*Technical Note No 85*

# Structural performance of systemised walls – Design charts and profile data

*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*

*This Technical Note describes the development and use of design charts and equivalent software. It also describes the supporting information required to allow full structural analysis of a profile used as a mullion or transom.*

## Introduction

Systemised curtain walling is constructed from a system comprising profiles, normally of aluminium, which can be connected together to form a grillage. The profiles are designed for use in many applications and configurations and it is necessary to select an appropriate profile for a given configuration and loading.

The selection and validation of a profile for any particular use may be undertaken on the basis of detailed structural calculations. However, for many common applications with simple configuration and loading, selection of a suitable profile is undertaken using a simple design chart or equivalent software. For simplicity the term design chart will be used throughout this Technical Note but the same considerations apply to the development and use of equivalent software.

Design charts are provided by the system (profile) supplier. This Technical Note describes the advantages and limitations of using design charts and the development of design charts by the system supplier.

To facilitate more detailed structural calculations, the system supplier also provides profile properties. This Technical Note describes the properties that are required to facilitate structural checks in accordance with BS EN 1999-1-1 (Eurocode 9).

This Technical Note adopts the terminology and symbols used in the Eurocode. A list of symbols is given in Appendix A.

## General principles

A design chart enables the curtain wall designer to select a suitable profile for use as a mullion based on the three parameters:

- Span
- Spacing
- Wind load

However, the calculations used to derive the design chart also include assumptions about how the load is distributed and the configuration of the mullion and its supports.

Design charts should always give a safe outcome. They are therefore based on assumptions of load and configuration that always give a safe answer provided the rules and limitations for application of the design chart are followed.

**Load** included in design charts is wind load that is usually assumed to be a uniformly distributed load. In practice glazing and infill panels are normally supported on four edges with loads transferred through the transoms. This gives a loading comprising trapezoidal load distributions and point loads. Assuming a uniformly distributed load always gives deflection and bending moment at least as great and is always safe. Making this assumption it is possible to ignore the exact position of any transoms.

Mullions are also subject to barrier loads. It is difficult to include barrier loads in a design chart as an additional variable. However, for many buildings the barrier load is the same as higher barrier loads are only required in places were people congregate. The basic barrier load should be included in design charts.

**Support conditions**

Design charts are normally produced for simply supported spans and may also be available for continuous dual spans, Figure 1. Design charts for simply supported spans will be conservative if used for off-set supports.

Span is the distance between supports. Where the support is a pinned connection to a bracket the support point may be taken at the position of the bolt. Where the end of the mullion is supported by a sliding spigot connection, the support position should be taken at the end of the mullion.

Where design charts for simply supported spans are used for multi storey applications the spigot joint should be within 20% of the span from the support and the span taken as the distance between brackets.

For continuous dual spans the two spans should not differ.

Where the top of the mullion extends above the bracket to form a cantilever, calculation is required to check the displacements at the tip of the cantilever and within the span and check the stresses in the mullion.

It follows that the use of design charts often gives a conservative outcome with actual deflections and bending moments that are less than those allowed by the design chart.

**Advantages and disadvantages**

Design charts simplify the selection of an appropriate profile and remove the need to engage a structural engineer. However, they will normally lead to an inefficient design (the selection of a heavier profile than necessary). The decision whether to rely on design charts or undertake full structural calculations will depend on the scale of the project (weight of aluminium to be used/saved) and any architectural requirement to use a smaller profile. Often an initial selection of a profile using a design chart will show that the next lightest profile will carry much less load. However, if the capacity of the lighter profile is close to that needed then a more detailed analysis may show that it can be used.

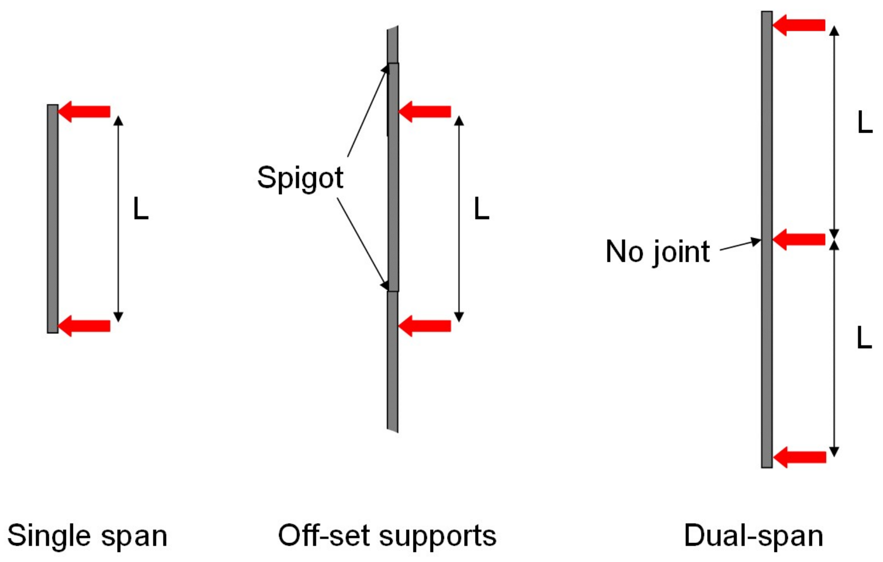


**Figure 1 Mullion-support configurations**

### Characteristic loads

What are often called 'design loads' on the curtain wall are characteristic or unfactored loads. These are factored and combined to give the loads used to calculate deflection ($\delta$), design moment ($M_{Ed}$), shear ($V_{,Ed}$) and reactions ($F_{Ed}$).

The factored loads are different for the serviceability limit state (SLS), for which deflections are calculated, and the ultimate limit state (ULS), for which moments and forces are calculated.

Design charts plot both the SLS and ULS criteria on common axes. To avoid confusion design charts should be based on characteristic (unfactored) loads. The load factors should then be embedded in the calculation of the design chart. Different factors apply in different regulatory regimes and a design chart may be valid in one country but not in another. CWCT TN 84 gives further details about load factors and load combinations.

### Typical design chart

Figure 2 shows a typical design chart.

For a design wind load of 1600 Pa, a span of 3.6m and mullion spacing of 1.5m it can be seen that a 'Profile ABC-150' is required for the mullion.

### Use of look-up charts

When using look up charts to select a mullion profile it is important to follow the assumptions embedded in the chart.

Firstly, the configuration should be the same:

- The ends of the profile should be fixed in the defined way
- The profile should not be drilled, notched or otherwise cut other than as shown in standard assembly drawings
- Transoms should not be spaced further apart than defined
- When using a design chart for continuous dual-spans the spans should be of the length assumed in the design chart.

Secondly, the loads should be those assumed in the design chart:

- The appropriate wind load should be used
- The barrier load should not exceed that assumed in the design chart
- The axial load should be that arising from a single or dual-span of the wall. Walls carrying greater axial compression require a full structural analysis.
- No additional loads should be present, for instance those caused by brise soleil, other forms of shading device, signage, light fittings and so on.

Finally, the design chart should not be used for span or spacing outwith those shown on the chart. Extrapolation outwith the chart may lead to a different failure mode than that covered by the chart.

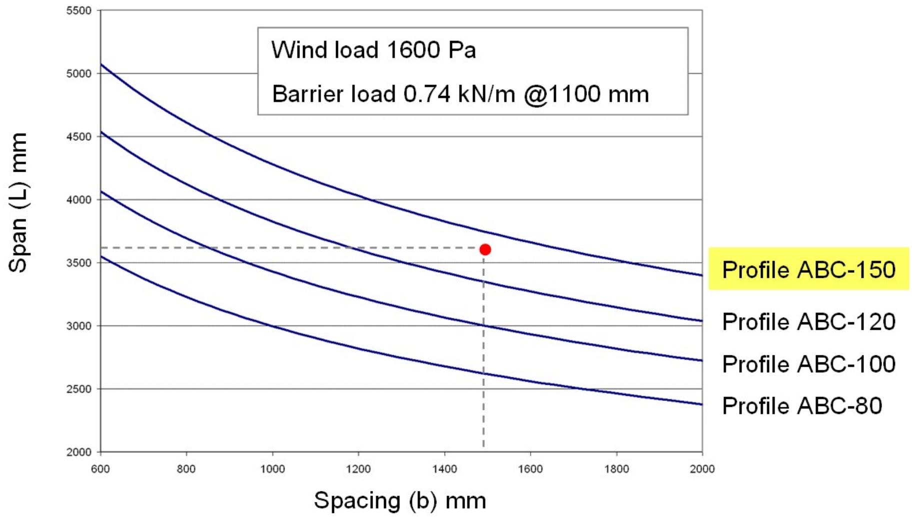


**Figure 2 Typical design chart**

## Failure modes

A mullion profile may fail by:

- Excess deflection
- Excess bending stress
- Local or web buckling
- Shear failure
- Bearing failure at a pin or bolt
- Lateral torsional buckling
- Flexural or torsional buckling

All of these possibilities should be considered when developing a design chart.

## Development of simply-supported single span design charts

Most simply supported applications are limited by deflection and a profile is selected to give an acceptable deflection. However, the other failure modes should be checked when developing a design chart.

### Deflection

For a simply supported span the deflection is given by:

$$\delta = \frac{5pbL^4}{384EI}$$

Where:

$\delta$ = Deflection (mm)
p = Pressure (N/mm$^2$)
b = Spacing between mullions (mm)
L = Span of mullion (mm)
E = Young's modulus (N/mm$^2$)
I = Second moment of area (mm$^4$)

Note: 1 N/mm$^2$ = 10$^6$ Pa

The deflection should be less than:

- L/200 $L < 3000$
- 5+L/300 $3000 \leq L < 7500$
- L/250 $L \geq 7500$

### Moment

For a simply supported span the moment is given by:

$$M_{Ed} = \frac{pbL^2}{8}$$

Where:

$M_{Ed}$ = Design Bending moment (Nmm)
p = Pressure (N/mm$^2$)
b = Spacing (mm)
L = span (mm)

The design bending moment should be less than both:

- $M_{Rd}$, the moment of resistance of the cross-section. This may be calculated following the procedures in BS EN 1999-1-1 or CWCT TN 87.

- $M_{cr}$, the moment at which lateral torsional buckling occurs. This may be calculated following the procedures in BS EN 1999-1-1 or CWCT TN 88.

### Shear

For a simply supported span the shear at each support is given by:

$$V_{Ed} = \frac{pbL}{2}$$

Where:

$V_{Ed}$ = design shear force (N)
p = Pressure (N/mm$^2$)
b = Spacing (mm)
L = span (mm)

$V_{Ed}$ should be less than the shear resistance of the section, $V_{Rd}$, which may be calculated according to BS EN 1999-1-1 or CWCT TN 87.

### Support Reaction

The wind load transmitted through a connection to a bracket on the supporting structure will be either:

$$F_{Ed} = \frac{pbL}{2}$$

if there is a single span and for end connections of multiple span walls or,

$$F_{Ed} = pbL$$

For intermediate supports of multi span walls where spigot joints are used.

$F_{Ed}$ should be less than the resistance of the connection $F_{Rd}$ which may be calculated according to BS EN 1999-1-1. CWCT TN 86 gives guidance on connections.

### Limiting criteria

For a given profile the criteria for $\delta$, $M_{Ed}$, $V_{Ed}$ and $F_{Ed}$ all define relationships between the span (L) and spacing (b) of the mullion profile. Each may be plotted as shown in Figure 3.

It can be seen that the deflection criterion is limiting at longer spans. At intermediate spans the moment criterion ($M_{Ed}$) is limiting and at shorter spans the shear or bearing criterion ($V_{Ed}$ or $F_{Ed}$) is limiting, Figure 4.

### Axial load

Axial loads cannot be accurately included in the look-up chart as they would introduce a fourth input parameter, the weight.

Axial loads do not affect the calculation of out-of-plane deflections and may be ignored when calculating the deflection limits.

Axial loads do affect the stresses in the aluminium and should be considered when calculating the moment limit.

Depending on whether the weight is transferred to the upper support (hung) or lower support (stood) the stresses caused by axial load will be tensile or compressive. Compressive stress is the most onerous when calculating the moment of resistance ($M_{Rd}$).

When developing a design chart either:

- The chart should be developed assuming the mullion is stood and has an axial compressive load. In which case the chart is safe for both support conditions.
- The chart should be developed assuming the mullion is hung and has a tensile axial load. The chart should not then be used to select mullions that are stood.

For mullions that transfer the weight of the wall to the primary structure at each storey, the axial stresses are normally very low and there is little economic disadvantage in assuming axial compression when developing the design chart.

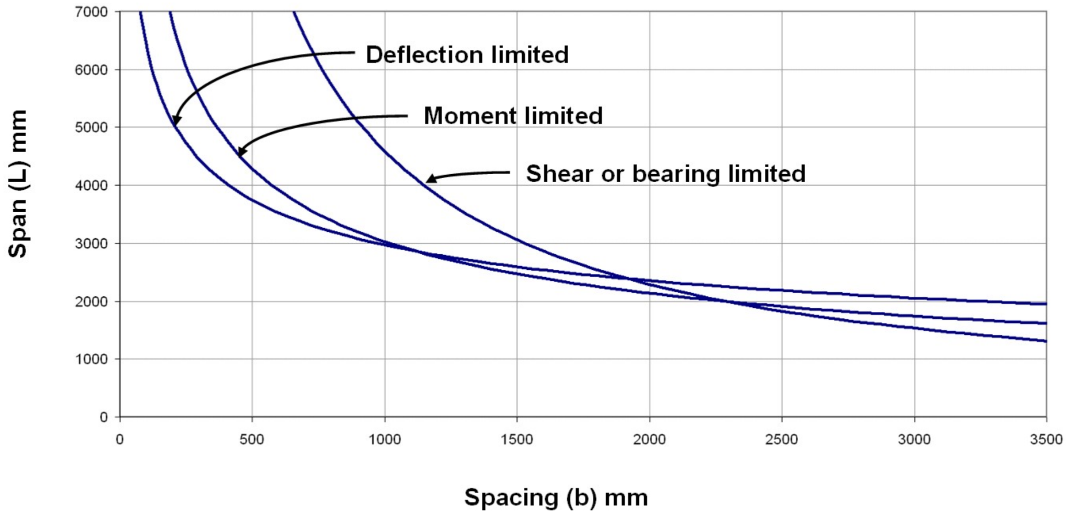


**Figure 3 Limiting curves for different failure criterion**

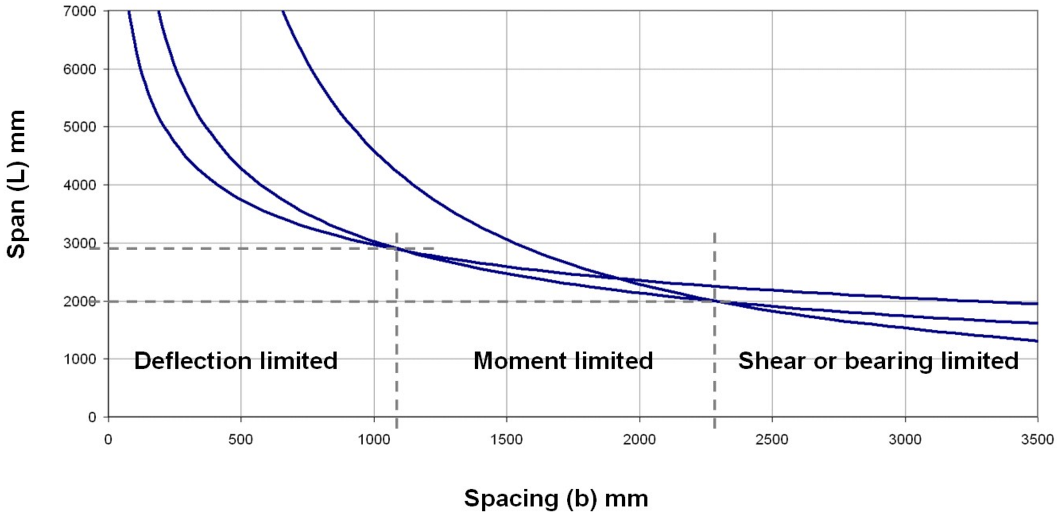


**Figure 4 Failure criteria related to different span/spacing**

There is a trend to stack mullions from the ground and transfer the weight of the wall to the base of the wall rather than to each floor. In this arrangement the axial compression in the mullion will be much larger. The use of design charts is not appropriate in this case and a full structural evaluation is required in order to select appropriate mullion profiles.

**Lateral-torsional buckling**

Lateral-torsional buckling may occur in slender or poorly supported mullions. It is unlikely to occur in symmetrical closed profiles but may be readily checked for these profiles.

The limiting criterion for lateral-torsional buckling is represented by a curve similar in shape to the deflection criteria shown in Figure 3. If the curve for lateral-torsional buckling lies below the deflection curve in Figure 3 then failure will occur by lateral-torsional buckling rather than by excessive deflection.

Resistance to lateral-torsional buckling depends on:

- Section properties of the profile
- Span
- Type of end support
- Intermediate support from transoms

For hollow closed profiles, lateral-torsional buckling is best restrained by preventing rotation of the end of the profile around the profile longitudinal axis. Design charts are normally developed on this assumption and will only apply to profiles supported appropriately. A pin passing through both walls of the profile and through supporting brackets on both sides of the mullion will prevent rotation about the longitudinal axis whilst allowing rotation to create a simple support.

CWCT TN 88 gives further guidance on lateral-torsional buckling.

**Development of continuous dual-span design charts**

In addition to the issues described above for simply-supported single span design charts the following also applies.

Dual-span design charts normally assume two spans of equal length for simplicity.

Using a mullion profile as a continuous dual-span over two storeys of the building will often allow the selection of a lighter profile as the deflections in a dual-span configuration are lower.

However, the bending moment is not reduced and it occurs at the centre support where there is often a hole to accept the pin of the support. Furthermore the reaction at the centre support is greater.

Whereas for simply supported spans deflection normally governs the selection of a profile; for continuous dual-spans, moment at the central support is commonly the limiting criterion.

**Deflection**
For a continuous dual span the deflection is given by:

$$\delta = \frac{pbL^4}{185EI}$$

The deflection should be less than:

- L/200 L < 3000
- 5+L/300 3000 ≤ L < 7500
- L/250 L ≥ 7500

**Moment**
For a continuous dual span the maximum bending moment is given by:

$$M_{Ed} = \frac{pbL^2}{8}$$

This bending moment occurs at the centre support. It should be less than $M_{Rd}$, the moment of resistance of the cross-section. This may be calculated following the procedures in BS EN 1999-1-1 or CWCT TN 87. Note that $M_{Rd}$ should be calculated allowing for any holes in the profile associated with the support.

For a continuous dual span the bending moment at the centre of each span is given by:

$$M_{Ed} = \frac{9pbL^2}{128}$$

This should be less than $M_{Rd}$ and $M_{cr}$, the moment at which lateral torsional buckling occurs.

**Shear**
For a continuous dual span the maximum shear is:

$$V_{Ed} = \frac{5pbL}{8}$$

**Support reaction**
For a continuous dual span the force due to wind load at the central support is given by:

$$F_{Ed} = \frac{5pbL}{4}$$

And at each end support it is:

$$F_{Ed} = \frac{3pbL}{8}$$

**Supporting information**

System suppliers provide data sheets showing the section properties of their profiles. These normally include:

I. Second moment of area ($cm^4$)
$W_{el}$, Elastic section modulus ($cm^3$)
A, cross-sectional area ($mm^2$)
P, perimeter (mm)

I and $W_{el}$ are commonly given as $cm^4$ and $cm^3$ respectively to reduce the number of noughts.

These are normally based on the gross section. I and $W_{el}$ may be given about the major axis or both the major and minor axes. However, calculation of structural performance in accordance with BS EN 1999-1-1 requires the properties of the net section allowing for holes in the profile where these occur in a critical zone.

It is also necessary to know the wall thickness in order to classify the profile in accordance with BS EN 1999-1-1.

**Net section**
The properties of the net section depend on the number, size and location of the holes in the profile. It is not easy for the profile supplier to know what allowance is necessary for holes on a particular project but they may assume a particular configuration for the holes and give values of I and $W_{el}$ for the resulting net section provided the assumptions are also documented.

A simpler and more robust approach is for the properties of the net section to be calculated on a project-by-project basis. To facilitate this it is necessary to know the position of the neutral axis. The distance to the extreme fibre may be calculated as I/ $W_{el}$ but this allows two possibilities for the position of the neutral axis. It is helpful if the depth to the neutral axis (centroid), z, of the gross section is given on data sheets making clear which extremity of the section the distance is being measured from.

**Section classification**
BS EN 1999-1-1 classifies sections into four classes related to the risk of local buckling. For elastic design it is sufficient to check that the section is not Class 4. If the section is Class 4, i.e. slender and prone to local buckling an effective section is assumed.

Classification is calculated using the width and thickness of each element of the section (web, flange, wall, outstand). To facilitate classification it is helpful if profile suppliers give the wall thicknesses of profiles.
However, a simpler, and overall, more efficient approach is for profile suppliers to show the classification of each profile on the data sheet. Most system profiles that are closed hollow sections are not slender; deep profiles with thin webs are more slender than profiles that are squatter or have thicker walls.

It is sufficient to simply classify profiles as slender or non-slender on the datasheets where:

| **Datasheet** | **BS EN 199-1-1** |
|---|---|
| Slender | Class 4 |
| Non-slender | Class 3<br>Class 2<br>Class 1 |

For non-slender members the moment of resistance $M_{Rd}$ can be simply calculated using the net section from:

$$M_{Rd} = \frac{f_o W_{net}}{\gamma_{M1}}$$

For slender members it is necessary to calculate modified section properties. This is described in CWCT TN 87.

**Torsion parameter**
To check resistance to lateral-torsional buckling of hollow closed profiles it is necessary to know the torsion constant. This may be calculated if the wall thicknesses of the profile are known. However, it could be shown in the datasheets prepared by the profile supplier.

The torsion constant is described in detail in CWCT TN 88.

## References

BS EN 1999-1-1
Eurocode 9. Design of aluminium structures. General structural rules



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# Appendix A

## Symbols

Symbols used in Eurocode

| | |
|---|---|
| $f_o$ | Characteristic proof strength |
| $F_{Ed}$ | Design load of connection |
| $F_{Rd}$ | Design resistance of connection |
| $I$ | Second moment of area |
| $M_{Ed}$ | Design bending moment |
| $M_{Rd}$ | Design resistance to bending |
| $r$ | Radius of gyration |
| $V_{Ed}$ | Design shear force |
| $V_{Rd}$ | Design shear resistance |
| $W_{net}$ | Elastic section modulus of the net section, allowing for holes |
| $W_{el}$ | Elastic section modulus of the gross section, |
| ~~z'~~ z | Distance to centroid (neutral axis) |
| $\gamma_{M1}$ | Partial factor for resistance of members |

Symbols specific to this series of Technical Notes ?

| | |
|---|---|
| A | Cross sectional area of member |
| b | Mullion spacing |
| P | Perimeter of section |
| p | pressure |