns replaced by rectangular columns. Structural behaviour is studied of RC dome using STAAD.Pro v8i.
- The assumed dimensions of beam is 350mm x 400mm, column of diameter 500mm & plate thickness is 250mm are safe for carrying various load. For the applied load cases and combination structure comes under safe zone.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest in publishing the paper.

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