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Analysis of Large Span Space Frame Roof by Comparing Different Roof Types and Cross Sections

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ABSTRACT: A growing interest in space frame structures has been witnessed worldwide over the last half century. The search for new structural forms to accommodate large unobstructed areas has always been the main objective of architects and engineers. With the advent of new building techniques and construction materials, space frames frequently provide the right answer and satisfy the requirements for lightness, economy, and speedy construction. Significant progress has been made in the process of the development of the space frame. In this work we compare nine space frame roof structure with 60m span and 120m length. The load calculations done as per IS codes. The structures were analysed in ETABS software. The results were obtained from comparing various analysis results like nodal displacements, axial forces and support reactions of structures. For that we considered nine models with different roof types (pitched roof, curved roof and mono slope roof) and with different material cross sections (circular hollow sections, square hollow sections and equal angles having same cross sectional area 7931mm²).

KEYWORDS: Space frame roof structure, IS codes and ETABS software.

I. INTRODUCTION

Space frames are 3D structures assembled of linear elements. These elements are arranged in a way to ensure 3D force transfer from load application point to supports. In past years, there is rapid increase in number of steel structure because of its structural potential and visual beauty. The structural members in space frame are connected at a single node at different angles posing problem of resolution of loads and subsequent effects. Space frame structures have many advantages compared to other types of roof structures like two-dimensional trusses, reinforced or pre-stressed concrete beams. Most important difference in space frame roof structure is three-dimensional load distribution in all parts of the structure. This causes a reduction in the weight of the structure by carrying loads with more members instead of single one, and thus maximum deflection along the structure is reduced. In addition, a separate design of every member in space frame members increases the efficiency in capacity use of members. Another important property of space frame structure is that they are indeterminate systems. This means, the failure of one or a few number of members on the structure does not necessarily lead to collapse of structure completely. By using higher safety margins in some critical members, the resistance of structure against to progressive collapse can be increased. Moreover, space frame roof structure has large volume of free space between top and bottom chords. This permits to install any type of mechanical or electrical service systems continuously along the structure. Additionally, every component of the space frame roof structure is prefabricated, and so the quality of each part is higher and the tolerance is lower compared to in-situ structures. The modular form also meets variety of architectural requirements easily.

II. METHODOLOGY

The study has been done for the finding of best model in light weight and economical. For that three roof types with three material cross sections i.e. nine models were considered. Modelling of the structure was the most important and preliminary step towards the efficient utilization of the structure for the purpose it was intended to. A structure can be considered worthy only if the structure withstands the loads it was expected to carry within its service life. This modelling and analysis was done using ETABS software. A successful structural model can be created through proper designing and selection of materials and sections. In this work nine models were considered with three different roof types and different cross section having same cross sectional area. They are,

Model 1: Pitched roof type space frame with CHS sections

Model 2: Pitched roof type space frame with SHS sections

Model 3: Pitched roof type space frame with equal angle sections

Model 4: Curved type roof space frame with CHS sections

- Model 5: Curved type roof space frame with SHS sections
- Model 6: Curved type roof space frame with equal angle sections
- Model 7: Mono slope type roof space frame with CHS sections
- Model 8: Mono slope type roof space frame with SHS sections
- Model 9: Mono slope type roof space frame with equal angle sections

Cross sections of materials selected for the analysis shown in Fig 1:

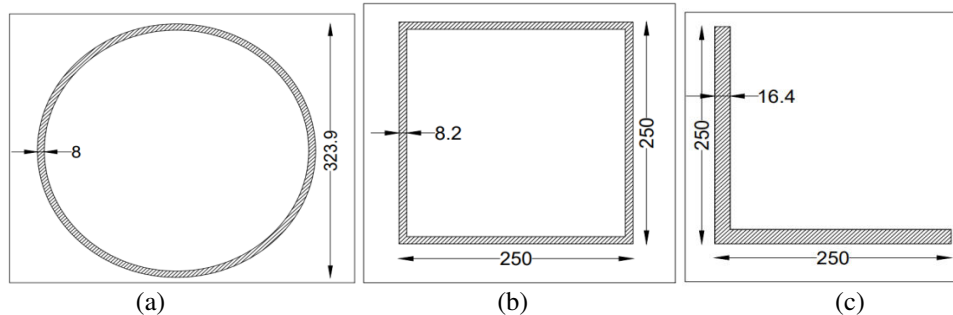


Fig 1 Material cross sections (the cross sectional area of sections 7931mm²)

- (a) Circular hollow section (CHS) (b) Square hollow section (SHS) (c) Equal angle

Geometry of space frame roof:

- Span of space frame roof = 60 m
- Length of space frame roof = 120 m
- Spacing of main lattice = 12 m
- Maximum height of bottom chord from column top = 6 m
- Top and bottom chord depth = 2m

Calculation of loadings on space frame roof:

A. Dead Load (DL)

IS: 875 (Part-1) – 1987 has been considered to calculate dead load.

- Weight of protected galvanized corrugated steel sheet = 0.069 kN/m²
- Additional weight = 0.02 kN/m²
- Total dead load, DL = 0.089 kN/m²

B. Live Load (LL)

IS: 875 (Part II) – 1987 has been considered to calculate live load. No access is provided in the roof except for repair and maintenance.

- Live Load, LL = 0.75 kN/m²

C. Wind Load (WL)

IS: 875 (Part III) – 2015 has been considered for the calculation of wind loads.

Assuming the life of the space frame structure to be 50 years and the land to be flat and surrounded by small buildings,

- V_b = Basic wind speed at Coimbatore, V_b = 39 m/s
- k₁ = probability factor or risk factor = 1 [for general buildings and structures]
- k₂ = terrain, height and structure size factor = 1.05 [for terrain of category 2]
- k₃ = topography factor = 1 [For flat topography]
- Design wind speed, V_z = V_b x k₁ x k₂ x k₃ = 47.09 m/s
- Design wind pressure, p_z = 0.6 V_z² = 1.131 kN/m²
- Wind directionality factor, K_d = 0.09
- Area averaging factor, K_a = 1
- Combination factor, K_c = 0.9
- Design wind pressure, P_d = K_d x K_a x K_c x P_z = 0.108 kN/m²
- Wind load, F = (C_{pe} - C_{pi}) x A x P_d
- Internal pressure coefficients, C_{pi} = 0.7 and -0.7 [Buildings with large openings]
- External pressure coefficients, C_{pe} = [As per clause 7.3.3.2, shown in Table-1, Table-2 and Table-3 for pitched roof, curved roof and mono sloped roof respectively]
- Eave height, h = 12



Table – 1 Wind loads on each node in the pitched space frame roof

Wind angle, α	Pressure coefficient			(Cpe - Cpi)		T.Area, A (m ²)	Pd (kN/m ²)	Wind load, F = (Cpe-Cpi) x A x Pd		Node
	Cpe		Cpi	Windward	Lee ward			Windward (EF)	Leeward (GH)	
	Windward	Lee ward								
0	-1.2	-0.4	0.7	-1.9	-1.1	0.987	0.108	-0.20	-0.12	Corner
				-1.9	-1.1	1.974	0.108	-0.40	-0.23	End
				-1.9	-1.1	3.948	0.108	-0.81	-0.47	Mid
			-0.7	-0.5	0.3	0.987	0.108	-0.05	0.03	Corner
				-0.5	0.3	1.974	0.108	-0.11	0.06	End
				-0.5	0.3	3.948	0.108	-0.21	0.13	Mid
							(EG)	(FH)		
90	-0.8	-0.6	0.7	-1.5	-1.3	0.987	0.108	-0.16		Corner
				-1.5	-1.3	1.974	0.108	-0.32	-0.28	End
				-1.5	-1.3	3.948	0.108	-0.64	-0.55	Mid
			-0.7	-0.1	0.1	0.987	0.108	-0.01		Corner
				-0.1	0.1	1.974	0.108	-0.02	0.02	End
				-0.1	0.1	3.948	0.108	-0.04	0.04	Mid

Table – 2 Wind loads on each node in the curved space frame roof

C	Pressure coefficient, Cpe			(Cpe - Cpi)			T.Area, A (m ²)	Pd (kN/m ²)	Wind load, F = (Cpe-Cpi) x A x Pd			Node
	C2		Cpi	C	Windward, C2	Lee ward, C2			C	Windward, C2	Leeward, C2	
	Windward	Lee ward										
-0.8	0.05	0.05	0.7	-1.5	-0.65	-0.65	1.06	0.108		-0.07	-0.07	Corner
				-1.5	-0.65	-0.65	2.11	0.108	-0.34	-0.15	-0.15	End
				-1.5	-0.65	-0.65	4.22	0.108	-0.68	-0.30	-0.30	Mid
			-0.7	-0.1	0.75	0.75	1.06	0.108		0.09	0.09	Corner
				-0.1	0.75	0.75	2.11	0.108	-0.02	0.17	0.17	End
				-0.1	0.75	0.75	4.22	0.108	-0.05	0.34	0.34	Mid

Table – 3 Wind loads on each node in the mono sloped space frame roof

Angle, θ	Roof portion	Cpe	Cpi	Cpe - Cpi	T.Area, A (m ²)	Pd (kN/m ²)	Wind load, F = (Cpe-Cpi) x A x Pd	Node
0°	H	-1	0.7	-1.7	2.01	0.108	-0.37	End
			0.7	-1.7	4.02	0.108	-0.74	Mid
			0.7	-1.7	1.005	0.108	-0.18	Corner
			-0.7	-0.3	2.01	0.108	-0.06	End
			-0.7	-0.3	4.02	0.108	-0.13	Mid
			-0.7	-0.3	1.005	0.108	-0.03	Corner
	L	-0.5	0.7	-1.2	2.01	0.108	-0.26	End
			0.7	-1.2	4.02	0.108	-0.52	Mid
			0.7	-1.2	1.005	0.108	-0.13	Corner
			-0.7	0.2	2.01	0.108	0.04	End
			-0.7	0.2	4.02	0.108	0.09	Mid
			-0.7	0.2	1.005	0.108	0.02	Corner

Continues...



Angle, θ	Roof portion	Cpe	Cpi	Cpe - Cpi	T.Area, A (m ²)	Pd (kN/m ²)	Wind load, F = (Cpe-Cpi) x A x Pd	Node
45°	H	-1	0.7	-1.7	2.01	0.108	-0.37	End
			0.7	-1.7	4.02	0.108	-0.74	Mid
			0.7	-1.7	1.005	0.108	-0.18	Corner
			-0.7	-0.3	2.01	0.108	-0.06	End
			-0.7	-0.3	4.02	0.108	-0.13	Mid
			-0.7	-0.3	1.005	0.108	-0.03	Corner
	L	-0.88	0.7	-1.58	2.01	0.108	-0.34	End
			0.7	-1.58	4.02	0.108	-0.68	Mid
			0.7	-1.58	1.005	0.108	-0.17	Corner
			-0.7	-0.18	2.01	0.108	-0.04	End
			-0.7	-0.18	4.02	0.108	-0.08	Mid
			-0.7	-0.18	1.005	0.108	-0.02	Corner
90° Applied to length w/2 from wind ward end	H & L	-1	0.7	-1.7	2.01	0.108	-0.37	End
			0.7	-1.7	4.02	0.108	-0.74	Mid
			0.7	-1.7	1.005	0.108	-0.18	Corner
			-0.7	-0.3	2.01	0.108	-0.06	End
			-0.7	-0.3	4.02	0.108	-0.13	Mid
			-0.7	-0.3	1.005	0.108	-0.03	Corner
90° Applied to reminder	H & L	-0.5	0.7	-1.2	2.01	0.108	-0.26	End
			0.7	-1.2	4.02	0.108	-0.52	Mid
			0.7	-1.2	1.005	0.108	-0.13	Corner
			-0.7	0.2	2.01	0.108	0.04	End
			-0.7	0.2	4.02	0.108	0.09	Mid
			-0.7	0.2	1.005	0.108	0.02	Corner
135°	H	-1	0.7	-1.7	2.01	0.108	-0.37	End
			0.7	-1.7	4.02	0.108	-0.74	Mid
			0.7	-1.7	1.005	0.108	-0.18	Corner
			-0.7	-0.3	2.01	0.108	-0.06	End
			-0.7	-0.3	4.02	0.108	-0.13	Mid
			-0.7	-0.3	1.005	0.108	-0.03	Corner
	L	-0.88	0.7	-1.58	2.01	0.108	-0.34	End
			0.7	-1.58	4.02	0.108	-0.68	Mid
			0.7	-1.58	1.005	0.108	-0.17	Corner
			-0.7	-0.18	2.01	0.108	-0.04	End
			-0.7	-0.18	4.02	0.108	-0.08	Mid
			-0.7	-0.18	1.005	0.108	-0.02	Corner
180°	H	-1	0.7	-1.7	2.01	0.108	-0.37	End
			0.7	-1.7	4.02	0.108	-0.74	Mid
			0.7	-1.7	1.005	0.108	-0.18	Corner
			-0.7	-0.3	2.01	0.108	-0.06	End
			-0.7	-0.3	4.02	0.108	-0.13	Mid
			-0.7	-0.3	1.005	0.108	-0.03	Corner
	L	-0.48	0.7	-1.18	2.01	0.108	-0.26	End
			0.7	-1.18	4.02	0.108	-0.51	Mid
			0.7	-1.18	1.005	0.108	-0.13	Corner
			-0.7	0.22	2.01	0.108	0.05	End
			-0.7	0.22	4.02	0.108	0.10	Mid
			-0.7	0.22	1.005	0.108	0.02	Corner

Roof types selected for the analysis shown in Fig 2

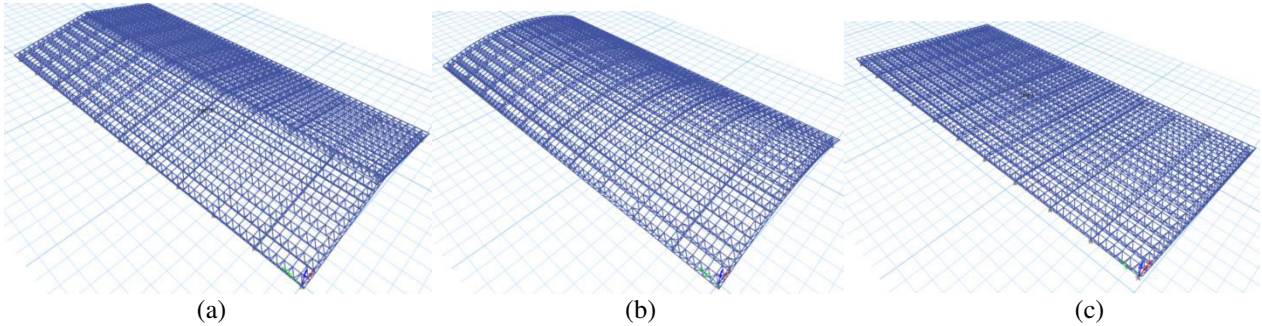


Fig 2 Space frame roof type

(a) Pitched roof (b) Curved roof (c) Mono sloped roof

III. ANALYSIS AND DISCUSSION

A. Analytical results of pitched space frame roof truss with CHS, SHS and equal angle cross sections (Model 1,2 & 3) was shown in Fig 3.

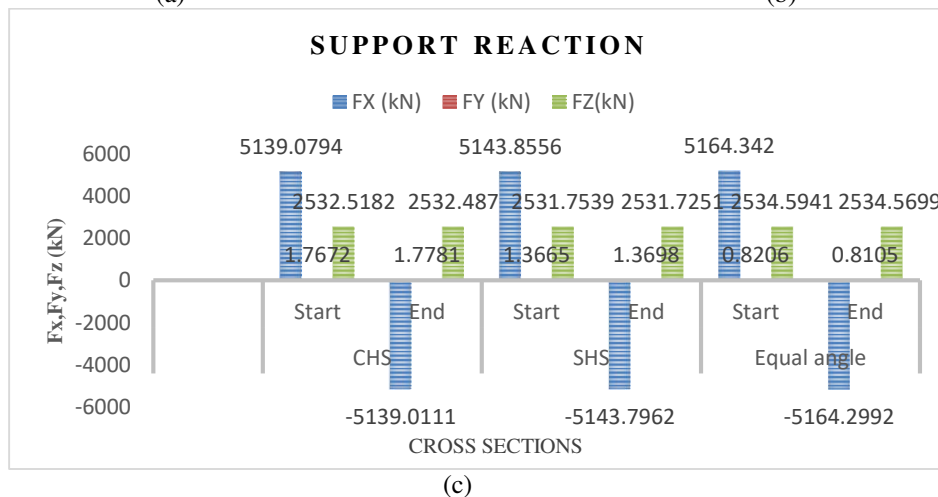
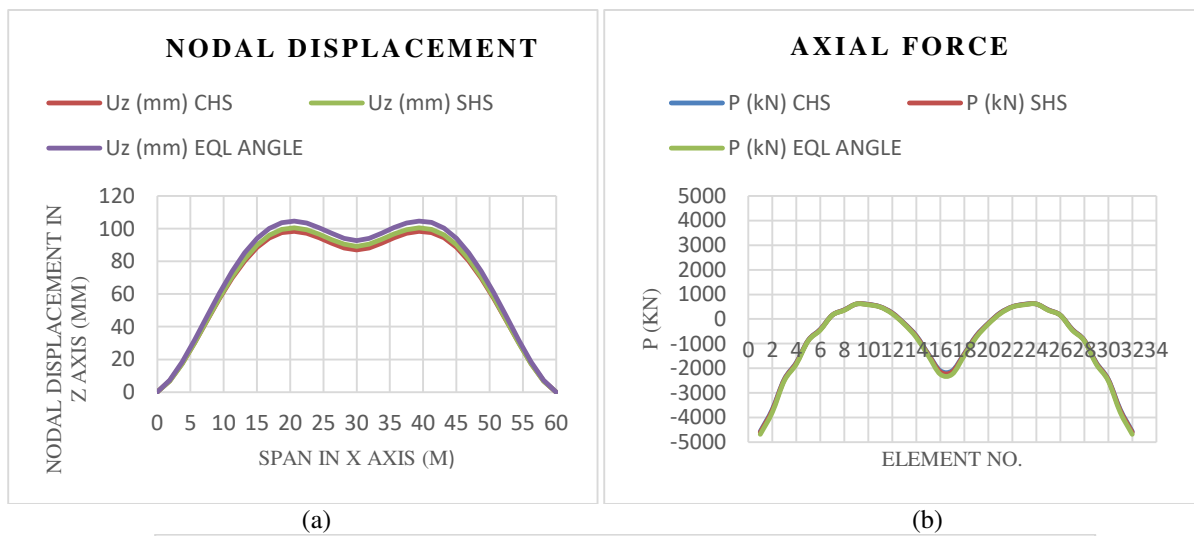


Fig 3 Analytical results of pitched space frame roof

(a) Nodal displacement of pitched roof (b) Axial forces of pitched roof (c) Support reactions at pitched roof

The analysis of pitched roof space frame structures was done using ETABS software with circular hollow sections, square hollow section and equal angle. In the case of pitched roof type obtained the maximum nodal displacements, axial forces and support reactions in 4th and 8th main lattice. By comparing these three models we can see that all the nodal displacement, axial force and support reactions were less in the case of CHS than SHS and equal angle.

B. Analytical results of curved space frame roof truss with CHS, SHS and equal angle cross sections (Model 4,5&6) was shown in Fig 4.

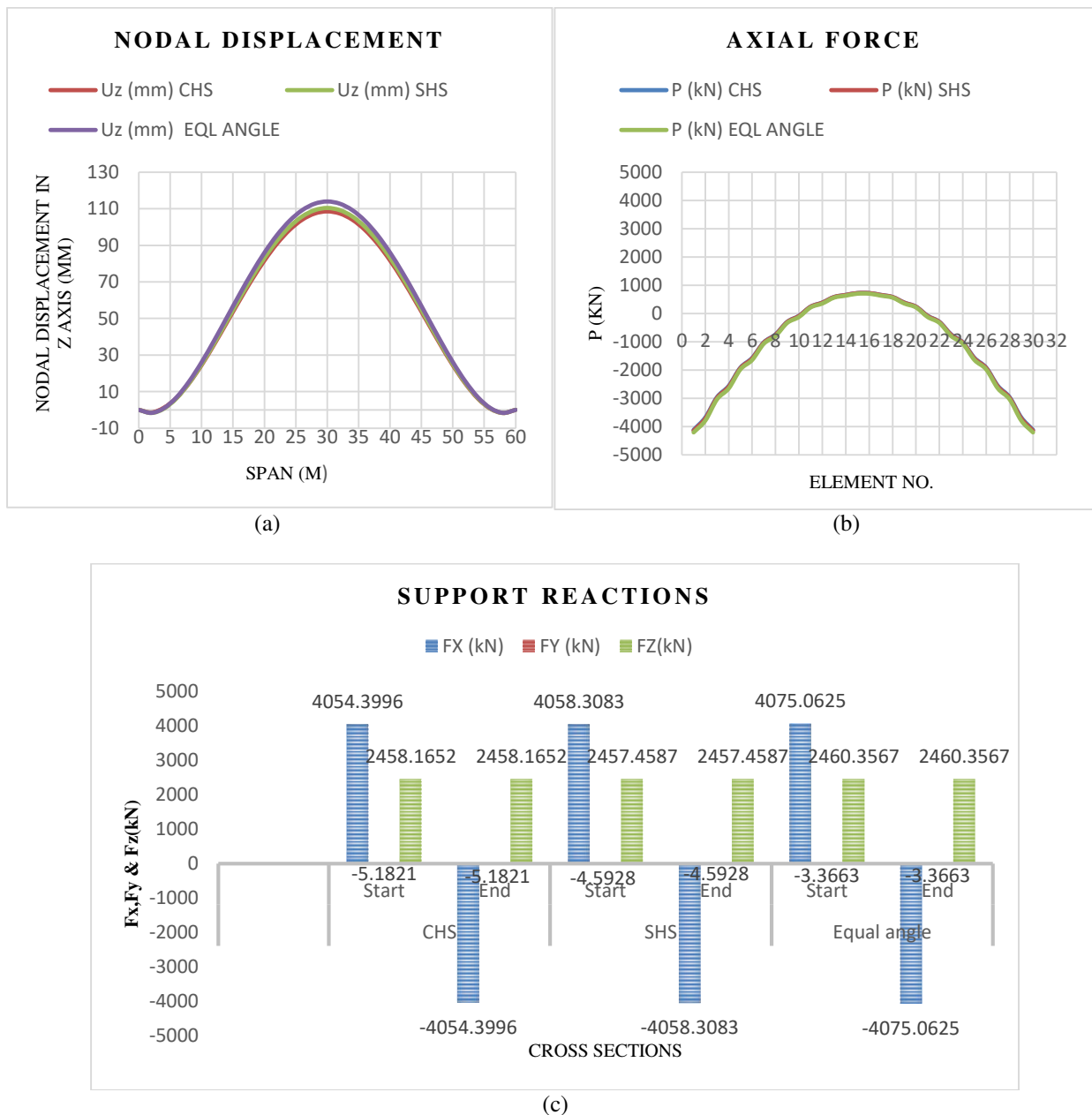
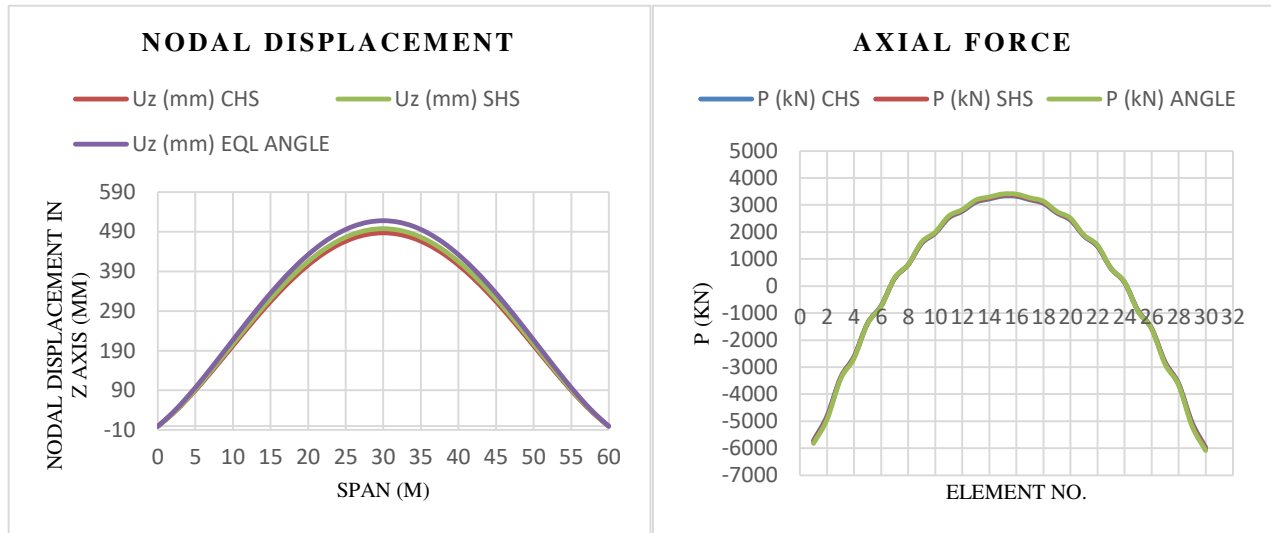


Fig 4 Analytical results of curved space frame roof

(a) Nodal displacement of curved roof (b) Axial forces of curved roof (c) Support reactions at curved roof

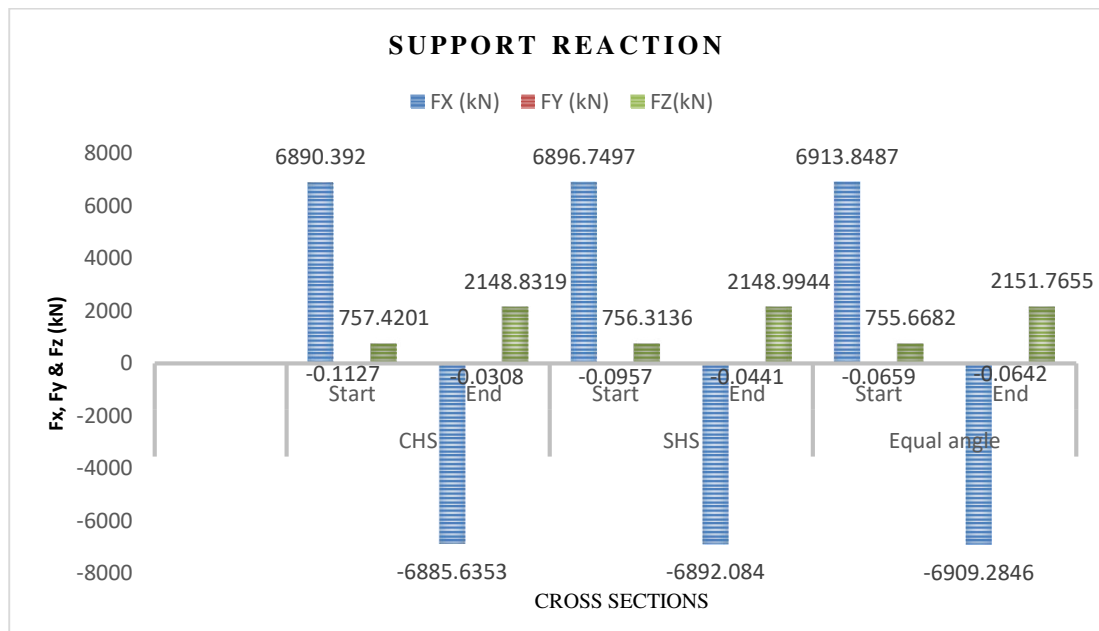
In the case of curved roof type obtained the maximum nodal displacements, axial forces and support reactions in 4th and 8th main lattice. Here also we can see that the CHS gives the best results.

C. Analytical results of mono sloped space frame roof truss with CHS, SHS and equal angle cross sections (Model 7,8&9) was shown in Fig 5.



(a)

(b)



(c)

Fig 5 Analytical results of mono sloped space frame roof

(c) Nodal displacement of mono sloped roof (b) Axial forces of mono sloped roof (c) Support reactions at mono sloped roof

But in the case of mono sloped roof type obtained the maximum nodal displacements, axial forces and support reactions in 6th main lattice of the structure. The equal angle showed the maximum result values than SHS and CHS. In the case of mono sloped roof also CHS was the best cross section.



The analytical summary of all models were shown in Table 4

Table – 4 Analysis results summary of nine models

ROOF TYPE	CROSS SECTIONS	MAX. RESULT MAIN LATTICE NO.	NODAL DISPLACEMENT		AXIAL LOAD			SUPPORT REACTIONS						
			LABEL (m)	Uz (mm)	Element Nos.	P (kN)		LABEL	FX (kN)		FY (kN)		FZ (kN)	
						Start	End		Start	End	Start	End	Start	End
PITCHED ROOF	CHS 323.9X8.0	4th & 8th	39.375 & 20.625	98	1 & 32	-4566	-4566	4 & 8	5139	-5139	1.8	1.8	2533	2532
	SHS 250X250X8.2	4th & 8th	39.375 & 20.625	101	1 & 32	-4605	-4605	4 & 8	5144	-5144	1.4	1.4	2532	2532
	ISA 250X250X16.4	4th & 8th	39.375 & 20.625	105	1 & 32	-4676	-4676	4 & 8	5164	-5164	0.8	0.8	2535	2535
CURVED ROOF	CHS 323.9X8.0	4th & 8th	30	109	1 & 30	-4113	-4113	4 & 8	4054	-4054	-5.2	-5.2	2458	2458
	SHS 250X250X8.2	4th & 8th	30	110	1 & 30	-4147	-4147	4 & 8	4058	-4058	-4.6	-4.6	2457	2457
	ISA 250X250X16.4	4th & 8th	30	114	1 & 30	-4207	-4207	4 & 8	4075	-4075	-3.4	-3.4	2460	2460
MONO SLOPE ROOF	CHS 323.9X8.0	6th	30	487	1 & 30	-5708	-5966	6	6890	-6886	-0.1	0.0	757	2149
	SHS 250X250X8.2	6th	30	497	1 & 30	-5753	-6013	6	6897	-6892	-0.1	0.0	756	2149
	ISA 250X250X16.4	6th	30	518	1 & 30	-5827	-6089	6	6914	-6909	-0.1	-0.1	756	2152

After analysis we can say that,

- In the pitched roof, curved roof and mono sloped roof the minimum analysis results were obtained in the CHS and maximum was in equal angles.
- And by comparing all models the curved roof space frame structure is more efficient. Because all the nodal displacements, axial forces and support reactions were less compared to all other models.
- So the most efficient structure was curved roof type space frame structure with CHS.

IV. CONCLUSION

This research presented the comparative study of analysis of different spaceframe roof types such as pitched, curved and mono sloped with different cross sections such as circular hollow sections, square hollow sections and equal angles. For the comparison, the analysis results of nodal displacements and axial forces on the main lattice bottom chord and support reactions at end supports were taken. Found the best model from the nine models by keeping same cross sectional area of material (7931mm²). From the analytical study the following conclusions were drawn,

- In curved and mono sloped roofs the maximum nodal displacements at the middle (at 30m) of span and in the case of pitched roof the maximum values were obtained at 20.625m and 39.375m from the left end.
- The higher nodal displacement and axial forces were obtained in mono slope roof and minimum in curved roof type.
- In the case of support reactions, maximum at the 4th & 8th main lattices in pitched roof and curved roof (two ends have same reactions).
- But in the case of mono slope roof two sides have different reactions i.e. the elevated side with lower value and bottom side with higher value.
- From the analysis of nine models, we can conclude that the curved space frame roof type with CHS was more efficient.
- Hence, the large span roof area without intermediate columns is possible with space frame roof structure.



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