Technical Note No. 26

INTRODUCTION TO STRUCTURAL DESIGN OF STICK CURTAIN WALLING

Introduction

Curtain walling is not generally expected to act as a structural element of the building; it is only required to support its own weight, wind loads and horizontal live loads arising from use of the building. It must be able to transfer these loads to the main structural frame of the building. This Technical Note describes the structural design procedures that may be used to ensure that the curtain wall can carry these loads without impairing the safety or serviceability of the structure.

Curtain walling

The primary structural elements of a stick curtain walling system are vertical mullions, which run the full height of the cladding. They are normally supplied in one or two storey lengths, which are connected by sleeved joints. These joints are usually designed to permit vertical movements and allow transfer of shear loads but do not transmit axial loads or moments. Mullions are typically spaced at between 1.0 and 1.8m centres and support transoms. Transoms are connected to the mullions using angle cleats, sleeves, spigots or proprietary brackets.

The framework of mullions and transoms supports infill panels, which may be glazing units or insulated panels.

Mullions and transoms are usually made of extruded aluminium but may be steel. A number of manufacturers produce standard systems using aluminium profiles, which have been specially designed to support the infill panels with weathertight joints. Aluminium profiles are generally based on thin walled extruded box sections, which may require reinforcement to accommodate concentrated loads at fixings. Longitudinal ribs are often used to increase the wall thickness to accommodate fixing screws for mullion brackets and cross webs may be incorporated to prevent squashing of the section by bracket fixing bolts passing through the section. Enlarged fixing holes with bushes may be used to distribute concentrated loads from fixing bolts. Figure 1 shows a typical profile.

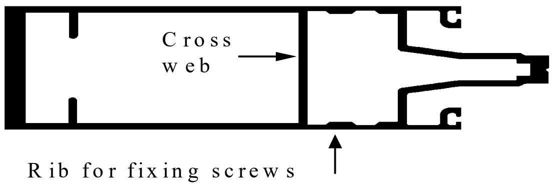

Figure 1 Section of typical curtain walling mullion

Loads

Wind is the dominant form of loading which is dependent upon site location, topography, ground roughness, building size and shape, and the number and location of openings within the building envelope. The wind pressure is calculated using the procedure in BS 6399: Part 2 or the simplified procedure in Technical Note No. 3 *Wind loading on wall cladding and windows of low-rise buildings.*

The wind load on an area of the infill panels will be a uniformly distributed load however part of this load will be transferred directly to the mullions while part will be transferred via the transoms. For approximate design purposes the load on the mullions may be assumed to be uniformly distributed but a more economical design may be obtained using the trapezoidal load distribution described in Technical Note 2 *Introduction to wind load on cladding.* For sloping surfaces or where the façade incorporates horizontal ledges snow loads may need to be considered. Snow loads are given in BS 6399: Part 3..

Dead loads of the curtain walling and any permanent fixtures attached to the curtain wall should be calculated in accordance with BS 6399 Part 1.

Live loads may arise from the use of ladders and cradles during maintenance work. The CWCT Standard for Curtain Walling clause 2.5.3 states that allowance for a load of 500N over a square of 100mm side should be made.

Requirement K2 of the Building Regulations 1991 requires protection to be provided at the edges of floors to prevent the risk of falling. This protection may be provided by the curtain wall, although in some situations barriers or guardrails will be provided. Section 3 of Approved Document K of the Building Regulations gives the loads to be resisted for different categories of building.

BS 8200 gives requirements for impact resistance on the external face of external walls. These loads are given in terms of impact energy rather than static force and compliance must be judged on the basis of test results rather than design calculations.

Loads may also be generated by restraint to movement, however it is normal to make provision for movement so that significant forces do not arise.

Although all the above loads need to be considered, it is not normally necessary to consider all loads acting at the same time and it is only necessary to include realistic load combinations. For example wind load is based on the 50-year return wind. It is unlikely that maintenance would be undertaken in such conditions and building occupants would probably keep clear of the façade due to the fear of breaking glass. In the UK, snow loading is unlikely to be associated with winds from the direction of the maximum wind load. It will normally be sufficient to allow for wind load in conjunction with the dead load but this needs to be confirmed for each situation.

Limiting conditions

As with most other structures the purpose of structural design is to ensure that the curtain wall is strong enough to withstand the loads to which it is subjected safely and without impairing performance.

Safety

To satisfy safety requirements the structure should be able to carry the design loads with an adequate margin of safety. In practice this is achieved by limiting the stresses on the components under a design load which is unlikely to be exceeded in service.

Serviceability

Although the safety requirement ensures that the structure can carry the design loads, the overall performance may be impaired. Excessive deflection of the framing under the action of horizontal loads may result in inadequate support to the infill panels. The performance of the curtain wall may also be impaired by failure of seals or drainage channels.

Deflection of transoms under the action of vertical loads could cause contact with the infill panel below the transom and therefore subject the infill panel to loads it has not been designed to take.

To ensure serviceability, limits are placed on the deflection under the design load. The check on serviceability or deflection is carried out at a lower load than used for the safety check.

Deflection limits are given in design codes and the CWCT Standard. Deflection limits are primarily governed by the material supported rather than by the framing material and different sources do not always give the same limits. For example the limits given in the CWCT Standard for members supporting glass are different from those in BS 8118 and are taken from BS 6262.

Design Methods

Design may be carried out using one of the following methods:

- Design calculations,
- Testing,
- Design charts.

Design calculations

There are several stages to design by calculation as follows:

- Establish the structural configuration(spans, joint types etc);
- Establish the loading(s);
- Calculate moments and forces which occur in the element as a result of the applied loading;
- Determine either the size of section required to carry these loads within the permitted stress and deflection limits or whether a proposed section is capable of carrying the load.

The first two stages will also be required when designing using tests or design charts. Calculation of the moments and forces in the components may be carried out by standard structural analysis techniques.

Codes of practice give formulae that can be used to calculate the capacity of structural components and limiting values for stresses. BS 8118 gives guidance on the design of aluminium structures and BS 5950 covers steel structures.

When carrying out calculations it is necessary to make assumptions. Depending on the design of the fixings, the behaviour of the mullions and transoms lies somewhere between that of a member with pinned ends (free to rotate) and that of a member with fixed ends (no rotation).

Brackets can be tested to determine the relationship between an applied moment and the resulting rotation of the member, and also to assess the behaviour of the brackets under shear load. The stiffness can then be taken into account in the design of the connected members. In the absence of such test data, curtain walling assembly and fixing connections may be assumed to have negligible rotational stiffness. This gives a safer design as 'real' structural joints have some rotational stiffness, which will increase the bending stiffness of the connected member.

It is normal practice to neglect the additional stiffness imposed by such elements as infill panels, pressure plates and cover caps when designing the frame sections because their stiffening effect is not easily quantified.

Both of these assumptions are safe but result in a loss of efficiency in the mullion and transom design.

Stresses and deflections vary along the length of the framing members. In design it is normal to calculate stresses and deflections where they are greatest and ensure that these values are acceptable. Assuming the cross section of the element is constant along its length, all other sections will also be adequate. The points of maximum bending stress, shear stress and deflection may not be coincident and it is necessary to establish the critical section for each criterion.

Testing

Tests may be carried out to establish the load carrying capacity of curtain walling. Tests may either be carried out on full size sections of the complete curtain wall or on individual components. If tests are carried out on components, care is necessary to ensure that the test conditions accurately simulate the conditions in the completed structure and that all parts of the system are tested.

Test criteria are given in he CWCT Standard and procedures are given in CWCT Test Methods for Curtain Walling. Tests are expensive to carry out but may give more economical design as strength of test assemblies may include effects ignored in calculation methods.

Design charts

To simplify the design process, most manufacturers of curtain walling systems produce design charts. These charts may have been derived from calculations in accordance with codes of practice or from load tests. Charts generally show the relationship between allowable mullion and transom spacing for different levels of wind load as illustrated in Figure 2.

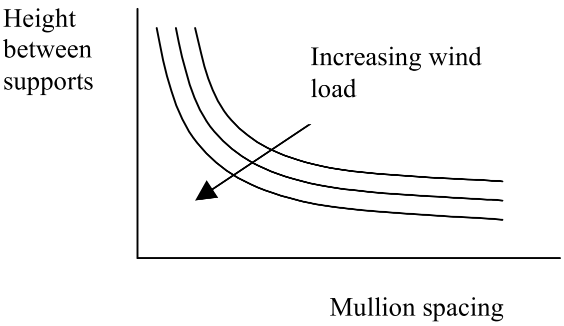

Figure 2 Form of typical design chart

Factors of safety

In structural design it is normal to apply a factor of safety to allow for the possibility of weaknesses in the material or loads being greater than expected. In some cases a single global factor may be used but it is more common to apply partial factors to both the loads and the material strengths. Different factors may be used for dead and live loads and when considering safety and serviceability.

It is important that the factors of safety are related to the design method as different design procedures may be based on different assumptions affecting safety. BS 8118 and BS 5950 give values for partial factors of safety for use in the design of aluminium and steel members respectively. The CWCT Standard gives safety factors for use in conjunction with load tests.

Structural systems

The structural behaviour of a curtain wall depends on the strength of the individual members and also on the way they are connected to each other and the supporting structure. Three ways of supporting the mullions may be used as described below. The calculation of bending moment, deflection and shear force for each support arrangement assumes that the only horizontal load is a uniformly distributed wind load with a total load of W on each storey height L.

The simplest method of construction is where the mullions are used as single span simply supported sections in which the ends of the members are free to rotate in response to the applied loads as shown in Figure 3. Typically the top of the section of mullion would be supported by the floor allowing transfer of dead and live load and the bottom would be supported by the section below via a sliding joint allowing transfer of horizontal live load only.

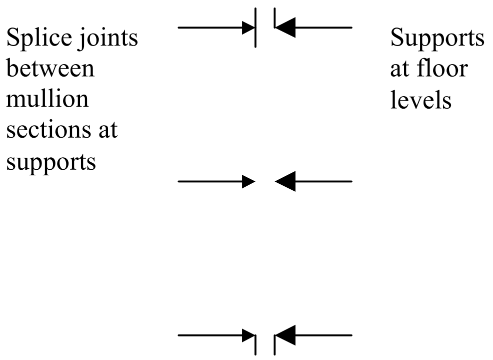

Figure 3 Simply supported storey height mullions

With this arrangement the maximum bending moment (M_{max}) in the mullion occurs at mid-span and is given by:

$$M_{max} = \frac{WL}{8},$$

the maximum deflection (δ_{max}) also occurs at mid-span and is given by:

$$\delta_{max} = \frac{5WL^3}{384EI},$$

and the maximum shear force (V_{max}) occurs at the ends of the mullion sections and is given by:

$$V_{max} = \frac{W}{2}.$$

This gives the least efficient structural behaviour. If the ends of the members are fixed to prevent rotation and hence transmit moments the member will generally be able to carry higher loads and give lower deflections. This could be achieved by a rigid support arrangement however this would require more complicated connections and a more convenient method which achieves a similar effect is to make the mullion continuous over more than one span. Figure 4 shows a section of mullion continuous over two spans. The supports at the ends of the section of mullion transfer loads as in the previous case and the central support transfers horizontal live load only.

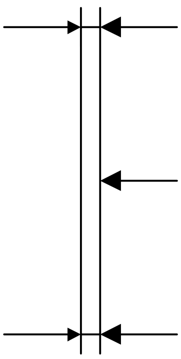

Figure 4 Two span continuous mullion

With this arrangement the maximum bending moment (M_{max}) in the mullion occurs at the central support and is given by:

$$M_{max} = \frac{WL}{8},$$

The maximum deflection (δ_{max}) occurs at 0.5785L from the central support and is given by:

$$\delta_{max} = \frac{WL^3}{185EI},$$

and the maximum shear force (V_{max}) occurs at the central support and is given by;

$$V_{max} = \frac{5W}{8}.$$

Although the value of the maximum moment is the same as for the single span case, the maximum deflection is reduced to less than half. As the design of aluminium mullions is generally governed by deflection rather than strength this gives a more efficient design.

An alternative arrangement that gives the benefit of continuity over the supports with single storey height mullion sections is to arrange the joints between mullion sections to occur approximately a fifth of the storey height above the support as shown in Figure 5.

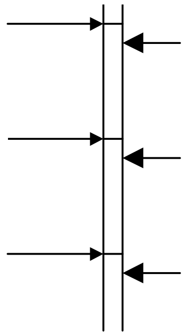

Figure 5 Single span mullion with joints offset from supports

With this arrangement the maximum bending moment (M_{max}) in the mullion occurs at the support and is given by:

$$M_{max} = \frac{WL}{12.5},$$

The maximum deflection (δ_{max}) occurs at 0.4628L from the support and is given by:

$$\delta_{max} = \frac{WL^3}{450EI},$$

and the maximum shear force (M_{ax}) occurs at the support and is given by:

$$V_{max} = \frac{W}{2}.$$

This arrangement gives a further reduction in deflection but also gives a reduced maximum moment. The shear force is also less than for the two span mullion section.

It is clearly essential that the curtain wall is erected with the same structural arrangements as used for the design

Fixings

Connections between transoms and mullions and between mullions and structural frame must also be designed. These connections normally consist of cleats or brackets screwed or bolted to the framing members and it is necessary to check the shear capacity of screws and bolts and the bearing capacity of the framing members. These connections often involve concentrated loads on thin webs of the framing members and it may be necessary to increase the bearing area by increasing the thickness of the webs or using larger diameter fixings.

Summary

Curtain walling is non-load bearing and is only required to support its own weight, wind loads and horizontal live loads arising from use of the building It must be able to transfer these loads to the main structural frame of the building.

The purpose of design is to ensure that this is achieved safely and without impairing the performance of the façade. Three methods of design are available as follows:

- Design calculations,
- Testing,
- Design charts.

References

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BS 6262, 1982, Code of practice for glazing for buildings, British Standards Institution.

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Part 1, 1996, *Code of practice for dead and imposed loads,*
Part 2, 1995, *Code of practice for wind loads*,
Part 3, 1988, *Code of practice for imposed roof loads*, British Standards Institution.

BS 8118: *Structural use of aluminium*, Part 1, 1985, *Code of practice for design,* British Standards Institution.

BS 8200, 1985, *Code of practice for design of non-loadbearing external vertical enclosures of buildings,* British Standards Institution.

CWCT, 1996, *Standard for curtain walling*, Centre for Window and Cladding Technology, University of Bath.

CWCT, 1996, *Test methods for curtain walling*, Centre for Window and Cladding Technology, University of Bath.

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