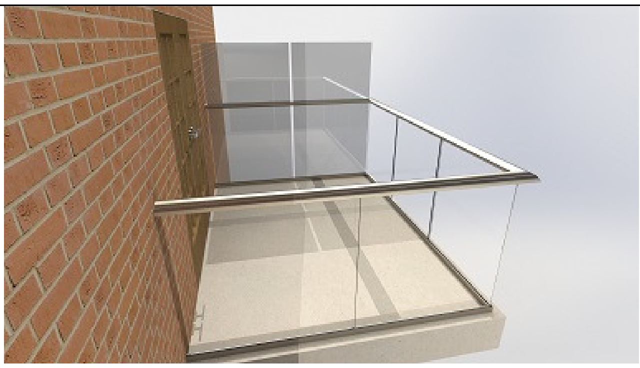
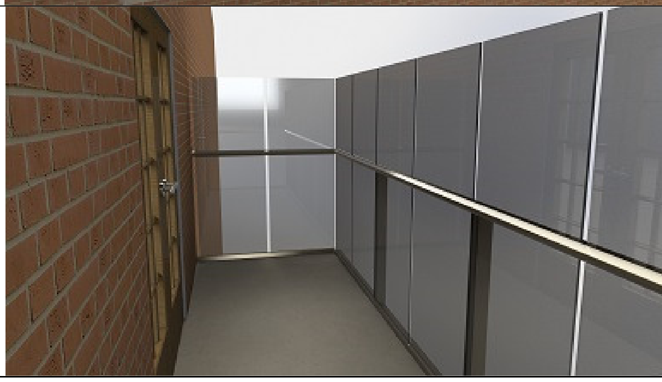
Balcony 2 pass through 1.8m privacy screen system: ***PAGE 1*** **(B2PTX240718)**

Structural Calculations for BALCONY 2 pass-through 1.8m privacy screen system for more severe wind loads: handrail with & without 58 x 4mm internal steel reinforcing bar: 60 x 60 x 5 SHS posts: alternative base plate options

Our ref: B2PTX240718 **Date of issue: July 2018**



Balcony 2 pass-through privacy screen fixed on one side only



Balcony 2 pass-through privacy screen on a 3 sided balcony

DESIGN TO EUROCODES & CURRENT BRITISH STANDARDS

Design standards:

EN 1990	Eurocode 0:	Basis of structural design.
EN 1991	Eurocode 1:	Actions on structures.
EN 1991-1-4:2002 + A1 2010 + NA	Eurocode 1:	Actions on structures – wind actions.
EN 1993	Eurocode 3:	Design of steel structures.
EN 1999	Eurocode 9:	Design of aluminium structures.
BS EN 1990:2002 + A1:2005	Eurocode:	UK National annex for Eurocode
BS 6180:2011		British Standard: Barriers in and about buildings.

Design imposed loads:

Occupancy class/es for which this design applies (Table 2: BS6180:2011)

Domestic and residential activities (i) & (ii)
Office and work areas not included elsewhere (iii), (iv) & (v)
Areas without obstacles for moving people and not susceptible to overcrowding (viii) & (ix).

Service load on handrail Q_k = 0.74 kN/m uniformly distributed line load acting 1100mm above finished floor level. (Table 2: BS6180:2011)

Service load applied to the glass infill Qk1 = A uniformly distributed load of 1.0 kN/m^2

Point load on glass infill = 0.50 kN applied to any part of the glass fill panels

Balcony 2 pass – through 1.8m privacy screen system for more severe wind loading: ***PAGE 2*** (B2PTX240718)

Table 2 **Minimum horizontal imposed loads for parapets, barriers and balustrades**

Type of occupancy for part of the building or structure	Examples of specific use	Horizontal uniformly distributed line load (kN/m)	Uniformly distributed load applied to the infill (kN/m²)	A point load applied to part of the infill (kN)
Domestic and residential activities	(i) All areas within or serving exclusively one single family dwelling including stairs, landings, etc. but excluding external balconies and edges of roofs	0.36	0.5	0.25
	(ii) Other residential, i.e. houses of multiple occupancy and balconies, including Juliette balconies and edges of roofs in single family dwellings	0.74	1.0	0.5
Offices and work areas not included elsewhere, including storage areas	(iii) Light access stairs and gangways not more than 600 mm wide	0.22	—	—
	(iv) Light pedestrian traffic routes in industrial and storage buildings except designated escape routes	0.36	0.5	0.25
	(v) Areas not susceptile to overcrowding in office and institutional buildings, also industrial and storage buildings except as given above	0.74	1.0	0.5
Areas where people might congregate	(vi) Areas having fixed seating within 530 mm of the barrier, balustrade or parapet	1.5	1.5	1.5
Areas with tables or fixed seatings	(vii) Restaurants and bars	1.5	1.5	1.5
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 including Juliette balconies and edges of roofs. Footways and pavements within building curtilage adjacent to basement/sunken areas	0.74	1.0	0.5

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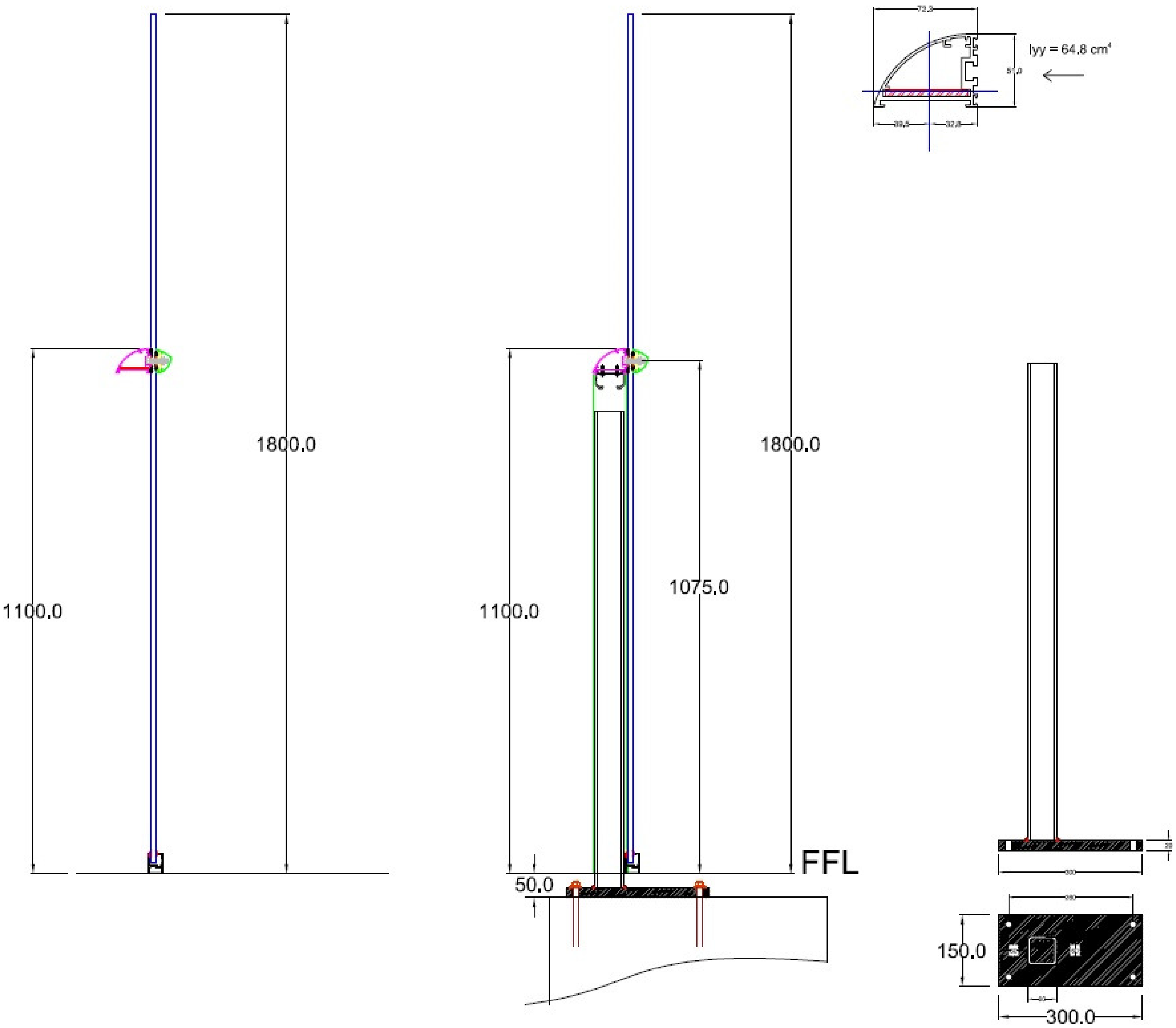
Table 2: BS6180:2011

- These loads are considered as three separate load cases. They are not combined. Wind loading is also considered as a separate design case.
- Factored loads are used for checking the limit state of static strength of a member.
- The service loads are multiplied by a partial factor for variable action $\gamma_{Q,1}$ of 1.5 to give the ultimate design load for leading variable action.

Deflection:

- All structural members deflect to some extent under load. Service loads are used to calculate deflections.
- The total displacement of any point of a barrier from its original unloaded position under the action of service loads is limited to 25mm.

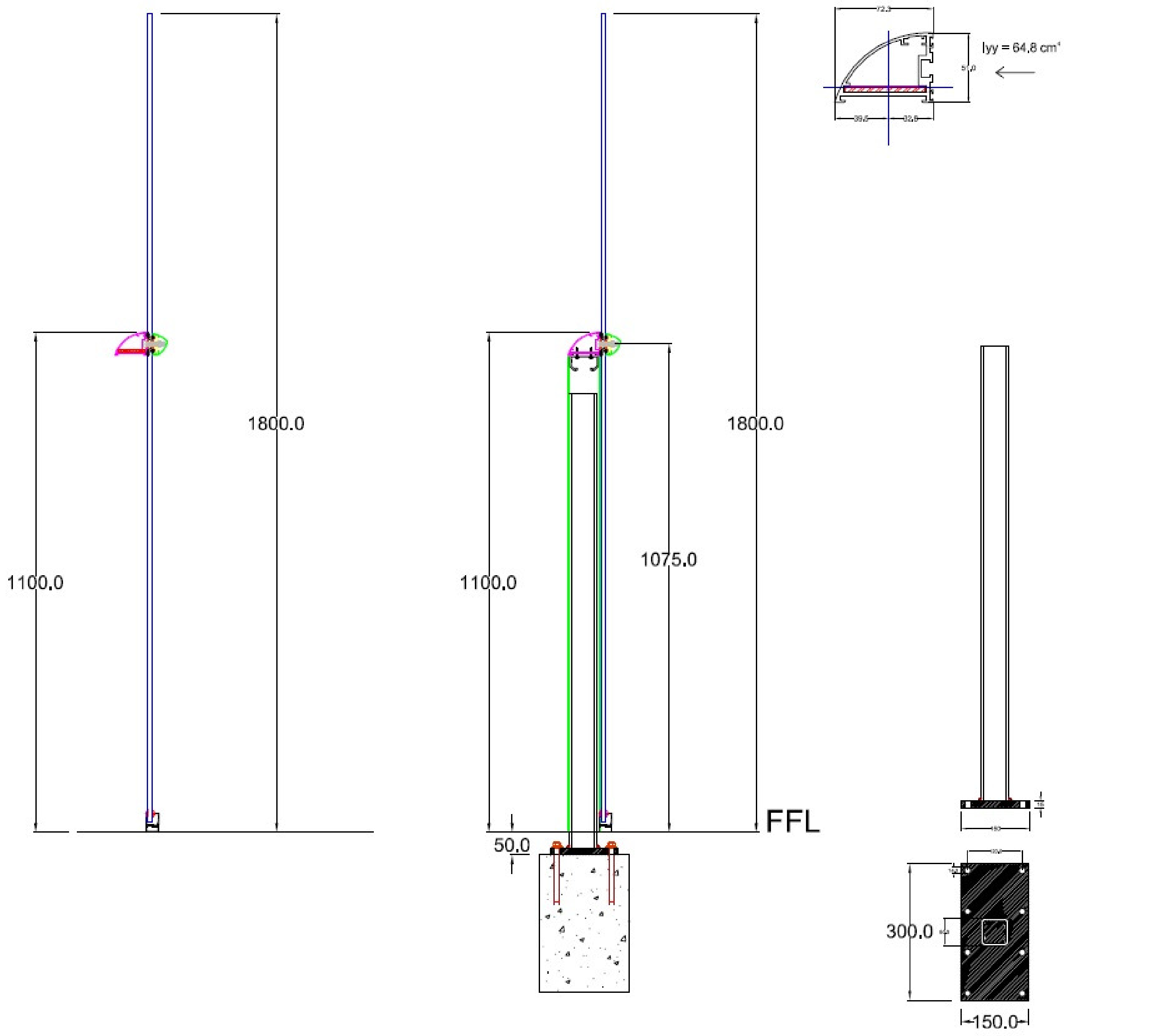
<u>Balcony 2 pass – through 1.8m privacy screen system for more severe wind loading</u>: ***PAGE 3*** **(B2PTX240718)**



Section of Balcony 2 pass-through 1.8m privacy screen system, post and <u>option 1</u> base plate details.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 4*** **(B2PTX240718)**

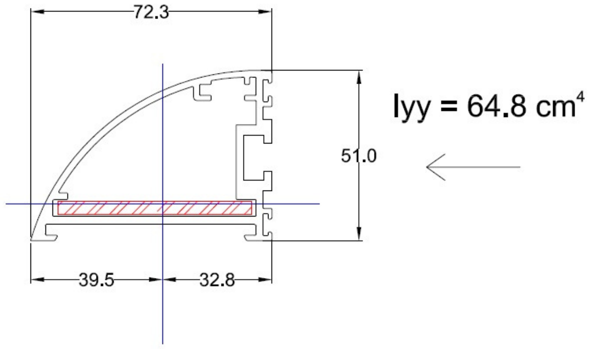
Section properties of handrail:



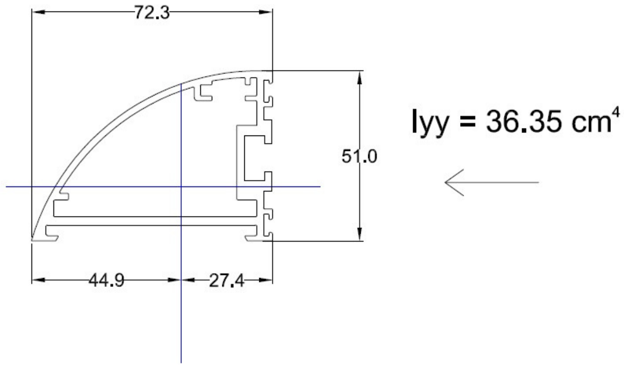
Section of Balcony 2 pass-through 1.8m privacy screen system, post and option 2 base plate details.

Balcony 2 pass-through 1.8m privacy screens for more severe wind loading: ***PAGE 5*** **(B2PTX240718)**

Section properties with bar



Section properties without bar



Handrail with reinforcing bar:

Material type	=	Extruded aluminium type 6063 T5		
Characteristic 0.2% proof stress	=	f_o	=	130 N/mm^2
Characteristic ultimate tensile strength	=	f_u	=	175 N/mm^2
Modulus of elasticity	=	E	=	70 000 N/mm^2
Shear modulus	=	G	=	27 000 N/mm^2
Moment of inertia about the y-y axis	=	I_{yy}	=	64.8 cm^4
Least elastic modulus about the y-y axis	=	W_{el}	=	16.405 cm^3
Partial factor for material properties	=	γ_{M1}	=	1.10
Value of shape factor (conservative value assumed)	=	α	=	W_{pl}/W_{el}
			=	1.2 say
Design ultimate resistance to bending about the y-y axis	=	M_{Rd}	=	$M_{o,Rd}$

$$= \alpha W_{el} f_o / \gamma_{M1}$$

$$= \frac{1.2 \times 16.405 \text{ cm}^3 \times 130 \text{ N/mm}^2 \times (10)^{-3}}{1.1}$$

$$= \mathbf{2.327\ kNm}$$

<u>Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading:</u>

<u>Design for imposed loads:</u>

Design ultimate horizontal imposed load on handrail: $F = 0.74\ kN/m \times 1.5 = 1.11\ kN/m$ (acting outwards)

Design horizontal moment on handrail between points of support, assuming simply supported spans (worst case): $M = \dfrac{F L^2}{8}$

Allowable span between points of support based upon the moment capacity of the handrail: $L = \left[\dfrac{8 \times M_{Rd}}{F}\right]^{0.5}$

$= \left[\dfrac{8 \times 2.327\ kNm}{1.11}\right]^{0.5}$

$= 4.095m$ say $= 4.0m$

In terms of bending capacity the handrail can support the design ultimate horizontal imposed load for span up to 4.0m simply supported between points of support. (ie. A handrail wall fixing, or a handrail corner joint.)

<u>Deflection: Handrail with reinforcing bar:</u>

For a single span simply supported handrail the service load deflection is limited to a maximum of 25mm.

Deflection (Δ) of a simply supported span (L) with an imposed UDL load (F): $\Delta = \dfrac{5 F L^4}{384 E I}$

For a handrail span of 4.0m simply supported: $\Delta = \dfrac{5\ (740 \times 4.0)\ (4000)^3}{384 \times 70\ 000 \times 64.80 \times (10)^4}$

$= 54.38mm > 25mm$ not OK

Deflection limitations therefore govern the allowable simply supported span of the handrail for imposed horizontal service loads.

For a handrail span of 3.25m simply supported: $\Delta = \dfrac{5\ (740 \times 3.25)\ (3250)^3}{384 \times 70\ 000 \times 64.80 \times (10)^4}$

$= 23.70mm < 25mm$ OK

In order that the calculated deflection of the handrail under the action of the imposed horizontal service load does not exceed 25mm the allowable simply supported span of the handrail is limited to 3.25m. However the allowable span is reduced for the design wind loading. See later calculations.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading:
Wind load design:

Design notes:
Design wind loads are influenced by a number of variable factors. These include site location, site altitude above sea level, type of terrain, height of balustrade/screen above ground level and balustrade/screen geometry.

These parameters and conditions are defined in BS EN 1991-1-4:2002 + A1: 2010 '*Actions on structures – wind actions' &* UK National Annex to EN 1991-1-4:2002 + A1:2010.

We have chosen to prepare a calculation for a wind screen 1.8m high with or without side returns based upon severe wind loading conditions that will cover the majority of sites in exposed locations in England and Wales.

The formula applied results in an overall c***haracteristic wind pressure***. The design and calculation will be relevant not only to the conditions specified herein but to any combination of factors that result in a characteristic wind pressure that is equal to or less than the one specified in the calculation. Sites that have a design ***characteristic wind pressure*** that exceeds **1.50 kN/m^2** as seen on page 8 below require separate calculation.

a) Sites located geographically within the 24m/sec isopleth in Figure NA.1 of the UK National Annex. This covers most of England and Wales except for the extreme West of Cornwall and the extreme North of England close to the Scottish border.

b) Site altitude 100 metres maximum above sea level.

c) Top of privacy screen located 40 metres maximum above ground level.

d) Site located in a coastal area exposed to the open sea, terrain category 0 of BS EN 1991 Table 4.1. This is the most severe exposure category. Smaller wind load coefficients apply to less exposed inland sites, terrain categories 1 to 1V.

e) Sites with no significant orography in relation to wind effects. Increased wind load factors apply to sites near the top of isolated hills, ridges, cliffs or escarpments.

f) Directional, seasonal, and probability factors are all taken as normal, for which the relevant factor is 1.0.

g) Wind loading is considered as a separate design case. It is not considered in combination with other design loads.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 8*** (B2PTX240718)

Wind load design:

The selected wind load coefficients are appropriate for privacy screens up to 1.8m high above finished floor level with side returns ≥ 1.8m long on sites within the parameters listed on page 7 of these calculations.

Basic wind speed	$V_{b\ map}$	=	24 m/sec	(Figure NA.1)
Site altitude above sea level	A	=	100 m	
Height to top of screen above site level	z	=	40 m	
Site altitude factor	C_{alt}	=	$1.0 + (0.001 \times A)(10/z)^{0.2}$	(Eqn. NA.2b)
		=	$1.0 + (0.10)(0.7579)$	
		=	$1.0 + 0.076$	
		=	1.076	
Directional factor	C_{dir}	=	1.0	
Seasonal factor	C_{season}	=	1.0	
Probability factor	C_{prob}	=	1.0	
Site wind speed	V_b	=	$V_{b\ map}(C_{dir} \times C_{season} \times C_{prob})(C_{alt})$	
		=	24 m/sec x 1.076	
		=	25.824 m/sec	
Site wind pressure	q_b	=	$0.613\ (V_b)^2$	
		=	$0.613\ (25.824)^2$	
		=	408.797 N/m^2	
Exposure factor	C_e (z)	=	3.58	(Figure NA.7)
Peak velocity pressure (characteristic wind pressure)	q_p	=	$q_b \times C_e$ (z)	
		=	0.409 kN/m^2 x 3.58	
		=	1.464 kN/m^2	
	say	=	**1.50 kN/m^2**	

Summary:

Characteristic design wind pressure	=	**1.50 kN/m^2**
Ultimate design wind pressure	=	1.50 kN/m^2 x 1.5 (γ_{Q1})
	=	**2.25 kN/m^2**

Balcony 2 pass-through 1.8m privacy screens for more severe wind loading: ***PAGE 9*** **(B2PTX240718)**

Glass panels: 10mm thick thermally toughened soda silicate safety glass with smooth float 'as produced' finish and polished edges. Glass panels can be of any length. For design purposes a nominal glass panel width of 1000mm has been used.

Design standard: Institution of Structural Engineers publication 'Structural use of glass in building (second edition) February 2014.'

Characteristic design strength of glass = $120\ N/mm^2$

Ultimate design stress $f_{g;d}$ = $\dfrac{K_{mod} \times K_{sp} \times K_{g;k}}{\gamma_{M;A}} + \dfrac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;V}}$

where K_{mod} = 30 second duration factor
= 0.89 for domestic balustrades

K_{sp} = glass surface profile factor
= 1.0 for float glass 'as produced'

$f_{g;k}$ = characteristic strength of basic annealed glass
= $45\ N/mm^2$

K_v = manufacturing process strengthening factor
= 1.0 for horizontal toughening

$f_{b;k}$ = characteristic bending strength of prestressed glass
= $120\ N/mm^2$

$\gamma_{M;A}$ = material partial factor
= 1.6 for basic annealed glass

$\gamma_{M;V}$ = material partial factor
= 1.2 for surface prestressed (toughened) glass

Ultimate design stress $f_{g;d}$ = $\dfrac{0.89 \times 1.0 \times 45}{1.6} + \dfrac{1.0\ (120 - 45)}{1.2}$

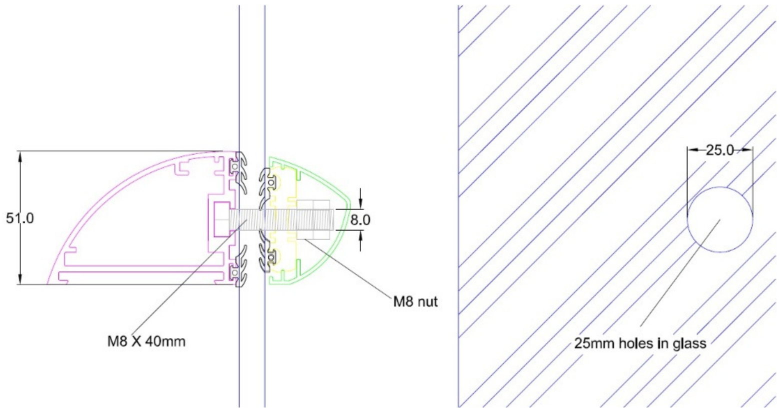
= $\mathbf{87.53\ N/mm^2}$

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 10*** **(B2PTX240718)**

Glass design:

The maximum bending moment on the glass occurs at the handrail fixing point. In this position the glass is connected to the handrail using 3 or 4 no. M8 bolts per 1000mm wide glass panel. The bolts are preset in the handrail channel and pass through 25mm diameter holes in the glass. As a worst design case the effective width of a 1000mm panel at the point of maximum moment is therefore taken as 900mm.

The more severe wind loading exceeds the design imposed loading listed on pages 1 and 2 of these calculations and is therefore the dominant design condition.



Inertia of glass panel 10mm thick x 1000mm wide (effectively 900mm) $\quad I_{xx} = \dfrac{900 \times (10)^3}{12} = 75000\text{mm}^4$

Modulus of glass panel 10mm thick x 1000mm wide (effectively 900mm) $\quad Z_{xx} = \dfrac{900 \times (10)^2}{6} = 15000\text{mm}^3$

Ultimate moment capacity of glass 12mm thick x 900mm effective width

$M_u = f_{g:d} \times Z$
$= 87.53\ \text{N/mm}^2 \times 15000 \times (10)^{-6}$
$=$ **1.31 kNm/m**

Ultimate design wind pressure on the glass panels $= 2.25\ \text{kN/m}^2$ (page 8)

Ultimate cantilever moment due to wind pressure on glass above handrail fixing point $= \dfrac{2.25\ \text{kN/m}^2 \times (0.725)^2}{2} = 0.591\ \text{kNm/m}$

$= < 1.31\ \text{kNm/m}$ = OK

Glass deflection – UDL loading:

Consider service load deflection of the glass on the vertical cantilever above the handrail.

Service UDL on cantilever $= 1.50\ \text{kN/m}^2$ (page 8)

Service load deflection of 725mm cantilever due to a UDL of 1.50 kN/m^2

$= \dfrac{W L^3}{8 E I}$

$= \dfrac{(1500 \times 0.725)(725)^3}{8 \times 70\,000 \times 75000}$

$= 9.87\text{mm} = < \text{span}/65$ OK

Additional deflection occurs due to the slope of the glass at the handrail (see page 11).

Balcony 2 pass-through 1.8m privacy screens for more severe wind loading: ***PAGE 11*** **(B2PTX240718)**

Glass deflection (cont)

Slope of glass at the handrail due to the service wind load of 1.50 kN/m^2 $\quad \Phi = \frac{M\,L}{3\,E\,I}$

where:

M = BM on the cantilever

= 1.50 kN/m^2 x $(0.725)^2$ /2 = 0.392 kNm/m

L = height of handrail above FFL = 1075mm

$\Phi = \frac{0.394 \text{ kNm} \times (10)^6}{3 \times 70000 \times 15000} = 2.502 \times (10)^{-5}$ radians

Deflection of cantilever due to this slope = 725mm x 2.502 x $(10)^{-5}$ radians

= 0.018mm

This is very small and can be neglected for practical design purposes.

Glass summary:

The more severe wind loading considered in this design exceeds the imposed design loads listed on pages 1 and 2 of these calculations and is therefore the dominant design condition. The 10mm thermally toughened safety glass has adequate moment capacity to support the ultimate design wind pressure and is within allowable service load deflection limitations. By inspection, moments due to wind and imposed loads acting on the infill between the balcony floor and the handrail, and also due to a point load of 0.5 kN applied in any position, will not be critical.

Handrail (with bar) - single span and corner screens:

Ultimate wind force on glass = 2.25 kN/m^2 (page 8)

Ultimate wind force on handrail = $\frac{2.25 \text{ kN/m}^2 \times 1.80 \times 0.90}{1.075}$ = 3.39 kN/m

(moments taken about the underside of the bottom rail)
(ie. where the bottom rail is fixed to the decking)

Ultimate moment capacity of handrail about the y-y axis = 2.327 kNm

Allowable span of handrail between points of support based upon the moment capacity of the handrail = $\left[\frac{8 \times 2.327 \text{ kNm}}{3.39}\right]^{0.5}$ = 2.343m **say 2.30m**

Service load deflection of handrail for a simply supported span of 2.30m = $\frac{5 \times (2260 \times 2.30)\,(2300)^3}{384 \times 70000 \times 64.8 \times (10)^4}$ = 18.15mm

= < 25mm = OK

Summary:

On single span and corner screens without posts, the handrail (with bar) has adequate moment capacity to support the design wind loading over spans of up to 2.30 metres between points of support (ie. a wall fixing or a handrail corner joint) without exceeding the service load deflection limit of 25mm.

Balcony 2 pass-through 1.8m privacy screens for more severe wind loading: *PAGE 12* (B2PTX240718)

Longer screens:

On longer screens the handrail (without bar) is used in conjunction with 60 x 60 x 5 SHS steel posts installed at 1.6m maximum centres to support the handrail. The handrail profile without the strengthening bar has a moment of inertia of 36.35 cm^4 about the y-y axis and does not require the strengthening bar where posts are at a maximum spacing of 1.6 metres. The overall combined displacement of the handrail + post at any point of the barrier from its original unloaded position is limited to a maximum of 25mm under service load conditions.

Ultimate design wind pressure on longer screens with posts = $2.25\ kN/m^2$ (page 8)

Ultimate design wind reaction on handrail on longer screens = $\dfrac{2.25\ kN/m^2 \times 1.8 \times 0.9}{1.075}$ = 3.39 kN/m

Ultimate BM on handrail for a post spacing of 1.6m = $\dfrac{3.39\ kN/m \times (1.6)^2}{8}$ = 1.085 kNm

Handrail without bar: Properties are similar to the handrail with bar (page 5) except as follows:

Moment of inertia about the y-y axis I_{yy} = $36.35\ cm^4$

Least elastic modulus about the y-y axis W_{el} = $8.10\ cm^3$

Design ultimate resistance to bending about the y-y axis M_{Rd} = $\dfrac{1.2 \times 8.10\ cm^3 \times 130\ N/mm^2 \times (10)^{-3}}{1.1}$

= 1.149 kNm

= > 1.085 kNm = OK

Service design wind load on handrail on longer screens F = $\dfrac{3.39\ kN/m}{1.5}$ = 2.26 kN/m

For a post spacing of 1.6 m service load deflection of the handrail (no bar) for the design imposed wind load Δ = $\dfrac{5\ F\ L^4}{384\ E\ I}$

= $\dfrac{5\ (2260 \times 1.0)\ (1000)^3}{384 \times 70\ 000 \times 36.35 \times (10)^4}$ = 7.58 mm

60 x 60 x 5mm SHS posts: properties of section:

Steel grade	=	S355 H to EN 10210-1		
Nominal value of yield strength	=	f_y	=	$355\ N/mm^2$
Nominal value of ultimate tensile strength	=	f_u	=	$510\ N/mm^2$
Inertia of section	=	I_{xx}	=	$50.50\ cm^4$
Elastic modulus of section	=	W_{el}	=	$16.80\ cm^3$
Plastic modulus of section	=	W_{pl}	=	$20.90m\ cm^3$
Partial factor for material properties	=	γ_{M1}	=	1.10
Partial factor for class 1 sections	=	γ_{MO}	=	1.00
Modulus of elasticity	=	E	=	$210\ 000\ N/mm^2$

Design ultimate resistance for bending $M_{pl,Rd}$ = $\dfrac{f_y \times W_{pl}}{\gamma_{Mo}}$

= $\dfrac{355\ N/mm^2 \times 20.90\ cm^3 \times (10)^{-3}}{1.0}$

= **7.42 kNm**

Balcony 2 pass-through 1.8m privacy screens for more severe wind loading: *PAGE 13* **(B2PTX240718)**

60 x 60 x 5 posts (cont):

Ultimate wind moment on posts at 1.6 m spacing M_d = 3.39 kN/m x 1.125 height x 1.6 c/c
= 6.102 kNm < 7.42 kNm OK

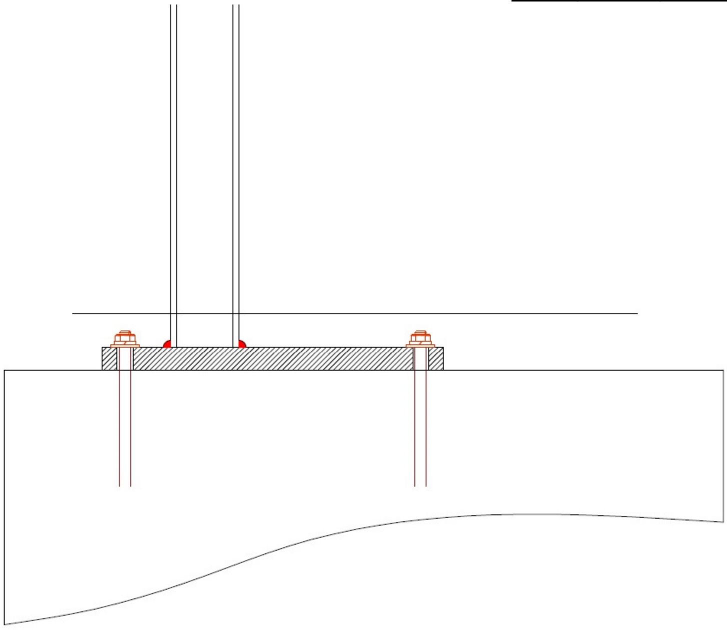
Service load deflection of post supporting 1.0m of handrail $\Delta = \frac{P\,L^3}{3\,E\,I} = \frac{(2260 \times 1.0)\,(1125)^3}{3 \times 210\,000 \times 50.50 \times (10)^4} = 16.18$ mm

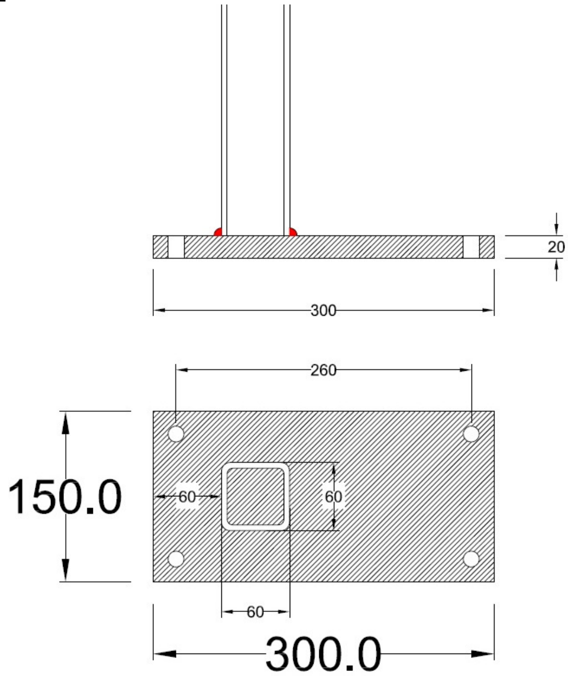
Service load deflection of handrail without bar on a simply supported span of 1.0 metres $\Delta = \frac{5\,F\,L^4}{384\,E\,I} = \frac{5\,(2260 \times 1.0)\,(1000)^3}{384 \times 70\,000 \times 36.35 \times (10)^4} = 7.58$ mm

Combined total service wind load deflection (post + handrail) Δ = 16.18 + 7.58 = 23.76mm
= < 25mm = OK

SUMMARY: On longer screens the Balcony 2 pass-through handrail (without bar), in conjunction with 60 x 60 x 5 SHS posts in steel grade S 355 H installed at a maximum spacing of 1.6 metre, is adequate to support the ultimate design wind loading.

Base plate option 1:





Base plate = option 1: 300 x 150 x 20mm

Spacing of posts = 1.0 m

Design ultimate wind moment on posts at 1.6 m spacing = 6.102 kNm (acts inwards or outwards)

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 14*** **(B2PTX240718)**

Vertical posts: Option 1 base plates: 300 x 150 x 20 witth 4 M12 HD bolts:

Service load wind moment on posts at 1.6 m c/c	=	$\dfrac{6.102\text{ kNm}}{1.5}$	=	4.068 kNm
Lever arm between the centres of bolts	=	260 mm		
Service load bolt tension on 2 No. bolts	=	$\dfrac{4.068\text{ kNm}}{2\text{ No.} \times 0.26}$	=	7.823 kN/bolt
Ultimate load bolt tension	=	7.823 x 1.5	=	11.73 kN/bolt

BS 6180:2011, section 6.5, recommends that barrier fixings, attachments and anchorages should be designed to withstand a greater load than the design loading for the barrier generally. This is intended to ensure that under an extreme load condition, barriers show indications of distress by distortion, before there is any possibility of sudden collapse due to failure of the fixings. A 50% increase in the design load on fixings is recommended.

Applying the 50% increase in loads on fixings recommended in BS 6180:2011, the design working load bolt tension becomes **11.73 kN/bolt.**

The nominal tension capacity of M12 (8.8 grade) bolts is 37.80 kN/bolt. Higher bolt forces can therefore be achieved by direct bolting to a suitable steel frame.

Separate consideration is required where it is proposed to use other types of fixings, or where fixings are to be inserted into weaker materials.

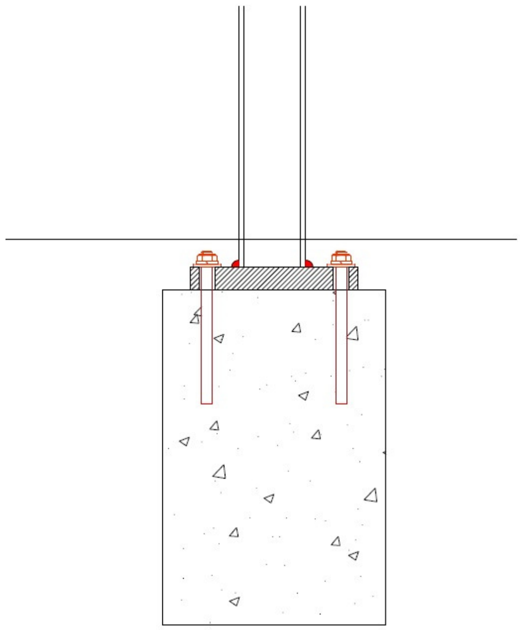
Base plates – option 1: 300mm long x 150mm wide x 20mm thick with 4 M12 bolts:

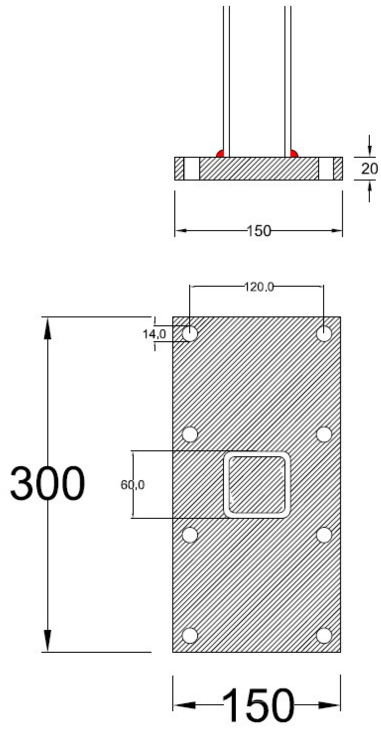
Ultimate wind load moment on posts at 1.6 m maximum c/c	M_a	=	6.102 kNm		
Plastic modulus of base 150mm wide x 20mm thick	W_{pl}	=	$\dfrac{150 \times (20)^2}{4}$	=	15000mm^3
Ultimate moment capacity of base in steel grade S355	M_u	=	$\dfrac{355\text{ N/mm}^2 \times 15000 \times (10)^{-6}}{1.0}$	=	5.325 kNm
Distance from centre of HD bolts to face of 10 FW post/base weld	d	=	300 – 20 – 60 – 60 - 10	=	150mm
Ultimate load bolt tension (not including BS 6180 50% increase)	T	=	11.73 kN		
Ultimate moment on base at face of post/base weld	M	=	11.73 kN x 2 No. x 0.15	=	3.519 kNm
(not including BS 6180 50% increase on bolt loads, which only applies to fixings, not other structural elements)		= $<$	5.325 kNm	=	OK

Base plates 300 x 150 x 20 in steel grade S355 are adequate for option 1.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 15*** **(B2PTX240718)**

Base plate – option 2: 300 wide x 150 deep x 20mm thick with 8 M12 bolts.





Tension pull-out loads on fixing bolts:

Ultimate wind load moment on posts at 1.6 m maximum c/c	M_a	=	6.102 kNm		
Distance between bolt centres	d	=	120mm		
Ultimate load bolt tension on 4 No. bolts	T_u	=	$\frac{6.102 \text{ kNm}}{4 \text{ No.} \times 0.12}$	=	12.71 kN/bolt
Working load bolt tension	T_w	=	12.71 / 1.5	=	8.47 kN/bolt

Applying the 50% increase in design loads on fixings recommended in BS 6180: 2011, the design working load bolt tension becomes **12.71 kN/bolt.**

The nominal tension capacity of M12 (8.8 grade) bolts is 37.80 kN. Higher bolt forces can therefore be achieved by direct bolting to a suitable structural steel frame.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 16*** **(B2PTX240718)**

Base plates – 300 x 150 x 20mm thick:

Plastic modulus of base 300 wide x 20mm thick	W_{pl}	=	$\frac{300 \times (20)^2}{4}$	=	30000mm^3
Moment capacity of base in steel grade S355	M_c	=	355 N/mm^2 x 30000 x (10)$^{-6}$		
		=	10.65 kNm		
		= >	6.102 kNm	=	OK
Ultimate load bolt tension (not including the 50% increase as BS 6180)	T_u	=	12.71 kN/bolt		
Ultimate moment on base at face of post/weld (not including BS 6180 50% increase, which applies only to fixings, not other structural elements)	M_u	=	12.71 kN x 4 No. x 0.02	=	1.068 kNm
		= <	10.65 kNm	=	OK

Base plates 300 wide x 150 deep x 20mm thick in steel grade S355 with 8 M12 bolts are adequate.

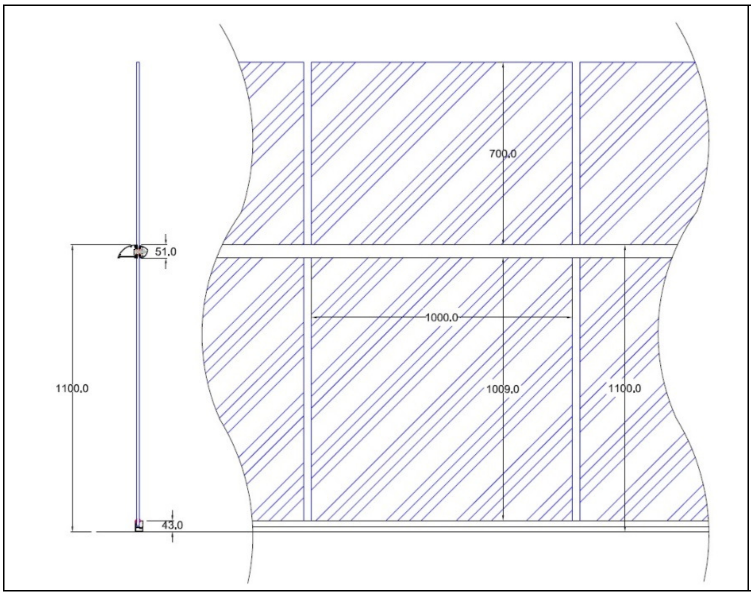
Welded connection between post & base plate:

The 60 x 60 x 5mm SHS post is welded to the top of the base by means of a full strength butt and/or fillet weld.

Elastic section modulus of post	W_{el}	=	16.80 cm^3		
Maximum ultimate elastic bending stress on post	$\frac{M_a}{W_{el}}$	=	$\frac{6.102 \times (10)^6}{16.80 \times (10)^3}$	=	363 N/mm^2
		=	1.815 kN/mm on 5mm thick section		
Transverse capacity of 10mm fillet weld with E42 electrode and S355 steel		=	2.188 kN/mm	=	OK

A continuous 10mm fillet weld around the perimeter of the post using E42 electrode and S355 steel, or a full strength butt weld, are adequate.

Glass infill:



Glass panels can be any length.

For the purposes of design and checking a nominal glass panel width of 1000mm simply supported between the bottom rail and the handrail has been used.

Separate design loading conditions on the infill are considered:

Ultimate UDL wind pressure on the infill of2.25 kN/m²

Ultimate moment on glass due to UDL on span of 1.0m Mu $= \frac{2.25\ kN/m^2 \times (1.0)^2}{8} = 0.281\ kNm/m$

$= \ < 1.459\ kNm = OK$

Point load on the infill of 0.5 kN

Point load on the glass = 0.5 kN point load applied in any position

Worst case for bending stress on the glass due to point load = point load applied at mid-height of glass

Ultimate moment on glass due to point load $= \frac{0.5\ kN \times 1.5 \times 1.0m}{4} = 0.1875kNm$

Conservatively, it is assumed that this bending moment is carried by a 300mm wide vertical strip of glass.

Moment capacity of 300mm strip of glass = 1.459 kNm x 0.3 = 0.4377 kNm
= > 0.1875kNm = OK

The glass has adequate strength to support the ultimate design imposed loads and also the design wind loading.

Glass deflection:

Consider service load deflection of the glass due to the design wind UDL:

Inertia of glass 10mm thick x 1000mm long $= \frac{1000 \times (10)^3}{12} = 83333\ mm^4$

Service wind load deflection due to a UDL of 2.835 kN/m² on a simply supported span of 1.0m (floor to handrail) $= \frac{5\ w\ L^4}{384\ E\ I}$

$= \frac{5 \times (1500 \times 1.0)\ (1000)^3}{384 \times 70\ 000 \times 83333}$

$= 3.348\ mm < \frac{span}{65} =$ OK

Conservatively, for deflection calculation purposes consider that the design point load is carried by a 300mm wide vertical strip of glass:

Inertia of glass 10mm thick x 300mm long $= 0.3 \times 83333\ mm^4 = 25000\ mm^4$

Service load deflection due to a point load of 0.5 kN applied at mid-span $= \frac{P\ L^3}{48\ E\ I}$

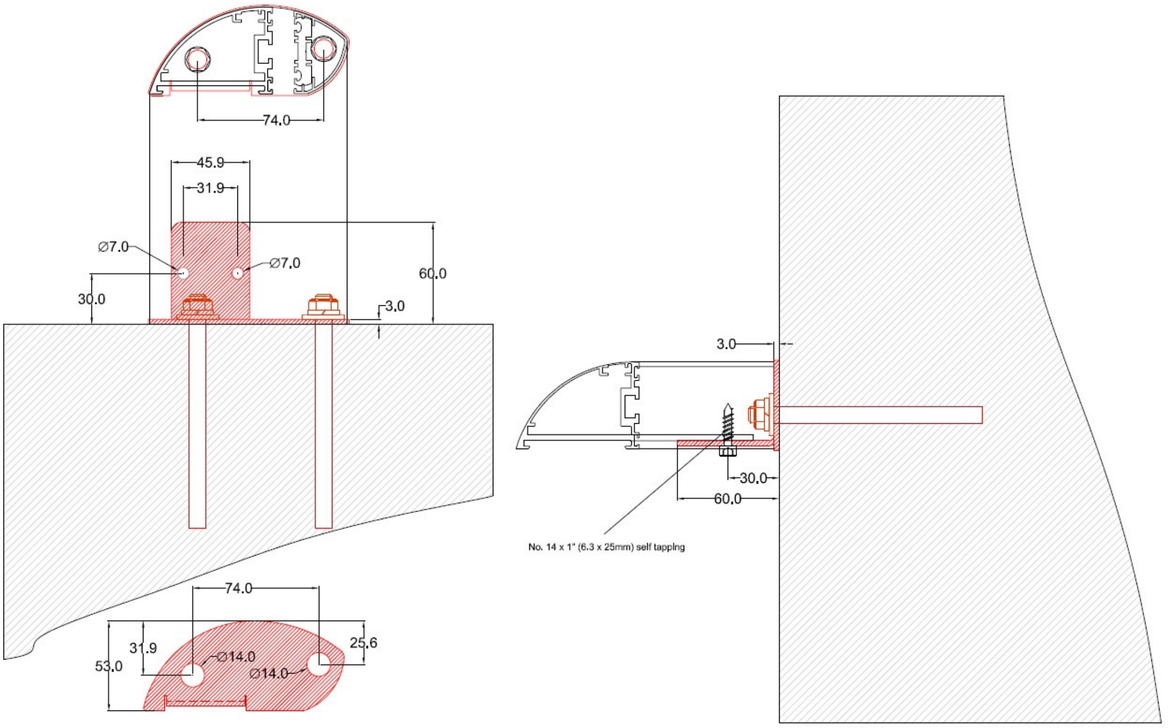
$= \frac{500 \times (1000)^3}{48 \times 70\ 000 \times 25000}$

$= 5.95\ mm < \frac{span}{65} =$ OK

SUMMARY: The glass is adequate to resist the design imposed and wind loads in terms of both bending strength and deflection.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: *PAGE 18* (B2PTX240718)

Wall fixings:



The handrail wall fixing consists of a 3mm thick stainless steel angle bolted to the wall with 2 No. M12 stainless steel drilled resin anchor bolts or similar and secured to the handrail with 2 No. 6.3mm diameter stainless steel Phillips self-tapping screws.

The max. simply supported span of the handrail with internal reinforcing bar between points of support is 2.30 m.

Service wind load on the wall fixing for a span of 2.30m	=	2.26 kN/m x 1.15m	=	2.60 kN/fixing

This load is transferred to the angle bracket by means of 2 No. 6.3mm diameter stainless steel Phillips self-tapping screws.

Ultimate shear force on self-tapping screws	=	$\frac{2.60 \times 1.5}{2}$	=	1.95 kN/screw

Applying the 50% increase in loads on fixings recommended in BS 6180:2011, this becomes **3.075 kN/screw**.

The ultimate shear loads on self-tapping screws are taken from the table in Lindab's technical literature.

Thickness of aluminium in the handrail at screw positions	=	2.5mm
Thickness of stainless steel brackets (Nom t mm)	=	3.0 mm

<u>Balcony 2 pass-through 1.8m privacy screen system for more severe wind loads:</u> ***PAGE 19*** **(B2PTX240718)**

<u>Wall fixing:</u>

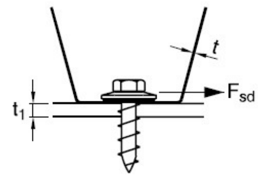
Ultimate shear capacity of 6.3mm diameter screws, safety class 1 = 6.76 kN/screw

For safety classes 2 and 3 this value is divided by 1.1 and 1.2 respectively. Safety class 3 is the highest safety class and has been assumed to apply to balustrades/barriers. The shear capacities given in Lindab's table are based upon material having a tensile yield limit of 350 N/mm^2. The values given in the table have been adjusted to allow for the yield stress of stainless steel type 304 (290 N/mm^2).

The ultimate shear capacity of 6.76 kN/screw has therefore been reduced by 290/350 and divided by 1.2 to represent safety class 3 and 290 N/mm^2 yield stress rather than 350 N/mm^2. The adjusted ultimate shear capacity is then 4.67 kN/screw, compared with the design value of 3.075 kN/screw, and is therefore adequate.

Shearing force, construction screws

Dimensioning value F_{sd} kN/screw. Attention is paid both to failure of the edge of the hole and shearing failure in the screw. Safety class 1.



Nom t mm	When calculating t mm	Tensile yield limit N/mm^2	Screw diameter 4.2 mm		Screw diameter 4.8 mm		Screw diameter 5.5 mm		Screw diameter 6.3 mm	
			t_1 =t	t_1 = 2.5 t	t1 =t	t_1 = 2.5 t	t_1 =t	t_1 = 2.5 t	t_1 =t	t_1 = 2.5 t
0.4	0.32	250	0.26	0.54	0.28	0.61	0.30	0.70	0.32	0.81
0.5	0.41	250	0.38	0.69	0.40	0.79	0.43	0.90	0.46	1.03
0.6	0.52	250	0.52	0.86	0.56	0.98	0.60	1.12	0.64	1.29
0.7	0.60	350	0.93	1.41	1.00	1.61	1.07	1.85	1.14	2.12
0.8	0.73	350	1.25	1.72	1.34	1.96	1.43	2.25	1.53	2,58
1.0	0.93	250	1.29	1.56	1.38	1.79	1.47	2.05	1.58	2,34
1,0	0,93	350	1,80	2,19	1,93	2,50	2,06	2,86	2,21	3,28
1,2	1,13	350	2,41	2,66	2,58	3,04	2,76	3,48	2,95	3,99
1,5	1,42	250	2,39	2,39	2,60	2,73	2,78	3,12	2,97	3,58
1,5	1,42	350	3,03*	3,03*	3,63	3,82 3,64	3,89	4,37	4,16	5,01
2.0	1.91	350	3.03*	3.03*	4.16 3.64	4.16 3.64	5.72 5.20	5.72 5.20	6.49	6.74
2.5	2.40	350	3.03*	3.03*	4.16 3.64	4.16 3.64	5.72 5.20	5.72 5.20	7.80 6.76	7.80 6.76

In the area of number pairs in the table and marked *, shearing failure in the screw is decisive.

The value to the left in each number pair relates to carbon steel screws, while the number to the right relates to stainless steel screws.

Table from Lindab's technical literature

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loads: *PAGE 20* (B2PTX240718)

Shear force on wall fixing bolts

Working wind load shear force on the 2 No. fixing bolts based upon a handrail span of 2.30 m	=	$\frac{2.60 \text{ kN}}{2 \text{ No.}}$	=	1.30 kN/bolt

Applying the 50% increase on fixing loads recommended in BS 6180:2011, this becomes **1.95 kN/bolt.**

This shear load should be within the working load capacity of M12 drilled resin anchor bolts or similar into good quality concrete or brickwork. Separate consideration is required when drilling into weaker materials or when using other less robust types of fixings.

Pull-out forces on wall fixings

The horizontal load on the handrail is applied to the fixing angles through the Phillips stainless steel self-tapping screws, located 30mm from the back of the angles. The wall fixing bolts are 74mm apart horizontally.

Working load pull-out force on the 2 No. anchor bolts on a span of 2.3m	=	$2.60 \text{ kN} \times \frac{30.0}{74}$	=	1.05 kN/bolt
Applying the 50% increase in load on fixings recommended in BS 6180:2011, this			=	**1.575 kN/bolt**

Wall fixing brackets:

Material type	=	stainless steel grade 304
Characteristic ultimate tensile strength	=	621 N/mm^2
Characteristic 0.2% proof stress	=	290 N/mm^2

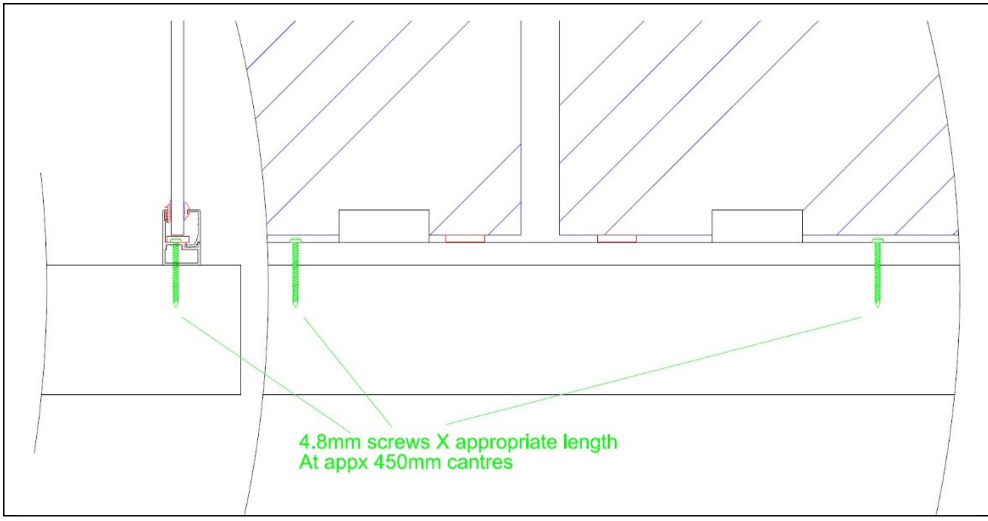
The horizontal part of the bracket measures 45.9mm wide x 3mm thick.

Plastic modulus of 45.9 x 3mm section for horizontal loads	=	$\frac{3 \times (45.9)^2}{4}$	=	1580mm^3
Resistance moment of section	=	$290 \text{ N/mm}^2 \times 1580\text{mm}^3 \times (10)^{-6}$		
for horizontal loads	=	0.458 kNm		
For a simply supported span of 2.30 m: ultimate load on end bracket	=	2.60 kN/m x 1.5	=	3.90 kN
Ultimate horizontal moment	=	(3.90 kN) (0.03)	=	0.117 kNm
applied to the bracket	=	< 0.458 kNm	=	OK
Shear capacity of section 45.9mm wide x 3mm thick	=	$\frac{A_v (f_y/\sqrt{3})}{\gamma_{M0}}$		
	=	$\frac{(45.9 \times 3)(290/1.732)}{1.1}$	=	20960 N
			=	OK

The wall fixing brackets are adequate.

Balcony 2 pass-through 1.8m privacy screen system for more severe wind loading: ***PAGE 21*** ***(B2PTX240718)***

Bottom rail fixing:



The standard bottom rail fixing consists of 4.8mm diameter screws at 450mm centres.

The worst case for design loading on the fixings is when the design service point load of 0.50 kN on the glass acts at the position of a fixing.
The fixing screw is then subjected to a working load shear force of 0.50 kN/screw.

The allowable load on the fixing screws varies depending upon the type and thickness of the material into which the screws are inserted.

As an example, fixing to a balcony deck comprising 15mm thick plywood strength class C16, group 1, the basic allowable working load single shear value given in BS 5268 : Part 2 : 1996 for a No. 10 (4.8mm) screw 45mm long is 0.519 kN.

Where a pre-drilled steel component of adequate strength is screwed to a timber member, the basic lateral load of 0.519 kN is multiplied by a modification factor of 1.25, making an allowable shear value of 0.648 kN, which is adequate in relation to the design working shear load shear force of 0.50 kN.

Other values of allowable shear loads on fixings will apply where the deck material is of different strength and/or thickness.

The installers should ensure that where the deck material has a lower strength than 15mm thick plywood, class C16, group 1, the spacing of the fixing screws is reduced accordingly.

SUMMARY

BALCONY 2 pass-through 1.8m privacy screen system: Handrail with 58 x 4mm steel internal reinforcing bar, or without bar using 60 x 60 x 5mm SHS posts at 1.0m maximum spacing, with two base plate options:

1) For sites within the parameters listed on page 7 of these calculations, and/or have a characteristic wind pressure that does not exceed **1.50 kN/m^2**, wind loading is the dominant design condition for privacy screens 1.8m high. Sites that do not come within these parameters require separate consideration.

2) On single span and corner balconies, the system is capable of supporting the ultimate design wind loads over spans up to **2.30 metres** between points of support. (i.e. a handrail wall fixing, or a handrail corner joint.)

3) On longer balconies where the length of the balustrade exceeds 2.30 metres, vertical posts are installed at a maximum spacing of **1.6m** between post centres. The posts are made from **60 x 60 x 5mm** square hollow steel sections (SHS) in steel grade **S 355 H.**

4) The handrail profile without internal reinforcing bar is adequate to support the design loading on longer screens where posts are installed at a maximum spacing of 1.6 m between post centres.

5) The SHS posts are welded (full strength butt or 10mm fillet welds) to steel base plates. Two options for base plates are considered. Option 1 is 300mm deep x 150mm wide x 20mm thick in steel grade S355, with 4 No. M12 HD bolts. The design working pull-out force on the HD bolts is **11.73 kN/bolt.** Option 2 is 150mm deep x 300mm wide x 20mm thick in steel grade S355, with 8 M12 HD bolts. The design working pull-out load on the holding down bolts is **12.71 kN/bolt.** These loads include a 50% increase on calculated values in accordance with the recommendations in BS 6180.

6) The installers should satisfy themselves that the fixing bolts chosen are suitable to resist the specified loads, and also that the structure into which they are installed can support these loads. Higher bolt loads could be achieved where fixings are made direct to a substantial structural steel frame.

7) For the maximum span of **2.30 metres** on single span and corner balconies, the horizontal working load shear force on the wall fixing bolts is **1.95 kN/bolt**, and the working load pull-out force is **1.05 kN/bolt**. These values include the 50% increase on calculated values recommended in BS 6180. Two 14mm diameter holes are provided in wall fixing brackets for M12 drilled anchor bolts or similar. The design loads should be achievable where bolts are installed into good quality concrete or brickwork.

SUMMARY (continued)

8) The 6.3mm diameter self-tapping stainless steel screws connecting the handrail to the stainless steel angle brackets at wall and post fixings are adequate to support the specified design loads. The 3mm thick stainless steel brackets are also adequate to support the design wall fixing loads.

9) The standard bottom rail fixing comprises 4.8mm diameter screws inserted into the balcony deck at 450mm centres. At this spacing the fixings are required to have a working load shear capacity of 0.50 kN/screw. The installers should satisfy themselves that the screws chosen are suitable to resist this load when inserted into the particular deck material present on a specific project. Where the deck material is of reduced strength and/or thickness the spacing of the screws should be reduced accordingly.

10) The 10mm thick thermally toughened safety glass is adequate to support the specified design loads.

Prepared for and on behalf of Balconette by
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