FINITE ELEMENT ANALYSIS OF GLAZED SURFACE

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Abstract- In the present work finite element analysis of a glazed surface of a structure is performed. Considering particular location, topography and terrain and considering glass panel of a particular type, size and thickness, analysis is performed for wind pressure and suction acting on the surface. Different cases are considered – (i) varying truss widths, (ii) varying cable position and (iii) varying number of cables.

The results of this work show that displacement, stress and weight of the steel of structure vary linearly with the variation in truss width. Displacement is found to be least for a certain range of truss width. Stresses decrease with increase in truss width and the weight of steel increases with increase in truss width. Having known this, one can choose economical and efficient steel supporting structure to support the glazing.

Keywords: Maximum major principal stress, maximum displacement, truss width, cable position.

1. INTRODUCTION

1.1 General

The present work is carried to study the effects of wind pressure on glass façade and the supporting steel frame. Here, analysis is carried out on structure models consisting of steel frame made up of truss, vertical columns, horizontal columns and cables and the glass façade. In the analysis different models are considered basically by varying (i) truss width (ii) number of cables (iii) position of cables. The finite element method (FEM) approach is adopted for modeling glass façade in the analysis. A wind analysis is performed on a structure subjected to a combination of dead and wind load. The structure is checked for deflection and stresses for various cases.

1.2 Software STAAD.PRO

STAAD.Pro provides a user friendly graphical user interface (GUI) to model, analyze, post process and design a structure. In the modeling STAAD.Pro V8i is used. It allows to assign material properties apart from default ones. STAAD input file helps edit commands easily. STAAD output file gives a detailed output that is easy to understand by anyone.

2. METHODOLOGY

2.1 Determination of Wind Pressure

<u>Given data</u>

Plan dimension:
Length = 75m
Width = 40m
Total height, h = 30.5m

Glass details:
Glass type - Annealed glass
Strength – 55N/mm^2
Panel size – 1.5mx4.2m
Thickness = 17.52mm

Other details:
Location – Mumbai, India
Basic wind speed, V_b = 44m/s
Terrain – Category 2, Class C

We Know That:
Modulus of elasticity for glass = 6-7 kN/m^2
Unit weight = 25 kN/m^3
Poisson's ratio = 0.2

2.1.1 Load Calculation

Dead load
Unit weight of glass = 25 kN/mm^3
DL = 1.5 x 4.2 x 0.1752 x 25
= 2.7594 kN/m

Wind Load
Knowing the location and terrain details, from IS: 875 (Part 3) - 1987 [16], coefficients are,
Probability factor (risk coefficient) $k_1 = 1.0$
Terrain, height and structure size factor $k_2 = 1.05$
Topography factor $k_3 = 1.0$

Design wind speed
$V_d = V_b \times k_1 \times k_2 \times k_3$
= 44 x 1 x 1.05 x 1
= 46.2 m/s

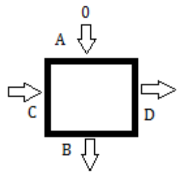
Design wind pressure
$P_z = 0.6 \times V_d^2$
= 0.6 x 46.2 x 46.2
= 1.28 kN/m^2

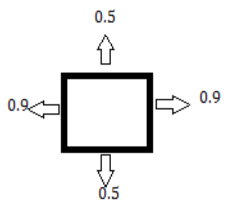
Net wind pressure is calculated using the formula,
$P_{net} = P_z \times (Cpe +/- Cpi)$
Where,
C_{pe} – external pressure coefficient (IS 875 part 3 tab le 4)
C_{pi} – internal pressure coefficient

To obtain C_{pe} from IS 875 part 3 we need, h/w and l/w ratios of the plan.
h/w = 0.7625
l/w = 1.875

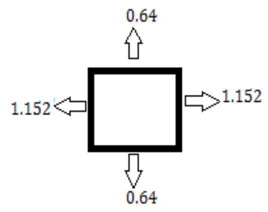
2.1.2 Resultant Pressure

1. Pressure Case
a. Z axis
For C_{pe} referring IS 875 part3 and C_{pi} = 0.2 (for 5% wall openings)





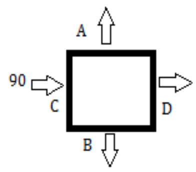
$(C_{pe}+C_{pi})$

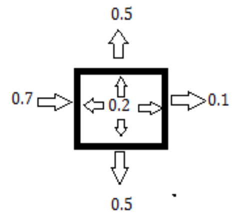


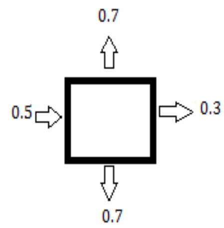
$P_z \times (C_{pe}+C_{pi})$

Fig-1: Pressure along z-axis

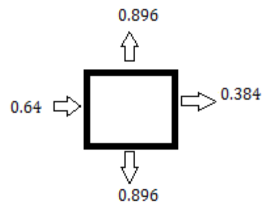
b. X axis







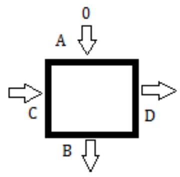
$(C_{pe}+C_{pi})$

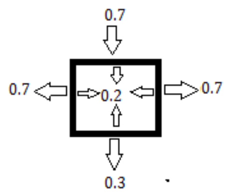


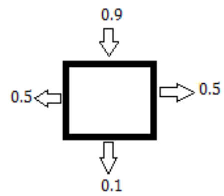
$P_z \times (C_{pe}+C_{pi})$

Fig-2: Pressure along x-axis

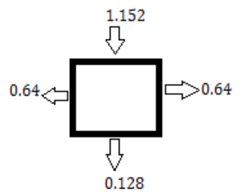
2. Suction Case
a. Z axis







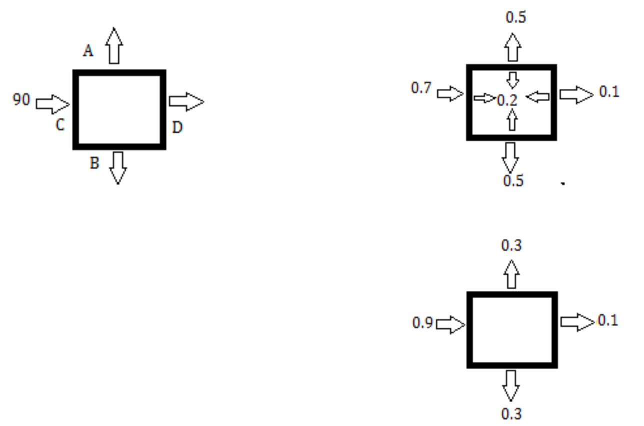
$(C_{pe}+C_{pi})$



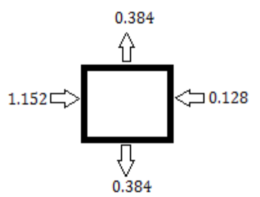
$P_z \times (C_{pe}+C_{pi})$

Fig-3: Suction along z-axis

b. X axis



$(C_{pe}+C_{pi})$



$P_z \times (C_{pe}+C_{pi})$

Fig-4: Suction along x-axis

Pressure = 0.896 kN/m^2
Suction = 1.152 kN/m^2

2.2 Modeling in STAAD.Pro

One of the objectives of model designing is to ensure it represents the characteristics of the structure. Many trials were made until a model was finalized. It consists of a combination of different types of members. It comprises of – (i) Steel frame, (ii) Glass façade and (iii) Connections.

2.2.1 Steel Frame

i.Truss

Height = 19.7m
Two parallel vertical members connected by short horizontal members.
Horizontal member width (varying) – 0.63m, 0.75m, 0.90m and 1.10m.
Vertical member – 1.05m
Sections used – Pipe Sections
Vertical members - 1651M Steel Pipe
Horizontal members – 889M Steel Pipe

ii. Vertical Columns

Height = 19.7m
Each member = 2.1m
Section used – Pipe
Section 1143M Steel Pipe

iii. Horizontal Supporting Members

Provided at 4 levels of height- 4.2m, 8.4m, 12.6m and 16.8m
Section used – Pipe section
1143M Steel Pipe
Length of each member = 1.5m

iv. Cables

Provided at varying levels of height –
(i) 2 down i.e. @ 2nd and 3rd level from top
(ii) 2 top i.e. @ 1st and 2nd level from top
(iii) 3 cables i.e. @ 1st, 2nd and 3rd level from top
(iv) Alternate 1 and 3 i.e. @ 1st and 3rd level from top
Section used – Solid Circular Steel section
Diameter = 0.01m
Initial tension assigned = 5 kN/m^2

2.2.2 Glass Façade

Designed as Plate member
Thickness = 17.52 mm
Rectangular meshing is done
Rectangular mesh of size 0.3mx0.3m each
Panel size – 1.5mx4.2m
Space between adjacent glass pane l- 2mm

2.2.3 Connections

Spider connections are adopted
4-armed and 2-armed spiders are used
4-armed spider is used at top and bottom ends of glass panels
2-armed spider is used at mid-height of the glass panels
Section used – Solid Circular Steel
section Diameter – 0.12m

4-armed spider:
2-arms are connecting top of the panel are assigned M_x, M_y, M_z releases.

2-arms connecting bottom of the spider are assigned F_y, M_x, M_y, M_z releases.

2- armed spider:
They are provided at mid-height of the panels.
Both the ends are released for F_y, M_x, M_y, M_z.

Connection arm between the spider and the steel frame
Section used – Solid Circular Steel section
Diameter = 0.12m

2.3 Supports

Four types of supports are used in the STAAD model-
(i) Pinned Support
(ii) Fixed but M_x released
(iii) Fixed but M_z released
(iv) Fixed but M_x & M_z released

2.4 Load Assigned in STAAD

i. Dead load
DL Selfweight
ii. Wind load
WPRE = -0.896 kN/m^2
WSUC = 1.152 kN/m^2
iii. Combinations
DL+0.75WPRE
DL+0.75WSUC
DL-0.75WPRE
DL-0.75WSUC

2.5 Analysis

After the model is designed and all the properties and loads are assigned, the file is saved and analysis is run. The results of analysis are obtained in post processing mode. The displacements at every node, reactions, stresses and steel take off etc are well produced in STAAD in an easy-to-understand manner. Graphs can be plot using MS Excel or any graph plotter to depict the trend of change in structure behavior under different conditions of loading and varying parameters.

2.6 Model

Table: 1- Models

Truss width in m	Cable position			
0.63	2 cables down	2 cables top	3 cables	Alternate cables @ 1 and 3 level
0.75	2 cables down	2 cables top	3 cables	Alternate cables @ 1 and 3 level
0.90	2 cables down	2 cables top	3 cables	Alternate cables @ 1 and 3 level
1.10	2 cables down	2 cables top	3 cables	Alternate cables @ 1 and 3 level

Considering an example model, with truss width 0.63m4 and 2 cables down at 2nd and 3rd levels.

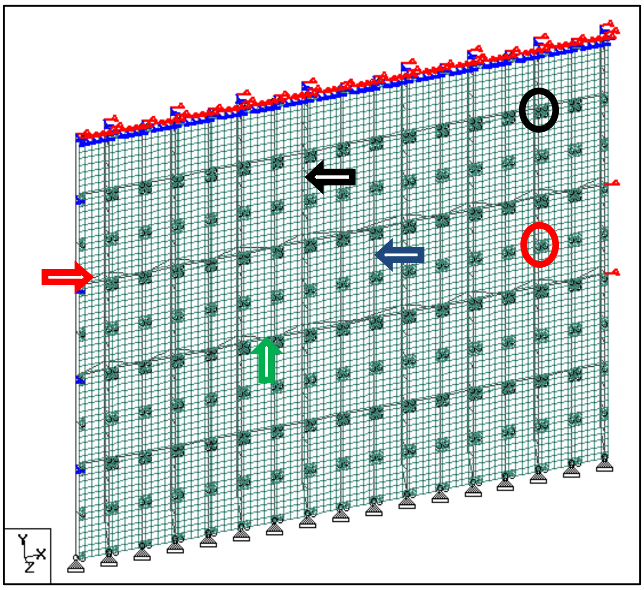


Fig-5: Model

In the fig-5

Indicates the truss, in the considered case width of which is 0.63m
Indicates the cables
Indicates the vertical column
Indicates the horizontal supporting member

Indicates the 4-armed spider connections
Indicates the 2-armed spider connections

Different views are shown as below from fig-6 to fig-9, however different cable positions are shown for other models from fig-10 to fig-12

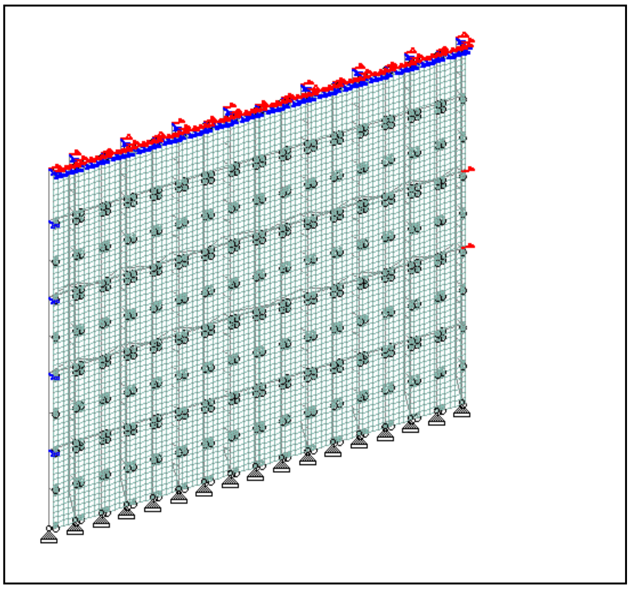


Fig-6: 2D front view

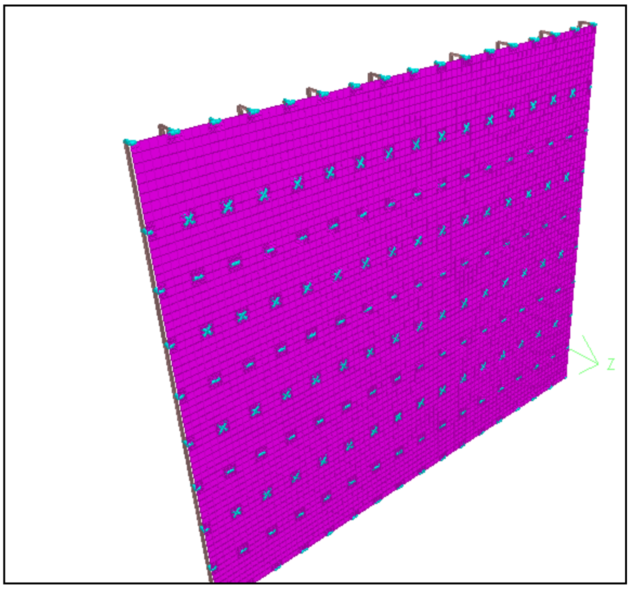


Fig-7: 3D front view

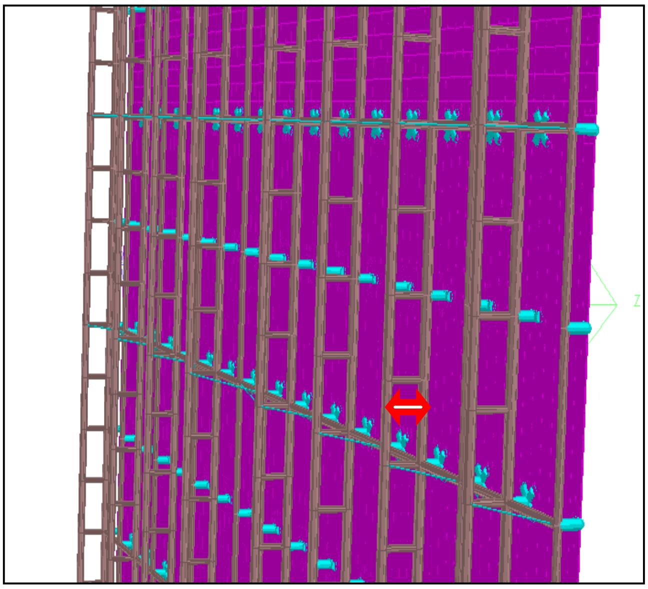


Fig-8: 3D back view indicating truss width

Indicates the truss width.
In this case truss width is 0.63m

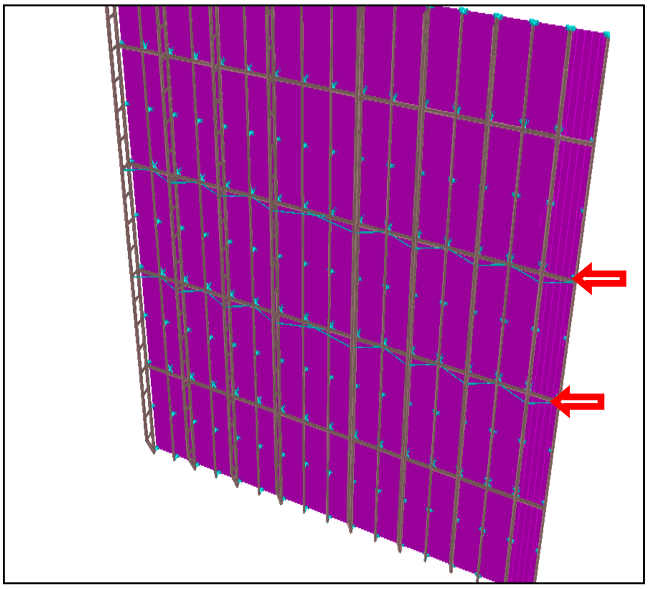


Fig-9: 3D back view indicating 2 cables down position

In this image the arrows point to the cables which are at 2nd and 3rd levels, as the name says 2 cables down.

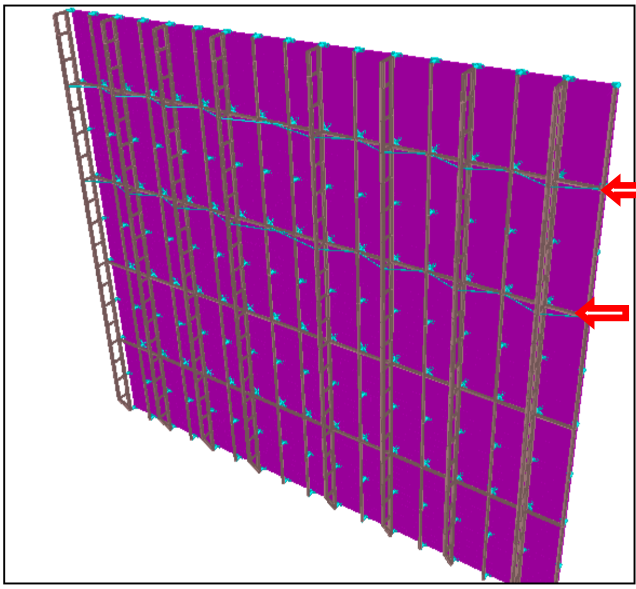


Fig-10: 3D back view indicating 2 cables top position

In this image the arrows point to the cables which are at 1st and 2nd levels, as the name says 2 cables top.

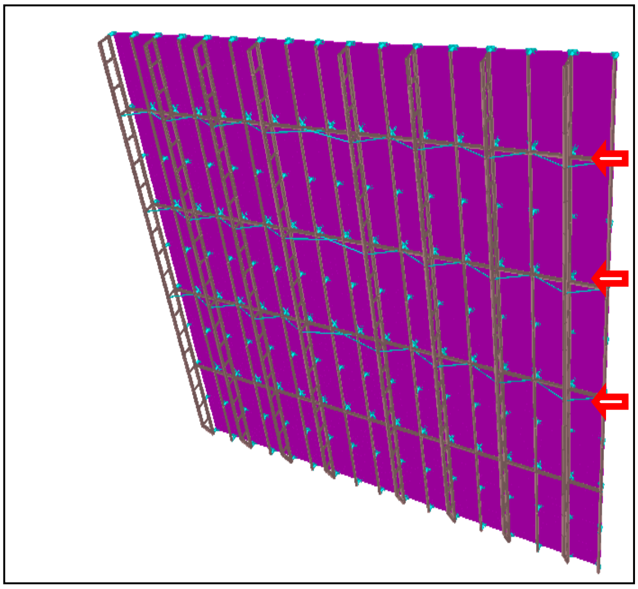


Fig-11: 3D back view indicating 3 cables position

The arrows point at the cables which are at the 1st, 2nd and 3rd levels, as the name says 3 cables.

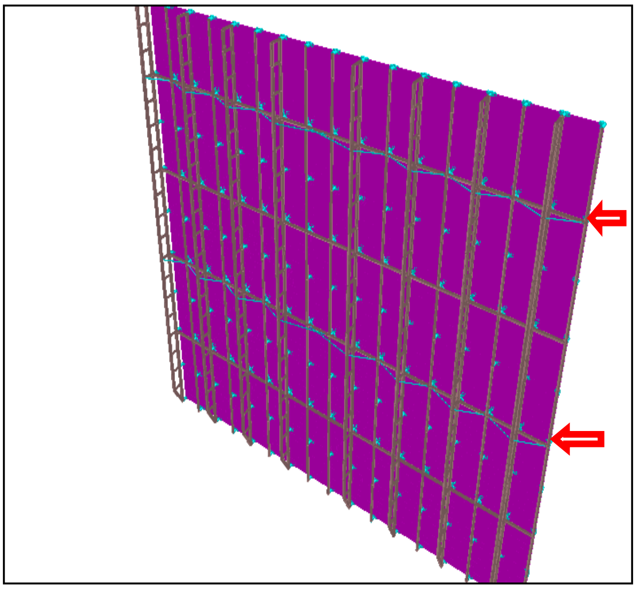


Fig-12: 3D back view indicating alternate 1 and 3 cables position

The arrows point at the cables which are at 1st & 3rd levels, as the name says alternate 1 n 3 levels.

3. STRESS DISTRIBUTION IN GLASS FAÇADE FOR VAROUS MODELS

3.1 0.63m truss

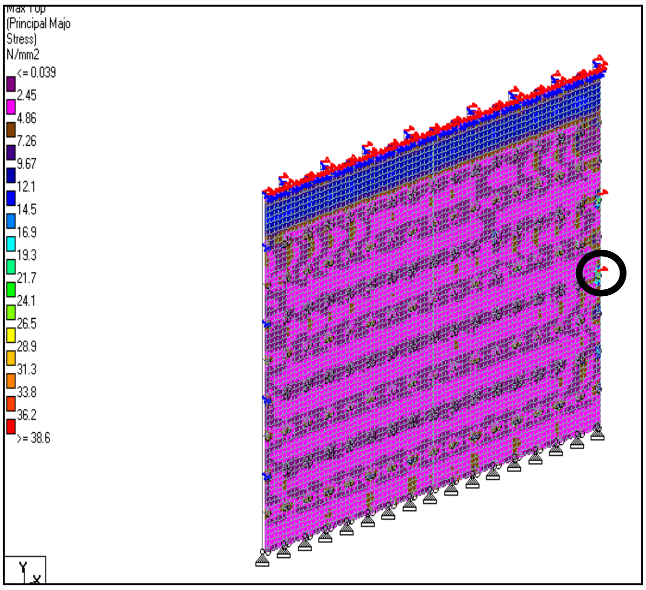


Fig-13: 2 cables down

Encircled region represents maximum stress.

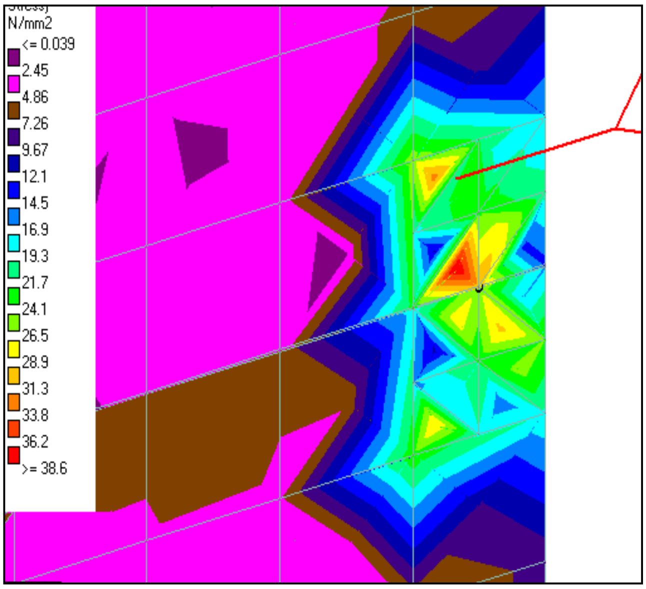


Fig-14: Closer view of encircled region showing stress distribution

Maximum major principal stress = 38.573 N/mm²

Similarly for other models stress distribution and maximum values of stress are shown in fig-15 to fig-29.

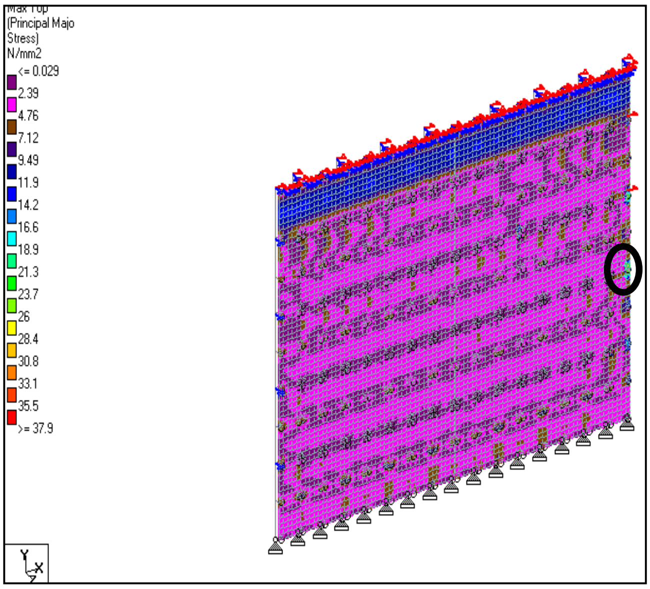


Fig-15: 2 cables top

Stress is found to be maximum in the encircled region, similar to the previous case.

Maximum major principal stress = 37.866 N/mm²

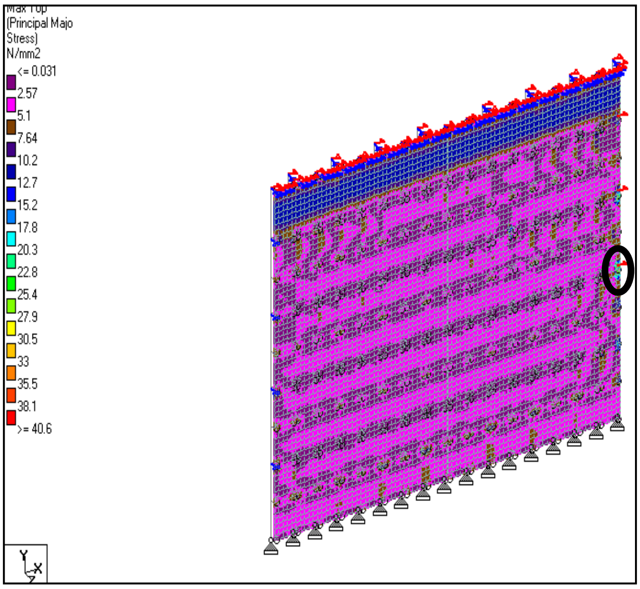


Fig-16: 3 cables

Maximum major principal stress = 40.599 N/mm²

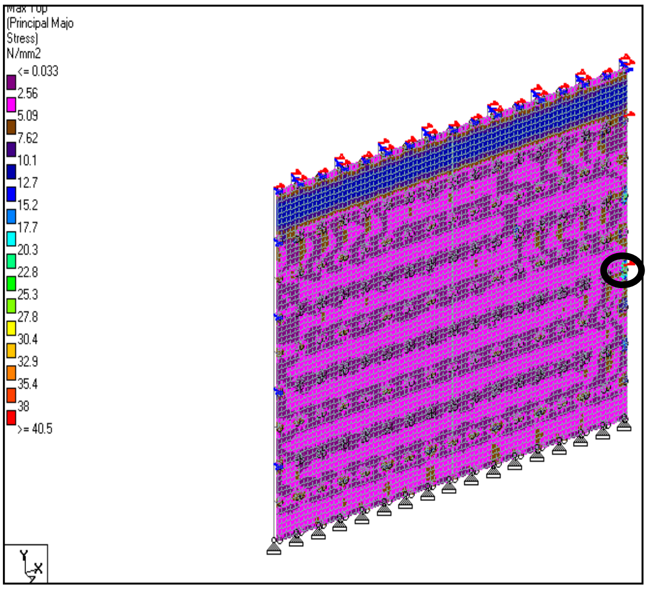


Fig-17: Alternate cables @ 1 & 3 level

Maximum major principal stress = 40.936 N/mm²

3.2 0.75m truss

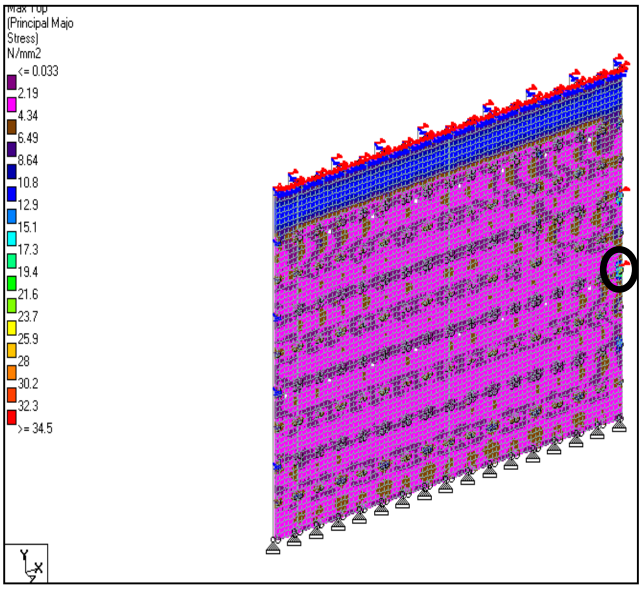


Fig-18: 2 cables down

Maximum major principal stress = 34.4691 N/mm²

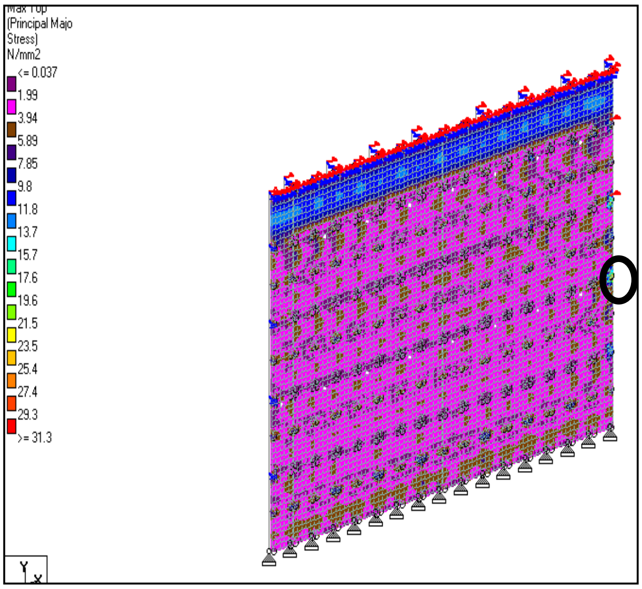


Fig-19: 2 cables top

Maximum major principal stress = 31.2794 N/mm²

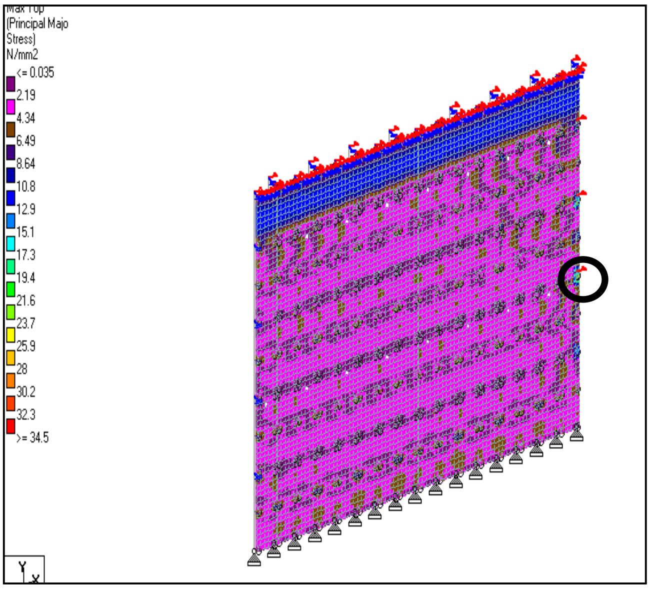


Fig-20: 3 cables

Maximum major principal stress = 34.4734 N/mm²

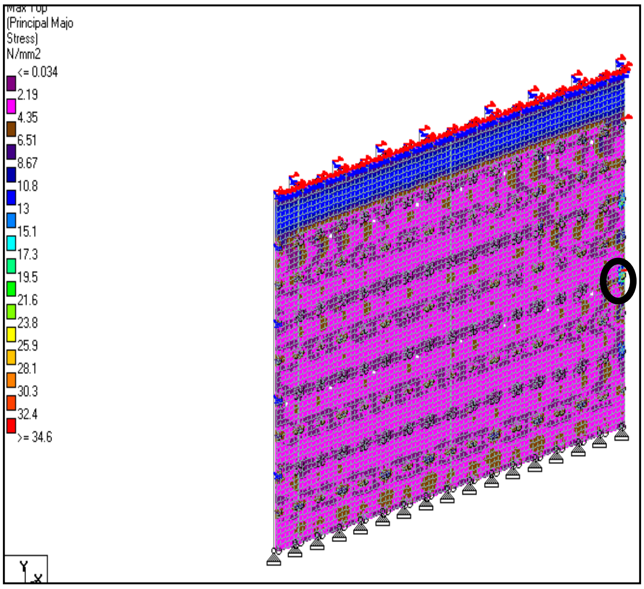


Fig-21: Alternate cables @ 1 & 3 levels

Maximum major principal stress = 34.5846 N/mm²

3.3 0.90m truss

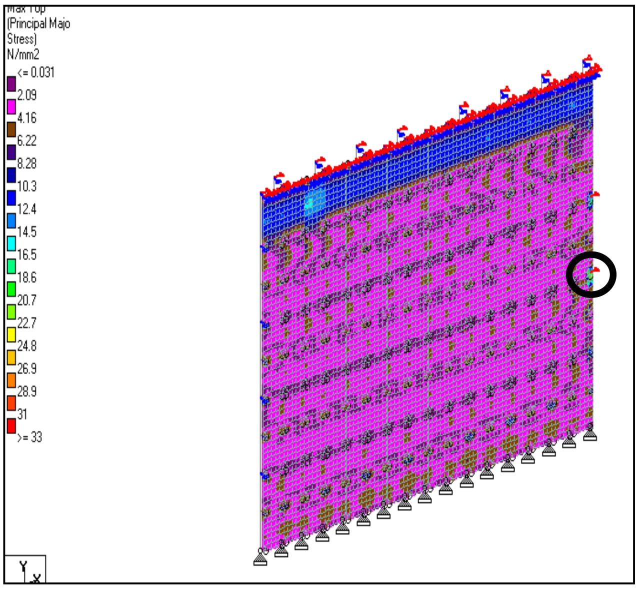


Fig-22: 2 cables down

Maximum major principal stress = 33.047 N/mm^2

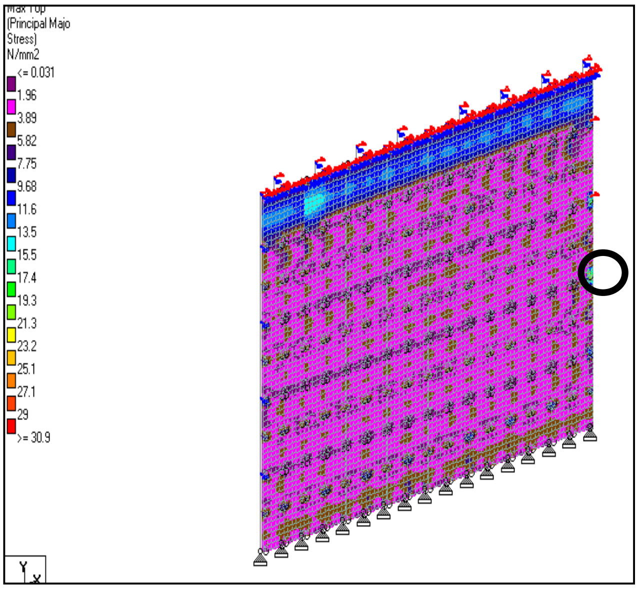


Fig-23: 2 cables top

Maximum major principal stress = 30.86 N/mm^2

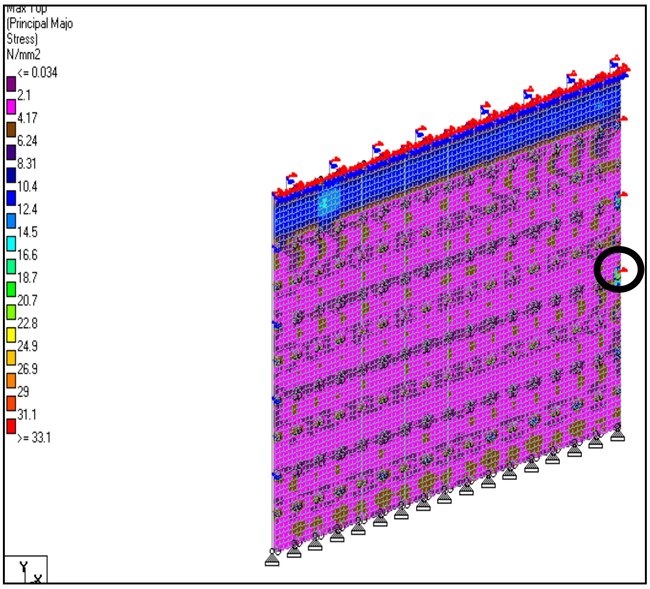


Fig-24: 3 cables

Maximum major principal stress = 33.139 N/mm^2

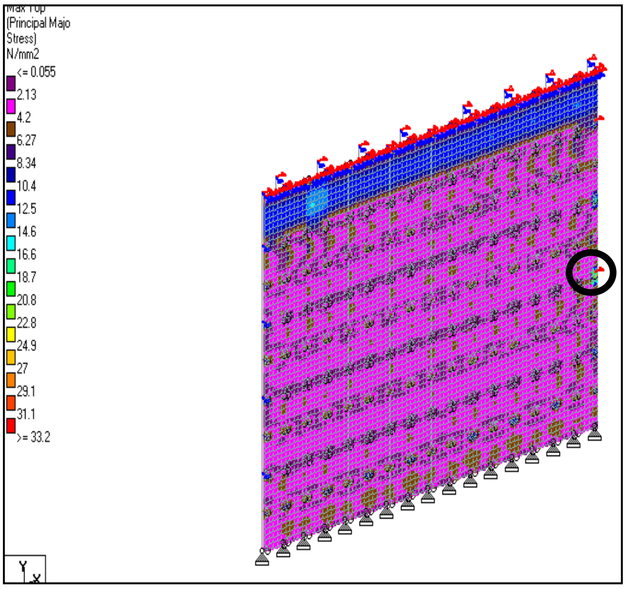


Fig-25: Alternate cables @ 1 & 3 levels

Maximum major principal stress = 33.2016 N/mm^2

3.4 1.10m truss

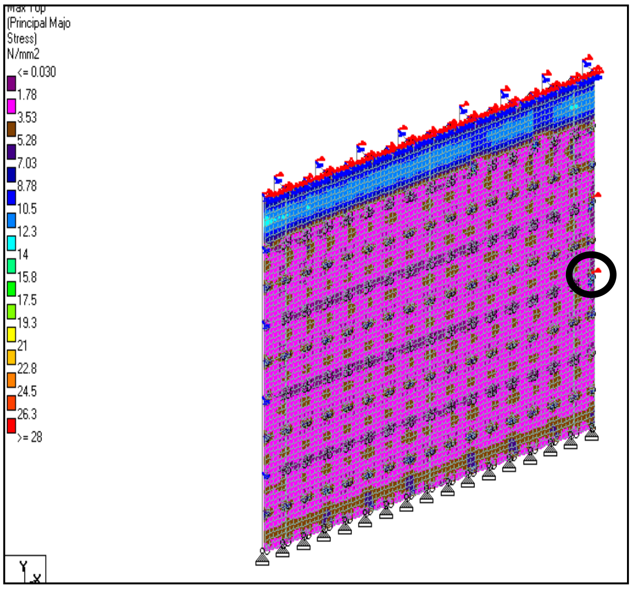


Fig-26: 2 cables down

Maximum major principal stress = 28.02 N/mm²

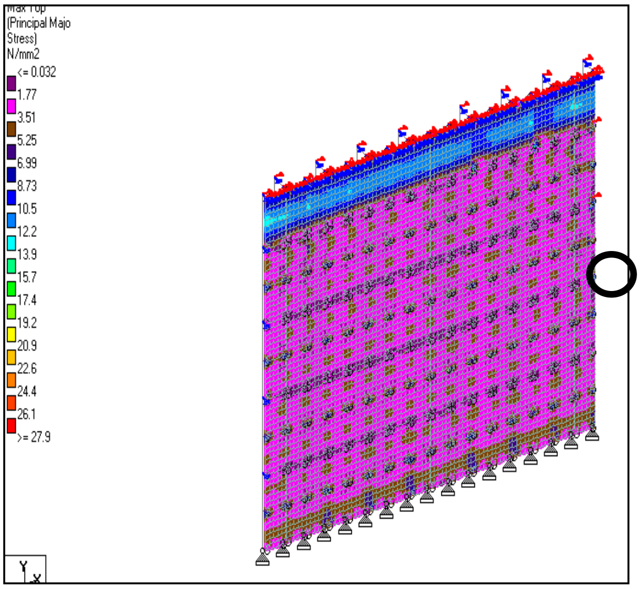


Fig-27: 2 cables top

Maximum major principal stress = 27.86N/mm²

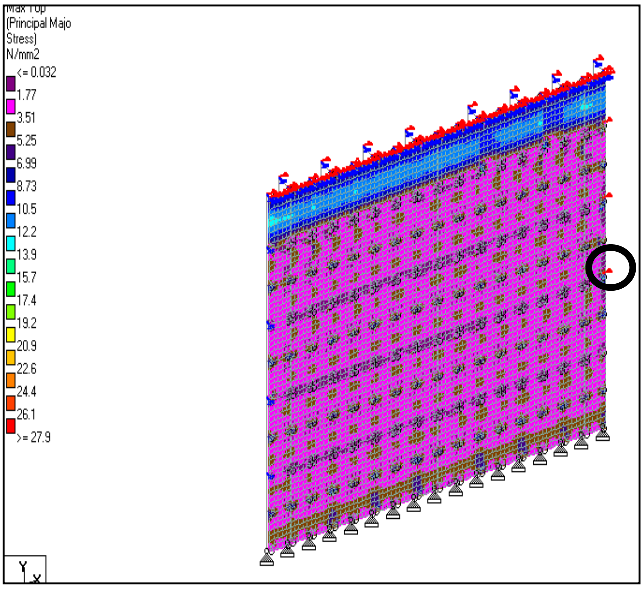


Fig-28: 3 cables

Maximum major principal stress = 27.855 N/mm²

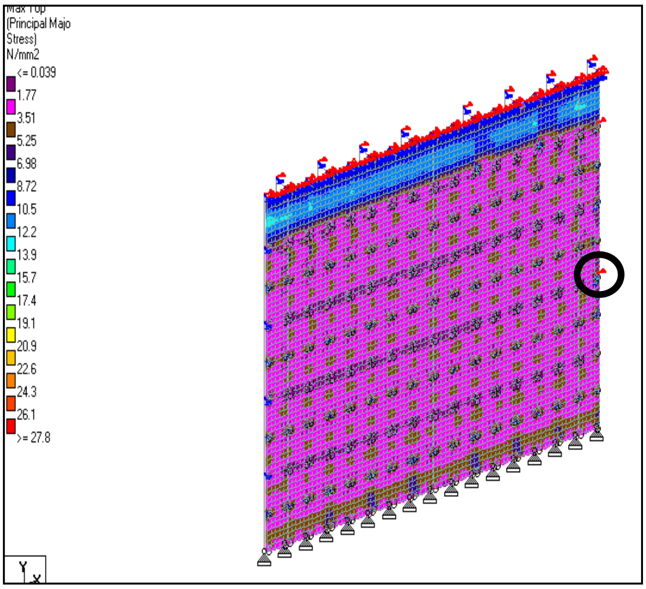


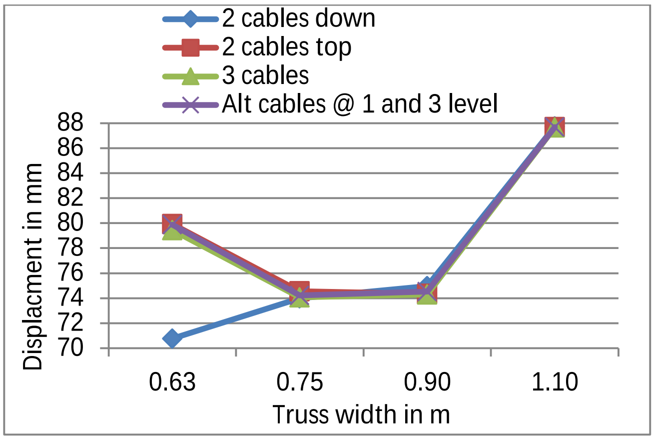
Fig-29: Alternate cables @ 1 & 3 levels

Maximum major principal stress = 27.8106N/mm²

4. TABLES AND GRAPHS

Table-2: Displacement (in mm) for various truss widths and corresponding cable positions

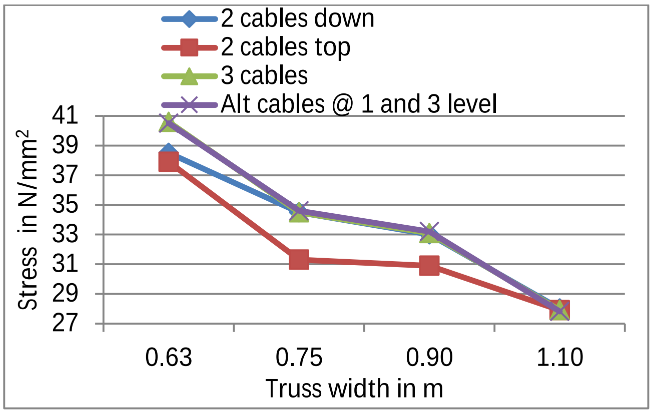
Cable position	Truss width in m			
	0.63	0.75	0.90	1.10
2 cables down	70.772	73.999	74.957	87.737
2 cables top	79.923	74.553	74.353	87.689
3 cables	79.445	74.062	74.306	87.654
Alt Cables @ 1 and 3 level	79.885	74.216	74.532	87.677



Graph-1: Displacement for various truss widths

Table-3: Stress (in N/mm²) for various truss widths and corresponding cable positions

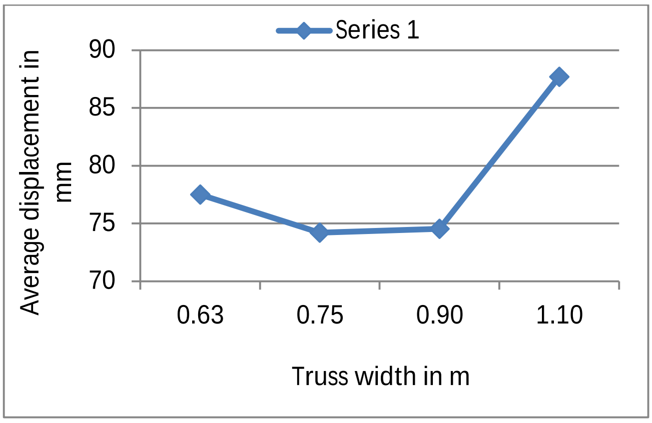
Cable position	Truss width in m			
	0.63	0.75	0.90	1.10
2 cables down	38.6	34.5	33.0	28.0
2 cables top	37.9	31.3	30.9	27.9
3 cables	40.6	34.5	33.1	27.9
Alt Cables @ 1 and 3 level	40.5	34.6	33.2	27.8



Graph-2: Stress for various truss widths

Table-4: Average displacement for various truss widths

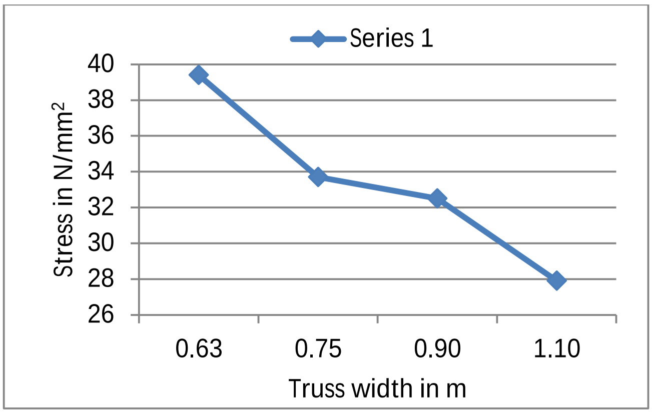
Truss width in m	Average displacement in mm
0.63	77.506
0.75	74.207
0.90	74.537
1.10	87.689



Graph-3: Average displacement for various truss widths

Table-5: Average stress for various truss widths

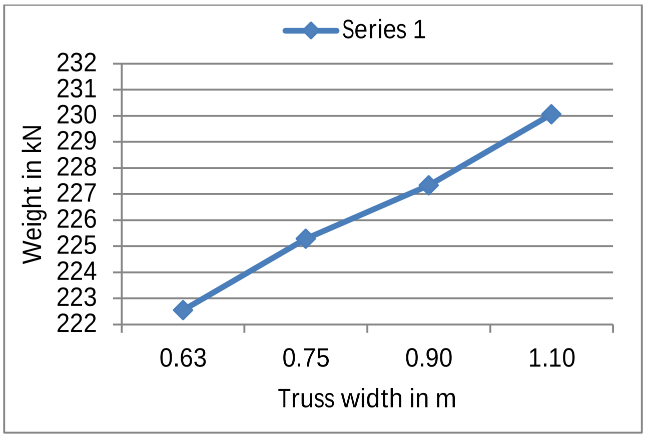
Truss width in m	Stress in N/mm²
0.63	39.4
0.75	33.7
0.90	32.5
1.10	27.9



Graph-4: Average stress for various truss widths

Table-6: Steel takeoff for various truss widths

Truss width in m	Weight in kN
0.63	222.550
0.75	225.290
0.90	227.328
1.10	230.059



Graph-5: Steel takeoff for various truss widths

5. OBSERVATIONS

5.1 Displacement

- It is seen that avg. displacement is less for 0.75m and 0.90m truss widths as compared to 0.63m and 1.10m truss widths.
- It is seen that for 0.63m truss least displacement is obtained for model with two cables, at 1st and 2nd levels.
- It is seen that for 0.75m truss least displacement is obtained for model with two cables, at 1st and 2nd levels.
- It is seen that for 0.90m truss the displacement is almost same with slight difference in decimal values. Amongst the four models, the one with 3 cables gives least displacement.
- It is seen that for 1.10m truss the displacement is almost same with slight difference in decimal values. Amongst the four models, the one with 3 cables gives the least displacement.
- When displacement for 2 cables down is plot for all truss widths, it can be seen that the displacement varies linearly. Displacement increases with increase in truss width.
- When displacement for 2 cables top is plot for all truss widths, it can be seen that displacement is least between truss widths 0.75m and 0.90m.Similar trend is observed for 3 cables and alternate 1 n 3 cables for all truss widths.

5.2 Stresses

- It is seen that maximum stress is least for 1.10m truss.
- Stress is seen to be decreasing with increase in truss width.
- It is seen that for 0.63m truss least stress is obtained for the model with two cables, at 1st and 2nd levels.
- It is seen that for 0.75m truss least stress is obtained for the model with two cables, at 1st and 2nd levels.
- It is seen that for 0.90m truss least stress is obtained for the model with two cables, at 1st and 2nd levels.
- It is seen that for 1.10m truss least stress is obtained for the model with two cables, at 1st and 3rd levels.
- When stress for 2 cables down is plot for all truss widths, it can be seen that stress decreases linearly with increase in truss width. Similar trend is observed for 2 cables top, 3 cables, and alternate 1 n 3 cables for all truss widths.

5.3 Steel takeoff

- It is seen that the weight of the steel increases with the increase in width of the truss.
- The difference in weight of the steel frames of different truss widths is in the range of 2-3 kN.

6. CONCLUSION

The average maximum stress obtained for model with 0.63m truss width is 39.4 N/mm^2 which is less than the yield strength of the glass used i.e. 55N/mm^2. The stress value is well within the limit. The model is said to be safe. Similarly, stresses for models with 0.75m, 0.90m and 1.10m truss widths are also well within the limits. The average displacement obtained for model with 0.63m truss width is 77.506mm which is less than 98mm (maximum allowable displacement for the structure). Similarly, displacements for models with 0.75m, 0.90m and 1.10m truss widths are also well within the limit. The graph of steel weight v/s truss width shows normal trend. The weight of steel increases with increase in truss width. Displacements for same cable position for different truss widths vary linearly. Displacements for same cable position are least for the truss width in the range of 0.75m to 0.90m. Stress for same cable position for different truss widths varies linearly. Stress for same cable position decrease along with increase in truss width.

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