Technical Note No 86

Structural performance of systemised walls - Connections

This Technical Note is one of a series describing the structural design and assessment of wall framing systems and brackets. The series comprises:

TN 84 Structural performance of systemised walls – Introduction
TN 85 Structural performance of systemised walls – Design charts and profile data
TN 86 Structural performance of systemised walls – Connections
TN 87 Structural performance of systemised walls – Closed profiles
TN 88 Structural performance of systemised walls – Buckling and torsion
TN 89 Structural performance of systemised walls – Open profiles
TN 90 Structural performance of systemised walls – Bracket requirements and principles
TN 91 Structural performance of systemised walls – Bracket calculations

These Technical Notes make reference to the Eurocodes for structural design and adopt the terminology of the Eurocodes

This Technical Note covers the design of mullion connections for aluminium curtain walls. It describes the types of mullion connection and gives the method for calculating load capacity of a mullion connection.

Introduction
This Technical Note allows the designer to check the load carrying capacity of a mullion connection in an aluminium curtain wall. The connections considered are:

- Pinned connections to brackets
- Moment resisting connections
- Spigot connections

It does not cover the selection of an appropriate mullion profile to carry the applied loads. However it may lead to the selection of a mullion profile with a thicker wall.

It does not cover the design of brackets which are covered in CWCT TN90 and 91.

The calculation of loads on the curtain wall and forces acting through the connections is covered by Technical Note 84.

Methods of calculation of connection capacity are given but a particular design may also be proven by testing.

Types of connection

Curtain wall mullions are connected to supporting brackets to transfer the self weight of the wall and loads acting on the wall to the primary structure of the building.

Connections may be categorized into three basic configurations as shown in Figure 1.

The type of connection adopted will depend on the overall configuration of the wall and the primary structure.

Type 1 connections comprise a moment resisting bracket connected to the primary structure and a pin or bolt passing through the bracket and the walls of the mullion to create a pinned connection.

Type 2 connections comprise a plate(s) connected rigidly to the wall of the mullion. This creates a moment carrying connection and a pin or bolt is passed through a hole in the plate(s) to make a connection to the primary structure. The pin or bolt normally connects to a moment resisting bracket connected to the primary structure. As an alternative to a pin or bolt, a hook-on configuration may be used.

Type 3 connections connect mullions end to end. A spigot is inserted into the end of one mullion and the second mullion is positioned over the spigot. The spigot transfers shear (load orthogonal to the axis of the mullion). The spigot does not create a moment resisting connection.

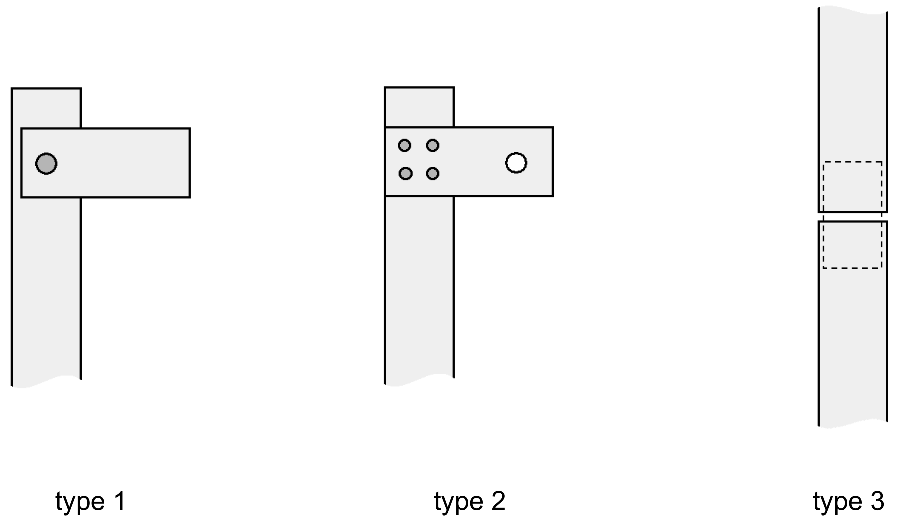

Figure 1 Types of mullion end connection

Where the joint in the mullion is required to accommodate longitudinal movement the spigot should be fixed to one of the mullions by screws or bolts and left free to slide in the other mullion. These fixings are required to prevent the spigot sliding out of position and are not required to carry large forces. If the joint is required to transmit axial load, the spigot should be fixed to both mullions, usually by bolts, which must be designed to carry the axial load.

This type of connection may also be used for a bracket at the end of a mullion where a short spigot is attached to a base plate. This may be left as a sliding connection and only carry transverse load or may be fixed to carry axial load.

Pinned connections are used to make connections that are assembled at site. Moment resisting joints require tighter tolerance work and are normally made in the factory.

Stick curtain walling

Stick curtain walling is site assembled and mullion connections are normally pinned (type 1) or spigotted (type 3). Note that if a pin or bolt is used at both ends of a mullion then a round hole is used at only one end and a slotted hole is used at the other end to allow for expansion, structural movement and tolerances. If a spigot is used it must accommodate adequate axial movement once installed.

For type 1 connections, the mullion is supported in one of the ways shown in Figure 2. The brackets are first mounted on the primary structure, the mullion is placed into position and a bolt or pin is passed through the brackets and mullion to retain the mullion in place.

(Note: *Construction sequence may need to be varied to accommodate jointing methods for mullions and transoms)*

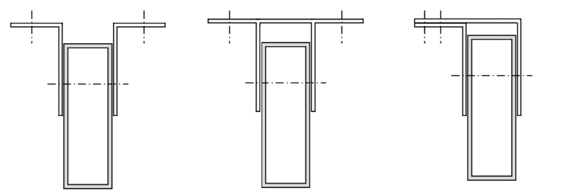

Figure 2 Site assembled connections to mullions

Unitised curtain wall

Unitised curtain walling is assembled in the factory and moment resisting connections (type 2) may be used. The units are then installed by pinning, or hanging, the assembly on the primary structure or brackets. Spigotted joints (type 3) are commonly used in combination with moment resisting joints.

If the connection is made in the factory one or two plates are fastened to the wall(s) of the mullion. These plates are then used to facilitate a connection to the bracket at site, Figure 3.

Moment resisting connections do not allow any movement. Axial movement of a mullion has to be accommodated by;

- Using a sliding spigot connection at the other end

or

- Within the connections to the primary structure.

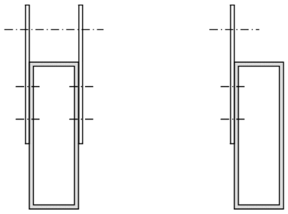

Figure 3 Factory assembled connections to mullions

Types of connector

The dominant load on a connector is wind load and so a full, or near full, reversal of load is possible. In these circumstances BS EN 1999-1-1 recommends that bearing type connections are used. It is in any case difficult to use pre-loaded bolts with hollow profiles and in practice all connections are of the bearing type.

Bearing type connectors are bolts, pins or rivets.

The CWCT Standard for systemised building envelopes allows a maximum displacement at the supports of 2mm between positive design wind load and negative design windload. This may be achieved provided the hole sizes do not exceed those described below.

Bearing type connections only work with slotted holes if no force is to be carried in the direction of the slot.

Bolts

Bolts or pins may be of either aluminium or stainless steel. Stainless steel bolts or pins are most commonly used for strength and to avoid corrosion.

Grades of stainless steel are 50, 70 or 80. It can be seen from Table 1 that Grade 50 stainless steel has adequate strength in most cases.

Aluminium bolts of Grade 6082 are most commonly used and 6082-T6 aluminium is normally required for strength.

Pinned connections

Holes

Connections that are assembled at site require sufficient clearance on holes to allow for tolerances and fit.

BS EN 1090-3 defines holes as;

- Normal size if:

  $d_o \leq d + 1.0$ mm

- Oversize if:

  $d_o \leq d + 2.0$ mm and
  $d_o \leq 1.15\,d$

  Where:

  d_o is the hole diameter
  d is the bolt diameter

Oversize holes are commonly used to facilitate installation but they should not be regarded as 'normal size' holes. Hole diameters should not exceed the limit for oversize holes.

Normal size holes may be required to limit movement to within the limits of the CWCT Standard.

Round holes are required where it is necessary to transfer both self-weight (vertical) and wind (horizontal) load.

Slotted holes

Slotted holes may be used where only the wind load is to be transferred and vertical movement accommodation is required. Slotted holes should not be used to transfer loads aligned with the long axis of the slot.

A short slotted hole has width d_o and length no greater than 1.5 d_o. Where d_o is no greater than given above.

A long slotted hole has width d_o and length no greater than 2.5 d_o. Where d_o is no greater than given above.

A short slotted hole has the same load capacity as an oversize hole. Long slotted holes generally have a lower load capacity than round or short slotted holes. However they may be necessary to accommodate movement and tolerances.

Where slotted holes are used it is preferable for the slot to be in the thicker metal. This will normally be the bracket.

Edge clearance
A bolt may fail by tearing a block of aluminium from the mullion. If the edge clearances to the side and end of the mullion are too small this mode of failure will occur.

This Technical Note limits the edge clearances to:

$e_1 \geq 3.0\ d_o$

and

$e_2 \geq 1.5\ d_o$

Note that e_2 is measured to the nearest edge, Figure 4.

This simplifies the assessment of pinned connections and is not an undue constraint to design. Smaller edge clearances may be adopted provided the full calculation method in BS EN 1999-1-1 is followed.

Bolt shear
A connection may fail by the bolt shearing.

The allowable shear on the bolt can be calculated from equation 8.9 of BS EN 1999-1-1;

$$F_{v,Rd} = \frac{\alpha_v f_{ob} A}{\gamma_{M2}}$$

Note f_{ob} is substituted for f_{ub} for elastic behaviour.

Assuming a stainless steel bolt, the allowable shear always exceeds the values given in Table 1 for load capacity.

Aluminium bolts may shear for some combinations of bolt diameter and wall thickness. These are shaded in grey in Table 1.

Bearing capacity
Bearing capacity of the mullion wall can be calculated from equation 8.11 of BS EN 1999-1-1;

$$F_{b,Rd} = \frac{k_1 \alpha_b f_o d t}{\gamma_{M2}}$$

Note f_o is substituted for f_u for elastic behaviour.

For aluminium or stainless steel bolts;

$F_{ob} \geq f_u$,

and if;

$e_1 \geq 3\ d_o$, $\alpha_b = 1.0$.

and if;

$e_2 \geq 1.5\ d_o$, $k_1 = 2.5$.

$\gamma_{M2} = 1.25$.

then,

$F_{b,Rd} = 2.0\ f_o\ d\ t$

For Grade 6063 T6 aluminium:

$F_{b,Rd} = 320\ d\ t$

but note that this is reduced depending on the hole type.

Figure 4 Edge clearance for round and slotted holes

Load capacity
Values of load capacity for a bolt through a single wall of aluminium are given for varying bolt diameters, wall thicknesses and hole types in Table 1. Note that the bolt will normally pass through both walls of a mullion profile and that the total load capacity of the connection will be double that in Table 1.

Alternative approaches

The load capacity of a pin or bolt may be increased by increasing its diameter.

Where the capacity of the connection is limited by bearing stresses instead of using a larger diameter pin or bolt an insert may be used as shown in Figure 5. Bearing stresses are reduced because the interface between the insert and the wall of the mullion has a larger diameter and the interface between the bolt and the insert is thicker. The insert is probably made of a stronger material than the mullion profile and is typically stainless steel.

Wall thickness (mm)	Bolt diameter (mm)	Hole type			
		Normal	Short slotted	Long slotted	Oversize
1.5	10	4.8	3.8	3.1	3.8
1.5	12	5.8	4.6	3.7	4.6
1.5	16	7.7	6.1	5.0	6.1
1.5	20	9.6	7.7	6.2	7.7
1.5	24	11.5	9.2	7.5	9.2
2.0	10	6.4	5.1	4.2	5.1
2.0	12	7.7	6.1	5.0	6.1
2.0	16	10.2	8.2	6.7	8.2
2.0	20	12.8	10.2	8.3	10.2
2.0	24	15.4	12.3	10.0	12.3
2.5	10	8.0	6.4	5.2	6.4
2.5	12	9.6	7.7	6.2	7.7
2.5	16	12.8	10.2	8.3	10.2
2.5	20	16.0	12.8	10.4	12.8
2.5	24	19.2	15.4	12.5	15.4
3.0	10	9.6	7.7	6.2	7.7
3.0	12	11.5	9.2	7.5	9.2
3.0	16	15.4	12.3	10.0	12.3
3.0	20	19.2	15.4	12.5	15.4
3.0	24	23.0	18.4	15.0	18.4
3.5	10	11.2	9.0	7.3	9.0
3.5	12	13.4	10.8	8.7	10.8
3.5	16	17.9	14.3	11.6	14.3
3.5	20	22.4	17.9	14.6	17.9
3.5	24	26.9	21.5	17.5	21.5

Assumes: Grade 6063 T6 aluminium mullion
Grade 6082 T6 aluminium bolt
Grade 50 or stronger stainless steel bolt
Grey shading indicates that aluminium bolts may not be used.

Table 1 Load capacity in kN for bolt or pin passing through one wall of Grade 6063 T6 aluminium

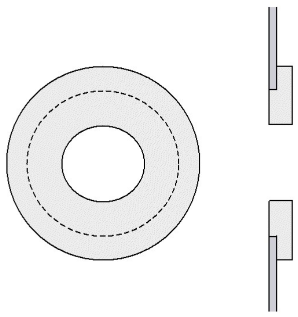

Figure 5 Insert used to increase bearing capacity

The bearing capacity of a bolted or pinned connection may be increased by increasing the thickness of the mullion wall. The wall of the extrusion may be thickened throughout or only where the bolt or pin bears on the mullion wall. If the thickened section is of lesser extent than the edge clearances given above then the strength of the connection should be verified by test.

Factory assembled connections

Factory assembled connections to mullions may be made using rivets, rivnuts or countersunk screws to connect a plate to the wall of the mullion.

In this case a group of fasteners may be used and it may be assumed that they share the load, Figure 6.

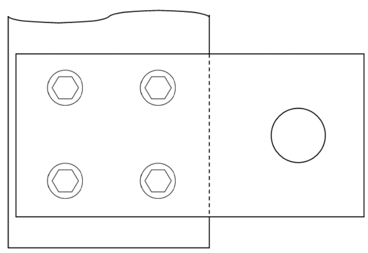

Figure 6 Group of fasteners

A single pin or bolt is used to connect the plate to the bracket on the primary structure, Figure 7. This is designed to carry forces in the same way as described above for a pinned connection.

Groups of fasteners

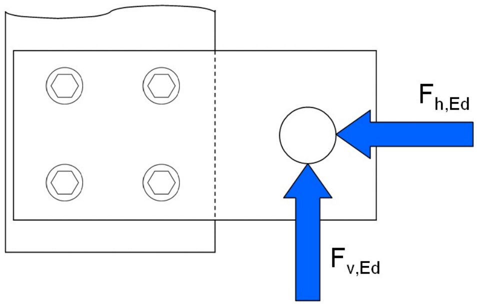

Figure 7 Forces acting on support

For a group of four fasteners as shown, the centroid of the group is at mid-height and mid-width of the group and the group has to carry a horizontal force $F_{h,Ed}$, a vertical force $F_{v,Ed}$, and a moment about the centroid;

$$M = 0 \times F_{h,Ed} + a \times F_{v,Ed}$$

Where a is the horizontal distance between the centroid of the group and the vertical force acting on the pin.

The distance from the centroid to each fastener is:

$$r = \frac{(b^2 + h^2)^{0.5}}{2}$$

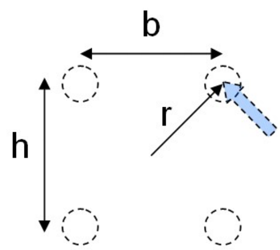

Figure 8 Fastener geometry

The force on each fastener due to the applied moment is, Figure 9;

$$F_m = \frac{M}{4r}$$

This can be decomposed into a horizontal component:

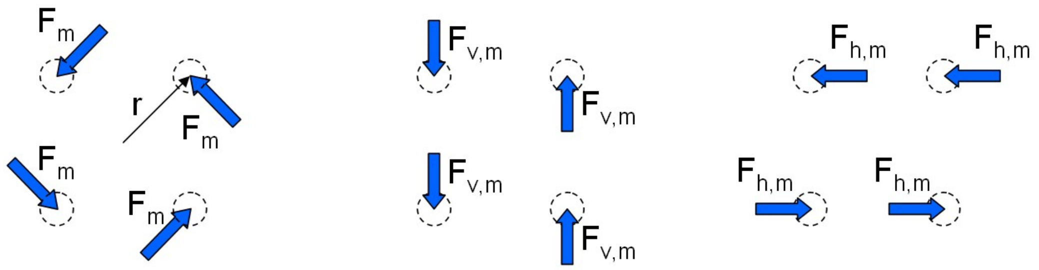

Figure 9 Forces due to applied moment

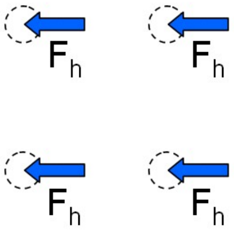

Figure 10 Horizontal forces

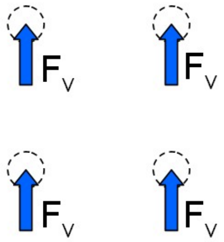

Figure 11 Vertical forces

$$F_{h,m} = F_m \cos\alpha$$

And a vertical component;

$$F_{v,m} = F_m \sin\alpha$$

as shown in Figure 9.

The horizontal force $F_{h,Ed}$ also gives rise to a horizontal forces on each fastener;

$$F_h = \frac{F_{h,Ed}}{4}$$

The vertical force $F_{v,Ed}$ also gives rise to a vertical force on each fastener;

$$F_v = \frac{F_{v,Ed}}{4}$$

As shown in Figures 10 and 11.

The maximum force on any fastener is then;

$F_{h,m} + F_h$ Horizontal

and

$F_{v,m} + F_v$ Vertical

and the design force is the resultant of these two which is;

$$F_{b,Ed} = \left((F_{h,m} + F_h)^2 + (F_{v,m} + F_v)^2\right)^{0.5}$$

The fastener and wall thickness have to be such that;

$F_{b,Rd} \geq F_{b,Ed}$

To ensure that all fasteners carry equal load the fasteners have to be a close fit in the holes and rivets or rivnuts are used for groups of fasteners.

Rivets

The use of solid rivets or rivnuts is described in BS EN 1999-1-1.

Rivets have to be used in reamed holes. This is possible for factory assembled connections as the holes in the mullion and the connection

plate can be reamed to high tolerances probably as a single operation.
The space between any two rivets should be at least 2.5 x d_o, where d_o is the hole diameter.

The following load capacities are only valid if all rivets have an edge clearance as great as that required for bolts described earlier. If the edge clearances are less, the full calculation method in BS EN 1999-1-1 should be followed.

Riveted connections may fail in one of two ways:

- By individual rivets suffering shear or bearing failure
- By the rivet group tearing aluminium from the mullion

Bearing or shear failure
Individual rivets may fail by bearing or shear. Load capacity, $F_{b,Rd}$, for rivets of different diameters and different wall thicknesses are given in Table 2.

It is assumed that if the connection plate attached to the mullion is aluminium it is at least as thick as the mullion wall and that the aluminium is at least as strong as the aluminium of the profile. If the connection plate is stainless steel it is assumed that it is of thickness at least one third that of the mullion wall. Other combinations of material, strength and thickness are possible and the full calculations described in BS EN 1999-1-1 should then be followed.

Tearing failure
The rivet group may fail by tearing a block of aluminium from the wall of the mullion.

BS EN 1999-1-1 gives a formula for the resistance load; this may be written as:

$$V_{eff,2,Rd} = (0.4b_t + 0.52b_v)f_o t$$

for a wall of uniform thickness t.

b_v and b_t for calculating

- $V_{eff,2,Rd} = F_{h,Ed}$

and

- $V_{eff,2,Rd} = F_{v,Ed}$

are shown in figures 12 and 13 respectively.

Wall thickness (mm)	Rivet diameter (mm)	Aluminium Grade 6082 T6	Stainless steel Grade 50
1.5	8	3.8	3.8
1.5	10	4.8	4.8
1.5	12	5.8	5.8
1.5	14	6.7	6.7
2.0	8	5.1	5.1
2.0	10	6.4	6.4
2.0	12	7.7	7.7
2.0	14	9.0	9.0
2.5	8	6.4	6.4
2.5	10	8.0	8.0
2.5	12	9.6	9.6
2.5	14	11.2	11.2
3.0	8	7.7	7.7
3.0	10	9.6	9.6
3.0	12	11.5	11.5
3.0	14	13.4	13.4
3.5	8	9.0	9.0
3.5	10	11.2	11.2
3.5	12	13.4	13.4
3.5	14	15.7	15.7

Assumes:
Grade 6063 T6 aluminium mullion

Table 2 Load capacities of rivets

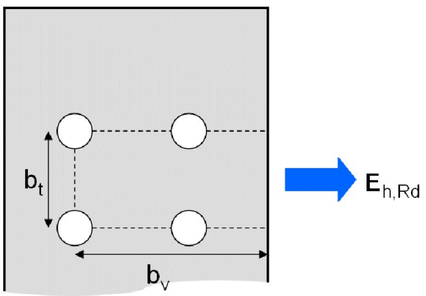

Figure 12 Horizontal block tearing

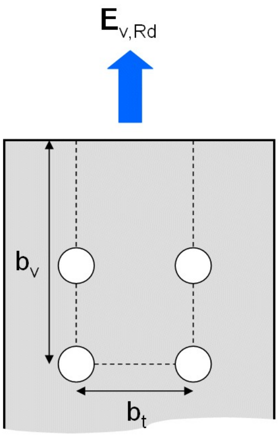

Figure 13 Vertical block tearing

Spigot joints

Spigots are normally short lengths of aluminium profile that are a snug fit in the end of the aluminium mullion. A plastic insert or sealant may be used to reduce movement of the spigot within the mullion profile.

The need to insert the spigot within a mullion profile at site means that a tight-fit is not possible and some rotation of the spigot within the mullion profile may occur in service. For this reason it should not be presumed that a rigid connection can be made and the spigot does not provide structural continuity or end fixity of the mullion.

The purpose of the spigot is to transfer shear, not moment, between the mullions. For this reason it can be of relatively short length.

Where a section of spigot is fixed to a base plate to form an end support, a short length of spigot should be used as a long spigot may lead to large moments in the bracket at the point where the spigot is attached to the base plate.

Attempts to prevent rotation of the spigot by through bolting at site are mistaken. The tolerances of the bolts within the holes will allow considerable rotation.

Reinforced profiles

Closed aluminium profiles may be reinforced with steel or aluminium inserts. This gives greater stiffness and strength.

The insert may be curtailed just short of a connection provided it is required to either:

- Reduce deflections

or

- Increase the bending resistance at mid-span

This is always the case for a simply supported span.

With a continuous dual span or off-set supports there will be a bending moment at the support and the insert may be required to be continuous at the support. For ease of construction a clearance hole is provided in the insert so that the insert does not bear on the pin or bolt. The load is transferred only by bearing of the aluminium profile on the pin or bolt and the bearing capacity is calculated as described above.

References

BS EN 1090-3, Execution of steel structures and aluminium structures. Technical requirements for aluminium structures

BS EN 1999-1-1, Eurocode 9: Design of aluminium structures - Part 1-1: General structural rules

CWCT Standard for systemised building envelopes.

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Appendix A

Symbols

α_v, α_b	Factors
A	Tensile stress area of bolt
b_t, b_v	Hole spacing
d	Bolt diameter
d_o	Hole diameter
e_1, e_2	Edge clearance (Figure 4)
f_o	Characteristic proof strength of member material
f_{ob}	Characteristic proof strength of bolt material
f_u	Characteristic ultimate strength of member material
f_{ub}	Characteristic ultimate strength of bolt material
$F_{b,Ed}$	Design bearing load
$F_{b,Rd}$	Design resistance to bearing
$F_{h,Ed}$	Design horizontal reaction
$F_{v,Ed}$	Design vertical reaction
$F_{v,Rd}$	Design shear resistance of bolt or rivet
k_1	Factor
t	Wall thickness
$V_{eff,2,Rd}$	Design tearing resistance
γ_{M2}	Partial factor for resistance of connections