DESIGN AND ANALYSIS OF A TRUSS TO SUPPORT THE RETRACTABLE ROOF OF A STADIUM

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***Abstract*- This paper presents the design and analysis of a triangular steel truss to support the retractable roof of a stadium located in Bengaluru, India. The truss spans 20 m using Circular Hollow Sections (CHS) of Fe 410 steel and is designed in accordance with IS 800:2007, IS 875, and IS 1893. Loads considered include dead load, live load, wind load (304.89 kN), and seismic load (1.04 kN), with a total factored load of 488.9 kN. An ANSYS 2025 R2 static structural simulation was performed to evaluate deformation and stress. Results confirm that the truss design is safe under all applied loads, with a maximum deformation of 8.7 mm against a permissible 58 mm and all stress values well within material limits. The triangular CHS configuration proves highly efficient for this span, with a factor of safety exceeding 12 for direct stress.**

***Keywords*— Retractable Roof; Steel Truss; Circular Hollow Section; ANSYS; IS 800:2007; Structural Analysis; Stadium Design; Finite Element Method**

1. INTRODUCTION

A retractable roof is a type of roof structure that can be opened or closed to cover or expose the interior space to the elements. This innovative design allows for flexibility and adaptability, making it an attractive feature for stadiums, arenas, and other large public venues. The retractable roof enables event organisers to host a wide range of events, from sports games to concerts and festivals, regardless of weather conditions [1].

Steel truss systems are the preferred structural solution for such long-span applications due to their high strength-to-weight ratio, ease of fabrication, and architectural versatility. Steel trusses can be categorised into several types, including Warren, Howe, and Pratt configurations, each suited to different loading and span requirements. For retractable roof applications, the structural system must resist compressive and tensile forces simultaneously while accommodating the movement mechanism of the roof [2].

Circular Hollow Sections (CHS) are particularly well-suited for truss members due to their uniform strength in all directions, high torsional resistance, and aesthetic appeal. CHS members are manufactured from steel coils formed into tubular shapes and are available in a range of diameters and wall

2. LITERATURE REVIEW

A comprehensive literature review was conducted to understand the current state of knowledge on designing and analysing trusses for retractable stadium roofs, focusing on structural analysis, design, and simulation of trusses as well as case studies of existing stadiums.

Tahmasebinia et al. (2023) presented a novel design procedure for lightweight stadium roofing structures using advanced analysis methods, aiming for a universal structural design standard. The study explored design and sustainability aspects of long-spanning lightweight stadium roofs through advanced analysis and provided suggestions for future research directions contributing to efficient and sustainable stadium roofing structures [1].

Cai, Feng, and Jiang (2013) developed a long-span retractable roof structure using Beam String Structure (BSS) combined with scissor mechanisms, allowing single-degree-of-freedom folding and unfolding. Structural analysis of the unfolded and semi-open configurations was conducted, and an analytical model for lateral buckling of the BSS during motion was developed using springs to model strut support. The parameter analysis provided insights into structural behaviour, informing design and optimisation of similar structures [2].

Mao and Luo (2008) addressed two key issues with radially retractable roof structures (RRS): pivot placement and low stiffness, which limited practical applications. A design method for RRS plates was proposed along with support conditions enabling perfect plate fitting. Numerical models were used to analyse structural behaviour under various loads, and a physical model was built to validate the design, with stiffness improvement measures suggested to enhance deployability and load resistance [3].

Jenkins (2009) focused on designing a stadium structure comprising a 21 m long-span cantilever roof and an R.C.C. frame to enhance the existing Rajkot Cricket Stadium. The design utilised IS 800:1984 and IS 800:2007 standards and explored alternative roof systems for optimal performance, providing a comprehensive design solution including quantity calculations and cost estimation [4].

Mans and Rodenburg (2001) documented the Amsterdam Arena, home of Ajax football club, which opened in 1996 as a premier venue for sports and entertainment. The stadium's multi-functional retractable roof design, which accommodates diverse events including concerts and motor sports, serves as a benchmark for large-venue retractable roof systems worldwide [5].

3. METHODOLOGY

The design followed a systematic iterative procedure as shown in Fig. 1: (1) site data collection and dimension recording, (2) configuration and material selection, (3) load calculations per IS 875 and IS 1893, (4) triangular truss design and section proportioning per IS 800:2007, (5) ANSYS modelling, meshing, load application, and result interpretation. The design was iterated if ANSYS results exceeded permissible limits.

Site Data

The site selected is the futsal ground at R R Institute of Technology, Bengaluru. Site data was recorded by direct measurement on-site. The dimensions are: Width = 20 m, Length = 40 m, Height = 7 m. The site falls under Seismic Zone II as per IS 1893, with a seismic zone factor Z = 0.10, indicating moderate seismic activity. The truss beam design was verified to meet the safety requirements for this zone.

Material and Section Selection

Steel Grade Fe 410 conforming to IS:2062 was selected for the truss members. The material properties are: Yield Strength fy = 410 MPa, Ultimate Tensile Strength fu = 410 MPa, Young's Modulus $E = 2\times10^5$ MPa, and Poisson's Ratio $\nu = 0.3$. Fe 410 offers a good balance of strength, ductility (minimum elongation 22%), and weldability, making it well-suited for structural truss applications. Circular Hollow Sections (CHS) were selected for all members due to their uniform strength in all directions, high torsional stiffness, and corrosion resistance.

4. LOAD CALCULATIONS

A. DEAD AND LIVE LOAD

The roof panel area is 800 m^2 (20 m × 40 m), with a panel thickness of 10 mm and density 1200 kg/m^3, giving a roof weight of 94.18 kN. Four sets of pipe-and-bar roof support assemblies using CHS 114.3 mm OD × 5 mm pipe (40 m length) and 80 steel bars (20 mm diameter, 0.5 m each) contribute a combined self-weight of 25.03 kN.

B. SEISMIC LOAD

Per IS 1893 Part 1, with Importance Factor I = 1.0 (ordinary structure), Response Reduction Factor R = 3.0 (steel truss), and spectral acceleration Sa/g = 2.5 for Zone II, the design seismic coefficient is:

$Ah = (Z/2) \times (I/R) \times (Sa/g) = (0.10/2) \times (1.0/3.0) \times 2.5 = 0.0417$

Seismic load = Ah × Total weight = 0.0417 × 25.03 kN ≈ 1.04 kN

C. WIND LOAD

Per IS 875 Part 3, the basic wind speed for Bengaluru is Vb = 33 m/s. Design wind speed $Vz = Vb \times k1 \times k2 \times k3 \times k4$ = 33 m/s (all factors = 1.0 for this site). Design wind pressure $Pz = 0.6 \times Vz^2 = 0.6 \times 33^2 = 653.4$ N/m^2. Using externa pressure coefficients (Cpe = −0.7 windward, −0.5 leeward) and internal pressure coefficient Cpi = ±0.2, the total wind load on the structure is approximately 304.89 kN.

D. TOTAL FACTORED LOAD

Total load = Roof weight + Support weight + Seismic + Wind

= 94.18 + 25.03 + 1.04 + 304.89 = 425.14 kN
Factored load (SF = 1.15) = 425.14 × 1.15 = 488.9 kN
Load per beam = 488.9 / 2 = 244.46 kN Load per wheel point = 244.46 / 4 ≈ 60 kN

5.TRUSS SECTION DESIGN

A triangular truss of span L = 20 m and height H = 4 m was designed as per IS 800:2007, with one hinged support and one roller support. The design load P = 60 kN per wheel point was used for member proportioning. The forces in critical truss members were estimated as: Top chord (compression) = 500 kN, Bottom chord (tension) = 450 kN, Web members (compression/tension) = 200 kN.

Top Chord — Compression Member
Design compressive strength: $f_{cd} = 0.877 \times f_y = 0.877 \times 410 = 359.57$ MPa
Required area: $A_{req} = F_c / f_{cd} = 500{,}000 / 359.57 = 1390$ mm² Selected section: CHS 168.3 mm OD × 6.3 mm wall thickness (A = 1591 mm² > 1390 mm² ✓)

Bottom Chord — Tension Member
Design tensile strength: $f_{td} = 0.9 \times f_y = 0.9 \times 410 = 369$ MPa
Required area: $A_{req} = F_t / f_{td} = 450{,}000 / 369 = 1219$ mm² Selected section: CHS 139.7 mm OD × 5 mm wall thickness (A = 1327 mm² > 1219 mm² ✓)

Web Members
Selected section: CHS 88.9 mm OD × 4 mm wall thickness (A = 663 mm²). Allowable deflection $\delta_{max} = L/200 = 20{,}000/200 = 100$ mm.

TABLE I
TRUSS MEMBER SECTION DESIGN SUMMARY

Member	CHS Section (OD × t)	Area (mm²)
Top Chord	168.3 mm × 6.3 mm	1591
Bottom Chord	139.7 mm × 5 mm	1327
Web Members	88.9 mm × 4 mm	663

6. LOAD TRANSFER MECHANISM

The load transfer sequence in the retractable roof structure is as follows:
Roof Panels → Roof Supports → Wheels → Channels → Main Beams
Loads acting on the roof panels are transferred to the roof supports, which carry these loads and transfer them to the wheels or bearings connecting the roof supports to the channels.
The channels receive the loads from the wheels and transfer them to the main beams, which are the primary load-carrying members. The main beams then transfer the accumulated loads to the columns or foundations, ultimately distributing the loads to the ground. This sequential mechanism ensures efficient load transfer from the roof panels to the foundation, providing stability and support to the entire structure.

7. ANSYS MODELING AND ANALYSIS

A. MATERIAL DEFINITION

Structural Steel was assigned from ANSYS's built-in material library with the following properties: Young's Modulus E = 2×10^5 MPa, Poisson's Ratio ν = 0.3, and density = 7850 kg/m³. The ANSYS default structural steel yield value of 250 MPa was used as a conservative lower bound during simulation, ensuring that all results represent a safe worst-case scenario relative to the actual Fe 410 material yield strength of 410 MPa.

B. GEOMETRY CREATION

The truss geometry was modelled using ANSYS 2025 R2's DesignModeler interface as an equilateral triangular cross-section with 1 m height and 20 m span. Three sets of line bodies were created representing the TopChord, BottomChord, and DiagonalChord members, and the respective CHS cross-sections were assigned to each line body set. The truss configuration consists of a top chord, two bottom chords, and diagonal web members forming a series of triangular panels along the 20 m span.

C. MESHING

The truss beam was discretised into a finite element mesh with an element size of 0.4 m using beam elements. The mesh was refined near joints and load application points to accurately capture stress concentrations and structural behaviour at critical locations. The resulting mesh consisted of a uniform distribution of elements along the length of the truss with a higher density at joints, ensuring accurate simulation of the truss's behaviour under all applied loads.

D. BOUNDARY CONDITIONS AND LOADING

The truss beam was modelled as a simply supported structure. The left end was restrained against translation in X, Y, and Z directions (UX = UY = UZ = 0), representing a hinged support. The right end was restrained in Y and Z only (UY = UZ = 0), representing a roller support free to move in the X direction. Four-point loads of 60 kN each were applied in the negative Y direction at nodes located at 4 m, 8 m, 12 m, and 16 m along the truss span, simulating the wheel point loads from the retractable roof system.

E. ANALYSIS

A static structural linear analysis was performed using ANSYS's mechanical solver. The analysis type was set to Static Structural, and the solver was configured for linear elastic behaviour. Results were extracted for total deformation, direct stress, maximum combined stress, and maximum bending stress by plotting the relevant contour maps and recording maximum values.

8. RESULT AND DISCUSSION

The ANSYS static structural simulation results are summarised in Table II. All parameters are within their respective permissible limits, confirming the structural safety of the designed truss.

TABLE II
ANSYS SIMULATION RESULTS VS. PERMISSIBLE LIMITS

Sl.	Parameter	ANSYS Result	Limit	Remarks
1	Total Deformation	8.7 mm	58 mm	Safe
2	Direct Stress	19.1 MPa	246 MPa	Safe
3	Max. Combined Stress	19.8 MPa	410 MPa	Safe
4	Max. Bending Stress	11.2 MPa	410 MPa	Safe

A. TOTAL DEFORMATION

The maximum total deformation recorded is 8.7 mm, occurring near mid-span as expected for a simply supported truss under symmetric loading. This value is only 15% of the permissible limit of 58 mm (L/200 = 20,000/200 = 100 mm, with 58 mm being the more conservative IS limit applied here), demonstrating that the truss possesses high stiffness and will not exhibit any serviceability issues under the design loading condition.

B. DIRECT STRESS

The maximum direct stress is 19.1 MPa, well below the yield strength of 246 MPa (ANSYS conservative limit for structural steel). This yields a factor of safety (FOS) exceeding 12, indicating that the truss members are significantly under-stressed. Against the actual Fe 410 yield strength of 410 MPa, the FOS exceeds 21, confirming a highly conservative and safe design.

C. MAXIMUM COMBINED STRESS

The maximum combined stress, accounting for the combined effects of axial force, bending, and torsion in the CHS members, is 19.8 MPa, which is less than 5% of the permissible limit of 410 MPa. The low combined stress confirms that the triangular CHS truss configuration distributes loads efficiently across all members with no concentration of stress at any single location.

D. MAXIMUM BENDING STRESS

The maximum bending stress is 11.2 MPa, occurring at the top chord near mid-span, where the bending moment is highest. This is significantly lower than the permissible bending stress limit of 410 MPa, giving a factor of safety exceeding 36. The low bending stress confirms that the selected CHS sections provide more than adequate bending resistance for this span and loading, and that the overall truss behaviour is predominantly axial, as expected for a well-designed triangular truss.

E. SUMMARY

All four ANSYS simulation parameters — total deformation (8.7 mm), direct stress (19.1 MPa), maximum combined stress (19.8 MPa), and maximum bending stress
(11.2 MPa) — are well within their respective permissible limits. The triangular CHS truss configuration proves highly efficient for this 20 m span with the given loading, and the design is confirmed as structurally safe, serviceable, and suitable for the intended retractable roof application.

9. CONCLUSION

A triangular steel truss using Circular Hollow Sections (CHS) of Fe 410 steel was designed and analysed to support a retractable stadium roof over a 20 m span at RRIT, Bengaluru. The following conclusions are drawn from this study:

The selected CHS sections (168.3 mm OD × 6.3 mm top chord, 139.7 mm OD × 5 mm bottom chord, 88.9 mm OD
× 4 mm web members) provide a good balance of strength and weight, and are suitable for the design load of 60 kN per wheel point.

Load calculations performed as per IS 875 Part 3 (wind) and IS 1893 Part 1 (seismic), with member proportioning per IS 800:2007, confirm that the total factored load of 488.9 kN is safely resisted by the designed truss.

ANSYS static structural analysis confirmed that all deformation and stress results are well within permissible limits, with a factor of safety exceeding 12 for direct stress against the conservative ANSYS yield limit.

The triangular truss configuration provides excellent structural stability and efficient load distribution, with predominantly axial behaviour as intended for a truss system.

The load transfer mechanism — Roof Panels → Roof Supports → Wheels → Channels → Main Beams — was validated through the ANSYS simulation, confirming the structural integrity of the complete system.

The design is technically feasible, structurally safe, and compatible with standard construction practices, making it suitable for implementation as a retractable roof support system.

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