Technical Note No. 69

Selection of glass to prevent falls from height

This Technical Note reviews the requirements for barriers provided to prevent falls from height and gives guidance on how these requirements should be applied to the design of glass barriers and the selection of glass for use in barriers.

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

In buildings, barriers are required at changes of level to prevent people from falling. Barriers may be in the form of balustrades or full height walls and in both cases glass is commonly used as an infill material. Glass may also be used as the primary structural material both in glass walls and balustrades.

Barriers are required to be designed to resist static loads however where glass is used in barriers, it is also necessary to consider impact loads.

Requirements for barriers are given in the Building Regulations and in BS 6180.

The requirements set out in these documents are quite complex and can lead to confusion. There have also been cases of barriers which comply with these documents proving unsatisfactory in service.

This Technical Note reviews the requirements for barriers protecting people from a fall and gives guidance on how these requirements should be applied to the design of glass barriers and the selection of glass for use in barriers.

Scope

This Technical Note is concerned with glass barriers protecting people against a fall. Protection against falling is required in domestic premises where there is a change in level of 600mm and in other buildings where there is a change in level of 380mm. It includes glazed walls, balustrades with a metal frame and glass infill and freestanding glass balustrades where the glass is the primary structural material. These three types of glass barrier are described in BS 6180.

Walls and balustrades where there is no change in level may be designed to the same standards but the following variations may apply:

- Loads may be applied from both sides and it is necessary to design for both directions of loading
- Glass may not be required to provide containment
- Walls may be required to provide security

Partitions are defined as non loadbearing internal dividing walls. Requirements for partitions are given in BS 5234. The requirements of BS 5234 differ from those of BS 6180. This Technical Note applies to internal dividing walls which separate spaces at different levels.

The requirements discussed in this Technical Note apply to lift enclosures however there are additional requirements relating to the operation of the lift that must be considered which are set out in BS EN 81. There is a specific requirement in BS EN 81 that glass in enclosures surrounding lifts be laminated glass for a height of at least 1.1m. Laminated glass may be required to extend to greater heights

depending on the proximity of moving equipment.

Double skin facades are required to fulfil the function of an external wall including provision of a barrier; however, as there are two layers to the construction the requirements for each layer must be determined. The requirements will depend on the level of access to the cavity. If the cavity is freely accessible to building occupants, the outer skin must provide the barrier function and the inner skin may be considered as a partition. Where access to the cavity is restricted to maintenance staff, the inner layer could be designed to provide the barrier for building occupants but the outer skin should then be designed to provide a barrier function for maintenance staff.

Design of glazed barriers should also consider general issues affecting the selection of glass for use overhead which are described in Technical Note 68.

Existing guidance

The requirement to provide a barrier to prevent falling at changes of level in buildings is given in Regulation K2 of the Building Regulations for England and Wales. Similar requirements are contained in Section 4 of the Technical Handbook in Scotland and Technical Booklet H in Northern Ireland.

Approved Document K (ADK) gives guidance on how this requirement can be satisfied. In most cases, the requirements of K2 can be satisfied by a barrier which is capable of resisting the loads given in BS 6399-1 which is:

- 1100mm high
- 900mm high on stairs
- 800mm high in front of opening windows which extend to within 800mm of the floor

Any glass in the barrier which is within 800 of floor level is required to provide containment.

It is not clear why it is considered safe to have an open window with a cill height 800mm above floor level but a balcony requires a balustrade 1100 mm high. People may be exposed to an open window for longer periods and may have to lean out to operate the window. The CWCT Standard for systemised building envelopes requires opening lights to be fitted with restrictors where there is a risk of falling from an open window. BS 8213 also requires a risk assessment to be carried out to determine whether restrictors are required for opening windows.

In Scotland, a wall with fixed glazing that does not resist the loads specified in BS 6399 can also be protected by a barrier 800mm high. This would imply that a curtain wall with a transom 800mm above floor level could be considered acceptable if the transom and spandrel panel are able to resist the loads given in BS 6399-1.

Containment is defined in ADK as the ability to prevent a person from falling from one floor to another. Reference for further guidance is made to BS 6180 which defines containment as the ability to resist penetration by an impacting body. The Scottish Handbook does not include the requirement for glazing to provide containment.

Where young children may be present, the barrier should also:

- Ensure there are no openings through which a 100mm diameter sphere can pass
- Be constructed so that it is not readily climbable by children.

Care should be taken if these requirements are not satisfied as children may sometimes be present in buildings normally restricted to adult occupation.

There are slightly reduced requirements for dwellings and in front of fixed seating in places of assembly.

Approved Document K makes reference to BS 6180 for further guidance. BS 6180 provides guidance on the design and construction of barriers including:

- Allowable deflection limits for glass barriers
- Tables giving allowable glass thickness to resist the loads given in BS 6399

- Restrictions on construction details such as edge cover to glass

The CWCT Standard for systemised building envelopes requires curtain walls to resist the barrier loads given in BS 6399-1.

Loads on barriers

Occupancy load
Up until the end of March 2010 the loading Standard in the UK was BS 6399. BS 6399-1 has now been superseded by BS EN 1991-1-1.

BS 6399-1 gives horizontal loads to be resisted by barriers in the following form:

- Line load in kN/m to be applied 1.1m above floor level irrespective of the height of the barrier
- Uniformly distributed load in kN/m^2 to be applied to infill below the barrier height
- Point load in kN to be applied to infill below the barrier height

These loads are alternative means of applying the load and should not be considered in combination. Different values are given in BS 6399-1 depending on the use of the building. For office buildings the loads are:

- Line load of 0.74 kN/m
- Uniformly distributed load of 1.0 kN/m^2
- Point load of 0.5 kN

BS EN 1991-1-1 gives the load on barriers in the form of a line load to be applied at the top of the barrier but not more than 1.2m above floor level. It does not give a distributed or point load on the infill. BS 1991-1-1 gives a range of values of the load depending on the building use. The National Annex adopts the values from BS 6399-1 however it does not comment on the height of application of the load.

BS 6399-1 also requires barriers to be able to resist a vertical load either in the form of a point load of 1kN or a line load of 0.6kN/m. The vertical load can act concurrently with the horizontal load. There is no requirement in BS EN 1991-1-1 for a vertical load.

The loading given in BS 6399-1 does not conflict with that given in BS EN 1991-1-1 but requires the horizontal load to be applied in different ways that are reasonably foreseeable and also requires a vertical load that is reasonably foreseeable. It is therefore considered appropriate to continue to design barriers to resist the loads as specified in BS 6399-1. It is anticipated that this will be included in a revision to BS 6180.

Application of the line load 1.1m above floor level can give anomalous results. Where a balustrade is provided with the top rail 1.1m above floor level it is clearly reasonable to apply the line load at this level. This is also reasonable for a full height glass wall with a storey height pane of glass although it might be appropriate to apply the load at shoulder level. However for a full height glass wall with a deep transom slightly less than 1.1m above floor level, the line load is most likely to be applied to the transom rather than the glass as this is where people leaning against the wall will come into contact with it. Application of the line load to the glass above the transom may require a thicker glass to be provided particularly if the glass thickness is determined from the Table in BS 6180. The Table in BS 6180 makes no allowance for the location of the line load whereas a line load near to one edge of the pane will have less effect than a line load at mid span. Applying the line load to the glass will reduce the load on the transom as some of the load will be taken by the other edges of the pane. However, because the transom is less than 1.1 m above floor level, a line load applied at transom level should be increased by 1.1/h where h is the transom height.

Wind load
In addition to the above loads, barriers will be subject to wind load, if they are external, and may be subject to thermal loads although normally allowance for movement will be made to prevent thermal loads developing.

Maintenance load
External maintenance loads on vertical surfaces are generally smaller than occupancy loads or wind loads.

In the case of a barrier which is only required to protect maintenance workers, ADK states that greater care can be expected and less demanding provisions could satisfy the

requirements. It also suggests that in locations where frequent maintenance is required, defined as at least once per month, provision such as that suggested for dwellings would satisfy the requirements.

Load combinations
BS 6180 does not give specific guidance on load combinations for barriers. The following advice is based on CWCT Technical Update 14.

Maintenance loads are highly unlikely to occur concurrently with the maximum wind load as maintenance work should be suspended when severe weather likely to give rise to high wind is forecast. It is therefore unnecessary to consider maintenance loads acting concurrently with the maximum wind loads. Maintenance loads will normally be very much less than the maximum windload so that the combination of maintenance load and a lower level of wind load is unlikely to be more critical than the maximum wind load on its own.

For a predominately glass façade it might be prudent for building occupants to be kept well back from the façade when severe winds approaching the maximum design wind load are forecast and as a result occupancy loads would not occur concurrently with the maximum wind load. However, this cannot be guaranteed and it is therefore necessary to consider the combination of occupancy loads and wind loads.

Depending on the nature of the building, occupancy loads may be equal to, or even exceed, the wind load for some parts of the façade. It has however been common practice for many years to assume that wind load does not occur concurrently with live loads and there is no evidence that this has given rise to failures.

Wind load is a short duration (approx 3 seconds) load and the design value will occur on average once in 50 years. A wind loading regime devised by BRE to represent 50 years of wind loading suggests that a wind load equal to fifty per cent of the design wind load will occur on average 24 times each year.

Barrier loads are also transient loads and are likely to apply for a few minutes. No statistics are available to predict the frequency of occurrence but it is likely that these loads will rarely be applied in residential and office accommodation but may occur more frequently in areas where people congregate.

Occupancy loads are outward loads and only need to be considered in conjunction with negative wind loads. Negative wind loads are normally greater than positive wind loads but high negative loads are limited to a small area of the façade.

It is recommended that:

- For office and residential accommodation, design should be carried out under the wind load or the occupancy load, whichever gives the more severe loading action.

- For areas where people may congregate, design for safety should be carried out under a combined load equal to the wind load plus half the occupancy load or the occupancy load plus half the wind load whichever gives the more severe loading action.
  Design for serviceability should be carried out under the wind load or the occupancy load, whichever gives the more severe loading action.

Multi-storey walls
In multi-storey buildings, barrier loading may be applied to a single floor or to several floors simultaneously and consideration should be given to the arrangement that gives the most critical effects. Loading of several floors simultaneously may occur in response to an event outside the building.

Applying the load to more than one floor may increase or reduce the effect depending on the structural arrangement. In the case of a wall constructed from storey height mullions with joints close to the brackets at floor level, the bending load on an individual mullion will be the same whether the load is applied to that mullion alone or to adjacent mullions as well. However, the load on the bracket at the intermediate floor will be greater where more than one span is loaded. For continuous mullions, loading adjacent spans may reduce the bending stresses in the mullions.

Design requirements

Strength
Barriers must be able to resist the loads, with an appropriate factor of safely, without suffering permanent damage.

Metal framing should be designed in accordance with an appropriate code of practice. For aluminium systems this was BS 8118 but is now BS EN 1999- 1.

Table 2 of BS 6180 gives sizes of fully framed glass panes that will resist the loads given in BS 6399-1. This Table assumes the load is carried by a single pane of glass which is normally the case for balustrades. For glazed walls, glazing units will normally be used. Use of glass complying with Table 2 of BS 6180 for the inner pane will be conservative as it ignores any contribution from the external pane. The sizes given in this table may also be conservative depending on the shape of the pane; calculation for the exact shape and size of pane may allow thinner glass to be used but design guidance is not readily available.

Where glass is used in other ways, reference should be made to the manufacturer or specialist literature for design guidance.

Deflection limits

In addition to being able to withstand the design load without permanent damage, barriers should not deflect excessively as this is likely to cause alarm to people.

Deflection limits for barriers are given in BS 6180. There is an overall limit of 25mm and deflection is also limited according to the design code for the material used. There is no structural design code for glass hence BS 6180 gives an additional limit for glass of L/65 where L is;

- the length of the longest side for a fully supported pane
- the span between supports for two edge supported or point supported glass
- 1300mm (giving a deflection limit of 20mm) for freestanding glass barriers.

For glazed walls, deflection limits for the framing are given in Part 3 of the CWCT Standard for systemized building envelopes. The deflection limits given are for wind load but it would be reasonable to apply the same limit to other loadings.

Impact performance

Glass in barriers is required to be selected to minimize risk of injury due to human impact. Injury may be caused by contact with sharp edges causing cutting injuries or by falling from height after passing through the barrier. The risk of cutting injuries applies to all glass barriers and is normally reduced by the use of a safety glass. The risk of injury after falling through the barrier only applies where the barrier protects a change in level and is reduced by using a glass which provides containment.

The performance of glass under impacts simulating human impact is currently assessed by testing in accordance with BS EN 12600. The assessment results in a classification in the form $\alpha(\beta)\Phi$

where,

α is highest impact energy class at which the product either does not break or breaks safely,

β is the mode of breakage

Φ is highest impact energy class at which the product either does not break or when it breaks it still provides containment.

The test is carried out with three levels of impact energy so that α and Φ may take the value 1, 2, 3 or 0. Class 1 is the highest level of performance and the impact energy decreases form 1 to 3. 0 indicates that the glass failed to give satisfactory performance at any level of impact energy.

Glass where α has been classified as 1, 2 or 3 is called a safety glass. Safety glass is used in areas where the glass may be subject to impact to reduce the risk of severe cutting and piercing injuries. This form of classification has been in use for many years and the previous method of test was given in BS 6206 giving three levels of performance A, B and C which are broadly equivalent to 1, 2 and 3 of BS EN 12600 respectively.

Glass where Φ has been classified as 1, 2 or 3 is able to provide containment at the given impact energy class. This aspect of performance was not included in BS 6206.

Part K of the building regulations requires all glass within 800mm of the floor in barriers protecting a change in level to provide containment however the appropriate impact energy is not specified. Reference is made to BS 6180 for further guidance.

BS 6180:1999 requires glass below the barrier height (ie 1100mm in most cases) to have appropriate impact performance but the required performance depends on the type of construction.

- Glass in full height barriers is required to meet the safety glazing recommendations in BS 6262-4. The requirements of BS 6262-4 are

only concerned with injury resulting from impact with glass and do not require the glass to provide containment.

- Glass in balustrades is required to provide containment. The impact energy to be resisted depends on the distance a person can travel perpendicular to the glass before hitting it, known as the free path. Where the free path is less than 1.5m the glass is required to provide containment under a class C impact of BS 6206 and where the free path is greater than 1.5m the glass is required to provide containment under a class A impact in BS 6206. It would be reasonable to accept glass with the equivalent classification in accordance with BS EN 12600 (ie with Φ equal to 3 or 1).

It is considered that the requirement for containment given for balustrades should also apply to glass in full height barriers. Full height glass walls potentially present a greater risk as there may not be a handrail whereas BS 6180 requires balustrades to have a handrail which will bridge the gap across a broken pane of glass.

BS 6180:1999 permits the use of single glazing with monolithic toughened glass in barriers if it is sufficiently thick to resist the specified impact without breaking. It is considered that this does not give a sufficient level of safety. Toughened glass provides no significant residual strength after fracture and may fracture for reasons other than impact leaving an unguarded opening. Glass should preferably be laminated with an interlayer of at least 0.76mm pvb or equivalent so that it provides some residual strength after failure. A glazing unit with two panes of toughened glass may be considered acceptable subject to a risk assessment.

Use of a glazing type that provides containment under the standard BS EN 12600 test does not ensure that the glass will provide containment when used in the barrier. In the standard test the glass is supported on four edges whereas glass in a barrier may be point supported, two edge supported or even supported on one edge acting as a cantilever. Under some methods of fixing the glass may be displaced from the support structure by the impact.

Requirements to minimize injury from contact with glass are given in Part N of the Building Regulations. Glass which provides an appropriate level of containment will normally satisfy the requirements of Part N however the requirements of Part N need to be considered for barriers where there is no change in level and in this situation containment is not necessarily required.

The requirements above relate to accidental impacts from people. In some cases barriers may be subject to greater impacts for example from loaded trolleys or people on skateboards or mobility scooters and these should be considered on a case by case basis.

Glass for use in barriers

Glass for use in barriers must be selected so that it can meet the specified performance requirements. These will include the load-bearing and impact requirements discussed above together with any other requirements for example for thermal 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 basis 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. Hazards include the possibility of glass falling from height and injuring people below and the risk that the barrier no longer provides effective protection against falls.

A risk assessment is required to determine the suitability of a particular glass selection, however, to meet the recommendations of this Technical Note, the selected glazing will normally be as follows:

Glazing unit which extends below barrier level in a glazed wall

The inner pane will normally be a laminated safety glass capable of providing containment. It may be acceptable to use toughened glass for the inner pane if the outer pane is a safety glass capable of providing containment. The outer pane needs to be selected to ensure that the risk from falling glass is acceptable in accordance with TN 68.

Single glazing in a balustrade or below barrier level in a glazed wall
This will be a laminated safety glass capable of providing containment.

A laminated safety glass composed of two plies of toughened glass may be too flexible to provide containment depending on the details of the installation. In case of doubt, a post breakage test should be carried out.

Where the glass is not fully framed it may be necessary to test the proposed glass and method of fixing to ensure that containment can be achieved.

Freestanding glass barriers are often fixed to the edge of the floor with bolted fixings. Monolithic toughened glass fixed in this way is highly likely to fall if it fails, even where there is no horizontal force applied to the glass.

Construction of glass barriers

Edge cover to framed glazing
BS 6180:1999 requires an edge cover of at least 15mm. This is difficult to achieve with a typical 50mm wide stick curtain wall framing system which typically provides about 12mm edge cover, yet these systems are frequently used in situations where the glass is required to provide a barrier function. Sometimes it is argued that the edge cover can be increased by including the cover provided by the gasket but this is rather dubious and cover should be limited to cover provided by the metal part of the frame. Toggle fixed glazing units may provide even less edge cover.

Edge cover is required to ensure that the glazing is securely held in the frame but the justification for requiring 15mm is unclear and the requirement is likely to be removed from the Standard when it is revised.

Edge cover is required to resist load on the glass when the glass is unbroken and numerous tests for wind load on standard curtain wall systems indicate that the standard 12mm edge cover is adequate to resist wind loads up to 3600Pa on storey height panes of glass. Barrier loadings will normally be much less than this.

Edge cover may need to be increased to retain glazing after fracture. This will apply particularly in the case of single glazing with laminated glass where the additional flexibility of the glass after fracture may allow it to slide past the gaskets. Where a glazing unit is used it is unlikely that both panes will break hence the unit is unlikely to be displaced from the frame.

Edge cover may be reduced by allowable cutting tolerances and movement. Use of anti-walk blocks will reduce the risk of the glass moving to one side of the frame and becoming three-edge supported.

Provision of handrails
BS 6180 requires the provision of a handrail for freestanding glass balustrades protecting a drop. The handrail should be able to span the gap if a pane of glass fails and falls from place ensuring that there is a minimum level of protection to the opening created by the falling glass. At the end of the barrier the handrail should be attached to the structure or an end post. The requirement in this Technical Note to use laminated glass reduces the risk of glass falling however laminated glass may require support from the handrail after fracture to prevent it from falling.

Balustrades with glass infill will have a handrail provided by the top rail of the frame and provide at least the same level of residual integrity as freestanding glass balustrades in the event of glass failure.

Glass in full height barriers is not required to have a handrail although some walls will have a transom at handrail level. Where a full height pane of glass is used without a handrail, the integrity of the barrier is entirely dependent on the glass. The recommendation in this Technical Note to use laminated glass ensures some residual integrity in the event of glass failure. The level of residual integrity will depend on the nature of the laminate and edge cover. Where a glazing unit is used the outer pane may remain unbroken and provide additional integrity.

Construction tolerances and induced loads
Stresses may be induced in glass if tolerances and movements are not taken into account. Problems are more likely to be encountered where bolted connections are used as these can generate high stresses and the connections are often more rigid than a gasketted frame. Bolted fixings can also lead to components being connected to different parts of the primary structure bridging movement joints in the primary structure. Long lengths of handrail may undergo significantly differential movement compared with the glass and connections should allow for this movement.

Summary

In buildings, barriers are required at changes of level to prevent people from falling. Barriers may be in the form of balustrades or full height walls and in both cases glass is commonly used as an infill material. Glass may also be used as the primary structural material both in glass walls and balustrades.

Barriers are required to resist loads from building occupants and may also be required to resist wind loads. The Eurocode does not consider all the foreseeable loads and it is considered appropriate to retain the loadings in BS 6399-1.

Glass in barriers is required to have appropriate impact performance to reduce the risk of injury to building occupants. This requires the use of a safety glass that can provide containment.

Glass build-ups to provide containment should always be designed by competent persons and normally comprise laminated glass with an interlayer not less than 0.76mm thick.

Glass should also be selected to reduce the risk of falling glass causing injury to people below the barrier if the glass breaks.

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