This Technical Note is one of a series describing the design and assessment of curtain 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

This Technical Note describes the structural behavior of open profiles; it should be read in conjunction with TN87 and TN88. TN 87 describes the behavior of closed profiles and this Technical Note describes how open profiles differ from closed profiles and additional requirements for their assessment and use.

**Introduction**

Open profiles are not the most efficient structural elements but they are used for practical reasons of ease of construction and to create profiles that mate together.

Open profiles have much lower torsional stiffness than a closed profile of similar proportions. As a result they:

- Twist more under load
- Are more prone to lateral torsional buckling

Open profiles are not generally amenable to checking by simple calculation. Assessment of structural performance is normally by testing or finite element analysis. However, an understanding of their behavior leads to better preliminary design and selection prior to verification of performance.

Design of cold-formed steel profiles is covered by BS EN 1993-1-3:2006.

Proprietary products such as studs are often accompanied by design/selection charts.

This Technical Note describes the characteristics of open profile framing members and their use as mullions, transoms, wall studs and carrier frames.

**Typical open profiles (curtain walling)**

Closed profiles are the most commonly used profiles in aluminium stick curtain walling.
d) Split mullion

**Figure 1 - Typical open curtain wall profiles**

Transoms may be open sections with a back plate or side plate as a clip in insert. This is done to allow the transom to be slid into place between the mullions after the cleats have been fixed to form a butt joint. Occasionally mullions may similarly be open profiles but structural efficiency normally precludes their use.

Split mullions comprise two interleaved profiles. These normally have a closed element to the profile as shown in the figure above. However completely open sections (channels) are sometimes used. Split mullions are used to accommodate movement in a wall and allow for tolerance during construction. Recently some systems have introduced split transoms to further accommodate movement.

Open channels are commonly used on the edges of units in a unitized wall.

**Typical open profiles (Built-up walls)**

Open profiles are commonly used in built-up walls both as studs spanning between floor slabs and as light weight carrier rails for cladding panels. Studs are most commonly cold formed steel profiles and aluminium is most commonly used for carrier rails.

**Figure 2 - Stud profiles**

Studs are typically channel, ‘C’ or ‘Z’ profiles. They are normally formed from light gauge steel and are often dependent on the attachment of sheathing and lining boards for their stability.

**Figure 3 - Top-hat profile**

Carrier rails are normally designed/selected for ease of fastening and the method of attaching the cladding panels; they may be ‘Top-hat’ ‘L’ or ‘T’ profiles. As a result of this they frequently have greater structural capacity than is required. However their structural behavior should still be verified.

**Characteristics of open profiles.**

Open profiles perform less well than closed profiles under torsional loads. The torsion stresses are generally low (not negligible) but rotation about the longitudinal axis may be unacceptably large.

Transverse loads applied to open profiles will normally give rise to secondary torsional loads in addition to bending. Open profiles rotate about their shear centre. If a transverse load applied to a profile acts through the shear centre no torsion results. A transverse load acting away from the shear centre will lead to torsional loads and will cause the profile to twist.

**Figure 4 - Effect of load position**

The load applied in the centre of the top flange in Figure 4 acts through the shear centre S and causes no torsion in the profile. However, the load applied at one edge of the top flange does not act through the shear centre and causes twisting of the profile. Structural engineers attempt to avoid torsional issues by arranging for loads to be applied centrally on a line of symmetry in the profile. However, this is not often possible with the complex geometry of many walls.

For a channel profile the shear centre always lies outside the outline of the profile and most
loads applied to the channel will cause torsion. Figure 5 shows the position of the shear centre for a channel. Any load not acting through the shear centre will cause the channel profile to twist about its shear centre.

Figure 5 - Shear centre of a channel profile

Shear centres

Knowing the position of the shear centre it is possible to avoid torsion by applying loads only through the shear centre. Where that is not possible the resulting torque can be calculated.

For a symmetrical profile the shear centre lies on the axis of symmetry. For a doubly symmetric profile the shear centre lies at the intersection of the two axes, Figure 6.

Figure 6 - Symmetric profiles

For a profile comprising only elements that radiate from a point the shear centre lies at that point of intersection, Figure 7.

Figure 7 - Radiating elements

For a skew symmetric profile the shear centre lies as shown in Figure 8.

Figure 8 - Skew symmetry

The position of the shear centre for a channel profile is shown in Figure 5.

Methods of determining the position of the shear centre are given in Appendix A.

Stabilising forces

For an open profile subject to torsion it may be possible to limit rotation. In the case of a unitized curtain wall a side member of a unit may be prevented from rotating by a transom within the height of the unit.

The rotation of a steel stud may be limited by sheathing and lining boards. Figure 9 shows a 'Z' profile carrying a load not acting through the shear centre. This gives rise to a torque causing the section to rotate clockwise. This may be resisted by the forces shown in blue that form an anti-clockwise couple. This resistance force is provided by the fixings to the sheathing and lining boards all of which must have sufficient strength.

Figure 9 - Rotational stability

Analysis

If a member is subjected to a load not acting through its shear centre the analysis proceeds by transforming the load as shown in Figure 10. The load now acts through the shear centre and the torsional effect of the actual load is replaced by a torque around the shear centre.
Warping

Unlike closed profiles there is no restraint to warping when an open profile is subject to torsion.

In the torsion equation;

\[ T = G \mathcal{I} \dot{\theta} - E H \dot{\theta}^3 \]

Where:

- \( T \) = torque
- \( G \) = shear modulus
- \( \mathcal{I} \) = St Venant torsion factor
- \( \theta \) = angle of twist
- \( \dot{\theta} \) = rate of change of \( \theta \) with distance \( \frac{\partial \theta}{\partial y} \)
- \( E \) = elastic modulus
- \( H \) = warping factor
- \( \ddot{\theta} \) = third derivative of \( \theta \), \( \frac{\partial^3 \theta}{\partial y^3} \)

For open sections the second term cannot be neglected and the warping factor \( H \) is required.

Methods of determining the warping factor are given in Appendix A.

Acceptable rotations

It may be possible to show that rotations are truly negligible otherwise it is necessary to assess the effect of any rotation of the profile.

There is no clear guidance on acceptable rotations of cladding framing members in the codes and standards or elsewhere. Requirements have therefore to be assessed on a project-by-project basis.

A starting point would be to assume that allowable deflections should be assessed by calculating the deflection of the most deflected side of a member including the effects of rotation. In practice this is a serviceability issue and for many components the additional deflection due to rotation is small in comparison with the deflection due to bending.

For a split mullion the two interfaced profiles will rotate in different directions causing either the joint at the front or the joint at the rear to open. Similarly for the two meeting edges of adjacent unitized panels, Figure 11.

Buckling

Open profiles are more prone to both local buckling and whole member buckling than closed profiles.

Free edges are unrestrained and more likely to buckle locally. The effect of local buckling may be reduced by reinforcing the edge of the profile with a return or a bulb. Local buckling is discussed in detail in TN88.

Resistance to lateral torsional buckling is provided principally by torsional resistance for a closed profile. For an open profile torsional resistance is much lower and lateral stiffness is normally relied on to prevent lateral torsional
Lateral torsional buckling is discussed in detail in TN88.

Enhancing performance

The performance of open profiles may be improved by:

- Providing rotational restraint within their length,
- Incorporating a closed portion within the profile,
- Reducing the off-set of the load from the shear centre.

Rotational restraint may be provided by a component such as a transom connected to a mullion to prevent the mullion rotating. This would also provide lateral restraint and greatly improve the buckling performance of the mullion. Rotational and lateral restraint may be provided by sheathing and lining boards in a built-up wall.

A closed portion may be provided within the profile. This is illustrated in Figure 12 for a channel and also in Figure 11 for a split mullion.

![Channel incorporating a closed section](Figure 12)

Reducing the off-set of the load from the shear centre is not always possible, particularly for channel sections. However it is possible for symmetric profiles and often for asymmetric profiles.

Further reading

BS EN 1993-1-3:2006; Design of steel structures - General rules – Supplementary rules for cold-formed members and sheeting.


J Dwight, Aluminium design and construction, 1999, E&FN Spon, ISBN 0 419 15710 7

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Appendix A  Shear centres and warping factors

Shear centres and warping factors are most easily obtained from CAD packages or finite element software, note that these profiles often have to be declared as thin walled sections. Methods for calculating the position of the shear centre and the warping profile for a thin walled section may be found in Dwight (1999).

Shear centres and warping factors for some common shapes are given below;

Channel profile

![Channel profile diagram]

Shear centre:
\[
e = \frac{3B}{f + 6}
\]
\[
f = \frac{Dt}{BT}
\]

Warping factor:
\[
H = \frac{D^2B^3T(2f + 3)}{12(f + 6)}
\]

'C' profile

![C profile diagram]

Shear centre:
\[
e = \frac{D^2B^2T}{l_{xx}} \left( \frac{1}{4} + \frac{C}{2B} - \frac{2C^3}{3D^2B} \right)
\]

Warping factor:
\[
H = \frac{B^2T}{6} \left( D^2B + 3D^2C - 6DC^2 + 4C^3 \right) - e^2l_{xx}
\]
Unequal ‘I’ profile

Shear centre:

\[ g = \frac{y_1 I_1 - y_2 I_2}{I_{yy}} \]

\( I_1 \) = \( I_{yy} \) of flange 1
\( I_2 \) = \( I_{yy} \) of flange 2

Warping factor:

\[ H = \frac{D^2 I_1 I_2}{I_{yy}} \]

‘Z’ profile (Skew-symmetric)

Shear centre:

Lies at the centroid

Warping factor:

\[ H = \frac{D^2 B^3 T (2f + 1)}{12(f + 2)} \]

\[ f = \frac{Dt}{BT} \]
‘Z’ profile with returns (Skew-symmetric)

Shear centre:
Lies at the centroid

Warping factor:

\[ H = \frac{B^2 T}{12(D + 2B + 2C)} \left[ D^2 (B^2 + 2DB + 4BC + 6DC) + 4C^2 (3D^2 + 3DB + 4BC + 2DC + C^2) \right] \]