Structural Calculations for “Mirror” Juliet balconies using BALCONY 1
System handrail & bottom rail (70mm Diameter)

Our ref: MJULB1NB040417
Date of issue: April 2017

DESIGN TO EUROCODES & CURRENT BRITISH STANDARDS

Design standards:
- EN 1990: Eurocode 0: Basis of structural design.

Design loads:
- 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 $Q_l = 0.74 \text{kN/m}$ 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/m²

Point load on glass infill $= 0.50 \text{kN}$ applied to any part of the glass fill panels.
These imposed 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 $\gamma_{Q1}$ 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 & handrail profile moment of inertia

\[ I_{yy} = 47 \text{ cm}^4 \]
Balcony 1 system: Section properties of handrail:

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 = $E = 70000$ N/mm$^2$
Shear modulus = $G = 27000$ N/mm$^2$
Moment of inertia about the y-y axis = $I_{yy} = 47$ cm$^4$
Least elastic modulus about the y-y axis = $W_{el} = 12.227$ cm$^3$
Partial factor for material properties = $\gamma_{M1} = 1.10$
Value of shape factor (conservative value) = $\alpha = W_{pl}/W_{el} = 1.2$ say
Design ultimate resistance to bending about the y-y axis:

\[
M_{Rd} = M_{\infty, Rd} = \alpha W_{el} f_o / \gamma_{M1} \]
\[
= 1.2 \times 12.227 \text{ cm}^3 \times 130 \text{ N/mm}^2 \times (10)^{-3} \]
\[
= \frac{1.734 \text{ kNm}}{1.1} \]

= 1.734 kNm
Design ultimate horizontal load on handrail = \( F = 0.74 \text{kN/m} \times 1.5 \)
Design horizontal moment on handrail between points of support.

\[ M = \frac{F \times L^2}{8} \]

Allowable span \( L \) between points of support based upon the moment capacity of the handrail

\[ L = \left[ 8 \times \frac{M_{rd}}{F} \right]^{0.5} \]

\[ = \left[ 8 \times 1.734 \text{kNm} \right]^{0.5} \]

\[ = 3.54\text{m} \quad \text{say} = 3.50\text{m} \]

In terms of bending capacity the handrail can span up to 3.50m simply supported between points of support.

However the service load deflection is limited to a maximum of 25mm.

The support brackets at each end of the handrail are 80mm wide. For a 3200mm long handrail the span centre to centre of the support brackets is 3120mm.

Deflection (\( \Delta \)) of span (\( L \)) for an imposed UDL (\( F \))

\[ \Delta = \frac{5 \times F \times L^4}{384 \times E \times I} \]

For a handrail 3.2m long with the span c/c support brackets 3.12m

\[ \Delta = \frac{5 \times (740 \times 3.12) \times (3120)^2}{384 \times 70 \times 000 \times 47 \times (10)^4} \]

\[ = 27.75\text{mm} \quad \text{slightly} > 25\text{mm} \quad \text{but say OK} \]

Therefore deflection limitations govern the allowable span of the handrail between points of support in respect of the horizontal imposed service uniformly distributed line load.

In order to comply with service load deflection limitations the allowable span of the handrail is limited to 3.12 metres between the centres of supporting brackets.

**Handrail brackets:**
The horizontal imposed design load on the handrail can only act over the clear width of the opening, ie. 2940mm for a handrail 3200mm long overall. The bracket design load \( H \) is calculated for a maximum loaded length equal to the maximum clear opening width.

For the maximum clear opening width of 2940mm:

Ultimate horizontal imposed load on the handrail bracket

\[ H = \frac{(0.74 \text{kN/m} \times 1.5) \times 2.94}{2} \]

\[ = 1.632 \text{kN} \]

**Section (A) dimensions**

- 80mm wide x 12mm thick, less 2 No. 12mm diameter holes for 10mm diameter bolts.
- 56 x 12mm effective section.

**Plastic section modulus**

\[ W_p = \frac{56 \times (12)^2}{4} \]

\[ = 2016 \text{mm}^3 \]
Bracket section (A)
Factored applied moment \[ M = 1.632 \text{kN} \times 0.068 \]
= 0.111 kNm

Limiting stress in bending \[ f_o = 130 \text{ N/mm}^2 \]

Moment capacity of section \[ M_c = \frac{130 \text{ N/mm}^2 \times 2016 \text{ mm}^3 \times (10)^{-6}}{1.1} \]
= 0.238 kNm > 0.111 kNm \text{OK}

Section (B)
Dimensions at section (B) \[ = 80 \text{ mm wide x 11mm thick} \]

Factored applied moment \[ M = 1.632 \text{kN} \times 0.052 \]
= 0.085 kNm

Plastic section modulus \[ W_{pl} = \frac{80 \times (11)^3}{4} \]
= 2420 mm³

Moment capacity of section \[ M_c = \frac{130 \text{ N/mm}^2 \times 2420 \text{ mm}^3 \times (10)^{-6}}{1.1} \]
= 0.286 kNm > 0.085 kNm \text{OK}
Handrail brackets:
Section (C)

Dimensions of section = 80 mm wide x 7 mm thick

Factored applied moment \( M \) = 1.632 kN x 0.033 = 0.054 kNm

Plastic section modulus \( W_{pl} \) = \( \frac{80 \times (7)^2}{4} \) = 980 mm³

Moment capacity of section \( M_c \) = \( 130 \text{ N/mm}^2 \times 980 \text{ mm}^3 \times (10)^{-6} \times 1.1 \) = 0.116 kNm > 0.054 kNm OK

Shear force at section (C) \( V \) = 1.632 kN

Design plastic shear resistance \( V_{pl, RD} \) = \( A_v \left( \frac{f_y}{\gamma_{MO}} \right) \)

\( \gamma_{MO} = \left( \frac{80 \times 7}{190 / 1.732} \right) \times (10)^{-3} \)

\( = 61.43 \text{ kN} > 1.632 \text{ kN} \) OK

The handrail brackets are adequate to resist the ultimate design bending and shear forces in respect of the maximum handrail span of 3.12 metres between bracket centres.

Handrail bracket fixing bolt forces:

(2 No. M10 bolts top; 1 No. M10 bolt bottom of bracket).

Moments taken about the lower bolt for the direct pull-out force on the top 2 No. bolts:

Consider the maximum span c/c brackets of 3.12 m (loaded length of handrail 2.94 m)

Factored load on bracket \( H \) = 1.632 kN

Direct tension on top 2 bolts \( T \) = \( \frac{1.632 \times 0.113}{0.0423} \) = 4.36 kN

\( = 2.18 \text{ kN/bolt} \) (ultimate load)

\( = 1.453 \text{ kN/bolt} \) (working load)

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 ultimate direct pull-out force on the upper bolts becomes 2.18 x 1.5 = 3.27 kN/bolt. The working load pull-out force on the upper bolts becomes 1.453 kN x 1.5 = 2.18 kN/bolt.

The nominal tension capacity of M10 (8.8 grade) bolts is greater than these design forces. The allowable load is therefore determined by the pull-out resistance of the drilled resin anchor bolts or similar, 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.
Handrail brackets: working loads on fixing bolts:
For shorter standard length handrails the pull-out forces on bracket fixing bolts are proportionally lower.

<table>
<thead>
<tr>
<th>Handrail length</th>
<th>opening size</th>
<th>working load tension on each upper bolt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1280mm</td>
<td>1020mm</td>
<td>0.76 kN</td>
</tr>
<tr>
<td>1500mm</td>
<td>1240mm</td>
<td>0.92 kN</td>
</tr>
<tr>
<td>1680mm</td>
<td>1420mm</td>
<td>1.05 kN</td>
</tr>
<tr>
<td>1860mm</td>
<td>1600mm</td>
<td>1.19 kN</td>
</tr>
<tr>
<td>2180mm</td>
<td>1920mm</td>
<td>1.42 kN</td>
</tr>
<tr>
<td>2450mm</td>
<td>2190mm</td>
<td>1.62 kN</td>
</tr>
<tr>
<td>2840mm</td>
<td>2580mm</td>
<td>1.91 kN</td>
</tr>
<tr>
<td>3200mm</td>
<td>2940mm</td>
<td>2.18 kN</td>
</tr>
</tbody>
</table>

Lower rail brackets: These brackets have the same sectional profile as the handrail brackets. The brackets support the dead load from the glass and rails.

Dead load from glass + rails = 0.26 kN/m x 1.35 (γ) = 0.351 kN/m factored

Factored vertical load per bracket for a lower rail length of 3200mm.

Factored moments:

- Section (A)
  - \( M = 0.562 \text{ kN} \times 0.08 = 0.045 \text{ kNm} \)
  - \( M_c = 0.238 \text{ kNm} \) = OK

- Section (B)
  - \( M = 0.562 \text{ kN} \times 0.07 = 0.039 \text{ kNm} \)
  - \( M_c = 0.286 \text{ kNm} \) = OK

- Section (C)
  - \( M = 0.562 \text{ kN} \times 0.008 = 0.0045 \text{ kNm} \)
  - \( M_c = 0.116 \text{ kNm} \) = OK

The brackets are adequate to resist the design factored moments.

Bolt loads: (2 No. 10mm diameter bolts top, 1 No. 10mm bolt bottom of bracket)

- Direct tension on top bolt \( T = \frac{0.562 \text{ kN} \times 0.086}{0.0423} = 1.143 \text{ kN} \)

Applying the 50% increase in fixing loads recommended in BS 6180, this becomes \( 1.71 \text{ kN/bolt} \) (ultimate load) and \( 1.143 \text{ kN/bolt} \) (working load).

Shear force: on 3 No. bolts \( = \frac{0.562 \text{ kN}}{3} = 0.187 \text{ kN/bolt say} \)

Applying the 50% increase as per BS 6180, this becomes \( 0.28 \text{ kN/bolt} \) (ultimate load) and \( 0.187 \text{ kN/bolt} \) (working load).
Glass infill:

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

Glass type = 10mm thermally toughened soda silicate safety glass with smooth ‘as produced’ finish with polished edges.

Characteristic design strength = 120 N/mm²

Ultimate design stress \( f_{gd} \) = \( \frac{K_{mod} \times K_{sp} \times K_{gk}}{\gamma_{M,A}} + \frac{K_{v} (f_{bk} - f_{gk})}{\gamma_{M,V}} \)

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’

\( f_{gk} \) = characteristic strength of basic annealed glass
= 45 N/mm²

\( K_{v} \) = manufacturing process strengthening factor
= 1.0 for horizontal toughening

\( f_{bk} \) = characteristic strength of processed glass
= 120 N/mm²

\( \gamma_{M,A} \) = 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 \( f_{gd} \) = \( \frac{0.89 \times 1.0 \times 45}{1.6} + \frac{1.0 (120 - 45)}{1.2} \)
= 87.53 N/mm²

Section modulus of glass

\( Z \) = \( \frac{1000 \times (10)^2}{6} \)
= 16667 mm³/m

Ultimate moment capacity of glass

\( M_u \) = \( f_{gd} \times Z \)
= 87.53 N/mm² \times 16667 mm³ \times (10)^{-6}
= 1.459 kNm/m
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.

Two separate design conditions are considered:

**Uniformly distributed service load on the infill of 1.0 kN/m²**

Ultimate UDL on glass  
= \(1.0 \text{ kN/m}^2 \times 1.5\)  
= \(1.5 \text{ kN/m}^2\)

Ultimate moment on glass due to UDL on 1.0m span  
= \(1.5 \text{ kN/m}^2 \times (1.0)^2 / 8\)  
= \(< 1.459 \text{ kNm/m} = \text{OK}\)

The reaction on the handrail from the UDL on the glass is less than the design horizontal UDL on the handrail. Therefore the design load on the glass is not a critical design case in terms of the handrail.

**Service point load of 0.5 kN applied in any position on the glass**

Worst case for bending stress occurs when the point load is applied at mid-height of the glass.

Ultimate moment on glass due to point load  
= \((0.50 \text{ kN} \times 1.5) \times 1.0\)  
= \(0.1875 \text{ kNm}\)

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

Moment capacity of 300mm strip  
= \(1.459 \text{ kNm} \times 0.30\)  
= \(0.4377 \text{ kNm}\)

**Glass deflection:**

Inertia of glass 1000 x 10mm  
= \(1000 \times (10)^3 / 12\)  
= \(83333 \text{ mm}^4\)

Service load deflection due to a UDL of 1.0 kN/m²  
= \(5 \times (1000 \times 1.0) (1000)^3 / 384 \times 70 000 \times 83333\)  
= \(2.232\)mm

Inertia of glass 300 x 10mm  
= \(0.03 \times 83333 \text{ mm}^4\)  
= \(25 000 \text{ mm}^4\)

Service load deflection due a point load of 0.5 kN at mid-span  
= \(500 \times (1000)^3 / 48 \times 70 000 \times 25 000\)  
= \(5.95\)mm

The glass is adequate in terms of both bending strength and deflection.
**Glass deflection:**
Consider service load deflection of the glass due to the design UDL:

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

Service load deflection due to a UDL of 1.0 kN/m\(^2\) on a simply supported span of 1.0m = \( \frac{5 \times (1000 \times 1.0)^3}{384 \times 70000 \times 83333} \) = 2.232 mm

< span = 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 = \( \frac{0.3 \times 83333}{4} \) = 25 000 mm\(^4\)

Service load deflection due to a point load of 0.5 kN applied at mid-span = \( \frac{500 \times (1000)^3}{48 \times 70000 \times 25000} \) = 5.95mm

< span = OK

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

**Handrail – bracket connection:**
The handrail is connected to the wall brackets by means of 2 No. 4.8mm diameter stainless steel self-tapping screws.

The maximum opening size (and therefore maximum loaded length of handrail) is 2.94m.

Horizontal service (working) load on the wall fixing for a clear span of 2.94m = 0.74 kN/m x 1.47m = 1.09 kN/fixing

Working load shear force on the 4.8mm x 19mm stainless steel self-tapping screws = 1.09 kN/2 = 0.545 kN/bolt or screw

Ultimate load shear force on the anchor bolts and screws = 0.545 kN/bolt x 1.5 = 0.8175 kN/bolt or screw
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.

<table>
<thead>
<tr>
<th>Nom t mm</th>
<th>When calculating t mm</th>
<th>Tensile yield limit N/mm²</th>
<th>Screw diameter 4,2 mm</th>
<th>Screw diameter 4,8 mm</th>
<th>Screw diameter 5,5 mm</th>
<th>Screw diameter 6,3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$t_1 = t$</td>
<td>$t_1 = 2.5t$</td>
<td>$t_1 = t$</td>
<td>$t_1 = 2.5t$</td>
</tr>
<tr>
<td>0,4</td>
<td>0.32</td>
<td>250</td>
<td>0.25</td>
<td>0.64</td>
<td>0.28</td>
<td>0.61</td>
</tr>
<tr>
<td>0,5</td>
<td>0.41</td>
<td>250</td>
<td>0.38</td>
<td>0.69</td>
<td>0.40</td>
<td>0.79</td>
</tr>
<tr>
<td>0,6</td>
<td>0.59</td>
<td>250</td>
<td>0.59</td>
<td>0.86</td>
<td>0.56</td>
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<td>0,7</td>
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<td>1.00</td>
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<td>0,8</td>
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<td>1.34</td>
<td>1.96</td>
</tr>
<tr>
<td>1,0</td>
<td>0.93</td>
<td>250</td>
<td>1.29</td>
<td>1.56</td>
<td>1.38</td>
<td>1.79</td>
</tr>
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</tr>
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<td>2.66</td>
<td>2.58</td>
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<td>1.42</td>
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<td>2.39</td>
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<td>2.60</td>
<td>2.73</td>
</tr>
<tr>
<td>1,5</td>
<td>1.42</td>
<td>250</td>
<td>3.03*</td>
<td>3.03*</td>
<td>3.63</td>
<td>3.82</td>
</tr>
<tr>
<td>2,0</td>
<td>1.91</td>
<td>350</td>
<td>3.03*</td>
<td>3.03*</td>
<td>4.16</td>
<td>4.16</td>
</tr>
<tr>
<td>2,5</td>
<td>2.40</td>
<td>350</td>
<td>3.03*</td>
<td>3.03*</td>
<td>4.16</td>
<td>4.16</td>
</tr>
</tbody>
</table>

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.

Excerpt of the table at the foot of page 7 of Lindab’s literature headed ‘Shearing force, construction screws’

Properties of stainless steel self-tapping screws:
- material type = stainless steel grade 304
- Characteristic ultimate tensile strength = 621 N/mm²
- Characteristic 0.2% proof stress = 290 N/mm²

Phillips self-tapping screws: ultimate shear loads taken from the table in Lindab’s technical literature.
- Thickness of aluminium in the handrail at screw positions = 5.4mm

Ultimate shear capacity of 4.8mm diameter screws, safety class 1 for Nom t = 2.5mm = 3.64 kN/screw (from Lindab’s table)

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. The shear capacities given in Lindab’s table are based upon material having a tensile yield limit of 350 N/mm². The values given in the table have been adjusted to allow for the yield stress of stainless steel type 304 (290 N/mm²). The ultimate shear capacity of 3.64 kN/screw has therefore been reduced by 290/350 and divided by 1.2 to represent safety class 3 and 290 N/mm² yield stress rather than 350 N/mm². The adjusted ultimate shear capacity is then 2.51 kN/screw. Exceeds 0.8175 kN/screw and therefore OK
SUMMARY

“Mirror” Juliet balconies using BALCONY 1 System handrail (70mm Diameter)

1. The Juliet Balconette system, comprising Balcony 1 type handrails and bottom rails in extruded aluminium grade 6063 T5, in conjunction with 10mm thick toughened glass panels, is adequate to support the imposed loads specified in relevant British and European standards in respect of the occupancy classes listed on page 2, for spans up to **3.12 metres** between the centres of handrail support brackets.

2. The handrail support brackets in extruded aluminium grade 6063 T5 are adequate to support the specified loads for spans up to **3.12 metres** between handrail bracket centres. The bottom rail brackets in extruded aluminium grade 6063 T5 are also adequate for spans up to 3.12 metres between the bracket centres.

3. For the design loading and 3.12 maximum span between handrail bracket centres, the calculated working load direct pull-out force on each of the top 2 No. bolts on the handrail bracket fixing bolts is **2.18 kN**. For smaller width openings the working load direct pull-out force on the top 2 No. bolts on the handrail brackets are reduced, as listed below:

<table>
<thead>
<tr>
<th>Handrail length</th>
<th>Opening size</th>
<th>Working load tension on each upper bolt (including 50% increase recommended in BS 6180)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1280mm</td>
<td>1020mm</td>
<td>0.76 kN</td>
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<tr>
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</tr>
<tr>
<td>3200mm</td>
<td>2940mm</td>
<td>2.18 kN</td>
</tr>
</tbody>
</table>

4. For bottom rail brackets installed at up to 3.12 metres between bracket centres, the calculated working load direct pull-out force on the top bolt is **1.143 kN**, including the 50% increase recommended in BS 6180. The calculated working load shear force on each of the 3 No. fixing bolts **0.187 kN/bolt**.

5. The installers should satisfy themselves that the fixing bolts chosen are suitable to resist the loads specified in items 3 and 4 above, and also that the structure into which they are to be installed can support these loads.

6. The 10mm thick thermally toughened safety glass panels are adequate to support the design loads specified in the relevant British and European Standards.

7. The 4.8mm diameter self-tapping stainless steel screws connecting the handrail to the aluminium wall brackets are adequate to support the design loads specified in relevant British and European Standards.

Prepared for and on behalf of Balconette by
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