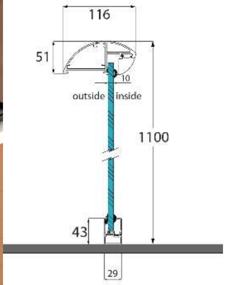
Aerofoil System handrail (without internal reinforcing bar): *PAGE 1* (B2WLBC31012023)

Structural Calculations for Aerofoil system balustrades fixed to steel structures using 60 x 24 RHS posts & 170 x 100 x 20 base plates

Our ref: B2WLBC31012023: **Issue Date: January 2023**

Aerofoil Balustrade fixed between two walls

Aerofoil Balustrade on a 3 sided balcony with a central post



Aerofoil section

DESIGN TO EUROCODES & CURRENT BRITISH STANDARDS

Design standards:

EN 1990	Eurocode 0:	Basis of structural design.
EN 1991	Eurocode 1:	Actions on structures.
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.
BS 8579:2020	BSI Standards Publication	Guide to the design of balconies and terraces

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	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	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 infill panels.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates: fitted to steel structures:

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

© BSI 2011 • 9

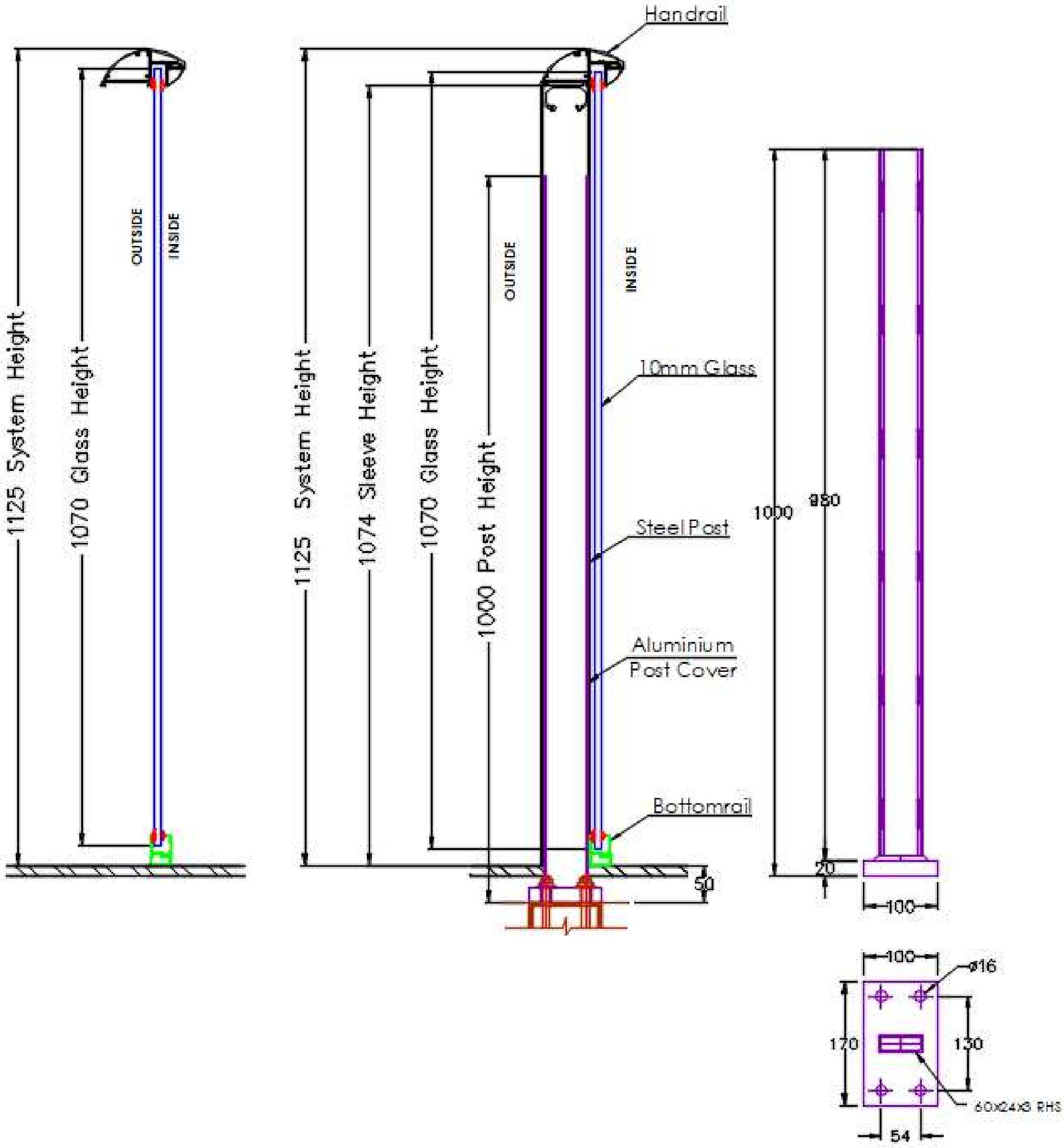
Table 2: BS6180:2011

- These loads are considered as three separate load cases. They are not combined. Wind loading is also considered as a separate load 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:

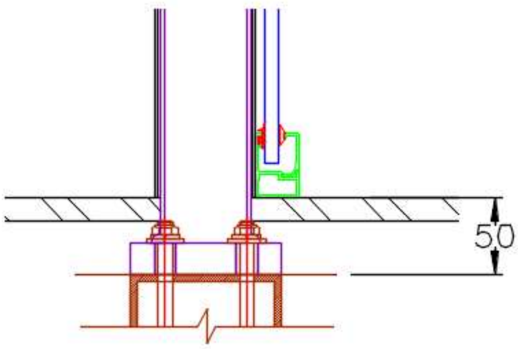
- All structural members deflect to some extent under load. Service loads are used to calculate deflections.
- The total displacement of any point of a barrier from its original unloaded position under the action of service loads is limited to 25mm.

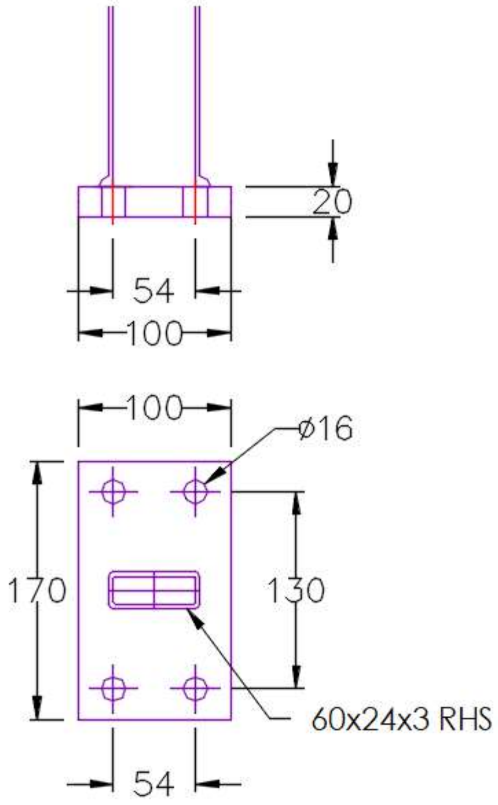
Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates: fitted to steel structures:



Section of Aerofoil system, post and base plate details.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates: fitted to steel structures:





Baseplate size 170 x 100 x 20mm

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Wind load parameters:

Design wind loads are influenced by several 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* and UK National Annex to EN 1991-1-4:2002 + A1:2010.

BS 8579:2020 '*Guide to the design of balconies and terraces*' further defines upper bound pressure coefficients for rectangular buildings which are up to 50m in height. These upper bound coefficients are different and dependent on the location of the balcony/terrace; top-level, mid-level, or on the corner of the building.

Each location, in combination with the position of the balcony/terrace on the building will result in a specific **characteristic wind pressure.** Wind pressure is treated as a separate design condition.

The calculation in this document uses a **characteristic wind pressure** of **1.32 kN/m^2.**

Characteristic wind pressure	=	**1.32 kN/m^2**
Wind load reaction on the handrail	=	1.32 kN/m^2 x 0.5625
	=	0.74 kN/m
	=	same value as the specified imposed line load

For sites that have a **characteristic wind pressure** of **1.32 kN/m^2**, the specified imposed uniformly distributed line load on the handrail and the characteristic design wind loading on the handrail are the same.

Wind pressure on the glass is greater than the specified overall design imposed UDL. Wind loading is therefore the controlling condition in terms of glass design.

Partial safety factor considering wind load as a separate leading variable action	γ_{Q1}	=	1.50
Ultimate design wind pressure		=	1.32 kN/m^2 x 1.50
		=	**1.98 kN/m^2**

Summary of design loads:

Element	**Service load**	**Ultimate load**
Horizontal imposed wind and line load applied to the handrail 1100mm above finished floor level (ie 1130mm above the top of the base).	0.74 kN/m	1.11 kN/m
Imposed UDL on the glass	1.00 kN/m^2	1.50 kN/m^2
Wind load on the glass.	1.32 kN/m^2	1.98 kN/m^2
Point load applied to the glass in any position	0.50 kN	0.75 kN

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Section properties of handrail (without internal 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}	=	87 cm^4
Least elastic modulus about the y-y axis	W_{el}	=	14.45 cm^3
Partial factor for material properties	γ_{M1}	=	1.10
Shape factor (assessment)	α	=	W_{pl}/W_{el}
		=	1.2 say

Design ultimate resistance to bending about the y-y axis M_{Rd} = $M_{o,Rd}$

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

$$= \frac{1.2 \times 14.45 \text{ cm}^3 \times 130 \text{ N/mm}^2 \times (10)^{-3}}{1.1}$$

= **2.049 kNm**

Handrail without bar: single spans, corners, and longer spans with posts:

Maximum span between points of support = 2100mm
Ie. a post, a handrail corner joint, or a wall fixing.

Design ultimate horizontal load on handrail F = 1.11 kN/m

Design horizontal moment on handrail between points of support, assuming simply supported spans (worst case) M

$$M = \frac{F L^2}{8}$$

$$= \frac{1.11 \times (2.10)^2}{8}$$

= **0.612 kNm**

= < 2.049 kNm = OK

Service load deflection on a simply supported span of 2100mm d

$$d = \frac{5 FL^4}{385 EI}$$

$$= \frac{5 (740 \times 2.10) (2100)^3}{384 \times 70\,000 \times 87 \times (10)^4}$$

= 3.08mm = OK

SUMMARY:

The handrail (without internal steel reinforcing bar) is adequate to support the design loading on single spans, corners, and longer balustrades with posts at up to 2100mm spacing centre to centre, in terms of both ultimate moment capacity and service load deflection limitations.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Aerofoil System handrail (without bar):

Longer balconies with posts:
On longer balconies vertical posts are installed at **2.1m** maximum spacing to support the handrail. There are two options for the vertical posts:

Option A:
The posts are manufactured from 2 No. steel channels welded together to form a rectangular hollow section (RHS) 60 x 24mm overall. To allow for the fact that the end flanges are not parallel, the post is considered to be equivalent to a RHS with 3mm thick side walls and 5mm thick end walls.

Section properties of posts made by welding channels together:

Steel grade	=	S 275 to EN 10025		
Nominal value of yield strength	=	f_y	=	275 N/mm^2
Nominal value of ultimate tensile strength	=	f_u	=	430 N/mm^2
Inertia of section about the x-x axis	=	I_{xx}	=	24.45 cm^4
Elastic modulus of section about the x-x axis	=	W_{el}	=	8.15 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
Shape factor Wpl / Wel (assessment)	=	α	=	1.2

Design ultimate resistance for bending about the x-x axis $M_{pl,Rd}$

$$= \frac{\alpha \times f_y \times W_{el}}{\gamma_{Mo}}$$

$$= \frac{1.2 \times 275\ \text{N/mm}^2 \times 8.15\ \text{cm}^3 \times (10)^{-3}}{1.0}$$

= **2.69 kNm**

Ultimate moment on post to top of base with posts at 2.1 m centres M_d

= (0.74 x 2.10) x 1.130 x 1.5
= 2.63 kNm
= < 2.69 kNm = OK

Service load deflection of post supporting 2.1m of handrail Δ

$$= \frac{P L^3}{3 E I}$$

$$= \frac{(740 \times 2.10)(1130)^3}{3 \times 210\,000 \times 24.45 \times (10)^4}$$

= **14.56mm**

Service load deflection of any point on the balustrade system is limited to 25mm.

Combined deflection of post + handrail = 14.56 + 3.08 = 17.64mm
= < 25mm = OK

SUMMARY:
60 x 24mm posts made from two channels welded together are adequate to support the design loading at up to 2.1m spacing in terms of both ultimate moment capacity and service load deflection limitations.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Aerofoil System handrail (without bar)

Posts option B:
Standard 60 x 24 x 3mm RHS. (Currently not listed by leading British suppliers, but available in Europe).

Minimum required ultimate resistance to bending about the x-x axis.	=	2.63 kNm		
Minimum required inertia about the x-x axis	=	$21.92 \times \frac{14.56}{24.45}$	=	13.05cm^4

SUMMARY
Standard manufactured 60 x 24 x 3mm RHS having the following minimum section properties are adequate in terms of both ultimate moment capacity and service load deflection limitations for posts at up to 2.1m spacing.

An ultimate moment capacity about the x-x axis	**=**	**2.63 kNm.**
A moment of inertia about the x -x axis	**=**	**13.05 cm^4**

Baseplates: 170 long x 100 wide x 20mm thick: 4 M12 HD bolts:
Baseplates are standard. HD bolts vary as follows:

Standard 8.8 grade bolts can be used where posts are fitted to open steel sections (UBs or UCs) and access is available to install them while maintaining 2.1m max. post spacing.

Proprietary Blind Bolts can be used when fitting to hollow sections (RHS or SHS), or in the case of blind fixings while maintaining 2.1m max. post spacing.

Forces on HD bolts:

Spacing of posts	=	2.10 m		
Design horizontal service imposed and wind load on handrail	=	0.74 kN/m		
Height from u/side base to line of action of horizontal imposed line load	=	1150mm		
Design service moment on posts to u/side base with posts at 2.1 m c/c	=	0.74 kN/m x 2.10 x 1.15	=	1.787 kNm
Lever arm between the centres of bolts in tension and compression	=	54 mm		
Working load bolt tension on 2 No. bolts	=	$\frac{1.787 \text{ kNm}}{2 \text{ No.} \times 0.054}$	=	16.55 kN/bolt

BS6180:2011, 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 **design working bolt load** becomes **24.83 kN/bolt**. The nominal ultimate tensile capacity of M12(8.8 grade) bolts is **37.80 kN/bolt**. This equates to a working load capacity of **25.20 kN/bolt** which is adequate.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Aerofoil system handrail (without bar):

Blind Bolts for connections to hollow steel sections or blind fixing while maintaining 2.1m max. post spacing:
Technical data sheet reference Blind-Bolt-Tech- Data-Metric gives the following values for M14 High Tensile Hot Dip. galvanised Blind Bolts designed to BS EN 1993-1-8:

Ultimate tensile resistance	=	34.80 kN/bolt	=	23.2 kN/bolt working load
			=	slightly below 24.83 kN/bolt but say OK.
Shear resistance over thread	=	46.70 kN		
Shear resistance over slot	=	29.00 kN		

By inspection, design shear forces on the bolts are low.

SUMMARY
Where access is available to install standard bolts while maintaining 2.1m max. post spacing, M12 (8.8 grade) bolts, nuts and washers can be used.

Where installation is onto RHS sections, or in the case of blind fixings while maintaining 2.1m max. post spacing, proprietary M14 Blind Bolts or similar can be used.

Baseplates: 170mm long x 100mm wide x 20mm thick.

Ultimate moment to top of base for posts at 2.1m max. spacing	M_a	=	(0.74 x 1.5) x 2.1 x 1.13	=	2.63 kNm
Plastic modulus of base 100mm wide x 20mm thick	W_{pl}	=	$\frac{100 \times (20)^2}{4}$	=	10000 mm^3
Ultimate moment capacity of base	Mu	=	$\frac{275\ N/mm^2 \times 10000mm^3 \times (10)^{-6}}{1.0}$	=	2.75 kNm
		=	> 2.63 kNm	=	OK

Welded connection between post & baseplate.
The 60 x 24mm RHS 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}	=	8.15 cm^3		
Maximum ultimate elastic bending stress on post	$\frac{M_a}{W_{el}}$	=	$\frac{2.63 \times (10)^6}{8.15 \times (10)^3}$	=	323 N/mm^2
		=	1.615 kN/mm on 5mm thick section		
		=	0.969 kN/mm on 3mm thick section		
Transverse capacity of 6mm fillet weld		=	1.155 kN/mm	=	OK for 3mm thick sections.
Transverse capacity of 10mm fillet weld		=	1.925 kN/mm	=	OK for 5mm thick sections.

SUMMARY
For 60 x 24 x 3mm factory formed RHS a continuous 6mm fillet weld around the perimeter of the post is adequate.

For 60 x 24 RHS made from two channels welded together, 6mm fillet welds can be used along the 60 x 3mm sides. and 10mm fillet welds along the 24 x 5mm ends.

Also adequate are a full-strength butt weld, or any combination of welds that achieves a full-strength connection.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Glass infill:

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

Glass type = 10mm thick thermally toughened soda silicate safety glass with smooth float 'as produced' finish with polished edges.

Characteristic design strength = 120 N/mm^2

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

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

$f_{b;k}$ = 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

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

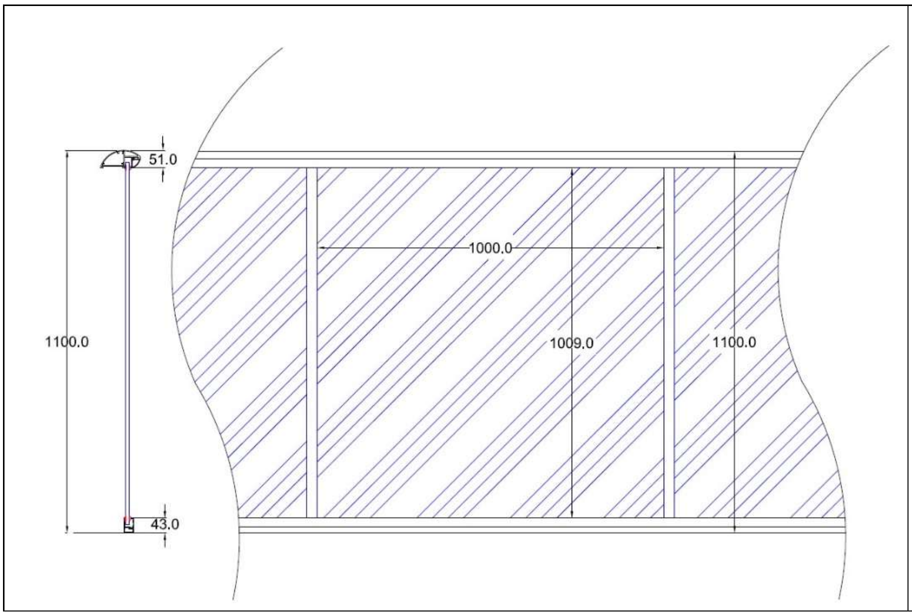
= **87.53 N/mm^2**

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Glass infill (cont):

Section modulus of glass 10mm thick $Z = \frac{1000 \times (10)^2}{6} = 16667\ mm^3/m$

Ultimate moment capacity of glass 1000mm wide x 10mm thick
$Mu = f_{g;d} \times Z$
$= 87.53\ N/mm^2 \times 16667mm^3 \times (10)^{-6}$
$= 1.459\ kNm/m$



Glass panels can be any length.

For the purposes of design and checking a nominal glass panel width of 1000mm simply supported over the full glass height of 1070mm between the bottom rail and the handrail has been used.

Separate design loading conditions are considered:

1. Uniformly distributed service wind load on the infill of 1.32 kN/m²

Ultimate UDL on glass $w = 1.32\ kN/m^2 \times 1.5 = 1.98\ kN/m^2$

Ultimate moment on glass due to UDL on span of 1.0m $Mu = \frac{1.98\ kN/m^2 \times (1.07)^2}{8} = 0.283\ kNm/m$

$= \; < 1.459\ kNm = OK$

2. Service 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 $\frac{0.5\ kN \times 1.5 \times 1.07m}{4} = 0.20kNm$

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

Moment capacity of 300mm strip $= 1.459\ kNm \times 0.3 = 0.4377\ kNm$
$= \; > 0.20kNm = OK$

The glass is adequate to support the ultimate design loading in terms of bending capacity.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Glass deflection:

1. Overall UDL:

Service load deflection due to the design overall 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 1.35 kN/m^2 on a simply supported span of 1.07m = $\frac{5\ w\ L^4}{384\ E\ I}$ = $\frac{5 \times (1350 \times 1.0)\ (1070)^3}{384 \times 70\ 000 \times 83333}$

= 3.69 mm < $\frac{span}{65}$ = OK

2. Point load:

Conservatively, for deflection calculation purposes it is considered 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 x 83333 mm^4 = 25 000 mm^4

Service load deflection due to a point load of 0.5 kN applied at mid-span = $\frac{P\ L^3}{48\ E\ I}$ = $\frac{500 \times (1070)^3}{48 \times 70\ 000 \times 25\ 000}$

= 7.29mm

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

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

Wall fixings:

The handrail wall fixing consists of 3mm thick stainless-steel angles bolted to the wall with 2 No. M8 stainless steel resin anchors or similar and secured to the handrail with 2 No. 4.8mm diameter stainless steel Phillips self-tapping screws.

The allowable simply supported span of the handrail (without bar) between points of support is 2.1m.

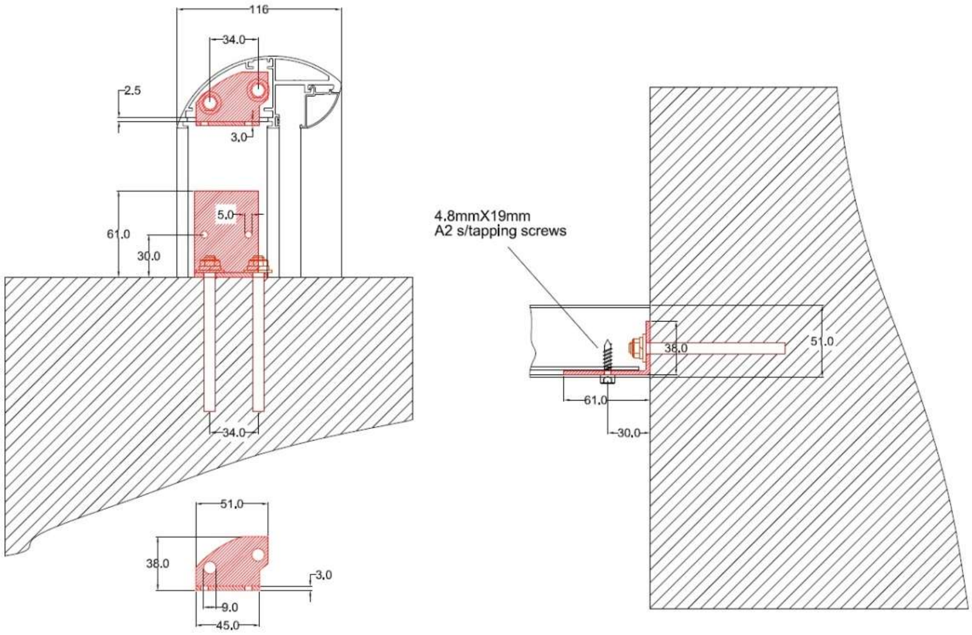
Horizontal service (working) load on the wall fixing for a span of 2.1m = 0.74 kN/m x 1.05m = 0.78 kN/fixing

There are two options for wall brackets: the standard wall bracket and the larger wall bracket. The larger wall bracket has a larger distance between the fixings and so allows a smaller load in the two bolts.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Standard Aerofoil wall fixings:

The horizontal load on the handrail is applied to the fixing angles at the position of the Phillips screws located 30mm from the back of the angles. The wall fixing bolts are 34mm apart horizontally.



Pull-out force on wall fixings: handrail corner spans of 2.1m:

Direct working load pull-out force from front handrail On 2 No. anchor bolts	=	0.74 kN/m 1.05m / 2 No	=	0.39 kN/b
Working load pull-out force from imposed load on side handrail	=	(0.74 x 1.05) x 30 / 34	=	0.69 kN/bolt
			=	1.08 kN/bolt

Applying a 50% increase on fixing loads as recommended in BS 6180:2011, this becomes **1.62 kN/bolt**.

SUMMARY:
For a handrail with corner spans of **2.1m** using the **standard Aerofoil wall bracket**, the **working load** pull-out force on the wall fixing bolts is **1.62 kN/bolt**, including the 50% increase as per BS 6180.

Shear force on wall fixings: handrail corner spans of 2.1m:

Working load shear force on the anchor bolts and the 4.8mm x 19mm stainless steel self-tapping screws	=	0.78 kN/2	=	**0.39 kN/bolt**

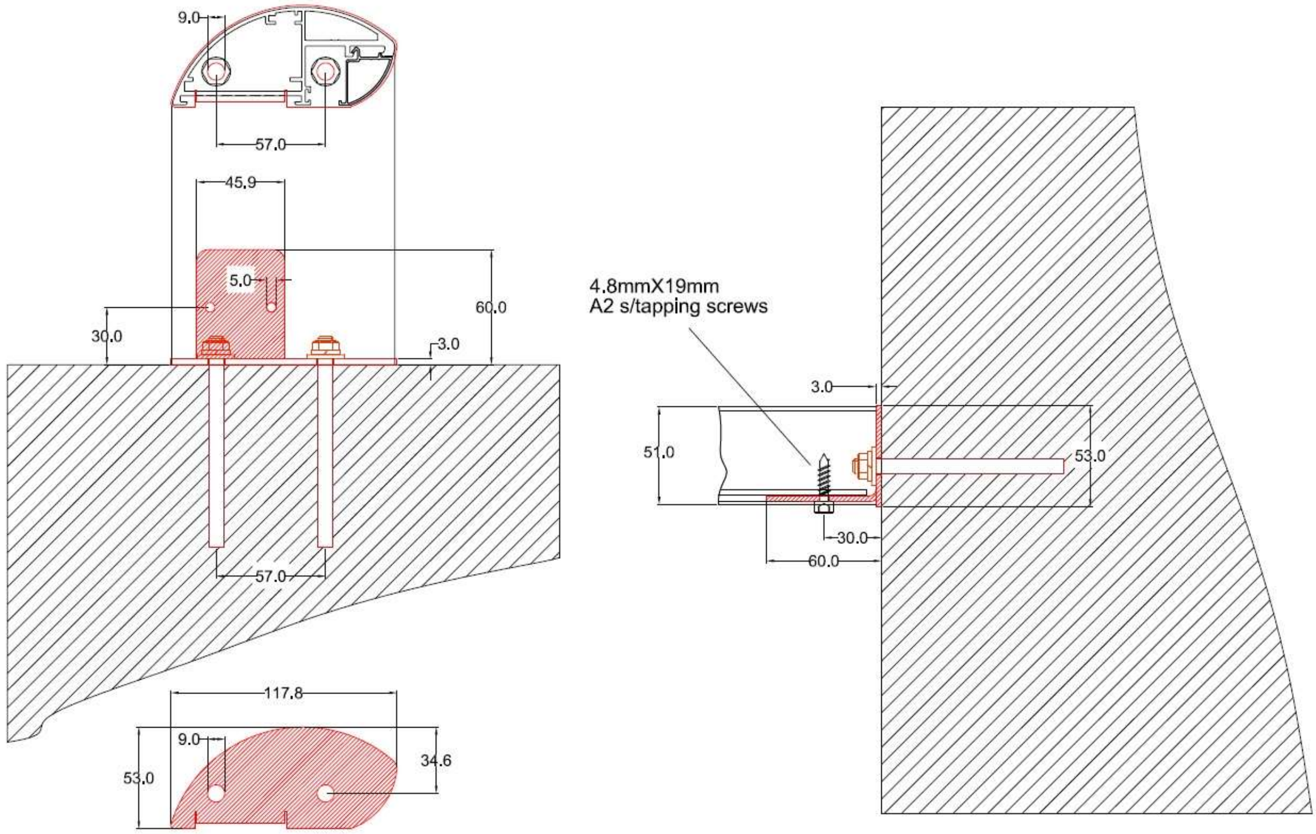
Applying a 50% increase on fixing loads as recommended in BS 6180:2011, this becomes **0.59 kN/bolt.**

SUMMARY
For a handrail with corner spans of **2.1m** using the **standard Aerofoil wall bracket**, the **working load** shear force on the wall fixing bolts is 0.59 kN/bolt, say **O.60 kN/bolt**, including the 50% increase as per BS 6180.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Larger Aerofoil wall fixings:

The horizontal load on the handrail is applied to the fixing angles at the position of the Phillips screws located 30mm from the back of the angles. The wall fixing bolts are 57mm apart horizontally.



Pull-out forces on wall fixings: handrail corner spans of 2.1m:

Direct working load pull-out force from front handrail on 2 No. fixing bolts	=	0.74 kN/m 1.05 / 2No	=	0.39 kN/bolt
Working load pull-out force from imposed load on side handrail on the anchor bolts	=	0.74 x 1.05 x 30 / 57	=	0.41 kN/bolt
				0.80 kN/bolt

Applying a 50% increase on fixing loads as recommended in BS 6180:2011, this becomes **1.20 kN/bolt**.

SUMMARY: For a handrail with corner spans of **2.1m** using the larger wall bracket, the **working load** pull-out force on the wall fixing bolts is **1.20 kN/bolt**, including the 50% increase as per BS 6180.

Shear forces on wall fixings: handrail (with bar):

Working load shear force on the anchor bolts and the 4.8mm x 19mm stainless steel self-tapping screws	=	0.74 x 1.05 / 2 No	=	0.39 kN/bolt

Applying a 50% increase on fixing loads as recommended in BS 6180:2011, this becomes 0.59 kN/bolt, **say 0.60 kN/bolt**.

SUMMARY: For a handrail with corner spans of **2.1m** using the larger wall bracket, the **working load** shear force on the wall fixing bolts is **0.60 kN/bolt**, including the 50% increase as per BS 6180.

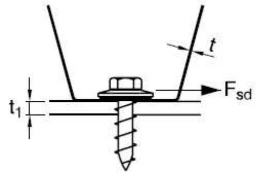
Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Phillips stainless steel self-tapping screws:

Ultimate load shear force on the anchor bolts and Phillips self-tapping screws = 0.60 kN/bolt x 1.5 = **0.90 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.



Nom t mm	When calculating t mm	Tensile yield limit N/mm²	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.

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

Thickness of stainless steel angle brackets (Nom t mm) = 3.0mm

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.)

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

Phillips self-tapping screws (continued):

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/mm^2 yield stress rather than 350 N/mm^2. The adjusted ultimate shear capacity is then **2.51 kN/screw.**

Ultimate shear force/screw on a	=	1.11 kN/m x 1.05m/2.0 No.		=	0.58 kN/screw
simply supported span of 2.1m			**say**	**=**	**0.60 kN/screw**

Applying the BS 6180 recommended increase on calculated loads on fixings this becomes			=	**0.90 kN/screw**
	=	**< 2.51 kN/screw**	**-**	**OK**

Stainless steel brackets:
The horizontal part of the bracket measures 45mm wide x 3mm thick.

Plastic modulus of 45 x 3mm section for horizontal loads	=	$\frac{3 \times (45)^2}{4}$	=	1519 mm^3
Resistance moment of section	=	290 N/mm^2 x 1519 mm^3 x (10)$^{-6}$		
for horizontal loads	=	0.44 kNm		
For a simply supported span of 2.1m:				
ultimate load on end bracket	=	1.11 kN/m x 1.05 x 1.5	=	1.75 kN

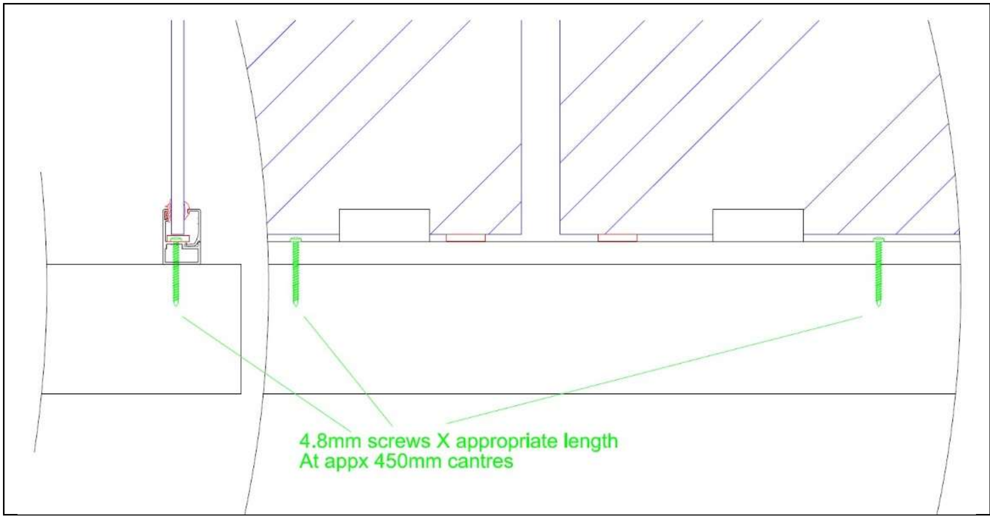
This load is applied 30mm from the rear face of the bracket.

Ultimate horizontal moment applied to the bracket on the maximum simply	=	1.75 x 0.03	=	0.053 kNm
supported span of 2.1m			=	< 0.44 kNm
			=	OK

The stainless-steel brackets are adequate to resist the design loading on handrail spans of 2.1 meres between points of support. ie. a post, a handrail corner joint, or a wall fixing bracket.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

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 (4.88mm) 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 force of 0.50 kN.

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

The installers should satisfy themselves that the fixings chosen are adequate to resist the design loads in relation to the fixing material in each individual installation.

Aerofoil System handrail: 60 x 24 RHS posts: 170 x 100 x 20 baseplates fitted to steel structures:

SUMMARY

Aerofoil Balcony 2 system for longer balustrades fitted to steel structures.

1) These calculations demonstrate that on longer balustrades fitted to steel structures, for sites that come within the parameters listed on pages (1) to (5), the Aerofoil Balcony 2 system with 60 x 24mm RHS posts at **2.1 metre** maximum centres is adequate to support the design imposed and wind loads specified in current European and British design standards.

2) Infill glass panels are 10mm thick thermally toughened safety glass with 'as produced' finish and polished edges and are adequate to support the design imposed and wind loads.

3) The Aerofoil handrail (without internal steel reinforcing bar) is used in conjunction with **60 x 24mm RHS** vertical posts welded to **170 x 100 x 20mm** baseplates. 16mm diameter holes are provided in baseplates for 4 No. holding down bolts.

4) For longer balconies, where the handrail (without bar) is used in conjunction with posts installed at a maximum spacing of **2.1m**, the design working load pull-out force on the baseplate holding down bolts is **16.55 kN/bolt**, which equates to an ultimate pull-out force of **24.83 kN/bolt**. These values include a 50% increase in calculated loads on fixings for balustrades as recommended in BS EN 6180:2011.

5) The baseplates are bolted to open steel structures (UBs or UCs) using standard **M12 (8.8 grade)** bolts, washers and nuts where access is available to install them while maintaining **2.1 meters** post spacing. In cases of blind fixing, or when connecting to hollow steel sections (RHS or SHS), **M14 Blind Bolts** can be used while maintaining **2.1 metres** post spacing.

6) The posts are made from **60 x 24mm** rectangular hollow steel sections (RHS) sheathed in aluminium. There are two post options: Option (A) comprises posts made by welding together two steel channels to form a 60 x 24mm RHS with an effective end wall thickness of 5mm and 3mm thick side walls. Option (B) consists of 24 x 60mm factory pre-formed RHS having a minimum ultimate moment capacity of **2.63 kNm** and a minimum I_{x-x} of **13.05 cm^4**.

7) The RHS posts are welded to the baseplates using full strength butt welds, fillet welds, or any combination of welds that achieves a full-strength connection. Where fillet welds (FW) are used, for posts option (A) **10 FW** are required across each 24mm end, with **6 FW** along the longer sides. Continuous **6 FW** can be used around the perimeter of 60 x 24mm pre-formed RHS sections.

8) Posts are not required at **90^0 corners**. Adequate restraint at 90^{0}corners is provided by the buttressing effect of the glass panels combined with direct tension in the side handrails fixed to the building structure by means of wall fixing brackets.
The length of side returns without posts is limited to **2.1 metres.**

9) There are two options for handrail wall fixing brackets: the **standard** wall bracket and the **larger** wall bracket. For **2.1 metres** long corners, the horizontal working pull-out load on the wall fixing bolts is **1.62 kN/bolt** for the **standard** wall bracket, and **1.20 kN/bolt** for the **larger** wall bracket. The horizontal **working shear load** on the wall fixing bolts is **0.60 kN/bolt** for both types of brackets. 9mm diameter holes are provided in wall fixing brackets for M8 drilled anchor bolts. These loads include a 50% increase on calculated loads, in accordance with BS 6180:2011.

(continued)

SUMMARY
(continued)

10) The installers and/or Engineers for the main building structure should satisfy themselves that the fixing bolts chosen are suitable to resist the specified loads, and that the structure into which they are installed can support these loads.

11) 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/fixing**. The installers should satisfy themselves that the fixings chosen are suitable to resist this load when inserted into the 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.

12) The 4.8mm 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 adequate to support these loads.

13) **Important note: The** Engineers for the main building structure should satisfy themselves that the steel structure at post positions is adequate to resist without significant movement an ultimate design moment at the underside of baseplates of **2.68 kNm** in conjunction with an ultimate horizontal design force of **2.33 kN** acting either inwards or outwards. Undue deflection or distortion of the supporting steel structure could result in unacceptable movement at handrail level.

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