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Cost Analysis of Anticlastic Shell Roofs

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Abstract:- This paper presents the cost analysis of anticlastic shell roofs. Shells are light weight structures with relatively small thickness, usually with no interior columns. The main classification of shells is based on gauss curvature - Synclastic shells and anticlastic shells. Anticlastic shells include hyperbolic paraboloid, conoid, and hyperboloid of revolution of one sheet. This paper focuses on hyperbolic paraboloid. Both reinforced concrete (Inverted Umbrella) and pre-stressed hyperbolic paraboloid shells are compared with conventional grid system. The main objective of this research is to design Prestressed hyperboloid of different geometry (Parabola, circular arc and rectangular hyperbola), Inverted umbrella roof (square) and formulate a comparative cost analysis with grid system. All the designs have been carried out by incorporating the recommendations of IS: 2210-1988 'Criteria for Design of Reinforced concrete shell structures and Folded plates', IS: 2204-1962 'Code of Practice for Construction of Reinforced concrete shell roof' and IS: 456-2000 'Code of Practice for Plain and Reinforced concrete'. The cost of shell roof per unit area has been estimated, compared and the most economical configuration has been identified.

Keywords:- Cost analysis , Grid Roof system, Inverted Umbrella , Prestressed Hyperboloid , Shell Roof .

I. INTRODUCTION

A Shell is generally defined as a curved slab with very small thickness compared to the other dimensions like radius of curvature and span. They can be cast in any shape. It has sufficient strength and also has a body to cover space. Reinforced concrete, unlike steel or wood can be used to cover space as in the case of slabs. This important property of reinforced concrete can be taken full advantage in shell construction. With prestressing, it is possible to cover large spans. This concept made the use of shells very popular in covering large areas like factories, hangers, assembly halls etc. The reduction in quantity of concrete and steel make shell construction very popular for large span roofs. In the initial stages, the high cost of curved formwork was a major drawback in using curved shells like domes which has been now replaced by the development of ruled surfaces. Figure 1 shows the classification of shell structures.

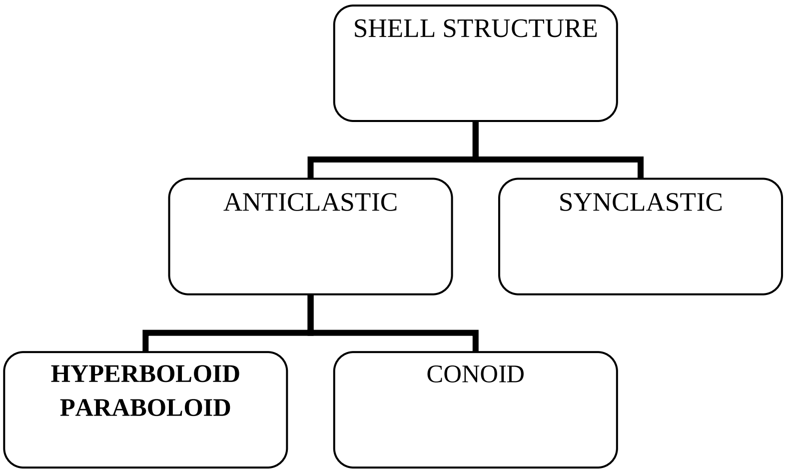

Figure 1. Classification of Shell Structure

Surfaces which can be generated entirely by straight lines are generally termed as "Ruled Surfaces". These involve linear formwork which decreases the amount of steel and concrete consumed. Shell structures have another major advantage. 75mm to 150 mm is the range of thickness used for shells. This important property of shell makes us think shell roofs as a replacement of conventional grid system which is used for large span. These hypars come under anticlastic shells whose gauss curvature is negative. In hyperbolic paraboloid whose gauss curvature is negative, the boundary effects due to edge members penetrate into the shell. This gives the extent of reinforcing of shell portion near the edge members.

Hyperbolic paraboloid is formed by two parabolas of opposite curvature. These shells were successfully used as roofing units by Silberkuhl[1]. These ruled hyperbolic paraboloid are used in long span buildings such as assembly halls and exhibition halls. The umbrella roof consists of four hypar units joined together at the center where the main supporting column is provided. The structural components of typical inverted umbrella hyperbolic paraboloid roof and forces acting on them are shown in Fig.2.

- Central supporting column
- Edge Beams
- Sloping Ribs connecting the column
- Shell surface

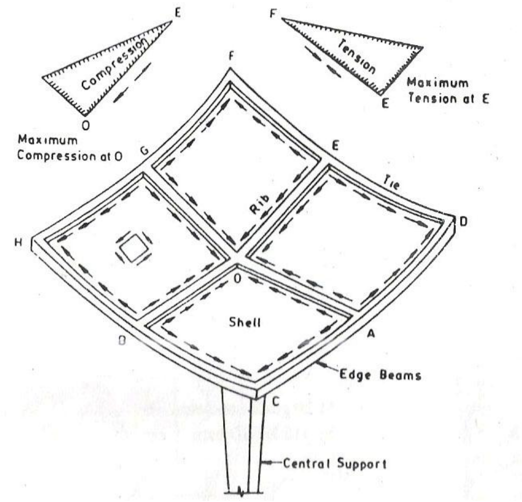

Figure 2. Forces in RC Inverted Umbrella roof

Grid roof system consist of beams in perpendicular direction at regular interval is used widely for roofing system in assembly halls. It has good architectural lighting and aesthetic view which makes grid floors superior than other roofing system. The tension in the edge beam is very high, if the span is very large. This leads to reinforcement congestion and also the concrete poured may not be compacted properly. The inverted umbrella is ideal for spans up to 30 m. In case of longer spans, following problems are encountered[2].

1. As the span of a hyperbolic shell become large, the tension in the edge beam reaches very high values demanding the provision of very heavy reinforcement, as mentioned above.
2. The deflections become excessive and they cause heavy transverse moments at the junction of edge beam and shell. These problems can be eliminated by prestressing the hyperbolic paraboloid shell roofs, as it has the following advantages :

   1. It reduces the quantity of reinforcement. This is demonstrated by Kirklandand Goldstein[3].
   2. Safety against limit state of collapse by inelastic buckling can be ensured . This is stated by Haas.
   3. Shrinkage, creep and cracks can be avoided to a decent extent.

The ruled surface units are suitable for pre-tensioning as it can be arranged to follow the straight line generators of shell units. Different geometrical properties of hyperbolic paraboloid shell structures are considered in this study.

II. NUMERICAL INVESTIGATION AND DISCUSSION

In this present work, an attempt has been made to study the design of different geometry (circular, parabolic and rectangular hyperbolic) of Prestressed Hyperbolic paraboloid, Reinforced concrete Inverted Umbrella and the conventional grid floor system which is used as roofing system. Cost analysis of these shell roofs has been estimated and it is compared with grid floor system. In this study, a span of 20 m is taken for all design purpose. A live load of 0.75 N/mm^2 has been considered. M20 grade of concrete and Fe415 steel are considered for RCC. For prestressed hyperbolic shells M50 grade concrete and high tensile steel wires conforming to IS: 1785 are considered. A crane capacity of 60 kN is considered in site. A shell thickness of 80 mm is considered throughout the study. Gopi[5] showed that the dip (x/3) gives the least cost per unit area covered from 8*8 m to 16*16 m. Therefore, a dip of x/3 is taken for economic purposes and analysis purpose. All the designs have been carried out by incorporating the recommendations of IS: 2210-1988 'Criteria for Design of Reinforced concrete shell structures and Folded plates', IS: 2204-1962 'Code of Practice for Construction of

Reinforced concrete shell roof' and IS: 456-2000 'Code of Practice for Plain and Reinforced concrete'. The cost of shell roof per unit area has been estimated, compared and the most economical configuration has been identified.

III. THEORIES USED FOR ANALYSIS

Membrane theory has been used for analysis of reinforced concrete inverted umbrella shell roof. The panel shear for a uniformly loaded hyperbolic paraboloid can be found using the formula (w *a*b/2*h), where a and b are horizontal projection of the shell and h is the central dip and is equal to a/3. Rankine Grishoff theory has been used for the analysis of grid roof system which is based on IS 456 :2000. The grid roof is analyzed as a solid slab for computation of moments and forces. The ribs are designed as flanged sections to resist moment and shear. In Rankine Grishoff theory, twisting moment due to beams is neglected.

IV. QUANTITY USED

Tables 1, 2 and 3 show the volume of steel and concrete used for Inverted umbrella shell roof, grid roof, prestressed hyperbolic shell roof, respectively.

Table 1 Volume of steel and concrete for Inverted umbrella shell roof.

Element	**Dimension (m)**	**Volume of concrete (m^3)**	**Volume of steel (m^3)**
Edge member	0.2 * 0.3	4.8	0.076
Compression member	0.2 * 0.65	6.25	0.076
Bays	20 * 20	28	0.134

Table 2 Volume of steel and concrete for grid roof.

Element	**Volume of concrete (m^3)**	**Volume of steel (m^3)**
Grid roof	135	0.46

Table 3 Volume of steel and concrete required for prestressed hyperbolic shell roofs.

Element	**Volume of concrete (m^3)**	**Volume of steel (m^3)**
Parabolic	4.40	0.39
Circular Arc	4.44	0.31
Rectangular Hyperboloid	4.37	0.29

V. COST COMPARISON

Table 4 shows the cost comparison of Reinforced concrete Inverted umbrella, Prestressed hyperboloid of different geometry such as circular arc, parabolic and rectangular hyperboloid and grid roof system.

Table 4 Cost Comparison of all the roofs considered.

Element	**Cost of concrete (Rs)**	**Cost of steel (Rs)**	**Total cost (Rs)**
Prestressed parabola	419510	214060	633570
Prestressed Circular Arc	423716	219365	643081
Prestressed R.H	416365	206136	622501
Inverted umbrella	390500	134878	525378
Grid floor	1350080	217992	1568072

Fig.3 shows the total cost comparison of different geometry such as circular arc, parabolic and Rectangular hyperbola of prestressed hyperbolic paraboloid.From the figure, it is clear that circular geometry of prestressed rectangular hyperboloid is costlier than the other two geometry. Fig.4 gives the graphical representation of cost comparison of Inverted umbrella, grid floor and circular Prestressed hyperboloid.

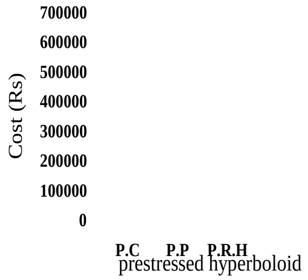

Figure 3. Cost Comparison of Prestressed Hyperboloid

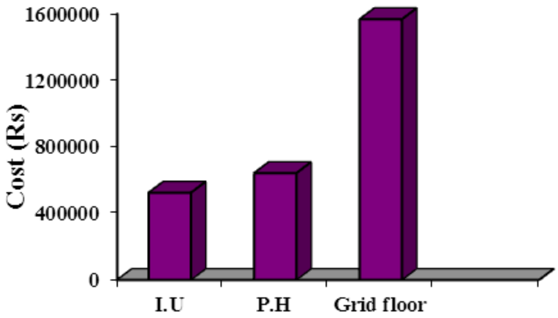

Figure 4. Cost Comparison of Shell roofs and Grid roof

VI. CONCLUSION

From the investigation, it is found that the cost of Reinforced Inverted Umbrella and Prestressed Hyperboloid is lesser than grid roof. For smaller span, Inverted Umbrella can be used as roofing system. For spans more than 20 m where heavy reinforcement is required, prestressed Hyperbolic paraboloid can be used which gives optimum use of steel and concrete and also the cost will be lesser than the conventional grid floor system.

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