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Typical Design Considerations for Construction of Long Span Flexible Roofs

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Abstract

Whereas dwellings need small or medium span roofs, spaces like auditorium, exhibition halls, airport terminals, sport stadiums need long span roofs without intermediate supports. It is either domical or cylindrical roofs or tension structures which are employed to cover long span spaces. Amongst these types, flexible roofs made of steel strands and cables are best suited for very long span column free areas. Whereas plan shape of a cable roof for a particular application is generally decided by the functional use of the space, cross-section such as convex or concave is decided by considering relative structural efficiency of various forms of cable roofs. Present paper describes typical design considerations for construction of cable roofs in general and circular cable roof in particular to achieve efficient and economical design. These design parameters include cable diameter, cable spacing, pretension in cables and rise/sag to span ratio. Influence of these parameters on the performance of cable roof are investigated and reported in this paper. The paper also recommends a set of these parameters most suitable for the application in construction of circular long span cable roofs.

Keywords

Cable Roof, Flexible Roof, Long Span Roof, Pretension, Steel Strand

1. Introduction

A cable roof is a structural system of roofing in which cables or a system of cables is used as a load carrying structural element. Cables are one of the most efficient structural elements for carrying transverse loads in pure tension. According to the manner in which cables are used, they can be classified as (i) cable-supported roofs, (ii) cable-cum-air supported roofs and (iii) cable suspended roofs. In cable suspended roofs, the system of cables carries roof load directly and acts as a primary structure function. According to the structure and bahaviour under load, cable suspended roofs are further classified as (i) simple suspended cable system, (ii) pre-tensioned cable trusses or beams and (iii) pre-tensioned cable nets and girders.

Cable nets consist of at least two families of intersecting cables lying within one surface. Various forms of cable nets are cable nets orthogonal in plan, non-orthogonal in plan and nets of uniform mesh. Flat nets are not very stiff and therefore, not a practical proposition for very large roofs. The geometries of the nets are function of their points of support and the tension of the cables. Cable grids may be considered as double layer nets or a multi-directional system of intersecting cable beams. From the point of view of structural efficiency and practical & geometrical considerations, only those which can be constructed as two- or three-directional convex, concave and convex-concave systems are practical possibilities. Because of the geometries of the cable beams, the use of grid is limited to roofs which are either circular or elliptical in plan. Due to self-balancing behaviour of cable beams, the forces required to be exerted by any clamps are small (Krishna, 1978; Garg, 1997).

Circular cable roofs can be made in the form of flat net, cable beam structure with inner rings or cable grid. While going through the available literature, one finds that very limited studies have been carried out to understand the behaviour of cable nets and grids under static and dynamic loads both experimentally and analytically (Agarwal, 1968; Natrajan, 1969; Gupta, 1971; Dass, 1974; Krishna, 1978; Ahuja, 1979; Jain, 1982; Garg, 1997).

In the present study, therefore, it has been planned to investigate the effect of various parameters on the behaviour of flat net type circular cable roof (Fig. 1) and circular convex cable grid roof (Fig. 2). These parameters are level of pretension (P), area of cross-section of cables (A) and spacing of cables in case of flat net type circular roof. Parameters to be considered in case of circular convex cable grid roof are level of pretension (P), area of cross-section of cables and struts (A) and height to span ratio (h/L) of trusses. Effects of these parameters on maximum deflection, maximum member force and maximum change in member force are planned to be observed. However due to paucity of space, the results of only flat net type circular roof are reported herein the form of non-dimensional graphs.

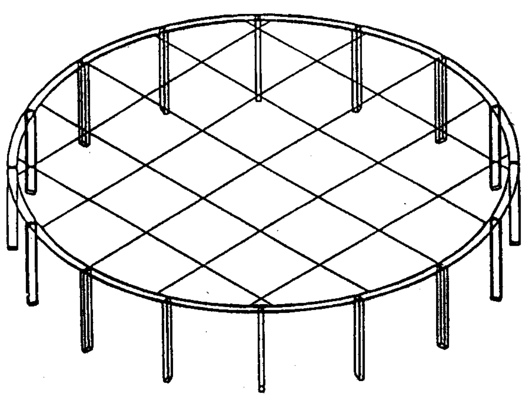

Figure 1 : Circular Cable Net Roof

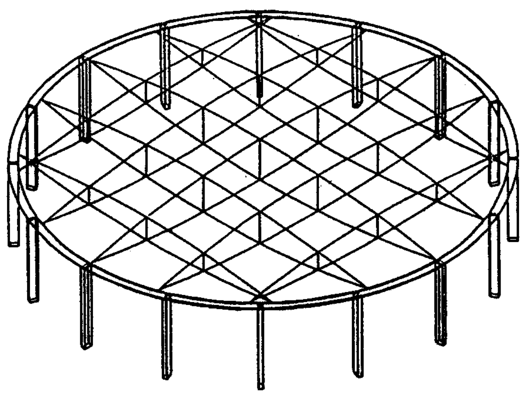

Figure 2 : Circular Convex Cable Grid Roof

2. Details of Circular Cable Net Roof

Circular cable roof with a diameter of 50 m is assumed to be made of parallel steel cables placed in two mutually perpendicular directions (Fig. 1). Crossing points of the cables are treated as hinged nodes in the analysis. Ends of the cables are attached to rigid circular ring and thus considered as fixed supports allowing rotational but not lateral movements. Cables are assumed to be zinc coated steel structural strand with modulus of elasticity $E = 1.66 \times 10^5$ N/mm^2. The area of cross-section of cables (A) is varied as 387.10, 871.0, 1548.40, 2419.0 and 3483.90 mm^2 with respect to diameter of 0.5, 1.0, 1.5, 2.0 and 2.5 inch (Krishna, 1978). Horizontal component of pre-tension (P) is varied as 100, 150, 200, 250 and 300 kN. In order to calculate the dead load, cladding of roof is assumed to be made of galvanized steel sheet with a weight of 160 N/ m^2. Weight of purlin is taken as 200 N/ m^2 and weight of cable as 60 N/ m^2. It results in a dead load of 420 N/ m^2. Values of point-laod at each node where cables cross each other are calculated using this value of dead load. Although nodes near the edge beam are subjected to lesser load compared to other nodes due to smaller area, it is taken same at all the nodes to be on the safer side. Three cases of nets with cables in each direction to be 5, 7 and 9 have been considered.

2.1 Cable Net Roof of 5x5 Cables

In this case, five cables each are placed in both X and Y directions at a distance of 8.33 m over a 50m central span. It has 45 nodes and 60 members (Fig. 3). Node numbers 1 to 25 are considered as flexible in nature and free to move in all directions. Node numbers 26 to 45 are treated as support points with rotational freedom only. A dead load of 29.143 kN is applied on all flexible nodes. Cable net is analysed five times by varying cross-sectional area of cables. However, area of cross-section of cables are kept the same in X and Y directions.

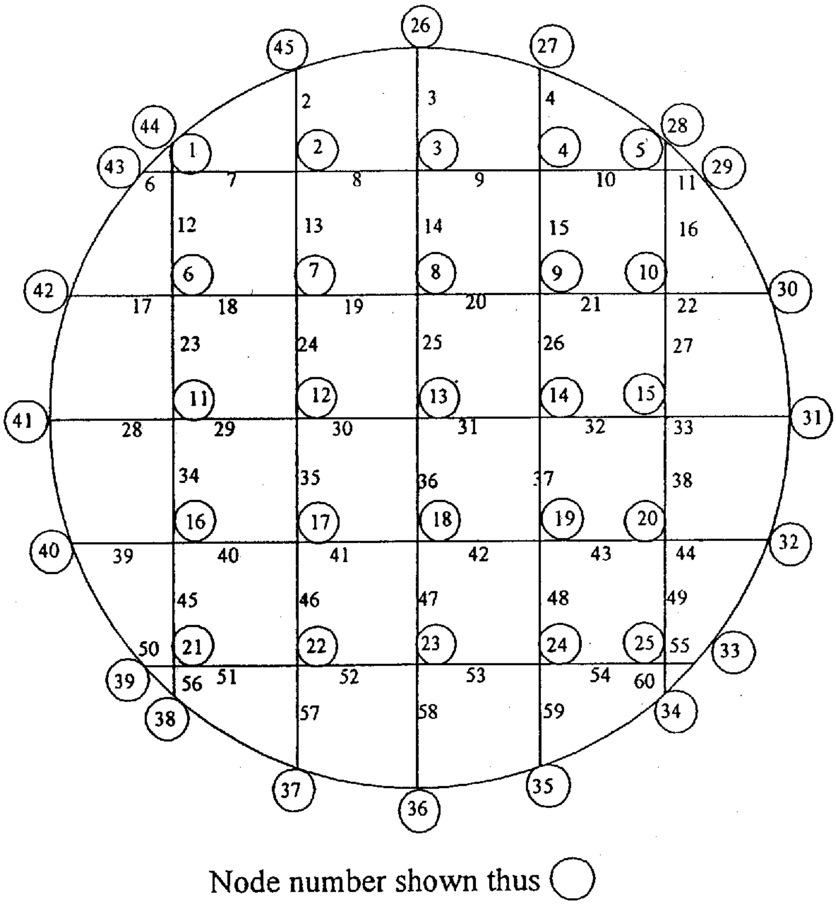

Figure 3 : Circular Cable Net Roof with 5x5 Cables

2.2 Cable Net Roof of 7x7 Cables

In case of net roof with 7 cables in each X and Y directions, cables are placed at a distance of 6.25 m. Total number of nodes in this case are 73 and total members 104. Node numbers 46 to 73 are support points. A dead load of 16.40 kN is applied at node numbers 1 to 45 and response of the net obtained for all five cases of cable cross-section.

2.3 Cable Net Roof of 9x9 Cables

When net if made of 9 cables in each X and Y directions, it has total 69 nodes and 156 members. Dead load applied at each of the non-support points is 10 kN.

3. Results and Discussion

As mentioned above, aim of the present study is to investigate the influence of certain parameters namely level of pretension (P), area of cross-section of cables (A) and spacing of cables on the behaviour of circular cable net roof in general and on maximum deflection, maximum member force and maximum change in member force in particular. Non-linear analysis of the roof is carried out using stiffness matrix method and results obtained are discussed in subsequent articles.

3.1 Level of Pretension

It is essential to pre-stress the cables of cable roofs before loading due to its flexible nature. By providing the pretension, cables do not deflect much and remain within safe limit. In the present study, pre-tension in both X and Y direction cables are kept the same. The static response of the structure or roof is obtained for five values of pre-tension, namely 100, 150, 200, 250 and 300 kN in all the cables. The influence of pre-tension on the behaviour of cable net roof is studied with different number of cables (n) i.e. 5x5 cables, 7x7 cables and 9x9 cables in cable net. The observations for maximum deflection, maximum member force and maximum change in member force for all cases with varying pre-tension are listed in Table 1.

Table 1 : Effect of Pretension on the Behaviour of Circular Cable Net

Sl. No.	Horizontal pretension (P, kN)	Node No.	Maximum deflection (w, mm)	Member No.	Maximum Force (F, kN)	P/H	w/L	F/H
Cable net of 5x5 cables								
1	100	13	887.5	3,28,33,58	742.58	0.50	0.0177	3.71
2	150	13	1087.7	3,28,33,58	559.56	0.75	0.0218	2.80
3	200	13	1085.2	3,28,33,58	550.20	1.00	0.0218	2.75
4	250	13	1049.6	3,28,33,58	563.29	1.25	0.0210	2.82
5	300	13	962.2	3,28,33,58	606.26	1.50	0.0193	3.03
Cable net of 7x7 cables								
1	100	23	966.7	3,49,56,102	470.93	0.50	0.0263	1.600
2	150	23	989.7	3,49,56,102	440.44	0.75	0.0219	1.943
3	200	23	948.3	3,49,56,102	452.92	1.00	0.0189	2.265
4	250	23	898.3	3,49,56,102	473.17	1.25	0.0168	2.568
5	300	23	847.8	3,49,56,102	497.15	1.50	0.0152	2.587
Cable net of 9x9 cables								
1	100	35	915.3	3,74,83,154	381.90	0.50	0.0183	1.909
2	150	35	891.1	3,74,83,154	381.29	0.75	0.0178	1.906
3	200	35	839.1	3,74,83,154	399.23	1.00	0.0168	1.996
4	250	35	784.7	3,74,83,154	422.27	1.25	0.0157	2.111
5	300	35	731.5	3,74,83,154	448.80	1.50	0.0146	2.243

Comparison of the values of maximum deflection in these tables indicates that cable net becomes stiff with the increase in number of cables and shows small deflection. For example, maximum deflection in case of net with 5x5 cables for horizontal pretension of 200 kN is 1085 mm, it reduces to 948 mm in case of net with 7x7 cables and further reduces to 839 mm in case of net with 9x9 cables. The reduction is 12.6% and 11.5% respectively.

Figure 4 shows the plot between different force of pretension (P/H) value and maximum deflection (w/L), where reference force of pretension (H) is kept 200 kN, and the value of horizontal component of pretension (P) is taken as 100, 150, 200, 250 and 300 kN. It is seen from the figure that cable net with 5x5 cables show large deflection and cable net with 9x9 cables show small deflections. Figure also indicates that as the force of pretension increases, the maximum deflection reduces. When P/H ratio lies between 0.5 and 0.75, maximum deflection in cable net roof of 5x5 cables and 7x7 cables slightly increase and then reduce. Cable net with 5x5 cables, being comparatively flexible, shows large non-linearity. As number of cables increases, net becomes stiff and non-linearity in deflection values are limited for small values of P/H only, i.e. up to P/H =1.0 for net with 7x7 cables and up to 0.5 for 9x9 cables net.

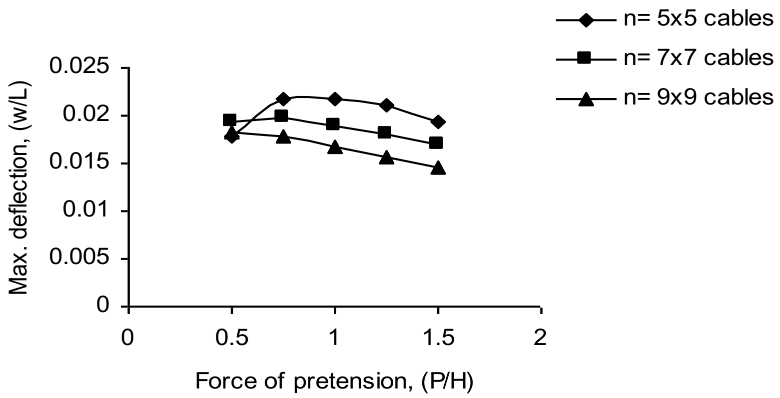

Figure 4 : Effect of Pretension on Maximum Deflection in Circular Cable Net Roof

Influence of force of pretension (P/H) on maximum member force (F/H) can be seen in Fig. 5. When P/H ratio lies between 0.5 and 0.75, there is sharp decrease in maximum member force in cable net roofs of 5x5 cables and 7x7 cables. But in case of 9x9 cables net roof, this effect is not noted. Later it increases with increase in pretension force. Whereas this increase is non-linear in case of cable net with 5x5 cables, net with 7x7 cables and 9x9 cables show linear variation.

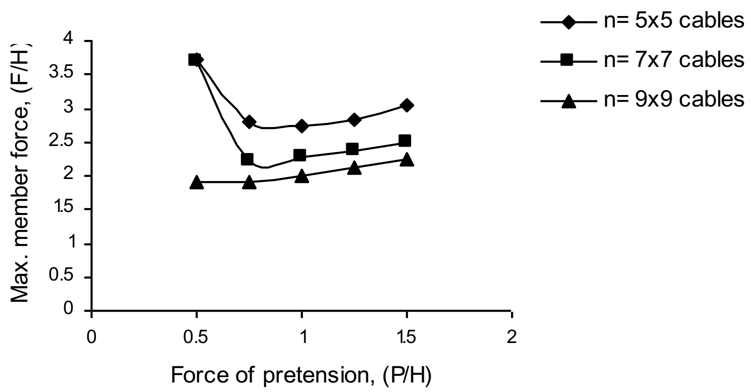

Figure 5 : Effect of Pretension on Maximum Member Force in Circular Cable Net Roof

3.2 Area of Cross-section of Cables

The influence of variation of area of cross-section of cables on the response of flat nets, are also studied. But due to paucity of space, results of this part of study are not reported herein. However, conclusions drawn are included in the next article.

4. Conclusions

Following conclusions are drawn from the study presented in this paper.

1. Deflections in cable net at various nodes are largely influenced by the force of pretension in cables. Deflection values reduce with increase in pretension. Further, cable net roofs show non-linear behaviour for small value of force of pretension.
2. Force of pretension in cable net roofs has similar effect on change in member forces as to deflection. With the increase in pretension, change in member forces reduces.
3. Cross-sectional area of cables in cable net roofs has also significant effect on reducing deflection at various nodes by its increase. Further, for small values of cross-sectional areas, net shows non-linear behaviour.
4. The effect of cross-sectional area of cable is to increase member force in nets with its increase. Change in member force also increases with cross-section area of cables.
5. The response of cable net is also affected by number of cables present in a roof of fixed dimension i.e. to say that the spacing of cable does influence the behaviour of cable nets.
6. It is advisable to use more number of cables with small cross-sectional area to make cable net instead of less number of cables with large cross-sectional area.

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