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October 2013

STRUCTURAL CALCULATIONS

FOR

SG10 SYSTEM BALUSTRADES

USING 21.5mm LAMINATED TOUGHENED GLASS
without the need for a handrail

BY

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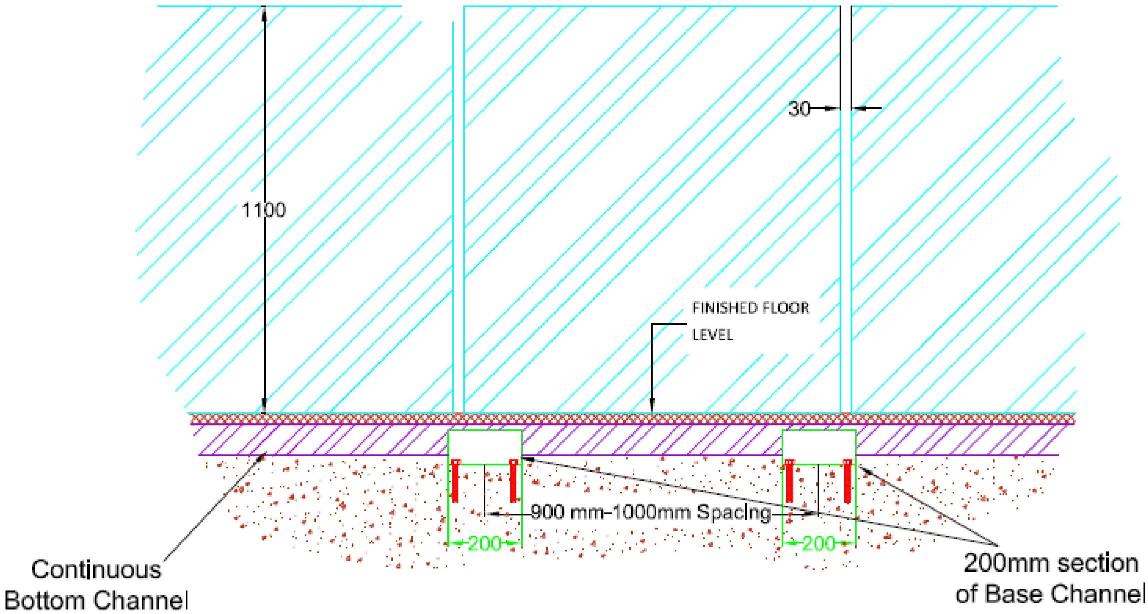
LAMINATED GLASS BALUSTRADE
without a handrail



STRUCTURAL SYSTEM ELEVATION

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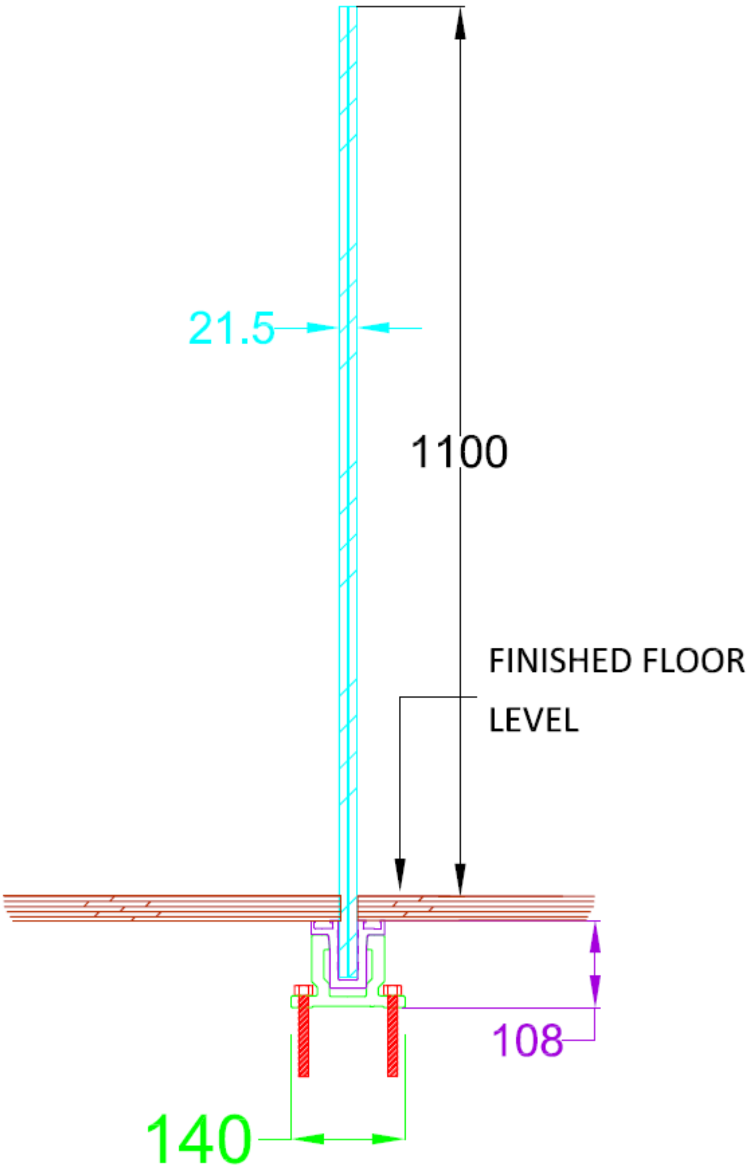

Structural System Section
with 21.5m Laminated Glass

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BALUSTRADE LOADS:

(a) Horizontal loads

The balustrade is designed to resist the horizontal imposed loads specified in **Table 4** of **BS 6399-1:1996** (see below), covering occupancy classes **A(i) and (ii), B(iii), (iv) and (v), C3(viii) and (ix).** The loads are separately applied, not co-existent. For the GS10 balustrade the horizontal uniformly distributed line load of 0.74 kN/m gives the most severe design condition. This load is applied 1100mm above finished floor level.

Table 4

Minimum horizontal imposed loads for parapets, barriers and balustrades, etc.

Type of occupancy for part of the building or structure	**Examples of specific use**	**Horizontal uniformly distributed line load (kN/m)**	**A uniformly distributed load applied to the infill (kN/m^2)**	**A point load applied to part of the infill (kN)**
A Domestic and residential activities	(i) All areas within or serving exclusively one **[A1]** single family **[A1]** dwelling including stairs, landings, etc but excluding external balconies and edges of roofs (see C3 ix)	0.36	0.5	0.25
	(ii) Other residential, (but also see C)	0.74	1.0	0.5
B and E Offices and work areas not included elsewhere including storage areas	(iii) Light access stairs and gangways not more than 600mm wide	0.22	N/A	N/A
	(iv) Light pedestrian traffic routes in industrial and storage buildings except designated escape routes	0.36	0.5	0.25
	(v) Areas not susceptible to overcrowding in office and institutional buildings also industrial and storage buildings except as given above	0.74	1.0	0.5
C Areas where people may congregate C1/C2 Areas with tables or fixed seating	(vi) Areas having fixed seating within 530 mm of the barrier, balustrade or parapet	1.5	1.5	1.5
	(vii) Restaurants and bars	1.5	1.5	1.5
C3 Areas without obstacles for moving people and not susceptible to overcrowding	(viii) Stairs, landings, corridors, ramps	0.74	1.0	0.5
	(ix) External balconies and edges of roofs. Footways and pavements within building curtilage adjacent to basement/sunken areas	0.74	1.0	0.5
C5 Areas susceptible to overcrowding	(x) Footways or pavements less than 3 m wide adjacent to sunken areas	1.5	1.5	1.5
	(xi) Theatres, cinemas, discotheques, bars, auditoria, shopping malls, assembly areas, studio. Footways or pavements greater than 3 m wide adjacent to sunken areas	3.0	1.5	1.5
	(xii) **[A1]** Grandstands and stadia **[A1]**	See requirements of the appropriate certifying authority		
D Retail areas	(xiii) All retain areas including public areas of banks/building societies or betting shops. For areas where overcrowding may occur, see C5	1.5	1.5	1.5
F/G Vehicular	(xiv) Pedestrian areas in car parks including stairs, landings, ramps, edges or internal floors, footways, edges of roofs	1.5	1.5	1.5
	(xv) Horizontal loads imposed by vehicles	See clause 11		
[A1] Not deleted [A1]				

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BALUSTRADE LOADS (continued):

(b) Vertical loads
The balustrades are designed to resist the vertical loading as specified by amendment [A_1] of BS6399-1:1996 (October 2002)). This stipulates that all parapets, barriers and balustrades should be designed for a vertical load of 0.60 kN/m or a concentrated load of 1.0 kN, whichever gives the worst design condition in combination with the horizontal loading given in Table 4.

FACTORED LOADS:
Factored loads are used for checking the limit state of static strength of the aluminium components. The imposed horizontal and vertical loads tabulated above are known as 'service loads'. These loads are multiplied by a load factor γ of 1.33 (Table 3.1 of BS8118:Part 1:1991 '*The structural use of aluminium*') to give 'limit state' or 'ultimate' design loads that are used in relation to the factored resistance capacity of aluminium members. The glass is designed for service loads.

PROPERTIES OF ALUMINIUM:

Design standard	=	BS8118:Part 1:1991 '*The structural use of aluminium*'.
Material type	=	Extruded aluminium type 6063 T5
Limiting stress for bending and overall yielding	=	P_o = 110 N/mm^2 (Table 4.1)
Limiting stress for tension or compression	=	P_s = 130 N/mm^2 (Table 4.1)
Limiting stress for shear	=	P_v = 65 N/mm^2 (Table 4.1)
Young's modulus of elasticity	=	E = 70,000 N/mm^2
Factored resistance capacity	=	Calculated member capacity based upon the limiting stresses P_o P_s and P_v divided by the material factor γm = 1.2

PROPERTIES OF GLASS:

Type	=	21.5mm thick laminated glass comprising 2 plies of 10mm toughened glass with a 1.52mm pvb interlayer.
Designated mechanical strength	=	120 N/mm^2
Design standard	=	BS EN 12150 Parts 1 and 2 '*Glass in buildings*' in conjunction with load tests carried out by the glass manufacturer
Short term working load stress	=	59 N/mm^2
Long term working load stress	=	35 N/mm^2
E value	=	70,000 N/mm^2

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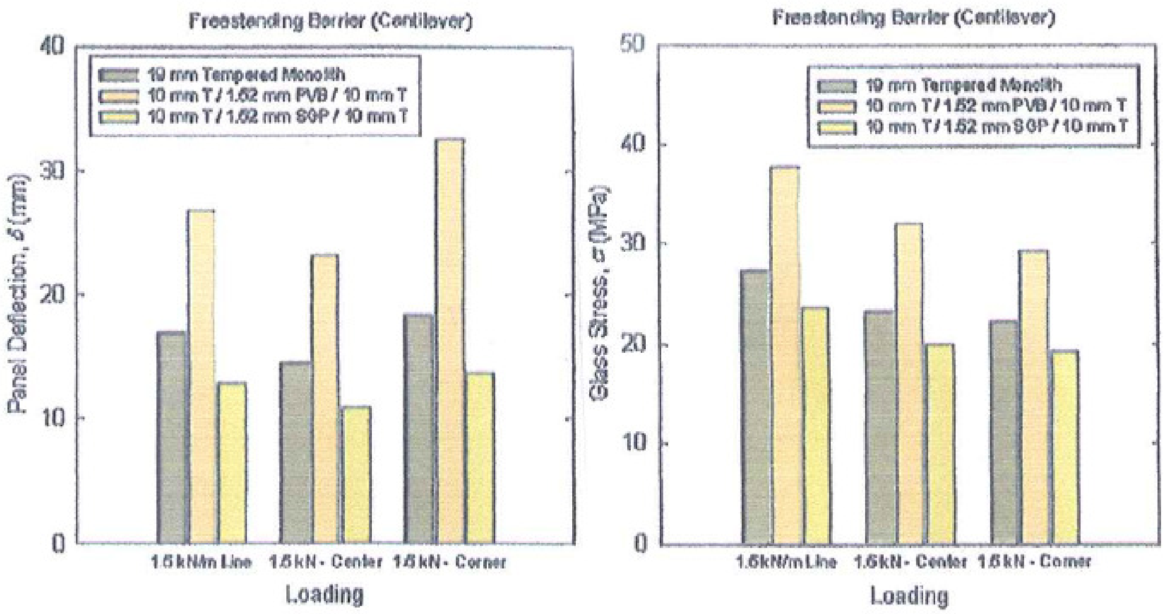
DEFLECTION:
All structural members deflect to some extent under load. For balustrades the deflection is limited to 25mm under service load conditions.

GLASS DESIGN:
Load tests carried out by the glass manufacturer, JCGC Limited, compare the performance of monolithic and laminated glass in freestanding barriers. It was found that stresses and deflection of laminated glass manufactured with a pvb interlayer differed from that of monolithic glass of similar overall thickness. To compensate for this difference in performance the design of the 21.5mm thick laminate glass is based upon an effective thickness of 15mm.

A summary of the test results, published in Glass Performance Days 2007, is shown below.



Comparison of monolithic and laminated glass subjected to barrier loads

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STRUCTURAL SYSTEM: The glass acts as a vertical cantilever to resist a horizontal force of 0.74 kN/m applied at a height of 1100mm above finished floor level (say 1150 to mid-height of the supporting channel).

Effective thickness of 21.5mm laminated glass for design purposes	=	15mm		
service load moment applied to glass	=	M	=	0.74 x 1.15
			=	0.851 kNm/m
1^{st} moment of area of glass	=	Z	=	$\frac{1000 \times (15)^2}{6}$
			=	37500 mm^3/m
bending stress	=	f_{bc}	=	$\frac{M}{Z}$
	=	$\frac{0.851 \times (10)^8}{37500}$	=	22.69 N/mm^2
	=	< 59 N/mm^2	=	OK
service load deflection of glass	=	Δ	=	$\frac{PL^3}{3EI}$
2^{nd} moment of area of glass	=	'I'	=	$\frac{1000 \times (15)^3}{12}$
			=	281250 mm^4/m
Young's modulus for glass	=	E	=	70000 N/mm^2
deflection	=	Δ	=	$\frac{740 \times (1150)^3}{3 \times 70000 \times 281250}$
	=	19.055m	=	<25mm OK
shear stress on glass (average)	=	qs	=	$\frac{740}{1000 \times 15}$
			=	0.05 N/mm^2 OK
vertical compressive stress based on 2 x 10mm thick plies	=	$\frac{600}{1000 \times 20}$	=	0.03 N/mm^2 OK

The 21.5mm thick laminated thermally toughened safety glass is adequate.

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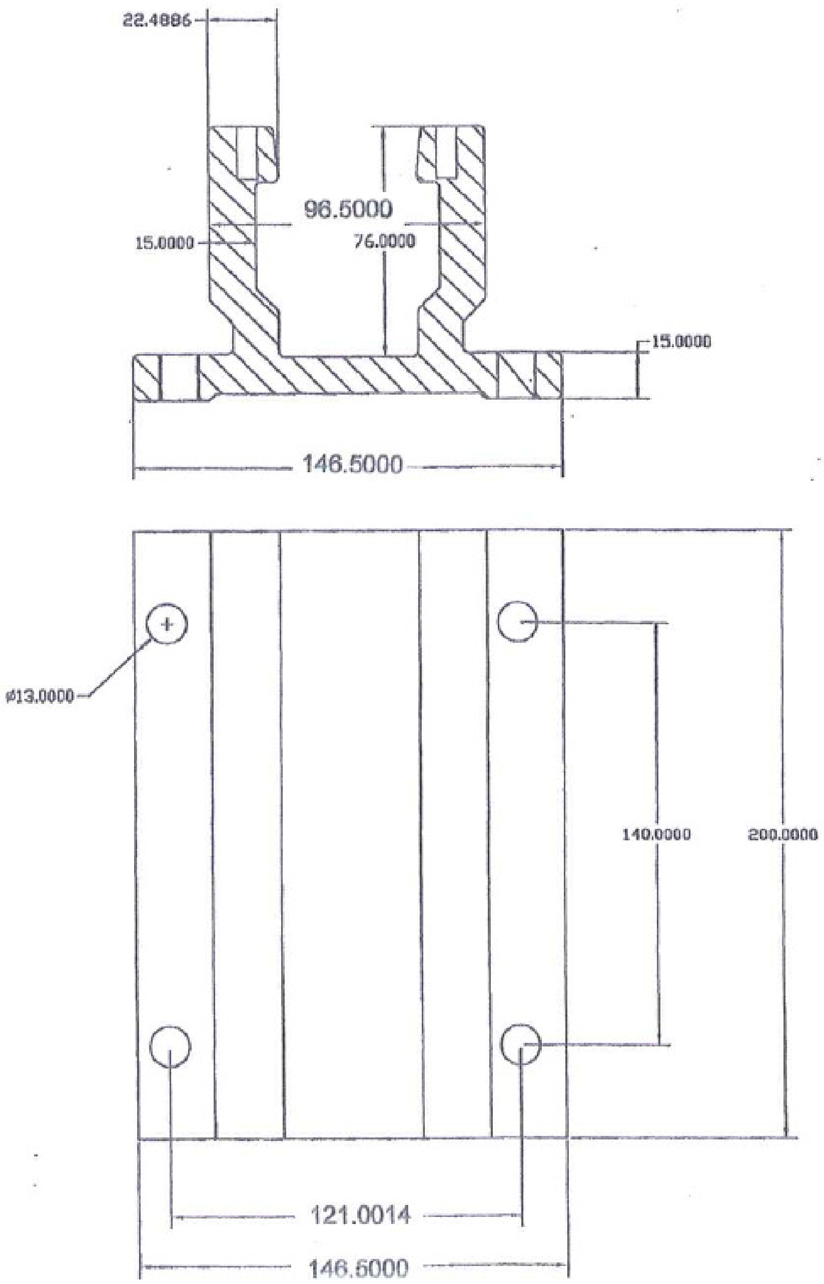
BASE FIXING CHANNELS:



BASE FIXING CHANNEL

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BASE FIXING CHANNELS: (continued)
Fixings are at 900mm centres.

Holding down bolts:

Applied service load moment		=	0.74 kN/m x 0.90 centres x 1.22
to top of concrete structure		=	0.8125 kNm/base fixing
transverse spacing of HD bolts		=	121.00mm
service load pull-out force on HD bolts		=	$\frac{\text{applied moment}}{\text{distance between the bolt centres}}$
		=	$\frac{0.8125}{0.121 \times 2 \text{ No.}}$
		=	3.357 kN/bolt
		=	within the safe working load capacity of most types of drilled resin anchor bolts or similar into concrete

Channels:

Factored moment applied	M	=	0.74 x (1.33) x 0.90 x 1.167
to channels @ 900 c/c		=	1.034 kNm
length of channel	L	=	200mm
thickness of metal	t	=	15mm
section modulus	Z	=	$\frac{200 \times (15)^2}{6}$
		=	$7500mm^3$
allowable bending stress	P_o	=	$110 N/mm^2$
material factor	y_m	=	1.20
moment capacity of section (one side)	Mc	=	$\frac{(P_o) \times (Z)}{(y_m)}$
		=	$\frac{110 N/mm^2 \times 7500}{1.2} \times (10)^{-8}$
		=	0.6875 kNm each side
		=	1.375 kNm for both sides
		=	> 1.034 kNm
		=	adequate

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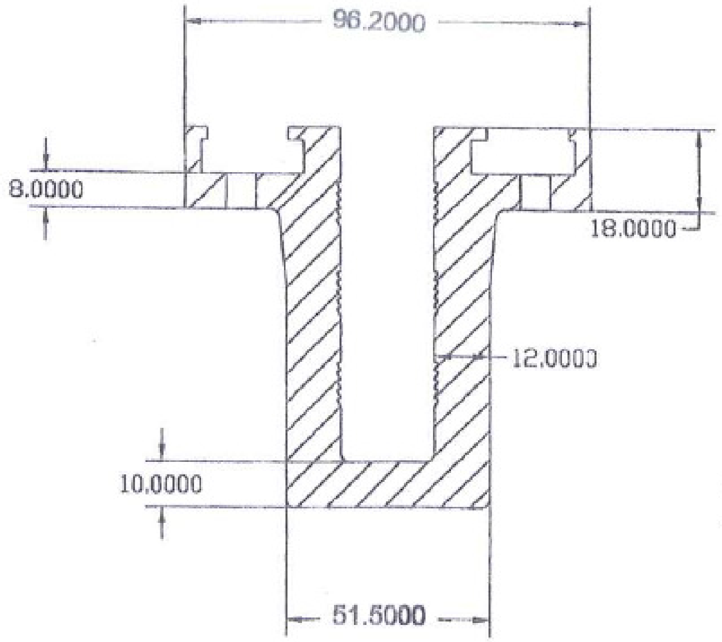
CONTINUOUS BOTTOM CHANNEL:



Continuous Channel

Vertical bending on channel:

Factored applied moment	=	0.74 kN/m x 1.33 (Y) x 1.15
	=	1.132 kNm/m
Z of one leg of channel	=	$\frac{1000 \times (12)^2}{6}$
	=	24000 mm^3/m
Bending stress	=	$\frac{1.132 \times (10)^6}{24000}$
	=	47.17 N/mm^2
	=	< 59 N/mm^2 = OK

Horizontal bending on channel:

Factored applied load	=	0.74 kN/m x 1.33 (Y)
	=	0.984 kN/m
Distance between centres of supports	=	900mm
Factored applied moment	=	$\frac{0.984 \times (0.9)^2}{8}$
	=	0.10 kN/m

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Horizontal bending on continuous bottom channel: (continued)

For design purposes consider a simplified 'U' shaped channel 83mm overall high x 45mm overall width, with 12mm thick sides and a 10mm thick base.

'I'yy $= 2\left[\left(\frac{83 \times 12^3}{12}\right) + (83 \times 12 \times [16.5]^2) + 10 \times \frac{(21)^3}{12} \right]$

$= 581661\text{mm}^4$

Zyy $= \frac{581661}{22.5}$

$= 25852\text{mm}^3$

bending stress $= \frac{0.10 \times (10)^6}{25852}$

$= 3.87\ \text{N/mm}^2$ negligible = OK

Torsion on bottom channel:
Consider an 'L' shaped half section as follows:

overall height	=	a	=	83mm
thickness of vertical leg	=	b	=	12mm
projection of btm leg	=	c	=	10.5mm
thickness of btm leg	=	d	=	10mm
largest inscribed circle	=	D	=	10mm
internal radius	=	r	=	2mm
area of section	=	A	=	1100mm^2

Properties of the complete 'U' shaped section will be twice that of the 'L' half section.

torsional shear stress = s = $\frac{T}{K} C_1$

where $C_1 = \dfrac{D}{1 + \dfrac{\pi^2 D^4}{16 A^2}} \left[1 + 0.15 \left(\dfrac{\pi^2 D^4}{16 A^2} - \dfrac{D}{2r} \right) \right]$

T = torsional moment

$K = K_1 + K_2 + \alpha D^4$

$K_1 = a b^3 \left[\frac{1}{3} - 0.21 \frac{b}{a} \left(1 - \frac{b^4}{12a^4} \right) \right]$

$K_1 = 83 \times (12)^3 \left[\frac{1}{3} - 0.21 \times \frac{12}{83} \left(1 - \frac{(12)^4}{12\,(83)^4} \right) \right]$

$= 43027$

$K_2 = cd^3 \left[\frac{1}{3} - 0.105 \frac{d}{c} \left(1 - \frac{d^4}{192c^4} \right) \right]$

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Torsion on bottom channel: (continued)

$$K_2 = 10.5 \times (10)^3 \left[\frac{1}{3} - 0.105 \times \frac{10}{10.5} \left(1 - \frac{(10)^4}{192\,(10.5)^4} \right) \right]$$

$$= 2415$$

$$\alpha = \frac{d}{b} \left(0.07 + 0.076 \frac{r}{b} \right)$$

$$= \frac{10}{12} \left(0.07 + 0.076 \times \frac{2}{12} \right)$$

$$= 0.069$$

$$K = K_1 + K_2 + \alpha D^4$$

$$= 43027 + 2415 + 0.069 \times (10)^4$$

$$= 46132$$

Torsional moment on channel = 0.984 kN/m x 1.15 x 0.35 = 0.396 kNm

$$\frac{\pi^2 D^2}{16 A^2} = \frac{(3.142)^2 (10)^4}{16 \text{ X } (1100)^2}$$

$$= 5.099 \text{ X } (10)^{-3}$$

$$1 + \frac{\pi^2 D^4}{16 A^2} = 1.0 \text{ approximately}$$

$$c_1 = \frac{10}{1.0} \left[1 + 0.15 \left(1.0 - \frac{10}{4}\right) \right.$$

$$= 7.75$$

torsional shear stress on U section $= \frac{T}{K} \times c_1$

$$= \frac{0.396 \times (10)^6}{46132 \times 2 \text{ No}} \times 7.75$$

$$= 33.27 \text{ N/mm}^2 \qquad \text{OK}$$

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SUMMARY

1. The SG10 laminated glass balustrade system by Balcony Systems Limited comprises 2 plies of 10mm thick thermally toughened safety glass with a 1.52mm pvb interlayer, without the need for a handrail.

2. The glass balustrade acts as a vertical cantilever from the balcony structure to resist the horizontal design loads imposed on the balustrade in accordance with Table 4 of BS6399-1:1996 for the occupancy classes listed on page 4 of these calculations.

3. Vertical design loads area transmitted direct through the glass to the balcony structure. Compressive stresses in the glass are low and acceptable.

4. The glass is secured into a continuous aluminium base channel that is anchored to the balcony structure by means of base fixing brackets at 900mm centres.

5. These structural calculations show that the SG10 system is adequate to support the horizontal and vertical balustrade design loads specified in BS6399-1:1996.

6. With the base fixing brackets at 900mm centres the calculated working load pull-out force on each of the holding down bolts is 3.357 kN.

7. A safe working load pull-out force of 3.357 kN per bolt should be readily achievable with 12mm diameter drilled resin anchor bolts or similar installed into sound concrete or bolted direct to a structural steel frame. Fixings to balconies constructed of materials other than concrete or steel should be separately assessed.

8. The installers should satisfy themselves that the fixing bolts chosen are suitable to resist the holding down pull-out load specified, and also that the structure into which the bolts are installed is adequate to support these loads.

END