# An Investigative approach to design of trussless roof by Indian codes & FEM

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**Abstract**: Trussless roofing being a relatively new construction technology, there are very few codal and reference guidelines available for designing such systems. Owing to lack of scientific research and literature, many companies are exploiting the system for commercial benefit. Few unscientific practices that can be seen in designs of suppliers who provide trussless roofing systems are no seismic considerations and wind force calculations by using foreign codes with incorrect the factors of safety and combinations. Scope of this paper is to establish a design method for such structures with Indian codes and do a comparative study with FEM analysis and publish the results.

Keywords: Trussless roof, Self-supporting Roofing structure, arch roofing systems

# 1. INTRODUCTION

Self-supported roofs or Trussless roofs were initially used for small industrial buildings of up to 20m width. These roofing systems gained popularity due to aesthetically pleasing curved look, low cost and faster erection. Major industries where these are used are storage buildings or factories where cranes or any other collateral loads like false ceiling ductings were not required. However with booming warehousing industries in India, trussless roofs provided the right fit of lower cost of projects and faster erection, resulting in faster ROI for owners.

The Components of these structures are manufactured directly on site by a mobile truck where standing seam sheets are first roll formed into a profile and then bent to achieve curved shape by means of a bending machine Fig.1. These sheets are bent in a single piece without any joints in one single span of sheet. The Profiles are then joined by a cold seaming process first at ground level and then at roof after lifting and placing it over column supports.



Fig.1 Process of making Curved Panel at site

The structural mechanics of a trussless roof or Self supported roof has its root in the theory of two hinged arches Fig.2. An arch is a pure compression form [1]. It spans a large area by distributing forces by means of internal compressive stresses, and thereby eliminating tensile stresses. This is called the arch action. As the forces in the arch are transferred to its base, the arch pushes outward at its base, denoted as "thrust" [2]. As the rise i.e the



height of the arch decreases the outward thrust increases. In order to preserve arch action and prevent collapse of the arch, the thrust must be restrained by columns and beams framing arrangements[3].



Fig.2 Diagram of Loadings and Supports of two Hinged Arch

2. MATERIAL & INSTALLATIONS The Main Material used for roofing is Galvalume Galvalume Steel. is a trademark invented in 1972 by Bethlehem Steel.Galvalume is a high quality, high pre-coated material grade having thicknesses of 0.8 to 1.6mm used as trussless roofing material. It is aluminumzinc alloy-coated steel sheets with 55% aluminum, 43.5% zinc and 1.5% silicon coating. Detailed specification has been given in table 1.

Table 1 technical Specifications ofgalvalume Steel

Base Metal	Cold Rolled Structural Quality Steel In Coil Form, Coil Width: 1250 Max +/-0.5mm
Steel Grade	350/550MPA
Thickness of Material used	0.7 to 2.0mm (Base metal thickness)

Coating Details	AZ 150, 150 Gms./Sq. M. Alu-Zinc-silicon Coating ( 55% A1, 43.5% Zn, 1.5% Si)
Coating Grade	AZ150 /AZ200
Standards	ASTM A792 D

The plane Sheet from the roll is passed through a Hydraulic Profile machine (MIC Machine) as shown in stage 1 of fig.1 to give it the Trapezoidal shape as shown in fig.3. The machine is basically a roll forming machine where the sheets are formed into a shape by a cold pressing process and then cut to the required length by a press cutter fitted at the end of the machine. After the profiling, these panels are passed through another Hydraulic machine as shown in stage 2 of fig.3 for Pre Curving as per the design. This process is also called crimp curving of the sheet which curves the sheet as per required radius.

Every Three such panels after curving are then placed at ground and joined together with the help of Seaming machine (fig.3). This is done to achieve better quality control and to avoid seaming done at height and also this helps in stability during lifting and erections.

A variety of roof seaming machines are available in the market, but they play an important role in joining sheets. A small error leads to heavy scratches and removal of coatings at joints. Machines are small and portable and are easy to handle by operator.

Seaming is like 'zipping up' rolled metal panels together using a Mechanical



Seaming machine. Panels are free from holes, nuts/bolts, overlaps and sealants which ensure almost zero maintenance.



Fig.3 Mechanical Seaming & Grouping of three members at Ground

Precurved Sheets seamed in a set of three will be lifted by Cranes and placed over supporting structure. Once placed the group of three members are then seamed at roof top with the help of the same roof seamer. Alignments and plumbs are checked and corrected during this phase. After placing the sheets on the supporting structure, it is then fixed by mechanical Anchors of 3 or 4 Nos.

Supporting structure can be of RCC or steel as per customer or Architects requirements as shown in Fig.4. A continuous member with sloping edge and gutter provision is needed in both the systems. Sheets will rest on these continuous members. The columns should withstand the lateral Deflection caused due to horizontal thrust by arch roofs.



Fig.4 RCC & Steel Continuous Beam Support for Trussless Roof

Location of Structure	Pune (India)
Width ( Span of Buildings)	18m
Column Height	4m
Arch height at center	8m from Ground level
Length of Buildings	60m
Column Spacings	7.5m
Wind Speed	39m/s
Seismic Zone	Zone III

#### 3. STRUCTURAL CONFIGURATION

#### 4. LOAD CALCULATIONS

Dead Loads on trussless roof are generally its self-weight and other miscellaneous items like turbo ventilators and skylights arrangements. Since we are modeling this structure in staad and FEM, only selfweight is considered.

Sheeting Weight	1.2mm Thick
	Sheets Considered
	12kg/m2

As per IS 875- Part 2-2015	0.75Kn/m2
Bay Spacing	=0.6m =0.6 X0.75Kn/m2 = 0.45Kn/m

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Wind calculations are considered per IS 875-3 -2015, where for columns table no 6 of code is considered and for roof table no 18 has been considered. All considered parameters are mentioned in Table no. 4 below:

Basic wind speed (Vb)	39m/s
Risk Coefficient (K1)	1
(Clause 6.3.1)	
Terrain category ( Clause	2
6.3.2.1)	
Terrain Height Factor	1
(K2)	
Topography Factor (K3)	1
Importance Factor for	1 (All other
Cyclonic Region(K4)	Structures)
Design Wind speed (Vz)	= Vb X k1 X k2
	X k3 X k4
	= 39 X 1 X 1 X
	1 X 1
	= 39m/s
Design Wind Pressure Pz	= 0.6 X Vz^2
at height z	= 0.6X 39X39
(Clause 7.2)	= 912.60 N/m2
	= 0.91 Kn/m2
If H < 10 m multiply Pz	= 0.91 X 0.8
with 0.8 (20 % reduction)	= 0.73 Kn/m2
clause 6.3 Note	

Wind directionality factor (Kd) Clause 7.2.1	1
Area Averaging Factor (Ka) Clause 7.2.2	1
Combination Factor (Kc) Clause 7.3.13	0.9
Design Wind Pressure Pd	= Kd X Ka X Kc X Pz
	= 1 X 1 X 0.9 X 0.91Kn/m2 = <b>0.66 Kn/m2</b>
Срі	0.2

Seismic Loadings applied as below:

Code	IS1893-2016 ( Part 1)
Zone	0.16
Response reduction Factor	3
Importance Factor	1
Rock and soil site factor	2
Type of structure	5
Damping ratio	0.05



Period in X direction	0.085 Seconds
Period in Z Direction	0.045 Seconds

## 5. STAAD MODELLING & FEM

Column is used of size ISMB 600 and the continuous member on which the trussless roof will rest is considered as Builtup tubular Member of size 300x300x8m thick of grade 250 mpa. Bracings have been considered as IS 100x100x10 back to back sections in the first and last bay.

Curved Member has been added at a spacing of 600mm for a length of 60m in a curve of 18m span as shown in Figure No.5. A dummy horizontal member has been added along the length to provide longitudinal stability to structure as in actual all sheets will be connected with each other.



Fig. No 5 Staad Wire frame model

Trussless members, which is a C section modified with new properties, has been modelled as a curved member and released in My & Mz direction at Continuous member where it will rest. This way it will not transfer any moments to Continuous Beam. Channel members have been rotated by 90 degrees to place in a similar way trussless roofs will be placed. The 3d Rendered view is shown in figure no.6



Fig No. 6 3d Rendered Model

Analysis performed using two codes i.e IS 800 (working stress method) for column and Built Up Box Beam and IS-801 for trussless roof Sections. Results of typical members are listed below for references. ISMB 600 are passing for columns, whereas Builtup Box sections of 300x300x8 mm are passing as continuous beams . 1.8mm thick trussless members are passing as per IS 801-code.



STAAD.PRO CODE CHECKING - ( IS-800:1984) v1.1

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IS-800 *					=====	SY =	875.3
				0.63>		SZ = RY =	875.3
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PARAMETER IN NEWT MM	51.9  L1		0			STRES	
IN NEWT MM		L107 L107L	107			IN M	NEWT MM
KL/R-Y= 63		110/1	L107	7		FA =	119.0
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To identify the actual stresses and to find correlation between the staad model and actual site practices, FEM model of the same building has been performed on staad itself. For ease of calculation, columns and continuous beams have been excluded from the scope of FEM. FEM Method is a powerful technique originally developed for numerical solution of complex structural mechanics problems [16]. The FEM method also helps to analyze the behavior of seamed joints, which is difficult to understand in other conventional calculations.

In finite element analysis, Structural system is modelled by a set of finite elements modelled by nodes interconnected.

Methods of FEM in staad are as per below steps:

- Node Modeling as per shape of structures as shown in Fig no. 7 &7a
- Generate mesh as per Quadrilateral meshing of appropriate sizes.
- Supports definitions
- Plate properties , thickness, grades and material types for all plates
- Loadings & Load Combinations
- Result analysis as shown in fig. no.9



Fig No. 7a Rendered Model



Loads and load combinations can be applied the same as per codal methods, however one can also check for critical Combinations. There is no need to define any codes or design parameters in staad for FEM. Post analysis one can review various type of stresses as listed below:

- Max Absolute
- Tau Max
- Von Mis
- Max tresca
- Global Moment
- Global Stress
- Base pressures
- Sx
- Sy



Fig.No. 9 Absolute Stress Results

The other results like reactions, displacement can also be obtained for

every load case and combinations and results can be interpreted.

### 6. RESULTS & DISCUSSION

A span of 18m trussless roof on 4m steel column has been designed using Indian & American codes. The same has also been analysed by FEM methods. Section sizes received in all the three methods have already been given in above chapters. Various results have been summarized in this chapter.

Column Sizes	ISMB600
Continuous Beam	Built Up Box
Size	300x300x8mm
Trussless Sheet thickness	IS 801 (Staad) - 1.8mm RSG CFC - 0.8mm FEM method- 0.8mm
Maximum vertical	36mm- ( Dead +
Deflections	Live + Wind load )
Maximum	Vertical
Reactions ( for	Downward
Connection design	Forces= 5.2Kn
of trussless with	Horizontal Force=
Continuous	4.145Kn
members )	Uplift= -7.2Kn
Maximum reaction for Foundation Design	Vertical Reaction = 99.Kn Horizontal reaction = 89.35Kn

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Moment= 352.3knm

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