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Modeling and Analysis of Retractable Roofs

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Abstract

This study presents the detailed analysis of retractable roofs. The roof works on a principle similar to a folding fabric concertina - with metal ribs or "trusses" supporting a translucent industrial fabric. Optimal design of a retractable roof structure is utmost importance because it requires a very large area and consumes more material for its construction. In this study, various loads is taken into consideration
followed by designing of roof truss and carrying out the analysis in Staad pro and modeling it. The analysis resulted that end beam of retractable roofs can withstand the moving action and external load applied on it.

Keywords: Analysis, design, modeling, roofing material, STAAD PRO, trusses

Introduction

Retractable roof structures in stadiums and sports halls can be defined as a type of roof structure, which can be completely or partly moved or folded in a short period of time so that the building can be used with an open or closed roof. A retractable roof structure is adopted to increase the revenue of a modern venues for which it can be used for multipurpose. Fundamental principles and rules for their design are found from increased number of sports arena and halls. The new possibilities for use of the building are rotation, sliding, folding and lifting. Various mechanisms are carried out to open or close the rigid roof structure and membranes which are few hundred of tones within few minutes.

Structural design and technology of movement in modern retractable roof structures are based on the application of structural systems of movement and their components. The design and analysis comprises of 4 different closing cases i.e., 25%, 50%, 75%, and 100% closing
conditions.

Objectives and Methodology

- The analysis of Retractable roofs is carried out using staad pro software to determine the total stresses at the end beam in the retractable roofs and to check whether roof is safe for applied load manually.

The methodology followed is:
- Modeling of truss
- Calculation of loads and its application
- Analysis and design of the truss and end beam using "STAAD PRO" software

Calculation of Loads and its Application

The loads which are acting on the roof are
1. Dead load (using IS 875 part 1)
2. Live load (using IS 875 part 2)
3. Wind load (using IS 875 part 3)
4. Impact load / kinematic load

Preliminary calculations:

Span= 70m & Spacing of each truss= 5m c/c
Rise of truss= 4m & Height of truss above ground level= 16m
Teflon sheet is used as roof covering (fluoro polymer coated) weighing about 1080gm/m^2= 10.59N/m^2
Thickness= 0.55mm and light transmission= 19%&Total number of panels= 6
Assume weight of purlin and other fixtures= 60N/m^2 per plane area

- Angle of roof truss α :- 6˚30'
- Length of principle rafter (PR) :-35.22m
- Half plan area:-175m^2
- Half slope area:-176.1m^2

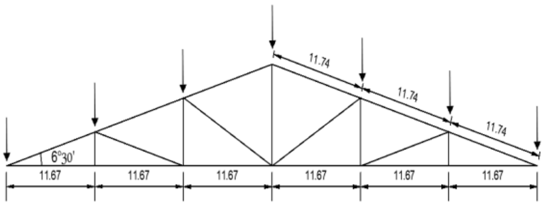

Fig1: Dimension of roof truss

Dead Load Calculations:

(As per IS: 875-1987 part I)

- Weight of roofing material{Teflon (PTFE)}:- 1866.66N
- Weight of purlins:-10500N
- Self-weight of roof truss:-49582.75N

Live Load Calculations:

(As per IS: 875-1987 part II)

For whole roof= 262.5 kN > 4.5 kN

Live Load on Full Panel Point (FPP) = 43.75 kN

Live Load of End panel Point (EPP) = 21.87 kN

Wind Load Calculations:

(As per IS: 875-1987 part III)

F = -291424.8181N = -291.42 kN

F_x = -291.42(cos 6˚30') = 289.54

F_y = -291.42(sin 6˚30') = 32.98

Impact Load Calculations:

For EOT (Electric overhead traveling) cranes: - 25% of the maximum static wheel load [4]

Table 1 Impact load [4]

Type of load		Impact allowance (percentage)
Vertical forces transferred to wheels		
a)	For EOT cranes	25% of the maximum static wheel load
b)	For hand-operated cranes	10% of the maximum static wheel load

Table 2 limiting deflection [5]

Category		Maximum deflection
Vertical deflection		
a)	Manually operated cranes	L/500
b)	EOT with a capacity of less than 500 kN	L/750

- Span of crane between rails = 70m
- Span of gantry girder = 10m
- Mass of rail section = 50kg/m
- Wheel base = 4m
- Height of rail section = 100mm

Load calculations:

Factored wheel load on each wheel (W_u) = 216.522 kN

3. Design of Truss and End Beam

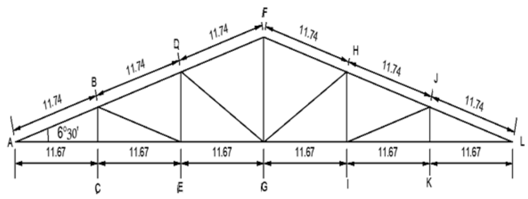

Fig 2: Nodal points

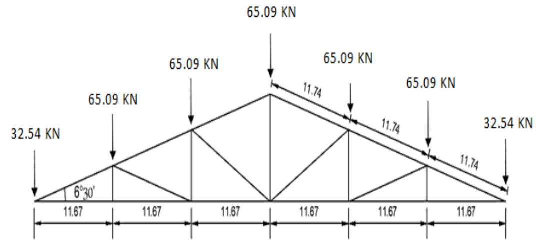

Fig 3: Dead + live loads

Dead load + Live load

Calculations of reactions:-

V_L=195.3114KN

V_A=195.218KN

From method of joints

Table 3: Forces in members representing half truss

Member	Forces in kN	Nature of force
AB	1434.846	Compression
AC	1425.594	Tension
BD	860.307	compression
CB	65.09	Tension
BE	574.549	compression
ED	130.130	Tension
DF	287.083	Compression
DG	584.226	Compression
FH	130.627	compression

Wind Load

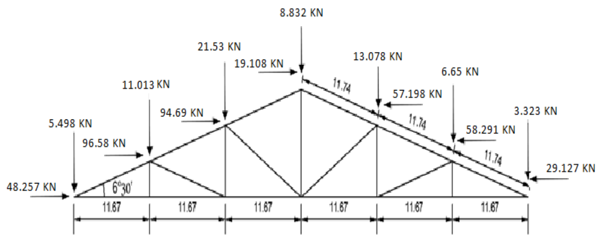

Fig 4: Wind Loads

Calculation of reactions

$\Sigma M_A=0$

$V_L=34.3106KN$

$V_A=35.7192KN$

$\Sigma H=0$

$H_A=113.9538+H_B$

From method of joints

Table 4: Forces in members representing full truss

Member	Forces in KN	Nature of force
AB	266.61	compression
AC	199.1939	tension
BD	218.001	compression
CB	11.013	compression
BE	145.73	tension
ED	38.1733	tension
DF	172	compression
DG	149.7477	compression
FH	182.748	compression
FG	12.14	compression
LJ	303.5592	compression
LK	18.893	tension
KL=KI	158.8931	tension
KJ	6.6518	tension
JH	297.65	compression
JI	54.23	compression
IH	18.61	tension
IG	104.94	tension
HG	171.49	compression

Design of Members

After the calculation of all the forces in the truss, member having maximum compression and tension values to be considered for design.

Hence after designing, 2 sections of ISA 200*200*25mm for compression members and 2 sections of ISA 150*150*20mm for tension members are considered. After the calculation of impact load or dynamic load the end beam of ISMB600 is considered.

Software Analysis

In this study, the end beam results and deflection of beam are calculated the analysis of retractable roofs are carried out in 4 different stages, i.e. -

- 25% closed
- 50% closed
- 75% closed
- 100% closed

The below figure represents the software for only one closed condition i.e., 25% closed case

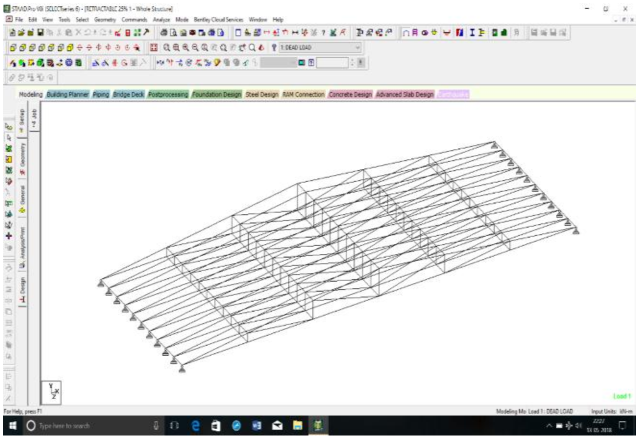

Fig 5: 25% closed

Results

1. Stress analysis of end beam value are calculated for different closing cases i.e., for 25%, 50%, 75% and 100% closing condition. The fig 6 shows only the end stresses for 25% closed for beam number 232.

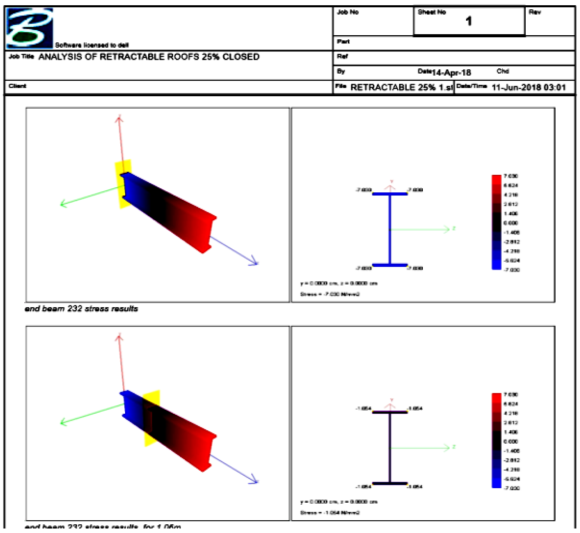

Fig 6: Stress analysis results for end beam no 232 for 25% closed conditions

2. After the application of dead load, live load, wind load and impact load on the roofs. **The end beam is safe** to take the above load for different moving condition, i.e., and 25%, 50%, 75% and 100% closing condition. The end beam did not fail and value are obtained i.e., STEEL DESIGN FOR END BEAMS FOR 25%, 50% 75% AND 100% respectively. Fig 7 gives the steel design value

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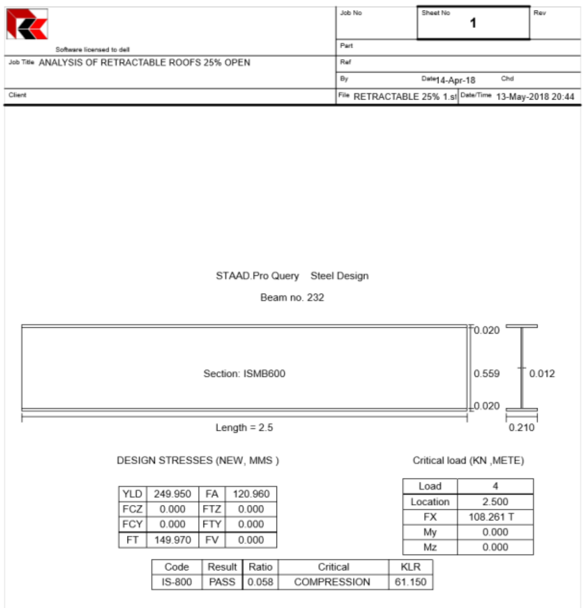


YLD	249.950	FA	120.960
FCZ	0.000	FTZ	0.000
FCY	0.000	FTY	0.000
FT	149.970	FV	0.000

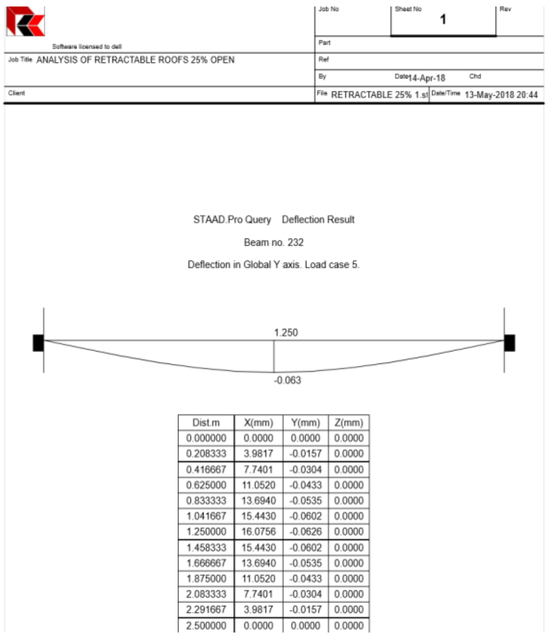
Load	4
Location	2.500
FX	108.261 T
My	0.000
Mz	0.000

Code	Result	Ratio	Critical	KLR
IS-800	PASS	0.058	COMPRESSION	61.150

Fig 7: Steel design for end beam no 232 for 25% closed condition

RESULT**: - Beam no 232 is PASSING**

3. Deflection value for different loads and opening cases on end beam are obtained fig 8 shows the deflection value for 25% closed condition for beam no 232



Dist.m	X(mm)	Y(mm)	Z(mm)
0.000000	0.0000	0.0000	0.0000
0.208333	3.9817	-0.0157	0.0000
0.416667	7.7401	-0.0304	0.0000
0.625000	11.0520	-0.0433	0.0000
0.833333	13.6940	-0.0535	0.0000
1.041667	15.4430	-0.0602	0.0000
1.250000	16.0756	-0.0626	0.0000
1.458333	15.4430	-0.0602	0.0000
1.666667	13.6940	-0.0535	0.0000
1.875000	11.0520	-0.0433	0.0000
2.083333	7.7401	-0.0304	0.0000
2.291667	3.9817	-0.0157	0.0000
2.500000	0.0000	0.0000	0.0000

Fig 8:- Deflection results for beam no 232 for 25% closed condition

RESULT**:-The deflection for beam no 232 for 25% closed condition is safe .i.e., the deflection values obtained are less than L/750 (as per Table 2) Hence safe**

- All 3 results are related to only 25% closed for beam no 232 and it is similar to different closed cases and similar to all other beams

Working Modeling of Retractable Roofs

Modeling of retractable roof for a scale of 3feet*3feet model is done in order to demonstrate the working and the movement of retractable roofs. In this working model the truss is fixed at one end and made free at another end for the movement of roof. Materials used for model making are,
Plywood sheet, Fabric material, Auto cut machine, Drilling machine, Motor, Remote, Dry cell, Metal rails, Wheels.

The modeling comprises of all the above components. The roof can move forward and backward, this can be achieved by implementing the drilling machine which is connected to power supply. The drilling machine is used for the movement. The connecting rod is fixed to the motor i.e., drilling machine on one end and other end connected to auto cut machine. From the help auto cut machine, the movement of roof stops automatically when it gets closer to other end i.e., when 100% closed situation. The ends of the roof are fixed with wheels and moves on the rail. Remote is used to operate the roof. The top part of the roof is covered with translucent material i.e., fabric material.

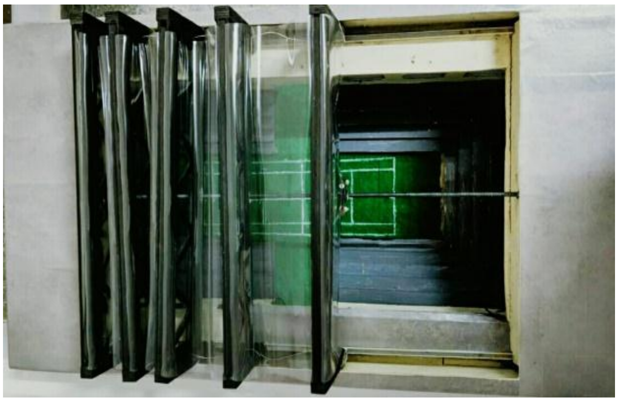


Fig 9:- Top view of retractable roof working model

Conclusions

Each roof itself weigh around hundred tones and after summing up all the 10 trusses it would weigh around 3000 to 4000 tones. All these loads along with live and wind load will be finally imparted on the end beams. The end beam should also take the moving action of the roof, which we have considered as the impact force on the beam, because of the sudden jerks applied on the end beam. So as result the end beam should be safe and sustainable to take all the different loads applied on it. The analysis of retractable roof is carried out in 4 different closing cases, to understand the moving action and loads generated in the end beam. All the result values shows the 25% closed condition only and for one beam (i.e., beam number 232 obtained from software), it is similar to different closing cases and similar to all the end beams.

1. From1st result i.e., fig. 6 gives the value of stress generated on the end beam.
2. From 2nd result i.e., fig. 7 gives the steel design value of the end beam and the end beam is safe and sustainable for the different loads applied and also for moving action.

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3. From 3rd result i.e., fig.8, shows the deflection value of the end beam and the deflected value is less than L/750, (Referring to table 2) hence from this reference the end beam is safe from deflection.

The prototype physical model of retractable roof demonstrates the movement of roof.

Hence, the END beams are safe & resistant to different load and moving condition, it is also safe from deflection and beam is economical.

The retractable roof structure is safe and economical for construction under different load cases compared to conventional roofs.

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