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18 OCT 2010

Architectural Railing Division
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SUBJ: GLASS CURTAIN WALL
POINT SUPPORTED WITH CRL SPIDER FITTINGS
TEST WALL PROTOTYPE

This testing was performed on a glass curtain wall supported by CRL FMH series spider fittings with half mounted to glass buttress fins and half to tubular steel posts. The purpose of the test wall prototype was to test the components in a completed typical assembly to evaluate system strength in accordance with ASTM E330 - 02 *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*. This test is to determine the structural performance of the glass and spider fitting system under static air pressure to simulate wind loading. In addition the wall was tested for lateral drift in accordance with AAMA 501.4-09 and AAMA 501.6-09 to verify the allowable horizontal displacement for seismic performance to show compliance with ASCE/SEI 7-05 section 13.5.9.

200 pound concentrated load (1 sf) any direction, any location on the wall
Live load 5 psf uniform load perpendicular glass, full area.
Wind Load (28.2 psf for test set up) (110 mph 3 sec gust exposure B)
Seismic loads – drift minimum of 0.0125* story height = 3" for test wall
tested drift = 4.5" for test specimen

For these conditions the system meets all applicable requirements of the 2006 International Building Code as adopted in the 2007 California Building Code. The wall strength and performance was verified by testing prepared by Smith-Emery Laboratories report number L-10-1477 dated August 27, 2010.

EXP 12/31/2011
Signed 10/18/2010

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Test protocol is based on AAMA 501-05:
Tests were performed in the order listed –

1.0 Preload the test specimen (ASTM E 330) at 50% of the specified positive design wind pressure (28.2 psf (194.4 kPa) full design pressure, 14.1 psf (97.2 kPa) at 50% load.)

2.0 The test for air leakage (ASTM E283) shall be conducted at an air pressure difference of 5 psf (34.47 kPa). The maximum allowable rate of air leakage must not exceed 0.06 cfm/ft^2 (0.3 L/sm^2).

3.0 The test for static water penetration (ASTM E331) shall be conducted at an air pressure difference of 6.9 psf (47.57 kPa). There shall be no water leakage as defined by AAMA 501.1 paragraph 5.5.

4.0 The test for water penetration under dynamic air pressure (AAMA 501.1) shall be conducted with a wind velocity equivalent to a static air pressure of 6.9 psf (47.57 kPa). There shall be no water leakage as defined by AAMA 501.1 paragraph 5.5 at this dynamic wind velocity.

5.0 Interstory displacement test shall be performed per AAMA 501.4 at 100% of the specified design displacement, 3.0". Repeat the air leakage (ASTM E 283) and static water resistance (ASTM E331) after the interstory displacement test.

6.0 The test for structural performance (ASTM E330) shall be conducted at the specified positive and negative design wind pressures, 20.0 psf (137.9 kPa). Deflection shall not exceed L/175 = 1.37".

7.0 Repeat the test for static water resistance (ASTM E331).

8.0 Repeat the test for structural performance (ASTM E330) at 150% of positive and negative design pressures, 30 psf (206.8 kPa). At this load no glass breakage or permanent damage to panels, fasteners, or anchors, shall occur, and permanent deformation to wall framing members shall not exceed 0.2% of their clear spans.

9.0 Repeat lateral displacement test (AAMA 501.4) to a peak displacement of 4.5"

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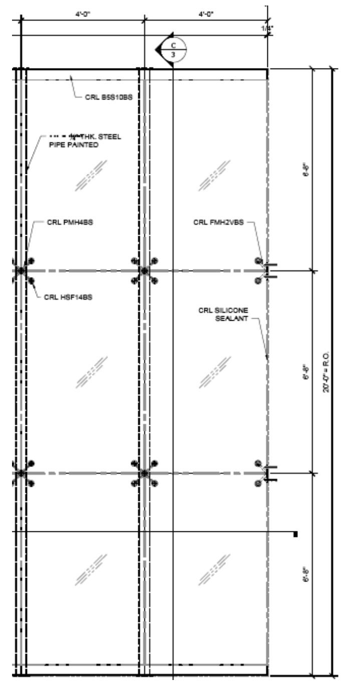
SEISMIC LOADS:

Seismic loads typically are much less than wind loads
$F_P = [(0.4*a_P S_{DS} I_P)/R_P][1+2z/h)$. ASCE/SEI 7-05 13.3.1



The primary seismic concern is the curtain wall's capacity to accommodate the story drift of the building frame as required in ASCE/SEI 7-05 13.5.9.
In accordance with ASCE/SEI 7-05 12.12 and Table 12.12-1 the allowable drift is dependent on the construction type and occupancy category.
The highest allowable drift is:
$\Delta_a = 0.025h_{xx}$
Thus the maximum drift capacity of the curtain wall (I = 1.0) is:
$\Delta_a \geq I*1.25*0.025h_{xx} = 0.03125h_{xx}$ maximum required
For the 20' height $\Delta_a = 0.03125*20'*12"/ft = 7.5"$
$\Delta_a \geq I*1.25*0.010h_{xx} = 0.0125h_{xx}$ minimum required
For the 20' height $\Delta_a = 0.0125*20'*12"/ft = 3"$
Maximum tested = 4.5" = $0.01875h_{xx}$

GLASS STRENGTH

All glass was fully tempered glass conforming to the specifications of ANSI Z97.1, ASTM C 1048-97b and CPSC 16 CFR 1201. The minimum Modulus of Rupture for the glass F_r = 24 ksi, typical acceptable minimum safety factor is 2.5 for curtain walls.

Allowable glass bending stress: 24,000/2.5 = 9,600 psi. – Tension stress calculated.

Allowable compression stress = 24,000psi/4 = 9,600 psi.

Bending strength of glass for the given thickness:

$$S = \frac{12"*(t)^2}{6} = 2*(t)^2 \text{ in}^3/\text{ft}$$

For 1/2" glass, t_{min} = 0.469" $S = 2*(0.469)^2 = 0.44 \text{ in}^3/\text{ft}$

$M_{allowable} = 9{,}600\text{psi}*0.44 \text{ in}^3/\text{ft} = 4{,}224\#"/\text{ft} = 352\#'/\text{ft}$

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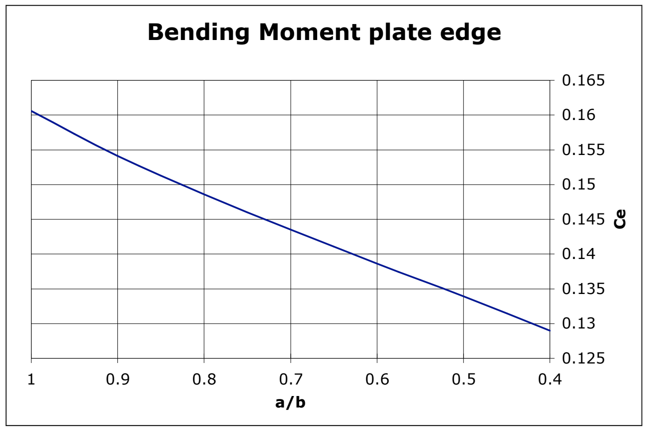
CHECK GLASS LOADS

Check glass bending in typical panel

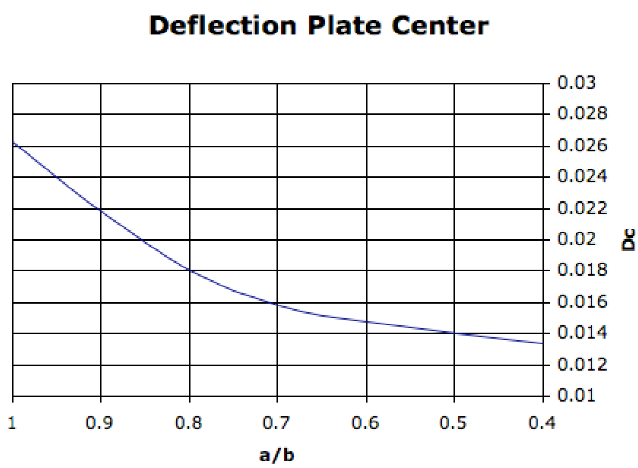
For middle lights each is supported near corners by spider fitting point supports. From flat plate theory the stress distribution may be conservatively modeled by calculating at the center and plate edge (mid span):
At edge of plate (always highest stress point):
$M_w = C_e wb^2$
$M_p = 2C_e Pb$ load at center of plate edge
$\alpha = a/b = 48"/80" = 0.6$
$C_e = 0.137$



determine maximum allowable wind load based on glass strength:
$w = 352'\#/(0.137*6.67'^2) = 57.7$ psf

Check deflection limit:
$\Delta \leq l/60 = 80"/60 = 1.333"$

$\Delta = D_c wb^4/(Et^3)$
$D_c = 0.0147$ (from chart for a/b = 0.6)
w in psi
b = in inches
solving for w:
$\Delta*/(Et^3)/[\ 12D_c b^4] = w$
$w = 1.33(10.4\text{x}10^6*0.5^3)/[12*0.0147*80^4]$
$w = 0.239$ psi = 34.5 psf



Limit wind load to 34.5 psf.
Maximum tested wind load was 30.0 psf.

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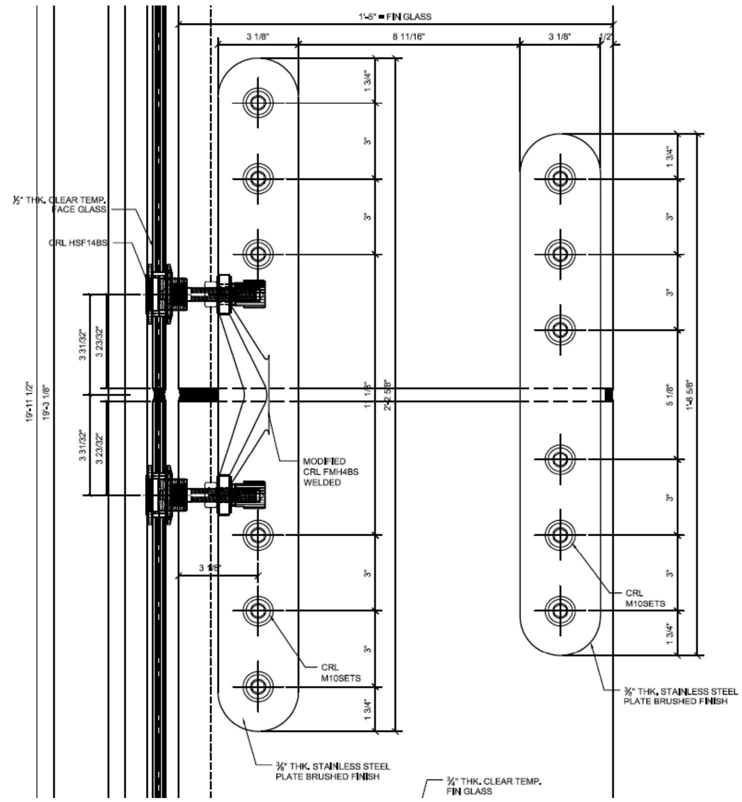
GLASS BUTTRESS FINS:

Determine loads on fins

Each glass light will distribute dead load to the top fitting and horizontal load equally to all fittings:

D = (4'*6.67')*6.5psf/2

D = 86.7#



For horizontal loads:

H = (4*6.67')*34.5psf/4

H = 230#

Moments on glass fin:

Check as fixed top and bottom and moment splices at joints

M_{end} = 4*230*6.667'/2 = 3,067'#

M_{splice} = 1/2M_{end} = 3,067/2 = 1,534'#

Top connection brackets:

Moment connection formed by couple acting between fin bolts to angles.

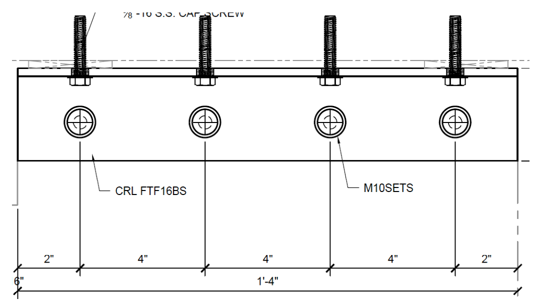
Determine reactions on the bolts using the $\sum M = 0$:

For $\sum M$ about the corner bolt:

0 = 3,067'# - 12"*B-8"^{2}/12"*B-4"^{2}/12"*B

Where B = reaction on end bolt; solving for B:

B = 3,067'#*12/(18.667) = 1,972#



Uses one row of bolts

Check shear strength of 5/16" bolt through glass to base shoe.

Bolt shear strength (double shear)

A_v = 0.0681 in^2

ϕV_n = 2*0.65*40.5ksi*0.0681 in^2 = 3,585#

V_s = 3,585/1.6 = 2,241# > 1,972# will not control load

Check glass shear at bolts:

Holes are 1.5" from bottom

f_V = 1,972#/(1.5"*0.75") = 1,753psi < 3,000 psi okay

Check glass bearing at bolts: 3/4" diameter holes

f_B = 1,972#/(0.75"*0.75") = 3,505 psi < 6,000 psi:

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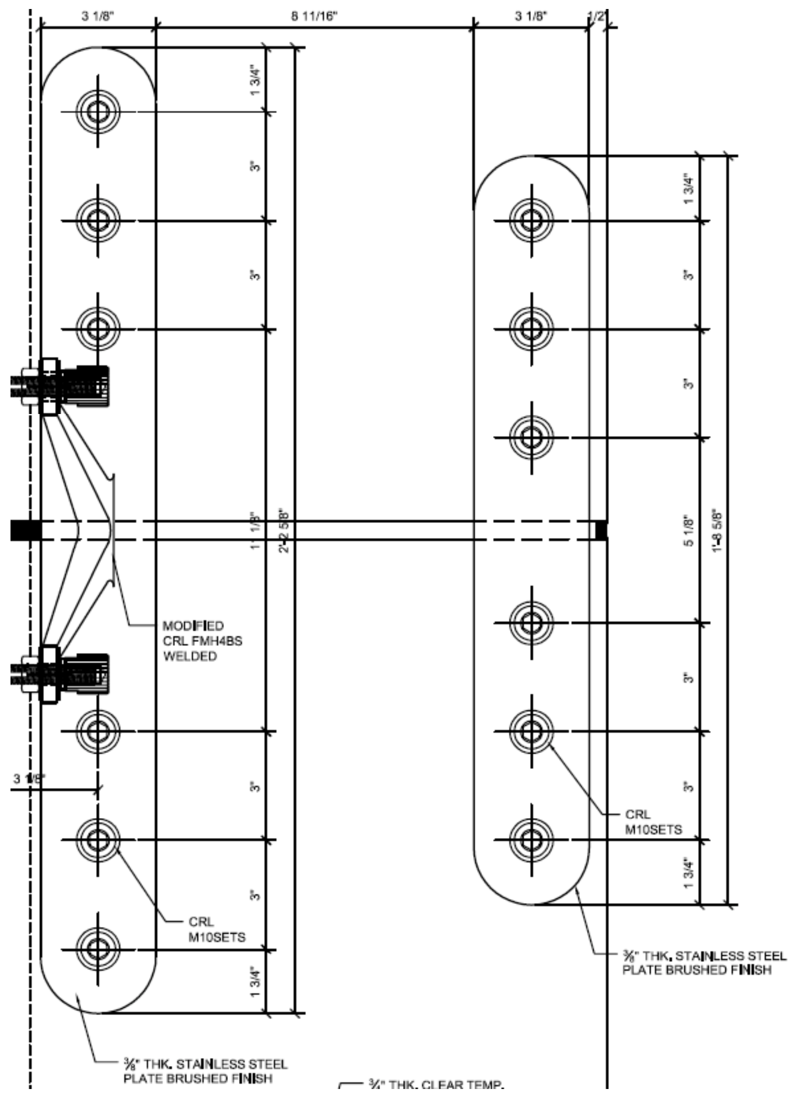
Glass bearing and shear strength is adequate.



Center Splice
Moment creates two stress modes in the splice plates:
Tension/compression tie,
Shear transfer.

For tension compression loads:
From $\sum$M about center of fin:
T = C = (1,534'#*12)/11.75
T = C = 1,567#
Shear at each bolt:
V = 1,567#/3 = 522#

For moment from shear transfer:
1/2 of shear load to each side:
v = 230#/2 = 115#
moment about center hole-
M = 115#*17.125 = 1,969"#
For $\sum$M about the center bolt determine reaction on other two bolts -
0 = 1,969"# - 3"*B-3"*B
Where B = reaction on end bolt; solving for B:
B = 1,969"#*6 = 328#

Resultant reaction on bolts:
$V_B = \sqrt{(522\#^2+328\#^2)} = 617\#$

Check glass shear at bolts:
Holes are 2" from edge
f_V = 617#/(2"*0.75") = 411psi < 3,000 psi okay

Check glass bearing at bolts: 3/4" diameter holes
f_B = 617#/(0.75"*0.75") = 1,097 psi < 6,000 psi:

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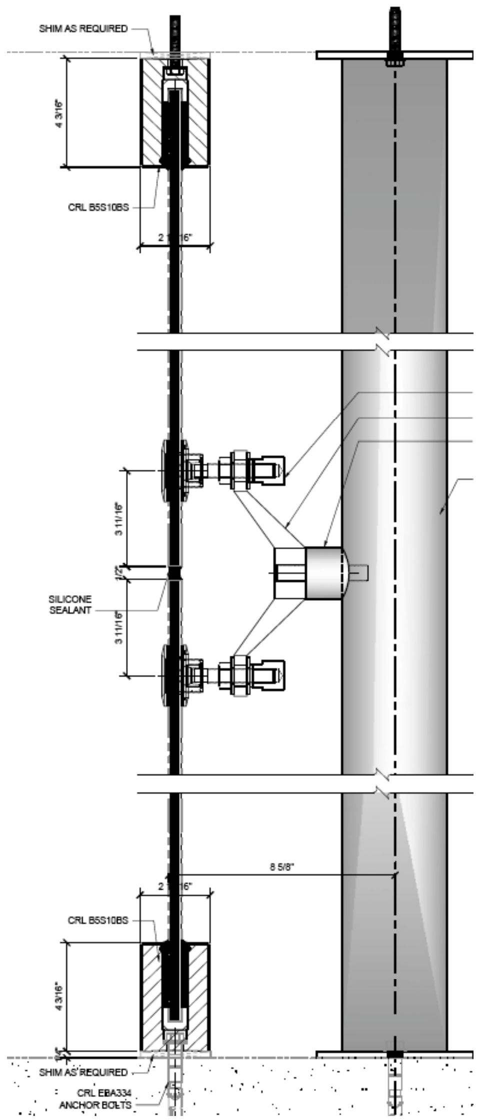
STEEL PIPE SUPPORT:

For spider fittings mounted to steel pipe support:
The pipe stiffness is much less than the stiffness of the glass fin so the pipe will behave as an elastic (spring) support. This will result in the top and bottom lights contributing only 3/8 of their height to the spider fittings attached to the posts and 5/8 tributary to the rigid base shoes at the top and bottom.



Dead load of bottom light will be carried by base shoe
Load to spider fitting:
2*(230#+173#) = 806# each

Pipe size = 4” Schedule 40 A500 Grade B
OD = 4.500”
t = 0.237”
$I = 7.23\ in^4$
$Z = (4.5^3-4.026^3)/6 = 4.311\ in^3$
F_y = 46 ksi (ASTM A312)
$øM_n$ = 0.9*4.311*46ksi = 178.5 k” =14,875’#

Maximum moment based on top and bottom pinned and continuous pipe:
M_u = 1.6*806#*6.667’+1.2*86.7*2*0.69’
M_u = 8,741’#

Check pipe deflection from this load:
$\Delta = Pa(3L^2-4a^2)/(24EI)$
$\Delta = 806\#*80''(3*240^2-4*80^2)/(24*29x10^6*7.23)$ = 1.677 in
L/Δ = 240/1.677” = 143
recommended maximum deflection is L/175.
Based on recommended deflection of L/175:
Δ_r = 240/175 = 1.371”
Allowable wind pressure based on the recommended deflection limit:
w = (1.371/1.677)*34.5 = 28.2 psf

For high wind pressures up to 34.5 psf pipe size may be increased to 5” schedule 40, 4” schedule 80, HSS 4x4x5/16, or HSS 4.5x4.5x3/16.

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CURTAINWALL DEFLECTIONS

Based on a deflection limit of L/175 in accordance with AAMA TIR-A11-04 and IBC 2403.3 the maximum allowable deflection is:
$\Delta = 240/175 = 1.371"$
Since this current wall design is unframed AAMA TIR-A11-04 and IBC 2403.3 is not strictly applicable since this applies to the frame around glazing. In this current wall the glazing is point supported is unframed.

Based on IBC Section 1604 there is no clear limit on the allowable deflections for a curtain wall. The closest limit from IBC Table 1604.3 is for Exterior walls with flexible finishes with the deflection limit of l/120 for wind loads.

In accordance with IBC Table 1604.3 footnote f "The wind load is permitted to be taken as 0.7 times the "component and cladding" loads for the purpose of determine deflection limits herein.

Based on the deflection criteria in the code and curtainwall standards the appropriate deflection limit is determined to be $\Delta \leq L/175$ at 70% of the design wind load. This is based on the industry standard curtainwall deflection criteria and the code defined load for checking the deflection limit.

TESTED DEFLECTIONS:

Based on the deflections in the test report prepared by Smith-Emery Laboratories report number L-10-1477 dated August 27, 2010.

At 20 psf wind load (70% of 28.2 psf target design wind load).
Glass buttress fins with tie bar splice:
Deflections measured at spider fittings – 1/3 points on wall height:
at 6.67': $\Delta = 1.127"$ at 13.33' : $\Delta = 0.924"$ For Positive pressure.
at 6.67': $\Delta = 1.053"$ at 13.33' : $\Delta = 1.293"$ For Negative pressure.

Steel pipe, 4" Schedule 40 A500 Grade B :
Deflections measured at spider fittings – 1/3 points on wall height:
at 6.67': $\Delta = 0.901"$ at 13.33' : $\Delta = 0.784"$ For Positive pressure.
at 6.67': $\Delta = 0.925"$ at 13.33' : $\Delta = 1.060"$ For Negative pressure.

Testing demonstrates that the glass buttress fin and the pipe support have adequate strength and stiffness to limit deflections below the allowable.

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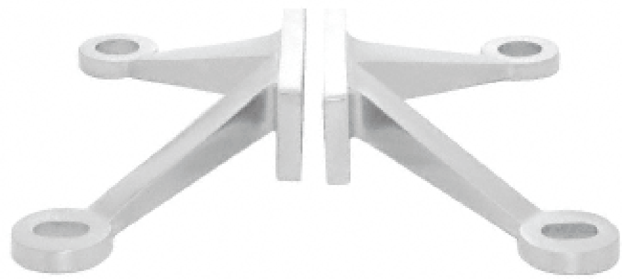
SPIDER FITTINGS

FMH4



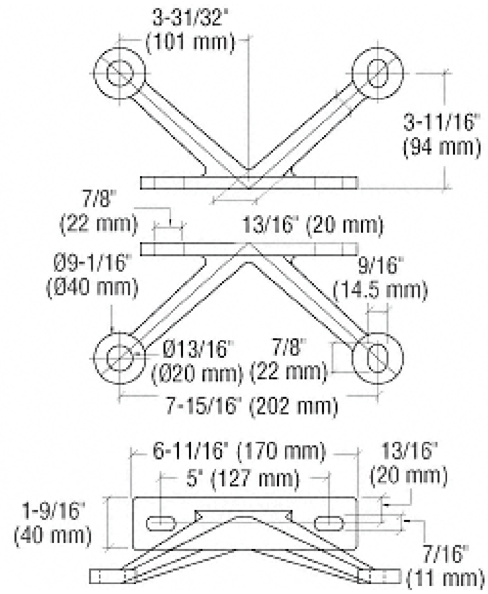
Determine standoff strength:

$M = P*2.5''$ where $P = V$ or H

Shear on screw $= Z = H$ or V

$C = T = M/(1.75''/2) = P*(2.5''/0.875'')$

$= 2.86P$



Strength of bolts into support plate

screw 316 Condition CW ASTM F593-86a

size 10 mm

$A_t = 57.99mm^2 = 0.0899in^2$

$A_v = 78.54mm^2 = 0.1217in^2$

$øV_n = 0.65*0.1217in^2*42.8\ ksi = 3{,}386\#$

$øT_n = 0.75*0.0899in^2*71.2\ ksi = 4{,}800\#$

Moment resistance of connection:

For vertical parallel loading

$øM_n = 3{,}386\#*(5'') = 16{,}930\#''$

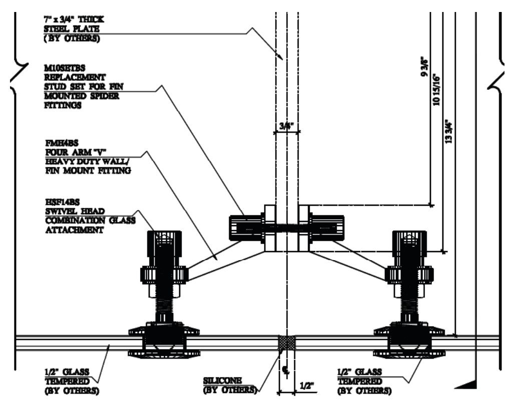
$M_s = øM_n/1.6 = 16{,}930/1.6 = 10{,}581\#''$

$V_s = øV_n/1.6 = 2*3{,}386/1.6 = 4{,}232.5\#$

Determine allowable horizontal load:

$V = \sqrt{[4{,}232.5^2-(10{,}581\#''/4'')^2]} = 3{,}304\#$

$3{,}304 < 2*(10{,}581/4)=5{,}290\#$



For Horizontal load:

$øM_n = 4{,}800\#*(1.5625''/2) = 3{,}750\#''$

$M_s = øM_n/1.6 = 3{,}750/1.6 = 2{,}344\#''$

$H_s = 2{,}344\#''/3.6875 = 636\#$

$V_s = øV_n/1.6 = 2*3{,}386/1.6 = 4{,}232.5\#$

Determine service load of standoff from interaction equation where:

$(M/M_s)^2+(Z/Z_s)^2 \leq 1.0$

$P = \sqrt{(H^2+V^2)} = Z$ and $M = 3.6875''*P$

substituting using P:

$(3.6875P/2{,}344)^2 + (P/4{,}232.5)^2 = 1$ then solving for P

$P = \{1/[(3.6875/2{,}344)^2 + 1/4{,}232.5^2]\}^{1/2}$

$P = 629\# =$ Maximum horizontal load

Vertical (dead load) will not reduce the allowable horizontal load until it is over:

$0.2*2*3{,}386 = 1{,}354\#$

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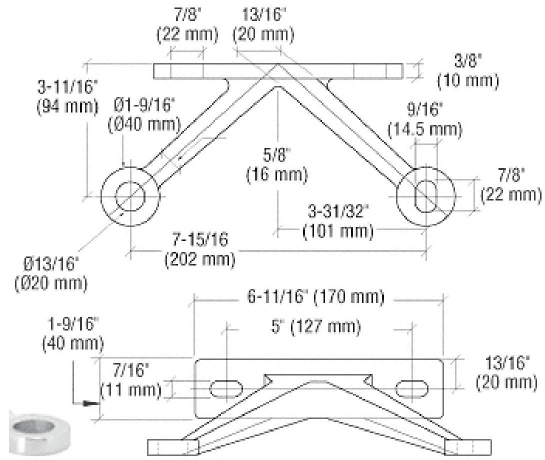
This greatly exceeds the maximum light weight because of other limitations.

Check strength of spider fitting arm
horizontal bending strength
@ junction b= 5/8", h = 7/8", a = 4.399"
$Z_{xx} = 5/8*0.875^2/4 = 0.1196\ in^3$
$M_s = øM_n/1.6 = 0.9*0.1196*45/1.6 = 3{,}028\#"$
$H_s = 3{,}028\#"/4.399" = 688\#$

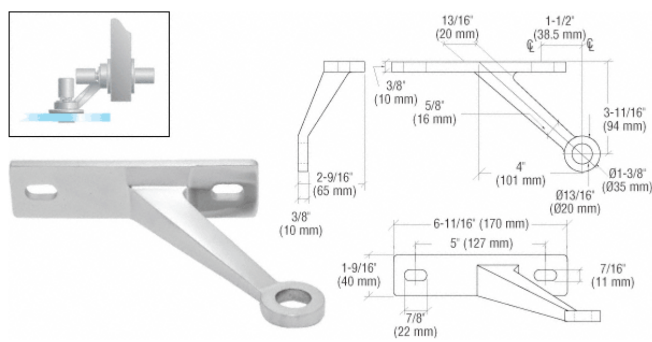


Allowable horizontal load on glass lite
each corner
H = 688#*4 fittings = 2,752#

For vertical loads:
$Z_{yy} = 0.875*0.884^2/4 = 0.1709\ in^3$
$M_s = øM_n/1.6 = 0.9*0.1709*45/1.2 = 5{,}769\#"$
$H_s = 5{,}769\#"/3.3125" = 1{,}742\# > 1{,}354\#$
Vertical/dead load will not control loads on fittings

Fitting variations:
FMH2
Fitting is identical to the FMH4 except only installed on one side of the support fin.
Same allowable load per arm.
Same allowable load on fitting.

FMH1
single arm allowable vertical load
is 167# per fitting.
Check eccentricity in fin plate:
$Z = 1.5625*0.375^2/4$
$Z = 0.0549 in^3$
$øM_n = 0.9*0.0549*45ksi = 2{,}225\#"$
$V_s = 2{,}225\#"/(1.2*3.3125) = 560\#$

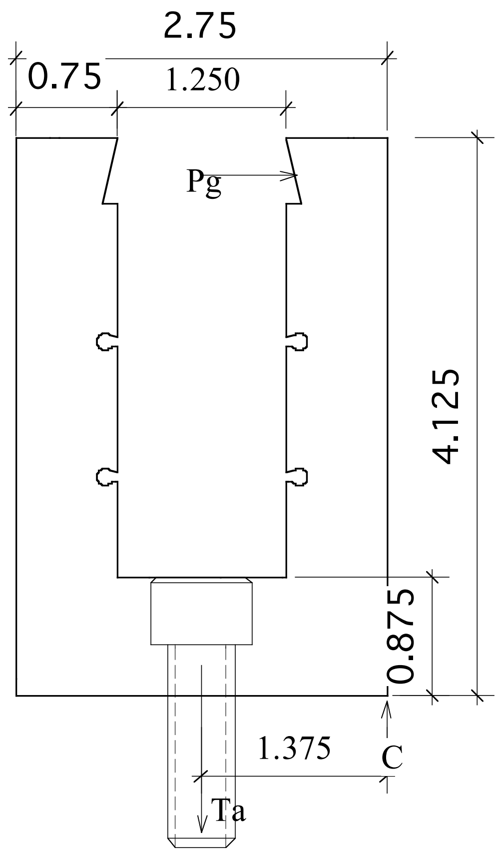


Bending in fin plate will limit
vertical/dead load to 560# maximum.

Torsional strength:
Plate size = 3/8"x1 9/16", b/c= 1.5625/0.375 = 4.17, α= 0.279
$T_n = \tau_y*(\alpha bc^3) = 45ksi*(0.279*1.5625*0.375^2) = 2{,}763\#"$

$øM_{nt} = 0.85*2*2{,}763 = 4{,}697\#"$
$H_n = øM_{nt}/a_t = 4{,}697\#"/3.6875" = 1{,}274\#$

2 3/4" X 4 1/8" GLASS BALUSTRADE BASE SHOE



6063-T6 Aluminum extrusion

Fully tempered glass glazed in place, either weight glazing cement or GlassWedges®.

Shoe strength – Vertical legs:
Glass reaction by bearing on legs to form couple. Allowable moment on legs:
$Ma = S_1\ Fy$
Fy = 20 ksi (ADM Table 2-24, Sec 3.4.4)
$S_1 = 12\text{"}*0.5\text{"}^2*/6 = 0.5\ in^3/ft$
$Ma = 20\ ksi*0.5\ in^3/ft = 10{,}000\text{"}\#/ft$

Leg shear strength @ groove
tmin = 0.343"
Fv= 8.5 ksi (ADM Table 2-24, Sec 3.4.20
V all = 0.343"*12"/ft*8.5 ksi = 35 k/ft

Imposed moment from design load:
M = 76'#/ft
Solve for anchor strength:
From ∑M about edge of base shoe = 0 and solve for bolt tension:
T = 76'#*12"/1.375" = 663# per foot

Anchor bolts: 3/8" Powers wedge-bolt+ into concrete deck with 3" embedment:
Strength based on ESR-2526 will exceed 663# per bolt.

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Anchor strength from Powers Fasteners catalog for the specified anchors in accordance with ESR-2526

Allowable Load Capacities for Wedge-Bolt and Wedge-Bolt OT installed in Normal-Weight Concrete at Critical Spacing and Edge Distances[1,2,3,4,5]

Anchor Diameter *d* in. (mm)	Minimum Embedment Depth h_v in. (mm)	Minimum Concrete Compressive Strength (f'_c)					
		2,000 psi (13.8 MPa)		**4,000 psi** (27.6 MPa)		**6,000 psi** (41.4 MPa)	
		Tension lbs. (kN)	Shear lbs. (kN)	Tension lbs. (kN)	Shear lbs. (kN)	Tension lbs. (kN)	Shear lbs. (kN)
1/4 (6.4)	1 (25.4)	180 (0.8)	260 (1.2)	335 (1.5)	520 (2.3)	415 (1.9)	600 (2.7)
	1 1/2 (38.1)	360 (1.6)	550 (2.5)	535 (2.4)	550 (2.5)	620 (2.8)	625 (2.8)
	2 (50.8)	600 (2.7)	550 (2.5)	985 (4.4)	550 (2.5)	1,245 (5.6)	730 (3.3)
	2 1/2 (63.5)	880 (4.0)	550 (2.5)	1,165 (5.2)	550 (2.5)	1,315 (5.9)	730 (3.3)
3/8 (9.5)	1 1/2 (38.1)	475 (2.1)	845 (3.8)	630 (2.8)	1,170 (5.3)	760 (3.4)	1,710 (7.7)
	2 (50.8)	750 (3.4)	1,110 (5.0)	980 (4.4)	1,270 (5.7)	1,300 (5.9)	1,710 (7.7)
	2 1/2 (63.5)	1,025 (4.6)	1,370 (6.2)	1,330 (6.0)	1,370 (6.2)	1,835 (8.3)	1,710 (7.7)
	3 (76.2)	1,450 (6.5)	1,425 (6.4)	1,935 (8.7)	1,480 (6.7)	2,475 (11.1)	1,710 (7.7)
	3 1/2 (88.9)	1,875 (8.4)	1,475 (6.6)	2,535 (11.4)	1,590 (7.2)	3,110 (14.0)	1,710 (7.7)

Edge distance is over 4.5" – no reduction for edge distance
Spacing is over 9" sp no reduction for spacing
For 3,000 psi minimum concrete strength the interpolated anchor strength is:
T_a = (1,450+1,935)/2 = 1,692#

Based on allowable anchor tension load the anchor spacing may be increased to 24".

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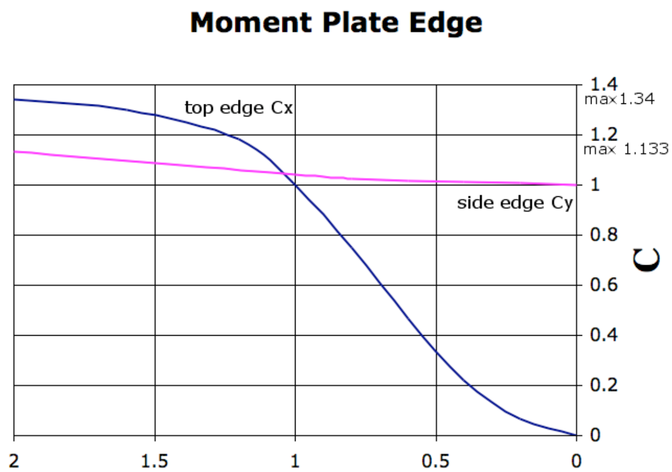
For bottom lights the glass is continuously supported at the bottom and point supported at the top corners.



Maximum moments:

at base shoe:

$M_b = wb^2/8$

at edge of glass at 5/8 b above base shoe:

$M_e = C_y*9/128*wb^2$

at center top edge of glass:

$M_t = C_x*1/8*wa^2$

For maximum light size of 5’11” x 9’

M_b = 5psf*9^2/8 =50.6’#/ft

a/b = 71”/108” = 0.66

b/a = 108/71 = 1.52

C_x = 1.28 (from b/a)

C_y = 1.03 (from a/b)

M_e = 1.03*9/128*5*9^2 = 29.3’#

at center top edge of glass:

M_t = 1.28*1/8*5psf*5.92^2 = 28.04’#

For concentrated load (maximum occurs at base for load at 0.57b above base shoe) at plate edge

M_p = C_y^2*0.192*P*b/a = 1.03^2*0.192*200*9’/5.92 = 61.9’#

For narrowest bottom light:

4-11.5”x 9’

a/b = 4.96/9 = 0.55, C_y = 1.02

M_p = C_y^2*0.192*P*b/a = 1.02^2*0.192*200*9’/4.96 = 72.5’#

For top lights moments will be significantly less since maximum light height is 6’-5”.

Based on allowable bending moments for 1/2” glass all lights are okay for bending.

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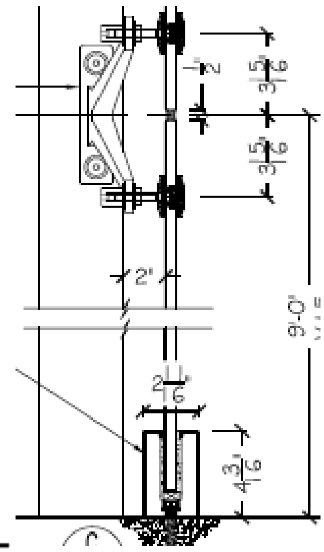
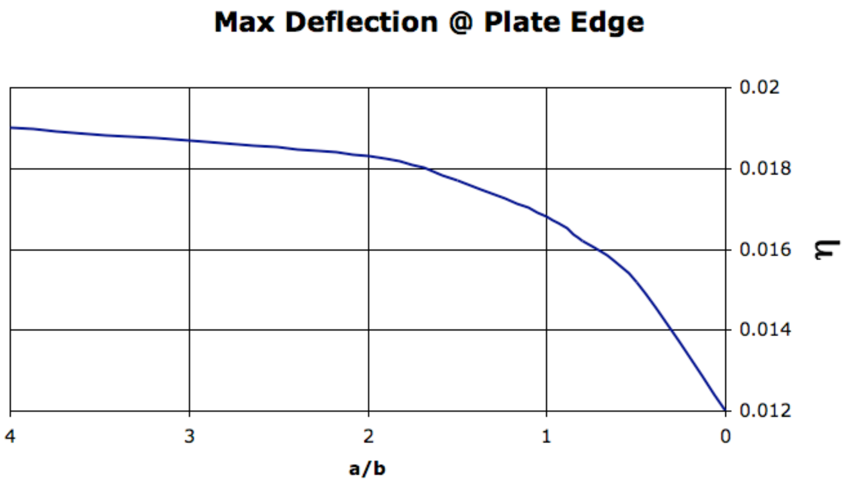
Check deflection of bottom light from concentrated load:



For 200# concentrated load at mid height the maximum deflection can be estimated as:
$\Delta = \eta P b^3/(EI)$
where I is calculated using the average glass thickness and a tributary width of actual light width or 1/2 b (light height) whichever is smaller.



a/b = 6’/9’ = 0.667
from graph $\eta = 0.0155$
$I = 4.5' * 0.5''^3 = 0.5625 \text{ in}^4$
$\Delta = 0.0155 * 200 * 108''^3/(10{,}400{,}000 * 0.5625) = 0.67''$

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