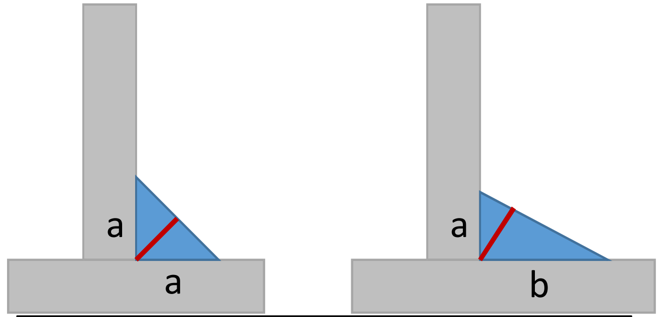
# Welded Connection Design – AISC Spec J

## General Welding Information

| Fillet Weld Size (in) | Number of Rod Passes |
|---|---|
| 3/16 | 1 |
| 1/4 | 1 |
| 5/16 | 1 |
| 3/8 | 3 |
| 7/16 | 4 |
| 1/2 | 4 |
| 5/8 | 6 |
| 3/4 | 8 |

<u>Welding Information</u>

- AISC Spec. J1 – General provisions for connection design
- AISC Spec. J2 – Welds
- AISC Spec. K – HSS & Box Member Connections
- AISC Part 8 – Design Considerations for Welds
- AISC Part 10 – Design of Simple Shear Connections
- AISC Part 11 – Design of Partially Restrained Moment Connections
- AISC Part 12 – Design of Fully Restrained Moment Connections
- AWS D1.1 – Structural Welding Code Steel




Equal leg fillet welds: $Throat_{eff} = 0.707a$

Unequal leg fillet welds: $Throat_{eff} = \frac{ab}{\sqrt{a^2+b^2}}$

**Table J2.4**

| Material Thickness of Thinner Part (in) | Minimum Size (in) |
|---|---|
| X ≤ 1/4 | 1/8 |
| 1/4 < X ≤ 1/2 | 3/16 |
| 1/2 < X ≤ 3/4 | 1/4 |
| 3/4 < X | 5/16 |

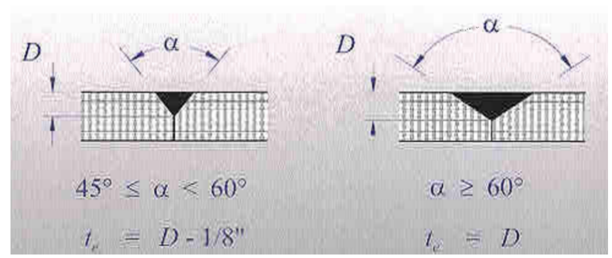
<u>Tables</u>

- AISC Table J2.1 – Effective Throat of PJP Groove Welds
- AISC Table J2.2 – Effective Throat of Flare Groove Welds
- AISC Table J2.3 – Min. Effective Throat of PJP Groove Welds
- AISC Table J2.4 – Min. Size of Fillet Welds
- **AISC Table J2.5 – ∅ values and Available Strength of Welded Joints**
- AISC Table 8-1 – Coefficient, C, for Conc. Loaded Weld Groups
- AISC Table 8-2 – Prequalified Welded Joints
    - Root tolerances, backing, etc.. From AWS.
- AISC Table 8-3 – Electrode Strength Coefficient, $C_1$
- AISC Table 8-4 to 8-11a – Coefficients, C, for Eccentric Loaded Weld Groups

Strength of PJP welds ➔ $t_e L(Weld\ Metal\ Strength)$

$\emptyset\ values\ and\ Weld\ Metal\ Strength\ taken\ from\ Table\ J2.5.$

$t_e$ can be determined from Tables 8-2.



# Welded Connection Design – AISC Spec J

## General Welding Information

Size Requirements for Fillet Welds

- Effective Area = (effective length) x (effective throat)
- Minimum Size of Fillet Welds
  - **Table J2.4 – By material thickness of parts joined**
- Maximum Size of Fillet Welds
  - For mtrl. < ¼" thick ➔ Not greater than the mtrl. Thickness
  - For mtrl ≥ ¼" thick ➔ Not greater than the mtrl thickness – 1/16"
- Effective Length of fillet weld must be at least 4x nominal size.
  - (e.g. ¼" fillet weld must be 1" long) **or min of 1-1/2" for intermittent welds, whichever is greater**
- Minimum Thickness of Connected Elements
  - Base member in tension

$$t_{min} = \frac{0.6F_{EXX}0.707(w)}{F_{u(base)}}$$

  - Base member in shear

$$t_{min} = \frac{0.6F_{EXX}0.707(w)}{0.6F_{u(base)}} \rightarrow \frac{F_{EXX}0.707(w)}{F_{u(base)}}$$

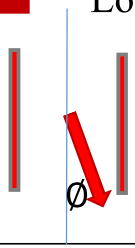
- Intermittent Fillet Welds
  - Minimum length is larger of **4x nominal size** or 1-1/2"
  - Built-up tension members ➔ max spacing is 300x$r_s$
    - Where $r_s$ =radius of gyration of smaller member being welded AISC D4
  - Built-up compression members ➔ max spacing is
    - To connect two rolled shapes = 24 in
    - See AISC Spec E6.2

Weld Strength

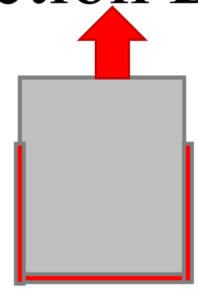
- Function of a) base metal, b) weld metal, c) welding process, & d) weld penetration
- Nominal resistance of a weld ($R_n$)
  - For Base Metal $R_n = F_{n,BM}A_{BM}$
  - For Weld Metal $R_n = F_{nw}A_{We}$
  - For Tensile Members ➔ $R_{ne} = UF_{nw}A_{we}$ Don't forget shear lag.
- Fillet Weld Strength
  - $F_w = 0.60F_{EXX}$
  - $V_n = t_eF_{nw}L = 0.707\ w\ 0.60F_{EXX}\ L = 0.707\left(\frac{1}{16}\ in\right)0.6\left(70\frac{k}{in}\right)1in$
  - Per inch of fillet weld ➔ 1.86 k/in/16$^{th}$
  - $\emptyset V_n = 0.75\left(\frac{1.86\frac{k}{in}}{16th}\right) = \frac{1.392\frac{k}{in}}{16th}$ ASD➔ $\frac{V_n}{\Omega} = \frac{1.86}{2} = \frac{0.928\frac{k}{in}}{16th}$
  - When the length (L) is over 100 times the leg size (w), multiply (L) by β
    - $\beta = 1.2 - 0.002(^{L}/_{w}) \leq 1.0$
    - If weld length is over 300w, use 180w.
- Necessary Tables
  - Table J2.1 – Effective throat of PJP welds
  - Table J2.2 – Effective Weld Sizes of Flare Groove Welds (common w/ HSS)
  - Table J2.3 – Minimum Eff. Throat Thickness of PJP groove welds
  - **Table J2.5 – Available Strength of Welded Joints (Very Important!!)**
- Limitations
  - Longitudinal fillet weld lengths may not be less than the distance between them because of **Shear Lag** (Case 4 Table D3.1).
  - In Lap Joints, minimum amount of lap permitted is 5x thickness of thinner part, but not less than 1 inch.

# Welded Connection Design – AISC Spec J

## Loaded Fillet Welds

A) 


&

C) 

<u>Transverse/Angled Loading of Fillet Welds</u>

- J2.4 allows transverse loading allows an increase of strength
  - A) For a linear weld group w/ uniform leg size, loaded through center of gravity,

    $R_n = F_{nw}A_{we}$ w/ $\emptyset = 0.75$

    $F_{nw} = 0.60F_{EXX}(1.0 + 0.50sin^{1.5}\theta)$

    $\theta$ measured off longitudinal axis.
  - B) For weld elements analyzed w/ ICR, $R_{nx}$ , $R_{ny}$ , & $M_n$ are permitted to be determined as given on AISC pg 16.1-116

  - C) Fillet weld groups concentrically loaded w/ longitudinal and transverse elements. $R_n$= greater of: w/ $\emptyset = 0.75$

    *1.* $R_n = R_{nwl} + R_{nwt}$

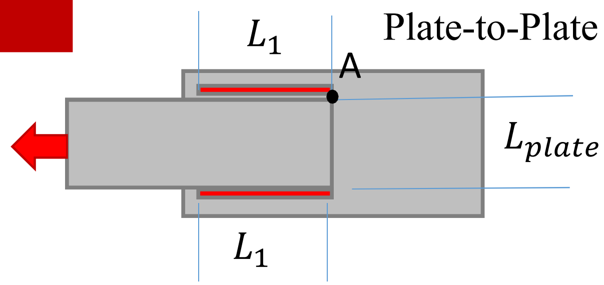
    Or

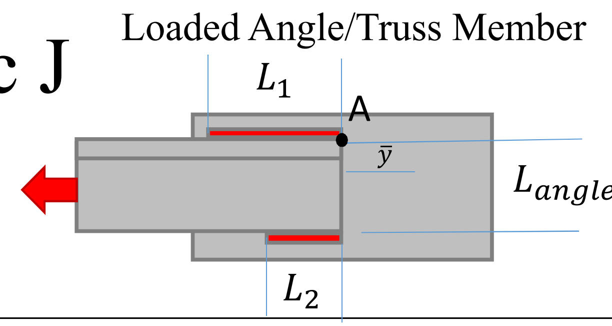
    *2.* $R_n = 0.85R_{nwl} + 1.5R_{nwt}$

    Note: Don't use $F_{nw} = 0.60F_{EXX}(1.0 + 0.50sin^{1.5}\theta)$ for these cases b/c transverse & longitudinal fillet welds have different deformation properties and limits. Use $R_{nwl}\&R_{nwt} = F_wA_w$

    $F_w$➔ commonly $0.60F_{EXX}$ & $A_w$➔ $(0.707)w(Length)$

# Welded Connection Design – AISC Spec J




U to Lengthen Welds @ end (preferred b/c accurate U factor)

↓

$R_u = lower\ of\ \emptyset P_n = \emptyset F_y A_g$ w/$\emptyset = 0.9$

↓

Select Fillet Weld Size & total length $L_w$ assuming U=1.0 $L_w = 2\ L_1$

↓

Shear Lag Factor from Case 4

$$L_{1,req} = \frac{L_{1,calc}}{U}$$

---

**Angle to Plate Welded Connections**

- Prescribing welds balanced about the neutral axis
  - Weld group centroid coincides w/ centroid of tensile load.

**Method 1**: Shear Lag Up Front

↓

Nominal Tensile Capacity of member with lower $A_g$

$R_u = lower\ of\ \emptyset P_n = \emptyset F_y A_g$ w/$\emptyset = 0.9$

$\emptyset P_n = \emptyset F_u A_e$ w/$\emptyset = 0.75$ & $A_e = UA_n$

Consider shear lag from Table 4.1 case 2 or 4. Some apply U=0.87 up front (case 4)

↓

Select Fillet Weld Size & total length $L_w$

↓

Take Moment about "Point A"

$$R_u(\bar{y}) - L_{angle}P_2 = 0$$

$$L_{2,calc} = \left(\frac{P_2}{Weld\ Str.per\ inch}\right)$$

$$L_{1,calc} = L_w - L_{2,calc}$$

↓

**Method 2**: Shear Lag to Lengthen Welds at the end (preferred b/c accurate U factor)

↓

$R_u = lower\ of\ \emptyset P_n = \emptyset F_y A_g$ w/$\emptyset = 0.9$

↓

Select Fillet Weld Size & total length $L_w$ assuming U=1.0

↓

Take Moment about "Point A"

$$R_u(\bar{y}) - L_{angle}P_2 = 0$$

$$L_{2,calc} = \left(\frac{P_2}{Weld\ Str.per\ inch}\right)$$

$$L_{1,calc} = L_w - L_{2,calc}$$

↓

Shear Lag Factor Higher of Case 2 or 4 (Case 2 & 4 evaluated w/ longer weld)

$$L_{1,req} = \frac{L_{1,calc}}{U} \qquad L_{2,req} = \frac{L_{2,calc}}{U}$$

←

Block Shear:

$R_n = 0.6F_u A_{nv} + U_{bs}F_u A_{nt} \leq 0.6F_y A_{gv} + U_{bs}F_u A_{nt}$ [AISC J4-5]

$U_{bs} = 1$ when tension stress is uniform, 0.85 otherwise

$A_{nv} = nominal\ area\ subject\ to\ shear = (L_w)t_{base}$

$A_{nt} = nominal\ area\ subject\ to\ tension = (L_{angle\ leg})(t_{base})$

$\boldsymbol{\emptyset R_n = 0.75R_n \geq R_u}$ ***calc'd in step 1 to find weld length***

# Welded Connection Design – AISC Spec J

## Eccentrically Loaded Weld Groups

<u>Eccentrically Loaded Weld Groups</u>

- Two commonly used methods
  - Elastic Method
  - Instantaneous Center of Rotation Method

<u>Elastic Method</u>

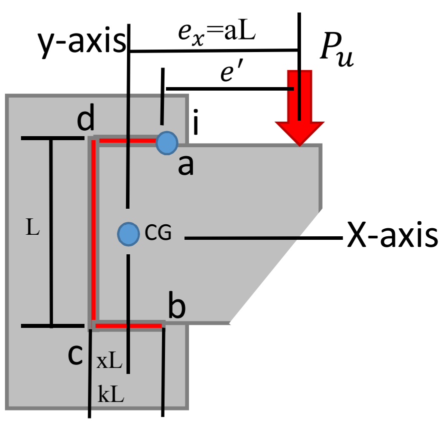
- Very Conservative
- More simplistic method when deign aids are unavailable
- Statics-based
- Pieces welded together are assumed to be completely rigid
  - All deformation is in the weld
- Based on a summation of forces in 3-D space from $P_{xyz}$ & $M_{xyz}$
- There are two ways to approach this method
  - 1) **Express/simplified methods** - for weld group shapes where location of max stress is known.
  - 2) **General method** – intensive hand calc, but applicable to all planar weld groups

<u>ICR Method Ultimate Strength Method</u>

- More accurate
- AISC Table 8-3 to 8-11 can be used to aid the design
- Nominal strength of weld group ➔ $R_{n,kips} = CC_1DL_{in}$ w/ $\emptyset = 0.75$
  - $C$ = coefficient from AISC Table 8-#
  - $C_1$= electrode coefficient from AISC Table 8-3 $(C_1 = 1.0\ for\ F_{EXX})$
  - D = number of 1/16ths of an inch of fillet weld size
  - $L_{in}$= characteristic length of weld group in inches
- Available strength must be greater than required strength
  - $P_u \leq \emptyset R_n$ ➔ $P_u \leq \emptyset CC_1DL_{in}$
- Minimum required values for C, D, & L are given in the Tables 8-#
  - $C_{min} = \frac{P_u}{\emptyset C_1 DL}$ $D_{min} = \frac{P_u}{\emptyset C_1 CL}$ $L_{min} = \frac{P_u}{\emptyset C_1 CD}$

# Welded Connection Design – AISC Spec J

Welded Bracket w/ Eccentric Shear




Express/Simplified Elastic Method Workflow (Max stress assumed @ point i): Size of required fillet weld

- Variables for Elastic Method

Total weld length: $L_{wt}$

Centroid Location (xL): use AISC Table 8-# for this if needed

MOI about X&Y-axis& Polar w/ unit weld lengths:

$$I_x = \sum \frac{bh^3}{12} + Ad^2 \rightarrow \frac{L^3}{12} + 2(KL)\left(\frac{L}{2}\right)^2$$

$$I_y = \sum \frac{bh^3}{12} + Ad^2 \rightarrow 2\frac{(KL)^3}{12} + 2(KL)\left(\frac{KL}{2} - (xL)\right)^2 + L(xL)^2$$

$J = I_0 = I_x + I_y$

- Forces @ points a & b

$$f_h = \frac{Tv}{J} \rightarrow \frac{((P_u)(e_x))\frac{L}{2}}{J} \qquad f_v = \frac{Th}{J} \rightarrow \frac{((P_u)(e_x))((KL)-(xL))}{J} \qquad f_s = \frac{P_u}{L_{wt}} \qquad f_r = \sqrt{f_h^2 + f_v^2 + f_s^2}$$

Required weld size $= \dfrac{f_r\,(\frac{kips}{inch})}{1.392\frac{kips}{in}/sixteenth} =$ ______ sixteenths of fillet weld. Check vs AISC Table J2-4

ICR Method Workflow: Use AISC Tables 8-5 to 8-11 depending on the shape of the weld group

A) Givens: L, $e'$, kL ➔ Determine required fillet weld size

Infer: $k = \frac{kL}{L}$ ➔ Table 8-# for "X" coefficient ➔ "xL" to get $e_x$ ➔ $e_x$ to get a $= \frac{e_x}{L}$ ➔ C from table

Solution: $D_{\min\,1/16ths} = \frac{P_u}{\emptyset C_1 CL}$ compare w/ AISC Table J2.4 mtrl thickness req.

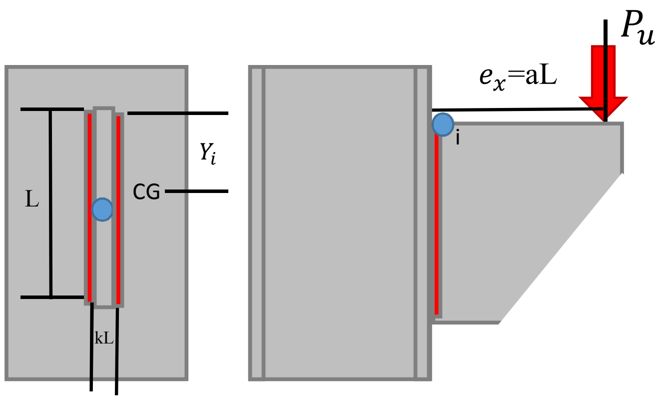
B) Givens: $e_x$ , $L$ ➔ Determine kL & required fillet weld size (D # of sixteenths)

Infer: Select initial D from steel thicknesses ➔ $C_{min} = \frac{P_u}{\emptyset C_1 DL}$ ➔ k from Table 8-# ➔ kL for that "D"

Solution: $D_{\min\,1/16ths} = \frac{P_u}{\emptyset C_1 CL}$ com

# Welded Connection Design – AISC Spec J

Welded Group Eccentrically Loaded Normal to Faying Surface




<u>Express/Simplified Elastic Method Workflow (Max stress assumed @ point i): Size of required fillet weld</u>

- Variables for Elastic Method

Total weld length: $L_{wt}$ $\quad (L_{wt} = 2L \quad in\ this\ case)$

MOI about X-axis w/ unit weld lengths:

$$I_x = \sum \frac{bh^3}{12} \rightarrow 2\frac{L^3}{12}$$

- Forces @ point I

$$f_v = \frac{P_u}{L_{wt}} \qquad f_h = \frac{P_u\, e\, Y_i}{I_x} \qquad f_r = \sqrt{f_h^2 + f_v^2}\ \frac{kips}{inch}$$

Required weld size = $\dfrac{f_r\,(\frac{kips}{inch})}{1.392\frac{kips}{in}/sixteenth}$ = ______ sixteenths of fillet weld. Check vs AISC Table J2-4

<u>ICR Method Workflow</u>:

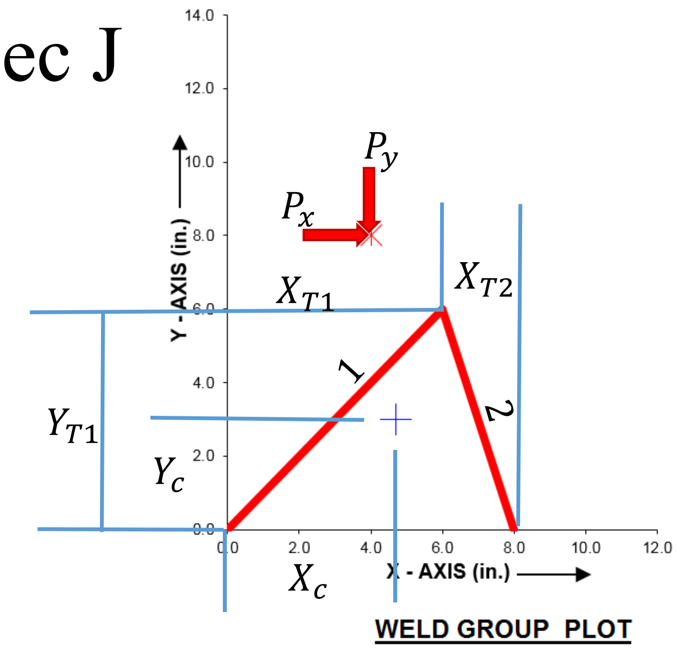
A) Givens: $e_x$ , $L$ ➔ Determine required fillet weld size (D # of sixteenths)

Infer: Assumption that K=0 (not ideal) , a= $\frac{e_x}{L}$

Solution: $D_{1/16ths} = \dfrac{P_u}{\emptyset C_1 C L}$ = ________ sixteenths of fillet weld. Check vs AISC Table J2-4

# Welded Connection Design – AISC Spec J

## General Elastic Method for Any Weld Group w/ Same Size Welds




General Elastic Method (as adopted from Alex Tomanovich)

1) Identify Weld Group Main Parameters

- $L_{wt}$ = total length of weld group
- Centroid of Weld Group
  - $X_c = \frac{\sum X_c}{L_{wt}}$ when $X_c = (X_{mid,indv})(L_{w,indv})$
  - $Y_c = \frac{\sum Y_c}{L_{wt}}$ when $Y_c = (Y_{mid,indv})(L_{w,indv})$
- Calculate $I_x$, $I_y$, J
  - $I_x = (\sum I_{x0}) - L_{wt}(Y_c)^2 \rightarrow I_{xo1} = \frac{(L_1)(Y_{T1})^2}{12} + L_1(Y_{mid,1})^2$ continue for each weld
  - $I_y = (\sum I_{y0}) - L_{wt}(X_c)^2 \rightarrow I_{yo1} = \frac{(L_1)(X_{T1})^2}{12} + L_1(X_{mid,1})^2$ continue for each weld
  - $J = I_x + I_y$

2a) Moment Summations about CG (for each point loaded)

- **USE RIGHT HAND RULE CENTERED ON THE $CG_{weld}$!!!!**

$M_{xfrom(P_y)} = (Z_{load\ point} - Z_{CG_{weld}})(P_y)$

$M_{xfrom(P_z)} = (Y_{load\ point} - Y_{CG_{weld}})(P_z)$

$M_{yfrom(P_x)} = (Z_{load\ point} - Z_{CG_{weld}})(P_x)$

$M_{yfrom(P_z)} = (X_{load\ point} - X_{CG_{weld}})(P_z)$

$M_{zfrom(P_x)} = (Y_{load\ point} - Y_{CG_{weld}})(P_x)$

$M_{zfrom(P_y)} = (X_{load\ point} - X_{CG_{weld}})(P_y)$

2b) Loads Transformed for Effects @ CG of Weld Group

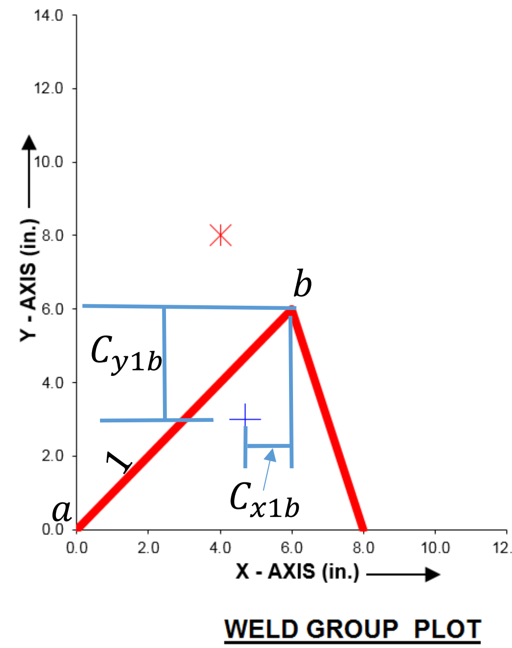
Notation $M_{xfrom(P_y)}$ indicates moment about x-axis caused by $P_y$.

- $\sum P_x = Applied\ P_x$
- $\sum P_y = Applied\ P_y$
- $\sum P_z = Applied\ P_z$
- $\sum M_x = Applied M_x + M_{xfrom(P_y)} + M_{xfrom(P_z)}$
- $\sum M_y = Applied M_y + M_{yfrom(P_x)} + M_{yfrom(P_z)}$
- $\sum M_z = Applied M_z + M_{zfrom(P_x)} + M_{zfrom(P_y)}$

# Welded Connection Design – AISC Spec J

## Elastic Method General Algorithm

General Elastic Method (as adopted from Alex Tomanovich)




3) Weld Forces @ Individual Points (Weld Ends): The forces are dependent on Cx & Cy, as measured from $CG_{weld}$

**BE AWARE OF THE MOMENT ORIENTATION AND RIGHT HAND RULE!!!**

- $f_z = \frac{\sum P_z}{L_{wt}} + \frac{(\sum M_x)(C_{y1b})}{I_x} + \frac{(\sum M_y)(C_{x1b})}{I_y}$
- $f_{vy} = \frac{\sum P_y}{L_{wt}} + \frac{(\sum M_z)(C_{x1b})}{J}$
- $f_{vx} = \frac{\sum P_x}{L_{wt}} + \frac{(\sum M_z)(C_{y1b})}{J}$ (e.g. positive moment about Z will produce force in negative X if $C_{y1b}$ is positive)
- $f_{resultant} = \sqrt{(f_z)^2 + (f_{vy})^2 + (f_{vx})^2}$ $\frac{Force}{Unit\ Length}$ ➔ Usually $\frac{Kips}{in}$

4) Weld Requirements and Base Metal Check

- Fillet weld size required (in 16ths of an inch) = $\frac{f_{resultant}}{0.75 * w * (0.6F_{EXX}) * (unit\ length)} = \frac{f_{resultant}}{1.392\ ^{k}/_{in}/_{16th}}$ for LRFD.
  - If using ASD, substitute $0.928^{k}/_{in}/_{16th}$ for $1.392\ ^{k}/_{in}/_{16th}$
- Base Metal Shear Allowable
  - LRFD: $\emptyset R_n = (1.00)(0.6)(F_{ybase})(Base\ Metal\ Thickness)$ ➔ ______ $^{force}/_{unit\ length}$ usually $\frac{Kips}{inch}$
  - Refer to AISC Spec. J4
  - $R_n = 0.6F_yA_{gv}$ $w/\ \emptyset = 1.00\ or\ \Omega = 1.5\ (This\ is\ where\ 0.4F_y\ for\ ASD\ comes\ from)$

# Welded Connection Design – AISC Spec K

HSS connections

Welding Information
- AISC Spec. K1 – Concentrated Forces on HSS
- AISC Spec. K2 – HSS to HSS Truss Connections
- AISC Spec. K3 – HSS to HSS Moment Connections
- AISC Spec. K4 – Welds of Plates & Branches to Rectangular HSS

Tables
- AISC Table K1.1 – Available Strength of Plate-to-Round HSS Connections
- AISC Table K1.2 – Available Strength of Plate-to-Rectangle HSS Connections
- AISC Table K2.1 – Available Strengths of Round HSS-to-HSS Truss Connections
- AISC Table K2.2 – Available Strengths of Rectangular HSS-to-HSS Truss Connections
- AISC Table K3.1 – Available Strengths of Round HSS-to-HSS Moment Connections
- AISC Table K3.2 – Available Strengths of Rectangular HSS-to-HSS Moment Connections
- AISC Table K3.3 – Effective Weld Properties for Connections to Rectangular HSS

Note: Each table is followed by the applicable limit states. If all criterion can't be met, you can't use that particular table.

**Method For Using Tables in AISC Spec. K To Determine Weld Sizes and Whether the HSS Must Be Reinforced**

↓

Check the Limits of Applicability in Table K#.#A

↓

Compute Nominal Strength and Design Strength for given Connection type.
- Lowest Limit State Governs

↓

Select welds based on the allowable load in previous step.

Sometimes CJPs are needed if the plate is small.