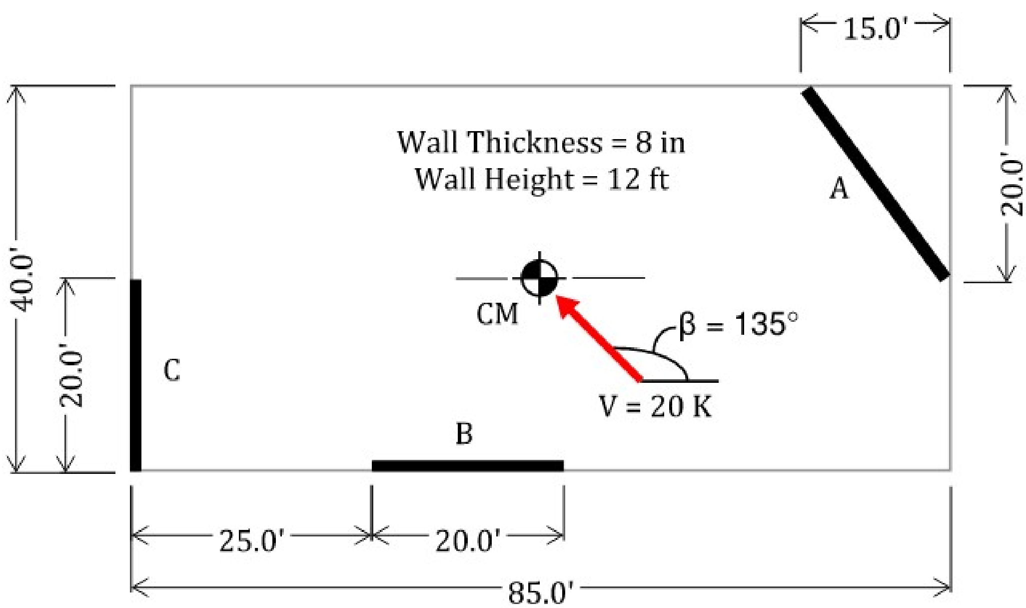
Hand Calculation

Problem Statement:
Determine the total shear applied to each element in the lateral force resisting system shown in the overall plan view

Wall thickness $b := 8\ in$
Wall height $H := 12\ ft$
Conc. Strength $f'c := 4000\ \frac{lbf}{in^2}$

Applied Shear $V := 20\ kip$
Angle of load application $\beta := 135\ deg$
Diaphragm length: $L_D := 85\ ft$
Diaphragm width: $W_D := 40\ ft$



Center of Wall A relative to origin
$x_1 := 77.5\ ft$

$y_1 := 30\ ft$

x and y component of Wall A
$x_{a1} := 15\ ft$

$y_{a1} := 20\ ft$

Center of Wall B relative to origin
$x_2 := 35\ ft$
$y_2 := 0\ ft$

x and y component of Wall B
$x_{a2} := 20\ ft$
$y_{a2} := 0\ ft$

Center of Wall C relative to origin
$x_3 := 0\ ft$
$y_3 := 10\ ft$

x and y component of Wall C
$x_{a3} := 0\ ft$
$y_{a3} := 20\ ft$

Solution:

Step 1: Calculate flexibility of wall in strong axis

Wall A:

Length of wall $L_a := \sqrt{x_{a1}^2 + y_{a1}^2} = 300\ in$

Area of wall $A_a := L_a \cdot b = 2400\ in^2$

$$I_{xx\_a} := \frac{b \cdot L_a^3}{12} = 18000000\ in^4$$

$$E_{b\_a} := 57000 \cdot \sqrt{f'c} = \left(3.605 \cdot 10^3\right)\ ksi$$

$$E_{v\_a} := 0.4 \cdot E_{b\_a} = \left(1.44199861304 \cdot 10^3\right)\ ksi$$

$$A_{strong\_a} := \frac{H^3}{12 \cdot E_{b\_a} \cdot I_{xx\_a}} + \frac{1.2\ H}{E_{v\_a} \cdot A_a} = \left(5.37653776495 \cdot 10^{-5}\right) \frac{in}{kip}$$

Wall B:

Length of wall $L_b := \sqrt{x_{a2}^2 + y_{a2}^2} = 240\ in$

Area of wall $A_b := L_b \cdot b = 1920\ in^2$

$$I_{xx\_b} := \frac{b \cdot L_b^3}{12} = 9216000\ in^4$$

$$E_{b\_b} := 57000 \cdot \sqrt{f'c} = \left(3.605 \cdot 10^3\right)\ ksi$$

$$E_{v\_b} := 0.4 \cdot E_{b\_b} = \left(1.44199861304 \cdot 10^3\right)\ ksi$$

$$A_{strong\_b} := \frac{H^3}{12 \cdot E_{b\_b} \cdot I_{xx\_b}} + \frac{1.2\ H}{E_{v\_b} \cdot A_b} = \left(6.99029798564 \cdot 10^{-5}\right) \frac{in}{kip}$$

Wall C

Length of wall $L_c := \sqrt{x_{a3}^2 + y_{a3}^2} = 240\ in$

Area of wall $A_c := L_c \cdot b = 1920\ in^2$

$$I_{xx\_c} := \frac{b \cdot L_c^3}{12} = 9216000\ in^4$$

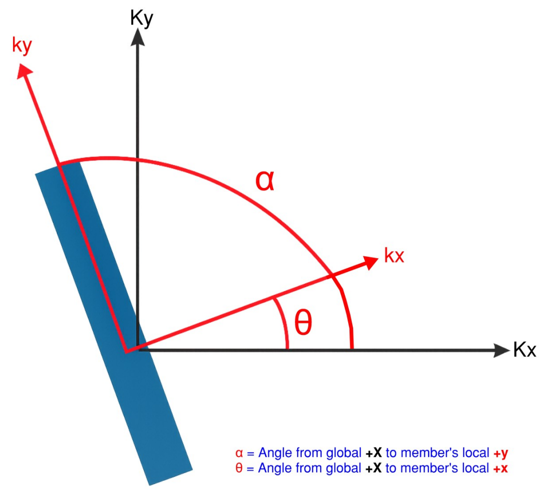
$$E_{b\_c} := 57000 \cdot \sqrt{f'c} = \left(3.605 \cdot 10^3\right)\ ksi$$

$$E_{v\_c} := 0.4 \cdot E_{b\_c} = \left(1.44199861304 \cdot 10^3\right)\ ksi$$

$$A_{strong\_c} := \frac{H^3}{12 \cdot E_{b\_c} \cdot I_{xx\_c}} + \frac{1.2\ H}{E_{v\_c} \cdot A_c} = \left(6.99029798564 \cdot 10^{-5}\right) \frac{in}{kip}$$

Step 2: Calculate angles α and θ

Wall A:



$$\alpha_a := 90\ deg + \operatorname{atan}\left(\frac{x_{a1}}{y_{a1}}\right)$$

$$\alpha_a = 126.87\ deg$$

$$\theta_a := \alpha_a - 90\ deg = 36.86989764584\ deg$$

Wall B:

$$\alpha_b := 0\ deg$$

$$\theta_b := \alpha_b - 90\ deg = -90\ deg$$

Wall C:

$$\alpha_c := 90\ deg$$

$$\theta_c := \alpha_c - 90\ deg = 0\ deg$$

Step 3: Calculate the stiffness (Kxx, Kxy, Kyx, Kyy) and K_{local} matrix for each wall

Wall A:

$K_{xx\_a} := 0$ Weak axis wall stiffness is considered to be negligible and it is considered to be zero

$K_{xy\_a} := 0$ *and* $K_{yx\_a} := 0$

$$K_{yy\_a} := \frac{1}{A_{strong\_a}} = 18599.33\ \frac{kip}{in}$$

$$K_{local\_a} := \begin{bmatrix} K_{xx\_a} & K_{xy\_a} \\ K_{yx\_a} & K_{yy\_a} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 18599.33 \end{bmatrix} \frac{kip}{in}$$

Wall B:

$K_{xx\_b} := 0$ Weak axis wall stiffness is considered to be negligible and it is considered to be zero

$K_{xy\_b} := 0$ *and* $K_{yx\_b} := 0$

$$K_{yy\_b} := \frac{1}{A_{strong\_b}} = 14305.542\ \frac{kip}{in}$$

$$K_{local\_b} := \begin{bmatrix} K_{xx\_b} & K_{xy\_b} \\ K_{yx\_b} & K_{yy\_b} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 14305.542 \end{bmatrix} \frac{kip}{in}$$

Wall C:

$K_{xx\_c} := 0$ Weak axis wall stiffness is considered to be negligible and it is considered to be zero

$K_{xy\_c} := 0$ *and* $K_{yx\_c} := 0$

$$K_{yy\_c} := \frac{1}{A_{strong\_c}} = 14305.542\ \frac{kip}{in} \qquad K_{local\_c} := \begin{bmatrix} K_{xx\_c} & K_{xy\_c} \\ K_{yx\_c} & K_{yy\_c} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 14305.542 \end{bmatrix} \frac{kip}{in}$$

Step 4: Calculate rotation matrix T for each wall

$$T_a := \begin{bmatrix} \cos(\theta_a) & \sin(\theta_a) \\ -\sin(\theta_a) & \cos(\theta_a) \end{bmatrix} = \begin{bmatrix} 0.8 & 0.6 \\ -0.6 & 0.8 \end{bmatrix}$$

$$T_b := \begin{bmatrix} \cos(\theta_b) & \sin(\theta_b) \\ -\sin(\theta_b) & \cos(\theta_b) \end{bmatrix} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

$$T_c := \begin{bmatrix} \cos(\theta_c) & \sin(\theta_c) \\ -\sin(\theta_c) & \cos(\theta_c) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Step 5: Calculate K_{global} for each wall

$$K_{global\_a} := T_a^{\mathrm{T}} \cdot K_{local\_a} \cdot T_a = \begin{bmatrix} 6695.759 & -8927.678 \\ -8927.678 & 11903.571 \end{bmatrix} \frac{kip}{in}$$

$$K_{global\_b} := T_b^{\mathrm{T}} \cdot K_{local\_b} \cdot T_b = \begin{bmatrix} 14305.542 & 0 \\ 0 & 0 \end{bmatrix} \frac{kip}{in}$$

$$K_{global\_c} := T_c^{\mathrm{T}} \cdot K_{local\_c} \cdot T_c = \begin{bmatrix} 0 & 0 \\ 0 & 14305.542 \end{bmatrix} \frac{kip}{in}$$

Step 6: Determine the Center of Rigidity of the diaphragm

$$\Sigma Kxx := K_{global\_a_{0,0}} + K_{global\_b_{0,0}} + K_{global\_c_{0,0}} = 21001.301\ \frac{kip}{in}$$

$$\Sigma Kxy := K_{global\_a_{0,1}} + K_{global\_b_{0,1}} + K_{global\_c_{0,1}} = -8927.678\ \frac{kip}{in}$$

$$\Sigma Kyx := K_{global\_a_{1,0}} + K_{global\_b_{1,0}} + K_{global\_c_{1,0}} = -8927.678\ \frac{kip}{in}$$

$$\Sigma Kyy := K_{global\_a_{1,1}} + K_{global\_b_{1,1}} + K_{global\_c_{1,1}} = 26209.113\ \frac{kip}{in}$$

$\Sigma x_1 Kxy := x_1 \cdot K_{global\_a_{0,1}} + x_2 \cdot K_{global\_b_{0,1}} + x_3 \cdot K_{global\_c_{0,1}} = -8302740.9\ kip$

$\Sigma x_1 Kyy := x_1 \cdot K_{global\_a_{1,1}} + x_2 \cdot K_{global\_b_{1,1}} + x_3 \cdot K_{global\_c_{1,1}} = 11070321.2\ kip$

$\Sigma y_1 Kxx := y_1 \cdot K_{global\_a_{0,0}} + y_2 \cdot K_{global\_b_{0,0}} + y_3 \cdot K_{global\_c_{0,0}} = 2410473.164\ kip$

$\Sigma y_1 Kxy := y_1 \cdot K_{global\_a_{0,1}} + y_2 \cdot K_{global\_b_{0,1}} + y_3 \cdot K_{global\_c_{0,1}} = -3213964.219\ kip$

Center of Rigidity, CR is:

$$y := \frac{\Sigma y_1 Kxx - \Sigma x_1 Kxy + \dfrac{\Sigma x_1 Kyy \cdot \Sigma Kxy - \Sigma y_1 Kxy \cdot \Sigma Kxy}{\Sigma Kyy}}{\Sigma Kxx - \dfrac{(\Sigma Kxy)^2}{\Sigma Kyy}} = 27.13178294574\ ft$$

$$x := \frac{y \cdot \Sigma Kxy - \Sigma y_1 Kxy + \Sigma x_1 Kyy}{\Sigma Kyy} = 36.17571059432\ ft$$

$CR := [x \ \ y] = [36.17571059432 \ \ 27.13178294574]\ ft$

Step 7: Determine the location of the center of each wall relative to the center of rigidity

Wall A
$x_a := x_1 - x = 41.32428940568\ ft$
$y_a := y_1 - y = 2.86821705426\ ft$

Wall B
$x_b := x_2 - x = -1.17571059432\ ft$
$y_b := y_2 - y = -27.13178294574\ ft$

Wall C
$x_c := x_3 - x = -36.17571059432\ ft$
$y_c := y_3 - y = -17.13178294574\ ft$

Step 8: Torsional Moment acting on the Diaphragm

Center of Mass, $CM := \left[\frac{L_D}{2} \ \ \frac{W_D}{2}\right] = [42.5 \ \ 20]\ ft$

From step 6:
Center of Rigidity, $CR := [x \ \ y] = [36.17571059432 \ \ 27.13178294574]\ ft$

$e_x := CM_{0,0} - CR_{0,0} = 6.32428940568\ ft$

$e_y := CM_{0,1} - CR_{0,1} = -7.13178294574\ ft$

$P_x := V \cdot \cos(\beta) = -14.14213562373\ kip$

$P_y := V \cdot \sin(\beta) = 14.14213562373\ kip$

$MP_x := -P_x \cdot e_y = -100.85864165762\ kip \cdot ft$

$MP_y := P_y \cdot e_x = 89.43895849892\ kip \cdot ft$

The torsional moment acting on the diaphragm is:
$T_p := MP_x + MP_y = -137.03619790437\ kip \cdot in$

Step 9: Determine the diaphragm displacement

$\Sigma xKxy := x_a \cdot K_{global\_a_{0,1}} + x_b \cdot K_{global\_b_{0,1}} + x_c \cdot K_{global\_c_{0,1}} = -4427159.585\ kip$

$\Sigma yKxx := y_a \cdot K_{global\_a_{0,0}} + y_b \cdot K_{global\_b_{0,0}} + y_c \cdot K_{global\_c_{0,0}} = -4427159.585\ kip$

$\Sigma xKyy := x_a \cdot K_{global\_a_{1,1}} + x_b \cdot K_{global\_b_{1,1}} + x_c \cdot K_{global\_c_{1,1}} = -307278.233\ kip$

$\Sigma yKxy := y_a \cdot K_{global\_a_{0,1}} + y_b \cdot K_{global\_b_{0,1}} + y_c \cdot K_{global\_c_{0,1}} = -307278.233\ kip$

$\Sigma xxKyy := {x_a}^2 \cdot K_{global\_a_{1,1}} + {x_b}^2 \cdot K_{global\_b_{1,1}} + {x_c}^2 \cdot K_{global\_c_{1,1}} = \left(5.62306998589 \cdot 10^9\right)\ kip \cdot in$

$\Sigma yyKxx := {y_a}^2 \cdot K_{global\_a_{0,0}} + {y_b}^2 \cdot K_{global\_b_{0,0}} + {y_c}^2 \cdot K_{global\_c_{0,0}} = \left(1.52436591783 \cdot 10^9\right)\ kip \cdot in$

$\Sigma xyKxy := x_a \cdot y_a \cdot K_{global\_a_{0,1}} + x_b \cdot y_b \cdot K_{global\_b_{0,1}} + x_c \cdot y_c \cdot K_{global\_c_{0,1}} = -1.52376655467 \cdot 10^8\ kip \cdot in$

$\Sigma J := 0$

$\Sigma xKxy - \Sigma yKxx = 0\ kip$

$\Sigma xKyy - \Sigma yKxy = 0\ kip$

$\Sigma xxKyy + \Sigma yyKxx - 2 \cdot \Sigma xyKxy + \Sigma J = \left(7.45218921466 \cdot 10^9\right)\ kip \cdot in$

From step 6

$\Sigma Kxx = \left(2.1 \cdot 10^4\right) \dfrac{kip}{in}$ $\Sigma Kxy = -8.928 \cdot 10^3 \dfrac{kip}{in}$ $\Sigma Kyy = \left(2.621 \cdot 10^4\right) \dfrac{kip}{in}$

From step 8

$P_x = -14.142\ kip$ $P_y = 14.142\ kip$ $T_p = -137.036\ kip \cdot in$

$$\begin{bmatrix} P_x \\ P_y \\ T_p \end{bmatrix} = \begin{bmatrix} \Sigma Kxx & \Sigma Kxy & \Sigma xKxy - \Sigma yKxx \\ \Sigma Kxy & \Sigma Kyy & \Sigma xKyy - \Sigma yKxy \\ 0 & 0 & \left(\Sigma xxKyy + \Sigma yyKxx - 2 \cdot \Sigma xyKxy + \Sigma J\right) \end{bmatrix} \cdot \begin{bmatrix} \Delta_x \\ \Delta_y \\ \Delta_\theta \end{bmatrix}$$

Substitute the various components into the matrix and solve for Δ_x, Δ_y, Δ_θ

$\Delta_x := -0.00051919\ in$

$\Delta_y := 0.00036273\ in$

$\Delta_\theta := -0.000000018388379 \cdot rad$

Step 10: Determine the global forces in x and y direction for each wall

Global Forces in x-direction

$$F_{xa\_direct} := K_{global\_a_{0,1}} \cdot \Delta_y + K_{global\_a_{0,0}} \cdot \Delta_x = -6.715 \ kip$$

$$F_{xb\_direct} := K_{global\_b_{0,1}} \cdot \Delta_y + K_{global\_b_{0,0}} \cdot \Delta_x = -7.427 \ kip$$

$$F_{xc\_direct} := K_{global\_c_{0,1}} \cdot \Delta_y + K_{global\_c_{0,0}} \cdot \Delta_x = 0 \ kip$$

$$F_{xa\_tor} := \left(-y_a \cdot K_{global\_a_{0,0}} + x_a \cdot K_{global\_a_{0,1}}\right) \cdot \Delta_\theta = 0.086 \ kip$$

$$F_{xb\_tor} := \left(-y_b \cdot K_{global\_b_{0,0}} + x_b \cdot K_{global\_b_{0,1}}\right) \cdot \Delta_\theta = -0.086 \ kip$$

$$F_{xc\_tor} := \left(-y_c \cdot K_{global\_c_{0,0}} + x_c \cdot K_{global\_c_{0,1}}\right) \cdot \Delta_\theta = 0 \ kip$$

$$F_{xa\_total} := F_{xa\_direct} + F_{xa\_tor} = -6.629 \ kip$$
$$F_{xb\_total} := F_{xb\_direct} + F_{xb\_tor} = -7.513 \ kip$$
$$F_{xc\_total} := F_{xc\_direct} + F_{xc\_tor} = 0 \ kip$$

$$F_{x\_global\_total} := F_{xa\_total} + F_{xb\_total} + F_{xc\_total} = -14.14 \ kip$$

Global Forces in y-direction

$$F_{ya\_direct} := K_{global\_a_{1,1}} \cdot \Delta_y + K_{global\_a_{1,0}} \cdot \Delta_x = 8.953 \ kip$$

$$F_{yb\_direct} := K_{global\_b_{1,1}} \cdot \Delta_y + K_{global\_b_{1,0}} \cdot \Delta_x = 0 \ kip$$

$$F_{yc\_direct} := K_{global\_c_{1,1}} \cdot \Delta_y + K_{global\_c_{1,0}} \cdot \Delta_x = 5.189 \ kip$$

$$F_{ya\_tor} := \left(-y_a \cdot K_{global\_a_{0,1}} + x_a \cdot K_{global\_a_{1,1}}\right) \cdot \Delta_\theta = -0.114 \ kip$$

$$F_{yb\_tor} := \left(-y_b \cdot K_{global\_b_{0,1}} + x_b \cdot K_{global\_b_{1,1}}\right) \cdot \Delta_\theta = 0 \ kip$$

$$F_{yc\_tor} := \left(-y_c \cdot K_{global\_c_{0,1}} + x_c \cdot K_{global\_c_{1,1}}\right) \cdot \Delta_\theta = 0.114 \ kip$$

$$F_{ya\_total} := F_{ya\_direct} + F_{ya\_tor} = 8.839 \ kip$$
$$F_{yb\_total} := F_{yb\_direct} + F_{yb\_tor} = 0 \ kip$$
$$F_{yc\_total} := F_{yc\_direct} + F_{yc\_tor} = 5.303 \ kip$$

$$F_{y\_global\_total} := F_{ya\_total} + F_{yb\_total} + F_{yc\_total} = 14.14 \ kip$$

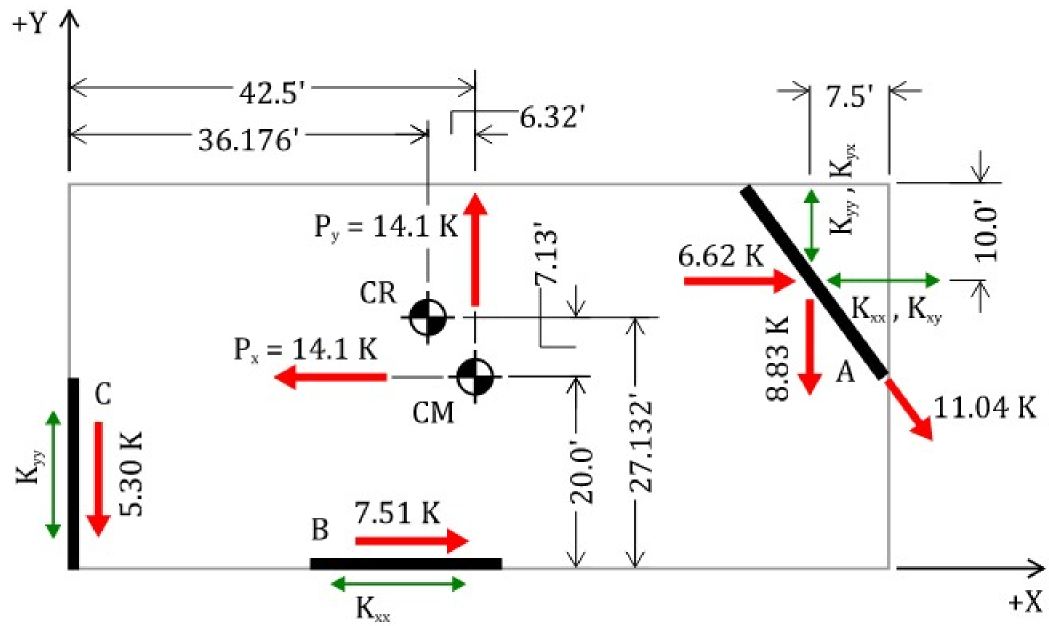
Step 11: Determine the local forces in the local x and y direction for each wall

$$F_{global\_a} := \begin{bmatrix} F_{xa\_total} \\ F_{ya\_total} \end{bmatrix} = \begin{bmatrix} -6.629 \\ 8.839 \end{bmatrix} \; kip \qquad F_{global\_b} := \begin{bmatrix} F_{xb\_total} \\ F_{yb\_total} \end{bmatrix} = \begin{bmatrix} -7.513 \\ 0 \end{bmatrix} \; kip$$

$$F_{global\_c} := \begin{bmatrix} F_{xc\_total} \\ F_{yc\_total} \end{bmatrix} = \begin{bmatrix} 0 \\ 5.303 \end{bmatrix} \; kip$$

$$F_{local\_a} := T_a \cdot F_{global\_a} = \begin{bmatrix} 0 \\ 11.048 \end{bmatrix} \; kip \qquad F_{local\_b} := T_b \cdot F_{global\_b} = \begin{bmatrix} 0 \\ -7.513 \end{bmatrix} \; kip$$

$$F_{local\_c} := T_c \cdot F_{global\_c} = \begin{bmatrix} 0 \\ 5.303 \end{bmatrix} \; kip$$



Note that this example is for illustration purposes only, hence, some of the assumptions were simplified to make the calculations and the logic easier to follow by our users. Some of the Items that are considered by ENERCALC SEL, but were not considered in this example are:

- *Accidental torsion*
- *Applying the shear load in many incremental angles to determine maximum shear per resisting element*
- *Applying each load at incremental eccentricity around the diaphragm*
- *Fully automated implementation of ASCE 7 Orthogonal Combination (100% + 30%) method*

See the following ENERCALC printed calc report for comparison

Torsional Analysis of Rigid Diaphragm

DESCRIPTION: Verification Example

General Information

Primary Lateral Force	20.0 k	Center of Shear Application :	
.....Additional Orthogonal Force	k	Distance from "X" datum point	42.50 ft
		Distance from "Y" datum point	20.0 ft
Resultant Load Used for Analysis :	20.0 k		

Note: This load is the SRSS resultant of the primary and orthogonal forces. It will be applied to the force resisting system at the angle or anglular increments defined below under Load Direction

		Ecc. as % of Maximum Dimension	0.00 %
		Maximum Dimensions :	
		Along "X" Axis	ft
Load Direction Angular Increment	135.0 ONLY	Along "Y" Axis	ft
Eccentricity Angular Increment	90.0 deg		
Center of Rigidity Location (calculated) . . .		Accidental Eccentricity:	
"X" dist. from Datum	36.176 ft	Along "X" Axis	+ / - 0.0 ft
"Y" dist. from Datum	27.132 ft	Along "Y" Axis	+ / - 0.0 ft

Wall Information

Label : A		X C.G. Location	77.5 ft	Length	25 ft
Local Flexibility:		Y C.G. Location	30 ft	Height	12 ft
		Angle CCW	126.87 deg	Thickness	8 in
Along local 'y'	5.3840E-005 in / k	Fixity About Local 'x'	Fix-Fix	Eb - Bending	3.6 Mpsi
Along local 'x'	Neglect	Fixity About Local 'y'	Fix-Fix	Ev - Shear	1.44 Mpsi
Label : B		X C.G. Location	35 ft	Length	20 ft
Local Flexibility:		Y C.G. Location	0 ft	Height	12 ft
		Angle CCW	0 deg	Thickness	8 in
Along local 'y'	7.0000E-005 in / k	Fixity About Local 'x'	Fix-Fix	Eb - Bending	3.6 Mpsi
Along local 'x'	Neglect	Fixity About Local 'y'	Fix-Fix	Ev - Shear	1.44 Mpsi
Label : C		X C.G. Location	0 ft	Length	20 ft
Local Flexibility:		Y C.G. Location	10 ft	Height	12 ft
		Angle CCW	90 deg	Thickness	8 in
Along local 'y'	7.0000E-005 in / k	Fixity About Local 'x'	Fix-Fix	Eb - Bending	3.6 Mpsi
Along local 'x'	Neglect	Fixity About Local 'y'	Fix-Fix	Ev - Shear	1.44 Mpsi

ANALYSIS SUMMARY

Maximum shear forces applied to resisting elements. Eccentricity with respect to Center of Rigidity

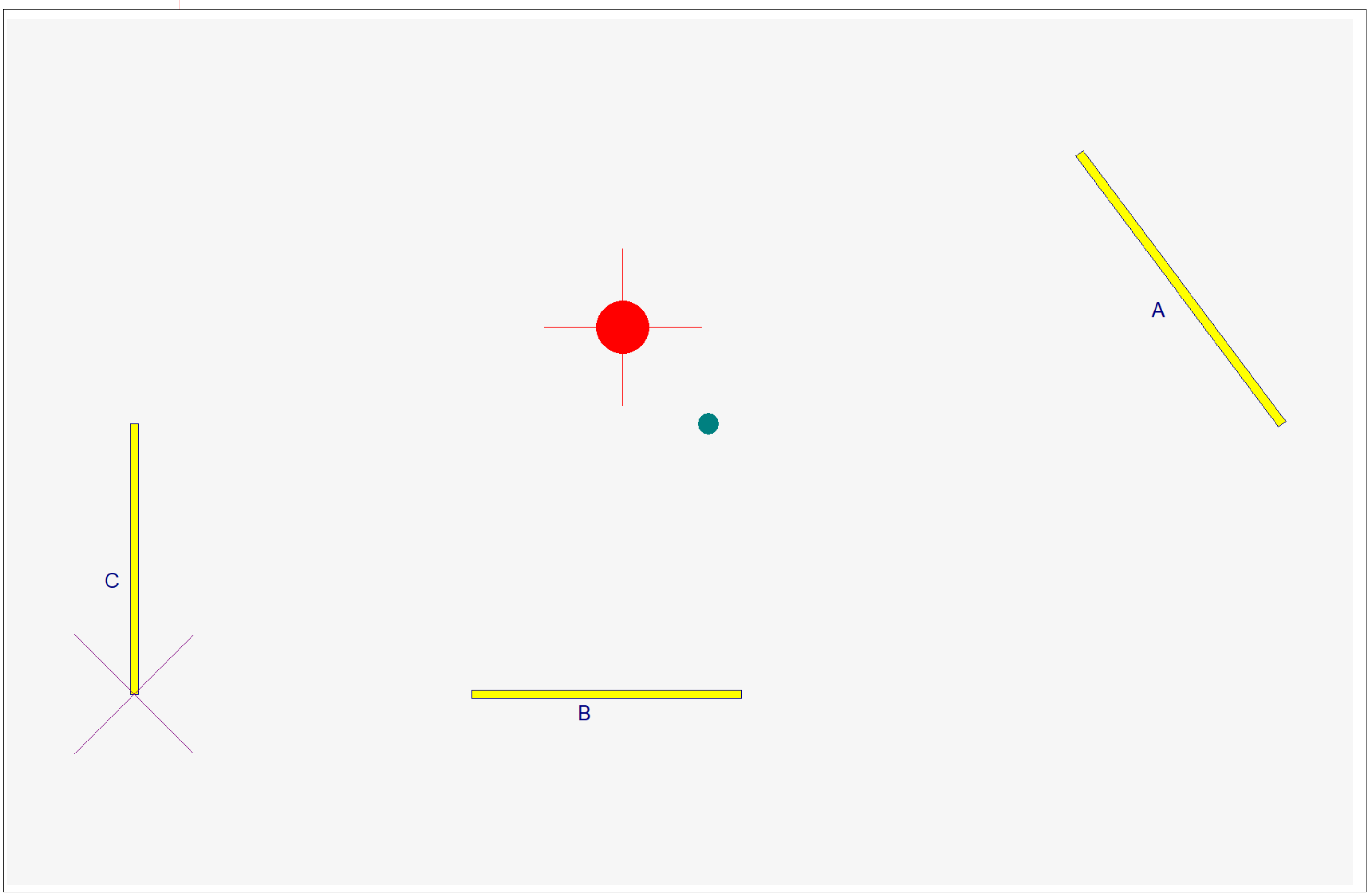
	Max Shear along Member Local "y-y" Axis				Max Shear along Member Local "x-x" Axis			
Resisting Element	Load Condition	X-Ecc (ft)	Y-Ecc (ft)	Shear (k)	Load Condition	X-Ecc (ft)	Y-Ecc (ft)	Shear (k)
A	135.00 deg	6.32	-7.13	**11.049**		0.00	0.00	**0.000**
B	135.00 deg	6.32	-7.13	**-7.513**		0.00	0.00	**0.000**
C	135.00 deg	6.32	-7.13	**5.303**		0.00	0.00	**0.000**

Torsional Analysis of Rigid Diaphragm

DESCRIPTION: Verification Example

Layout of Resisting Elements

Legend : Defined Wall | Datum | Center of Rigidity | Center of Mass | Accidental eccentricity application boundary



Torsional Analysis of Rigid Diaphragm

DESCRIPTION: Verification Example

Analysis Notes

This calculation evaluates how a rigid diaphragm distributes applied lateral loads to its resisting elements based on their relative stiffness.

For Wall or Bending Member elements, flexibility along the local x and y axes is calculated from user-defined section properties and end-fixity. For Generic Resisting Elements, flexibility values are entered directly. These flexibility values are then used to determine element local stiffnesses.

Each element location is specified by X and Y coordinates to its center of gravity, along with an optional counter-clockwise rotation relative to the global axes. This positional and orientation data is used to transform local stiffnesses into the global coordinate system. The resulting global stiffnesses establish the diaphragm center of rigidity and dictate how shear is distributed among elements according to their positions and stiffnesses.

Once the global stiffnesses have been defined, loading is applied to the system. The applied loads consist of a primary shear and an optional orthogonal shear. User-defined accidental eccentricities and plan dimensions define an elliptical load path. Analysis proceeds along this path in discrete stations. At each station, the applied shear is rotated through a series of specified load angles, each representing a different direction of loading relative to the global axes. For every load angle, direct and torsional shears are calculated for all elements before advancing to the next station along the ellipse.

This process generates a detailed set of results for each element, reflecting its response to numerous load angles applied at varying eccentricities from the center of load application. Global X and Y forces and the corresponding local shears are calculated for every element, and the governing forces and shears are identified and reported.