Technical Note No 84

Structural performance of systemised walls - Introduction

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 provides an introduction to the structural design of systemised walls. It describes the different structural configurations, the loads to be carried and the calculation of design forces and moments.

Introduction

Curtain walling, rainscreen and other forms of systemised building envelope are normally designed to carry only the actions applied to them: wind load, self-weight, barrier loads, snow loads and loads caused by attachments.

They are not normally structural elements contributing to the load carrying capacity and stiffness of the primary structural frame of the building.

Systemised building envelopes are normally designed to accommodate the movement of the primary structural frame so that forces are not transferred to them from the primary structure. CWCT TN55 and CWCT TN56 give guidance on design for movement accommodation.

Structural systems

Most framing systems for curtain walling comprise vertical framing members (mullions) spanning between the edges of the floor slabs and often horizontal framing members (transoms) inserted between the mullions to support the glazing or infill panels.

A similar grillage of framing members may be used to construct slope glazing.

The rectangular grillage described above may be skewed on some facades with mullions and or transoms inclined in the plane of the wall.

In some constructions the horizontal framing members span across the glazed opening with vertical framing members inserted between them.

In the case that both the vertical and horizontal framing members are structurally continuous across more than one opening a more detailed calculation may be carried out than is described in this series of Technical Notes.

Rainscreen systems may employ vertical rails spanning between floor slabs but commonly use lighter rails supported by the back wall. The rainscreen panels are often supported directly by the vertical rails. Horizontal rails may be used either on their own in place of vertical rails or in conjunction with vertical rails.

This Technical Note focuses on vertical rectangular grillages but most of the guidance is directly applicable to other structural geometries.

Construction

Stick system curtain walling
This is assembled at site from factory machined mullion and transom profiles. The transoms are connected to the mullions using cleats or
shear blocks and the ends of the transoms are effectively free to rotate in-plane.

The mullions may be arranged in one of the following structural configurations:

- Simply supported single or multiple spans
- Continuous dual-spans
- Multiple spans with off-set joints

**Simply supported** storey height mullion lengths span between floor slabs. The ends of the mullion lengths are supported by pinned connections that allow rotation of the mullion. A pinned connection is created by using a single bolt through the walls of the member.

For multi storey construction, mullion lengths can be joined close to the supports by a spigot which acts as a pinned connection, Figure 1a. The spigot may be secured to the ends of both mullion sections so that it can transfer axial load or may be left as a sliding fit in one mullion to allow vertical movement.

![Figure 1 Mullion joints](image)

**Continuous** (single) mullion profiles are used over more than one storey height and supported at each floor slab by pinned connections.

The ends of the mullion profile are free to rotate in-plane. Rotation of the member at an intermediate support is constrained by the continuity of the profile.

This type of construction is normally only possible over two storey heights due to limitations on the processing and handling of long profiles.

For a particular profile this configuration will give smaller deflections than for the simply supported configuration and may give a more economical solution.

**Off-set joints** and storey height lengths of mullion, Figure 1b, may be used to give improved structural performance.

If the joints are placed at the appropriate height above the supports (approximately 20% of the span) the separate lengths of mullion behave as a continuous beam. In this configuration both the deflections and moments are reduced, when compared to the simply supported configuration, and a more economical solution results.

Note that off-setting the joints by more than 20% may give greater moments and deflection than for the simply supported solution.

**Unitised curtain walling**

This comprises factory assembled framing members, glazing and infill panels that form units typically of storey height and one or two glazing bays in width.

The horizontal joints between units may be located level with the floor slabs or off-set to window sill level. This off-set distance is not optimum for structural performance but is necessary for construction and appearance.

Structural performance is similar to that of a stick wall. However, transom to mullion joints may have greater rigidity.

**Supports**

The framing system of the wall will be connected to the primary structural frame by support brackets. The brackets are required to transfer loads from the wall to the structure but must also allow for differential movement to avoid inducing additional loads in the wall.

Each mullion should be restrained from moving out-of-plane at all of its supports.

Where a mullion is formed from a single length of profile or where mullion lengths are joined by spigots that permit vertical movement, each mullion length should be restrained from moving vertically in-plane at only one support and free to move vertically in-plane at the other supports.

Where a mullion is formed from a number of lengths of profile connected by spigots which do not allow vertical movement, the complete mullion should be restrained from moving vertically in-plane at only one support and free to move vertically in-plane at all other supports.

Mullions are typically hung from their top support and allowed to move vertically at the
lower support so that the gravity loads cause tensile stress.

A single length of mullion spanning both storeys of a two storey building may be more easily fixed against vertical movement at its base with relative vertical movement allowed at the connections to the other floor slabs. In this case the gravity loads cause compressive stress.

Where mullion lengths are connected by spigots that do not allow movement, it is normally easier to stack the mullions from the base. Where these walls extend for more than two storeys, they require a more detailed structural appraisal of buckling and possible progressive collapse.

Rainscreens
Rainscreen panels are normally supported by vertical cladding rails, either directly or in combination with horizontal rails. Rails may span between floors, particularly in refurbishment projects, in which case they will behave in a similar manner to the simply supported mullions described above. Rails may be supported by a backing wall with brackets at closer centres. This allows the rails to act in a similar manner to continuous mullions and allows rails of lighter section.

The backing wall may be masonry or a framed wall composed of vertical studs of storey height, spanning between the floor slabs. The ends of the framing studs are invariably free to rotate. Performance is similar to the simply supported mullion described above.

The structural performance of the backing wall should be checked as well as that of the support rails and brackets.

Profiles
Framing members may be formed from a range of materials including:

- Aluminium
- Steel
- Timber
- PVC-u

A framing member normally comprises several profiles. The dominant profile is the section that is assumed to carry the applied loads. Other profiles serve to retain the glazing and infill panels and provide the aesthetic appearance of the wall.

The selection of materials is governed by consideration of:

- Appearance
- Durability
- Stiffness
- Strength

Material properties of the main framing materials are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Modulus (kN/mm²)</th>
<th>Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>70</td>
<td>160</td>
</tr>
<tr>
<td>PVC-u</td>
<td>3-4</td>
<td>5-100</td>
</tr>
<tr>
<td>Steel</td>
<td>210</td>
<td>275</td>
</tr>
<tr>
<td>Timber</td>
<td>7-20</td>
<td>14-70</td>
</tr>
</tbody>
</table>

Note: These are indicative values only, design should be based on actual material properties.

Aluminium profiles are open or closed extruded sections that may be used alone or, for closed sections, reinforced with a steel insert to increase stiffness and or resistance of the framing member.

A number of manufacturers produce standard systems using aluminium profiles. These are generally extruded thin wall box sections with separate profiles as pressure plates to retain the glazing and infill and cover caps to provide an aesthetic appearance. Standard system profiles are available in different depths and are selected on a project-by-project basis to give an economical solution that is adequate for the spans and loads.

Steel profiles are either:

- Open or closed cold formed sections
- Hot rolled sections.

A number of manufacturers produce walling systems using cold formed sections. Steel profiles are used as beads or caps to retain the glazing infill panels.
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**Introduction**

Figure 3. Cold formed profiles

Hot rolled profiles are used with glazing profiles to retain the glazing and infill panels.

Figure 4 Hot rolled profile

Timber profiles are solid sections. Timber may be used to form the structural parts of the frame but often aluminium and plastic components are used to retain the glazing and infill panels.

PVC-u profiles are hollow extruded sections. PVC-u profiles have to be reinforced with steel or aluminium inserts even for use as windows. In walling systems the PVC-u makes virtually no contribution to the structural performance of the frame and it is assumed that all of the loads are carried by the metal reinforcement.

Composite members comprise profiles of more than one material for instance a thermally broken aluminium profile comprising two aluminium extrusions and a polyamide thermal break.

**Loads**

Building envelopes are required to carry some or all of the loads described below when they act separately or in combination.

Wind loading is the dominant action on walls. It may occur as a positive or negative pressure and depends on the wind direction, building shape and size, adjacent buildings and the topography of the land surrounding the site.

Internal pressure is also taken into account to determine the net pressure acting on the wall.

The wind pressure is calculated following the procedure given in BS EN 1991-1-4 and the National Annex, additional information is available in PD 6688-1-4.

The wind pressure is transferred from the glazing and infill panels to the mullions as a uniformly distributed load if there are no transoms, or to the transoms and Mullions as either a triangular distributed load or a trapezoidal distributed load depending on the aspect ratio of the opening. Load taken by the transoms will be transferred to the Mullions as point loads.

Snow load may occur on sloping glazing and on ledges. Snow load is calculated following the procedure in BS EN 1991-1-3 and the National Annex.

Dead load is always present and arises from the self-weight of the framing members, glazing, infill panels and any permanent fixtures. The mass of components and density of materials may be known but guidance is available in BS EN 1991-1-1 and the National Annex. For materials that can absorb water the saturated weight of the material should be used.

Occupancy loads arise when occupants lean against a wall or step on a transom or similar ledge. Occupancy loads are given in BS EN 1991-1 and the National Annex.

BS EN 1991-1 does not include a vertical occupancy load but the CWCT Standard for systemised building envelopes and BS 6399-1 require a vertical load of 1 kN or a distributed load of 0.6 kN/m. This load is also given in PD 6688-1-1.

Access load arises during maintenance and repair operations. CWCT Standard for systemised building envelopes specifies a load of 500N acting over a square of side 100mm. This load represents a ladder leaning against a wall. Greater loads may be caused by some access methods.

Induced loads due to changes of temperature and moisture arise if the movement of a component is restrained.

Impact load may be relatively small, caused by vandalism or somebody falling against the wall, or they may be much larger, for instance impact by a vehicle.
The smaller impact loads are described in detail in CWCT TN75. They are given in terms of impact energy not static actions and are assessed on the basis of test results, not included in structural calculations.

The larger impact loads may cause gross damage and deflections to framing members. It is assumed that repair will be necessary following such an impact. However, the designer should check that the damage is limited in extent and that progressive collapse will not occur.

**Load combinations** occur when two or more loads act simultaneously. However it is unlikely that all loads will occur simultaneously at maximum value.

The following load combinations are considered:

- Dead
- Dead + access
- Dead + wind
- Dead + occupancy
- Dead + wind + snow
- Dead + wind + occupancy

Note that wind loading may be either positive or negative pressure.

Access loads do not occur with wind load. It is assumed that maintenance operations will not be undertaken at times of high windloading.

The loads calculated above are known as unfactored loads. Load factors are applied to these loads to account for the possibility that a particular load may be exceeded.

Additionally load combination factors are applied in recognition that not all loads act fully at the same time. These are described in detail below.

**Design assessment**

The structural adequacy of a design may be checked by calculation, testing or the use of design charts.

A flow chart of the assessment process is given in Figure 5.

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**Figure 5** Design assessment process
Use of design charts
Design charts may be provided for proprietary wall systems, these may be embedded in software such as simple spreadsheets.

Design charts are based on particular configurations that are selected to be always safe in use. They normally assume a mullion to be a single span with pin supports at each extreme end.

Where a mullion is continuous over two or more spans or has off-set joints it may be advantageous to select a profile on the basis of calculation.

Calculations
These require assumptions to be made about the materials, joints and geometry of the structure. They give safe answers but are inherently conservative.

Use of test results
Testing to ascertain the strength and deflections of a building envelope is expensive but may be necessary for a complex envelope for which the behaviour of the profiles and joints is not well understood. In these circumstances it may lead to a more efficient design.

When testing separate components it is important to mount them with the same support conditions that they experience in the wall.

When testing assemblies or panels of wall it may not be possible to proof test components such as fixings, which have a higher material factor than other components. These components have to be evaluated by testing them separately from the wall.

Design criteria
The building envelope should have sufficient resistance (strength) to carry the actions (loads) safely and be sufficiently stiff to limit deflections.

Ultimate limit state requires the wall to have adequate resistance to meet the safety requirement. This is achieved by limiting the stresses in the framing members so that tensile, compressive or buckling failure is only caused by loads that are unlikely to be exceeded in practice.

Each load is multiplied by the relevant factor below to allow for the possibility that the load is greater than anticipated:

<table>
<thead>
<tr>
<th>Load type</th>
<th>( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load (unfavourable)</td>
<td>1.35</td>
</tr>
<tr>
<td>Dead load (favourable)</td>
<td>1.00</td>
</tr>
<tr>
<td>Variable load</td>
<td>1.50</td>
</tr>
</tbody>
</table>

The factored loads are then combined to give the load cases. The following load combinations are considered:

Dead
Dead + access
Dead + wind
Dead + occupancy
Dead + wind + 0.5* snow
Dead + snow + 0.5* wind

* The factors above are taken from NA to BS EN 1990; note that BS 5516 and CWCT TU14 apply a factor of 0.6

and for places where people congregate:

Dead + wind + 0.5 occupancy
Dead + occupancy + 0.5 wind

For each load case the resistance of the framing member is calculated and compared with the loads applied. TN87 and TN89 give guidance on calculating the resistance of framing members.

Serviceability limit state requires adequate stiffness to meet the deflection requirement.

The unfactored loads are combined to give the following load cases:

Dead
Dead + access
Dead + wind
Dead + occupancy
Dead + wind + 0.5* snow
Dead + snow + 0.5* wind

* The factors above are taken from NA to BS EN 1990; note that BS 5516 and CWCT TU14 apply a factor of 0.6

For each load case the deflections of each framing member are calculated and compared with the allowable deflections. TN87 gives guidance on calculation of deflections.
**Allowable deflections**

Allowable deflections are given in CWCT Standard for systemized building envelopes and BS EN 13830.

The values below are taken from the former:

**Overall deflection of a mullion:**

For a mullion spanning between floor slabs, with span H, the out-of-plane deflection should be limited to:

<table>
<thead>
<tr>
<th>Length</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>H ≤ 3000</td>
<td>Δ ≤ H/200</td>
</tr>
<tr>
<td>3000 &lt; H &lt; 7500</td>
<td>Δ ≤ 5 + H/300</td>
</tr>
<tr>
<td>7500 ≤ H</td>
<td>Δ ≤ H/250</td>
</tr>
</tbody>
</table>

*All dimensions are in mm*

For roof glazing larger deflections may be acceptable. However, the roof should retain an adequate gradient to drain water from its surface.

**Local deflection of a framing member:**

Allowable out-of-plane local deflections of a framing member are dependent on the infill material being supported by the member. Out-of-plane local deflection should be limited to:

<table>
<thead>
<tr>
<th>Infill type</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single glazing</td>
<td>Δ ≤ L/125</td>
</tr>
<tr>
<td>Double glazing</td>
<td>Δ ≤ L/175</td>
</tr>
<tr>
<td>Brittle materials*</td>
<td>Δ ≤ L/360</td>
</tr>
<tr>
<td>Other materials</td>
<td>Consult manufacturer</td>
</tr>
</tbody>
</table>

* Smaller deflections may be required by the infill manufacturer

Where L is the length of the supported edge of the panel.

**Vertical deflection of transom:**

In-plane deflection of a transom should be limited to 1/500 of the span or 3mm whichever is the lesser. Smaller deflections may be required depending on the geometry of the profile.

**Calculation procedure**

It is first necessary to calculate the effect of the loads on each framing member and on each connection or support.

The connections and supports in most walling systems do not provide restraint against rotation at the ends of framing members and simple forms of analysis usually lead to economic solutions.

BS EN 1993-1-1 and BS EN 1999-1-1 allow both elastic and plastic behaviour but walling systems are normally designed on the basis of elastic behaviour and elastic limiting stresses (yield stress or proof stress, not ultimate stress). The dominant variable load is wind loading and this will vary frequently from a positive to a negative load. BRE Digest 346 Shows that wind load in excess of 40% design wind load may occur over 6000 times in a period of fifty years and load reversals of this magnitude may lead to low cycle fatigue.

In any case, for thin walled hollow box sections the difference in magnitude between the elastic resistance moment and the plastic resistance moment is typically only 10 to 15%.

For each load combination the bending moments, shear force and torsion in the member are calculated.

The reactions at the member supports are calculated to allow checking of the joints and connections.

It may be obvious that some load combinations are of the same distribution but lower magnitude than others. These may be disregarded when checking the resistance and deflection of the member.

**Reactions** are the forces and moments transmitted to the joints or connections that support the framing member. There will be no moment at an end support if the framing member is free to rotate.

**Bending moments** vary along the length of the framing member. The bending moment at any section is the sum of the moments of forces acting on the member to one side of that section and at any point along the member is given by:

\[ M_x = \sum_{i=right} F_i a_i \]

Where:

- F is a load or reaction
- a is distance from the point to the load.
Shear force varies along the length of the framing member. The shear force at any section is the sum of forces acting to one side of the section and at any point is given by:

$$V_x = \sum_{right} F_i$$

Torsion varies along the length of the framing member. The torsion at any section is given by:

$$T_x = \sum_{right} T_i$$

In all cases the design values calculated should be less than the resistance values of the profile.

For closed profiles; in most cases shear force and torsion give rise to low stresses and the bending moment dominates.

Reactions, bending moments and shear forces for common load patterns are given in Appendix A. Bending moments, shear force and torsion may also be calculated using structural analysis software.

Calculation of design values and resistance values is covered in TN 87.

References

CWCT Standard for systemised building envelopes.

CWCT TN 75 Impact performance of building envelopes: guidance on specification

CWCT TN55 Movement accommodation in building envelopes

CWCT TN56 Accommodation of structural movement

CWCT TU14, Load combinations


NA to BS EN 1990
National Annex to Eurocode 0, Basis of structural design.

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### Reactions and bending moments

<table>
<thead>
<tr>
<th>Condition</th>
<th>$R_a$</th>
<th>$R_b$</th>
<th>$M_c$</th>
<th>$M_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(L-a) \leq L$</td>
<td>$\frac{Pa}{L}$</td>
<td>$\frac{P(L-a)}{L}$</td>
<td>$\frac{Pa}{2}$, $a \leq \frac{L}{2}$</td>
<td>$\frac{P(L-a)a}{L}$</td>
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<td>$P \leq L$</td>
<td>$P$</td>
<td>$P$</td>
<td>$Pa$</td>
<td>$Pa$</td>
</tr>
<tr>
<td>$\frac{w}{2}$</td>
<td>$\frac{wL}{2}$</td>
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<td>$\frac{wL^2}{8}$</td>
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<td>$\frac{w(L-a)}{2}$</td>
<td>$\frac{w(L-a)}{2}$</td>
<td>$\frac{w(L^2 - \frac{La}{4} + \frac{a^2}{3})}{8}$</td>
<td>$\frac{w(L^2 - \frac{La}{4} + \frac{a^2}{3})}{8}$</td>
</tr>
<tr>
<td>$\frac{w}{4}$</td>
<td>$\frac{wL}{4}$</td>
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<td>$\frac{wL^2}{12}$</td>
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<tr>
<td>$\frac{M}{L}$</td>
<td>$-\frac{M}{L}$</td>
<td>$\frac{M}{2}$</td>
<td>$\frac{Ma}{L}$, $a \geq \frac{L}{2}$</td>
<td></td>
</tr>
</tbody>
</table>