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July 2012

STRUCTURAL CALCULATIONS

FOR

BALUSTRADES

USING SG10 SYSTEM

BY

BALCONY SYSTEMS LIMITED

Prepared by : WRD Engineers Limited
Registered in England: No. 07977613 : The Stables, Rear of 60 The Avenue, SOUTHAMPTON, SO17 1XS
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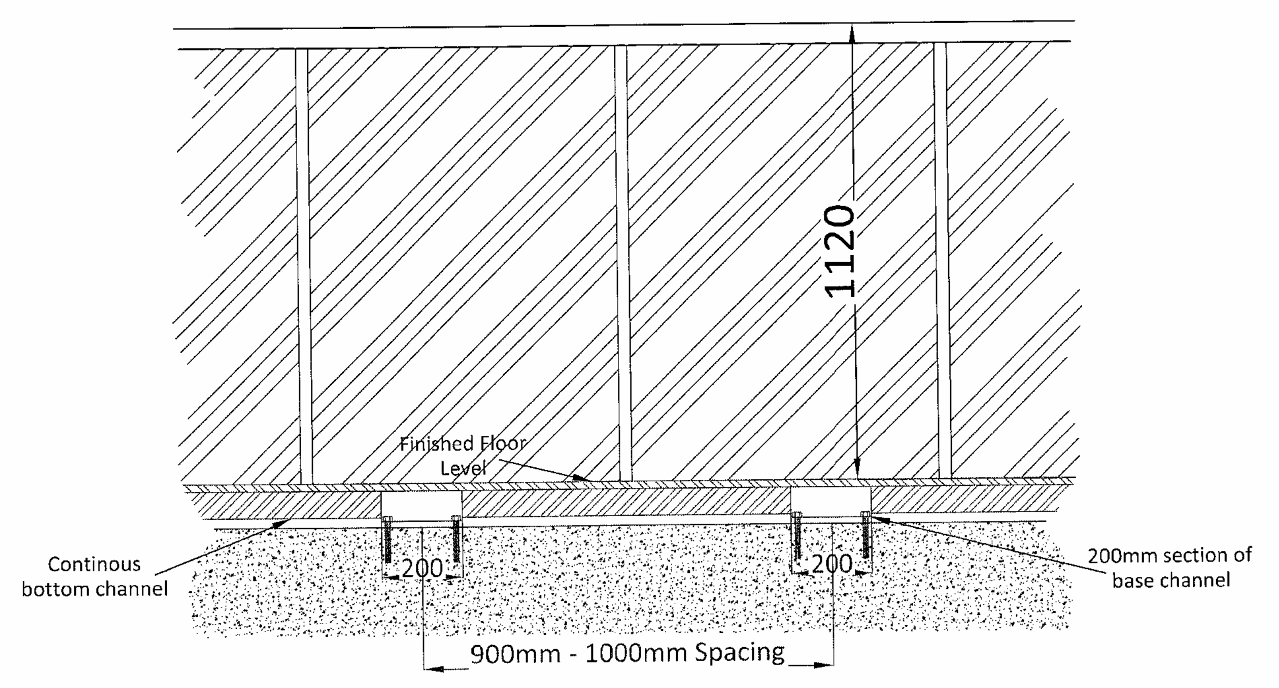

Structural System Side Section

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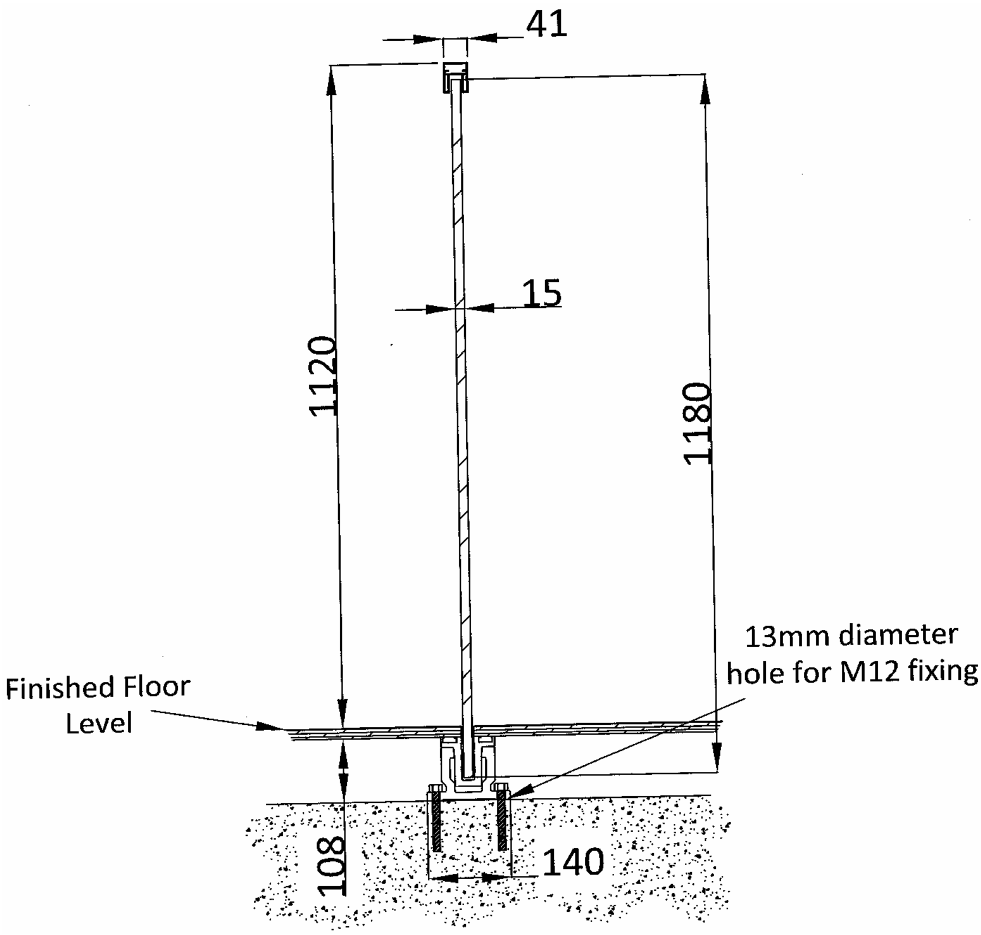

Structural Section

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BALUSTRADE 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), and (iii), (iv) and (iii).** The loads are separately applied, not co-existent. For the GS 10 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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VERTICAL LOADS:
BS 6399:1996 also specifies that handrails shall be designed for a vertical uniformly distributed imposed live 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 in Table 4.

Vertical loads on the handrail are transmitted direct to the balcony structure through the 15mm thick thermally toughened safety glass. The concentrated load of 1.0 kN is spread by the handrail. The maximum compressive stress on the glass is 600/15 x 1000 = 0.04 N/mm^2. This is a low value of compressive stress and well within the safe allowable stress recommended by Pilkington Glass Ltd, the glass manufacturer.

PROPERTIES OF ALUMINIUM:

Design standard	=	BS 8118: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	=	Calculated member capacity based upon the limiting stresses P_o P_s & P_v divided by the material factor γ_m = 1.2		

FACTORED LOADS:
Factored loads are used for checking the limit state of static strength of the aluminium members. The imposed loads tabulated on page 4 are known as 'service loads'. These loads are multiplied by a load factor γ of 1.33 (Table 3.1) to give 'limit state' design loads that are used in relation to the factored resistance capacity of a member. The glass is designed for service loads.

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PROPERTIES OF GLASS:

Type	=	15mm thick thermally toughened soda lime silicate safety glass.
Designated mechanical strength	=	120 N/mm^2
Design standard	=	BS EN 12150 Parts 1 and 2 *'Glass in building'*
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

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

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).

service load moment applied to glass = $M = 0.74 \times 1.15$

$= 0.851$ kNm/m

1st moment of area of glass = $Z = \frac{1000 \times (15)^2}{6}$

$= 37500\ mm^3/m$

bending stress = $f_{bc} = \frac{M}{Z}$

$= \frac{0.851 \times (10)^6}{37500}$

$= 22.69\ N/mm^2$

$= < 59\ N/mm^2$ = OK

service load deflection of glass = $\Delta = \frac{P L^3}{3 E I}$

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2nd 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	=	$\frac{740 \times (1150)^3}{3 \times 70000 \times 281250}$		
			=	19.055mm		
			=	< 25 mm	=	OK
shear stress on glass (average)	=	qs	=	$\frac{740}{1000 \times 15}$		
			=	0.05 N/mm^2	=	OK

The 15mm thick thermally toughened safety glass is adequate.

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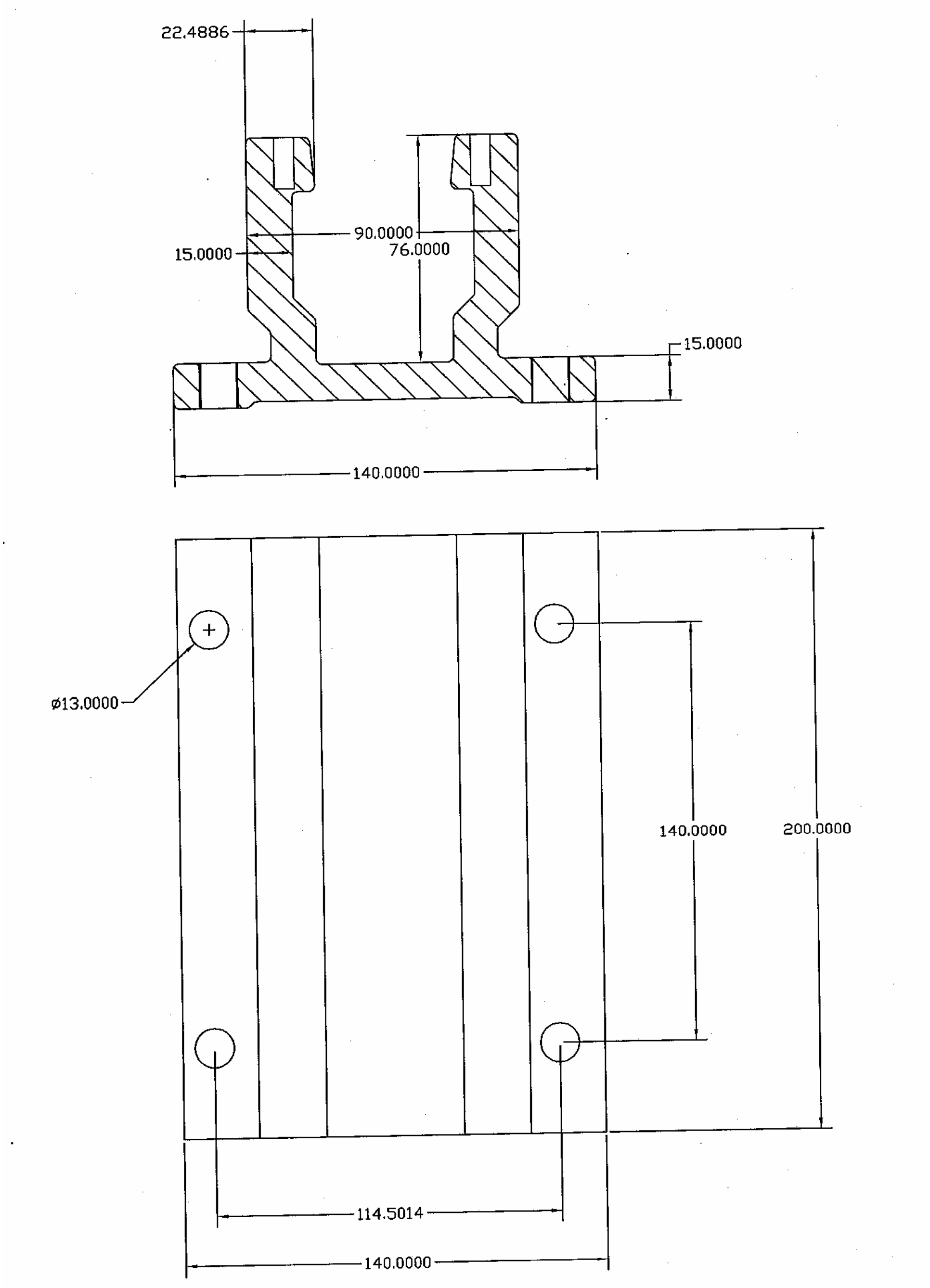
BASE FIXING CHANNELS:



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	=	114.50 mm
service load pull-out force on HD bolts	=	applied moment / distance between the bolt centres
	=	0.8125 / 0.1145 x 2 No.
	=	3.548 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	=	200 mm
thickness of metal	t	=	15 mm
section modulus	Z	=	$\frac{200 \times (15)^2}{6}$
		=	7500 mm^3
allowable bending stress	P_o	=	110 N/mm^2
material factor	y_m	=	1.20
moment capacity of section (one side)	M_c	=	$\frac{(P_o) \times (Z)}{(y_m)}$
		=	$\frac{110\ N/mm^2 \times 7500}{1.2} \times (10)^{-6}$
		=	0.6875 kNm each side
		=	1.375 kNm for both side
		=	> 1.034 kNm
		=	adequate

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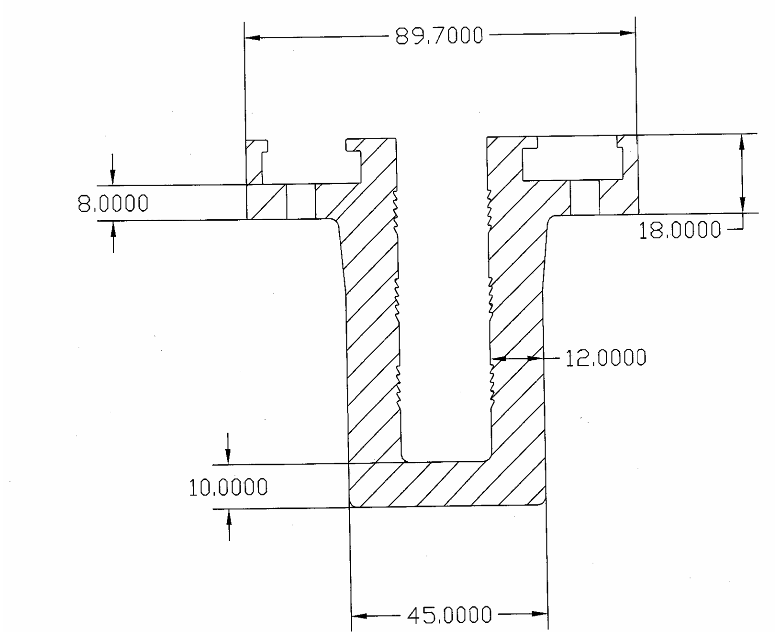
CONTINUOUS BOTTOM CHANNEL:



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	=	900 mm
Factored applied moment	=	$\frac{0.984 \times (0.9)^2}{8}$
	=	0.10 kNm

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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

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

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

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

$= 43027$

$K_2 = c d^3 \left[\dfrac{1}{3} - 0.105 \dfrac{d}{c} \left(1 - \dfrac{d4}{192 c^4} \right) \right]$

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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

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

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

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

$$c_1 = \frac{10}{1.0} \left[1 + 0.15 \left(1.0 - \frac{10}{4} \right) \right]$$
$$= 7.75$$

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

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

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

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SUMMARY

1. The SG10 balustrade system by Balcony Systems Limited comprises 15mm thick thermally toughened soda lime silicate safety glass that resists horizontal loads imposed on the balustrade by cantilever action from the balcony structure. The glass is secured into a continuous aluminium channel that is anchored to the balcony structure by means of base fixing brackets at 900mm centres.

2. These structural calculations show that the SG10 system is adequate to support the balustrade design loads specified in Table 4 of the BS 6399-1:1996, relating to horizontal uniformly distributed line loading of 0.74 kN/m (Occupancy types A, B, E and C3 in Table 4).

3. With the base fixing brackets at 900mm centres the working load pull-out force on each of the holding down bolts is 3.584 kN.

4. A safe working load pull-out force of 3.584 kN per bolt should be readily achievable with 12mm diameter drilled resin anchor bolts or similar installed into concrete or bolted direct to a structural steel frame. Fixings to balconies constructed of materials other than concrete or steel should be separately assessed.

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

6. Any handrail shape can be chosen to be placed on top of the glass as this does not change the calculations herein.

END

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