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Analysis of Non Composite and Composite Space Frame for Varying Support Condition

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Abstract

A planar space frame is a skeleton structural system assembled of linear elements so arranged that forces are transferred in a three-dimensional manner. Architects and Engineers aims for new structural forms to accommodate large unobstructed areas. Space frames satisfy their objectives as well as it provides lightness, economy, and speedy construction. Research in these areas proved that using concrete slab acting compositely with the top chord to reduce the buckling problems of the compression chord members and improve the overall behavior of the space frame to be used as floor construction. The development of space frame is influenced by space frame type, method of support, module size and their depth, and finally optimized cross sectional area. In case of development of composite space frame, optimized cross sectional area, concrete strength and concrete thickness are of interest. This paper deals with the development of space frame using ANSYS for roof and floor system for the wedding hall building of a plan 30m x 30m for varying support condition. The maximum central deflection produced in the structure has been calculated and compared.
Keywords: Space Truss, ANSYS, Support Condition, Composite Space Truss

I. INTRODUCTION

In the preliminary stage of planning a space frame to cover a specific building, a number of factors should be studied and evaluated before proceeding to analysis and design. These factors include structural adequacy and functional requirements. Since a space frame was assembled from straight, linear elements connected at nodes, the geometrical arrangement of the elements such as shape of the building, number of layers and space truss type needs to be studied carefully in the light of various pertinent requirements. The geometry of the space frame would influence both the bearing capacity and weight of the structure. The module size of the space frame was developed from the overall building dimensions, while the depth of the frame, the size of cladding, and the position of supports would also have a pronounced effect upon it. A compromise between these various aspects usually has to be made to achieve a satisfactory solution. Connecting joints have a decisive effect on the strength and stiffness of the structure and compose around 20 to 30% of the total weight. There are a number of proprietary systems that are used for space frame structures. Mero connector consists of a spherical node with flat facets and tapped holes. Members in the space frame are circular hollow sections with cone shaped steel forgings welded at the ends which accommodate connecting bolts. Bolts are tightened by means of a hexagonal sleeve and dowel pin arrangement, resulting in a completed joint. This joint has the advantage that the axes of all members pass through the centre of the node, eliminating completely the eccentricity loading. Then tensile forces are carried along the bolts and resisted by the members whereas compressive forces are distributed to the node through the hexagonal sleeves.

II. DEVELOPMENT OF 30M X 30M SPACE FRAME ROOF

The development of space frame as roof was influenced by space frame type, method of support, module size and their depth and optimized cross section area of the member. A wedding hall building of plan 30m x 30m space frame roof was developed by placing cross section area of the member to be a variable. The remaining factors need to be assumed to carry out the linear elastic analysis using ANSYS.

A. *Effect of Space Frame Type*

Space frame type was chosen comprehensively by considering the shape of the building, size of the span, supporting conditions and architectural requirements. Since it was a double layer grid steel consumption directly depends on the aspect ratio of the plan rather than span of the grid. Table 2.1 shows the space frame type for 30m x 30m plan.

Table - 2.1
Space Frame Type for 30m x 30m

Shape of the plan	*Square*
Aspect ratio	*1:1*
Supporting condition	*Along perimeters*
Recommended type	*Orthogonal square pyramid; differential square pyramid; diagonal square pyramid*

Chosen	*Orthogonal square pyramid*

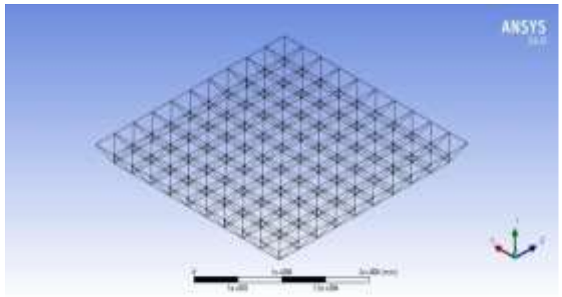

Fig. 2.1: Geometry of Space Frame Roof 30m x 30m

B. Method of Support

The configuration of the building grid plan enhances the location of the support. Ideal double layer grids would be square or rectangular with overhanging and continuous supports along the perimeters. This plate type of design approach minimizes the maximum bending moment. The only constraint in developing a space frame roof for wedding hall building was to avoid intermediate supports other than the perimeters. Number of supports and their location along the perimeter were considered to be a variable as it directly affects the economy of the structure. Four support conditions (as in Table 2.4) were chosen for developing a space frame roof 30m x 30m.

Table - 2.2
Support Conditions for 30m x 30m

Support Conditions	*Columns along perimeter*
1) Corner Supported	*4*
2) Edge Supported 3mc/c	*40*
3) Edge Supported 9m c/c	*12*
4) Opposite Edge Supported	*22*

C. Optimized Cross Sectional Area

With the chosen space frame type orthogonal square pyramid, module size 3m x 3m and their depth 2.121m, the optimized cross sectional area of the member was obtained by trial and error linear elastic analysis with a live load of 1.5kN/m^2 for four different support conditions mentioned in the section 2.3. The steel tubular structural sections for the member were considered as per IS 1161.1988 – Steel tubes for structural purposes - Specification.

1) Corner Supported Space Frame Roof

Space frame roof supported by four columns placed at the corners. The Finite element linear elastic analysis for corner supported condition was made using ANSYS and the results of central deflection were tabulated as in Table 2.5 and the graph results shown in Figure 2.3. Figure 2.2 represent the deflection diagram of 30m x 30m corner supported space frame.

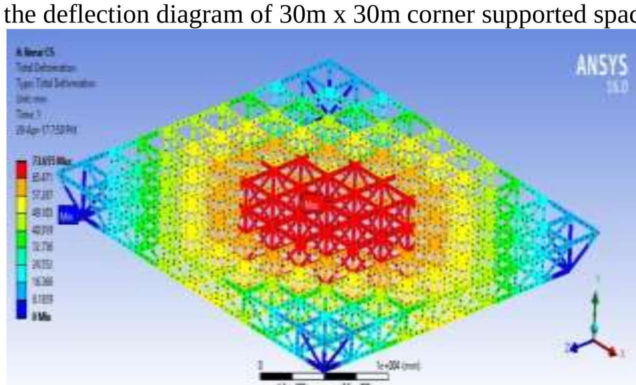

Fig. 2.2: Corner Supported Space Frame Central Deflection for 1730mm^2

Table - 2.5
Corner Supported Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
1550	*77.39*	
1730	*73.65*	*83.33*
1840	*67.54*	

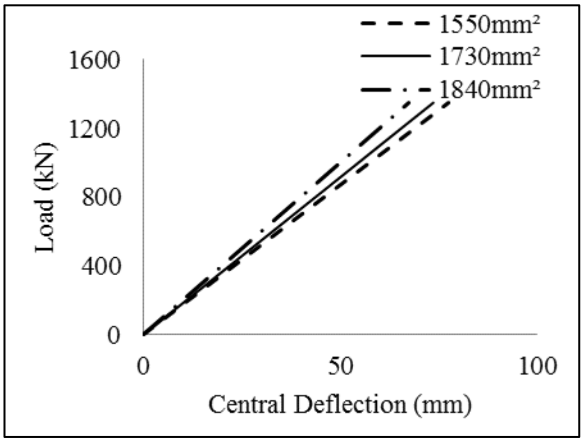

Fig. 2.3: Corner Supported Space Frame Central Deflection for 1730mm^2

2) All Edge Supported Space Frame Roof

Space frame roof supported by 40 columns each placed at 3m c/c on the perimeter edge. The Finite element linear elastic analysis for all edge supported condition was made using ANSYS and the results of central deflection were tabulated as in Table 2.6 and the graph results shown in Figure 2.5. Figure 2.4 represent the deflection diagram of 30m x 30m all edge supported space frame.

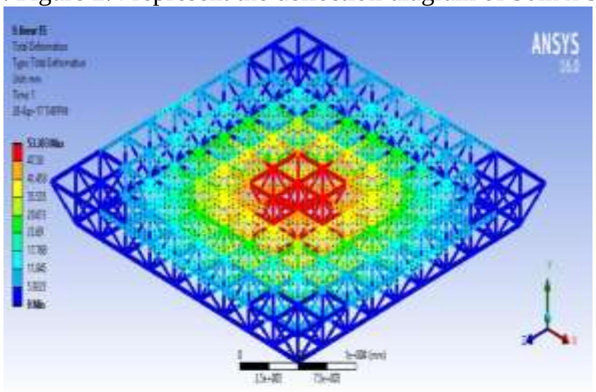

Fig. 2.4: All Edge Supported Space Frame Central Deflection for 641mm^2

Table - 2.6
All Edge Supported Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
556	*67.13*	*83.33*
641	*53.30*	
732	*45.79*	

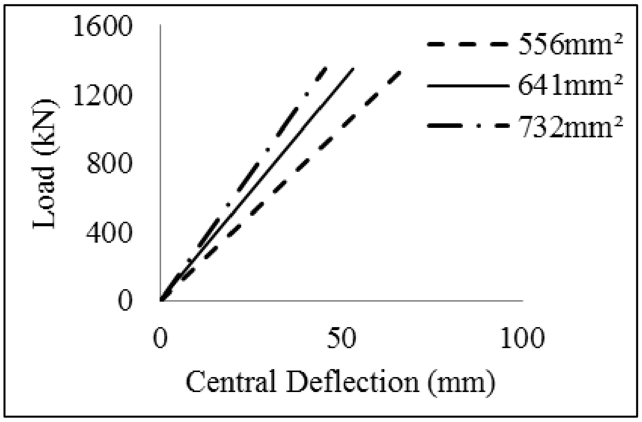

Fig. 2.5: All Edge Supported Space Frame Central Deflection for 641mm^2

3) Edge Supported Space Frame Roof

Space frame roof supported by 12 columns each placed at 9m c/c on the perimeter edge. The Finite element linear elastic analysis for partial edge supported condition was made using ANSYS and the results of central deflection were tabulated as in Table 2.7 and the graph results shown in Figure 2.7. Figure 2.6 represent the deflection diagram of 30m x 30m edge supported space frame.

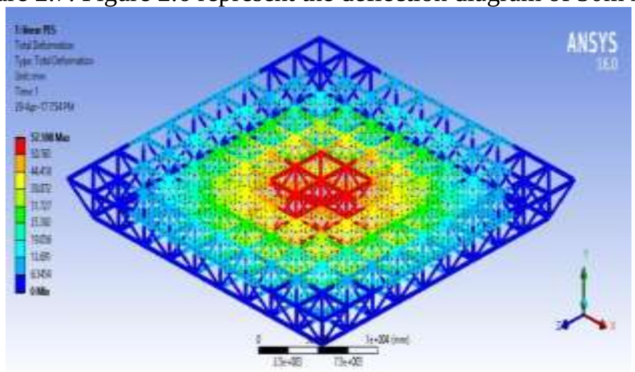

Fig. 2.6: Edge Supported Space Frame Central Deflection for $732mm^2$

Table - 2.7
Edge Supported Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
641	*66.53*	*83.33*
732	*57.11*	
788	*55.85*	

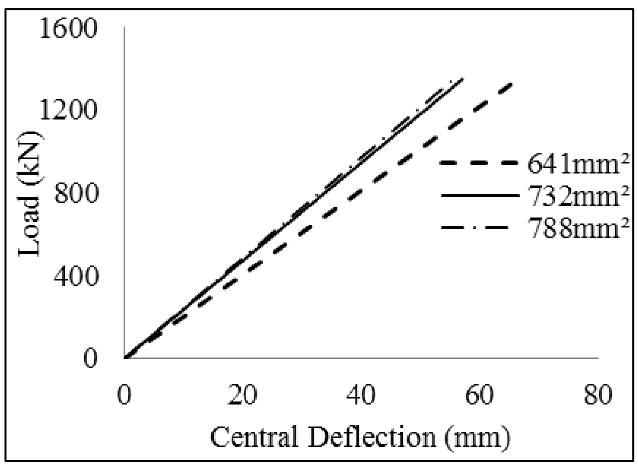

Fig. 2.7: Edge Supported Space Frame Central Deflection for $732mm^2$

4) Opposite Edge Supported Space Frame Roof

Space frame roof supported by 22 columns each placed at 3m c/c on the two opposite perimeter edge. The Finite element linear elastic analysis for two opposite edge supported condition was made using ANSYS and the results of central deflection were tabulated as in Table 2.8 and the graph results shown in Figure 2.9. Figure 2.8 represent the deflection diagram of 30m x 30m opposite edge supported space frame.

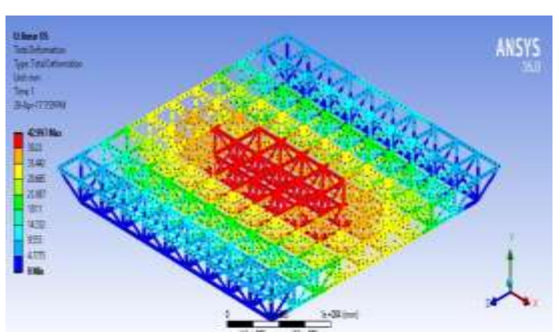

Fig. 2.8: Opposite Edge Supported Space Frame Central Deflection for $1230mm^2$

Table - 2.8
Opposite Edge Supported Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
1070	*66.55*	
1110	*51.59*	*83.33*
1230	*43.00*	

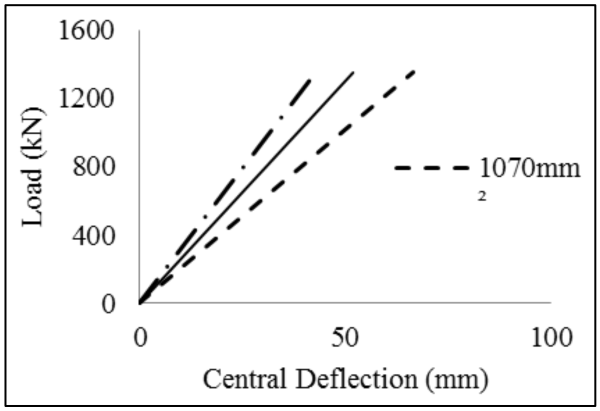

Fig. 2.9: Opposite Edge Supported Space Frame Central Deflection for $1230mm^2$

III. DEVELOPMENT OF 30M X 30M SPACE FRAME FLOOR

The development of space frame as floor was majorly influenced by optimized cross section area of the member, concrete strength, concrete thickness and other factors of roof as mentioned in section 2 was also included. A wedding hall building of plan 30m x 30m space frame floor was developed by placing cross section area of the member and thickness of the concrete to be a variable. The remaining factors need to be assumed to carry out the linear elastic analysis using ANSYS.

A. Optimized Cross Sectional Area

With the chosen space frame type orthogonal square pyramid, module size 3m x 3m and their depth 2.121m, light weight concrete strength M25 Grade and initially assumed concrete thickness 40mm the optimized cross sectional area of the member was obtained by trial and error linear elastic analysis with a live load of $5kN/m^2$ for four different support conditions mentioned in the section 2.3. The steel tubular structural sections for the member were considered as per IS 1161.1988 – Steel tubes for structural purposes - Specification.

1) Corner Supported Space Frame Floor

The results of central deflection for corner supported space frame floor were tabulated in Table 2.9 and the graph results shown in Figure 2.11. Figure 2.10 represent the deflection diagram of 30m x 30m corner supported composite space frame.

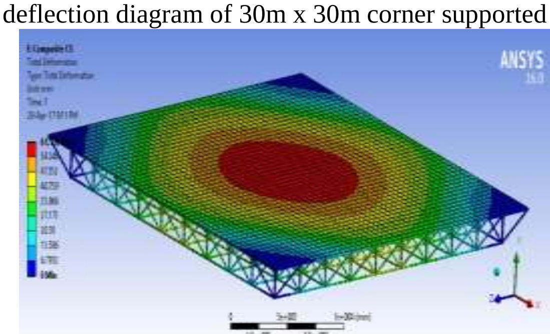

Fig. 2.10: Corner Supported Composite Space Frame Central Deflection for $2710mm^2$

Table - 2.9
Corner Supported Composite Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
2500	*88.69*	
2710	*78.33*	*83.33*
2760	*69.69*	

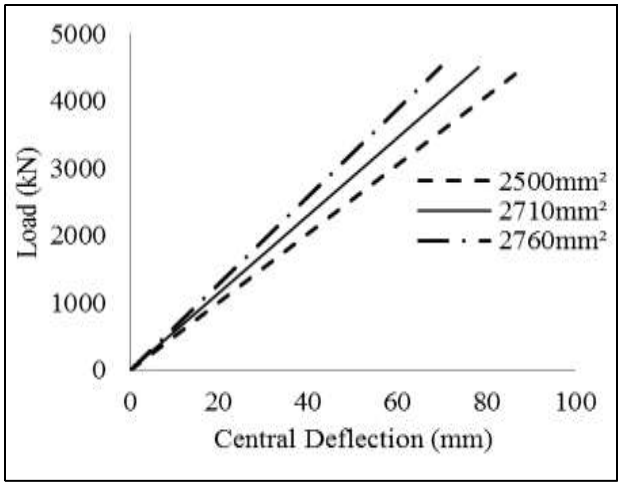

Fig. 2.11: Corner Supported Composite Space Frame Central Deflection for 2710mm^2

2) All Edge Supported Space Frame Floor

The results of central deflection for all edge supported space frame floor were tabulated in Table 2.10 and the graph results shown in Figure 2.13. Figure 2.12 represent the deflection diagram of 30m x 30m all edge supported composite space frame.

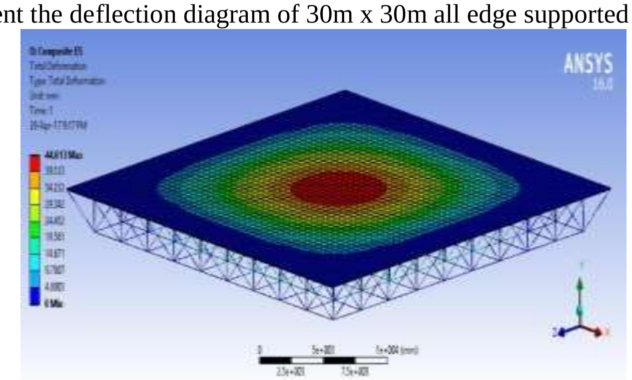

Fig. 2.12: All Edge Supported Composite Space Frame Central Deflection for 732mm^2

Table - 2.10
All Edge Supported Composite Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
556	*58.22*	
641	*46.92*	*83.33*
732	*40.78*	

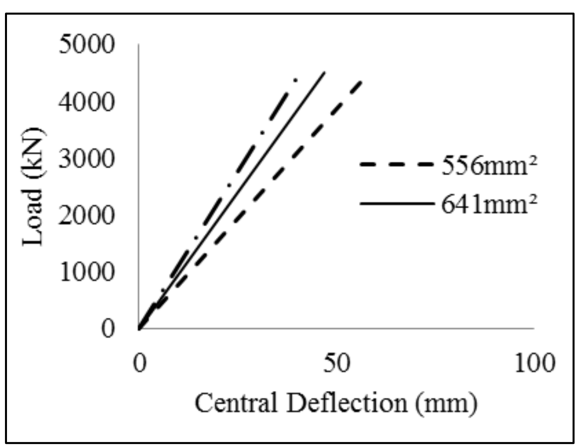

Fig. 2.13: All Edge Supported Composite Space Frame Central Deflection for 732mm^2

3) Edge Supported Space Frame Floor

The results of central deflection for partial edge supported space frame floor were tabulated in Table 2.11 and the graph results shown in Figure 2.15. Figure 2.14 represent the deflection diagram of 30m x 30m edge supported composite space frame.

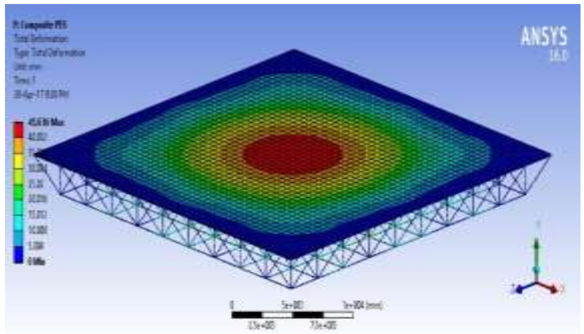

Fig. 2.14: Edge Supported Composite Space Frame Central Deflection for 1070mm^2

Table - 2.11
Edge Supported Composite Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
861	*60.34*	*83.33*
1010	*49.64*	
1070	*47.91*	

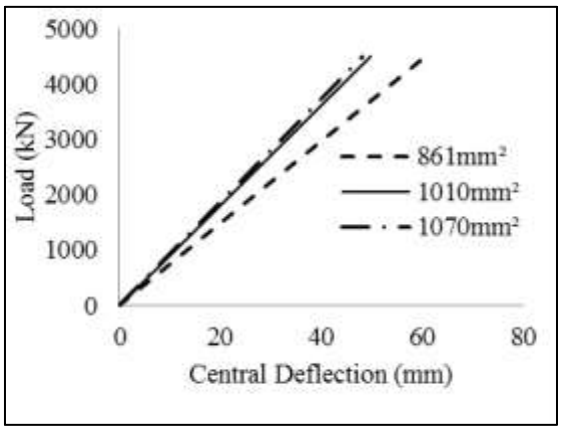

Fig. 2.15: Edge Supported Composite Space Frame Central Deflection for 1070mm^2

4) Opposite Edge Supported Space Frame Floor

The results of central deflection for opposite edge supported space frame floor were tabulated as in Table 2.12 and the graph results shown in Figure 2.17. Figure 2.16 represent the deflection diagram of 30m x 30m opposite edge supported composite space frame.

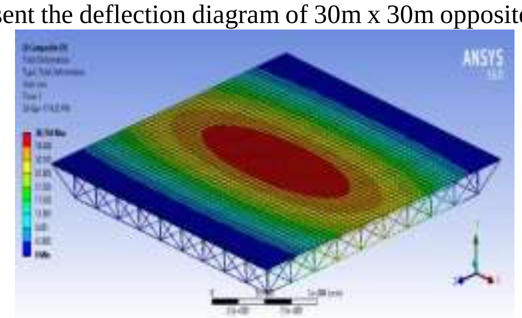

Fig. 2.16: Opposite Edge Supported Space Frame Central Deflection for 1230m^2

Table - 2.12
Opposite Edge Supported Composite Space Frame Central Deflection results

C/S Area	*Central Deflection (ANSYS)*	*IS Code Permissible Deflection (L/360)*
mm^2	*mm*	*mm*
1070	*53.41*	*83.33*
1110	*50.50*	
1230	*43.00*	

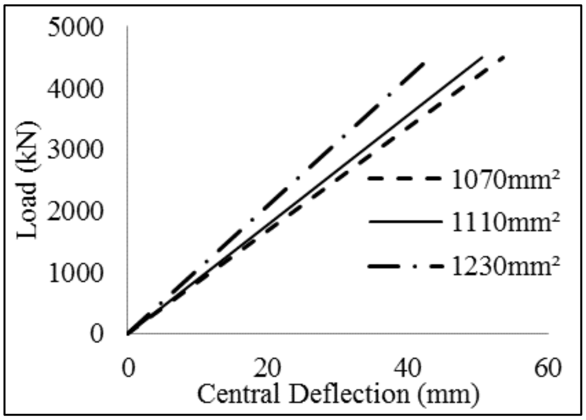

Fig. 2.17: Opposite Edge Supported Composite Space Frame Central Deflection for 1230mm^2

IV. RESULTS AND DISCUSSION

Consider the geometric nonlinearity and material nonlinearity into the space frame as well as composite space frame structure by running nonlinear finite element analysis by ANSYS for the above obtained elastic results. The exact central deflection results were tabulated (as in table from (Table 2.17 to 2.24)) for the optimized cross sectional area and the graph results are shown from (Figure 2.18 to 2.25).

Table - 2.17
Corner Supported Space Frame Roof Central Deflection Nonlinear Results for1730mm^2

Load Step	*Load*	*Central Deflection*
	kN	*mm*
0	*0*	*0.00*
1	*270*	*15.38*
2	*540*	*30.81*
3	*810*	*46.25*
4	*1080*	*62.02*
5	*1350*	*81.90*
6	*1620*	*113.61*
7	*1890*	*173.67*
8	*2160*	*282.86*

Table - 2.18
All Edge Supported Space Frame Roof Central Deflection Nonlinear Results for 641mm^2

Load Step	*Load*	*Central Deflection*
	kN	*mm*
0	*0*	*0.00*
1	*270*	*11.14*
2	*540*	*22.30*
3	*810*	*33.55*
4	*1080*	*47.19*
5	*1350*	*70.53*
6	*1620*	*108.01*
7	*1890*	*162.99*
8	*2160*	*264.13*

Table - 2.19
Edge Supported Space Frame Roof Central Deflection Nonlinear Results for 732mm^2

Load Step	*Load*	*Central Deflection*
	kN	*mm*
0	*0*	*0.00*
1	*270*	*11.93*
2	*540*	*23.89*
3	*810*	*35.88*
4	*1080*	*48.09*
5	*1350*	*68.01*
6	*1620*	*103.78*
7	*1890*	*167.42*
8	*2160*	*283.90*

Table - 2.20
Opposite Edge Supported Space Frame Roof Central Deflection Nonlinear Results for 1230mm^2

Load Step	*Load*	*Central Deflection*
	kN	*mm*
0	*0*	*0.00*
1	*270*	*8.98*
2	*540*	*17.98*
3	*810*	*27.00*
4	*1080*	*36.18*
5	*1350*	*50.70*
6	*1620*	*82.72*
7	*1890*	*152.18*
8	*2160*	*250.91*

Table - 2.21
Corner Supported Space Frame Floor Central Deflection Nonlinear Comparative Results for 2710mm^2

Load Step	*Load*	*Central Deflection*	
		Non Composite	*Composite*
	kN	*mm*	*mm*
0	*0*	*0*	*0*
1	*900*	*27.526*	*12.364*
2	*1800*	*55.052*	*24.727*
3	*2700*	*82.839*	*37.095*
4	*3600*	*114.15*	*53.298*
5	*4500*	*225.77*	*73.212*
6	*5400*	*1350.26*	*98.726*
7	*6300*		*182.94*
8	*7200*		*809.33*

Table - 2.22
All Edge Supported Space Frame Floor Central Deflection Nonlinear Comparative Results for 732mm^2

Load Step	*Load*	*Central Deflection*	
		Non Composite	*Composite*
	kN	*mm*	*mm*
0	*0*	*0*	*0*
1	*900*	*35.535*	*9.1003*
2	*1800*	*79.999*	*18.201*
3	*2700*	*406.84*	*27.301*
4	*3600*		*37.716*
5	*4500*		*57.979*
6	*5400*		*160.19*
7	*6300*		*653.67*
8	*7200*		*1311.9*

Table - 2.23
Edge Supported Space Frame Floor Central Deflection Nonlinear Comparative Results for 1070mm^2

Load Step	*Load*	*Central Deflection*	
		Non Composite	*Composite*
	kN	*mm*	*mm*
0	*0*	*0*	*0*
1	*900*	*26.602*	*9.1883*
2	*1800*	*53.204*	*18.377*
3	*2700*	*82.164*	*27.565*
4	*3600*	*260.06*	*41.962*
5	*4500*	*986.54*	*71.926*
6	*5400*		*198.22*
7	*6300*		*635.44*
8	*7200*		*1333.7*

Table - 2.24
Opposite Edge Supported Space Frame Floor Central Deflection Nonlinear Comparative Results for 1230mm^2

Load Step	*Load*	*Central Deflection*	
		Non Composite	*Composite*
	kN	*mm*	*mm*
0	*0*	*0*	*0*
1	*900*	*28.665*	*7.8156*
2	*1800*	*63.245*	*15.631*

3	*2700*	*364.32*	*23.447*
4	*3600*		*31.262*
5	*4500*		*42.242*
6	*5400*		*132.77*
7	*6300*		*411.27*
8	*7200*		*710.76*

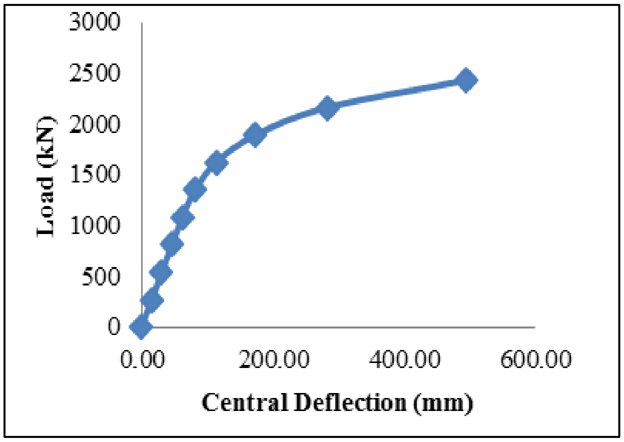

Fig. 2.18: Corner Supported Space Frame Roof Nonlinear Deflection for 1730mm^2

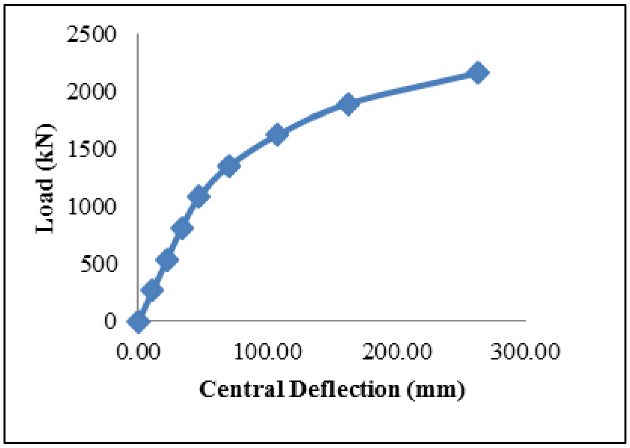

Fig. 2.19: All Edge Supported Space Frame Roof Nonlinear Deflection for 641mm^2

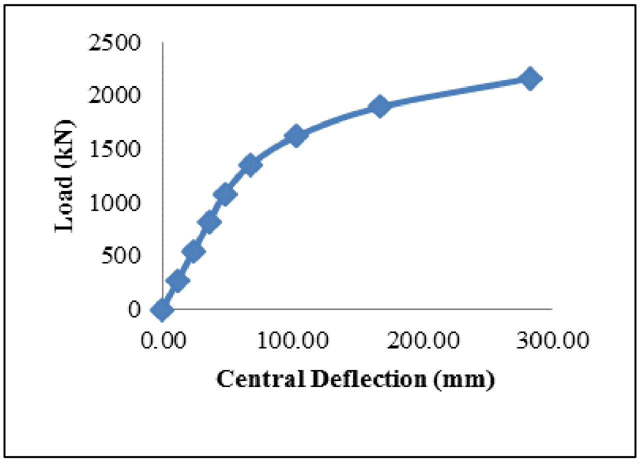

Fig. 2.20: Edge Supported Space Frame Roof Nonlinear Deflection for 732mm^2

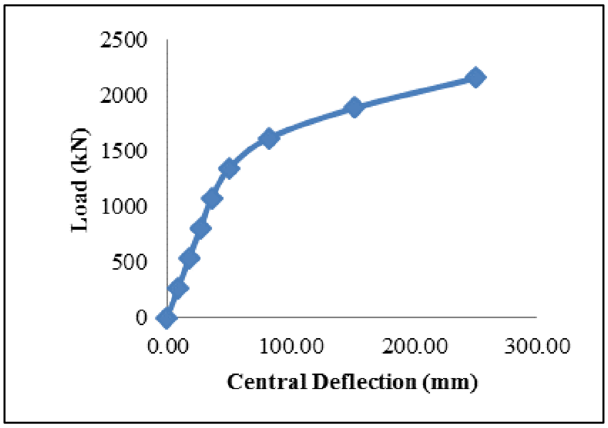

Fig. 2.21: Opposite Edge Supported Space Frame Roof Nonlinear Deflection for 1230mm^2

V. CONCLUSION

1) Corner Supported Space Truss leads to heavier section of members and in a floor slab, it attains 19.7% increase in load carrying behavior within the yield load.
2) All Edge Supported Space Truss proved to be economical but it need maximum number of columns on the perimeter and in a floor slab, it attains 31.3% increase in load carrying behavior with the yield load.
3) Partial Edge Supported Space Truss at 9m c/c proved to be economical only when large openings are needed on the wall or use less number of columns on the perimeter and it attains 22.6% increase in load carrying behavior within the yield load.
4) Opposite Edge Supported Space Truss are provided only when openings on two opposite edges are needed for architectural purposes and preferred for roof only.

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