Frameless Juliet Balustrade system using 21.5mm laminated glass ***PAGE 1*** **(ref: FJUL21.5LAM150517)**

Structural Calculations for Frameless Juliet balustrade System using 21.5mm laminated glass

Our ref: FJUL21.5LAM150517 **Date of issue: May 2017**

Frameless Juliet Balconies using 21.5mm laminated glass

DESIGN TO EUROCODES & CURRENT BRITISH STANDARDS

Design standards:

EN 1990	Eurocode 0:	Basis of structural design.
EN 1991	Eurocode 1:	Actions on 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 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	Q_{k1}	=	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.

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

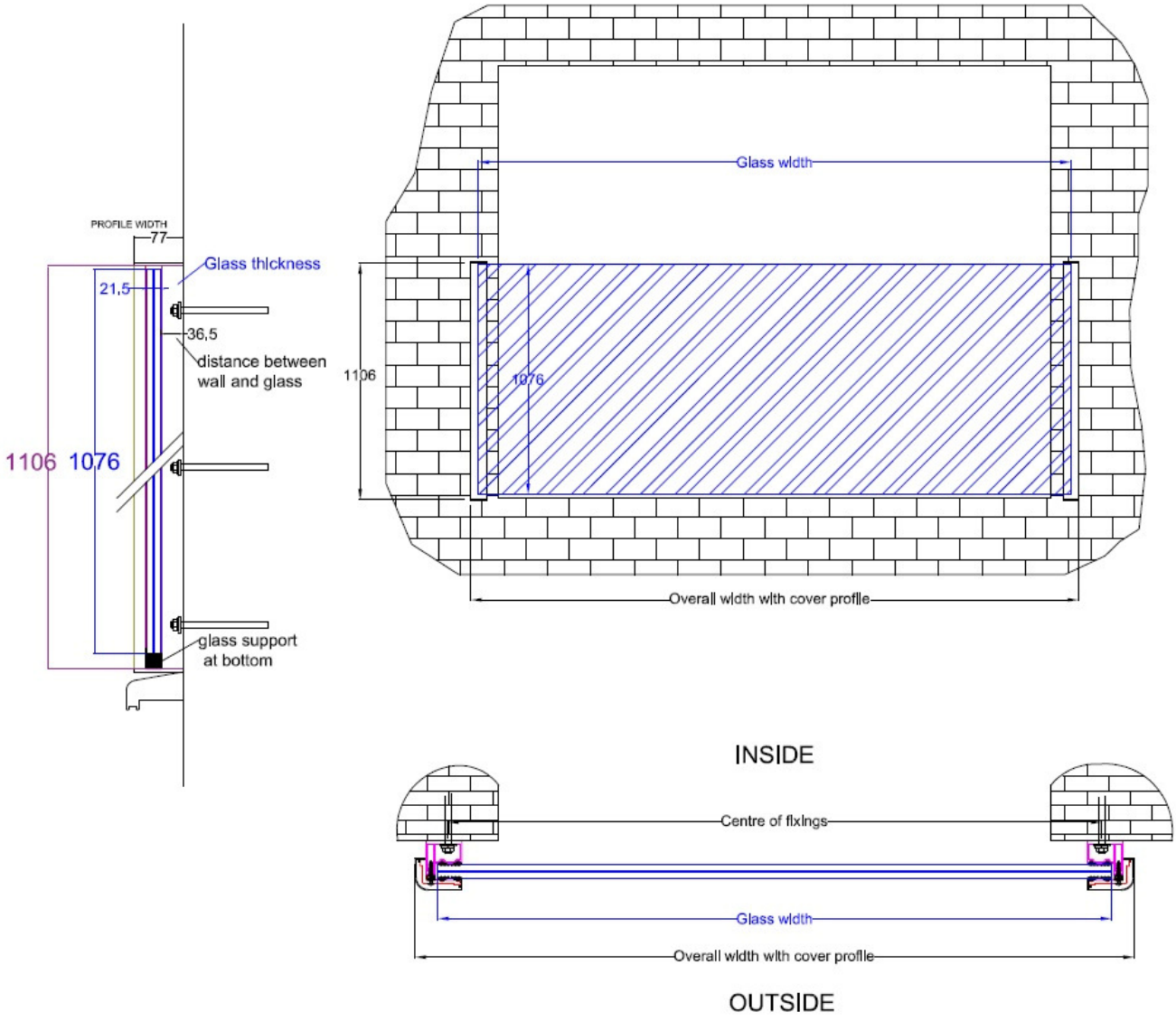
Type of occupancy for part of the building or structure	Examples of specific use	Horizontal uniformly distributed line load (kN/m)	Uniformly distributed load applied to the infill (kN/m²)	A point load applied to part of the infill (kN)
Domestic and residential activities	(i) All areas within or serving 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 imposed service loads are considered as three separate load cases. They are not combined.
- 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.



Typical section, elevation and plan section

21.5mm laminated glass system:

Structural system: The glass spans horizontally between points of support anchored to the main building structure each side of door or window openings. The horizontal imposed service load of 0.74 kN/m is applied towards the top of the glass.

As a result of shear lag effects more of this load will be carried by the top half of the glass than the bottom.

The glass is approximately 1100mm high. For design purposes it is considered reasonable to assume that 60% of the horizontal imposed line load is carried by the top 550mm of glass and the remaining 40% by the bottom 550mm.

The calculations for the 21.5mm laminated glass system are based upon a maximum horizontal span of 3200mm between points of support on the main building structure.

Glass type: 21.5mm overall thickness of laminated glass, comprising 2 x 10mm thick plies of thermally toughened soda lime silicate safety glass bonded by means of a 1.5mm PVB interlayer. Smooth float 'as produced' finish with polished edges.

Characteristic strength = 120 N/mm^2

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

Design strength $f_{g;d} = \frac{K_{mod} \times K_{sp} \times K_{g;k}}{\gamma_{M;A}} + \frac{K_v (f_{b;k} - f_{g;k})}{\gamma_{M;V}}$

where:

K_{mod} = 30 second duration factor
= 0.89 for a domestic balustrade load

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 strengthening

$f_{b;k}$ = glass characteristic strength

$\gamma_{M;A}$ = 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 $f_{g;d} = \frac{0.89 \times 1.0 \times 45}{1.6} = \frac{1.0 (120 - 45)}{1.2}$

= 25.03 + 62.50

= **87.53 N/mm^2**

Three separate design conditions are considered:

(A) Imposed horizontal uniformly distributed line load applied 1100mm above FFL:

The top 550mm of glass is considered to resist 60% of the horizontal imposed line load over a span of 3200mm between points of support:

Factored uniformly distributed line load on 550mm strip = 0.74 kN/m x 1.5 load factor x 60%
= 0.666 kN/m

Factored BM on strip = $\frac{0.666 \text{ kN/m} \times (3.2)^2}{8}$ = 0.852 kNm

Effective thickness of laminated glass in terms of bending stress = $h_{ef;w}$

= $\{ \Sigma h_k^3 + 12 \acute{w} (\Sigma h_k \ h_{m;k}^2 \}^{1/3}$

where: h_k = thickness of plies
= 10mm

$\acute{w}$ = coefficient of shear transfer; standard grade PVB family 2; personal load; normal duty
= 0.10

$h_{ef;w}$ = $\{ (10)^3 + 12 \times 0.1 (10)^3 \}^{1/3}$

= $\{ 2200 \}^{1/3}$ = 13mm

Section modulus (Z) of 550mm wide strip x 13mm effective thickness = $\frac{550 \times (13)^2}{6}$ = 15492 mm^3

Ultimate bending stress = $\frac{0.852 \times (10)^6}{15492}$ = 55 N/mm^2

= < 87.53 N/mm^2

= OK

(B) Uniformly distributed service load of 1.0 kN/m² applied to the surface area of the glass:

Factored bending moment = $\frac{1.0 \text{ kN/m}^2 \times 1.5 \text{ load factor} \times 3.2^2}{8}$ = 1.92 kNm/m

Section modulus of glass 1000mm wide x 13mm effective thickness = $\frac{1000 \times (13)^2}{6}$ = 28167 mm^3/m

Moment capacity of glass 1000mm wide x 13mm effective thickness = 87.53 N/mm^2 x 28167 mm^3 x $(10)^{-6}$ = 2.465 kNm/m

> 1.92 kNm/m

= OK

(C) Service point load of 0.5 kN applied in any position on the glass

Worst case for bending occurs when the point load is applied at mid-span towards the top or bottom of the glass.

Ultimate moment on glass due to point load = $\frac{(0.50\ \text{kN} \times 1.5\ \text{load factor}) \times 3.2}{4}$ = 0.60 kNm

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

Moment capacity of 300mm strip = 2.465 kNm/m x 0.30
= 0.74 kNm > 0.60 kNm = OK

Glass deflection:
Service load deflection on 550mm x 21.5mm strip due to a UDL of 0.74 kN/m x 60%:

$$\Delta = \frac{5\ w\ L^4}{384\ E\ I}$$

where:
w = imposed service load per metre
= 740 N/m x 60% = 444 N/m

L = span between points of support = 3200mm

E = Young's modulus of glass = 70,000 N/mm^2

I = 2nd moment of area of strip

$$\frac{550 \times (21.5)^3}{12} = 455509\text{mm}^4$$

$$\Delta = \frac{5 \times (444 \times 3.2)\ (3200)^3}{384 \times 70000 \times 455509} = 19.01\text{mm}$$

= < 25mm OK

Deflection due to the uniformly distributed service load of 1.0 kN/m^2 applied to the 550mm wide strip:

$$\Delta = \frac{5 \times (550 \times 3.2)\ (3200)^3}{384 \times 70000 \times 455509} = 23.55\text{mm}$$

= < 25mm OK

Deflection due to a point service load of 0.50 kN applied at mid-span to a 300mm wide strip:

$$\Delta = \frac{500\ \text{N} \times (3200)^3}{48 \times 70000 \times 248460} = 19.62\text{mm}$$

= < 25mm OK

The glass is adequate in terms of both bending strength and deflection.

Fixing bolts: The horizontal imposed design load can only act over the clear width of the opening. ie. 2940mm for a balustrade width of 3200mm between points of support. The fixing bolt load is calculated for a maximum loaded length equal to the clear width of the opening.

Conservatively, it will be assumed that the top fixing bolt resists the whole of the pull-out force from the imposed horizontal service load of 0.74 kN/m acting over the clear opening width of 2.94m between points of support.

Bolt tension due to the	T	=	0.74 kN/m x 1.47
imposed service load		=	1.09 kN

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 above recommendation, the **working** load pull-out force on the upper bolts becomes 1.09 kN x 1.5 = 1.635 kN/bol**t** say **1.64 kN/bolt.**

The nominal tension capacity of M10 or larger (8.8 grade) bolts is greater than the design pull-out force. The allowable load is therefore determined by the pull-out resistance of the drilled resin anchor bolts or other anchorages used, and also by the strength of the structure into which they are installed to support these loads, and not by the tension capacity of the bolts themselves.

For shorter standard length balustrades the pull-out forces on the upper fixing bolts are proportionally lower.

span c/c supports	**opening size**	**working load tension on upper fixing bolt** (including 50% increase recommended in BS 6180)
1280mm	1020mm	0.57 kN
1500mm	1240mm	0.69 kN
1680mm	1420mm	0.79 kN
1860mm	1600mm	0.89 kN
2180mm	1920mm	1.07 kN
2450mm	2190mm	1.22 kN
2840mm	2580mm	1.44 kN
3200mm	2940mm	1.64 kN

SUMMARY

Frameless Juliet balustrades using 21.5mm laminated glass

1. The 21.5mm laminated glass balustrade system comprises two 10mm thick plies of thermally toughened soda lime silicate safety glass bonded together by means of a 1.5mm thick PVB interlayer to give an overall glass thickness of 21.5mm.

2. The glass is secured to the building structure by means of aluminium profiles bolted to the structure each side of door or window openings in accordance with the details shown on page 3 of these calculations.

3. The 21.5mm laminated glass system is adequate to support the balustrade design loads specified in Table 2 of BS 6180:2011, in respect of the occupancy classes highlighted on page 2 of these calculations, for spans of up to 3.2 metres between points of supports.

4. In accordance with BS 6180:2011, the structural design allows for a horizontal uniformly distributed line load of 0.74 kN/m applied to the glass 1100mm above finished floor level, a uniformly distributed load of 1.0 kN/m^2 applied to the surface area of the glass, or a point load of 0.50 kN applied to any position. These are service (working) loads. They are multiplied by a load factor of 1.5 to give ultimate design loads.

5. Calculated displacement of any point on the barrier from its original unloaded position is limited to 25mm under service load conditions.

6. For the maximum span of 3.2 metres between points of support the design working load pull-out force on the anchor bolts is 1.64 kN/bolt.

7. For shorter standard length balustrades the pull-out forces on the fixing bolts are proportionally lower.

span c/c supports	**opening size**	**working load tension on upper fixing bolt** (including 50% increase recommended in BS 6180)
1280mm	1020mm	0.57 kN
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2450mm	2190mm	1.22 kN
2840mm	2580mm	1.44 kN
3200mm	2940mm	1.64 kN

8. The installers should satisfy themselves that the anchor bolts chosen are suitable to resist these pull-out forces, and also that the structure into which the bolts are installed is adequate to support this load.

Prepared for and on behalf of Balconette by
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