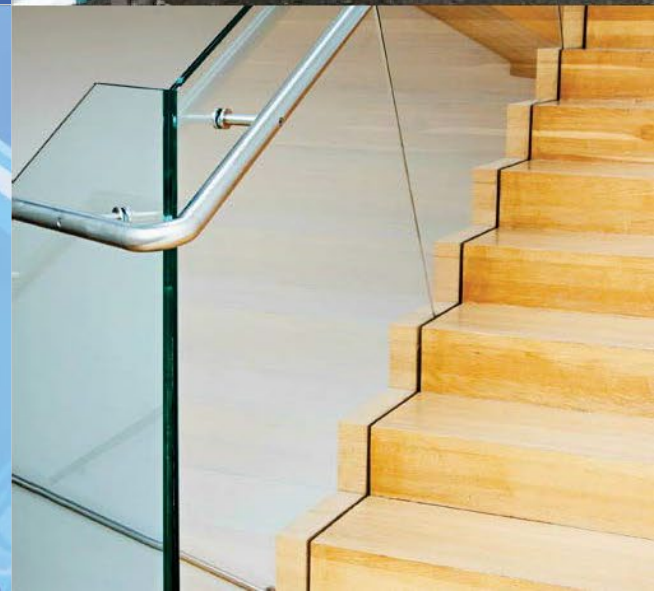




2018年 玻璃結構 作業守則



前言

《玻璃結構作業守則》（本守則）為建築物結構玻璃的設計、建造、測試和品質保證提供指引。

雖然本守則並非法定文件，但遵照本守則所列的要求將可視為符合《建築物條例》及相關規例的規定。

本守則由屋宇署編撰，內容是根據屋宇署委聘的顧問在督導委員會監督下進行玻璃結構研究所得的結果編撰而成。督導委員會的成員來自學術界、專業學會和相關的政府部門。對於督導委員會委員在編撰本守則時所付出的努力和貢獻，謹此致謝。

本守則將作定期檢討，歡迎業界提供改善建議。

本守則可在屋宇署網站 <http://www.bd.gov.hk> 瀏覽，亦可按網站所訂的條款及細則下載。

屋宇署

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1 GENERAL

1.1 SCOPE

The Code of Practice for the Structural Use of Glass (the Code), provides guidelines on the design, construction, testing, and quality assurance of glass structures or elements in buildings.

1.2 DESIGN CONSIDERATIONS

1.2.1 Aim of glass design

In the Code, the limit state design principle is adopted for structures using structural glass with the aim to achieve the following:

- a) Overall stability and buckling resistance against the design loads;
- b) Strength against collapse under the design loads and the imposed deformations of supporting structures;
- c) Integrity and robustness against progressive collapse under the design loads;
- d) Serviceability under the design loads and the imposed deformations of supporting structures;
- e) Water and air tightness;
- f) Durability;
- g) Quality; and
- h) Maintainability during its design working life.

1.2.2 Design references

The Code has made references to various international standards in Annex A.

Where an alternative method or a performance-based approach is adopted, adequate information, including proposals on compliance testing, must be provided to demonstrate that the aim of glass design specified in clause 1.2.1 can be achieved.

1.3 GLOSSARY OF TERMS AND DEFINITIONS

bite width of structural sealant used to bond the glass to supporting members.

buckling resistance
limit of force or moment that a member can withstand without buckling failure.

curtain wall
non load-bearing enclosure fixed onto the load-bearing structure with its dead loads, imposed loads and wind loads transferred to the structure through fixings.

ultimate design strength
ultimate design strength obtained by applying partial material factor to the specified minimum yield strength or tensile strength of the material.

gasket plastic-like solid material used to separate glass and other brittle materials from contact with each other or supporting frames.

glass

annealed glass
ordinary float glass commonly manufactured by floating the molten glass on a bed of molten tin until it sets. It can be cut by scoring and snapping. It will break into large fragments with sharp edges.

decorative glass
clear or patterned glass processed by craftsmen for decorative effect. Sand-blasted, acid-etched, embossed, fritted and printed glass fall into this category. Decorative interlayers may also be incorporated in laminated glass.

heat strengthened glass

glass which has been heated past its softening point and chilled rapidly to increase its strength. It breaks like annealed glass.

Insulating Glass Unit (IGU)

assembly consisting of two or more panes of glass that are spaced apart with spacer bars to form a cavity between the glass panes.

laminated glass

assembly consisting of two or more panes of glass that are bonded together by interlayer material.

patterned glass

glass having a pattern impressed/embossed on one side or both sides.

safety glass

glass or glass assemblies that are "break safe" such as laminated or tempered glass.

tempered glass

glass, also known as "thermally toughened glass" which has been subjected to a thermal treatment characterised by rapid cooling to produce a compressively stressed surface. It will break into small fragments with rough edges.

tinted glass

glass which has small amounts of colourants added to the glass to give it solar control properties.

wired glass

glass incorporated with wire mesh.

glass wall

wall mainly formed by structural glass elements spanning between floors.

heat soak process

quality control process to heat up tempered glass for a period of time to reduce the possibility of spontaneous breakage in service.

instability

inability to carry further load due to vanishing stiffness.

interlayer

layer or multiple layers of material acting as an adhesive between glass panes which enhance the performance of the finished assembly, for example, composite action, impact resistance, solar control, acoustical insulation, etc.

load

dead load

any permanent structural or non-structural loads that remain throughout the service life of a structure as stated in the Building (Construction) Regulations and the Code of Practice for Dead and Imposed Loads.

dynamic load

part of an imposed load resulting from motion.

factored load

specified load multiplied by the relevant partial safety factor.

imposed load

applied load, with the exception of dead and wind loads, likely to arise during its service life of a structure as stated in the Building (Construction) Regulations and the Code of Practice for Dead and Imposed Loads.

wind load

applied load as calculated in accordance with the Code of Practice on Wind Effects in Hong Kong.

linear analysis

structural analysis based on elastic stress and the original geometry prior to deformation for stress computation.

local stability

stability of element or part of element against local buckling.

members**glass beam**

horizontal load-bearing element predominantly subject to bending.

glass column

vertical load-bearing element predominantly carrying axial force and possibly moments.

glass fin

vertical or sloping glass beam used to support façade and glass wall which are predominantly subject to wind load and other lateral load.

mullion

vertical member in curtain wall or glass wall system that directly supports a glass/cladding element.

transom

horizontal member in curtain wall or glass wall system that directly supports a glass/cladding element.

restraints**lateral restraint for a glass fin**

restraint that prevents lateral movement of the compression edge.

torsional restraint

restraint that prevents rotation of a member about its longitudinal axis.

nonlinear analysis

structural analysis that allows for nonlinear effects such as large deflection effect and membrane action. Nonlinear analysis can be second-order direct and second-order indirect analysis of which the former does not require effective length for flexural buckling check and the latter still requires effective length for flexural buckling check.

overall stability

stability of overall structure against buckling, overturning, uplift and sliding.

setting block

block of resilient non-absorbent material placed between the bottom edge of the glass and frame to support the dead load of the glass to the frame at specific points to limit deformation of the supporting member.

slenderness

effective length divided by the radius of gyration.

stability

resistance to failure by buckling or loss of static equilibrium.

window

framed glazing in an opening of an external wall to allow natural light and/or ventilation through the building.

window wall

windows spanning between floor slabs of the building.

1.4 MAJOR SYMBOLS

A	Cross-sectional area of the member
E	Modulus of elasticity
G	Shear modulus
L	Span between end supports or Length
M_d	Ultimate design moment obtained from loading
M_w	Working design moment obtained from loading
M_{cr}	Critical elastic buckling moment
M_e	Elastic moment capacity
M_u	Ultimate moment capacity
R	Factored design pressure
bi	Minimum structural sealant bite
c	Strength coefficient
k_{pane}	Load sharing factor of glass pane
t	Minimum thickness of glass pane
t_{eq}	Equivalent laminated glass thickness
C_t	Tensile stress (lateral load) of secondary (structural) sealant
I_{eq}	Equivalent second moment of area due to composite action in laminated glass
I	Second moment of area of monolithic glass with total thickness equal to sum of individual glass
p_b	Permissible design bond strength for structural sealant
p_y	Ultimate design strength
p_{yf}	Ultimate design strength of glass fin
γ_d	Strength reduction factor
γ_f	Partial load factor
γ_s	Glass surface treatment reduction factor
γ_m	Partial material factor
λ	Degree of composite action in terms of stiffness
ρ	Density of glass pane
δ	Deflection of glass pane or Deflection due to member curvature and loads
ν	Poisson's ratio

2 LIMIT STATE DESIGN

2.1 GENERAL

The limit state design considers the functional limits of strength, stability and serviceability of both structural elements and the structure as a whole. The limit state can be defined as the state beyond which the structure no longer fulfills the relevant design criteria.

The limit state design is based on the requirement that the “Resistance” of the structure should exceed the “Load Effects” for all potential modes of failure, including allowance for uncertainties in load effects and variability in resistance and material properties, i.e.,

$$\text{Resistance} \geq \text{Load effects} \quad (2.1)$$

The load effects shall be determined by normal structural analysis methods for axial, bending, shear or torsion in structural members and components, multiplied by a partial load factor (γ_f) to give an upper bound estimate of load effects. Resistance effects shall be determined by normal strength of materials, geometry of member and material properties. The material strength shall be divided by a partial material factor (γ_m) to give a lower bound estimate for material properties, covering the variability of material strength, member dimensions and product variability. Partial factors are specified in clause 5.4.

Limit states considered in the Code are either the ultimate limit state or the serviceability limit state. Glass structures or elements should be designed by considering the limit states beyond which these structures would become unfit for their intended use. Appropriate partial factors should be applied to provide adequate degrees of reliability for ultimate and serviceability limit states. Ultimate limit states concern the safety of the whole or part of the structure whereas serviceability limit states correspond to limits beyond which specified service criteria are no longer met.

Apart from γ_m , the overall level of safety in any design has to take into account a partial load factor (γ_f) covering the loading and variations of expected structural behaviour.

The values assigned to γ_f depend on the type of load and the load combination. The characteristic loads are multiplied by the partial load factor to check the ultimate strength and stability of a structure.

2.2 ULTIMATE LIMIT STATE

2.2.1 Definition

Ultimate limit state considers the strength and stability of structures and structural members against failure.

2.2.2 Strength and stability

For satisfactory design of an element at the ultimate limit state, the ultimate design resistance or capacity of the glass pane must be greater than or equal to the ultimate design load effects. The ultimate design resistance of glass pane is evaluated by reducing the ultimate design strength of glass by a partial material factor. The ultimate design loads are evaluated by multiplying the characteristic loads by partial load factors as described in clause 5.4. The layout of the structure and the interaction between the structural members should be in a manner achieving a robust and stable design.

2.2.3 Progressive collapse

Glass structures should be planned and designed against disproportionate collapse such that it will not be unreasonably susceptible to situations where damage or failure of single glass element or small areas of a structure may lead to progressive collapse of a major part of the structure. For example, failure of a glass column may lead to the failure of glass beam and glass floor. In case of a failure of one single element, the portion of the glass structure at risk of collapse should not exceed 70 m² (floor, frontal or total area), due to the failure of one single element. Additional measure and special consideration should be provided to enhance the structural integrity and robustness in order to minimise the risk of a localised damage leading to the collapse of a major part of the structure.

2.3 SERVICEABILITY LIMIT STATE

2.3.1 Definition

The serviceability limit state considers service requirements for a structure or structural elements under serviceability design loads. For instance, deflection, human induced vibration and wind induced oscillation are considered in the serviceability limit state.

For a satisfactory design of an element at serviceability limit state, the serviceability design resistance must be greater than or equal to the serviceability design load effects as described in clause 5.5.

2.3.2 Deflection

Deflection or deformation of a structure or any part of it should not adversely affect its efficiency or performance. Deflection should also be compatible with the degree of movement governed by other connected elements.

2.3.3 Vibration

Structural analysis should be applied to determine the natural frequencies of vibration of glass structures in order to mitigate excessive oscillation due to the dynamic effects of human and other forces. For the design of glass floor or staircase, it may be necessary to consider the vibration of the members for human comfort. Reference should be made to relevant design guidelines and specialist literature.

3 LOADS

3.1 GENERAL

All relevant loads should be considered separately and in such realistic combinations as to give the most critical effects on the structural elements and the structure as a whole. The magnitude and the frequency of loads should also be considered to prevent resonance of glass structure sensitive to vibration.

Loads induced on glass structure by construction or settlement of supports should also be considered.

3.2 DEAD, IMPOSED AND WIND LOADS

For characteristic dead, imposed and wind loads, reference should be made to the Building (Construction) Regulations, the Code of Practice for Dead and Imposed Loads and the Code of Practice on Wind Effects in Hong Kong.

3.3 LOAD EFFECTS FROM MOVEMENTS

Glass design should take into account vertical and horizontal movements. Curtain wall, window wall, glass wall or glass supporting structures should be designed to accommodate movements due to dead, imposed, wind and/or thermal load. Due consideration should also be taken to the following building movements:

- (1) Movements due to concrete creep, settlement and shrinkage.
- (2) Horizontal movement due to inter storey drift.
- (3) Vertical movement due to possible relative deflections between consecutive floors.

3.4 LOAD EFFECTS FROM TEMPERATURE CHANGE

The glazing structure should be designed for the following temperature ranges:

- (1) Surface not under direct sunlight, the range is 0-40°C.
- (2) Surface exposed to outside and under direct sunlight, the range is 0-50°C for clear glass and 0-90°C for tinted glass.

The load effects should take into consideration the temperature at installation of the glazing structure.

3.5 LOAD DURATION

Load resistance of a glass structural element is determined by a given probability of breakage and load duration. Load duration is defined as follows:

- (1) Short-term load duration is defined as the duration of load applying not more than 3 seconds (e.g. wind load and horizontal imposed load for protective barrier).
- (2) Medium-term load duration is defined as the duration of load applying more than 3 seconds but not more than 1 day (e.g. maintenance load and temperature load).
- (3) Long-term load duration is defined as the duration of load applying more than 1 day (e.g. load types other than short-term and medium-term load durations).

4 GLASS MATERIALS, TYPES AND ASSEMBLIES

4.1 GLASS

4.1.1 General

Glass is a brittle material and normally fails in a sudden and catastrophic manner. Glass is weak in tension because of the nature of its atomic structure and the resulting susceptibility to flaws and inability to resist crack propagation. When glass is loaded in tension it behaves purely elastically until it fails suddenly at the ultimate tensile strength, unlike structural steels, aluminium alloys and even reinforced concrete that can accommodate plastic deformation after yield point (Figure 4.1). Stress or moment re-distribution does not occur in glass and local failure commonly leads to global failure. Glass strength is highly statistical in nature in common with other brittle materials. Highly stressed and larger stressed area results in a higher probability of failure.

In most structural applications of glass, it is necessary for the components to sustain mechanical stress. When a material is stressed, it deforms, and strains are created. At a low level of stress, most materials obey Hooke's law, that is, strain is linearly proportional to stress. For ductile materials such as metals and plastics; after they reach their yield point, they undergo a significant portion of plastic deformation. On the other hand, brittle materials such as glasses and ceramics, can accommodate very little, if any, plastic deformation and fail suddenly (Figure 4.1).

Glass at normal temperatures does not creep or "flow" and does not undergo fatigue in the metallurgical sense. Rather, there is slow growth of micro-cracks under sustained or cyclical loads. Once the cracks have reached a critical size, the glass may fail suddenly in a brittle manner.

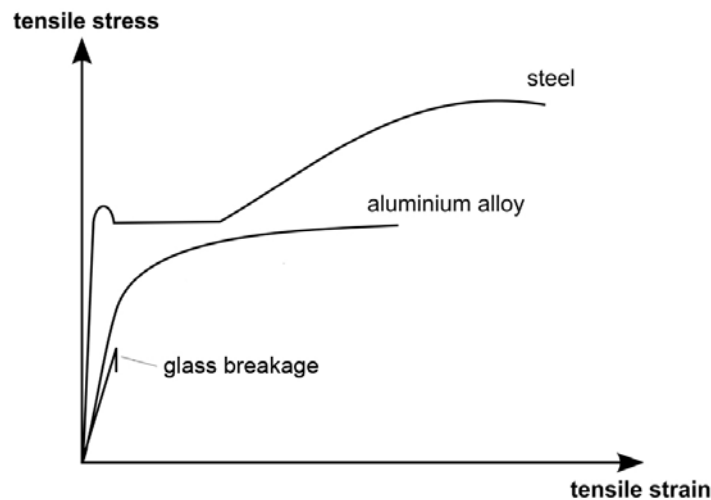


Figure 4.1 Stress-strain behaviour of glass, steel and aluminium alloy.

4.1.2 Glass material

Glass is an inorganic solid with a non-crystalline (amorphous) atomic structure and is produced from a wide variety of constituent materials. The Code applies to soda lime silicate glass commonly used in buildings.

The typical composition and physical properties of soda lime silicate glass are shown in Tables 4.1 and 4.2 respectively.

Table 4.1 Typical composition of soda lime silicate glass

Chemical Name	Chemical Formula	Weight Percentage
Silica	SiO ₂	69% - 74%
Lime	CaO	5% - 14%
Soda	Na ₂ O	10% - 16%
with small amounts of magnesium, aluminium, iron and other elements		

Table 4.2 Typical physical properties of glass

Property	Symbol	Value
Modulus of elasticity	E	70,000 N/mm ²
Shear modulus	G	$E / [2(1 + \nu)]$
Poisson's ratio	ν	0.22
Coefficient of thermal expansion	α	$9 \times 10^{-6} / ^\circ\text{C}$
Density	ρ	2,650 kg/m ³

4.2 GLASS TYPES

4.2.1 Annealed glass

Annealed glass, also known as float glass, is the basic product in the form of glass sheet through the float process. After the glass sheet is formed on the float bath, annealing, a slow, controlled heating and cooling process, would be carried out to the glass sheet allowing internal stresses to be relieved. Annealed glass breaks into large jagged shards and in an extremely dangerous manner.

Annealed glass is relatively susceptible to impact, bending stress, thermal stress and imposed strains. Fracture of annealed glass depends on the flaws in the glass, the stress level, the stressed surface area and the duration of the load. The flaws in the glass may be inherent or may result from the cutting, grinding or drilling of the glass and from the environment to which the glass has been subjected (e.g. humidity promotes crack growth).

4.2.2 Heat strengthened glass

Heat strengthened glass is produced from annealed glass by first cutting to shape and put under a thermal cycle. This cycle involves heating the glass to a temperature slightly above the annealing point followed by air quenching of the glass surface. This has caused the effect of cooling and solidifying the surface first. As the interior starts to cool, the glass tries to shrink inside and goes into tension and with the stresses balanced by the compressive stresses at the surface. This heat treatment results in a fracture characteristic that produces fragments smaller but still like annealed glass. After the heat treatment process, the surface compressive stress is to be greater than 24 MPa but less than 52 MPa.

The surface compressive stress could be measured by Grazing Angle Surface Polarimeter (GASP) on the "tin side" of flat, soda-lime float glass. Tin side is the side of glass that was in contact with the molten tin bath in the float process. The GASP is based on a non-destructive photoelastic test method, using light rays traveling along the glass surface.

The inherent benefit of the heat strengthening process is that, unlike annealed glass, surface cracks do not easily propagate as the heat strengthened glass is under compressive stress.

4.2.3 Tempered glass

Tempered glass, also known as “fully tempered” or “thermally toughened” glass, is produced in the same way as heat strengthened glass, except that it is quenched more rapidly. This heat treatment results in a larger variation between the compressive stress at the surface and tensile stresses at the interior, as shown in Figure 4.2. After the heat treatment process, the surface compression stress should not be less than 69 MPa. When tempered glass breaks, it will fracture into small, roughly cubic fragments.

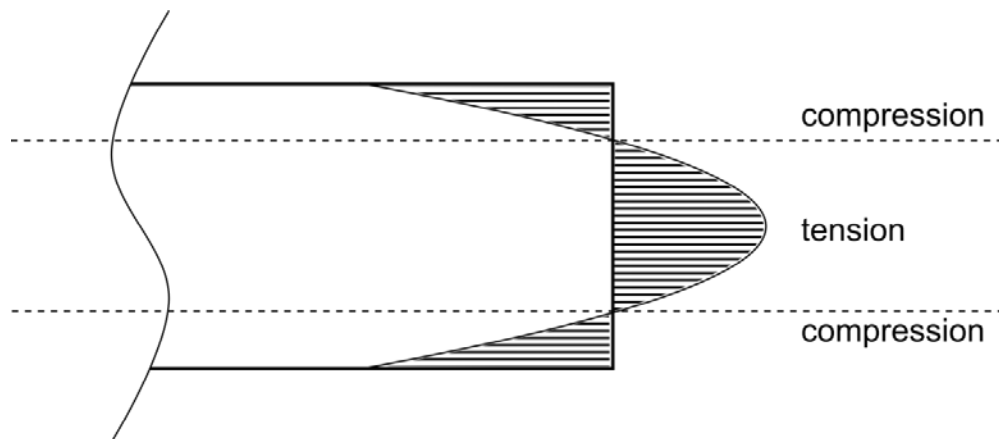


Figure 4.2 Stress profile in tempered glass

The surface compressive stress of tempered glass could be measured by the GASP. Tempered glass exhibits high values of bending strength because of the locked-in compressive surface stresses. In some cases, the design is controlled by deflections and the strength of tempered glass may not be fully exploited.

Bolt holes do not cause large changes in surface stress, as long as their diameter is at least equal to the thickness of the glass. This enables cooling air to pass readily through the holes so that glass edges along the bolt holes cool at a similar rate as the parent glass pane. All cutting and drilling and grinding of glass must be carried out before the glass is toughened, in order to avoid glass shattering. Tempered glass has a better resistance against stress concentration at openings.

Tempered glass is susceptible to “spontaneous breakage” due to Nickel Sulphide (NiS) inclusions inside the high tensile zone at the interior. The process causing breakage occurs when α -NiS particles are trapped in the tensile zone of the glass during production and transformed to the larger volume β -NiS phase. As the transformation continues the volume eventually increases and induces stresses in the glass pane causing spontaneous breakage. To avoid spontaneous breakage, tempered glass should go through heat soak process during its production as tempered glass containing NiS inclusions will break during the process and would not be put in use. Requirement and quality assurance of heat soak process are given in clause 9.3.

4.3 STRENGTH OF GLASS

The strength of glass varies greatly depending on the particular heating and cooling cycle(s) (heat treatment) that are applied in its production resulting in different types of glass. The types of glass commonly used for construction are outlined in clauses 4.2.1 to 4.2.3.

Breakage of glass is due to the stress concentrated at the microcracks on its surface. The ultimate design strength of glass is defined as the strength at which not more than 8 out of 1000 glass panes would fail.

The ultimate design strength (p_y) of glass under short-term load duration is given in Table 4.3.

As the strength of glass depends on load duration, a strength reduction factor (γ_d) should be applied to p_y for medium and long-term load duration for different glass types as given in Table 4.4. Definition of load duration is given in clause 3.5.

Also, as the strength of glass depends on different glass surface treatment, a glass surface treatment reduction factor (γ_s) should be applied to p_y as given in Table 4.5. Design strength of glass with surface treatment should be verified by bending test.

Table 4.3 Ultimate design strength (p_y) for different glass types under short-term load duration

Type of glass	Ultimate design strength (p_y) under short-term load duration (MPa)
Annealed	20
Heat strengthened	40
Tempered	80

Table 4.4 Strength reduction factor (γ_d) applied to p_y for different load durations and glass types

Type of glass	Strength reduction factor (γ_d)		
	Short-term load duration	Medium-term load duration	Long-term load duration
Annealed	1.00	0.53	0.29
Heat strengthened	1.00	0.73	0.53
Tempered	1.00	0.81	0.66

Table 4.5 Glass surface treatment reduction factor (γ_s) for different glass types

Type of glass	Glass surface treatment reduction factor (γ_s)
Flat clear, tinted or coated glass	1.0
Ceramic fritted or enamelled painted glass	0.625
Patterned (embossed), sand blasted or acid etched glass	0.5

4.4 GLASS ASSEMBLIES

4.4.1 Laminated glass

Laminated glass is formed by two or more glass panes bonded by means of an interlayer. The principal materials for the interlayer described in clause 7.4 are films such as polyvinyl butyral (PVB), resin or equivalent. The interlayer usually ranges from 0.38 mm to 6.0 mm in thickness. As described in clause 5.3.3, laminated glass shall be designed with no composite action unless otherwise justified by tests.

Laminated glass can incorporate any of the different glass types and panes with different thicknesses. However, it is recommended to use same glass type and the difference of glass thickness not greater than one thickness grade. The flexibility in the selection of the individual glass panes allows a range of products to be produced with mechanical and optical properties tailored to suit particular applications.

Heat strengthened glass and tempered glass have different amplitude waves on the surface caused by rolling process. In this connection, precaution should be taken to address the risk of separation and delamination by providing sufficient thickness of interlayer. For glass panes with surface treatment applied on the inner surface of the laminated glass, durability tests may be required to examine the quality and durability of lamination.

Glass panes are assembled with an extruded sheet of interlayer between them. The glass assembly is then passed through an oven at about 70°C, from which it passes between rollers that squeeze out any excess air and form the initial bond. The assembly then moves to an autoclave where it is heated to about 140°C under a pressure of about 0.8 N/mm² in a vacuum bag.

Laminated glass is considered as a safety glass with high reliability, suitable for glass balustrade, as the glass debris is adhered to the interlayer even after breakage. Replacement of damaged laminated glass should be carried out as soon as possible because the entire glass pane may still fall from height. To ensure the lamination quality and minimise the risk of delamination, adequate quality control measures as described in clause 9.2.1 should be implemented. Besides, it is a good practice if the edges of laminated glass are to be protected from direct exposure to weather.

4.4.2 Insulating glass unit

The insulating glass unit (IGU) is formed by two or more panes of glass spaced apart and hermetically sealed to form a single-glazed unit with an air space between glass panes as shown in Figure 4.3. IGU provides better performance in sound and heat insulation. It can further be made to become reflective and low-emissivity (low-E) glass, however the coating at the edge of IGU should be removed to ensure the adhesion of secondary seal. The common form of IGU incorporates spacer bar with desiccant filled, primary seal and secondary seal. Spacer bar shall be made of material compatible with seals and desiccant filled to ensure seal durability to ASTM E2190. Primary seal is of low permeability and serves to minimise water vapour and gas permeating the air cavity between the glass panes of IGU. Secondary seal shall be two-part structural sealant which completely covers spacer with no gaps or voids, continuously bonded to glass. The gap between the two or more panes of glass provides relatively good insulation compared to the normal glass. The gap can be filled by gas, such as hexafluoride, which is a good sound insulator. Tin side of the glass panes should be located on the outermost surfaces of IGU for future surface stress measurement.

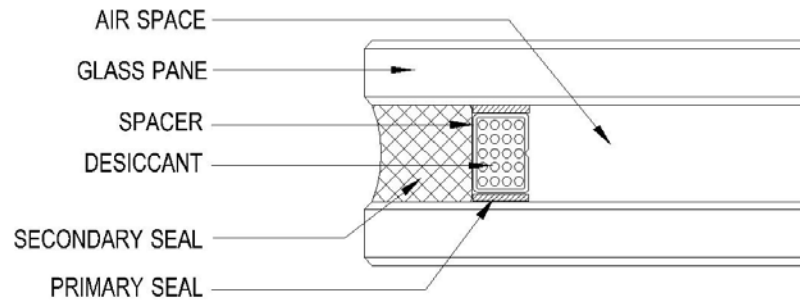


Figure 4.3 Edge of typical IGU

4.4.3 Low-E glass

Low-E glass has a coating or treatment applied that tunes the performance of glass to reduce energy consumption. The glass surface does not absorb radiation heat and reflects it so the thermal insulation properties can be improved. The effect of using low-E glass may not be on structural aspect, except that the surface temperature may have some effects on the surface thermal stress and it is in general insignificant for tempered glass.

4.4.4 Fire-rated glass

Glass is generally non-combustible. However, when exposed to the effects of heat, normal glass products shatter easily because of their low tensile bending strength in conjunction with their relatively high coefficient of thermal expansion.

Fire-rated glass commonly uses a clear intumescent interlayer “gel” in a laminated or multi-laminated glass assemblies. At elevated temperature, the intumescent interlayer turns into a rigid and opaque fire shield. The higher the fire resistance rating requirement, the thicker the glass assembly and the greater the number of interlayers. Durability tests for fire-rated glass such as high-temperature test, humidity test and radiation test should be carried out.

4.4.5 Decorative glass and fritted glass

A wide variety of techniques may be employed to apply decorative treatments to glass surface. The most common methods include coating, acid etching, sand blasting, fritting, screen printing, ink-jet printing, body tinting, embossing and abrading. Decorative interlayers may also be incorporated in laminated glass. The purpose of these treatments is to confer aesthetic benefits. It is possible that some of these treatments, such as fritting and engraving, may reduce the strength and durability of the glass, the effect of which on the ultimate design strength of glass pane is given in clause 5.4. For decorative treatments to glass, the effect of which on the ultimate design strength of glass should be examined by bending tests in accordance with BS EN 1288-3.

5 ANALYSIS AND DESIGN OF GLASS PANE

5.1 GENERAL

The methods of analysis should be based on as accurate a representative behaviour of the structure as is reasonably practicable. The primary objective is to obtain a set of forces and moments that are in equilibrium with the design loads derived from the load combinations. In general, it is satisfactory to determine the forces and moments by linear analysis or nonlinear analysis where appropriate for ultimate limit state and serviceability limit state.

As the effect of change in the geometry under loads is significant in thin glass panes, the advanced large deflection method of analysis is more accurate and computer programs are widely used for this type of analysis. Formulae for designing standard rectangular panes in the large deflection range are provided in clauses 5.4.5 and 5.5.2. For irregular shaped glass panes, the finite element method should be used for linear and large deflection nonlinear analysis. The boundary condition should be defined as edge-free-to-pull-in unless otherwise justified. For glass panes with small thickness, it would be subject to the nonlinear effects from the membrane stress due to out-of-plane deflections in addition to the bending stress.

In the determination of the stress and the deflection for the design purpose, the minimum glass pane thickness should be adopted as specified in Table 5.1.

Table 5.1 Glass thickness for analysis and design

Nominal glass pane thickness (mm)	6	8	10	12	15	19	22	25
Minimum glass pane thickness, t (mm) (for analysis and design)	5.56	7.42	9.02	11.91	14.2	18.26	21.44	24.61

5.2 SPECIAL DESIGN REQUIREMENTS

5.2.1 Safety requirement against glass breakage

- (1) Laminated glass should be used in glass elements resisting long-term load, such as roof, canopy, skylight, sloped glazing, staircase, floor, beam, column, etc., and glass balustrade.
- (2) Tempered glass or laminated glass should be used in the parts of building exterior façade also serving as protective barrier.
- (3) Where tempered glass is used in building exterior façade, the glass should be in the form of laminated glass if it meets the following conditions:
 - (i) The size of glass pane exceeds 2.5 m^2 ; and
 - (ii) Any point of the glass pane installed is at a height 5m or more above the finished floor level of the accessible area on either side of the pane.
- (4) Where IGU is used in building exterior façade, the requirement in item (3) above applies to the outermost pane of the IGU only.

5.2.2 Safety requirement against failure of glass elements

Glass roofs, accessible canopies and skylights, staircases, and floors subject to medium or long term loads should be constructed with multi-layered glass panes and designed for ultimate design loads. These elements should also be provided with structural redundancy such that in case of failure of any single glass pane, the remaining glass pane(s) shall be able to support the unfactored characteristic loads without failure.

5.3 ANALYSIS AND LOAD SHARING OF GLASS PANE

5.3.1 Linear analysis of glass pane

Linear analysis is based on the original geometry prior to deformation for stress computation. It is applicable when the material stress-strain relationship is linear and when the deflection is "small". The deflection is considered "small" when it is less than 3/4 of the glass pane thickness. In the case of large deflection, the linear analysis may be too conservative as it does not take into consideration of the membrane action in addition to bending action of the glass pane.

5.3.2 Nonlinear analysis of glass pane

When a pane is subjected to small deflection, stresses are predominantly due to bending and linear analysis is still adequate to reflect the structural behaviour. As deflection increases, stresses redistribute from bending to membrane action. At large deflection, linear analysis overestimates the stress in the pane. In such situation, a nonlinear analysis would give more accurate result.

A four-side simply supported rectangular glass pane deflects under lateral loads, e.g., wind loads, will undergo nonlinear behaviour. When the deflection is greater than its thickness, the membrane action becomes important and could be dominant over the bending action and large deflection nonlinear analysis is more accurate to reflect the actual structural behaviour.

For glass panes with curved surface and under complicated boundary conditions with edges not fully restrained or for the glass panes with irregular shape, finite element method should be used. For typical four-side simply supported rectangular glass panes, the thickness of glass pane can be derived from the equations 5.9, 5.10 and 5.11, which are based on the nonlinear behavior of glass panes.

5.3.3 Analysis of laminated glass

Generally, laminated glass should be analysed and designed without the composite action, and the individual glass panes is to resist load shared in accordance with the stiffness of the individual panes.

The strength and stiffness of each individual glass pane shall be checked where the proportion of the total load to be resisted by each pane is k_{pane} .

$$k_{pane} = \frac{t_{pane}^3}{\sum_i t_i^3} \quad (5.1)$$

where

k_{pane} = load sharing factor of glass pane being checked

t_{pane} = minimum thickness of glass pane being checked

t_i = minimum thickness of each glass pane within the assembly

i = total number of glass panes within the assembly

The load sharing equation is derived from the fact that all glass panes are deflected together and the deflection of a glass pane is reversely proportional to the cube of the thickness and is proportional to the pressure.

Where composite action is justified by bending tests as outlined in Annex B1 and full considerations have been given to the long term effects on interlayer materials described in clause 5.5.5, it may be incorporated in the design provided that the degree of composite action is not greater than 70% of the stiffness of an equivalent monolithic glass pane with a total thickness equals to the sum of thickness of the individual glass panes. The bending tests should confirm that the interlayers have the capacity to adhere the two or more panes rigidly such that they form a monolithic body.

If the degree of composite action is determined by bending test as detailed in Annex B1, the laminated glass can be considered as a monolithic glass pane, having an equivalent thickness equals to the sum of the individual pane thickness, with its stiffness multiplied by the coefficient for degree of composite action as given in equation 5.2. The composite action should only be utilised for resistance to short-term load. The equivalent thickness of the laminated glass should then be used for the computation of deflection and bending stress.

$$\lambda = \frac{I_{eq}}{I} = \left(\frac{t_{eq}}{\sum_i t_i} \right)^3 \quad (5.2)$$

where

- t_{eq} = Equivalent laminated glass thickness (mm)
- t_i = Minimum thickness of each pane of glass within the assembly (mm)
- I_{eq} = Equivalent second moment of area (mm⁴), $I_{eq} = B t_{eq}^3 / 12$
- I = Second moment of area (mm⁴), $I = B (\sum_i t_i)^3 / 12$
- B = Width of the laminated glass (mm)
- λ = Degree of composite action but not more than λ_{test} or 0.7 whichever is the less.
- λ_{test} = Degree of composite action justified by bending tests in Annex B1
- i = Total number of glass panes within the assembly

5.3.4 Analysis of IGU

The load sharing between the panes of an IGU can be determined by their relative stiffness. However, such assumption is not valid for glass panes separated by deep cavities. Deep cavities mean the air gap is greater than the sum of the thicknesses of the glass panes. Since the IGU is sealed, it is affected by temperature changes and atmospheric pressure changes. The loads on each glass pane of the IGU have to be increased by 25% to account for the effects due to temperature changes and atmospheric pressure changes.

The strength and stiffness of each individual glass pane shall be checked where the proportion of the total load to be resisted by each pane is k_{pane} .

$$k_{pane} = \frac{1.25 \times t_{pane}^3}{\sum_i t_i^3} \quad (5.3)$$

where

- k_{pane} = load sharing factor of glass pane being checked
- t_{pane} = minimum thickness of glass pane being checked
- t_i = minimum thickness of each pane of glass within the assembly
- i = total number of glass panes within the assembly

5.4 ULTIMATE LIMIT STATE DESIGN

Ultimate design loads Q_{ult} are obtained by multiplying the characteristic loads Q_{char} by a partial load factor (γ_f):

$$Q_{ult} = \gamma_f Q_{char} \quad (5.4)$$

Design load effects S_{ult} are obtained from the ultimate design loads:

$$S_{ult} = f(\text{effects of } Q_{ult}) \quad (5.5)$$

Ultimate design resistance R_{ult} is a function of the characteristic or specified material strengths divided by a partial material factor (γ_m) to allow for manufacturing tolerances,

variations of material strengths (p_y) and product variability from their characteristic values given in Table 4.3; and multiplied with the strength reduction factor (γ_d) given in Table 4.4 and the glass surface treatment reduction factor (γ_s) given in Table 4.5.

$$\text{For glass: } R_{ult} = f \left(\frac{\gamma_d \gamma_s p_y}{\gamma_m} \right) \quad (5.6)$$

For design of a structural element at ultimate limit states, the design resistance R_{ult} must be greater or equal to the design load effects S_{ult} :

$$R_{ult} \geq S_{ult} \quad (5.7)$$

5.4.1 Partial load factors

The partial load factor γ_f serves to allow for variation of loads from their characteristic values; the reduced probability that various loads acting together will reach their characteristic values at the same time; and errors in calculation and variations in structural behaviour. Partial load factors and their combinations are given in clause 5.4.2.

5.4.2 Load factors and combinations

The following principal load combinations should be considered:

Load combination 1: Dead load, imposed load, earth, water and temperature loads

Load combination 2: Dead load, wind load, earth, water and temperature loads

Load combination 3: Dead load, imposed load, wind load, earth, water and temperature loads

The load factors and their combinations given in Table 5.2 apply to the strength and the stability for normal design conditions.

Table 5.2 Partial load factors (γ_f) for load combinations under normal design conditions

Load combination (including wind, water and temperature pressure, where present)		Load type						
		Dead		Imposed		Earth and water pressure	Wind	Temperature
		Adverse	Beneficial	Adverse	Beneficial			
1	Dead, imposed, earth, water and temperature	1.4	1.0	1.6	0	1.4	-	1.2
2	Dead, wind, earth, water and temperature	1.4	1.0	-	-	1.4	1.4	1.2
3	Dead, imposed, wind, earth, water and temperature	1.2	1.0	1.2	0	1.2	1.2	1.2

Notes:

- Where the action of earth or water pressure is beneficial, the partial load factor γ_f should not exceed 1.0. The value of γ_f should be taken such that γ_f multiplied by the design earth or water pressure equals the actual earth or water pressure.
- All partial load factors for adverse condition are taken as 1.0 for serviceability limit states.

5.4.3 Partial material factors

For glass, the partial material factor γ_m on properties such as material strength and modulus of elasticity is taken as 1.0.

5.4.4 Combined effects of different design resistance under different load durations

The combined effect of different design resistance under different load durations against the corresponding design load effects should satisfy the equation below.

$$\left(\frac{S_{ult}}{R_{ult}}\right)_{short-term} + \left(\frac{S_{ult}}{R_{ult}}\right)_{medium-term} + \left(\frac{S_{ult}}{R_{ult}}\right)_{long-term} \leq 1.0 \quad (5.8)$$

5.4.5 Design of glass pane thickness

For four-side simply supported glass pane with aspect ratio (b/a) less than 5, the minimum required glass thickness t should not be less than the minimum of t_1 and t_2 below.

$$t_1 = 4.87 a^{0.965} b^{0.22} \left(\frac{R}{c}\right)^{0.545} \quad (5.9)$$

$$t_2 = 2.33 (ab)^{0.665} \left(\frac{R}{c}\right)^{0.87} - 1.62 \left(\frac{a}{b}\right) + 1.2 \quad (5.10)$$

For aspect ratio equal to or greater than 5, the glass thickness t should not be less than t_3 below:

$$t_3 = 6.2 a^{1.15} \left(\frac{R}{c}\right)^{0.5} \quad (5.11)$$

where

- a = Length of shorter side of glass pane (m)
- b = Length of longer side of glass pane (m)
- R = Factored design pressure on individual glass pane (kPa)
= γ_f x design pressure
- c = Strength coefficient ($c = c_1 \times \gamma_d \times \gamma_s$)

in which

- c_1 – Glass type (Heat treatment)
= 1.0 for annealed glass
= 2.0 for heat strengthened glass
= 4.0 for tempered glass
- γ_d – Load duration factor given in Table 4.4
- γ_s – Glass surface treatment reduction factor given in Table 4.5

Equations 5.9, 5.10 and 5.11 are used to calculate the required glass thickness, taking into account different glass type, load duration and glass surface treatment. These are only applicable to four-side simply supported glass pane.

Equation 5.8 is used to check combined load duration effects by first assuming glass thickness and then calculating design load effects S_{ult} and design resistance R_{ult} under each load duration (i.e. the calculation method shall refer to recognised formulae or finite element analysis for all support configurations).

5.5 SERVICEABILITY LIMIT STATE DESIGN

5.5.1 General

The serviceability limit state considers service requirements for a structure or structural elements under applied loads.

For satisfactory design of an element at serviceability limit state, the deflection resistance must not be less than the serviceability design load effects. Partial load factor for all load types is taken as 1.0 for the serviceability design.

5.5.2 Deflection of glass pane

The deflections in general should not impair the structural and the serviceability performance of a structural system. Deflection of a glass pane can be computed by the finite element method allowing for large deflection effects where appropriate or by the following equations for rectangular glass panes.

$$\text{Four-side simply supported: } \delta = t e^{r_0+r_1x+r_2x^2} \quad (5.12)$$

$$\text{in which, } x = \ln \left[\ln \frac{p [ab]^2}{E t^4} \right]$$

$$\text{Two-side simply supported: } \delta = \frac{5}{32} \frac{p a^4}{E t^3} \quad (5.13)$$

where

- δ = Centre deflection (mm)
- a = Length of shorter side of glass pane (mm)
or loaded span in two-side simply supported case (mm).
- b = Length of longer side of glass pane (mm)
- t = Minimum glass pane thickness (mm)
- p = Design pressure on individual glass pane (kPa)
- E = Modulus of elasticity of glass pane (kPa)

$$r_0 = 0.553 - 3.83 \left(\frac{b}{a}\right) + 1.11 \left(\frac{b}{a}\right)^2 - 0.0969 \left(\frac{b}{a}\right)^3$$

$$r_1 = -2.29 + 5.83 \left(\frac{b}{a}\right) - 2.17 \left(\frac{b}{a}\right)^2 + 0.2067 \left(\frac{b}{a}\right)^3$$

$$r_2 = 1.485 - 1.908 \left(\frac{b}{a}\right) + 0.815 \left(\frac{b}{a}\right)^2 - 0.0822 \left(\frac{b}{a}\right)^3$$

5.5.3 Deflection limit of glass pane

The deflection limit (δ_{limit}) of glass pane should be taken as follows:

$$\text{Four-side simply supported: } \delta_{limit} = 1/60 \text{ of the short span}$$

$$\text{Three-side simply supported: } \delta_{limit} = \min. [b/60 , a/30] , \text{ (see Figure 5.1)}$$

$$\text{Two-side simply supported: } \delta_{limit} = 1/60 \text{ of the loaded span}$$

$$\text{Cantilever: } \delta_{limit} = 1/30 \text{ of the span}$$

$$\text{Point supported: } \delta_{limit} = 1/60 \text{ of the longer span between supports}$$

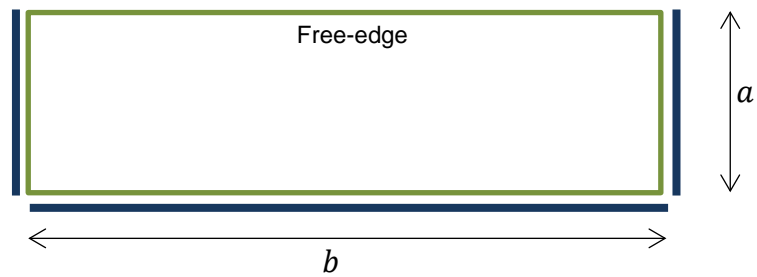


Figure 5.1 Dimensions of glass for three-side supported case

5.5.4 Deflection limit of structural member supporting glass pane

The deflection limit of structural member should be taken as the smaller of $1/180$ of the span or 20 mm for span not greater than 7.2 m. For span greater than 7.2 m, the deflection limit of a member can be taken as $1/360$ of the span.

For cantilever type member, the deflection limit should be taken as the smaller of $1/90$ of the span or 20 mm.

5.5.5 Durability

Durability of certain components in a glass structural system need special design, quality control and testing consideration. Interlayer materials being used in laminated glass with composite action and structural sealants under long term exposure to sunlight could have their load resisting capacity reduced, which should be considered in the design life of the structure. Durability tests may be required to carry out taking local conditions into consideration. Durability tests such as boil test and weathering test can be referred to ANSI Z97.1 or BS EN ISO 12543.

6 GLASS ELEMENT DESIGN

6.1 GLASS WALL

There are many variations in glass wall systems using glass fins, tension rods, cables, etc, in vertical, sloped and horizontal manner.

The use of glass fin requires analysis to determine the buckling resistance under combined in-plane and out-of-plane loads. Side wind effect at the corner of glass wall should be considered simultaneously. The column or the glass fin at the corner should be designed to resist the induced moments and forces.

Structural sealant or point-supporting bolt systems can be used for the connections between glass panes. However, special care is needed to consider the effects of local stress concentration and the stability. Tempered glass has a better resistance against stress concentration at openings.

For point supported systems, simple bolt, patch and countersunk bolt can be used. Clearance, distances from edges, movement, stability and stress concentration around openings require careful consideration during design and fabrication. Direct contact between hard materials should be avoided.

Structural spider fixing is commonly used as fixing device in glass wall systems. The design of structural spider can be verified by means of proof load test. The mechanical properties, dimensions, load capacities and specific proprietary model number/series of a spider should be provided in the design report. In addition, attention should be made to its detailing at the interface connection with the glass panes, which should be designed such that the structural glass in contact with the spider fixing should not cause high stress concentration greater than the design strength of glass. The interface connection should be filled up with resilient gasket made with a less stiff material.

Where glazing is supported by a structural system using stainless steel tension rods or cables, special attention should be paid to the geometrically nonlinear behaviour, differential temperature change, possible creep effect under long-term load and support movement, in addition to conventional loads. A comprehensive consideration of all possible load cases should be given in the design.

In addition to a full-scale mock-up test, performance-based design approach with rigorous design and advanced nonlinear analysis may be required for glass wall system or glass supporting system, depending on the complexity in the interaction and load transfer between various components.

6.1.1 Design of glass fin / glass beam

The use of glass in structural applications may require analysis to determine buckling resistance under combined in-plane and out-of-plane loads. Glass fins and glass beams can become unstable if they are not adequately restrained. Glass fins and glass beams should be restrained from rotation and held in position to ensure stability.

When glass fins / glass beams subject to bending about its major axis, the ultimate design strength should be reduced by 40% (e.g. 80 MPa to 48 MPa for tempered glass fins). Apart from the rigorous nonlinear finite element analysis approach in equation 6.4, the following simplified equations 6.1 to 6.3 can be used for checking the glass fin / glass beam.

Local buckling

The free edge of a glass fin should be checked against local buckling:

$$\frac{E t^3}{6(1 + \nu)} > M_w \quad (6.1)$$

where

M_w = Working design moment in the glass fin (in-plane moment) with load factor γ_f equal to 1.0

E = Modulus of elasticity

- ν = Poisson's ratio
 t = Minimum thickness of glass pane being checked

Lateral torsional buckling

The formulae in Annex C for glass fins could be used to check the critical elastic buckling moment (M_{cr}). It should be at least 1.7 times the ultimate design moment (M_d).

$$M_{cr} > 1.7 M_d \quad (6.2)$$

where

- M_{cr} = Critical elastic buckling moment given in Annex C
 M_d = Ultimate design moment in the glass fin

Elastic moment capacity

The elastic moment capacity of glass fin should not be less than the ultimate design moment.

$$M_e = \gamma_d \times \gamma_s \times p_{yf} \times Z > M_d \quad (6.3)$$

where

- M_e = Elastic moment capacity
 M_d = Ultimate design moment in the glass fin (in-plane moment)
 p_{yf} = Ultimate design strength of glass fin as described in clause 6.1.1
 Z = Elastic section modulus of glass fin
 γ_d = Load duration factor given in Table 4.4
 γ_s = Glass surface treatment reduction factor given in Table 4.5

Nonlinear finite element analysis

A geometrically nonlinear finite element analysis by shell element with imperfection equal to 0.5% of the length of the glass fin should be carried out to determine the ultimate moment capacity M_u of the glass fin. Ultimate moment capacity M_u refers to the minimum moment, accounting for geometrically nonlinear effects that caused the maximum stress in the glass fin equals to its design glass strength.

$$M_u > M_d \quad (6.4)$$

where

- M_u = Ultimate moment capacity evaluated from nonlinear finite element analysis
 M_d = Ultimate design moment in the glass fin with appropriate load factor γ_f given in Table 5.2

Alternatively, in finite element analysis by shell element, the maximum principal stress (s_1) of the glass pane should be smaller than the ultimate design strength of glass fin (p_{yf}).

6.1.2 Deflection of glass fin / glass beam

The deflection limit of glass fin / glass beam should be taken as the smaller of 1/180 of the span or 20 mm for the span not greater than 7.2 m. For span greater than 7.2 m, the deflection limit of glass fin / glass beam should be taken as 1/360 of the span.

6.1.3 Design of glass column

Glass column is the primary structural element supporting glass beams or glass floors. Glass column should therefore be adequately restrained from rotation and held in position to ensure stability. Glass columns are typically slender and therefore governed by the tensile forces arising from buckling stress and out-of-plane bending. Moreover, the design of glass columns should have sufficient structural redundancy.

The design of glass columns or glass fin under compression buckling should be referred to relevant literature with adequate design justification. The design of glass columns may also be needed to deal with the design of such miscellaneous systems. A performance-based design approach derived from first principles should be adopted together with component and system testing in order to ensure the structural adequacy and safety.

6.2 CURTAIN WALL, WINDOW AND WINDOW WALL

A system that incorporates glazing must be designed to safely sustain and transmit the combined dead loads, imposed loads and wind loads to the load-bearing structure without excessive deflection or deformation that causes damage to the system or impairs its stability.

Design of glass supporting frames should follow relevant codes of practice for steel, aluminium and stainless steel.

Owing to the complexity in the interaction and load transfer between various components in a system such as curtain wall system, a full-scale mock-up test as specified in clause 8.3 should be carried out to verify if the performance of the system satisfies the limit states.

Design, fabrication and installation of curtain wall, window and window wall systems should achieve the required safety standard. Attention should be given to the requirements on horizontal imposed loads, protection of openings, function of glass balustrades, corrosion protection, quality control of materials and protection against the spread of fire and smoke between floors.

There are numerous types of curtain wall systems, broadly as stick and unitised systems. They all need to be designed for possible building movements, displacement due to lateral load, thermal expansion and against water and air leakage, durability and corrosion, in addition to general consideration for structural safety.

6.3 TENSIONING STRUCTURAL SYSTEM

Stainless steel tension rods and cables provide aesthetic supports to glass with maximum transparency. These tension rods and cables are very slender and buckle easily when in compression, but they are strong and stiff in tension. To ensure that these structural elements are always in tension, they can be pre-tensioned or pre-stressed as such that they are always in tension under all load combinations by limiting the compression induced loads smaller than the pre-tensioned forces.

Where a glazing is supported by a structural system using stainless tension rods or cables which is deflection sensitive, the geometrically nonlinear behaviour, differential temperature change, possible creep effect under long-term load or imposed load, and support movement of the system should be considered, in addition to the wind loads on the system. Therefore, in this respect, a detailed consideration of all possible load cases should be given in the design of tensioning structural system.

6.4 GLASS BALUSTRADE

Glass balustrade panes shall be classified as infill or free-standing glass panes.

6.4.1 Glass balustrade acting as protective barrier

When a glass balustrade also serves as a protective barrier, the glass pane or the top handrail shall be designed to resist horizontal imposed load or wind pressure. The glass pane shall be tested for its impact resistance. Handrail should either be fixed continuously to the top of the glass pane or fixed to the balustrades. Side wind effect at the corner of glass balustrade should be considered simultaneously. The balustrades at the corner should be designed to resist the induced moments and forces.

The main frame of glass balustrade (viz. handrail and balusters) is designed to withstand all loads applied to the handrail and the glass is used to form the infill panes. The glass pane should not be taken to provide any support to the main frame or handrail.

The glass pane shall be designed to withstand all the design loads. When the glass pane is subjected to a loading derived from the most unfavourable condition of wind load or horizontal imposed loads, the maximum horizontal displacement at the top rail level of the balustrade should not exceed deflection limit given in clause 5.5.3.

In case the free-standing glass balustrade has a continuous run of 2 panels of glass or more and is designed as panic barrier in areas where people may congregate or susceptible to overcrowding, the top rail should be attached to the glass in such a manner that it would bridge over the failed glass, remain stable and is capable of resisting the working load applied across the resulting gap without causing the structural failure of the protective barrier system. Alternatively, the top rail may be omitted if the remaining intact glass pane of laminated glass used in the balustrade is capable of resisting the working load when one layer in a laminated glass pane is broken.

Continuous bottom fixing clamps should be used for free-standing glass balustrade. Such clamps on each side of the glass panes should have a minimum width of 100 mm and be made of metal of minimum thickness of 12 mm. The clamps should be continuous for the entire length of the glass pane and have a maximum bolt spacing of 500 mm. Other clamping methods may also be used provided that such methods provide effective clamping over the length of the glass panes. Where a clamping system not relying on bolts is used, the depth over which the clamping force operates should not be less than 90 mm, unless specific tests have been carried out to prove the integrity of the structural system in resisting the design loads. Figures 6.1 and 6.2 illustrate the typical clamping detail for free-standing glass balustrade.

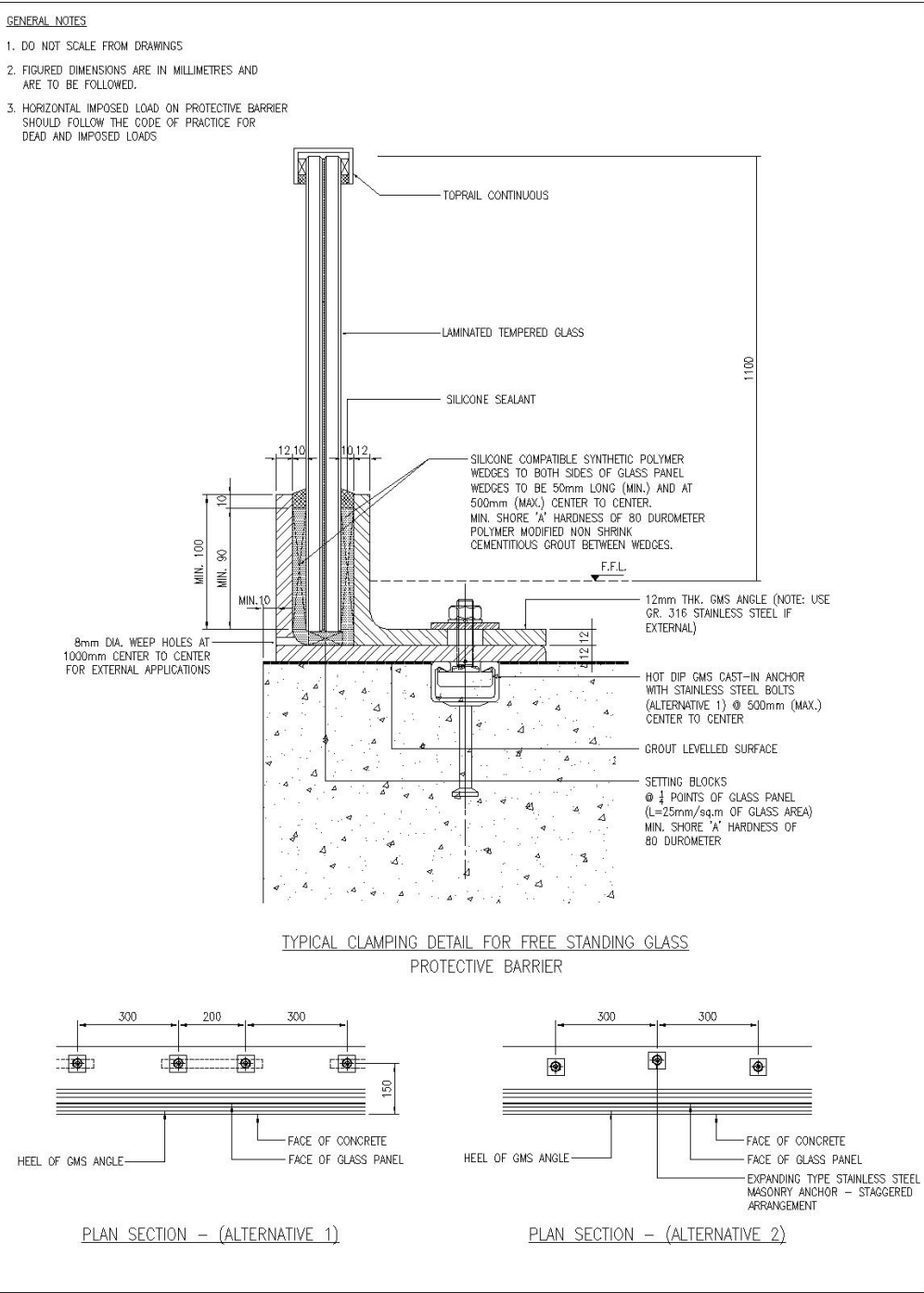


Figure 6.1 Typical glass balustrade details - Bolting

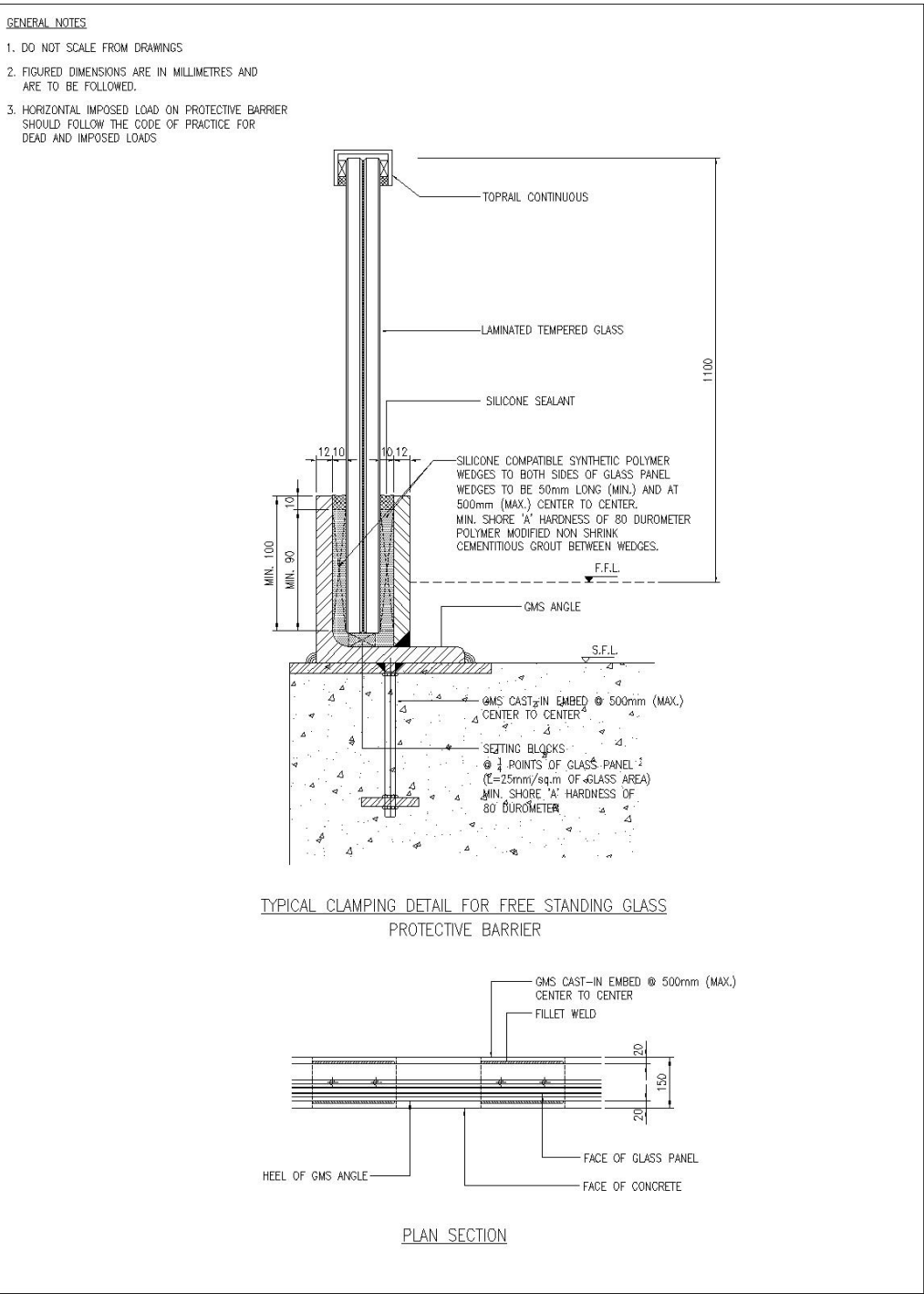


Figure 6.2 Typical glass balustrade details - Welding

6.4.2 Impact resistance of glass pane as protective barrier

Portions of glass measured up to 1100 mm from the finished floor level of the surface adjoining the barrier are defined as critical locations which are subjected to human collision and consequently likely to cause glass breakage. Glass situated at these critical locations and to be used as protective barriers should satisfy the impact test to Class 1 requirements with no glass breakage for safety glazing materials given in recognised testing standards BS EN 12600 “Glass in building – Pendulum test – Impact test method and classification for flat glass”.

Glass pane for protective barriers shall be designed to resist the minimum horizontal imposed loads when separately applied or the wind load (where applicable). Glass used for protective barriers should comply with the impact test requirements for safety glazing materials given in the testing requirements above. In addition, the glass material for protective barrier will not be broken when subjected to the appropriate impact test loads.

7 DESIGN FOR GLASS CONNECTION

7.1 SEALANT

Sealant has functions in structural strength and water penetration resistance. Weather sealant is used for the prevention of water penetration. Structural sealant can be used for both the purpose of holding the structural glass pane and the prevention of water penetration. The permissible design strength of common type of structural sealant under short-term and medium-term loads is 138 kPa. The movement capability of structural and weather sealant should not be less than a strain of $\pm 25\%$.

An example of sealant bite-to-thickness is given in Figure 7.1. The sealant bite is calculated from the permissible design strength and the thickness of sealant is determined from the calculated movement. The minimum structural sealant bite should be 6 mm. The sealant must have sufficient thickness to prevent tearing during thermal movement. The bite-to-thickness ratio should be between 1 : 1 and 3 : 1. If bite-to-thickness ratio is greater than 3 : 1, the thickness of structural sealant should be reviewed by sealant manufacturer. Structural sealant should not be used in glass subjected to long-term loads.

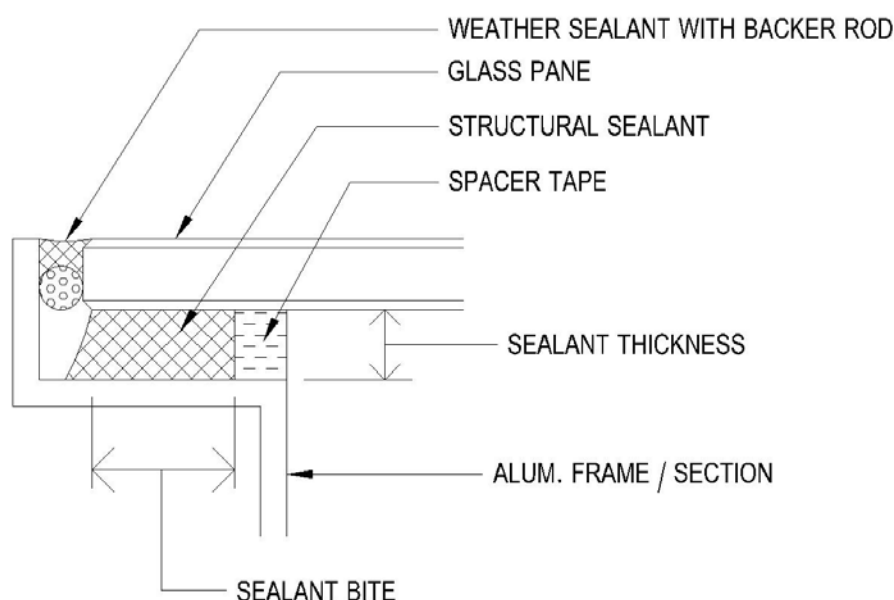


Figure 7.1 Example of sealant bite-to-thickness ratio

Structural sealant should be applied strictly according to the manufacturer's recommendation. Long-term exposure of the structural sealant to water or vapour should be prevented. Sealant manufacturers should provide test reports for strength, elongation, shear (including under elevated temperature), bonding, adhesion (compatibility) and durability.

The structural sealant glazing shall be designed and constructed in accordance with the following standards or equivalent:

- (1) BS EN 13022-2: 2006: Glass in Building – Structural Sealant Glazing.
- (2) BS EN 15434: 2006: Glass in Building – Product Standard for Structural and/or Ultra-violet Resistant Sealant.
- (3) ASTM C1184-14: Standard Specification for Structural Silicon Sealants.

7.1.1 Structural sealant for glazing

Structural sealant is commonly used for connecting a glass pane to a metal frame or another glass pane. The structural sealant should be compatible with the glazing system and the supporting structural frame.

The structural performance of a structural sealant depends on a number of factors such as risks to building occupants and pedestrians, long-term durability, degree of redundancy, nature of applied loads, and quality control during fabrication and erection. Façade system or glass element with structural sealant glazing application shall be designed to prevent any fall of glass pane in the event of bond failure in the structural sealant. Retaining devices for such structural sealant glazing in the form of feature capping, angle, bracket or insert, etc. shall be designed and constructed at the top and the bottom of the glass pane for the added purpose of restraining the glass pane from dislocation or falling in case of bond failure of structural sealant. The self-weight of the glass panes shall be mechanically supported by setting blocks.

For a four-sided structural sealant support, the controlling variables which affect the structural sealant bite requirement are the shorter span of the rectangular glass pane and the design wind load. The minimum structural sealant bite (bi) for wind load and glass dimension should be determined by the following equation.

$$bi = \frac{0.5 \times p \times L_s}{p_b} \quad (7.1)$$

where

- bi = Minimum structural sealant bite (mm)
- L_s = Length of shorter span of rectangular glass pane (mm)
- p = Design wind pressure (kPa) for allowable stress design
- p_b = Permissible design bond strength (kPa)

For other types of structural glazing application such as two-sided or three-sided, or structural glazing of irregular glass pane, the structural sealant bite should be evaluated in accordance with the load distribution on the glass pane. The glass panes should be designed as simply supported (i.e. "floated") on a supporting frame and avoid contact with metal and local bending effects due to prying effect at supports.

7.1.2 Secondary seal for IGU

Typical IGU for structural glazing application is illustrated in Figure 7.2. Glass panes of IGU should be properly supported by setting blocks. For structural glazing application, the width of secondary seal for IGU should be calculated for tensile stress (C_t) due to lateral load by the following equation.

For tensile stress (lateral load),
$$C_t = \frac{0.5 \times p_o \times L_s}{p_b} \quad (7.2)$$

where

- C_t = Minimum width of secondary seal due to lateral load (mm)
- L_s = Length of shorter span of rectangular glass pane (mm)
- p_o = Design pressure (kPa) for allowable stress design on outer pane
- p_b = Permissible design bond strength (kPa)

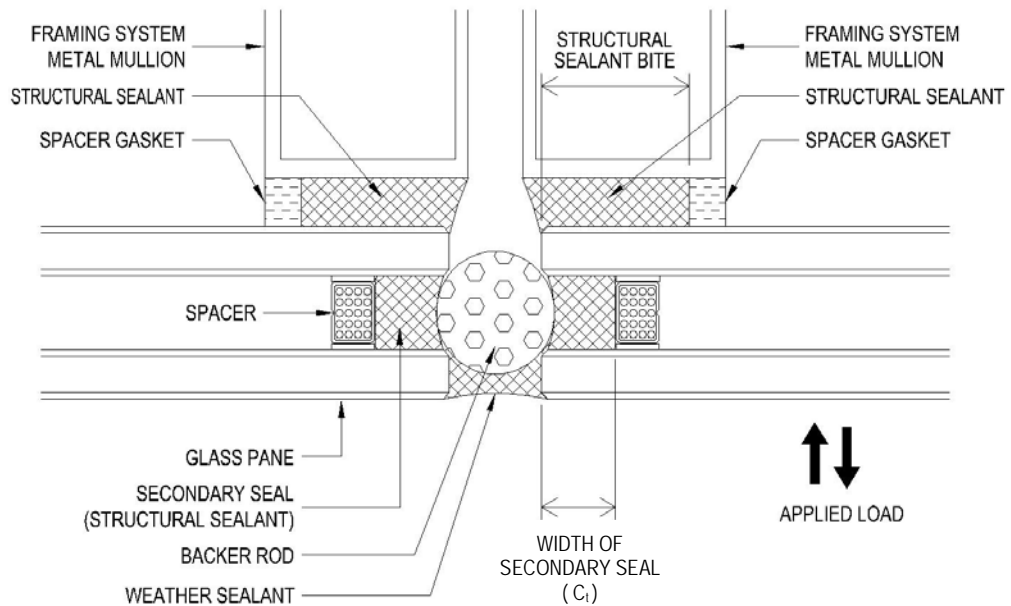


Figure 7.2 Example of IGU for structural glazing application

7.2 GLASS CONNECTION

Contact between glass and any other hard substance with hardness greater than the hardness of glass should be avoided. Gaskets or other glazing materials should be used with frame systems. Where bolted connections are used, it is essential to ensure that the glass does not come into direct contact with the bolt or the clamping plates. Proper bushing material shall be used in which its hardness shall be less than the glass material. The use of setting blocks and distance pieces to support and locate glass panes should be referred to clause 7.5.2. Requirements for structural sealant glazing are given in clause 7.1. Other standards for fixing of glass are acceptable if the equivalent performance can be demonstrated.

7.2.1 Framed infill glass pane

For fully framed or two-edged framed infill glass pane, the framed section should give a minimum of 10 mm edge cover, minimum 6 mm edge clearance and minimum 5 mm front and back clearances to the glass pane as shown in Figure 7.3. The edge cover is recommended not less than the thickness of glass pane in contact. Reference can be made to BS 6262 or relevant design guidelines. The framed section and its connections to the main frame should be capable of withstanding the design load transferred through the glass panes.

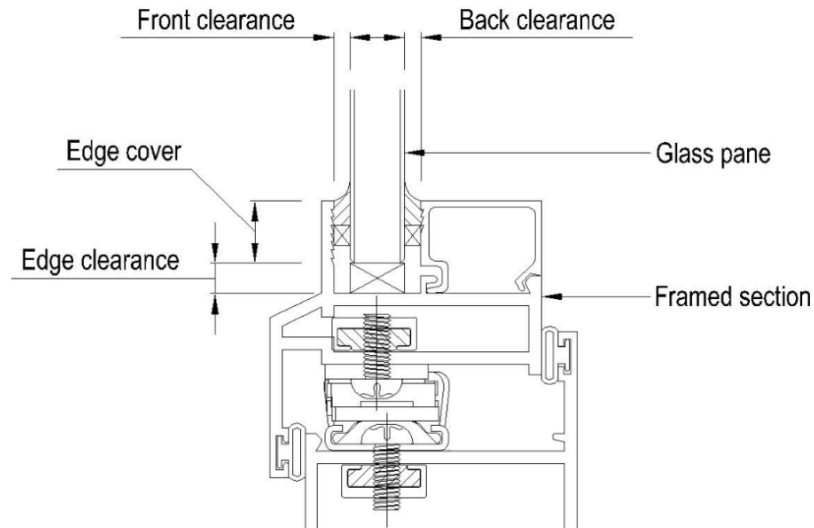


Figure 7.3 Edge cover and clearances of framed infill glass pane

7.2.2 Adhesive based connection

Typical design and considerations of adhesive based connection by using structural sealant are given in clause 7.1. One of the most common forms of adhesive connection is the use of silicone to form glass-to-glass right angle butt joints. Such fixings allow the glass to rotate within the frame and are thus deemed to be simply supported for such a design of glass connections.

7.2.3 Point bolted supports

Tempered glass should be used and the position of the connectors should not allow the glass panes to undergo reverse curvatures, as these could lead to very high stress concentration at bolted connections. There should be clamping plates and gaskets on both sides of the glass panes that provide a minimum of 50 mm diameter cover to the glass panes. Where the length of a glass pane is greater than the span between the bolted connectors, giving rise to a cantilevered portion of the glass pane, the length of the cantilevered portion should be less than one-quarter of the span between the bolted connectors. The fixing of the bolted connectors to the main frame should be capable of withstanding the design loads transferred through the glass panes. Typical arrangement of bolt connection which allows in-plane movement or provides in-plane restraint is shown in Figure 7.4.

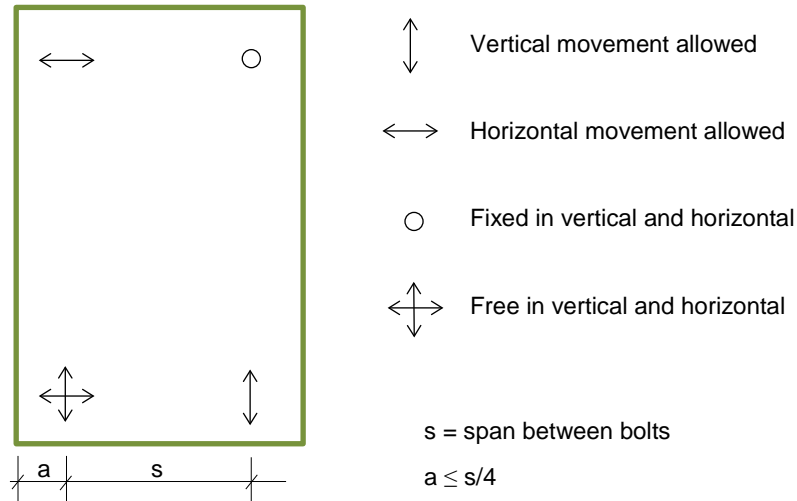


Figure 7.4 Allowable in-plane movements at bolted connections

7.2.4 Clipped infill glass pane

For clipped infill glass pane, the clips should be positioned around the periphery of infill glass panes, at a maximum spacing X of 600 mm between fixings. There shall be a minimum of four fixings per glass pane. The clips should be positioned not more than $X/4$ from the corner. Each clip should be not less than 50 mm in length and give a minimum depth of cover to the glass panes of 25 mm. The clips and their connections to the main frame should be capable of withstanding the design loads transferred through the glass panes. Typical arrangement of clips is shown in Figure 7.5.

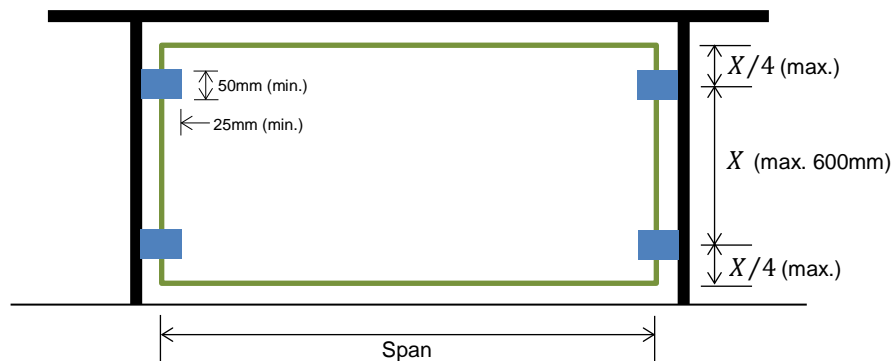


Figure 7.5 Clipped infill glass pane

7.3 HOLES IN GLASS

7.3.1 General

The presence of holes leads inevitably to stress concentration on the glass pane and should not be ignored. For an infinite thin plate with a hole under tensile load, conventional peak stresses near the hole can be up to three times as stresses away from the hole.

For splice connection of glass fins using bolts, structural analysis/calculation should be made to check the contact bearing stress on the glass hole. The conventional peak stress near the hole is calculated by the tensile load generated by the bolt in the hole divided by cross sectional area formed by a strip width equivalent to the hole radius on both sides of the hole. From mechanics, the tensile stress can be up to three times as stresses away from the hole. In these circumstances, a stress concentration factor of 3.0 should be applied to the induced tensile stress. Alternatively, for more accurate assessment of the stress concentration effects

at the contact area of the hole in the glass, rigorous finite element analysis of glass pane with hole opening should be conducted.

For glass panes under lateral loads and supported by bolting and point fittings, rigorous finite element analysis of glass pane with hole opening or notch should be conducted to provide more accurate assessment of stress concentration effects at the contact area of hole opening or notch in the glass pane.

Since the design is based on well-defined parameters, no specific test is required to demonstrate the structural performance of the bolted connection. Attention should be paid to its detailing at the bolt/glass interface of the bolted connection, which should be filled up with sufficient thickness of resilient gasket or less stiff material.

7.3.2 Placement of holes

Dimensions and positions of holes in glass should follow Figures 7.6 to 7.8 below.

- (1) The minimum distance from any edge of a glass pane to the nearest point on the rim of a hole must be 6 mm or 2 times the thickness of the glass, whichever is greater.
- (2) The minimum distance between the rims of adjoining holes must be at least 10 mm or 2 times the thickness of glass, whichever is greater.

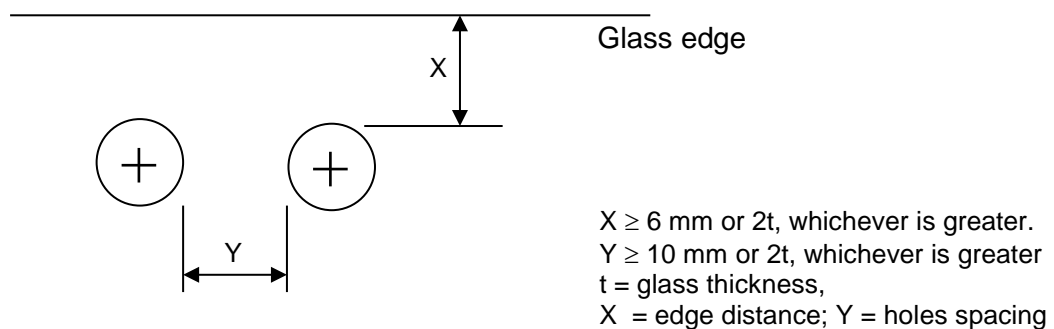


Figure 7.6 Placement of holes

- (3) Holes near corners must be located so that the nearest edge of the hole is at least 6.5 times the thickness of a glass pane from the tip of the corner when the corner is 90° or more.

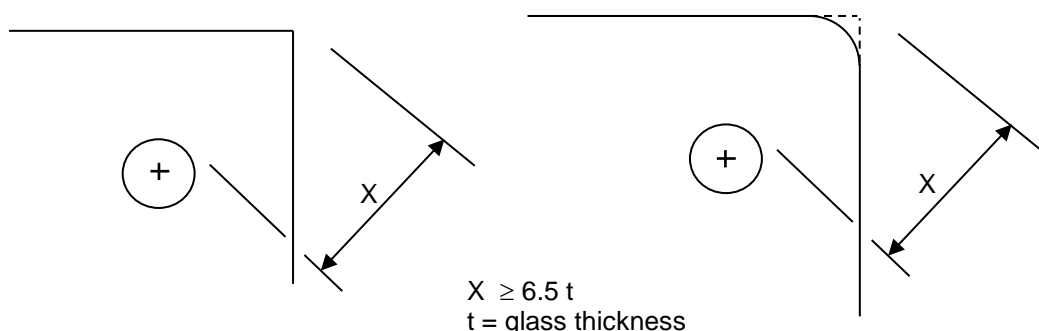


Figure 7.7 Location of holes near corners

- (4) Minimum dimension of holes – Circular holes must have a minimum diameter of 6.4 mm or the thickness of a glass pane, whichever is greater. In other than circular holes, any corners must have fillets, the radius of which must be equal to or greater than the thickness of the glass pane.

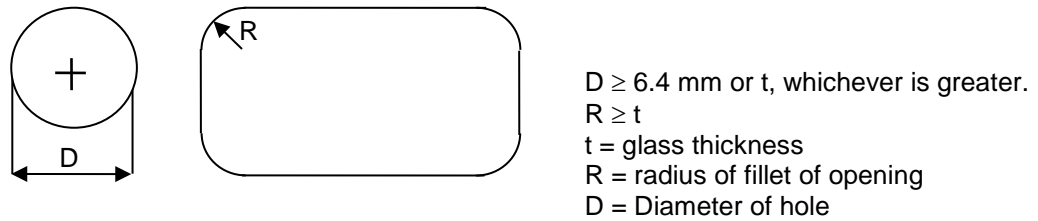


Figure 7.8 Minimum dimension of holes

7.4 INTERLAYER MATERIALS

Interlayer materials are used to bond glass panes in laminated glass. The interlayer materials can be, but not limited to, polyvinyl butyral (PVB), polyester, ethylvinyl acetate, resins, ionoplast, or intumescent. It can be a layer or multiple layers of material acting as an adhesive between glass panes enhancing the performance of the finished assembly, for example, composite action, impact resistance, solar control, acoustical insulation, etc.

There are a number of different interlayer materials and their claimed performance can vary widely. In this regard, delamination is a great concern for this type of glass and measures such as good quality control and avoidance of contact between sealant and the interlayer(s) should be taken. Boil test in Annex B2 (or ANSI Z97.1 / BS EN ISO 12543) should be carried out to ensure the assembly has minimum risk of delamination.

7.4.1 PVB

PVB is the most common sheet interlayer material. The process includes glass panes preparation, assembling, de-airing and autoclaving. Delamination needs to be prevented and boil test in Annex B2 (or ANSI Z97.1 / BS EN ISO 12543) should be carried out to ensure the lamination quality. Typical properties of PVB are given in Table 7.1 below.

Table 7.1 Typical properties of PVB

Ultimate Tensile Strength	28.1 MPa	ASTM D638, 23°C / 50% RH
Elongation at Break	275%	ASTM D638, 23°C / 50% RH
Young's Modulus	11 MPa	ASTM D5026, 1% strain, 23°C / 50% RH

7.4.2 Resins

Resins and other liquid can be used as laminated interlayer for laminated glass by pouring the liquid between glass panes followed by chemical and UV curing. The design of laminated glass using resins should follow the performance-based tests specified in Annex B1 and Annex B2.

7.4.3 Ionoplast

Ionoplast is a type of interlayer material used for laminated glass. As it has higher modulus and less loss of strength at elevated temperature than PVB, it is much stronger and stiffer interlayer material than PVB. The design of laminated glass using ionoplast or other interlayers should follow the performance-based tests specified in Annex B1 and Annex B2.

7.5 GLAZING ACCESSORIES

7.5.1 Gasket

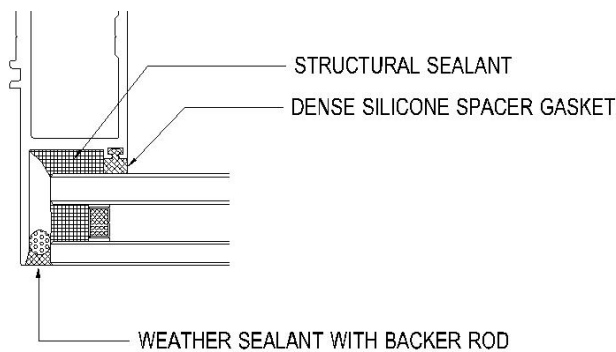
Gasket shall be compatible with other contact materials. Durability, compatibility, strength and ductility are required to be considered. Typical gasket types are given in Figure 7.9.

Weather strips, glazing gaskets and glazing blocks shall be manufactured from extruded silicone rubber, Ethylene Propylene Diene Monomer (EPDM) rubber or other gasket material such as neoprene and Thermoplastic Elastomer (TPE) compatible with silicone sealant. Gaskets shall be provided on both sides of the vent glass unless it is structurally glazed. All gaskets/ weather seals/ spacers shall have continuous mechanical engagement to the framing members.

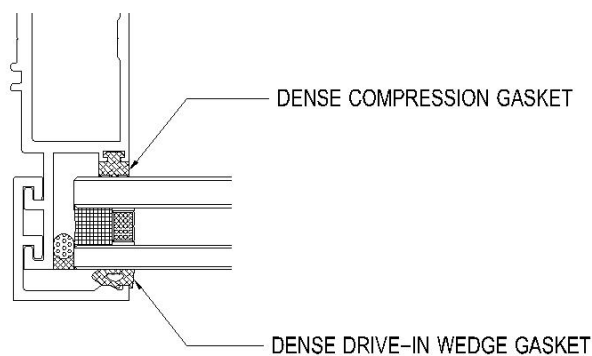
Dense or wedge gaskets should be extrusions with a minimum Shore A hardness of 70 durometer for hollow profiles and 55 durometer for solid profiles. Outdoor and indoor gaskets shall be silicone rubber, EPDM rubber or other gasket material such as neoprene and TPE compatible with silicone sealant. Wedge gasket needs to have a lock-in procedure to prevent disengagement from the metal frame.

Sponge gaskets should be extrusions with a minimum Shore A hardness of 35 durometer and designed with 20% to 35% deformation in compression. Sponge gaskets can only be used as gap fillers and should not be used where the performance is relied on compression resistance.

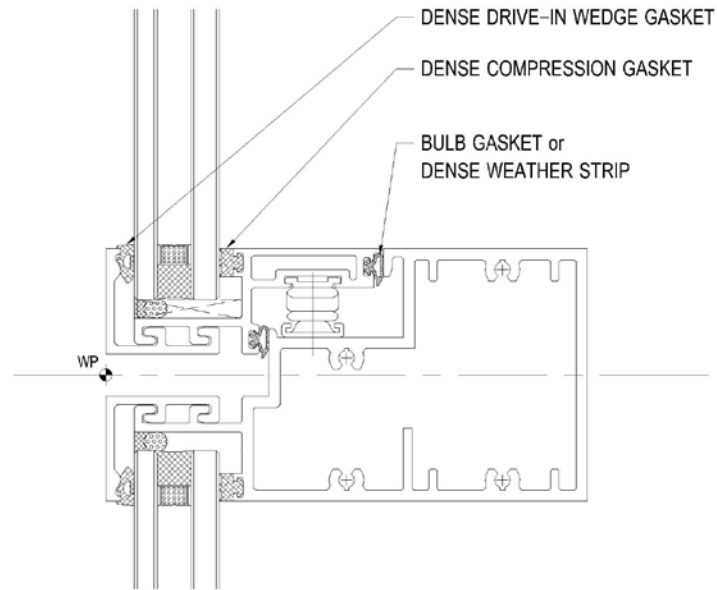
Glazing gaskets, sealant backers within glazing pockets and continuous glass spacer pads at structural sealant should be black heat cured silicone rubber.



a) Typical mullion (structural sealant)



b) Typical mullion (pressure cap)



c) Typical transom with sash

Figure 7.9 Example of typical gasket types

7.5.2 Setting block

Setting block should be placed firmly and permanently in the frame members. Compatible sealant, setting chair or other means is needed to avoid block movement.

Setting block should be dense heat cured silicone rubber, EPDM rubber or other material such as neoprene and TPE compatible with silicone sealant. Setting blocks are to support the glass for a minimum of 80% of the glass thickness and are to be minimum Shore A hardness of 80 durometer. They should have a length equivalent to 25 mm for every 1 square metre of glass area, with a minimum length of 100 mm for each setting block for glass panel of width greater than 800 mm.

Setting blocks should be at equidistance from the glass centreline located at the glass quarter points. To minimise bending of the transom under dead load, the setting blocks may be moved to eighth points but should not be closer than 150 mm from the vertical glass edge nearest to the setting block. For other glass supporting cases such as bolting and point fittings, finite element analysis should be used to check the induced glass stresses. Side blocks should be located between the mid-height and top corner of the glass. Side blocks, setting blocks and chairs should be positively retained in position. Typical locations of setting blocks are shown in Figure 7.10.

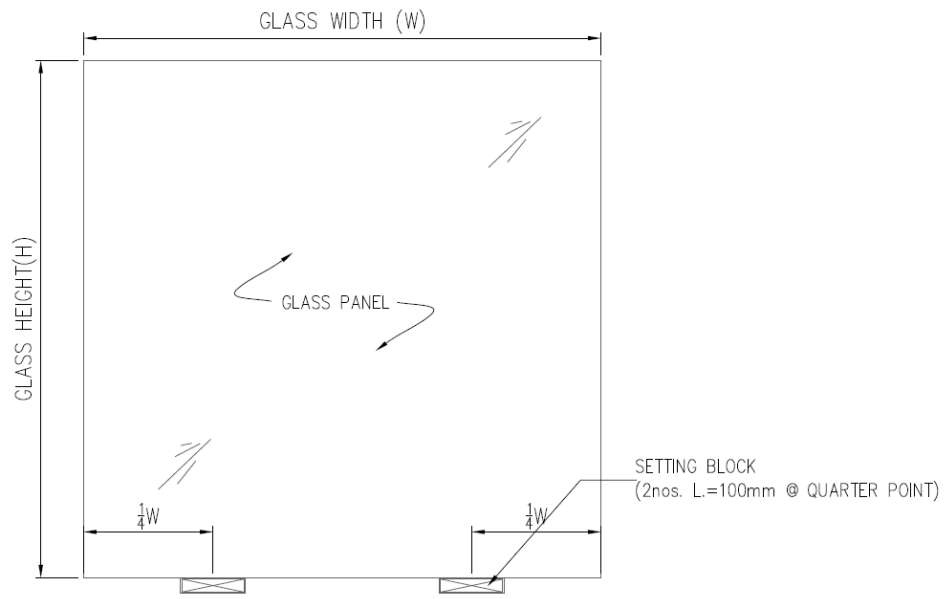


Figure 7.10 Typical location of setting blocks

8 TESTING AND MEASUREMENT

Quality control testing should be carried out by the manufacturer or supplier. Clauses 8.1 and 8.2 give recommendations on basic physical and mechanical tests for glass and structural sealant. Clause 8.3 gives recommendation on safety test for curtain wall system and other complex systems.

8.1 GLASS

8.1.1 Heat soak process

Heat soak process is a widely recognised quality control procedure of tempered glass for minimising risk of spontaneous breakage in tempered glass by glass manufacturer. It accelerates the expansion of nickel sulphide intrusions in tempered glass. The heat soak process conformed to BS EN 14179-1 standard should be carried out to all tempered glass panes to be used.

The heat soak process contains three phases. The heating phase commences with all the glass panes at ambient temperature until the surface temperature of the last glass pane has reached 250°C. The holding phase commences when the surface temperature of all the glass panes has reached a temperature of 250°C. The duration of the holding phase is 2 hours minimum. The surface temperature of the glass panes should be maintained in the range of 260°C±10°C during the holding phase. The cooling phase commences when the last glass pane to reach 250°C has completed its holding phase. The cooling phase can be concluded when the air temperature in the oven reaches 70°C. The heating and cooling rates is usually determined by the characteristics of the oven and loading of individual heat soak process and could be varied on batch by batch basis.

8.1.2 Fragmentation test

Fragmentation test for verifying the surface compressive stress of tempered glass should be carried out to each batch of tempered glass in accordance with section 10 of BS EN 14179-1 after the heat soak process by the glass manufacturer from representative batch of glass as quality control record during glass production.

The particle count of each test specimen over 50 mm by 50 mm square area should not be less than 40 individual particles for glass thickness less than 15 mm and 30 individual particles for glass thickness equal to 15 mm or above. The length of the longest particle should not exceed 100 mm.

8.1.3 Surface compressive stress

Surface compressive stress of heat strengthened and tempered glass panes should be measured by GASP with valid calibration certificate in accordance with ASTM C1279. Compliance of the glass should be assessed based on ASTM C1048. This is a non-destructive method to measure the surface compressive stress in flat glass. Each of these measurements should be obtained by averaging ten individual measurements – five locations with two orthogonal measurements at each location.

The surface compressive stress of heat strengthened glass should be greater than 24 MPa but less than 52 MPa. The surface compressive stress of tempered glass should be greater than 69 MPa. The surface compressive stress should be measured by the glass manufacturer from representative batch of glass as quality control record during glass production.

8.1.4 Thickness and flatness

The manufactured thickness of glass may vary from the specified nominal thickness resulting in a difference between the design strength and actual strength. Therefore, the glass thickness should comply with manufacturing specification and should not be less than the minimum thickness adopted in calculation.

For laminated glass, each measurement should be separated into the thicknesses of the individual glass panes and of the interlayers. Similarly, for IGUs, each measurement should be separated into the thicknesses of the individual glass panes and of the voids. The overall thickness of laminated glass can be measured by caliper, but not the interlayer thickness. The thickness of individual glass panes and the air space of IGU can be measured by optical/laser equipment.

Glass thickness, flatness and roller waves in glass panes should be checked in accordance with ASTM C1036, C1048 and C1651 by the glass manufacturer from representative batch of glass as quality control record during glass production.

8.1.5 Blemish inspection

Blemish is imperfection in the body or on the surface of a glass pane. Blemish should be detected but it is seldom a structural problem. General requirements and inspection method as stated in the ASTM C1036 should be adopted.

8.1.6 Boil test

The purpose of the boil test is to examine the lamination quality of the laminated glass subjected to exposure to high temperature and humidity conditions for 2 hours. Boil test as described in Annex B2 (or ANSI Z97.1 / BS EN ISO 12543) should be carried out by the glass manufacturer before the production of laminated glass to ensure the lamination quality and minimise the risk of delamination.

8.1.7 Impact test

Impact test should be carried out to BS EN 12600 for glass barriers and glass balustrades functioning as protective barrier by the glass manufacturer.

If the test specimen is made of asymmetric materials (e.g. laminated glass of different pane thicknesses or IGU of different types of glass panes), the number of test specimen should be doubled for impact test on both faces unless they are solely intended for installation in situations where the risk of impact is from one side only.

Acceptance criteria should satisfy Class 1 requirements as specified in BS EN 12600 with no glass breakage. The test specimen should be selected from representative batch of glass to be used as glass barrier in the project.

8.1.8 Bending test

Standard four point bending test on flat glass to BS EN 1288-3 under room temperature should be carried out to verify the minimum bending strength of decoratively treated glass and fritted glass such as ceramic fritted and enamelled painted glass.

Bending test should be carried out by an independent laboratory accredited under the Hong Kong Laboratory Accreditation Scheme (HOKLAS) within its scope of accreditation. The characteristic value of bending strength at breakage of the at least 5 test specimens of surface treated glass should not be less than the reduced glass design strength with factor of safety of 2.0.

A modified four point bending test at elevated temperature (50°C) aims to verify the composite action of laminated glass with interlayer materials. Bending test procedures and requirements are given in Annex B1. The effects of various factors (e.g. stiffness, thickness,

inter-layer materials and temperature) on the degree of composite action under bending test should be reviewed and assessed before adopting in design and requirements are specified in Annex B1.

8.2 STRUCTURAL SEALANT

Where structural sealant is proposed as structural glazing application or secondary seal of IGU, compliance certificate comprising print review report, sealant compatibility report and sealant adhesion report should be prepared.

8.2.1 Print review

All structural sealant joint details for effective curing should be reviewed by the sealant manufacturer. The minimum design requirement for structural sealant width and thickness should be calculated and tabulated in the Print Review Report.

8.2.2 Adhesion test

Adhesion test certificates for every sealant used with all materials in the vicinity of the sealant should be provided.

Adhesion test to ASTM C794 should be carried out by the sealant manufacturer. The content of the test report should follow ASTM C794.

8.2.3 Compatibility test

Compatibility test certificates for every sealant used should be provided to confirm the compatibility of the sealant with all surrounding materials including finishes (anodising, paint etc.), glass coatings, glazing gaskets, setting blocks, spacers, backing rod, concrete, steel, etc.

Compatibility test to ASTM C1087 should be carried out by the sealant manufacturer. The content of the test report should follow ASTM C1087.

8.3 SYSTEM TESTING

8.3.1 Curtain wall system

Safety test on a representative portion of the proposed curtain wall system should be carried out by an independent HOKLAS accredited laboratory within its scope of accreditation prior to commencement of construction.

The performance test mock-up of curtain walls includes:

- (1) Minimum of 2-storey height or full height of curtain wall with operable sash;
- (2) Minimum of 3-module width with turning corner(s), if any; and
- (3) Architectural feature(s), if any.

Loading sequence and duration of the operation of cyclic test are presented in Table 8.1.

Table 8.1 Sequence and duration of tests for both positive and negative pressures

Test	Test Preparation	Repeated Test	Test Safety
Pressure	0- p_1 -0- p_1 -0- p_1 -0	0- p_2 -0- p_2 -0- p_2 -0- p_2 -0- p_2 -0	0- p_3 -0
Duration	The period of transition from one pressure value to another should be not less than 1 second. The pressures are to be held at maximum or minimum values for at least 3 seconds.		

Notes:

- (a) For the test preparation, p_1 should be 0.5 p_2 .
- (b) For the repeated positive and negative pressure test, p_2 should be the pressure obtained from the product of the total pressure coefficient c_p and the design wind pressure q_z appropriate to that part of the building, determined in accordance with the Code of Practice on Wind Effects in Hong Kong. The number of pressure pulses should not be less than 5.
- (c) During the repeated positive and negative pressure tests, the deflection of any structural element of the specimen should not exceed:
 - a) 1/180 of the span or 20 mm, whichever is the less, for span not greater than 7.2 m.
 - b) 1/360 of the span for span greater than 7.2 m.
 - c) 1/90 of the span or 20 mm, whichever is the less, for cantilever type member.
- (d) The glass should not break and the deflection of glass pane should not exceed 1/60 of the span during the repeated positive and negative pressure tests.
- (e) For the safety test, the maximum required pressure p_3 should be 1.4 p_2 .
- (f) The extent of recovery of deformation 15 minutes after the removal of the test load should be at least 95% and the specimen should not show any signs of separation, plastic deformation or deleterious effect.

8.3.2 Other systems

Other types of systems or building enclosures could be used provided that the system will not fail, break or disengage from supports or supporting structures. When necessary, safety test with suitable test loads should be adopted to confirm the accuracy of structural design and analysis and their underlying assumptions.

9 QUALITY ASSURANCE

Quality assurance systems are required to ensure the safe use of glass in buildings. Quality assurance systems in the factory should cover all aspects from manufacturing, testing and inspection. A certificate from glass manufacturer confirming compliance to the standards is acceptable.

9.1 GLASS

9.1.1 General

Quality of flat glass should comply with the general specification given in ASTM C1036 or other equivalent international standards. The quality of heat strengthened and tempered glass should comply with ASTM C1048 or other equivalent international standards. Glass manufacturer should keep record for glass production and quality control test records in the factory.

9.1.2 Heat strengthened glass

Where heat strengthened glass is used in building construction, surface compressive stress of the glass should be measured as part of the quality assurance scheme. The designer should ensure that the surface compressive stress must be between 24 MPa and 52 MPa. Heat strengthened glass with a surface compressive stress greater than 52 MPa should be rejected. In addition, basic physical test and mechanical test given in clause 8.1 should be carried out if applicable. To ensure that the heat strengthened glass panes are of good quality, proper supervision and adequate quality control are necessary during the production of heat strengthened glass. Heat strengthened glass should be manufactured by a factory with the ISO 9001 quality assurance certification.

9.1.3 Tempered glass

Tempered glass is susceptible to spontaneous breakage induced by nickel sulphide inclusions. Extreme care and considerations to the occurrence of spontaneous breakage should therefore be taken in the manufacturing process of tempered glass prior to its use. Glass of suitable type, thickness and size should be selected to provide an appropriate degree of safety, taking into account the intended use and the possibility of catastrophic consequences in the event of breakage.

To ensure that the tempered glass panes are of good quality, proper supervision and adequate quality control are necessary during the production of tempered glass. Tempered glass should be manufactured by a factory with the ISO 9001 quality assurance certification.

Where tempered glass is used in building construction, an acceptable quality assurance scheme adopted by the glass manufacturer should be provided. The quality assurance scheme should include the following items:

- (1) Heat soak process to all tempered glass panes;
- (2) Calibration of heat soak oven and laboratory equipment for quality control tests;
- (3) Surface compressive stress measurement of glass;
- (4) Quality control procedures and requirements such as thickness measurement, flatness measurement, roller wave measurement, fragmentation test and impact test; and
- (5) Frequency and extent of inspection and audit by staff of the manufacturer, and independent parties.

9.2 GLASS ASSEMBLIES

9.2.1 Quality control of laminated glass

Delamination in laminated glass is a serious concern and it is important that adequate quality control and proper supervision for laminated glass production are necessary, especially where composite action is accounted for in the structural design of laminated glass. The requirements of quality assurance of laminated glass include laminating procedures and autoclaving parameters such as temperature, pressure and time interval.

Boil test conducted by glass manufacturer as described in clause 8.1.6 is one of the quality control measures on laminated glass in respect of the probable effects of exposure to high temperature and humidity conditions.

9.2.2 Quality control of IGU

Details of IGU, including construction details, primary and secondary seals, gas filling, corner treatment, nature of spacers, evacuation and assembly process should be provided by the glass manufacturer. To ensure a hermetic seal for effective load sharing, quality control on seal durability is required. In this regard, test report/certificate produced by IGU manufacturer indicating compliance with ASTM E2190 with respect to specification and seal durability for IGU should be submitted as quality assurance documents. Secondary seal shall comply with ASTM C1249 - Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications.

9.3 HEAT SOAK PROCESS

All tempered glass panes should be heat soak treated. The heat soak process is the most effective means of eliminating tempered glass with nickel sulphide inclusions, and it minimised the residual risk of spontaneous breakage of tempered glass during its normal serviceability life. The heat soak process conformed to the BS EN 14179-1 standard should be carried out to all tempered glass panes to be used with enhanced calibration and monitoring requirement.

9.3.1 Compliance report

Compliance report for heat soak process should be prepared and issued by the glass manufacturer. The compliance report should contain the following information:

- (1) Name of the tempered glass manufacturer;
- (2) Name of the project using the manufacturer's tempered glass;
- (3) Total number and surface area of tempered glass panes used in the project;
- (4) Location and identity number of the ovens, in which the heat soak process of the glass panes in (3) was conducted;
- (5) Calibration report as detailed in clause 9.3.2 of the ovens in accordance with the BS EN 14179-1 standard;
- (6) Quantity and configuration of thermocouples used to measure the glass surface temperatures in the oven. Eight thermocouples should be used as temperature monitoring records. The location of the eight thermocouples should be determined from the calibration report of the oven;
- (7) Recorded temperature versus time graphs for each of the eight thermocouples during heating phase, holding phase and cooling phase of the heat soak process;
- (8) Quantity, dimensions and thickness of the tempered glass panes conforming to the BS EN 14179-1 standard, and the record of breakages of panes in each heat soak process with corresponding oven number; and
- (9) Date of carrying out the heat soak process.

9.3.2 Calibration report

The heat soak oven should be calibrated to the BS EN 14179-1 standard at regular intervals in order to ensure the accuracy in achieving the correct temperature during the heat soak process. Usually, the calibration period of the oven is set at one-year interval by an independent laboratory related to curtain wall testing and with experience in heat soak oven calibration.

The measurements of the air temperature in the oven and the glass surface temperatures should be carried out when the oven is fully loaded. This maximum load should be defined by the glass manufacturer and should not exceed the maximum load as defined by the oven manufacturer. The maximum of total glass weight in regular operation should be referred to maximum load in calibration report.

The glass panes used for oven calibration should be either one thickness type (e.g. 8 mm) or a combination of two consecutive thickness types (e.g. 8mm and 10 mm). Thicker glass pane (e.g. 22 mm) should not be used in oven calibration because the large difference of glass thickness will affect the measurement of heating time. The maximum dimension of glass pane in regular operation (i.e. height of glass pane relative to the oven) should be referred to the largest glass pane in calibration report. Location of the eight monitoring thermocouples used to measure the glass surface temperatures in the oven for regular operation should be determined from calibration report of the oven.

9.3.3 Monitoring thermocouple

In addition to the oven calibration, thermocouples are used to monitor the highest and lowest temperatures on the glass pane surfaces. For the fully loaded oven in calibration, four locations for the four highest temperatures and four locations for the four lowest temperatures during heating phase should be identified. Therefore, a total of eight thermocouples covered by insulating pad should be determined from calibration report to monitor the glass pane surface temperatures in the oven for regular operation. The thermocouple first reaches 250°C may not be the thermocouple with the highest temperature during heating phase. The thermocouples should be calibrated at 6-month intervals as recommended in the HOKLAS Supplementary Criteria No.2. All thermocouples should be calibrated with proper temperature range including temperatures at 100°C, 200°C and 300°C.

The largest and the thickest glass panes should be monitored by one of the eight thermocouples in the oven for regular operation. In case the monitoring thermocouple fails to measure the surface temperature due to spontaneous breakage of tempered glass, this heat soak process can still be accepted unless the monitoring thermocouple refers to the lowest or highest temperatures during heating phase of this operation. During heating phase, the rate of heating should be steadily increased and controlled to minimise the risk of glass breakage, and the glass surface temperature should not exceed 290°C. The maximum heating rate is 3°C per minute. When the glass surface temperature exceeds 270°C during heating phase, the period of glass surface temperature in excess of 270°C should be minimised. However, the actual heating and cooling rates are usually determined by the characteristics of the oven and loading of individual heat soak process and could be varied on batch by batch basis.

9.3.4 Quality control supervision

Quality control supervisors should be assigned to provide supervision of the heat soak process of all tempered glass panes in the factory.

To ensure the proper conduct of the heat soak process by the glass manufacturer, the quality control supervisors should measure at least one glass surface temperature independently by using his/her own data logger. The location of this glass surface temperature measurement should be closely placed to one of the eight monitoring thermocouples given by the oven calibration report. This glass surface temperature measurement should be the largest and/or thickest glass pane in the oven. The information recorded by the data logger should be set at one-minute intervals and kept in the factory. The data logger is recommended to be calibrated by HOKLAS or equivalent laboratory with proper temperature range including temperatures at 100°C, 200°C and 300°C.

The compliance of the heat soak process should be based on the temperature readings from the glass manufacturer. The quality control supervisor's temperature data is used as reference for ensuring the glass manufacturer has performed the heat soak process. However, the heat soak process should be reviewed / examined if the discrepancy of thermocouples readings from the quality control supervisor and the glass manufacturer at the same location is larger than 5% during holding phase. The details of heat soak process for tempered glass panes should be recorded in the log book and kept in the factory.

9.4 STRUCTURAL SEALANT FOR GLAZING APPLICATION

Design drawings should be submitted to sealant manufacturer for review and the print review report should be completed successfully prior to sealant application. Chemically incompatible glazing accessories (i.e., glazing spacer tape, gasket, setting bock, backer rod, etc.) can lead to sealant discoloration and/or loss of sealant adhesion to the substrates. Therefore, samples of the glazing accessories materials that are representative of those to be used in the projects should be submitted to the sealant manufacturer to perform compatibility test for the approval of their use prior to sealant application. Poor adhesion of sealant to the glazing substrates (i.e., glass, aluminium, stainless steel, etc.) can lead to structural failure. Therefore, samples of the glazing substrates that are representative of those to be used in the projects should be submitted to the sealant manufacturer to perform adhesion test for the approval of their use prior to sealant application.

Cleaning, priming, applying sealant and tooling sealant are four basic steps for proper structural sealant joint preparation and sealant application. Sealant manufacturer's recommendations on sealant application should be followed. Optimum temperature range for sealant application is 10-35°C. For sealant application below 10°C, the potential for dew point and frost should be considered. Quality control testing such as butterfly test and snap-time test should be carried out at the start-up of equipment for factory applied two-part structural sealant. Peel-in-adhesion test is also required as a means to verify sealant adhesion on production materials. The daily quality control testing and document should be recorded in a log book and kept in the factory.

Deglazing test is a method of quality inspection used to confirm if the sealant application has strictly followed the recommendations outlined in the sealant manufacturer's print review and adhesion test report. Deglazing test should be carried out in accordance with the sealant manufacturer's suggested percentage of total number of structurally glazed glass panes to ensure the on-site structural glazing quality of the factory structural glazing quality before transportation to the site for installation. The inspection should include the following:

- (1) Size of structural bite and thickness,
- (2) Adhesion of silicone sealant with glass pane and frame,
- (3) Joint type/condition of sealant applied, and
- (4) Appearance of the sealant / uniformity of colour / bubble.

9.5 INSPECTION, MAINTENANCE AND REPAIR

Curtain wall, window and window wall systems consist of numerous components and connections, which must withstand the external environment. As such, there are many potential initiation points and forms of deterioration. Further, the typical location of these systems above pedestrian areas makes consideration of their conditions a critical concern. Therefore, regular inspection and maintenance of glazing systems is an important aspect of building maintenance for the safety of occupants and the public, and for the reduction of long-term costs.

In view of the situation above, the purpose of Annex D of the Code is to recommend a standard of good practice for the maintenance of glazing systems by building owners. The recommendations provide a basic outline of inspection and maintenance procedures, and documentation and management tasks that can form an effective strategy for meeting the owner's obligations.

Annex A

REFERENCES

A1 REFERENCED STANDARDS

AS 1288-2006	Glass in Buildings - Selection and Installation (Incorporating Amendment Nos. 1 and 2)
AAMA 501.1	Standard Test Method for Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure
AAMA 501.2	Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems
AAMA 501.3	Field Check of Water and Air Leakage Through Installed Exterior Windows, Curtain Walls, and Doors by Uniform Air Pressure Difference
ASTM C719-14	Standard Test Method for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement (Hockman Cycle)
ASTM C794-15	Standard Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants
ASTM C920-14a	Standard Specification for Elastomeric Joint Sealants
ASTM C1087-00 (2006)	Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems
ASTM C1036-11e1	Standard Specification for Flat Glass
ASTM C1048-12e1	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM C1172-14	Standard Specification for Laminated Architectural Flat Glass
ASTM C1184-14	Standard Specification for Structural Silicone Sealants
ASTM C1249-06a(2010)	Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications
ASTM C1279-09	Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered Flat Glass
ASTM C1369-14	Standard Specification for Secondary Edge Sealants for Structurally Glazed Insulating Glass Units
ASTM C1651-11	Standard Test Method for Measurement of Roll Wave Optical Distortion in Heat-Treated Flat Glass
ASTM C1401-09a	Standard Guide for Structural Sealant Glazing
ASTM C1464-06(2011)	Standard Specification for Bent Glass
ASTM D638-10	Standard Test Method for Tensile Properties of Plastics
ASTM D5026-06	Standard Test Method for Plastics: Dynamic Mechanical Properties: In Tension
ASTM E283-04(2012)	Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
ASTM E330-14	Standard Test Method for Structural Performance of Exterior

	Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference
ASTM E331-00(2016)	Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
ASTM E547-00(2016)	Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference
ASTM E1300-12ae1	Standard Practice for Determining Load Resistance of Glass in Buildings
ASTM E2190-10	Standard Specification for Insulating Glass Unit Performance and Evaluation
ANSI Z97.1-2009	Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test
BS 952-1:1995	Glass for Glazing. Part 1: Classification
BS 952-2:1980	Glass for Glazing. Part 2: Terminology for Work on Glass
BS 5516-1: 2004	Patent Glazing and Sloping Glazing for Buildings. Code of Practice for Design and Installation of Sloping and Vertical Patent Glazing
BS 5516-2: 2004	Patent Glazing and Sloping Glazing for Buildings. Code of Practice for Sloping Glazing
BS 6180: 1999	Barriers in and about Buildings. Code of Practice
BS 6206: 1981	Specification for Impact Performance Requirements for Flat Safety Glass and Safety Plastics for Use in Buildings
BS 6213:2000+A1:2010.	Selection of Construction Sealants. Guide.
BS 6262: 2005	Glazing for Buildings
BS EN 572: 2004	Glass in Building - Basic Soda Lime Silicate Glass Products
BS EN 1279-1: 2004	Glass in Building - Insulating Glass Units Part 1: Generalities, Dimensional Tolerances and Rules for the System Description
BS EN 1288-3:2000	Glass in Building - Determination of the Bending Strength of Glass. Part 3: Test with Specimen Supported at Two Points (Four Point Bending)
BS EN 1863-1: 2011	Glass in Building. Heat Strengthened Soda Lime Silicate Glass. Definition and Description
BS EN 1863-2: 2004	Glass in Building. Heat Strengthened Soda Lime Silicate Glass. Evaluation of Conformity. Product Standard
BS EN 12600: 2002	Glass in Building - Pendulum Test. Impact Test Method and Classification for Flat Glass
BS EN 13022-2: 2006	Glass in Building. Structural Sealant Glazing. Assembly Rules
BS EN 14179-1: 2016	Glass in Building - Heat-soaked Thermally Toughened Soda Lime Silicate Safety Glass. Part 1: Definition and Description
BS EN 15434: 2006	Glass in Building. Product Standard for Structural and/or Ultra-violet Resistant Sealant
BS EN ISO 12543	Glass in Building. Laminated Glass and Laminated Safety

	Glass.
CAN/CGSB-12.20-M89	Structural Design of Glass for Buildings
GB 15763-2: 2005	Safety Glazing Materials in Building. Part 2: Tempered Glass
GB 15763-3: 2009	Safety Glazing Materials in Building. Part 3: Laminated Glass
GB 15763-4: 2009	Safety Glazing Materials in Building. Part 4: Heat Soaked Thermally Tempered Glass

Annex B

TESTING PROCEDURES AND REQUIREMENTS FOR DETERMINATION OF COMPOSITE ACTION OF LAMINATED GLASS

B1 BENDING TEST PROCEDURES AND REQUIREMENTS

- 1) Test specimen
 - a. Dimension of glass panes: 360 mm (wide) x 1100 mm (long)
 - b. Number of specimens: 5 pieces per each sample glass type
 - c. Temperature of specimens: 50°C for degree of composite action of laminated glass
- 2) Test methodology and instrumentation
 - a. Measure the width, length and thickness of the specimen and describe the edge finish.
 - b. Place the heated sample under the Universal Test Machine.
 - c. Set the bending rollers, length of which is at least the specimen's width, spacing to $L_b = 200$ mm and the supporting rollers, length of which is at least the specimen's width, spacing to $L_s = 1000$ mm, as shown in Figure B1.1.
 - d. Place 4 nos. of transducers on the glass face at the location as shown in Figure B1.1.
 - e. Stick adhesive film on the side of the specimen facing the bending rollers (i.e. on the compression surface).
 - f. Carefully place and centre the specimen on the testing table with strips of rubber, of 3 mm thick and of hardness (40 ± 10) IRHD in accordance with the ISO 48 standard, placed between the specimen and the bending rollers.
 - g. Set the loading machine and transducers to zero readings.
 - h. Test the specimens under $50^\circ\text{C} \pm 3^\circ\text{C}$ for degree of composition action.
 - i. Apply the load at a uniform stress rate $r = 2.0 \pm 0.4$ MPa/sec until failure occurs.
 - j. Record the load and deflections throughout the test.
 - k. Record the failure load F_{max} and the time taken to reach this load.
 - l. Observe and record the location of the origin of fracture.
 - m. Repeat Steps 2a. to 2l. for all specimens.

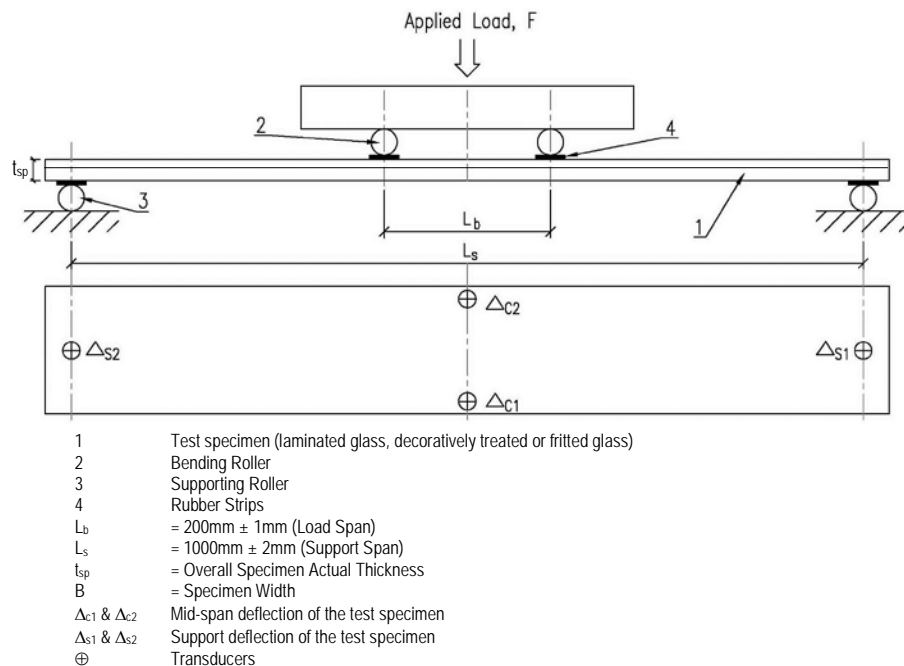


Figure B1.1 Test set-up

- 3) Determine the stiffness of a laminated glass pane specimen

Plot the load-deflection readings to a convenient scale using the average net mid-span deflection and draw a straight line to represent the average of the plotted points for the linear portion of the curve. (Figure B1.2).

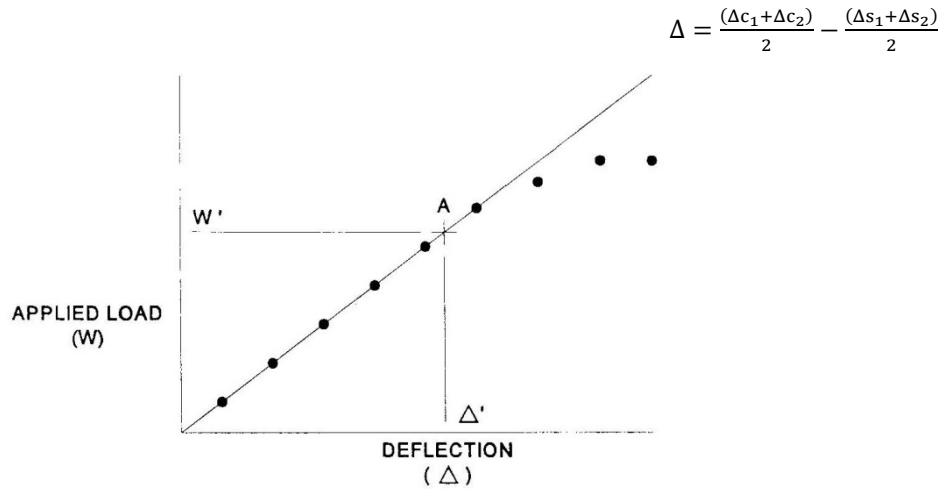


Figure B1.2 Typical load-deflection plot.

- 4) Data analysis for equivalent thickness of laminated glass

The measured load-displacement (mid-span deflection) curve should be plotted for each of the specimens. Equivalent stiffness ($\frac{W}{\Delta}$) of the test specimen should be evaluated by best-fit line of linear stage of the measured load-displacement curve. Based on the characteristic value of the equivalent stiffness, the equivalent thickness (t_{eq}) is calculated by the following equation.

$$t_{eq} = \sqrt[3]{\frac{k \left(\frac{W}{\Delta}\right)}{BE}} \cdot L_s \quad (B1)$$

in which $k = \frac{3a}{4L_s} - \left(\frac{a}{L_s}\right)^3$ and $a = \frac{L_s - L_b}{2}$

where:

t_{eq} is the equivalent thickness (mm)

t_{sp} is the overall thickness of test specimen (mm)

$\frac{W}{\Delta}$ is the characteristic value of equivalent stiffness from the test results (N/mm)

Characteristic value = Average value – K-factor × Standard deviation

K-factor may be taken as 3.41 for at least 5 test specimens; it is corresponding to larger nos. of test specimens may be used if appropriate.

L_b is the load span set as 200 mm

L_s is the support span set as 1000 mm

B is the width of sample set as 360 mm

E is the Modulus of elasticity of glass (70,000 N/mm²)

λ_{test} is the degree of composite action in terms of stiffness developed and is calculated by the following equation:

$$\lambda_{test} = \frac{I_{eq}}{I} = \left(\frac{t_{eq}}{t_{sp}}\right)^3 \quad (B2)$$

I_{eq} is the equivalent second moment of area (mm⁴), $I_{eq} = B t_{eq}^3 / 12$

I is the second moment of area of test specimen (mm⁴), $I = B t_{sp}^3 / 12$

B2 BOIL TEST PROCEDURES AND REQUIREMENTS

Boil test for laminated glass should be carried out by the glass manufacturer with quality supervision to determine the probable effect of exposure to high temperature and humidity conditions for 2 hours.

Three 300 mm by 300 mm flat specimens should be immersed in water at $66^{\circ}\text{C} \pm 6^{\circ}\text{C}$ for 3 minutes and then quickly transferred to and similarly immersed in boiling water. The specimens should be kept in the boiling water for 2 hours.

The laminated glass pane may crack in the test, but no bubble or other defects should develop more than 12 mm from the outer edge of the specimen or from any crack that may develop. Any specimen in which the glass cracks to an extent confusing the results should be discarded without prejudice and tested again with another specimen.

Annex C

STABILITY OF GLASS FINS AND BEAMS

This Annex references to Appendix C of Australian Standard AS 1288 – 2006,
Glass in Buildings – Selection and Installation

DESIGN OF GLASS FIN TO PREVENT BUCKLING

C1 INTRODUCTION

In glass façades which use glass stiffening fins located on the inside to provide the necessary support for the façade panes, it is necessary to ensure that buckling of the fin will not occur when it is subjected to the design loads.

Since there are many possible configurations for glass stiffening fins, it is not practicable to provide a simplified design approach. Consequently, each design must be analysed in accordance with accepted engineering principles.

The analysis requires a knowledge of the critical elastic buckling moment (M_{cr}), and values for particular situations can be obtained from standard texts on structural analysis. However, as an aid to design, some values of the critical elastic moment are presented in this Annex.

The design moment for a particular structural situation should not exceed more than the critical elastic buckling moment (M_{cr}) divided by a factor of safety of 1.7.

The following recommendations are applicable to end-supported beams of bi-symmetrical cross-section for which the contribution of warping stiffness to the buckling strength may be neglected.

The ends at supports are assumed to be effectively restrained against twisting. This condition will be satisfied if the supports possess a torsional stiffness in excess of $20GJ/L$, which GJ is the torsional rigidity of the beam and L is its length.

C2 BEAMS WITH INTERMEDIATE BUCKLING RESTRAINTS

The critical elastic value of the maximum moment between two buckling restraints may be taken as –

$$M_{cr} = (g_1/L_{ay}) [(EI)_y (GJ)]^{1/2} \quad (C1)$$

where

- M_{cr} = critical elastic buckling moment
- g_1 = constants obtained from Table C1
- L_{ay} = distance between effectively rigid buckling restraints
- $(EI)_y$ = effective rigidity for bending about the minor axis
- (GJ) = effective torsional rigidity

In computing the effective torsional rigidity of beams of solid rectangular cross-section, the value of the torsional moment of inertia (J) may be taken as

$$J = \frac{db^3}{3} \left(1 - 0.63 \frac{b}{d}\right)$$

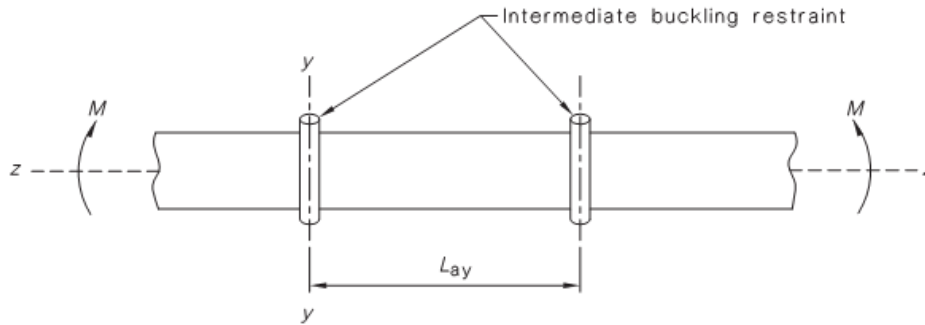
where d and b are the depth (fin thickness) and breadth of the fin respectively.

G and E are taken as $28,700 \text{ N/mm}^2$ and $70,000 \text{ N/mm}^2$ for glass fins.

TABLE C1
COEFFICIENTS FOR SLENDERNESS FACTOR
OF BISYMMETRICAL BEAMS WITH
INTERMEDIATE BUCKLING RESTRAINTS

Moment parameter (β) (see Figure C1(c))	Slenderness factor (g_1)	
	Free restraint condition*	Fixed restraint condition*
1.0	3.1	6.3
0.5	4.1	8.2
0.0	5.5	11.1
-0.5	7.3	14.0
-1.0	8.0	14.0

* The buckling restraints must prevent rotation of the beam about the z-axis. The terms 'free' and 'fixed' restraint condition refer to the possibility for rotation of the beam about y-y axis at the restraint locations, as shown in Figure C1.



(a) Side view of beam



(b) Top view of beam



(c) Diagram of bending moment between buckling restraints

FIGURE C1 NOTATION FOR BEAMS WITH INTERMEDIATE BUCKLING RESTRAINTS

C3 BEAMS WITH NO INTERMEDIATE BUCKLING RESTRAINTS

The critical elastic value of maximum moment of beams with no intermediate buckling restraints may be taken as –

$$M_{cr} = (g_2/L_{ay})[(EI)_y (GJ)]^{1/2} \left[1 - g_3(y_h/L_{ay})[(EI)_y / (GJ)]^{1/2} \right] \quad (C2)$$

where

- M_{cr} = critical elastic buckling moment
- g_2, g_3 = constants obtained from Table C2
- L_{ay} = distance between effectively rigid buckling restraints
- $(EI)_y$ = effective rigidity for bending about the minor axis
- (GJ) = effective torsional rigidity
- y_h = height above centroid of the point of load application

NOTE: in Table C2, the values of the coefficients g_2 and g_3 apply to beams with lateral restraints only at their end points. However, these coefficients may be used for any other beam load system that has a similar shape of bending moment diagram between points of lateral restraint.

TABLE C2

COEFFICIENTS FOR SLENDERNESS FACTORS OF BISYMMETRICAL BEAMS WITH NO INTERMEDIATE BUCKLING RESTRAINTS

Loading	Bending moment (M)	Condition of end restraint against rotation about y-y axis*	Slenderness factors	
			g ₂	g ₃
		Free Fixed	3.6 6.1	1.4 1.8
		Free Fixed	4.1 5.4	4.9 5.2
		Free Fixed	4.2 6.7	1.7 2.6
		Free Fixed	5.3 6.5	4.5 5.3
		Free Fixed	3.3 —	1.3 —
		Fixed	4.0	2.0
		Fixed	6.4	2.0

* For direction of the v-v axis, see diagram in Figure C2 (free ends of cantilevers expected).

C4 CONTINUOUSLY RESTRAINED BEAMS

For beams of bisymmetrical cross-section continuously restrained against lateral displacement at a distance y_0 from the neutral axis, the critical elastic moment M_{CR} may be taken as –

$$M_{cr} = \frac{(\pi/L_{ay})^2 (EI)_y \left[\frac{d^2}{12} + y_0^2 \right] + (GJ)}{(2y_0 + y_h)} \quad (C3)$$

where

- M_{cr} = critical elastic buckling moment
- L_{ay} = distance between effectively rigid buckling restraints

$(EI)_y$ = effective rigidity for bending about the minor axis

d = depth of beam

(GJ) = effective torsional rigidity

y_h = location from the neutral axis of the loading point [see Figure C2].

NOTE: The parameter y_h may take on negative values, subject to the direction of the applied load and the position of the restraint.

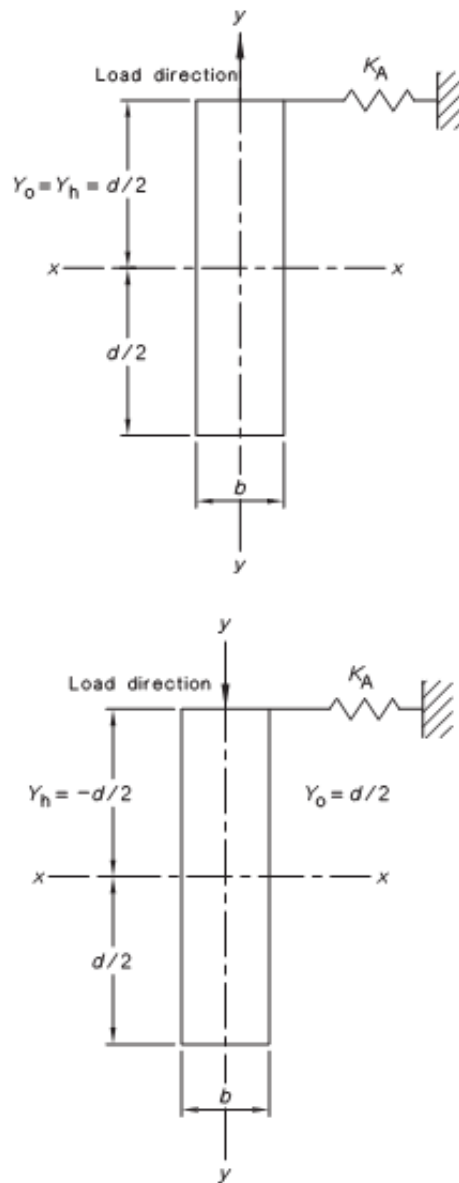


FIGURE C2 BEAM LATERAL RESTRAINTS

C5 BUCKLING RESTRAINTS

For most design situations, no check needs to be made on the effectiveness of buckling restraints. However, for an unusually light restraint system being used for a critical (i.e., non-load-sharing) engineered structure, it may be advisable to assess the effect and the capacity of the restraints.

For a design of slender beams having equally spaced buckling restraints, the restraint system is considered a lateral one as shown in Figure C2 where the restraint stiffness (K_A) is defined as follows:

$$P_R = K_A \Delta_A \quad (C4)$$

where

P_R = restraint force

K_A = restraint stiffness

Δ_A = beam displacement

The restraint force (P_R) occurs when the point of attachment of the restraint to the beam undergoes a displacement (Δ_A). It is assumed that the ends of beams are effectively restrained against torsional rotation.

For members of rectangular section and for box beams, the design force (P_R) on the lateral restraints is given by the following equation:

$$P_R = \frac{0.1 M_a}{d (n + 1)} g_4 \quad (C5)$$

where

M_a = the applied bending moment on the beam

g_4 = constant

= lesser of $(m + 1)/2$ and 5

d = depth of beam

n = number of equally spaced intermediate restraints

m = number of members supported by each restraint system

ANNEX D

INSPECTION, MAINTENANCE AND REPAIR

D1 GENERAL

Glazing system inspections and maintenance are generally carried out in two complementary ways:

- a) frequent routine inspections carried out by personnel with relevant experience and followed by maintenance works carried out by contractors with relevant experience in glazing system works; and
- b) periodic planned inspections, but less frequent than routine inspections, carried out by building professionals with relevant experience, following detailed procedures and documentation requirements as agreed with the building owners and maintenance works as recommended by the building professionals.

This Annex provides a general guideline for the aforesaid inspections and maintenance works including: the management approach; advice on the supporting documentation that can assist with the tasks; and suitable record keeping to produce effective long-term outcomes.

D2 DETERIORATION AND FAILURE OF GLAZING SYSTEMS

It is important that the persons inspecting and maintaining glazing systems are conversant with the forms of deterioration and failure that may occur. Some of these mechanisms are of particular importance to or are specific to glass and glazing systems.

D2.1 Typical forms of deterioration

Typical forms of deterioration, which may be observed include, but are not limited to:

- a) cracked, loose, broken or missing glass panes;
- b) significant scratches, chips, blemishes or other defects;
- c) bulging, bowing, separation, delamination, rotation, or displacement of panes;
- d) corrosion of metallic components, especially where moisture and debris have accumulated or incompatible metals are in contact (bimetallic corrosion);
- e) condensation or fogging between IGU panes;
- f) delamination of laminated glass;
- g) staining from corrosion, chemicals or water;
- h) missing, damaged, loose or deteriorated fixings;
- i) deteriorated, missing or displaced gaskets;
- j) missing, poorly applied, damaged or deteriorated (e.g., split, weathered, cracked, hardened, poorly adhered) sealant; and
- k) water seepage or moisture behind curtain wall, window or window wall.

D2.2 Glass failure

Failure of glass, especially in high-rise buildings, creates a significant safety hazard. Failure incidents must be examined and addressed immediately by suitable persons with relevant experience to try to identify the cause and rectification measures required. Failures typically occur due to the following reasons (not in order of importance):

- a) excessive stress from wind pressure or other loads and/or insufficient glass thickness;
- b) thermal stress due to differential temperature on different parts of the pane (for 33°C, the thermal stress is 20.7 N/mm²);
- c) buckling due to large compression (e.g. glass rod and glass fins);
- d) surface or edge damage;
- e) deep scratches or gouges;
- f) severe weld splatter;

- g) windborne missile (i.e. debris impact);
- h) direct contact with metal (e.g. window aluminium frame); and
- i) spontaneous breakage of tempered glass due to NiS inclusions.

D3 MAINTENANCE MANAGEMENT

D3.1 Maintenance management actions

Glazing or cladding system that is not properly maintained may deteriorate and become so insecure that it fails under relatively light loads, and may cause injury to persons or damage to property. The risks and expense of such incidents could far outweigh the cost of suitable, regular maintenance.

Owners or parties required to maintain buildings should undertake regular maintenance inspections and works, which can be arranged by themselves or through an agent. For buildings maintained by a single owner, arrangement of maintenance is fairly straightforward. For owners of individual flats in a multi-storey building, it may be necessary in practice for an Owners' Corporation to discharge the maintenance responsibility on behalf of the individual owners, usually through a property management company.

The basic management action to be undertaken is to ensure that inspections are satisfactorily completed with maintenance works promptly carried out. This may be best accomplished by following a detailed maintenance manual, as described below. If a dedicated maintenance manual for the building is not available, it is strongly advisable to commission building professionals with relevant experience to produce one.

D3.2 Maintenance manual

A building's maintenance manual is the most important document guiding the management of glazing systems. It should contain a dedicated section or appendix covering the inspection and maintenance of the glazing systems, as they have special requirements. For new development, the section or appendix for glazing systems including design documentation should be written by the relevant designer, which should follow a consistent framework, and provide sufficient detail for the specific building and glazing systems adopted, taking into account individual characteristics of the design. Guidance should also be provided on the management approach and record-keeping requirements, as described below.

If no dedicated manual or manual section is available for glazing systems, the owners should commission building professionals with suitable experience to produce one at the earliest possible time.

D3.3 Coordinated approach to managing glazing systems

A number of different actions may be taken in managing glazing systems. The primary tasks are to ensure satisfactory completion of different types of inspections and subsequent maintenance. To produce the most effective outcomes it is beneficial to have a coordinated approach to managing these tasks. The coordinated approach for achieving the outcomes should be clearly defined in the maintenance manual, which should state the objectives of different inspections, appropriate maintenance measures based on the inspection findings and the documentation required for all actions. In this way, property managers or agents can review the information at any stage and make informed decisions. Ideally the coordinated approach will be linked through an asset management plan for the building, which will ensure efficient budgeting and scheduling.

D3.4 Record-keeping

Comprehensive and accurate record-keeping is critical to enabling the coordinated maintenance approach described above. As a minimum, the following should be made available:

- a) a building maintenance manual with a section covering the glazing systems of the building;

- b) inspection and maintenance records, which comply with the format and specifications specified in the maintenance manual;
- c) records of any servicing, repairs or modifications;
- d) approved drawings and related design documents;
- e) a listing of all glazing system components along with supplier/manufacturer names and contact details;
- f) supplier/manufacturer data sheets, warranties and other relevant documentation; and
- g) method statements and related approved design documentation covering all relevant details of the systems including maintenance procedures and recommendations.

The above information should be kept by the owner or the appointed agent with suitable provisions made in regard to accessibility, security and backup copies.

D4 ROUTINE INSPECTIONS AND MAINTENANCE

D4.1 Purposes and scope of routine inspections and maintenance

Routine inspections and maintenance should be carried out in order to rectify issues that present a short-term risk to safety and functionality and to flag longer term issues that may require further investigation. When the presence of any existing cladding that may obscure the inspection of key structural component and fixtures, the removal of such cladding should be considered to ensure a thorough inspection. Key aspects of this stage include, but are not limited to:

- a) repair or replacement of broken components;
- b) identification and securing of any loose components;
- c) cleaning, particularly in regard to the removal of any debris that may block drainage systems; and
- d) identification of any staining that may be a sign of leakage or corrosion issues.

Review of the design, materials or components may be required if any issues are found to occur frequently or in many locations. This is especially important to note in regard to components, which are failing or becoming loose and could fall from the building. In this case and for any other significant issues that cannot be easily resolved further investigation and advice should be sought from building professionals with suitable experience.

D4.2 Personnel for routine inspections and maintenance

As the scope of the routine inspections and maintenance only covers the identification and rectification of basic defects, any personnel with relevant experience inspecting and maintaining such systems may carry out the work, including building management and maintenance staff with suitable experience. Nevertheless, the advantage of using professionally qualified staff for this work is that specific issues may be identified at an earlier stage and more effective solutions may be recommended.

D4.3 Routine maintenance works

Most of the maintenance works arising from the routine inspections will be common tasks, which can be completed by registered contractors experienced with glazing systems.

The maintenance and repair procedures and methodologies should be contained in the maintenance manual and adhered to wherever possible. Ideally the works should preserve the original design and comply with manufacturer's requirements for the original and replacement products. In cases where there is need or justification for modifying the original design or where the works are not covered under the common tasks in the maintenance manual, advice should be sought from building professionals with relevant experience.

D4.4 Records for routine inspections and maintenance

Simple record sheets should be kept for routine inspections and maintenance. It should be completed in two stages, i.e. on completion of the inspections and on completion of maintenance works. The owners, owners' corporation, and property management company, as appropriate, responsible for the routine inspections and maintenance should ensure a suitable system in place and all works have a corresponding record. A comprehensive archive of all approved records is maintained. These records will be very helpful for engineers or professionals in identifying any long-term performance issues with the glazing systems.

D5 PLANNED INSPECTIONS AND MAINTENANCE

D5.1 Purposes and scope of planned inspections and maintenance

Planned Inspections and maintenance should be targeted at providing the optimal long-term actions for a building as opposed to the more immediate actions served by the Routine Inspections and maintenance. A detailed inspection of the glazing systems by building professionals with relevant experience should identify longer term issues that require attention.

The long-term focus allows the subsequent maintenance to be planned well in advance with the main objective being to avoid more costly repairs, which would be required if the issue was not addressed until it became critical. This approach also has the benefit of minimising disruption to building occupants over the life of the building.

Inspections and maintenance are commonly carried out by an external party with the scope of such an assignment typically covering:

- a) desktop review of maintenance manual, previous inspection and maintenance reports and other relevant documentation;
- b) detailed condition survey, which may incorporate testing, especially non-destructive testing and selected destructive tests, particular of sealant;
- c) comprehensive survey report with any relevant photos and measurement data, and recommendations for subsequent maintenance action;
- d) updating of the maintenance manual if necessary;
- e) design, costing and planning of maintenance works; and
- f) supervision of maintenance works (it can be beneficial, although not essential, for the building professional that conducted the inspections to supervise the maintenance works).

When the presence of any existing cladding that may obscure the inspection of key structural component and fixtures, the removal of such cladding should be considered to ensure a thorough inspection. The inspections may determine that no particular maintenance or only minor maintenance is required. In this case the last two steps above may not be required.

D5.2 Personnel for planned inspections and maintenance

The inspections should be carried out by building professionals with relevant experience in the inspection and maintenance of glazing systems and understanding of the relevant deterioration and failure mechanisms.

Where considered necessary, the inspecting building professionals should advise the owner or party required to maintain the building to consult a qualified structural engineer for any suspected structural problems identified during the inspection.

As for routine maintenance inspections, most common tasks can be completed by contractors experienced with glazing systems. For more significant issues and structural issues, specialised contractors with experience in the particular glazing systems should be employed.

D5.3 Maintenance works from the planned inspections

The recommended maintenance works arising from the inspections may cover the full spectrum, depending on the circumstances, from routine maintenance as covered in D4.3 to

detailed design work. In general, any works that are not covered by the maintenance manual should be specified by the building professionals with relevant experience.

D5.4 Records for planned inspections and maintenance

Detailed records should be kept for planned inspections and maintenance. It should be completed in two stages, i.e. on completion of the inspections and on completion of maintenance works. The owners, owners' corporation, and property management company, as appropriate, responsible for the planned inspections and maintenance should ensure a suitable system in place and all works have a corresponding record. A comprehensive archive of all approved records is maintained. The maintenance manual should be updated and revised for any modification of system in the planned inspections and maintenance. These records will be very helpful for engineers or professionals in identifying any long-term performance issues with the glazing system.