This Technical note deals with the selection of glass to limit the risk of injury from falling glass. It is concerned with the risk of failure, failure mode and post-failure behaviour of the glazing.

This Technical Note is one of eight describing the use and performance of glass. They are:

- TN61 Glass types
- TN62 Specification of insulating glass units
- TN63 Glass breakage
- TN65 Thermal fracture of glass
- TN66 Safety and fragility of glazed roofing: guidance on specification
- TN67 Safety and fragility of glazed roofing: testing and assessment
- TN68 Overhead glazing
- TN69 Selection of glass to prevent falls from height

**Introduction**

Glass used overhead may present a risk to people if it breaks and falls. This was acknowledged for overhead sloping glazing in the CWCT Standard for slope glazing systems published in 1999. This advice was subsequently extended by CWCT Technical Update 10. These documents provide guidance on glass selection and give limits on the types of glass that were considered appropriate for use in overhead slope glazing systems. More recently concern has grown about the safety of vertical overhead glazing particularly when used in large panes or with novel fixing systems.

This Technical Note describes the risks associated with the use of different types of glazing in roofs and facades. It discusses methods of risk analysis and of assessing post failure behaviour and gives guidance on the selection of glazing. It supersedes the advice on glass selection in the CWCT Standard for slope glazing systems and Technical Update 10 and extends the advice to include vertical glazing. The topic of overhead glazing is covered in greater detail in ‘Guidance on glazing at height’, CIRIA (2005).

**Definitions**

In this Technical Note the following definitions apply

- **Overhead glazing** is glazing that has the potential to fall on breakage, causing safety and other related concerns, including:
  - All types of façade (vertical and sloping)
  - Glass roofs and canopies
  - Glass in barriers protecting against a fall from height.

This is the definition used for ‘glazing at height’ in the CIRIA document.

- **Vertical glazing** is glazing which is nominally vertical.

- **Sloping glazing** is any glazing that is not nominally vertical.

These definitions of vertical and sloping glazing differ from those used in BS 6262 and BS 5516 where vertical glazing is considered to include glazing up to 15° from true vertical. The distinction between vertical and sloping glazing in this Technical Note relates to the risk of glass falling from its frame after fracture. It is considered that gravity is likely to cause broken glass to fall at slopes within 15° of vertical.

**Scope**

This Technical Note provides guidance relating to:
• **Vertical glazing in facades and balustrades that is above head height**

• **Sloping glazing in facades, glass roofs and canopies**

Roof glazing may also be required to prevent maintenance operatives and their tools from falling through it. This is covered in CWCT TN66 and TN67.

Glass in facades or balustrades that is required to protect people against a fall should satisfy the requirements in this Technical Note for glass in a vertical façade but the selection of the glass is likely to be dominated by the requirement to provide containment to prevent a person from falling. This is covered in CWCT TN69.

Different standards apply to glass lifts and lift enclosures (BS EN 81) and the information given in this Technical Note does not apply to them.

The structural use of glass in floors, staircases and bridges requires detailed structural appraisal and is beyond the scope of this Technical Note.

The structural use of glass in facades also requires structural calculations and provision of alternative load paths which is outside the scope of this Technical Note.

**Causes and risk of failure**

This Technical Note is primarily concerned with safety risks however it should be recognised that the selection of glass also involves performance risks and financial risks.

Performance risks are primarily associated with appearance and include:

• Distorted reflections due to the use of heat treated glasses

• Colour variations, particularly in coated glasses.

Financial risks may be direct or indirect. Direct financial risks include the cost of replacing broken glass and indirect financial risks include loss of property value or business resulting from a glass failure.

There is always a residual risk that glass may fracture. Glass may fracture as a result of:

• Thermal stress

• Vandalism

• Accidental damage

• Localised stresses

• A weak pane of glass or excessive load

• Nickel sulfide inclusions

Glass may also fracture under severe conditions such as fire or bomb blast. Where fire or blast resistance are a design requirement specialist products are available however there are also situations where these are not design requirements but it is desirable to minimise the consequences of their occurrence. Hence post breakage behaviour may be a consideration even if facades are not blast resistant.

**Thermal fracture** of glass is described in CWCT TN65. Glass should be selected to withstand anticipated thermal stress. However, there is a residual risk of failure due to edge damage of the glass. The use of heat strengthened or toughened glass will eliminate the risk of thermal fracture in non-fire situations. Thermal fracture can also occur as a result of modifications to the building and/or its fit-out.

**Vandalism** takes many forms and includes impact loads or impact from air rifle pellets which may lead to fracture of the glass. The risk of damage due to vandalism will depend on the location of the building, access to the building and building use. This has to be evaluated on a project by project basis.

**Accidental impact** by objects or people may occur from activities of building occupants or objects dropped onto a glass roof.

**Localised stresses** may occur where the glass comes into contact with the glazing frame.
Good design and workmanship in accordance with BS8000-7 will keep this risk to a minimum.

A weak pane of glass may fracture under the design load. Glass strength is variable and depends on small undetectable surface flaws as well as visible surface and edge damage. It is possible that 1 in 2000 panes may break if the design load is applied.

Nickel sulphide inclusions may cause failure of toughened glass as described in CWCT TN61 and CWCT TN63. Heat soaking the glass will reduce but not eliminate the risk of failure due to a nickel sulphide inclusion. The risk of failure due to nickel sulphide inclusions is given in CWCT (2002). The risk can be eliminated by using annealed glass. There risk is greatly reduced when heat strengthened glass is used although cases of nickel sulphide failure have been reported.

Design assumption

Glass should be selected to have adequate initial strength according to BS6262-3 or BS5516. The glass may also have to meet other performance criteria including thermal and acoustic performance.

Glass is a brittle material and gives no warning of failure such as excessive deflection or deformation. It is therefore always assumed that a pane of glass may fracture in service.

Glass should always be selected on the assumption that:

1. It normally carries the design loads without fracturing and within acceptable deflection limits,
2. It may fail due to the design loads or other causes,
3. Its post failure behaviour is acceptable and does not create an unacceptable hazard.

A risk assessment is required to determine the suitability of a particular glass selection.

Risk assessment

A risk assessment of a glass selection has three elements to it:

1. The probability of glass fracture,
2. The probability of glass falling post failure,
3. The consequences of the glass falling.

Risk has to be assessed on a project by project basis.

Probability of fracture will depend on:

- The type of glass
- Applied loads
- Environmental conditions

The causes of failure given above should each be considered if appropriate.

Probability of glass falling will depend on the orientation of the glass, glass type, size of pane, method of retention, cause of failure and loads applied. It may be assessed by reference to experience or by testing.

Consequences of the glass falling will depend on the mode of breakage, the size of pane, the presence of meshes or other devices to fragment or catch the glass and the number of people passing beneath the glass.

The consequence of the glass falling will depend on the operation of the building and may impact on the businesses of the occupier and owner. Where possible, all parties involved in the design, construction, use and ownership of the building should be consulted when preparing a risk assessment. A risk assessment should establish any residual risk and who is responsible for the risk.

Acceptable risk

Guidance on tolerable and acceptable risk is given in HSE (2001).

- The limit of tolerability for involuntary risk by the general public is one fatality in 10,000 people per year and glazing should never present a greater risk than this.
- A broadly acceptable risk is one fatality in 1,000,000 people.
The broadly acceptable risk of 1 in 1,000,000 is a desirable aim for the hazard presented by glazing.

It is appropriate to use the limit of tolerability when assessing whether a fractured pane of glass creates an ‘unsafe structure’ that requires an area to be closed to the public.

It is difficult to apply these levels of risk to the selection of glass as there is insufficient data available to quantify risk.

The aim when selecting glass is to achieve a risk level that is as ‘as low as reasonably practical’, (ALARP). This requires the relative risk of different glass types to be assessed rather than quantifying the actual risk. The term reasonable does allow a judgement of what is practical in economic terms. This approach would always lead to the selection of the material giving the lowest risk unless this is outweighed by the increased cost or reduction in performance. Even this approach is difficult to apply as it requires comparison of very low level risks that can only be estimated subjectively.

Selection of glass for vertical glazing

Traditionally vertical glazing at height has not been subject to risk assessment. Moderate size panes of annealed glass set into four sided frames present a low risk of injury from falling glass. However, when using large panes of glass, point supported glass or structural sealant glazing above a busy thoroughfare designers are now advised to undertake a risk assessment.

The risk associated with vertical glazing is often assumed to be less than that associated with slope glazing as it is less likely to fall when fractured. However with sloping glazing there is generally only one pane directly overhead whereas with vertical glazing in a tall building there may be many panes directly overhead.

The risk depends on the glass type (annealed, heat strengthened, toughened), form used (monolithic or laminated) and the method of retention (4 sided rebate, 2 sided, patch plates, bolted, silicone bonded).

Vertical glazing in modern facades is normally in the form of glazing units although where double skin facades are employed the outer skin may be single glazed. Glazing screens between atria and the rest of the building may also be single glazed. The concern will normally be glazing falling outside the building but for walls of atria the glass may fall into an occupied atrium.

In some buildings there may be concern that an explosion may cause glass shards to be blown into the building causing injury to occupants. Laminated glass may be used to reduce this risk. This is not directly related to the glass being overhead.

The behaviour of annealed glass after failure depends on the cause of failure. For glass to fall, there needs to be a horizontal force to cause the broken particles to be displaced. Broken particles extending to the edge of a glazing unit will be restrained by the bond to the edge spacer; island particles will be more likely to fall. Thermal fracture or stress concentrations from contact with the frame are unlikely to cause island particles. Impact may cause particles to fall, however for glazing units a very severe impact on the internal pane would be required to displace particles from the outer pane.

Glazing units in vertical facades

Any type of glass can be used for either pane provided that the glass can meet all the performance requirements for the location. Performance requirements that may limit the types of glass that can be used include;

- Glass in a vertical façade or balustrade that is required to prevent people from falling should provide some residual strength after fracture. This will normally require laminated glass to be used. This is discussed in greater detail in TN 69.

- Where bolted glass is used, heat strengthened or toughened glass will be required to resist the fixing stresses.

- Heat strengthened or toughened glass may be required to resist thermal stresses.

When selecting the type of glass to be used, the following should be considered as part of the risk assessment.
Annealed glass breaks into shards with sharp edges. When used in a vertical frame with four edge support it will normally remain in place when fractured. Shards are more likely to fall if

- The glass is subject to impact
- The glass is subject to explosion
- The glass fails under severe wind load

When the glass is used in a glazing unit a severe impact is required to break both panes. It is therefore unlikely that an accidental impact on the inside of the glazing will cause the outer pane to fall. The most likely forms of impact for the external pane of vertical overhead glazing are missiles such as stones and airgun pellets or maintenance activities. Missiles are of low mass, tend to cause localised failure and are unlikely to cause large pieces of glass to fall. Impacts from large heavy bodies such as access equipment may cause large pieces of glass to be displaced but the risk can be mitigated by ensuring cradles are fitted with appropriate restraints and buffers and restricting access to areas below maintenance work.

In severe wind storms when glass may be broken either by wind alone or windborne debris, people will normally be advised to remain inside and the risk of injury from falling broken glass will be low.

Where a building is in an area which may be subject to bomb blast, non laminated annealed glass may not be considered appropriate.

Heat strengthened glass will perform in a similar manner to annealed glass; it will have greater resistance to thermal fracture but will not be as flat.

Toughened glass breaks forming small particles called dice. The formation of the fracture pattern causes the pane to expand. If this expansion is not restrained the particles are more likely to separate and fall. If this expansion is restrained on one face, as in structural sealant glazing, the pane may bow. If the pane bows outwards sufficiently, it may fall under gravity.

Moderate size panes in a rebated frame normally remain in place. Large storey height panes held by structural sealant are more likely to fall. This is because larger panes will expand more and the restraint on the pane is eccentric. If the glass falls it may fall in the form of plates 0.5m² or more in size which only separate into dice after hitting the ground or other hard obstruction.

If the inner pane remains unbroken and the outer broken pane of toughened glass does not fall immediately, it may stay in place for some considerable time. However, it may fall at any time and, particularly if it is above a populated area, it should be removed as soon as possible.

Heat soaking toughened glass reduces the probability of failure due to nickel sulfide but the probability of a broken pane falling is unchanged.

Toughened glass is resistant to thermal fracture. It is stronger than annealed or heat strengthened glass and, if broken in an explosion, the particles are less hazardous than shards of annealed or heat strengthened glass.

Laminated glass will normally remain in place if broken, either due to the residual integrity of the broken laminate or support from the unbroken pane of the glazing unit. Where there is a risk of laminated glass falling from a frame, it can be prevented from falling by bonding the glass to the frame. In the case of bolted laminated glass, it may be necessary to select the interlayer so that it can resist tearing around the fixings.

The blast resistance of laminated glass will depend upon the glass and interlayer thicknesses and edge support conditions.

Strength of residual panes in IGUs

If only one pane of a glazing unit is broken the unbroken pane will be required to resist all the applied loads. Where glazing units are designed assuming load sharing between the panes, the unbroken pane will not be able to resist the full design load. The load capacity of the unbroken pane should be assessed and it may be necessary to provide additional protection.

With bolted glazing and structural sealant glazing, failure of one pane of a glazing unit may leave the unbroken pane inadequately
supported. For example a stepped edge glazing unit may be held in place by structural sealant on the inner face of the outer pane. If this pane is composed of monolithic toughened glass and it breaks, the inner pane will not be securely retained. Non structural spacer tapes or weather seals may be sufficient to prevent the glass falling in the short term but cannot be relied upon unless this has been considered as a design requirement.

**Single glazing in vertical façades**

Single glazing in a vertical façade will break in the same way as for glass in a glazing unit but it is more likely to fall for the following reasons;

- There will be no unbroken pane to carry residual horizontal loads
- An accidental impact is more likely to pass through the plane of the glazing
- Shards will not be held in place by the bond to the edge spacer of the unit and may be able to slip out of a rebate.

Large panes of monolithic annealed or heat strengthened glass are not normally considered acceptable in this location.

**Selection of glass for slope glazing**

The CWCT Standard for slope glazing systems gave requirements for the selection of glass. This was subsequently updated by CWCT Technical update 10. Similar requirements are now given in BS5516-2. These documents permit the glass types listed below but require the selection to be based on a risk assessment.

The requirements set out below do not apply to commercial or domestic glass houses used for plant growing. Experience and risk analysis show that glass used in these constructions presents a low hazard due to the relatively low height of the glass and the small number of people hours spent beneath it.

**Lowest pane of glass of slope glazing**

The lowest pane of glass whether single glazing or the lower pane of an insulating glazing unit should be selected from one of the following:

- Laminated glass (subject to the conditions given below)
- Heat soaked toughened glass (subject to the conditions given below)
- Wired glass
- Plastics glazing material

**Laminated glass** should be selected so that it will not fall from place when broken unless it will be retained by a restraint such as wires or bars.

Laminated glass supported on only two edges is more likely to fall from place post failure than that supported on four edges.

Laminated glass supported on bolted fixings may fall if the fixings tear through the interlayer of the laminated glass.

Laminated glass in which all plies are toughened glass may be sufficiently flexible to fall from a frame unless it is bonded to the framing members. There is little benefit from using a toughened-toughened laminate but if one is used it should be shown by testing that it will not fall from place if both plies fracture.

Laminated glass in which at least one ply is not toughened will have the lowest risk of falling from place.

When testing or otherwise assessing the post-fracture behaviour of glass it is important to take account of the softening of the interlayer at the elevated temperatures that commonly occur in roof glazing. The degree of softening of the interlayer depends on the interlayer material and in the case of pvb, the grade of pvb used.

**Heat soaked toughened glass** will fall from place if it is used as a monolithic pane.

Heat soaked toughened glass should not be used more than 13 m above lowest floor level. Toughened glass may fragment when fractured but fragments falling from this height will gain sufficient kinetic energy to cause a serious injury.
Heat soaked toughened glass may be used at heights of between 5 and 13 m above lowest floor level provided a risk analysis shows that the resulting hazard is tolerable.

Toughened glass used in these situations should be no more than 6 mm thick and the pane size should not exceed 3 m². Thicker glass will break into larger fragments. A pane of this size weighs 45 kg and even if fully fragmented larger masses of glass should not be allowed to fall from these heights.

When toughened glass fractures the small fragments may fall as large clumps weighing 2 kg or more and this may cause a serious injury or fatality when falling from these heights. It may be necessary to provide a mesh below the glass to retain or separate the glass fragments.

Heat soaked toughened glass may generally be used at heights less than 5 m above lowest floor level. Fragments falling from this height are less likely to cause serious injury. However, a risk assessment should still be undertaken.

**Wired glass** will break into shards that are held together by the wires. Following breakage the wires will corrode and fractured wired glass should not be left in place long term.

**Plastics glazing materials** including polycarbonate and acrylic in sheet or cellular form are good at resisting impact and will remain in place if correctly framed. Plastics glazing materials are more flexible than glass and deeper glazing rebates are required. They may also become brittle or discoloured with age, are combustible and are not generally a good substitute for glass.

**Meshes** may be provided in the form of screens, sun shading and so on and do not necessarily detract from the appearance of the glazing. When used at height, a wire mesh may not be apparent to the casual viewer. However, meshes are more likely to be used as a remedial measure for an existing building than for new construction.

It is recommended that broken toughened glass should break into clusters no larger than 25mm square by a wire mesh unless a risk assessment shows otherwise.

**Upper and intermediate panes of slope glazing**

If the lower pane has been selected to remain in place post-failure then it may be assumed that an upper or intermediate pane that fractures will be retained on the lowest pane and will not fall from height.

If the lower pane is toughened glass it may fall from position and the next lowest pane may have the potential to fall from height. In this case the next lowest pane should be selected to perform as the lowest pane of glass as described above.

**Upper panes** of glass may be required to resist impact from objects dropped onto the roof particularly where there are adjacent areas at higher levels. TN 66 gives advice on impact testing where glass is subject to impact during maintenance work but there is no published guidance on the severity of impacts which may be experienced during normal building use.

**Practical glass selection for slope glazing**

A common combination in normal service is toughened glass above a laminated glass that does not contain any plies of toughened glass.

Sloping glazing is more susceptible to thermal fracture than vertical glazing and this may require the use of heat strengthened or toughened glass.

**Summary**

Both vertical and slope glazing used overhead may present a hazard from glass falling on people and a risk assessment is required when using glass in these situations.

The risk assessment should take account of:

- The probability of glass failure
- The probability of broken glass falling
- The consequences of glass falling.

**References**

Overhead glazing

BS 6262-3, 2005, Glazing for buildings – Part 3
Code of practice for fire, security and windloading,

BS 8000-7, 1990, Workmanship on building sites.
Code of practice for glazing

BS EN 81 (various parts) Safety rules for the
construction and installation of lifts.

CIRIA, 2005, C632 Guidance on glazing at height,

CWCT, 1999, Standard for slope glazing systems,
ISBN 1 874003 56 4, CWCT, Bath, UK.

CWCT, 2002, Glass in buildings, Breakage-the
influence of nickel sulfide, ISBN 1 874003 27 0,
CWCT.

CWCT 2003, Technical Update 10, The use of glass
overhead

HSE, 2001, Reducing risks, protecting people,
Health and Safety Executive, UK,
www.hsebooks.co.uk

LDWA, 2002, Guidance notes on nickel sulphide
inclusions in toughened glass, London District
Surveyors Association, ISBN 0 9531229