THERMAL ANALYSIS OF GLAZED SURFACE BY FEM

Raghunath .D. Deshpande[1], Gayatri Chiniwal[2], Laxmi Golsangi[3]

[1]*Assistant Professor, Civil Engineering Department, Gogte Institute of Technology Belagavi, Karnataka, India*
[2]*Trainee Civil Engineer, Telecommunication Engineering Department, Black and Veatch Pvt. Ltd, Pune, Maharashtra, India*
[3]*M.Tech Scholar, Civil Engineering Department, Gogte Institute of Technology Belagavi, Karnataka, India*

Abstract- In the current work finite element analysis (FEA) of glazed surface of a structure is performed by considering its thermal breakage due to atmospheric temperature changes. Especially location, topography, terrain, type of glass panel and size and thickness of panel are considered. Later the analysis is performed for wind pressure, suction acting on the surface and temperature difference. Different cases are considered – (i) varying truss widths, (ii) varying cable position and (iii) varying number of cables.

After reviewing the results one can choose an economical and efficient steel supporting structure to support the glazing which yields minimum displacement and stresses.

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

1. INTRODUCTION

1.1 General

The current work is carried out to study the effects of temperature change on glass façade and the supporting steel frame. Here, analysis are 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 various iterations of 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. Later combinations of temperature, wind pressure and dead load are considered and analysis is performed. The models are checked for deflection and stresses for different iterations as mentioned.

1.2 Software STAAD.Pro

Pre processor, processor and post processors for the analysis were carried out by using STAAD.Pro V8i which is a user friendly graphical user interface (GUI). Which is having provision to assign material properties apart from default ones.

2. METHODOLOGY

2.1 Data Considered for Study

Glass details:
Glass type - Annealed glass
Strength – 55N/mm^2
Panel size – 1.5mx4.2m
Thickness = 17.52mm
Modulus of elasticity for glass = 60-70GPa
Unit weight = 25 kN/m^3

Other details:
Location – Mumbai, India
Basic wind speed, V_b = 44m/s
Terrain – Category 2, Class C
Mean maximum temperature = 33.5^{0}C
Mean minimum temperature = 20.8^{0}C

Plan dimension:
Length = 75m
Width = 40m
Total height, H = 30.5m
Height of the model, h=19.7m
Maximum allowable displacement:
Span/200 = 19700/200
= 98.5mm
≈ 98mm

2.2 Modeling in STAAD.Pro

Main objectives of modeling are to ensure that it represents the characteristics of the real structure. Many trials were made until a model was finalized. It consists of a combination of different types of members. It comprises of – (i) Glass façade, (ii) Steel frame, (iii) Connections and (iv) Cables.

2.2.1 Glass Façade

Designed as Plate member
Thickness = 17.52 mm
Rectangular mesh of size 0.3mx0.3m each is done
Panel size – 1.5mx4.2m
Space between adjacent glass pane 2 - 4mm

2.2.2 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

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

2.2.4 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

2.3 Supports

Four types of supports are used in the STAAD model-
(i) Fixed but F_x, F_y, M_x, M_y, M_z released.
(ii) Fixed but F_z, F_y, M_x, M_y, M_z released.
(iii) Fixed but F_y, M_x, M_y, M_z released.
(iv) Pinned Support

2.4 Load Assigned in STAAD

i. Dead load
Selfweight = 2.7594 kN/m

ii. Wind load
WPRE = -0.896 kN/m^2
WSUC = 1.152 kN/m^2

iii. Combinations

Dead load ± 0.75Wind load + Temperature load (DL±0.75WL+TL)

- Dead load + 0.75Wind pressure + Temperature load (DL+0.75WPRE+TL)
- Dead load + 0.75Wind suction + Temperature load (DL+0.75WSUC+TL)
- Dead load - 0.75Wind pressure + Temperature load (DL+0.75WPRE+TL)
- Dead load - 0.75Wind suction + Temperature load (DL+0.75WSUC+TL)

2.5 Analysis

Models for different iterations are designed and all the materials, properties and loads are assigned. And analysis is run. The results of analysis are imported in post processing. The displacements at every nodes, reactions, and stresses etc are well produced in STAAD in an easy-to-understand manner. Graphs are plotted in MS Excel to reprent the trend of change in structure behavior under different conditions of loading and varying parameters.

2.6 Model

In the current study 16 models are analyzed by considering 4 different truss widths and 4 different types of cable positions to obtain an economic and efficient structure. Each model with a specific truss width is analyzed considering 4 types of cable positions.

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 0.63m and 2 cables down at 2nd and 3rd levels.

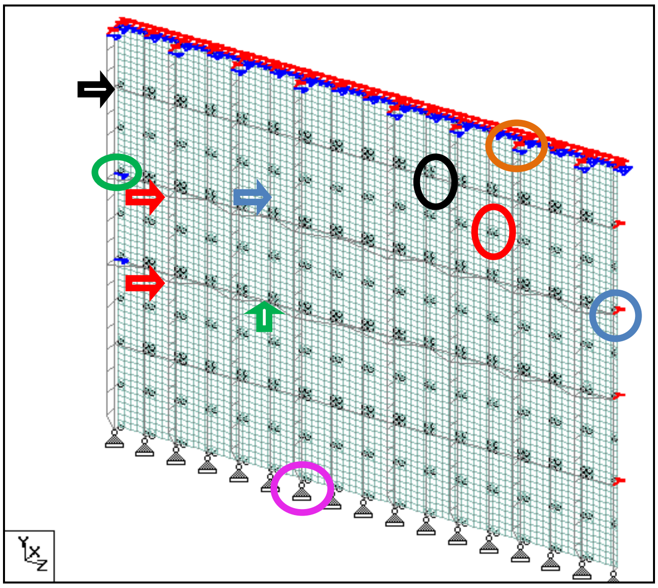


Fig-1: Model

In the fig-1

Shows the truss. In the considered case , width of which is 0.63m.

Shows the cables

Shows the vertical column

Shows the horizontal supporting member

Shows the 4-armed spider connections

Shows the 2-armed spider connections

Shows the pinned support

Shows the fixed but F_x, F_y, M_x, M_y, M_z released support

Shows the fixed but F_y, F_z, M_x, M_y, M_z released support

Shows the fixed but F_y, M_x, M_y, M_z released support

Various views are shown as below from fig-2 to fig-5, however different cable positions are shown for other models from fig-6 to fig-8

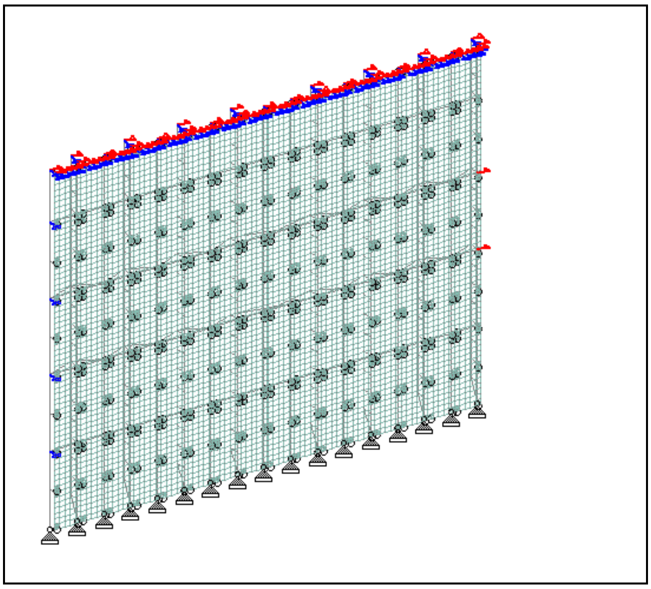


Fig-2: 2D front view

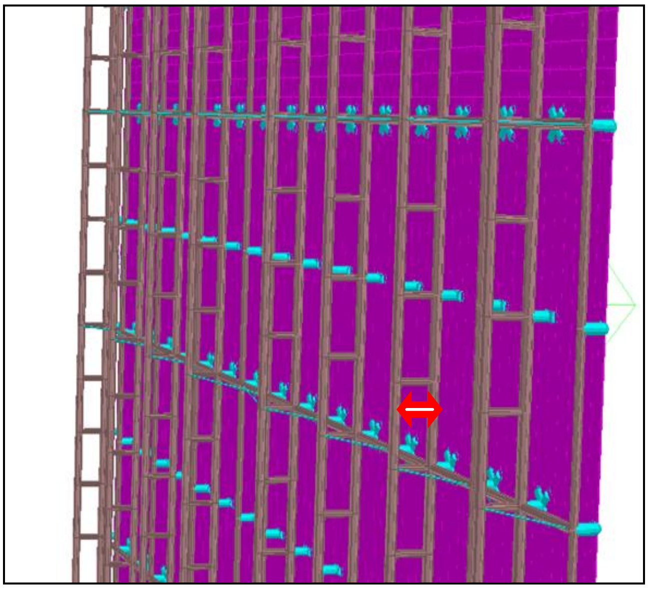


Fig-4: 3D back view indicating truss width

⟺ Shows the truss width.
In this case truss width is 0.63m

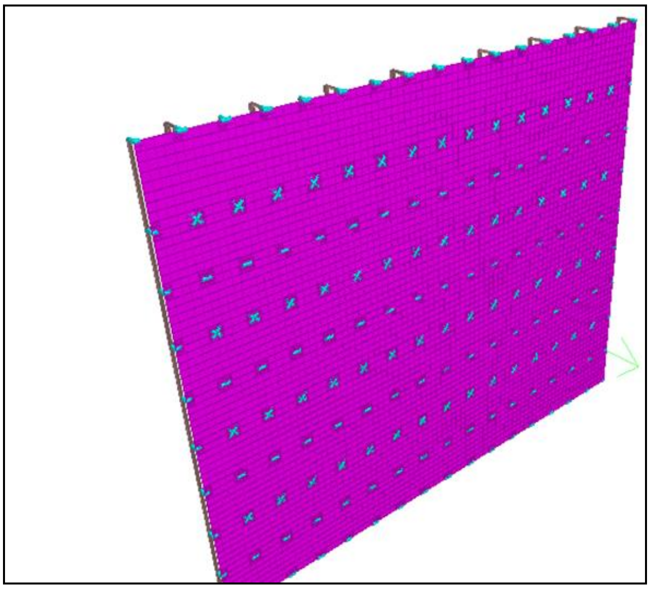


Fig-3: 3D front view

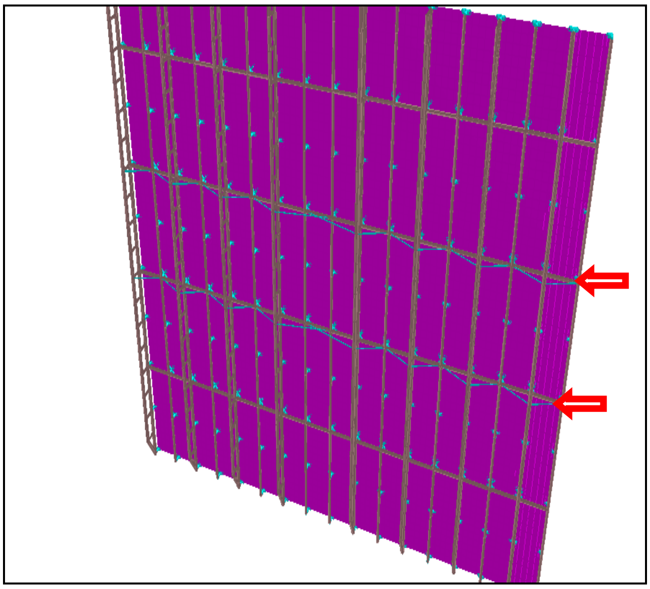


Fig-5: 3D back view indicating 2 cables down position

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

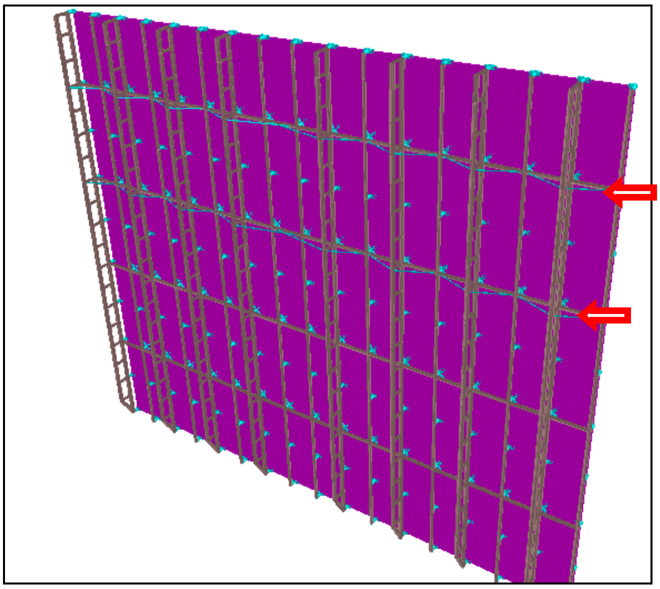


Fig-6: 3D back view indicating 2 cables top position

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

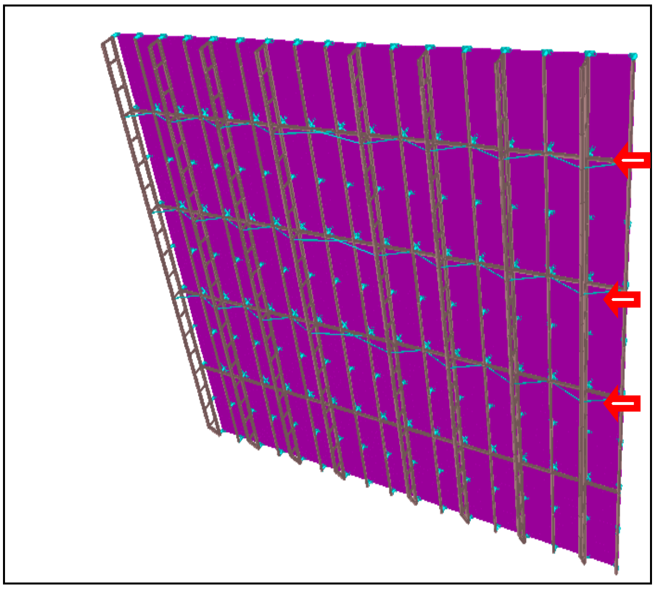


Fig-7: 3D back view indicating 3 cables position

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

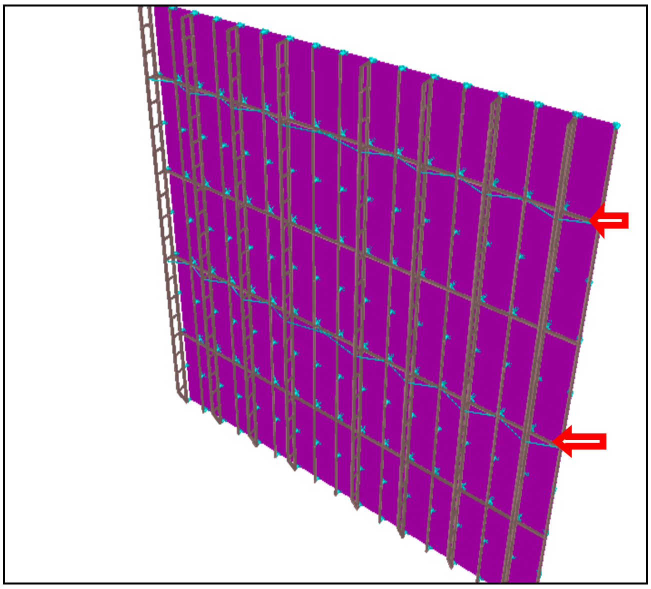


Fig-8: 3D back view indicating alternate 1 and 3 cables position

The arrows point at the cables which are at 1st & 3rd levels, as the name says alternaten1 and 3 levels.

3. STRESS DISTRIBUTION IN GLASS FACADE DUE TO TEMPERATURE LOAD

3.1 0.63m truss

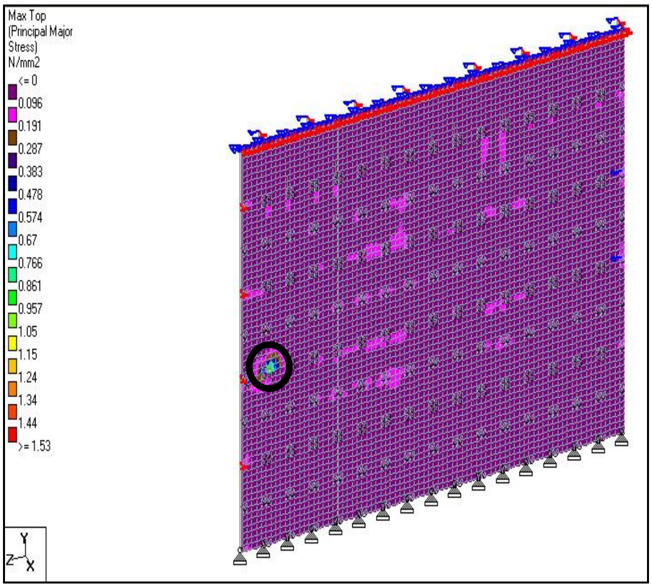


Fig-9: 2 cables down

Encircled region represents maximum stress.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 01 |May -2015 www.irjet.net p-ISSN: 2395-0072

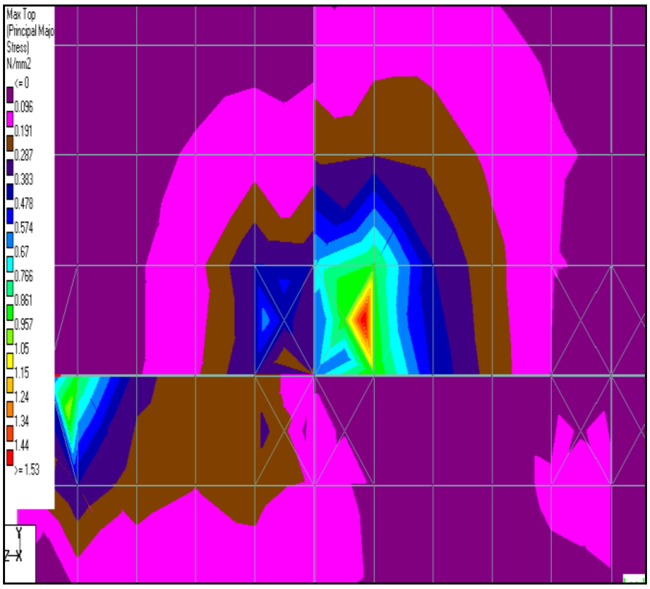


Fig-10: Closer view of encircled region showing stress distribution

Maximum principal major stress = 1.53 N/mm²

Similarly for other models stress distribution and maximum values of stress are shown in fig-11 to fig-25.

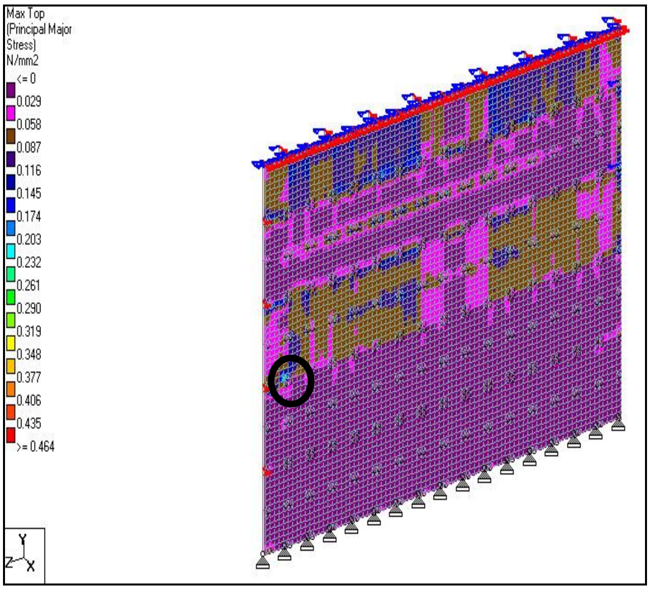


Fig-11: 2 cables top

Maximum principal major stress = 0.464 N/mm²

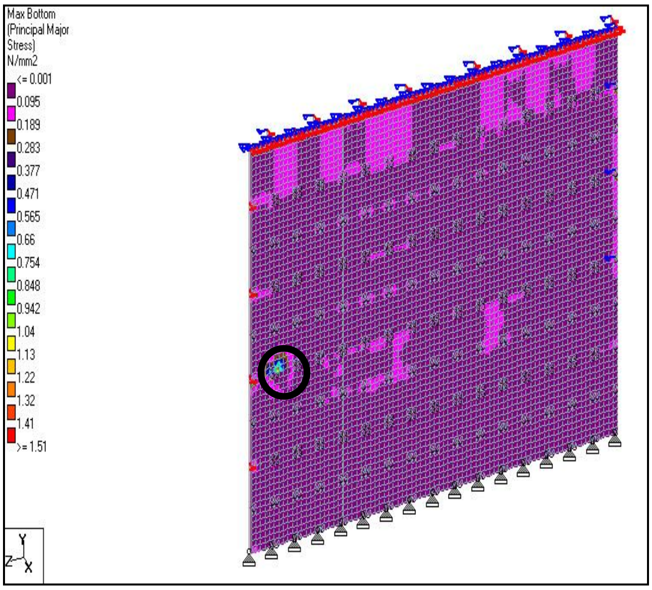


Fig-12: 3 cables

Maximum principal major stress = 1.51 N/mm²

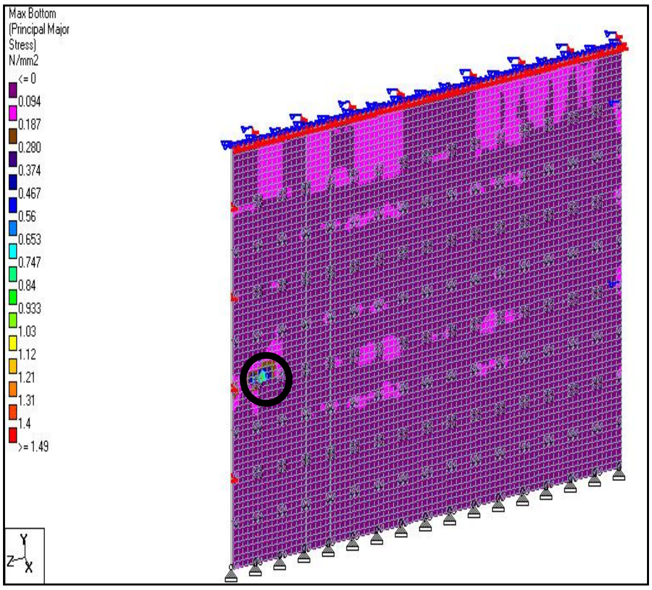


Fig-13: Alternate cables @ 1 and 3 level

Maximum principal major stress = 1.492 N/mm²

3.2 0.75m truss

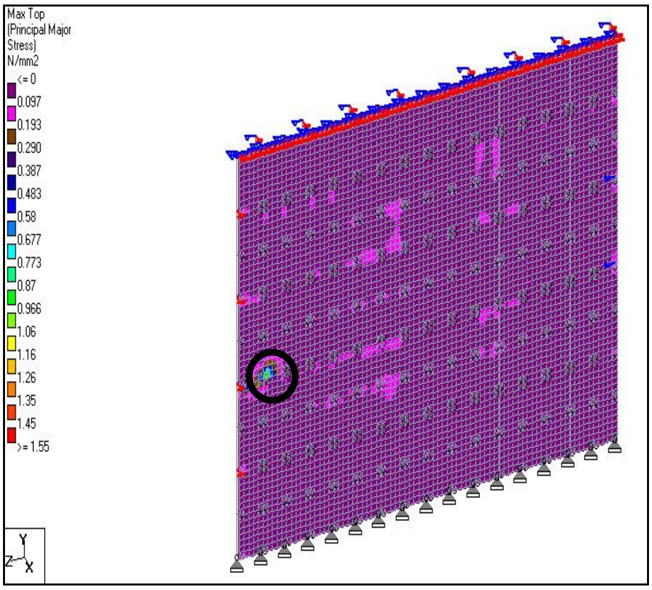


Fig-14: 2 cables down

Maximum principal major stress = 1.546 N/mm^2

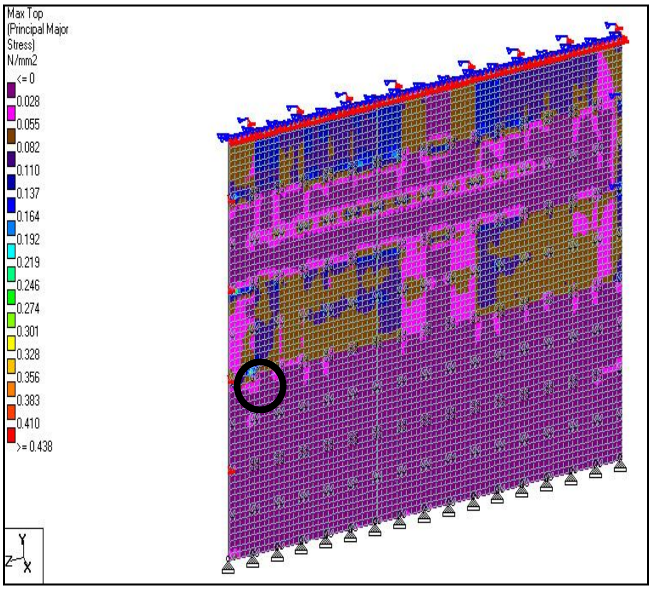


Fig-15: 2 cables top

Maximum principal major stress = 0.437 N/mm^2

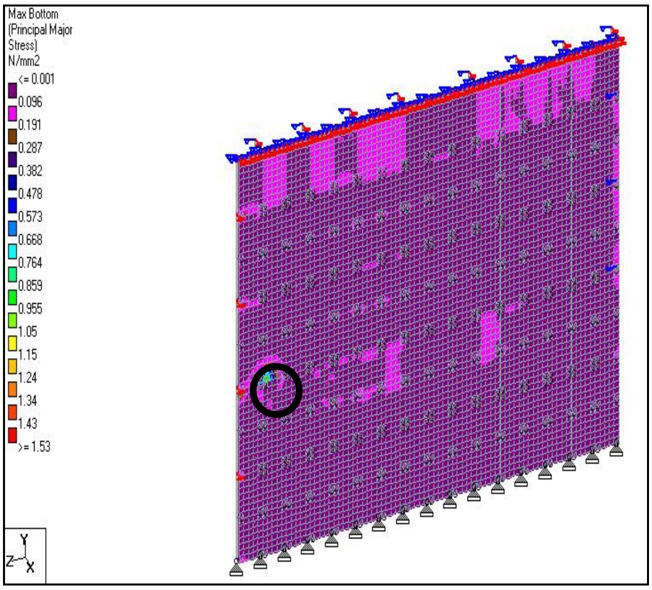


Fig-16: 3 cables

Maximum principal major stress = 1.526 N/mm^2

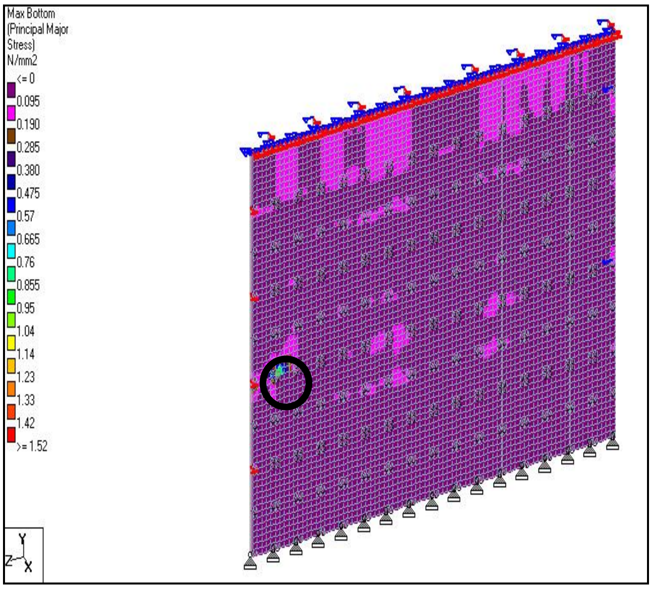


Fig-17: Alternate cables @ 1and 3 level

Maximum principal major stress = 1.519 N/mm^2

3.3 0.90m truss

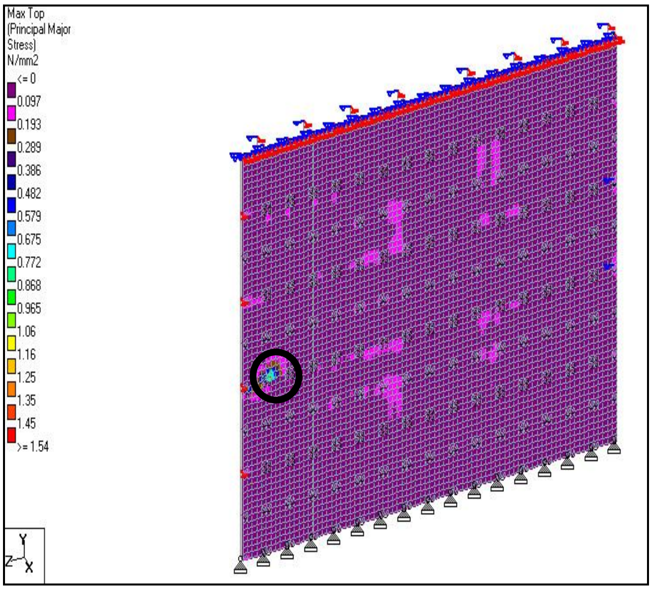


Fig-18: 2 cables down

Maximum principal major stress = 1.543 N/mm^2

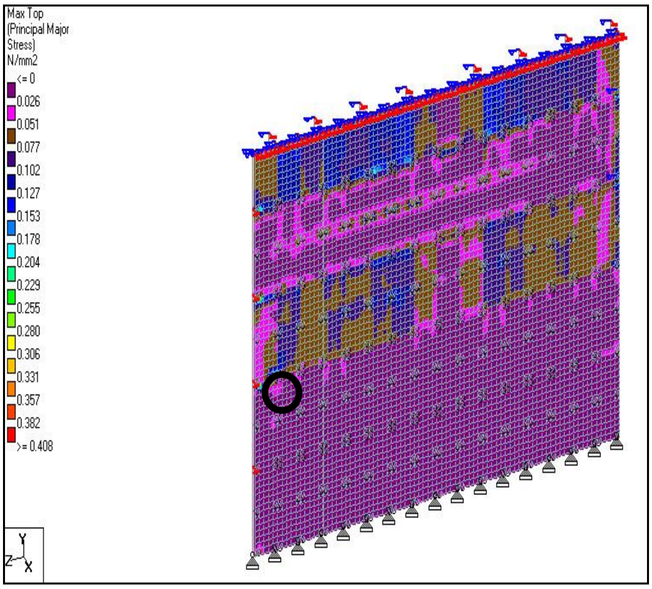


Fig-19: 2 cables top

Maximum principal major stress = 0.407 N/mm^2

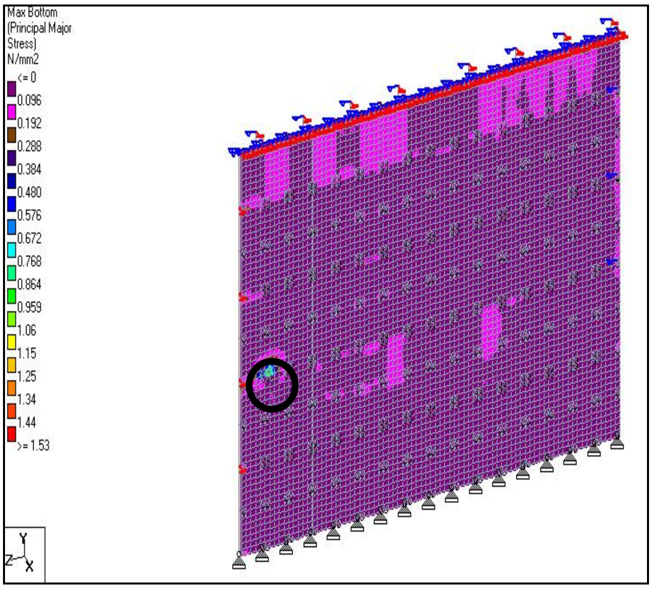


Fig-20: 3 cables

Maximum principal major stress = 1.53 N/mm^2

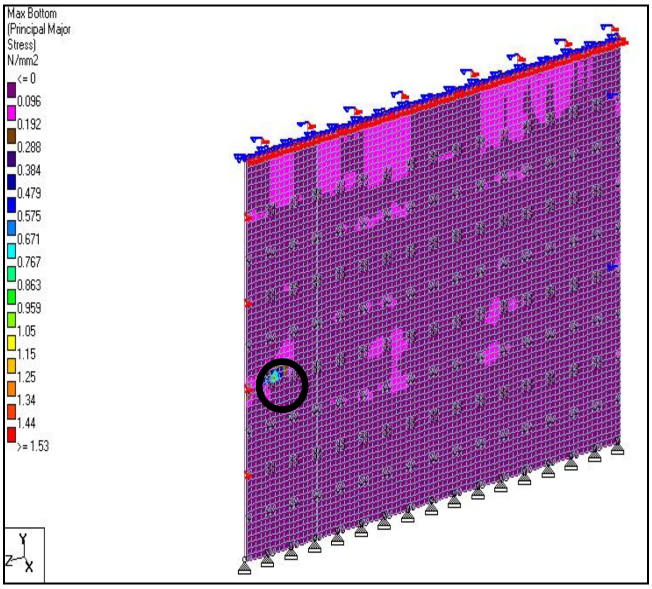


Fig-21: Alternate cables @ 1 and 3 level

Maximum principal major stress = 1.533 N/mm^2

3.4 1.10m truss

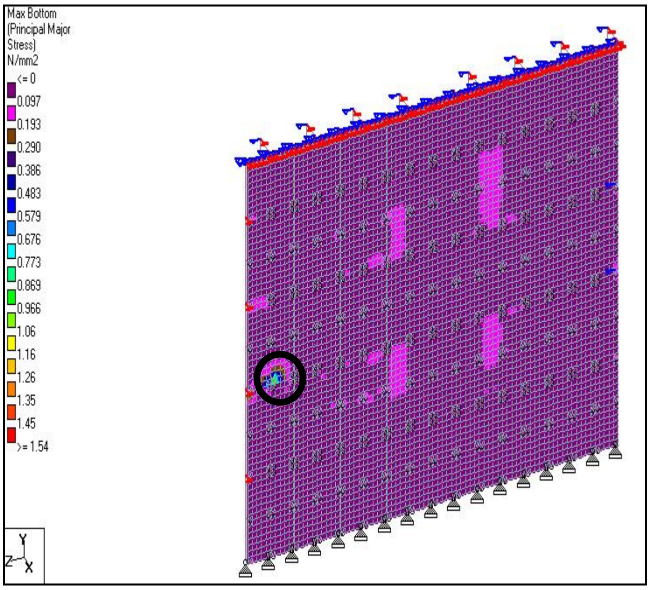


Fig-22: 2 cables down

Maximum principal major stress = 1.545 N/mm^2

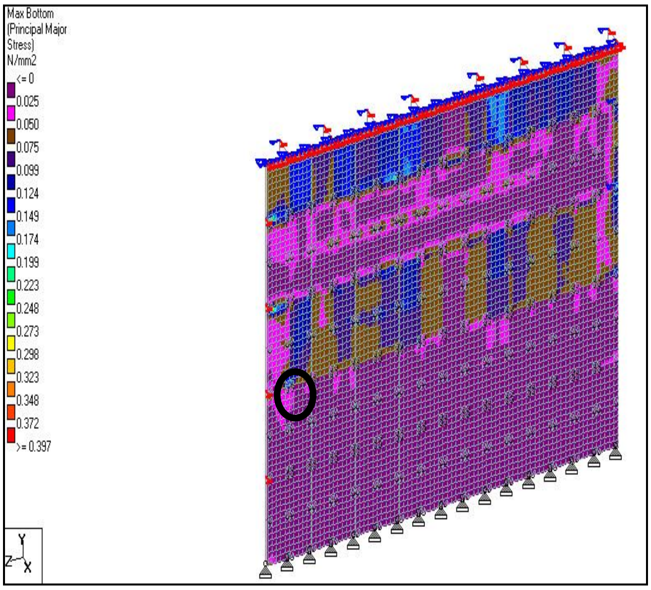


Fig-23: 2 cables top

Maximum principal major stress = 0.397 N/mm^2

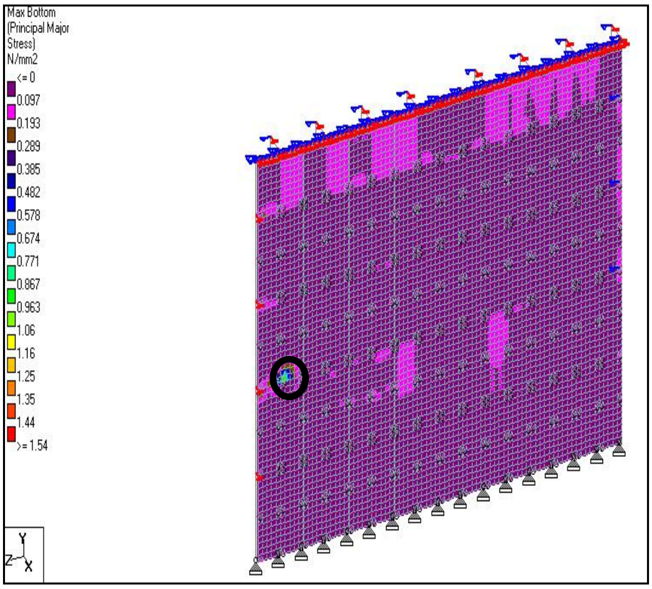


Fig-24: 3 cables

Maximum principal major stress = 1.54 N/mm^2

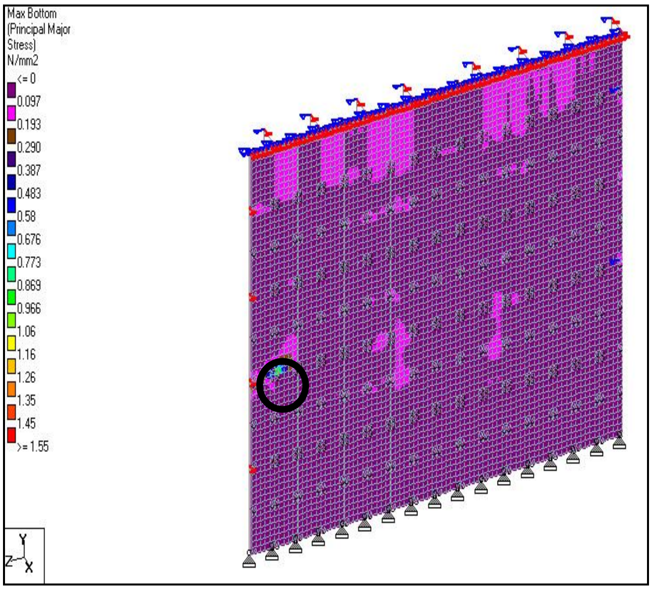


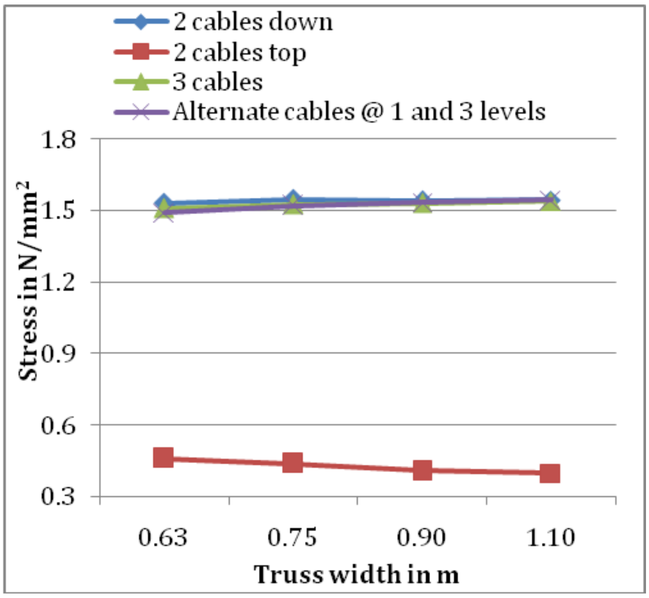
Fig-25: Alternate cables @ 1 and 3 level

Maximum principal major stress = 1.545 N/mm^2

3.5 Tables and Graphs

Table-1: 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	1.530	1.546	1.543	1.545
2 cables top	0.464	0.437	0.407	0.397
3 cables	1.510	1.526	1.530	1.540
Alternate cables @ 1 and 3 level	1.492	1.519	1.533	1.545



Graph-1: Stress for various truss widths

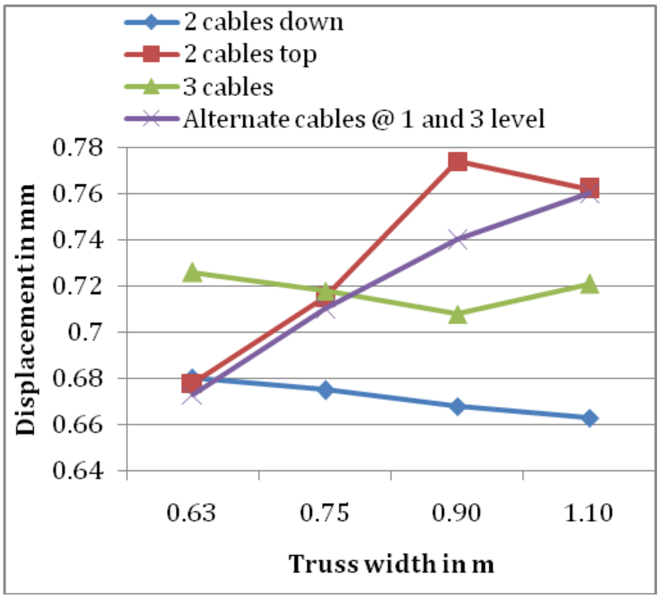
Table-2: Average stress for various truss widths

Truss width in m	Average stress in N/mm²
0.63	1.249
0.75	1.257
0.90	1.253
1.10	1.256

Graph-2: Average stress for various truss widths

Table-3: Displacement (in mm) for various truss widths and corresponding cable positions

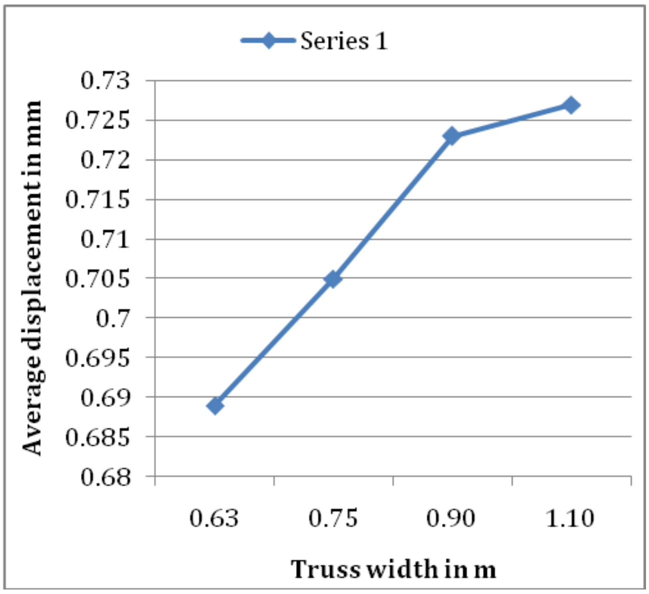
Cable position	Truss width in m			
	0.63	0.75	0.90	1.10
2 cables down	0.680	0.675	0.668	0.663
2 cables top	0.678	0.715	0.774	0.762
3 cables	0.726	0.718	0.708	0.721
Alternate cables @ 1 and 3 level	0.673	0.710	0.740	0.760



Graph-3: Displacement for various truss widths

Table-4: Average displacement for various truss widths

Truss width in m	Average displacement in mm
0.63	0.689
0.75	0.705
0.90	0.723
1.10	0.727



Graph-4: Average displacement for various truss widths

4. STRESS DISTRIBUTION IN GLASS FACADE DUE TO LOAD COMBINATIONS (DL±0.75WL+TL)

Stress and displacement values obtained for the temperature load case are too smaller than the yield strength of the glass and maximum allowable displacement for the model, therefore analysis has been done by considering the load combinations to check the overall performance of the structure.

4.1 0.63m Truss

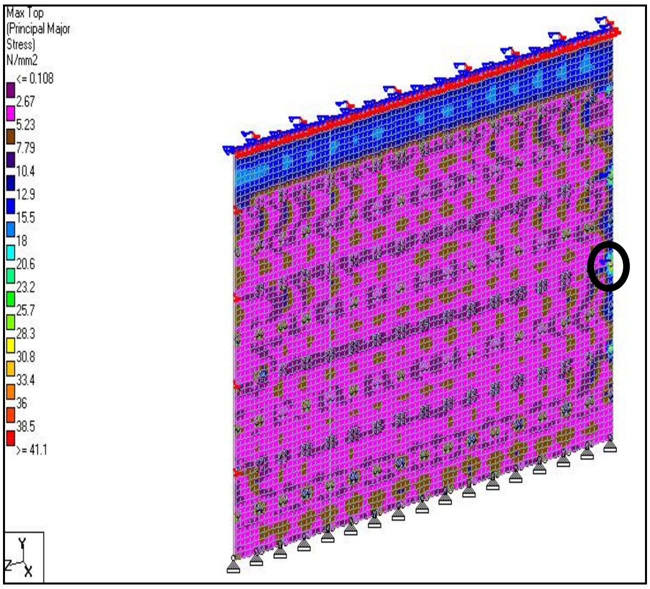


Fig-26: 2 cables down

Encircled region represents maximum stress.

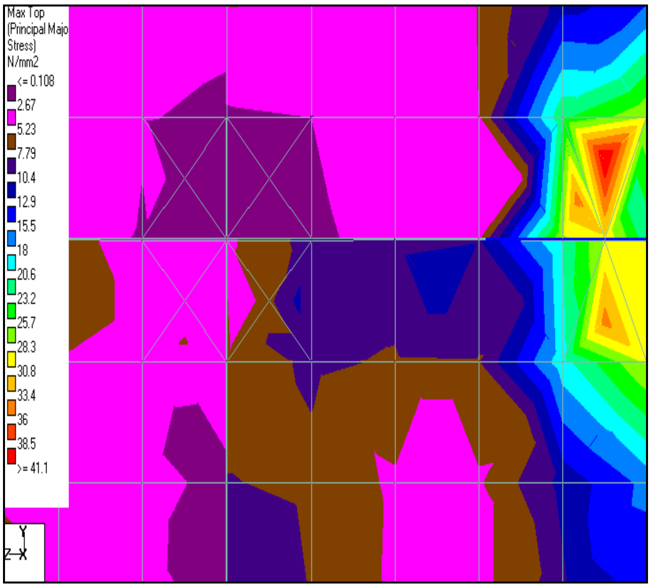


Fig-27: Closer view of encircled region showing stress distribution

Maximum principal major stress = 41.078 N/mm^2

Similarly for other models stress distribution and maximum values of stress are shown from fig-28 to fig-42.

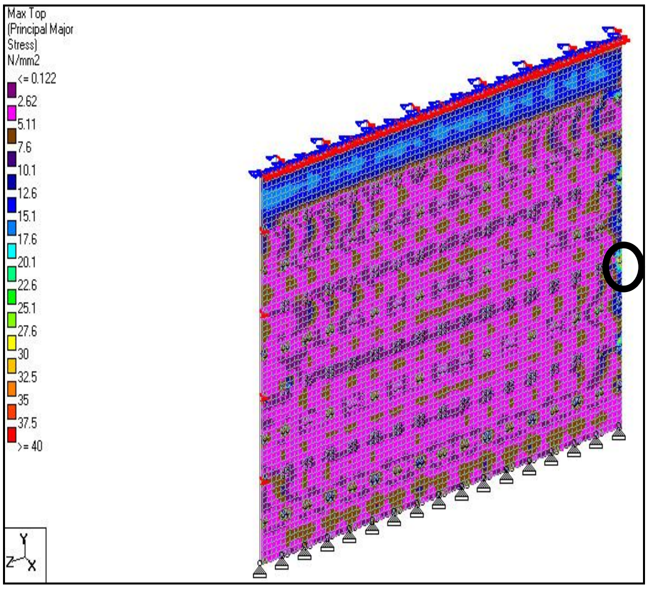


Fig-28: 2 cables top

Maximum principal major stress = 40.017 N/mm^2

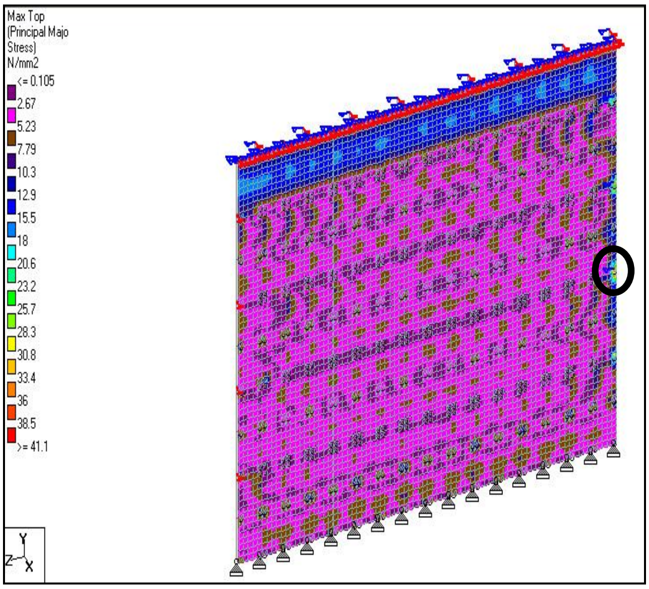


Fig-29: 3 cables

Maximum principal major stress = 40.078 N/mm^2

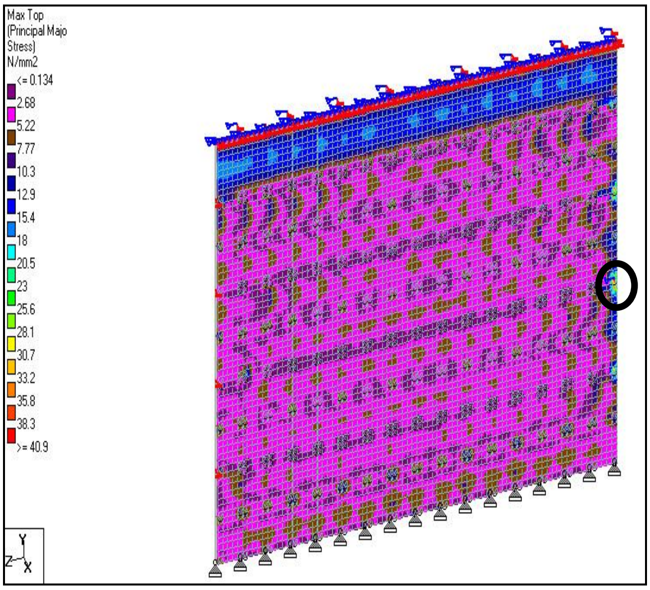


Fig-30: Alternate cables @ 1 and 3 level

Maximum principal major stress = 40.858 N/mm^2

4.2 0.75 truss

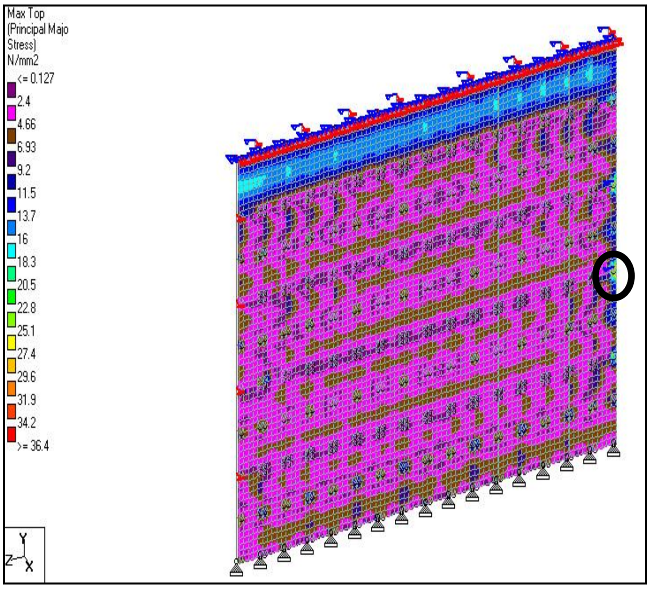


Fig-31: 2 cables down

Maximum principal major stress = 36.420 N/mm^2

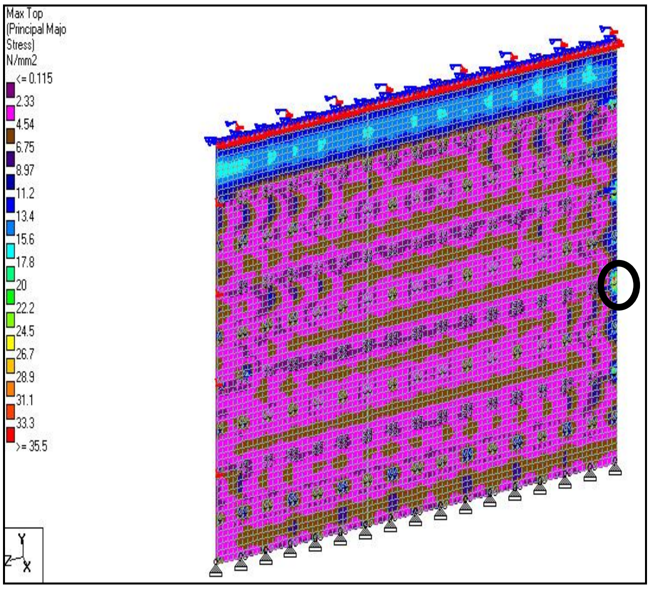


Fig-32: 2 cables top

Maximum principal major stress = 35.518 N/mm^2

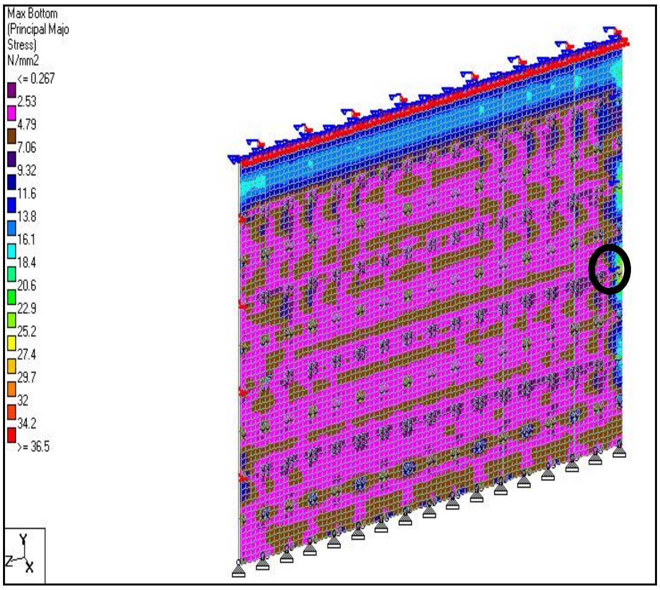


Fig-33: 3 cables

Maximum principal major stress = 36.477 N/mm^2

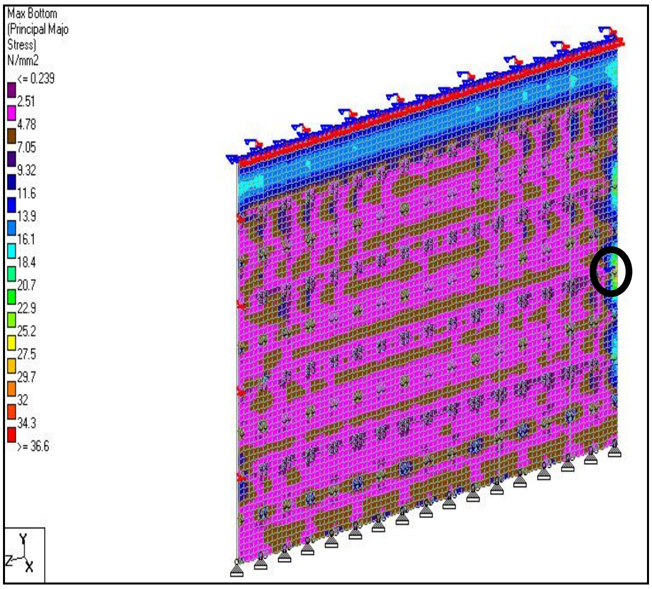


Fig-34: Alternate cables @ 1 and 3 level

Maximum principal major stress = 36.551 N/mm^2

4.3 0.90m truss

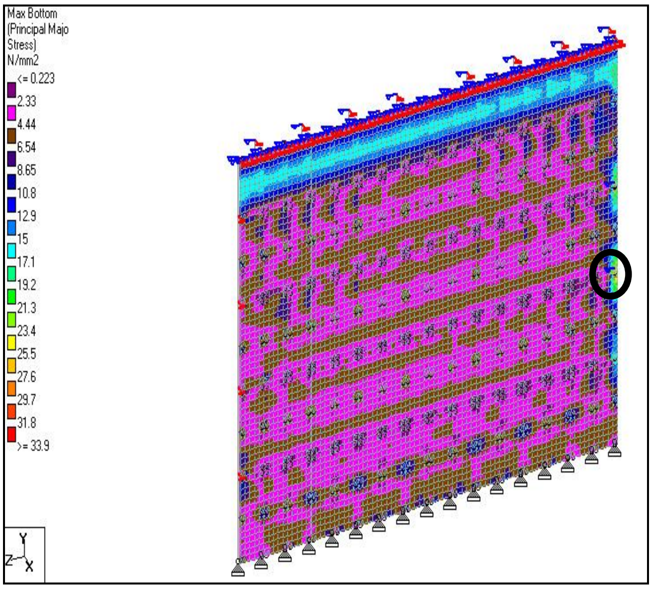


Fig-35: 2 cables down

Maximum principal major stress = 33.930 N/mm^2

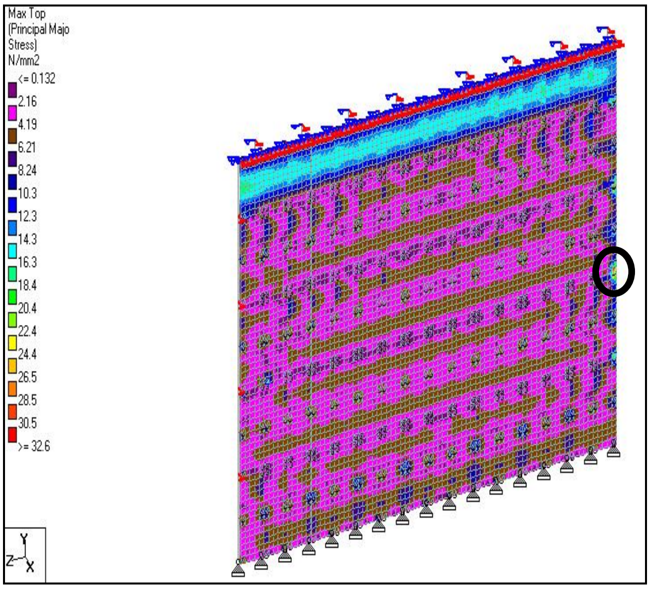


Fig-36: 2 cables top

Maximum principal major stress = 32.556 N/mm^2

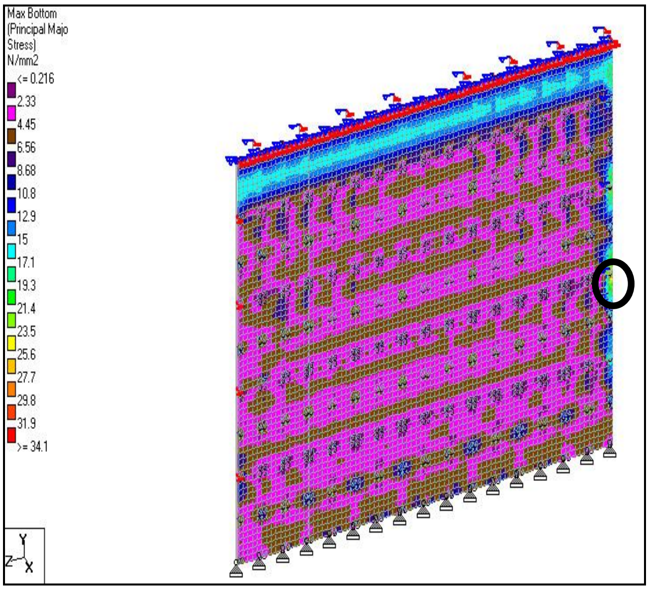


Fig-37: 3 cables

Maximum principal major stress = 34.058 N/mm^2

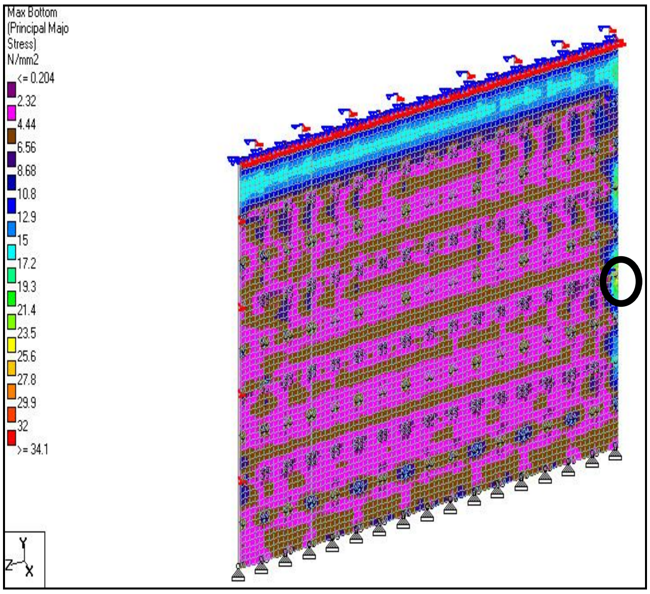


Fig-38: Alternate cables @ 1 and 3 level

Maximum principal major stress = 34.119 N/mm^2

4.4 1.10 m truss

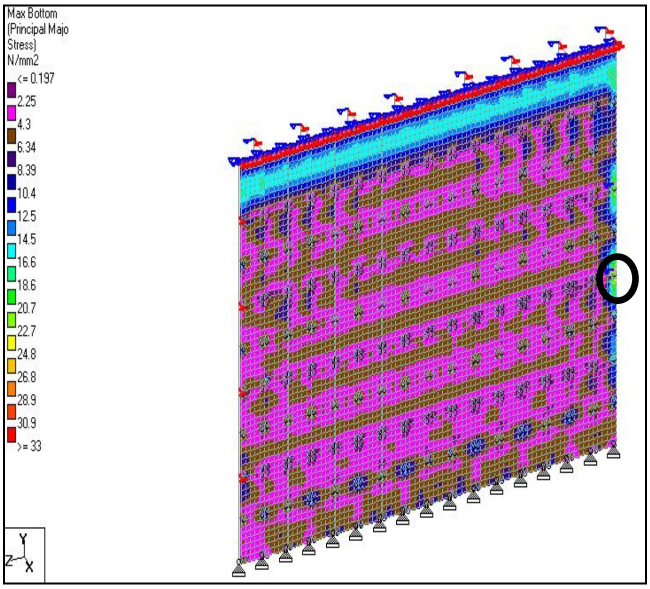


Fig-39: 2 cables down

Maximum principal major stress = 32.981 N/mm^2

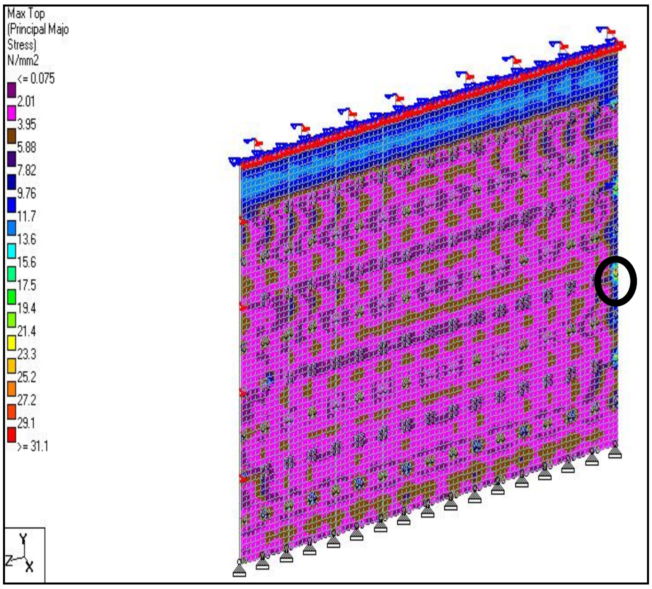


Fig-40: 2 cables top

Maximum principal major stress = 31.057 N/mm^2

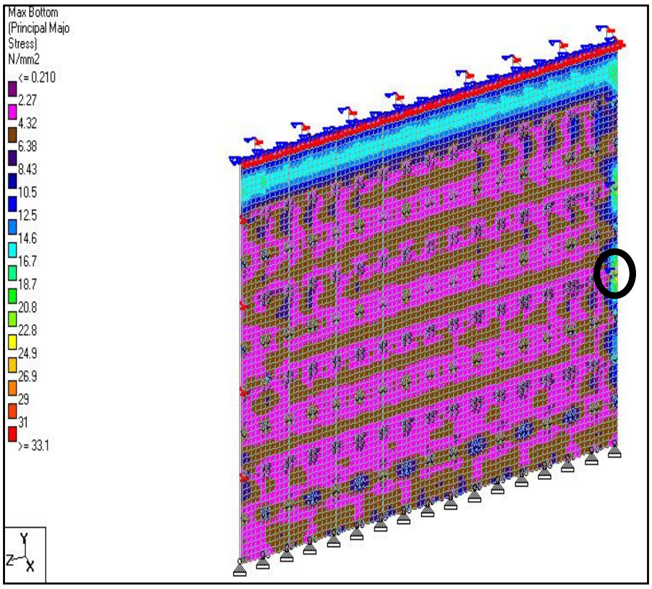


Fig-41: 3 cables

Maximum principal major stress = 33.106 N/mm^2

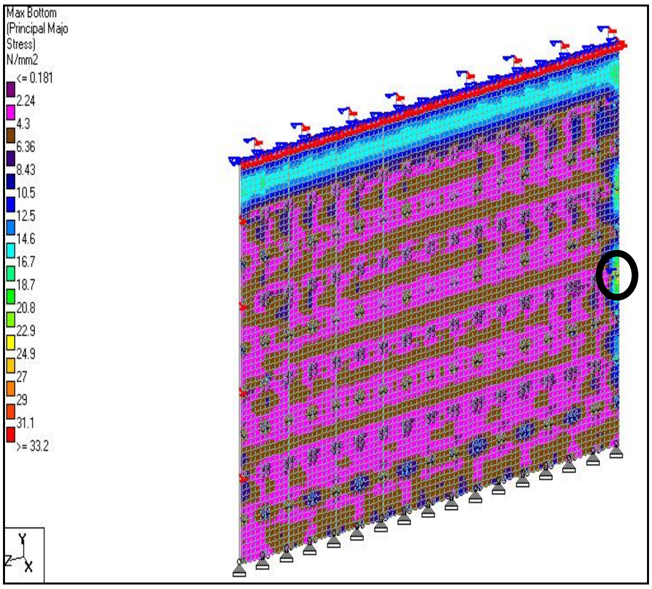


Fig-42: Alternate cables @ 1 and 3 level

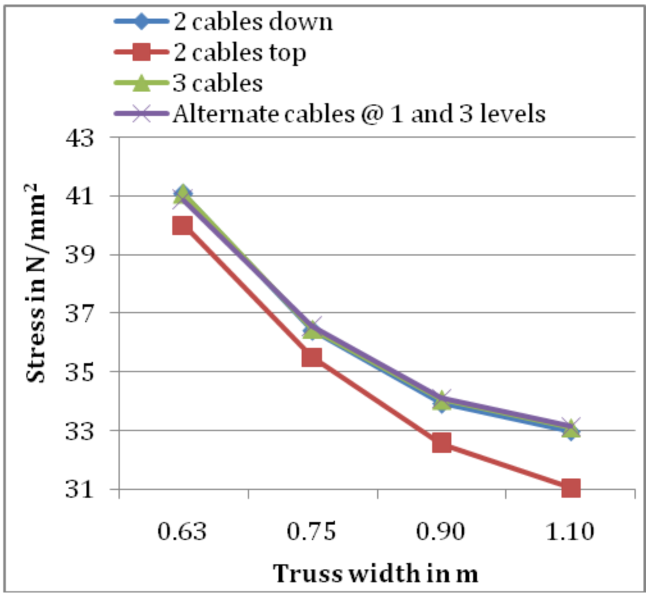
Maximum principal major stress = 33.106 N/mm^2

4.5 Tables and Graphs

Table-5: Stress (in N/mm^2) 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	41.078	36.420	33.930	32.981
2 cables top	40.017	35.518	32.556	31.057
3 cables	41.078	36.477	34.058	33.106
Alternate cables @ 1 and 3 level	40.858	36.551	34.119	33.160

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 01 |May -2015 www.irjet.net p-ISSN: 2395-0072



Graph-5: Stress for various truss widths

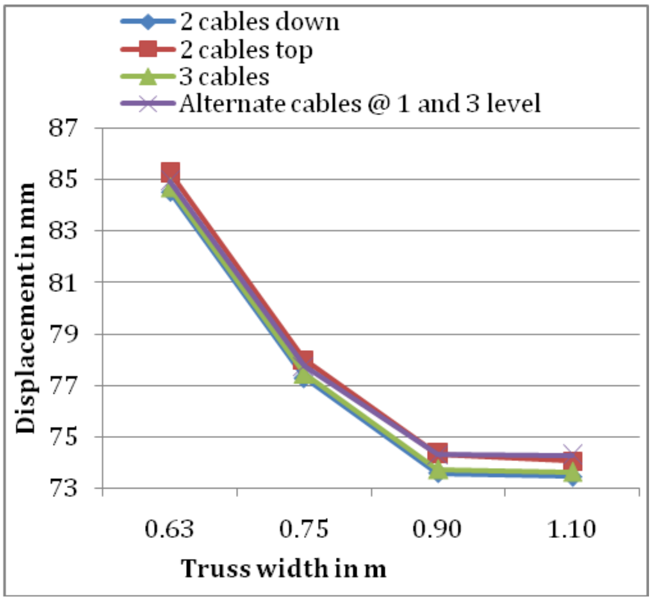
Table-6: Average stress for various truss widths

Truss width in m	Average stress in N/mm²
0.63	40.757
0.75	36.241
0.90	33.665
1.10	32.576

Graph-6: Average stress for various truss widths

Table-7: Displacement (in mm) for various truss widths and corresponding cable positions

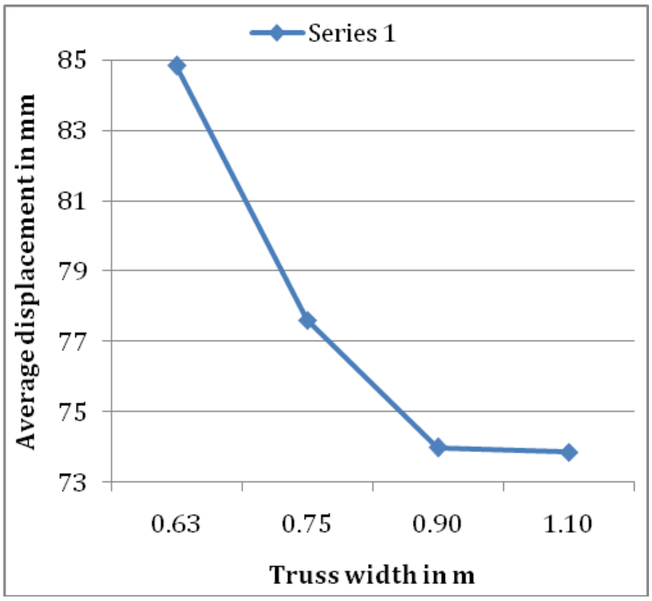
Cable position	Truss width in m			
	0.63	0.75	0.90	1.10
2 cables down	84.515	77.276	73.569	73.444
2 cables top	85.240	77.995	74.322	74.059
3 cables	84.674	77.437	73.735	73.641
Alternate cables @ 1 and 3 level	84.925	77.742	74.293	74.278



Graph-7: Displacement for various truss widths

Table-8: Average displacement for various truss widths

Truss width in m	Average displacement in mm
0.63	84.839
0.75	77.613
0.90	73.979
1.10	73.855



Graph-8: Average displacement for various truss widths

5. OBSERVATIONS

5.1 Temperature Load Case

5.1.1 Displacement

- It was observed that for 0.63m truss minimum displacement is obtained for model with two cables at 1st and 3rd levels and maximum displacement is obtained for model with three cables at 1st, 2nd and 3rd levels.
- It was observed that for 0.75m truss minimum displacement is obtained for model with two cables at 2nd and 3rd levels and maximum displacement is obtained for model with three cables at 1st, 2nd and 3rd levels.
- It was observed that for 0.90m and 1.10m trusses minimum displacement is obtained for model with two cables at 2nd and 3rd levels and maximum displacement is obtained for model with two cables at 1st and 2nd levels.
- It was observed that average displacement is almost same with slight difference in decimal values.

5.2.2 Stresses

- It was observed that for all the trusses minimum stress is obtained for model with two cables at 1st and 2nd levels and maximum stress is obtained for model with two cables at 2nd and 3rd levels.
- It was observed that average stress is almost same with slight difference in decimal values.

5.2 Load Combinations Case

5.2.1 Displacement

- It was observed that for 0.63m and 0.75m trusses minimum displacement is obtained for model with two cables at 2nd and 3rd levels and maximum displacement is obtained for model with two cables at 1st and 2nd levels.
- It was observed that for 0.90m truss minimum displacement is obtained for model with two cables at 1st and 3rd levels and maximum displacement is obtained for model with three cables at 1st, 2nd and 3rd levels.
- It was observed that for 1.10m truss minimum displacement is obtained for model with two cables at 1st and 2nd levels and maximum displacement is obtained for model with three cables at 1st, 2nd and 3rd levels.
- It was observed that average displacement is less for 0.90m and 1.10m truss widths as compared to 0.63m and 0.90m truss widths.

5.2.2 Stresses

- It was observed that for all the trusses minimum stress is obtained for model with two cables at 1st and 2nd levels.
- It was observed that for 0.75m, 0.90m and 1.10m truss widths maximum stress is obtained for model with two cables at 1st and 3rd levels and for 0.63m truss it is same for model with two cables at 2nd and 3rd levels and three cables at 1st, 2nd and 3rd levels.
- It was observed that average stress is less for 0.90m and 1.10m truss widths as compared to 0.63m and 0.90m truss widths.

6 CONCLUSIONS

The average maximum stress obtained for model with 0.63m truss width is 40.757 N/mm2 which is well below than the yield strength of the glass used i.e. 55 N/mm^2. The stress values for all iterations are well within the limit. Hence model is said to be safe. The average displacement for model with 0.63m truss width is 84.839mm which is less than allowable displacement for the structure i.e. 98mm. The displacement values for all iterations are well within the limit. Hence model is said to be safe. The stresses and displacements due to the temperature load alone are small; hence they affect least to the overall performance of the structure.

REFERENCES

[1] Guardian Sunguard, "Technical Guidelines", www.sunguardglass.com

[2] Kenneth Zammit and Mauro Overend, "Improved Computational Methods for Wind Pressures and Glass Thickness in Facades", University of Cambridge, UK.

[3] S.L.Chan, "Basic Structural Design Considerations and Properties of Glass and Aluminium Structures", RCATISE.

[4] Code of Practice for Use of Glass In Buildings, derived from Australian Standard, AS 1288 1994 and British Standard, BS 6262.

[5] Hatsuo Ishizaki, "On the Large Deflections of Rectangular Glass Panes under Uniform Pressure", Dec 1972.

[6] Ronald R Geren, "Glass and Glazing", International Building Code. 2012.

[7] Code of practice for design loads for buildings and structures derived from Indian Standard IS: 875 (Part 3)-1987.

[8] Indian meteorological department - National data center: ndc@imdpune.gov.in

[9] Chapter 24 Glass and Glazing, International Building Code 2006, New Jersey Edition.

[10] Raghunath .D. Deshpande, Gayatri Chiniwal, "Finite Element Analysis of Glazed Surface", International Research Journal of Engineering and Technology, Volume-02, March-2015.

BIOGRAPHIES

Raghunath .D. Deshpande (M.tech structural Engg.)

Assistant Professor, Civil Engineering Department, Gogte Institute of Technology Belagavi, Karnataka, India.

Email: rddeshpande@git.edu

Gayatri Chiniwal (M.tech structural Engg.)

Trainee Civil Engineer, Telecommunication Engineering Department, Black and Veatch Pvt. Ltd, Pune, Maharashtra, India.

Email: chiniwalgayatri@gmail.com

Laxmi Golsangi (M.Tech Scholar)

M.Tech Scholar, Civil Engineering Department, Gogte Institute of Technology Belagavi, Karnataka, India.

Email: laxmigolsangi@gmail.com

