Conceptual Design of Wide Span Spherical Dome

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Abstract - *In the recent years, there have been an increasing number of structures using concrete and steel domes as one of the most efficient shapes in the world. This paper concentrates on analyzing and designing of dome structure for larger spans which is more efficient and economical as it will not have the interrupted columns. The study of shell theory and their possible way of failure is also presented in this paper. The use of pre- stressed concrete sections is done as it is suitable for larger spans. The M-40 grade of concrete and Fe-415 HYSD bars is adopted. The result shows that the rise is inversely proportion to the stress. The validation of obtained results with manual results for different spans to central rise ratios is also carried out. The approach used to achieve this objective is by adopting working stress method and analyzing of concrete dome using computer software STAAD.Pro. As per the obtained results it can be concluded that the stresses are less in dome which is having central rise of 1/5th of the span. Rise of 1/4th of the span cannot be adopted as its angle should not be greater than 51^0 52', to keep the shell in compression zone.*

Key Words: *dome structure, spherical Shell, wide span, non-uniform loading*

1. INTRODUCTION

Many types of thin shell roof constructions are of recent origin and became popular only after World War II, even though progress was made in reinforced concrete after World war I. this modern material (reinforced concrete) can be cast in any shape. Like steel, it has strength. Besides, it has the body to cover the space. Steel by itself is rarely used to Cover space whereas reinforced concrete is used to construct slabs, shells, etc. This in addition to spanning length can also cover space. This important property of reinforced concrete can be taken full advantage in shell construction.

The concept of shell construction can be considered as a slow evolution made from masonry arches and domes, which were in use from the very early days of human existence. Brickwork could take only compression and no tension. Reinforced concrete is homogeneous and continues and its action is different from that of brick work made of individual brick with mortar joints. It is a very interesting study as how, without the availability of modern materials, our ancient architects were able to design and construct structures like large domes and vaults to cover large space for monumental buildings.

1.1 Design approach

1. A specific design approach is defined to fulfill all of the objectives mentioned earlier. Design is an iterative process which can become extremely taxing, if not planned beforehand. The overall order of the design strategy adopted in this report is mentioned below. Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:
2. All theory related to shell design is acquired and studied. This includes study of different spherical shell & their structural behavior and also the possible ways they can fail.
3. The entire history of concrete shell industry is studied. An attempt is made to learn about their ways and methods. They have an impressive list of shell structures that exist and function today.
4. Currently functioning kudal sangam (Sabhabavan) (Bagalkot Karnataka) steel dome structure, there I had visited to have a better understanding of structure, rise of dome and ring beam
5. Based on the three steps mentioned above, pre-design considerations are drawn up. They essentially serve as design boundaries or constraints, only within which, the designer can freely operate. This step marks the beginning of the actual design process. Once all factors are taking into consideration, the outline of the main design process is created. This procedure is strictly followed during the entire course of design.
6. Finally the behavior of the designed shell is studied and recorded, under various load combinations (DL+LL+ Temperature Stresses), to ensure proper functioning of the structure.

The first three steps constitute the literature study performed, before commencing the actual design of the roof of the structure. They help to create a sound design process which is then applied to obtain the final proposal. This design process is explained in detail during the course of this report.

2. Planning of spherical Domes

There can be a number of cases of shell analysis for various loading such as:

1. Uniform dead load (DL) on a full shell surface with a central load on the apex

2. Uniform line loading over surface on top of a shell with skylight
3. Uniform line load assumed constant over the projected area (plan area) of shell surfaces
4. Shell with thickening of the edges and consequent variations of dead load.

Now, will deal with only first case, it is a common practice to adjust live load, and even wind load to be considered as an equivalent dead load. But we must remember that non-uniform loading can produce shear stresses also. Wind loads on surfaces which are horizontal or inclined up to 400 to the horizontal (depending on height to width ratio) can produce suction, which is usually neglected as it reduces the stresses in the shell.

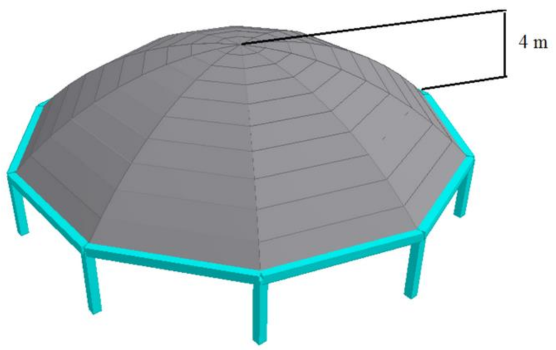

Fig -1: 20m spanned dome, Model 1

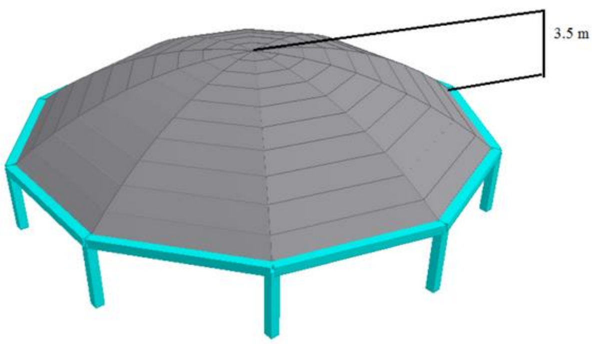

Fig -2: 20m spanned dome, Model 2

Table -1: Design 1, Model 1, 2

Materials		Design data	
Concrete Mix	M20	Span	20m
Steel	Fe 415 HYSD Bars	Central Rise	1) 4m (Span/5) 2) 3.5m (Span/6) 3) 3m (Span/7) 4) 2.5m (Span/8)
		Shell Thickness	0.1m

Table -2: Design 2, Model 1, 2

Materials		Design data	
Concrete Mix	M20	Span	30m
Steel	Fe 415 HYSD Bars	Central Rise	1) 6m (Span/5) 2) 5m (Span/6)
		Shell Thickness	0.1m

3. DESIGN: 1 MODEL 1

3.1 DATA

Thickness of Dome Shell = (t) 0.1 m

Grade of Concrete = (M) 20 N/mm2

Grade of Steel = (fck) 415 N/mm2

3.2 DESIGN DATA

Diameter of Dome = (D) 20 m

Rise of Dome = (h) = Span ÷ 5 4 m

Radius of Dome = (r) 10 m

Radius of Shell = (R) 14.5 m

Angle of radius of shell = Ø 43.360

3.3 LOADS ON SHELL

Dead Load = (DL) 2.5 kN/m2

Live Load = (LL) 1 kN/m2

Wind Load & Temp Stress = 1 kN/m2

Total Load = (Wu) 6.75 kN/m2

Crown Weight = (P) 2 kN

Table -3: Stresses in shell

Angle	Ø0	g*R/ 1+cosθ	P/ 2*π*R* sin^2Ø	Nө	g*R*Cosө	NØ
0	0	48.93	∞	48.9	97.875	48.9
10	0.17	49.31	0.724	50.0	96.38	46.3
20	0.34	50.45	0.188	50.6	91.97	41.3
30	0.52	52.45	0.088	52.5	84.74	32.1
40	0.69	55.41	0.053	55.4	74.98	19.5
43.3	0.75	56.67	0.047	56.7	71.14	14.4

Max Compression 0.57 N/mm2

Permissible Stress in Concrete 5 N/mm2

Hence, obtained Stresses are low, and only nominal steel is necessary.

We Provide 0.12-0.3% Steel both ways using HYSD bars

Area of Steel = (Ast) 300 mm^2/m

The Stress in the dome is within the safe permissible limit

∴ Provide min% of steel in circumferentially 0.3 % of Steel

Providing the dia of bar = 8 mm

Spacing of bar on Both the side = 170 mm,C/C

3.4 COMPRESSION CHECK FOR BUCKLING

$\sigma cr = E * t/R * \sqrt{3}$

E = 20000 N/mm2

R = 14500 mm

t = 100 mm

∴ σcr = 80 N/mm2

σcr = with factor of safety 4 = 20 N/mm2

Permissible Compressive Stress > Max Compressive Stress in shell

Hence vary safe against Buckling

3.5 TENSION (T) & DESIGN OF RING BEAM

Hoop tension in ring beam = $(N\theta * \cos\theta *) * r$

$(N\theta * \cos\theta)$ = t' = 41.23 kN/m

Total Tension T = 412.3 kN

Area of Steel = (Ast) 2945 mm2

Equivalent area of steel provided with bar dia (mm) = 20 mm

Number of Bars = 10 No's

Ast provided = 3142 mm2

Area of Concrete = 304842.7 mm2

Provide beam size of = 550 x 600 mm

Provided area of concrete = 330000 mm

3.6 DESIGN FOR SHEAR BETWEEN BOTTOM RING BEAM AND DOME

Shear = $R*h*g/r$

V = 39.15 kN/m

V = 39150 N/m

Area of steel required = Ast = $V/1000 * \sigma st$

Ast = 280 mm2

Provide bar Size of = 8 mm

Spacing = 200 mm,C/C

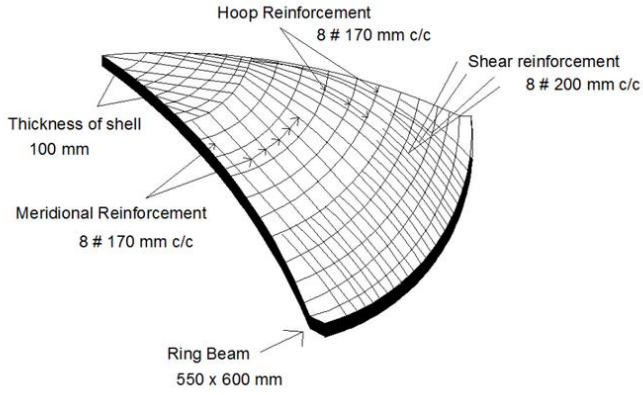

Fig -3: Reinforcement Detailing of Design 1, Model 1

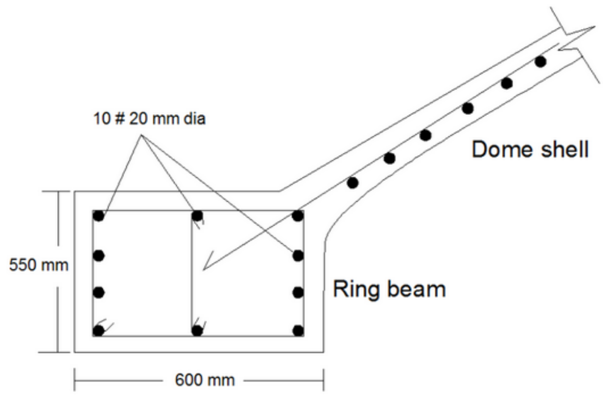

Fig -4: Sectional view of Ring beam

4. Results and Discussion

Analysis of thin roof shell structure is done for different span and span-rise ratios. As we seen in last chapter, design of spherical dome structure for different spans, gives different stresses for same loading and thickness of shell. In this present work, Staad pro software has been used for the analysis of stress in the shell and it is compared with the manual design done by working stress method. The shell structures are designed and compared manually with varying rise and span dimensions for their stresses

A stress analysis is performed on the proposed simple shell designs. Each design has four models varying of rise and same load combinations, each of which gives different stress analysis results. In all cases the first model (High rise = Span/5) was found out to be the safe one and the last model (Low rise = Span/8) was found to be critical. All four models have been shown in below discussion

Table -3: Stress table of 20meter spanned dome

Diameter of dome	Load on roof shell	Rise of the dome	Max stress in shell
20m	6.75 kN/m^2	4m	0.57 N/mm^2
		3.5m	0.61 N/mm^2
		3m	0.67 N/mm^2
		2.5m	0.77 N/mm^2

Design of 20 meter span dome with four different models gives stresses and the first model has compressive stress of 0.57 N/mm^2. With same loading, another model gives higher stress. And as the rise decreases the stresses get increases. Now the results will plot in graph for better understanding of behavior of load on structure.

Table -4: Stress table of 30meter spanned dome

Diameter of dome	Load on roof shell	Rise of the dome	Max stress in shell
30m	6.75 kN/m2	6m	0.86 N/mm2
		5m	0.94 N/mm2
		4m	1.09 N/mm2
		3.75m	1.15 N/mm2

Stresses are higher at the rise of 3.75m for 30 m dome. And it shows the critical rise for this span. And 6m rise gives low compressive stresses for 6.75kN/m2 load. And it is gradually increases with decrease in rise. And it is under safe buckling load. Here M20 grade concrete is been used and for this concrete direct stresses of 5N/mm2 is the critical stress limit.

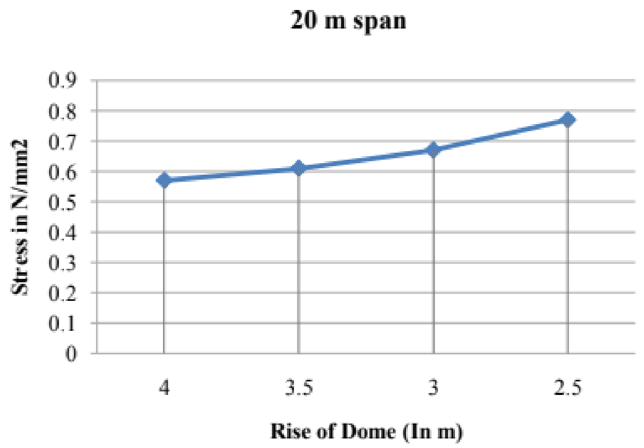

Chart -1: Relation of Rise to Stress for 20m span

20m span dome gives higher stresses for 2.5m rise. And lower stresses for 4m rise. We can see here that, stresses are depends on rise of the dome. As rise decreases the stresses get increases. Stresses are inversely proportional to the rise of the dome. And 2.5 meter rise dome is the critical design for 20m span, because it gives higher stress at 2.5m rise but at 4m it gives lower stresses with same loading.

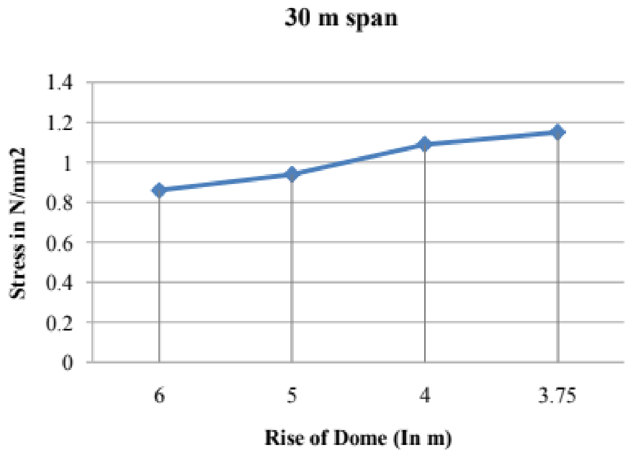

Chart -1: Relation of Rise to Stress for 30m span

This graph clearly shows that critical stress for the structure lies at the rise of 3.75m. And it is safe for the same load at the rise of 6m. 5m, and 4m are the in between options that we can adopt those rises if the architectural design demands it. So here higher rise give lower stress and will be safe against buckling.

4. CONCLUSIONS

A thin concrete shell structure has been designed, for a large area. This is the overlying conclusion of this study. The roof is required to cover a large area, which can use in public buildings like Assembly halls, Indoor Stadiums, etc... The main objective was to create a functioning concrete roof structure, which was expected to maintain a fine balance between aesthetical, structural and constructional efficiency. Attempts have been made throughout the thesis, to create such a shell structure by taking these factors into account.

1) The spherical dome has captured the imagination of generations of builders proving the time less beauty of the simplest of shapes. The dome is elegantly combined with rest of the arena to provide a better visual representation of the roof. This is an attempt to enhance the aesthetical efficiency of the roof system, although it should be pointed out that the fulfillment of this objective is subjective to the reader.
2) Up to 30m span with 6.75 kN/m2 loading can build with RCC elements
3) M20 grade concrete can satisfies the buckling failure of the shell
4) 0.3% of reinforcement is enough for reinforcement of dome shell.
5) It is interesting that the shell can built without any support up to 50m span with minimum reinforcement.
6) Stresses are inversely proportion to the rise of the structure and it also varies with variation in span 7.
7) Roof Shell gives lower stresses compared to slab.
8) Software results gives +/- 30% higher than manual result values

9) For 30m span with rise of 4m give high tension in the ring beam. And ring beam need to be pre-stressed
10) The kicking out forces on the ring beam gets higher as the compressive stress in the shell increases, it is depends on the rise of the dome. So that the rise of dome is directly proportional to the tension induced in the ring beam.

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