Design Consideration of Facade Wall system

Author : Rakesh R. Makwana
M.E.CASAD student, L.D.College of Engineering, Ahmedabad, Gujarat.

Abstract

Façades, the first aesthetical feature of a building which distinguishes one building from another, have to fulfil the basic aspects like protection against fire and burglary, climatic influence and environmental pollution. Development in facades has made it more functional, providing designers with the flexibility to create high performance solutions, which are visually exciting, both internally and externally. This paper is the state-of-art discussing the types of glasses in facades, their applications, functional and strength requirements in tall buildings.

Keywords: Facades, Failures, Stresses, deflection, Analysis using STAAD-pro.

1. Introduction

Structural Facades plays an essential role in science and building industry. Glass is a material commonly used in facade systems. It is a material known for millennia and has been used in buildings for centuries. Nowadays it is being used as a structural material rather than a transparent infill within a supporting frame. The changing approach to the use of glass has been made possible by the improved quality of glass, development of the float glass and thermal strengthening (tempering) process and the availability of analysis tools. The use of glass to create large transparent screens, roofs and floors has been driven by the architectural desire to achieve lightness of construction, transparency and the availability of larger panes of glass. Glass being a brittle building material is weak in tension because of its non-crystalline molecular structure. Glass balances the practical functions of thermal insulation, solar control, safety and security, acoustic insulation, fire protection etc. It has the failing that it is a brittle material but engineers are learning to design within the necessary safety parameters. A further limitation to the use of glass has been the ability to make structural connections. However, many proven solutions are now available. For the design of facade systems in India, ASTM / Euro Codes are normally followed as Indian Codes do not address such information. This necessitates more study on the structural performance of glass panels for Indian conditions. In the proposed study, the glass panels with different end conditions, at different loadings and for different aspect ratio will be analysed which will help the designers. This paper is the state-of-art discussing the types of glasses in facades, their applications, functional and strength requirements in tall buildings.

2. Types of Glasses in Facades

The following are the types of glasses commonly used in building industry as facades- Annealed Glass; Tempered or Toughened Glass; Heat Strengthened Glass; Reflective Glass and Laminated Glass.

2.1 Normal or Annealed Glass

Annealed or float glass is glass that has been cooled gradually from a high temperature during manufacture to minimize residual stress. It allows the glass to be cut by scoring and snapping for required size. It is the most commonly available type of flat glass. Standard thicknesses of annealed glass in mm are 3, 4, 6, 8, 10, 12, 15,19&25. This glass is one of the weakest glass types and has a significant potential to break when subjected to over loads. On breakage, the glass tends to form sharp-edged, pointed shards which may cause piercing and cutting injuries. The post failure behaviour of the glass will be dominated by its lack of residual strength on breakage. The glass may not be able to resist loads potentially causing (i) full or partial collapse of the glass structure (ii) penetration of the glass structure and (iii) glass fragments or shards to fall when it is used at height. It is for these reasons that monolithic annealed glass is not used as a highly stressed structural glass. Annealed glass is subject to stress corrosion cracking under long duration loads. This phenomenon is due to chemical corrosion at the tips of surface micro-cracks caused by the action of water, which elongate the crack. There is a threshold stress below which stress corrosion cracking is no longer a significant factor and this is taken as 7 N/mm2. Another phenomenon to which annealed glass is vulnerable is thermal shock. This causes cracking due to internal stresses resulting from temperature differences between different parts of the same sheet of glass. The critical temperature difference has been found to be 33°C. Annealed glass can be processed to produce other glass types such as tempered, laminated and insulating.

2.2 Tempered or Toughened Glass

Tempered glass is an extremely strong glass which is heat treated to a uniform temperature of approximately 650ºC and rapidly cooled to induce compressive stresses of 770 kg/m2 to 1462 kg/m2 on the surfaces and of the order of 680 kg/m2 on the edges. Tempered or toughened glass gains its added strength from the compressed surfaces. However, if a deep scratch or an impact penetrates the surface, the glass will break into a number of small particles. The heat treatment process for tempered glass requires that all fabrication be completed prior to toughening. Drilling, grinding or sand blasting and edge cutting after toughening may result in glass breakage. The heat treatment process does not change the light transmission and solar radiant heat properties of the glass. In the event of breakage, toughened glass generally breaks into small, relatively blunt, glass fragments called dice. These fragments do not have sharp edges and are unlikely to cause deep cutting injuries. However, they may form blunt-edged clumps. These are less likely to cause piercing injuries than shards of annealed or heat strengthened glass but may still cause injury. Due to the inherent superior features of tempered glass like more strength, ability to withstand sudden impacts and breaking safely into small pieces, it is used as a safety glazing; applications where glass safety is needed is facades on higher floors with risk of falling glass.

2.3 Heat Strengthened Glass

Heat strengthened glass is a type of tempered glass which has been strengthened thermally by inducing a surface compression of 422 to 658 kg/cm2 as compared to a range of 770 to 1462 kg/cm2 in case of fully tempered glass. In the manufacturing process, a permanent compressive surface stress and a permanent tensile internal stress are induced in the glass. The compressive surface stresses give the glass a bending strength higher than that of annealed glass and reduce the likelihood of glass failure. Heat strengthening of glass is a separate process; heat strengthened glass is valued for its mechanical strength, which is twice that of normal annealed glass though half of fully tempered glass. With the exception of strength and breakage characteristics, heat strengthened glass retains the normal properties of annealed glass. Heat strengthened glass provides necessary resistance to thermal stress associated with high performance glazing materials such as tinted glass and reflective glass. It also provides necessary resistance to building heat when used as spandrel glass.Heat Strengthened glass is suitable for spandrel and vision panels of curtain walls and structural glazing as they safeguards against thermal breakage. It is used for making laminated glass panels for safety combined with strength. It is used in complex glass combinations like double-glazing.

2.4 Laminated Glass

Laminated glass is composed of two or more layers of glass with one or more layers of a transparent/ pigmented and specially treated plastic Polyvinyl Butyral [PVB] sandwiched between the glass layers. The glass panes (layers) can be either normal glass or tempered glass. When the glass is broken, fragments tend to adhere to the plastic [PVB] interlayer thereby reducing the risk of injury and helping to resist further damage by weather. The strength, breakage characteristics, and post failure behaviour of laminated glass are dependent upon the glass types, glass thicknesses, and interlayer types and thicknesses used in construction. Laminated glass does not shatter like ordinary glass. It absorbs impact, resists penetration and remains intact even if broken, holding glass fragments in place and lowering the risk of injury. It resists intrusion because the interlayer continues to safeguard the building even after the glass itself is broken. It tends to resist impact. It can even resist bullets, heavy objects or small explosions. It is capable to stop flying debris and limit or avoid splintering on opposite side of the impact. It is an excellent barrier to noise. When exposed to heat, laminated glass breaks but stays in place longer. The risk of thermal breakage is avoided only when heat strengthened / tempered laminated glass is used. Areas where laminated glass is used are: Curtain wall glazing, sloped glazing, skylights, glass roofs and floors, aquariums, safety glazing for partitions and security glazing for banks against bullets/ hand propelled objects. There can be made the distinction in annealed glass (Float-glass) with a tensile strength of 45 MPa, heat strengthened glass with a tensile strength of 70 MPa and thermally toughened glass with a tensile strength of 120 MPa.

2.5 Properties of different glasses are as under

Table - 01

	Normal Glass	Toughened Glass	Laminated Glass	Heat Strengthened Glass
Density (g/cm^3)	2.42-2.52	2.42-2.52	2.42-2.52	2.42-2.52
Tensile Strength (N/mm^2)	40	120-200	32	120-200
Compressive Strength (N/mm^2)	1000	1000	1000	1000
Modulus of Elasticity (Gpa)	70	70	70	70
Poisson's ratio	0.22	0.22	0.22	0.22
Available thickness (mm)	2-25	3-25	4.38-20.76	3-25
Available sizes (mm x mm)	2440 x 3660	2440 x 3660	2000 x 3210	2440 x 3660

3. Reasons of Glass Plate Failure

Glass plates are thin rectangular plates with continuous edge supports. The plate supports are designed to allow the plate edges to rotate and to slip in the plane of the plate, but to limit the lateral displacement of the plate. The design load for a typical glass plate is a uniform lateral load representative of wind forces. Glass plates normally experience lateral deflections which are in excess of their thicknesses when exposed to design loads. When a plate undergoes deflection of this magnitude the middle surface of the plate stretches, resulting in the introduction of membrane stresses.

The surfaces of glass plates are covered with minute flaws of varying geometries and orientations. These flaws result from the manufacturing process and subsequent exposure. When a glass plate is loaded, the surface flaws interact with surface tensile stresses and cause large local stress concentrations. Glass failure is of concern as it may impair or lead to the failure of the structure and allow glass to fall and injure people. Glass plate failure occurs when the local stress associated with one of the surface flaws becomes large enough to initiate fracture. The critical flaw is the surface flaw which initiates the fracture. The magnitude of the stress-raising potential of a particular flaw depends upon its geometry and orientation, with respect to the nominal tensile stress field. There is considerable variability associated with the stress-raising characteristics of glass plate surface flaws. Therefore, the location of the flaw which initiates glass plate failure does not necessarily correspond
to the point of maximum stress. Glass failure may be due to impact or thermal stress.

3.1 Impact

Failure is caused by a sudden localized contact with a force that is sufficient to overcome the strength of the glass. This contact force may be caused by contact with a hard body or a soft body and may be caused accidentally, deliberately or by the forces of nature. Hard body impacts are caused by stones and larger objects that may be thrown, dropped or carried by extreme winds. Soft body impacts are caused by human bodies and objects such as footballs.

3.2 Thermal Stress

Failure is caused by a temperature difference between the center and edge of a glass pane, which induces stresses within the glass. The centre of the glass is heated by sunlight, and the edge of the glass remains relatively cold (under the shade of frame). This results in the expansion of the centre of the glass which produces a tensile stress on the glass edges and causes failure. The other common causes of glass failure are inclusions, malicious damage, small projections, scratching, deliberate impact, failure of heat-treated glass and blast.

During strong windstorms, various cladding (glazing panels) are often damaged. Damage to windows and glazing has generally been outstanding in both residential structures and high-rise buildings.

4. Analysis of Unitized Facade wall

4.1 General

Unitized Facade wall is not an integral part of structure and it carries only out of plane loading due to wind load and it is not supposed to contribute anything in lateral load resisting system of structure. The facade wall is fixed with main structural member such that no in plane stresses are induced in facade wall. Normally aluminium is used as a material for framing around glass in this system. Once the type of glass to be used is selected, the thickness of glass depends on following factors:

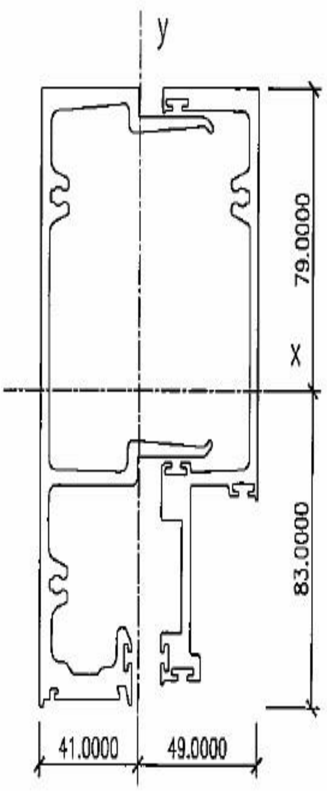
(1) Area of panel
(2) Support conditions- i.e. four, three or two side fixing, or point fixing at corners.

(3) Aspect ratio of glass pane (length/width)
(4) Wind pressure at level of panel IS875-1987 part3)
(5) Strength/Load carrying capacity of glass.

4.2 Design Example

A unitized facade wall system of size 6mx6m is modelled in software Staad-pro with glass panes of size 1.5mx1.5m confined by aluminium section in
all four edges as shown in fig-2. 6mm thick Annealed glass is taken for analysis whose properties are given in table-1.
Frame consists of vertical member (mullions) & horizontal members (transoms) spaced at 1.5m c/c made of aluminium, whose properties are as under. Young's modulus – 6.8947 kN/m^2
Poisson's ratio – 0.33
Density – 26.6 kN/m^3
Aluminium sections are available in different shapes and size and following section given in fig-1 is considered here for analysis.

The linear analysis is carried out in STAAD-Pro for the given system. Fig-3 shows stresses in glass plates under the action of Uniform wind pressure 3.6kN/m2 normal to glass plates. As per Australian standard AS 1288-2006, Table-B1, permissible stresses for 6mm thick Annealed glass at edge is 28.96N/mm2 and for toughened glass permissible stress at edge is 72.39N/mm2. Here analysis result shows that stress in glass is 46N/mm2. Therefore 6mm thick annealed glass is not fit for the given facade wall and toughened glass is to be adopted.
Here maximum deflection in glass is 19.388 mm which is smaller than span/60 as per AS1288-2006, thus satisfying the serviceability limit. Fig.-4 shows that maximum deflection in vertical member (mullion) is 19.177mm which is smaller than span/180 as per BS8118, hence mullion is safe in deflection.
Similarly, different glasses with different boundary conditions can be analysed using software for selection of glass thickness against given wind pressure.



MASS PROPERTIES (UNIT)	VALUES
Area (mm²) :	2764.8890
Perimeter (mm) :	1367.9708
Bounding Box – X (mm):	–40.5700 to 49.4300
Bounding Box – Y (mm):	–83.3005 to 79.1995
Centroid – X (mm) :	0.0000
Centroid – Y (mm) :	0.0000
Moments of inertia – X (mm⁴) :	8379601.0445
Moments of inertia – Y (mm⁴) :	2821450.0272
Product of inertia – XY (mm⁴) :	991637.9147
Radii of gyration – X (mm) :	55.0520
Radii of gyration – Y (mm) :	31.9446
Principal moments along X–Y (mm⁴) :	2649829.6118 along [0.1705 0.9854]
Principal moments along Y–X (mm⁴) :	8551221.4600 along [–0.9854 0.1705]
Elastic Modulus – Zx (mm³):	I / y–max= 100594.7980
Elastic Modulus – Zy (mm³):	J / x–max= 57079.7340

Fig.-1

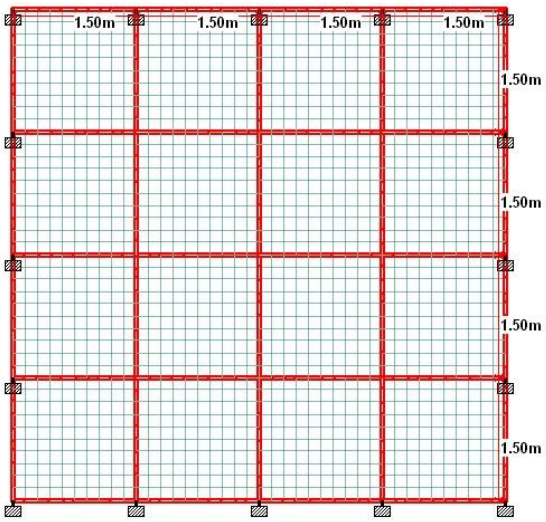


Fig-2

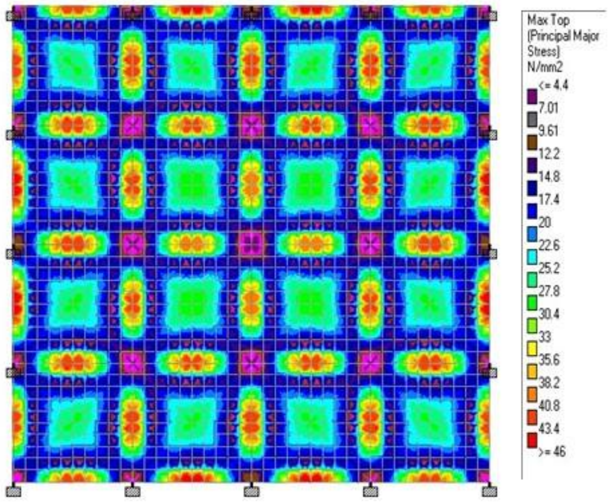
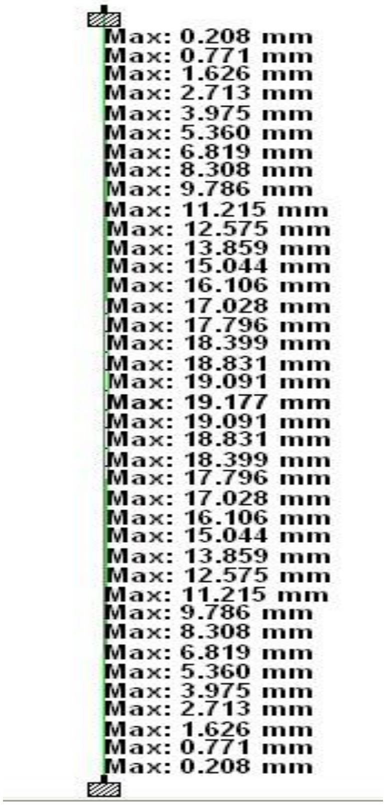


Fig-3



5.0 Conclusion

In this paper, Unitized facade wall has been introduced, and analysis using software STAAD-Pro is demonstrated.

6.0 References

[1] Australian standard- glass in buildings-selection and installation AS1288-2006.
[2] BS8118, Structural use of aluminium, British standard Institute, part 1, 1991.
[3] IS 3548-1988 Code of practice for glazing in buildings.
[4] Guidelines on use of glass in buildings by CCPS (Confederation of construction products & services, new delhi)
[5] IS 875-1987 part3
[6] ASTM E1300, standard practice for determining load resistance for glass buildings, 2002.