Technical Note No. 27

STRUCTURAL DESIGN OF STICK CURTAIN WALLING - Sample calculations

CENTRE FOR WINDOW AND CLADDING TECHNOLOGY

Introduction

Technical Note 26 describes the procedures that may be used to design stick curtain walling. This Technical Note gives examples of calculations for the design of aluminium stick curtain wall sections in accordance with BS 8118.

Example 1

Design a transom for a curtain wall with mullions spaced at 1.2m centre to centre (transom length of, say, 1.15m) and transoms spaced at 1.6m. The wall is glazed with 6/12/6 double glazed units.

Vertical loading

The transom must be designed to carry the dead load of the glass. The dimensioned assembly, together with the resulting bending moment and shear stress distribution in the transom due to dead loads, is illustrated in Figure 1.

The dead load of the glass unit is:

$$W_{glass\ unit} = \rho g X Y t$$

where:

- ρ is the density of glass, 2500 kg/m^3,
- g is the acceleration due to gravity, 9.81 m/s^2,
- t is the total thickness of glass, in m,
- X & Y are the length and height dimensions of the glass, in m,

Substituting the known values into the above equation:

$$W_{glass\ unit} = 2500 \times 9.81 \times 1.2 \times 1.6 \times 0.012$$

$$= 565\text{N}$$

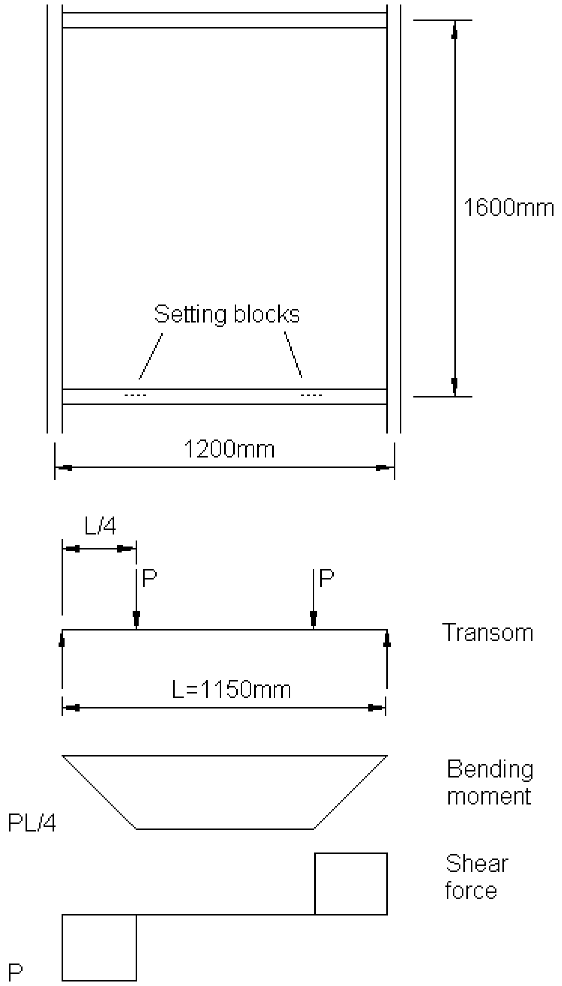


Figure 1 Dead loading on curtain wall transom and resulting stresses

Note that the glass occupies less area than the grid dimensions used in the calculation above (1.2 by 1.6m) but this over-estimate is compensated by neglecting the self-weight of the transom.

Glass units are supported on setting blocks and thus the dead load is applied as two vertical loads (assumed as point loads, P) on the transom generating bending and shear stresses (Figure 1). Here, a load of 283N (565/2) is applied through each of the two setting blocks to the transom (and thence the mullion). The bending moment and deflection of the transom will depend on the distance between the setting blocks and the ends of the transom. The calculations below assume that the setting blocks are placed at the quarter points of the transom, which are the preferred points of support for the glazing unit. To reduce the moment and deflection of the transom, the setting blocks are normally placed closer to the ends of the transom. The minimum distance from the edge of the unit to the start of the setting block is normally 30mm which puts the centre of the setting block about 100mm from the end of the transom. It is clearly important to ensure that the actual positions of the setting blocks in the structure are not further from the ends of the transom than assumed in design.

For design in accordance with BS 8118 a safety factor (γ_f) is applied to the load. In the case of strength calculations for dead load only γ_f takes the value 1.2 giving a design load of 340N. For calculation of deflection γ_f is taken as 1.0.

The design bending moment in the transom due to the weight of the glass is given by:

$M = \gamma_f PL/4 = (1.2\times283\times1.15)/4 = 98$Nm.

The design shear force is:

$V = \gamma_f P = 340$N

Bending resistance

Assuming elastic behaviour, the basic theory of bending gives:

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

where:

- M is the moment at the cross-section under consideration, Nmm,
- I is the second moment of area, $mm^{4,}$
- σ is the bending stress, $N/mm^{2,}$ at a distance y mm from the neutral axis,
- E is the Young's Modulus of the material, $N/mm^{2,}$
- R is the radius of curvature of bending, mm.

Rearranging this equation the maximum moment the section can carry is given by:

$$M_{max} = \sigma_{max} Z$$

Where $Z = I / y_{max}$, and is called the elastic section modulus.

Clause 4.5.2.2 of BS 8110 gives moment resistance as:

$$M = p_0 S \quad \text{or} \quad M = p_0 Z$$

where S and Z are, respectively, the plastic and elastic section models and p_o is the limiting stress in the aluminium.

Since bending resistance is unlikely to be the governing criterion and Z is easier to determine than S, use $p_o Z$.

The limiting stress p_o depends on the grade of aluminium and can be obtained from BS 8118 Table 4.2. The most common grade of aluminium for curtain wall sections is 6063 alloy in temper T6 for which the limiting stress is $160N/mm^2$. For design purposes this value is reduced by dividing by a safety factor γ_m which takes the value 1.2 from Table 3.3 of BS8118.

For example a proprietary transom 50mm wide and 28mm deep with $I_{yy} = 11\times10^4$ mm^4 and y_{max} = 25 mm would give

$M_{max} = (160/1.2)\times11\times10^4/25 = 587\times10^3$ Nmm

This greatly exceeds the applied moment and the section is satisfactory.

For the above equation to be valid the section must be able to develop the bending stresses. If the webs are too thin they may buckle before the maximum bending stress is reached and BS 8118 requires a check to ensure that buckling will not occur. This will be satisfied if;

$\beta < \beta_o$. where

- β is the slenderness parameter for a part of the section (for example a flange or web) which is determined in accordance with clause 4.3.2 of BS 8118. β varies according to the stress distribution in the element.

- β_o is a limiting value of β calculated in accordance with Table 4.3 of BS 8118.

In this case, $\beta = 0.35d/t$ for the web and b/t for the flange

where:

- d is the depth of the web element of the section (i.e. the clear depth of web between flanges), 45.8 mm,
- b is the width of the flange (i.e. the clear width of the flange between webs), 18.5 mm,
- t is the element thickness, 2.1mm.

hence:

$\beta_{web} = 0.35 \times 45.8/2.1 = 7.6$

$\beta_{flange} = 18.5/2.1 = 8.8$

$\beta_o = 22(250/p_o)^{1/2}$

where:

- p_o is 160 N/mm^2 as defined above

$\therefore \beta_o = 22(250/160)^{1/2} = 27.5$

Both values of β are less than β_o and therefore the section can develop the full elastic moment.

Shear resistance

It is first necessary to check whether the section is likely to be affected by buckling. A compact section is unaffected by buckling and from BS 8118 Clause 4.5.5.1 a section is compact if:

$d/t \leq 49(250/p_o)^{1/2}$

where the symbols are as defined above. By inspection the section considered above is compact.

Factored shear force resistance V_{RS} is given by:

$$V_{RS} = \left[\frac{(p_v A_v)}{\gamma_m}\right]$$

where:

- p_v is the limiting stress in shear, 95 N/mm^2 for aluminium alloy 6063 of temper condition T6 (BS 8118: Part 1),
- A_v is the effective shear area, mm^2,
- γ_m is the material factor = 1.2.

$A_v = 0.8 \times N \times D \times t$

where:

- D is the overall depth of web measured to the outer surfaces of flanges, 50 mm in the example,
- t is the web thickness, 2.1 mm,
- N is the number of webs, 2.

$\therefore A_v = 0.8 \times 2 \times 50 \times 2.1 = 168\text{mm}^2$

$$\therefore V_{RS} = \left[\frac{(95 \times 168)}{1.2}\right] = 13300\text{N} > 340\text{ N} \therefore \text{OK}$$

The peak shear force and bending moment coexist at the same cross-section along the transom and the capacity of the section may, therefore, be reduced by the combination of stresses. However, since the applied shear force is not more than half of the factored shear resistance, the factored bending moment resistance of the transom section can be assumed to be unaffected (Clause 4.5.4, BS 8118: Part 1).

Check deflection

The maximum deflection, $\delta_{max,}$ of a simply supported beam subject to two equal point loads is given by:

$$\delta_{max} = \frac{PL^3}{6EI}\left[\frac{3a}{4L} - \left(\frac{a}{L}\right)^3\right]$$

where:

- P is the point load, N,
- L is the span, mm,
- E is Young's Modulus of the material, 70×10^3 N/mm^2 for grade 6063 aluminium (BS 8118: Part 1),
- I is the second moment of area of the section about the axis of bending, 11×10^4 mm^4,
- a is the distance from the support to the point load, mm.

BS 6262 states that for fixed windows, setting blocks should usually be positioned as near to the quarter points as possible. Here, this is 300mm (i.e. 1200/4), which is assumed to be the dimension 'a' in the above equation. The deflection of the transom is limited to 5mm to guard against the glazed transom touching the glass unit below. The maximum deflection is given by:

$$\delta_{max} = \frac{283\times1150^3}{6(70\times10^3)(11\times10^4)}\left[\frac{3(300)}{4(1150)} - \left(\frac{300}{1150}\right)^3\right]$$

$= 2$ mm $\therefore$ OK

Horizontal loading

The glass units deflect under positive and negative wind loading, compressing the inner/outer gaskets and causing bending about the major axis of the supporting transom and mullion members. A trapezoidal wind loading distribution across the panel may be assumed, where a portion of the wind load is resisted by the transom (and transferred to the mullions as point loads) (see Technical Note 2 *Introduction to wind loading on cladding* and Figure 2).

If a wind load of 1600Pa is assumed, the total lateral load on the transom is:

W_{wind} = Area (m^2) × pressure (N/m^2)

Loaded area below transom = (0.4 × 0.4) + (0.4 × 0.4) = 0.32 m^2

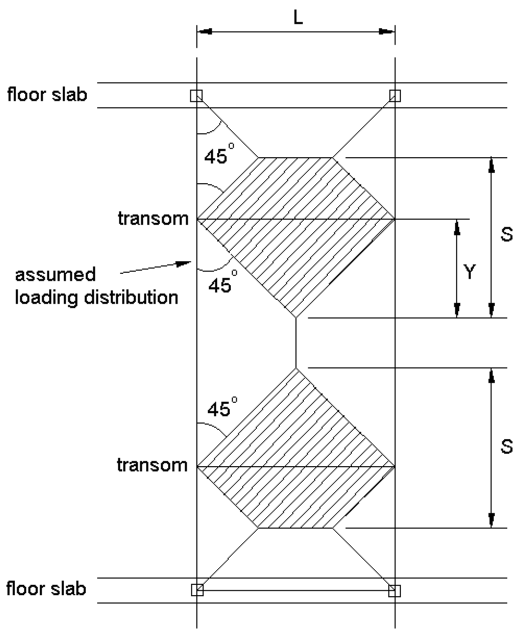
Loaded area above transom = 0.6 × 0.6 = 0.36 m^2

W_{wind} = Area (m^2) × pressure (N/m^2)

= 0.68 × 1600

= 1088 N

This wind load can be assumed to be uniformly distributed over the length of the transom.



L = length of transom, 1200 mm (approx.)
Y = maximum extent of load on transom, 600 mm
S = typical spacing of load between transoms, 400 + 600 mm = 1000 mm

Figure 2 Trapezoidal wind loading area resisted by transoms

Stresses

The design bending moment is equal to:

$M = \gamma_f WL/8 = (1.2\times1088 \times 1.15)/8 = 188$ Nm.

The design shear force is:

$V = \gamma_f W/2 = 1.2\times1088/2 = 653$ N

Bending resistance

For the transom selected above values for I and y_{max} for bending in the horizontal plane are 6.3 $\times 10^4$ mm^4 and 22.7 mm respectively and the maximum moment is therefore given by:

M_{max} = $(160/1.2) \times 6.3\times10^4/22.7$

= 370 Nm $\therefore$ OK

Check for buckling

$\beta_{web} = 0.6 \times d/t = 0.6 \times 18.5/2.1 = 5.3$

$\beta_{flange} = b/t = 45.8/2.1 = 21.8$

$\beta_o = 22(250/160)^{1/2} = 27.5$

Both values of β are less than β_o and the section is therefore satisfactory.

Shear resistance

Factored shear force resistance V_{RS} is given by:

$$V_{RS} = \left[\frac{(p_v A_v)}{\gamma_m}\right]$$

where:

$A_v = 0.8 \times N \times D \times t$

where:

- D is the overall depth of web measured to the outer surfaces of flanges, 28 mm,
- t is the web thickness, 2.1 mm,
- N is the number of webs, 2,

$\therefore A_v = 0.8 \times 2 \times 28 \times 2.1 = 94\ mm^2$

$$\therefore V_{RS} = \left[\frac{(95\times 94)}{1.2}\right] = 7441\text{N} > 653\text{ N} \therefore \text{OK}$$

Since the shear force is not more than half of the factored shear resistance, the factored bending moment resistance of the mullion section can be assumed to be unaffected (Clause 4.5.4, BS 8118: Part 1).

Check lateral deflection

The maximum deflection of a simply supported, uniformly loaded beam is:

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

where:

- W is the total load, in N,
- other terms as previously defined.

$$\delta_{max} = \frac{5\times 1088\times(1150)^3}{384(70\times10^3)(6.3\times10^4)} = 5\text{mm}$$

For framing members supporting double glazing units, the maximum frontal deflection under positive and negative peak wind load should not exceed the lesser of 1/175 of the length along the unit edge (here, 1200/175 = 6.9 mm) or 15mm (CWCT, 1996). Therefore, the deflection limit is satisfied.

Combined loading

The above calculations have considered the effects of dead and wind loads separately. As these loads can act at the same time it is necessary to check the effect of combining the loads. The full procedure is given in BS 8118 clause 4.8 however in this case the following condition should be satisfied

$$\frac{M_{xdesign}}{M_{x\,max}} + \frac{M_{ydesign}}{M_{y\,max}} \leq 1$$

substituting values determined above gives

$$\frac{188}{370} + \frac{98}{587} = 0.68 \therefore \text{OK}$$

Example 2

Design a mullion which spans over two floors (say, 6.4m) to resist a wind load of 1600 Pa (1.6 kN/m²) and the dead loads transferred from the connecting transoms in Example 1. Assume a *uniform distribution of wind loading on the facade.*

Loading

The dimensioned assembly, together with the resulting bending moment and shear stress distribution in the mullion due to the applied wind load, is illustrated in Figure 3. This loading is assumed to be uniformly distributed along the length of the mullion. Assuming it is supported at the top, the mullion is also subject to tension due to dead loads.

For a mullion spacing of 1.2m the total wind load per span is:

$W = \text{Area (m}^2) \times \text{Pressure (N/m}^2)$

$= (1.2 \times 3.2) \times 1600$

$= 6144$ N

Stresses

The most highly stressed cross-section occurs at the intermediate support where the bending moment is given by:

$M = \gamma_f WL/8 = (1.2 \times 6144 \times 3.2)/8 = 2950$ Nm.

This is also the region of peak shear force, given by:

$V = (5/8)\gamma_f W = (5/8)\ 1.2 \times 6144 = 4608$ N.

Bending resistance

The mullion can be designed as a simply supported continuous beam (Figure 3) by following the procedure described above. For example a proprietary mullion 50mm wide and 105mm deep with $I_{xx} = 165 \times 10^4$ mm^4 and y_{max} = 64 mm would give

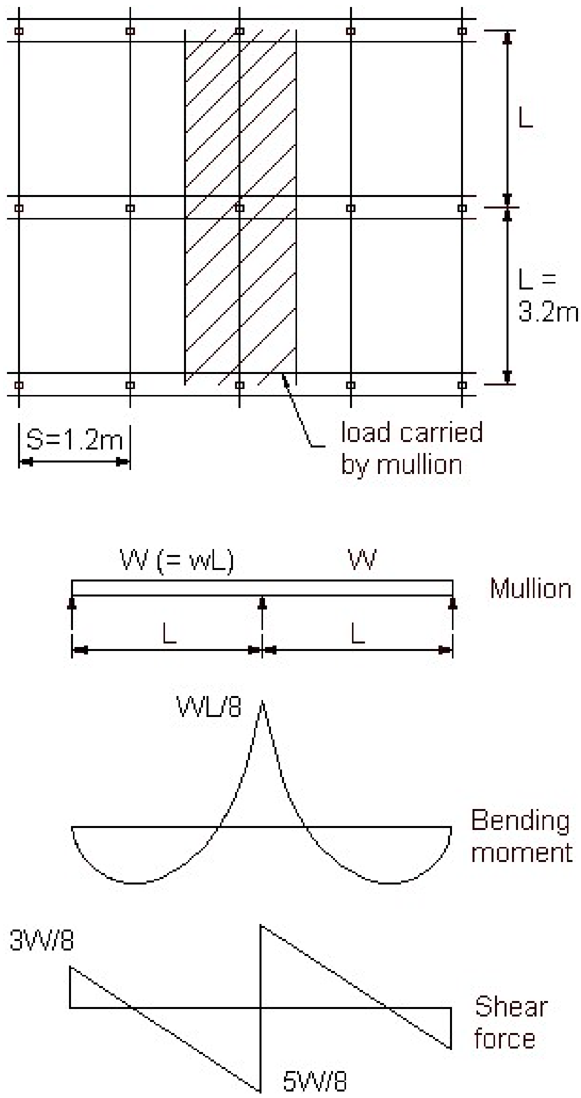


Figure 3 Live loading on curtain walling mullion

$M_{max} = (160/1.2) \times 165 \times 10^4/64 = 3438$ Nm

Check for buckling

$\beta_{web} = 0.5 \times d/t = 0.5 \times 86/2.1 = 20.5$

$\beta_{flange} = b/t = 45.8/2.1 = 21.8$

$\beta_o = 22(250/160)^{1/2} = 27.5$

Both values of β are less than β_o and the section is therefore satisfactory.

Shear resistance

Section is compact. Factored shear force resistance V_{RS} is given by:

$$V_{RS} = \left[\frac{(p_v A_v)}{\gamma_m}\right]$$

$A_v = 0.8 \times N \times D \times t$

where:

- D is the overall depth of web measured to the outer surfaces of flanges, 105 mm;
- t is the web thickness, 2.1 mm
- N is the number of webs, 2

$\therefore A_v = 0.8 \times 2 \times 105 \times 2.1 = 353\ mm^2$

$$\therefore V_{RS} = \left[\frac{(95 \times 353)}{1.2}\right] = 27900N > 4608\ N \therefore OK$$

Since the shear force is not more than half of the factored shear resistance, the factored bending moment resistance of the mullion section can be assumed to be unaffected (Clause 4.5.4, BS 8118: Part 1).

Check deflection

The maximum deflection of a continuous beam with two equal spans subject to a uniformly distributed load occurs at 0.5785 × span L, from the central support and is given by:

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

where:

- W is the total load on one span, N,
- L is the span between fixing points, mm,
- Other terms as previously defined.

Substituting known values gives:

$$\delta_{max} = \frac{WL^3}{185EI} = \frac{6.15 \times 10^3 \times 3200^3}{185 \times 70 \times 10^3 \times 165 \times 10^4}$$

$= 9.4mm$

The criteria for determining the deflection limit are the same as for the horizontal deflection of the transom. In this case the limit is 15 mm and the deflection is therefore acceptable.

Check tensile stress

The transoms either side of the mullion transfer the dead load from the infill elements to the mullion as an axial load; there is no net moment induced where transoms of equal span and loading connect on either side of the mullion. With the grid dimensions of the example wall, four transoms connect through either side of each two-storey mullion. The total vertical load on each such mullion is therefore:

- Half the weight of eight glass units = (8 × 565)/2 = 2300N
- Half the weight of eight transoms (1.19kg/m) = (1.19 × 9.81 × 1.35 × 8)/2 = 63.0 N
- Self-weight of mullion (2.99 kg/m) = 2.99 × 6.4 = 19.1 N

Total vertical load = 2382 N

Allowing for a safety factor of 1.2 gives a design load of 2860 N.This load, equal to approximately 1/5 of the wind load, causes tension in the mullion, assuming that the mullion is suspended. Note that this vertical load is transferred to the mullion at some eccentricity ‘e’ from its major axis, so inducing major axis bending in the member, however this moment is negligible compared with the maximum wind induced moment.

The factored tension resistance (P_{RS}) of the mullion is the lesser of the two values corresponding to:

1. General yielding along the member based on the general cross section;

2. Local failure at a critical section allowing for fixing holes.

General yielding along the member

$$P_{RS} = \left[\frac{(p_0 A)}{\gamma_m} \right]$$

where:

- A is the gross section area (i.e. the area of aluminium ignoring and drilled holes), mm^2

Substituting known values into the above equation gives:

$$P_{RS} = \left[\frac{(160)(954)}{1.2} \right] = 127 \times 10^3 \text{ N}$$

Local failure at critical section

$$P_{RS} = \left[\frac{(p_a A_n)}{\gamma_m} \right]$$

where:

- p_a is the limiting stress for local capacity of section under tension/compression, N/mm^2,
- A_n is the net section area, with deduction for holes, in mm^2.

The limiting tensile stress for an extrusion of alloy 6063, temper T4 is 175 N/mm^2 (BS 8118: Part 1). If a 13mm diameter hole through both webs is assumed at the support, then the tension resistance is:

$$P_{RS} = \left[\frac{(175)(954 - 2(13 \times 2.1))}{1.2} \right]$$

$$= 131 \times 10^3 \text{ N}$$

The lesser value of the factored tension resistance (P_{RS}) is 131kN which is far in excess of the tension caused by the transom loading (2.4kN). Therefore the mullion has adequate tension resistance in this case.

Summary

This Technical Note has followed calculations for the design of transoms and mullions of stick curtain walling to resist dead and wind load. Calculations have been included for flexural stresses and deflections, shear, local buckling and axial force. The design of brackets to connect the transoms to the mullions or the mullions to the structure has not been included.

The calculations are broadly in accordance with BS 8118 however no allowance for plastic behaviour, which is permitted by BS 8118, has been made.

References

BS 8118: Part 1, 1991, *Structural use of aluminium*, *Code of practice for design,* British Standards Institution.

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

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