06 July 2020

Architectural Railing Division
C.R.Laurence Co., Inc.
2503 E Vernon Ave.
Los Angeles, CA 90058

SUBJ: GRS – GLASS RAIL SYSTEM –
TOP RAILS AND HANDRAILS

The GRS Glass Rail System utilizes an aluminum extruded base shoe to anchor and support structural glass balustrades which support a variety of top rails and handrails to construct guards and dividers. The GRS may be used for residential, commercial and industrial applications except for vehicle impacts. The GRS is designed for the following:

On Cap/Top/Hand/Grab Rail:

Concentrated load = 200 lbs any direction, any location
Uniform load = 50 plf, any direction perpendicular to rail

The GRS system will meet all applicable requirements of the 2012 and 2009 *International Building Code* and state codes adopted from them, 2013 and 2010 *California Building Code, Florida Building Code,* and *2012 and 2009 International Residential Code*. The GRS System complies with ASTM E 2358-04 *Standard Specification for the Performance of Glass in Permanent Glass Railing Systems, Guards, and Balustrades*. Aluminum components are designed in accordance with the *2005 Aluminum Design Manual*. Stainless steel components are designed in accordance with SEI/ASCE 8-02 *Specification for the Design of Cold-Formed Stainless Steel Structural Members*. Wood components are designed in accordance with the *National Design Specification for Wood Construction*. Glass lights are designed in accordance with AAMA CW 12-84 *Structural Properties of Glass*. When constructed as recommended the guards will meet the testing requirements of ICC AC 439 *Acceptance Criteria for Glass Railing and Balustrade System*, ASTM E-2353-06 *Standard Test Methods for Performance of Glass in Permanent Glass Railing Systems, Guards and Balustrades*. For a complete code compliant installation an appropriate cap/top rail or grab rail shall be installed on appropriately sized glass installed in a matching base shoe properly mounted to the supporting structure. This report is in support of the the approval of the system in ESR-3269.

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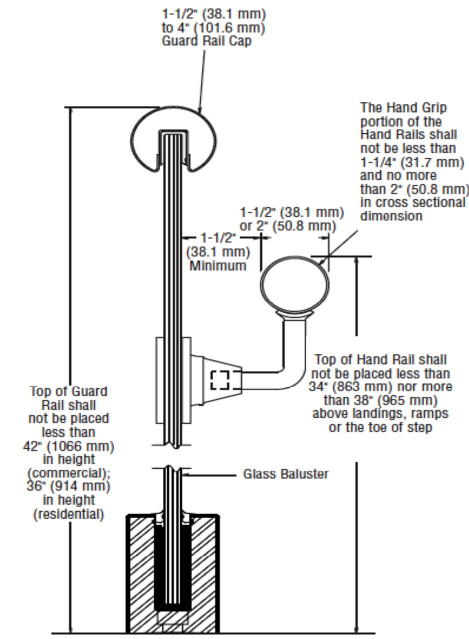
CONTENTS:

Hand Rail/Guard Rail



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EXP 03/31/2023

Registered Professional Engineer — Edward C. Robison — No. C 65883 — Civil — State of California

Colorado Licensed Professional Engineer — Edward C. Robison — 54027

Edward C. Robison — License No. 63683 — State of Florida — Professional Engineer
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THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION

04/30/2022

Signature Expiration Date of the License

Licensed Structural Engineer — EDWARD C. ROBISON — 081.007077 — State of Illinois
EXP 11/30/2020

State of Maryland — Edward C. Robison — 52500 — Professional Engineer

Professional Certification. I hereby certify that these documents were prepared or approved by me, and that I am a duly licensed professional engineer under the laws of the State of Maryland, License No. 52500, Expiration Date: 04/09/2020

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TOP/CAP RAILS DESIGN

Guard applications require a top rail or handrail. The rail shall have adequate strength to support the live load of 200 lb concentrated or 50 plf distributed load assuming the failure of one glass light at the location of the loading. No US building codes or adopted standards define the limit state of the guard cap rail for this condition. IBC 2407.1.2 states "shall be otherwise supported to remain in place should one baluster fail." There is no additional explanation in the IBC as to how this is to be determined. ICC Acceptance Criteria 439 was adopted to provide a methodology for determining if a glass balustrade guard meets the requirements of IBC 2407. ICC AC 439 requires the rail to be capable of supporting a 334# load (SF = 1.67 for 200# load) with no more than 12" deflection, yielding or other damage is permitted since the loss of a glass light will necessitate guard repairs. For light failure only the horizontal load case applies for laminated glass. The terms top rail and cap rails are synonymous herein.

Stainless Steel Cap Rails:

The stainless steel cap rails are fabricated from 304 or 316 annealed sheet. The rail strength was evaluated in accordance with SEI/ASCE 8-02 Specification for the Design of Cold-Formed Stainless Steel Structural Members.

From Section 3.3.1.1 *Nominal section strengt*h 2. *Procedure II - Based on Inelastic Reserve Capacity*:

$M_n = 1.25S_eF_y$

$ø = 1.0$ (Small local distortions are acceptable)

or for ultimate strength

$M_{nult} = S_eF_{cr}$

F_{cr} is a function of rail geometry and is the maximum extreme fiber stress at compression element buckling failure.

Cap Rail Bending Moments

For a typical installation the cap rail will be continuous supported along at least one glass light with a simple support on the opposite end or cantilevered.

The bending moments are conservatively estimated as:

$M_w = wL^2/10$ For uniform load case

$M_c = PL/5$ For concentrated load at mid span load case

Or for cantilevered case, end light failure

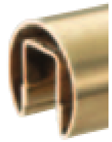
$M_{wc} = wL^2/2$ For uniform load case

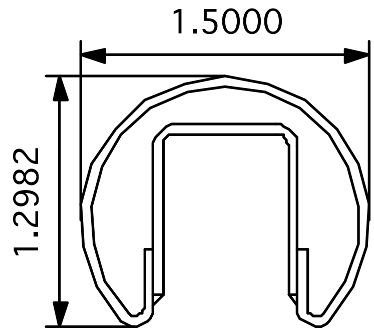
$M_{cc} = PL$ For concentrated load at end of rail

Brass Cap Rails: No design standard exists for brass therefore design is based on a either bending tension yield or compression buckling whichever controls with 1.6 load factor and 0.9 resistance factor.

NOTE: The cap rail properties, strengths and maximum spans herein are provided to assist the specifier in the selection of an appropriate cap rail. It is the specifier's responsibility to determine suitability for a specific application.

GR 15 SERIES CAP RAIL





Area: 0.3343 sq in
Perim: 13.093 in
I_{xx}: 0.0504 in^4
I_{yy}: 0.07395 in^4
r_{xx}: 0.3883 in
r_{yy}: 0.4703 in
C_{xx}: 0.6647 in
C_{yy}: 0.75 in
S_{xx}: 0.07583 in^3 or 0.07956 in^3
S_{yy}: 0.09859 in^3
t = 0.05 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed 304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.5 (from table A6a)
k = $3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
E_0 = 27.0 x10^3 ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(0.5991''/0.05'')^2} = 339.9 \text{ ksi but} \le F_U$$

$M_n = 1.25*S_eF_y$ = 1.25*0.07583*30 ksi = 2.844 k" Vertical loading Controls
1.25*0.09859*30 ksi = 3.697 k" Horizontal load
or $M_{ULT} = S_fF_{cr}$ = 0.07583*75 ksi = 5.687 k" Vertical load
0.09859*75 ksi = 7.394 k" Horizontal load Controls
Determine allowable rail spans (ignoring deflection), multiple spans
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(2{,}844/12 \bullet 10/(1.6*50plf))^{1/2}$ = 5.443'
concentrated →L = 2,844*5/(334#) = 42.57" = 3' -6 9/16"
ultimate strength →L = 5,687*4/(334#) = 68.1" = 5' 8"
Horizontal → uniform → L= $(3{,}697/12 \bullet 10/(1.6*50plf))^{1/2}$ = 6.206' = 6' -1.5"
concentrated →L = 3,697*5/(334#) = 55.34" = 4'-7 5/16"
ultimate strength →L = 7,394*4/(334#) = 88.5" = 7' -4 1/2"
Cantilever: L = 5,678/334" = 17"
Maximum glass light length for GR 15 SS rail is 4' 7"

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GR 15 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0 = 4.0$ for circular shape
$\mu = 0.34$
$E_0 = 16.9 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(0.5991''/0.05'')^2} = 214.6 \text{ ksi but} \leq F_y$$

$M_n = S_eF_y = 0.07583*43$ ksi = 3.261 k" Vertical loading Controls
0.09859*43 ksi = 4.128 k" Horizontal load

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(0.9*3{,}261/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 5.529'
concentrated →L = 0.9*3,261*5/(334#) = 43.94" = 3' -7 15/16"
cantilevered →L = 0.9*3,261/(334#) = 8.79"

Horizontal → uniform → L= $(0.9*4{,}128/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 6.221' = 6' -2 5/8"
concentrated →L = 0.9*4,128*5/(334#) = 55.62" = 4' -7 5/8"
cantilevered →L = 0.9*4,128/(334#) = 11.123"

Maximum glass light length with 1-1/2" brass rail is 3' 7"

Connector Sleeves

The sleeves fit tight (radial compression required) inside the rail and are secured with adhesive. The sleeve provides shear transfer between rail sections, vertically and horizontally. The sleeves can be used to connect straight or curved rail sections to corners and other rail sections.

Minimum shear strength of connectors:

For stainless steel:

$F_{yv} = 17$ ksi

$t = 0.05$", $h = 2.95$" (for 1-1/2" rail)

$V_n = 4.84E_o t^3(G_s/G_o)/h$; $\phi = 0.85$

$G_s/G_o = 0.90$; $E_o = 24{,}000$ ksi

$V_n = 4.84*24{,}000\text{ksi}*0.05^3(0.90)/2.95" = 4{,}429\#$

or $V_n = 0.95*(17\text{ ksi}*0.05"*2.95") = 2{,}382\#$

$V_s = \phi V_n/1.6 = 0.85*2{,}382/1.6 = 1{,}265\#$

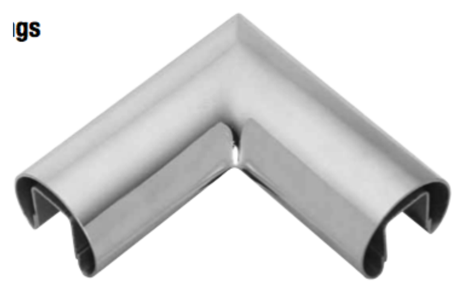
For Brass:

$F_{yv} = 25$ ksi

$t = 0.05$", $h = 2.95$" (for 1-1/2" rail)

$V_n = 0.95*(25\text{ ksi}*0.05"*2.95") = 3{,}503\#$ controls

$V_s = \phi V_n/1.6 = 0.85*3{,}503/1.6 = 1{,}861\#$



Welded Corners

Constructed from the standard rail sections. Corners are welded all around full thickness of metal.

Load on corner is limited to shear and tension at corner.

Shear strength is same as the connector sleeve (weld length is same as connector perimeter)

Tension: $= 1/0.6*V = 1.667V$

$T_{ss} = 1.667*1{,}265\# = 2{,}108\#$

$T_{br} = 1.667*1{,}861 = 3{,}102\#$

Maximum load, shear or tension is 200# therefore okay.

Custom Angle Corners

Corners may be welded at any angle, vertical or horizontal angles.

Compound angles may be used.

The strength of the angle is not decreased below that for the 90˚ angle used for the standard calculation therefore strength adequacy is demonstrated for all angles.

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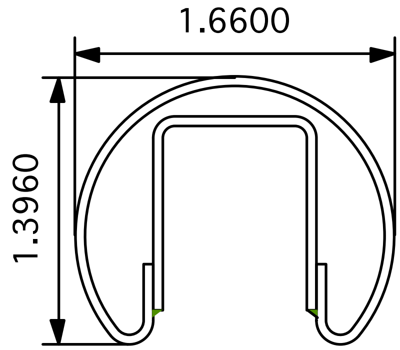
GR 16 SERIES CAP RAIL



Area: 0.3695 sq in
Perim: 14.02 in
I_{xx}: 0.06699 in^4
I_{yy}: 0.10145 in^4
r_{xx}: 0.4258 in
r_{yy}: 0.524 in
C_{xx}: 0.73135 in
C_{yy}: 0.830 in
S_{xx}: 0.0916 in^3 or 0.1008 in^3
S_{yy}: 0.1222 in^3
t = 0.05 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.50 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
$E_0 = 27.0 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.50 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(0.698"/0.05")^2} = 250.4 \text{ ksi but} \le F_U$$

$M_n = 1.25*S_eF_y$ = 1.25*0.0916*30 ksi = 3,435 k" Vertical loading Controls
1.25*0.1222*30 ksi = 4.583 k" Horizontal load
or $M_{ULT} = S_fF_{cr}$ = 0.0916*75 ksi = 6.870 k" Vertical load
0.096*75 ksi = 7.2 k" Horizontal load Controls

Determine allowable rail spans (ignoring deflection), multiple spans
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(3,435/12 \bullet 10/(1.6*50plf))^{1/2}$ = 5.982'
concentrated →L = 3,435*5/(334#) = 51.42" = 4' 3 3/8"
ultimate strength →L = 6,870*4/(1.6*200#) = 85.875" = 6' 4 7/8"
Horizontal → uniform → L= $(4,583/12 \bullet 10/(1.6*50plf))^{1/2}$ = 6.909'
concentrated →L = 4,583*5/(334#) = 68.61" = 5' 8-5/8"
ultimate strength →L = 7,200*4/(334#) = 86.23"

Cantilever: L = 6,870/334" = 20.57"

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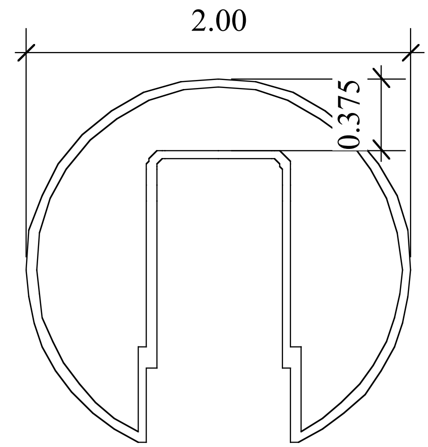
CRL GR 20 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails



Area: 0.473 sq in
Perim: 17.78 in
I_{xx}: 0.142 in^4
I_{yy}: 0.174 in^4
r_{xx}: 0.548 in
r_{yy}: 0.606 in
C_{xx}: 0.980 in
C_{yy}: 1.000 in
S_{xx}: 0.148 in^3 or 0.138
S_{yy}: 0.169 in^3
t = 0.05"

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02

From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \dfrac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A8a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

μ = 0.3

E_0 = 27.0 x10^3 psi

$F_{cr} = \dfrac{\pi^2 * 4.0 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(0.95''/0.05'')^2}$ = 135.2 ksi but ≤ F_U

$M_n = 1.25 * S_e F_y$ = 1.25*0.138*30 ksi = 5.18k" Vertical loading Controls

1.25*0.169*30 ksi = 6.33k" Horizontal load

or $M_{ULT} = S_f F_{cr}$ = 0.148*75 ksi = 11.1k" Vertical load Controls

0.169*75 ksi = 12.675k" Horizontal load

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Horizontal → uniform → L= $(6,330/12 \bullet 10/(1.6*50plf))^{1/2}$ = 8.12'

concentrated →L = 6,330*5/(334#) = 94.76" = 7' 10 ¾"

cantilevered →L = 6,330/(334#) = 18.95" = 1' 6 15/16"

ULTIMATE STRENGTH

Vertical → uniform → L= $(11,100/12 \bullet 8/(1.6*50plf))^{1/2}$ = 9.617'= 9'-7 ⅜"

concentrated →L = 11,100*4/(334#) = 132.93"

cantilevered →L = 11,100/(334#) = 33.23" = 2' 9 1/4"

GR 20 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
$\mu = 0.34$
$E_0 = 16.9 \text{ x}10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \text{ x}10^3 \text{ ksi}}{12(1-0.34^2)(0.95''/0.05'')^2} = 87.75 \text{ ksi but} \leq F_y$$

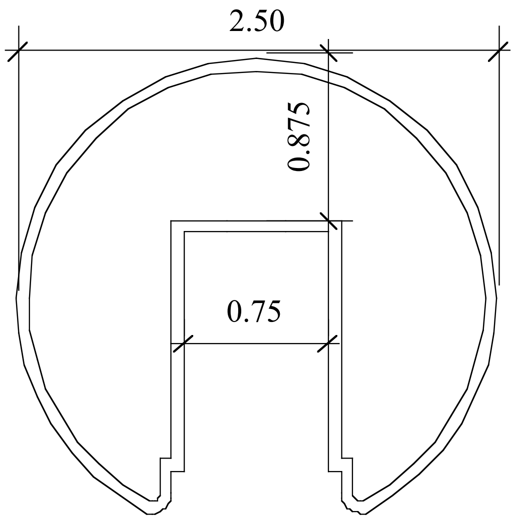
$M_n = S_eF_y$ = 0.138*43 ksi = 5.934 k” Vertical loading Controls
0.169*43 ksi = 7,267 k” Horizontal load

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(0.9*5{,}934/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 8.333’ = 8’- 4”
concentrated →L = 0.9*5,934*5/(334#) = 79.95” = 6’ -7 15/16”
cantilevered →L = 0.9*5,934/(334#) = 16” = 1’ 4”

Horizontal → uniform → L= $(0.9*7{,}267/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 8.254’ = 8’- 3”
concentrated →L = 0.9*7,267*5/(334#) = 97.91” = 8’- 1 7/8”
cantilevered →L = 0.9*7,267/(334#) = 19.58 = 1’ - 7 9/16”

Connector Sleeves
Corners
The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2” size.

CRL GR 25 SERIES CAP RAIL
Used as the top rail on glass balustrade panel guardrails



Area: 0.656 sq in
I_{xx}: 0.333 in^4
I_{yy}: 0.387 in^4
r_{xx}: 0.712 in
r_{yy}: 0.768 in
C_{xx}: 1.213 in
C_{yy}: 1.250 in
S_{xx}: 0.274 in^3 or 0.259
S_{yy}: 0.310 in^3
t = 0.0625"

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)
k = $3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
E_0 = 27.0 x10^3 psi

$F_{cr} = \frac{\pi^2 * 4.0 * 0.50 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.20"/0.0625")^2}$ = 84.7 ksi but ≤ F_U

$M_n = 1.25 * S_e F_y$ = 1.25*0.274*30 ksi = 10.27k" Vertical loading Controls
1.25*0.310*30 ksi = 11.62k" Horizontal load
or $M_{ULT} = S_f F_{cr}$ = 0.259*75 ksi = 19.425k" Vertical load Controls Ultimate
0.310*75 ksi = 23.25k" Horizontal load
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(10{,}270/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 9.722'
concentrated →L = 10,270*5/(334#) = 153.74
cantilevered →L = 10,270/(334#) = 30.75" = 2' 6 3/4"

ULTIMATE STRENGTH
Vertical → uniform → L= $(19{,}425/12 \bullet 8/(1.6*50\text{plf}))^{1/2}$ = 12.723'
concentrated →L = 19,425*4/(334#) = 232.63"
cantilevered →L = 19,425/(334#) = 58.16" = 4' 10 1/8"

GR 25 SERIES CAP RAIL For Brass:

Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn

Cap rail fabricated from cold rolled sheet

$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

$\mu = 0.34$

$E_0 = 16.9 \text{ x}10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \text{ x}10^3 \text{ ksi}}{12(1-0.34^2)(1.2"/0.05")^2} = 53.48 \text{ ksi but} \leq F_y$$

$M_n = S_e F_y = 0.274*43$ ksi = 11.782 k" Vertical loading

0.310*43 ksi = 13.33 k" Horizontal load

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Vertical → uniform → L= $(0.9*11{,}782/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 10.51' = 10'-6"

concentrated →L = 0.9*11,782*5/(334#) = 158.74" = 12' 3.5"

cantilevered →L = 0.9*11,782/(334#) = 31.75" = 2' 7 3/4"

Horizontal → uniform → L= $(0.9*13{,}330/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 11.178' - 11'-2"

concentrated →L = 0.9*13,330*5/(334#) = 179.60

cantilevered →L = 0.9*13,330/(334#) = 35.92" = 2' 11 7/8"

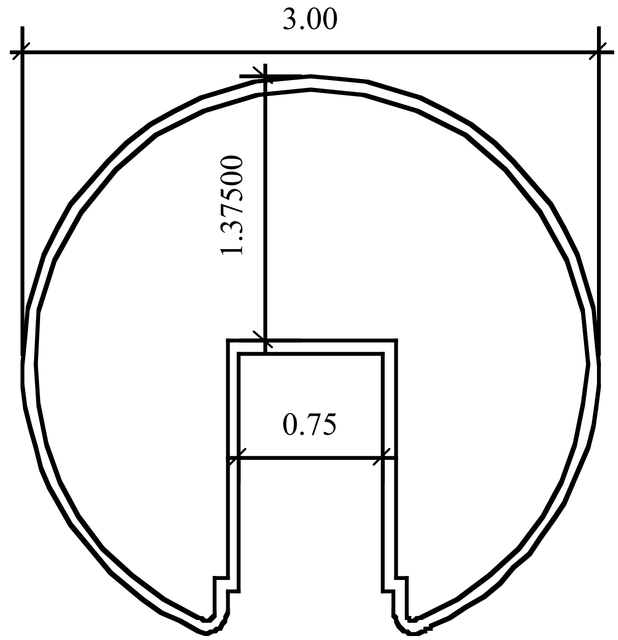
Connector Sleeves

Corners

The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

CRL GR 30 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails



Area: 0.755 sq in
I_{xx}: 0.608 in^4
I_{yy}: 0.653 in^4
r_{xx}: 0.897 in
r_{yy}: 0.930 in
C_{xx}: 1.54 in
C_{yy}: 1.50 in
S_{yy}: 0.405 in^3
S_{xx}: 0.424 in^3 or 0.447 in^3
t = 0.0625"

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02

From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

$\mu = 0.3$

$E_0 = 27.0 \times 10^3$ psi

$F_{cr} = \frac{\pi^2 * 4.0 * 0.50 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.375"/0.0625")^2}$ = 63.2 ksi but ≤ F_U

$M_n = 1.25 S_e F_y$ = 1.25*0.424*30 ksi = 15.9k" Vertical loading
1.25*0.405*30 ksi = 15.19k" Horizontal load Controls

or $M_{ULT} = S_f F_{cr}$ = 0.447*63.2 ksi = 28.25k" Vertical load
0.405*63.2 ksi = 25.596k" Horizontal load Controls Ultimate

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Horizontal → uniform → L= $(15,190/12 \bullet 10/(1.6*50plf))^{1/2}$ = 12.579'
concentrated →L = 15,195*5/(334#) = 227.47" = 18' 11.47"

ULTIMATE STRENGTH

Horizontal → uniform → L= $(25,596/12 \bullet 8/(1.6*50plf))^{1/2}$ = 14.60'
concentrated →L = 25,596*5/(334#) = 383"
cantilevered →L = 25,596/(334#) = 76.63" = 6' 4 5/8"
cantilevered →L = $\sqrt{[2*25,596/12/(1.8*50\#)]}$ = 6.885'

GR 30 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0 = 4.0$ for circular shape
$\mu = 0.34$
$E_0 = 16.9 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(1.375''/0.05'')^2} = 40.7 \text{ ksi but} \leq F_y$$

$M_n = S_eF_y = 0.424*43$ ksi = 18,232 k" Vertical loading
0.405*43 ksi = 17,415 k" Horizontal load
or $M_n = S_fF_{cr} = 0.447*40.7$ ksi = 18,193 k" Vertical load Controls
0.405*40.7 ksi = 16,483 k" Horizontal load Controls
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(0.9*18{,}193/12 \cdot 10/(1.6*50\text{plf}))^{1/2} = 14.6'$
concentrated →L = 0.9*18,193*5/(1.6*200#) = 255"
cantilevered →L = 18,193/(334#) = 54.47" = 4' 6 7/16"

Horizontal → uniform → L= $(0.9*16{,}483/12 \cdot 10/(1.6*50\text{plf}))^{1/2} = 13.9'$
concentrated →L = 0.9*16,483*5/(1.6*200#) = 231" = 19'-3"
cantilevered →L = 16,483/(334#) = 49.35" = 4' 1 5/16"

Connector Sleeves
Corners
The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

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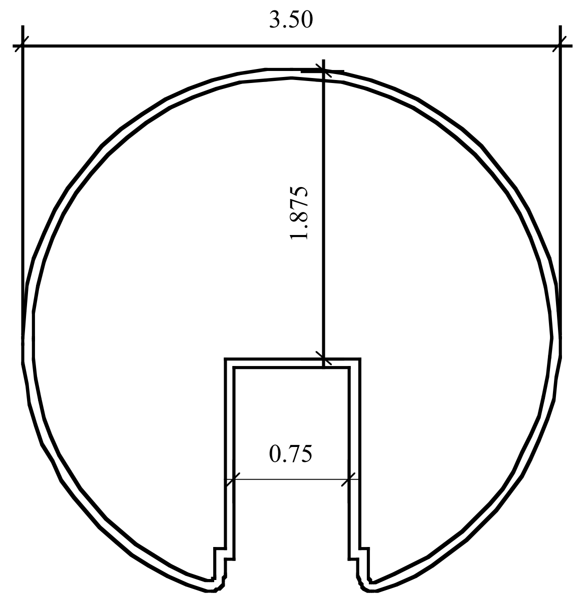
CRL GR 35 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails



Area: 0.866 sq in
I_{xx}: 1.02 in^4
I_{yy}: 1.05 in^4
r_{xx}: 1.086 in
r_{yy}: 1.102 in
C_{xx}: 1.769 in
C_{yy}: 1.75 in
S_{yy}: 0.583 in^3
S_{xx}: 0.594 in^3 or 0.607 in^3
t = 0.0625"

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02

From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \dfrac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

μ = 0.3

E_0 = 27.0 x10^3 psi

$F_{cr} = \dfrac{\pi^2 * 4.0 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.70"/0.0625")^2}$ = 42.2 ksi but ≤ F_U

$M_n = 1.25{*}S_eF_y$ = 1.25*0.594*30 ksi = 22.27k" Vertical loading
1.25*0.583*30 ksi = 21.86k" Horizontal load Controls

or $M_{ULT} = S_fF_{cr}$ = 0.607*42.2 ksi = 25.615k" Vertical load
0.583*42.2 ksi = 24.603k" Horizontal load Controls Ultimate

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Horizontal → uniform → L= $(21{,}860/12 \bullet 10/(1.6{*}50\text{plf}))^{1/2}$ = 15.09'
concentrated →L = 21,860*5/(334#) = 327" = 37' 3"
cantilevered L = 21,860/334 =65.45" = 5' 5 7/16"

Ultimate strength

Horizontal → uniform → L= $(24{,}603/12 \bullet 8/(1.6{*}50\text{plf}))^{1/2}$ = 14.319'
concentrated →L = 24,603*4/(334#) = 294.65
cantilevered L = 24,603/334 =73.66" = 6'-2 ⅔"

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GR 35 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
$\mu = 0.34$
$E_0 = 16.9 \times 10^3$ ksi

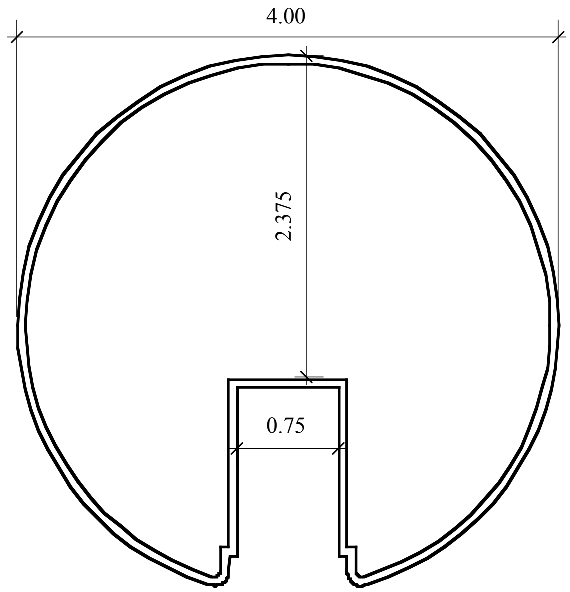
$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(1.70''/0.05'')^2} = 41.4 \text{ ksi but} \leq F_y$$

$M_n = S_e F_y = 0.594*43$ ksi = 25.542 k" Vertical loading
0.583*43 ksi = 25.069 k" Horizontal load
or $M_n = S_f F_{cr} = 0.607*41.4$ ksi = 25.130 k" Vertical load Controls
0.583*41.4 ksi = 24.136 k" Horizontal load Controls

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(0.9*25{,}130/12 \bullet 8/(1.6*50\text{plf}))^{1/2}$ = 13.729'
concentrated →L = 0.9*25,130*4/(334#) = 282.7"
cantilevered L = 0.9*25,130/334 =67.72" = 5' 7 11/16"
Horizontal → uniform → L= $(0.9*24{,}136/12 \bullet 8/(1.6*50\text{plf}))^{1/2}$ = 13.454'
concentrated →L = 0.9*24,136*4/(334#) = 271.52"
cantilevered L = 0.9*24,136/334 =66.04" = 5' 6"

Connector Sleeves
Corners
The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

CRL GR 40 SERIES CAP RAIL
Used as the top rail on glass balustrade panel guardrails



Area: 0.952 sq in
I_{xx}: 1.553 in^4
I_{yy}: 1.529 in^4
r_{xx}: 1.277 in
r_{yy}: 1.267 in
C_{xx}: 2.131 in
C_{yy}: 2.000 in
S_{xx}: 0.729 in^3
or 0.831 in^3
S_{yy}: 0.765 in^3
t = 0.0625"

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \qquad \text{(eq 3.3.1.1-9)}$$

η = 0.5 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
$E_0 = 27.0 \times 10^3$ psi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.95"/0.0625")^2} = 32.09 \text{ ksi but} \le F_U$$

$M_n = 1.25*S_eF_y$ = 1.25*0.729*30 ksi = 27.33k" Vertical loading
1.25*0.765*30 ksi = 28.687k" Horizontal load
or $M_{ULT} = S_fF_{cr}$ = 0.831*32.09 ksi = 26.667k" Vertical load Controls
0.765*32.09 ksi = 24.549k" Horizontal load Controls ultimate
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(26{,}667/12 \bullet 10/(1.6*50plf))^{1/2}$ = 16.667' = 16' - 8"
concentrated →L = 26,667*5/(334#) = 399.21"
cantilevered L = 26,667/334 = 79.84" = 6'-7 13/16"

Horizontal → uniform → L= $(24{,}549/12 \bullet 10/(1.6*50plf))^{1/2}$ = 15.991' = 15'-11 7/8
concentrated →L = 24,549*5/(334#) = 367.5"
cantilevered L = 24,549/334 = 73.5" = 6'- 1 1/2"

GR 40 SERIES CAP RAIL For Brass:

Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn

Cap rail fabricated from cold rolled sheet

$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

$\mu = 0.34$

$E_0 = 16.9 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(1.95''/0.05'')^2} = 20.25 \text{ ksi but} \leq F_y$$

$M_n = S_eF_y$ = 0.729*43 ksi = 31,347 k" Vertical loading

0.765*43 ksi = 32,895 k" Horizontal load

or $M_n = S_fF_{cr}$ = 0.831*20.25 ksi = 16.83 k" Vertical load Controls

0.765*20.25 ksi = 15.491 k" Horizontal load Controls

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or 200 lb concentrated load

Vertical → uniform → L= (0.9*16,830/12•10/(1.6*50plf))$^{1/2}$ =12.561' =10' -6 ¾"

concentrated →L = 0.9*16,830*5/(334#) = 226.75"

cantilevered L = 0.9*16,830/334 = 45.35" = 3' - 9 ⅜"

Horizontal → uniform → L= (0.9*15,491/12 • 10/(1.6*50plf))$^{1/2}$ = 17.085' = 17'-1"

concentrated →L = 0.9*15,491*5/(334#) = 208.7"

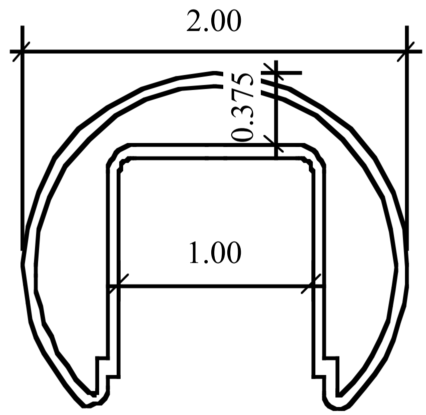
cantilevered L = 0.9*15,491/334 = 41.74" = 3'-5 ¾"

Connector Sleeves

Corners

The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

CRL GR 207 SERIES CAP RAIL



Used as the top rail on glass balustrade panel guardrails. Use with 3/4" glass balustrades

Area: 0.529 sq in

I_{xx}: 0.141 in^4

I_{yy}: 0.222 in^4

r_{xx}: 0.516 in

r_{yy}: 0.648 in

C_{xx}: 0.929 in C_{yy}: 1.00 in

S_{xx}: 0.152 in^3 or 0.132 in^3

S_{yy}: 0.221 in^3

t = 0.05"

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02

From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

$\eta = 0.5$ (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0 = 4.0$ for circular shape

$\mu = 0.3$

$E_0 = 27.0 \times 10^3$ psi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(0.95"/0.05")^2} = 135.2 \text{ ksi but} \le F_U$$

$M_n = 1.25 S_e F_y$ = 1.25*0.132*30 ksi = 4.95k" Vertical loading Controls

1.25*0.221*30 ksi = 8.287k" Horizontal load

or $M_{ULT} = S_f F_{cr}$ = 0.152*75 ksi = 11.4k" Vertical load Controls Ultimate

0.221*75 ksi = 16.575k" Horizontal load

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Vertical → uniform → L= $(4,950/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 7.181'

concentrated →L = 4,950*5/(1.6*200#) = 77.34" = 6' 5 5/16"

cantilevered L = 4,950/334 = 15.47"

Ultimate Strength

Vertical → uniform → L= $(11,400/12 \bullet 8/(1.6*50\text{plf}))^{1/2}$ = 9.75' = 9'-9"

concentrated →L = 11,400*4/(334#) = 136.53"

cantilevered L = 11,400/334 = 34.13" = 2'-10 ⅛"

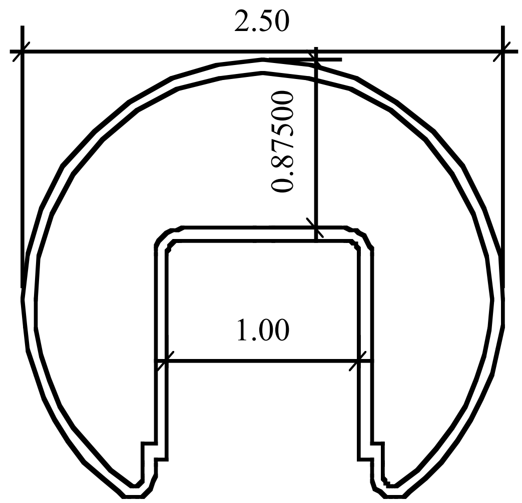
Connector Sleeves and Corners

The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

No Brass option for GR 207

CRL GR 257 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails



Area: 0.634 sq in
I_{xx}: 0.295 in^4
I_{yy}: 0.402 in^4
r_{xx}: 0.682 in
r_{yy}: 0.796 in
C_{xx}: 1.165 in
C_{yy}: 1.25 in
S_{xx}: 0.253 in^3
or 0.221 in^3
S_{yy}: 0.321 in^3
t = 0.05"

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02 From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.5 (from table A6a)
k = $3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
E_0 = 27.0 x10^3 psi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.20''/0.05'')^2} = 84.7 \text{ ksi but} \le F_U$$

M_n =1.25 S_eF_y = 1.25*0.221*30 ksi = 8.287k" Vertical loading Controls
1.25*0.321*30 ksi = 12.037k" Horizontal load
or M_{ULT} = S_fF_{cr} = 0.253*75 ksi = 18.975k" Vertical load   Controls ultimate
0.321*75 ksi = 24.075k" Horizontal load

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= (8,287/12 • 10/(1.6*50plf))$^{1/2}$ = 9.291'
concentrated →L = 8,287*5/(334#) = 124" = 10' 4"
cantilevered   L = 8,287/334 = 24.81"

Ultimate Strength
Vertical → uniform → L= (18,975/12 • 8/(1.6*50plf))$^{1/2}$ = 12.57' = 12'-7"
concentrated →L = 18,975*4/(334#) = 227.25"
cantilevered   L = 18,975/334 = 56.81" = 4' 8 13/16"

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GR 257 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
$\mu = 0.34$
$E_0 = 16.9 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(1.20''/0.05'')^2} = 53.5 \text{ ksi but} \leq F_y$$

$M_n = S_eF_y = 0.253*43$ ksi = 10.879 k" Vertical loading Controls
0.321*43 ksi = 13.803 k" Horizontal load

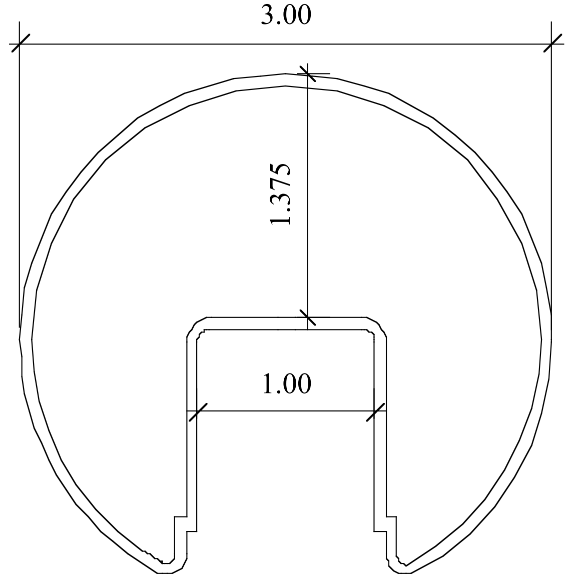
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → $L=(0.9*10{,}879/12\bullet10/(1.6*50\text{plf}))^{1/2}$ =10.099'=10'-1 3/16"
concentrated →L = 0.9*10,879*5/(334#) = 146.57"
cantilevered L = 0.9*10,879/334 = 29.315" = 2'- 5 5/16"

Horizontal → uniform → $L= (0.9*13{,}803/12\bullet10/(1.6*50\text{plf}))^{1/2}$ = 11.376'= 11'-4.5"
concentrated →L = 0.9*13,803*5/(334#) = 185.97"
cantilevered L = 0.9*13,803/334 = 37.19"

Connector Sleeves
Corners
The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

CRL GR 307 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails



Area: 0.743 sq in
I_{xx}: 0.560 in^4
I_{yy}: 0.677 in^4
r_{xx}: 0.868 in
r_{yy}: 0.955 in
C_{xx}: 1.494 in
C_{yy}: 1.500 in
S_{xx}: 0.375 in^3
or 0.372 in^3
S_{yy}: 0.451 in^3
t = 0.0625"

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.50 (from table A6a)
k = $3(Is/Ia)^{1/3}+1<4.0$ = 4.0 for circular shape
μ = 0.3
$E_0 = 27.0 \times 10^3$ psi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.45"/0.0625")^2} = 61.44 \text{ ksi but} \le F_U$$

$M_n = 1.25 S_e F_y$ = 1.25*0.372*30 ksi = 13.95k" Vertical loading Controls
1.25*0.451*30 ksi = 16.912k" Horizontal load
or $M_{ULT} = S_f F_{cr}$ = 0.375*61.44 ksi = 23.04k" Vertical load Controls ultimate
0.451*61.44 ksi = 27.71k" Horizontal load

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(13{,}905/12 \bullet 10/(1.6*50plf))^{1/2}$ = 12.035'
concentrated →L = 13,905*5/(334#) = 208" = 17' 4"
Cantilevered L = 13,905/334 = 41.63"

Ultimate strength
Vertical → uniform → L= $(23{,}040/12 \bullet 8/(1.6*50plf))^{1/2}$ = 13.856' = 13'-10 ¼"
concentrated →L = 23,040*4/(334#) = 275.93"
Cantilevered L = 23,040/334 = 68.98" = 5'-9"

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GR 307 SERIES CAP RAIL For Brass:
Alloy C26000, Cartridge Brass, 70% Cu, 30% Zn
Cap rail fabricated from cold rolled sheet
$F_{yu} \geq 43$ ksi

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$$

$\eta = 0.49$
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
$\mu = 0.34$
$E_0 = 16.9 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 16.9 \times 10^3 \text{ ksi}}{12(1-0.34^2)(1.45"/0.05")^2} = 36.628 \text{ ksi but} \leq F_y$$

$M_n = S_eF_y$ = 0.372*43 ksi = 15.996 k" Vertical loading
0.451*43 ksi = 19.393 k" Horizontal load
or $M_n = S_fF_{cr}$ = 0.375*36.628 ksi = 13.736 k" Vertical load Controls
0.451*36.628 ksi = 16.519 k" Horizontal load Controls
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform →L= $(0.9*13{,}736/12•10/(1.6*50\text{plf}))^{1/2}$=11.348'=11'-4 3/16"
concentrated →L = 0.9*13,736*5/(334#) = 185.07"
cantilevered L = 0.9*13,736/334 = 37.0" 3' -1"

Horizontal → uniform → L= $(0.9*16{,}519/12•10/(1.6*50\text{plf}))^{1/2}$ = 12.444' = 12'-5 ⅓"
concentrated →L = 0.9*16,519*5/(334#) = 222.56"
cantilevered L = 0.9*16,519/334 = 44.51" = 3' 8 1/2"

Connector Sleeves
The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

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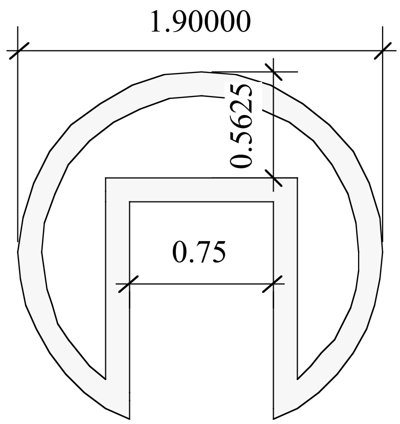
ALUMINUM CAP RAILS

Aluminum cap rail strength evaluated in accordance with the 2005 *Aluminum Design Manual*, Part I-A. Allowable Stress Design

GR19 Aluminum



Area: 0.966 sq in
I_{xx}: 0.242 in^4
I_{yy}: 0.328 in^4
r_{xx}: 0.501 in
r_{yy}: 0.583 in
C_{xx}: 0.948 in
C_{yy}: 0.950 in
S_{xx}: 0.255 in^3
or 0.254 in^3
S_{yy}: 0.345 in^3
t = 0.125"

Allowable stresses ADM Table 2-24 6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{1.9"}{0.125} = 15.2$ line 16.1

$F_{Cb} = 18.5 - 0.593(15.2)^{1/2} = 16.18$ ksi
$M_{all\ horiz} = 16.18^{ksi} \bullet (0.345) = 5{,}582^{\#"}$

For vertical load → bottom in tension top comp.

$F_b = 18$ ksi
bottom stress: $M_{all\ vert} = (0.254in^3) \bullet 18$ ksi $= 4{,}572^{"\#}$ or
top stress: $=(0.255in^3)*16.45$ ksi $= 4{,}195^{"\#}$ controls

Vertical load will determine maximum allowable span

max span 50 plf horizontal load or 200 lb concentrated load
$S = [4{,}195^{"\#}*8/(50plf*12^{"/'})]^{1/2} = 7.48'$ or
$S = 4{,}195^{"\#}*4/200^{\#} = 83.9$ inches = 7' Controls

For cantilevered case:

$S_C = 4{,}195/200 = 20.975"$

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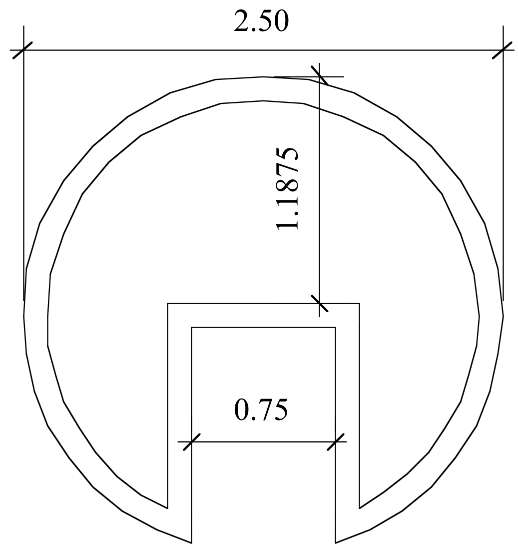
GR25 Aluminum

Area: 1.206 sq in
I_{xx}: 0.622 in^4
I_{yy}: 0.712 in^4
r_{xx}: 0.718 in
r_{yy}: 0.768 in
C_{xx}: 1.269 in
C_{yy}: 1.25 in
S_{xx}: 0.490 in^3
or 0.505 in^3
S_{yy}: 0.569 in^3
t = 0.125"



Allowable stresses ADM Table 2-24
6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{2.5"}{0.125} = 20$ line 16.1

$F_{Cb} = 18.5 - 0.593(20)^{1/2} = 15.84$ ksi
$M_{all\ horiz} = 15.84^{ksi} \bullet (0.569) = 9{,}013^{\#"}$

For vertical load → bottom in tension top comp.

$F_b = 18$ ksi
bottom stress: $M_{all\ vert} = (0.490in^3) \bullet 18$ ksi $= 8{,}820"^{\#}$ or
top stress: $=(0.505in^3)*15.84$ ksi $= 7{,}999"^{\#}$ controls

Vertical load will determine maximum allowable span

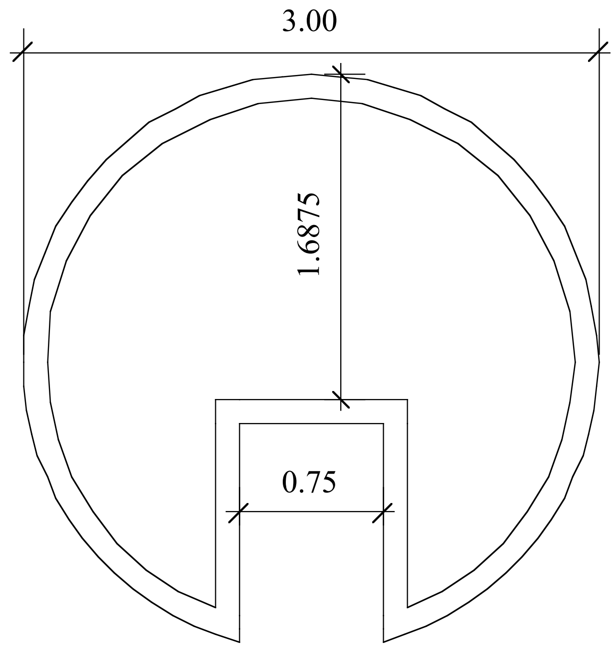
max span 50 plf horizontal load or 200 lb concentrated load
$S = [7{,}999"^{\#}*8/(50plf*12"^{/'})]^{1/2} = 10.32'$ or
$S = 7{,}999"^{\#}*4/200^{\#} = 160$ inches = 13' 4"

For cantilevered case:

$S_C = 7{,}999/200 = 40"$

GR30 Aluminum

Area: 1.407 sq in
I_{xx}: 1.160 in^4
I_{yy}: 1.222 in^4
r_{xx}: 0.908 in
r_{yy}: 0.932 in
C_{xx}: 1.569 in
C_{yy}: 1.50 in
S_{xx}: 0.740 in^3
or 0.811 in^3
S_{yy}: 0.815 in^3
t = 0.125"



Allowable stresses ADM Table 2-24 6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{3"}{0.125} = 24$ line 16.1

$F_{Cb} = 18.5 - 0.593(24)^{1/2} = 15.59$ ksi
$M_{all\ horiz} = 15.59^{ksi} \bullet (0.815) = 12{,}710^{\#"}$

For vertical load → bottom in tension top comp.

$F_b = 18$ ksi
bottom stress: $M_{all\ vert} = (0.740in^3) \bullet 18$ ksi $= 13{,}320^{"\#}$ or
top stress: $=(0.811in^3)*15.59$ ksi $= 12{,}643^{"\#}$ controls

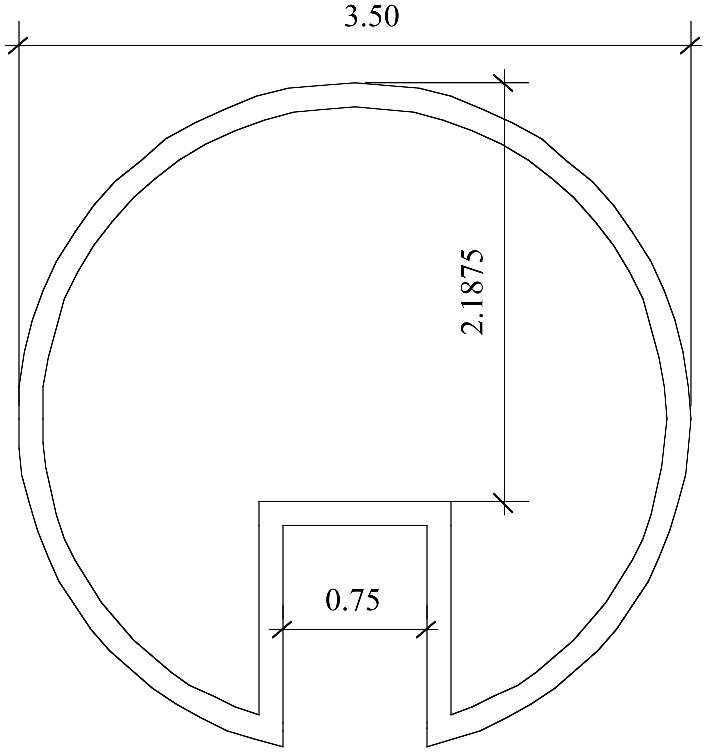
Vertical load will determine maximum allowable span

max span 50 plf horizontal load or 200 lb concentrated load
$S = [12{,}643^{"\#}*8/(50plf*12^{"/'})]^{1/2} = 12.98'$ or
$S = 12{,}643^{"\#}*4/200^{\#} = 253$ inches = 21' 1"

For cantilevered case:

$S_C = 12{,}643/200 = 63.215"$

GR35 Aluminum



Area: 1.606 sq in
I_{xx}: 1.942 in^4
I_{yy}: 1.943 in^4
r_{xx}: 1.10 in
r_{yy}: 1.10 in
C_{xx}: 1.856 in
C_{yy}: 1.750 in
S_{xx}: 1.046 in^3
or 1.181 in^3
S_{yy}: 1.111 in^3
t = 0.125”

Allowable stresses ADM Table 2-24
6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{3.5”}{0.125} = 28$
line 16.1

$F_{Cb} = 18.5 - 0.593(28)^{1/2} = 15.36$ ksi
$M_{all\ horiz} = 15.36^{ksi} \bullet (1.111) = 17{,}067^{\#”}$

For vertical load → bottom in tension top comp.

$F_b = 18$ ksi
bottom stress: $M_{all\ vert} = (1.046in^3) \bullet 18$ ksi = 18,828”# or
top stress: =(1.181in³)*15.36 ksi = 18,140”#

Horizontal load will determine maximum allowable span

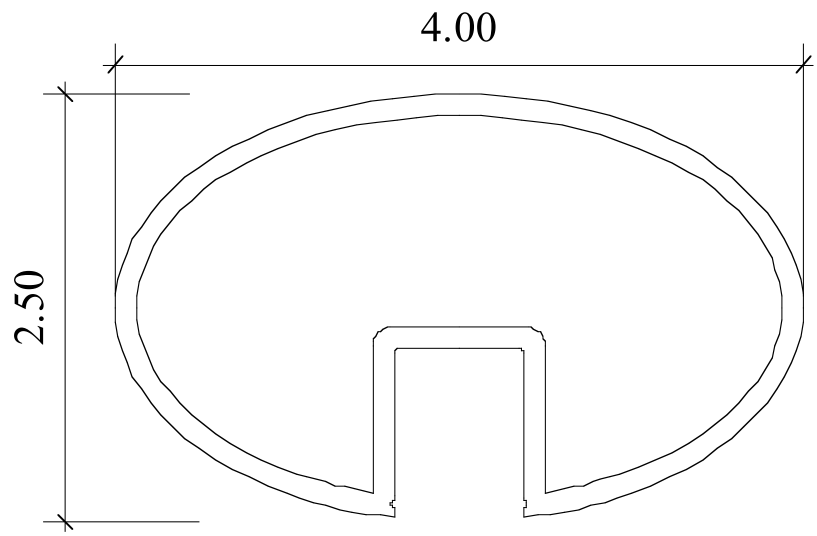
max span 50 plf horizontal load or 200 lb concentrated load
$S = [17{,}067^{”\#}*8/(50plf*12^{”/’})]^{1/2} = 15.08’$ or
$S = 17{,}067^{”\#}*4/200^{\#} = 341$ inches = 28’ 5”

For cantilevered case:

$S_C = 17{,}067/200 = 85.335”$

GROV4 Aluminum

Area: 1.466 sq in
I_{xx}: 0.950 in^4
I_{yy}: 2.078 in^4
r_{xx}: 0.805 in
r_{yy}: 1.190 in
C_{xx}: 1.286 in
C_{yy}: 2.00 in
S_{xx}: 0.739 in^3
or 0.783 in^3
S_{yy}: 1.039 in^3
t = 0.125"



Allowable stresses ADM Table 2-24 6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{2.5"}{0.125}$ = 20 horizontal load or 4/0.125 = 32 for vertical loads

line 16.1

$F_{Cb} = 18.5 - 0.593(20)^{1/2} = 15.84$ ksi
$M_{all\ horiz} = 15.84^{ksi} \bullet (1.039) = 15{,}245^{\#"}$

$F_{Cb} = 18.5 - 0.593(32)^{1/2} = 15.14$ ksi
For vertical load → bottom in tension top comp.

F_b = 18 ksi
bottom stress: $M_{all\ vert}$ = $(0.739in^3) \bullet 18$ ksi = $13{,}302"^{\#}$ or
top stress: $=(0.783in^3)*15.14$ ksi = $11{,}855"^{\#}$

Vertical load will determine maximum allowable span

max span 50 plf horizontal load or 200 lb concentrated load
$S = [11{,}855^{"\#}*8/(50plf*12^{"/'})]^{1/2} = 12.57'$ or
$S = 11{,}855^{"\#}*4/200^{\#}$ = 237 inches = 19' 9"

For cantilevered case:

S_C = 11,885/200 = 59.425"

Sleeve connectors and corners can be inferred from calculations for GR15 rails.

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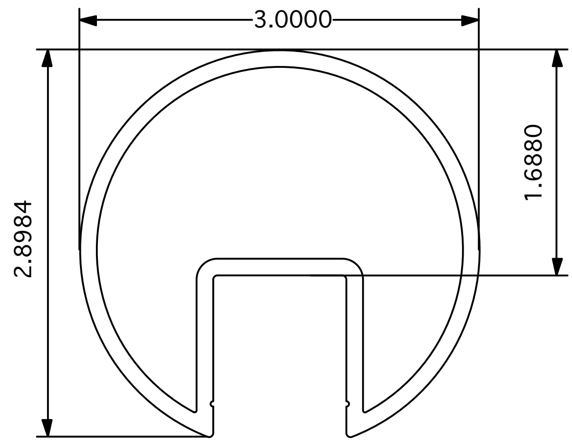
GR307M Aluminum

Area: 1.412 sq in
I_{xx}: 1.078 in^4
I_{yy}: 1.258 in^4
r_{xx}: 0.874 in
r_{yy}: 0.944 in
C_{xx}: 1.520 in
C_{yy}: 1.500 in
S_{xx}: 0.709 in^3 or 0.782 in^3
S_{yy}: 0.839 in^3
t = 0.125”



Allowable stresses ADM Table 2-24
6063-T6 Aluminum

$F_{Cb} \rightarrow R_b/t = \frac{1.5”}{0.125} = 12$

line 16.1
$F_{Cb} = 18.5 - 0.593(20)^{1/2} = 16.45$ ksi

$M_{all\ horiz} = 16.54^{ksi} \bullet (0.839) = 13{,}877^{\#”}$

For vertical load → bottom in tension top comp.

$F_{bt} = 18$ ksi
bottom stress: $M_{all\ vert} = (0.709in^3) \bullet 18$ ksi $= 12{,}762^{”\#}$ or
top stress: $=(0.782in^3)*16.45$ ksi $= 12{,}864^{”\#}$

Vertical load controls span:
max span 50 plf horizontal load or 200 lb concentrated load

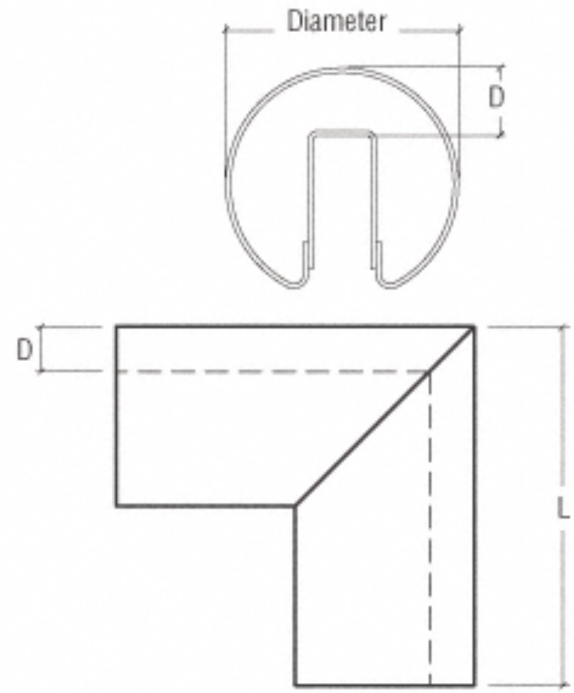
$S = [12{,}762^{”\#}*10/(50plf*12^{”/’})]^{1/2} = 14.584’$ or
$S = 12{,}762^{”\#}*5/200^{\#} = 319$ inches

For cantilevered case:

$S_C = 12{,}762/200 = 63.81”$

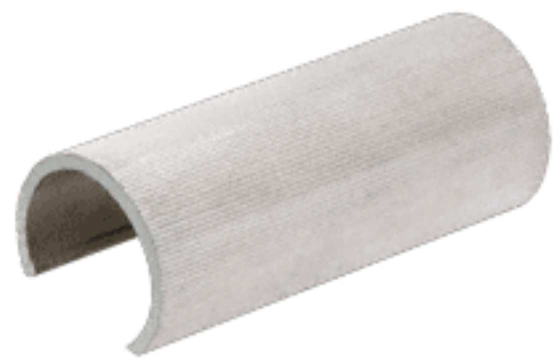
Sleeve connectors and corners can be inferred from calculations for GR15 rails.

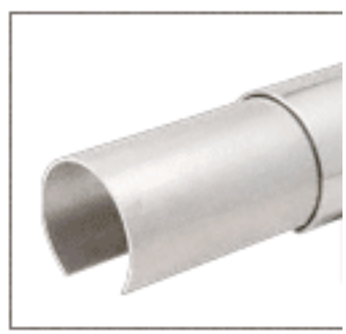
Welded Aluminum Corners and Splices:



When the 6063-T6 aluminum alloy is welded the tempering is lost within the area of the weld affected zone reducing the allowable stress in the tubes to 5.5 ksi within 1" of the weld. This reduces bending strength to 30% of the bending strength for the unaffected cap rail.

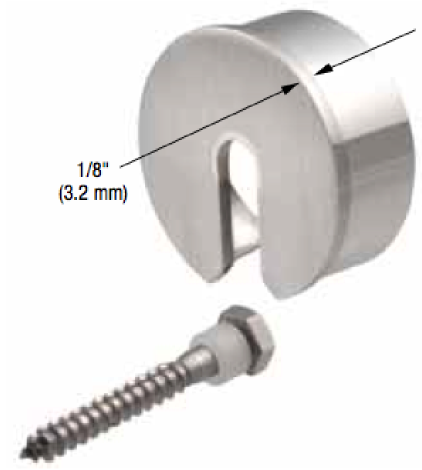
All welds shall be located as close as possible to a zero moment inflection point or at a location where the weld may be assumed to behave as a hinge without causing an unstable condition.





Stabilizing End Cap

Used to attach cap rail or hand rail to wall or post to provide one anchor point.



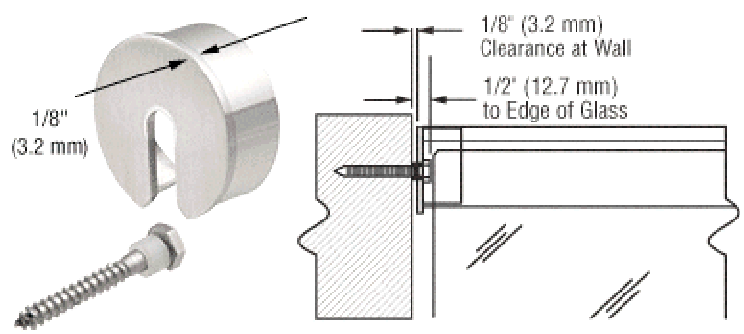
End cap sized to match rail:
Maximum design load to End Cap:
200# concentrated load
For distributed load = 50 plf* light size/2
R = 10’*50plf/2 = 250#
(from broken end light) (250# maximum)
Cap thickness is 1/8”
Anchor size is 1/4”
Bearing pressure on end cap:
F_B = 250#/(0.25*0.125) = 8,000 psi
This is significantly below the allowable bearing stresses for all material types used:

304 SS = 2*0.65*75 ksi/1.6 = 60.92 ksi
6063 T6 AL = 31 ksi
Brass = 2*0.65*43ksi/1.6 = 34.9 ksi

Anchor strength:
1/4” wood screw to wood, G >0.42
Use wood screw style - ANSI B18.6.1 rolled thread.
Z’ = Z*C_d = 151#*1.33 = 200#, NDS Table 11M - 11 gage edge plate and #14 screw
To wood requires maximum light size of 8’
R = 50plf*8’/2 = 200# (200# load to end cap)

To Concrete or CMU:
1/4” Wedge-Bolt® screw in anchor
V = 260# (ESR-1678) 2,000 psi concrete

STABILIZING END CAP MATCHED TO TOP RAIL OR HAND RAIL



1/4" x 1" TEK SCREW TO STEEL
(16 GA MINIMUM)
1/4"X 1.5" WEDGE-BOLT+ SCREW TO
CMU OR CONCRETE
#14X 2" FLAT HEAD WOOD SCREW
1-1/2" MIN WOOD THICKNESS

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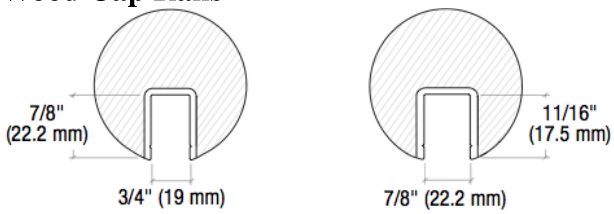
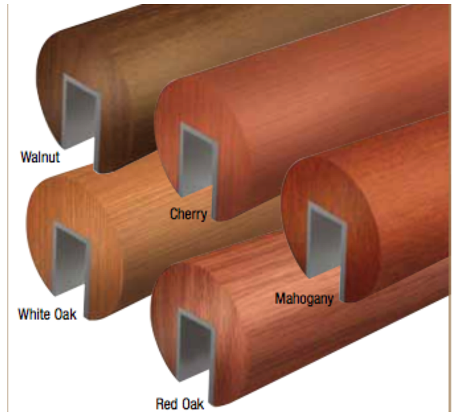
Wood Cap Rails





Composite rail made of select clear wood bonded with aluminum channel.
Determine equivalent section:
$n = E_a/E_w$
n = 10,100/1,400 = 7.2
for aluminum channel thickness = 0.1”
equivalent wood = 7.2*2*0.1 = 1.44”
maxim notch width = 0.75”+2*0.1 = 0.95” < 1.44” therefore can assume that section is equivalent to a solid round .
Wood stress from National Design Specification for Wood Construction Supplement, 2001 edition, mixed oak
$F'_b = F_b{*}C_D{*}C_F{*}C_S$ =1150 psi*1.33*1.5*1.18 = 2,707 psi

Three rail sizes:
2” dia: $S = \pi 2^3/32 = 0.786\ in^3$
M_a = 0.786*2,707 psi = 2,128#”
max span 50 plf horizontal load or 200 lb concentrated load
  $S = [2{,}128^{\#}{*}8/(50plf{*}12^{"/'})]^{1/2}$ = 5.33’ = 5’-4”or
  $S = 2{,}128^{"\#}{*}4/200^{\#}$ = 42.56” inches = 3’-6”
For cantilevered case:
  S_C = 2,128/200 = 10.64”

2.5” dia: $S = \pi 2.5^3/32 = 1.534\ in^3$
M_a = 1.534*2,707 psi = 4,153#”
max span 50 plf horizontal load or 200 lb concentrated load
  $S = [4{,}153^{"\#}{*}8/(50plf{*}12^{"/'})]^{1/2}$ = 7.44’ = 7’5” or
  $S = 4{,}153^{"\#}{*}4/200^{\#}$ = 83” inches = 6’-11”
For cantilevered case:
  S_C = 4,153/200 = 20.765”

3.0” dia: $S = \pi 3^3/32 = 2.65\ in^3$
M_a = 2.65*2,707 psi = 7,174#”
max span 50 plf horizontal load or 200 lb concentrated load
  $S = [7{,}174^{"\#}{*}8/(50plf{*}12^{"/'})]^{1/2}$ = 9.78’ = 9’ 9 1/4” or
  $S = 7{,}174^{"\#}{*}4/200^{\#}$ = 143.5” inches = 11’-11.5”
For cantilevered case:
  S_C = 7,174/200 = 35.87”

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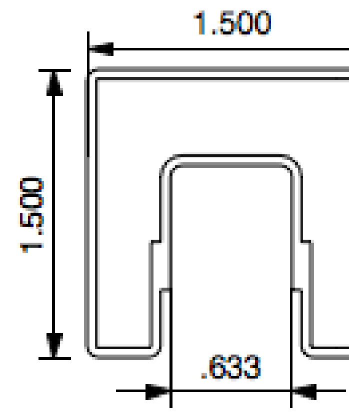
Square Stainless Steel Cap Rails

GRS15/GRSC15 CAP RAIL



Area: 0.4009 sq in
Perim: 15.2514 in
I_{xx}: 0.0961 in^4
I_{yy}: 0.1518 in^4
r_{xx}: 0.4895 in
r_{yy}: 0.5360 in
C_{xx}: 0.77125 in
C_{yy}: 0.7500 in
S_{xx}: 0.1246 in^3 or 0.1319 in^3
S_{yy}: 0.1534 in^3
t = 0.05 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_u = 75ksi, for A304 stainless steel sheet used to form the rail. ø = 1.0. Ultimate strength not calculated because of shape.

$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.0961/0.1518)^{1/3}+1 = 3.58 \le 4.0$
μ = 0.3
E_0 = 27.0 $x10^3$ ksi

$F_{cr} = \frac{\pi^2 * 3.58 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.40''/0.05'')^2} = 54.6 \text{ ksi but} \le F_y$

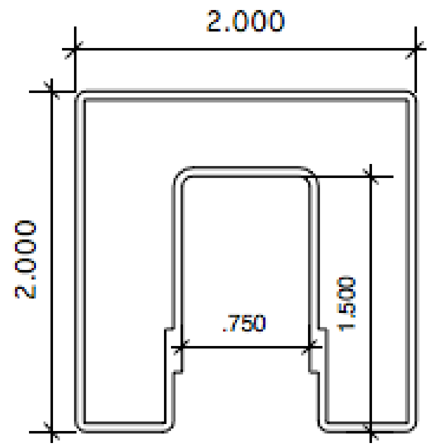
Use reserve capacity method (1.25*30 = 37.5ksi ≤ 54.6 ksi) okay
$M_n = 1.25*S_eF_y$ = 1.25*0.1246*30 ksi = 4,672.5"# Vertical loading Controls
M_{nH} = 1.25*0.1534*30 ksi = 5,752.5"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(4,672.5/12*10/(1.6*50plf))^{1/2}$ = 6.977' = 6' -11 11/16"
concentrated →L = 4,672.5*5/(1.6*200#) = 73.0" = 6' -1"

Horizontal → uniform → L= $(5,752.5/12*10/(1.6*50plf))^{1/2}$ = 7.740' = 7' - 7/8"
concentrated →L = 5,752.5*5/(1.6*200#) = 89.89"

Cantilevered section:
For 200# concentrated load:
L = 4,672.5/(1.6*200) = 14.6" = 1'-2 9/16

GRS20/ GRSC20 CAP RAIL



Area: 0.5504 sq in
Perim: 21.2518 in
I_{xx}: 0.2519 in^4
I_{yy}: 0.2726 in^4
r_{xx}: 0.6766 in
r_{yy}: 0.7038 in
C_{xx}: 1.0322 in
C_{yy}: 1.000 in
S_{xx}: 0.2441 in^3 or 0.2603 in^3
S_{yy}: 0.2726 in^3
t = 0.05 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_u = 75ksi, for A304 stainless steel sheet used to form the rail. ø = 1.0. Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k\eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.5 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.2519/0.2726)^{1/3}+1 = 3.58 \le 4.0$
μ = 0.3
$E_0 = 27.0 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 3.58 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.90''/0.05'')^2} = 54.6 \text{ ksi but} \le F_y$$

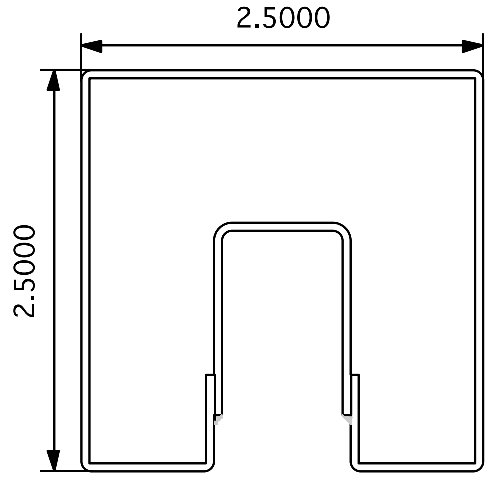
Use reserve capacity method (1.25*30 = 37.5ksi ≤ 54.6 ksi) okay
$M_n = 1.25*S_eF_y$ = 1.25*0.2519*30 ksi = 9,446"# Vertical loading Controls
M_{nH} = 1.25*0.2726*30 ksi = 10,222.5"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(9{,}446/12*10/(1.6*50\text{plf}))^{1/2}$ = 9.919' = 9'- 11"
concentrated →L = 9,446*5/(1.6*200#) = 165.0"

Horizontal → uniform → L= $(10{,}222.5/12*10/(1.6*50\text{plf}))^{1/2}$ = 10.320' = 10'- 3 7/8"
concentrated →L = 10,222.5*5/(1.6*200#) = 178.58"

Cantilevered section:
For 200# concentrated load:
L = 9,446"#/(1.6*200) = 29.52" = 2' - 5 ½"

GRS25 CAP RAIL



Area: 0.6516 sq in
Perim: 25.257 in
I_{xx}: 0.4946 in^4
I_{yy}: 0.5141 in^4
r_{xx}: 0.8712 in
r_{yy}: 0.8883 in
C_{xx}: 1.2864 in
C_{yy}: 1.250 in
S_{xx}: 0.3825 in^3 or 0.4075 in^3
S_{yy}: 0.4113 in^3
t = 0.05 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_u = 75ksi, for A304 stainless steel sheet used to form the rail. ø = 1.0. Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.50 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.4946/0.5141)^{1/3}+1 = 3.96 \leq 4.0$
μ = 0.3
E_0 = 27.0 x10^3 ksi

$$F_{cr} = \frac{\pi^2 * 3.96 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(2.40''/0.05'')^2} = 20.97 \text{ ksi but} \leq F_y$$

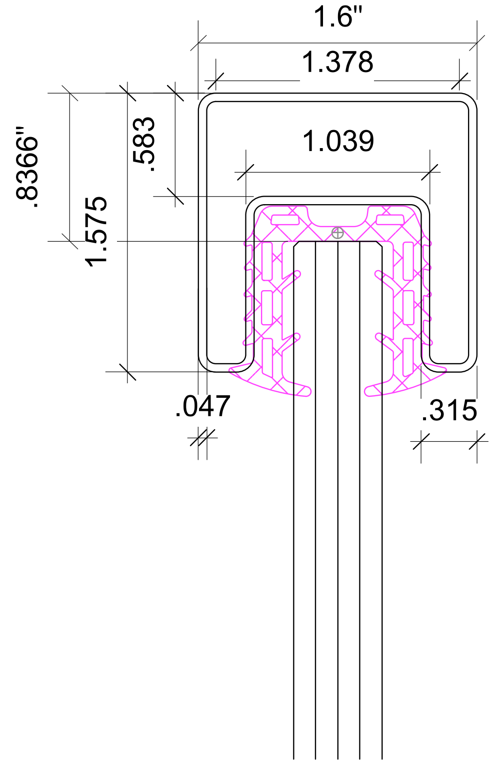
Check reserve capacity method
Check based on compression distortions permitted: f_b = 1.2*20.97ksi = 25,164 psi
$M_n = S_e f_b$ = 0.3825*25,164 psi = 9,625"# Vertical loading Controls
M_{nH} = 0.4113*25,164 psi = 10,350"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(9{,}625/12*10/(1.6*50\text{plf}))^{1/2}$ = 10.013' = 10'- 1/8"
concentrated →L = 9,625*5/(1.6*200#) = 150.39"

Horizontal → uniform → L= $(10{,}350/12*10/(1.6*50\text{plf}))^{1/2}$ = 10.383' = 10'- 4 5/8"
concentrated →L = 10,350*5/(1.6*200#) = 161.72"

Cantilevered section:
For 200# concentrated load:
L = 9,625"#/(1.6*200) = 30.08" = 2' - 6"

SRF15 CAP RAIL



Area: 0.366 sq in
I_{xx}: 0.09363 in^4
I_{yy}: 0.1299 in^4
r_{xx}: 0.5058 in
r_{yy}: 0.5958 in
C_{xx}: 0.843 in
C_{yy}: 0.7875 in
S_{xx}: 0.1111 in^3 Bottom or 0.12799 in^3 Top
S_{yy}: 0.1554 in^3
t = 0.053 in
Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_u = 75ksi, for A304 stainless steel sheet used to form the rail. ø = 1.0.
Ultimate strength not calculated because of shape.

$F_{cr} = \dfrac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.09363/0.1299)^{1/3}+1 = 3.69 \le 4.0$
μ = 0.3
E_0 = 27.0 x10^3 ksi

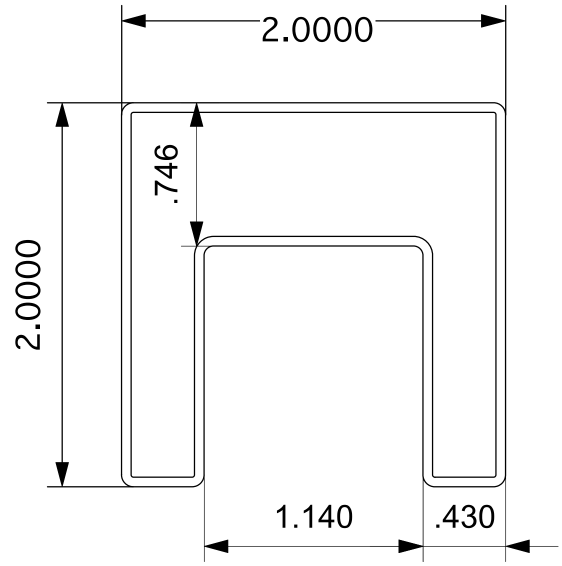
$F_{cr} = \dfrac{\pi^2 * 3.69 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.385"/0.0475")^2}$ = 52.96 ksi but $\le F_y$

Use reserve capacity method (1.25*30 = 37.5ksi ≤ 54.6 ksi) okay
$M_n = 1.25*S_eF_y$ = 1.25*0.1111*30 ksi = 4,166”# Vertical loading Controls
M_{nH} = 1.25*0.1554*30 ksi = 5,828”# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(4,166/12*10/(1.6*50plf))^{1/2}$ = 6.5876’ = 6’ -7”
concentrated →L = 4,166*5/(1.6*200#) = 65.09” = 5’ -5”

Horizontal → uniform → L= $(5,828/12*10/(1.6*50plf))^{1/2}$ = 7.7916’ = 7’ - 9 1/2”
concentrated →L = 5,828*5/(1.6*200#) = 91.06”

Cantilevered section:
For 200# concentrated horizontal load:
L = 5,828/(1.6*200) = 18.2” = 1’-6 3/16”



SRF20 CAP RAIL

Area: 0.5074 sq in

I_{xx}: 0.2201 in^4 I_{yy}: 0.2870 in^4

r_{xx}: 0.6587 in r_{yy}: 0.7521 in

C_{xx}: 1.063 in from bottom C_{yy}: 1.0 in

S_{xx}: 0.2071 in^3 or 0.2349 in^3

S_{yy}: 0.2870 in^3

t = 0.047 in

Allowable stresses:

For stainless steel options: design using SEI/ ASCE 8-02

From Table A1, F_y = 30 ksi, F_u = 75ksi, for A304 stainless steel sheet used to form the rail. ø = 1.0. Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

$\eta = 0.5$ (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1 = 3(0.2201/0.2870)^{1/3}+1 = 3.75 \le 4.0$

$\mu = 0.3$

$E_0 = 27.0 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 3.75 * 0.5 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.87''/0.047'')^2} = 28.9 \text{ ksi but} \le F_y$$

$M_n = S_eF_{cr}$ = 0.2071*28.9 ksi = 5,985"# Vertical loading Controls

M_{nH} = 0.287*28.9 ksi = 8,294"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:

Live loads: 50 plf uniform or 200 lb concentrated load

Vertical → uniform → L= $(5{,}985/12*10/(1.6*50\text{plf}))^{1/2}$ = 7.896'

concentrated →L = 5,985*5/(1.6*200#) = 93.5" = 7' - 9.5"

Horizontal → uniform → L= $(8{,}294/12*10/(1.6*50\text{plf}))^{1/2}$ = 9.295'

concentrated →L = 8,294*5/(1.6*200#) = 129.59"

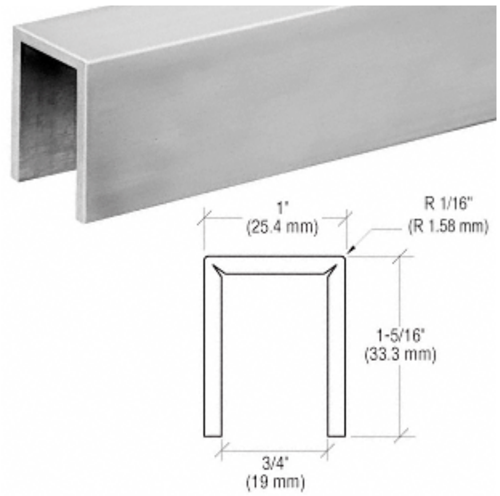
Cantilevered section horizontal load

For 200# concentrated load:

L = 5,985/(1.6*200) = 18.7"

For vertical load:

L = 8,294/(1.6*200) = 25.9"



GRLC10 CAP RAIL
Area: 0.404 sq in
Perim: 7.231 in
I_{xx}: 0.06997 in^4
I_{yy}: 0.06530 in^4
r_{xx}: 0.4162 in
r_{yy}: 0.4021 in
C_{xx}: 0.7875 in
C_{yy}: 0.50 in
S_{xx}: 0.08885 in^3 or 0.13328 in^3
S_{yy}: 0.13059 in^3
t = 0.1177 in (11 ga)
Allowable stresses:
F_y = 48 ksi, F_u = 94ksi, for A304 stainless steel sheet mill certification, used to form the rail. ø = 1.0 Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.49 (from SEI/ASCE 8-02 table A8a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.06997/0.06530)^{1/3}+1 = 4.08 \leq 4.0$
$\mu = 0.3$
$E_0 = 27.0 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.1948''/0.1177'')^2} = 464 \text{ ksi but} \leq F_y$$

Use reserve capacity method
$M_n = 1.25*S_eF_y$ = 1.25*0.08885*48 ksi = 5,331"# Vertical loading Controls
M_{nH} = 1.25*0.13059*48 ksi = 7,835"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(5{,}331/12*10/(1.6*50plf))^{1/2}$ = 7.452' = 7'-5 7/16"
concentrated →L = 5,331*5/(1.6*200#) = 83.3" = 6' -11 ¼"

Horizontal → uniform → L= $(7{,}835/12*10/(1.6*50plf))^{1/2}$ = 9.034' = 9'- 3/8"
concentrated →L = 7,835*5/(1.6*200#) = 122.42"

Cantilevered section:
For 200# concentrated load:
L = 7,835"#/(1.6*200) = 24.48" = 2'- ½"

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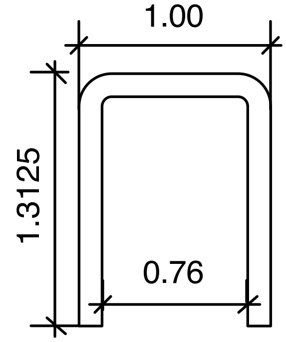
GRL10 CAP RAIL



Area: 0.3949 sq in
I_{xx}: 0.06763 in^4
I_{yy}: 0.06324 in^4
r_{xx}: 0.4139 in
r_{yy}: 0.4002 in
C_{xx}: 0.7760 in
C_{yy}: 0.50 in
S_{xx}: 0.08716 in^3 or 0.12606 in^3
S_{yy}: 0.1265 in^3
t = 0.1177 in (11 ga)
Allowable stresses:
F_y = 48 ksi, F_u = 94ksi, for A304 stainless steel sheet mill certification, used to form the rail. ø = 1.0 Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \qquad \text{(eq 3.3.1.1-9)}$$

$\eta = 0.49$ (from SEI/ASCE 8-02 table A8a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.06763/0.06324)^{1/3}+1 = 4.07 \leq 4.0$
$\mu = 0.3$
$E_0 = 27.0 \times 10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.49 * 27.0 \times 10^3 \text{ ksi}}{12(1-0.3^2)(1.1198''/0.1177'')^2} = 464 \text{ ksi but} \leq F_y$$

Use reserve capacity method
$M_n = 1.25*S_eF_y$ = 1.25*0.08716*48 ksi = 5,230"# Vertical loading Controls
M_{nH} = 1.25*0.1265*48 ksi = 7,590"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(5{,}230/12*10/(1.6*50\text{plf}))^{1/2}$ = 7.381' = 7'-4 7/16"
concentrated →L = 5,230*5/(1.6*200#) = 81.72" = 6' -9 11/16"

Horizontal → uniform → L= $(7{,}590/12*10/(1.6*50\text{plf}))^{1/2}$ = 8.892' = 9'- 10 11/16"
concentrated →L = 7,590*5/(1.6*200#) = 118.59"

Cantilevered section:
For 200# concentrated load:
L = 7,590"#/(1.6*200) = 23.72" = 1'- 11 11/16"

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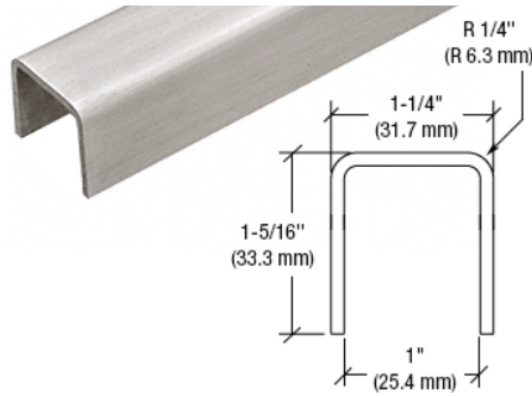
GRL107/GRLC107 CAP RAIL



1 1/4" x 1 5/16" x 11 Ga
Area: 0.4463 sq in
I_{xx}: 0.07768 in^4
I_{yy}: 0.1122 in^4
r_{xx}: 0.417 in
r_{yy}: 0.501 in
S_{xx}: 0.0957 in^3
S_{yy}: 0.1793 in^3

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 45 ksi for 1/16 hard A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

η = 0.49 (from table A8a)
$k = 3(Is/Ia)^{1/3}+1<4.0 = 3(0.07768/0.1122)^{1/3}+1 = 3.6547$
$\mu = 0.3$
$E_0 = 27.0 \text{ x}10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 3.6547 * 0.49 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.0625''/0.125'')^2} = 650 \text{ ksi but} \le F_y$$

$M_n = S_eF_y$ = 0.0957*45 ksi = 4,307 k" Vertical loading
0.1793*45 ksi = 8,069 k" Horizontal load

Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or 200 lb concentrated load rail continuous one end
Vertical → uniform → $L= (4{,}307\#''/12 \bullet 10/(1.6*50plf))^{1/2} = 6.698'$
concentrated →L = 4,307*(16/3)/(1.6*200#) = 71.78"
cantilevered →L = 4,307*/(1.6*200#) = 13.46"
→$L = (4{,}307\#''/12 \bullet 2/(1.6*50plf))^{1/2} = 2.995'$

Horizontal → uniform → $L= (8{,}069\#''/12 \bullet 10/(1.6*50plf))^{1/2} = 9.168'$ controls
concentrated →L = 8,069*(16/3)/(1.6*200#) = 134.48"
cantilevered →L = 8,069*/(1.6*200#) = 25.2"
→$L = 8{,}069/12 \bullet 2/(1.6*50plf))^{1/2} = 4.100'$

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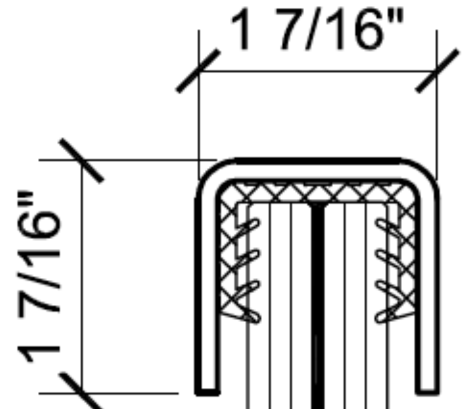
L10 CAP RAIL



Area: 0.4653 sq in
I_{xx}: 0.09776 in^4 ; I_{yy}: 0.1572 in^4
r_{xx}: 0.4584 in ; r_{yy}: 0.5813 in
C_{xx}: 0.7185 in ; C_{yy}: 0.890 in
S_{xx}: 0.1098 in^3 or 0.1787 in^3
S_{yy}: 0.209 in^3
t = 0.1177 in (11 ga)
Allowable stresses:
$F_y \geq 45$ ksi, $F_u =\geq 90$ksi, for A304 stainless steel sheet mill certification, used to form the rail. ø = 1.0 Ultimate strength not calculated because of shape.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

$\eta = 0.49$ (from SEI/ASCE 8-02 table A8a)
$k = 3(I_s/I_a)^{1/3}+1 = 3(0.1572/0.09776)^{1/3}+1 = 3.51 \leq 4.0$
$\mu = 0.3$
$E_0 = 27.0 \text{ x}10^3$ ksi

$$F_{cr} = \frac{\pi^2 * 3.51 * 0.49 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.188''/0.1177'')^2} = 412 \text{ ksi but} \leq F_y$$

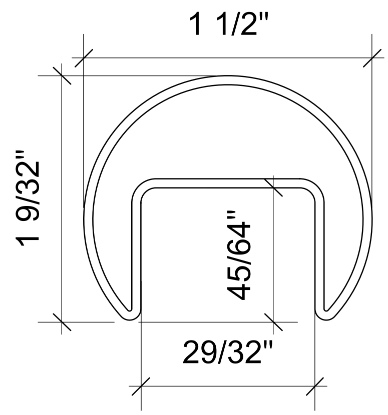
Use reserve capacity method
$M_n = 1.25*S_eF_y = 1.25*0.08716*48$ ksi = 5,230"# Vertical loading Controls
$M_{nH} =$ 1.25*0.1265*48 ksi = 7,590"# Horizontal load

Determine allowable rail spans (ignoring deflection) assumes multiple spans:
Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L= $(5{,}230/12*10/(1.6*50\text{plf}))^{1/2}$ = 7.381' = 7'-4 7/16"
concentrated →L = 5,230*5/(1.6*200#) = 81.72" = 6' -9 11/16"

Horizontal → uniform → L= $(7{,}590/12*10/(1.6*50\text{plf}))^{1/2}$ = 8.892' = 9'- 10 11/16"
concentrated →L = 7,590*5/(1.6*200#) = 118.59"

Cantilevered section:
For 200# concentrated load:
L = 7,590"#/(1.6*200) = 23.72" = 1'- 11 11/16"

CRL GRRF15 SERIES CAP RAIL



Used as the top rail on glass balustrade panel guardrails.
Area: 0.269 sq in
I_{xx}: 0.03726 in^4
I_{yy}: 0.07091 in^4
r_{xx}: 0.3721 in
r_{yy}: 0.5134 in
C_{xx}: 0.731 in C_{yy}: 0.75 in
S_{xx}: 0.05176 in^3 or 0.0677 in^3
S_{yy}: 0.08538 in^3
t = 0.053”

Allowable stresses:
For stainless steel options: design using SEI/ASCE 8-02
From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2} \quad \text{(eq 3.3.1.1-9)}$$

$\eta = 0.5$ (from table A6a)
$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape
$\mu = 0.3$
$E_0 = 27.0 \text{ x}10^3$ psi

$$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(0.75”/0.05”)^2} = 216 \text{ ksi but} \le F_U$$

$M_n = 1.25 S_e F_y$ = 1.25*0.05176*30 ksi = 1,941”# Vertical loading Controls
1.25*0.08538*30 ksi = 3,202”# Horizontal load
or $M_{ULT} = S_f F_{cr}$ = 0.05176*75 ksi = 3,882”# Vertical load Controls Ultimate
0.08538*75 ksi = 6,404”# Horizontal load
Determine allowable rail spans (ignoring deflection)
Live loads: 50 plf uniform or concentrated load
Vertical → uniform → L= $(1,941/12 \bullet 10/(1.6*50plf))^{1/2}$ = 6.1509’
concentrated →L = 1,941*5/(1.6*200#) = 56.75” = 4’ 8 3/4”
cantilevered L = 1,941/(1.6*200) = 6 1/16”
Ultimate Strength
Vertical → uniform → L= $(3,882/12 \bullet 8/(1.6*50plf))^{1/2}$ = 5.688’ = 5’-8 1/4”
concentrated →L = 3,882*4/(320#) = 48.5” = 4’ 0 1/2”
cantilevered L = 3,882/320 = 12 1/8”

Connector Sleeves and Corners

The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2” size.

CRL GRRF20 SERIES CAP RAIL

Used as the top rail on glass balustrade panel guardrails.

Area: 0.3765 sq in

I_{xx}: 0.0909 in^4

I_{yy}: 0.1509 in^4

r_{xx}: 0.4914 in

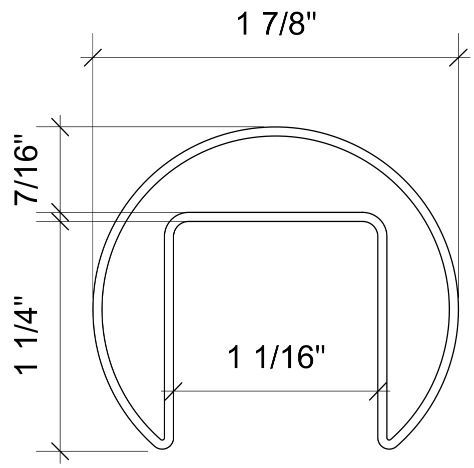
r_{yy}: 0.6332 in

C_{xx}: 0.949 in C_{yy}: 0.9375 in

S_{xx}: 0.09689 in^3 or 0.123 in^3

S_{yy}: 0.123 in^3

t = 0.053"



Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02

From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \dfrac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

μ = 0.3

E_0 = 27.0 x10^3 psi

$F_{cr} = \dfrac{\pi^2 * 4.0*0.5*27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(0.95''/0.05'')^2}$ = 135.2 ksi but ≤ F_U

$M_n = 1.25S_eF_y$ = 1.25*0.09689*30 ksi = 3,632"# Vertical loading Controls

1.25*0.123*30 ksi = 4,613"# Horizontal load

or $M_{ULT} = S_fF_{cr}$ = 0.09689*75 ksi = 7,267"# Vertical load Controls Ultimate

0.123*75 ksi = 9,225"# Horizontal load

Determine allowable rail spans (ignoring deflection)

Live loads: 50 plf uniform or concentrated load

Vertical → uniform → L= (3,632/12 • 10/(1.6*50plf))$^{1/2}$ = 6.1509'

concentrated →L = 3,632*5/(1.6*200#) = 56.75" = 4' 8 3/4"

cantilevered L = 3,632/(1.6*200) = 11.35"

Ultimate Strength

Vertical → uniform → L= (7,267/12 • 8/(1.6*50plf))$^{1/2}$ = 7.782' = 7'-9 3/8"

concentrated →L = 7,267*4/(334#) = 87.0"

cantilevered L = 7,267/334 = 21.76"

Connector Sleeves and Corners

The connector sleeves and corners are demonstrated as adequate based on strength for the 1-1/2" size.

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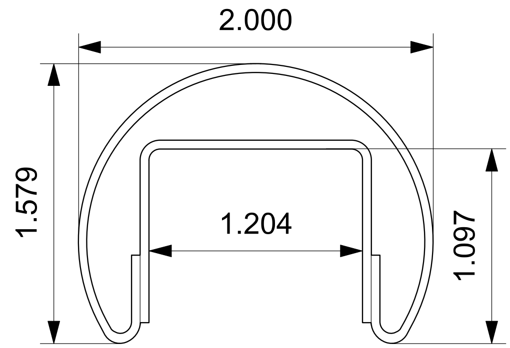
CRL LR20 SERIES CAP RAIL



Used as the top rail on glass balustrade panel guardrails.

Area: 0.4193 sq in

I_{xx}: 0.09118 in^4 I_{yy}: 0.1915 in^4

r_{xx}: 0.4663 in r_{yy}: 0.6757 in

C_{xx}: 1.0 in C_{yy}: 0.791 in (from bottom)

S_{xx}: 0.1154 in^3 or 0.1157 in^3 S_{yy}: 0.1915 in^3

t = 0.053"

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02, From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \dfrac{\pi^2 k\eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

μ = 0.3

E_0 = 27.0 x10^3 psi

$F_{cr} = \dfrac{\pi^2 * 4.0 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1"/0.053")^2}$ = 137.1 ksi but ≤ F_U

$M_n = 1.25 S_e F_y$ = 1.25*0.1154*30 ksi = 4,328"# Vertical loading Controls

1.25*0.1915*30 ksi = 7,181"# Horizontal load

or $M_{ULT} = S_f F_{cr}$ = 0.1154*75 ksi = 8,655"# Vertical load Controls Ultimate

0.1915*75 ksi = 14,363"# Horizontal load

Determine allowable rail spans (ignoring deflection) spans 2 lights minimum

Live loads: 50 plf uniform or concentrated load

Vertical → uniform → L= (4,328/12 • 10/(1.6*50plf))$^{1/2}$ = 6.714'

concentrated →L = 4,328*5/(1.6*200#) = 67.625

cantilevered L = 4,328/(1.6*200) = 13.5"

Ultimate Strength

Vertical → uniform → L= (8,655/12 • 10/(1.6*50plf))$^{1/2}$ = 9.495'

concentrated →L = 8,655*4/(334#) = 103.65"

cantilevered L = 8,655/334 = 25.91"

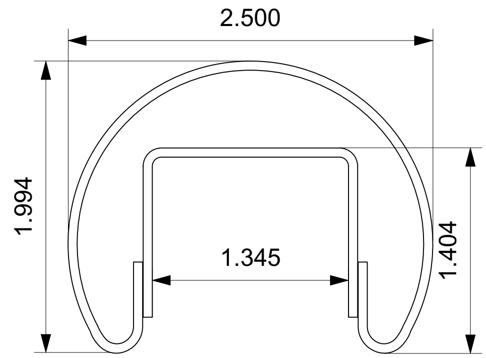
For laminated glass end light length based on horizontal strength

Cantilevered end

Vertical → uniform → L= (14,363/12 • 2/(1.6*50plf))$^{1/2}$ = 5.47'

concentrated →L = 14,363/(334#) = 43.0"

CRL LR25 SERIES CAP RAIL



Used as the top rail on glass balustrade panel guardrails.

Area: 0.65177 sq in

I_{xx}: 0.2250 in^4 I_{yy}: 0.4484 in^4

r_{xx}: 0.5875 in r_{yy}: 0.8295 in

C_{xx}: 1.25 in C_{yy}: 0.986 in (from bottom)

S_{xx}: 0.2282 in^3 or 0.2232 in^3 S_{yy}: 0.3587 in^3

t = 0.053”

Allowable stresses:

For stainless steel options: design using SEI/ASCE 8-02, From Table A1, F_y = 30 ksi, F_U = 75ksi for annealed A304 stainless steel sheet used to form the rail.

$F_{cr} = \frac{\pi^2 k \eta E_0}{12(1-\mu^2)(w/t)^2}$ (eq 3.3.1.1-9)

η = 0.5 (from table A6a)

$k = 3(I_s/I_a)^{1/3}+1<4.0$ = 4.0 for circular shape

μ = 0.3

$E_0 = 27.0 \text{ x}10^3$ psi

$F_{cr} = \frac{\pi^2 * 4.0 * 0.5 * 27.0 \text{ x}10^3 \text{ ksi}}{12(1-0.3^2)(1.25”/0.053”)^2}$ = 87.7 ksi but $\leq F_U$

$M_n = 1.25 S_e F_y$ = 1.25*0.2282*30 ksi = 8,558”# Vertical loading Controls

1.25*0.3587*30 ksi = 13,451”# Horizontal load

or $M_{ULT} = S_f F_{cr}$ = 0.2282*75 ksi = 17,115”# Vertical load Controls Ultimate

0.3587*75 ksi = 26,903”# Horizontal load

Determine allowable rail spans (ignoring deflection) spans 2 lights minimum

Live loads: 50 plf uniform or concentrated load

Vertical → uniform → L= $(8{,}558/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 9.442’

concentrated →L = 8,558*5/(1.6*200#) = 133.72

cantilevered L = 8,558/(1.6*200) = 26.7”

Ultimate Strength

Vertical → uniform → L= $(17{,}115/12 \bullet 10/(1.6*50\text{plf}))^{1/2}$ = 13.352’

concentrated →L = 17,115*4/(334#) = 205”

cantilevered L = 17,115/334 = 51.24”

For laminated glass end light length based on horizontal strength

Cantilevered end

Vertical → uniform → L= $(26{,}903/12 \bullet 2/(1.6*50\text{plf}))^{1/2}$ = 7.487’

concentrated →L = 26,903/(334#) = 80.55”

Fr 12” deflection: L = $[12*3*20\text{x}10^6*0.4484/334]^{1/3}$ = 98.87” (doesn’t control)

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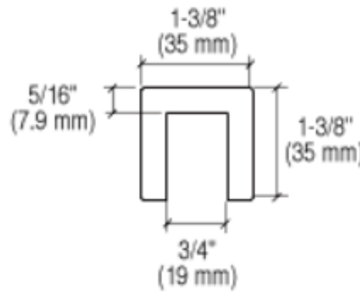
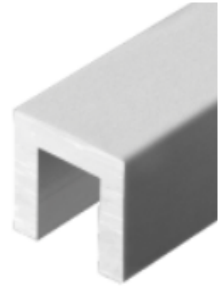
Blumcraft 324 Aluminum
6063-T5 Aluminum





Area: 1.0916 sq in
I_{xx}: 0.18765 in^4; I_{yy}: 0.25952 in^4
r_{xx}: 0.41462 in; r_{yy}: 0.48759 in
C_{xx}: 0.6875 in; C_{yy}: 0.803 in
S_{xx}: 0.2338 in^3 (bottom) or 0.328 in^3 (top)
Z_{xx}: 0.3996 in^3
S_{yy}: 0.3775 in^3; Z_{yy}: 0.4974 in^3
t = 0.3125"
Strength per 2015 ADM Section F.1 and F.2
$b/t = \frac{1.0625}{0.3125} = 3.4 \le 14.5$ Lateral torsional buckling won't control.

Vertical loads
$M_{nxy} = F_y Z_{xx}$ = 16ksi*0.3996 in^3 = 6,394"#
$M_{nxu} = F_u Z_{xx}$ = 22ksi*0.3996 in^3 = 8,791"#
$M_{ax} = M_{nxy}/n_s \le M_{nxu}/n_u$ = 6,394/1.65 = 3,875"# ≤ 8,791/1.95 = 4,508"#

Horizontal loads
$M_{nyy} = F_y Z_{yy}$ = 16ksi*0.4974 in^3 = 7,958"#
$M_{nyu} = F_u Z_{yy}$ = 22ksi*0.4974 in^3 = 10,943"#
$M_{ax} = M_{nxy}/n_s \le M_{nxu}/n_u$ = 7,958/1.65 = 4,823"# ≤ 10,943/1.95 = 5,612"#

Vertical load:
max span 50 plf horizontal load or 200 lb concentrated load
S = [3,875$^{"\#}$*10/(50plf*12$^{"/'}$)]$^{1/2}$ = 8.036' or
S = 3,875$^{"\#}$*5/200$^{\#}$ = 96.875 inches
For cantilevered case:
S_C = 3,875/200 = 19.375"

Horizontal load:
max span 50 plf horizontal load or 200 lb concentrated load
S = [4,823$^{"\#}$*10/(50plf*12$^{"/'}$)]$^{1/2}$ = 8.966' or
S = 4,823$^{"\#}$*5/200$^{\#}$ = 120.575 inches
For cantilevered case:
S_C = 4,823/200 = 24.11"

For light failure only horizontal load case applies for laminated glass.

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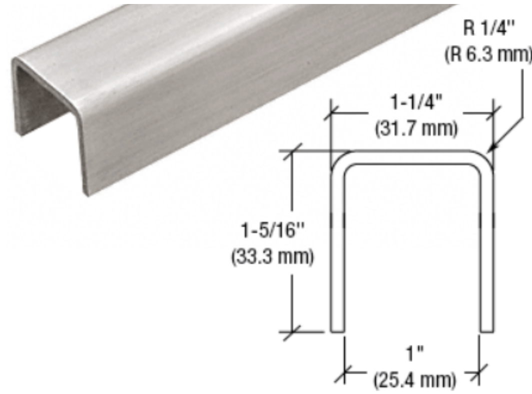

GRL107MBL CAP RAIL
6063-T6 Aluminum
1 1/4" x 1 5/16" x 11 Ga
Area: 0.4463 sq in
I_{xx}: 0.07768 in^4
I_{yy}: 0.1122 in^4
r_{xx}: 0.417 in
r_{yy}: 0.501 in
S_{xx}: 0.0957 in^3
S_{yy}: 0.1793 in^3

Strength per 2015 ADM Section F.1 and F.2
$b/t = \frac{1.0625}{0.125} = 8.5 \leq 14.5$ Lateral torsional buckling won't control.
Vertical loads
$M_{nxy} = F_y Z_{xx} = 25ksi*0.0957\ in^3 = 2{,}393"\#$
$M_{nxu} = F_u Z_{xx} = 30ksi*0.0957\ in^3 = 2{,}871"\#$
$M_{ax} = M_{nxy}/n_s \leq M_{nxu}/n_u = 2{,}393/1.65 = 1{,}450"\# \leq 2{,}871/1.95 = 1{,}472"\#$

Horizontal loads
$M_{nyy} = F_y Z_{yy} = 25ksi*0.1793\ in^3 = 4{,}483"\#$
$M_{nyu} = F_u Z_{yy} = 30ksi*0.1793\ in^3 = 5{,}379"\#$
$M_{ax} = M_{nxy}/n_s \leq M_{nxu}/n_u = 4483/1.65 = 2{,}717"\# \leq 5{,}379/1.95 = 2{,}758"\#$

Vertical load:
max span 50 plf horizontal load or 200 lb concentrated load
$S = [2{,}717^{"\#}*10/(50plf*12^{"/'})]^{1/2} = 6.73'$ or
$S = 2{,}717^{"\#}*5/200^{\#} = 67\ 5/8"$
For cantilevered case:
$S_C = 2{,}717/200 = 13\ 9/16"$

Horizontal load:
max span 50 plf horizontal load or 200 lb concentrated load
$S = [1{,}450^{"\#}*10/(50plf*12^{"/'})]^{1/2} = 4.916'$ or
$S = 1{,}450^{"\#}*5/200^{\#} = 36.25"$
For cantilevered case:
$S_C = 1{,}450/200 = 7.25"$

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L10MBL CAP RAIL

Area: 0.4653 sq in
I_{xx}: 0.09776 in^4 ; I_{yy}: 0.1572 in^4
r_{xx}: 0.4584 in ; r_{yy}: 0.5813 in
C_{xx}: 0.7185 in ; C_{yy}: 0.890 in
S_{xx}: 0.1098 in^3
S_{yy}: 0.209 in^3
t = 0.125 in

Strength per 2015 ADM Section F.1 and F.2
$b/t = \frac{1.0625}{0.125} = 8.5 \le 14.5$ Lateral torsional buckling won't control.

Vertical loads
$M_{nxy} = F_y Z_{xx}$ = 25ksi*0.1098 in^3 = 2,745"#
$M_{nxu} = F_u Z_{xx}$ = 30ksi*0.1098 in^3 = 3,294"#
$M_{ax} = M_{nxy} / n_s \le M_{nxu}/n_u$ = 2,745/1.65 = 1,664"# ≤ 3,294/1.95 = 1,689"#

Determine allowable rail spans (ignoring deflection) assumes multiple spans:

Live loads: 50 plf uniform or 200 lb concentrated load

Vertical → uniform → L = $(1{,}664/12*10/(50plf))^{1/2}$ = 5.266' = 4'-4 3/16"

concentrated →L = 1,664*5/(200#) = 41.6" = 3' - 5 5/8"

Cantilevered section:
For 200# concentrated load:

L = 1,664"#/(200) = 23.72" = 8'- 5/16"

Horizontal loads
$M_{nyy} = F_y Z_{yy}$ = 25ksi*0.209 in^3 = 5,225"#
$M_{nyu} = F_u Z_{yy}$ = 30ksi*0.209 in^3 = 6,270"#
$M_{ax} = M_{nxy} / n_s \le M_{nxu}/n_u$ = 5,225/1.65 = 3,167"# ≤ 6,270/1.95 = 3,215"#

Horizontal → uniform → L= $(3{,}167/12*10/(50plf))^{1/2}$ = 7.265' = 7'- 4"

concentrated →L = 3,167*5/(200#) = 79 3/16"

Cantilevered section:
For 200# concentrated load:

L = 3,167"#/(200) = 23.72" = 1'- 3 7/8"

GRL10MBL CAP RAIL

Area: 0.3949 sq in
I_{xx}: 0.06763 in^4
I_{yy}: 0.06324 in^4
r_{xx}: 0.4139 in
r_{yy}: 0.4002 in
C_{xx}: 0.7760 in
C_{yy}: 0.50 in
S_{xx}: 0.08716 in^3
S_{yy}: 0.1265 in^3
t = 0.1177 in (11 ga)

Strength per 2015 ADM Section F.1 and F.2

$b/t = \frac{1.18}{0.125} = 9.5 \le 14.5$ Lateral torsional buckling won't control.

Vertical loads

$M_{nxy} = F_y Z_{xx}$ = 25ksi*0.08716 in^3 = 2,179"#
$M_{nxu} = F_u Z_{xx}$ = 30ksi*0.08716 in^3 = 2,615"#
$M_{ax} = M_{nxy}/n_s \le M_{nxu}/n_u$ = 2,179/1.65 = 1,321"# ≤ 2,615/1.95 = 1,341"#

Determine allowable rail spans (ignoring deflection) assumes multiple spans:

Live loads: 50 plf uniform or 200 lb concentrated load
Vertical → uniform → L = $(1{,}321/12*10/(50plf))^{1/2}$ = 4.692' = 4'-8 5/16"
concentrated →L = 1,321*5/(200#) = 33.0" = 2' - 7"

Cantilevered section:
For 200# concentrated load:
L = 1,321"#/(200) = 6- 5/8"

Horizontal loads

$M_{nyy} = F_y Z_{yy}$ = 25ksi*0.1265 in^3 = 3,163"#
$M_{nyu} = F_u Z_{yy}$ = 30ksi*0.1265 in^3 = 3,795"#
$M_{ax} = M_{nxy}/n_s \le M_{nxu}/n_u$ = 3,163/1.65 = 1,917"# ≤ 3,795/1.95 = 1,946"#

Horizontal → uniform → L= $(1{,}917/12*10/(50plf))^{1/2}$ = 5.652' = 5'- 7 13/16"
concentrated →L = 1,917*5/(200#) = 47.925" = 3' -11 7/8"

Cantilevered section:
For 200# concentrated load:
L = 1,917"#/(200) = 9.585" = 9 9/16"

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HANDRAILS/GRAB RAILS

Guard applications require a top rail or grab rail. The grab rail shall have adequate strength to support the live load of 200 lb concentrated or 50 plf distributed load based on the applicable requirements for the material type. When installed along stairs a grab rail is required at between 34” and 38” above the stair tread nosing in accordance with IBC Section 1012. The terms handrail and grab rail are synonymous herein.

Stainless Steel Grab Rails:

The stainless steel grab rails are fabricated from 304 or 316 tube. The rail strength was evaluated in accordance with SEI/ASCE 8-02 Specification for the Design of Cold-Formed Stainless Steel Structural Members.

From Section 3.3.1.1 *Nominal section strengt*h 2. *Procedure II - Based on Inelastic Reserve Capacity*:

$M_n = 1.25S_eF_y$

ø = 0.9 for no local distortions allowed at nominal bending strength.

F_{cr} is a function of rail geometry and is the maximum extreme fiber stress at compression element buckling failure, for t >0.5” F_{cr} will exceed F_y.

Brass Grab Rails: No design standard exists for brass therefore design is based on a either bending tension yield or compression buckling whichever controls with 1.6 load factor and 0.9 resistance factor.

Grab Rail Bending Moments

For a typical installation the grab rail will be continuous over a minimum of three simple supports with the ends cantilevered.

The bending moments are conservatively estimated as:

$M_w = wL^2/8$ For uniform load case

$M_c = PL/4$ For concentrated load at mid span load case

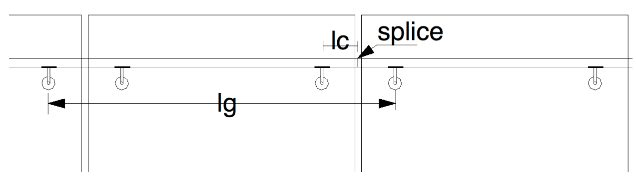
Or for cantilevered ends

$M_{wc} = wL^2/2$ For uniform load case

$M_{cc} = PL$ For concentrated load at end of rail.

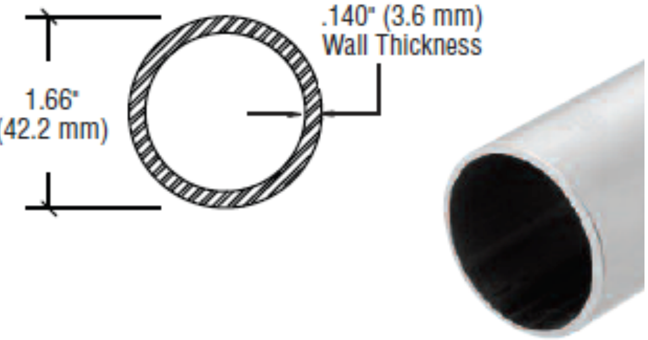
Locate splice within lc of a support.

When mounted to glass lights there shall be a minimum of two brackets per glass light.



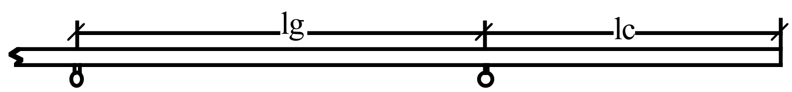
NOTE: The grab rail properties, strengths and maximum spans herein are provided to assist the specifier in the selection of an appropriate grab rail. It is the specifier’s responsibility to determine suitability for a specific application.

GRAB RAIL –1-1/4” SCHEDULE 40 PIPE RAIL
Stainless Steel



Pipe properties:
O.D. = 1.66”
I.D. = 1.38”, t = 0.140”
$A = 0.669 \text{ in}^2$
$I = 0.195 \text{ in}^4$
$S = 0.235 \text{ in}^3$
r = 0.540 in
Stainless steel pipe in accordance with ASTM A312, or A554
Rail Service Loading:
Brushed stainless steel, $F_y \geq 30$ ksi, $F_u \geq 75$ ksi
$øM_n = 0.9*1.25*S*F_y = 0.9*1.25*0.235*30$ ksi
$øM_n$ = 7,931”#
$M_l = øM_n/1.6$ = 7,931/1.6 =4,957”# = 413.1’#

Allowable Span:
Check based on simple span and cantilevered section.



Design Loads: 50 plf distributed load, any direction or 200# concentrated load any direction. Wind load not applicable to pipe rails.

> $M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
> $lg = (8M/w)^{1/2} = [8*(413.1'\#/50plf)]^{1/2}$ = 8.13’ = 8’ -1.5” or
> $lg = (4M/P) = 4*413.1'\#/200\#$ = 8.262’
> Maximum allowable span for supports at both ends = 8’-1.5”-----Controlling span

For cantilevered section

> $M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
> $lc = (2M/w)^{1/2} = (2*413.1'\#/50plf)^{1/2}$ = 4.06’
> $lc = M/P = 413.1'\#/200\#$ = 2.0655’ = 2’ -3/4” ----- Controlling span

Locate splice within lc of a support.

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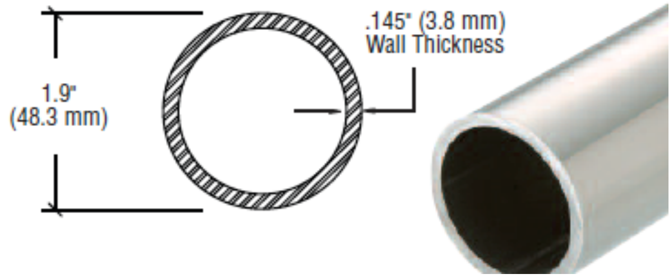
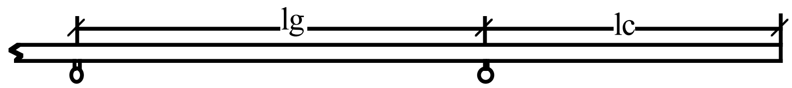
GRAB RAIL –1-1/2" SCHEDULE 40 PIPE RAIL
Stainless Steel

Pipe properties:
O.D. = 1.90"
I.D. = 1.61", t = 0.145"
$A = 0.799\ in^2$
$I = 0.293\ in^4$
$S = 0.309\ in^3$
$Z = 0.421\ in^3$ minimum
r = 0.623 in



Stainless steel pipe in accordance with ASTM A312, or A554
Rail Service Loading:
Brushed stainless steel, $F_y \geq 30$ ksi, $F_u \geq 75$ ksi
$øM_n = 0.9*1.25*S*F_y = 0.9*1.25*0.309*30$ ksi
$øM_n = 10{,}429$"#
$M_l = øM_n/1.6 = 6{,}518$"# = 543.16'#

Allowable Span:
Check based on simple span and cantilevered section.



Design Loads: 50 plf distributed load, any direction or 200# concentrated load any direction. Wind load not applicable to pipe rails.

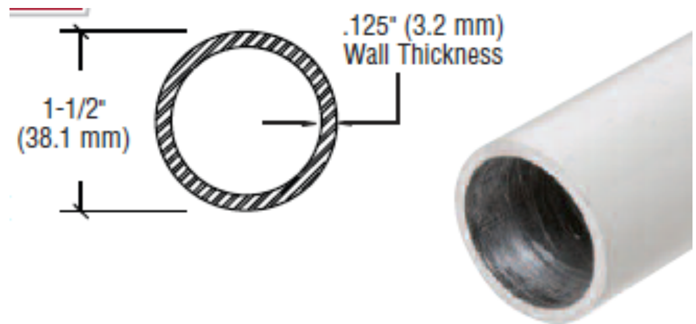
> $M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
> $lg = (8M/w)^{1/2} = [8*(543.16'\#/50plf)]^{1/2} = 9.322'$ = 9'- 3" or
> lg = (4M/P) = 4*543.16'#/200# = 10.863'
> Maximum allowable span for supports at both ends = 9'-3"-----Controlling span

For cantilevered section

> $M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
> lc = (2M/w)1/2 = $(2*543.16'\#/50plf)^{1/2} = 4.787'$ = 4' 9.5" or
> lc = M/P = 543.16'#/200# = 2.716' = 2' -8 1/2" ----- Controlling span

Locate splice within lc of a support.

GRAB RAIL –HRH15 1-1/2” x 1/8” WALL

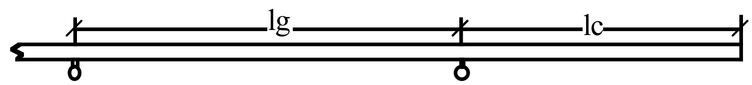


Stainless Steel

Pipe properties:
O.D. = 1.50”
I.D. = 1.25”, t = 0.125”
$A = 0.540\ in^2$
$I = 0.129\ in^4$
$S = 0.172\ in^3$
$Z = 0.236\ in^3$ minimum
$r = 0.488$ in, $J = 0.255\ in^4$

Stainless steel tube in accordance with ASTM A554-10
Rail Service Loading:
Brushed stainless steel, $F_y \geq 45$ ksi, $F_u \geq 91$ ksi (From Mill Certification Tests)
$øM_n = 0.9*1.25*S*F_y = 0.9*1.25*0.172*45$ ksi
$øM_n$ = 8,707.5”#
$M_l = øM_n/1.6$ = 5,442.2”# = 453.52’#

Allowable Span:
Check based on simple span and cantilevered section.



$M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
$lg = (8M/w)^{1/2} = [8*(453.52'\#/50plf)]^{1/2} = 8.518'$ or
$lg = (4M/P) = 4*453.52'\#/200\# = 9.07'$
Maximum allowable span for supports at both ends = 8’-6 3/16”-Controlling span

For cantilevered section
$M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
$lc = (2M/w)1/2 = (2*453.52'\#/50plf)^{1/2} = 4.259'$ or
lc = M/P = 453.52’#/200# = 2.268’ = 2’ -3 3/16” ----- Controlling span

Locate splice within lc of a support.

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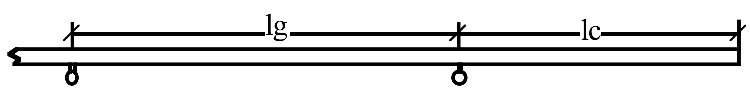
GRAB RAIL –1 1/2" x 0.05" WALL
HR15
Stainless Steel
Pipe properties:
O.D. = 1.5"
I.D. = 1.40", t = 0.05"
$A = 0.2277\ in^2$
$I = 0.0599\ in^4$
$S = 0.0799\ in^3$
r = 0.5129 in

Stainless steel tube in accordance with ASTM A554-10
Rail Service Loading:
Brushed stainless steel, $F_y \geq 45$ ksi, $F_u \geq 91$ ksi
$F_{cr} = \pi^2 k E_o/[12(1-\mu^2)(w/t)^2] = 4*\pi^2 27{,}000ksi/[12(1-0.3^2)(0.70/0.05)^2] = 124.5ksi$
$øM_n = 0.9*1.25*S*F_y = 0.9*1.25*0.0799*45$ ksi
$øM_n = 4{,}045$"#
$M_l = øM_n/1.6 = 2{,}528$"# = 210.67'#

Allowable Span:
Check based on simple span and cantilevered section.



$M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
$lg = (8M/w)^{1/2} = [8*(210.67'\#/50plf)]^{1/2} = 5.806'$ or
$lg = (4M/P) = 4*210.67'\#/200\# = 4.213'$
Maximum allowable span for supports at both ends = 4'-2 9/16"-Controlling span

For cantilevered section
$M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
$lc = (2M/w)1/2 = (2*210.67'\#/50plf)^{1/2} = 2.903'$ or
lc = M/P = 210.67'#/200# = 1.053' = 1' -5/8" ----- Controlling span

Locate splice within lc of a support.

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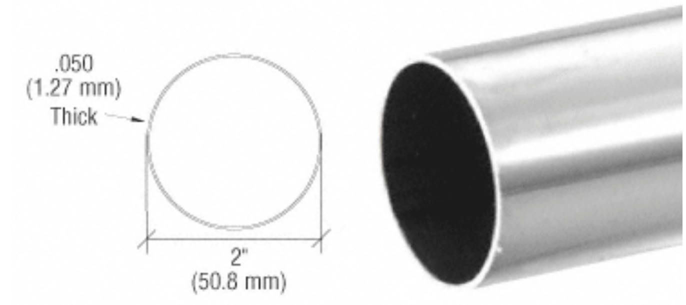
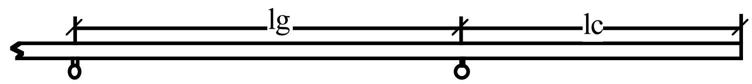
GRAB RAIL –2” x 0.05” WALL
Stainless Steel



Pipe properties:
O.D. = 2.0”
I.D. = 1.90”, t = 0.05”
$A = 0.306\ in^2$
$I = 0.1457\ in^4$
$S = 0.1457\ in^3$
r = 0.6896 in

Stainless steel tube in accordance with ASTM A554-10
Rail Service Loading:
Brushed stainless steel, $F_y \geq 45$ ksi, $F_u \geq 91$ ksi
$F_{cr} = \pi^2 kE_o/[12(1-\mu^2)(w/t)^2] = 4*\pi^2 27{,}000ksi/[12(1-0.3^2)(0.95/0.05)^2] = 67.6ksi$
$øM_n = 0.9*1.25*S*F_y = 0.9*1.25*0.1457*45$ ksi
$øM_n = 7{,}376”\#$
$M_l = øM_n/1.6 = 4{,}610”\# = 384.17’\#$

Allowable Span:
Check based on simple span and cantilevered section.



$M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
$lg = (8M/w)^{1/2} = [8*(384.17’\#/50plf)]^{1/2} = 7.840’$ or
$lg = (4M/P) = 4*384.17’\#/200\# = 7.683’$
Maximum allowable span for supports at both ends = 7’-8 3/16”-Controlling span

For cantilevered section
$M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
$lc = (2M/w)1/2 = (2*384.17’\#/50plf)^{1/2} = 3.920‘$ or
$lc = M/P = 384.17’\#/200\# = 1.921’ = 1’ \text{-}10”$ ----- Controlling span

Locate splice within lc of a support.

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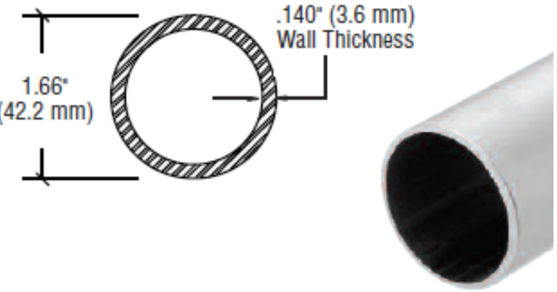
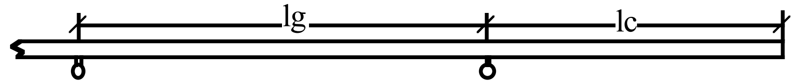
GRAB RAIL –1-1/4" SCHEDULE 40 PIPE RAIL
6063-T6 Aluminum



Pipe properties:
O.D. = 1.66"
I.D. = 1.38", t = 0.140"
$A = 0.669\ in^2$
$I = 0.195\ in^4$
$S = 0.235\ in^3$
r = 0.540 in
Allowable stresses from ADM Table 2-24
$F_{bt} = 18.0$ ksi; $R_b/t = 0.69/0.14 = 4.9 < 35$; $F_{bc} = 18.0$ ksi
$M_a = S*F_y = 0.235*18$ ksi = 4,230"# = 352.5'#

Allowable Span:
Check based on simple span and cantilevered section.



Design Loads: 50 plf distributed load, any direction or 200# concentrated load any direction. Wind load not applicable to pipe rails.

$M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
$lg = (8M/w)^{1/2} = [8*(352.5'\#/50plf)]^{1/2} = 7.510'$ = or
$lg = (4M/P) = 4*352.5'\#/200\# = 7.05'$
Maximum allowable span for supports at both ends = 7'-9/16"--Controlling span

For cantilevered section
$M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
$lc = (2M/w)^{1/2} = (2*352.5'\#/50plf)^{1/2} = 3.755'$
lc = M/P = 352.5'#/200# = 1.7625' = 1' - 9 1/8" ----- Controlling span

Locate splice within lc of a support.

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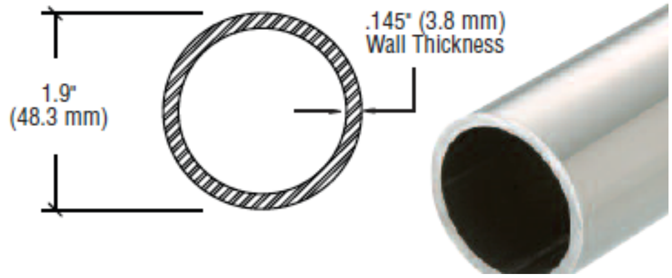
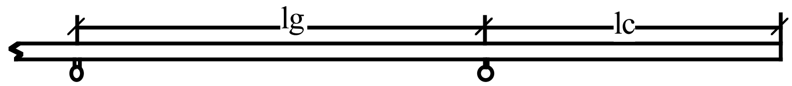
GRAB RAIL –1-1/2" SCHEDULE 40 PIPE RAIL
6063-T6 Aluminum



Pipe properties:
O.D. = 1.90"
I.D. = 1.61", t = 0.145"
$I = 0.293\ in^4$
$S = 0.309\ in^3$
$Z = 0.421\ in^3$ minimum
r = 0.623 in
Allowable stresses from ADM Table 2-24
$F_{bt} = 18.0$ ksi; $R_b/t = 0.805/0.145 = 5.6 < 35$; $F_{bc} = 18.0$ ksi
$M_a = S*F_y = 0.309*18$ ksi = 5,562"# = 463.5'#

Allowable Span:
Check based on simple span and cantilevered section.



Design Loads: 50 plf distributed load, any direction or 200# concentrated load any direction. Wind load not applicable to pipe rails.

$M = w(lg)^2/8$ or $= P(lg)/4$ Solve for lg:
$lg = (8M/w)^{1/2} = [8*(463.5'\#/50plf)]^{1/2} = 8.612'$ or
lg = (4M/P) = 4*463.5#/200# = 9.07'
Maximum allowable span for supports at both ends = 7'-1"-Controlling span

For cantilevered section
$M = w(lc)^2/2$ or $= P(lc)$ Solving for lc
$lc = (2M/w)1/2 = (2*463.5'\#/50plf)^{1/2} = 4.306'$ or
lc = M/P = 463.5'#/200# = 2.318' = 2' -3-1/2" ----- Controlling span

Locate splice within lc of a support.

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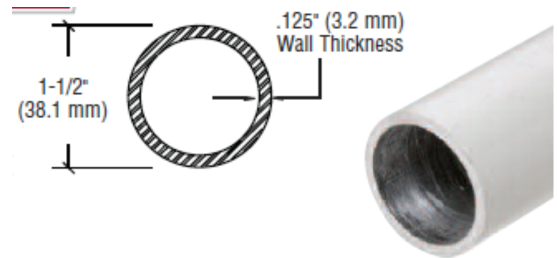
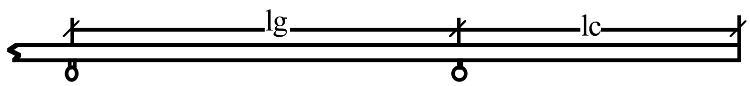
GRAB RAIL –1-1/2" x 1/8" WALL
ARHR15S
6005-T5 Aluminum



Pipe properties:
O.D. = 1.50"
I.D. = 1.25", t = 0.125"
$A = 0.540 \text{ in}^2$
$I = 0.129 \text{ in}^4$
$S = 0.172 \text{ in}^3$
Allowable stresses from ADM Table 2-220
$F_{bt} = 24.0$ ksi; $R_b/t = 0.625/0.125 = 5 < 29$; $F_{bc} = 25.0$ ksi

M_a= $S*F_y$ = 0.172*24 ksi = 4,128"# = 344.0'#

Allowable Span:
Check based on simple span and cantilevered section.



$M = w(lg)^2/8$ or = P(lg)/4 Solve for lg:
$lg = (8M/w)^{1/2} = [8*(344.0'\#/50plf)]^{1/2} = 7.419'$ or
lg = (4M/P) = 4*344.0'#/200# = 6.88'
Maximum allowable span for supports at both ends = 6'-10 9/16"-Controlling span

For cantilevered section
$M = w(lc)^2/2$ or = P(lc) Solving for lc
lc = (2M/w)1/2 = $(2*344'\#/50plf)^{1/2}$ = 3.709' or
lc = M/P = 344'#/200# = 1.72' = 1' -8 5/8" ----- Controlling span

Locate splice within lc of a support.

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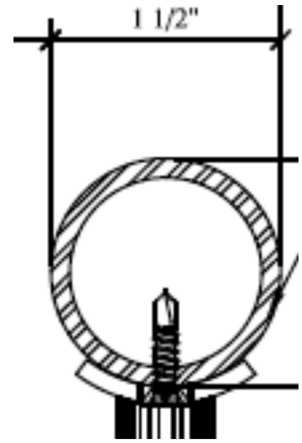
Grab rail attachment to bracket:

(2) #10 screws through 1/8” thick saddle plate into rail tube.

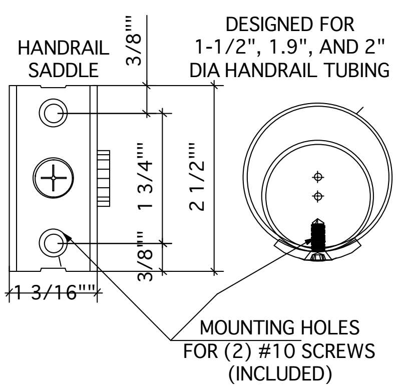


Shear strength of the screws:
$øV_n = 0.65*0.0211in^2*33.7ksi = 462\#$
Bearing on grab rail (1/8” wall minimum)
For 6063 T5 aluminum
$øB_n = 0.75*0.125"*0.164"*30ksi = 461\#$
Allowable shear load:
$V_s = 2*462\#/1.6 = 577\#$

Tension strength of screw into grab rail
$øT_{ns} = 0.75*0.014in^2*60ksi = 630\#$

For screw pullout:
For stainless steel:
$øT_n = øA_{sn}*t_c*0.6*F_{tu}$
$A_{sn} = 0.334\ in^2/in$
$øT_n = 0.75*0.334*0.125*0.6*70ksi = 1315\#$

For aluminum:
$P_{not} = K_sDt_cF_{ty2} = 1.2*0.164*0.128*16ksi = 403\#$
$P_a = nP_{not}/n_s = 2screws*403\#/3 = 269\#$



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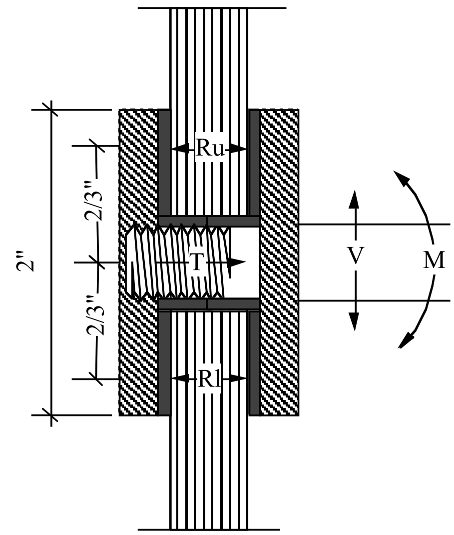
BRACKET MOUNTED TO GLASS

Check strength of bracket bearing on glass

2" round standoff

Determine bearing load on glass:



From $\sum M_{CL} = 0$

$0 = 2/3" R_u + 2/3" R_l - M$

$R_u = -R_l$

$R = M*(3/4)$ or

$M = 4/3R$

From $\sum F_H = 0$

$T = R_u + -R_l = 2 R$

For 3/8" 316 SS bolt

$F_u = 85ksi$

$A_t = 0.0775\ in^2$

$øT_u = øA_t*F_u = 0.75*0.0775in^2*85ksi$

$T_u = 4.94\ k$

$T_{serv} = T_n/\lambda = 4{,}940\#/1.6 = 3{,}088\#$

Determine service moment by substituting T for R and solve for M and V

$M = 4/3R = 2/3T = 2/3*3{,}088 = 2{,}059"\#$

$V = M/3.5" = 588\#$

For glass bearing pressure:

$A = 1.25\ in^2$

$f_B = \frac{2{,}059"\#/1"*4}{1.25in^2} = 6{,}589$ psi max, Spacer strength > 7.5 ksi therefore okay

For brackets with bearing diameter larger than 2" the contact pressure will be less and thus okay by inference. **The Bearing on glass will not control the allowable load for any of the bracket series.**

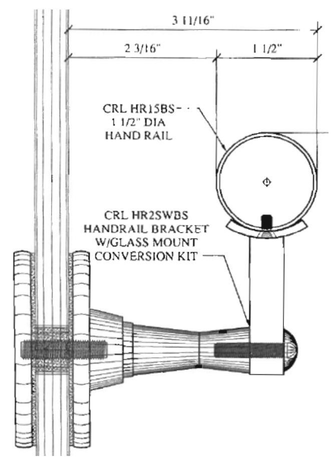
GRAB RAIL BRACKET – HR2S Manhattan Series

MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or
50 plf distributed load

Grab rail bracket –
316 Stainless steel rod
Yield strength of steel:
316 1/4 hard round rod
$F_y = 75$ ksi – tension

Vertical bar
1/2" x 3/4" bar
$Z_{bar} = 0.75*0.5"^2/4 = 0.04687\ in^3$
$M_n = øM_u = 0.9*(0.04687in^3*75ksi)$
$øM_n = 3{,}164"\#$

Allowable load per bracket
$\lambda P = M_n/e$
$\lambda = 1.6$ for live load
$P_s = (3{,}164"\#/1.6)/3" = 659\#$



Horizontal bar
Minimum
$Z_{bar} = 0.5"^3/6 = 0.0208\ in^3$
$M_n = øM_u = 0.9*(0.0208in^3*75ksi)$
$M_n = 1404"\#$
@ Bracket:
$Z_{bar} = 0.75"^3/6 = 0.0703\ in^3$
$M_n = øM_u = 0.9*(0.0703in^3*75ksi)$
$M_n = 4{,}746"\#$
$P_s = (1{,}404"\#/1.6)/1.5" = 585\#$ or
$P_s = (4{,}746"\#/1.6)/3.25" = 913\#$

Vertical bar connection to horizontal bracket:
5/16" screw, ASTM F593-98 CW or stronger; $F_{ut} = 90$ksi
$A_t = 0.0524in^2$
$øP_{nt} = 0.75*90ksi*0.0524in^2 = 3{,}537\#$
Allowable horizontal load on grab rail from $\sum M$:
$øH_n = øP_{nt}*0.375"/3" = 3{,}537\#*0.375"/3" = 442\#$
$H_s = øH_n/1.6 = 442/1.6 = 276\#$

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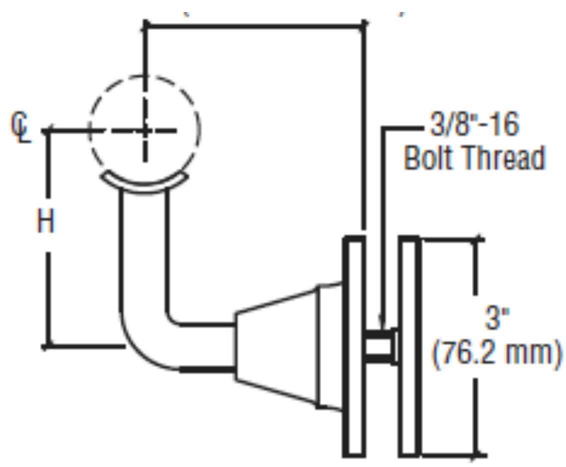
GRAB RAIL BRACKET – HR2D Newport Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load

Grab rail bracket –
1/2" Dia. 316 Stainless steel rod
Yield strength of steel:
316 1/4 hard round rod
F_y = 75 ksi – tension

$Z_{bar} = 0.5"^3/6 = 0.0208$ in^3
$M_n = øM_u = 0.9*(0.0208in^3*75ksi)$
M_n = 1404"#

Allowable load per bracket
$\lambda P = M_n/e$
λ = 1.6 for live load
e = 2.875"
P = 1404"#/(1.6*2.9375") = 299#



For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 299# PER BRACKET.

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GRAB RAIL BRACKET – HR2E Malibu Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load
Grab rail bracket –
3/4" Dia. 316 Stainless steel bar attached to mount with 3/8" threaded rod. Bracket strength will be determined by couple between threaded rod in tension and compression in 3/4" bar edge.

For 3/8" 316 SS rod ASTM F593-98 CW or stronger; F_{ut} = 90ksi

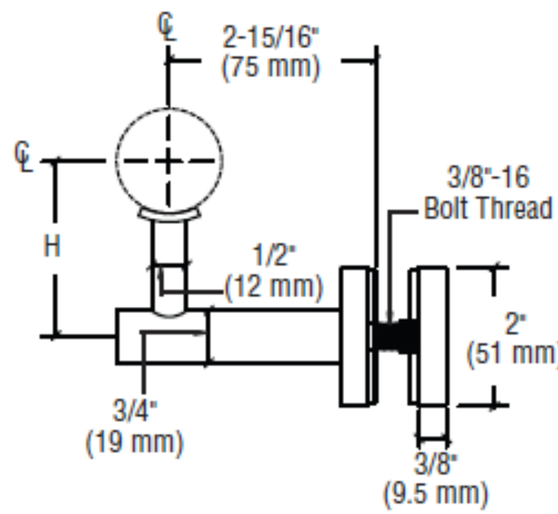
$T_u = A*90\text{ ksi} = 0.0775\text{in}^2*90\text{ksi}$

$T_u = 6{,}975\#$

$T_n = øT_u = 0.75*6{,}975\# = 5{,}231\#$

$T_{serv} = T_n/\lambda = 5{,}231/1.6 = 3{,}270\#$

$\lambda = 1.6$ for live load



Couple moment strength:
$M_s = 3{,}270\#*2/3*3/4" = 1{,}635"\#$
Factored load per bracket
For maximum H = 2.5"
$P = M_s/e$
$e = H+1" = 3.5"$
$P = 1{,}635"\#/(3.5") = 467\#$

Bending in 1/2" vertical bar, hardened SS:
$Z = 0.5^3/6 = 0.02083\text{ in}^3$
$øM_n = 0.02083*45\text{ksi} = 937"\#$
Vertical service load:
$V_S = [(M_n)/\Omega]/H = [937/1.67]/2.25 = 250\#$

For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 250# PER BRACKET.

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GRAB RAIL BRACKET – HR3E Malibu Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load
Grab rail bracket –
3/4" Dia. 316 Stainless steel bar threaded to the mounting plate.

Mounting plates attached through glass with 3/8" threaded rod. Bracket strength will be determined by couple between threaded rod in tension and compression in mounting plates on glass.

For 3/8" 316 SS rod ASTM F593-98 CW or stronger; F_{ut} = 90ksi

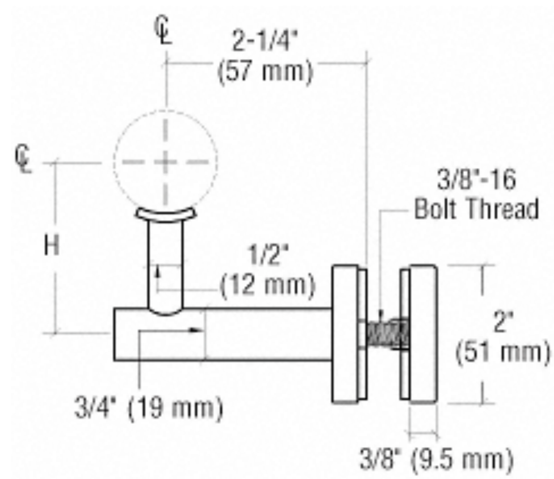
$T_u = A*90$ ksi = 0.0775in^2*90ksi

T_u = 6,975#

$T_n = øT_u$ = 0.75*6,975# = 5,231#

$T_{serv} = T_n/\lambda$ = 5,231/1.6 = 3,270#

λ = 1.6 for live load



Couple moment strength:
M_s = 3,270#*2/3*3/4" = 1,635"#
Factored load per bracket
For maximum H = 2.5"
P = M_s/e
e = H+1" = 3.5"
P = 1,635"#/(3.5") = 467#

Bending in ¾" horizontal bar:
Z = 0.75^3/6 = 0.0703 in^3
$øM_n$ = 0.9*0.0703*30ksi = 1,898"#
Vertical service load:
V_S = [($øM_n$)/1.6]/2.25" = [1898/1.6]/2.25 = 527#

Bending in 1/2" vertical bar, hardened SS:
Z = 0.5^3/6 = 0.02083 in^3
$øM_n$ = 0.02083*45ksi = 937"#
Vertical service load:
V_S = [(M_n)/Ω]/H = [937/1.67]/2.25 = 250#

For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 250# PER BRACKET.

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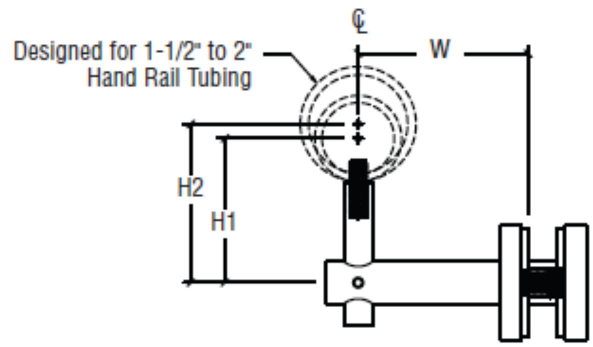
GRAB RAIL BRACKET – HR2F Coastal Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load
Grab rail bracket –
3/4" Dia. 316 Stainless steel bar attached to mount with 3/8" threaded rod. Bracket strength will be determined by couple between threaded rod in tension and compression in 3/4" bar edge.

For 3/8" 316 SS rod ASTM F593-98 CW or stronger;
F_{ut} = 90ksi

$T_u = A*90$ ksi = 0.0775in^2*90ksi
T_u = 6,975#
$T_n = øT_u$ = 0.75*6,975# = 5,231#
$T_{serv} = T_n/\lambda$ = 5,231/1.6 = 3,270#
λ = 1.6 for live load



Couple moment strength:
M_s = 3,270#*2/3*3/4" = 1,635"#
Factored load per bracket
For maximum H = 2.5"
P = M_s/e
e = H+1" = 3.5"
P = 1,635"#/(3.5") = 467#

Bending in 1/2" vertical bar, hardened SS:
Z = 0.5^3/6 = 0.02083 in^3
$øM_n$ = 0.02083*45ksi = 937"#
Vertical service load:
$V_S = [(M_n)/\Omega]/H$ = [937/1.67]/2.25 = 250#

For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 250# PER BRACKET.

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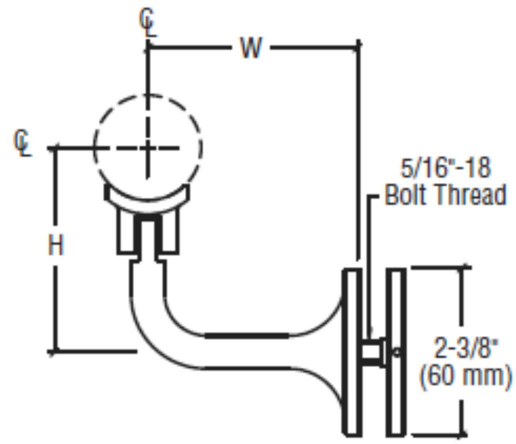
GRAB RAIL BRACKET – HR15G/HR20G La Jolla Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load

Grab rail bracket –
1/2" Dia. 316 Stainless steel rod
Yield strength of steel:
316 1/4 hard round rod
F_y = 75 ksi – tension

$Z_{bar} = 0.5"^3/6 = 0.0208\ in^3$
$M_n = øM_u = 0.9*(0.0208in^3*75ksi)$
M_n = 1404"#

Shear strength of screw connecting saddle to bracket arm:
#8 screw in double shear-
$A_v = 0.014\ in^2$
$V_a = 2*A_v*0.6F_u/3$ (for double shear)
V_a = 2*0.014*0.6*75ksi/3 = 420#

Allowable load per bracket
$\lambda P = M_n/e$
λ = 1.6 for live load
e = 2.875"
P = 1404"#/(1.6*2.9375") = 299#



For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 299# PER BRACKET.

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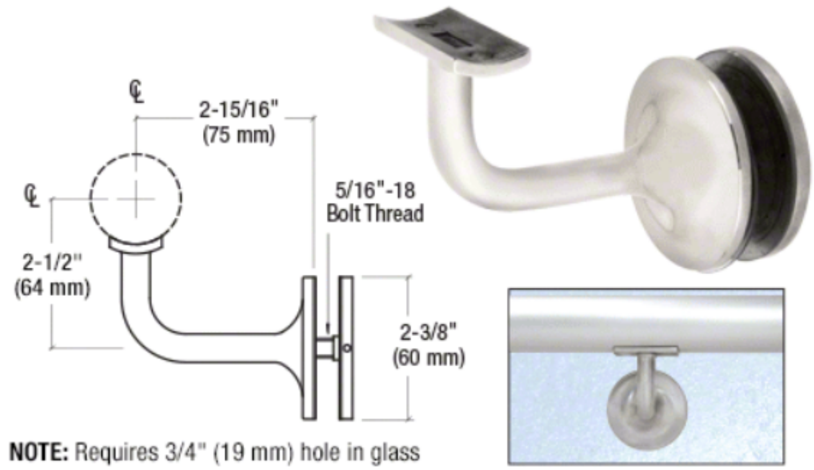
GRAB RAIL BRACKET – HR15G/HR20G Pismo Series
MOUNTED TO 1/2” GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load



Grab rail bracket –
1/2” Dia. 316 Stainless steel rod
Yield strength of steel:
316 1/4 hard round rod
F_y = 75 ksi – tension

$Z_{bar} = 0.5''^3/6 = 0.0208\ in^3$
$M_n = \varnothing M_u =$
$0.9*(0.0208in^3*75ksi)$
$M_n = 1404''\#$

Allowable load per bracket
$\lambda P = M_n/e$
$\lambda = 1.6$ for live load
e = 2.875”
P = 1404”#/(1.6*2.9375”) = 299#

For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 299# PER BRACKET.

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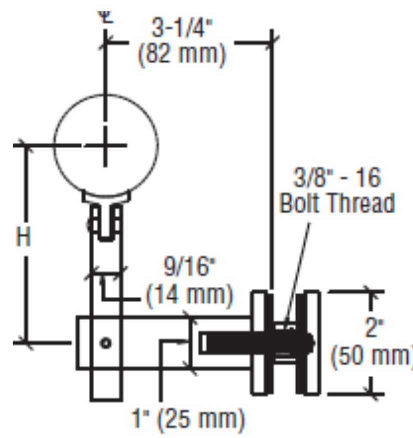
GRAB RAIL BRACKET – HR2J Sunset Series

MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load
Grab rail bracket –
1" Dia. 316 Stainless steel bar attached to mount with 3/8" threaded rod. Bracket strength will be determined by couple between threaded rod in tension and compression in 1" bar edge.

For 3/8" 316 SS rod ASTM F593-98 CW or stronger; F_{ut} = 90ksi

$T_u = A*90\text{ ksi} = 0.0775\text{in}^2*90\text{ksi}$
$T_u = 6{,}975\#$
$T_n = øT_u = 0.75*6{,}975\# = 5{,}231\#$
$T_{serv} = T_n/\lambda = 5{,}231/1.6 = 3{,}270\#$
$\lambda = 1.6$ for live load



Couple moment strength:
$M_s = 3{,}270\#*2/3*1" = 2{,}180"\#$
Factored load per bracket
$P = M_s/e$
$e = 3.5"$
$P = 2{,}180"\#/(3.5") = 623\#$

Bending in 1/2" vertical bar, hardened SS:
$Z = 0.5^3/6 = 0.02083\text{ in}^3$
$øM_n = 0.02083*45\text{ksi} = 937"\#$
Vertical service load:
$V_S = [(M_n)/\Omega]/H = [937/1.67]/2.25 = 250\#$

For strength of bracket on glass refer to HR2S calculations

CONTROLLING ALLOWABLE LOAD IS 250# PER BRACKET.

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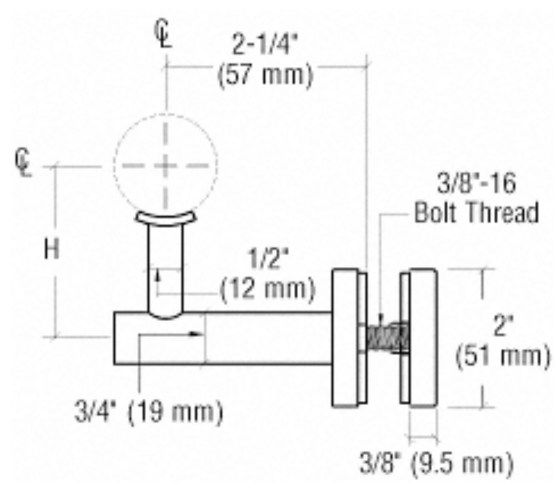
GRAB RAIL BRACKET – HR5E Shore Series
MOUNTED TO 1/2" GLASS PANEL
Loading 200 lb concentrated load or 50 plf distributed load
Grab rail bracket –
3/4" square 316 Stainless steel bar pressed to the mounting plate.

Mounting plates attached through glass with 3/8" threaded rod. Bracket strength will be determined by couple between threaded rod in tension and compression in mounting plates on glass.

For 3/8" 316 SS rod ASTM F593-98 CW or stronger;
F_{ut} = 90ksi

T_u = A*90 ksi = 0.0775in^2*90ksi
T_u = 6,975#
T_n = øT_u = 0.75*6,975# = 5,231#
T_{serv} = T_n/λ = 5,231/1.6 = 3,270#
λ = 1.6 for live load



Couple moment strength:
M_s = 3,270#*2/3*3/4" = 1,635"#
Factored load per bracket
For maximum H = 2.5"
P = M_s/e
e = H+1" = 3.5"
P = 1,635"#/(3.5") = 467#

Bending in ¾" horizontal bar:
Z = 0.75^3/4 = 0.1055 in^3
øM_n = 0.9*0.1055*30ksi = 2,848"#
Vertical service load:
V_S = [(øM_n)/1.6]/2.25" = [2,848/1.6]/2.25 = 791#

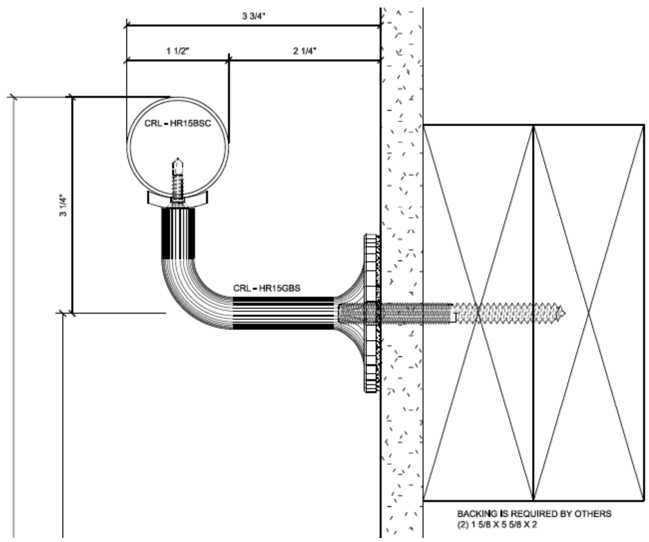
Bending in 1/2" vertical bar, hardened SS:
Z = 0.5^3/4 = 0.03125 in^3
øM_n = 0.03125*45ksi = 1,406"#
Vertical service load:
V_S = [(M_n)/Ω]/H = [1,406/1.67]/2.25 = 374#

For strength of bracket on glass refer to HR2S calculations
CONTROLLING ALLOWABLE LOAD IS 250# PER BRACKET.

Grab Rail Attachment to Walls:

Bracket is secured to solid wood blocking using 3/8” closet screw, uses same thread as lag screw so withdrawal and shear capacity is the same as for 3/8” lag screw.

Withdrawal strength for screw into HF or denser wood ($G \geq 0.43$)
From NDS Table 11.2A:
W = 243#/in
$W' = W*C_d*e$ = 243#/”*1.33*2”
W’ = 646#



Moment strength of connection:
M_a = 646#*1.25” = 807.5”#

Allowable load on grab rail:
$\sum M = 0$ = 807.5”#-P*3”
P = 807.5/3 = 269#
horizontal or vertical load:

For shear (NDS Table 11K)
Z = 160#
$Z' = Z*C_d$ = 160*1.33 = 213#

Shear strength will control for vertical loads:
maximum spacing:
s = 213#/50plf = 4.26’

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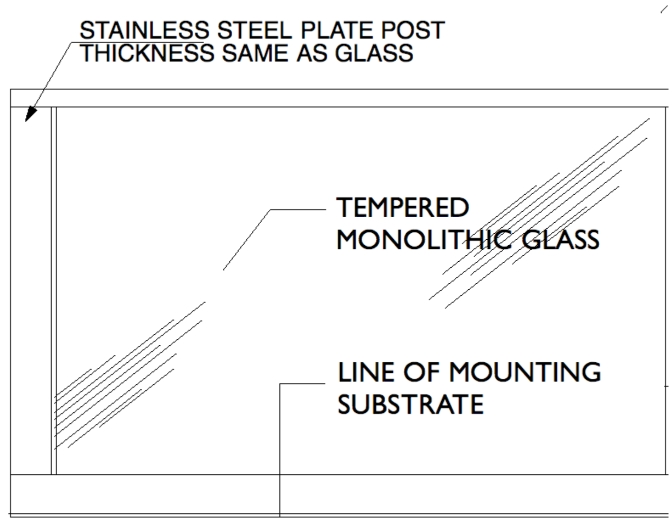
END PLATE POST

Stainless steel end post for insertion in base shoe to support the top rail where end support is required.



Post strength must be adequate to support 200# concentrated load (334# ultimate load strength).

M_u = 334#*42" = 14,028"#

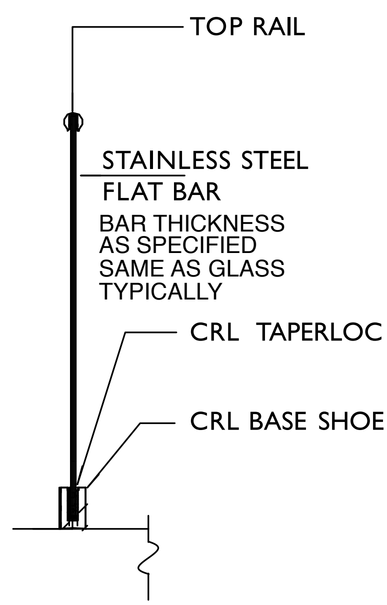
For stainless steel plate, 304 or 316, annealed condition:

F_y = 30 ksi, F_u = 70 ksi

ø = 1.0 weak axis bending

$M_n = 1.25*F_y*b*t^2/6 \geq 14{,}028$"#

t = glass nominal thickness and b = post width



Solving for b:

$b = 14{,}028*6/(1.25*30{,}000*t^2) = 2.245/t^2$

For ½" glass:

$b = 2.245/0.5^2 = 9$"

For ⅝" glass

$b = 2.245/0.625^2 = 5.75$"

For ¾" glass

$b = 2.245/0.75^2 = 4$"

Maximum thickness that can be used in base shoe:

B5 shoes; t = 1":

$b = 2.245/1^2$ = 2-¼"

B6 shoes; t = 1 1/8" :

$b = 2.245/1.125^2$ = 1-13/16"

B7 shoes; t = 1.25" :

$b = 2.245/1.25^2$ = 1-7/16"

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