Accommodation of structural movement

This Technical Note is one of a series of three describing the design and assessment of supporting structures and cladding systems to ensure that building envelopes are serviceable throughout their design life. The series comprises:

TN 55 Movement accommodation in building envelopes
TN 56 Accommodation of structural movement
TN 57 Cladding movement

This Technical Note should be read in conjunction with:

TN 14 Curtain walling types
TN 30 Cladding of buildings subject to earthquakes

Introduction

Building envelopes have to accommodate movement of their components and of the supporting structure. Building structures have to be sufficiently stiff to make this possible. This Technical Note describes the ability of building envelopes to accommodate structural movements and the issues of reconciling calculated and actual movement.

Structural codes

Structural engineers design and analyse largely on the basis of design codes. These give requirements for strength and serviceability (deflection).

Many structures are designed for strength and a check is made that the deflections are acceptable. With larger floor spans and lighter forms of construction it is increasingly necessary to design for serviceability and check that the strength is acceptable.

The structural design codes give default deflection limits to be used in the absence of deflection limits agreed between the structural engineer and client. The default values are for generic forms of construction such as beams carrying brittle finishes. No mention is made of supporting cladding.

The deflection limits may be relaxed when designing industrial buildings. However, many forms of building envelope will require that the deflection limits are tighter than the code default values.

Structural Engineers design to the codes listed in the bibliography.

Calculated and actual structural movements

Actual deflections are often less than the deflections calculated by structural engineers for the following reasons:

- The Structural Engineer may simply check that deflections are within the code limits rather than calculate the actual values.
- The Structural Engineer may use simplified calculation methods.
- Structural calculations omit additional stiffening from secondary elements such as infill walls and staircases.
Accommodation of structural movement

- Design loads are conservative and will rarely be achieved.

Reconciling calculated deflections and movement accommodation

Structural movements are described in the following sections of this Technical Note. Movement accommodation is described in this document and in CWCT TN 55.

Structural movement and movement accommodation may be reconciled by:

- Improved calculation of structural deflections
- Structural stiffening
- Improved movement accommodation in the cladding

Improved calculation of structural deflections
A more realistic calculation of structural deflections will require more time on the part of the structural engineer and may require the use of better calculation methods or more advanced software. However, this approach is always more economical than stiffening the structure.

Structural stiffening
The primary structure may be stiffened to reduce the calculated deflections. Whilst this may appear expensive or inelegant to the structural engineer, the limited deflections implicit in the Architect's chosen façade solution need to be reconciled with the structural design at an early stage.

Improved movement accommodation of the cladding
There is limited scope to improve the movement accommodation of many cladding systems without changing their appearance or even their form of construction. Movement accommodation within envelope systems is discussed in TN 55 Movement accommodation in building envelopes.

Movement of the structure

Structural movement comprises some combination of the following:

- Floor deflections
- Column shortening
- Wind sway
- Seismic sway
- Settlement
- Thermal movement.

Floor deflections
Floor deflections result from dead load (self-weight of the floor slab and screed) and live load (occupation loads). Dead load deflections are present when the cladding is installed and may be allowed for in the same manner as accommodating tolerance. Live loads may not be the same on each floor and it is this difference that gives rise to differential floor movements that have to be accommodated by the cladding.

Structural engineers commonly regard the weight of the cladding as part of the dead load as it is never removed while the building is in service. However, the weight of the cladding is applied as the cladding is installed and may cause movement that affects the cladding. For example each cladding panel attached to the edge of a floor slab will experience further movement as following panels are installed. It may be necessary to allow for this movement as a live load or it may be possible to adjust the position of the cladding panels after they have all been installed.

Default limits for live load floor deflections are typically:

$$\delta < \frac{L}{250} \to \delta < \frac{L}{360}$$

For a span of 7200 mm this is a mid-span deflection of up to 20 – 29 mm. Of course, this is total deflection and the differential deflection between floors will be less. Some codes limit deflections to an absolute limit, typically 20mm. Clearly tighter limits have to apply to floor slabs supporting most types of building envelope. This may simply require a more
realistic calculation rather than a stiffening of the structure.

Depending on the façade solution selected by the architect and the span of the slab edge, the deflections may need to be tightened to L/500, L/1000 or even L/2000 to match the movement limitations of the façade system.

**Column shortening**
Column shortening may occur as shrinkage or elastic shortening.

Shortening as a result of shrinkage affects concrete columns. It occurs during the first six months after pouring the concrete. The cladding is normally installed before shrinkage is complete. Shrinkage will typically cause column shortening of 0.5 mm in a column of length 3000 mm.

Elastic column shortening arises due to compressive stress in the columns and may be significant for tall structures. If it occurs prior to the installation of the cladding it may be accommodated as if it were a tolerance issue. However, if the cladding is installed as the primary structure is erected the cladding on the lower floors will experience column shortening as a result of all subsequent construction. Elastic column shortening may be up to 1.5 mm in a column of length 3000 mm.

**Wind and seismic sway**
Horizontal loads give rise to lateral movement of the floor slabs. The movement of one floor slab relative to the one below is known as inter-storey drift.

Sway due to wind load and earthquake are live loads that occur after the cladding has been installed. They are short-term stochastic reversible movements that may occur at any time and may exceed the design levels.

Sway deflection due to wind loading varies widely depending on the form of building structure and its design. For braced frames it is generally less than 3 mm in each storey height. For unbraced frames the default deflection limits are typically:

\[ \delta_v \leq \frac{L}{500} \]

Where:

- \( \delta_v \) = Differential settlement between adjacent columns
- \( L \) = Column spacing

Long buildings and building extensions are more prone to differential settlement, or heave, and their structure may comprise several independent structures.

Earthquake events may cause failure of the cladding. There will be a serviceability earthquake event defined for which the cladding is required to remain serviceable and undamaged. A larger event will be defined that may lead to a cladding serviceability failure but should not lead to collapse of the cladding or building structure. Movement due to seismic events is described in greater detail in TN 30 Cladding of buildings subject to earthquakes.

**Settlement**
Settlement, or heave, generally occurs during the early life of a building as a result of foundation movement. It may occur later as a result of subsidence or other changes in the ground conditions.

There may be no anticipated settlement, or heave. If movement is anticipated the structural engineer will generally restrict the differential movement to:

\[ \delta_v \leq \frac{H}{300} \]

Where:

- \( \delta_v \) = Inter-storey drift
- \( H \) = Storey height

Tighter limits may be required for particular types of building envelope or if there are lifts and elevators within the building. Again this may simply require a more realistic calculation rather than a stiffening of the structure.
with movement joints between them. In these buildings movement due to settlement, or heave, is concentrated at the structural movement joints.

Settlement and heave tend to be gradual and one-way.

**Primary/secondary structure**

All of the loads on the building are carried by the primary building structure. All components of the primary structure act together and contribute to the stiffness of the structure.

Secondary structures are sometimes used. A secondary structure carries only its own weight and loads applied to it. It is not designed to contribute to the stiffness of the primary structure. It should not have loads induced in it by movement of the primary structure and its removal should not affect the integrity of the primary structure.

Secondary structures are used to support atria roofs and the like and to provide a stiffer support for cladding when a floor edge is too flexible, Figure 1.

![Secondary structure used to support curtain walling](image)

**Figure 1 Secondary structure used to support curtain walling**

The secondary structure may be designed independently of the primary structure taking account only of the loads transferred to the primary structure. Note that when trusses are needed along the edge of floor slabs it is often the case that the project structural engineer and the Cladding Contractor’s structural engineer have not worked collaboratively. It is usually more economical to stiffen the floor slab than introduce the truss. However, better calculation may predict slab deflections that are acceptable.

**Effects of structural movement**

Floor deflections and column shortening will cause vertical movement of the floor slabs and cause the vertical spacing between the cladding supports to change. Note that it is the vertical movement of one floor slab relative to the other that is important, not the absolute movement. Figure 2 shows the movement experienced by a mullion movement joint.

Vertical deflection of the floor slab will be greatest at mid-span and cause it to curve. This leads to different vertical movement of each mullion and change of shape of each glazing opening, Figure 3.

![Differential vertical movements](image)

**Figure 2 Differential vertical movements**

Sway and torsion of the primary frame will give rise to horizontal movement of the floor edges. This may arise due to wind loading or a seismic event. The different horizontal movement at the head and foot of a cladding bay will cause the cladding to rack (shear), Figure 4.

Similarly settlement of columns will give rise to different vertical movements along the edge of a floor slab or at either end of a cladding bay. This also causes the cladding to shear and the glazing openings to change shape.
Accommodation of movement in stick system walls

The ability of framing members in a stick curtain wall to move or deflect in-plane without contacting the glass is governed by the edge clearance between the glass and the frame, CWCT TN 55.

The glass and infill panels will limit mullion shortening and racking (shear) of the wall.

Mullion shortening

Shortening of mullions is normally achieved by the provision of movement joints, Figure 2. These comprise a gap, left between two lengths of mullion and bridged by a spigot that transfers out-of-plane load. The gap can be of any length but:

- Movement will be limited by the ability to seal the gap.
- Any movement will be limited by the ability of the glazing opening to contract without contacting the glass. This distance is the edge clearance in the top rebate less the deflection of the transom.

Shear

Glazing and most cladding infill panels are stiff in shear and will not conform to the building movements and movement of the cladding brackets. They depend on a rebated frame or an overlap so that the frame can move independently of the glazing or infill.

In general, frames offering greater edge clearance will accommodate greater structural movement.
Horizontal racking
In a stick wall racking of the frame to accommodate wind or seismic shear is possible until the edge clearance is reduced to zero, Figure 5.

The angle of rotation of the mullion can be calculated as:

\[ \gamma = \frac{\delta_h}{h} \]

Where:
- \( \delta_h \) = Edge clearance (at side)
- \( h \) = height of panel

However:

\[ \gamma = \frac{\Delta_h}{H} = \frac{\delta_h}{h} \]

Where:
- \( \Delta_h \) = Inter-storey drift
- \( H \) = Storey height

It follows that for a given storey height more horizontal movement can be accommodated if the glazing or panel is less tall.

Vertical racking
Floor deflections will also give rise to racking of a stick curtain wall frame. In this case the mullions move, while remaining vertical, causing the transoms to rotate. In a stick wall racking of the frame to accommodate floor deflections or settlement is possible until the edge clearance is reduced to zero, Figure 6.

The maximum angle of the transom is given by:

\[ \gamma = \frac{\delta_h}{h} \]

Where:
- \( \delta_h \) = Edge clearance (at side)
- \( h \) = height of panel

It again follows that less tall panes or panels may allow greater vertical racking.

Combined movement
Horizontal and vertical racking may occur simultaneously. In this case the accommodation of each type of movement will be limited by the other.

Edge clearance at the top may be reduced by mullion shortening and transom deflections.

Vertical racking will reduce the edge clearance at the side and will reduce the ability to accommodate horizontal racking.
Larger movements

For horizontal racking movements greater than those described above, the glazing or panel will contact the frame and be forced to rotate, Figure 7.

![Figure 7: Infill rotation under large horizontal racking](image)

Rotation may be possible but ultimately the infill will make contact with the frame at diagonally opposed corners and act as a diagonal strut. This will induce large stresses in the infill.

Note that any glass to frame contact may cause high localised stresses in the glass.

Practical limits to movement of stick system walls

Stick systems comprising 50 mm wide transoms are unlikely to accommodate more than 4 mm vertical differential movement of the floors. Those comprising 60 mm wide transoms are unlikely to accommodate more than 9 mm vertical differential movement. The exact movement accommodation may be less and should be confirmed by the cladding designer.

Inter-storey drift must be limited to:

<table>
<thead>
<tr>
<th>Frame width</th>
<th>50 mm</th>
<th>60 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storey height glass</td>
<td>5 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Intermediate transom</td>
<td>10 mm</td>
<td>20 mm</td>
</tr>
</tbody>
</table>

With glass to frame contact (rotation):

<table>
<thead>
<tr>
<th>Frame width</th>
<th>50 mm</th>
<th>60 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storey height glass</td>
<td>15 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>Intermediate transom</td>
<td>20 mm</td>
<td>40 mm</td>
</tr>
</tbody>
</table>

Note that tighter limits might apply and limits to movement should be checked with the cladding designer.

The edge clearance around the glass has to accommodate all of the following movement:

- Relevant slab edge deflections
- Structural sway
- Column shortening
- Thermal expansion and contraction

It also has to accommodate tolerances due to:

- Glass manufacture
- Façade fabrication
- Installation

If frame to glass contact occurs there is a risk of glass breakage. Most Clients will want no contact to occur under the design wind loading.

The larger sway limits that involve glass to frame contact are applicable to more extreme events such as seismic sway, when some glass breakage may be acceptable.
Movement accommodation of unitised walls

Shortening
Units in a unitised wall are designed without movement joints within them and movement is accommodated at the horizontal joints at the head and foot of each unit.

In a unitised wall the horizontal joints occur at floor level or window sill level and wider joints can be concealed by a sill or feature flashing.

The horizontal joints can individually accommodate more movement than a stick wall if designed correctly. Only the movement accommodation of the internal seal and the depth of any external flashing limit the movement possible.

Floor deflections
Floor deflections may lead to vertical movement of the panels, Figure 8, or rotation and vertical movement of the panels Figure 9. The former only occurs if the panels are prevented from rotating by some horizontal restraining force or a clash with columns or panels in an adjacent bay. Rotation of the panels will be limited by the horizontal closure possible at the joints and this may determine which type of movement occurs.

Settlement
Differential settlement of the columns either end of a structural bay will cause deflections of the floor slab or edge beam. This may be accommodated by vertical or rotational movement of the panels similar to that shown in Figures 8 and 9. Again purely vertical movement only occurs if the panels are prevented from rotating.

Sway
Horizontal racking may be accommodated by one of two mechanisms. Either:

a) The units of one storey slip past those of the storey above and below, Figure 10.

b) The units rotate as shown in Figure 11.

Movement at the joints comprises predominantly slippage along the line of the joints. However, if the panels rotate the joint widths will reduce, but only by a fraction of a millimetre.

Figure 8 Vertical movement of units due to floor deflection
Forces on brackets
In many cases of movement accommodation, the panel movement does not conform to the floor deflection and one of the support brackets wants to lift from the floor.

In this case, if the brackets are able to lift off then the weight of the unit is carried on one bracket, Figure 12, and horizontal forces, $f_h$, occur at the brackets and between the units. If a bracket is unable to lift off its support then a force, $f_v$, is induced in the
support and the force in the other bracket is greater than the weight of the unit, Figure 13.

![Figure 12 Forces on an unrestrained unit](image1)

Where vertical joints are required to part, Figure 9, they will normally accommodate smaller movements than the horizontal joints.

Damage to the fit-out and internal finishes is likely to be a greater restraint to movement accommodation.

Large sway movements may be accommodated provided slippage at the unit joints is not restricted. Dowels or spigots are provided to transfer out-of-plane shear forces at the horizontal joints but these may be arranged to allow some slippage at the joint. However, damage to the fit-out or internal panels is again likely to be a greater restraint to movement accommodation.

The cladding designer should be consulted on exact limits to movement.

**Movement accommodation of panellised walls**

Panels are normally supported from the columns and are independent of floor deflections. They are affected only by column shortening, sway and settlement.

**Shortening**

Panellised walls accommodate shortening in the same way as unitised walls, the concealed horizontal joints occurring at floor level.

![Figure 14 Horizontal sway of a panellised wall](image2)
Accommodation of structural movement

Sway
The panels are stiff in shear and the only mechanism for accommodating sway is for a panel to slip past those above and below it, Figure 14.

Settlement
The panels are stiff in shear and can only accommodate settlement by rotating

Practical limits to movement accommodation of panellised walls
Although the panels are supported independently of the floor slabs floor deflections cannot be ignored. The panels are stiff, comprising either a steel truss or concrete panel, and undergo very little vertical deflection. Any deflection of the floor slab will lead to a relative deflection of similar magnitude relative to the wall and this may damage the internal fit-out.

Panellised walls can always be designed to accommodate the limited movements due to column shortening.

Large sway movements may be accommodated provided slippage at the panel joints is not restricted. Dowels or spigots are often provided to transfer out-of-plane shear forces at the horizontal joints but these may be arranged to allow some slippage at the joint. However, damage to the fit-out or internal panels is again likely to be a greater restraint to movement accommodation.

Localised structural movement
Where the primary structure comprises two or more independent structures with movement joints between them, then large differential movements may occur on the plane between them.

Figure 15 shows the concrete columns of two adjoining structures and the cladding that is common to both structures. Differential settlement has occurred early in the life of the building and both the concrete cladding unit and the stick wall are distressed.

Figure 15 Localised movement

Split mullions are sometimes used to allow for localised movement in stick curtain walling. They comprise two profiles with seals between them that allow vertical slippage to occur, Figure 16.

Figure 16 Split mullion
References

CWCT

CWCT

CWCT
TN 30, Cladding of buildings subject to earthquakes, CWCT 2000.

CWCT
TN 55, Movement accommodation in building envelopes, CWCT 2007

CWCT

Bibliography

BS 5950 Structural use of steelwork in building.

BS 8110-1 Structural use of concrete. Code of practice for design and construction

BS 8118-1 Structural use of aluminium. Code of practice for design


