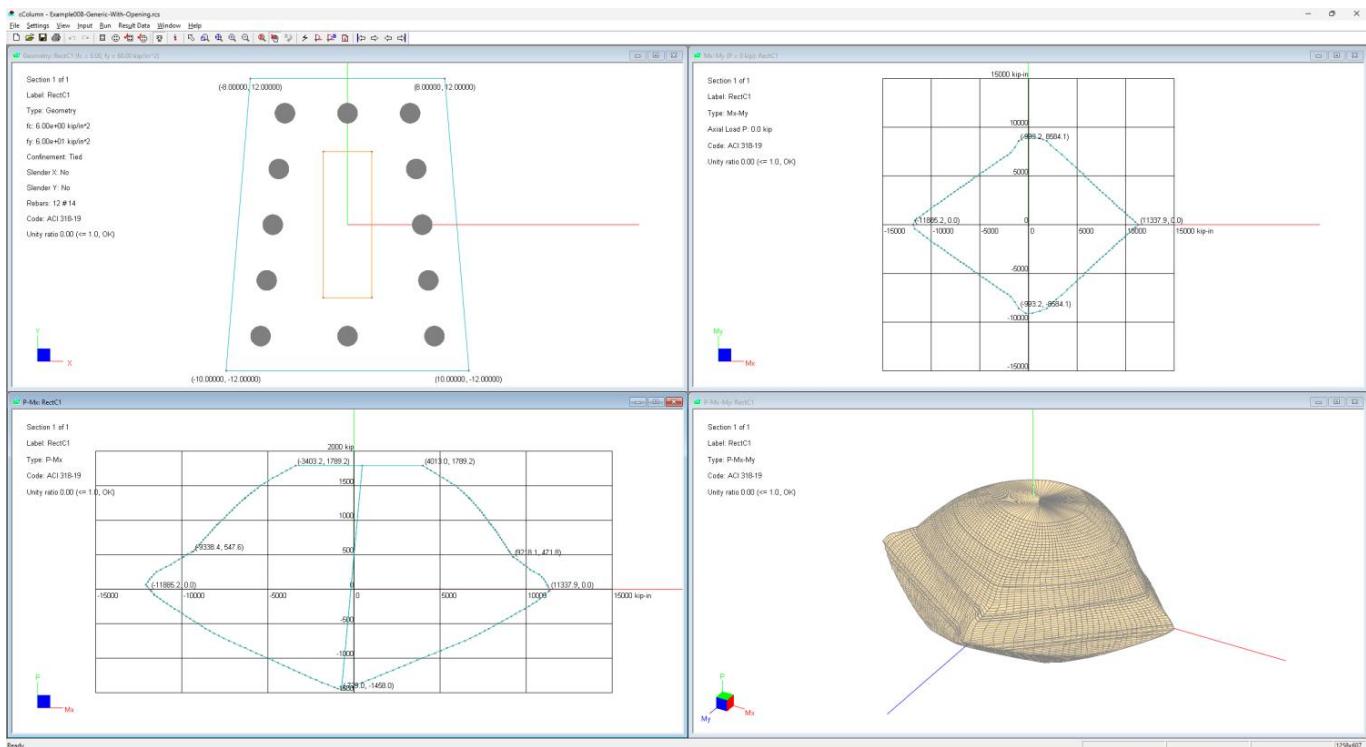


cColumn

Concrete Column Design & Investigation Software



Accuracy, Reliability, Ease of Use

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Revised Feb, 2025

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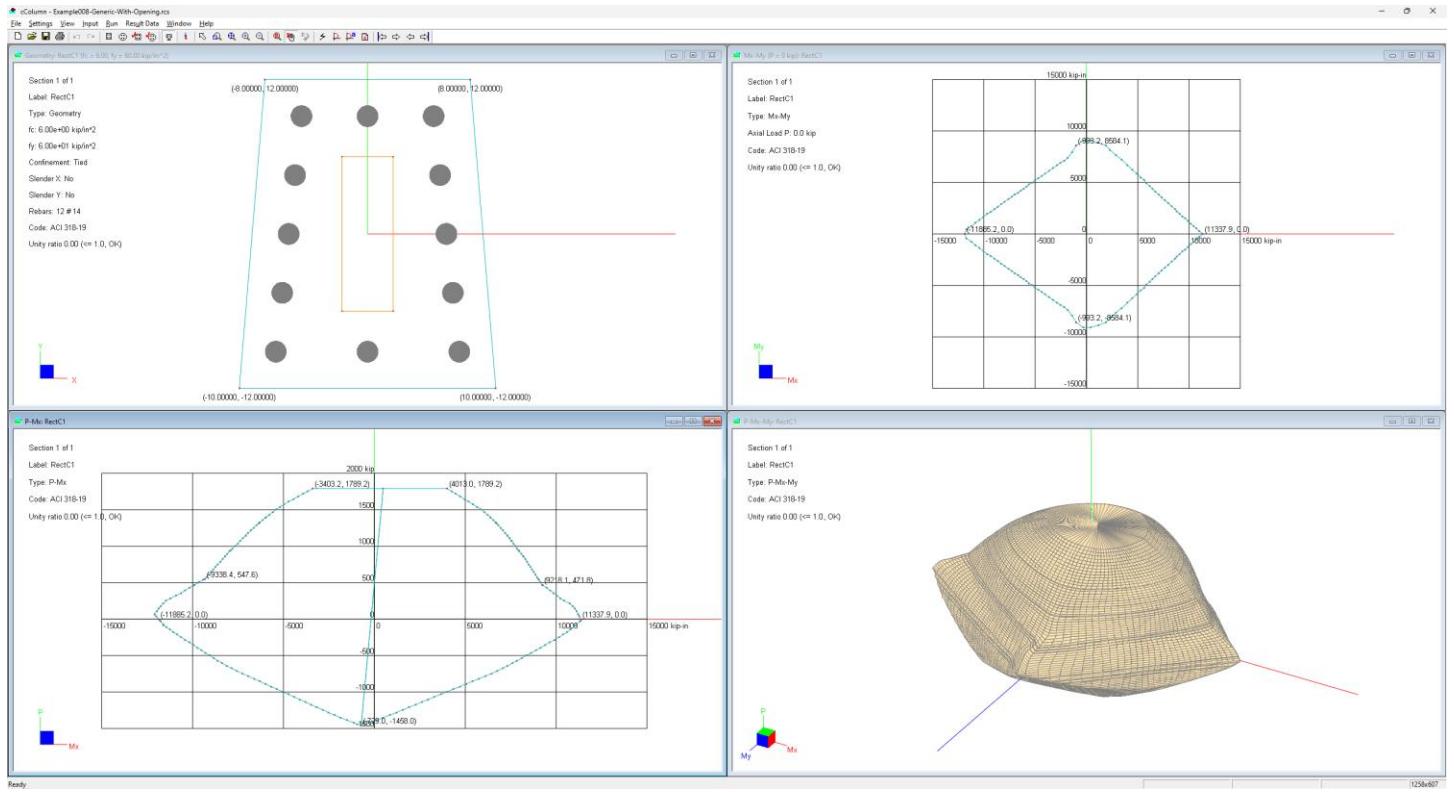
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Introduction

cColumn™ is a robust Windows program designed specifically for structural engineers to perform axial-flexural analysis and design of concrete sections (columns, walls, and beams) according to ACI 318-2019/2014/2011/2008/2005/2002/1999. It analyzes the uniaxial- or biaxial-bending capacity of multiple sections of various regular and generic shapes (with openings) simultaneously in a lightning fast and user-friendly manner. Loads may be input and checked against capacity of sections. Column slenderness may be optionally considered. cColumn is an invaluable tool to shorten the trial-and-error concrete design process.



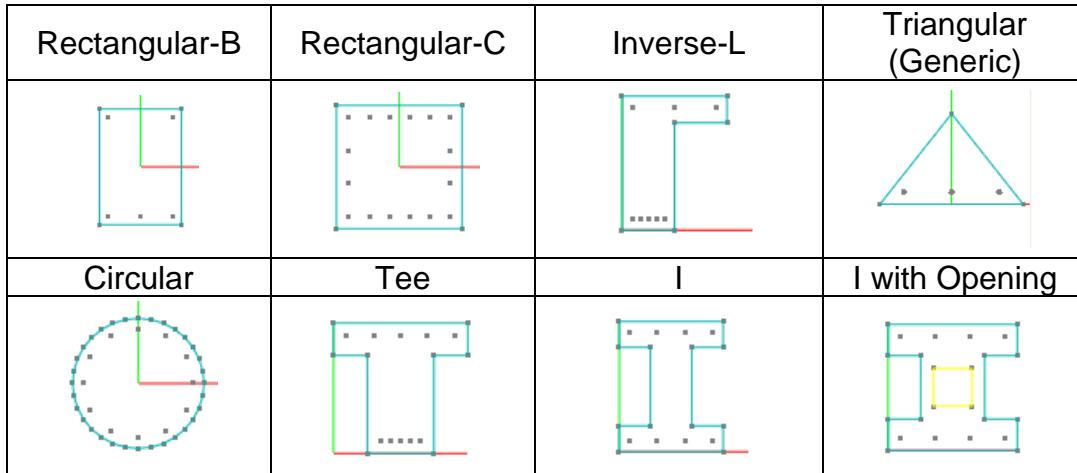
Key Features

Codes: ACI 318-2019/2014/2011/2008/2005/2002/1999

Units: English, Metric, or Mixed

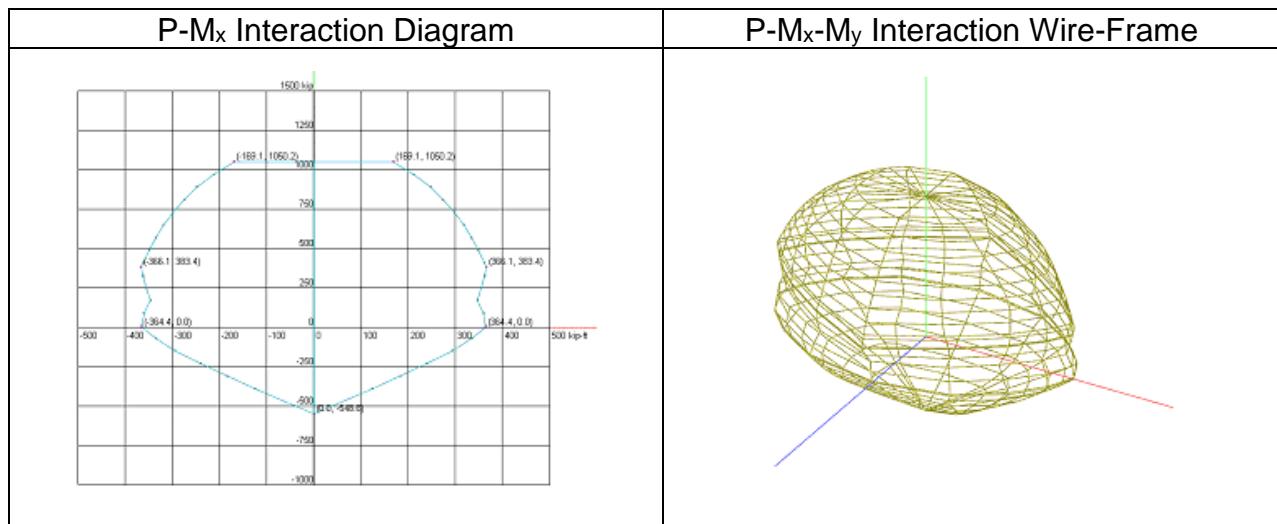
Section Shapes: Unlimited number of Rectangular, Circular, I, Tee, Inverse L, and Generic (with up to 3 openings) sections are supported. Multiple rectangular and circular sections can be parametrically generated with different section sizes and reinforcement configurations, providing a very flexible way to design concrete sections, particularly columns. Regular sections may be converted to generic sections at any time.

Loads: Unlimited number of load sets (P_u , M_{ux} , M_{uy}) may be input. Moments can be magnified by considering column slenderness. Adequacy of each section to carry the loads is computed in terms of simple unity ratio.



Solver: Unique, blazingly fast solution algorithms can accurately solve hundreds even thousands of sections uniaxially or biaxially simultaneously in seconds. Solution options include strength reduction factor, tied or spiral confinement, variable number of neutral axis steps, variable biaxial angle steps, variable axial steps for display and inclusion or exclusion of displaced concrete. The latest solver can even take advantage of multiple CPU architecture present in today's computers.

Diagrams: The program displays 2D P - M_x , P - M_y and M_x - M_y interaction diagram and 3D P - M_x - M_y interaction surface or wire-frame. Key points are shown automatically on the interaction diagrams. Critical input load for each section is shown with color on 2D interaction diagram and 3D interaction surface denoting the adequacy of the section to resist loads.



Result Data: Very detailed result data is tabulated in spreadsheets. P-M result includes neutral axis depth, maximum tensile strain and strength reduction factor, as well as axial capacity P and moment capacity M . Result data may be copied to another spread sheet program such as Microsoft Excel.

Report: Professional reports can be generated in the format of Microsoft Word or PDF document.

System Requirements

x64-based Windows: Windows 7, 8, 10, or 11

ARM64-based Windows: Windows 11

Part 1

Menus

Chapter 1: File

The File main menu provides commands that are related to files. It also provides commands related to file import and export, saving diagrams, and report generation. Input data for a model is saved in one single text file (also called a model file in this program) and has the default extension of “rcs”. *Each input file may contain unlimited number of sections.* You may save or open model files with different extensions. The program provides Multiple Document Interface (MDI), that is, you may open and work on multiple files at the same time. A binary result file for a model may be optionally saved together with the input file. The result file has the same name as the input file but with the extension of “rcr”.

The program can generate reports in plain text, Microsoft Word, and PDF file format. Various report options are provided to customize the reports to suit your needs.

New

File | New creates a new cColumn model file.

Open

File | Open opens an existing cColumn model file. You may open one or multiple files at one time. To open multiple files, simply go to the file list in Open dialog box (Figure 1.1) and click the files while pressing CTRL or SHIFT.

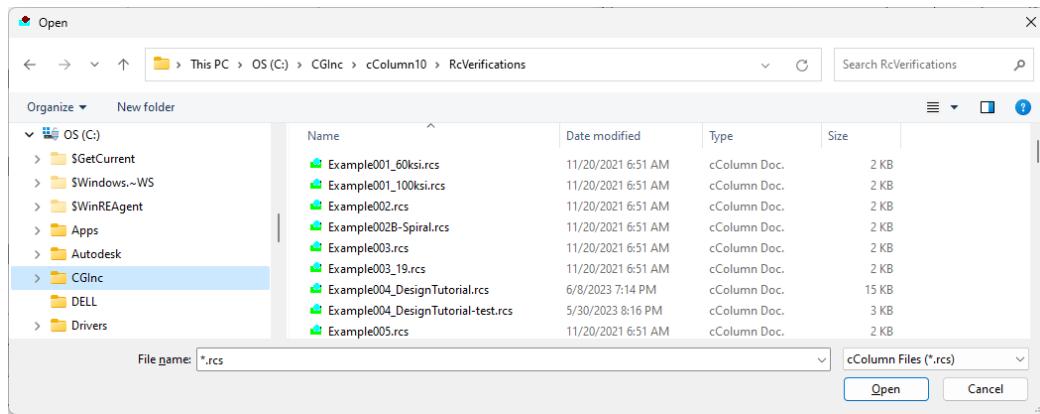


Figure 1.1

Multiple Document Interface (MDI) makes it easy for you to share data and compare results between different models. Multiple windows or views may be associated with a single file. These windows may have different display settings with respect to zooming, panning, display or hiding various structural entities or annotations etc. For example, you may have one window for geometry, another window for P-M_x interaction diagram.

Close

File | Close closes the active cColumn model file. You will be prompted to save the document if changes have been made since it was last saved. You may close all opened documents without exiting the program.

Save

File | Save saves the model. If the model has not been saved before, the Save As dialog box will be displayed prompting you to enter a file name.

Save As

File | Save As saves the model under a different name. It may be used if you have never saved the model or if you want to keep the original file.

Import Sections | From cColumn Text Files

File | Import Sections | From cColumn Text Files allows you to import one or more section files that conforms the cColumn section text file format (refer to the details below). You have the option to specify the material strength multiplier, coordinate multiplier, and bar area multiplier for your imports (Figure 1.2).

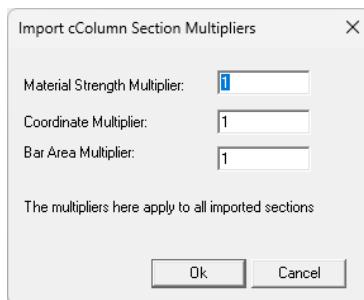


Figure 1.2

To illustrate the format of the cColumn section text file, here is an example:

Materials

6 60 0

Boundary

4
-10 -12
10 -12
8 12
-8 12

Openings

1
4

```

-2    -6
2     -6
2      6
-2     6
Rebars
12
2.25 -7.1535   -9.1535
2.25 -6.6535   -4.57675
2.25 -6.1535    0
2.25 -5.6535   4.57675
2.25 -5.1535   9.1535
2.25  7.1535   -9.1535
2.25  6.6535   -4.57675
2.25  6.1535    0
2.25  5.6535   4.57675
2.25  5.1535   9.1535
2.25  0        -9.1535
2.25  0        9.1535

```

The **Materials** block includes one line of data: fc, fy, and confinement(0=tied, 1=spiral).

The **Boundary** block consists of a line that indicates the total number of points (N) defining the boundary. Subsequently, N lines of point data follow, where each line specifies the x and y coordinates of a boundary point.

The **Openings** block consists of a line that indicates the total number of openings (M), with a maximum of three openings allowed. Following this line, there are M opening sub-blocks. Each opening sub-block begins with a line specifying the number of points (N) that make up the opening edge. Subsequently, N lines of point data follow, where each line contains the x and y coordinates of an individual point along the opening edge.

The Rebars block includes a line specifying the number of rebars (N) within the section. This is followed by N lines of rebar data, where each line specifies the bar area as well as the x and y coordinates of a rebar.

Note: data on a line must be separated by spaces or tabs.

Import Sections | From spColumn Text Files

File | Import Sections | From spColumn Text Files allows you to import one or more section files that conform to the StructurePoint's spColumn v10 section text file format. In addition, section text files must include both geometry and reinforcement data. You have the option to specify the material properties, confinement, coordinate multiplier, and bar area multiplier (Figure 1.3).

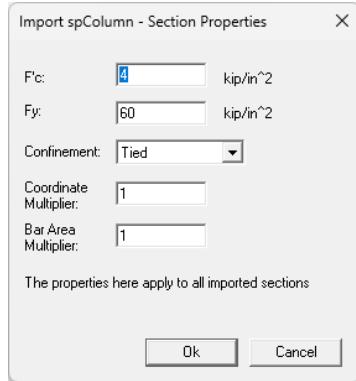


Figure 1.3

Export Sections | To cColumn Text Files

File | Export Sections | To cColumn Text Files allows you to export one or more sections to a cColumn section text files (Figure 1.4). Exported files are saved to the same folder as the current cColumn model file location. Therefore, you must first save the cColumn model before export is allowed.

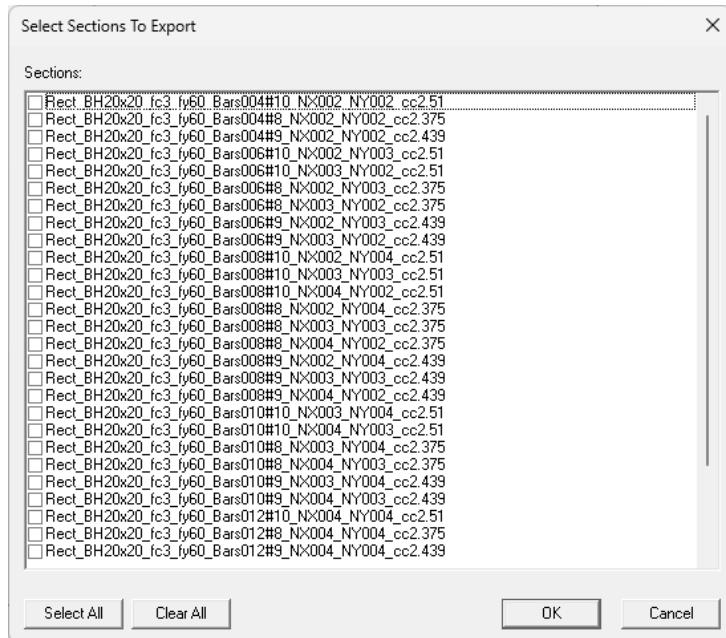


Figure 1.4

Export Sections | To spColumn Text Files

File | Export Sections | To spColumn Text Files allows you to export one or more sections to files that conform to StructurePoint's spColumn v10 section text file format (Figure 1.4). The exported files are automatically saved in the same folder as the current location of the cColumn model file. It is important to note that in order to perform the export, you must first save the cColumn model.

Notes

File | Notes prompts you with the following dialog box (Figure 1.5). You may enter a project/job name, engineer name, and a description about the model (up to 1020 characters long).

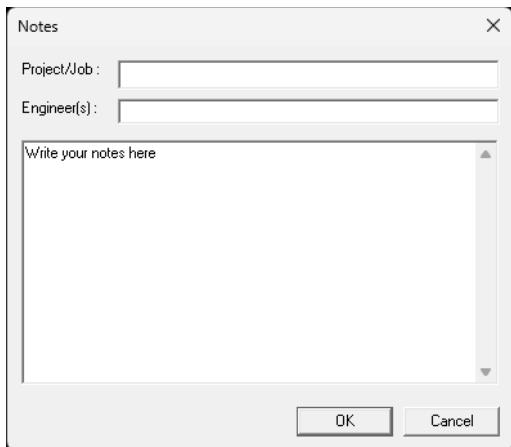


Figure 1.5

Report

File | Report prompts you with the following dialog box (Figure 1.6). It allows you to generate a report for input and/or output data in a plain text, Microsoft Word, or PDF file format.

The command provides different options to control the contents of the report. For example, you may generate a report for selected sections only. It is generally preferable to use Portrait orientation unless you need to use larger font sizes for your reports. Please note that it may take a long time to generate a Word or PDF report if too many sections are selected, especially when table of contents is included.

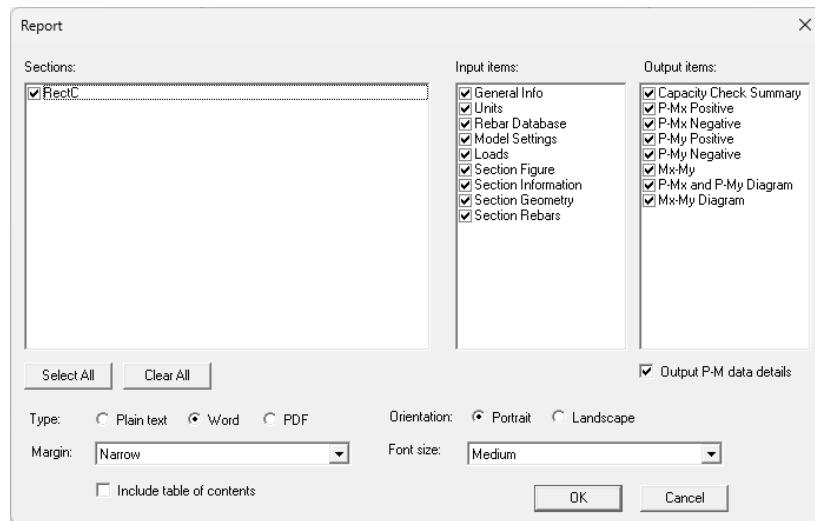


Figure 1.6

Save PM Diagrams to Images

File | Save PM Diagrams to Images allows you to save PM interaction diagrams to high-resolution image files for selected sections (Figure 1.7).

Save MM Diagrams to Images

File | Save MM Diagrams to Images allows you to save MM (Mx-My) interaction diagrams to high-resolution image files for selected sections (Figure 1.8).

Open Containing Folder

File | Open Containing Folder takes you to the folder where the model file resides.

Print Setup

File | Print Setup allows you to set up the printing page layout.

Print Preview

File | Print Preview allows you to preview the printing layout before printing P-Mx and P-My (PM) interaction diagram, or Mx-My (MM) interaction diagram. When the Mx-My interaction diagram view is the active window, Print Preview will allow you to preview printing layout for MM interaction diagrams for all sections. When you are in a Geometry, P-Mx, P-My, or P-Mx-My interaction diagram view is the active window, Print Preview will allow you to preview printing layout for PM interaction diagrams for all sections.

Print

File | Print prints PM or MM interaction diagram. When the Mx-My interaction diagram view is the active window, Print will allow you to print MM interaction diagrams for all sections. When the Geometry, P-Mx, P-My, or P-Mx-My interaction diagram view is the active window, Print will allow you to print PM interaction diagrams for all sections. *It is recommended that you run File | Print Preview before running this command.*

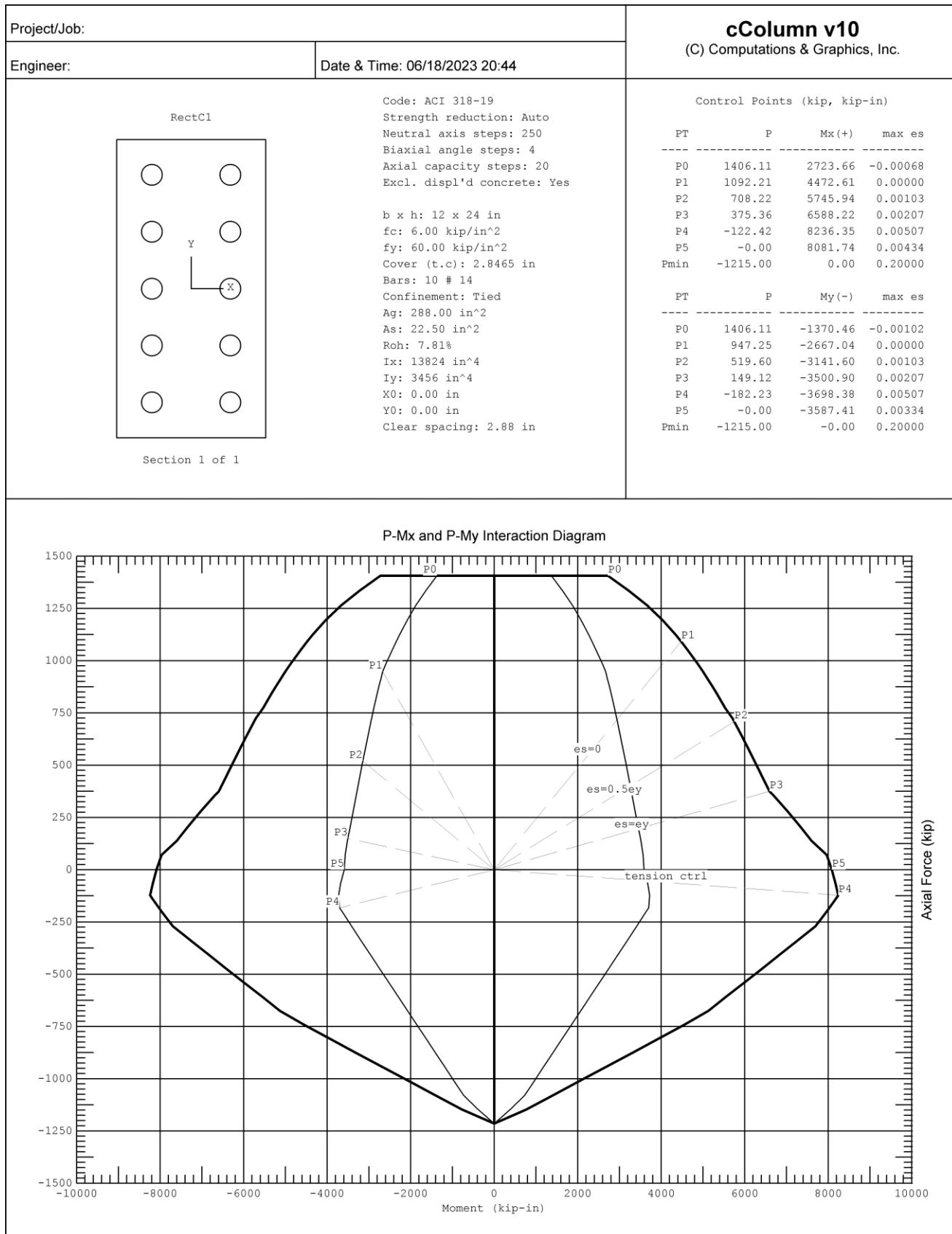


Figure 1.7

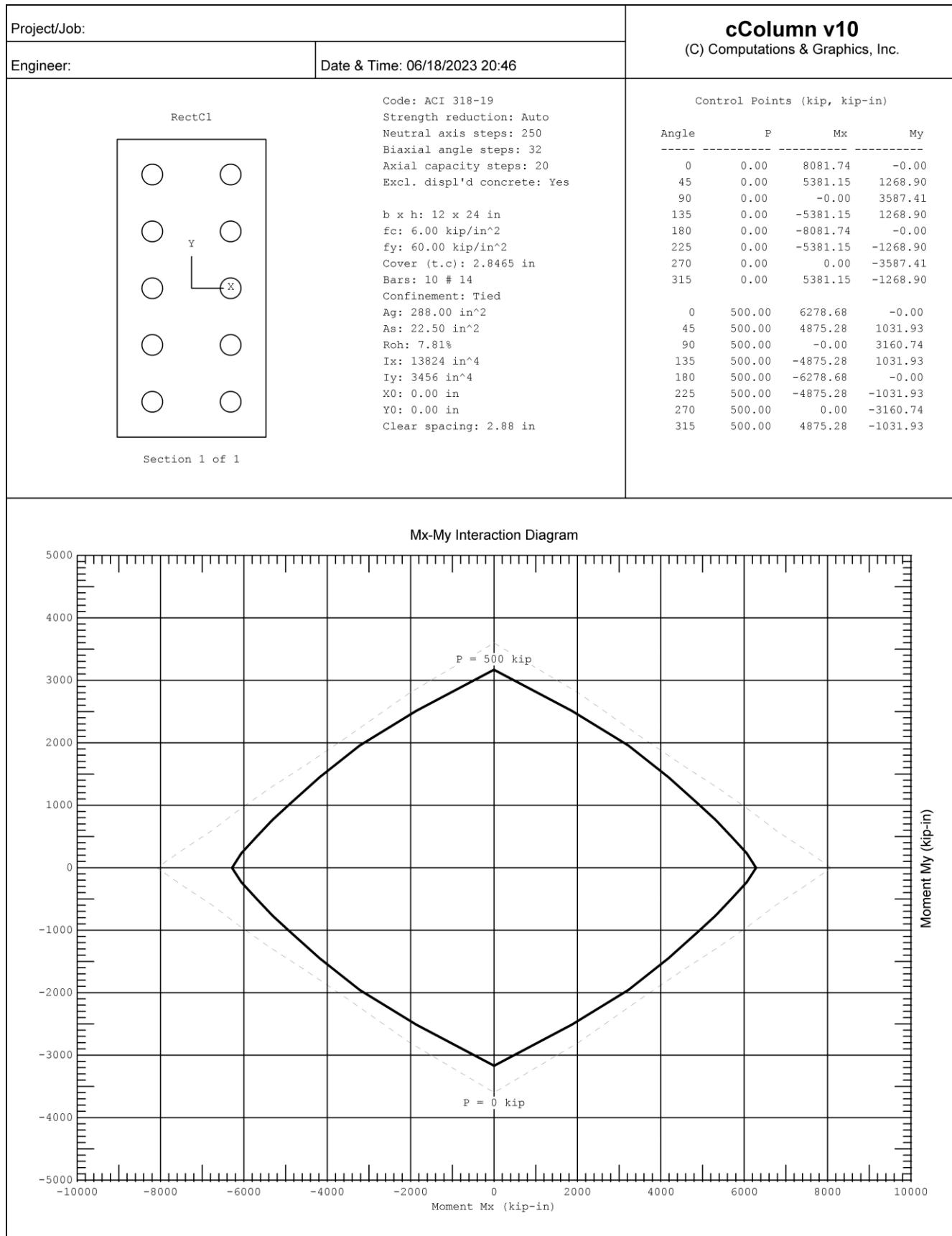


Figure 1.8

Chapter 2: Settings

The Settings main menu provides commands related to settings for model data and graphical entities in model views. Some of these settings may be applied beyond the current model, that is, they may be saved for use in future models.

Units & Precisions

Settings | Units & Precisions prompts you with the following dialog box (Figure 2.1). You may select different units and precisions for various physical measurements used in the model. You may run this command as many times as you like. You may convert existing data associated with a unit in the model by checking or unchecking the box to the right of that unit. For example, if you mistakenly enter all geometry coordinates in a wrong length unit, you may select the correct length unit and uncheck the conversion checkbox to correct the input.

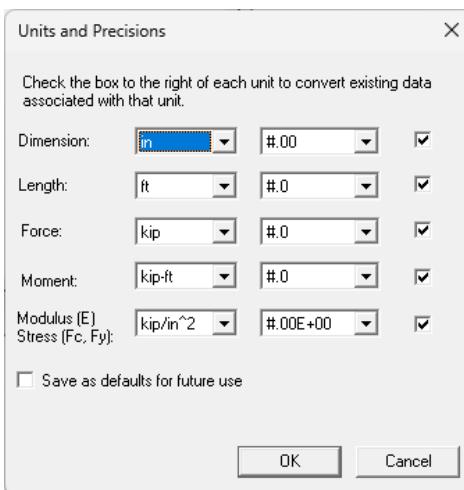


Figure 2.1

You may set the precision for each unit in either decimal or scientific format. Precision settings are used in displaying data in spreadsheets, diagrams, and reports.

By checking “Save as defaults for future use”, units will be saved in the registry for use in future models.

Data Options

Settings | Data Options prompts you with the following dialog box (Figure 2.2).

The “Undo/redo levels” sets the maximum undo/redo levels which the program will perform. The program requires computer memory for each undo/redo level. The default levels are 100, but you may adjust it based on the size of your model.

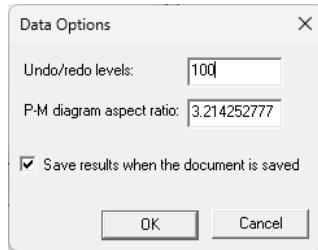


Figure 2.2

P-M diagram aspect ratio is used to adjust the diagram aspect ratio in P-M_x, P-M_y, or P-M_x-M_y interaction diagrams or surface

The “Save results when the document is saved” checkbox provides you with the option to save available results to a file when saving the model input data. The result file is saved in a binary format and shares the same name as the model input file, but with an extension of “rcr”. It’s worth noting that the result file may be significantly larger in size compared to the model input file.

Rebar Database

Settings | Rebar Database presents you with the following dialog box (Figure 2.3). It allows you to set the proper rebar database for your model. If needed, you have the flexibility to customize the rebar database by modifying the "cColumn.ini" file located within the cColumn installation folder. To ensure safety, it is highly recommended to create a backup copy of the "cColumn.ini" file before making any updates.

	Bar Designation	Diameter [in]	Area [in ²]
1	#3	0.375	0.11
2	#4	0.5	0.2
3	#5	0.625	0.31
4	#6	0.75	0.44
5	#7	0.875	0.6
6	#8	1	0.79
7	#9	1.128	1
8	#10	1.27	1.27
9	#11	1.41	1.56
10	#14	1.693	2.25
11	#18	2.257	4
12			

Figure 2.3

Colors

Settings | Colors prompts you with the following dialog box (Figure 2.4). You may set the background color of the model views to be either white or black. Color settings are always saved in the registry for future use.

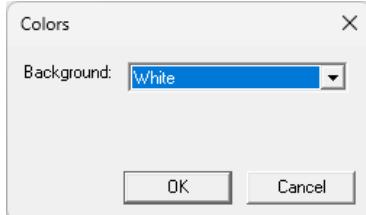


Figure 2.4

Preferences

Settings | Preferences prompts you with the dialog box below (Figure 2.5). The “Data Folder” determines the default folder or directory when a file is saved or opened.

The “Automatic file backup period” determines how frequently the model files are saved automatically. Enter 0 for no auto-backups. Backup files have the extension “rcs.rcs”.

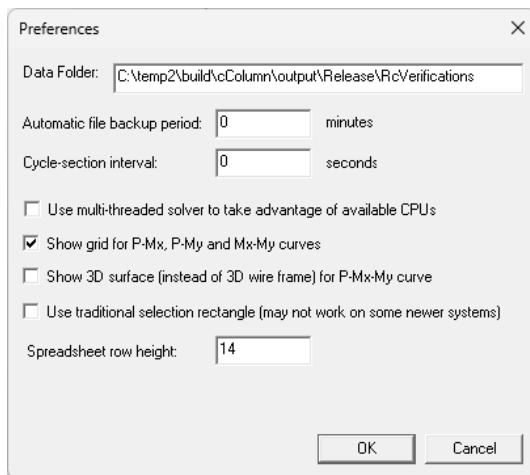


Figure 2.5

Setting for “Cycle section interval” is used to set the timer interval for use in section slide show (refer to View | Section Slide Show menu).

If you have a computer with multiple CPUs, you may choose to “Use multi-threaded solver to take advantage of available CPUs”. The speed increase the solution is almost proportional to the number of CPUs. A fair warning: the solver messages may be intertwined due to the nature of multi-threading.

Options are provided here also for showing grid in the 2D P-M_x, P-M_y and M_x-M_y interaction diagrams. P- M_x-M_y interaction diagram may be shown in 3D surface or wire frame.

Preferences are always saved in the registry for future use.

Enable/Disable Hardware Acceleration

Settings | Enable/Disable Hardware Acceleration allows you to turn on or off OpenGL hardware acceleration. By default, OpenGL hardware acceleration is turned on. If you encounter graphics problems (due to faulty graphics drivers) in the software, you may want to try to disable hardware acceleration. The graphics performance may degrade significantly but should be acceptable on most modern systems.

This command may also be useful when using virtual Windows on Mac machine, and ARM64-based Windows.

Status Bar

Settings | Status Bar shows or hides the status bar.

Toolbar

Settings | Toolbars shows or hides toolbars.

Chapter 3: View

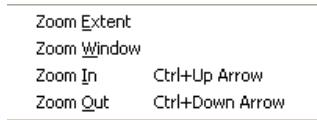
The View main menu provides commands to graphically view input such as section geometry and loading, perform annotations, and display 2D or 3D result diagrams.

Restore Model

View | Restore restores original (internally defined) settings for the model view.

Zoom

View | Zoom pop-up menu has the following submenus.



Zoom | Zoom Extent

View | Zoom | Zoom Extent displays the entire model in the view.

Zoom | Zoom Window

View | Zoom | Zoom Window zooms in a specific part of the model by click and dragging the left mouse button. The command remains in effect until another command is selected or right mouse button is clicked or ESC is pressed.

Zoom | Zoom In

View | Zoom | Zoom In zooms in the model by a preset factor (1.25). You may run this command by pressing CTRL+UP arrow or CTRL+RIGHT arrow.

Zoom | Zoom Out

View | Zoom | Zoom Out zooms out the model by a preset factor (1.25). You may run this command by pressing CTRL+DOWN arrow or CTRL+LEFT.

Pan

View | Pan pop-up menu has the following submenus.

Pan-Screen	
Left	Left Arrow
Right	Right Arrow
Up	Up Arrow
Down	Down Arrow

Pan | Pan Screen

View | Pan | Pan Screen pans (move) the model by clicking and dragging the left mouse button. The command remains in effect until another command is selected or right mouse button is clicked or ESC is pressed.

Pan | Left

View | Pan | Left pans the model to the left by a preset screen distance. You may run this command by pressing CTRL+LEFT arrow.

Pan | Right

View | Right pans the model to the right by a preset screen distance. You may run this command by pressing CTRL+RIGHT arrow.

Pan | Up

View | Pan | Up pans the model to the top by a preset screen distance. You may run this command by pressing CTRL+UP arrow.

Pan | Down

View | Pan | Down pans the model to the bottom by a preset screen distance. You may run this command by pressing CTRL+DOWN arrow.

Rotate

View | Rotate pop-up menu has the following submenus. They are available for 3D view of P-M_x-M_y interaction surface or wire frame.

+X	Shift+Down Arrow
-X	Shift+Up Arrow
+Y	Shift+Right Arrow
-Y	Shift+Left Arrow
+Z	Ctrl+Shift+Up Arrow
-Z	Ctrl+Shift+Down Arrow

Rotate | +X

View | Rotate | +X rotates the model view about X by a preset positive angle (5 degrees). You may run this command by pressing SHIFT+DOWN arrow.

Rotate | -X

View | Rotate | -X rotates the model view about X by a preset negative angle (5 degrees). You may run this command by pressing SHIFT+UP arrow.

Rotate | +Y

View | Rotate | +Y rotates the model view about Y by a preset positive angle (5 degrees). You may run this command by pressing SHIFT+RIGHT arrow.

Rotate | -Y

View | Rotate | -Y rotates the model view about Y by a preset negative angle (5 degrees). You may run this command by pressing SHIFT+LEFT arrow.

Rotate | +Z

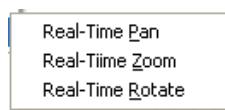
View | Rotate | +Z rotates the model view about Z by a preset positive angle (5 degrees). You may run this command by pressing CTRL+SHIFT+UP arrow or CTRL+SHIFT+RIGHT arrow

Rotate | -Z

View | Rotate | -Z rotates the model view about Z by a preset negative angle (5 degrees). You may run this command by pressing CTRL+SHIFT+DOWN arrow or CTRL+SHIFT+LEFT arrow

Real Time Motion

View | Real Time Motion pop-up menu has the following submenus.



Real Time Motion | Real-Time Pan

View | Real Time Motion | Real-Time Pan allows you to pan the model view in real time by clicking and dragging the left mouse button. The command remains in effect until another command is selected or right mouse button is clicked or ESC is pressed.

Real Time Motion | Real-Time Zoom

View | Real Time Motion | Real-Time Zoom allows you to zoom in or out the model view in real time by clicking and dragging the left mouse button up or down. The command remains in effect until another command is selected or right mouse button is clicked or ESC is pressed.

Real Time Motion | Real-Time Rotate

View | Real Time Motion | Real-Time Rotate allows you to rotate the model view in real time by clicking and dragging the left mouse button. The command remains in effect until another command is selected or right mouse button is clicked or ESC is pressed. This command is only available for 3D view of P-M_x-M_y interaction surface or wire frame.

Diagram Type

View | Diagram Type allows you to change the current view to another type (Figure 3.1). They are five types of view in the program: geometry, P-M_x, P-M_y, M_x-M_y and P-M_x-M_y. By default, the view is the geometry type. Other views are meaningful only after a solution is performed. For M_x-M_y interaction (or contour) view, you should set the right axial force level. For P-M_x, P-M_y, M_x-M_y and P-M_x-M_y interaction diagrams, you may enter an appropriate value for P-M diagram aspect ratio.

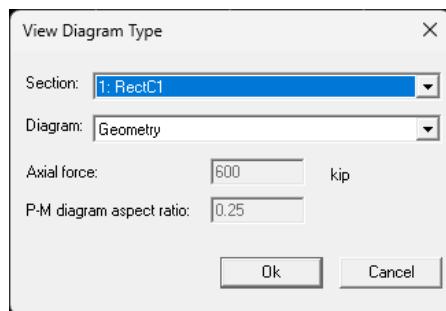


Figure 3.1

Result Diagrams

View | Result Diagrams displays P-M_x, M_x-M_y and P-M_x-M_y diagrams all at once.

Section Slide Show

View | Section Slide Show cycles through all sections on the screen. You may adjust the timer interval for the slide show from the command Settings | Preferences.

Axes & Legend

View | Axes & Legend shows or hides the legend at the top-left window corner and the global axes at bottom-left window corner. You may run this command by pressing F5.

Chapter 4: Input

The Input main menu provides commands to create sections, input loads, set up slenderness parameters and design criteria. It also includes Undo and Redo editing commands.

Section Mode

Input | Section Mode offers five different modes for section design and investigation. They include Design Rectangular, Design Circular, Investigate Rectangular, Investigate Circular, and Advanced.

Sections may be generated automatically and/or input individually using these commands. Each section must obey the following rules:

1. *Rebar covers (either from input or computed by the program) are all measured from edge of the section to the center of the longitudinal rebars.*
2. *Duplicate rebars at the same location will be merged into one bar.*
3. *Two rebars with a distance of less than the radius of the smallest database bar will be merged into one bar.*
4. *Rebars must be inside the section geometry and outside any openings.*
5. *Openings must be inside the section boundary*

Section Mode | Design Rectangular

The Input | Section | Design Rectangular mode facilitates the design of rectangular sections by providing the ability to parametrically generate multiple sections of different dimensions and reinforcement layouts. Upon performing the solution, you will receive one or more candidate sections for a given set of loads (Figure 4.1).

Note: In this mode, the specification for "Clear cover to tie" is utilized instead of "cover to bar center". The program will automatically calculate the cover distance to the longitudinal bar center for each individual section generated. Additionally, if the size of longitudinal bars is #11 or larger, the ties size will be a minimum of #4, even if #3 ties size is specified.

You should use your sound engineering judgment to select appropriate parameters in order to avoid generating thousands of sections each time. For square columns, make sure to check “Square sections (bars on each side are equal)”. This will greatly reduce the number of sections being generated.

Please be aware that executing this command will result in the removal of the existing sections within the model.

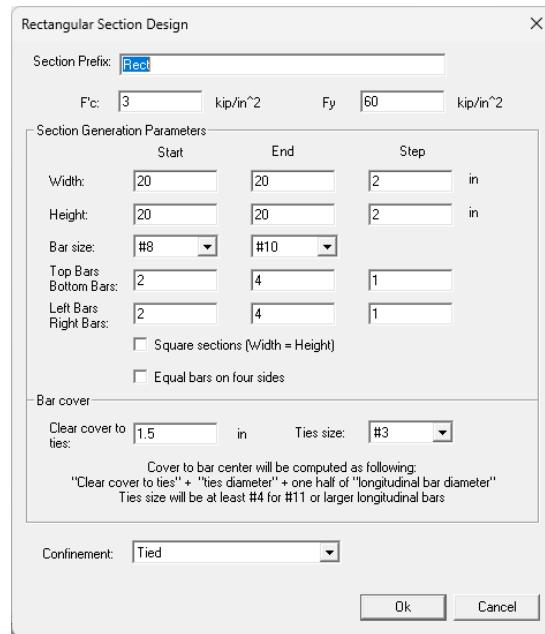


Figure 4.1

Section Mode | Design Circular

The Input | Section | Design Circular mode facilitates the design of circular sections by providing the ability to parametrically generate multiple sections of different dimensions and reinforcement layouts. Upon performing the solution, you will receive one or more candidate sections for a given set of loads (Figure 4.2).

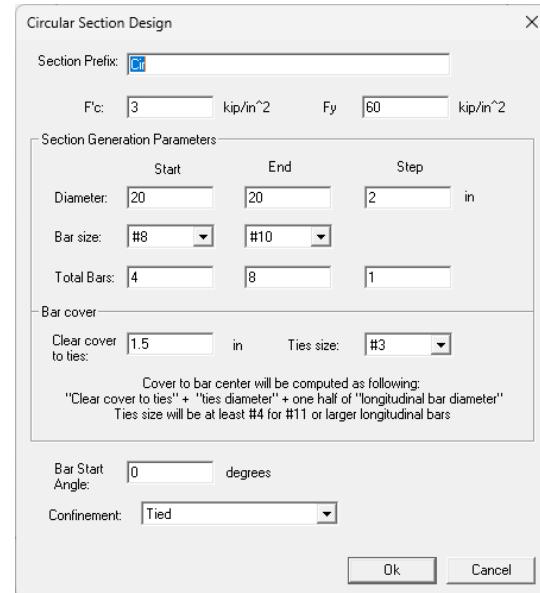


Figure 4.2

Note: In this mode, the specification for "Clear cover to tie" is utilized instead of "cover to bar center". The program will automatically calculate the cover distance to the longitudinal bar

center for each individual section generated. Additionally, if the size of longitudinal bars is #11 or larger, the ties size will be a minimum of #4, even if #3 ties size is specified.

You should use your sound engineering judgment to select appropriate parameters in order to avoid generating thousands of sections each time.

Please be aware that executing this command will result in the removal of the existing sections within the model.

Section Mode | Investigate Rectangular

Input | Section | Investigate Rectangular allows you to investigate a single rectangular section (Figure 4.3). By clicking on the “Calculate” button, you can calculate the cover to bar center using the clear cover to ties, ties size, and longitudinal bar size (Figure 4.4).

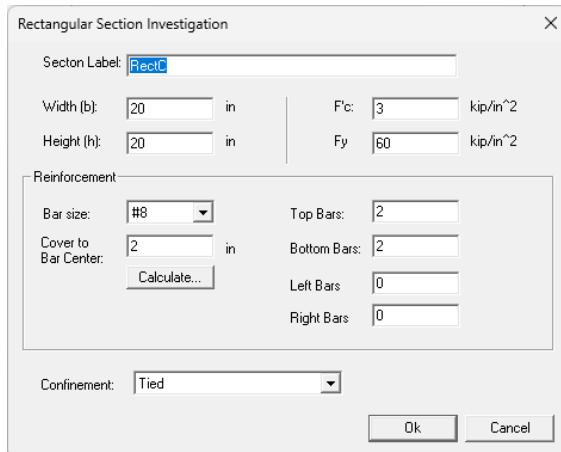


Figure 4.3

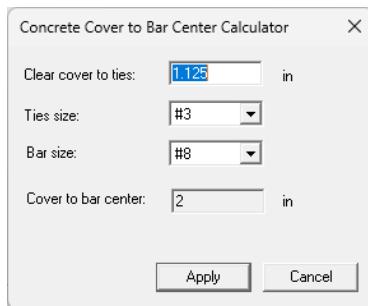


Figure 4.4

Please be aware that executing this command will result in the removal of the existing sections within the model.

Section Mode | Investigate Circular

Input | Section | Investigate Circular allows you to investigate a single circular section (Figure 4.5). By clicking on the “Calculate” button, you can calculate the cover to bar center using the clear cover to ties, ties size, and longitudinal bar size (Figure 4.4).

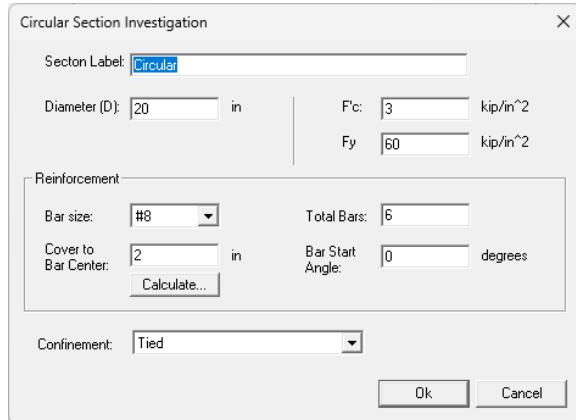


Figure 4.5

Please be aware that executing this command will result in the removal of the existing sections within the model.

Section Mode | Advanced

Input | Section | Advanced allows you to add, modify, copy and delete sections of different types (Figure 4.6). Each file may include multiple sections of different types. You can switch to Advanced mode from one of the design or investigation modes without the existing sections being removed.

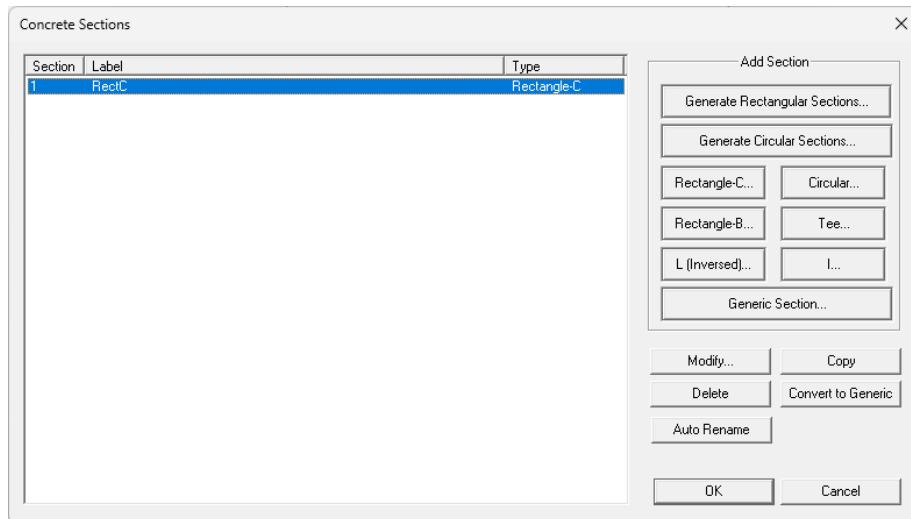


Figure 4.6

“Generate Rectangular Sections” (Figure 4.7) and “Generate Circular Sections” (Figure 4.8) may be used to generate multiple rectangular or circular sections with different dimensions and reinforcement layouts.

Note: “Clear cover to tie” is specified here instead of “cover to bar center”. The program will automatically calculate cover to longitudinal bar center for each individual section generated. Additionally, if the size of longitudinal bars is #11 or larger, the ties size will be a minimum of #4, even if #3 ties size is specified.

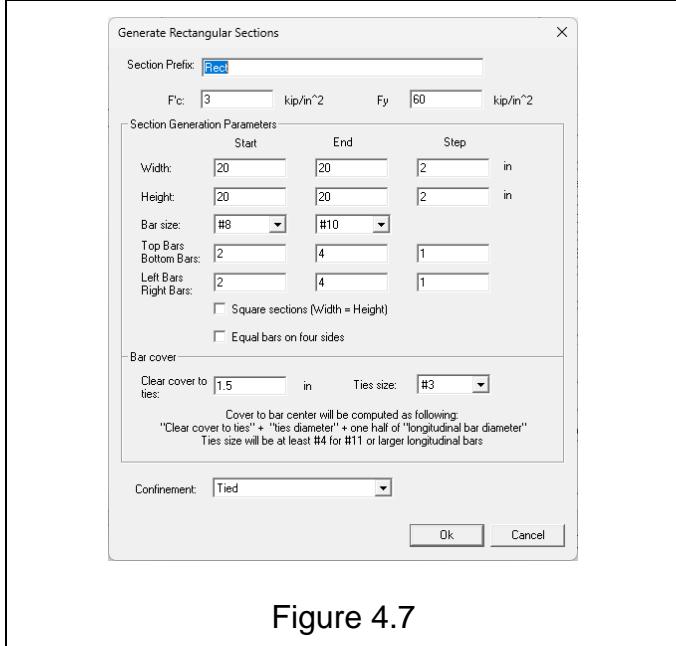


Figure 4.7

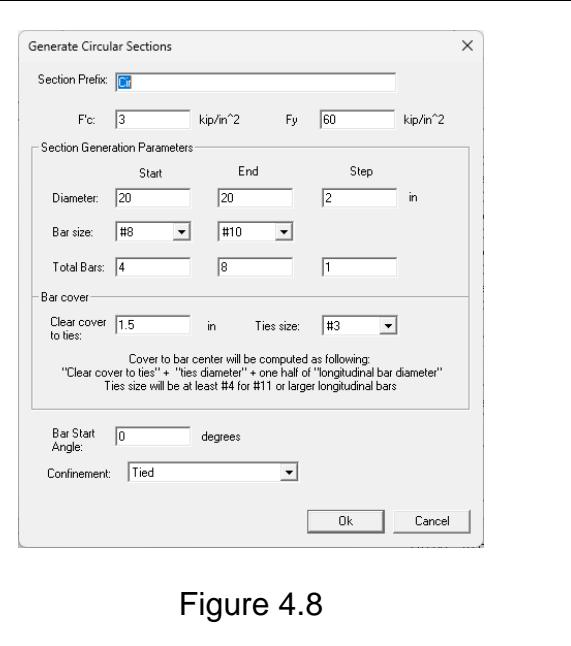


Figure 4.8

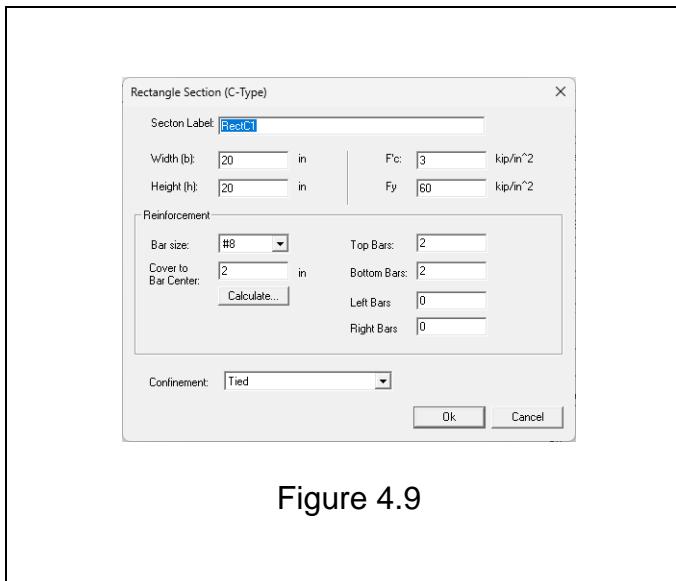


Figure 4.9

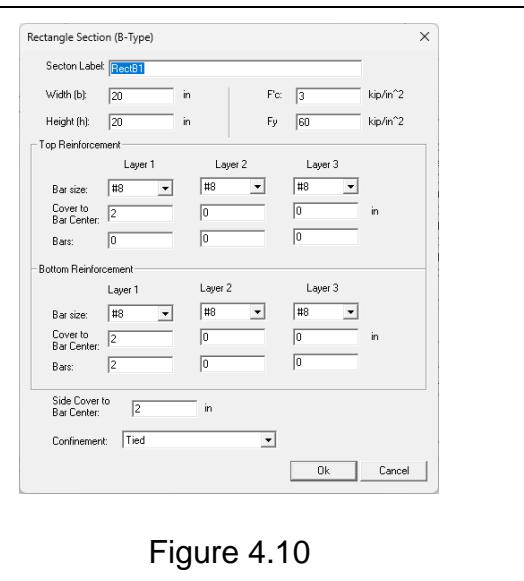


Figure 4.10

Rectangular sections can be input conveniently as either Rectangle-B or Rectangle-C. There are no essential differences between the two other than for input conveniences. Rectangle-C type is primarily for section of column type (Figure 4.9). Reinforcement may be input for top, bottom, left and right sides. Rectangle-B type is primarily for section of beam type (Figure 4.10). Up to three layers of reinforcement may be input for either top or bottom.

Input for Circular, Tee, Inversed L and I type are straight forward. For circular section, different bar pattern may be arranged with the adjustment of bar start angle.

Generic type is for irregular section with boundary geometry not belonging to any of the types above (Figure 4.11). The section may contain up to three openings. The vertices of section and opening boundaries must be continuous in either clockwise or counterclockwise direction. You can also use “Rectangular”, “Circular”, and “I” button to generate points in a rectangular, circular (or ellipse), and I-shaped patterns.

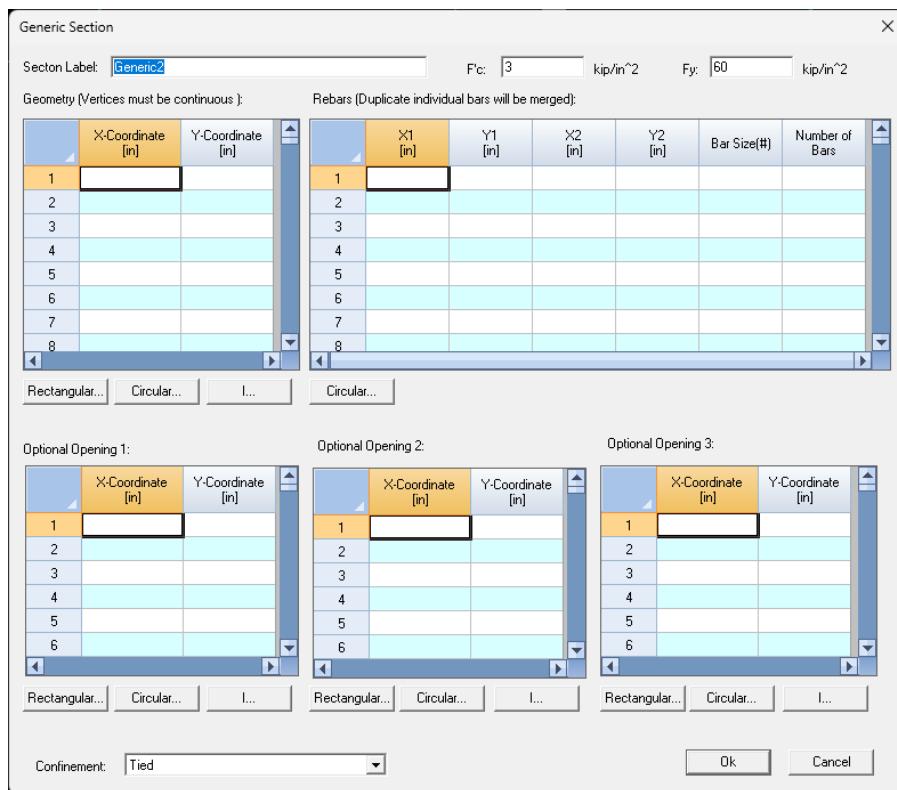


Figure 4.11

Also, the section and opening boundaries must not be self-intersecting. For example, the solution will fail in the following cases:



For input convenience, bars are entered as uniformly distributed along a line. Single bar can be input by placing it on a line where both two end points coincide. If duplicate bars exist on different bar lines at the same location, they will be automatically merged.

You may “Copy”, “Modify” and “Delete” existing sections. You may also convert any regular section to a generic section. Conversion of a circular section to a generic section may result in a minor loss of accuracy due to the approximation of a circle with a polygon. The “Auto Rename” button allows you to rename all sections as Section_1, Section_2, etc.

Loads

Input | Loads allows you to input loads P_u , M_{ux} , M_{uy} at column top and bottom (Figure 4.12). Loads must be calculated beforehand by the code-specified factored load combinations, including overall second-order ($P-\Delta$) effects. The program may consider slenderness ($P-\delta$) effects along individual column length. β_d and C_m are used in the moment magnification calculation in the program. The β_d (β_{dns} or Beta_d) is the ratio of maximum factored axial sustained load over maximum factored axial load associated with the same load combination. It must be less than 1.0. The term C_m is an equivalent moment correction factor. For members without transverse loads between supports, $C_m = 0.6 + 0.4 * (M1 / M2)$. If a value of 0 is entered for C_m , the program will calculate C_m according to this formula. C_m must be greater than 0.4. It is generally recommended that a value of 1.0 is used for C_m .

Factored Load Data							
	P_u [kip]	$M_{ux - Top}$ [kip-ft]	$M_{ux - Bottom}$ [kip-ft]	$M_{uy - Top}$ [kip-ft]	$M_{uy - Bottom}$ [kip-ft]	β_d	C_m
1	920.4	111.7	62.5	0	0	0.94	0.82
2							
4							
<input type="button" value="Generate From Service Loads..."/> <input type="button" value="Import From spColumn Service Loads..."/>				<input type="button" value="OK"/> <input type="button" value="Cancel"/>			
1	<input type="button" value="New Rows"/>	<input type="button" value="Print..."/>					

Figure 4.12

You have the option to let the program automatically generate factored loads from service loads (Figure 4.13). You must specify axial load, M_x at the top and bottom of the column, M_y at the top and bottom of the column for Dead, Live, Wind, Earthquake, and Roof Live (or Snow, or Rain) load cases.

Service Load Data						
	Load Case	P [kip]	Mx - Top [kip-ft]	Mx - Bottom [kip-ft]	My - Top [kip-ft]	My - Bottom [kip-ft]
1	Dead					
2	Live					
3	Wind					
4	Earthquake					
5	Roof Live (Snow, Rain)					

Figure 4.13

The program will automatically calculate the factored loads, β_d , C_{mx} , C_{my} for different load combinations based on the currently selected ACI 318 code.

For ACI 318-11, 14, and 19, the following load combinations will be used.

$$U = 1.4D$$

$$U = 1.2D + 1.6L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + 1.0L$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + 0.5W$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) - 0.5W$$

$$U = 1.2D + 1.0W + 1.0L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D - 1.0W + 1.0L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.0E + 1.0L + 0.2S$$

$$U = 1.2D - 1.0E + 1.0L + 0.2S$$

$$U = 0.9D + 1.0W$$

$$U = 0.9D - 1.0W$$

$$U = 0.9D + 1.0E$$

$$U = 0.9D - 1.0E$$

For ACI 318-02, 05, and 08, the following load combinations will be used. cColumn currently does not support load cases for fluid weight/pressure (F), temperature (T), or soil weight/pressure (H).

$$U = 1.4D$$

$$U = 1.2D + 1.6L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + 1.0L$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + 0.8W$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) - 0.8W$$

$$U = 1.2D + 1.6W + 1.0L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D - 1.6W + 1.0L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.0E + 1.0L + 0.2S$$

$$U = 1.2D - 1.0E + 1.0L + 0.2S$$

$$U = 0.9D + 1.6W$$

$$U = 0.9D - 1.6W$$

$$U = 0.9D + 1.0E$$

$$U = 0.9D - 1.0E$$

For interoperability purpose, cColumn provides the option to import loads from one or more text files that conform to spColumn service load text file format. You also have the option to specify force and moment multipliers in cases different units are used or moment signs need reversal (Figure 4.14).

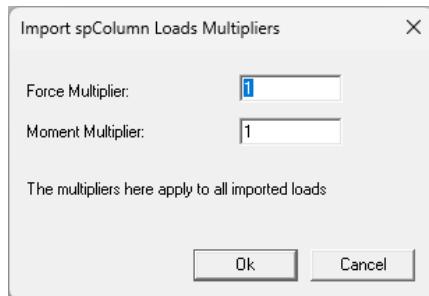


Figure 4.14

A Service Loads to Factored Loads Example

Service Loads

	P	Mx - Top	Mx - Bottom	My - Top	My - Bottom
Dead	718	79	40	89	-30
Live	80	30.3	15.3	50	-12
Wind	8	1.1	4.3	15	-2.3
Earthquake	15	5	10	12	-3
Roof Live (Snow, Rain)	12	2	3	4	-6

Factored Loads According to ACI 318-08

Pu	Mux - Top	Mux - Bottom	Muy - Top	Muy - Bottom	Beta-d	Cmx	Cmy
1005.2	110.6	56	124.6	-42	1	0.802532	0.465169
995.6	144.28	73.98	188.8	-58.2	0.865408	0.805101	0.476695
960.8	128.3	68.1	163.2	-57.6	0.896753	0.812315	0.458824
887.2	98.88	56.24	125.2	-47.44	0.971145	0.827508	0.448435
874.4	97.12	49.36	101.2	-43.76	0.985361	0.803295	0.427036
960.4	127.86	71.68	182.8	-54.68	0.897126	0.824245	0.48035
934.8	124.34	57.92	134.8	-47.32	0.921694	0.786328	0.459585
959	130.5	73.9	169.6	-52.2	0.898436	0.826513	0.476887
929	120.5	53.9	145.6	-46.2	0.927449	0.778921	0.473077
659	72.86	42.88	104.1	-30.68	0.980577	0.83541	0.482113
633.4	69.34	29.12	56.1	-23.32	1	0.767984	0.433725
661.2	76.1	46	92.1	-30	0.977314	0.841787	0.469707
631.2	66.1	26	68.1	-24	1	0.757337	0.459031

Factored Loads According to ACI 318-19

Pu	Mux - Top	Mux - Bottom	Muy - Top	Muy - Bottom	Beta-d	Cmx	Cmy

1005.2	110.6	56	124.6	-42	1	0.802532	0.465169
995.6	144.28	73.98	188.8	-58.2	0.865408	0.805101	0.476695
960.8	128.3	68.1	163.2	-57.6	0.896753	0.812315	0.458824
884.8	98.55	54.95	120.7	-46.75	0.973779	0.823034	0.44507
876.8	97.45	50.65	105.7	-44.45	0.982664	0.807901	0.431788
955.6	127.2	69.1	173.8	-53.3	0.901632	0.817296	0.47733
939.6	125	60.5	143.8	-48.7	0.916986	0.7936	0.464534
959	130.5	73.9	169.6	-52.2	0.898436	0.826513	0.476887
929	120.5	53.9	145.6	-46.2	0.927449	0.778921	0.473077
654.2	72.2	40.3	95.1	-29.3	0.987771	0.823269	0.476761
638.2	70	31.7	65.1	-24.7	1	0.781143	0.448233
661.2	76.1	46	92.1	-30	0.977314	0.841787	0.469707
631.2	66.1	26	68.1	-24	1	0.757337	0.459031

Slenderness

Input | Slenderness allows you to consider slender column ($P-\delta$) effects in major and/or minor axes along the column length (Figure 4.15). The unbraced length of a column, L_u , is taken as the clear distance between floor slabs, beams, or other members capable of providing lateral support in the direction being considered. Where column capitals or haunches are present, L_u is measured to the lower extremity of the capital or haunch in the plane considered.

The effective length factor K may be calculated by alignment charts in ACI 318 Code or by other approximate methods. It is generally recommended to use a value of 1.0 for K . You have the option to consider minimum factored moment $M_{min} = P_u * (0.6 + 0.03h)$. In the calculation of critical column load capacity (P_c), the stiffness (EI) may be taken as one of the following two values, the first of which is more accurate.

$$EI = \frac{(0.2E_c I_g + E_s I_{se})}{1 + \beta_d} \quad \text{or} \quad EI = \frac{0.4E_c I_g}{1 + \beta_d}$$

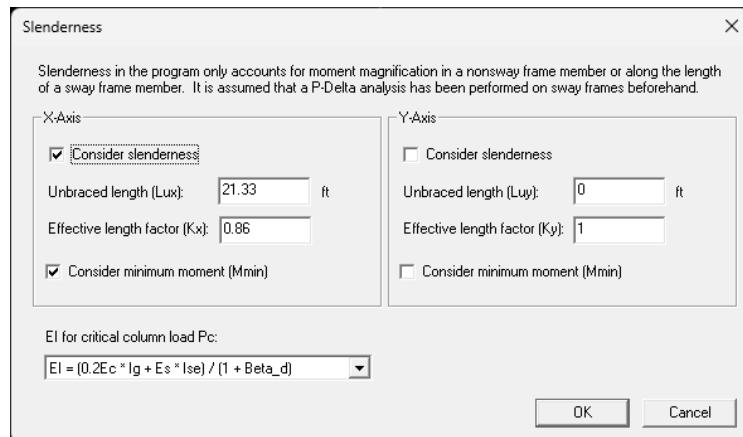


Figure 4.15

Design Criteria

Input | Design Criteria defines the minimum and maximum reinforcement ratios, preferred unity ratios, bar selection method, and minimum clear spacing between bars (Figure 4.16). The reinforcement ratio normally is between 1% and 8%. A unity ratio of less than 1.0 means the section is safe to resist the loads. During or after the solution, sections with unity ratios outside the limits may be optionally eliminated. The bar section method is used in ranking the sections for design. The section ranking algorithm first check for unity ratio range and reinforcement ratio range (pass/failure), then sort sections based on section areas in ascending order, then sort sections based on areas of steel in ascending ordering or clear spacings between bars in descending order. The minimum clear spacing between bars can be specified here to replace the code requirement of 1.5 inches.

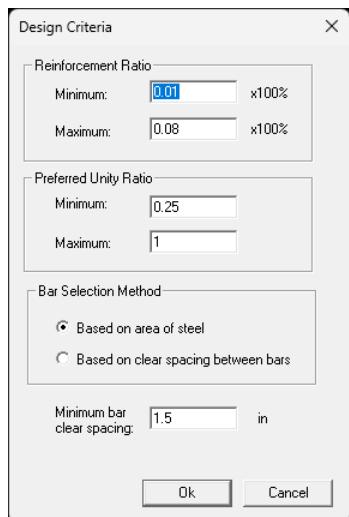


Figure 4.16

Note: At least one section will be kept even if unity ratios are outside the minimum and maximum unity ratios for all sections.

Undo

Input | Undo undoes the previous command. By default, you may undo up to 100 levels. You may set a different number of undo levels by running Settings | Data Options. Some commands such as zooming or panning may not be undone. More undo levels requires more computer memory.

Redo

Input | Redo reverses the previous undo command.

Chapter 5: Run

The Run main menu provides commands to set solver options, run the solver or generate a text report for input and output.

Options

Run | Options allows you to set important solver options (Figure 5.1). It is highly recommended that you read the method of solution in the technical part of this document in order to understand these options. You should run this command before running the solver.

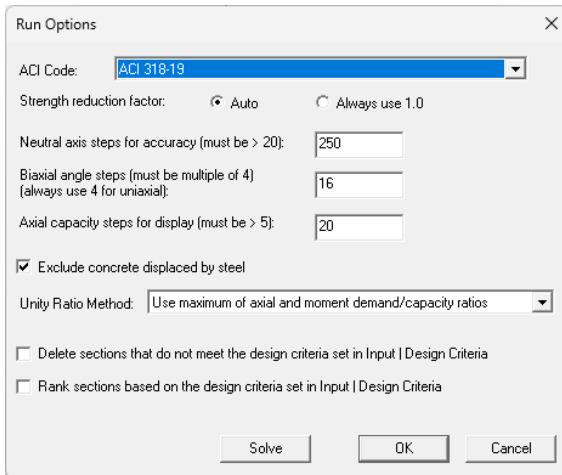


Figure 5.1

Design Code	Specifies design codes. Currently the program supports ACI 318-2019/2014/2011/2008/2005/2002/1999.
Strength reduction factor	<i>Auto</i> – strength reduction factor will be based on the selected Code. <i>Always use 1.0</i> – No strength reduction is applied. Capacity is the nominal strength. You must not use this option in actual engineering designs.
Neutral axis steps for accuracy	Neutral axial steps affect the solution accuracy and speed. A value of 250 ~ 500 for neutral axis steps is sufficiently accurate for most sections. The adequacy of neutral axis steps can be determined by smoothness of the P-M _x and/or P-M _y interaction diagrams.
Biaxial angle steps	Biaxial angle affects the solution accuracy and speed. For biaxial problems, steps must be multiple of 4. A value of 16 or 32 is sufficiently accurate for most sections. The adequacy of biaxial angle steps can be determined by smoothness of the M _x -M _y interaction diagram. For uniaxial runs about X or Y axis, biaxial angle steps should be set to 4. This will give P-M _x (+) at 0 degree angle, P-M _x (-) at 180 degrees angle, P-M _y (+) at 90

	degree angle, P-M _y (-) at 270 degrees angle.
Axial capacity steps for display	Specifies the number of axial steps for the display of interaction diagrams / surfaces and result data in the spreadsheet. This value should be smaller than neutral axis steps. A value of 20 to 50 is usually adequate.
Exclude concrete displaced by steel	Should almost always be checked. This option is provided for verifications with textbooks only!
Unity ratio method	This sets the method to calculate the unity ratio. There are two options: 1). Use maximum of axial and moment demand/capacity ratios 2). Use moment demand/capacity ratio (not recommended)
Delete sections that do not meet the design criteria	If this option is set and the model is in a design or advanced mode, sections that do not meet the limits of reinforcement ratios, unity ratios, and clear spacing between bars specified in the Input Design Criteria will be deleted during solution. This allows you to pick a desired section for design more easily. <i>Note: At least one section will be kept in the model.</i>
Rank sections based on the design criteria	If this option is set, the solver will re-arrange the order of the sections according to whether they meet the design criteria, the section sizes, the area of steel or clear spacing between bars, and the capacity ratios. The best candidates for design will be placed at the top of the section list.

Solve

Run | Solve perform the solution for each section. It starts with checking the validity of all input. If there are any errors, the solution stops. *You may also stop the solver during the solution process by pressing [ESC] key.*

Report

Run | Report command is the same as File | Report. It is provided here for conveniences only.

Log File

Run | Log File command allows you to view solution messages that is saved in the log file.

Concrete Cover Calculator

Run | Concrete Cover Calculator is a utility that allows you to calculate the concrete cover to the longitudinal bars based on clear cover to ties, ties size, longitudinal bar size (Figure 5.2).

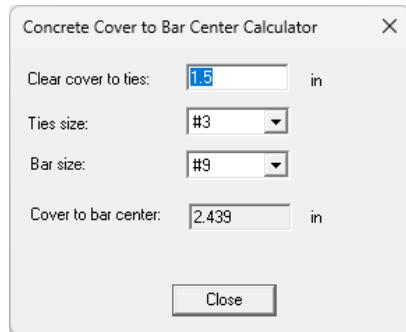


Figure 5.2

Chapter 6: Result Data

The Result Data main menu provides commands to view result data in spreadsheets.

Section Properties

Result Data | Section Properties displays the section properties such as the coordinates of section centroid, section area and moment inertias about X and Y axes, radii of gyration about X and Y axes as well as moment of inertia of reinforcement about centroidal axis of member cross section I_{se-x} and I_{se-y} . It is important to point out that loads (M_x , M_y) and moment inertias (I_x , I_y) are based on the section centroid. Moment inertias for a generic section are approximately calculated by dividing the section into 100 by 100 small rectangles. For practical applications, this approximation is sufficiently accurate. (Figure 6.1).

	Section Label	X0 [in]	Y0 [in]	Ag [in ²]	Ix [in ⁴]	Iy [in ⁴]	rx [in]	ry [in]	Ise-x [in ⁴]	Ise-y [in ⁴]
1	RectC1	0.0000	0.0000	288.000	13824.000	3456.000	6.9282	3.4641	942.599	223.753
2										

Figure 6.1

P-M_x (+)

Result Data | P-M_x (+) displays the P-M_x result data in a spreadsheet, with positive moment about the section major axis (at biaxial angle of 0 degree) (Figure 6.2).

P-M_x (-)

Result Data | P-M_x (-) displays the P-M_x result data in a spreadsheet, with negative moment about the section major axis (at biaxial angle of 180 degrees).

P-Mx(+), Compression on Top						
Section: 1: RectC						X
	Neutral Axis Depth [in]	phi * Pn	phi * Mnx [kip-ft]	Eccentricity [in]	Maximum Steel Tensile Strain	Phi
1	[Pure Compression]	690.6	0.0	0.00	-0.00300	0.650
2	17.82	690.6	104.0	1.81	-0.00038	0.650
3	17.82	690.6	104.0	1.81	-0.00038	0.650
4	16.95	656.0	120.9	2.21	-0.00025	0.650
5	16.03	621.5	136.1	2.63	-0.00010	0.650
6	15.56	599.7	144.9	2.90	-0.00000	0.650
7	15.56	599.7	144.9	2.90	-0.00000	0.650
8	15.56	599.7	144.9	2.90	-0.00000	0.650
9	15.56	599.7	144.9	2.90	0.00000	0.650
10	15.25	587.0	149.7	3.06	0.00006	0.650
11	14.43	552.4	161.7	3.51	0.00024	0.650
12	13.62	517.9	172.3	3.99	0.00043	0.650
13	13.27	502.8	176.5	4.21	0.00052	0.650
14	13.27	502.8	176.5	4.21	0.00052	0.650
15	13.27	502.8	176.5	4.21	0.00052	0.650
16	13.27	502.8	176.5	4.21	0.00052	0.650
17	12.83	483.4	181.6	4.51	0.00064	0.650
18	12.07	448.9	189.8	5.07	0.00087	0.650

Figure 6.2

P-My (+)

Result Data | P-My (+) displays the P-My result data in a spreadsheet, with positive moment about the section minor axis (at biaxial angle of 90 degrees).

P-My (-)

Result Data | P-My (-) displays the P-My result data in a spreadsheet, with negative moment about the section minor axis (at biaxial angle of 270 degrees).

Mx-My

Result Data | Mx-My displays the Mx-My result data for a given axial load in a spreadsheet (Figure 6.3).

Mx-My					
Section: 1: RectC					
	phi * Pn	phi * Mnx	phi * Myr	Neutral Axis Depth	Maximum Steel Tensile Strain
	[kip]	[kip-ft]	[kip-ft]	[in]	[Degree]
1	0.0	131.4	0.0	2.38	0.01658 0.0
2	0.0	123.8	76.7	5.85	0.00743 22.5
3	0.0	112.5	112.5	7.46	0.00585 45.0
4	0.0	76.7	123.8	5.85	0.00743 67.5
5	0.0	-0.0	131.4	2.38	0.01658 90.0
6	0.0	-76.7	123.8	5.85	0.00743 112.5
7	0.0	-112.5	112.5	7.46	0.00585 135.0
8	0.0	-123.8	76.7	5.85	0.00743 157.5
9	0.0	-131.4	-0.0	2.38	0.01658 180.0
10	0.0	-123.8	-76.7	5.85	0.00743 202.5
11	0.0	-112.5	-112.5	7.46	0.00585 225.0
12	0.0	-76.7	-123.8	5.85	0.00743 247.5
13	0.0	0.0	-131.4	2.38	0.01658 270.0
14	0.0	76.7	-123.8	5.85	0.00743 292.5
15	0.0	112.5	-112.5	7.46	0.00585 315.0
16	0.0	123.8	-76.7	5.85	0.00743 337.5
17					

Figure 6.3

Capacity Check

Result Data | Capacity Check displays unity ratio for each section against all loads. Sections with unity ratios less than 1.0 are adequate to resist the loads (Figure 6.3). Sections with unity ratios greater than 1.0 are inadequate to resist the loads. For definition of unity ratios, refer to the method of solution in the technical issues part of this documentation.

Capacity check also includes other useful design parameters such as reinforcement ratio calculated as total steel area (A_s) divided by section gross area (A_g); minimum clear spacing between longitudinal bars; critical load number for which unity ratio is calculated. M_{cx} and M_{cy} denote the magnified M_x and M_y moments of the critical load. The moment magnification factors can be computed M_{cx} / M_x and M_{cy} / M_y .

A row is colored red if the section unity ratio is more than 1.0 or outside the range of preferable unity ratio specified in the Input | Design Criteria; A row is colored orange if the section reinforcement ratio or clear spacing between bars is outside the range specified in the Input | Design Criteria.

Capacity Check										
A section is marked red if its unity ratios is greater than 1.0 or outside the preferred minimum and maximum unity ratios. A section is marked orange if reinforcement ratio or minimum bar clear spacing is outside the normal range (see Input Design Criteria)										
	Section Label	Unity Ratio	Critical Load No.	M_{cx} [kip-ft]	M_{cy} [kip-ft]	Reinf. Ratio	A_s [in^2]	A_g [in^2]	Clear Spacing [in]	▲
1	Rect22x22_f5_ly60_12#11_NX4_NY4_cc2.564	0.959	1	300.0	125.0	2.479%	12.00	484.0	4.50	
2	Rect22x22_f5_ly60_8#11_NX3_NY3_cc2.705	0.935	1	300.0	125.0	2.579%	12.48	484.0	6.88	
3	Rect22x22_f5_ly60_12#11_NX4_NY4_cc2.635	0.845	1	300.0	125.0	3.149%	15.24	484.0	4.31	
4	Rect24x24_f5_ly60_4#11_NX2_NY2_cc2.705	0.825	1	300.0	125.0	1.083%	6.24	576.0	17.18	
5	Rect20x20_f5_ly60_4#11_NX2_NY2_cc2.564	1.787	1	300.0	125.0	1.000%	4.00	400.0	13.74	
6	Rect20x20_f5_ly60_4#10_NX2_NY2_cc2.635	1.736	1	300.0	125.0	1.270%	5.08	400.0	13.46	
7	Rect20x20_f5_ly60_4#11_NX2_NY2_cc2.705	1.687	1	300.0	125.0	1.560%	6.24	400.0	13.18	
8	Rect20x20_f5_ly60_8#3_NX3_NY3_cc2.564	1.712	1	300.0	125.0	2.000%	8.00	400.0	6.31	
9	Rect20x20_f5_ly60_8#10_NX2_NY2_cc2.635	1.649	1	300.0	125.0	2.540%	10.16	400.0	6.10	
10	Rect20x20_f5_ly60_12#11_NX4_NY4_cc2.564	1.633	1	300.0	125.0	3.000%	12.00	400.0	3.83	
11	Rect20x20_f5_ly60_8#11_NX3_NY3_cc2.705	1.572	1	300.0	125.0	3.120%	12.48	400.0	5.88	
12	Rect20x20_f5_ly60_12#10_NX4_NY4_cc2.635	1.294	1	300.0	125.0	3.810%	15.24	400.0	3.64	
13	Rect20x20_f5_ly60_12#11_NX4_NY4_cc2.705	1.093	1	300.0	125.0	4.680%	18.72	400.0	3.45	
14	Rect22x22_f5_ly60_4#8_NX2_NY2_cc2.564	1.362	1	300.0	125.0	0.826%	4.00	484.0	15.74	
15	Rect22x22_f5_ly60_4#10_NX2_NY2_cc2.635	1.398	1	300.0	125.0	1.050%	5.08	484.0	15.46	
16	Rect22x22_f5_ly60_4#11_NX2_NY2_cc2.705	1.267	1	300.0	125.0	1.289%	6.24	484.0	15.18	
17	Rect22x22_f5_ly60_8#3_NX3_NY3_cc2.564	1.167	1	300.0	125.0	1.653%	8.00	484.0	7.31	
18	Rect22x22_f5_ly60_8#10_NX2_NY2_cc2.635	1.040	1	300.0	125.0	2.099%	10.16	484.0	7.10	

Figure 6.3

Rank Sections

Result Data | Rank Sections will re-arrange the order of the sections according to whether they meet the design criteria, the section sizes, the area of steel or clear spacing between bars, and the capacity ratios. The best candidates for design will be placed at the top of the section list.

Chapter 7: Window

The Window main menu provides commands to create new windows and arrange existing windows. A window may be used interchangeably with a view. The program has two types of views: model view and report view. The model view contains the graphical display of the input in a model. The report view contains text or graphical report in the html format for the input or output in a model.

New Window

Window | New Window creates a new window or view based on the current view. You may create different model views with different display settings with respect to zooming, panning. You may create as many views as you want. However, too many views may clutter the view area and make graphic display sluggish.

Tile Horizontal

Window | Tile Horizontal arranges all opened windows horizontally.

Tile Vertical

Window | Tile Vertical arranges all opened windows vertically.

Tile Cascade

Window | Cascade arranges all opened window in overlapped manner

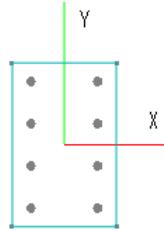
Part 2

Technical Issues

Chapter 8: Method of Solution

Coordinate System - Geometry

1. Geometry coordinate system (GCS) is a 2D plane X-Y rectangular coordinate system. Axis X points from left to right while axis Y points from bottom to top. GCS is used to define section geometry and reinforcing rebar locations.



2. For regular sections such as rectangular and tee sections, the program automatically generates section vertices and rebar locations based on simple input through dialog boxes. The program can parametrically generate multiple rectangular or circular sections based on parameters such as section dimensions, rebar sizes, numbers, and rebar layout. This is very useful in concrete column design where tedious trial-and-error process is the norm.
3. For a generic or irregular section, vertices and rebar locations may be input manually in spreadsheets. Vertices of a section must be continuous in either clockwise or counterclockwise direction. Up to 3 openings may be defined in a generic section.
4. The geometry and rebar locations of any regular section may be converted to a generic section from where you can make modifications such as adding openings or unusual rebar layout.
5. Each section must obey the following rules:
 - Rebar covers (either directly from input or computed by the program) are all measured from edge of the section to the center of the (longitudinal) rebars.*
 - Duplicate rebars at the same location will be merged into one bar.*
 - Two rebars with a distance of less than the radius of the smallest database bar will be merged into one bar.*
 - Rebars must be inside the section geometry and outside any openings.*
 - Openings must be inside the section geometry*
6. For columns, minimum concrete cover to ties is 1.5 inches (Ref. 2). Minimum sizes of ties are #3 for longitudinal bars #5 to #10, and #4 for #11, #14 or #18 longitudinal bars.

Minimum depth from nearest faces to center of longitudinal bars

Bar Size	#5	#6	#7	#8	#9	#10	#11	#14	#18
Depth (in)	2.1875	2.25	2.3125	2.375	2.439	2.51	2.705	2.8465	3.1285

Since different longitudinal bar sizes may be used during automatic section generation, the program computes concrete cover to bar center based on the following formula:
“cover to ties” + “ties diameter” + one half of “longitudinal bar diameter”

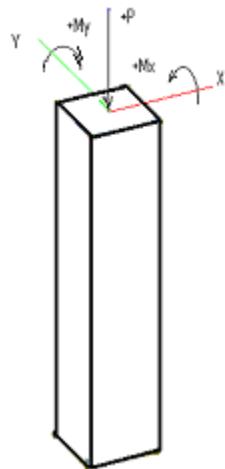
Loads and Capacity

1. Axial force P acts perpendicular to the section. Moments M_x and M_y acts about section X and Y axis respectively. They have the following sign conventions.

Axial Force P : positive for compression; negative for tension

Moment M_x : Positive when section top most fiber is under compression.

Moment M_y : Positive when section rightmost fiber is under compression.



2. All moments are referenced about the geometric centroid of the gross section.
3. Unlimited number of **factored** load sets can be input via spreadsheet. Loads are the required strength computed by the code-specified factored load combinations using either hands or analysis program such as Real3D. It is assumed that an overall 2nd order P-Delta (P-Δ) analysis has been performed on a sway structure. If desired, the program uses ACI 318 moment magnification procedure to calculate the P-delta (P-δ) effect, which accounts for slenderness of columns in non-sway structure or for slenderness along the lengths of columns in sway structure.
4. Unity ratio is computed for each section based on the magnified factored loads and the capacity of the section. Unity ratio equal or less than 1.0 means the design strength is greater than the required strength and the section is adequate. Unity ratio greater than 1.0 means the design strength is less than the required strength and the section is inadequate.

Solution Assumptions

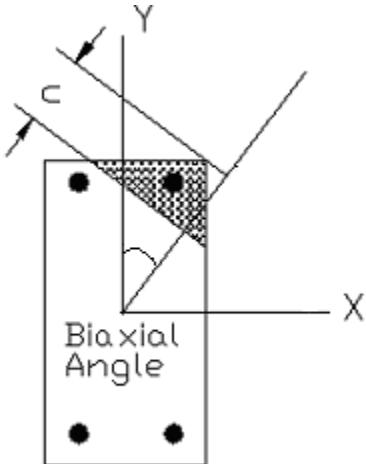
1. The strain in reinforcement and concrete is directly proportional to the distance from the neutral axis (ACI 318-19/14 22.2.1.2, ACI 318-11/08/05/02 10.2.2).
2. The maximum usable strain at the extreme concrete compression fiber is equal to 0.003 (ACI 318-19/14 22.2.2.1, ACI 318-11/08/05/02 10.2.3).
3. The stress of steel is $f_s = E_s * \epsilon_s$ but $f_s \leq f_y$ where $E_s = 29000$ ksi, ϵ_s is steel strain and f_y is the yield strength of steel (ACI 318-19/14 20.2.2.1, ACI 318-11/08/05/02 10.2.4).
4. The tensile strength of the concrete is neglected in flexural calculation (ACI 318-19/14 20.2.2.2, ACI 318-11/08/05/02 10.2.5).
5. A uniformly distributed stress of $0.85f_c$ is assumed over an equivalent compression zone bounded by the edge of the cross section and a line parallel to the neutral axis at a distance $a = \beta_1 * c$ where c is the distance from extreme compression fiber to neutral axis.

$$\beta_1 = 0.85 - 0.05 * (f_c - 4)$$
 and $0.65 \leq \beta_1 \leq 0.85$ and f_c unit is ksi (ACI 318-19/14 22.2.2.3, 22.2.2.4, ACI 318-11/08/05/02 10.2.7.1).
6. Reinforcement ratio ρ should be $1\% \leq \rho \leq 8\%$ for column sections (ACI 318-19/14 10.6.1.1, ACI 318-11/08/05/02 10.9.1). *You can override this limit in the design criteria.*

Solution Algorithms

1. Biaxial Solution

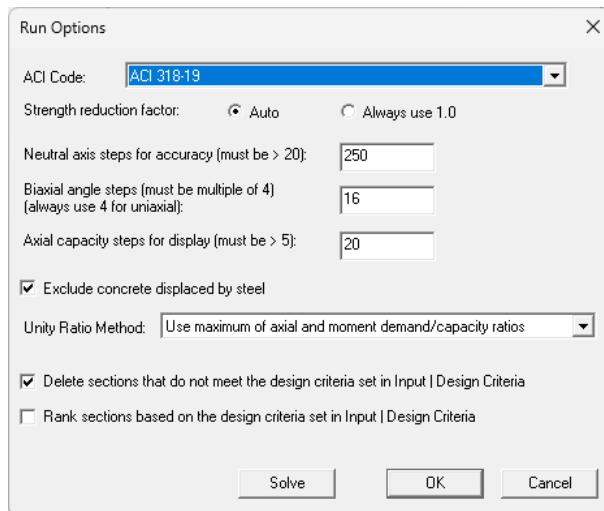
All sections are solved biaxially based on the solution assumption above. Each section is solved based on the following steps.



2. Nominal Strength Calculation (P_n , M_{nx} , M_{ny})

- 2a. The nominal capacity of a section is computed at successive choices of biaxial angles. The choices of angles are based on the user input for biaxial angle steps found in the command Run | Options. Biaxial angle steps affect the solution accuracy and speed. For biaxial problems, steps must be multiple of 4. A value of 16 ~ 32 is sufficiently accurate for most sections. The adequacy of biaxial angle steps can be determined by smoothness of the

M_x - M_y interaction diagram. For uniaxial problems, biaxial angle steps should be set to 4. This will give P - M_x (+) at 0 degree angle, P - M_x (-) at 180 degrees angle, P - M_y (+) at 90 degree angle, P - M_y (-) at 270 degrees angle.



Biaxial angle steps is analogous to the number of sides in a polygon used to approximate a circle or ellipse. A uniaxial solution in the program is therefore analogous to using a square to approximate a circle; or a rectangle to approximate an ellipse. A biaxial solution with 16 angle steps is analogous to using a 16-sided polygon to approximate a circle or an ellipse. Obviously, the 16-sided polygon is more accurate to approximate a circle than a square. The moral of this comparison is that a low value of biaxial angle steps tends to give more conservative biaxial capacity for the section.

2b). For each biaxial angle, P_n , M_{nx} , M_{ny} , and maximum tensile steel strain ϵ_t are computed at successive choices of neutral axis distance (c) using strain compatibility and stress-strain relations to establish bar forces and the concrete compressive results. **The nominal moment capacity is found by summing the moments of all the internal forces about the geometric centroid of the section because this is the axis about which moments are computed in a conventional structural analysis.** The choices of c (neutral axis distance) are based on the neutral axial steps found in the command Run | Options. Neutral axial steps affect the solution accuracy and speed. A value of 250 ~ 500 for neutral axis steps is sufficiently accurate for most sections. The adequacy of neutral axis steps can be determined by smoothness of the P - M_x and/or P - M_y interaction diagrams. In addition, the program always computes several control points. They are maximum P_n (compression), minimum P_n (tension), $f_s = 0$; 0.25f_y; 0.5f_y and 1.0f_y (balanced condition). Concrete displaced by steel may be optionally included or excluded (default).

2c). M_{nx} - M_{ny} contour curves are computed for successive choices of axial forces. This is achieved through interpolation on the P_n , M_{nx} and M_{ny} already calculated for each biaxial angle in the procedure above. The choices of axial forces are based on the neutral axial steps found in the command Run | Options.

3. Design Strength Calculation (ϕP_n , ϕM_{nx} , ϕM_{ny})

3a). ACI 318-19

Design strength according to ACI 318-19 is obtained by multiplying P_n , M_{nx} and M_{ny} of each biaxial angle by applying strength reduction factor ϕ as determined in the following:

$\Phi_c = 0.65$, $\alpha = 0.80$ for tied confinement

$\Phi_c = 0.75$, $\alpha = 0.85$ for spiral confinement

For ($\epsilon_t \leq \epsilon_y$)

$$\phi = \Phi_c$$

For ($\epsilon_t \geq \epsilon_y + 0.003$)

$$\phi = 0.90$$

For ($\epsilon_y < \epsilon_t < \epsilon_y + 0.003$)

$$\phi = \Phi_c + (0.9 - \Phi_c) * (\epsilon_t - \epsilon_y) / 0.003$$

where ϵ_t is maximum tensile steel strain for the biaxial angle and ϵ_y is steel yield strain (at balanced condition)

In addition, ϕP_n must be always less than $\phi P_{n, max}$

$\Phi_c * \alpha * [0.85 * f'_c * (A_g - A_s) + f_y * A_s]$ if concrete displaced by steel is excluded or

$\Phi_c * \alpha * [0.85 * f'_c * A_g + f_y * A_s]$ if concrete displaced by steel is not excluded

It is important to note that f_y is limited to 80 ksi when calculating $P_{n, max}$

3b). ACI 318-02/05/08/11/14

Design strength according to ACI 318-02/05/08/11/14 is obtained by multiplying P_n , M_{nx} and M_{ny} of each biaxial angle by applying strength reduction factor ϕ as determined in the following:

$\Phi_c = 0.65$, $\alpha = 0.80$ for tied confinement

$\Phi_c = 0.70$, $\alpha = 0.85$ for spiral confinement for ACI 318-02/05

$\Phi_c = 0.75$, $\alpha = 0.85$ for spiral confinement for ACI 318-08/11/14

For ($\epsilon_t \leq \epsilon_y$)

$$\phi = \Phi_c$$

For ($\epsilon_t \geq 0.005$)

$$\phi = 0.90$$

For ($\epsilon_y < \epsilon_t < 0.005$)

$$\phi = \Phi_c + (0.9 - \Phi_c) * (\epsilon_t - \epsilon_y) / (0.005 - \epsilon_y)$$

where ϵ_t is maximum tensile steel strain for the biaxial angle and ϵ_y is steel yield strain (at balanced condition)

In addition, ϕP_n must be always less than

$\Phi_c * \alpha * [0.85 * f'_c * (A_g - A_s) + f_y * A_s]$ if concrete displaced by steel is excluded or

$\Phi_c * \alpha * [0.85 * f'_c * A_g + f_y * A_s]$ if concrete displaced by steel is not excluded

3c). ACI 318-99

Design strength according to ACI 318-99 is obtained by multiplying P_n , M_{nx} and M_{ny} of each biaxial angle by applying strength reduction factor ϕ as determined in the following:

$\Phi_c = 0.70$, $\alpha = 0.80$ for tied confinement

$\Phi_c = 0.75$, $\alpha = 0.85$ for spiral confinement

For tension and pure flexure ($P_n \leq 0$)

$$\phi = 0.90$$

For compression ($P_n > 0$)

$$P_{n1} = \text{smaller of } 0.1 * f_c' * A_g / \Phi_c \text{ and } P_{nb}$$

Where A_g is the gross section area and P_{nb} is the nominal strength at balanced condition for the biaxial angle.

If $P_n > P_{n1}$ then $\phi = \Phi_c$

If $P_n \leq P_{n1}$ then $\phi = \Phi_c + (0.9 - \Phi_c) * (P_{n1} - P_n) / P_{n1}$

In addition, ϕP_n must be always less than

$\Phi_c * \alpha * [0.85 * f_c' * (A_g - A_s) + f_y * A_s]$ if concrete displaced by steel is excluded or

$\Phi_c * \alpha * [0.85 * f_c' * A_g + f_y * A_s]$ if concrete displaced by steel is not excluded

4. Unity Ratio

Unity ratio is computed for each section based on the loads and the capacity of the section. There are two methods to calculate the unity ratio:

1). Use maximum of axial and moment demand/capacity ratios

For a given load set (P_u, M_{ux}, M_{uy}), find the section capacity M_x - M_y contour at $\phi P_n = P_u$. The unity ratio for the load set is larger of the following two demand/capacity ratios:

$$\left(\frac{\sqrt{(M_{ux})^2 + (M_{uy})^2}}{\sqrt{(\phi M_{nx,max})^2 + (\phi M_{ny,max})^2}}, \frac{P_u}{(\phi P_{n,max})} \right)$$

Where $(\phi M_{nx,max}, \phi M_{ny,max})$ is the interaction point between the line from point (M_{ux}, M_{uy}) to point $(0, 0)$ and M_x - M_y contour line. $\phi P_{n,max}$ is the maximum compression or tension capacity of the section, depending on the positive or negative sign of P_u . If P_u is outside maximum compression or tension capacity, a unity ratio of 99.9 is assigned.

The unity ratio of a section is the maximum unity ratio for all input load sets. Unity ratio equal or less than 1.0 means the design strength is greater than the required strength and the section is adequate to resist all input loads. Unity ratio greater than 1.0 means the design strength is less than the required strength and the section is inadequate to resist all input loads.

2). Use moment demand/capacity ratio (not recommended)

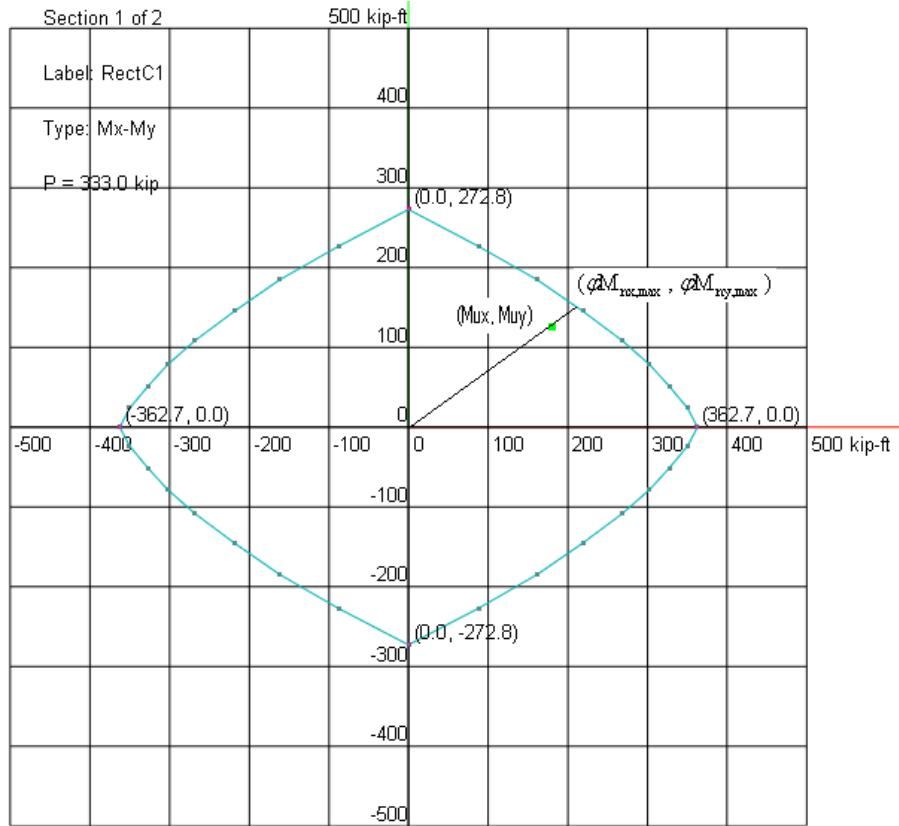
This option is similar to the first option except $P_u/\phi P_{n,max}$ is not considered. This option is not as accurate as the first option above and is therefore not recommended.

It is important to realize that unity ratio defined in the program is just a measure of section adequacy against loads. It should not be regarded as the factor of safety.

5. Unity Ratio Calculation Example

To illustrate the calculation of unity ratio in the program, see the following example.

For a given load set $(P_u, M_{ux}, M_{uy}) = (333 \text{ kip}, 180 \text{ ft-kip}, 125 \text{ ft-kip})$, a M_x - M_y capacity contour at $\phi P_n = 333 \text{ kip}$ is obtained as shown below. In addition, the maximum compression capacity $\phi P_{n,\max} = 1050.2 \text{ kip}$. Use maximum of axial and moment demand/capacity ratios



The interaction point between the line from point $(180 \text{ ft-kip}, 125 \text{ ft-kip})$ to point $(0, 0)$ and the contour line is obtained as $(214.1 \text{ ft-kip}, 148.7 \text{ ft-kip})$

$$\frac{\sqrt{(M_{ux})^2 + (M_{uy})^2}}{\sqrt{(\phi M_{nx,max})^2 + (\phi M_{ny,max})^2}} = \frac{\sqrt{(180)^2 + (125)^2}}{\sqrt{(214.1)^2 + (148.7)^2}} = 0.841$$

$$\frac{P_u}{(\phi P_{n,\max})} = \frac{333}{1050.2} = 0.317$$

Therefore, the unity ratio corresponds to the load set is 0.841. The section is adequate to resist this load.

6. Slenderness

It is assumed that an overall 2nd order P-Delta ($P-\Delta$) analysis has been performed on a sway frame prior to using cColumn. The program has the option to consider slenderness to account for 2nd order effect on columns in non-sway frames as well as the 2nd order ($P-\delta$) effect along lengths of columns in sway frames. Most of structural analysis programs today

are capable of P-Δ analysis to evaluate magnification of the end moments. However, to account for moment magnification (P- δ effect) along the length of a compression member, it is generally required to subdivide the member into multiple segments. The ACI 318 moment magnification method, implemented in the program, eliminates the need to artificially breaking up the physical member into multiple segments to account for the P- δ effect along the member length.

The moment magnification δ is calculated as following.

$$\delta = \frac{C_m}{1 - \frac{P_u}{0.75P_c}} \geq 1.0$$

$$P_c = \frac{\pi^2 EI}{(kL_u)^2}$$

$$EI = \frac{(0.2E_c I_g + E_s I_{se})}{1 + \beta_d} \quad \text{or} \quad EI = \frac{0.4E_c I_g}{1 + \beta_d}$$

The term C_m is an equivalent moment correction factor. For members without transverse loads between supports,

$$C_m = 0.6 + \frac{M_1}{M_2} \geq 0.4 \text{ but } \leq 1.0$$

If a value of 0 is entered for C_m, the program will calculate C_m according to this formula. C_m must be greater than 0.4 but less than or equal to 1.0. It is generally recommended that a value of 1.0 is used for C_m.

The term β_d is the ratio of maximum factored axial sustained load to maximum factored axial load associated with the same load combination. It must be less than or equal to 1.0. For example, for the load combination 1.2*Dead + 1.6*Live load combination, P = 230 kip under unfactored dead (sustained) load, P = 173 under unfactored live load. β_d is calculated as

$$\beta_d = \frac{1.2 * 230}{1.2 * 230 + 1.6 * 173} = 0.499$$

You must enter β_d explicitly as part of load input in the program.

Part 3

Verifications & Tutorial

Chapter 9: Examples

Verification Example 001 – Uniaxial Analysis, Square, ACI 318-19

<p>[Ref. 10, Example 7.11 and Example 7.12, “Design Guide on the ACI 318 Building Code Requirements for Structural Concrete” 1st Edition, Concrete Reinforcing Steel Institute, 2020]</p> <p>Uniaxial Analysis, Square, ACI 318-19 section 18x18 inch, concrete cover 2.44 inch, 4#9, $f'_c = 4 \text{ ksi}$, $f_y = 60 \text{ ksi}$ and $f_y = 100 \text{ ksi}$, tied confinement</p> <p><i>Exclude concrete displaced by steel</i></p>	
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Note: Rectangular column may be created from Input | Section Mode | Investigate Rectangular or Input | Section Mode | Advanced.

Comments:

This example was solved manually first in Example 7.11 for $f_y = 60 \text{ ksi}$ and in Example 7.12 for $f_y = 100 \text{ ksi}$ in the reference. The following comparison between cColumn and the reference shows almost identical results.

For $f_y = 60 \text{ ksi}$

	Neutral axis depth (in)		ϕP_n (kip)		ϕM_n (ft-kip)	
	cColumn	Ref.	cColumn	Ref.	cColumn	Ref.
max tensile strain						
max capacity	17.82	*	690.6	690.6	104.0	*
$\epsilon_s = 0$	15.56	15.56	599.7	599.9	144.9	144.8
$\epsilon_s = 0.50f_y$	11.57	11.57	425.8	425.6	194.6	194.7
$\epsilon_s = 1.00 f_y$	9.21	9.21	307.0	307.1	214.8	214.8
Tension controlled	5.79	*	247.3	*	252.8	*
pure flexure	2.38	2.38	0	0	131.4	132.1

* Denotes that the value is not given in the reference

For $f_y = 100 \text{ ksi}$

	Neutral axis depth (in)		ϕP_n (kip)		ϕM_n (ft-kip)	
	cColumn	Ref.	cColumn	Ref.	cColumn	Ref.
max tensile strain						
max capacity	18.48	*	732.2	732.2	103.5	*
$\epsilon_s = 0$	15.56	15.56	617.1	617.3	154.4	154.4
$\epsilon_s = 0.50 f_y$	9.88	9.88	349.9	350.0	213.3	213.3
$\epsilon_s = 1.00 f_y$	7.24	7.24	185.3	185.3	230.5	230.5
Tension controlled	4.94	*	124.4	*	271.4	*
pure flexure	3.19	3.19	0.0	0	210.3	210.4

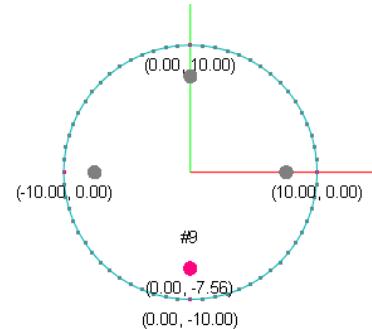
* Denotes that the value is not given in the reference

Verification Example 002 – Uniaxial Analysis, Circular, Tied, ACI 318-19

[Ref. 10, Example 7.13, "Design Guide on the ACI 318 Building Code Requirements for Structural Concrete" 1st Edition, Concrete Reinforcing Steel Institute, 2020]

Uniaxial Analysis, Square, ACI 318-19
*section diameter 20 inch, concrete cover 2.44 inch,
 4#9, $f'_c = 4 \text{ ksi}$, $f_y = 60 \text{ ksi}$, tied confinement*

Exclude concrete displaced by steel



Note: Circular column may be created from Input | Section Mode | Investigate Circular or Input | Section Mode | Advanced.

Comments:

This example was solved manually first in Example 7.13 in the reference. The following comparison between cColumn and the reference shows almost identical results.

	Neutral axis depth (in)		ϕP_n (kip)		ϕM_n (ft-kip)	
	cColumn	Ref.	cColumn	Ref.	cColumn	Ref.
max tensile strain						
max capacity	18.51	*	673.2	673.2	88.9	*
$\epsilon_s = 0$	17.56	17.56	636.8	637.1	104.1	104.3
$\epsilon_s = 0.50 f_y$	13.06	13.06	435.0	435.1	156.0	156.1
$\epsilon_s = 1.00 f_y$	10.39	10.39	297.8	297.5	168.0	168.0
Tension controlled	6.53	*	126.3	*	185.1	*
pure flexure	4.52	4.52	0	0	137.9	137.9

* Denotes that the value is not given in the reference

Verification Example 002B – Uniaxial Analysis, Circular, Spiral, ACI 318-19/14

<p>[Ref 8, CD/4-15, "CRSI Handbook 2008" 10th Edition, Concrete Reinforcing Steel Institute, 2008]</p> <p>Uniaxial Analysis, Circular, ACI 318-19/14 section diameter 20 inch, concrete cover 2.439 inch, 6#9, $f'_c = 6 \text{ ksi}$, $f_y = 60 \text{ ksi}$, Spiral confinement</p> <p><i>Exclude concrete displaced by steel</i></p>	
--	--

Comments: The following shows identical results between cColumn and the reference using ACI 318-14. For this example, there is no code provision difference between ACI 318-08, ACI 318-11, and ACI 318-14.

	ϕP_n (kip)		ϕM_n (kip-inch)	
	cColumn	Ref.	cColumn	Ref.
max tensile strain				
max capacity	1231.4	1231	1490.9	1491
$\epsilon_s = 0$	909.8	910	2870.1	2870
$\epsilon_s = 0.25f_y$	735.9	736	3223.4	3223
$\epsilon_s = 0.50f_y$	603.7	604	3361.2	3361
$\epsilon_s = 1.00 f_y$	384.3	384	3377.8	3378
$\epsilon_s = 0.005$	111.3	111	2949.0	2949
pure flexure	0	0	2353.4	2353

The following shows the almost identical results between cColumn results using ACI 318-19 and ACI 318-14 code. Note that the tension controlled strains for ACI 318-14 and ACI 318-19 are 0.005 and 0.00507 respectively, causing the slight difference of results at these points.

	ϕP_n (kip)		ϕM_n (kip-inch)	
	ACI 318-14	ACI 318-19	ACI 318-14	ACI 318-19
max tensile strain				
max capacity	1231.4	1231.4	1490.9	1490.9
$\epsilon_s = 0$	909.8	909.8	2870.1	2870.1
$\epsilon_s = 0.25f_y$	735.9	735.9	3223.4	3223.4
$\epsilon_s = 0.50f_y$	603.7	603.7	3361.2	3361.2
$\epsilon_s = 1.00 f_y$	384.3	384.3	3377.8	3377.8
Tension controlled	111.3	105.3	2949.0	2927.6
pure flexure	0	0	2353.4	2353.4

Verification Example 003 – Uniaxial Analysis, Rectangular, ACI 318-19/14

<p>[Ref. 8, pp. 3-6, "CRSI Handbook 2008" 10th Edition, Concrete Reinforcing Steel Institute, 2008]</p> <p>Uniaxial Analysis, Rectangular, ACI 318-19/14 section 12x24 inch, concrete cover 2.8465 inch, 10#14, $f'_c = 6$ ksi, $f_y = 60$ ksi, tied confinement</p> <p><i>Exclude concrete displaced by steel</i></p>	
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Comments:

The reference is a very reputable publication with over 60 years of history. This example was done manually in the reference which gives exact solution. The following shows identical results between cColumn and the reference using ACI 318-14. For this example, there is no code provision difference between ACI 318-08, ACI 318-11, and ACI 318-14.

cColumn vs the Reference - Major Axis

	Neutral axis depth (in)		ϕP_n (kip)		ϕM_n (kip-inch)	
	cColumn	Ref.	cColumn	Ref.	cColumn	Ref.
max tensile strain						
max capacity	27.3088	27.3088	1406.1	1406	2723.7	2724
$\epsilon_s = 0$	21.1535	21.1535	1092.2	1092	4472.6	4473
$\epsilon_s = 0.25f_y$	18.0427	18.0427	880.9	881	5211.6	5212
$\epsilon_s = 0.50f_y$	15.7295	15.7295	708.2	708	5745.9	5746
$\epsilon_s = 1.00 f_y$	12.5194	12.5194	375.4	375	6588.2	6588
$\epsilon_s = 0.005$	7.9326	7.9326	-111.1	-111	8276.4	8276
pure flexure	8.6460	8.6460	0	0	8124.6	8125

cColumn vs the Reference - Minor Axis

	ϕP_n (kip)		ϕM_n (kip-inch)	
	cColumn	Ref.	cColumn	Ref.
max tensile strain				
max capacity	1406.1	1406	1370.5	1370
$\epsilon_s = 0$	947.2	947	2667.0	2667
$\epsilon_s = 0.25f_y$	723.1	723	2934.3	2934

$\epsilon_s = 0.50f_y$	519.6	520	3141.6	3142
$\epsilon_s = 1.00 f_y$	149.1	149	3500.9	3501
$\epsilon_s = 0.005$	-173.5	-174	3726.6	3727
pure flexure	0	0	3599.3	3599

The following shows the almost identical results between cColumn results using ACI 318-19 and ACI 318-14 code. Note that the tension controlled strains for ACI 318-14 and ACI 318-19 are 0.005 and 0.00507 respectively, causing the slight difference of results at these points. Also note that the slight moment difference at pure flexure is due to the difference in interpolating strength reduction factors in ACI 318-14 and ACI 318-19 code.

cColumn ACI 318-19 vs ACI 318-14 - Major Axis

	Neutral axis depth (in)		ϕP_n (kip)		ϕM_n (kip-inch)	
	ACI 318-14	ACI 318-19	ACI 318-14	ACI 318-19	ACI 318-14	ACI 318-19
max tensile strain						
max capacity	27.3088	27.3088	1406.1	1406.1	2723.7	2723.7
$\epsilon_s = 0$	21.1535	21.1535	1092.2	1092.2	4472.6	4472.6
$\epsilon_s = 0.25f_y$	18.0427	18.0427	880.9	880.9	5211.6	5211.6
$\epsilon_s = 0.50f_y$	15.7295	15.7295	708.2	708.2	5745.9	5745.9
$\epsilon_s = 1.00 f_y$	12.5194	12.5194	375.4	375.4	6588.2	6588.2
Tension controlled	7.9326	7.8648	-111.1	-122.4	8276.4	8236.4
pure flexure	8.6460	8.6460	0	0	8124.6	8081.7

Verification Example 004 – A Column Design Tutorial, ACI 318-19

[Ref 3, pp. 7-46, “Notes on ACI 318-02 Building Code Requirements for Structural Concrete”, 8th Edition, Portland Cement Association, 2002]

Biaxial Square Column Design, ACI 318-19

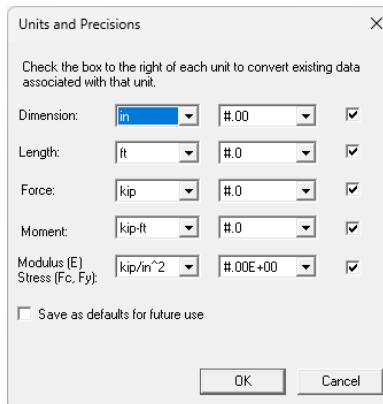
Design a square tied column size and reinforcement for the load set

$P_u = 1200 \text{ kips}$, $M_{ux} = 300 \text{ ft-kips}$, $M_{uy} = 125 \text{ ft-kips}$

$f'_c = 5 \text{ ksi}$, $f_y = 60 \text{ ksi}$

Step 1:

From Settings | Units and Precisions, make sure the units are set correctly.



Step 2:

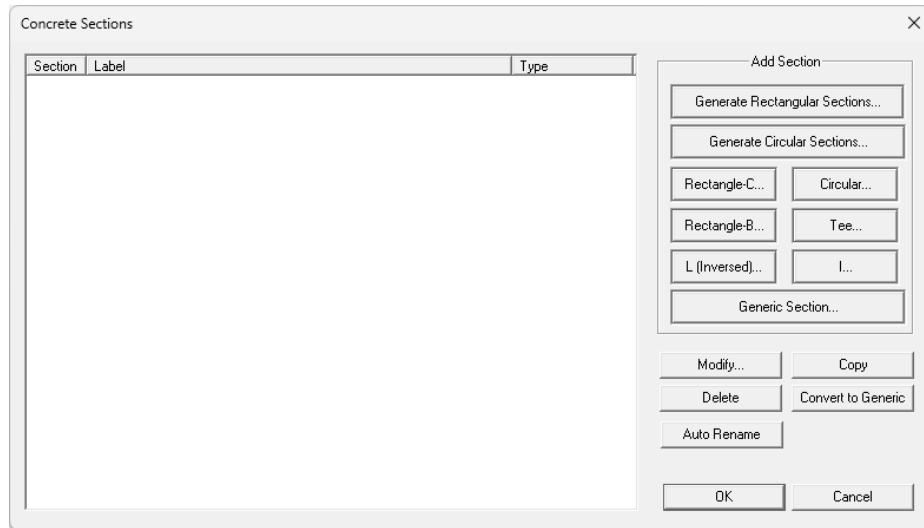
From Settings | Rebar Database, make sure the rebar database is set correctly.

	Bar Designation	Diameter [in]	Area [in ²]
1	#3	0.375	0.11
2	#4	0.5	0.2
3	#5	0.625	0.31
4	#6	0.75	0.44
5	#7	0.875	0.6
6	#8	1	0.79
7	#9	1.128	1
8	#10	1.27	1.27
9	#11	1.41	1.56
10	#14	1.693	2.25
11	#18	2.257	4
12			

OK Cancel

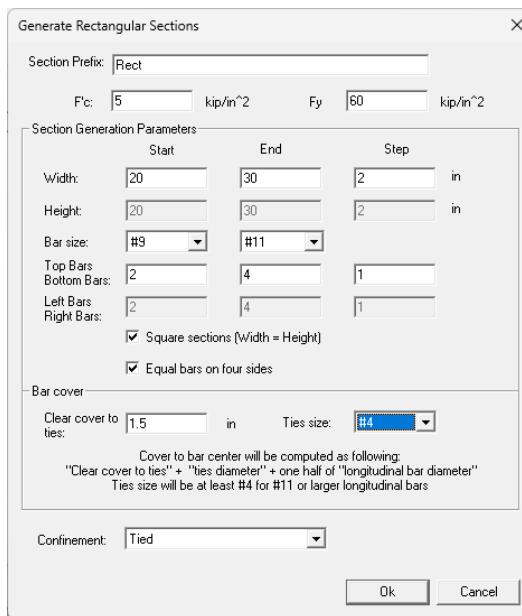
Step 3:

From Input | Section Mode | Advanced, launch the Concrete Sections dialog box. *Note: you can also use Input | Section Mode | Design Rectangular command instead.*



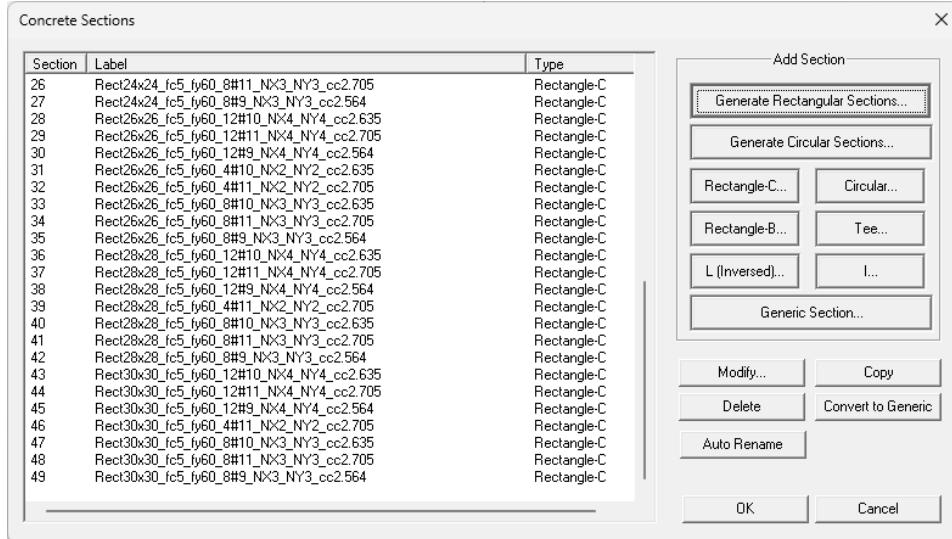
Step 4:

As this is a design problem where the precise column size and reinforcement layout are uncertain, it becomes necessary to explore various column sizes and reinforcement arrangements. To facilitate this process, the software provides a highly capable "Generate Rectangular Sections" command within the Concrete Sections dialog box. This command empowers us to automatically generate multiple sections parametrically, saving us valuable time and effort. To proceed, simply click on the "Generate Rectangular Sections" button within the Concrete Sections dialog box and input the parameters as shown below.



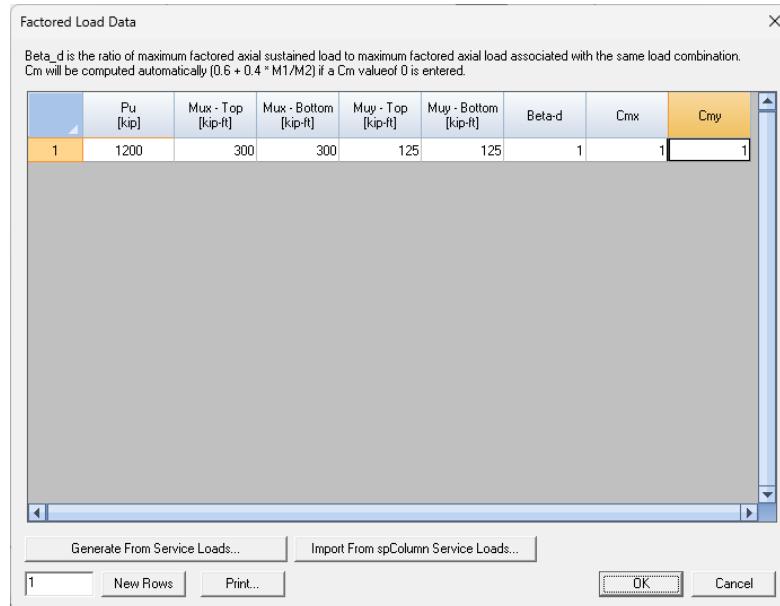
This dialog box plays a crucial role in the design of rectangular sections. It allows for the generation of numerous sections with varying sizes and reinforcement layouts, ranging from a few to potentially thousands. While the program boasts a remarkably fast solver, it is always beneficial to limit the number of sections to be solved. Drawing upon your expertise, it is advisable to select reasonable parameters to avoid an excessive number of generated sections.

In the case of designing a square column, like in the provided example, ensure that both "Square sections" and "Equal bars on four sides" options are selected. This will significantly reduce the number of sections generated. Using the parameters as illustrated above will result in the generation of 49 sections.



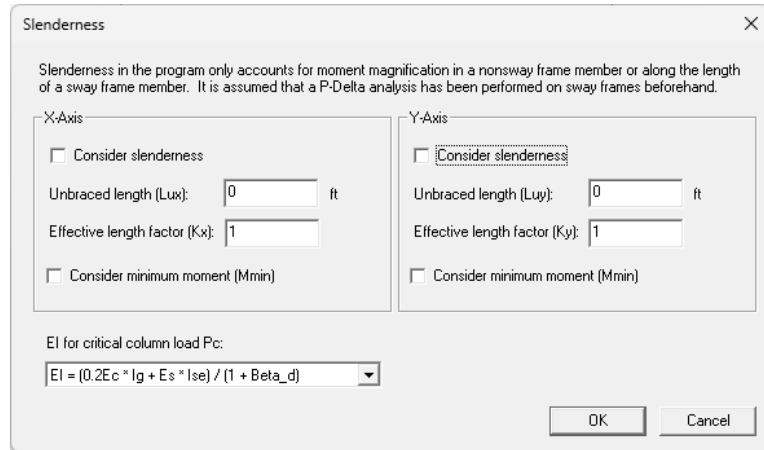
Step 5:

From Input | Loads, bring up the Load Data dialog box. Click on the button "New Rows" and enter the load set as shown.



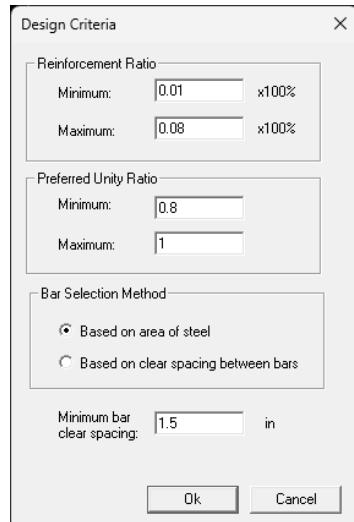
Step 6:

From Input | Slenderness, do not consider slenderness. Do not consider minimum moments either.



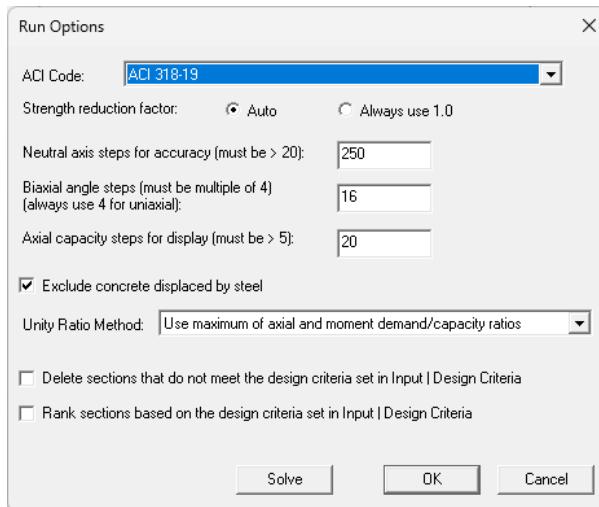
Step 7:

From Input | Design Criteria, input the parameters as shown below. In particular, we set our preferred unit ratio to be within range of [0.8, 1.0] (The default range is [0.25, 1.0]).



Step 8:

From Run | Options, bring up the Run Option dialog box before we proceed with the solution. Make sure ACI 318-19 is selected. It is important to point out that the neutral axis steps and biaxial angle steps directly affect the accuracy and speed of our solution. Here we need to balance the solution accuracy and solution speed. You are encouraged to try different settings to see the differences. If you are solving thousands of sections simultaneously, you may want to choose less accurate and faster solution in the first run, delete most of the sections based on unity ratios (say 0.8~1.0 due to the conservative solution) and then perform a more accurate and slower solution in the second run.



In this case, a value of 250 for neutral axis steps is adequate for our problem. Since this is a biaxial problem, biaxial angle steps is set to 16. Axial capacity steps for display is set to 20 (far less than 250) so that we do not crowd our graphical and numerical display of result data. Note “Exclude concrete displaced by steel” should almost always be checked. This option is provided only for checking example problems in textbooks!

Click on “Solve” to start the solving process.

Step 9:

From Result Data | Capacity Check, bring up the Capacity Check dialog box. Here each of the 54 sections is checked against the loads (one set in this case). Those sections with unity ratios less than 1.0 are safe while those with unity ratios greater than 1.0 are unsafe.

Capacity Check										
A section is marked red if its unity ratios is greater than 1.0 or outside the preferred minimum and maximum unity ratios. A section is marked orange if reinforcement ratio or minimum bar clear spacing is outside the normal range (see Input Design Criteria)										
	Section Label	Unity Ratio	Critical Load No.	M _{cx} [kip-ft]	M _{cy} [kip-ft]	Reinf. Ratio	A _s [in ²]	A _g [in ²]	Clear Spacing [in]	
1	Rect20x20_f5_ly60_12#10_NX4_NY4_cc2.635	1.294	1	300.0	125.0	3.610%	15.24	400.0	3.64	
2	Rect20x20_f5_ly60_12H11_NX4_NY4_cc2.705	1.093	1	300.0	125.0	4.680%	18.72	400.0	3.45	
3	Rect20x20_f5_ly60_12#9_NX4_NY4_cc2.564	1.633	1	300.0	125.0	3.000%	12.00	400.0	3.83	
4	Rect20x20_f5_ly60_4#10_NX2_NY2_cc2.635	1.736	1	300.0	125.0	1.270%	5.08	400.0	13.46	
5	Rect20x20_f5_ly60_4#11_NX2_NY2_cc2.705	1.687	1	300.0	125.0	1.560%	6.24	400.0	13.18	
6	Rect20x20_f5_ly60_4#9_NX2_NY2_cc2.564	1.787	1	300.0	125.0	1.000%	4.00	400.0	13.74	
7	Rect20x20_f5_ly60_8#10_NX3_NY3_cc2.635	1.649	1	300.0	125.0	2.540%	10.16	400.0	6.10	
8	Rect20x20_f5_ly60_8#11_NX3_NY3_cc2.705	1.572	1	300.0	125.0	3.120%	12.48	400.0	5.88	
9	Rect20x20_f5_ly60_8#9_NX3_NY3_cc2.564	1.712	1	300.0	125.0	2.000%	8.00	400.0	6.31	
10	Rect22x22_f5_ly60_12#10_NX4_NY4_cc2.635	0.845	1	300.0	125.0	3.149%	15.24	484.0	4.31	
11	Rect22x22_f5_ly60_12H11_NX4_NY4_cc2.705	0.755	1	300.0	125.0	3.668%	18.72	484.0	4.12	
12	Rect22x22_f5_ly60_12#9_NX4_NY4_cc2.564	0.959	1	300.0	125.0	2.479%	12.00	484.0	4.50	
13	Rect22x22_f5_ly60_4#10_NX2_NY2_cc2.635	1.398	1	300.0	125.0	1.050%	5.08	484.0	15.46	
14	Rect22x22_f5_ly60_4#11_NX2_NY2_cc2.705	1.267	1	300.0	125.0	1.289%	6.24	484.0	15.18	
15	Rect22x22_f5_ly60_4#9_NX2_NY2_cc2.564	1.362	1	300.0	125.0	0.826%	4.00	484.0	15.74	
16	Rect22x22_f5_ly60_8#10_NX3_NY3_cc2.635	1.040	1	300.0	125.0	2.099%	10.16	484.0	7.10	
17	Rect22x22_f5_ly60_8#11_NX3_NY3_cc2.705	0.935	1	300.0	125.0	2.579%	12.48	484.0	6.88	
18	Rect22x22_f5_ly60_8#9_NX3_NY3_cc2.564	1.167	1	300.0	125.0	1.653%	8.00	484.0	7.31	

In order to pick our final section size and reinforcement easily, we can run the Result Data | Rank sections menu. This will automatically rank our sections based on the design criteria set from Input Data | Design Criteria.

Capacity Check										
	Section Label	Unity Ratio	Critical Load No.	M _{cx} [kip-ft]	M _{cy} [kip-ft]	Reinf. Ratio	A _s [in ²]	A _g [in ²]	Clear Spacing [in]	
1	Rect22x22_Ic5_ly60_12#9_NX4_NY4_cc2.564	0.959	1	300.0	125.0	2.479%	12.00	484.0	4.50	
2	Rect22x22_Ic5_ly60_8#11_NX3_NY3_cc2.705	0.935	1	300.0	125.0	2.579%	12.48	484.0	6.88	
3	Rect22x22_Ic5_ly60_12#10_NX4_NY4_cc2.635	0.845	1	300.0	125.0	3.149%	15.24	484.0	4.31	
4	Rect24x24_Ic5_ly60_4#11_NX2_NY2_cc2.705	0.825	1	300.0	125.0	1.083%	6.24	576.0	17.18	
5	Rect20x20_Ic5_ly60_4#9_NX2_NY2_cc2.564	1.787	1	300.0	125.0	1.000%	4.00	400.0	13.74	
6	Rect20x20_Ic5_ly60_4#10_NX2_NY2_cc2.635	1.736	1	300.0	125.0	1.270%	5.08	400.0	13.46	
7	Rect20x20_Ic5_ly60_4#11_NX2_NY2_cc2.705	1.687	1	300.0	125.0	1.560%	6.24	400.0	13.18	
8	Rect20x20_Ic5_ly60_8#9_NX3_NY3_cc2.564	1.712	1	300.0	125.0	2.000%	8.00	400.0	6.31	
9	Rect20x20_Ic5_ly60_8#10_NX3_NY3_cc2.635	1.649	1	300.0	125.0	2.540%	10.16	400.0	6.10	
10	Rect20x20_Ic5_ly60_12#9_NX4_NY4_cc2.564	1.633	1	300.0	125.0	3.000%	12.00	400.0	3.83	
11	Rect20x20_Ic5_ly60_8#11_NX3_NY3_cc2.705	1.572	1	300.0	125.0	3.120%	12.48	400.0	5.88	
12	Rect20x20_Ic5_ly60_12#10_NX4_NY4_cc2.635	1.294	1	300.0	125.0	3.810%	15.24	400.0	3.64	
13	Rect20x20_Ic5_ly60_12#11_NX4_NY4_cc2.705	1.093	1	300.0	125.0	4.680%	18.72	400.0	3.45	
14	Rect22x22_Ic5_ly60_4#9_NX2_NY2_cc2.564	1.362	1	300.0	125.0	0.826%	4.00	484.0	15.74	
15	Rect22x22_Ic5_ly60_4#10_NX2_NY2_cc2.635	1.398	1	300.0	125.0	1.050%	5.08	484.0	15.46	
16	Rect22x22_Ic5_ly60_4#11_NX2_NY2_cc2.705	1.267	1	300.0	125.0	1.289%	6.24	484.0	15.18	
17	Rect22x22_Ic5_ly60_8#9_NX3_NY3_cc2.564	1.167	1	300.0	125.0	1.853%	8.00	484.0	7.31	
18	Rect22x22_Ic5_ly60_8#10_NX3_NY3_cc2.635	1.040	1	300.0	125.0	2.099%	10.16	484.0	7.10	

We also have the option to delete the sections that do not meet our design criteria altogether by running the Input | Design Criteria menu again. Since the sections have been solved, you will be prompted with the message “Sections have been solved. Do you want to delete the sections that do not meet the design criteria?”. Click “Yes” to proceed. Now go to the Result Data | Capacity Check, we will only see the sections that meet the design criteria.

Capacity Check										
	Section Label	Unity Ratio	Critical Load No.	M _{cx} [kip-ft]	M _{cy} [kip-ft]	Reinf. Ratio	A _s [in ²]	A _g [in ²]	Clear Spacing [in]	
1	Rect22x22_Ic5_ly60_12#9_NX4_NY4_cc2.564	0.959	1	300.0	125.0	2.479%	12.00	484.0	4.50	
2	Rect22x22_Ic5_ly60_8#11_NX3_NY3_cc2.705	0.935	1	300.0	125.0	2.579%	12.48	484.0	6.88	
3	Rect22x22_Ic5_ly60_12#10_NX4_NY4_cc2.635	0.845	1	300.0	125.0	3.149%	15.24	484.0	4.31	
4	Rect24x24_Ic5_ly60_4#11_NX2_NY2_cc2.705	0.825	1	300.0	125.0	1.083%	6.24	576.0	17.18	
5										

Another way to rank the sections and/or delete unwanted sections is to check the following options on the Run | Options dialog box prior to solution:

“Rank sections based on the design criteria set in Input | Design Criteria”

“Delete sections that do not meet the design criteria set in Input | Design Criteria”.

After filtering out the sections that do not meet our design criteria, we have only four sections left as our final candidates. We can pick “Rect24x24_fc5_fy60_4#11_NX2_NY2_cc2.705” (width=24 inch, height=24 inch, 4#11 bars) as our final section which happens to be the one used by the reference [Ref 3, 7-46].

Note: The biaxial solutions given in the reference [Ref 3, 7-46] are based on some approximate methods such as Bresler Reciprocal Load Method and PCA Load Contour Method. The solution given by cColumn is an exact solution. The former is tedious and approximate while the latter is easy and exact.

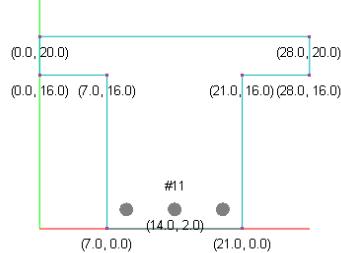
This concludes our tutorial.

Verification Example 005 – Pure Bending, Tee, ACI 319-19

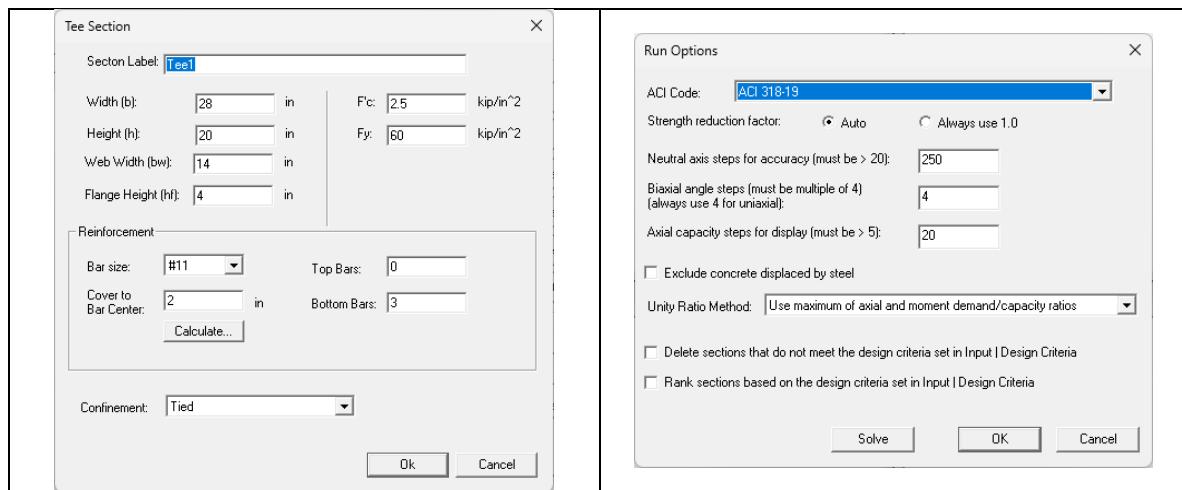
[Ref. 4, pp. 116, Leet & Bernal, "Reinforced Concrete Design" 3rd Edition, McGraw-Hill, 1997]

Pure Bending Analysis, Tee, ACI 318-19
 Section width=28, height=20, flange height=4 and web width=14 inch, concrete cover 2.0 inch,
 3#11, $f'_c = 5 \text{ ksi}$, $f_y = 60 \text{ ksi}$

Do not exclude concrete displaced by steel



Note: Tee section must be created from Input | Section Mode | Advanced



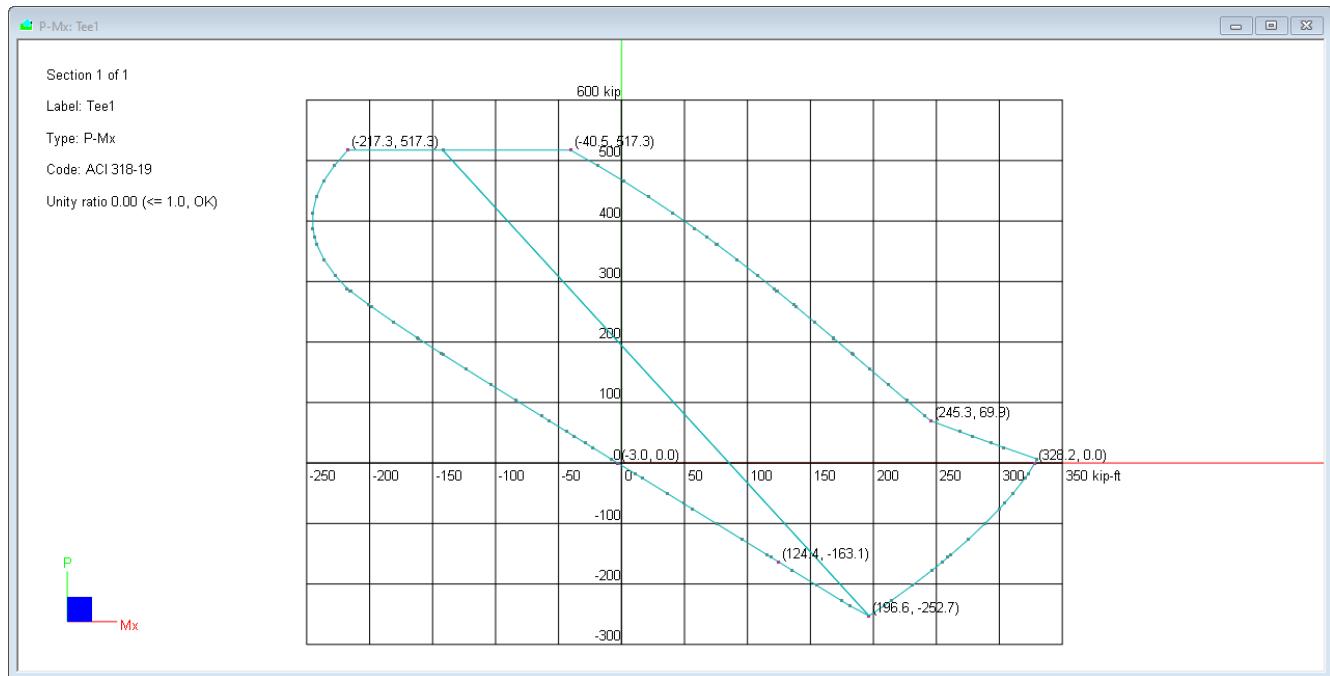
Comments: The comparison between the program and the reference is excellent

cColumn: @ $\varphi P_n = 0$, $\varphi M_n = 328.2 \text{ (kip-ft)}$

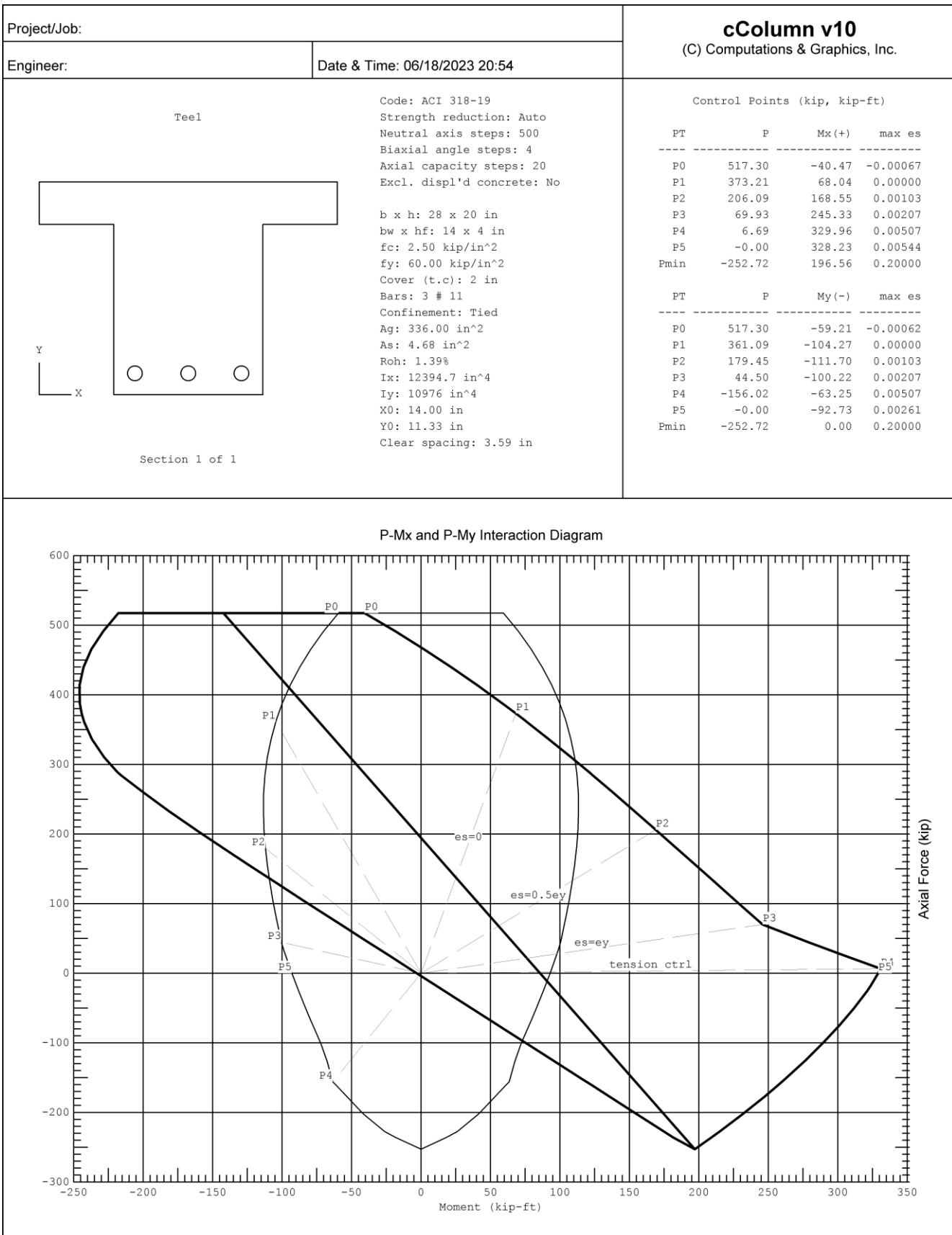
References: @ $\varphi P_n = 0$, $\varphi M_n = 328.25 \text{ (kip-ft)}$

Although this is a pure flexure (uniaxial) problem, the program still solves it biaxially. It is sufficient to set the biaxial angle steps of 4. The only point that we are interested in is @ $\varphi P_n = 0$. By running View | Result Diagrams, we can view the P-Mx interaction diagram. Notice the diagram is skewed as shown below. This is typical for unsymmetrical sections and is due to the fact that the moments are taken about the geometric centroid and forces in unsymmetrical bars generate a net moment about the centroid. This is particularly true for the condition of the maximum axial load capacity where the whole section is under uniform strain 0.003 or for the condition of "pure tension" where concrete is ignored altogether.

You may convert this Tee section to a generic section. The results would be the same.



We can also save our P-Mx and P-My interaction diagram to a high resolution png file from File | Save PM Diagrams to Images as shown in the following page.



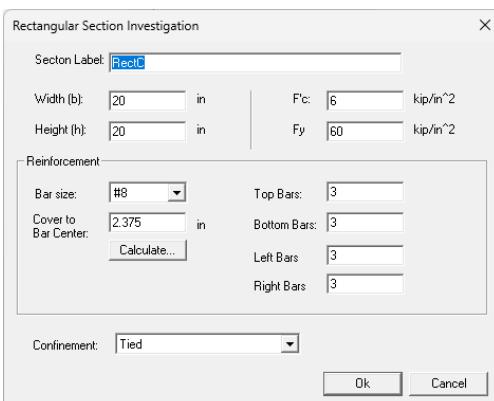
Verification Example 006 – Uniaxial Analysis, Slender Rectangular, ACI 318-19

[Ref 6, pp. 11-24, "Notes on ACI 318-08 Building Code Requirements for Structural Concrete", 10th Edition, Portland Cement Association, 2008]

Uniaxial Slender Rectangular Column Analysis, ACI 318-19

*Design a square tied column size and reinforcement for the load set $P_u = 920.4$ kips, top $M_{ux} = 111.7$ ft-kips, bottom $M_{ux} = 62.5$ ft-kips. Try Section 20 x 20 in. 8#8 bars
 $f'_c = 6$ ksi, $f_y = 60$ ksi, cover to the center of main bars = 2.375 in,
Unbraced length = 21.33 ft, unbraced length factor $K = 0.86$, $C_m = 0.82$, $\beta_d = 0.94$*

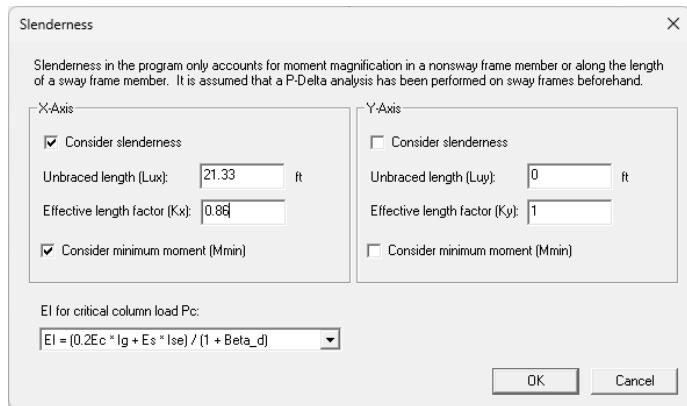
The following are relevant input and output in the program. Since the column is designed uniaxially, we do not consider slenderness and minimum moment about the minor axis of the section. The moment magnification factor can be calculated as $\delta = M_{cx} / M_{ux} = 224.1 / 111.7 = 2.006$ (The referenced value 2.01) where M_{cx} is the critical magnified X-moment. We can create the rectangular column by using Input | Section Mode | Investigate Rectangular or Input | Section Mode | Advanced | Rectangle-C.



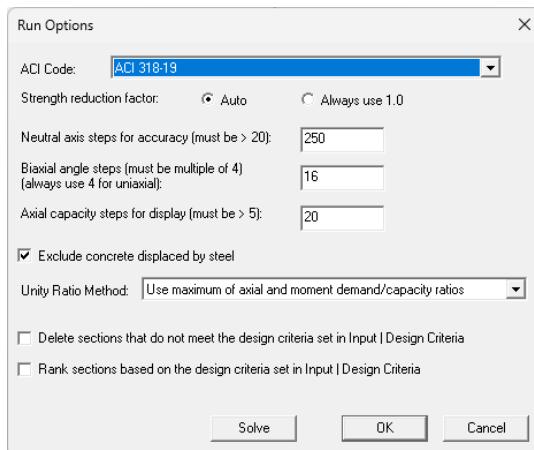
From Input | Loads:

Factored Load Data							
Beta_d is the ratio of maximum factored axial sustained load to maximum factored axial load associated with the same load combination. Cm will be computed automatically ($0.6 + 0.4 \times M_1/M_2$) if a Cm value of 0 is entered.							
	P_u [kip]	$M_{ux - Top}$ [kip-ft]	$M_{ux - Bottom}$ [kip-ft]	$M_{uy - Top}$ [kip-ft]	$M_{uy - Bottom}$ [kip-ft]	Beta-d	Cmx
1	920.4	111.7	62.5	0	0	0.94	0.82
<input type="button" value="Generate From Service Loads..."/> <input type="button" value="Import From spColumn Service Loads..."/>							
1	<input type="button" value="New Rows"/>	<input type="button" value="Print..."/>				<input type="button" value="OK"/>	<input type="button" value="Cancel"/>

From Input | Slenderness:



From Run | Options and then Solve:



From Result Data | Capacity Check:

Capacity Check

A section is marked red if its unity ratios is greater than 1.0 or outside the preferred minimum and maximum unity ratios. A section is marked orange if reinforcement ratio or minimum bar clear spacing is outside the normal range (see Input | Design Criteria)

	Section Label	Unity Ratio	Critical Load No.	Mcx [kip-ft]	Mcy [kip-ft]	Reinf. Ratio	As [in^2]	Ag [in^2]	Clear Spacing [in]
1	RectC1	0.742	1	224.1	0.0	1.580%	6.32	400.0	6.63
2									

Verification Example 007 – Generic Section Analysis, ACI 318-19

[Ref 1, pp. 304-307, Author H. Nilson, "Design of Concrete Structures" 13th Edition, WCB/McGraw-Hill, 2004]

Uniaxial Slender Rectangular Column Analysis, ACI 318-19

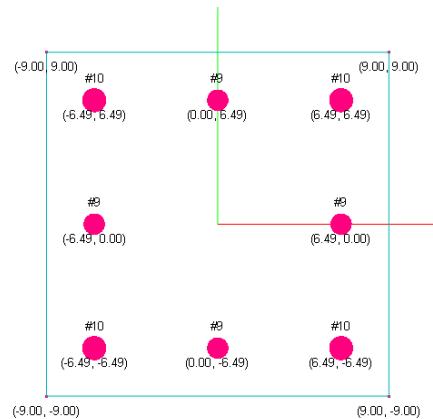
Design a square tied column size and reinforcement for the load set

$P_u = 553 \text{ kips}$, top $M_{uy} = 158 \text{ ft-kips}$, bottom $M_{uy} = 175 \text{ ft-kips}$

$f'_c = 4 \text{ ksi}$, $f_y = 60 \text{ ksi}$, cover to the center of main bars = 2.51 in

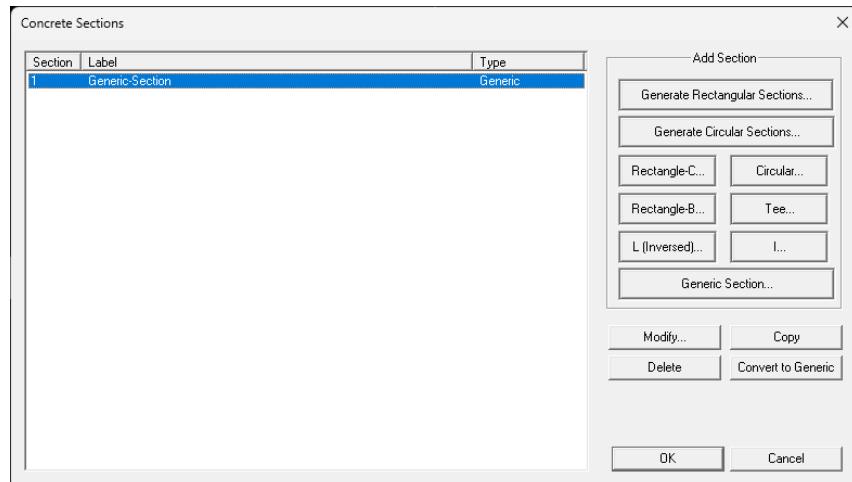
Section 18 x 18 in. 4#10 + 4#9 bars

Unbraced length = 13 ft, unbraced length factor $K = 0.87$, $C_m = 0.96$ (auto-calculated), $\beta_d = 0.50$



The following are relevant input and output in the program. Since the column is designed uniaxially, we do not consider slenderness and minimum moment about the major axis of the section. *It is important to point out that the generic section is used due to different rebar sizes are used in the section.* C_m may be automatically calculated if a value of 0 is entered. The magnified moment given by cColumn is 200.9 ft-kips. The magnified moment given by the reference is 201 ft-kips.

Generic section must be created from Input | Section Mode | Advanced.



Click on “Generic Section” button on the dialog above:

Generic Section

Section Label: Generic-Section	F'c: 4 kip/in ²	Fy: 60 kip/in ²																																																																																									
Geometry (Vertices must be continuous): Rebars (Duplicate individual bars will be merged):																																																																																											
<table border="1"> <tr><th></th><th>X-Coordinate [in]</th><th>Y-Coordinate [in]</th></tr> <tr><td>1</td><td>-9</td><td>-9</td></tr> <tr><td>2</td><td>9</td><td>-9</td></tr> <tr><td>3</td><td>9</td><td>9</td></tr> <tr><td>4</td><td>-9</td><td>9</td></tr> <tr><td>5</td><td></td><td></td></tr> <tr><td>6</td><td></td><td></td></tr> <tr><td>7</td><td></td><td></td></tr> <tr><td>8</td><td></td><td></td></tr> </table>		X-Coordinate [in]	Y-Coordinate [in]	1	-9	-9	2	9	-9	3	9	9	4	-9	9	5			6			7			8			<table border="1"> <tr><th></th><th>X1 [in]</th><th>Y1 [in]</th><th>X2 [in]</th><th>Y2 [in]</th><th>Bar Size(#)</th><th>Number of Bars</th></tr> <tr><td>1</td><td>-6.49</td><td>6.49</td><td>6.49</td><td>6.49</td><td>#10</td><td>2</td></tr> <tr><td>2</td><td>-6.49</td><td>-6.49</td><td>6.49</td><td>-6.49</td><td>#10</td><td>2</td></tr> <tr><td>3</td><td>0</td><td>-6.49</td><td>0</td><td>6.49</td><td>#9</td><td>2</td></tr> <tr><td>4</td><td>-6.49</td><td>0</td><td>6.49</td><td>0</td><td>#9</td><td>2</td></tr> <tr><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>6</td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td></tr> </table>		X1 [in]	Y1 [in]	X2 [in]	Y2 [in]	Bar Size(#)	Number of Bars	1	-6.49	6.49	6.49	6.49	#10	2	2	-6.49	-6.49	6.49	-6.49	#10	2	3	0	-6.49	0	6.49	#9	2	4	-6.49	0	6.49	0	#9	2	5							6							7							8						
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From Input | Loads:

Factored Load Data

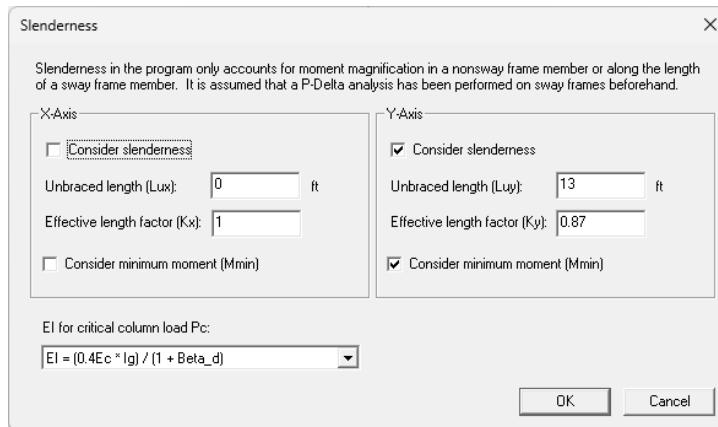
Beta_d is the ratio of maximum factored axial sustained load to maximum factored axial load associated with the same load combination. Cm will be computed automatically ($0.6 + 0.4 \times M1/M2$) if a Cm value of 0 is entered.

	P _u [kip]	M _{ux} - Top [kip-ft]	M _{ux} - Bottom [kip-ft]	M _{uy} - Top [kip-ft]	M _{uy} - Bottom [kip-ft]	Beta-d	C _{mx}	C _{my}
1	553	0	0	158	175	0.5	1	0.96
2								

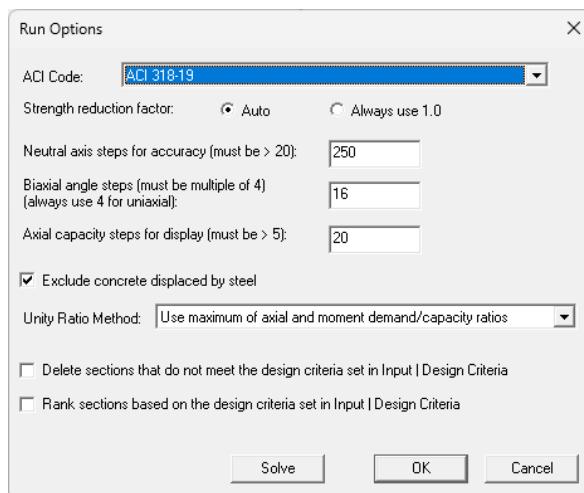
Generate From Service Loads... | **Import From spColumn Service Loads...**

1 | **New Rows** | **Print...** | **OK** | **Cancel**

From Input | Slenderness:



From Run | Options:



From Result Data | Capacity Check:

Capacity Check

A section is marked red if its unity ratios is greater than 1.0 or outside the preferred minimum and maximum unity ratios. A section is marked orange if reinforcement ratio or minimum bar clear spacing is outside the normal range (see Input | Design Criteria)

Print... Close

	Section Label	Unity Ratio	Critical Load No.	Mcx [kip-ft]	Mcy [kip-ft]	Reinf. Ratio	As [in^2]	Ag [in^2]	Clear Spacing [in]
1	Generic-Section	0.910	1	0.0	200.9	2.802%	9.08	324.0	5.29
2									

Comments: We used generic section due to two different bar sizes are used in the section. The comparison between the program and the reference is excellent. The unity ratio given by cColumn is 0.91. The section is adequate against the input load condition.

Verification Example 008 – Generic Section with Openings, ACI 318-19

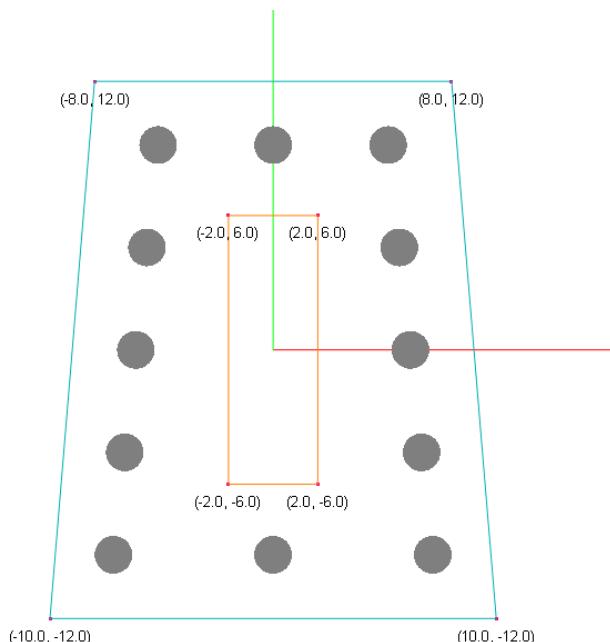
Investigate the following trapezoid section with opening, according to ACI 318-2019. The section top and bottom widths are 16 and 20 inches respectively. The section height is 24 inches. The opening is 4 x 12 inches rectangle. The figure below shows the vertex coordinates of the section.

Find the section capacity (ϕP_n and ϕM_n) corresponding to 50% tension at the bottom steel bars.

Material properties: $f'_c = 6$ ksi, $f_y = 60$ ksi

Concrete cover to the center of main bars = 2.8465 inches.

Reinforcement bars: 12 #14 as shown below.



Solution:

Step 1: Calculate the neutral depth c at 50% tension. The distance to row 5 bars from extreme compression surface $D_{s5} = 24 - 2.8465 = 21.1535$ in.

The tensile stress in row 5 bars = $0.5 * 60 = 30$ ksi.

$$\text{The neutral depth } c = \frac{21.1535}{1+30/(29000*0.003)} = 15.7295 \text{ in.}$$

Step 2: Calculate the centroid of the net section.

$$\text{Whole section area } A_{\text{whole}} = \frac{16+20}{2} * 24 = 432 \text{ in}^2$$

$$\text{Whole section centroid distance from base } Y_{\text{whole}} = \frac{20+16*2}{3(16+20)} * 24 = 11.555556 \text{ in}^2$$

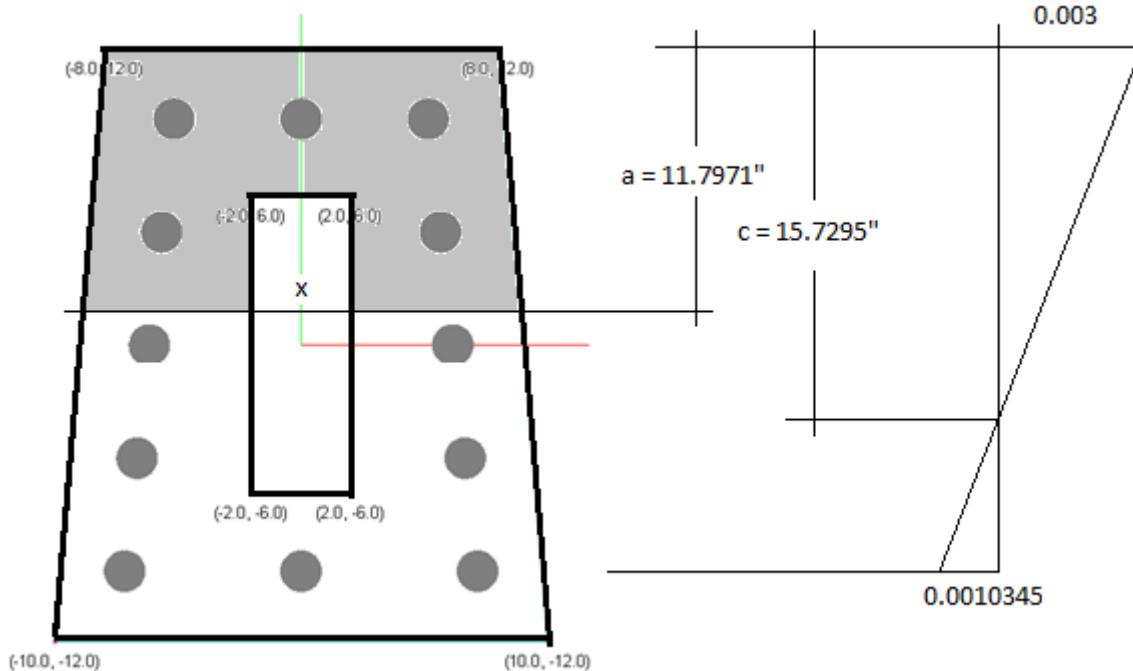
$$\text{Opening area } A_{\text{open}} = 4 * 12 = 48 \text{ in}^2$$

Distance to the net section centroid from the section base

$$Y_{\text{net}} = \frac{-48*12+432*11.555556}{432-48} = 11.5 \text{ in}^2$$

Step 3: Calculate the intercepted section and opening properties at the depth a , where $a = \beta_1 * c = 0.75 * 15.7295 = 11.7971$ in.

$$\text{Intercepted trapezoid base } x = \frac{11.7971 * 2 * 2}{24} + 16 = 17.96618 \text{ in}$$



$$\text{Intercepted trapezoid area: } A_{i_whole} = \frac{16+17.96618}{2} * 11.7971 = 200.3512 \text{ in}^2$$

Distance to the centroid of the intercepted trapezoid from section top:

$$y_{i_whole} = 11.7971 - \frac{2*16+17.96618}{3*(16+17.96618)} * 11.7971 = 6.0124 \text{ in}$$

$$\text{Intercepted opening area: } A_{i_open} = (11.7971 - 6) * 4 = 23.1884 \text{ in}^2$$

Distance to the centroid of the intercepted opening from section top

$$y_{i_open} = 6 + (11.7971 - 6) / 2 = 8.8986 \text{ in}$$

$$\text{Intercepted net area } A_{i_net} = A_{i_whole} - A_{i_open} = 200.3512 - 23.1884 = 177.1628 \text{ in}^2$$

Step 4: Calculate concrete force and moment about the net section centroid (distance from the section base is $Y_{net} = 11.5$ in).

$$C_c = 0.85 * f'_c * A_{i_net} = 0.85 * 6 * 177.1628 = 903.53 \text{ kips}$$

$$\begin{aligned} M_{c_whole} &= 0.85 * f'_c * A_{i_whole} * (12 - 6.0124 + 0.5) \\ &= 0.85 * 6 * 200.35 * (12 - 6.0124 + 0.5) = 6628.9 \text{ in-kips} \end{aligned}$$

$$\begin{aligned} M_{c_opening} &= 0.85 * f'_c * A_{i_open} * (12 - 6.0124 + 0.5) \\ &= 0.85 * 6 * 23.1884 * (12 - 8.8986 + 0.5) = 425.9 \text{ in-kips} \end{aligned}$$

$$M_c = M_{c_whole} - M_{c_opening} = 6628.9 - 425.9 = 6203 \text{ in-kips}$$

Step 5: Calculate steel bar forces and moments about the net section centroid (distance from the section base is $Y_{net} = 11.5$ in.). For bars located in the compression zone ($D_{si} < a$), the bar compressive force is reduced by compressive force of the displaced concrete (see Note 1 and 2 below).

Row	D_{si} (in)	Steel Strain	Steel Stress (ksi)	Force (kips)	Signed Distance to Net Section Centroid	Moment (in-kips)
1	2.8465	0.0024571	60	370.575*	9.6535	3577.3
2	7.4233	0.0015842	45.942	183.789**	5.0767	933.0
3	12	0.0007113	20.628	92.826	0.5	46.4
4	16.5768	-0.0001616	-4.686	-21.087	-4.0768	86.0
5	21.1535	-0.0010345	-30	-202.5	-8.6535	1752.3
				Total 423.6		Total 6395.1

Note 1: * Steel force is reduced by $0.85 * 6 * 3 * 2.25 = 34.425$ kips

Note 2: ** Steel force is reduced by $0.85 * 6 * 2 * 2.25 = 22.95$ kips

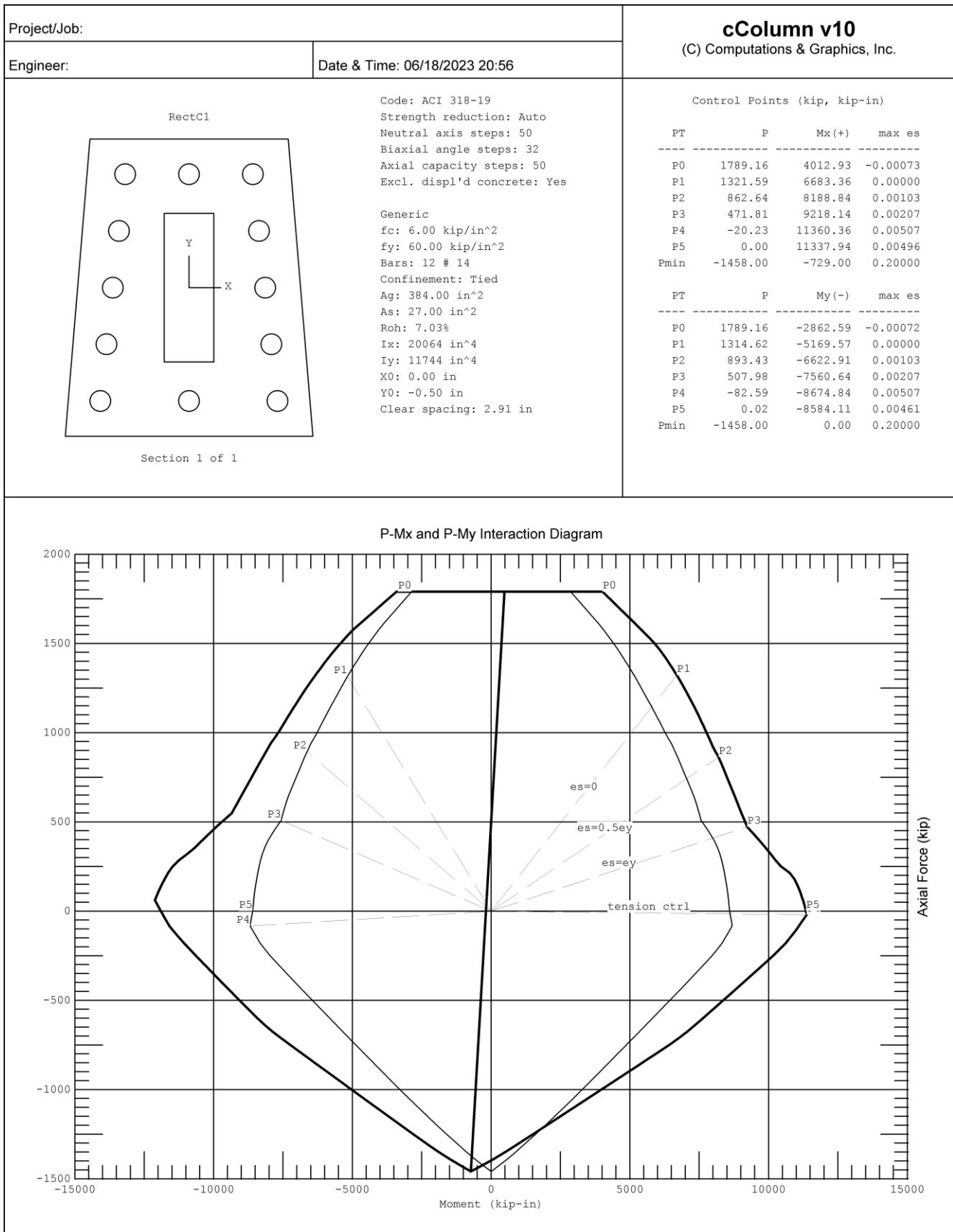
Step 6: Calculate the section capacity.

$$P_n = 903.53 + 423.6 = 1327.1 \text{ kips}; \quad \phi P_n = 0.65 * 1327.1 = 862.6 \text{ kips}$$

$$M_n = 6203 + 6395.1 = 12598.1 \text{ in-kips}; \quad \phi M_n = 0.65 * 12598.1 = 8188.8 \text{ in-kips}$$

Comments:

The manual computation above is verified exactly by cColumn. The control point P2 ($P_u = 862.64$ kip, $M_{ux} = 8188.84$ in-kip) in cColumn P-Mx and P-My interaction diagram below corresponds to 50% tension for bottom bars.

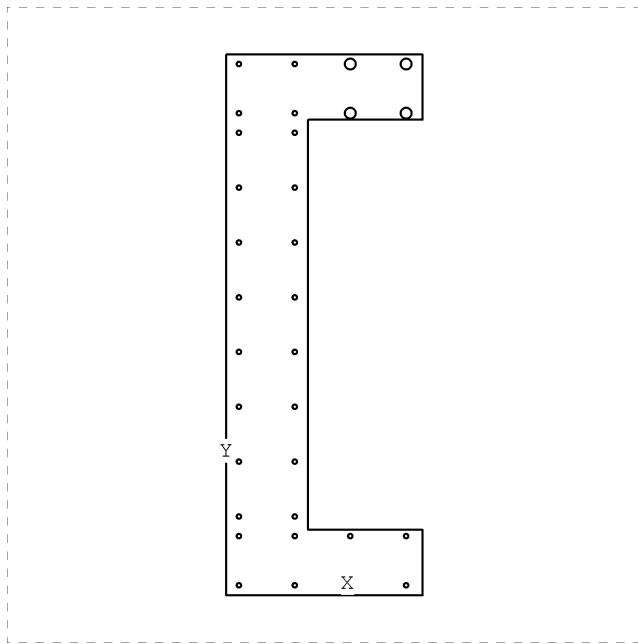


Verification Example 009 – Shear Wall (Metric Unit), ACI 318-19

Investigate the following shear wall according to ACI 318-2019.

Material properties: $f'_c = 35 \text{ MPa}$, $f_y = 420 \text{ Mpa}$

Confinement: tied



Section Boundary

Point #	X mm	Y mm	Point #	X mm	Y mm	Point #	X mm	Y mm
1	0.00	0.00	2	600.00	0.00	3	600.00	200.00
4	250.00	200.00	5	250.00	1450.00	6	600.00	1450.00
7	600.00	1650.00	8	0.00	1650.00			

Section Rebars

Area mm ²	X mm	Y mm	Area mm ²	X mm	Y mm	Area mm ²	X mm	Y mm
129.03	40.00	30.00	129.03	210.00	30.00	129.03	380.00	30.00
129.03	550.00	30.00	129.03	40.00	180.00	129.03	210.00	180.00
129.03	380.00	180.00	129.03	550.00	180.00	129.03	40.00	240.00
129.03	40.00	407.14	129.03	40.00	574.29	129.03	40.00	741.43
129.03	40.00	908.57	129.03	40.00	1075.71	129.03	40.00	1242.86
129.03	40.00	1410.00	129.03	210.00	240.00	129.03	210.00	407.14
129.03	210.00	574.29	129.03	210.00	741.43	129.03	210.00	908.57
129.03	210.00	1075.71	129.03	210.00	1242.86	129.03	210.00	1410.00
129.03	40.00	1470.00	129.03	210.00	1470.00	129.03	40.00	1620.00
129.03	210.00	1620.00	1006.45	380.00	1620.00	1006.45	550.00	1620.00
1006.45	380.00	1470.00	1006.45	550.00	1470.00			

The following shows almost identical results between cColumn and spColumn v10. Please note that the sign convention for M_x are reversed between cColumn and spColumn.

P-M_x (Positive) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	1836.27	1836	10097.3	10097.3	2430.3	-2430.27	21.0	20.95
f _s = 0	1620.00	1620	9099.8	9099.9	2980.8	-2980.79	64.7	64.70
f _s = 0.5 F _y	1199.92	1200	7225.1	7225.5	3586.5	-3586.47	184.4	184.35
balanced	952.84	953	6006.4	6006.9	3742.3	-3742.36	254.2	254.14
Tension control	599.96	600	5999.9	6000.4	4850.1	-4850.38	520.5	520.55
Pure bending	97.13	97	-0.1	0.0	1329.5	-1329.58	129.4	129.46
Pure tension	0.00	0	-2887.4	-2887.4	-955.2	955.19	-364.2	-364.23

P-M_x (Negative) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	1906.65	1907	10097.3	10097.3	-1190.3	1190.42	-90.8	-90.83
f _s = 0	1620.00	1620	8272.9	8273.0	-2299.0	2298.92	-153.6	-153.58
f _s = 0.5 F _y	1199.92	1200	5941.3	5941.7	-3235.3	3235.22	-154.5	-154.55
balanced	952.84	953	4265.7	4266.2	-3721.7	3721.74	-205.3	-205.37
Tension control	599.96	600	3440.7	3441.1	-4917.9	4918.04	-155.1	-155.07
Pure bending	177.56	178	-0.1	0.0	-3119.3	3119.40	-89.8	-89.76
Pure tension	0.00	0	-2887.4	-2887.4	-955.2	955.19	-364.2	-364.23

P-M_y (Positive) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	673.27	673	10097.3	10097.3	627.7	-627.80	630.5	630.51
f _s = 0	560.00	560	6989.0	6989.3	595.2	-595.24	900.4	900.38
f _s = 0.5 F _y	414.79	415	3327.1	3327.5	527.4	-527.49	899.3	899.37
balanced	329.38	329	2320.8	2321.2	459.7	-459.73	856.2	856.27
Tension control	207.39	207	1321.0	1321.2	402.3	-402.34	913.6	913.63
Pure bending	138.06	138	0.2	0.0	-3.6	3.68	615.4	615.41
Pure tension	0.00	0	-2887.4	-2887.4	-955.2	955.19	-364.2	-364.23

P-M_y (Negative) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	518.52	519	10097.2	10097.3	77.3	-77.29	-486.7	-486.68
$f_s = 0$	550.00	550	10097.3	10396.1*	127.8	-127.88	-417.7	-417.65
$f_s = 0.5 F_y$	407.38	407	8956.7	8957.0	-139.4	139.31	-715.2	-715.20
balanced	323.49	324	7835.2	7835.6	-431.0	430.94	-908.9	-908.91
Tension control	203.69	204	5965.8	5966.4	-955.2	955.19	-1400.3	-1400.30
Pure bending	58.98	59	0.1	0.0	-955.2	955.19	-863.4	-863.43
Pure tension	0.00	0	-2887.4	-2887.4	-955.2	955.19	-364.2	-364.23

* There is a discrepancy for ϕP_n at $f_s = 0$ between cColumn and spColumn. In cColumn, ϕP_n cannot be greater than P_{max} at any points.

Section Properties

	cColumn	spColumn
Total Section Area (A_g), mm ²	552500.00	552500
Total Steel Area (A_s), mm ²	7638.69	7639
Reinforcement Ratio (Rho)	1.383 %	1.38 %
Moment of Inertia of Section I_x , mm ⁴	1.67640+011	1.6764e+011
Moment of Interia of Section I_y , mm ⁴	1.298484+010	1.29848e+010
Centroid-X (X_0), mm	201.02	201.018
Centroid-Y (Y_0), mm	825.00	825
Clear Spacing between Bars, mm	47.30	47

Verification Example 010 – Circular Section with Opening, ACI 318-19

Investigate the following circular section with an opening according to ACI 318-2019.

Material properties: $f'_c = 4.5 \text{ ksi}$, $f_y = 60 \text{ ksi}$

Section diameter: 40 in

I-shaped opening: width x height x web width x flange height = 15 x 15 x 2 x 3 in

Rebars: 11 # 10

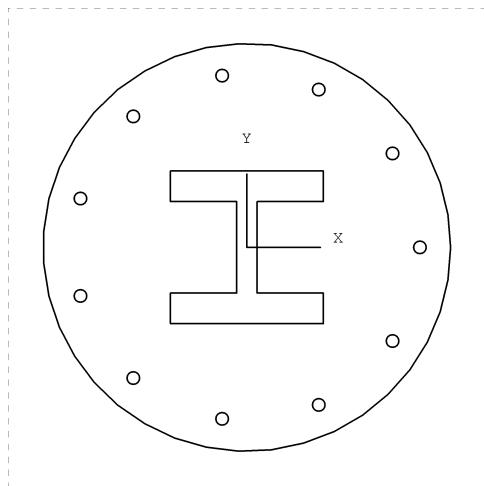
Confinement: tied

Cover to rebar center: 3 in

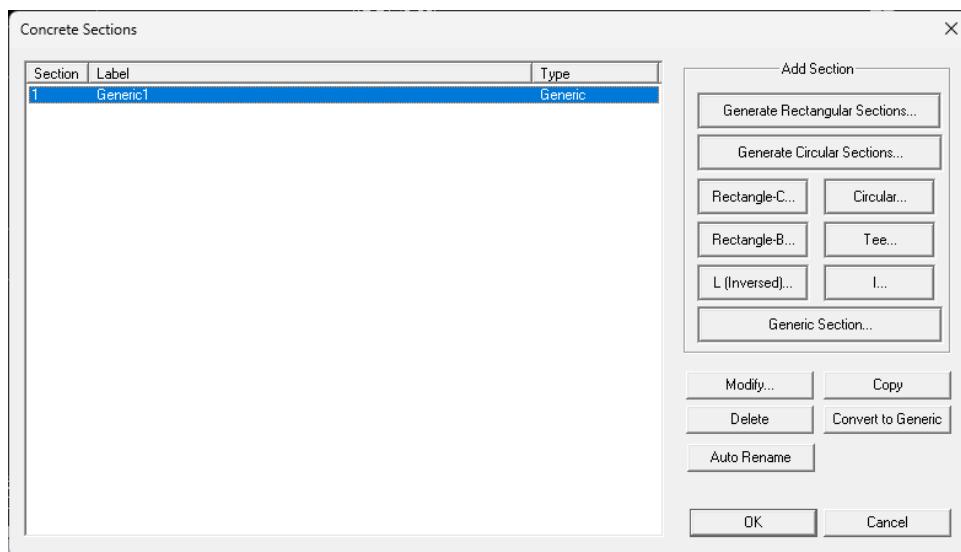
Consider slenderness: $L_{ux} = L_{uy} = 30 \text{ ft}$

Dead Loads: $P_u: 750 \text{ kip}$, $M_{ux_top}: 250$, $M_{ux_bot}: 175$, $M_{uy_top}: 80$, $M_{uy_bot}: 145 \text{ kip-ft}$

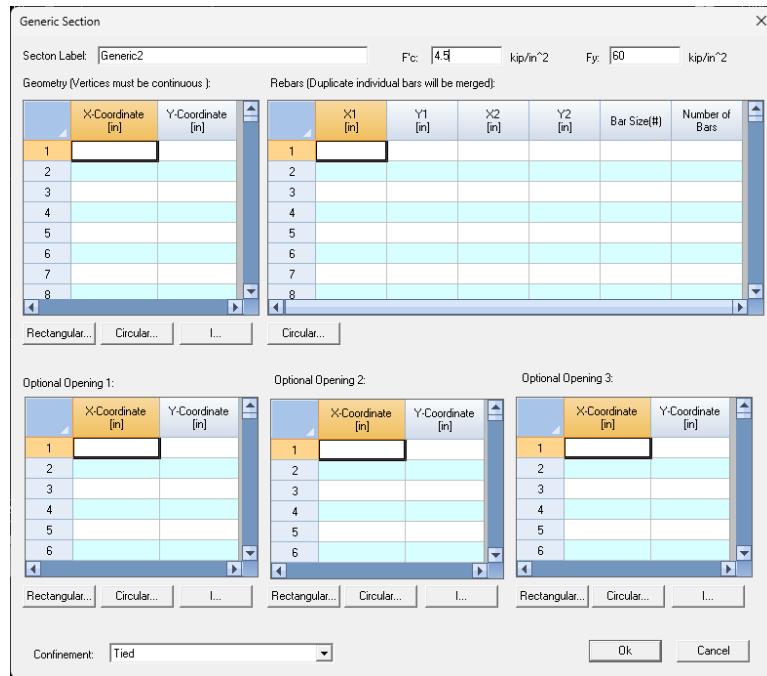
Live Loads: $P_u: 500 \text{ kip}$, $M_{ux_top}: 240$, $M_{ux_bot}: 165$, $M_{uy_top}: 70$, $M_{uy_bot}: 235 \text{ kip-ft}$



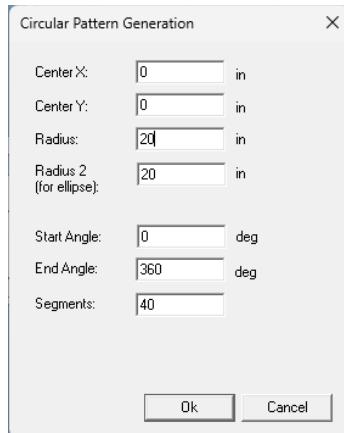
From Input | Section Mode | Advanced menu, bring up the Concrete Sections dialog



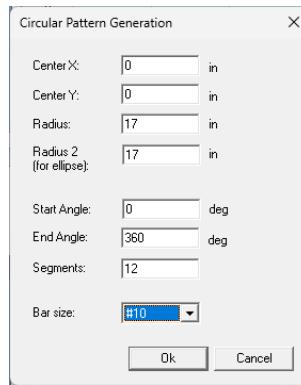
Click on the “Generic Section” button and enter the material properties fc and Fy on the Generic Section dialog



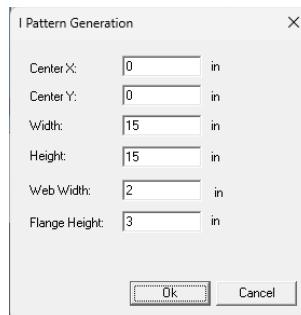
Click on the “Circular” button under the Geometry data grid to generate circular pattern points of the section boundary



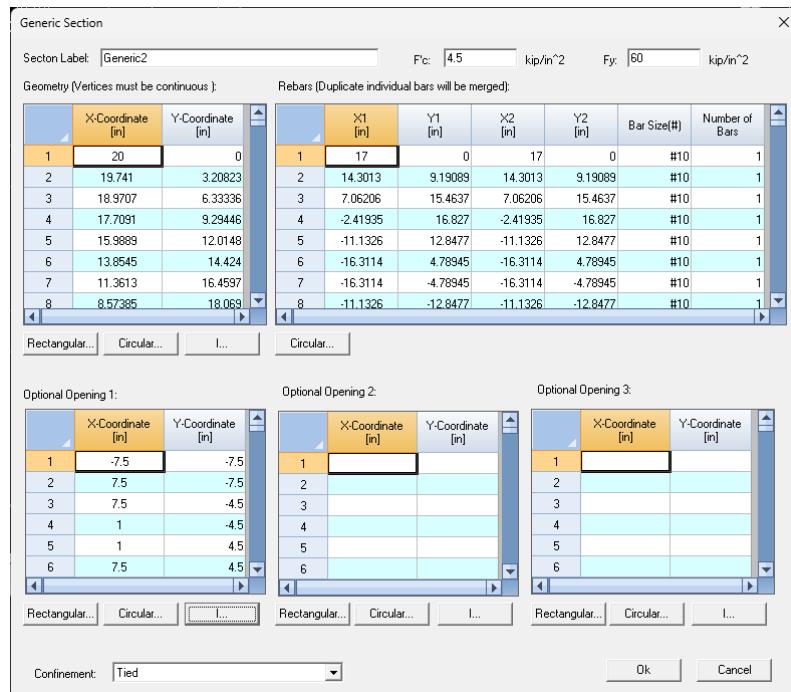
Click on the “Circular” button under the Rebars data grid to generate circular pattern rebars



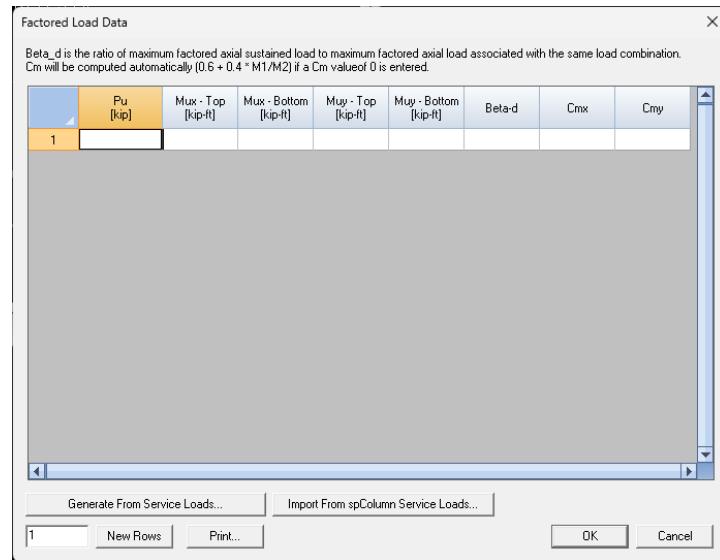
Click on the “I” button under the Optional Opening 1 data grid to generate the I-shaped opening



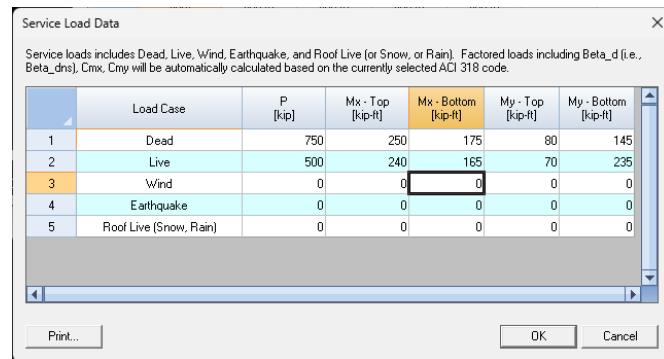
The finished generic section input is shown below



From Input | Loads menu, bring up the Factored Load Data dialog



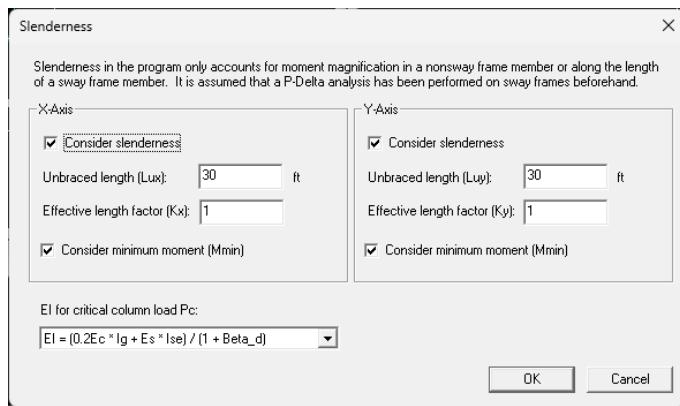
Click on the “Generate From Service Loads” button and enter the dead and live loads.



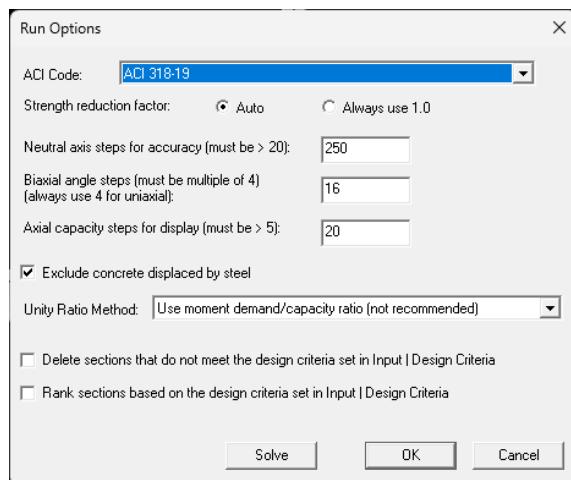
Factored loads will be automatically calculated as shown below

Factored Load Data								
Beta_d is the ratio of maximum factored axial sustained load to maximum factored axial load associated with the same load combination. Cm will be computed automatically (0.6 + 0.4 * M1/M2) if a Cm value of 0 is entered.								
	Pu [kip]	Mux - Top [kip-ft]	Mux - Bottom [kip-ft]	Muy - Top [kip-ft]	Muy - Bottom [kip-ft]	Beta-d	Cmx	Cmy
1	1050	350	245	112	203	1	0.88	0.82069
2	1700	684	474	208	550	0.529412	0.877193	0.751273
3	1400	540	375	166	409	0.642857	0.877778	0.762347
4	900	300	210	96	174	1	0.88	0.82069
5	900	300	210	96	174	1	0.88	0.82069
6	1400	540	375	166	409	0.642857	0.877778	0.762347
7	1400	540	375	166	409	0.642857	0.877778	0.762347
8	1400	540	375	166	409	0.642857	0.877778	0.762347
9	1400	540	375	166	409	0.642857	0.877778	0.762347
10	675	225	157.5	72	130.5	1	0.88	0.82069
11	675	225	157.5	72	130.5	1	0.88	0.82069
12	675	225	157.5	72	130.5	1	0.88	0.82069
13	675	225	157.5	72	130.5	1	0.88	0.82069
14								

From the Input | Slenderness menu, enter the slenderness parameters



From the Run | Options, enter the solver options



The following shows almost identical results between cColumn and spColumn v10. Please note that the sign convention for Mx are reversed between cColumn and spColumn.

P-Mx (Positive) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	38.30	38.30	2681.9	2681.9	775.1	-775.08	-0.8	-0.79
fs = 0	36.81	36.81	2565.5	2565.5	880.3	-880.31	-0.0	-0.03
fs = 0.5 Fy	27.37	27.37	1831.6	1831.6	1306.4	-1306.41	-2.3	-2.34
balanced	21.79	21.79	1262.3	1262.3	1416.8	-1416.80	0.4	0.36
Tension control	13.69	13.69	784.8	784.8	1671.4	-1671.45	2.2	2.20
Pure bending	7.56	7.57	-0.0	0.0	984.7	-984.69	-0.9	-0.87
Pure tension	0.00	0.00	-754.4	-754.4	0.0	0.00	0.0	0.00

P-Mx (Negative) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	38.30	38.30	2681.9	2681.9	-775.1	775.08	-0.8	-0.79
fs = 0	36.81	36.81	2565.5	2565.5	-880.3	880.31	-0.0	-0.03
fs = 0.5 Fy	27.37	27.37	1831.6	1831.6	-1306.4	1306.41	-2.3	-2.34
balanced	21.79	21.79	1262.3	1262.3	-1416.8	1416.80	0.4	0.37
Tension control	13.69	13.69	784.8	784.8	-1671.4	1671.45	2.2	2.20
Pure bending	7.56	7.57	-0.0	0.0	-984.7	984.69	-0.9	-0.87
Pure tension	0.00	0.00	-754.4	-754.4	0.0	0.00	0.0	0.00

P-My (Positive) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	38.35	38.35	2681.9	2681.9	-0.0	0.00	777.0	776.97
fs = 0	36.31	36.31	2526.7	2526.7	-0.0	0.00	912.7	912.72
fs = 0.5 Fy	27.00	27.00	1750.6	1750.7	-0.0	0.00	1344.1	1344.10
balanced	21.49	21.49	1272.9	1272.9	-0.0	0.00	1446.7	1446.69
Tension control	13.50	13.50	750.2	750.2	-0.0	0.00	1655.9	1655.92
Pure bending	7.77	7.77	0.0	0.0	-0.0	0.00	993.5	993.46
Pure tension	0.00	0.00	-754.4	-754.4	0.0	0.00	0.0	0.00

P-My (Negative) Control Points

	Neutral axis depth (mm)		ϕP_n (kN)		ϕM_{nx} (kN-m)		ϕM_{ny} (kN-m)	
	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn	cColumn	spColumn
Pmax	38.25	38.25	2681.9	2681.9	0.0	0.00	-773.5	-773.52
$f_s = 0$	36.94	36.94	2579.1	2579.1	0.0	0.00	-867.1	-867.06
$f_s = 0.5 F_y$	27.46	27.46	1799.6	1799.6	0.0	0.00	-1332.8	-1332.79
balanced	21.86	21.86	1313.3	1313.3	0.0	0.00	-1441.5	-1441.46
Tension control	13.73	13.73	802.3	802.3	0.0	0.00	-1679.4	-1679.43
Pure bending	7.45	7.45	-0.0	0.0	0.0	0.00	-981.1	-981.18
Pure tension	0.00	0.00	-754.4	-754.4	0.0	0.00	0.0	0.00

Others

	cColumn	spColumn
Total Section Area (A_g), in ²	1143.21	1143.21
Total Steel Area (A_s), in ²	13.97	13.97
Reinforcement Ratio (Rho)	1.222 %	1.22 %
Moment of Inertia of Section I_x , in ⁴	121151.78	121152
Moment of Interia of Section I_y , in ⁴	122886.91	122887
Centroid-X (X_0), in	0.00	0
Centroid-Y (Y_0), in	0.00	0
Clear Spacing between Bars, in	8.31	8.31
Critical Axial Force P_u , kip	1700	1700
Magnified moment M_{cx} , kip-ft	858.5	858.48
Magnified moment M_{cy} , kip-ft	272.8	272.78
Unity Ratio *	0.679	0.67

* In order to compare with spColumn, we used the moment demand/capacity ratio method (not recommended) to compute the unity ratio. In general, the maximum of axial and moment demand/capacity ratios method is recommended for unity ratio calculation.

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1. Author H. Nilson, "Design of Concrete Structures" 12th Edition, WCB/McGraw-Hill, 1997
2. "CRSI Handbook 2002" 9th Edition, Concrete Reinforcing Steel Institute, 2002
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5. Junlin Xu, "Real3D Manual", Computations & Graphics, Inc.
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8. "CRSI Handbook 2008" 10th Edition, Concrete Reinforcing Steel Institute, 2008
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10. "Design Guide on the ACI 318 Building Code Requirements for Structural Concrete" 1th Edition, Concrete Reinforcing Steel Institute, 2020

The following works are not referenced directly in this documentation, but are the primary programming references in the development of this program

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- c. D.J. Kruglinski, "Inside Visual C++", Microsoft Press, 1996
- d. M. Woo & J. Neider & T. Davis & D. Shreiner, "OpenGL Programming Guide", Addison-Wesley Publishing Company, 1999
- e. C. Petzold, "Programming Windows 95", Microsoft Press, 1996
- f. C. Musciano & B. Kennedy, "HTML The Definitive Guide" 3rd ed., O'Reilly & Associates, Inc., 1998

Appendix

Designations, diameters and areas of standard bars

ASTM 615 (English)			ASTM 615 96a (Metric)		
Bar No	Diameter (in)	Area (in ²)	Bar No	Diameter (mm)	Area (mm ²)
#3	0.375	0.11	#10	9.5	71
#4	0.500	0.20	#13	12.7	129
#5	0.625	0.31	#16	15.9	199
#6	0.750	0.44	#19	19.1	284
#7	0.875	0.60	#22	22.2	387
#8	1.000	0.79	#25	25.4	510
#9	1.128	1.00	#29	28.7	645
#10	1.270	1.27	#32	32.3	819
#11	1.410	1.56	#36	35.8	1006
#14	1.693	2.25	#43	43.0	1452
#18	2.257	4.00	#57	57.3	2581

Unit Conversions

From English to Metric			From Metric to English		
1 ft	=>	0.3048 m	1 m	=>	3.28084 ft
1 in	=>	25.4 mm	1 mm	=>	0.03937 in
1 kip	=>	4.44822 kN	1 kN	=>	0.22481 kip
1 lb	=>	4.44822 N	1 N	=>	0.22481 lb
1 kip-ft	=>	1.35582 kN-m	1 kN-m	=>	0.73756 kip-ft
1 kip-in	=>	0.112985 kN-m	1 kN-m	=>	8.85073 kip-in
1 lb-ft	=>	1.35582 N-m	1 N-m	=>	0.73756 lb-ft
1 lb-in	=>	0.112985 N-m	1 N-m	=>	8.85073 lb-in
1 kip/in ²	=>	0.00689476 kN/mm ²	1 kN/mm ²	=>	145.04 kip/in ²
1 lb/in ²	=>	0.00689476 N/mm ²	1 N/mm ²	=>	145.04 lb/in ²