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Evolution of Economical Structural System of Single Storey Long Span Halls

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ABSTRACT

The composite structure consisting of steel truss or girder with concrete columns is most commonly used technique in long span structures. In short span structures, columns cover a lot of space, and create visibility problem that's why it is better to design long span halls so that internal space can be used more efficiently. The selection of most economical steel roof system is a major concern these days. For a given span, economy of truss depends on its configuration. As, there is no guideline available to fix this parameter which lead to minimum weight of truss, therefore an attempt is being made to obtain economical configuration of all trusses. The work focuses on most common steel roof structural system in order to propose cost effective roof for long span. The span selected for roofing system is 120ft long. Three different types of trusses (Arch, Quadrangular and Pratt truss) and lattice girder are investigated. Gravity, seismic and wind loads are considered for design of these structural systems. The codes used were ACI 318-14, UBC 1997, and ASCE 7-05 for gravity, seismic, and wind load respectively. Steel roof structural system (steel trusses and steel girder) are analyzed and designed in ETABS and total weights of each structural system are obtained. The one with minimum weight of material is considered as economical structural system. It is observed that among these steel roof structural systems, lattice girder is 5.89% more economical as compared to steel trusses in terms of weight of the roofing system.

Keywords: Economical Structural Systems, Arch Truss, Quadrangular Truss, Pratt Truss, Steel Girder

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1. Introduction:

Long span halls are characterized as those that exceed 15m or 50ft in span (Patel et al. 2017). These halls can make adaptable, column free inner space and can lessen substructure expenses and development times. They are usually utilized as a part of extensive variety of building types such as concert halls, lectures hall, cinema hall and arenas (Patel et al. 2017). The basic and acoustical parts of this sort of halls or structures have a more prominent variety with different kinds of structures or halls, since its need to accommodate a variety of events with acoustics appropriate for numerous types. In the economical aspect, it is of great advantage to have a multipurpose auditorium instead of having various auditoriums of different types (Nithya et al. 2015).

The use of conventional structural systems in long span halls can be quite challenging and hardly leads to cost effective solutions. Long span structures tend to develop large bending moments under external loading which in turn lead to excessive deformations and vertical displacements (Antoniou et al. 2014). In long span structures, the composite structure of steel truss or girder over a concrete wall has developed recently. These are adapted as an alternative to conventional structures owing to its less structural weight, seedy construction and ability to bear high bending moment without any column interruption for long span (Nithya et al. 2015).

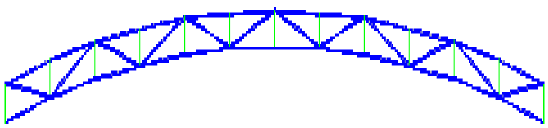
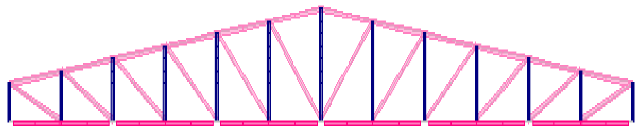
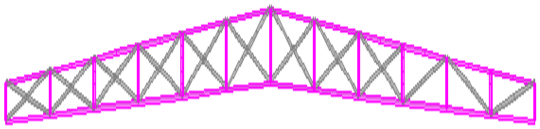
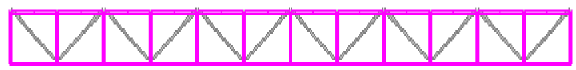
Now a days, steel roof systems (steel trusses and steel girders) are widely used for long span structures and attempt is made to design an economical steel roof system. The truss configuration is essential which influences economy of truss since loads acting, load carrying mechanism, length of members and number of joints depend on configuration only (Varma et al. 2014). If wrong type of truss is chosen for the given span, the entire truss may become inefficient and costly. In this manner, an endeavor was made to choose a configuration which gives least weight and accordingly economy (Varma et al. 2014).

In short span structures, columns cover a lot of space and also create a visibility problem. Therefore, it is desired to design the column free long span hall so that internal space can be used more efficiently. For a given span, economy of truss also depends on its configuration. As, there is no guideline available to fix this parameter which lead to minimum weight of truss, therefore an attempt is being made to obtain economical configuration among selected trusses. For the study, only three types of truss configurations Arch, Quadrangular and Pratt truss and lattice girder for a span of 120ft are considered. In this study gravity, earthquake and wind load is considered. All the trusses are analyzed and designed in ETABS software and total weight of each structural system is calculated. The one with minimum weight of the material is considered as economical structural system.

2. Selection of Trusses

For roof of these halls, three different types of trusses (Arch, Quadrangular and Pratt) and lattice girder are used. These trusses are shown in Figure 2-1.

Figure 2-1: Truss Configurations

	
Arch Truss	**Pratt-N Truss**
	
Quadrangular Truss	**Lattice Girder**

3. Methodology

In this project long span halls of size 120ft x 200ft are designed by using ETABS software. Gravity, seismic and wind load are considered for design of these halls. For gravity load, ACI 318-14 is used, for seismic load UBC 1997 is used and for wind load ASCE 7-05 is used. The trusses are used with top chord, bottom chord and web members which are rested on the RCC columns. The trusses are spaced at 12.5ft and depth of trusses is 12ft (Punmia 2005). The height of columns is 12ft and the panel length of trusses is 10ft (Bhavikatti 2007). Purlins are provided at 5ft spacing (Bhavikatti 2007). The sections which are composed of trusses and girders are angles, tees and channels. For top and bottom chords of trusses, tee section is used and for web members, angle section is used. Sag rods are provided at 6.25ft (Raz 2002). For the structure to be stable and to resist the wind load, the horizontal cross bracing is provided in bottom chord of trusses and the section which is used for this purpose are angle section. On top of all trusses GI sheets are provided. These halls with steel roof system are analyzed in ETABS. The steel roof system which gives least weight for same span (120ft), panel length and height is considered as economical system.

Table 3-2: Truss Configuration and Design Input.

Span (ft)	120ft
Type of Structure	Single storey industrial structure
Location	Islamabad, Pakistan
Area of Buildings	24,000sq.ft
Height of truss (ft)	12ft
Spacing of Truss (ft)	12.5ft
Number of Bays	16
Single bay length	12.5ft
Basic Wind Speed (mph)	110mph
Exposure Type	B
Category	II
Spacing Between Purlins (ft)	5ft
Spacing Between Sag Rods (ft)	6.25ft
Seismic Zone	2B
Soil type	SD

4. Load calculations:

4.1. Dead load

Roofing materials - GI sheeting with unit weight of 3.047psf
Purlins - unit weight of purlin is 7.25psf
Total dead load = 3.047 + 7.25=10.297psf
Dead load on plan area = Load x Purlin spacing x Bay spacing
= 10.297 x 5 x 12.5
Dead load = 643.56 lb at each node.

4.2. Live load

Total live load on plan area = 20psf (ACI318-14).

4.3. Earthquake load

Earthquake loads are calculated as per UBC-97.

- Zone = 2B
- Soil type = SD (stiff soil)
- Importance factor = 1
- Over strength factor = 5.5

4.4. Wind load

Wind load is calculated as per ASCE7-05.

- Basic wind speed = 110mph.
- Exposure = B (Section 6.5.6.3).
- Category = II
- Gust Factor = 0.85 (Section 6.5.8)
- Wind Directionality Factor (K_d) = 0.85 (Table 6.4)
- Wind Topographic Factor (K_{zt}) = 1.51 (Figure 6.4)
- Importance factor (I) = 1 (Table 6.1)

Velocity pressure exposure coefficient (K_z) = 0.70

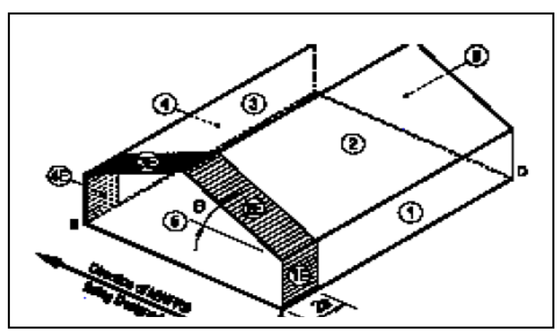
$Velocity\ Pressure\ (qz) = 0.00256kz\ kzt\ kd\ I\ v^{\wedge}2$

= 0.00256 x 0.70 x 1.51 x 0.85 x 1 x 110^2

= 27.83psf or 0.0278ksf

$Design\ Wind\ Pressure\ (P) = qh[(GCpf) - qi(GCpi)]$

Wind Pressures on Main Wind Force Resisting System						
Surface	GCpf	+GCpi	-GCpi	qh (psf)	Min P (psf)	Max P (psf)
1	0.56	0.18	-0.18	27.88	10.59	20.63
2	0.21	0.18	-0.18	27.88	0.84	10.87
3	-0.43	0.18	-0.18	27.88	-17.01	-6.97
4	-0.37	0.18	-0.18	27.88	-15.33	-5.30
5	-0.45	0.18	-0.18	27.88	-17.56	-7.53
6	-0.45	0.18	-0.18	27.88	-17.56	-7.53
1E	0.69	0.18	-0.18	27.88	14.22	24.26
2E	0.27	0.18	-0.18	27.88	2.51	12.55
3E	-0.53	0.18	-0.18	27.88	-19.80	-9.76
4E	-0.48	0.18	-0.18	27.88	-18.40	-8.36

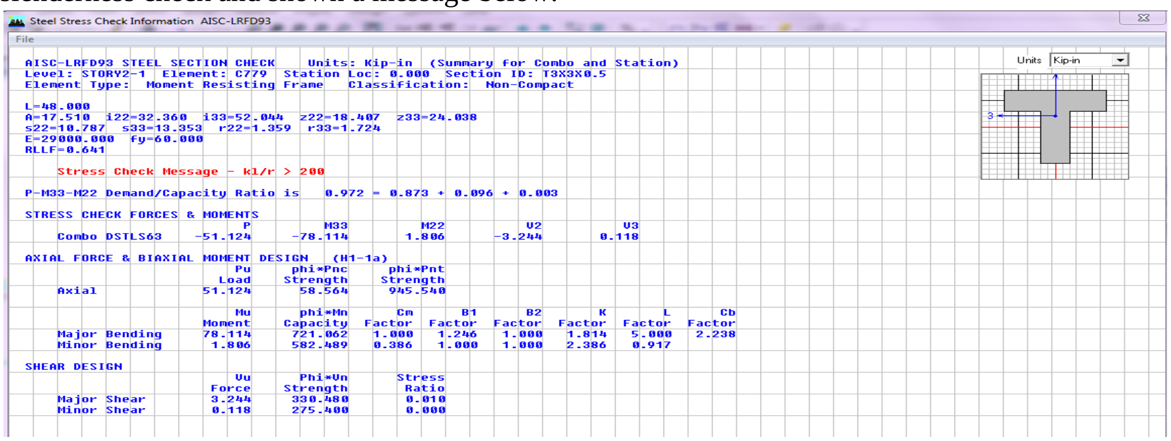


5. Results and Discussion:

5.1. Slenderness ratio

kl/r ratio is called slenderness ratio. It is the ratio of the effective length of column to the least radius of gyration of its cross section. kl/r ratio or slenderness ratio should not exceed 200 for a members whose design is based on compressive force and also should not exceed 300 for a members whose design is based on tensile force (AISC, 2007).

In all compression and tension members of models slenderness ratio lies below than expected range (200 and 300). If we further decrease the member sizes then buckling occurs and the member fail in slenderness check and shown a message below.



5.2. Axial Force Demand Ratio

Axial Force Demand to capacity ratio should be near to 1 for an economical structural system. It is between 0.3 to 0.98 in all steel roof structural systems. In some members, ratio can be increased however; they may fail because of slenderness effect. The axial force demand capacity ratio for Pratt-N, Quadrangular, Arch and Lattice girder is shown in figure 5.2.1, 5.2.2, 5.2.3 and 5.2.4.

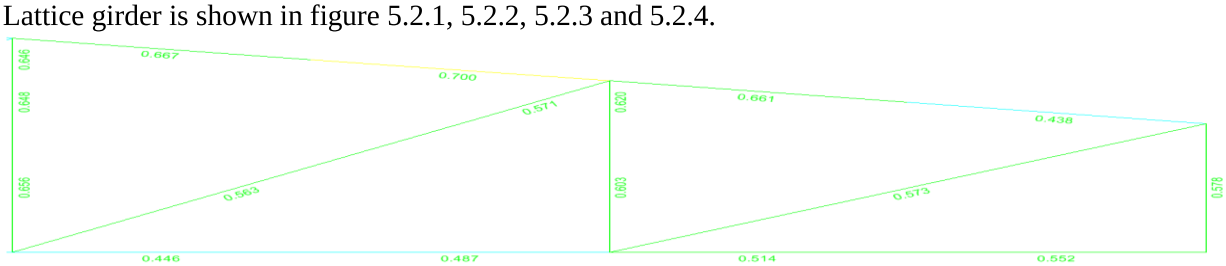


Figure 5.2.1 Axial Force Demand Ratio of Pratt-N truss

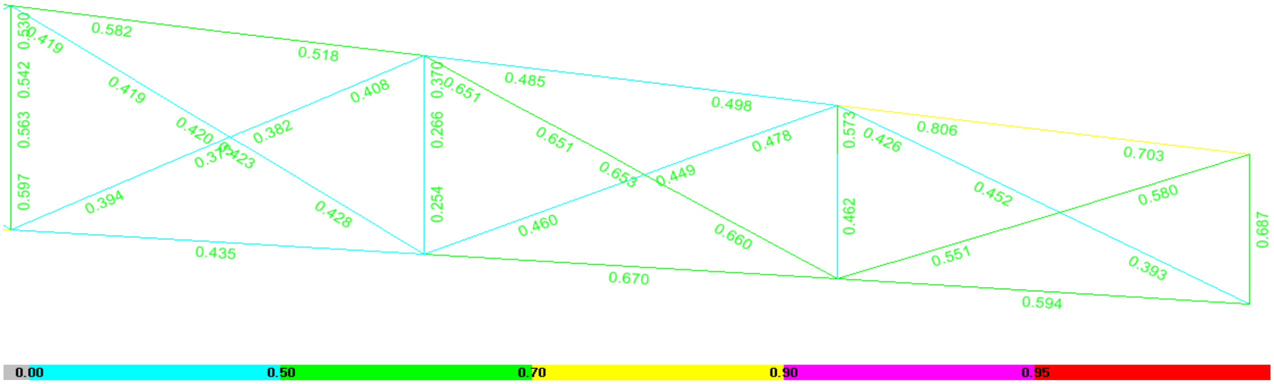


Figure 5.2.2 Axial Force Demand Ratio of Quadrangular truss

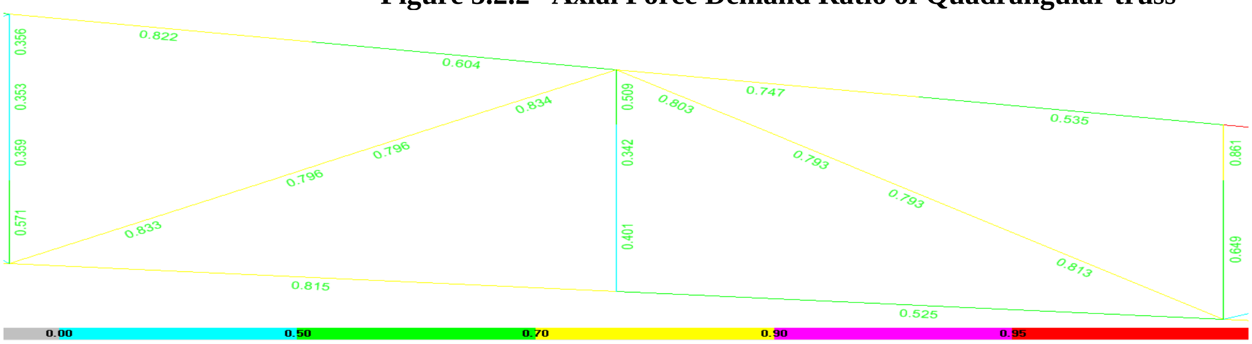


Figure 5.2.3 Axial Force Demand Ratio of Arch truss

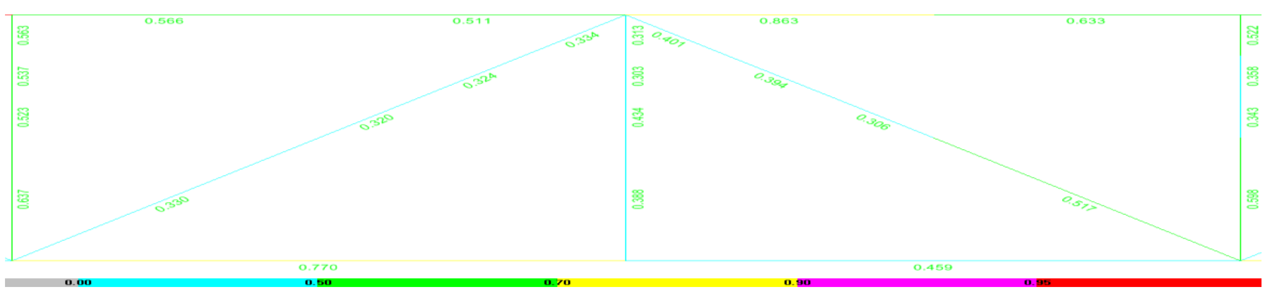


Figure 5.2.4 Axial Force Demand Ratio of Lattice girder

5.3. Comparison of Weight

The weight comparison of Pratt-N, Quadrangular, Arch and Lattice girder are shown in Table 5.3.1, 5.3.2, 5.3.3 and 5.3.4

Table 5.3.1 Total Weight of Arch Truss

Sr. No.	Section	Material	Use	Dimensions (AISC)	Weight (Kip)
1.	Tee	Steel	Top and Bottom Chords	WT10.5X36.5	207.41
2.	Angle	Steel	Diagonal Members	L6X6X9/16	47.84
3.	Angle	Steel	Cross Bracing	L8X8X5/8	162.57
4.	Channel	Steel	Purlins	C4X4.5	22.26
5.	Round	Steel	Above Purlins	S2.5	32.40
				Total =	**472.48**

Table 5.3.2 Total Weight of Pratt-N Truss

Sr. No.	Section	Material	Use	Dimensions (AISC)	Weight (Kip)
1.	Tee	Steel	Top and Bottom Chords	WT9X30	182.63
2.	Angle	Steel	Diagonal Members	L6X6X5/8	61.75
3.	Angle	Steel	Cross Bracing	L7X4X5/8	134.50
4.	Channel	Steel	Purlins	C4X4.5	22.39
5.	Round	Steel	Above Purlins	S1.7	14.93
				Total =	**416.2**

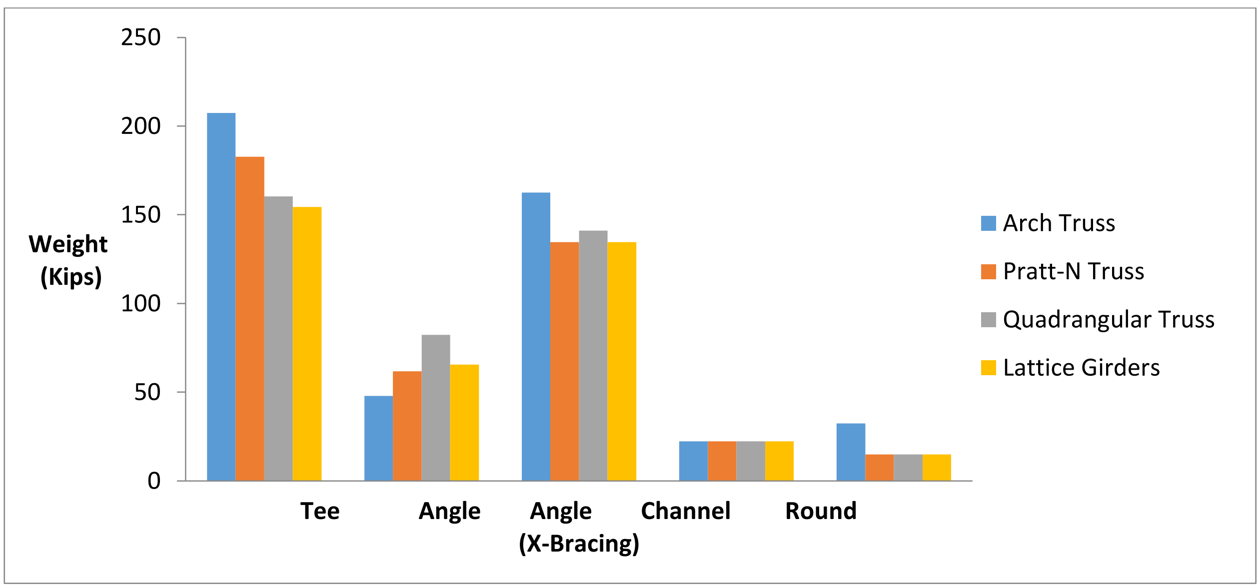
Table 5.3.3 Total Weight of Quadrangular Truss

Sr. No.	Section	Material	Use	Dimensions (AISC)	Weight (Kip)
1.	Tee	Steel	Top and Bottom Chords	WT9X30	160.31
2.	Angle	Steel	Diagonal Members	L6X6X9/16	82.25
3.	Angle	Steel	Cross Bracing	L8X6X1/2	141.03
4.	Channel	Steel	Purlins	C4X4.5	22.39
5.	Round	Steel	Above Purlins	S1.7	14.93
				Total =	**420.91**

Table 5.3.4 Total Weight of Lattice Girder

Sr. No.	Section	Material	Use	Dimensions (AISC)	Weight (Kip)
1.	Tee	Steel	Top and Bottom Chords	WT9X27	154.35
2.	Angle	Steel	Diagonal Members	L6X6X5/8	65.53
3.	Angle	Steel	Cross Bracing	L7X4X5/8	134.50
4.	Channel	Steel	Purlins	C4X4.5	22.39
5.	Round	Steel	Above Purlins	S1.7	14.93
				Total =	**391.7**

Figure 5.1 Comparison of weight of various steel roof structural systems



1. Conclusion:

- It is concluded that the total weight of the Lattice girder 5.89% is less as compared to steel trusses. Hence, Lattice girder is more economical among all selected steel roof system.
- Among three trusses, Pratt-N truss is economical as compared to Arch and Quadrangular trusses and next to come is Quadrangular truss.
- Arch truss is costly among all selected steel trusses and girder.

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