Peripheral Building Facade: A Design Process for Improvised Dynamism

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ABSTRACT: A facade is a glazing structure which consists of glass panel fixed inside a aluminum frame work. The aluminum frame work consists of mullion and transom. Mullion is a vertical bar between the panes of glass in a window. Transom is a horizontal bar between the panes of glass in a window. The complete glass panel with aluminum frame work is fixed to the structural member by the support from a bracket. The bracket holds the mullion. The bracket is fixed either to the column or slab by anchors. A facade consists of dead load and wind load, live load. Here seismic load is not considered for facade.

KEYWORDS: Facade, Dead load, Live load, Glass, Terminal structure.

I. INTRODUCTION

Glass is one of the most popular construction materials due to its combination of transparency, strength and durability. Since it offers the possibility of natural light transmission, soon it earned a major influence in window glazing systems. The engineer has to be aware of several distinct problems, such as material's behavior and its interaction with others requirements. It consists of stress analysis and deformation of the facade structure for the two cases of models. The results are more encouraging for simple glazing systems against double glazing, with a maximum relative error of 7%. The model is quite conservative because it only considers that stress transmission occurs through bolts which is not true, due to the direct contact that exists all over the surface.

II. Review of Literature

Jose Sanches 2013 paper showed how to design two examples where frequently glass is used as a structural material. It was verified that for a shortest span of 1200 mm it is necessary to bond more sheets. The author concluded that how the connection geometry and chosen material may influence the maximum stress in glass fins. STAAD. Pro is the best software for modeling and analysis of the ground plus three floor structure and the designing can be done manually. Also design of beam, shear wall, column, slab, stair case, water tank, retaining wall and an isolated footing could also be done for better analysis. Detailing is prepared using AUTOCAD 2016 (Nasreen. M. Khan 2016). Earthquake is the most acute loading condition for all land based structures located in the seismically dynamic regions. The use of shear walls is one of the potential options for earthquake resistant system. Shear walls majorly repel the seismic force and wind forces. It even can be built on soils of feeble bases by adopting several ground improvement techniques (G.Amar et al 2016). Footings of the building structures are designed based on the safe bearing capacity of existing soil. For designing of beams and columns, it is required to identify the moments they are exposed to. For this determination, frame analysis is carried out using Limit State Method. While designing of slabs it is necessary to decide whether it is a one - way / a two way slab, the loading and the end conditions. From the slabs, the loads are conveyed to the beam. (V.Varalakshmiet al 2014). The Façade Engineering is the skill of determining aesthetic, structural and environmental issues to attain the enclosure of comfortable space. By utilizing steel as a load bearing arrangement, it is likely to keep the transparency controlling structures thin. Glass varies from other building materials in phase of being an exceptionally brittle material and infringement without a premonition. This solid property of fragility has to be taken into justification when designing huge glass facades(Taywade et al 2015). Glass will not crack alike concrete and it is much more fragile than steel. This shows the destruction of glass building due to substantial wind pressure and to resolve this problem a design procedure is required for determining the thickness of glass with design procedure. The rate of facade inhabits a high proportion of the overall construction cost. The design of aluminum and glass necessitates special attention as the linear theory of design and analysis applicable to design of concrete structures is not effective in many cases. The use of non-linear analysis not only helps to a safer design, but also to an additional cost-effective solution as no critical members will be under- designed and terminated members overdesigned (S.L. Chan 2006).

III. Methodology

3.1. Site location

The terminal building site should be so selected such that it will satisfy the following requirement: Centrally located with respect to the runways, Easy access to highway, Favorable orientation with respect to wind, topography, etc., Ease to get public facilities like water, sewage disposal, telephone, etc., Adequate space available for parking, enough provision for future expansion.

3.2. Analysis of Glass for Exterior Facade

Based on the wind pressure, deflection on glass due to dead load, wind load and combination of load is analyzed using STAAD pro.

3.2.1. Design of Mullion:

In design of mullion, load on mullion due to dead load, wind load and combination of load is calculated. Using this load, required moment of inertia and section modulus of mullion is calculated.

3.2.2. Design of Transom:

In transom calculation, load on transom due to dead load, wind load and combination of load is calculated. Using this load, required moment of inertia and section modulus of mullion is calculated.

3.2.3. Design of Bracket

Reaction due to mullion and transom load at supports is analyzed using STAAD pro. Based on this reaction, design of projecting leg of bracket, design of base plate, design of weld and force in anchors is calculated.

3.3. Analysis of Terminal Building

Based on dead load, live load, wind load and façade load, the terminal building is analysed using STAADpro.

3.3.1. Design of Slab

In design of Slab, firstly, whether the slab is one way slab or two way slabs is found out. Then, maximum bending moment, shear force, main reinforcement, and distribution reinforcement is calculated and slab detailing is done.

3.3.2 Design of Beam

In design of beam, maximum bending moment, shear force, main reinforcement, and distribution reinforcement is calculated and beam detailing is done.

3.3.3. Design of Column

In design of column, longitudinal reinforcement and design of ties is calculated and slab detailing is done.

3.3.4 Design of Foundation

In design of foundation, based on the load from the superstructure, the foundation is designed. It can be an isolated footing, trapezoidal footing or combined footing.

IV. Results and analysis

Analysis of Exterior Facade

Wind Pressure Calculation

Design Wind Speed:

Consider basic wind speed is 39 m/s as per IS 875: Part 3.

Design Wind Speed, $V_z = k_1 \text{x } k_2 \text{x} k_3 \text{x} V_B$ [from IS 875: Part 3, Cl.5.3]

Where, k_1 – Risk Coefficient = 1.08

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k_2 – Terrain Coefficient = Category 2 = 1.12

k_3 – Topography Factor = 1.0

V_B – Basic Wind Speed

V_z = 1.08 x 1.12 x 1.0 x 39 = 47.17 m/s

Internal and External Pressure Coefficient:

Let, h – Height of building = 7.2 m

l – Length of building = 75.6 m

w – Width of building = 22.8 m

$\frac{h}{w} = \frac{7.2}{22.8} = 0.32$ [$\frac{h}{w} < \frac{1}{2}$]

$\frac{l}{w} = \frac{75.6}{22.8} = 3.32$ [$1 < \frac{l}{w} < \frac{3}{2}$]

Based on the value of $\frac{h}{w}$ and $\frac{l}{w}$, the value of pressure coefficient is taken from table 2 of IS 456: part 3.

C_{pe} – External Pressure Coefficient = -1

C_{pi} – Internal Pressure Coefficient = -0.2

Design Wind Pressure

Design Wind Pressure, P = 0.6 x V_z^2 x $(C_{pe} + C_{pi})$ [from IS 875: Part 3, Cl.5.3]

= 0.6 x 47.17^2 x (-1 – 0.2)

P = 1.602 kN/m^2

Analysis of Glass for DGU

Check for Glass Panel = 1.2x2.4m, 6mm +12mm AG + 6mm

Design of Exterior Facade Mullion Calculation

Design Assumption:

i. Designed as simply supported beam with one end simply supported and other end roller support.
ii. Mullion is suspended from above slab.
iii. Deflection is limited to L/175 or 20 mm whichever less is.
iv. Load combination shall be design load or combination load which is equal to 2DL + 1.5WL.
v. Dead load includes as follows
   a. Glass weight = 25 kN/m^2
   b. Total thickness of glass = 12 mm [Glass Specification = 6 mm thickness glass + 12 mm gap + 6 mm thickness glass]
   c. Mullion and Transom weight = 0.098 kN/m^2 [Approximate]
vi. Live load and seismic load shall not be considered for facade.

Load: Tributary Area = Width x Height= 1.2 x 3.6= 4.32 m^2

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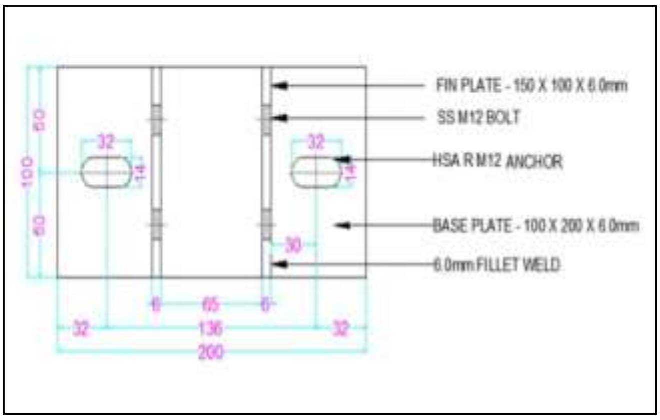
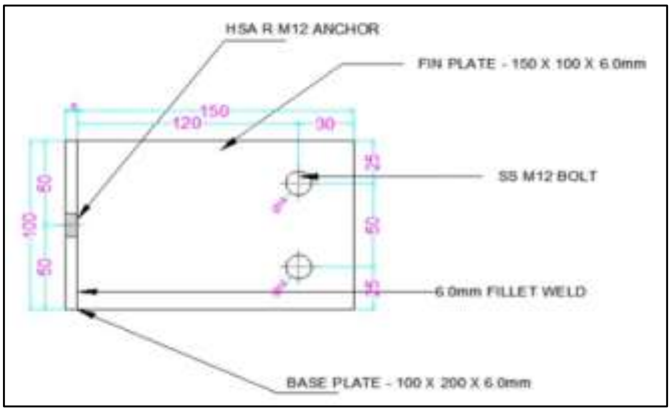
Table 1.Load Calculation

Load	Description	Unit Weight	Weight
DL	Glass weight for 12 mm thickness	25 kN/m^2	= 4.32 x 25 x 0.012 = 1.296 kN
	Mullion and Transom	0.098 kN/m^2	= 4.32 x 0.098 = 0.423 kN
		Total DL	1.719 kN
WL	1.602 kN/m^2		=1.602 x 4.32 = 6.92 kN

DL = 1.719 kN





WL = 6.92 kN

Figure 1.Elevation of Bracket

Figure 2. Side Elevation of Brackets

Load Combination = 2DL + 1.5WL

= (2 x 1.719) + (1.5 x 6.92) = 13.82 kN

UDL over Mullion $= \frac{13.82}{3.6}$ = 3.84 kN/m

Reaction due to Mullion and Transom

Bracket Calculation

Forces:

FY = 2.528 kN

FX = 0.267 kN

Factor Forces

FX = 0.267 x 1.5 = 0.4 kN

FY = 2.528 x 1.5 = 3.792 kN

Design of Projecting Leg

Plate – 100 x 6 mm thickness

i. Check for Tensile Stress due to the Wind Load

Max. Axial Force on each Plate = 0.4/ 2 = 0.2 kN.

Cross sectional Area, A_g = 100 x 6 = 600 mm^2

Net sectional Area, A_n = 600 – (2 x 12 x 6) = 456 mm^2

Yielding due to gross Section

T_{dg} = (f_y x A_g) / γ_{mo} [from IS 800: 2007, Cl.6.2] = (250 x 600) /1.1 = 136 kN

Rupture of Net Section

T_{dn} = (0.9 x f_y xA_n) / γ_{ml}

[From IS 800: 2007, Cl.6.3.1]= (0.9 x 410 x 456)/1.25

= 134 kN

The Design Tensile Strength =134 kN > 0.2 kN Hence Safe

ii. Design Bending Capacity of the section due to dead Load

Dead Load on each plate = 3.792/2 = 1.9 kN

Loading Point (eccentric) = 0.12 m

Max. Bending Moment = 1.9 x 0.12 = 0.228 kN-m

iii**.** Design Bending Strength

M_d = (Z_e x f_y) /γ_{mo} [from IS 800: 2007, Cl.8.2.1.2]

Where, $Z_e = \frac{bd^2}{6} = \frac{6\ x\ 100^2}{6}$ =10000 mm^2

M= (1.0 x 10000 x 250) / 1.1= 2.27 kN-m Hence Safe

iv. Check for M12, SS 316; Property Class 50 Bolt: (Connecting Mullion to Bracket)

Factored Forces:

FX = 0.267 x 1.5 = 0.4 kN

FY = 2.528 x 1.5 = 3.792 kN

Resultant Shear Force on the bolt = $\sqrt{0.4^2 + 3.792^2}$ = 3.82 kN

Load per bolt = 3.82/2 = 1.91 kN

Check for Shear stress

Permissible Shear Stress = 145 N/mm^2

Area of cross section = $\frac{\pi}{4}$ x 12^2 x 0.75 = 84 mm^2

Shear Stress induced in the Bolt = $\frac{1.91\ x\ 10^3}{2\ x\ 84}$ = 11.44 N/mm^2< 145 N/mm^2 Hence Safe

Design of Weld

i. Factor Forces

FX = 0.267 x 1.5 = 0.4 kN

FY = 2.528 x 1.5 = 3.792 kN

Assume 6 mm thickness fillet weld around the section

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Length of the weld = 100 mm

ii. Check for Axial & Shear Load

No of 100 mm Weld Line = 4

Axial Load per Line = 0.4 /4 = 0.1 kN

Shear Load per line = 3.792 /4 = 0.9 kN

Eccentric Moment = 0.9 x 0.12 = 0.108 kN-m

iii. Check for shear stress

Direct Shear stress = $\frac{p}{t_t \mathrm{x} l_w}$

[From IS 800: 2007, Cl.10.5.9] = $\frac{0.9 \text{ x } 10^3}{0.7 \text{ x } 6.0 \text{ x } 100}$

= 2.15 N/mm^2< 157.8 N/mm^2 Hence Safe

iv. Check for Normal stress

Normal stress =$\frac{p}{t_t \mathrm{x} l_w}$ [from IS 800: 2007, Cl.10.5.9]

= $\frac{0.9 \text{ x } 10^3}{0.7 \text{ x } 6.0 \text{ x } 100}$ = 0.24 N/mm^2< 157.8 N/mm^2

Normal Stress due to Eccentric Moment = $\frac{M}{Z}$

= $\frac{0.108 \text{ x } 106}{(0.7 \text{ x } 6 \text{ x } 100 \text{ x } 100)\ /6}$ = 15.5 N/mm^2

Hence Safe.

v. Check for combination of stresses

a. $f_c = \sqrt{({f_a}^2 + 3q^2)}$ [from IS 800: 2007, Cl.10.5.10.1.1]

= $\sqrt{((0.24 + 15.5)^2 + 3\ x\ (2.15)^2)}$

=16.2 N/mm^2

b. $\frac{f_u}{\sqrt{3}\ x\ \gamma_{mw}} = \frac{410}{\sqrt{3}\ x\ 1.5}$ [from IS 800: 2007, Cl.10.5.7.1.1]

= 157 N/mm^2

Hence provide 6 mm thickness fillet weld.

Design of Column

Column of Dimension – *3.6m*

Design Data

Length of column, L – 3.6m

Diameter of Column, D – 700mm

Characteristic Load, P – 1850 KN

Ultimate Axial Load,

Pu =1850x1.5

= 2775 KN

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f_{ck} - 25 N/mm^2

f_y - 415 N/mm^2

Load Factor – 1.5

Step II – Size of Column Calculation

Based on Short column Criteria,

$\frac{le}{D} < 12$

Effective Length of Column, $l_e = \frac{L}{\sqrt{2}}$

= 0.707 x 3600 = 2545.2mm

$\frac{le}{D} < \frac{2545.2}{700} < 12 = 4.5 < 12$ I

Hence, It is a Short Column.

Check for Eccentricity

$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{3600}{500} + \frac{700}{30} = 30.53 < 20mm$

Hence, e_{min} = 30.53mm

$e_{min} \leq 0.05D = 0.05 \times 700 = 35mm$

Comparing Condition i and ii,

$e_{min} < 0.05D = 30.53 < 35$ II

Hence, It is Axially Loaded Column.

Longitudinal Reinforcement Calculation

From Clause 39.3 & 39.4, IS 456 – 2000.

$P_u = 1.05\ (0.4f_{ck}A_c + 0.67f_yA_{sc})$

Circular column with helical reinforcement, strength is increased by 5%.

$Ag = \pi \times \frac{700^2}{4} = 384845.1mm^2$

$A_c = A_g – A_{sc}$

$P_u = 1.05\ \{0.4 \times 25 \times (384845.1 - A_{sc}) + (0.67 \times 415 \times A_{sc})\}$

$\frac{4500 \times 10^3}{1.05} = 10102183.88 – 10.5A_{sc} + 278.05A_{sc}$

$5816469.59 = 267.55A_{sc}$

$A_{sc} = 4908.74\ mm^2$

Provide 25mm diameter bars

Number of Bars = $\frac{4908.74}{\frac{\pi}{4} x\ 25^2} = 10$

Provide minimum A_{sc} of 10 no's of 25mm diameter bars.

Design of Ties

From clause26.5.3.2, IS 456 – 2000,

ϕ of ties $> \frac{1}{4}$ x largest ϕ of longitudinal bar = $\frac{1}{4}$ x 25 = 6.25mm or 5mm whichever is more.

Provide 8mm diameter spiral for ties.

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Spacing or pitch > 75mm

Spacing > diameter of core / 6 [∵ Clear cover = 40mm for columns]

Diameter of core = Outer to outer distance between spirals = D – (2 x clear cover)

Spacing= $\frac{(D-2\ x\ clear\ cover\ to\ the\ main\ reinforcement)}{6}$

Spacing = $\frac{(700-2\ x\ 40)}{6}$ = 620 / 6 = 103.33 mm

a. Spacing < 25mm

b. Spacing < 3 x diameter of helical reinforcement = 3 x 8 = 24mm

c. $\rho_s < 0.36(\frac{A_g}{A_{core}} - 1)\frac{f_{ck}}{f_y}$ -------(1)

$\rho_s = \frac{Volume\ of\ spiral\ in\ one\ loop}{Volume\ of\ core\ of\ concrete\ in\ one\ loop}$

Volume of spiral = perimeter of spiral x Area of spiral rft

Perimeter = π x D_s

D_s = Diameter of core – ϕ of helical reinforcement

D_s = 620 – 8 = 612mm

$\rho_s = \frac{(\pi\ x\ 612)x\ (\frac{\pi}{4}\ x\ 8^2)}{\frac{\pi}{4}\ x\ 620^2\ x\ pitch}$

$\rho_s = \frac{0.32}{pitch} = \frac{0.32}{S_v}$-----------(2)

$\rho_s < 0.36(\frac{A_g}{A_{core}} - 1)\frac{f_{ck}}{f_y}$

$\frac{A_g}{A_c} = \frac{\frac{\pi}{4}\ x\ 700^2}{\frac{\pi}{4}\ x\ 620^2} = 1.27$

$\rho_s < 0.36(1.27 - 1)\frac{25}{415} = 0.00542$

Subsitute ρ_s value in equation 2,

$\frac{0.32}{S_v} = 0.00542$

S_v = 59.04mm

Provide 8mm diameter spiral at 65mm pitch.

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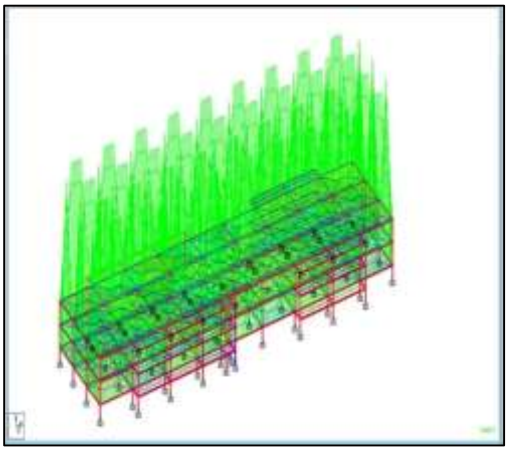

Figure 3. Dead Load

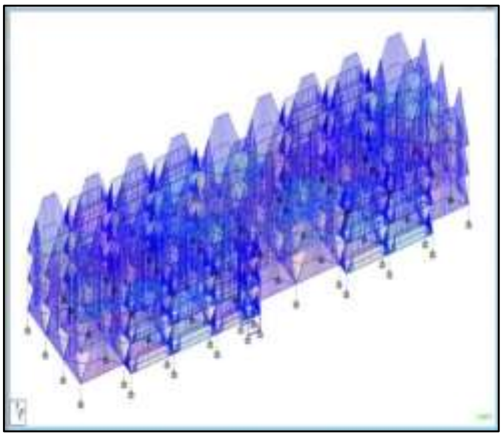

Figure 4. Live Load

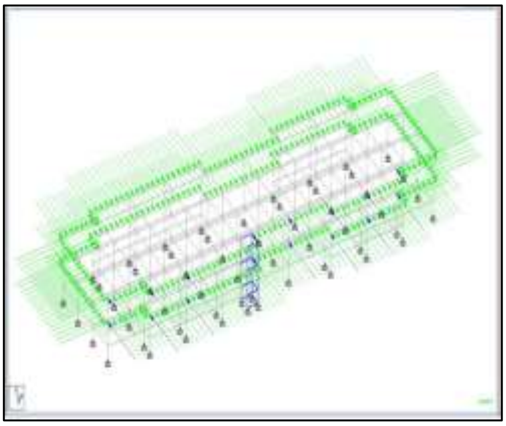

Figure 5. Facade Load

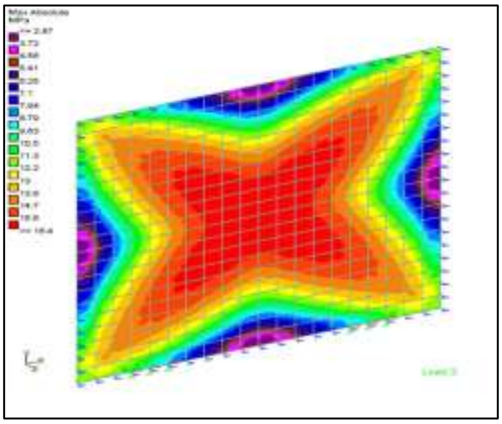

Figure 6. Wind Load Distribution

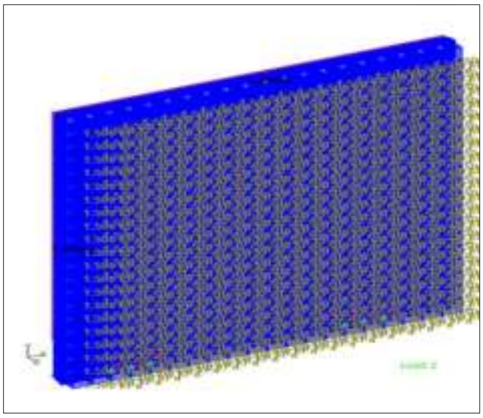

Figure 7. Facade Load Distribution

V. Conclusion

Based on the wind load, the deflection of double glass unit of thickness 12mm (6mm + 6mm) and single glass unit of thickness 6mm is found to be safe in STAAD pro. Hence, based on the safer deflection of glass, the design of

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mullion, transom and bracket is carried out and proved to be safe. The load from the bracket is applied to the beam of the airport terminal building in addition to dead load, live load and wind load. Now the structure is analyzed using STAADpro and found to be safe. The design of beam, slab, column and foundation is carried out as per IS 456-2000 and found to be safe. The detailing of the beam, column, slab and foundation is also done. The double glass unit is provided in the visible area and the single glass unit is provided in the invisible area like false ceiling for hiding the false ceiling visible from outside view and to provide deceptive appearance..

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