Blast mitigation measures for stick curtain wall systems

Version 1, May 2021

Physical Security

Introduction

Windows are extremely vulnerable to the effect of blast. Windows that have been 'blown in or out', by the blast, are likely to cause injury to people, widespread damage inside of the building, damaging and destroying working spaces and assets and making recovery more difficult and costly. People outside the building or those attempting to evacuate the building or involved in the recovery phase may also be vulnerable to falling glass, especially if the glass falls from upper stories of the building.

Curtain wall systems use large panes of glass to cover the exterior of a building[1]. This increase in glazed area heightens the building's vulnerability to a blast threat. CPNI has conducted research to determine effective mitigation measures to reduce the potential hazard from these systems.

Stick curtain wall systems is one of several generic types of glass curtain walling system. A number of manufacturers offer these systems which are designed to comply with Building Regulations, although the details and overall capacity of these systems vary between manufacturers. Research has shown that implementing the mitigation measures outlined in this Guidance Note can significantly improve the blast performance of a stick curtain wall system against a VBIED threat, by reducing the standoff which failure occurs by half.

CPNI would like to acknowledge the Home Office for their support in the development of this work.

The aim of this document

The aim of this guidance note is to provide Security Managers, Architects and Engineers with an understanding of the vulnerabilities of a stick curtain wall system to a blast load, the likely hazards it may create, and the mitigation measures that can be implemented to reduce the potential hazard.

Technical annexes are provided at the end of this guidance note detailing the recommended mitigation measures.

This guidance note should be read in conjunction with the suite of guidance notes produced by CPNI on the effects of blast on glass and windows. These can be found on the CPNI website. Where required, detailed design advice should be sought from Engineers and Specialists competent in the field of blast protection. Suitable Engineers and Specialists may be members of the Register of Security Engineers and Specialists (RSES) (www.rses.org.uk) or will be able to demonstrate that they have the training and experience to meet the appropriate RSES competences.

NOTE: The façade must also comply with all other project requirements such as wind and other imposed loads and the appropriate building regulations.

[1] See CPNI Guidance Note – Introduction to Glass Curtain Wall Systems

Use and design of stick curtain wall systems

Stick curtain wall systems are one of the most common types of curtain wall systems. They are typically utilised in shopping centres and low-rise office buildings, because they are cost effective and versatile.

Stick curtain wall systems are designed to be connected to the edges of the floors of a framed structure and are required to support their own self-weight i.e. a curtain wall does not form part of the main structure of the building. Individual components are assembled on site to create the complete stick curtain wall system (Figure 1). Annex A explains the individual components of this system, with the key elements summarised below:

- Curtain Wall Frame - The curtain wall frame is formed using hollow aluminium sections referred to as mullions (vertical) and transoms (horizontal).
- Curtain Wall Frame Connections – Individual elements of the curtain wall frame are connected using components that are often hidden from view. Manufacturers offer a range of connection options and selection is normally driven by project design loads (e.g. wind loads) and appropriate building regulations.
- Connection of Frame to the Building Structure - The mullion is connected to the edge of the structure by a base plate. This is a flat metal plate connected to a spigot[2] which is inserted into the hollow mullion section. A similar fixing is used at each floor.
- Glass Pane – The glass pane fits inside the curtain wall frame. The glass specification will vary depending on the project requirements and can comprise of single or double glazed units.
- Glass Retention – The glass can be retained by using a pressure plate, known as a capped system, or by using toggles. Capped systems use external pressure plates which are screwed to the front of the mullions and transoms to clamp the glass in position. A cover plate is then clipped over the top of the pressure plate to hide the fixings. Toggle fixings are used to secure the glass to the mullion and/or transom using clamps which fix either into channels within the edge seals of the insulated glass unit (IGU) or clamp the inner glass assembly. Toggle fixings avoid clamping the outer glass surface.

[2] A spigot is a long section of aluminium which is inserted inside the hollow aluminium mullion, allowing the frame to be connected to the structure.

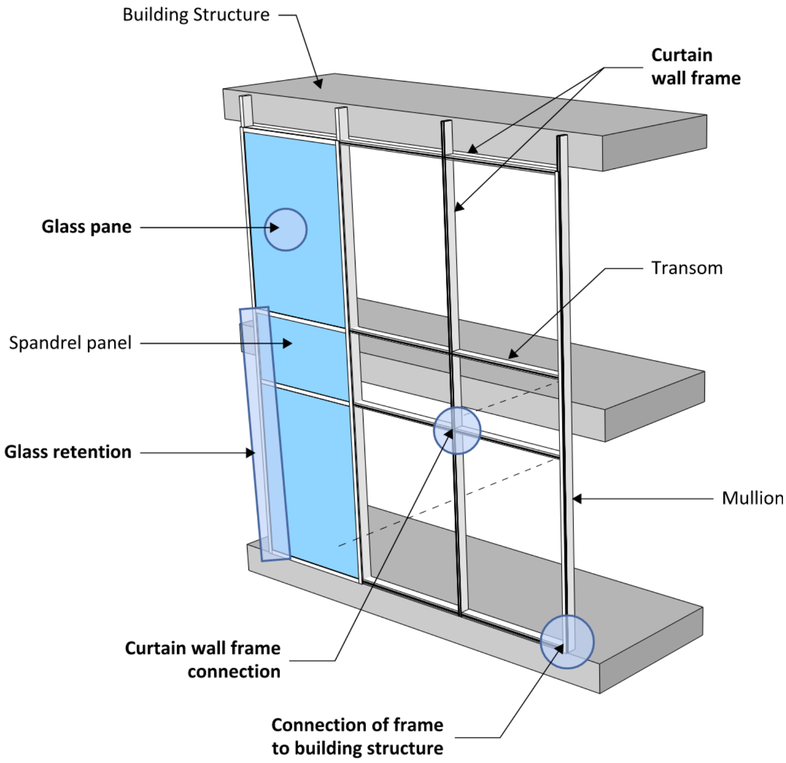


Figure 1: Key components of a stick curtain wall system

How do stick curtain wall systems perform against a blast load?

Stick curtain wall systems, designed to meet conventional project requirements, are not expected to perform well against a blast load. The mullions and transoms are designed to create a strong frame to hold the glass in position against a wind load, and the glass retention systems are designed to retain the glass against a much smaller negative wind load.

The performance of a stick curtain wall system will vary depending on the magnitude of the blast load which is dependent on the charge size and its distance from the facade. Against a VBIED threat, large panes of glass are likely to fall outwards, as the glass retention system doesn't have the capacity to hold the glass. For a larger blast load the frame and/or connections may also fail, projecting the complete system inside the building, creating a much greater hazard.

Whilst the ground floor is the most vulnerable area, it is important to note that the glazing on the floors above will also be subjected to the blast load and could fail in a similar manner. Large panes of glass typically used in these systems can weigh more than one tonne, which would be a significant hazard to people outside the building if it were to fall from height.

What measures can be used to reduce the hazard?

There are two types of measures that can be adopted to reduce the hazards from stick curtain wall systems:

- Protection measures – complete systems that have been designed and/or tested to provide a specific level of protection against a defined blast load i.e. a specified charge size and standoff from the façade.

- Mitigation measures – measures that can be implemented in a system designed to meet conventional project requirements to reduce the hazard against a blast load.

CPNI has conducted research to understand the performance of standard stick curtain wall systems against a blast load and has identified effective mitigation measures for capped stick curtain wall systems which address the weak elements in the system against a VBIED threat. Implementing these mitigation measures will achieve a balanced design with components that are broadly matched in strength and thus reducing the standoff which failure occurs by half that of a system designed to meet conventional project requirements. **Based on CPNI research to date, we have found inherent vulnerabilities with toggle retention systems (continuous or intermitted) and have been unable to find a method of practically improving their performance. CPNI, therefore recommends that such systems are not used unless the supplier can demonstrate, with test evidence[3], that they have a system that can significantly reduce the hazard.**

[3] Testing in accordance with CPNI Test Standard for the Explosion Resistance of Curtain Walling

Recommended CPNI mitigation measures

The CPNI mitigation measures, for capped stick curtain wall systems, focus on **five** key elements of the façade design. **All five of the recommended key elements must be implemented to achieve the hazard reduction**.

The five key elements are:

1. **Connection between the frame and the structure –** a robust spigot section should be used (see Annex B and C for the design specification).
2. **Curtain wall frame –** the mullion and transom section properties should meet the minimum requirements (as detailed in Annex B).
3. **Transom to mullion connection –** a robust connection which can take inward and rebound loads is required (as detailed in Annex B).
4. **Glass pane –** as a minimum, the innermost glass pane should be laminated glass, with a PVB interlayer (see Annex B for details).
5. **Glass retention –** metal pressure plates with an increased number of fixings should be used (as detailed in Annex B). No recommendations are currently available for toggle systems.

Technical information, for engineers and specifiers, on how to implement the five key elements of the mitigation measures is provided in Annex B and C.

The specific details outlined in this guidance note should be used for stick curtain wall systems with approximate dimensions illustrated in Figure 2. The common approaches within this guidance note are also applicable to stick curtain wall systems with different frame dimensions. Detailed design advice should be sought from Engineers and Specialists competent in the field of blast design for facades that have frame dimensions greater than those specified in this guidance note.

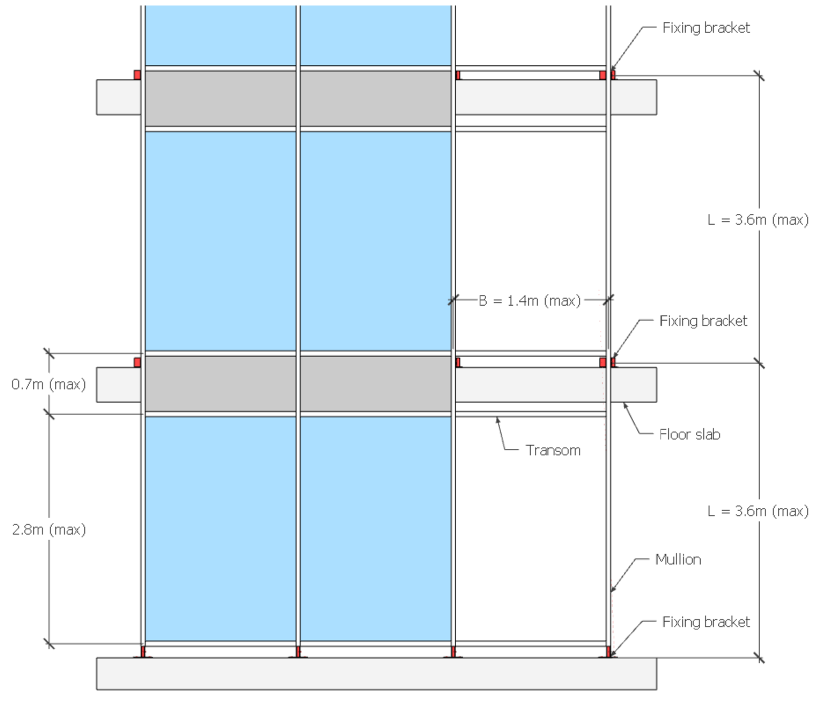


Figure 2: Maximum dimensions to be used with the mitigation measures stated in this guidance note

How much will these mitigation measures cost?

The mitigation measures in this guidance note use components that are readily available from stick curtain wall manufacturers. These mitigation measures could increase the façade costs by up to approximately 10% per square metre compared to a system designed to conventional project requirements only. The increase in costs is driven by the additional material cost and labour time[4].

[4] This figure is based upon a cost review study undertaken by CPNI in 2019

ANNEX A – Stick curtain wall system components

Stick curtain wall systems are produced by a number of manufacturers. The systems are unique to each manufacturer, but the design, fabrication and installation follow similar principles. Figures A-1 to A-6 show typical details of a stick curtain wall systems, and Table A-1 summarises the identified key components.

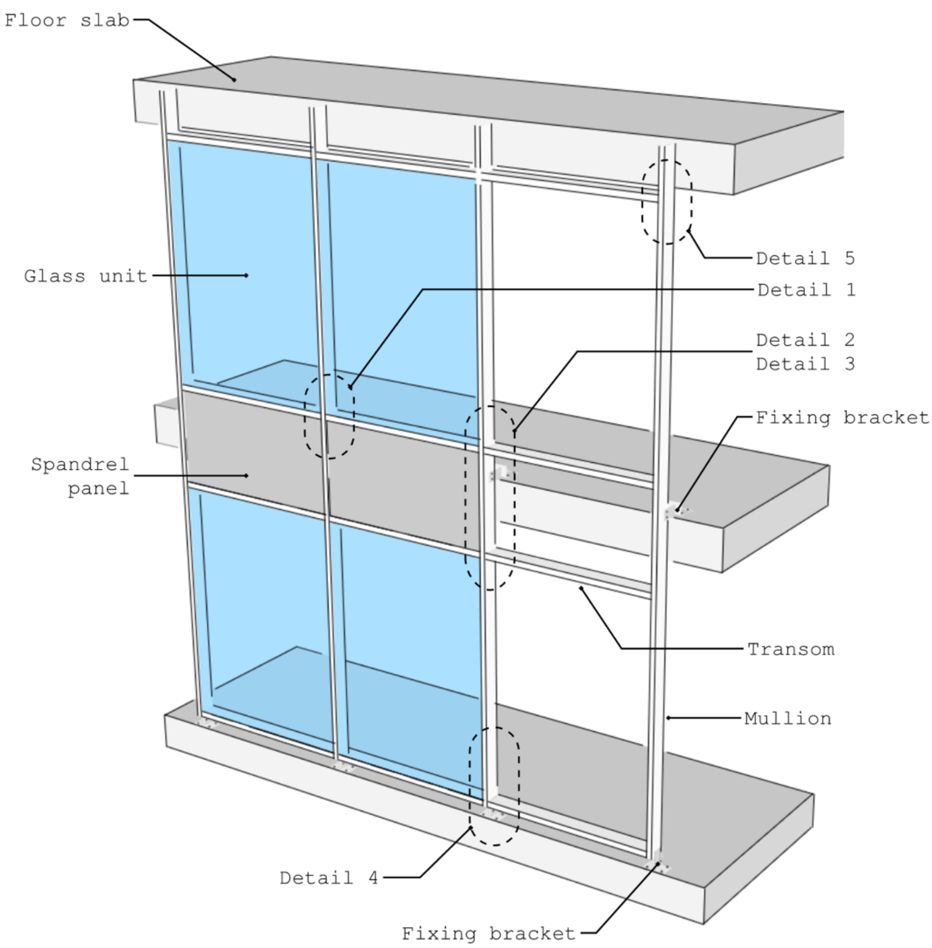


Figure A-1: Components of a curtain wall

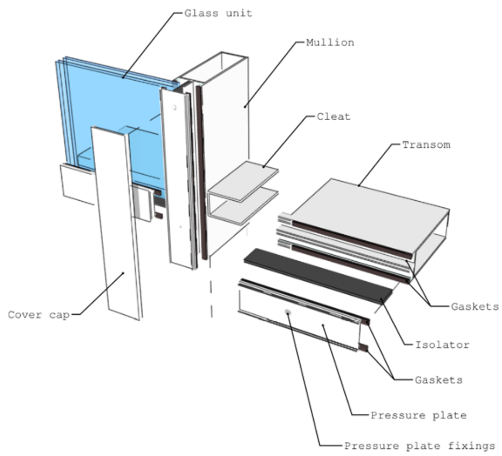


Figure A-2: Detail 1 - Components of a capped stick curtain wall

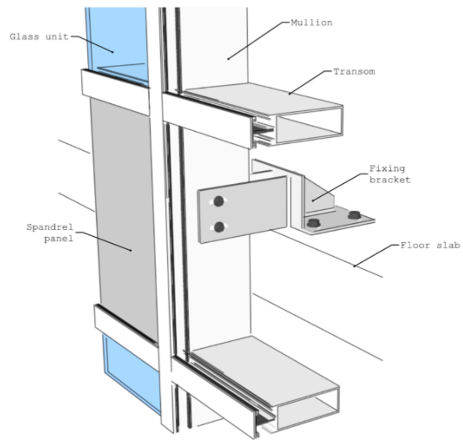


Figure A-3: Detail 2 - Intermediate fixing bracket to edge of floor slab

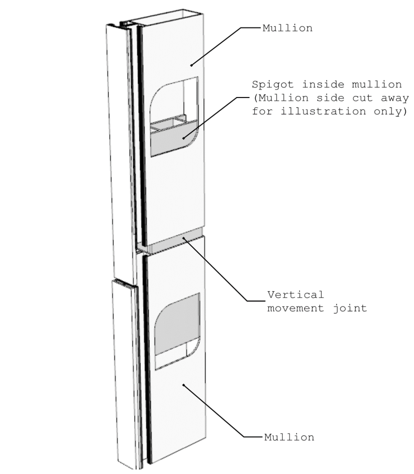


Figure A-4: Detail 3 – Splice connection between two mullions

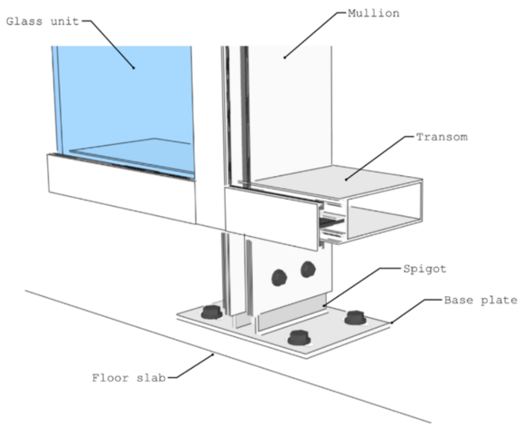


Figure A-5: Detail 4 - Base plate and spigot fixing bracket

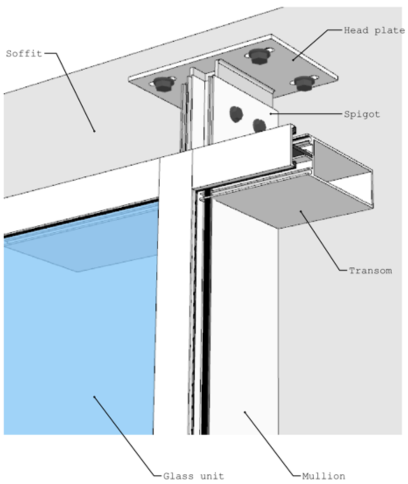


Figure A-6: Detail 5 – Head plate and spigot fixing bracket

Table A-1: Summary of the key components of a stick curtain wall system

Component	Description	Common Terminology and Sizes
Mullions	Vertical framing members of a curtain wall. The mullions typically span between floors and are cut to length either in a factory for larger installations or on site for smaller installations, e.g. a small shop front. The most common profile of a mullion is a hollow aluminium box. The size and shape of the profile vary by manufacturer but are broadly similar in design. The profiles are commonly extruded from aluminium grades EN-AW 6060-T6 and EN-AW 6060-T66.	Other names: - Sticks - Bars - Verticals Common size: 50mm (w) x 150mm (d)
Transoms	Horizontal framing members of a curtain wall. The transom spans between the mullions and carry the weight of the glass panels. Like the mullion, the most common profile of a transom is a hollow aluminium box. The transom can be cut to length either in the factory or on site depending on the project size.	Other names: - Sticks - Bars - Horizontals Common size: 50mm (w) x 150mm (d)
Transom connector cleat	The mullions and transoms are mechanically connected via mechanical connection(s) that are blocks / profiles shaped to fit within the hollow cavity of a transom.	Other names: - Button cleat / Spring cleat - Channel cleat - U cleat - Shear block - T-connection
Fixing brackets / Spigots	Components designed to provide support and to transmit the loads from the curtain wall to the building. The curtain wall is connected to the structure via a fixing bracket or spigot is used to connect the facade to the structure. Fixing brackets are used to connect the mullions to the edge of the floor slab when the mullions span several floors. Spigots are inserted inside the cavity of the mullions, either top or bottom, and are used to connect to the floor or soffit.	Other names: - Base Plates - Slab edge bracket
Splice Connection	The splice connection is used to connect two lengths of mullion section together and is usually located close to a fixing bracket. If mullions are continuous over multiple floors the splice connection may be located at 1/4 or 1/5 of the span height away from a support. This connection typically consists of an extruded profile that fits within the cavity of the two mullions and is held in position by bolts. The connection is designed to transfer horizontal load and may allow a small amount of vertical movement between the two mullions due to thermal expansion.	Other names - Stack joint
Thermal break	The thermal break provides a barrier between the external pressure plates and the internal mullions and transoms, minimising the heat loss through the facade system. This is typically a flexible foam or plastic which is fitted into a receiving channel in the front of the mullion/transom section.	Other names: - isolator
Glazing	The glazing panes are installed once the grid of mullions and transoms has been constructed.	Other names: - Vision panels - Insulated Glass Units (IGU)

Component	Description	Common Terminology and Sizes
Spandrel panel	A spandrel panel is typically an opaque panel (often glass) which is installed into the facade to hide the structural frame i.e. in front of the edge of a concrete slab.	Other names: - Non-vision panels - Infill panels
Gaskets	Gaskets are preformed and profiled lengths of sealing material installed between the inner and outer surface of the glass (or infill panel) and the surrounding frame (mullion or transom) or pressure plate.	Other names: - Glazing bead
Pressure plates	Pressure plates clamp the glass against the mullion and/or transom. The pressure plates vary in width and are typically formed from aluminium. Holes along the centreline of the pressure plates are often drilled or punched in the factory for the fixings to pass through. The pressure plates are fixed with screws driven into the thermal break.	Other names: - Pressure caps
Cover cap	Profiled external cover applied to the pressure plate to provide an architectural finish and hide the pressure plate fixings.	Other names: - Face cover
Toggle fixings	Toggle fixings offer an alternative to screw-fixed pressure plates. The toggles are used to secure the glass to the mullion and/or transom using clamps which fix either into channels within the edge seals of the insulated glass unit (IGU) or clamp the inner glass assembly. Toggle fixings avoid clamping the outer glass surface. **Note: This Guidance Note is not suitable for toggle glazed systems.**	Other names: - Toggle clamps - Structural glazing (but should not be confused with silicone structural glazed/bonded glass)

ANNEX B – Recommended Mitigation Measures for Capped Stick Curtain Wall Systems (only)

This annex provides the technical information required for engineering and specifiers to implement the recommended blast mitigation measures for stick curtain wall systems. It does not address any other loading requirements.

Table B-1 provides a summary of the mitigation measures recommended to improve the performance of a capped stick curtain wall systems against a blast threat. These should be considered as the minimal requirement and all five elements must be implemented to reduce the blast hazard.

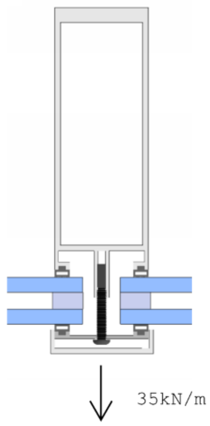
The values in Table B-1 align with readily available components for stick curtain wall systems, meaning bespoke component should not be required. Please note, the values listed in Table B-1 are the minimum requirements.

Table B-1: Summary of the mitigation requirements for a capped stick curtain wall system.

Component	Requirement
Glazing	As a minimum, the innermost ply shall be laminated glass with a 1.52 mm PVB interlayer. Performance of the glazing should be balanced against the performance of the transoms, mullions and connections, i.e. it is inappropriate to use overly stiff glass with a flexible curtain wall system as this may create an unbalanced design and will not necessarily improve the performance. Testing has demonstrated that the following glazing compositions provide a balanced design when implemented with the other recommended modifications: **Tested Glass Specification 1:** Outer Ply: 11.52 mm Heat strengthened & PVB laminated (2x5 mm plies + 1.52 mm PVB) Cavity: Typical 16 mm (Depth not critical) Inner Ply : 9.52 mm Heat strengthened & PVB laminated (2x4 mm plies + 1.52 mm PVB) **Tested Glass Specification 2:** Outer Ply: 6 mm Toughened Cavity: Typical 16 mm (Depth not critical) Inner Ply: 11.52 mm Annealed & PVB laminated (2x5 mm plies + 1.52 mm PVB) Note: Other factors, e.g. the wind load, must also be considered when determining the appropriate glass specification.

Component	Requirement
Mullions	As a minimum the mullions shall have section properties equal to or greater than the following values. The values listed below are typical of a mullion measuring approximately 50 mm wide and 150 mm deep. $A = 12\ cm^2$ (cross-section area) $I_x = 400\ cm^4$ (strong-axis second moment of area) $I_y = 40\ cm^4$ (weak-axis second moment of area) $W_x = 43\ cm^3$ (strong-axis elastic section modulus) $W_y = 17\ cm^3$ (weak-axis elastic section modulus) The mullion shall provide 14 mm or greater glass bite. The mullion sections shall be extruded from aluminium grades EN-AW6060-T6 or EN-AW6060-T66, or stronger.
Transoms	As a minimum the transom shall have section properties equal to or greater than the following values. The values listed below are typical of a mullion measuring approximately 50 mm wide and 150 mm deep. $A = 12\ cm^2$ (cross-section area) $I_x = 295\ cm^4$ (strong-axis second moment of area) $I_y = 40\ cm^4$ (weak-axis second moment of area) $W_x = 36\ cm^3$ (strong-axis elastic section modulus) $W_y = 17\ cm^3$ (weak-axis elastic section modulus) The transom shall provide 14 mm or greater glass bite The transom sections shall be extruded from aluminium grades EN-AW6060-T6 or EN-AW6060-T66, or stronger.

Component	Requirement
Spigot/Support brackets	The aluminium spigot profile should fit tightly inside the mullion section selected. As a minimum the spigot profile shall have section properties equal to or greater than the following values: A = 11 cm^2 (cross-section area) W_x = 35 cm^3 (strong-axis elastic section modulus) The spigot profile shall have an insertion depth of at least 250 mm into the mullion. The support bracket connection (i.e. a spigot connected to an endplate and fixings to the structure), which connects the mullion to the structure, shall be stronger than the capacity of the mullions. As a minimum requirement, the detailed design of the connection shall be undertaken for a design load equal to 1.5x the calculated support reaction when the mullions have reached their full plastic bending resistance under a uniformly distributed load (see Annex C for worked example). As a minimum the detailed design of the connections shall be checked for vertical loads due to self-weight of the façade in combination with the horizontal reaction force. As a minimum, two separate load cases shall be considered. 1) Vertical loads due to self-weight + horizontal reaction acting in the positive (inward) direction. 2) Vertical loads due to self-weight + horizontal reaction acting in the positive (outward) direction. It is the responsibility of the design engineer to check the connection for additional loads that may arise as part of the specific protect detail i.e. moments caused by eccentric loads. For mullions spanning multiple floors, consideration shall be given to the bending moments within the span and over intermediate supports, which will result in a different ultimate resistance of the mullion and therefore different support reactions. The mullion does not require a mechanical connection to the spigot i.e. a bolt through the spigot, when the recommended insertion depth is met. The spigot and support brackets shall be extruded from aluminium grades EN-AW6060-T6 or EN-AW6060-T66, or stronger.

Component	Requirement
Splice connection	The splice connection shall be located away from the area that the maximum bending moment occurs. The designer shall ensure that yielding of the mullion profile will occur within the main span before occurring at the splice connection. This is typically achieved by locating the splice connection between 1/4 and 1/5 of the span height away from a support when the mullions are continuous over multiple floors. The splice sections shall have an insertion depth into each mullion of at least 300mm or two times the depth of the mullion profile, whichever is greater. As a minimum the splice sections shall have section properties equal to or greater than the following values: $A = 11\ cm^2$ (cross-section area) $W_x = 35\ cm^3$ (strong-axis elastic section modulus) The splice sections shall be extruded from aluminium grades EN-AW6060-T6 or EN-AW6060-T66, or stronger.
Mullion - transom connections	There are several tested and approved connections. Details of these connections are included in CPNIs CSE (Catalogue of Security Equipment). The use of spring-loaded (button) cleats is not permitted. If an alternative connection detail is required, the connection strength in the positive and negative horizontal direction shall be proven via testing in accordance with BS EN16758:2016. The connection strength shall be equal to or greater than the approved connections in the CSE.
Thermal break	The thread of the pressure plate fixings must breach the sides of the isolator material and engage with the inner sides of the aluminium nose on the mullions and transoms.
Pressure plates and fixings	Non-metallic pressure plates (e.g. plastic) are not permitted. Capacity of the pressure plates and pull-out capacity of the fixings that retain the glass panels shall be equal to, or greater than 35 kN/m. Regardless of the fixing capacity, the spacing of the pressure plate fixings shall be no greater than 150 mm. 
Cover cap	Standard flat cover caps that do not project more than 25 mm from the external surface of the glass are considered suitable. Following the initial installation, the cover caps must be checked to ensure that they are correctly installed and fully engaged with the pressure plate.

ANNEX C – Example showing how to calculate the support reaction to be used for the detailed design of the connection between the mullion and the structure

This worked example provides a method which can be used by an Engineer to determine a suitable horizontal design load acting on the support between the stick curtain wall mullions and the structure under blast conditions.

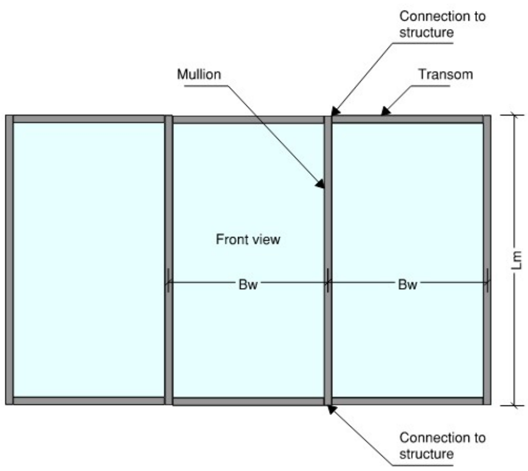
The support bracket connection, which connects the mullion to the structure, shall be designed to be stronger than the capacity of the stick curtain wall system. The actual capacity of the stick curtain wall system will be higher than stated within the manufacture literature. For this reason, when considering the design of components subject to blast loading it is common practice to use the ultimate resistance of structural elements. The ultimate resistance (plastic resistance) is the resistance of a component above the point at which it will yield (elastic resistance).

The design of mullion and transom profiles under normal static loading is normally governed by the deflection under wind loading. As such, it is common for manufacturers to only provide the basic flexural properties of these profiles in their literature. The following example is based upon the assumption that there is only basic information available about the stick curtain wall system. Where possible the manufacturer's information that is available should be used. Where the required information is not available this example will provide a method to estimate the missing information.

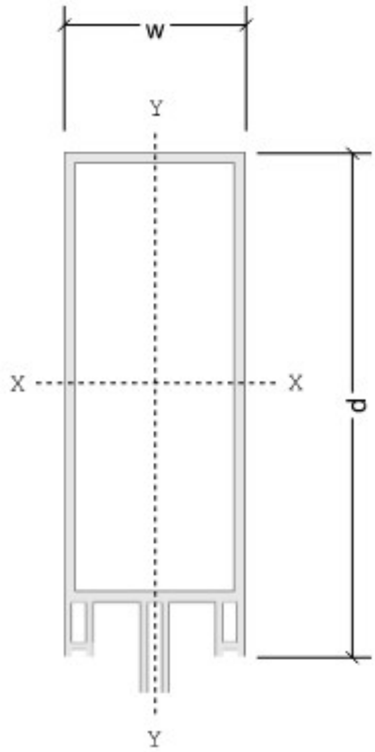
The minimum information required to use this method is highlighted in yellow.

Vertical span between support brackets $L_m = 3.6$ m

Width of the bay $B_w = 1.4$ m



Width of the mullion profile	w_{mul} = 50 mm
Depth of the mullion back-box measured from rear face to gasket	d_{mul} = 150 mm
Second moment of area about strong axis (x-x) of mullion profile	$I_{x.mul}$ = 400 cm^4 = 4,000,000 mm^4
Width of the transom profile	w_{tran} = 50 mm
Depth of the transom back-box measured from rear face to gasket	d_{tran} = 150 mm
Second moment of area about strong axis (x-x) of transom profile	$I_{x.tran}$ = 300 cm^4 = 3,000,000 mm^4



The aluminium alloy grade that the mullion and transom profiles are produced from may be stated in the manufactured literature. However, if this is not stated, it is common for aluminium curtain wall profiles to be produced from aluminium alloy grade (EN-AW 6060-T66).

Aluminium alloy EN-AW 6060-T66 yield stress (0.2% proof stress)	f_o = 160 N/mm^2

Based upon observations from blast testing of stick curtain wall systems with mullion spans up to 3.6 m and bay widths up to 1.4 m wide will result in the mullions exceeding their elastic limits and all the transoms remaining elastic, including internal transoms. As such, the capacity of the system is based upon the plastic resistance of the mullions and the elastic resistance of the transoms.

If possible, you should obtain the values for the plastic section modulus of the mullion profile from the manufacturer. However, if this information is not available Equation 1 can be used for an estimate of the plastic section modulus from the value for the second moment of area and the dimensions of the mullion profile. The factor of 1.3 has been determined from a review of mullion profiles from a number of different manufacturers and is appropriate for calculating a conservative estimate of the plastic modulus of a typical mullion profile.

Plastic section modulus of the mullion profile about the strong axis (x-x)	$W_{pl.x.mul} := 1.3\left[\frac{2(I_{x.mul})}{d_{mul}}\right] = 69333 \cdot mm^3$	[EQUATION 1]

If possible, you should obtain the values for the elastic section modulus of the transom profile from the manufacturer. However, if this information is not available Equation 2 can be used for an estimate the elastic section modulus from the value for the second moment of area and the dimensions of the transom profile.

Elastic section modulus of transom profile about the strong axis (x-x)	$W_{el.x.tran} := \left[\frac{2(I_{x.tran})}{d_{tran}}\right] = 40000 \cdot mm^3$	[EQUATION 2]

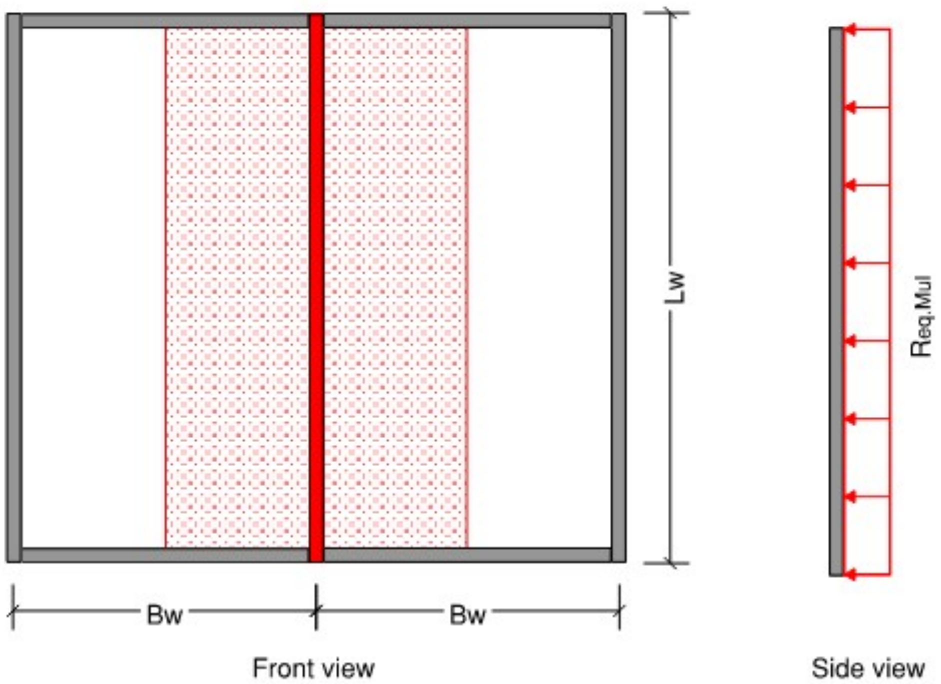
The bending resistance of the profiles are calculated using Equation 3 and 4

Plastic bending resistance of the mullion profile	$M_{Rd.mul} = W_{pl.x.mul}\,(f_o) = 1.11 \times 10^7$ Nmm	[EQUATION 3]
Elastic bending resistance of the transom profile	$M_{Rd.tran} = W_{el.x.tran}\,(f_o) = 6.40 \times 10^6$ Nmm	[EQUATION 4]

The equivalent resistance of the mullions is calculated based upon the plastic bending resistance of the profile with uniform load distribution.

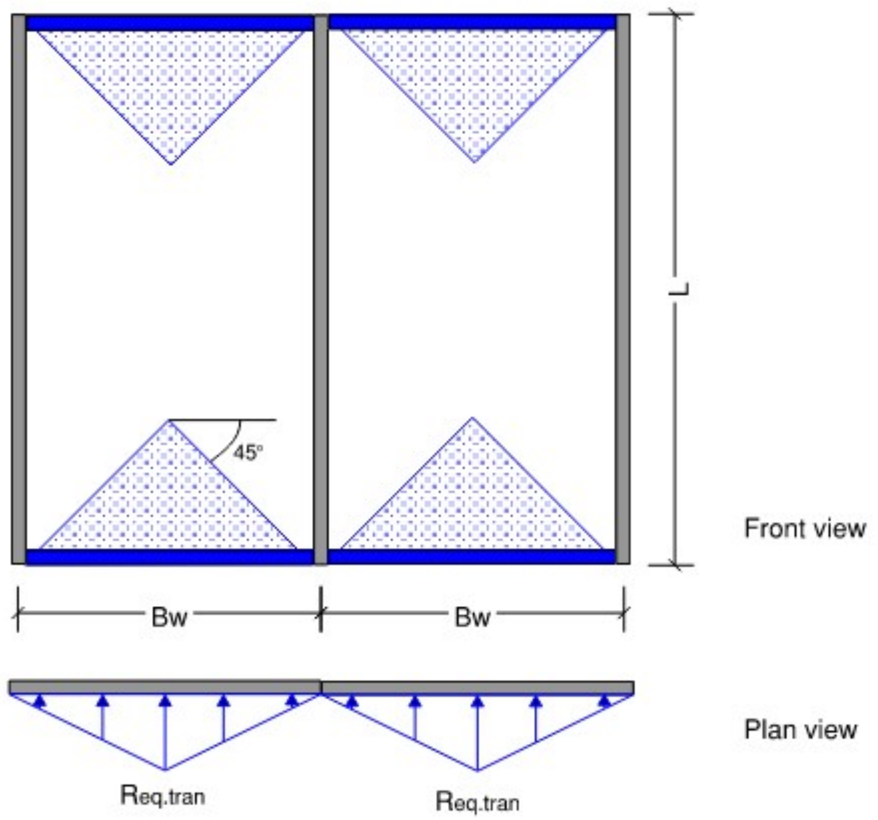
Equivalent resistance of the mullion with a rectangular loaded area	$R_{eq.mul} := \frac{8\left(M_{Rd.mul}\right)}{L_m} = 25 \cdot kN$	[EQUATION 5]

Equation 5 is only valid for a single mullion span with pinned supports. Mullions with multiple spans and/or different support conditions will have a different equivalent resistance which is not within the scope of this example.



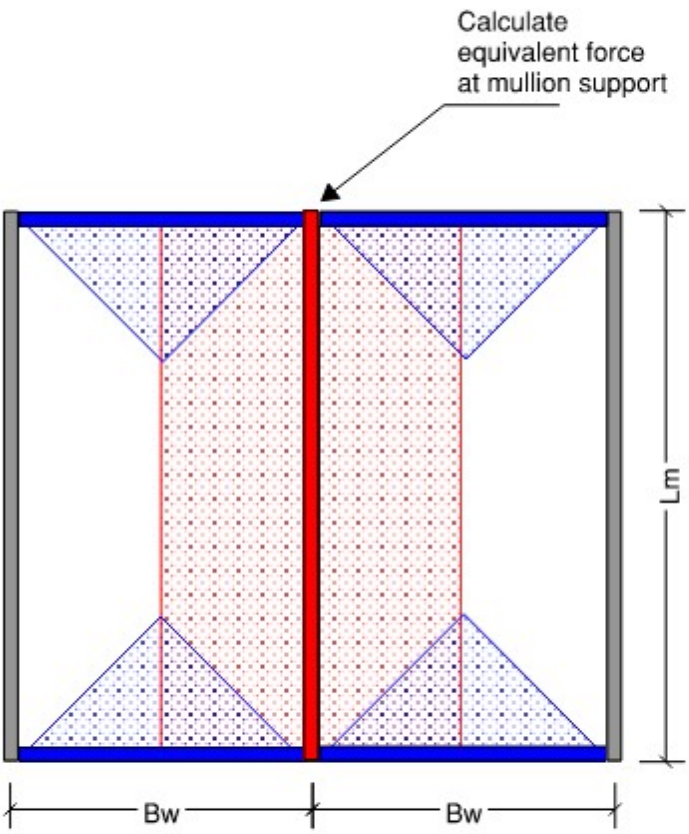
Transoms are not as heavily loaded as mullions and tend to remain elastic, even internal transoms loaded by glass above and below the transom. End transoms are the same profile but loaded only on one side, so the maximum elastic utilisation will be 50%, so the reaction should be calculated from 50% of the elastic bending capacity

Equivalent resistance of the transom with a triangular loaded area.	$R_{eq.tran} := 0.5\left[\frac{6\left(M_{Rd.tran}\right)}{B_w}\right] = 14 \cdot kN$	[EQUATION 6]



The total equivalent force acting on the support is the sum of the resistance of the mullion (Equation 5) and the transoms (Equation 6) multiplied by their respective loaded areas. The loaded area in the corners of each bay are counted twice but this is conservative for the calculation.

Equivalent force acting at mullion support.	$F_{eq} := \frac{R_{eq.mul}}{2} + 2\left(\frac{R_{eq.tran}}{2}\right) = 26 \cdot kN$	[EQUATION 7]



Front view

As a minimum the design of the connections shall be checked for vertical loads due to self-weight of the stick curtain wall system in combination with the horizontal equivalent design force from Equation 7. As a minimum, two separate load cases shall be considered.

1) Vertical loads due to self-weight +horizontal load acting in the positive (inward) direction
2) Vertical loads due to self-weight +horizontal load acting in the negative (outward) direction