

Interaction Curves

SectionPro Tutorial: classical 2D interaction diagrams
with load combination verification

BridgeKernel · 2026

Introduction

The interaction curve module computes classical 2D interaction diagrams for reinforced concrete sections. By fixing one force component (N , M_z , or M_y) at a chosen value, SectionPro computes the resistance boundary in the remaining two-component plane. Load combinations are scattered onto the plot: loads inside the curve appear in **green** (safe), loads outside in **red** (failing). This gives a direct visual check without computing numerical safety factors.

Two modes are available. In fixed-component mode, one component is set to a specific value (e.g. $N = 0$) and the interaction curve is drawn in the remaining plane. The fixed value must lie within the resistance domain of the section, otherwise no curve exists at that level.

In envelope mode, SectionPro draws two curves: one for the maximum value of the fixed component across all load combinations, and one for the minimum value. This allows validating multiple load cases with different fixed-component values in a single figure, without generating a separate curve for each value. The fixed-component values of all load combinations must lie within the resistance domain of the section. In this mode, a third color is used:

- **Green**: inside both curves, safe at both extremes of the fixed component.
- **Red**: outside both curves, fails at both extremes.
- **Grey**: between the two curves, uncertain. The load may or may not be safe depending on its actual fixed-component value. A more precise check is required, either by fixing the component at the load's actual value, by inspecting the 3D interaction surface, or by running the internal equilibrium solver.

Computed results

Interaction curve

Fixed component (N , M_z , or M_y)
Closed 2D resistance boundary
Envelope mode (min/max)

Visual verification

Load points scattered on the plot
Green (safe) / Red (fails) / Grey
(uncertain)

Exports

PDF: 2D curve + scattered loads
XLS: curve coordinates
TXT: tabular results (columns)

Octagonal section (Eurocode 2)

Input data

The section geometry, reinforcement, and material laws are identical to those used in Articles #4–6:

Concrete

- Octagonal cross section
- $b_1 = 2.00$ m, $b_2 = 0.50$ m
- $h_1 = 1.00$ m, $h_2 = 0.60$ m

Reinforcement

- 48 bars, uniform spacing 150 mm
- Diameter $\varphi = 32$ mm, cover 50 mm

Material laws (EC2)

- Concrete C30/37: $f_{ck} = 30$ MPa
- Steel B500B: $f_{yk} = 500$ MPa

Figure 1: Octagonal cross section.

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Interaction curves

The first curve shows the biaxial bending capacity at zero axial force ($N = 0$) under the serviceability limit state (SLS-C), while the second shows the classical axial force–bending interaction at zero out-of-plane moment ($M_y = 0$) under the ultimate limit state (ULS-F).

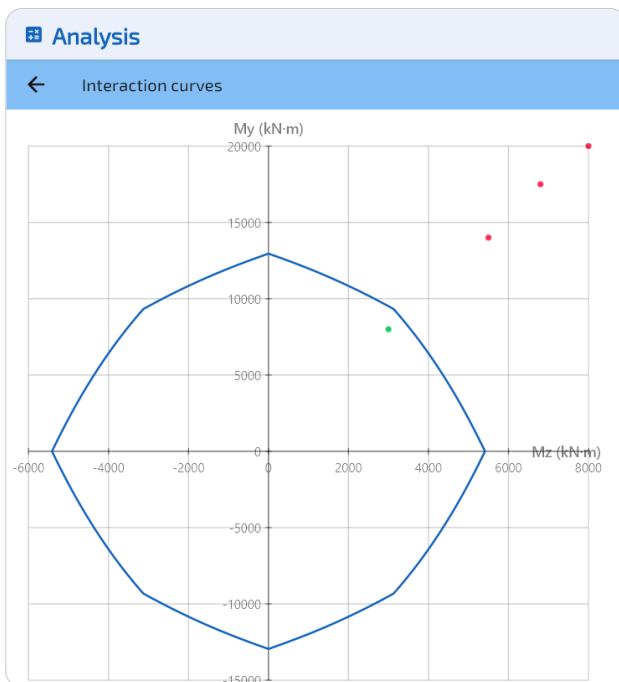


Figure 2: Serviceability (characteristic): M_z – M_y at $N = 0$.

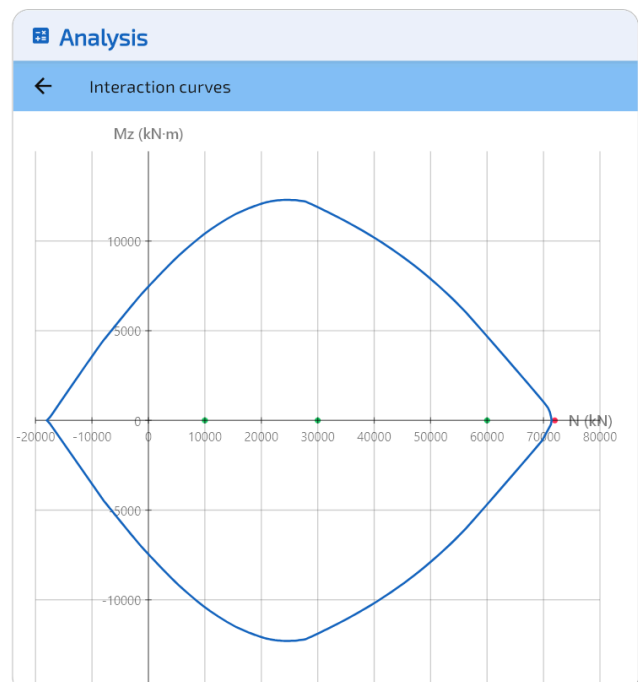


Figure 3: Ultimate (fundamental): N – M_z at $M_y = 0$.

The 30 load combinations are the same as in the distances article (15 ULS-F, 15 SLS-C). All green loads had $\eta < 1$ in the 3D analysis, and all red loads had $\eta > 1$: the 2D curves are fully consistent with the 3D distance results.

Envelope mode

The envelope mode requires that all load combinations have their fixed-component value within the resistance domain. Some of the original 30 loads from the distances article have components that exceed the section capacity: for instance, load #4 at ULS-F has $N = 72000$ kN while the axial resistance is approximately 70700 kN. These loads cannot be used in envelope mode, so a reduced set of internal loads is used here.

The two figures below show the envelope for the serviceability limit state (N as fixed component, plotting M_z-M_y) and the ultimate limit state (M_y as fixed component, plotting $N-M_z$). Each envelope consists of two curves: one computed at the minimum value of the fixed component across all loads, and one at the maximum value.

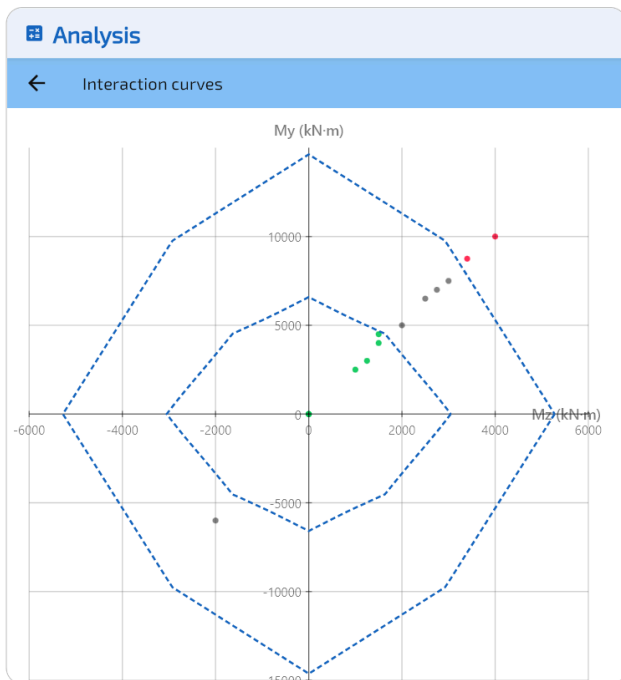


Figure 4: Serviceability: envelope on N .

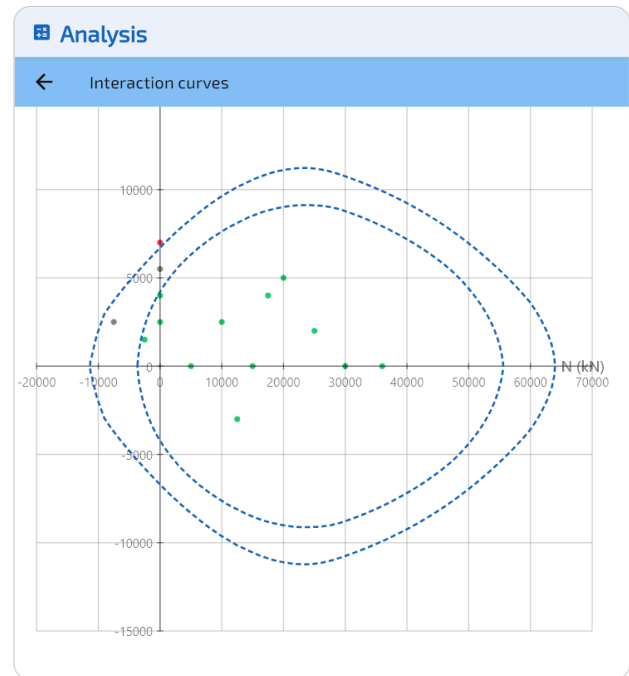


Figure 5: Ultimate: envelope on M_y .

The green markers fall inside both bounding curves: they are within the resistance domain at both the minimum and maximum values of the fixed component, and are therefore verified safe. The red markers fall outside both curves, meaning they exceed the section capacity at both extremes. The grey markers lie between the two curves: they are inside the resistance domain at one extreme but not the other. Their status is ambiguous: the engineer should either verify them individually using the fixed-component mode at the load's actual value, or use the 3D interaction surface or the internal equilibrium solver for a definitive answer.

Elliptical section (ACI 318)

Input data

Concrete

- Elliptical cross section
- Width = 3.00 m, Height = 2.00 m

Reinforcement

- 40 bars along the perimeter
- Diameter $\varphi = 40$ mm, cover 50 mm

Material laws (ACI 318)

- Concrete: $f'_c = 30$ MPa
- Steel: $f_y = 500$ MPa

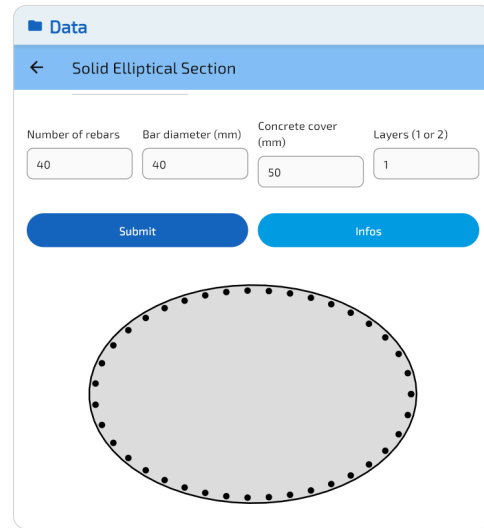


Figure 6: Elliptical cross section.

Interaction curves

The first curve shows the biaxial bending capacity at zero axial force ($N = 0$) under the serviceability limit state, while the second shows the axial force–bending interaction at $M_y = 0$ under the ultimate limit state. The Whitney stress block and φ -factors are applied natively to the ultimate curve.

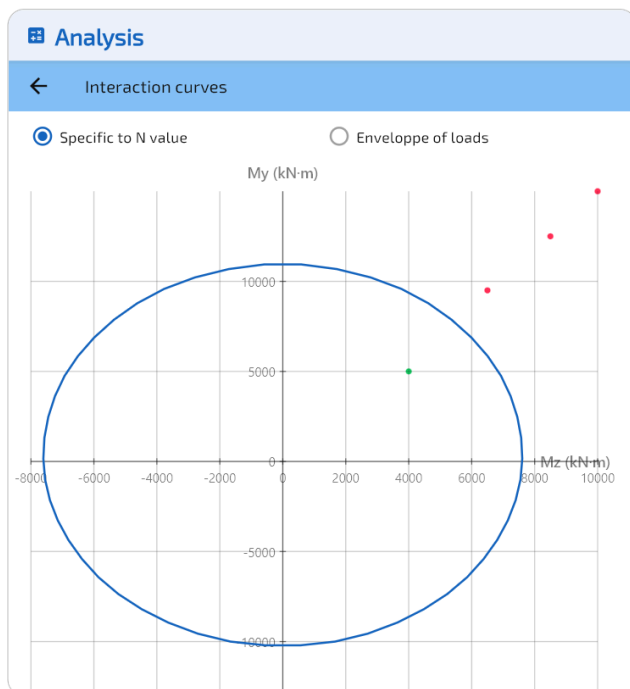


Figure 7: Serviceability: M_z – M_y at $N = 0$.

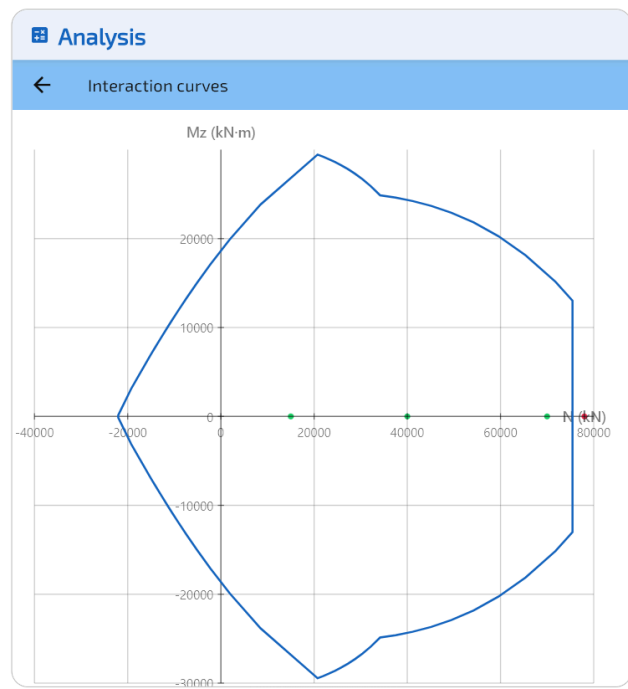


Figure 8: Ultimate: N – M_z at $M_y = 0$ (Whitney).

The ultimate curve (right) clearly shows the effects of the ACI 318 Whitney block formulation. The maximum compressive force is capped at $\varphi P_{n,max}$: the flat vertical boundary on the right side of the diagram, where the curve stops abruptly instead of continuing to higher N values. This cap reflects the code-mandated maximum axial load reduction ($\varphi_c \times 0.80$ for tied columns). The transition zone

between tension-controlled ($\varphi = 0.90$) and compression-controlled ($\varphi = 0.65$) regions is also visible as a change in curvature near the balanced point. By contrast, the serviceability curve (left) uses linear elastic stress-strain laws without reduction factors, resulting in a smooth, symmetric shape typical of biaxial bending interaction.

Envelope mode

The same reduced load set is used. The envelope computes two curves at the minimum and maximum values of the fixed component: N for the M_z – M_y contour (serviceability) and M_y for the N – M_z contour (ultimate, Whitney). The same three-color classification applies.

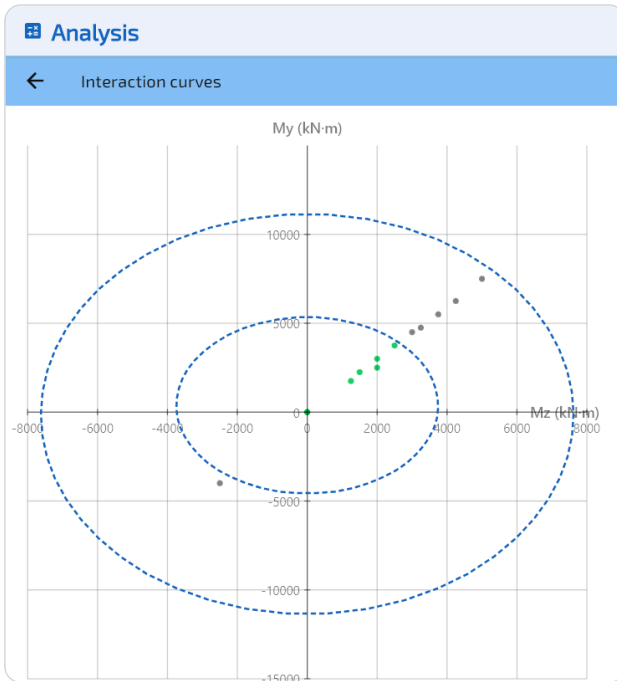


Figure 9: Serviceability: envelope on N .

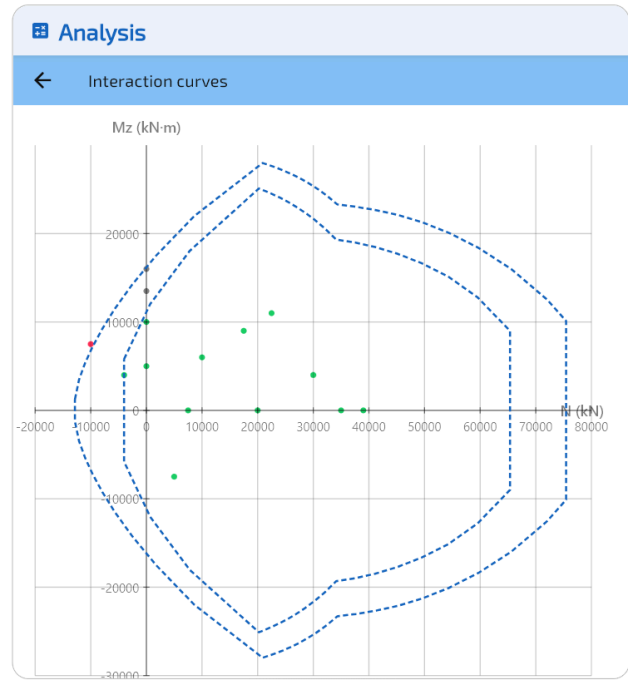


Figure 10: Ultimate: envelope on M_y (Whitney).

Performance benchmark

The interaction curve computation depends on the mesh resolution selected by the user. Higher resolutions produce smoother curves at the cost of longer computation times. The table below shows the total computation time (median of 3 runs) for both sections.

Mesh resolution	Octagonal EC2 (ms)	Elliptical ACI (ms)
51×50	8.5	6.5
101×100	11.0	7.0
201×200	14.5	9.0

All computations remain under 15 ms even at the highest resolution, making the interaction curves essentially instantaneous for the engineer.

Conclusion

The 2D interaction curves provide the classical engineering diagrams that complement the 3D surface:

- Loads scattered on the curve show immediately which are safe (green) and which exceed capacity (red), without computing numerical safety factors.
- The Internal/External classification from the 3D distance evaluation is fully consistent with the 2D curve position.
- The 2D curves for ACI 318 are computed with the Whitney block and ϕ -factors natively.
- The envelope mode validates multiple load cases with different fixed-component values in a single figure, using three-color classification (green/grey/red).
- Curves are generated in milliseconds, even at high mesh resolutions.

The interaction curve module does not currently compute a numerical safety factor (η) for each load; this is provided by the distances module (Article #5). A future version may combine both: the visual 2D curve with per-load η values annotated directly on the plot.

Export

SectionPro exports the interaction curves in PDF, TXT and XLS formats. The PDF report includes the 2D curve with scattered load points and an accompanying results table.

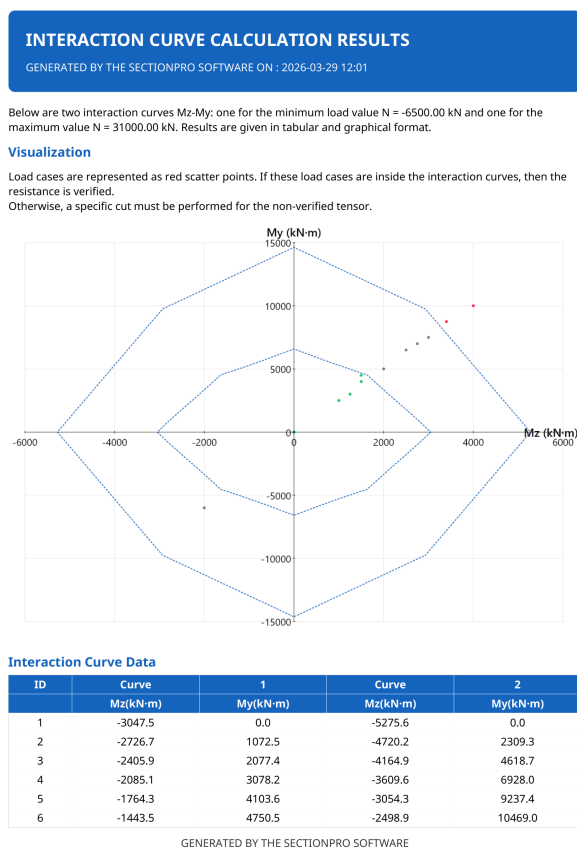


Figure 11: PDF export, page 1: interaction curve with loads.

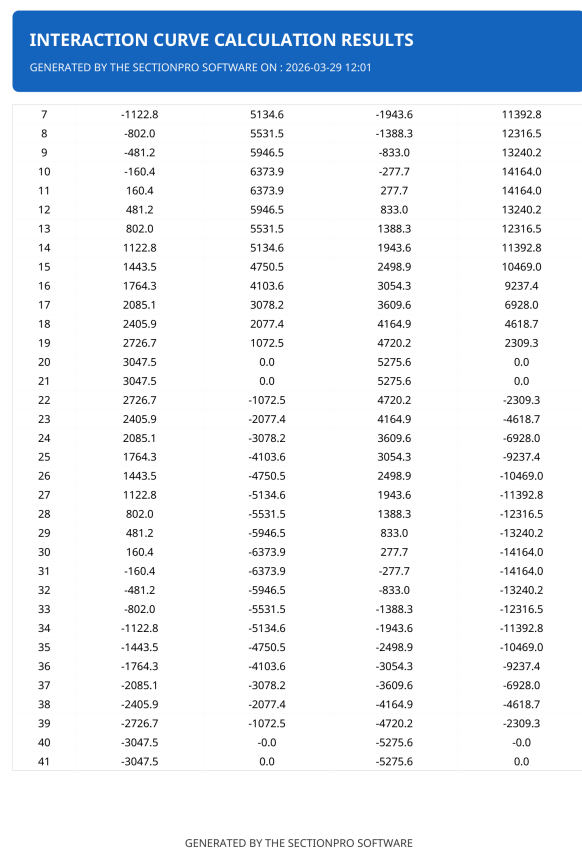


Figure 12: PDF export, page 2: curve coordinates.