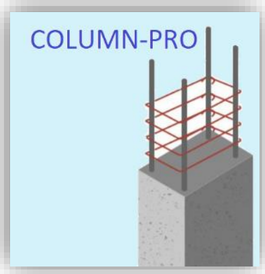
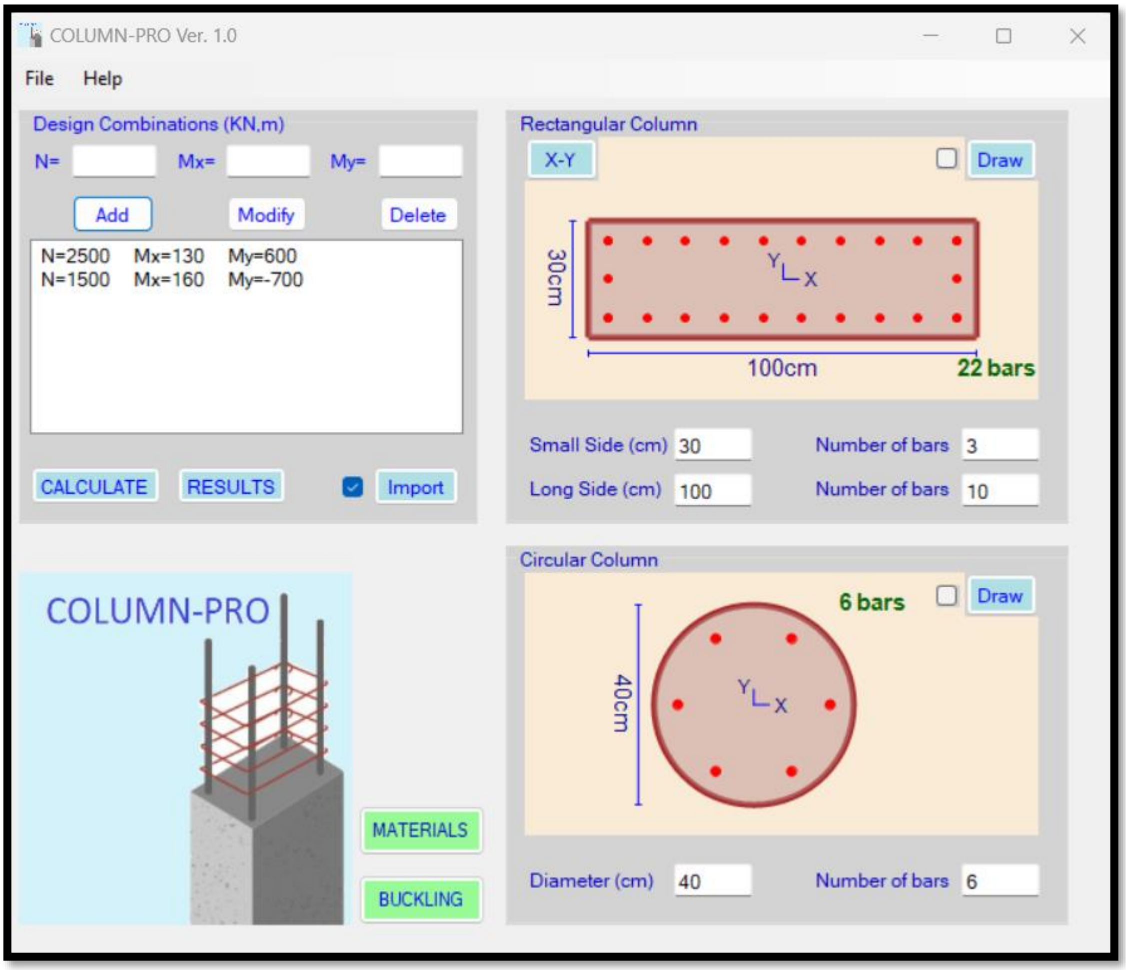
Introduction



COLUMN-PRO is an innovative application for analysis and design of reinforced concrete columns. In this first version, only rectangular and circular columns are considered. Further developments will include columns of generic shape and CAD drawings generation (sections and elevations).



COLUMN-PRO is conceived for Engineers who need an easy and powerful tool to quickly design columns with few mouse clicks.

The main features of **COLUMN-PRO** are:

- ***Design of columns under axial force and bi-axial moments according to ACI 318-19 metric.***
- ***Friendly graphical interface*** allowing for a quick introduction of loads and parameters.
- ***Two ways to introduce loads***. Ultimate combinations for the triplet (N, Mx, My) can be directly introduced by the user by typing in the related textboxes. Combinations can also be imported from Autodesk Robot. The main difference between the two methods is that the second one allows to consider a huge number of combinations where loads at top and bottom nodes of the column. The usage of the moments at top and bottom nodes is mainly related to the determination of the coefficient C_m that magnifies the moments when considering slenderness effects.
- In the present version, slenderness effects are considered in the case of non-sway columns.
- ***All combinations are analyzed***. Unlike other programs, **COLUMN-PRO** displays in a ***detailed summary table the design under all combinations*** with their related working ratios.
- The user can check the interaction diagrams (N, M) and (Mx, My) under any load case.
- ***Generation of (N,My,Mz) interaction diagrams*** to verify the capacity of the section.
- Generation of high-quality report where results are displayed by the mean of ***graphics and tables***.

COLUMN-PRO ***combines simplicity with state-of-the-art technologies*** to help you safely and accurately design the columns of your project.

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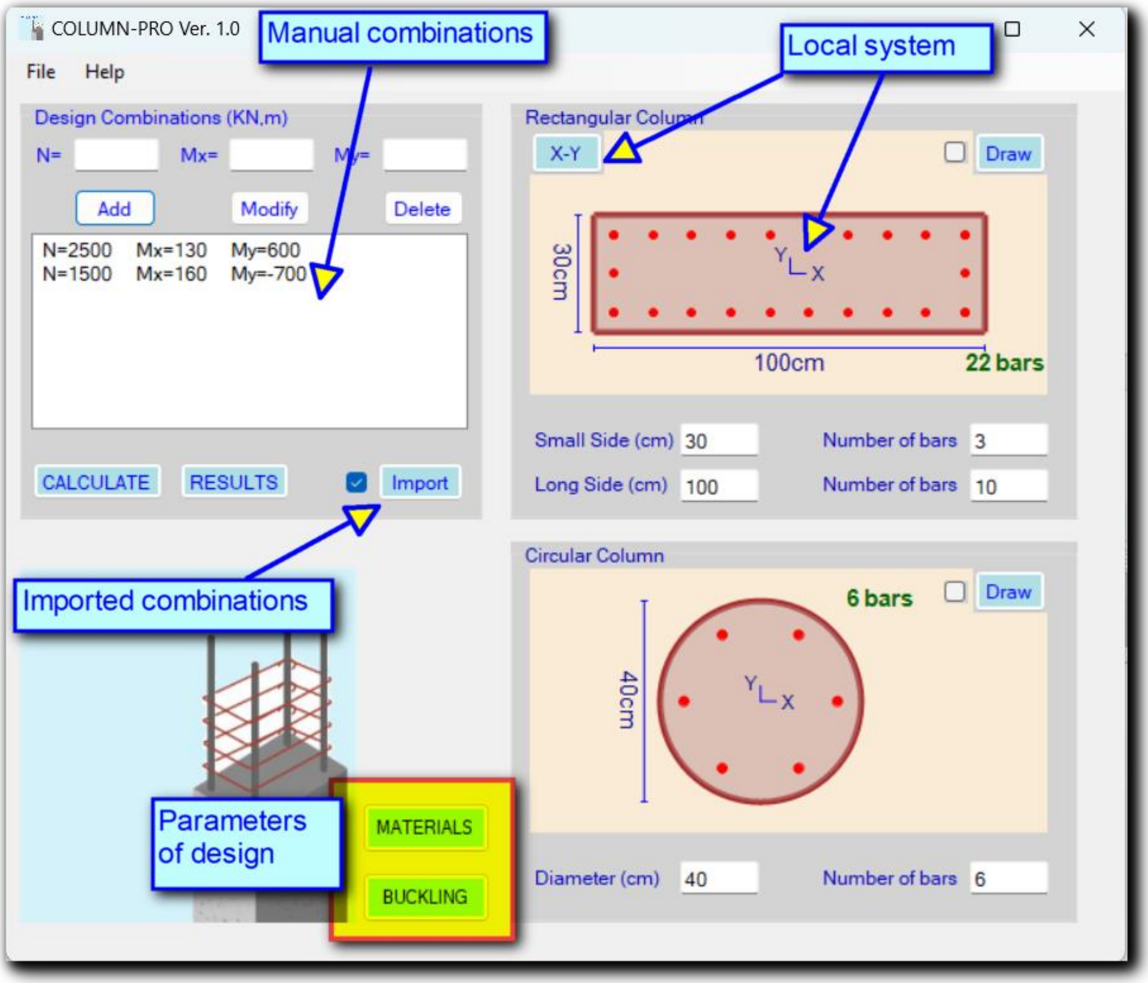
General overview



Manual combinations

Manual combinations can be introduced one by one in the “Design Combinations” group box. Axial force is positive if compression; Mx and My are about the local reference that is shown in the center of the column, in the figures at the right. It is possible to rotate the local reference by clicking on the “X-Y” button. Since the loads are introduced at a specific location (could be at the top or bottom node of the column), the software needs to assume when considering slenderness effects (buckling analysis) the curvature shape of the column. Refer to the “Slenderness effects” section in the present document regarding this subject.

Imported combinations

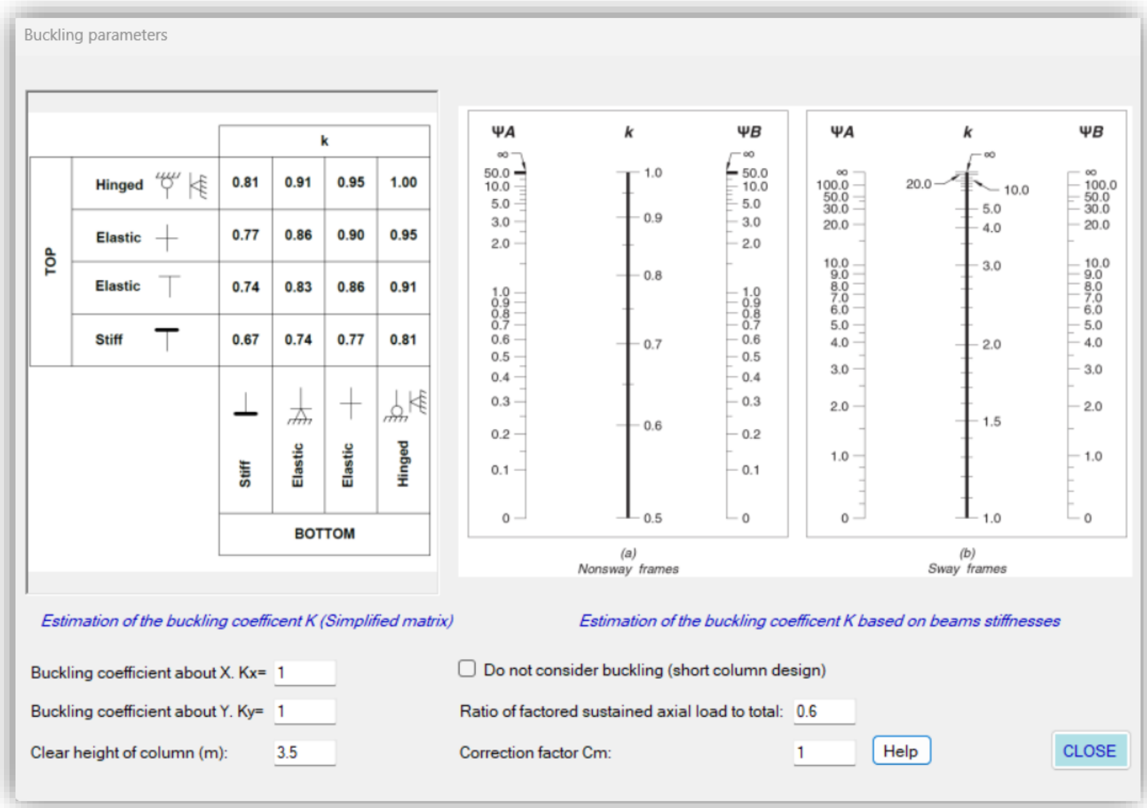
To import combinations from Autodesk Robot, click on the “Import” button and then check the checkbox. Refer to Annex A at the end of this document for the details of the procedure. Alike the manual combinations, the moments orientation follows the same convention. Moments at top and bottom nodes of the columns are imported. The software can thus accurately calculate the correction factor C_m that directly intervenes in the moment magnification procedure.

Columns dimensions

The section of the columns should be introduced together with the imposed number of bars. The software will select the smallest reinforcement diameter from the list (refer to the "materials" button) that satisfies the design. The software does not modify the number of bars; it is up to the user to control this parameter. The checkbox corresponding to the circular or rectangular column should be checked prior to launching calculations. The software will design either a rectangular or a circular section (depending on the checked checkbox) and will propose the optimal reinforcement diameter. The "X-Y" button switches the orientation of the local reference. This option is very helpful in the case where the loads are imported from Robot. It allows to adjust the inertias orientation of the rectangular column to match its orientation in the original model.

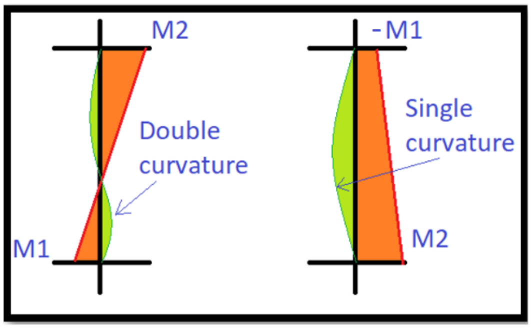
Parameters of design

Buckling parameters (Slenderness effects)



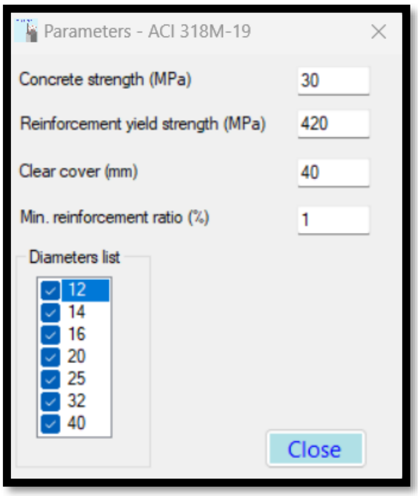
Buckling coefficients Kx and Ky reflect the boundary conditions at the ends of the column. In the actual version of the software, slenderness effects are considered for non-sway columns only, where buckling coefficient cannot exceed 1. Buckling length is equal to the product of buckling coefficient and the clear height of the column. Coefficient β_{dns} is proper to each combination. Actually, it is introduced as a constant for all the combinations, manual and imported. β_{dns} is equal, for a given combination, to the ratio of the sustained axial forces to the total axial forces. Considering, for instance, combination 1.2D+1.6L, β_{dns} can be considered equal to 1.2D/{1.2D+1.6L}, where D and L correspond respectively to the axial forces produced by dead and live loads. Care to be considered in the estimation of the buckling coefficient and the column clear height. The critical buckling force Pc contains the square of the buckling length at the denominator of the fraction. Small values of Pc lead to high values for the magnification factor δ.

The software considers, for simplification, a value of 0.6 for this coefficient, as permitted by ACI.



ACI 318-19 differentiates between single and double curvature, as the latter is less critical with regards to the moment's magnification procedure. This distinction is based on the sign of the ratio M1/M2. The magnification factor $\delta = \frac{C_m}{1 - \frac{P_u}{0.75 P_c}}$ contains the correction coefficient Cm = 0.6-(0.4*M1/M2). M2 is the bigger moment, per definition. The calculation of the correction coefficient requires the knowledge of the top and bottom moments with their signs. In Autodesk Robot, when M1 and M2 are of opposite sign, it means the column is bending with an inflection point (double curvature). The software recognizes this difference between both conventions. When the loads are introduced manually, either moments at top or at bottom are of concern, and the coefficient C_m should be modified by the user since it cannot be automatically calculated by the software. An upper value of 1 can be retained.

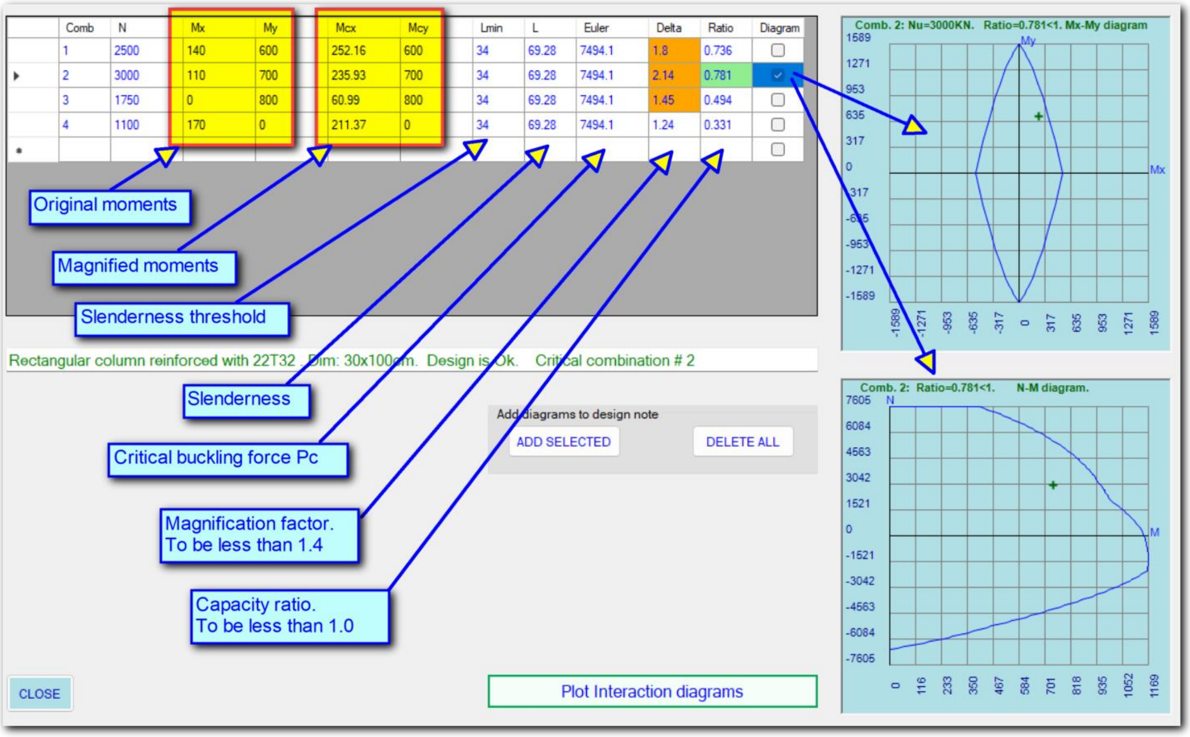
Material parameters



Clear cover value is used by the software to accurately generate the interaction diagrams based on the exact location of the reinforcement within the section. The software will select from the diameters list the smallest one that satisfies strength criteria, while respecting the minimum reinforcement ratio set by the user. The "1%" ratio is advised by ACI 318-19.

It is important to note that the program does not check if the maximal reinforcement ratio is exceeded. It is up to the user to make this verification.

Results



Once the optimal diameter is found, the program displays a table that verifies the section under all the introduced loads. In the figure above, the rectangular column of dimensions 30x100cm, reinforced with 22T32, is checked for all four combinations. The second combination (Comb. #2) with the highest capacity ratio is the most critical. The design is Ok because this ratio (0.781) is less than 1, otherwise the cell will be colored red instead of green. Failing column means the software tried all the diameters of the list without reaching a satisfying solution. In this case the corresponding capacity ratio will be displayed, with a value greater than 1.

Another important factor is the magnification one, δ. The introduced first-order moments will be magnified, consequently to the slenderness effects procedure for non-sway columns. Mcx and Mcy are the magnified moments. The factor δ is function of the coefficient Cm and of the Euler buckling force Pc. The smaller the latter, and bigger is δ. If the slenderness λ is less than the threshold λ_{min} , buckling analysis will not be performed and δ remains equal to 1. In the figure above, λ=69.28 and λ_{min} = 34. The magnification factor amplifies the first order moments. If δ>1.4 then the corresponding cell is orange colored. ACI 318-19 states that if the magnification factor exceeds 1.4, the column section should be revised even if the capacity ratio is less than 1.

The Mx-My interaction diagram corresponds to the axial force N in the selected combination. Interaction diagram M-N is generated in the plane (direction) of the (Mcx,Mcy) vector. The coordinates of the load become (M,N), where M=$\sqrt{M_{cx}^2 + M_{cy}^2}$ and N is the axial force in the selected combination.

Calculations report

It is possible to generate comprehensive Word report for the designed columns, by selecting "Generate Report" from the "File" menu.

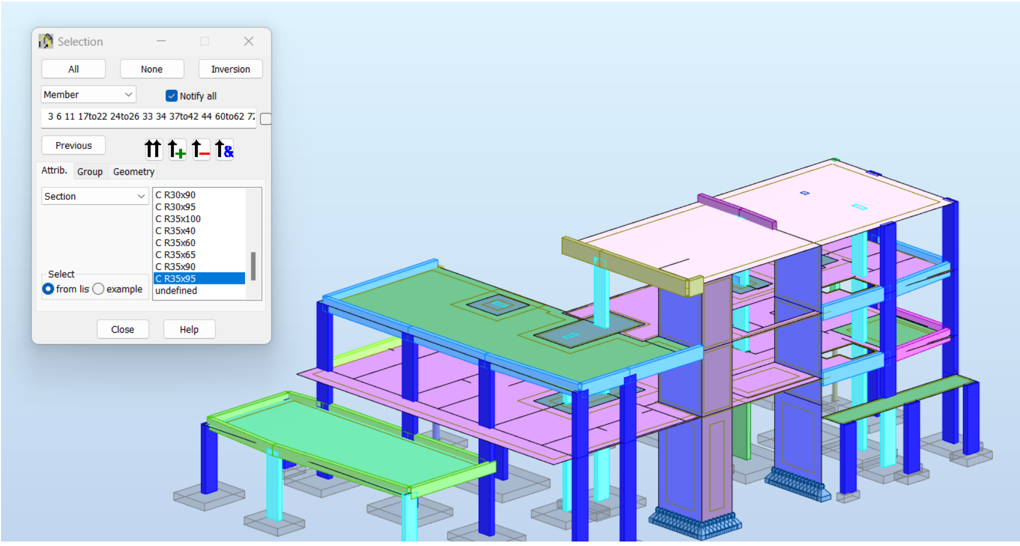
The user can include in the report chosen interaction diagrams by clicking on the button "Add selected" located in the "Results" window. Each time this button is clicked, the interaction diagrams corresponding to the active combination are saved to the memory of the computer. Once the report is generated, these images will be pasted with their corresponding title.

The summary table of results will be generated for either the manual or imported combinations. The reason is that the required reinforcement is not necessarily the same for both types of combinations and this might lead to confusion if summary tables for different reinforcements are displayed. If the checkbox next to the "Import" button is checked, the results table for the imported combinations will be created in the report.

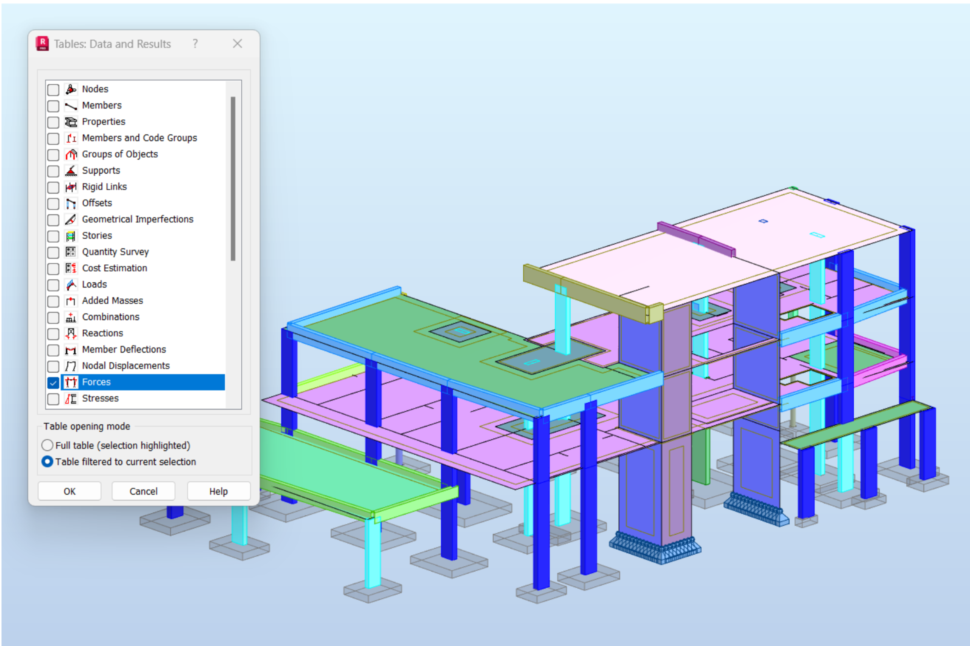
ANNEX A – Importing loads

How to import loads on columns from Robot

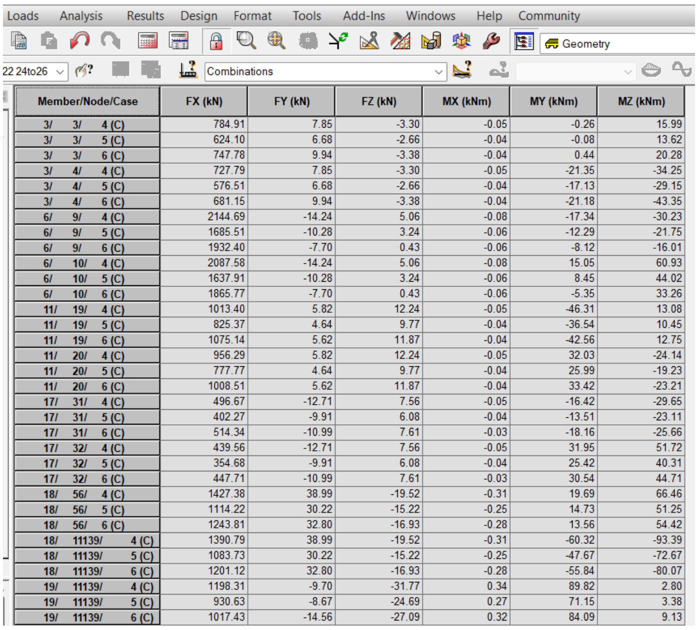
Step 1: Select the columns that have the same section.



Step 2: Open the table of forces for the selected columns.

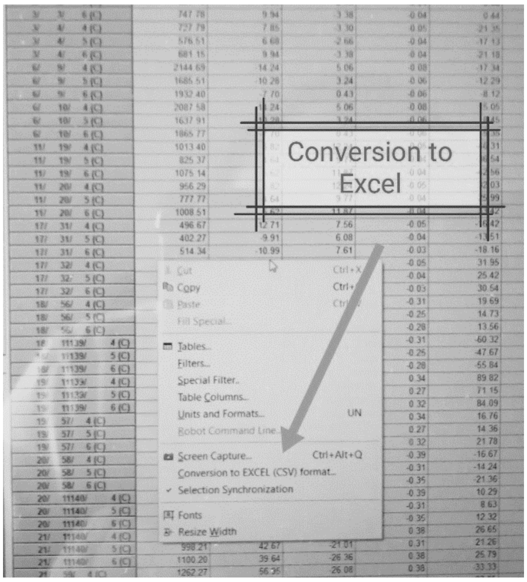


Step 3: Make sure to select all the required combinations from the menu above the table.

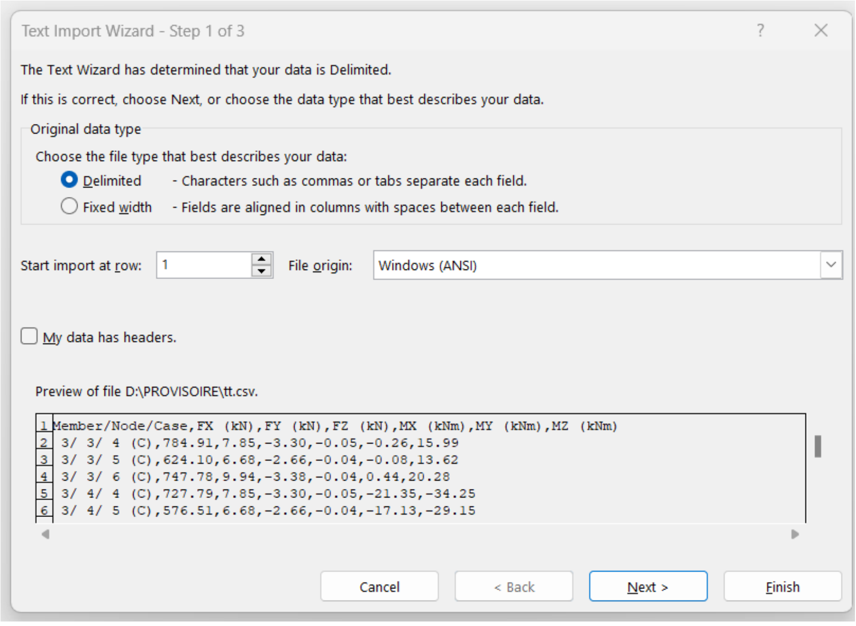


Member/Node/Case	FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
3/ 3/ 4 (C)	784.91	7.85	-3.30	-0.05	-0.26	15.99
3/ 3/ 5 (C)	624.10	6.68	-2.66	-0.04	-0.08	13.62
3/ 3/ 6 (C)	747.78	9.94	-3.38	-0.04	0.44	20.28
3/ 4/ 4 (C)	727.79	7.85	-3.30	-0.05	-21.35	-34.25
3/ 4/ 5 (C)	576.51	6.68	-2.66	-0.04	-17.13	-29.15
3/ 4/ 6 (C)	681.15	9.94	-3.38	-0.04	-21.18	-43.35
6/ 9/ 4 (C)	2144.69	-14.24	5.06	-0.08	-17.34	-30.23
6/ 9/ 5 (C)	1685.51	-10.28	3.24	-0.06	-12.29	-21.75
6/ 9/ 6 (C)	1932.40	-7.70	0.43	-0.06	-8.12	-16.01
6/ 10/ 4 (C)	2087.58	-14.24	5.06	-0.08	15.05	60.93
6/ 10/ 5 (C)	1637.91	-10.28	3.24	-0.06	8.45	44.02
6/ 10/ 6 (C)	1865.77	-7.70	0.43	-0.06	-5.35	33.26
11/ 19/ 4 (C)	1013.40	5.82	12.24	-0.05	-46.31	13.08
11/ 19/ 5 (C)	825.37	4.64	9.77	-0.04	-36.54	10.45
11/ 19/ 6 (C)	1075.14	5.62	11.87	-0.04	-42.56	12.75
11/ 20/ 4 (C)	956.29	5.82	12.24	-0.05	32.03	-24.14
11/ 20/ 5 (C)	777.77	4.64	9.77	-0.04	25.99	-19.23
11/ 20/ 6 (C)	1008.51	5.62	11.87	-0.04	33.42	-23.21
17/ 31/ 4 (C)	496.67	-12.71	7.56	-0.05	-16.42	-29.65
17/ 31/ 5 (C)	402.27	-9.91	6.08	-0.04	-13.51	-23.11
17/ 31/ 6 (C)	514.34	-10.99	7.61	-0.03	-18.16	-25.66
17/ 32/ 4 (C)	439.56	-12.71	7.56	-0.05	31.95	51.72
17/ 32/ 5 (C)	354.68	-9.91	6.08	-0.04	25.42	40.31
17/ 32/ 6 (C)	447.71	-10.99	7.61	-0.03	30.54	44.71
18/ 56/ 4 (C)	1427.38	38.99	-19.52	-0.31	19.69	66.46
18/ 56/ 5 (C)	1114.22	30.22	-15.22	-0.25	14.73	51.25
18/ 56/ 6 (C)	1243.81	32.80	-16.93	-0.28	13.56	54.42
18/ 11139/ 4 (C)	1390.79	38.99	-19.52	-0.31	-60.32	-93.39
18/ 11139/ 5 (C)	1083.73	30.22	-15.22	-0.25	-47.67	-72.67
18/ 11139/ 6 (C)	1201.12	32.80	-16.93	-0.28	-55.84	-80.07
19/ 11139/ 4 (C)	1198.31	-9.70	-31.77	0.34	89.82	2.80
19/ 11139/ 5 (C)	930.63	-8.67	-24.69	0.27	71.15	3.38
19/ 11139/ 6 (C)	1017.43	-14.56	-27.09	0.32	84.09	9.13

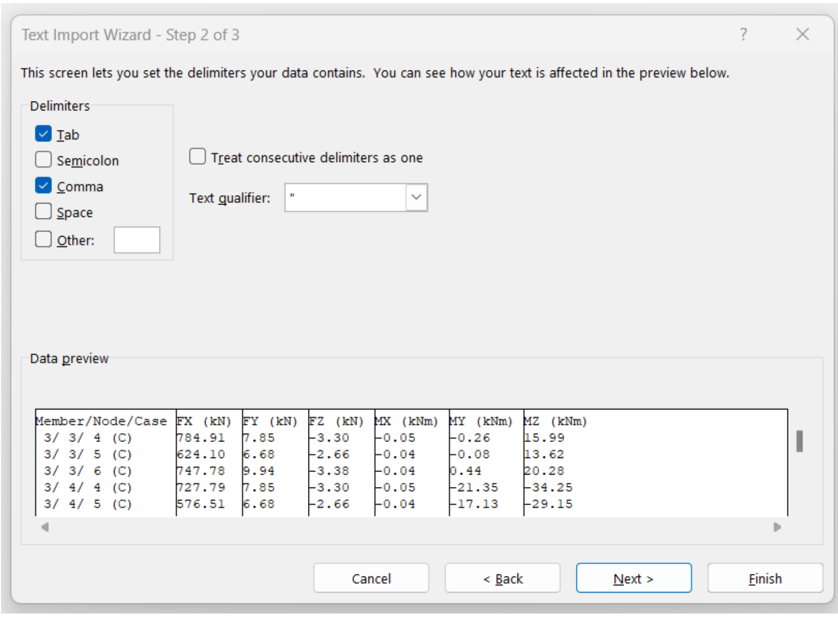
Step 4: Right-click the mouse and select conversion to Excel .CSV format.



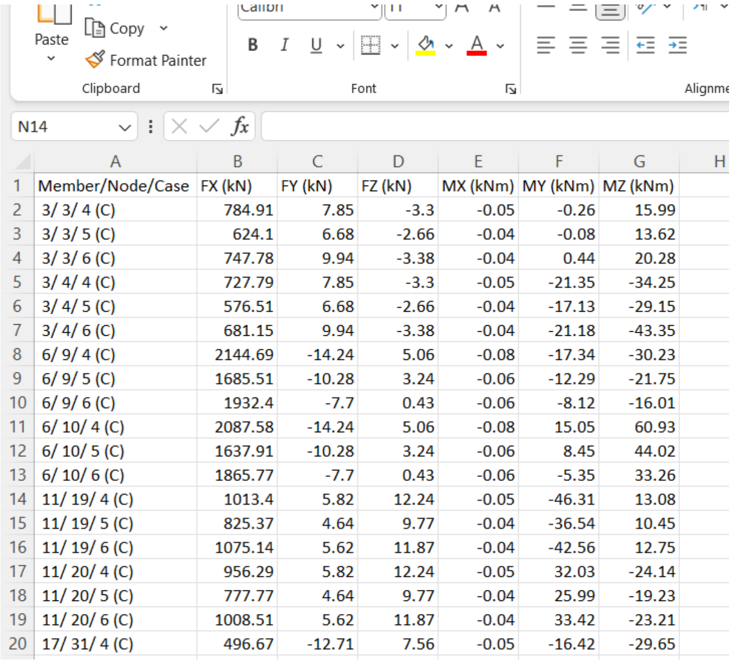
Step 5: Start Excel and then open the saved file.



Step 6: Click next then select “comma” then click next and finally click finish.

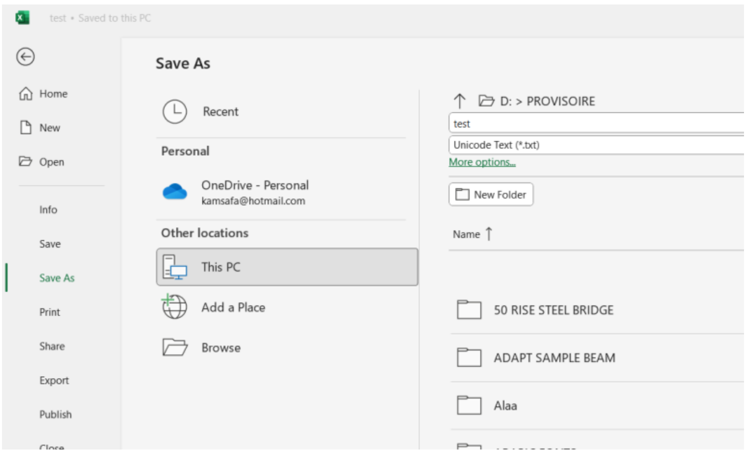


Step 7: The final Excel file should look like this snapshot. Save



Member/Node/Case	FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
3/ 3/ 4 (C)	784.91	7.85	-3.3	-0.05	-0.26	15.99
3/ 3/ 5 (C)	624.1	6.68	-2.66	-0.04	-0.08	13.62
3/ 3/ 6 (C)	747.78	9.94	-3.38	-0.04	0.44	20.28
3/ 4/ 4 (C)	727.79	7.85	-3.3	-0.05	-21.35	-34.25
3/ 4/ 5 (C)	576.51	6.68	-2.66	-0.04	-17.13	-29.15
3/ 4/ 6 (C)	681.15	9.94	-3.38	-0.04	-21.18	-43.35
6/ 9/ 4 (C)	2144.69	-14.24	5.06	-0.08	-17.34	-30.23
6/ 9/ 5 (C)	1685.51	-10.28	3.24	-0.06	-12.29	-21.75
6/ 9/ 6 (C)	1932.4	-7.7	0.43	-0.06	-8.12	-16.01
6/ 10/ 4 (C)	2087.58	-14.24	5.06	-0.08	15.05	60.93
6/ 10/ 5 (C)	1637.91	-10.28	3.24	-0.06	8.45	44.02
6/ 10/ 6 (C)	1865.77	-7.7	0.43	-0.06	-5.35	33.26
11/ 19/ 4 (C)	1013.4	5.82	12.24	-0.05	-46.31	13.08
11/ 19/ 5 (C)	825.37	4.64	9.77	-0.04	-36.54	10.45
11/ 19/ 6 (C)	1075.14	5.62	11.87	-0.04	-42.56	12.75
11/ 20/ 4 (C)	956.29	5.82	12.24	-0.05	32.03	-24.14
11/ 20/ 5 (C)	777.77	4.64	9.77	-0.04	25.99	-19.23
11/ 20/ 6 (C)	1008.51	5.62	11.87	-0.04	33.42	-23.21
17/ 31/ 4 (C)	496.67	-12.71	7.56	-0.05	-16.42	-29.65

Step 8: Save the file as a text file (extension .txt) as shown in this snapshot.

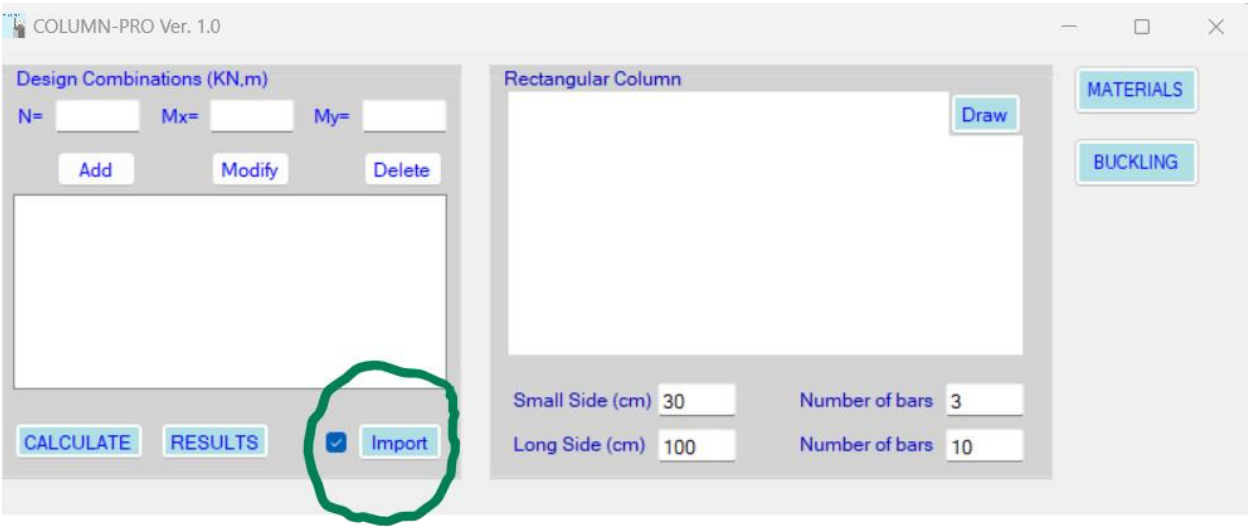


Step 9: Open the text file to check that the forces are in separate columns, as below.

```
test
File   Edit   View

Member/Node/Case        FX (kN) FY (kN) FZ (kN) MX (kNm)        MY (kNm)        MZ (kNm)
 3/ 3/ 4 (C)    784.91  7.85    -3.3    -0.05   -0.26   15.99
 3/ 3/ 5 (C)    624.1   6.68    -2.66   -0.04   -0.08   13.62
 3/ 3/ 6 (C)    747.78  9.94    -3.38   -0.04   0.44    20.28
 3/ 4/ 4 (C)    727.79  7.85    -3.3    -0.05   -21.35  -34.25
 3/ 4/ 5 (C)    576.51  6.68    -2.66   -0.04   -17.13  -29.15
 3/ 4/ 6 (C)    681.15  9.94    -3.38   -0.04   -21.18  -43.35
 6/ 9/ 4 (C)    2144.69 -14.24  5.06    -0.08   -17.34  -30.23
 6/ 9/ 5 (C)    1685.51 -10.28  3.24    -0.06   -12.29  -21.75
 6/ 9/ 6 (C)    1932.4  -7.7    0.43    -0.06   -8.12   -16.01
 6/ 10/ 4 (C)   2087.58 -14.24  5.06    -0.08   15.05   60.93
 6/ 10/ 5 (C)   1637.91 -10.28  3.24    -0.06   8.45    44.02
 6/ 10/ 6 (C)   1865.77 -7.7    0.43    -0.06   -5.35   33.26
 11/ 19/ 4 (C)  1013.4  5.82    12.24   -0.05   -46.31  13.08
 11/ 19/ 5 (C)  825.37  4.64    9.77    -0.04   -36.54  10.45
 11/ 19/ 6 (C)  1075.14 5.62    11.87   -0.04   -42.56  12.75
 11/ 20/ 4 (C)  956.29  5.82    12.24   -0.05   32.03   -24.14
 11/ 20/ 5 (C)  777.77  4.64    9.77    -0.04   25.99   -19.23
 11/ 20/ 6 (C)  1008.51 5.62    11.87   -0.04   33.42   -23.21
```

Step 10: Open COLUMN-PRO and import the text file. The checkbox must be checked too.

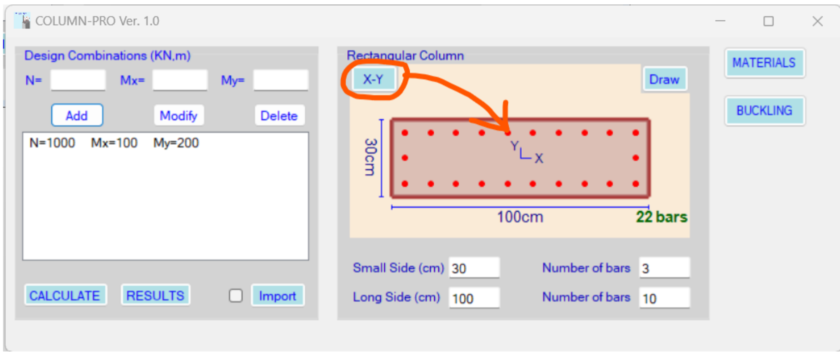


If the checkbox is unchecked, the software will consider the loads that are introduced in the window, instead of the imported Robot loads.

When the button "calculate" is selected, if the checkbox is checked, the design will be performed based on the imported loads. If the checkbox is unchecked, the user must manually introduce the loads.

The button "results" will display the results of the design in a table.

Step 11: Make sure the orientation of the (X,Y) reference conforms with the imported loads.



Always, once loads are imported, the software considers that Mx is equal to the imported My and My is equal to the imported Mz. As per the sketch here-above, Mx is about the weak inertia and My is about the strong inertia.

Mx in the software → My in Robot

My in the software → Mz in Robot

If in Robot, the moments My and Mz are acting respectively about the strong and weak inertias of the section, then the reference (X,Y) should be switched in COLUMN-PRO. By clicking on the “X-Y” button, the software will permute X and Y. Moments Mx and My will thus be applied respectively about the strong and weak inertias of the column.