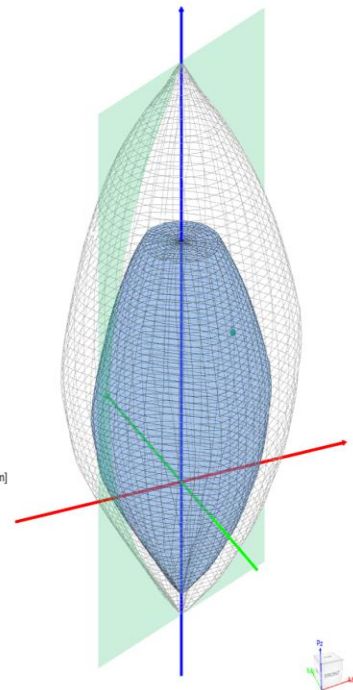
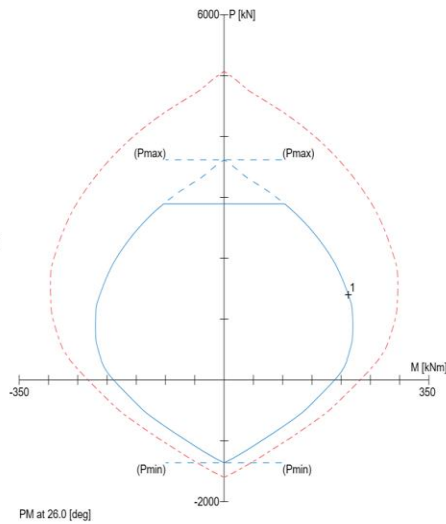
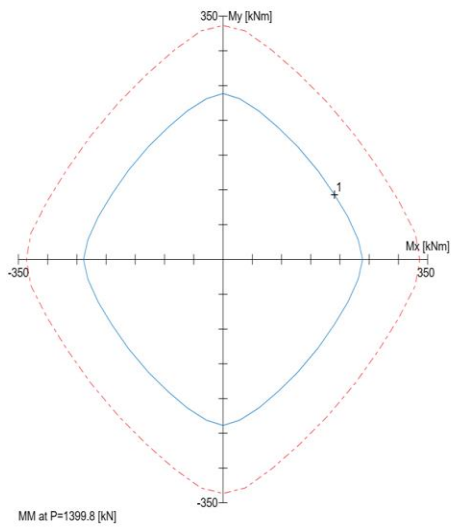
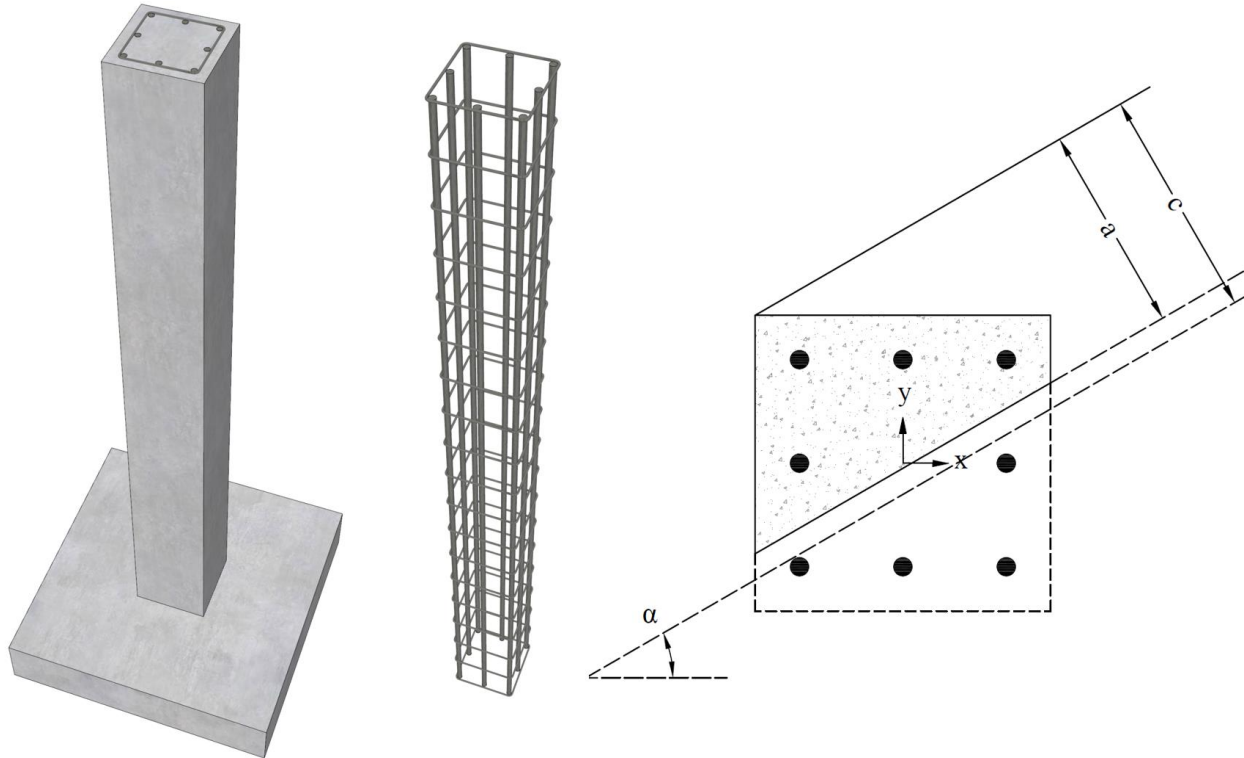


**Biaxial Bending Interaction Diagram for Square Reinforced Concrete Column Design (CSA A23.3-19)**



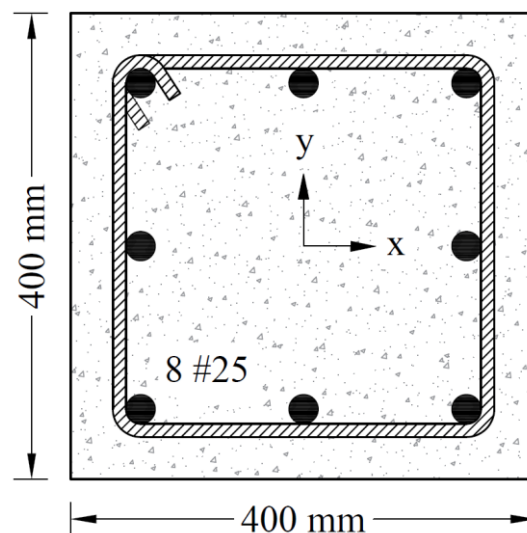
### Biaxial Bending Interaction Diagram for Square Reinforced Concrete Column Design (CSA A23.3-19)

Biaxial bending of columns occurs when the loading causes bending simultaneously about both principal axes. The commonly encountered case of such loading occurs in corner columns. Corner and other columns exposed to known moments about each axis simultaneously should be designed for the combined effect of biaxial bending and axial load.

A uniaxial interaction diagram defines the load-moment strength along a single plane of a section under an axial load  $P$  and a uniaxial moment  $M$ . The biaxial bending resistance of an axially loaded column can be represented schematically as a surface formed by a series of uniaxial interaction curves drawn radially from the  $P$  axis. Data for these intermediate curves are obtained by varying the angle of the neutral axis (for assumed strain configurations) with respect to the major axes.

The difficulty associated with the determination of the strength of reinforced concrete columns subjected to combined axial load and biaxial bending is primarily an arithmetic one. The bending resistance of an axially loaded column about a particular skewed axis is determined through iterations involving simple but lengthy calculations. These extensive calculations are compounded when optimization of the reinforcement or cross-section is sought.

This example demonstrates the determination of the factored axial load resistance,  $P_r$ , and the factored moments resistance,  $M_{rx}$  and  $M_{ry}$ , corresponding to the following case: The neutral axis position crosses the vertical axis of symmetry ( $y$ -axis) at 242.24 mm. below the top of the section, at an angle of  $30^\circ$  counterclockwise from the  $x$ -axis of the cross section. The figure below shows the reinforced concrete square column cross section in consideration. The calculated values of the column axial resistance and biaxial bending resistance are compared with the exact values from [spColumn](#) engineering software program from [StructurePoint](#). The steps to develop the three-dimensional failure surface (interaction diagram) using [spColumn](#) will be shown in detail as well.



**Figure 1 – Reinforced Concrete Column Cross-Section**

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## Code

Design of Concrete Structures (CSA A23.3-19)

## References

- Reinforced Concrete Mechanics and Design, 8<sup>th</sup> Edition, 2021, James Wight, Pearson, Example 11-5
- Notes on ACI 318-11 Building Code Requirements for Structural Concrete, Twelfth Edition, 2013 Portland Cement Association
- [spColumn Engineering Software Program Manual v10.10, STRUCTUREPOINT, 2023](#)
- [“Interaction Diagram - Tied Reinforced Concrete Column \(Using CSA A23.3-14\)”](#) Design Example, [STRUCTUREPOINT](#), 2017
- [“Biaxial Bending Interaction Diagrams for Square Reinforced Concrete Column Design \(ACI 318-19\)”](#) Design Example, [STRUCTUREPOINT](#), 2022
- [“Biaxial Bending Interaction Diagrams for Rectangular Reinforced Concrete Column Design \(ACI 318-19\)”](#) Design Example, [STRUCTUREPOINT](#), 2022
- [“Biaxial Bending Interaction Diagrams for C-Shaped Concrete Core Wall Design \(ACI 318-19\)”](#) Design Example, [STRUCTUREPOINT](#), 2022
- [“Biaxial Bending Interaction Diagrams for Spiral Reinforced Circular Concrete Column Design \(ACI 318-19\)”](#) Design Example, [STRUCTUREPOINT](#), 2022
- [“Manual Design Procedure for Columns and Walls with Biaxial Bending \(ACI 318-11/14/19\)”](#) Design Example, [STRUCTUREPOINT](#), 2022

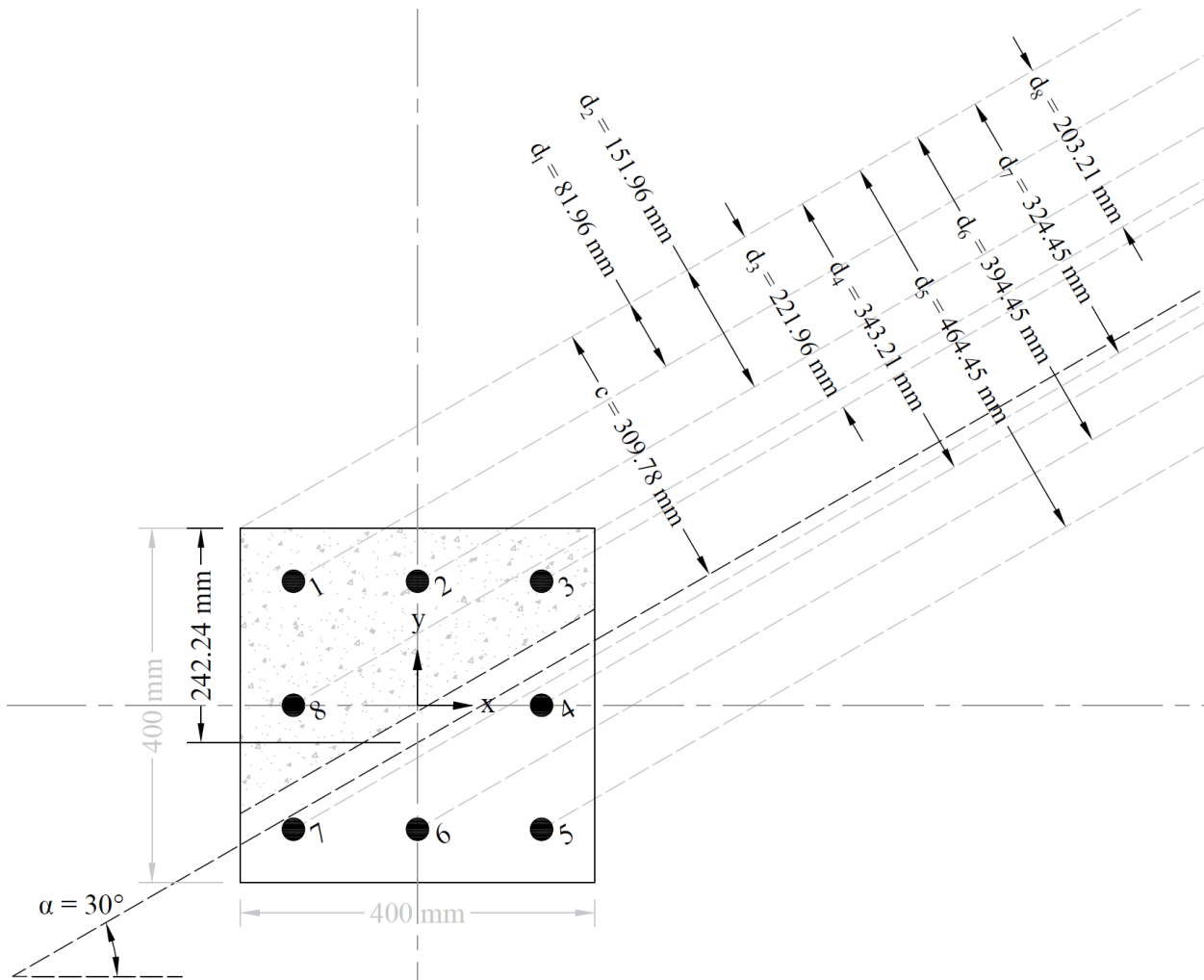
## Design Data

$$f_c' = 27.5 \text{ MPa}$$

$$f_y = 400 \text{ MPa}$$

Cover = 60 mm to bar center of the reinforcement

Column dimensions and reinforcement locations are shown in following figure.

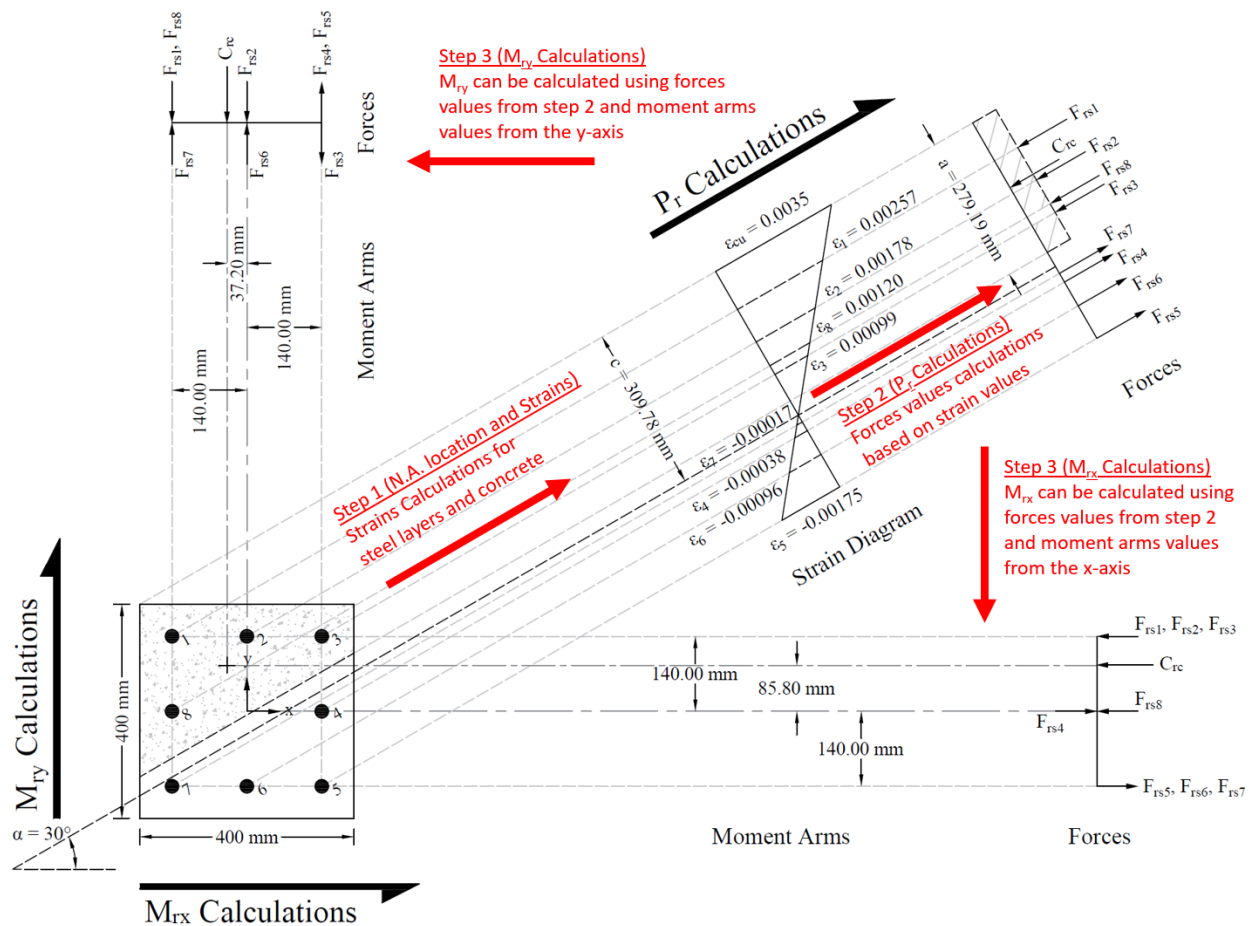


**Figure 2 – Reinforced Concrete Column Cross-Section and Reinforcement Locations**

**Solution**

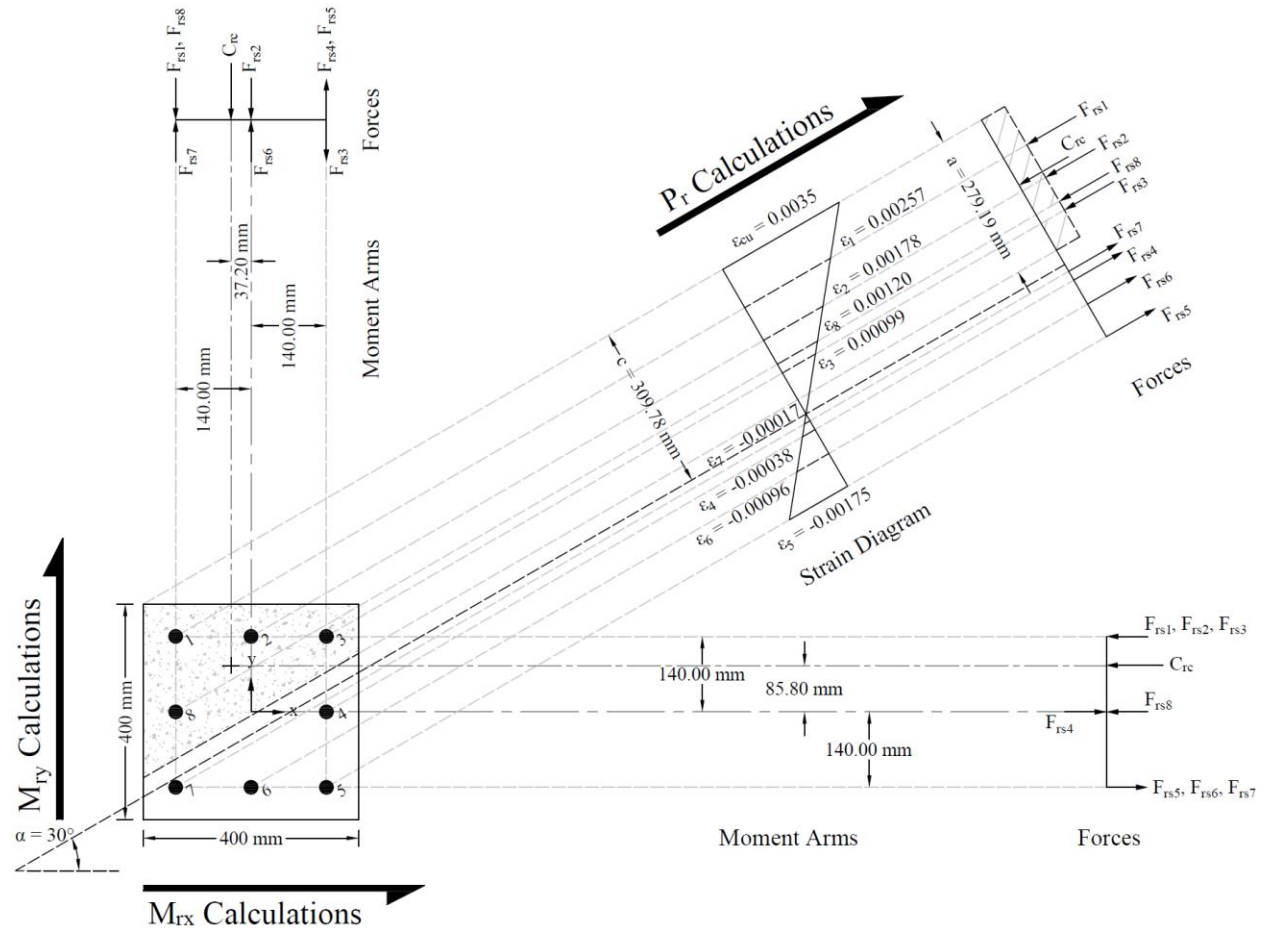
In a reinforced concrete column, the determination of the axial load resistance,  $P_r$ , and the biaxial moment resistance,  $M_{rx}$  and  $M_{ry}$ , involves a trial-and-error process for calculating the neutral axis depth and angle  $\alpha$ . The neutral axis depth and angle are provided as an input (The neutral axis position crosses the vertical axis of symmetry of the section at 242.24 mm leading to  $c = 309.78$  mm and an angle of  $\alpha = 30.0^\circ$ ) for illustration.

The steps to calculate biaxial flexural strength of a reinforced concrete column for a given nominal axial strength and moment ratio of biaxial bending moments is discussed in details in “[Biaxial Bending Interaction Diagrams for Rectangular Reinforced Concrete Column Design \(ACI 318-19\)](#)” design example.



**Figure 3 – Axial Load Resistance and Biaxial Moment Resistance Calculation Methods for a Reinforced Concrete Column**

**1. Concrete Column Biaxial Resistance Calculations**



**Figure 4 – Strains, Forces, and Moment Arms Diagram**

### 1.1. Location of Neutral Axis and Concrete Compression Force

The trial-and-error process for calculating the neutral axis depth and angle  $\alpha$  is not required in this example since these values are given ( $c = 309.78$  mm and  $\alpha = 30.0^\circ$ ). Where  $c$  is the distance from the fiber of maximum compressive strain to the neutral axis and  $\alpha$  is the angle of the neutral axis.

CSA A23.3-19 (3.2)

$$\varepsilon_y = \frac{f_y}{E_s} = \frac{400}{200,000} = 0.0020$$

$$\varepsilon_{s5} = (c - d_s) \times \frac{\varepsilon_{cu}}{c} = (309.78 - 464.45) \times \frac{0.0035}{309.78} = -0.00175 \text{ (Tension)} < \varepsilon_y \rightarrow \text{reinforcement has not yielded}$$

$$\phi_c = 0.65 \quad \text{CSA A23.3-19 (8.4.2)}$$

$$\phi_s = 0.85 \quad \text{CSA A23.3-19 (8.4.3(a))}$$

$$a = \beta_1 \times c = 0.901 \times 309.78 = 279.19 \text{ mm} \quad \text{CSA A23.3-19 (10.1.7)}$$

$$\varepsilon_{cu} = 0.0035 \quad \text{CSA A23.3-19 (10.1.3)}$$

Where:

$a$  = Depth of equivalent rectangular stress block

$$\alpha_1 = 0.85 - 0.0015 \times f'_c = 0.85 - 0.0015 \times 27.5 = 0.809 > 0.67 \quad \text{CSA A23.3-19 (Equation 10.1)}$$

$$\beta_1 = 0.97 - 0.0025 \times f'_c = 0.97 - 0.0025 \times 27.5 = 0.901 > 0.67 \quad \text{CSA A23.3-19 (Equation 10.2)}$$

$$C_{rc} = \alpha_1 \times \phi_c \times f'_c \times A_{comp} = 0.809 \times 0.65 \times 27.5 \times 82,766.18 = 1196.50 \text{ kN (Compression)}$$

CSA A23.3-19 (10.1.7)

Where (see the following figure):

$$A_{comp} = A_1 + A_2 = (91.45 \times 400.00) + \left( \frac{1}{2} \times 230.94 \times 400.00 \right) = 82,768.00 \text{ mm}^2$$

$$\bar{x} = \left( \frac{A_1 \times \bar{x}_1 + A_2 \times \bar{x}_2}{A_1 + A_2} \right) - 200.00 = \left( \frac{36,580.00 \times 200.00 + 46,188.00 \times 133.33}{36,580.00 + 46,188.00} \right) - 200.00 = -37.20 \text{ mm}$$

$$\bar{y} = \left( \frac{A_1 \times \bar{y}_1 + A_2 \times \bar{y}_2}{A_1 + A_2} \right) - 122.39 = \left( \frac{36,580.00 \times 276.66 + 46,188.00 \times 153.96}{36,580.00 + 46,188.00} \right) - 122.39 = 85.80 \text{ mm}$$



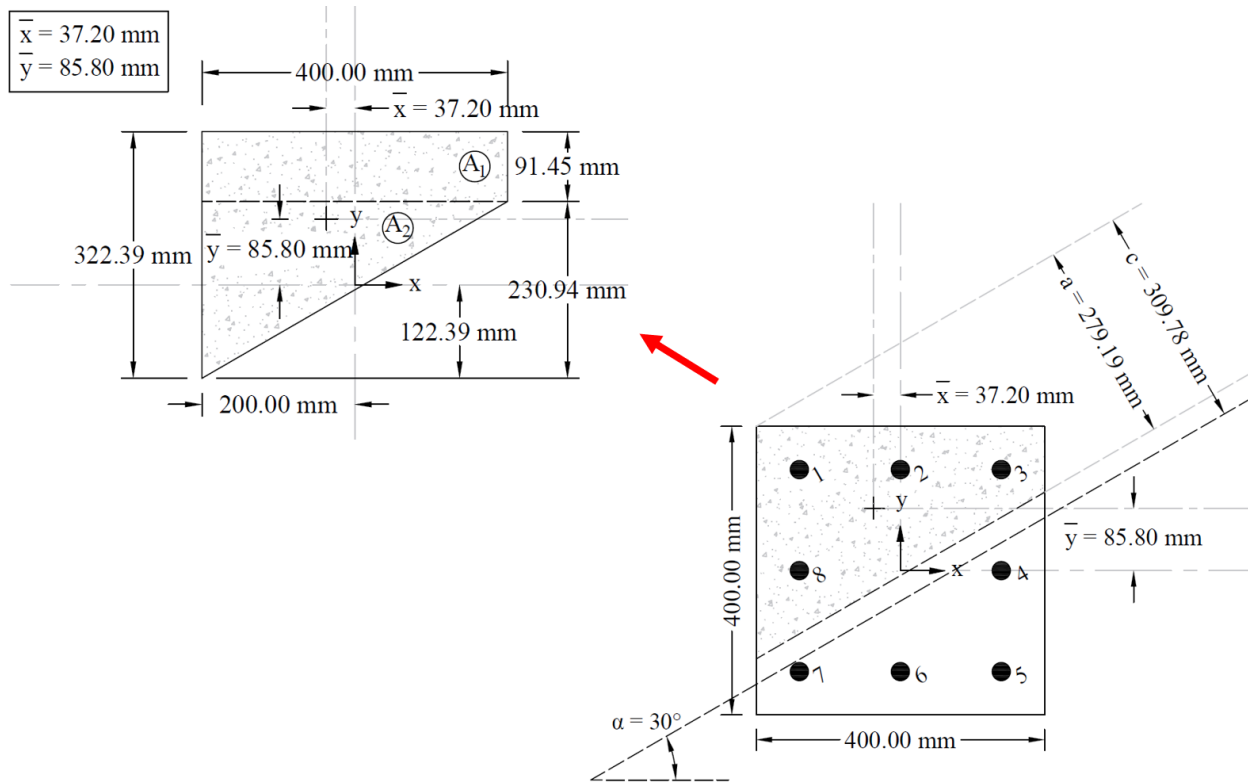


Figure 5 – Cracked Concrete Column Section Centroid Calculations

## 1.2. Strains and Forces Determination in Reinforcement Layers

The following shows the calculations of forces in the reinforcement layers with the extreme tension (at bar 5) and extreme compression (at bar 1) strains. The calculations for the rest of layers are shown the table at the end of this section.

For extreme tension reinforcement layer (at bar 5):

$$\varepsilon_{s5} = -0.00175 \text{ (Tension)} < \varepsilon_y \rightarrow \text{reinforcement has not yielded}$$

$$\therefore f_{s5} = \varepsilon_{s5} \times E_s = -0.00175 \times 200,000 = -349.49 \text{ MPa}$$

$$F_{rs5} = \phi_s \times f_{s5} \times A_{s5} = 0.85 \times -349.49 \times (1 \times 500) = -148.53 \text{ kN (Tension)}$$

For extreme compression reinforcement layer (at bar 1):

$$\varepsilon_{s1} = (c - d_1) \times \frac{\varepsilon_{cu}}{c} = (309.78 - 81.96) \times \frac{0.0035}{309.78} = 0.00257 \text{ (Compression)} > \varepsilon_y \rightarrow \text{reinforcement has yielded}$$

$$\therefore f_{s1} = f_y = 400 \text{ MPa}$$

The area of the reinforcement in this layer is included in the area used to compute  $C_{rc}$  ( $a = 279.19 \text{ mm} > d_1 = 81.96 \text{ mm}$ ). As a result, it is necessary to subtract  $\alpha_1 \phi_c f_c'$  from  $\phi_s f_s$  before computing  $F_{rs1}$ :

$$F_{rs1} = (\phi_s \times f_s - \alpha_1 \times \phi_c \times f_c') \times A_{s1} = (0.85 \times 400 - 0.809 \times 0.65 \times 27.5) \times (1 \times 500) = 162.77 \text{ kN (Compression)}$$

The same procedure shown above can be repeated to calculate the forces in the remaining reinforcement locations, results are summarized in the following table:

Table 1 - Strains, internal force resultants and Moments									
Location	d, mm	$\epsilon$ , mm/mm	$f_s$ , MPa	$F_{rs}$ , kN	$C_{rc}$ , kN	Moment arm (x), mm	$M_{ry}$ , kN-m	Moment arm (y), mm	$M_{rx}$ , kN-m
Concrete	---	0.00350	---	---	1196.53	37.20	44.52	85.80	102.66
Bar 1	81.962	0.00257	400.00	162.77*	---	140.00	22.79	140.00	22.79
Bar 2	151.962	0.00178	356.62	144.34*	---	0.00	0.00	140.00	20.21
Bar 3	221.962	0.00099	198.45	77.11*	---	-140.00	-10.80	140.00	10.80
Bar 4	343.205	-0.00038	-75.52	-32.1	---	-140.00	4.49	0.00	0.00
Bar 5	464.449	-0.00175	-349.49	-148.53	---	-140.00	20.79	-140.00	20.79
Bar 6	394.449	-0.00096	-191.31	-81.31	---	0.00	0.00	-140.00	11.38
Bar 7	324.449	-0.00017	-33.14	-14.08	---	140.00	-1.97	-140.00	1.97
Bar 8	203.205	0.00120	240.83	95.12*	---	140.00	13.32	0.00	0.00
Axial Load and Biaxial Bending Moments Resistance			$P_r$ , kN	1399.85		$M_{ry}$ , kN-m	93.14	$M_{rx}$ , kN-m	190.60

\* The area of the reinforcement in this layer has been included in the area used to compute  $C_{rc}$ . As a result,  $\alpha_1 \phi_c f_c'$  is subtracted from  $\phi_s f_s$  in the computation of  $F_{rs}$ .

### 1.3. Calculation of $P_r$ , $M_{rx}$ and $M_{ry}$

$$P_r = C_{rc} + \sum F_{rs} \quad (+) = \text{Compression} \quad (-) = \text{Tension}$$

$$M_{ry} = C_{rc} \times \left( \frac{b}{2} - x_c \right) + \sum_{i=1}^{n=8} \left( F_{rsi} \times \left( \frac{b}{2} - x_i \right) \right) \quad (+) = \text{Counter Clockwise} \quad (-) = \text{Clockwise}$$

$$M_{rx} = C_{rc} \times \left( \frac{h}{2} - y_c \right) + \sum_{i=1}^{n=8} \left( F_{rsi} \times \left( \frac{h}{2} - y_i \right) \right) \quad (+) = \text{Counter Clockwise} \quad (-) = \text{Clockwise}$$

## 2. Column Biaxial Bending Interaction Diagram – spColumn Software

[spColumn](#) is a StructurePoint software program that performs the analysis and design of reinforced concrete sections subjected to axial force combined with uniaxial or biaxial bending. Using the provisions of the Strength Design Method and Unified Design Provisions, slenderness considerations are used for moment magnification due to second order effect (P-Delta) for sway and non-sway frames.

For biaxial runs, the values of maximum compressive axial load capacity and maximum tensile load capacity are computed. These two values set the range within which the moment capacities are computed for a predetermined number of axial load values. For each level of axial load, the section is rotated in 10-degree increments from 0 degrees to 360 degrees and the  $M_x$  and  $M_y$  moment capacities are computed. Thus, for each level of axial load, an  $M_x$ - $M_y$  contour is developed. Repeating this for the entire range of axial loads, the three-dimensional failure surface is computed. A three-dimensional visualization of the resulting entire nominal and factored failure surface is provided to support enhanced understanding of the section capacity.

The “**biaxial**” feature allows the user to investigate the P-M interaction diagrams, the  $M_x$ - $M_y$  moment contour plots, as well as the 3D failure surface for even the most irregular column and shear wall sections quickly, simply, and accurately.

For this column section, we ran in investigation mode with “**biaxial**” option for “Run Axis” using the CSA A23.3-19.

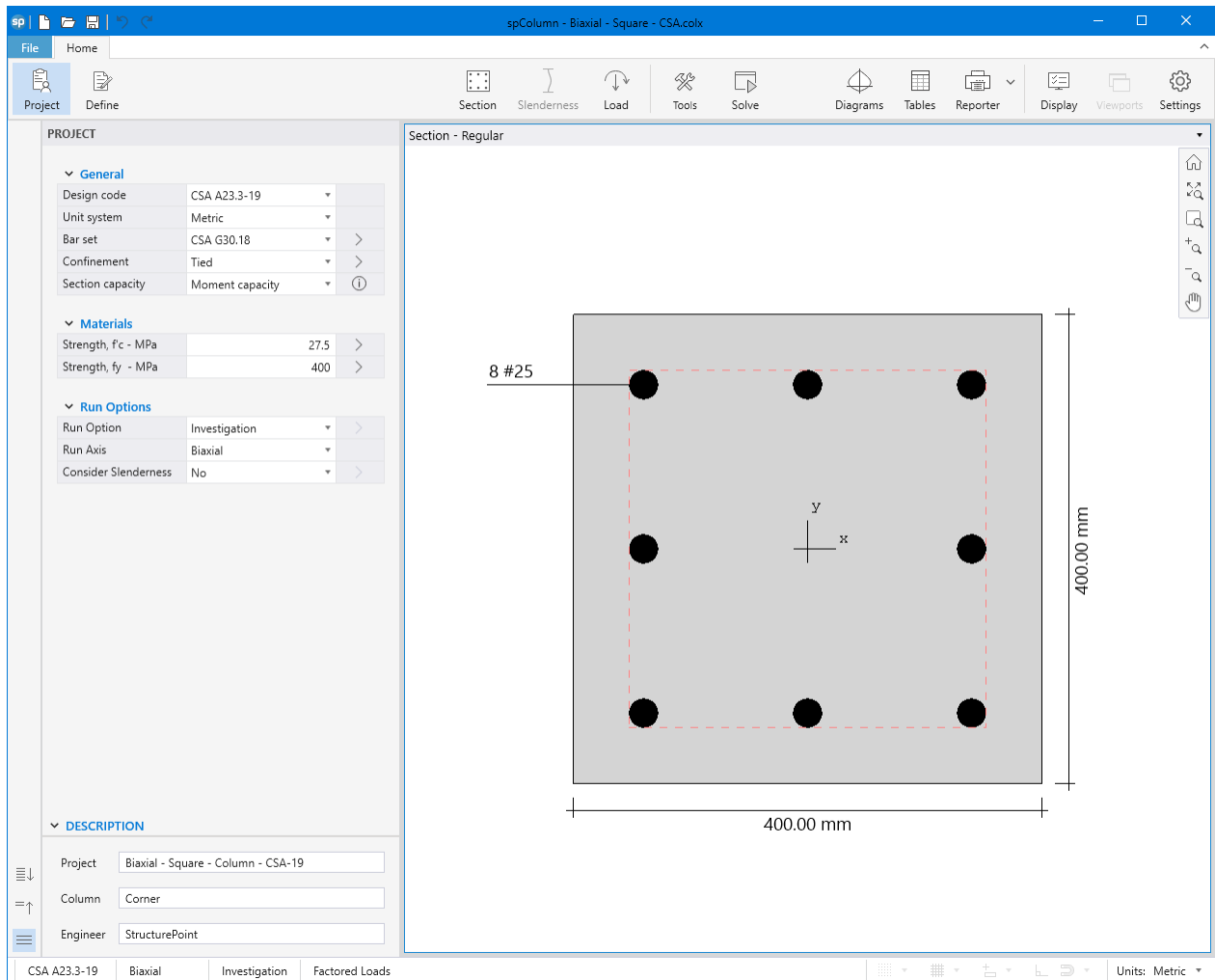


Figure 6 – spColumn Interface

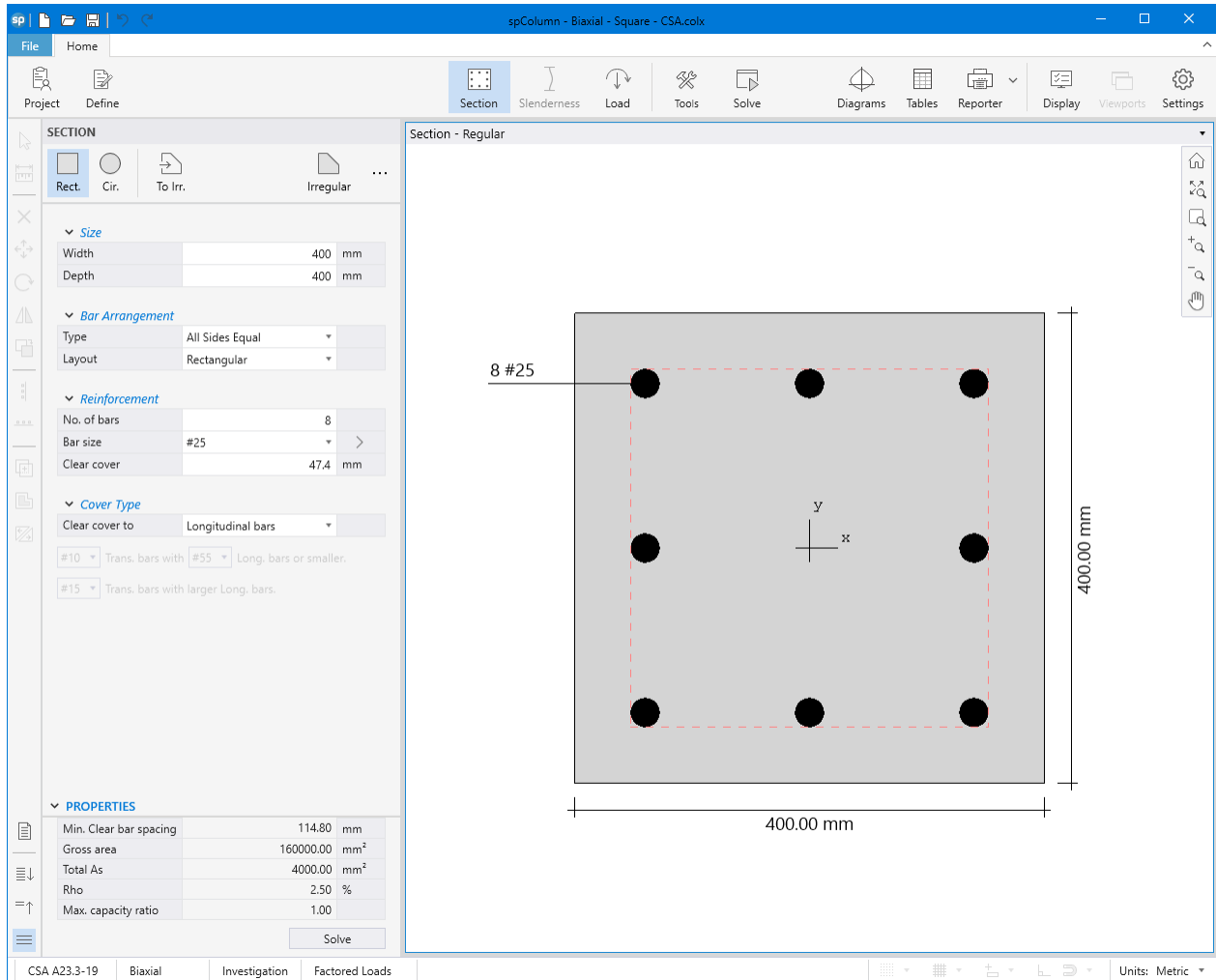


Figure 7 – spColumn Model Editor

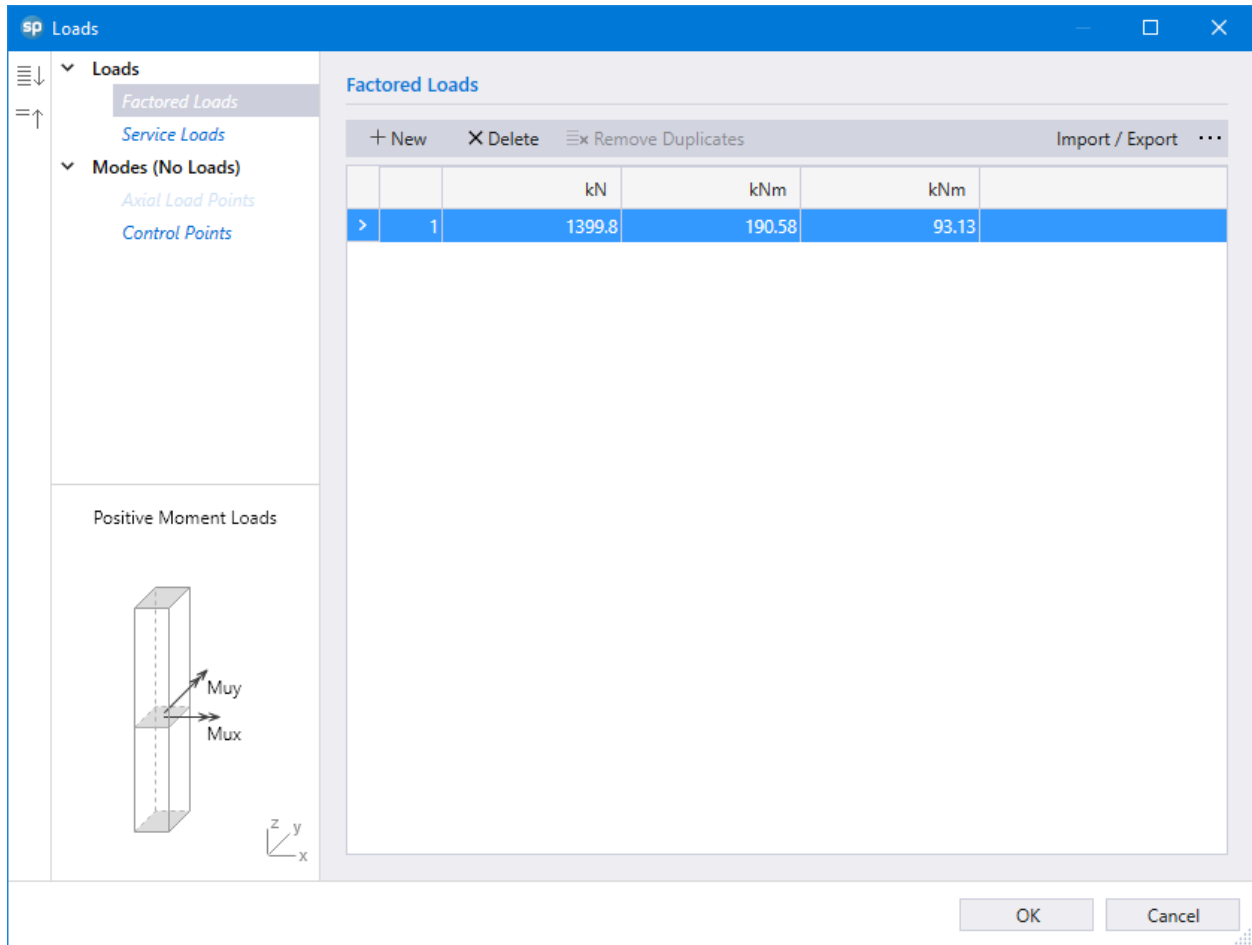


Figure 8 – Defining Loads / Modes (spColumn)

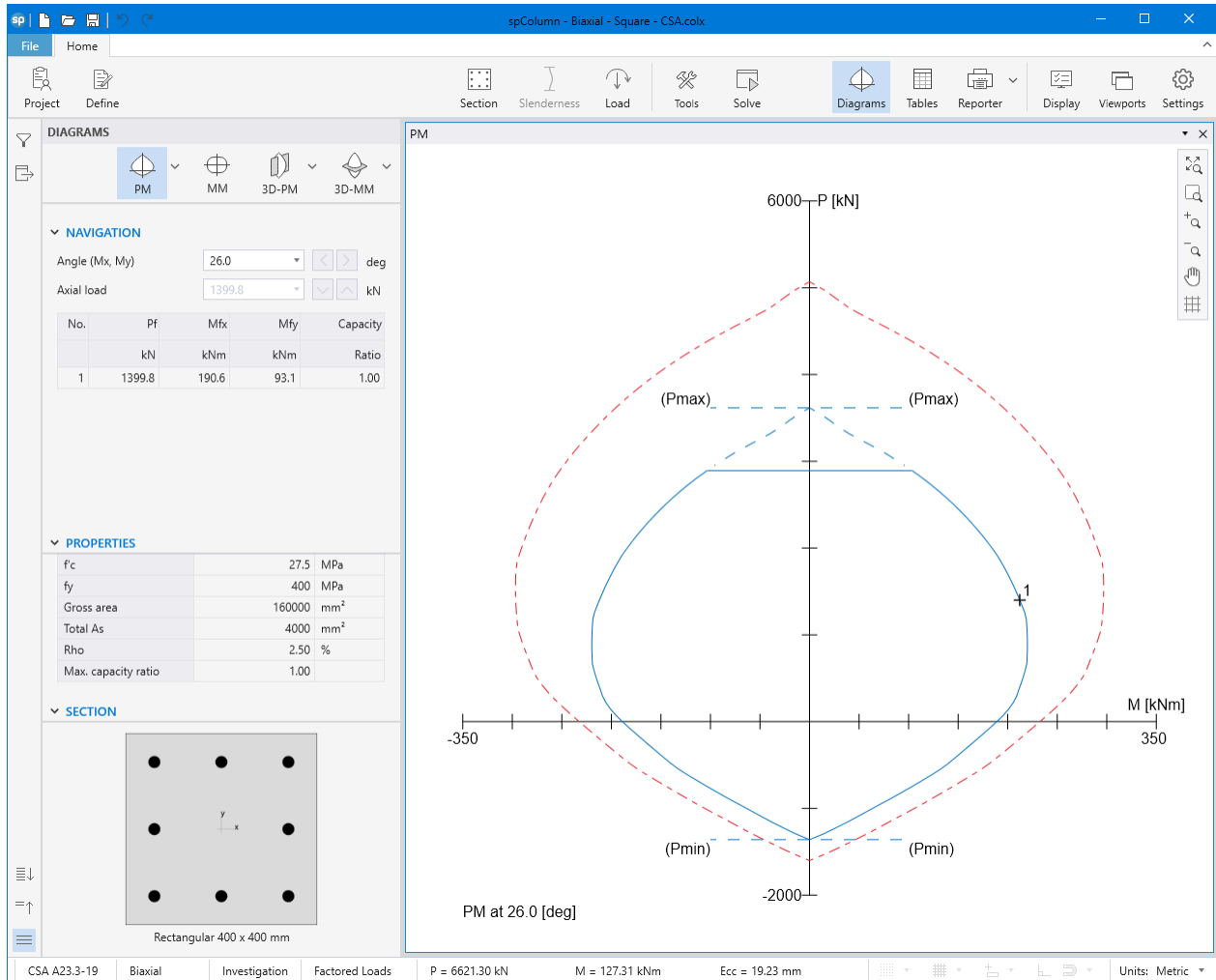


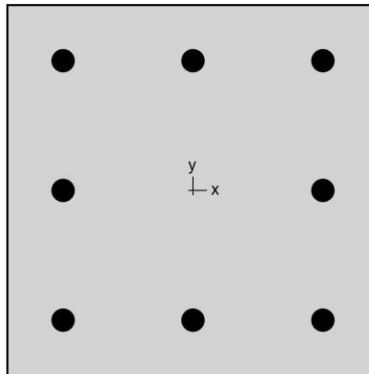
Figure 9 – Column Section Interaction Diagram at 26° (spColumn)



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spColumn v10.10 (TM)  
Computer program for the Strength Design of Reinforced Concrete Sections  
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StructurePoint

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## 1. General Information

File Name	E:\StructurePoint\...Biaxial - Square - CSA.colx
Project	Biaxial - Square - Column - CSA-19
Column	Corner
Engineer	StructurePoint
Code	CSA A23.3-19
Bar Set	CSA G30.18
Units	Metric
Run Option	Investigation
Run Axis	Biaxial
Slenderness	Not Considered
Column Type	Structural
Capacity Method	Moment capacity

## 2. Material Properties

### 2.1. Concrete

Type	Standard
$f'_c$	27.5 MPa
$E_c$	25800.8 MPa
$f_c$	22.2406 MPa
$\epsilon_u$	0.0035 mm/mm
$\beta_1$	0.90125

### 2.2. Steel

Type	Standard
$f_y$	400 MPa
$E_s$	200000 MPa
$\epsilon_{ty}$	0.002 mm/mm

## 3. Section

### 3.1. Shape and Properties

Type	Rectangular
Width	400 mm
Depth	400 mm
$A_g$	160000 mm <sup>2</sup>
$I_x$	2.13333e+009 mm <sup>4</sup>
$I_y$	2.13333e+009 mm <sup>4</sup>
$r_x$	115.47 mm
$r_y$	115.47 mm
$X_o$	0 mm
$Y_o$	0 mm

### 3.2. Section Figure

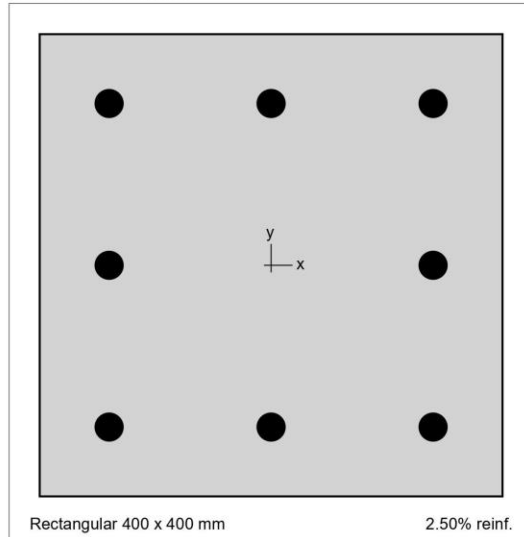


Figure 1: Column section

## 4. Reinforcement

### 4.1. Bar Set: CSA G30.18

Bar	Diameter mm	Area mm <sup>2</sup>	Bar	Diameter mm	Area mm <sup>2</sup>	Bar	Diameter mm	Area mm <sup>2</sup>
#10	11.30	100.00	#15	16.00	200.00	#20	19.50	300.00
#25	25.20	500.00	#30	29.90	700.00	#35	35.70	1000.00
#45	43.70	1500.00	#55	56.40	2500.00			

### 4.2. Confinement and Factors

Confinement type	Tied
For #55 bars or less	#10 ties
For larger bars	#15 ties
<b>Material Resistance Factors</b>	
Axial compression, (a)	0.8
Steel ( $\phi_s$ )	0.85
Concrete ( $\phi_c$ )	0.65
Minimum dimension, h	400 mm

### 4.3. Arrangement

Pattern	All sides equal
Bar layout	Rectangular
Cover to	Longitudinal bars
Clear cover	47.4 mm

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Bars	8 #25
Total steel area, $A_s$	4000 mm <sup>2</sup>
Rho	2.50 %
Minimum clear spacing	115 mm

### 5. Control Points

About Point	P kN	X-Moment kNm	Y-Moment kNm	NA Depth mm	d, Depth mm	$\epsilon_t$
X @ Max compression	3615.2	0.00	0.00	793	340	-0.00200
X @ Allowable comp.	2892.2	104.25	0.00	390	340	-0.00045
X @ $f_s = 0.0$	2490.8	151.27	0.00	340	340	0.00000
X @ $f_s = 0.5 f_y$	1742.0	215.47	0.00	264	340	0.00100
X @ Balanced point	1150.9	255.34	0.00	216	340	0.00200
X @ Pure bending	0.0	198.28	0.00	99	340	0.00847
X @ Max tension	-1360.0	0.00	0.00	0	340	9.99999
Y @ Max compression	3615.2	0.00	0.00	793	340	-0.00200
Y @ Allowable comp.	2892.2	0.00	104.25	390	340	-0.00045
Y @ $f_s = 0.0$	2490.8	0.00	151.27	340	340	0.00000
Y @ $f_s = 0.5 f_y$	1742.0	0.00	215.47	264	340	0.00100
Y @ Balanced point	1150.9	0.00	255.34	216	340	0.00200
Y @ Pure bending	0.0	0.00	198.28	99	340	0.00847
Y @ Max tension	-1360.0	0.00	0.00	0	340	9.99999
-X @ Max compression	3615.2	0.00	0.00	793	340	-0.00200
-X @ Allowable comp.	2892.2	-104.25	0.00	390	340	-0.00045
-X @ $f_s = 0.0$	2490.8	-151.27	0.00	340	340	0.00000
-X @ $f_s = 0.5 f_y$	1742.0	-215.47	0.00	264	340	0.00100
-X @ Balanced point	1150.9	-255.34	0.00	216	340	0.00200
-X @ Pure bending	0.0	-198.28	0.00	99	340	0.00847
-X @ Max tension	-1360.0	0.00	0.00	0	340	9.99999
-Y @ Max compression	3615.2	0.00	0.00	793	340	-0.00200
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-Y @ Balanced point	1150.9	0.00	-255.34	216	340	0.00200
-Y @ Pure bending	0.0	0.00	-198.28	99	340	0.00847
-Y @ Max tension	-1360.0	0.00	0.00	0	340	9.99999

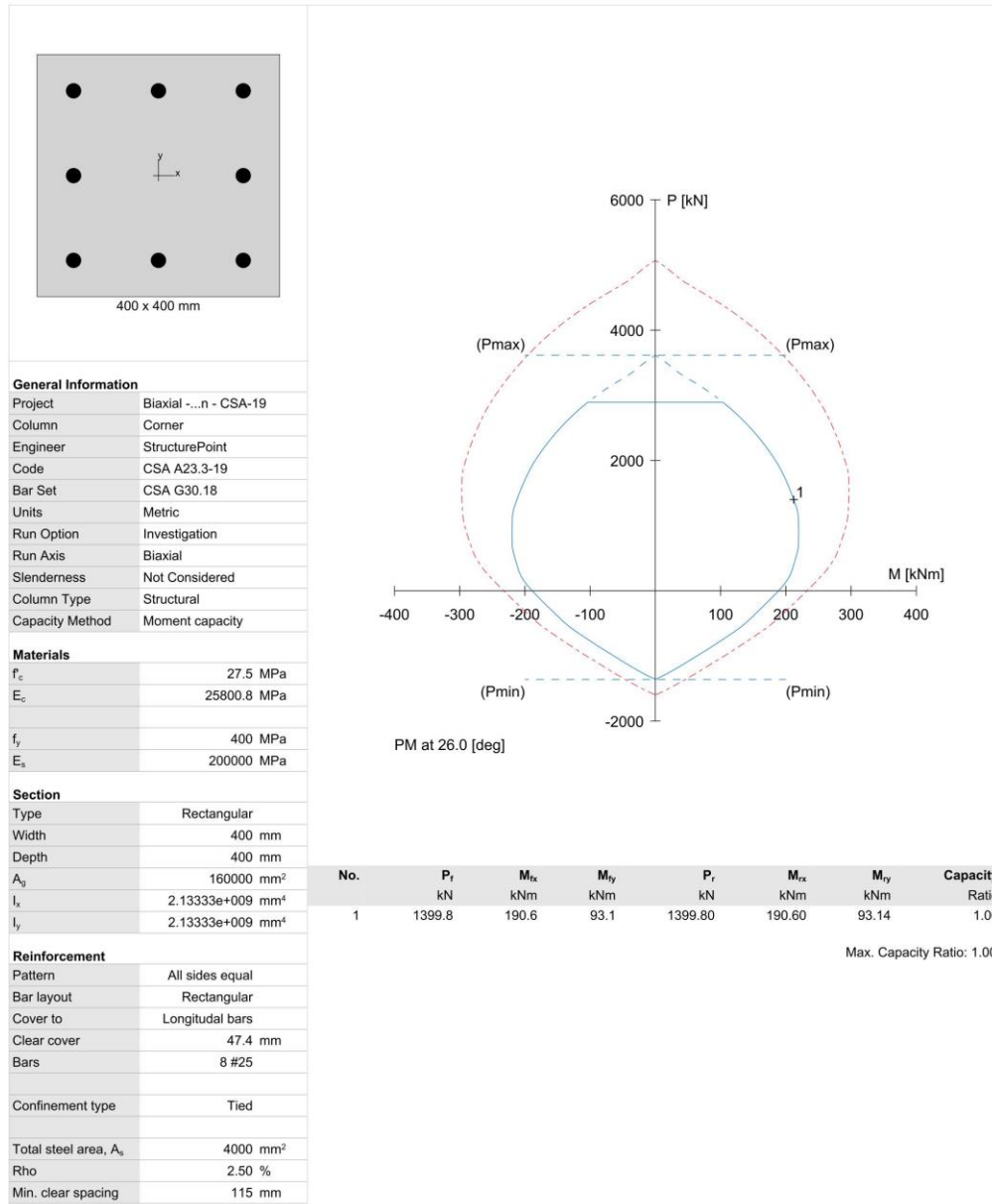
### 6. Factored Loads and Moments with Corresponding Capacity Ratios

NOTE: Calculations are based on "Moment Capacity" Method.

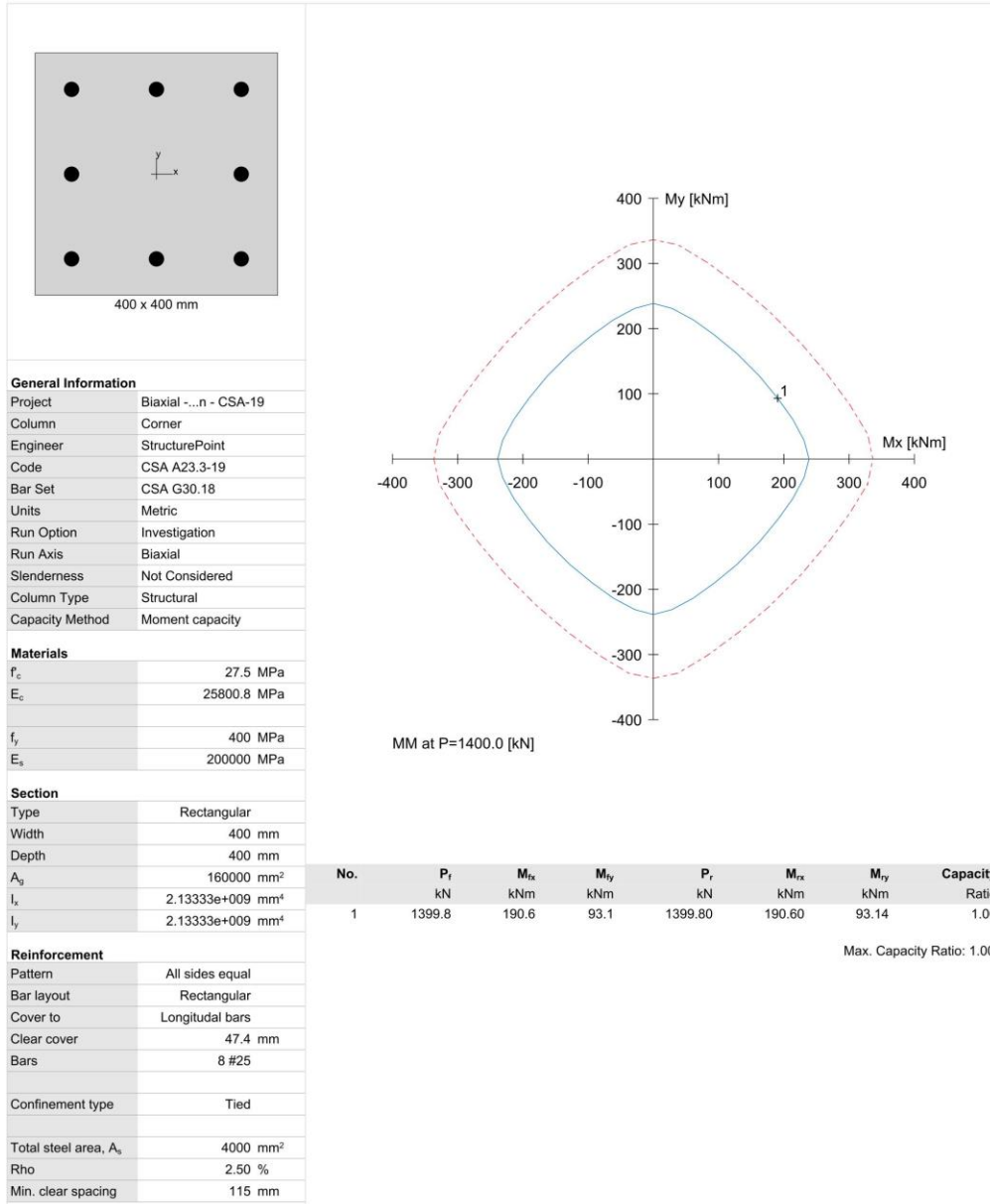
No.	Demand			Capacity			Parameters at Capacity		Capacity Ratio
	$P_f$ kN	$M_{fx}$ kNm	$M_{fy}$ kNm	$P_r$ kN	$M_{rx}$ kNm	$M_{ry}$ kNm	NA Depth mm	$\epsilon_t$	
1	1399.80	190.58	93.13	1399.80	190.60	93.14	310	0.00175	1.00

## 7. Diagrams

### 7.1. PM at $\theta=26$ [deg]



**7.2. MM at P=1400 [kN]**



### 3. Summary and Comparison of Design Results

Table 2 – Comparison of Results		
Parameter	Hand	<a href="#">spColumn</a>
c, mm	309.78	310
d <sub>s</sub> , mm	464.45	464.45
ε <sub>s5</sub> , mm/mm	0.00175	0.00175
P <sub>r</sub> , kN	1399.85	1399.80
M <sub>rx</sub> , kN-m	190.60	190.60
M <sub>ry</sub> , kN-m	93.14	93.14

In all of the hand calculations illustrated above, the results are in good agreement with the automated exact results obtained from the [spColumn](#) program.

#### 4. Conclusions & Observations

The analysis of the reinforced concrete section performed by [spColumn](#) conforms to the provisions of the Strength Design Method and Unified Design Provisions with all conditions of strength satisfying the applicable conditions of equilibrium and strain compatibility.

In most building design calculations, such as the examples shown for [flat plate](#) or [flat slab](#) concrete floor systems, all building columns may be subjected to biaxial bending ( $M_x$  and  $M_y$ ) due to lateral effects and unbalanced moments from both directions of analysis. This requires an investigation of the column P- $M_x$ - $M_y$  interaction diagram in two directions simultaneously (axial force interaction with biaxial bending).

This example shows the calculations needed to obtain one point on the three-dimensional failure surface (biaxial  $M_x$ - $M_y$  interaction diagram). Generating the three-dimensional failure surface (interaction diagram) for a column section subjected to a combined axial force and biaxial bending moments is tedious and challenging for engineers and the use of a computer aid can save time and eliminate errors. StructurePoint's [spColumn](#) program can, quickly, simply and accurately generate the three-dimensional failure surface (interaction diagram) for all commonly encountered column, beam or wall sections in addition to highly complex and irregular cross-sections.



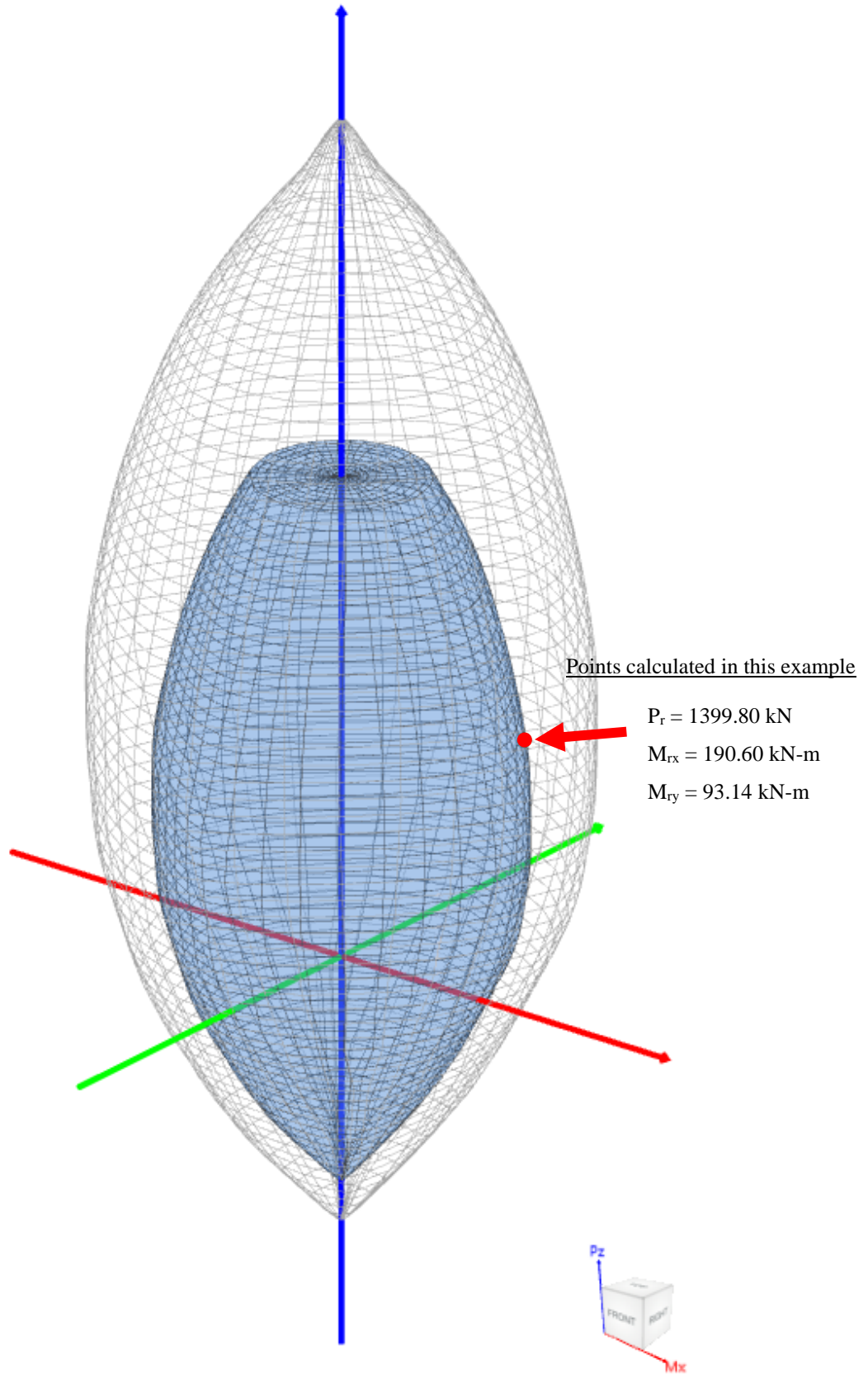


Figure 10 – Interaction Diagram in Two Directions (Biaxial) (spColumn)

The [spColumn](#) “Diagrams” module is a powerful tool especially for investigating interaction diagrams (failure surfaces) for columns and walls sections subjected to a combined axial force and biaxial bending moments. The module allows the user to view and analyze 2D interaction diagrams and contours along with 3D failure surfaces in a multi viewport environment. The following figure shows three views of:

1. P-M interaction diagram cut at angle of  $26^\circ$
2.  $M_x$ - $M_y$  interaction diagram cut at axial load of 1399.80 kN in compression
3. A 3D failure surface (interaction diagram) showing the points calculated in this example.

Figures 12, and 13 show 3D visualization of failure surface with a horizontal and vertical plane cut, respectively.

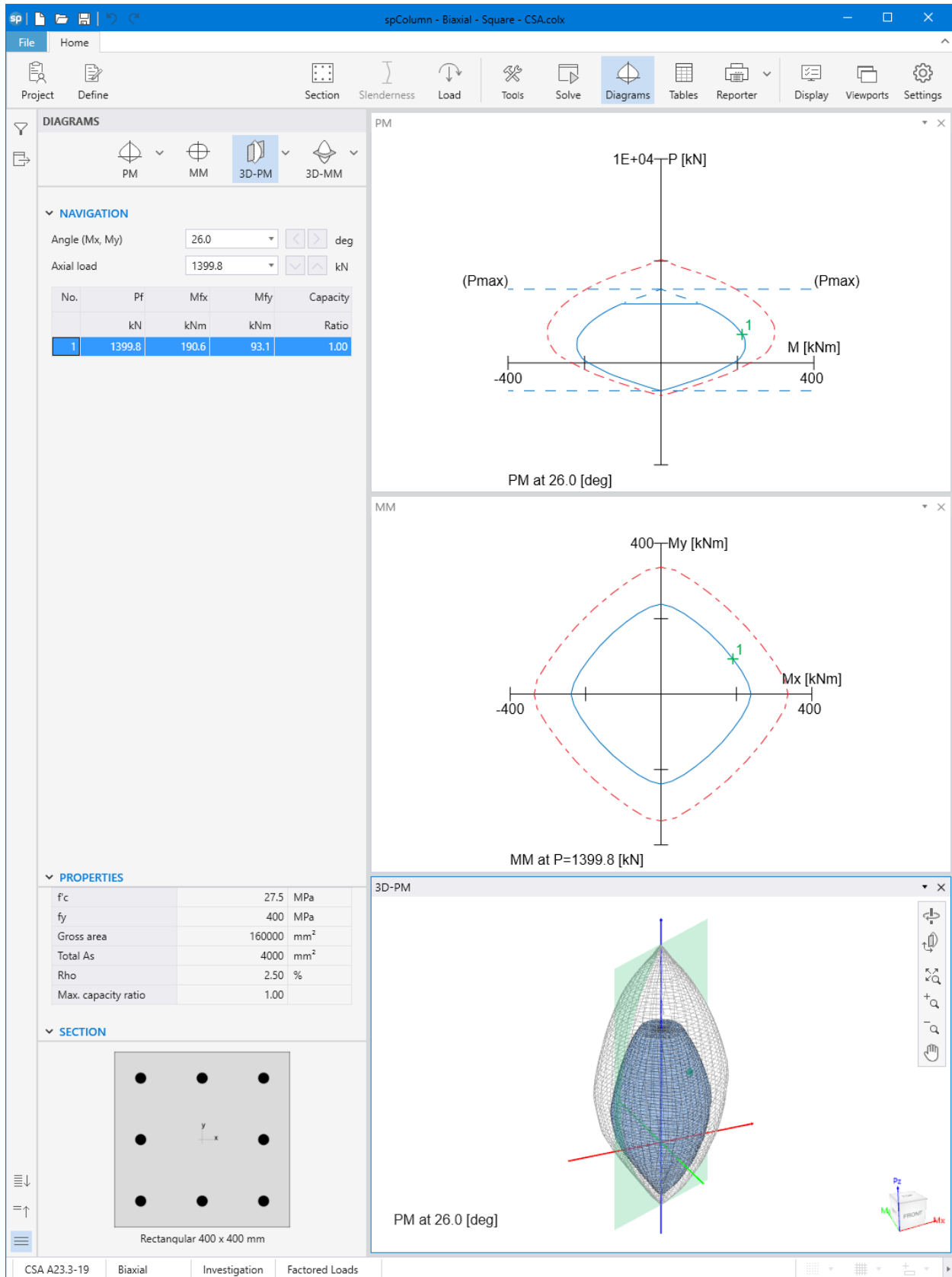


Figure 11 – Diagrams Module (spColumn)

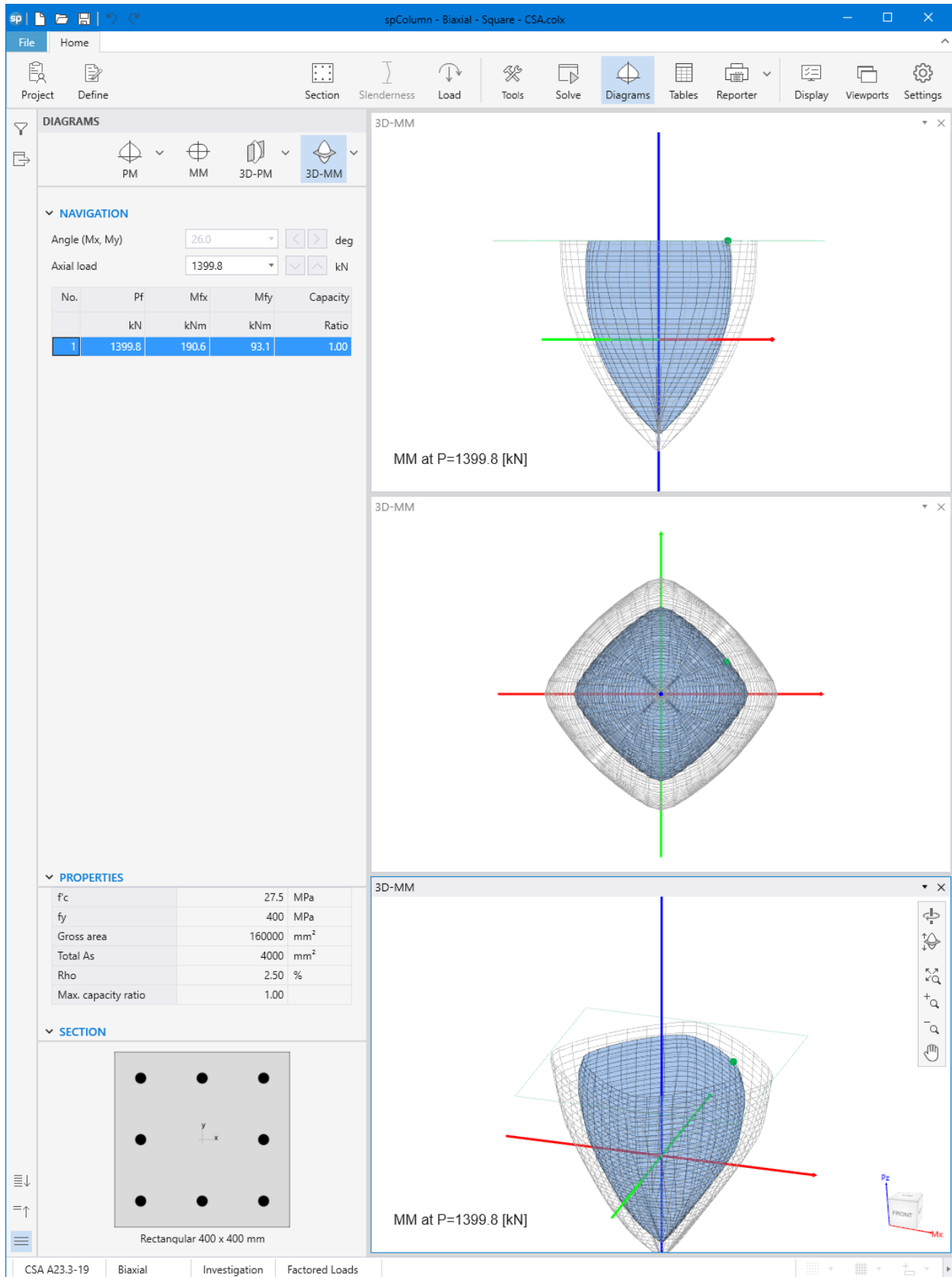


Figure 12 – 3D Visualization of Failure Surface with a Horizontal Plane Cut at  $P = 1399.80$  kN (spColumn)

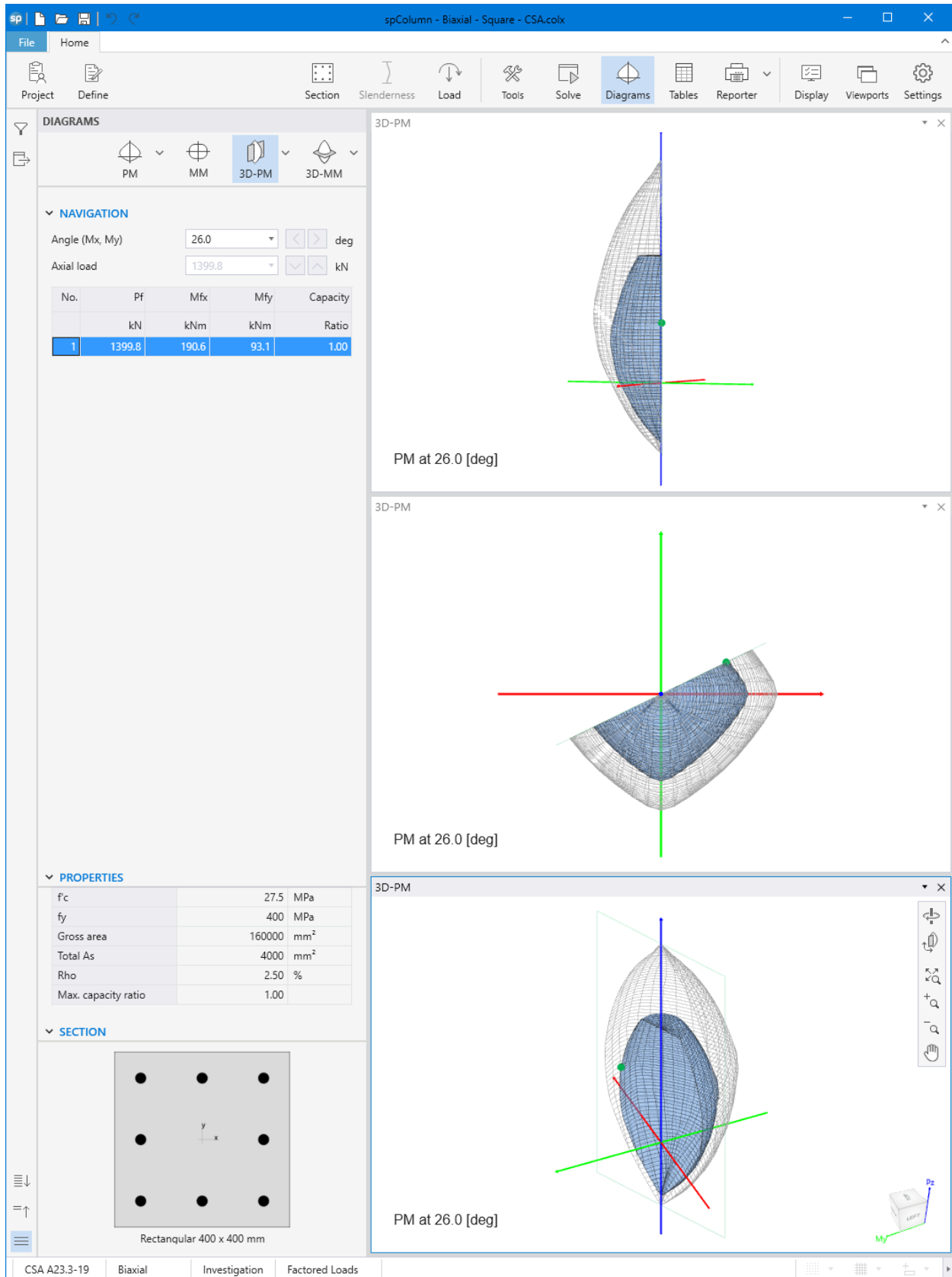


Figure 13 – 3D Visualization of Failure Surface with a Vertical Plane Cut at 26° (spColumn)