MALAYSIAN STANDARD

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Use of glass in building – Code of practice: Part 2 – Design and analysis

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The Chartered Institute of Building Malaysia
Universiti Teknologi Malaysia

The Working Group on Code of Practice for Glass (NSC 04/TC 9/WG 6) which developed this Malaysian Standard consists of representatives from the following organisations:

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Safety Glass Processor Association of Malaysia
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Foreword

This Malaysian Standard was developed by the Working Group on Code of Practice for Glass (NSC 04/TC 9/WG 6) under the authority of the National Standards Committee on Building and Civil Engineering Works (NSC 04).

MS 2753 consists of the following parts, under the general title Use of glass in building – Code of Practice

Part 1: Selection of glass
Part 2: Design and analysis

Compliance with a Malaysian Standard does not of itself confer immunity from legal obligations.

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Use of glass in building – Code of Practice – Part 2: Design and analysis

1 Scope

This document provides guidelines on the design, construction, testing, quality assurance and installation of glass structures or elements in buildings.

1.1 Design considerations

1.1.1 Aim of glass design

The limit state design principle is adopted for structures using glass with the aim to achieve the following:

i) Overall stability and buckling resistance against the design loads;

ii) Strength against collapse under the design loads and the imposed deformations of supporting structures;

iii) Integrity and robustness against progressive collapse under the design loads;

iv) Serviceability under the design loads and the imposed deformations of supporting structures;

v) Water and air tightness;

vi) Durability;

vii) Quality; and

viii) Maintainability during its design working life.

1.1.2 Design references

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 1.1.1 can be achieved.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

MS 1135, Float glass – Specification

MS 1498, Safety glass in building – Specification

MS 2397, Coated glass in building - Specification

MS 2666, Glass in buildings - Insulating Glass Unit (IGU) - Performance and evaluation

MS 2676, Wired glass – Specification

BS EN 14179, Glass in building - heat soaked thermally toughened soda lime silicate safety glass

Code of practice for structural use of glass

BS EN 13022-2, Glass in Building – Structural Sealant Glazing.

BS EN 15434, Glass in Building – Product Standard for Structural and/or Ultra- violet Resistant Sealant.

ASTM C1184-14, Standard Specification for Structural Silicon Sealants.

ASTM C1401-02, Standard Guide for Structural Sealant Glazing

ASTM C1249, Standard Guide for IGU Structural Sealant Glazing

ASTM C1249-93, Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
bite
width of structural sealant used to bond the glass to supporting members.

3.2
buckling resistance
limit of force or moment that a member can withstand without buckling failure.

3.3
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.

3.4
ultimate design strength
ultimate design strength obtained by applying partial material factor to the specified minimum yield strength or tensile strength of the material.

3.5
gasket
plastic-like solid material used to separate glass and other brittle materials from contact with each other or supporting frames.

3.6 Glass

3.6.1
annealed glass
sheet, plate, float or rolled glass that is processed to allow residual internal stresses to be relaxed so that it can be freely cut complied to MS 1135.

3.6.2
decorative glass
clear or tinted 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.

3.6.3
heat-soaked process
quality control process to heat up tempered glass for a period of time to reduce the possibility of spontaneous breakage in service due to “nickel sulphide inclusions”.

3.6.4

heat strengthened glass
glass which has been subjected to a special heat treatment so that the residual surface compression stresses lie between 24 MPa to 52 MPa.

Note 1 to entry: Monolithic heat strengthened glass is not suitable for the safety glazing application

3.6.5
heat treated
a generic term for glass that has been heat strengthened or tempered in order to increase its mechanical strength and resistance to thermal breakage.

3.6.6
Insulating Glass Unit (IGU)
an assembly consisting of at least two panes of glass, separated by one or more spacers, hermetically sealed along the periphery, mechanically stable and durable.

Note 1 to entry: Systems are available where the spacer and hermetic seal are included within a single edge sealing system.

3.6.7
laminated glass
glass consisting of two or more sheets of glass permanently bonded together by one or more sheets of plastic interlayer. Plastic interlayer can consist of polyvinyl butyral (PVB), thermoplastic polyurethane (TPU), ethyl vinyl acetate (EVA), polyethylenes, polycarbonates, polyurethanes and other plastics.

3.6.8
patterned glass
glass having a pattern impressed/embossed on one side or both sides.

3.6.9
safety glass
glass or glass assemblies that are "break safe" such as laminated or tempered glass.

3.6.10
tempered glass
glass of any shape that has been subjected to a thermal treatment process characterised by uniform heating followed by rapid uniform cooling to produce comprehensively stressed surface layers.

3.6.11
tinted glass
glass to which a small amount of colour has been added consistently through the glass batch which reduces glare and absorbs heat.

3.6.12
wired glass
a single sheet of glass with wire completely embedded in the glass. The wired glass shall complied with MS 2676.

3.7
glass wall
wall mainly formed by structural glass elements spanning between floors.

3.8
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.

3.9
instability
inability to carry further load due to vanishing stiffness.

3.10
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.

3.11 Load

3.11.1
dead load
any permanent structural or non-structural loads that remain throughout the service life of a structure as stated in the Uniform Building By Law (UBBL).

3.11.2
dynamic load
part of an imposed load resulting from motion.

3.11.3
factored load
specified load multiplied by the relevant partial safety factor.

3.11.4
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 Uniform Building By Law (UBBL).

3.11.5
wind load
applied load as calculated in accordance with the Code of Practice on Wind Loading for Building Structure in Malaysia.

3.12
linear analysis
analysis based on elastic stress and the original geometry prior to deformation for stress computation.

3.13
local stability
stability of element or part of element against local buckling.

3.14 Members

3.14.1
glass beam
one-dimensional load-bearing element predominantly subject to bending.

3.14.2
glass column
vertical load-bearing element predominantly carrying axial force and possibly moments.

3.14.3
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.

3.14.4
transom
horizontal member in curtain wall or glass wall system that directly supports a glass/ cladding element.

3.15 Restraints

3.15.1
lateral restraint for a glass fin
restraint that prevents lateral movement of the compression edge.

3.15.2
torsional restraints
restraint that prevents rotation of a member about its longitudinal axis.

3.16
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.

3.17
overall stability
stability of overall structure against buckling, overturning, uplift and sliding.

3.18
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.

3.19
single glazing
single glazed window is constructed using a single pane of glass, or a laminated glass.

3.20
single pane
single homogeneous piece of glass as opposed to laminated glass or insulating glass unit.

3.21
slenderness
effective length divided by the radius of gyration.

3.22
stability
resistance to failure by buckling or loss of static equilibrium.

3.23
wardrobe doors
doors that provide access to built-in storage areas excluding those fitted to pieces of furniture that are not built into the building.

3.24
window
framed glazing in an opening of an external wall to allow natural light and/or ventilation through the building.

3.25
window wall
windows spanning between floor slabs of the building.

4 Limit state design

4.1 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 fulfils 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.,

$$Resistance \geq Load\ effects \tag{1}$$

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

The values assigned to γf 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.

4.2 Ultimate limit state

4.2.1 Definition

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

4.2.2 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 6.4. The layout of the structure and the interaction between the structural members should be in a manner achieving a robust and stable design.

4.2.3 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 m^2 (floor, frontal or total area), due to the failure of one single element. Additional measures and special considerations should be provided to enhance the structural integrity and robustness to minimise the risk of a localised damage leading to the collapse of a major part of the structure.

4.3 Serviceability limit state

4.3.1 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 6.5.

4.3.2 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.

4.3.3 Vibration

Structural analysis should be applied to determine the natural frequencies of vibration of glass structures 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.

5 Loads

5.1 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.

5.2 Dead, imposed and wind loads

For characteristic dead, imposed and wind loads, reference should be made to the Uniform Building By-Laws UBBL 1984 (Act 133), or the Code of Practice on wind loading in Malaysia.

5.3 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:

a) Movements due to concrete creep, settlement and shrinkage;

b) Horizontal movement due to inter storey drift; and

c) Vertical movement due to possible relative deflections between consecutive floors.

5.4 Load effects from temperature change

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

a) Surface not under direct sunlight, the range is 15 °C – 45 °C; and

b) Surface exposed to outside and under direct sunlight, the range is 20 °C – 90 °C. For situations outside this range, refer to specialist literature.

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

5.5 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:

a) 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).

b) 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).

c) 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).

6 Analysis and design of glass pane

6.1 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 6.4.5 and 6.5.2. 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 glass pane thickness should be adopted as specified in Table 1.

Table 1 – Glass thickness for analysis and design

Nominal glass pane thickness (mm)	4	5	6	8	10	12	15	19
Minimum glass pane thickness, t (mm) for analysis and design	3.7	4.7	5.7	7.4	9.4	11.2	14.2	17.8

6.2 Special design requirements

6.2.1 Safety requirement against glass breakage

a) 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.

b) Tempered glass or laminated glass should be used in the parts of building exterior façade also serving as protective barrier.

c) 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.

d) Where IGU is used in building exterior façade, the requirement in item (c) above applies to the outermost pane of the IGU only.

6.2.2 Safety requirement against failure of glass elements

Glass roofs, accessible canopies and skylights subject to medium or long term loads should be constructed 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.

6.3 Analysis and load sharing of glass pane

6.3.1 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.

6.3.2 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 10, 11 and 12, which are based on the nonlinear behaviour of glass panes.

6.3.3 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.

$$Kpane = \frac{t_{pane}3}{\Sigma_i t_i 3} \qquad (2)$$

where

$k$pane = load sharing factor of glass pane being checked

tpane = minimum thickness of glass pane being checked

ti = 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 A.1 and full considerations have been given to the long term effects on interlayer materials described in Clause 6.5.5, 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 A.1, the laminated glass can be considered as a monolithic glass pane, having an equivalent thickness equal to the sum of the individual pane thickness, with its stiffness multiplied by the coefficient for degree of composite action as given in equation 3. 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.

$$\lambda = \frac{I_{eq}}{I} = \left(\frac{t_{eq}}{\Sigma_i t_i}\right)3 \qquad (3)$$

where

teq = equivalent laminated glass thickness (mm)

ti = minimum thickness of each pane of glass within the assembly (mm)

Ieq = equivalent second moment of area (mm^4), Ieq = Bteq ^{3}/12

I = second moment of area (mm^4), $I = B\,(\sum_i t_i)^3/12$

B = width of the laminated glass (mm)

λ = degree of composite action but not more than λ_{tes} or 0.7 whichever is the less.

$\lambda test$ = degree of composite action justified by bending tests in Annex A1

i = total number of glass panes within the assembly

6.3.4 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.

$$Kpane = \frac{1.25 \ \ X \, t_{pane}3}{\Sigma_i t_i 3} \tag{4}$$

where

$k$pane	=	load sharing factor of glass pane being checked
$t$pane	=	minimum thickness of glass pane being checked
ti	=	minimum thickness of each glass pane within the assembly
i	=	total number of glass panes within the assembly

6.4 Ultimate limit state design

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

$$Q_{ult} = \gamma_f \, Q_{char} \tag{5}$$

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

$$S_{ult} = f\ (effects\ of\ \ Q_{ult}) \tag{6}$$

Ultimate design resistance Rult is a function of the characteristic or specified material strengths divided by a partial material factor (γm) to allow for manufacturing tolerances, variations of material strengths (py) and product variability from their characteristic values given in Table 3; and multiplied with the strength reduction factor (γd) given in Table 4 and the glass surface treatment reduction factor (γs) given in Table 5.

$$\text{For glass: } R_{ult} = f(\frac{\gamma_d \, \gamma_s p_y}{\gamma_m}) \tag{7}$$

For design of a structural element at ultimate limit states, the design resistance $Rult$ must be greater or equal to the design load effects Sult:

$$R_{ult} \geq \ S_{ult} \tag{8}$$

6.4.1 Partial load factors

The partial load factor 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 6.4.2.

6.4.2 Load factors and combinations

The following principal load combinations should be considered:

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

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

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

The load factors and their combinations given in Table 2 apply to the strength and the stability for normal design conditions.

Table 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:

a) Where the action of earth or water pressure is beneficial, the partial load factor γf should not exceed 1.0. The value of γf should be taken such that γf multiplied by the design earth or water pressure equals the actual earth or water pressure.

b) All partial load factors for adverse condition are taken as 1.0 for serviceability limit states.

6.4.3 Partial material factors

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

6.4.4 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.

$$\left(\frac{S_{ult}}{R_{ult}}\right)_{short-term} + \left(\frac{S_{ult}}{R_{ult}}\right)_{medium-term} + \left(\frac{S_{ult}}{R_{ult}}\right)_{long-term} \leq 1.0 \qquad (9)$$

6.4.5 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 maximum of t_1 and t_2 below.

$$t_1 = 487\, a^{0.965}\, b^{0.22} \left(\frac{R}{c}\right)^{0.545} \qquad (10)$$

$$t_2 = 2.33\,(ab)^{0.665} \left(\frac{R}{c}\right)^{0.87} - 1.62 \left(\frac{a}{b}\right) + 1.2 \qquad (11)$$

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

$$t_3 = 6.2\, a^{1.15} \left(\frac{R}{c}\right)^{0.5} \qquad (12)$$

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)

= $\gamma_f \times$ design pressure

c = Strength coefficient ($c = c_1 \times \gamma_d \times \gamma_s$) in which

c_1 – Glass type

= 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

γ_s = Glass surface treatment reduction factor given in Table 5

Equations 10, 11 and 12 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 9 is used to check combined load duration effects by first assuming glass thickness and then calculating design load effects S_{ult} 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).

Table 3 – Ultimate design strength (p_y) for different glass types under short-term load duration

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

Table 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 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
Ceramic fritted or enameled painted glass	0.625
Patterned (embossed), sand blasted or acid etched glass	0.5

6.5 Serviceability limit state design

6.5.1 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.

6.5.2 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.

6.5.3 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.

$$\text{Four-side simply supported: } \delta = t\, e^{r_0 + r_1 x + r_2 x^2} \tag{13}$$

$$\text{In which, } x = ln\left(ln\ \frac{p\,(ab)2}{E\,t^4}\right)$$

$$\text{Two-side simply supported: } \delta = \frac{5}{32}\frac{p\,a^4}{E\,t^4} \tag{14}$$

where

δ = Centre deflection (mm)

a = Length of shorter side of glass pane (mm)

or loaded span in two-side simply supported case

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)

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

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

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

6.5.4 Deflection of glass pane

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

Four-side simply supported: δ_{limit} = 1/60 of the short span

Three-side simply supported: δ_{limit} = min. $b/60$, $a/30$, (see, Figure 1)

Two-side simply supported: δ_{limit} = 1/60 of the loaded span

Cantilever: δ_{limit} = 1/30 of the span

Point supported: δ_{limit} = 1/60 of the longer span between supports

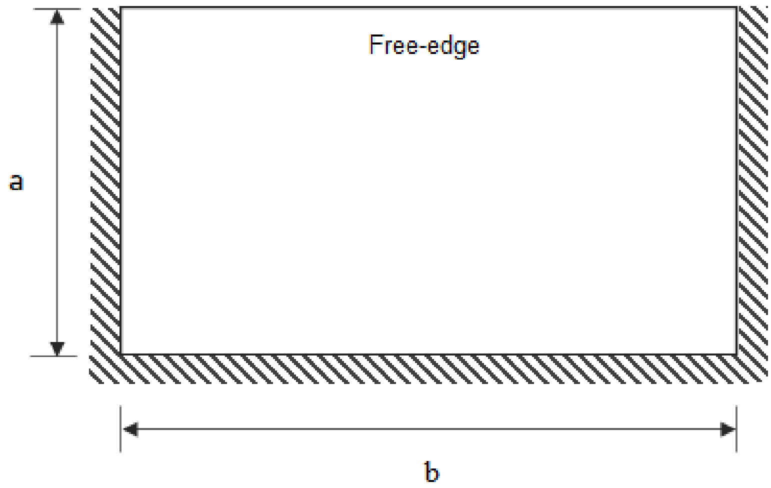


Figure 1 – Dimensions of glass for three-side supported case

6.5.5 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.

6.5.6 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 MS 1498.

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 2. 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.

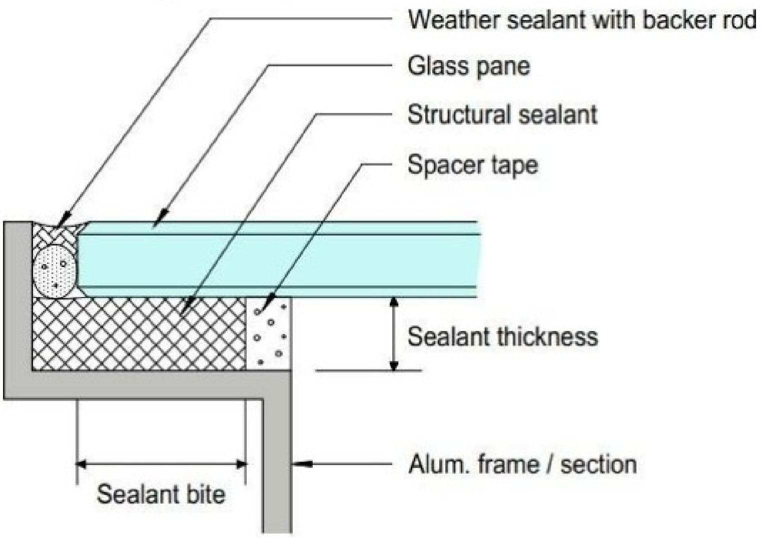


Figure 2 – Example of sealant bite-to-thickness ratio

Note: 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:

a) BS EN 13022-2: Glass in Building – Structural Sealant Glazing.

b) BS EN 15434: Glass in Building – Product Standard for Structural and/or Ultra- violet Resistant Sealant.

c) ASTM C1184-14: Standard Specification for Structural Silicon Sealants.

d) ASTM C1401-02: Standard Guide for Structural Sealant Glazing

e) ASTM C1249-93: Standard Guide for IGU Structural Sealant Glazing

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 (bb) for wind load and glass dimension should be determined by the following equation.

$$b_i = \frac{0.5 \times p \times L_s}{p_b} \tag{15}$$

where

b_i = Minimum structural sealant bite (mm)

L_s = Length of shorter span of rectangular glass pane (mm)

p = Design win pressure (kPa) for allowable stress design

p_b = Permissible design bond strength (138kPa)

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 3. 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.

$$\text{For tensile stress (lateral load), } c_t = \frac{0.5 \times p_o \times L_s}{p_b} \tag{16}$$

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 (138kPa)

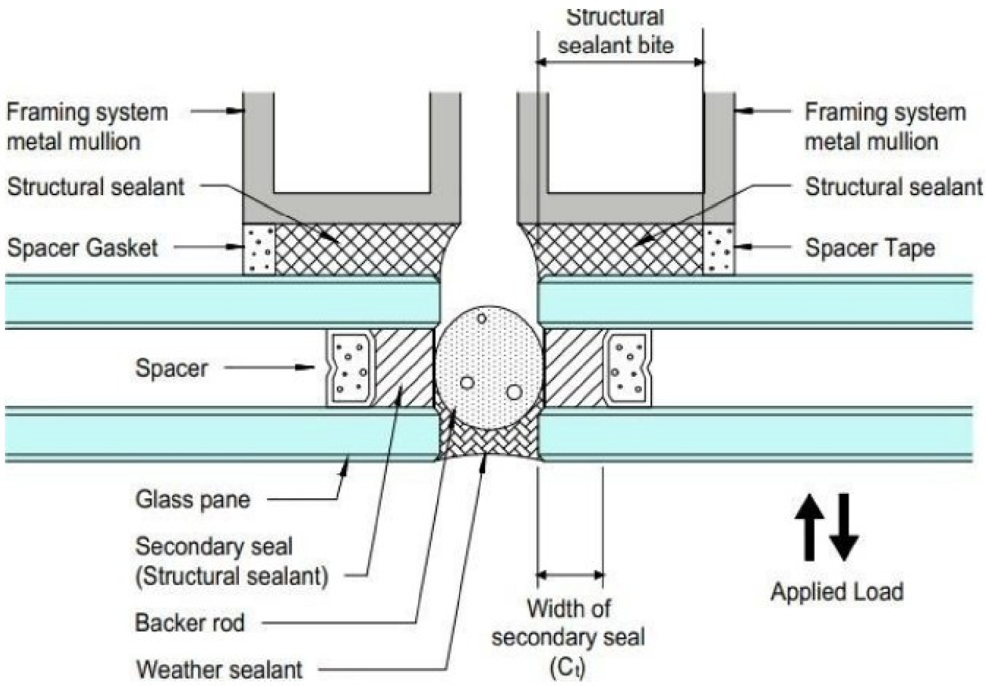


Figure 3 – Example of IGU for structural glazing application

7.1.3 Weather seal silicone sealant

Weather proofing silicone sealant is a one-part, neutral cure, architectural grade sealant extrudes in any weather and cures at ambient temperature by reaction with moisture in the air to form a durable, flexible silicone rubber seal.

All weather seal silicone sealants shall have non-hazardous formulation, low odour and very low volatile organic compounds (VOC) contents.

Clean all joints removing all foreign matter and contaminants such as grease, oil, dust, water, frost, surface dirt, old sealants or glazing compounds and protective coatings.

All sealant, weather and structural integrity of the Exterior Wall System, should be supplied by one manufacturer.

When in direct contact with silicone sealants, all gaskets, spacers, setting blocks, backer rod, PVDF (polyvinylidene fluoride), polyester, powder coating and PU paint shall be heat cured silicone rubber-based material which is chemically compatible with the silicone sealant and with sufficient hardness for the specific purpose intended. Compatibility testing by the silicone sealant supplier/manufacturer shall be required.

Test method according to ASTM D2202, ASTM C 679, ASTM D 2240, ASTM C 412, ASTM C 719 and ASTM D 624.

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, softer than glass, shall be used. 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 4. The edge cover should be at least equal to the thickness of the glass pane. 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.

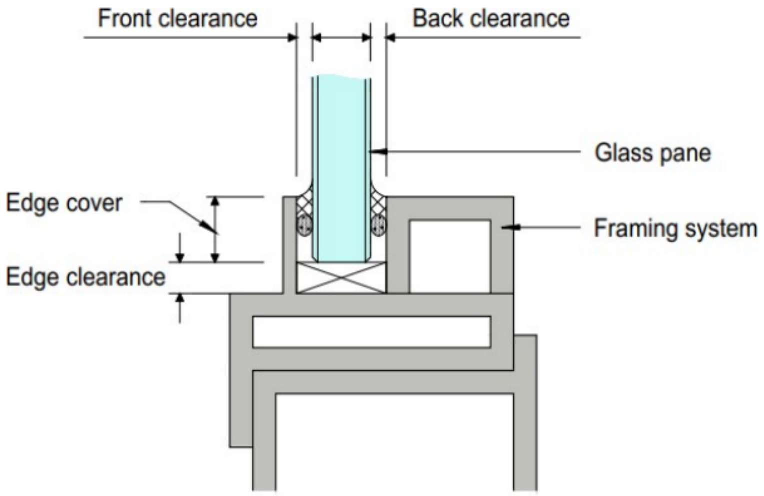


Figure 4 – Edge cover and clearances of framed infill glass pane

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 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 5.

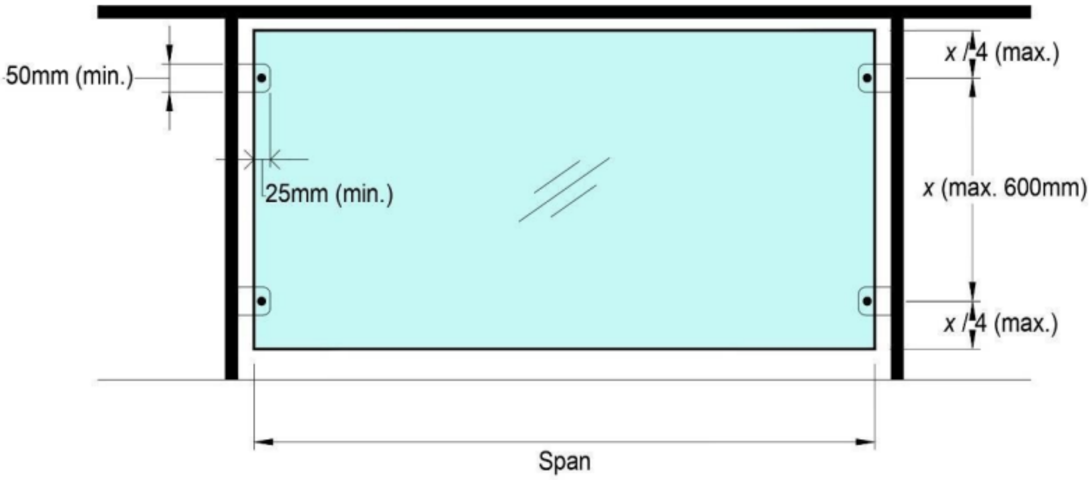


Figure 5 – Clipped infill glass pane

7.2.4 Point bolted supports

Tempered glass should be used and the position of the connectors should not allow the glass panes to undergo reversed 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 6.

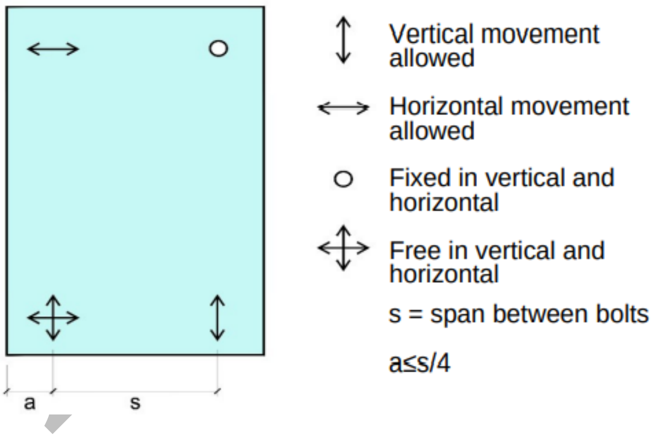


Figure 6 – Allowable in-plane movements at bolted connection

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 of less stiff material.

7.3.2 Diameter of holes

The diameter of holes shall not be less than the nominal thickness of the glass. For diameter of holes less than nominal thickness of the glass is not recommended.

7.3.3 Limitation on position of holes

In general, the limitation on hole positions relative to the edge of the glass pane, the corner of the glass pane and to each other depend on:

a) nominal glass thickness (d);

b) dimensions of the pane (B,H);

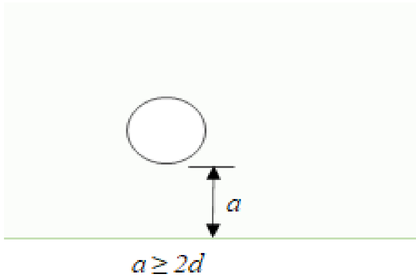
c) hole diameter (Ø);

d) shape of the pane; and

e) number of holes.

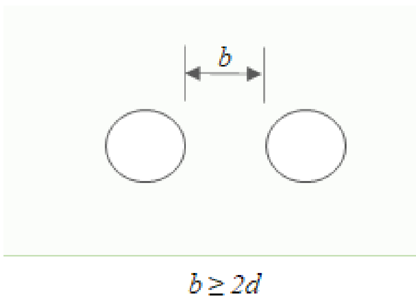
The recommendations given below are those which are normally available and are limited to panes with a maximum of four holes.

7.3.4 Holes distances



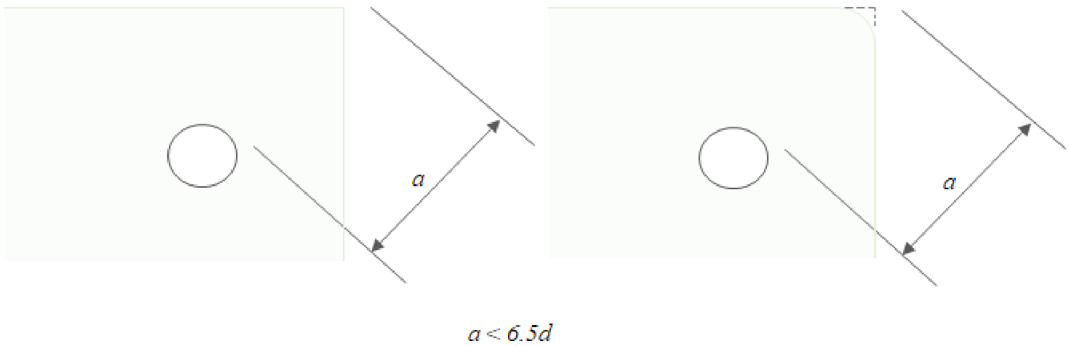
NOTE: The distance, *a*, of the edge of a hole to the glass edge should not be less than *2d*

Figure 7 – Position of hole to the edge



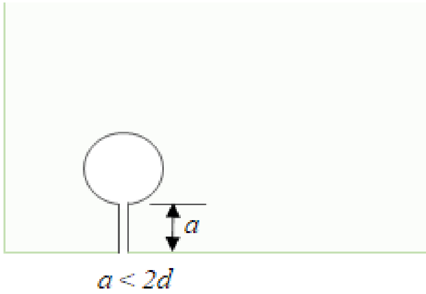
NOTE: The distance, *b,* between the edges of two holes should not be less than 2*d*

Figure 8 – Minimum distances between two holes



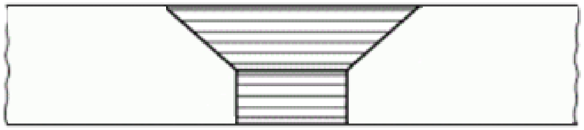
NOTE: The distance, *a*, between the edges of a hole to the corner of the glass should not be less than 6.5*d*

Figure 9 – Hole position at corner of glass



NOTE: The distance, *a*, of the edge of a hole to the glass edge is less than 2*d*, cut holes is recommended

Figure 10 – Cut holes



NOTE: There are available countersunk holes. The manufacture shall be consulted for the tolerances on hole position, hole shape/dimensions and edge work

Figure 11 – Countersunk hole

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 (EVA), resins, ionoplast (Ethylene-methacrylic acid copolymer), or TPU (Aliphatic Thermoplastic Polyurethane).

7.4.1 Polyvinyl butyral (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 A.1 should be carried out to ensure the lamination quality. Typical properties of PVB are given in Table 6 below.

Table 6 – 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 Resin

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 A.1 and Annex A.2.

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 A.1 and Annex A.2.

7.4.4 Ethylvinyl Acetate (EVA)

EVA is typically used in interior glass and decorative applications and it can also be used in some open edge applications. Known for its superior adhesion, flexibility and moisture resistance. Due to high adhesion level in low temperature, EVA is often used in applications where materials (such as pictures, leaves, etc) are embedded in the laminate for decorative purposes. This EVA shall complied with MS 1498.

The downside of high adhesiveness of EVA is that it leads to poor impact resistance performance, thus normal EVA does not often fulfill the requirements of laminated safety glass. The design of laminated glass using ionoplast or other interlayers should follow the performance-based tests specified in Annex A.1, Annex A.2 and Annex B.4.

7.4.5 Aliphatic Thermoplastic Polyurethane (TPU)

TPU is an advanced interlayer material increasingly utilized in laminated glass production due to its exceptional strength, elasticity, and clarity. Offering superior impact resistance and flexibility compared to traditional interlayers, TPU is ideal for high-performance applications such as ballistic glass, automotive windshields, and structural glazing. Its excellent adhesion properties, weather resistance, and ability to maintain transparency under extreme conditions make TPU a cutting-edge choice for enhancing the durability and safety of laminated glass. The design of laminated glass using TPU should follow the performance-based tests specified in Annex A1 and Annex A.2

7.5 Glazing accessories

7.5.1 Gasket

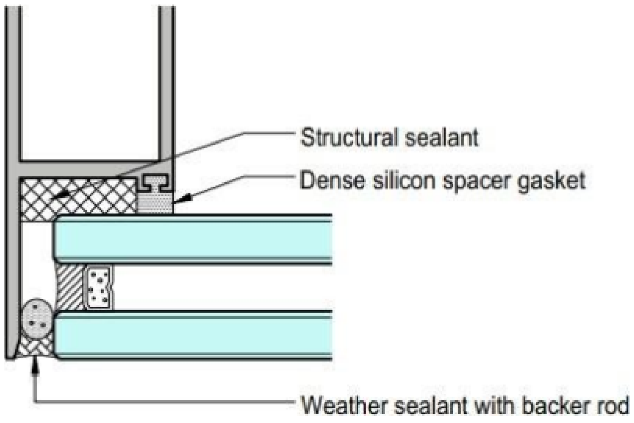
Gasket shall be compatible with other contact materials. Durability, compatibility, strength and ductility are required to be considered. Typical gasket types are given in Figure 12.

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.

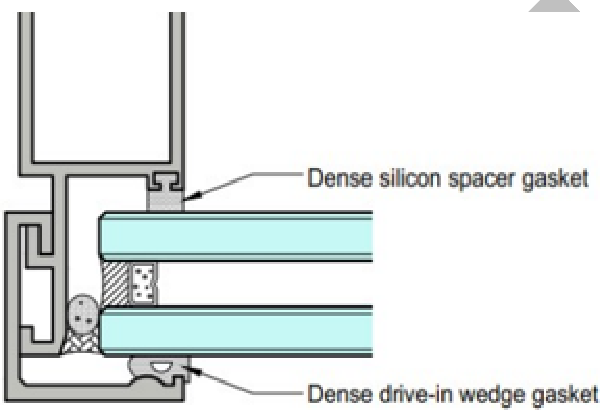
Dense or wedge gaskets should be extrusions with a minimum Shore A hardness of 70 durometer for hollow profiles and 55 durometer for solid profiles. Outdoor and indoor gaskets shall be silicone rubber, EPDM rubber or other gasket material such as neoprene and TPE compatible with silicone sealant. Wedge 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.

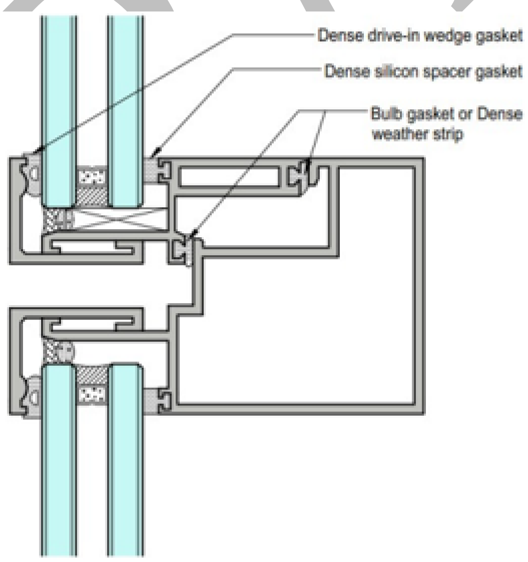
Glazing gaskets, sealant backers within glazing pockets and continuous glass spacer pads at structural sealant should be black heat cured silicone rubber.



a) Typical mullion (structural sealant)



b) Typical mullion (pressure cap)



c) Typical transom with sash

Figure 12 – Example of typical gasket types

7.5.2 Setting block

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

Setting block shall be positioned as shown in Figure 13 and 14 to ensure uniform support and load distribution. The typical location is approximately one-quarte of the glass width from each corner, as illustrated.

The typical location, number and location of setting blocks shall be as shown in Figures 13, 14, 15 and 16. Generally, all setting blocks shall be:

a) positioned at quarter points or not less than 30 mm from the corner whichever is lesser;

b) the minimum width of each setting block shall be not less than the glass thickness; and

c) the minimum thickness of the setting block for drained glazing systems shall be 6 mm.

Setting blocks shall be located to equally support all panes of glass and shall be fixed to prevent displacement during installation and service.

The minimum length of each setting block (or two blocks side by side) shall be 25 mm in length for every square metre of glass area, with a minimum length of 50 mm.

Example:

For a 3.2 m^2 glass area, 3.2 $\times$ 25 mm = 80 mm long, i.e., 80 mm for each setting block.

Setting blocks shall be of resilient, load bearing, non-absorbent, rot-proof, material that is compatible with all other glazing materials that may come into contact with the blocks.

The material hardness of the setting blocks shall be in accordance with Figure 14 (Shore A 80 ± 5), and the block length shall be approximately 10 % of the glass width unless otherwise justified by design.

NOTES:

1. Setting block positions and dimensions shall conform to Figure 13 and 14 for typical installations.
2. Setting blocks are used between the bottom edge of the unit and the frame to centralize and equally support both panes of glass.

3. Setting block width and location should not restrict water drainage.
4. Extruded rubber material width 80 - 90 Shore-A hardness is recommended.
5. Shaped setting blocks will be required for a glazing platform.
6. The suitable material for setting block shall be santoprene, neoprene, EPDM and silicone rubber.

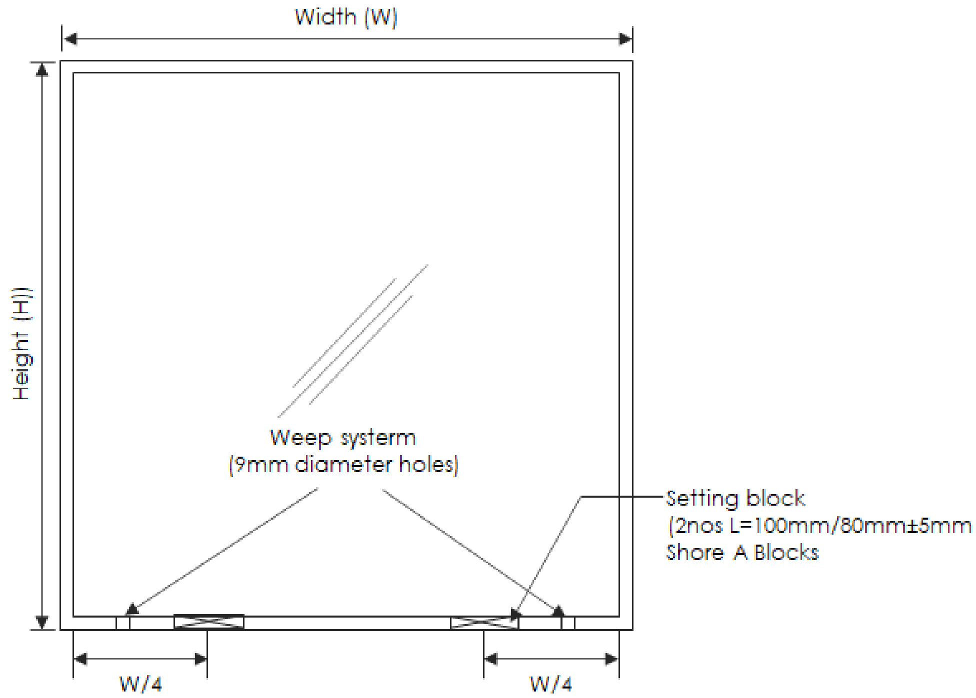


Figure 13 – Typical location of setting blocks

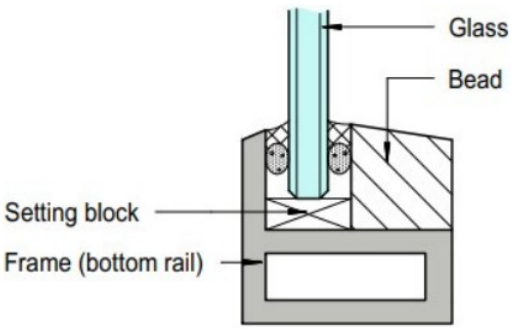


Figure 14 – Position of setting block (section)

7.5.3 Location 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.

The number and position of location blocks shall be as shown in Figure 15 and Figure 16. Location blocks shall be:

a) a minimum of 25 mm long;

b) at least as wide as the glass thickness;

c) positively located to prevent displacement in service; and

d) sufficiently resilient to accommodate movement within the frame, without imposing stress on the glass, and of resilient, non-absorbent material

NOTES:

1. Location blocks are used between the edges of the glass and the frame to prevent movement of the glass within the frame by thermal expansion or when the window or door is opened or closed. They are required to prevent the weight of the glass from causing the frame to become out of square.
2. Extruded rubber material with 55-65 shore-A hardness is recommended.

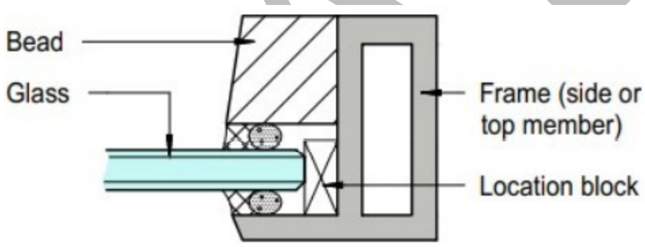
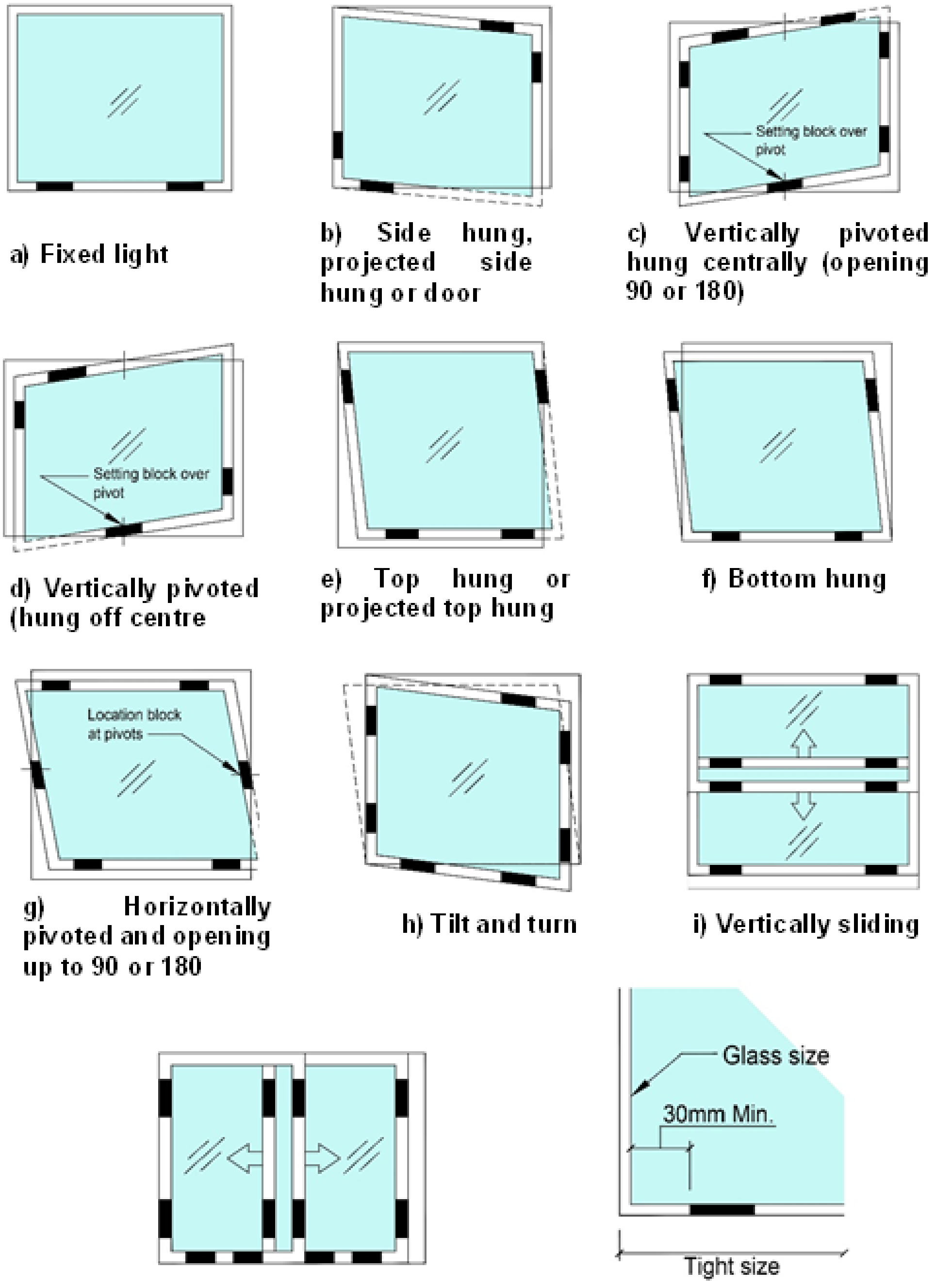


Figure 15 – Position of location block (plan)



a) Fixed light

b) Side hung, projected side hung or door

c) Vertically pivoted hung centrally (opening 90 or 180)

d) Vertically pivoted (hung off centre

e) Top hung or projected top hung

f) Bottom hung

g) Horizontally pivoted and opening up to 90 or 180

h) Tilt and turn

i) Vertically sliding

j) Horizontal sliding (6 block to each pane)

k) Minimum positions of blocks for all types of casements and sliding windows

Figure 16 – Recommended positions of setting and location blocks for the site glazing of some types of doors and windows

7.5.4 Distance pieces

Distance pieces, as shown in Figure 17, where required, shall be:

a) of resilient, non-absorbent material;
b) 25 mm long and of a height to suit the depth of the rebate and the method of glazing; and
c) spaced opposite each other, approximately 50 mm from each corner at intervals of not more than 300 mm.

The thickness shall be equal to the front and back clearance, to retain the glass firmly in the frame.

NOTES:

1. Distance pieces are required to prevent displacement of glazing compounds or sealant by external loading, such as wind pressure.
2. Extruded rubber material with 55 - 65 shore-A hardness is recommended.

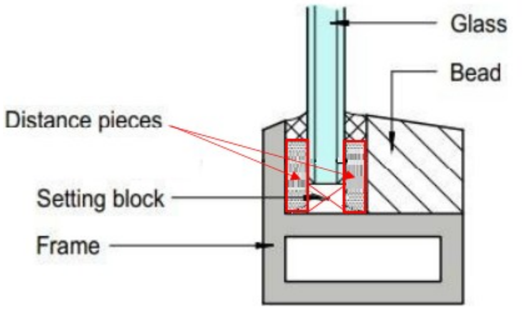


Figure 17 – Position of distance pieces

7.5.5 Preparation of rebates and grooves

Rebates, grooves and beads shall be cleaned and free from grease, moisture and other contaminants. All sealant surfaces shall be primed or sealed in accordance with the recommendations of the manufacturer of the glazing material.

The number and location of setting blocks and location blocks shall be as shown in Figures 12, 13 and 14, wherever necessary to maintain the requisite edge clearance. Each block shall support the full thickness of the glass.

7.5.6 Glazing beads

Where used, glazing beads shall be capable of restraining the glass under all design actions.

7.5.7 Weatherseal silicone sealant

Weather proofing silicone sealant is a one-part, neutralcure, architectural grade sealant extrudes in any weather and cures at ambient temperature by reaction with moisture in the air to form a durable, flexible silicone rubber seal.

All weather seal silicone sealant shall have non-hazardous formulation, low odour and very low volatile organic compounds (VOC) contents

Clean all joints removing all foreign matter and contaminants such as grease, oil, dust, water, frost, surface dirt, old sealants or glazing compounds and protective coatings

All sealant, weather and structural integrity of the Exterior Wall System, should be supplied by one manufacturer.

When in direct contact with silicone sealants, all gaskets, spacers, setting blocks, backer rod, pvdf, polyester, powder coating and pu paint shall be heat cured silicone rubber-based material which is chemically compatible with the silicone sealant and with sufficient hardness for the specific purpose intended. Compatibility testing by the silicone sealant supplier/manufacturer shall be required.

Test method according to ASTM D2202, ASTM C 679, ASTM D 2240, ASTM C 412, ASTM C 719 and ASTM D 624.

7.5.8 Backer rod

7.5.8.1 Closed cell backer rod

Closed cell material shall be as per ASTM C 1330. Round, flexible, shall be continuous lengths of extruded, closed-cell polyethlene foam backer rod.

The size depth of the sealant bead shall be oversized (20-50%) to fit tightly into the joint, and function as a bondbreaker to prevent bottom-side adhesion of the sealant.

Property and test method according to ASTM C1016, ASTM D 1622, ASTM C 1253, ASTM D 3575 and ASTM D 5249.

The type usage of closed cell or open cell backer rod subject silicone sealants manufacture recommendation and façade designer approval.

7.5.8.2 Open cell backer rod

Closed cell material shall be as per ASTM C 1330. Round, flexible, shall be continuous lengths of extruded, open-cell polyethlene foam backer rod

The size depth of the sealant bead, shall be oversized 50% to fit tightly into the joint, and function as a bondbreaker to prevent bottom-side adhesion of the sealant

Property and test method according to ASTM C1016, ASTM D 1622, ASTM C 1253, ASTM D 3575 and ASTM D 5249.

7.5.9 Double sided tape

Double sided glazing tape shall be semi-rigid foam tape with an aggressive pressure-sensitive adhesive and is used as a spacer for joint dimension control in structural silicone glazing systems.

The compression set resistance, open-cell structure for structural silicone curing, durable acrylic adhesive for a temporary bond during assembly. Open-cell polyurethane foam tapes to allow air and moisture to reach the silicone for optimum curing of the silicone and compatible with all silicone sealants.

Double sided glazing tape shall be low thermal conductivity improves the performance of the wall.

Double sided glazing tape shall be excellent resistance to temperature variations, fungi and oxidation.

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

For compliance purpose, the glass shall comply with the below standards:

Table 7 – Glass type compliance requirements

Type of glass	Related Standard
Float glass	MS 1135
Coated glass	MS 2397
Safety glass	MS 1498
Wired glass	MS 2676
Insulated glass unit (IGU)	MS 2666
Heat soaked	BS EN 14179-1 and BS EN 14179-2
Fire rated glass	BS 476 Part 22

8.1.1 Heat soaked 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 25°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 $\pm$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

The fragmentation test determines whether the glass breaks in the manner prescribed for a tempered glass and it should be carried out to each production cycle batch of tempered glass in accordance with MS 1498.

In order to classify a glass as a tempered glass, the particle count of each test specimen shall not be less than the values given in Table 8.

In order to classify the glass as a tempered glass, the length of the longest particle shall not exceed 100 mm.

Table 8 – Minimum particles count values

Nominal thickness, *d* (mm)	Minimum particle count
3	15
4 to 12	40
≥ 15	30

8.1.3 Surface compression test

Surface compression test of heat strengthened and tempered glass panes should be measured by Grazing Angle Surface Polarimeter (GASP) or Differential Stress Refractometer (DSR) with valid calibration certificate in accordance with ASTM C1279. Compliance of the glass should be assessed based on MS 1498.

The surface compression test could be measured by GASP or DSR on the "tin side" of float glass. Tin side is the side of glass that was in contact with the molten tin bath in the float process. This is a non-destructive method. Each of these measurements should be obtained by averaging ten individual measurements – five locations with two orthogonal measurements at each location.

The surface compression of heat strengthened glass should be greater than 24 MPa but less than 52 MPa. The surface compression of tempered glass should be greater than 69 MPa. For both tempered and heat strengthened glass, all individual measured locations shall comply with the minimum surface compression, and with maximum $\pm$10 MPa difference in between the measured locations. The surface compression 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 for overall bow and local bow in glass panes should be complied in accordance with MS 1135, MS 1498, MS 2397, MS 2666 and MS 2676.

8.1.5 Blemish and quality 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 MS 1135 and MS 1498 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 MS 1498 should be carried out by the glass manufacturer of laminated glass to ensure the lamination quality and minimise the risk of delamination.

8.1.7 Pendulum impact test

The purpose of pendulum test is to evaluate by means of soft body impactors, safety breakage characteristics of glazing products intended to reduce cutting and piercing injuries to persons through accidental impact.

Pendulum impact test should be carried out to MS 1498 for all safety glass.

For asymmetric materials that are intended for installation where the risk of impact is from both sides, the test shall be carried out on both sides.

Unless both sides are impacted, the classification only applied to the impacted side and this shall be reported in the test report.

8.1.8 Weathering test

The purpose of these tests is to determine whether the glass these safety glazing materials and coated glass will successfully retain their safety and appearance characteristics after exposure to weathering conditions for an extended period of time.

For laminated glass and coated glass the performance shall comply with MS 1498 and MS 2397. The specimens shall be irradiated by ultraviolet rays for 1 000 h. The temperature shall be maintained at 45 °C ±5 °C with the distance between the light source and test specimen shall be approximately 230 mm. The light source shall be mercury lamp with 750 W ±50 W.

There shall be no significant changes on physical appearance either on the glass, interlayer or film such as delamination, bubbles, cracks, discoloration or any other defects.

The difference of visible light transmittance before and after 1 000 h ultraviolet exposure shall not be more than 4%.

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 Curtain walls system

Safety test on a representative portion of the proposed curtain wall system should be carried out by an independent accredited laboratory, ISO/IEC 17025 within its scope of accreditation prior to commencement of construction.

The performance test mock-up of curtain walls includes:

(i) Minimum of 2 and half storey height or full height of curtain wall with operable sash;

(ii) Minimum of 5-module width with turning corner(s), if any; and

(iii) Architectural feature(s), if any.

Loading sequence and duration of the operation of cyclic test are presented in Table 9.

Table 9 – Sequence and duration of tests for both positive and negative pressures

Test	Test Preparation	Repeated Test	Test Safety
Pressure	0-p1-0-p1-0-p1-0	0-p2-0-p2-0-p2-0-p2-0-p2-0	0-p3-0
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.		
Note: AMMA 501/05 or ASNZ 4284			

Notes:

1. For the test preparation, p1 should be 0.5 p2.
2. For the repeated positive and negative pressure test, p2 should be the pressure obtained from the product of the total pressure coefficient cp and the design wind pressure qz appropriate to that part of the building, determined in accordance with the Code of Practice on Wind Loading for building structure in. The number of pressure pulses should not be less than 5.
3. During the repeated positive and negative pressure tests, the deflection of any structural element of the specimen should not exceed:
   i) 1/240 of the span or 20 mm, whichever is the less, for span not greater than 7.2 m
   ii) 1/360 of the span for span greater than 7.2 m
   iii) 1/180 of the span or 20 mm, whichever is the less, for cantilever type member.
4. 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.
5. For the safety test, the maximum required pressure p3 should be 1.5p2
6. 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.

8.4 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 as stated in Clause 8.1. 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 compression of the glass should be measured as part of the quality assurance scheme. The designer should ensure that the surface compression must be between 24 MPa and 52 MPa. Heat strengthened glass with a surface compression greater than 52 MPa should be rejected. 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 shall be manufactured by a factory that certified with MS 1498.

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 shall be manufactured by a factory that certified with MS 1498.

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

a) Glass orientation in the tempered furnace must parallel to the horizontal (sill) or base dimension

b) Surface compression measurement of glass;

c) Quality control procedures and requirements such as thickness measurement, flatness measurement, local bow measurement, fragmentation test, surface compression and pendulum impact test.

9.1.4 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 is one of the quality control measures on laminated glass in respect of the probable effects of exposure to high temperature and humidity conditions. The product performance shall comply with MS 1498.

9.1.5 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 MS 2666 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. The product performance shall comply with MS 2666.

9.2 Heat soak process

All tempered glass is recommended to 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 or equivalent Malaysia Standard should be carried out to all tempered glass panes to be used with enhanced calibration and monitoring requirement.

9.2.1 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:

a) Name of the tempered glass manufacturer;

b) Name of the project using the manufacturer's tempered glass;

c) Total number and surface area of tempered glass panes used in the project;

d) Location and identity number of the ovens, in which the heat soak process of the glass panes in (c) was conducted;

e) Calibration report as detailed in Clause 9.2.2 of the ovens in accordance with the BS EN 14179 or equivalent Malaysian Standard;

f) Quantity, dimensions and thickness of the tempered glass panes conforming to the BS EN 14179 or equivalent Malaysian Standard, and the record of breakages of panes in each heat soak process with corresponding oven number;

g) Recorded temperature versus time graphs for each of the eight thermocouples es during heating phase, holding phase and cooling phase of the heat soak process; and

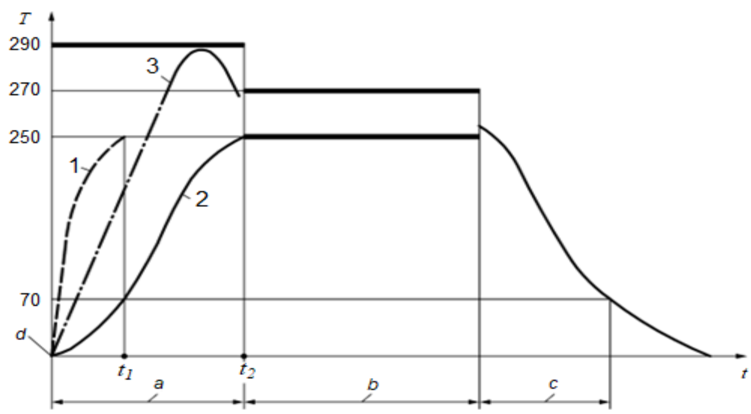
h) Date of carrying out the heat soak process.

9.2.2 Calibration report

The heat soak oven should be calibrated to the BS EN 14179 or equivalent Malaysian 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. 8 mm 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.



Key:

T	glass temperature at any point, ˚C	3	glass temperature
t	time, h	d	ambient temperature
t_1	time for the first glass to reach 250˚C	a	heating phase
t_2	time for the last glass to reach 250˚C	b	holding phase
1	first glass to reach 250˚C	c	cooling phase
2	last glass to reach 250˚C		

Figure 18 – Time/temperature regime as calibration criteria

9.2.2.1 Heating phase

The heating phase commences with all the glasses at ambient temperature and concludes when the surface temperature of the last glass reaches 250°C. The maximum heating rate is 3°C per minute. The time to reach this temperature is defined in the calibration process. This time will be dependent on the size of the oven, the amount of glass to be treated, the separation between glasses and the heating system capacity.

NOTES

1. The glass separation and rate of heating should be controlled to minimize the risk of glass breakage as a result of thermal stress. To facilitate economic heating, the air temperature within the oven may exceed 290 °C. However, the glass surface temperature shall not be allowed to exceed 290 °C. The period of glass surface temperature in excess of 270 °C shall be minimized.

2. Care should be taken to ensure the maximum temperature of the glass does not exceed 270 °C as there is a possibility of the nickel sulphide inclusion reconverting.

9.2.2.2 Holding phase

The holding phase commences when the surface temperature of all the glasses has reached a temperature of 250 °C. The minimum duration of the holding phase is 2 hours.

Precise oven control is necessary in order to ensure that the glass surface temperature shall be maintained in the range of 260 °C $\pm$ 10 °C during the holding phase.

9.2.2.3 Cooling phase

The cooling phase commences when the last glass to reach 250 °C has completed its holding phase, i.e. been held for minimum 2 hours at 260 °C $\pm$ 10 °C. During this phase the glass temperature shall be brought down to ambient temperature.

The cooling phase can be concluded when the air temperature in the oven reaches 70 °C.

The rate of cooling should be controlled to minimize the risk of glass breakage as a result of thermal stress.

9.3 Heat soak process system

9.3.1 General

The heat soak process system consists of:

a) oven (see 9.3.2);

b) glass support (see 9.3.3);

c) separation system (see 9.3.4).

The oven shall be calibrated, see 7.5 and Annex A, and this determines the method of operation of the heat soak process system during manufacture of heat soaked thermally toughened soda lime silicate safety glass.

9.3.2 Oven

The oven shall be heated by convection and shall allow an unhindered air circulation around each glass pane. In the event of glass breakage, the airflow shall not be hindered. The airflow in the oven shall be led parallel to the glass surfaces.

The openings in the oven for the air ingress / egress should be designed to ensure that fragments of broken glass do not cause blockages.

9.3.3 Glass support

Glasses may be supported vertically or horizontally. The glasses shall not be fixed or clamped; they have to be supported to allow free movement.

NOTE
1. Vertically means true vertical or up to 15° either side of true vertical.
2. The distance between glasses affects the airflow, heat exchange and the heating time. Glass to glass contact shall not be allowed.

9.3.4 Glass separation

The glasses shall be separated in a manner that does not hinder the airflow. The separators shall also not hinder the airflow e.g. see Figure 19.

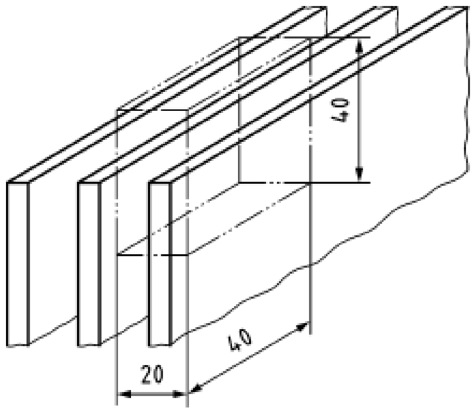


Figure 19 – Example of a vertical glass separator

The minimum separation of the glasses shall be determined during the calibration of the oven, see 10.3.5 and BS EN 14179-1 Annex A.

Generally, a minimum separation of 20 mm is recommended (see Figure 20).

NOTE: If glasses of very different size are put on the same stillage, they will require greater separation in order to prevent glass breakage when the furnace is opened after the heat soak process. The same applies to glasses with holes, notches and cut-outs.

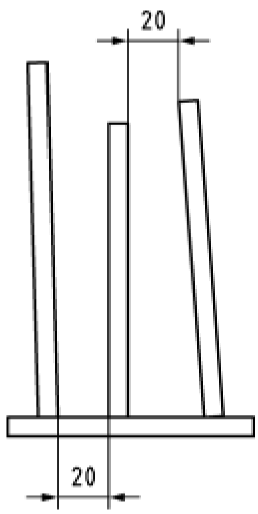


Figure 20 – Recommended separation between glass

The positioning of the separators, material of the manufacture and their shape shall be specified during the calibration test of the oven and shall be reproduced during the manufacturing process.

9.3.5 Calibration

The heat soak system, e.g. oven, glass separation, separators, etc., shall be calibrated, see BS EN 14179-1 Annex A.

The calibration shall determine the heating phase of the process, glass separation distance, the positioning, material and shape of separators, the type and positioning of stillage(s) and define the operating conditions for use during manufacture.

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 °C - 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 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:

(i) Size of structural bite and thickness;

(ii) Adhesion of silicone sealant with glass pane and frame;

(iii) Joint type/condition of sealant applied; and

(iv) Appearance of the sealant / uniformity of colour / bubble.

In view of the situation above, the purpose of Annex B 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
(informative)

Testing procedures and requirements for determination of composite action of laminated glass

A.1 Boil test for laminated glass

This test shall be carried out to determine the probable effect of exposure to high temperature and humidity conditions for a long period of time. The test method shall refer to MS 1498.

The glass itself may crack during this test, but no bubbles or other defects shall develop more than 12 mm from the outer edge of the specimen or from any crack that may develop. All specimens shall be able to meet this requirement; if one specimen does not meet the requirement then the result for this testing is failed and the specimens do not comply with Class 1 requirements.

A.2 Weathering test

The specimens shall be irradiated by ultraviolet rays for 1 000 h. The temperature shall be maintained at 45 °C ± 5 °C with the distance between the light source and test specimen shall be approximately 230 mm.

The light source shall be mercury lamp with 750 W ± 50 W. There shall be no significant changes on physical appearance either on the glass, interlayer or film such as delamination, bubbles, cracks, discoloration or any other defects.

The difference of visible light transmittance before and after 1 000 h ultraviolet exposure shall not be more than 4%.

A.3 Fragmentation test

A.3.1 General

The fragmentation test determines whether the glass breaks in the manner prescribed for a tempered glass.

A.3.2 Dimensions and number of test specimens

The dimensions of the test specimens shall be (360 mm x 1 100 mm) ± 2 mm without holes, notches or cut-outs. Five specimens shall be tested.

A.3.3 Test procedure

Each test specimen shall be impacted, using a pointed steel tool, at a position of 13 mm in front of the longest edge of the test specimen at the mid-point of that edge, until breakage occurs (see Figure A.1).

Examples of steel tools are a hammer of about 75 g mass, a spring-loaded centre punch or other similar appliance with a hardened point. The radius of curvature of the point should be approximately 0.2 mm.

The test specimen shall be laid flat on a table without any mechanical constraint. In order to prevent scattering of the fragments, the specimen shall be simply held at the edges, e.g. by a small frame, adhesive tape, etc., so that the fragments remain interlocked after breakage yet extension of the specimen is not hindered.

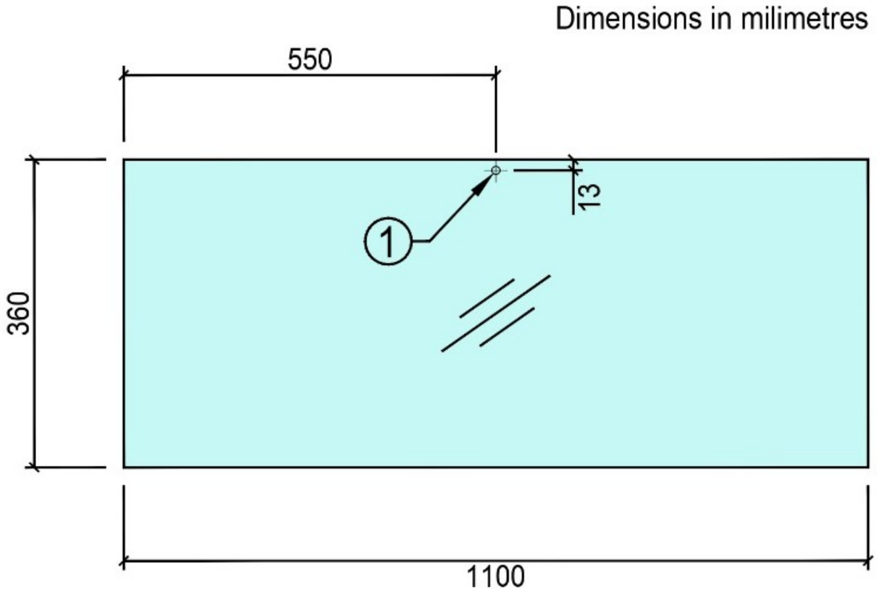


Figure A.1 – Position of impact load

A.3.4 Assessment of fragmentation

The particle counts and measuring of the dimensions of the largest particle shall be made between 4 min to 5 min after fracture. An area of radius 100 mm, centred on the impact point, and a border of 5 mm, round the edge of the test specimen (see Figure A.2), shall be excluded from the assessment.

The particle count shall be made in the region of coarsest fracture (the aim being to obtain the minimum value). The particle count shall be made by placing a mask of (50 ± 1) mm × (50 ± 1) mm on the test piece. The number of crack-free particles within the mask shall be counted. A particle is considered 'crack-free' if it does not contain any cracks which run from one edge to another (see Figure A.3).

Dimensions in milimetres

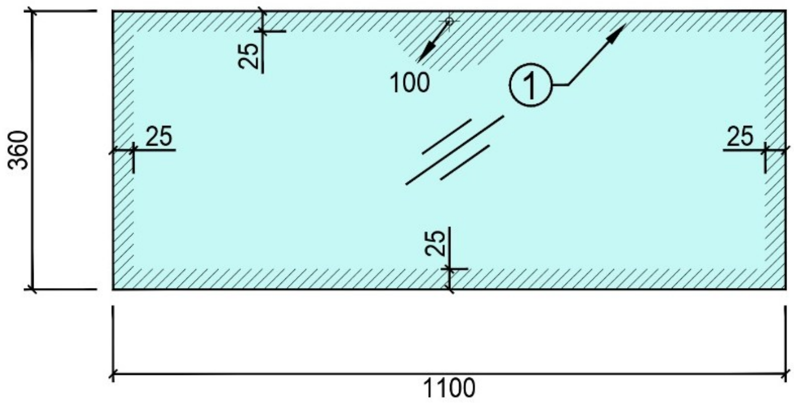


Figure A.2 – Area to be excluded from the particle count determination and largest particle measurement

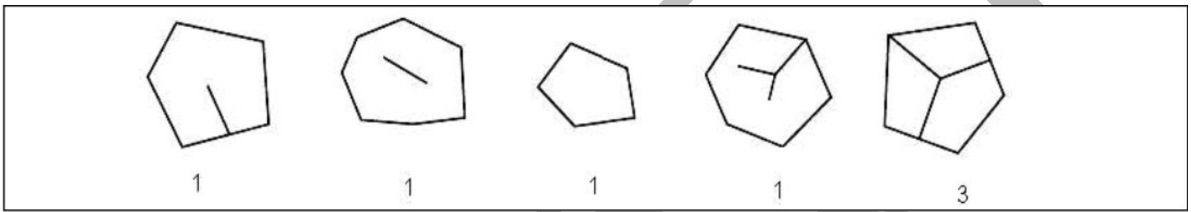


Figure A.3 – Examples of crack-free particles and the assessment regarding the number

In the particle count, all particles wholly contained within the area of the mask shall be counted as one particle each and all the particles which are partially within the mask shall be counted as 1/2 particle each.

A.3.5 Minimum values from the particle count

In order to classify a glass as a thermally tempered glass, the particle count of each test specimen shall not be less than the values given in Table A.1.

Table A.1 – Minimum particle count values

Nominal thickness, *d* (mm)	Minimum particle count
3	15
4 - 12	40
≥ 15	30

A.3.6 Selection of the longest particle

The longest particle shall be chosen from the body of the test specimen. It shall not be in the excluded area (see Figure A.2).

A.3.7 Maximum length of longest particle

In order to classify the glass as a thermally tempered glass, the length of the longest particle shall not exceed 100 mm.

A.4 Pendulum impact test

A.4.1 Test equipment

The test apparatus shall comprise:

a) a stable main frame;

b) a clamping frame which is fitted onto the main frame and is used to hold the test piece in position for the duration of the test;

c) a dual tyre impactor with a suspension device and release mechanism; and

d) a main frame (see Figures A.4, A.5 and A.6).

The test equipment shall be constructed from welded or bolted hot rolled steel channel sections with rounded edges, designed to present a rigid and flat surface to the sub-frame. The lower cross members shall be securely fixed to a concrete floor.

NOTE

Additional support to the frame can be provided, if required, by means of horizontal steel sections fixed to an adjacent rigid wall (see Figure A.5).

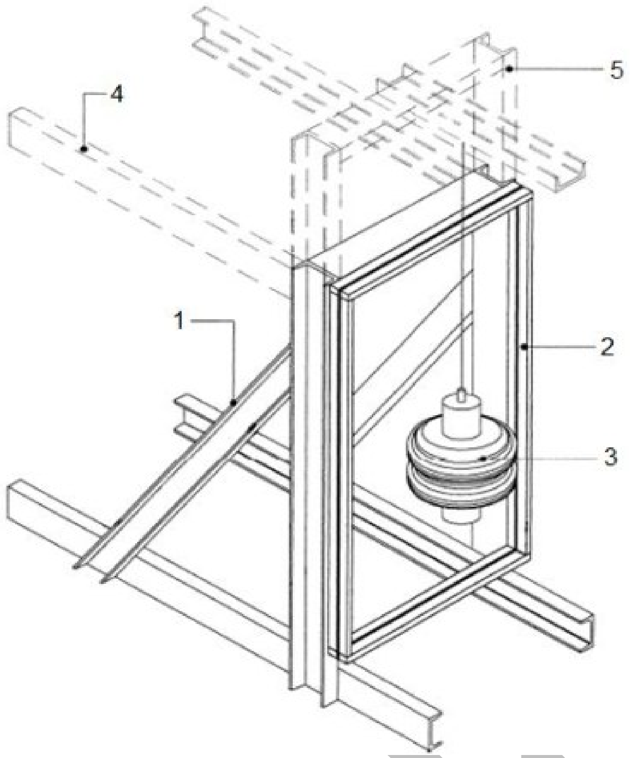
The dimensions of the main frame should be based on the following conditions:

a) internal width: (847 ± 5) mm; and

b) internal height: $(1\,910 \pm 5)$ mm.

Clamping frame which is used to hold the test piece in the apparatus, shall consist of two rectangular parts clamping the test piece along its perimeter. The inner part of the clamping frame is attached to the main frame. Each part of the clamping frame shall be fitted with a rubber strip. The rubber strips shall be the only element in contact with the test piece and shall be (20 ± 2) mm wide and (10 ± 1) mm thick and have a hardness of (60 ± 5) International Rubber Hardness Degrees (IRHD) value.

NOTE: It is recommended to use polychloroprene or a similar material.



Key

1 Main frame

2 Clamping frame

3 Impactor

4 Optional support member

5 Optional suspension device

Figure A.4 – Test frame with impactor

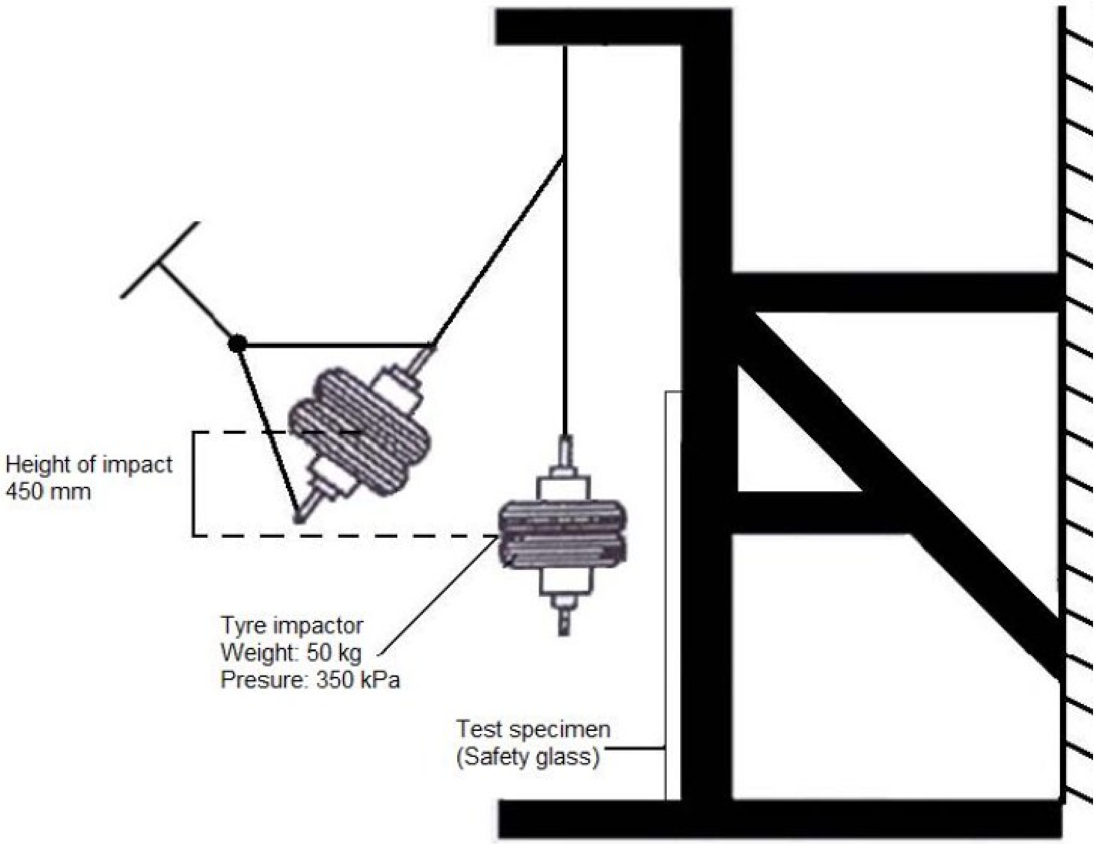


Figure A.5 – Testing setup for the 450 mm impact height

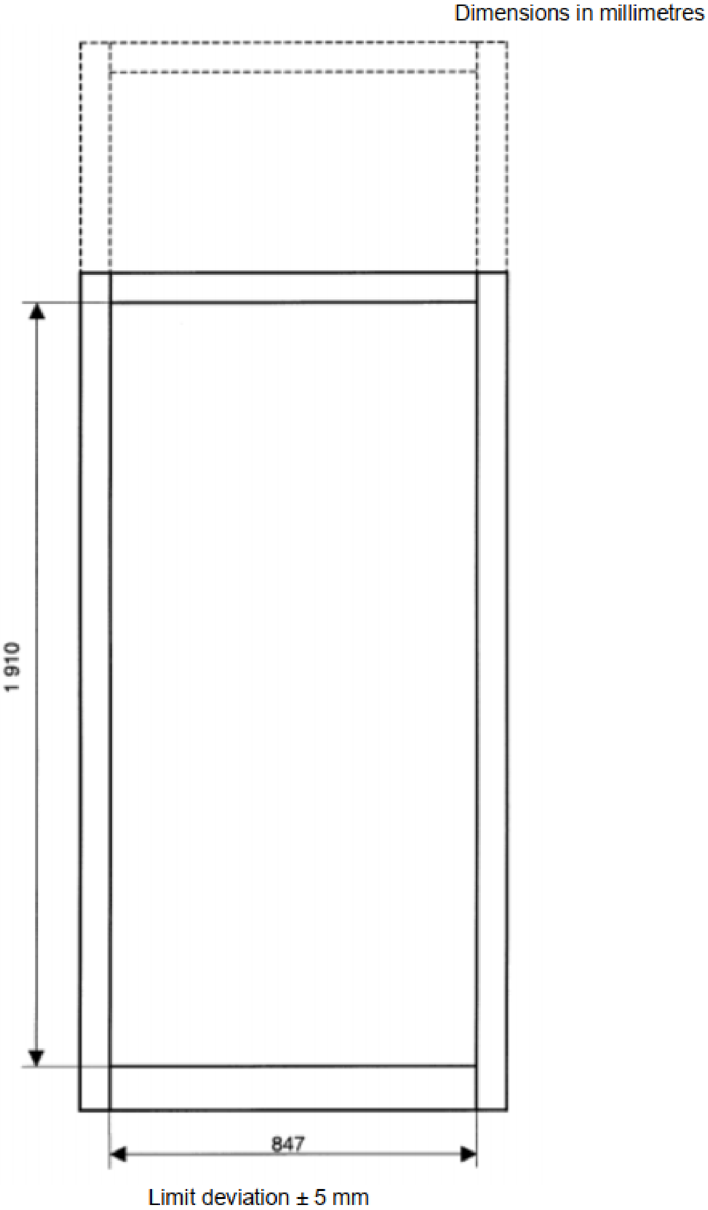


Figure A.6 – Dimensions of the front elevation of the frame

A.4.2 Impactor (see Figures A.4 and A.5)

Impactor shall consist of two pneumatic tyres, Tyre 3.50-R8 4PR with round section and flat longitudinal tread. The tyres shall be fitted to the rims of the wheels that carry two steel weights of equal mass. The weights shall be so dimensioned that the total mass of the impactor is (50 ± 0.1) kg.

A.4.3 Specimen

Each test piece shall comprise a single pane of glass product and be representative of the normal production of the type of product submitted for test.

A.4.3.1 Dimensions of the test pieces

All four test pieces should have the following dimensions:

a) width (876 ± 2) mm; and

b) height (1 938 ± 2) mm.

Results obtained with test pieces of these dimensions are valid for classification purposes of the glass product with any of the service dimensions.

A.4.3.2 Number of test pieces

The test shall be carried out at each drop height on four pieces of identical structure and the same nominal thickness.

For compliance of product classification, all four pieces shall comply with the test specification. If the test pieces are of an asymmetric material, their number shall be doubled unless they are intended solely for installation in situations where the risk of impact is from one side only.

A.4.4 Test requirement

Each test piece shall either not break or shall break as defined in one of the following ways:

a) for laminated glass, plastic film bonded to glass - numerous cracks appear, but no shear or opening is allowed within the test piece through which a 76 mm diameter sphere can pass when a maximum force of 25 N is applied. Additionally, if particles are detached from the test piece for up to 3 min after impact, they shall, in total, weigh no more than a mass equivalent to 10 000 mm^2 of the original test piece. The largest single particle shall weigh less than the mass equivalent to 4 400 mm^2 of the original test piece.

b) for tempered glass - disintegration occurs and the 10 largest crack-free particles collected within 3 min after impact and weighed, all together, within 5 min of impact shall weigh no more than the mass equivalent to 6 500 mm^2 of the original test piece.

   The particles shall be selected only from the portion of the original test piece exposed in the test frame. Only the exposed area of any particle retained in the test frame shall be considered in determining the mass equivalent; and

c) for other materials - the safety criteria can only be met if they do not break when tested.

NOTE: Materials other than those specified in a) and b) do not have recognised break.

A.4.5 Calculation

The requirement of maximum weight for broken glass particles shall be calculated based on this standard conversion. The weight in ounces of 10 inch^2 of glass is equal to 14.5 multiply the glass thickness in inches. The weight in grams of 10 inch^2 of glass is equal to 412 multiply the glass thickness in inches (16.18 g/mm).

A.4.6 Test method

The test procedures for pendulum impact test shall be as follows.

a) Testing shall be conducted based on the applicant declaration on the product classification as in Table A.2.

b) The test shall be carried out at (25 ± 5) °C.

c) Place each test piece in the clamping frame so that its edges are encased in the rubber to a minimum depth of 10 mm. When clamped, the rubber shall be compressed by not more than 20 % of its thickness.

d) Inflate both impactor tyres to a pressure of (350 ± 20) kPa. Pressure shall be checked before each drop height.

e) Raise the impactor to the intended drop height and stabilise. At the drop height the suspension cable shall be taut, and the axis of the impactor and cable shall be in line (see Figure A.5).

f) Release the impactor so that it falls with a pendulum movement and without initial velocity. The direction of impact on the centre of the test piece shall be normal to the surface. If the impactor strikes the test piece more than once the test shall be deemed to be invalid. The weights shall not contact the test piece during the impact.

g) For asymmetric materials that are intended for installation where the risk of impact is from both sides, the test shall be carried out on both sides.

Unless both sides are impacted, the classification only applies to the impacted side and this shall be reported in the test report.

h) Inspect the test piece after impact and note whether:

i) it remained unbroken;

ii) it broke in accordance with either the requirements of a) or b) of A.4.4; or

iii) it broke and failed to conform to the requirements of A.4.4.

i) All of four test specimens shall comply with the requirements of A.4.4 If any of the four test sample fails to conform to the requirements of A.4.4, terminate the procedure.

NOTE. If the material remained unbroken, the same sample(s) may be used.

j) In the case of asymmetric materials, the complete test shall be carried out on both sides, using separate sets of test pieces, and the classification shall be based on the worst performance. But in the case of asymmetric materials intended solely for installation in situations where the risk of impact is from one side only, the complete test shall be carried out on the risk side only. The impacted side shall be reported in the test result.

A.4.7 Classification

Classification of safety glass shall be as in Table A.2. below.

Table A.2 – Drop height and safety requirements

Class	Drop height, mm	Sample conditions
1	1200 ± 10	- No breakage or breaks safely - Comply with performance test requirements
2	450 ± 10	
3	190 ± 10	

Annex B
(informative)

Inspection, maintenance and repair

B.1 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.

B.2 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.

B.2.1 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.

B.2.2 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.

B.3 Maintenance management

B.3.1 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 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.

B.3.2 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, considering 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.

B.3.3 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.

B.3.4 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.

B.4 Routine inspection and maintenance

B.4.1 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.

B.4.2 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.

B.4.3 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.

B.4.4 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.

B.5 Planned inspections and maintenance

B.5.1 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.

B.5.2 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.

B.5.3 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 B.4.3 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.

B.5.4 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.

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Acknowledgement

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