

RSPile

Interaction Diagrams

Verification Examples Manual

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1. Verification Example 1

A rectangular section as shown in Fig. 1-1, with concrete cylinder strength $f_c' = 4.0$ ksi, and steel rebar yield strength $f_y = 60.0$ ksi. This example was solved by Rodriguez and Aristizabel-Orcha (1999). The section is originally an example given in Wang and Salmon (1973). The section dimensions are 18" by 12" as shown in Fig.1-1. Note that there is a typo in the article mentioned above where the 18 inches were typed as 16 inches.

The solution from RSPile was compared with the results of Rodriguez and Aristizabel-Orcha for an angle of 21.75° and with the results of the spColumn software for 0° , 45° and 90° angles and with solved points in the textbook of Wang and Salmon.

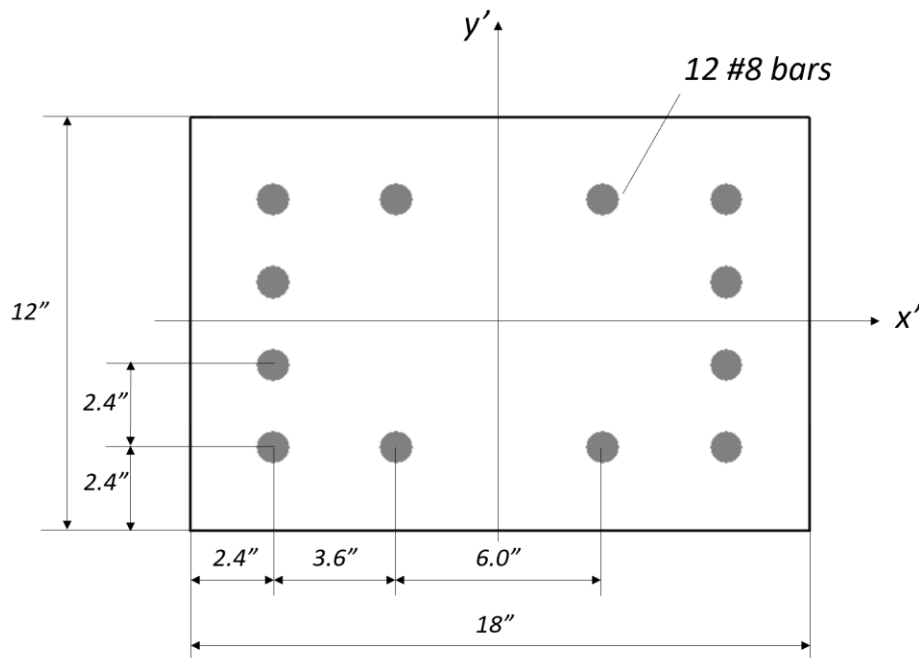


Fig.1-1, Section of Example 1, Wang and Salmon, 1973.

1.1. Comparison with Rodriguez and Aristizabel-Orcha results

Fig. 1-2 shows the comparison between RSPile results and the example in the article. The Example is solved for a point of application of the load on a line making an angle from x' , $\alpha = 21.75$ degrees (note that the example in the paper adopts reversed axis notations so the angle there is 68.25°).

The original solution was based on a forced strain $\epsilon_o = 0.002$ while RSPile calculates that automatically. Also, there is a little difference in modulus of elasticity of concrete, but it is negligible. RSPile uses ACI 318 definition for E_c . The tension in the concrete is considered in RSPile but it seems that for this example that did not have any significant effect as the section is heavily reinforced. The results are quite acceptable. Both calculations use modified Hognestad (1955) stress strain function for concrete. The mentioned article did not show points of solution, so the graph is picked and reproduced manually.

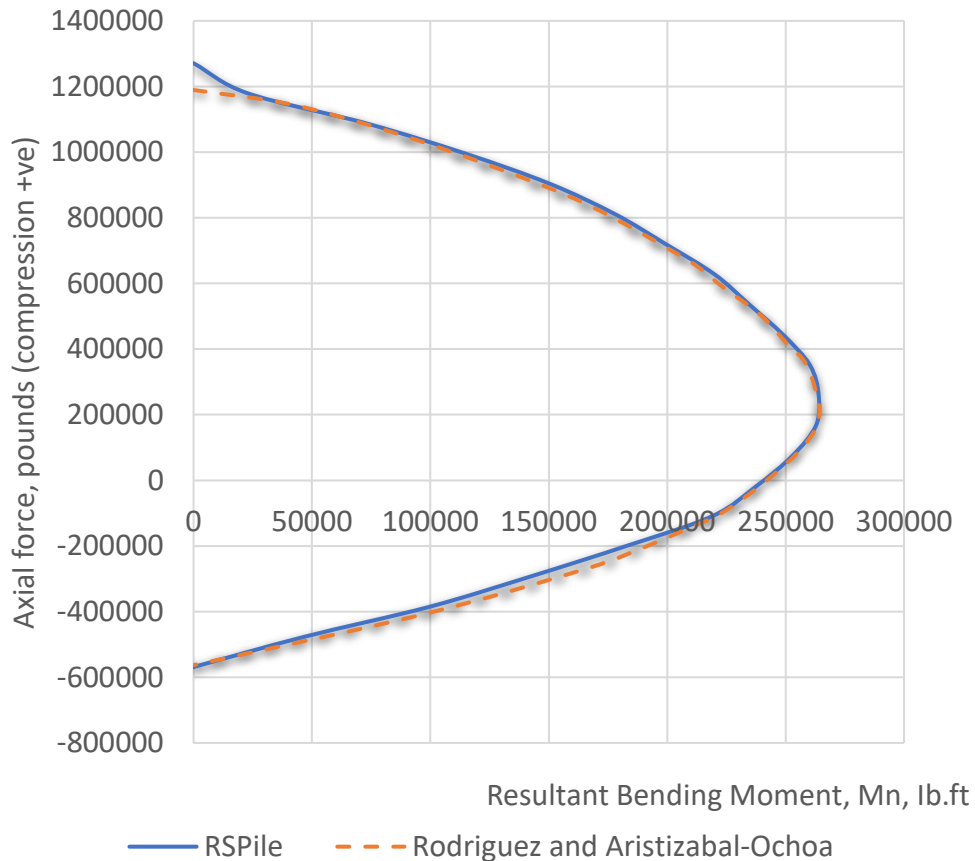


Fig. 1-2, Results of Example 1, angle of load application 21.75°. Comparison with results of Rodriguez and Aristizabal-Orcha (1999).

1.2. Comparison with SpColumn results

It is important to note that spColumn uses Whitney Block and ACI 318 provisions and assumes the angle of neutral axis constant during the search for neutral axis depth. The results of RSPile were very close to spColumn and more rigorous. Three angles are used for comparison, $\alpha=0^\circ$, 45° and 90° corresponding to moment around y axis (strongest axis), moment around a line 45° (section is symmetric around an axis making 45 degrees with the y axis) and moment around x axis. The results of the comparison are shown in Fig. 1-3 through 1-5. The original Wang and Salmon textbook example results are also shown as gray dots while the maximum moment is shown as a dashed gray line. The dots in moment axis or load axis are identical to the program results while the ones near the maximum moments are not. This is because the method adopted in the book was using graphs of the approximate beta method.

Also, the factored ACI 318 graph from RSPile results is presented in Fig. 1-3 for convenience.

The last graph for this example, Fig. 1-6, presents the comparison of the M_{nx}' , M_{ny}' plots for the section at a load of 500kips. The match with spColumn is very good.

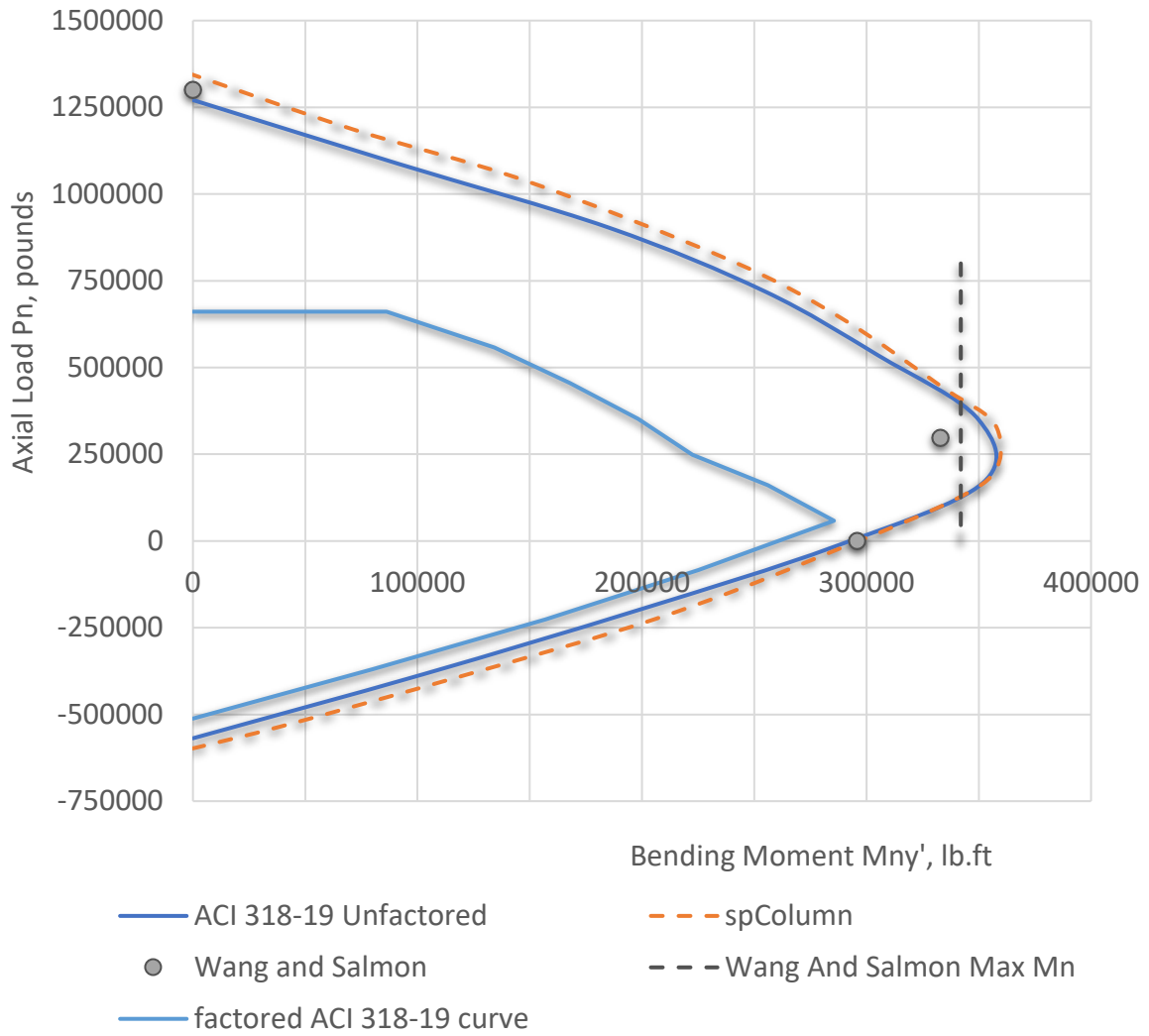


Fig.1-3, Comparison between RSPile and spColumn for Example 1 for moment about y' axis.

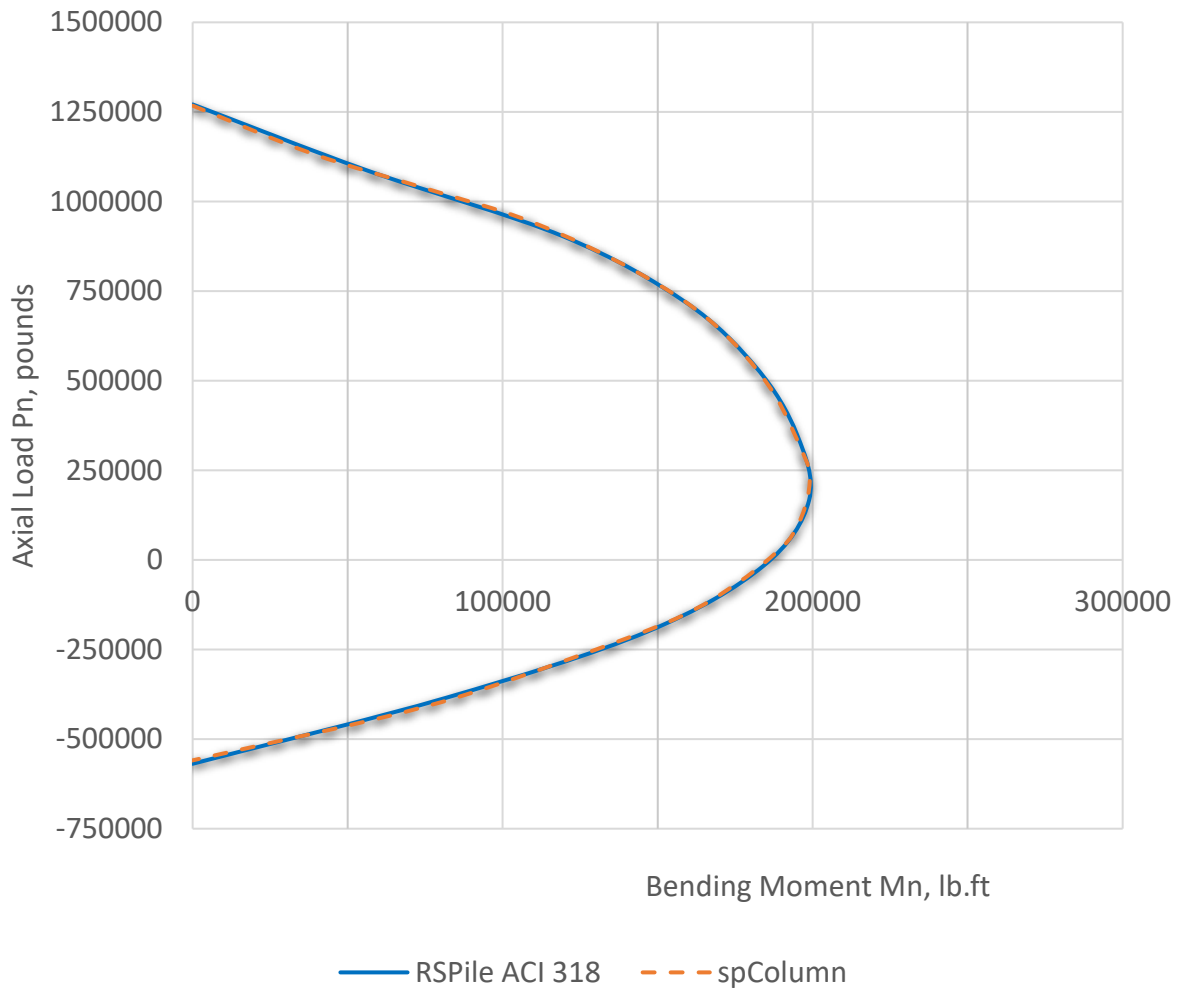


Fig.1-4, Comparison between RSPile and spColumn for Example 1 for moment about a line 45° CW from y' axis.

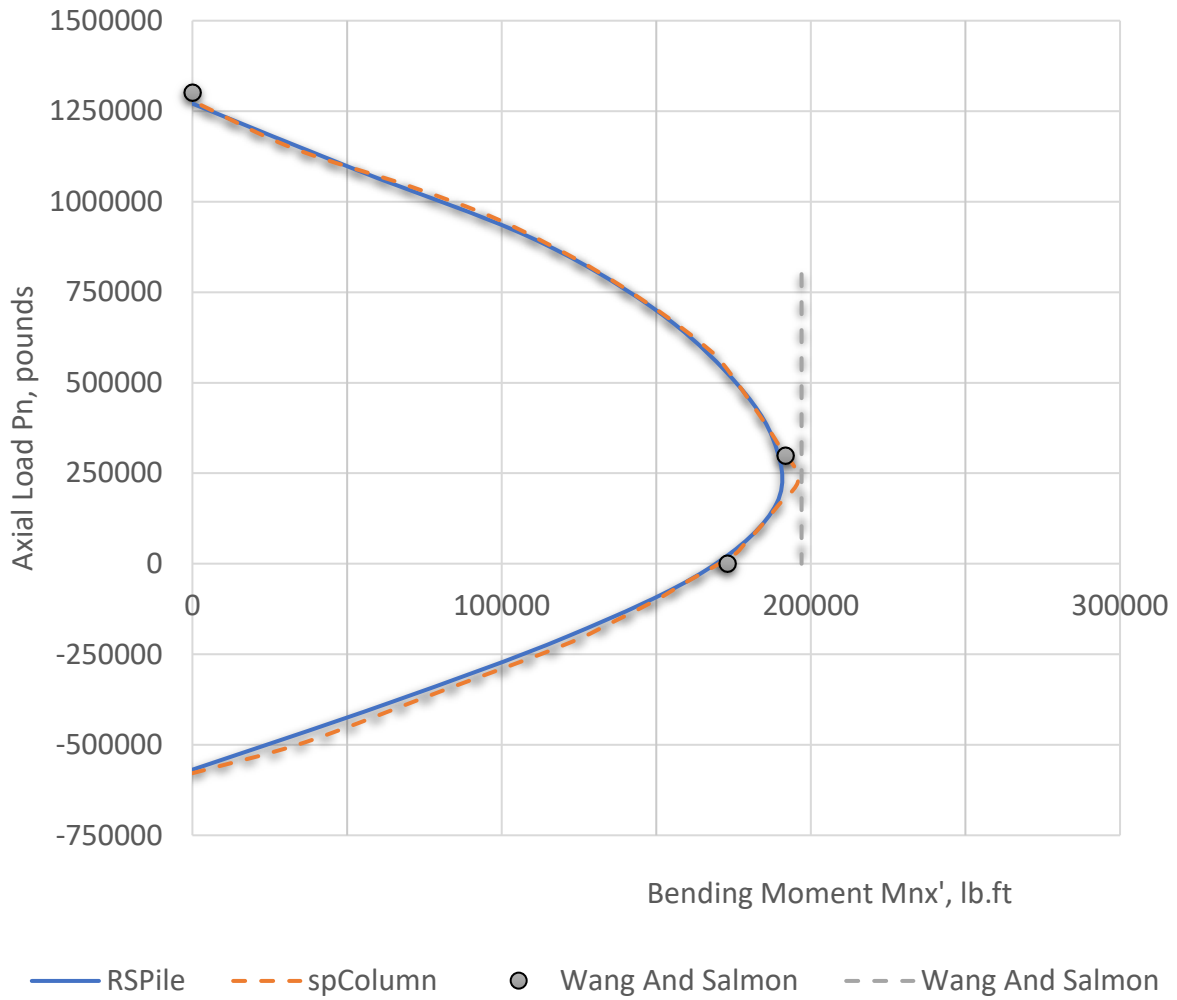


Fig.1-5, Comparison between RSPile and spColumn for Example 1 for moment about x' axis.

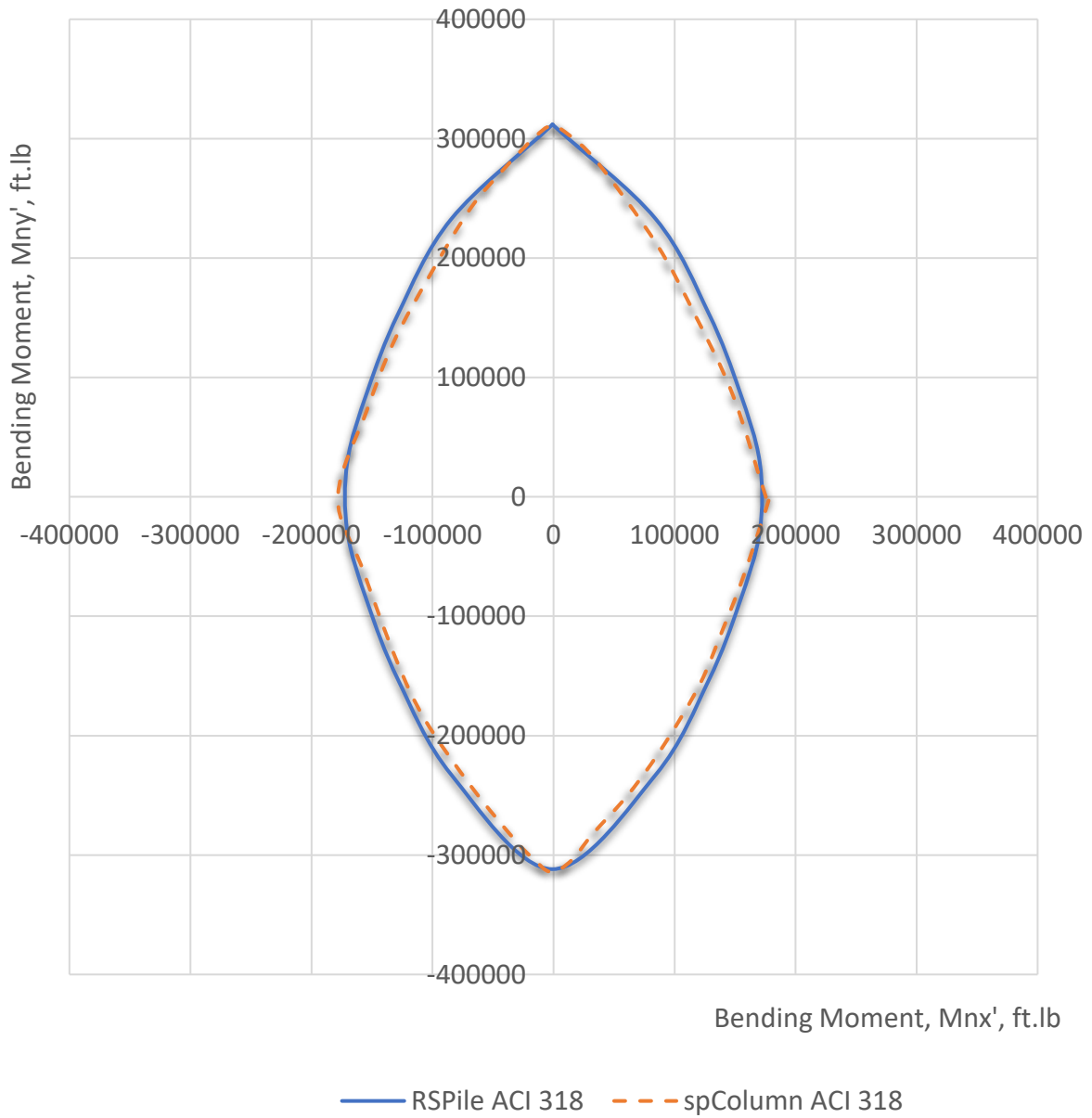


Fig. 1-6, Comparison of Mnx, Mny plots between spColumn and RSPile for Example 1.

2. Verification Example 2

A circular section of reinforced concrete with peripherally distributed rebars was solved for interaction diagram with Section Builder Software. The section is as shown in Fig. 2-1. The concrete strength $f_c' = 34$ MPa, reinforcement yield strength $f_y = 420$ MPa, yield strength of casing steel is 250 MPa. The modulus for steel is 200 GPa. The load at which the $M_{nx}' - M_{ny}'$ diagram was obtained was 10100 kN and the $P_n - M_n$ diagram of course is almost the same at any angle due to section symmetry.

The results are shown in Fig. 2-2 and Fig. 2-3. The other software applies a cap to the P_n values while RSPile does not apply a cap at this time. Future releases may include code factors and limits.

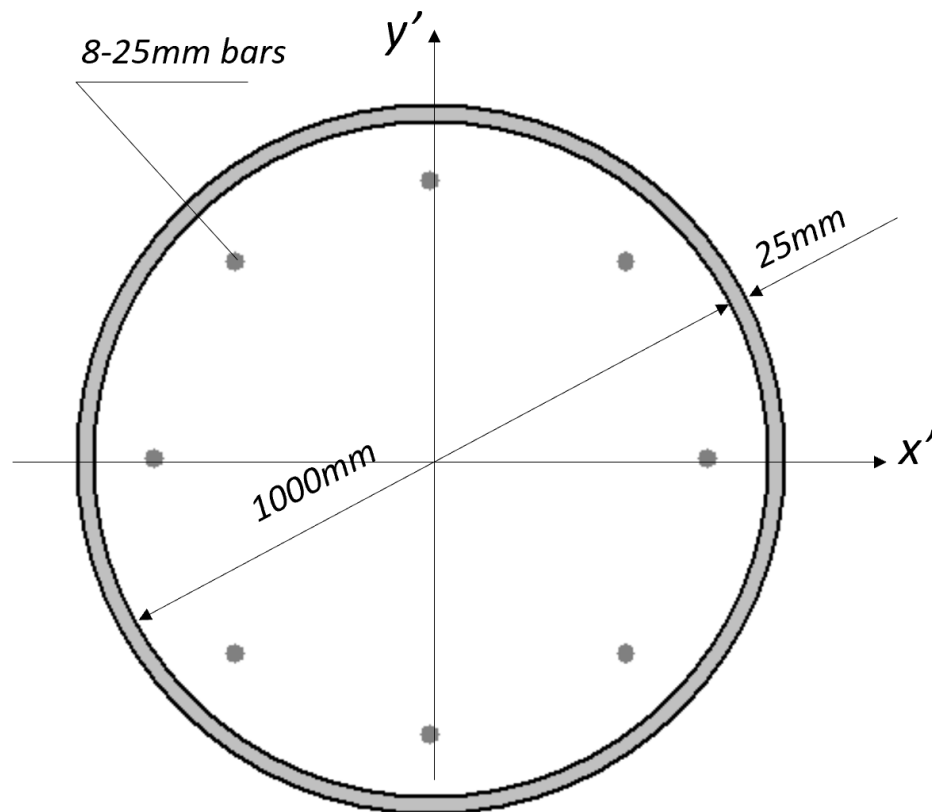


Fig. 2-1, Circular section with steel casing, Example 2.

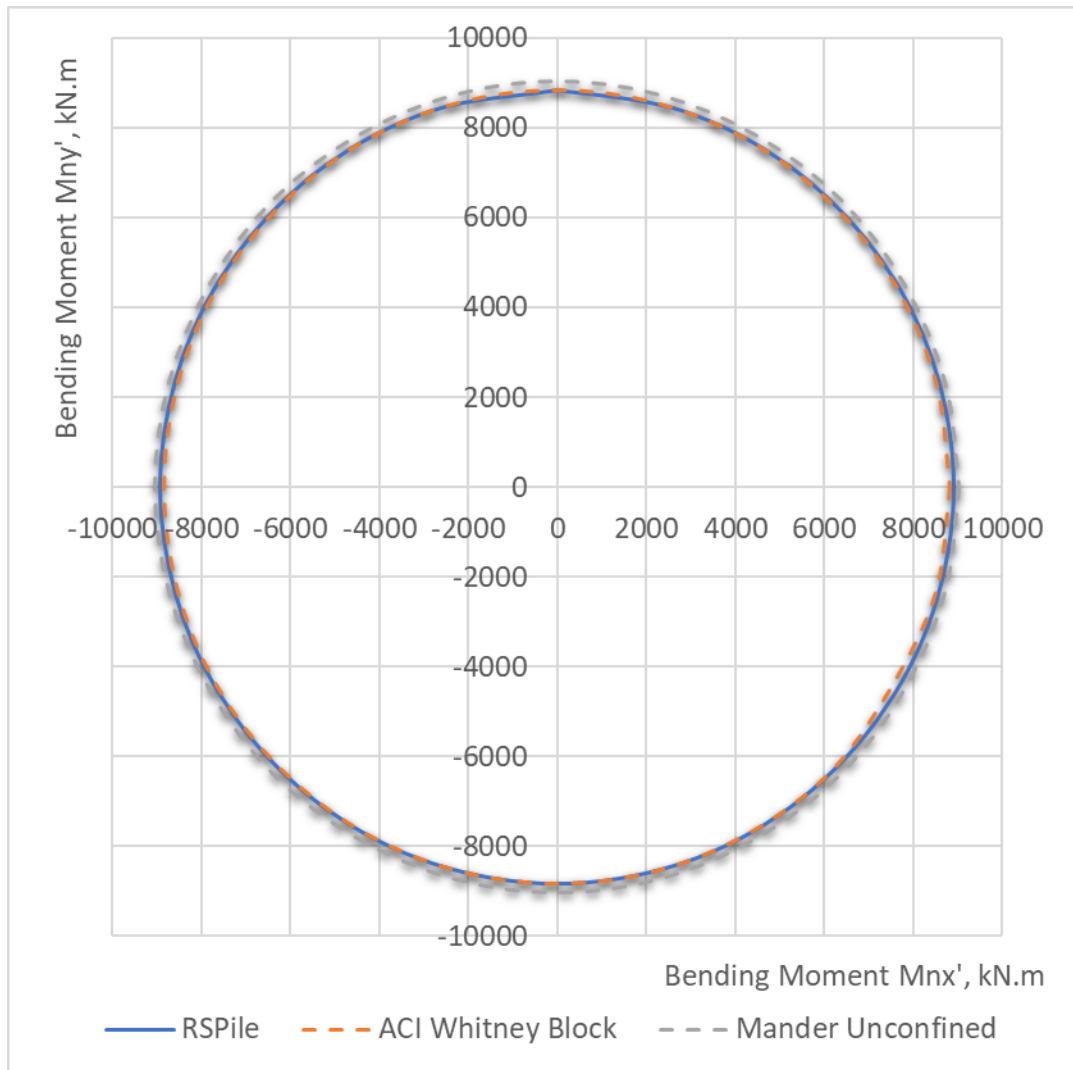


Fig. 2-2, Interaction diagram $M_{nx'}$ - $M_{ny'}$ at load $P_n=10100\text{kN}$ for Example 2.

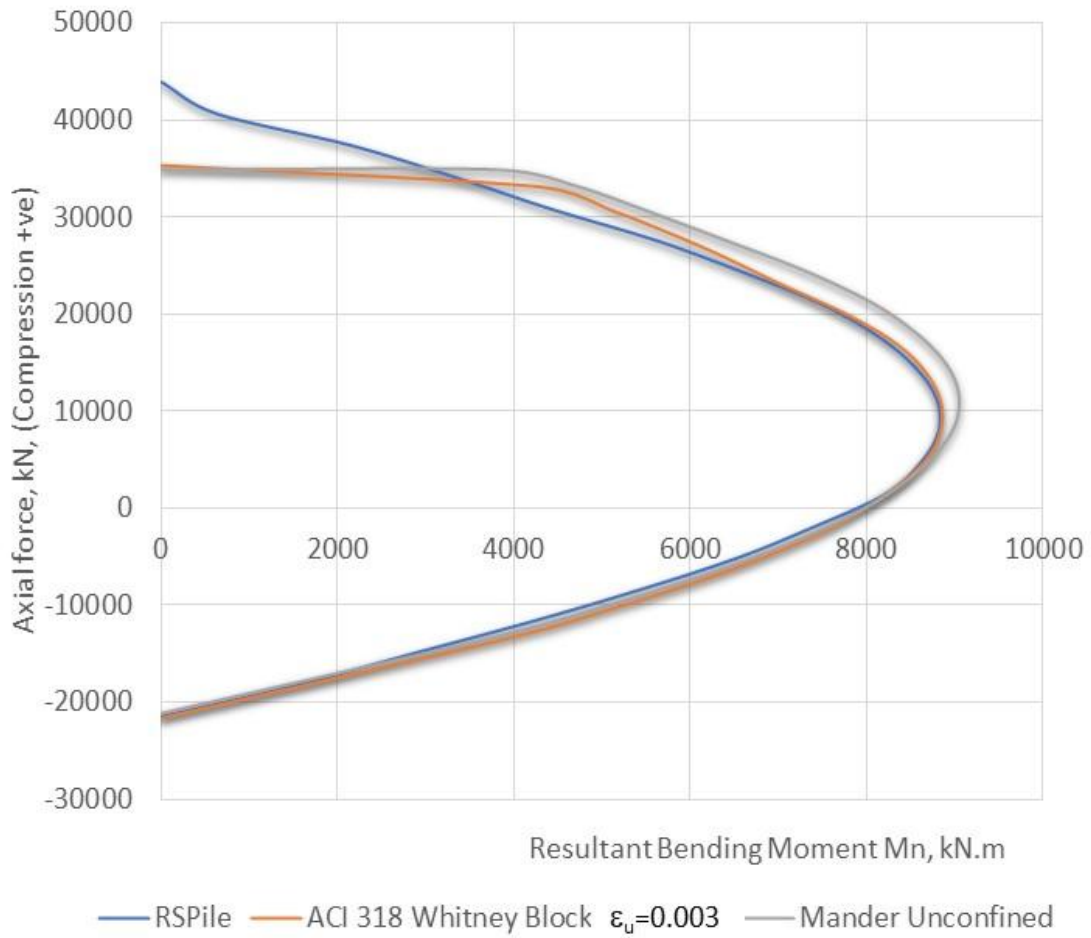


Fig. 2-3, Interaction diagram for direction of load application at any angle.

3. Verification Example 3

The same section of Example 2 is solved again with adding I-beam, HP 16x88, into the section instead of the casing which is removed (see Fig. 3-1). The yield strength for the I beam is 250 MPa. The results of RSPile for a 45 degrees angle are compared with Section Builder software and the comparison is shown using Mander Unconfined stress strain distribution for the concrete. The results are very close to RSPile output. The cap on Section Builder curve was removed manually. A cut in interaction diagram for $M_n x'$ - $M_n y'$ at 13400 kN is shown in Fig. 3-3 for comparison. It should be noted that Mander distribution depends on an ultimate strain of 0.005 while RSPile Hognestad distribution ends with an ultimate strain of 0.0038. In the future releases these figures will be user defined.

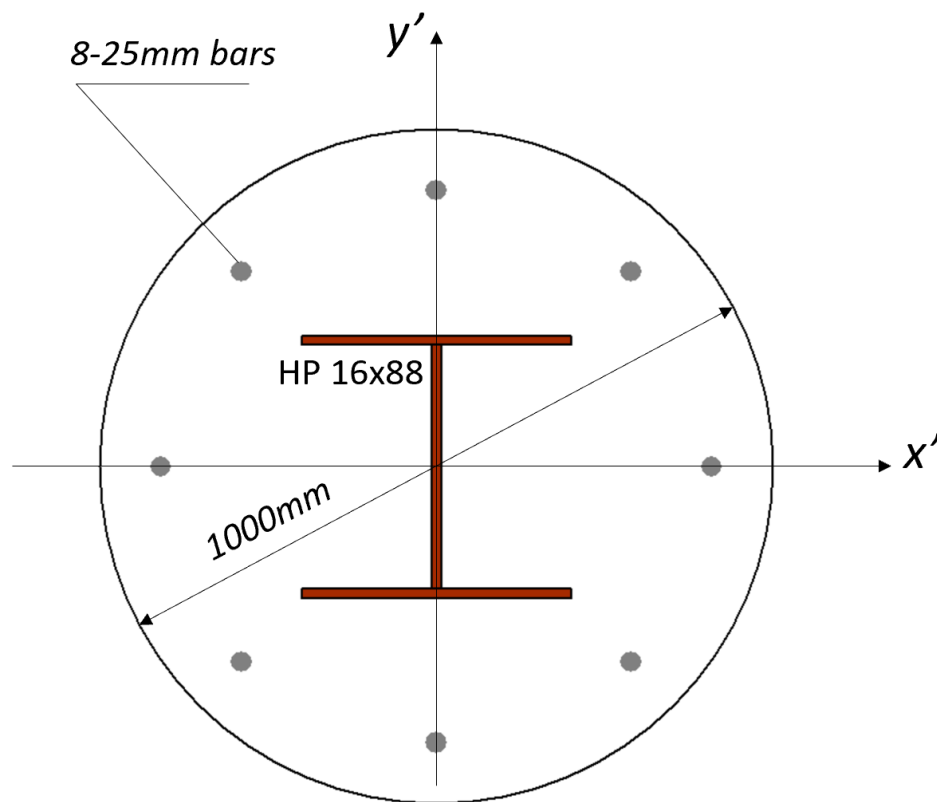


Fig. 3-1, Section of Example 3.

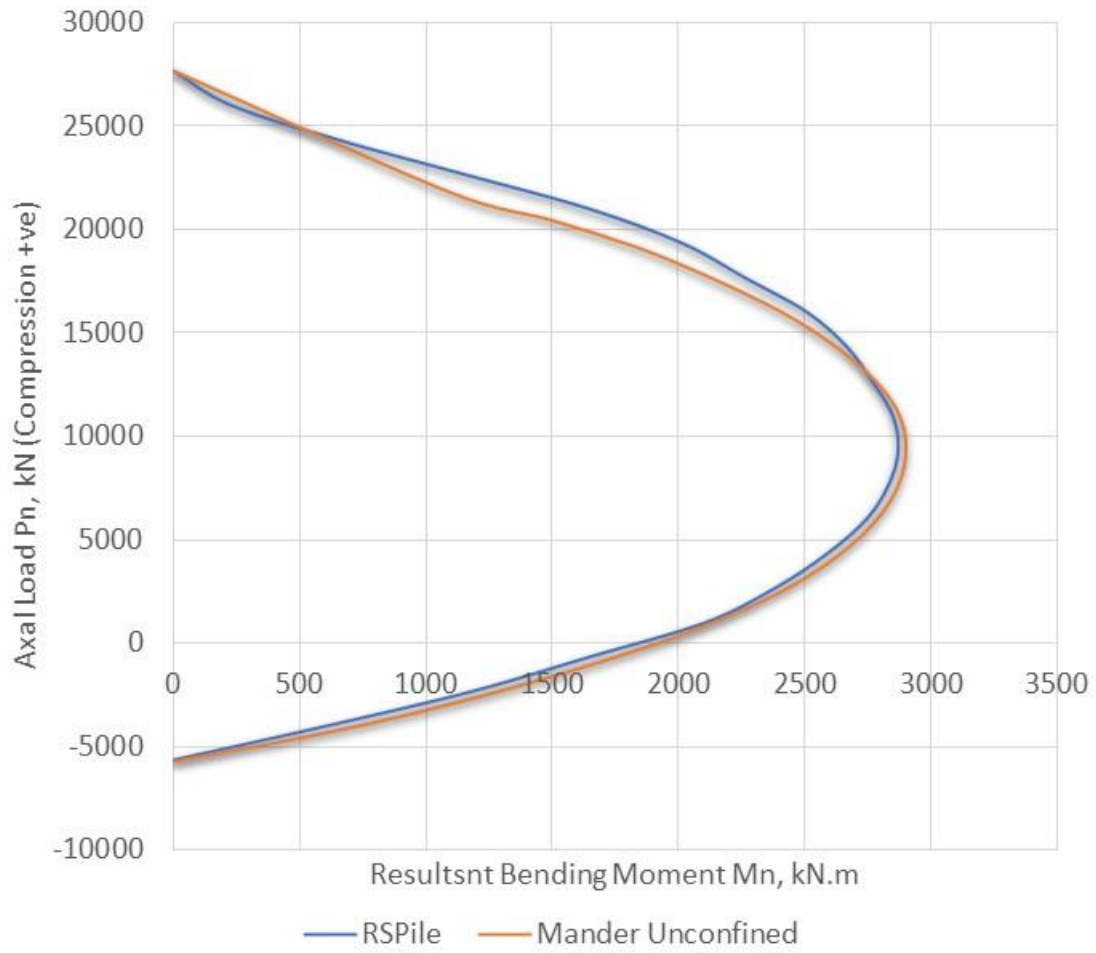


Fig. 3-2, Interaction diagram M_n - P_n at 45 degrees for Example 3.

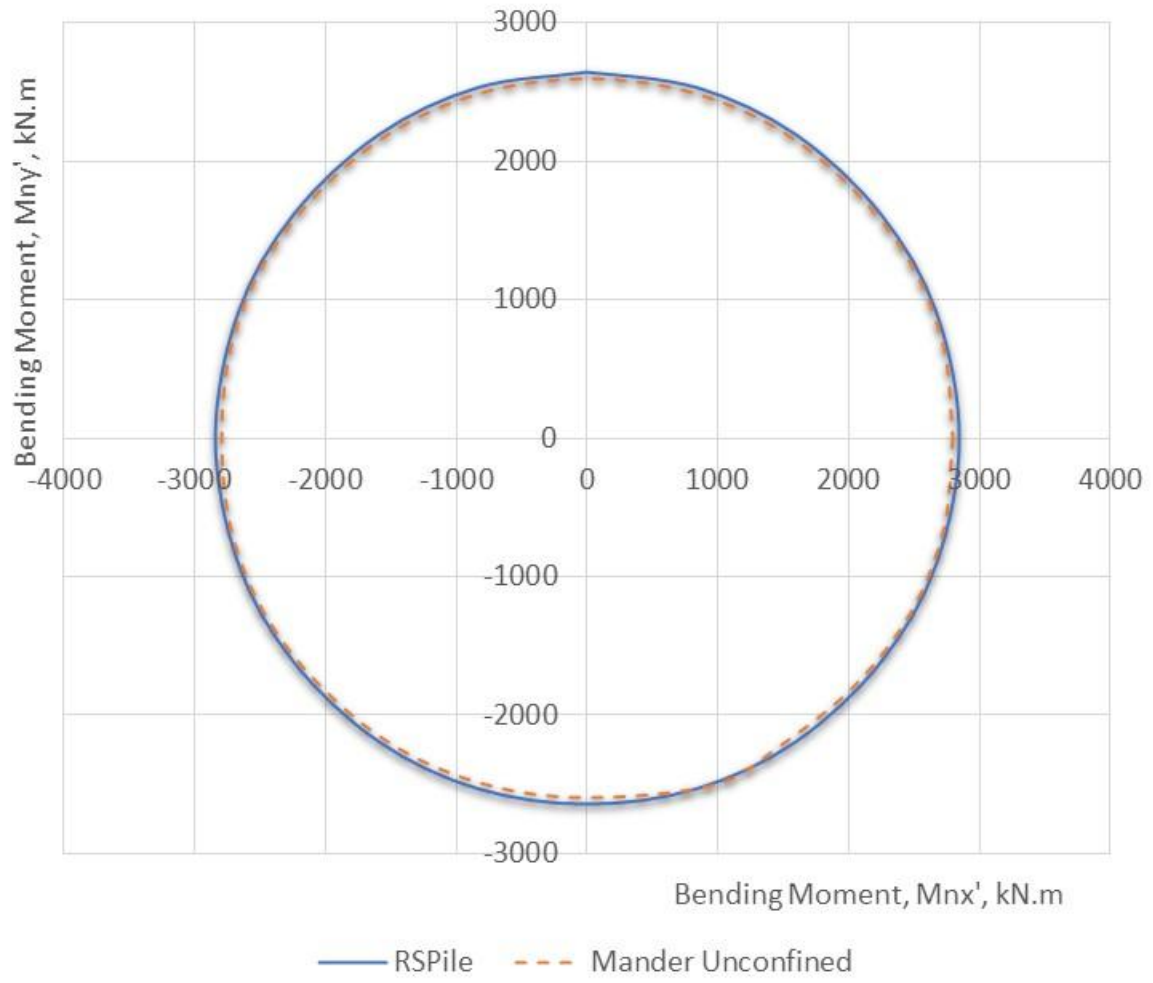


Fig. 3-3, Interaction diagram M_{nx}' - M_{ny}' at a load of 13400 kN, Example 3.

4. References

Rodriguez, J.A. and Aristizabal-Ochoa, J. D. (1999): *Biaxial Interaction Diagrams for Short RC Columns of Any Cross Section*. J. Struct. Eng., Vol.125. pp.672-683.

Hognestad, E. (1951): *A Study of Combined Bending and Axial Load in Reinforced Concrete Members*. University of Illinois Engineering Experiment Station, Bulletin Series No.399, Bulletin No.1, 28pp.

Wang, C. and Salmon, C. G. (1973): *Reinforced Concrete Design, 2nd ed.*, Intext Educational Publishers, New York.