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December 2014

STRUCTURAL CALCULATIONS

FOR

JULIET BALCONY BALUSTRADES

USING

21.5mm LAMINATED GLASS SYSTEM

BY

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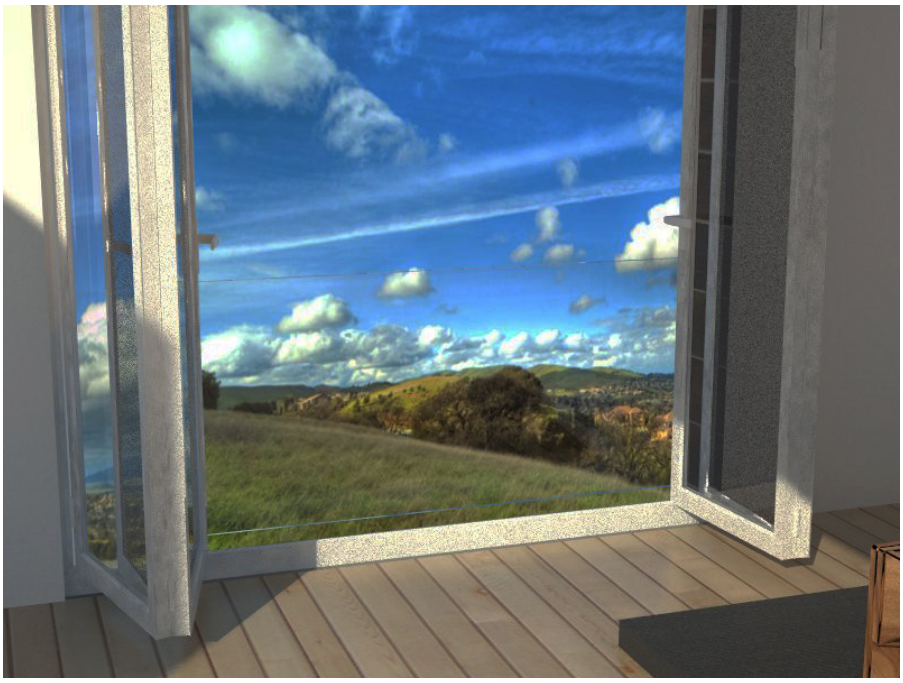

LAMINATED GLASS SYSTEM

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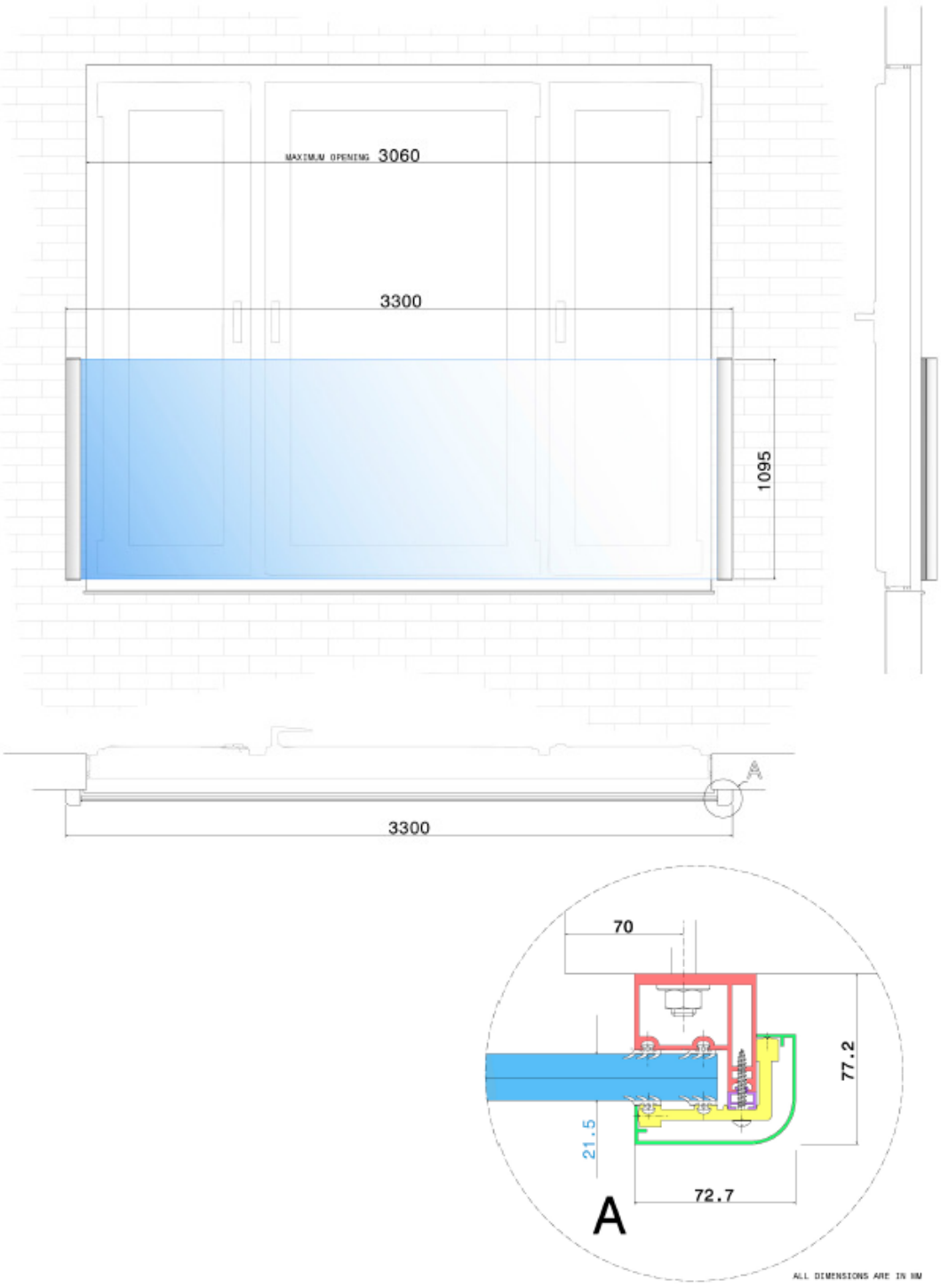

21.5m LAMINATED GLASS SYSTEM

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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 (iii), (iv), (viii) and (ix).** The loads are separately applied, not co-existent. The horizontal uniformly distributed line load of 0.74 kN/m 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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JULIET BALCONIES – LAMINATED GLASS SYSTEM:

Horizontal loads: The glass is designed to resist a horizontal imposed service line load of 0.74 kN/m applied 1100mm above finished floor level, or a uniformly distributed load of 1.0 kN/m^2 or a point load of 0.5 kN applied at any position. The loads are separately applied, not additive.

Vertical loads: The glass is designed to resist a vertical concentrated service load of 1.0 kN applied in any position along the length, or a uniformly distributed load of 0.60 kN/m, whichever gives the worst design condition in combination with the horizontal load.

Factored loads: Factored loads are used for checking the limit state of static strength of the glass. The imposed service loads noted above are multiplied by a load factor of γ_a which is related to the risk involved in failure of the member under consideration. For balustrades and barriers where failure would involve a risk of falling γ_a is taken as 1.5.

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

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.

Owing to '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.

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

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JULIET BALCONIES – 21.5mm laminated glass system:

Design data:

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

Glass type = 21.5mm laminated glass, comprising 2 x 10mm thick plies of thermally toughened sheets of 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 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 load 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 toughening

$f_{b;k}$ = 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

Design stress (ultimate) $f_{g;d}$ = $\frac{0.89 \times 1.0 \times 45}{1.6} + \frac{1.0 (120 - 45)}{1.2}$

= 25.03 + 62.50

= **87.53 N/mm^2**

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JULIET BALCONIES – 21.5mm laminated glass system:

Consider the top 550mm of glass subject to horizontal line loading over a span between points of support of 3200mm:

factored uniformly distributed line load on 550mm strip = 0.74 kN/m x 60% x 1.5 load factor
= 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) = $\sqrt[3]{\Sigma\ h_k^3 + 12\ \hat{w}\ \{\Sigma\ h_k\ h_{m;k}^2\}}$

where: h_k = thickness of plies
= 10mm

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

$H_{ef;w}$ = $\sqrt[3]{(10)^3 + 12 \times 0.1\ (10)^3}$

= $\sqrt[3]{2200}$

= 13mm

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

ultimate bending stress $\frac{M}{Z}$ = $\frac{0.852 \times (10)^6}{15492}$

= 54.996 N/mm^2

= < 87.53 N/mm^2

= OK

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JULIET BALCONIES – 21.5mm laminated glass system:

Service load deflection on 550 x 21.5mm strip (Δ) $= \frac{5\ w\ L^4}{384\ E\ I}$

Where:

w = service load per metre
= 60% x 740 N/m
= 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 mm^4

$\Delta = \frac{5 \times (444 \times 3.2)\ (3200)^3}{384 \times 70000 \times 455509}$
= 19.01mm
= < 25mm
= OK

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

factored load = 1.0 kN/m^2 x 0.55 x 1.5 load factor
= 0.825 kN/m

factored BM $= \frac{0.825 \times (3.2)^2}{8}$
= 1.056 kNm

ultimate bending stress $\frac{M}{Z} = \frac{1.056 \times (10)^6}{15492}$
= 68.16 N/mm^2
= < 87.53 N/mm^2
= OK

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JULIET BALCONIES – 21.5mm laminated glass system:

Check deflection on 550mm wide strip resisting a service load of 0.55 kN/m arising from the UDL load of 1.0 kN/m^2.

$$\Delta = \frac{5 \times (0.55 \times 3.2) (3200)^3}{384 \times 70000 \times 455509}$$

$$= 23.55\text{mm}$$

$$= < 25\text{mm}$$

$$= \text{OK}$$

Vertical loads:

Structural system:
The glass is required to support a vertical imposed uniformly distributed load of 0.60 kN/m or a concentrated vertical point load of 1.0 kN applied at any position along the length. These are service loads. A load factor of 1.5 is applied to the loads to give design ultimate loads.

In resisting vertically applied loads the glass acts as a narrow beam that is laterally unrestrained between the points of support at either ends. Lateral torsional buckling is a key criterion in the design.

The Institution of Structural Engineers' publication *'Structural use of glass in buildings (second edition) February 2014'* make reference to the Australian code of practice on the design of structural glass for guidance on the buckling analysis of glass beams.

Appendix C of AS 1288-2011 recommends that for unrestrained beams the buckling resistance can be obtained from the following equation:

$$M_{CR} = \frac{(g_2)}{(L_{ay})} \times [(EI)_y (GJ)]^{1/2} \{1 \times g_3 (y_{r1}) [EI)y (GJ)]^{1/2}\}$$

where:

M_{CR} = critical elastic buckling moment

L_{ay} = distance between points of effective rigid rotational restraints

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JULIET BALCONIES – 21.5mm laminated glass system:

Vertical loads on glass (continued)

	(E I)y	=	effective rigidity for bending about the minor axis
	(GJ)	=	effective torsional rigidity
	g_2	=	slenderness ratio for mid-point load with major axis restraint only = 4.2 for simply supported
	g_3	=	slenderness ratio for mid-point load with major axis restraint only = 1.7 for simply supported
	yh	=	distance from the I_{xx} axis to the point of application of the load = d/2 = 550mm
modulus of rigidity	G	=	28700 N/mm^2
depth of beam	d	=	1100mm (nominal)
effective width	b	=	14mm
second moment of area about minor axis	Iy	=	$\frac{d\,b^3}{12}$
		=	$\frac{1100 \times (14)^3}{12}$
		=	251533mm^4
polar moment of area	J	=	$\frac{d\,b^3}{3}\left(1 - 0.63 \times \frac{14}{1100}\right)$
		=	$\frac{1100 \times (14)^3}{3}\left(1 - 0.63 \times \frac{14}{1100}\right)$
		=	1 x (10)^{6}mm^4
effective torsional rigidity	(GJ)	=	28700 x (10)^{6}N/mm^2
		=	2.87 x (10)^{10}N/mm^2

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JULIET BALCONIES – 21.5mm laminated glass system:

Vertical loads on glass (continued)

$(GJ)^{1/2}$	=	$[2.87 \times (10)^{10}]^{1/2}$	=	169410 N/mm^2
(EI)y	=	70000 N/mm^2 x 251533mm^4	=	$1.76 \times (10)^{10}$
$[(EI)y\ (GJ)]^{1/2}$	=	$[169410 \times 1.76 \times (10)^{10}]^{1/2}$	=	$54.6 \times (10)^3$N/mm^2
$\frac{(g_2)}{(Lay)}$	=	$\frac{4.2}{3200}$	=	$1.31 \times (10)^{-3}$
$\frac{(yh)}{(Lay)}$	=	$\frac{550}{3200}$	=	0.172

Critical buckling moment:

M_{CR} = $\frac{(g_2)}{(Lay)} \times [(Ely)\ (GJ)]^{1/2} \{1 \times g_3\ \frac{(yh)}{(Lay)}\ [(Ely)\ (GJ)]^{1/2}$

= $1.31 \times (10)^{-3}\ [54.6 \times (10)^3\ \{1 \times 1.7\ (0.172)\ [54.6 \times (10)^3]\}$

= $11412 \times (10)^3$Nmm

= 11.412 kNm

factored central point load	=	1.50 kN			
factored BM from point load	=	$\frac{1.50 \times 3.2}{4}$	=	1.20 kNm	
	=		=	< 11.412 kNm	OK
factored UDL	=	0.60 kN/m x 1.5	=	0.90 kN/m	
factored BM from UDL	=	$\frac{0.90 \times (3.2)^2}{8}$	=	1.152 kNm	
			=	< point load BM	
section modulus Z based on 2 x 10mm panes	=	$\frac{12 \times (1100)^2}{6}$	=	$2.42 \times (10)^6$ mm^3	
factored bending stress M/Z	=	$\frac{1.2 \times (10)^6}{2.42 \times (10)^6}$	=	0.496 N/mm^2	
			=	v. small	
combined ultimate bending stress	=	68.53 + 0.496	=	69.026 N/mm^2	
			=	< 87.53 N/mm^2	
			=	OK	

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JULIET BALCONIES – 21.5mm laminated glass system:

Fixing bolts: Conservatively, it will be assumed that the top fixing bolt resists the whole of the pull-out force arising from the imposed horizontal service load of 0.74 kN/m, plus tension from the vertical imposed service load of 1.0 kN acting at the support, plus tension from the self weight of the glass.

Bolt tension due to the horizontal imposed load of 0.74 kN/m	=	0.74 kN/m x 1.6	=	1.184 kN
Bolt tension due to vertical imposed load of 1.0 kN on a 50mm cantilever	=	1.0 kN x 0.050	=	0.050 kN
Bolt tension due to self weight of the glass 21.5mm thick @ 2500 kg/m^3	=	25 kN/m3 x 0.0215 x 0.50	=	0.027 kN
		Σ	=	1.261 kN
		say	=	1.30 kN

SUMMARY

1. The 21.5mm laminated glass system for Juliet balconies by Balcony System Solutions Limited comprises two 10mm thick panes 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 brackets bolted to the structure each side of door or window openings as shown on the details on page 3 of these calculations.

3. The structural calculations show that the 21.5mm laminated glass system is adequate to support the balustrade design loads specified in Table 4 of BS 6399-1:1996, relating to occupancy classes A, B, E and C3, up to a maximum span between points of support of 3.2 metres..

4. The design allows for a horizontal uniformly distributed line load of 0.74 kN/m applied to the glass 1100mm above finished floor level, or a uniformly distributed load of 1.0 kN/m^2. In addition the design allows for a vertical point load of 1.0 kN applied in any position along the top of the glass, or a uniformly distributed vertical load of 0.60 kN/m.

5. On the maximum span of 3.2 metres between points of support the design working load pull-out force on the fixing bolts is 1.3 kN/bolt. This should be readily achievable with 10mm or 12mm diameter resin anchor bolts.

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

END