SG12 Frameless Glass Balustrade system using 21.5mm laminated glass:

Structural Calculations for SG12 system balustrades for 0.74 kN loading using 21.5mm laminated toughened glass without the need for a handrail

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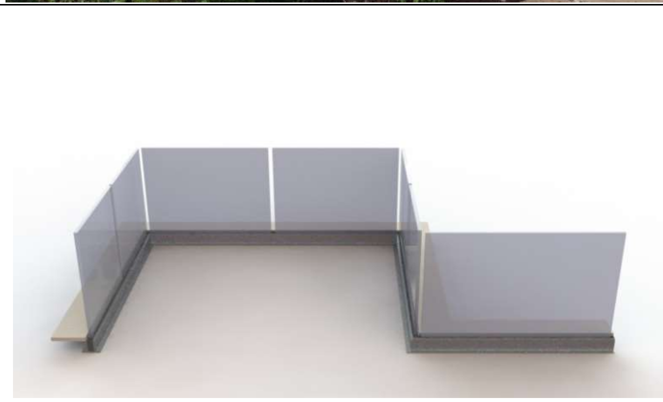


SG12 balustrade fixed above FFL **SG12 balustrade fixed below FFL**

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.

<u>Design imposed loads:</u>
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

SG12 Frameless Glass Balustrade system using 21.5mm laminated glass: ***PAGE 2*** **(SG12FF010717RA)**

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

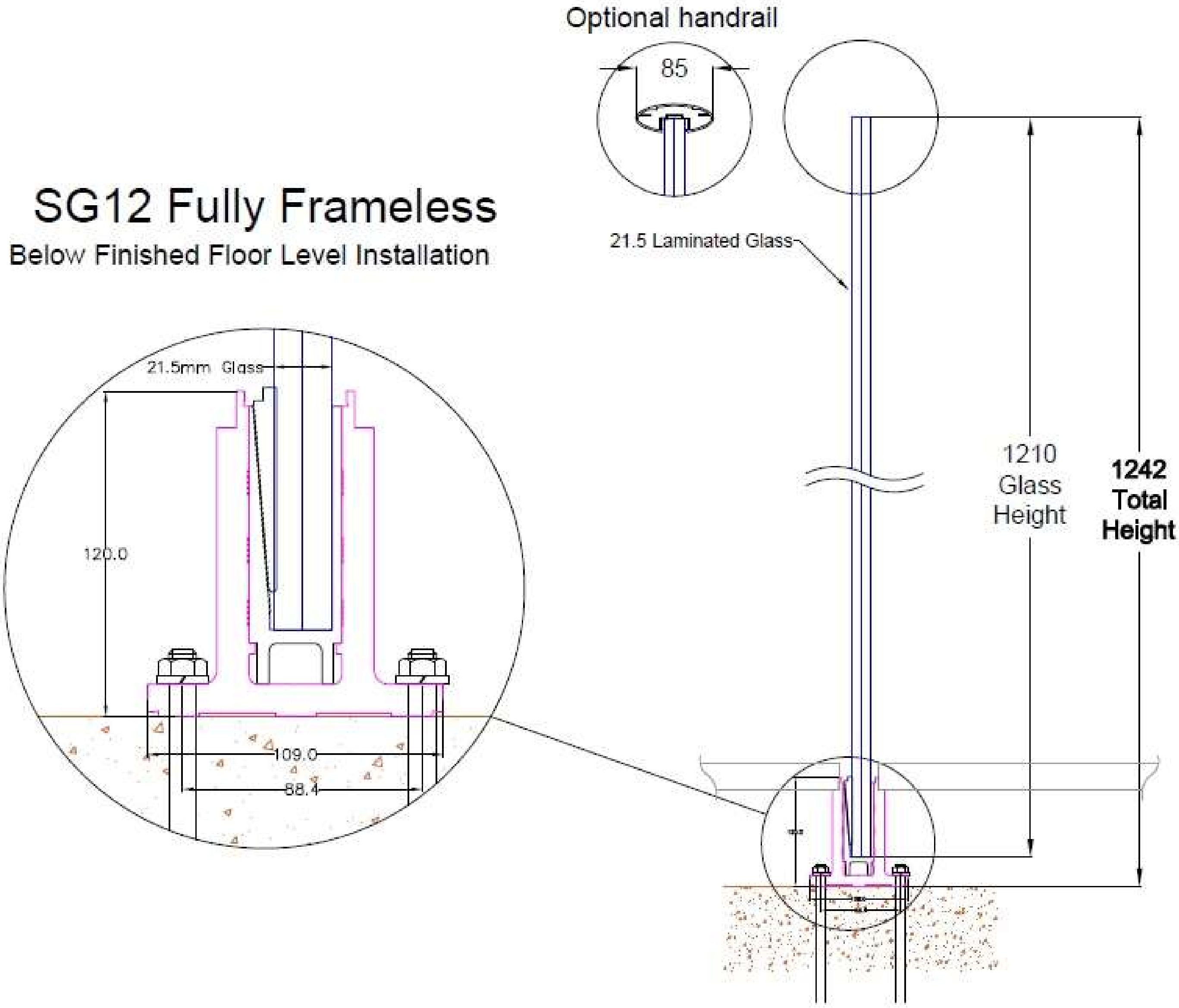
Table 2: BS6180:2011

- 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.

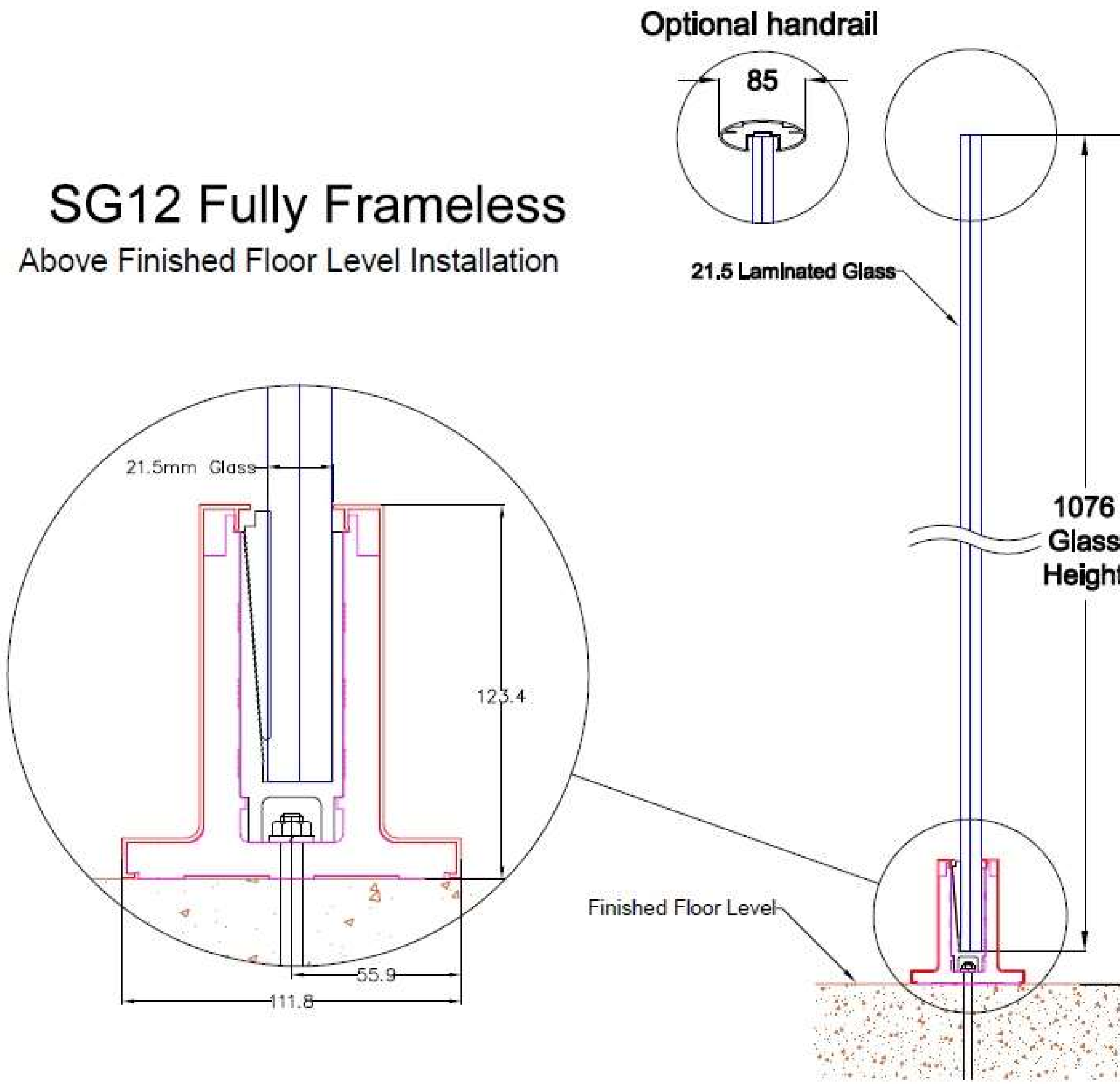
SG12 Frameless Glass Balustrade system using 21.5mm laminated glass:



Section of SG12 balustrade system using 21.5mm thick laminated glass fitted below FFL

Unit 6 Systems House, Eastbourne Road, Blindley Heath, Surrey, RH7 6JP - Tel 01342 410411

SG12 Frameless Glass Balustrade system using 21.5mm laminated glass: ***PAGE 4*** **(SG12FF010717RA)**



Section of SG12 balustrade system using 21.5mm thick laminated glass fitted above FFL

Structural system:

The glass acts as a vertical cantilever from a continuous aluminium bottom channel to resist the imposed loads listed on page 2 and also the design wind loading.

The channel may be located above finished floor level (case 1) or below finished floor level (case 2).

Design for imposed loads:

Case 1: Base **channel located above FFL:**

Design for service line load of 0.74 kN/m:

Design ultimate horizontal imposed line load on glass	F_L	=	0.74 kN/m x 1.5	=	1.11 kN/m

This load is applied 1100mm above FFL. The overall height of the base channel is 120mm. The glass extends approximately 90mm into the channel. The distance from the centre of the glass anchorage in the channel to the line of action of horizontal imposed line load is 1100 - 120 + 45 = 1025mm.

Ultimate moment on glass from the imposed line load of 1.11 kN/m	M_g	=	1.11 kN/m x 1.025	=	1.138 kNm/m
Ultimate moment to underside of the base channel from the imposed line load of 1.11 kN/m	M_b	=	1.11 kN/m x 1.10	=	1.221 kNm/m

Design for uniform distributed load of 1.0 kN/m^2:

Design ultimate UDL on glass	F_u	=	1.0 kN/m^2 x 1.5	=	1.50 kN/m^2
Ultimate moment on glass from UDL	Mg	=	$\frac{1.5 \text{ kN/m}^2 \times (1.025)^2}{2}$	=	0.788 kNm/m
Ultimate moment to underside of the base channel from the UDL	Mb	=	$\frac{1.5 \text{ kN/m}^2 \times (1.108)^2}{2}$	=	0.921 kNm/m

Wind load design:

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

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 based on certain conditions, resulting in specific coefficients.

The formula applied results in an overall ***characteristic 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 ***characteristic wind pressure*** that exceeds **1.50 kN/m^2** as determined on page 7 below require separate calculation.

Wind load parameters for more severe wind loading:

a) Sites located geographically within the 24m/sec isopleth in Figure NA1 of the UK National Annex. This covers the majority of sites in England and Wales.

b) Site altitude 100m maximum above sea level.

c) Top of balustrade located 40m 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. (ie. orography coefficient 1.0). 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) Sites located in country terrain or less than 1.0 km inside town terrain.

Wind load design:

Basic wind speed	$V_{b\ map}$	=	24 m/sec	
Site altitude factor	C_{alt}	=	1.076	(Equation NA 2b)
Directional factor	C_{dir}	=	1.0	
Seasonal factor	C_{season}	=	1.0	
Probability factor	C_{prob}	=	1.0	
Site wind speed	V_b	=	$V_{b\ map}(C_{dir} \times C_{season} \times C_{prob})\ (C_{alt})$	
		=	23 m/sec x 1.076	
		=	24.824 m/sec	
Site wind pressure	q_b	=	$0.613\ (V_b)^2$	
		=	$0.613\ (24.824)^2$	
		=	409 N/m^2	
Exposure factor	$C_e\ (z)$	=	3.58	(Figure NA7)
Peak velocity pressure	q_p	=	$q_b \times C_e\ (z)$	
		=	0.409 x 3.58	
		=	1.464 kN/m^2	
	say	**=**	**1.50 kN/m^2**	
Partial safety factor for leading variable action	γ_{Q1}	=	1.50	
Ultimate design wind pressure		=	1.50 kN/m^2 x 1.5	
		=	**2.25 kN/m^2**	

Wind load design: (cont)

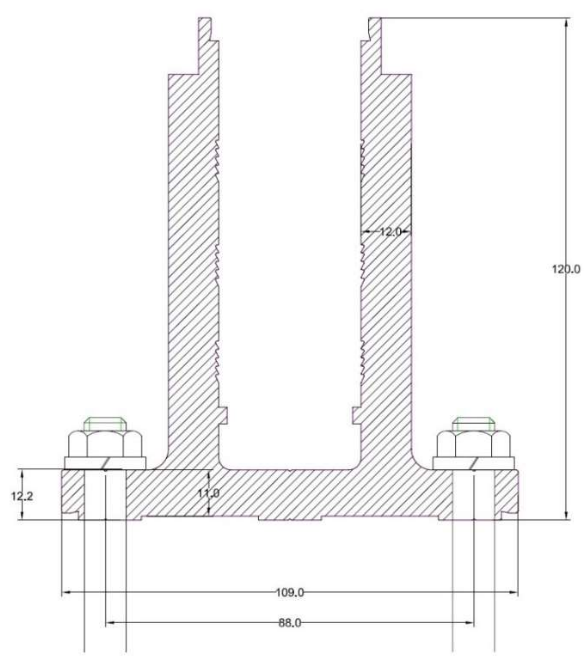
For sites that come within the parameters listed on page 6 of these calculations, the characteristic design wind loading exceeds the specified imposed load. Wind loading is therefore the controlling design condition.

Summary of design loads:

Element	**Service load**	**Ultimate load**
Horizontal imposed line load applied 1100mm above FFL	0.74 kN/m	1.11 kN/m
Wind UDL load on the glass	1.50 kN/m^2	2.25 kN/m^2
Point load applied in any position	0.50 kN	0.75 kN

Case 2: Base channel fixed below FFL:

Glass height		=	1210mm		
Height to top of glass above FFL		=	1108mm		
Height to top of glass above underside of base channel		=	1242mm		
Depth of glass embedment in base channel		=	90mm approximately		
Height centre of embedment to top of glass		=	1180mm		
Ultimate wind moment to underside of base channel	M_{ub}	=	2.25 kN/m^2 x 1.108 x 0.693	=	1.728 kNm/m
Ultimate wind moment to centre of glass embedment in base channel	M_{uc}	=	2.25 kN/m^2 x 1.108 x 0.626	=	1.561 kNm/m



Properties of glass:

Type 21.5 mm thick laminated glass comprising 2 plies of 10mm thick thermally toughened safety glass with smooth float 'as produced' finish and polished edges, with a 1.5mm PVB interlayer. 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 = 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

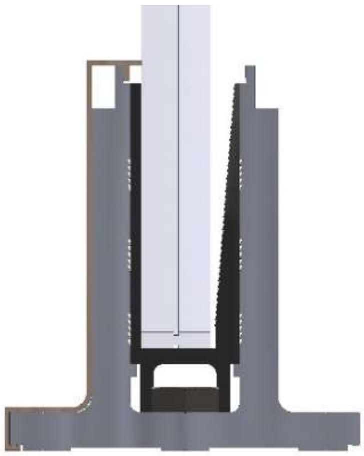
$\gamma_{M;V}$ = material partial factor
= 1.2 for surface prestressed (toughened) glass

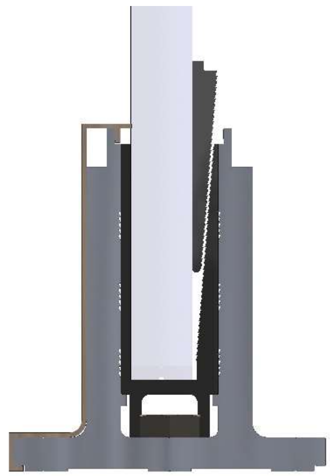
Ultimate design stress $f_{g;d} = \dfrac{0.89 \times 1.0 \times 45}{1.6} + \dfrac{1.0\,(120 - 45)}{1.2}$

= **87.53 N/mm^2**

Glass Wedges

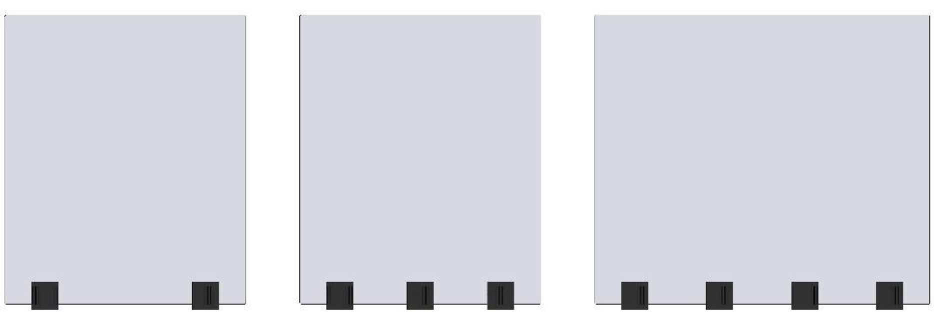
Injection molded glass holders and wedges are used to secure the glass into position. These are made from ABS plastic.





The glass bases and wedges should be spaced as follows

For glass panel widths smaller than 550mm two bases are required.
For glass panel widths between 550-900mm three bases are required.
For glass panel widths above 900-1250mm four bases are required.



For larger panels a maximum spacing of 320mm between centres of wedges.

Glass design:

Effective thickness in terms of bending stress	$h_{ef;w}$	=	$\sqrt[3]{\Sigma h_k^3 + 12\dot{\omega}(\Sigma h_k h_{m,k})^2}$
where	$\dot{\omega}$	=	coefficient of shear transfer of the interlayer
		=	0.3 for standard grade PVB: family 2: for non-Mediterranean locations
	h_k	=	10mm thickness of plies
	$h_{m,k}$	=	5.75mm distance from the mid plane of the glass plies to the centre of the PVB interlayer
	$h_{ef;w}$	=	$\sqrt[3]{\{(10)^3 + (10)^3 + 12 \times 0.3 (10 \times 5.75^2)\}}$
		=	$\sqrt[3]{\{1000 + 1000 + 3.6 (331)\}}$
		=	$\sqrt[3]{(3192)}$
		=	14.723mm say = 15mm
1st moment of area of glass based upon an effective thickness of 15mm and a nominal length of 1000mm		=	$\frac{1000 \times (15)^2}{6}$ = $37500 mm^3/m$
Moment capacity of glass	M_u	=	$87.53 N/mm^2 \times 37500 \times (10)^{-6}$
		=	3.28 kNm/m
		=	> ultimate design moment of 1.561 kNm/m
		=	OK
Effective thickness of glass used to calculate deflection	$h_{ef;w}$	=	$\sqrt[3]{\{t^3 + t^3 + 12\dot{\omega}(t \times h^2 + t \times h^2)\}}$
where	t	=	thickness of plies = 10mm
	$\dot{\omega}$	=	coefficient of shear transfer, which varies from 0 to1
		=	0.3 for standard grade PVB;Family 2: for wind loads in non-Mediterranean locations.
	h	=	distance from mid-plane of each ply to centre of PVB.
	$h_{ef;w}$	=	$\sqrt[3]{\{(10)^3 + (10)^3 + 12 \times 0.3[10(5.75)^2 + 10(5.75)^2]\}}$
		=	$\sqrt[3]{\{1000 + 1000 + 3.6(330 + 330)]}$
		=	$\sqrt[3]{\{4376\}}$
		=	16.35mm
characteristic wind pressure		=	$1.50 kN/m^2$
cantilever height of glass to centre of embedment in base channel		=	1180mm
2nd moment of area of glass 1000mm wide x 16.35mm effective thickness	I_{xx}	=	$\frac{1000 \times (16.35)^3}{12}$
		=	$364227 mm^4/m$

Service load deflection of glass due to design service loading	Δ	=	$\frac{w L^4}{8 E I_{xx}}$		
		=	$\frac{(1500 \times 1.18)(1180)^3}{8 \times 70000 \times 364227}$		
		=	14.26mm		
		=	< 25mm OK		

The 21.5mm laminated glass comprising 2 x 10mm plies with a 1.5mm PVB interlayer is adequate in terms of bending strength and deflection criteria.

Case 2: base fixing channel and HD bolts: base channel located below FFL:

Ultimate wind moment to the underside of the base channel	M_u	=	1.728 kNm/m		
Distance between the centres of bolts	d	=	88.0mm		
Ultimate load bolt tension	T_u	=	$\frac{1.728}{0.088}$	=	19.64 kN/m
Working load bolt tension	Tw	=	$\frac{19.64}{1.5}$	=	13.09 kN/m

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 working load bolt tension becomes **19.64 kN/m.** Bolt forces vary depending upon the bolt spacing selected. eg:

Working load bolt tension:

Bolts installed @ 600mm centres	=	19.64 kN/m x 0.60	=	11.78 kN/bolt
Bolts installed @ 500mm centres	=	19.64 kN/m x 0.50	=	9.82 kN/bolt
Bolts installed @ 400mm centres	=	19.64 kN/m x 0.40	=	7.86 kN/bolt
Bolts installed @ 300mm centres	=	19.64 kN/m x 0.30	=	5.89 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.

The installers should satisfy themselves that the fixing bolts chosen are suitable to resist these loads, and also that the structure into which they are installed can support these loads.

Base channel: properties of aluminium:

Material type		=	Extruded aluminium type 6063 T5
Limiting stress for bending	P_o	=	110 N/mm^2
Limiting stress for tension or compression	P_s	=	130 N/mm^2
Limiting stress for shear	P_v	=	65 N/mm^2
Young's modulus of elasticity	E	=	70,000 N/mm^2

<u>Case 2: Base channel</u>: (cont)

Ultimate resistance capacity	M_c	=	Member capacity based upon Po Ps and Pv divided by the material factor γ_m	=	1.2
Thickness of sides of channel		=	12mm		
Modulus of side of channel		=	$\frac{1000 \times (12)^2}{6}$	=	24000mm³/m
Moment capacity of side of channel per metre	M_c	=	$\frac{110\ N/mm^2 \times 24000\ mm^3 \times (10)^{-6}}{1.2}$		
		=	2.20 kNm/m		
		= >	applied moment on glass	=	OK

The base channels are adequate to support the design imposed and wind loading.

<u>Case 1: base channel located above FFL:</u>

Glass height	=	1076mm		
Height underside of base to top of glass	=	1108mm		
Depth of embedment of glass in base channel	=	80mm approximately		
Ultimate BM to underside of base channel	=	$2.25\ kN/m^2 \times 0.988 \times 0.614$	=	1.365 kNm/m
Width of base channel	=	109mm		
Bolts are located centrally: centre of bolts to edge	=	54.5mm		

Assume a Δ stress block 27.25mm long under base:

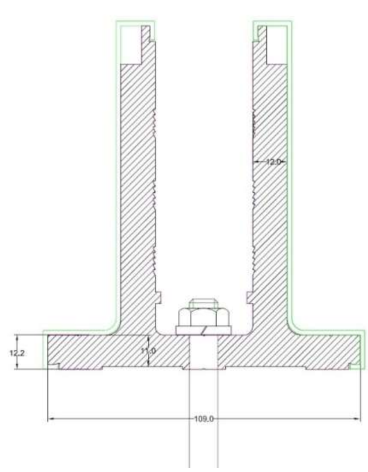
Distance centre of stress block to centre of bolts	=	45.42mm say	=	45mm
Ultimate load bolt tension	=	1.365 kNm/0.045	=	30.33 kN/m
Applying the BS 6180 50% increase working load bolt tension	=	30.33 kN/m		

Bolt forces vary depending upon the spacing selected. eg.
Working load bolt tension:

Bolts installed @ 400mm centres	=	30.33 x 0.40	=	12.13 kN/bolt
Bolts installed @ 300mm centres	=	30.33 x 0.30	=	9.10 kN/bolt
Bolts installed @ 250mm centres	=	30.33 x 0.25	=	7.58 kN/bolt

The installers should satisfy themselves that the fixing bolts chosen are suitable to resist these loads, and also that the structure into which they are installed can support these loads.

Maximum pressure under the base channel	=	30.33 kN/13.63	=	$2.23\ N/mm^2$
			=	OK



SUMMARY

SG12 balustrade system using 21.5mm thick laminated glass without the need for a handrail

1) For sites within the parameters listed on page 6 of these calculations, and/or have a characteristic wind pressure that does not exceed **1.50 kN/m²**, wind loading is the dominant design condition. Sites that do not come within these parameters require separate consideration.

2) The system comprises 2 plies of 10mm thick thermally toughened safety glass with a 1.5mm PVB interlayer. A handrail can be provided as an option, but is not required for structural reasons.

3) The glass acts as a vertical cantilever from a continuous aluminium channel bolted to the balcony structure. These calculations demonstrate that the system is adequate to support the design imposed and wind loads in accordance with British and European Standards.

4) The base channels may be installed either above or below finished floor level (FFL). When fixed above FFL the channel is secured to the balcony structure by means of centrally located M12/M10 drilled resin anchor bolts or similar. Pull-out forces on the bolts depends upon the spacing selected. Working load bolt pull-out forces for various spacing of bolts centre to centre are listed below.

Bolt spacing	Working load pull-out force
400 mm	12.13 kN/bolt
300 mm	9.10 kN/bolt
250 mm	7.58 kN/bolt
150 mm	4.55 kN/bolt

5) Where the base channels are installed below FFL the channel profile is used with M12/M10 holding down bolts located in the side projections of the base. Working load pull-out forces for various bolt spacing centre are listed below.

Bolt spacing	Working load pull-out force
600mm	11.78 kN/bolt
500mm	9.82 kN/bolt
400mm	7.86 kN/bolt
300mm	5.89 kN/bolt
200mm	3.93 kN/bolt

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 the specified loads and moments.

7) Higher bolt loads could be achieved where fixings are made direct to a substantial structural steel frame. Lower bolt forces would most likely need to be taken where fixings are made into materials having a lower strength than good quality concrete.

8) In accordance with our O & M guidelines, the balustrading should be inspected at least annually by a competent person to see that nothing has worked loose or become degraded.

Prepared for and on behalf of Balconette by
A. G. Bice CEng, FICE, FIStructE