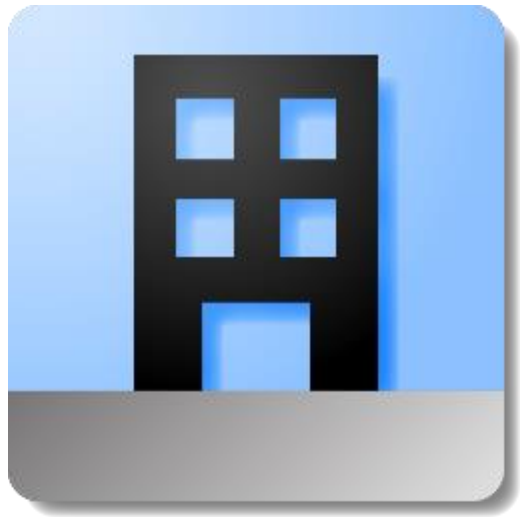
Fire Design of Columns
AS 3600 & EC2



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Overview

- AS 3600 – 2009 &2018 Incl. AMDT No. 1 & 2
  - Deemed to comply fire tables
    - Table 5.6.3, 5.6.4, 5.7.2
  - FRP equation introduced in 2018
    - Eqn. 5.6.3(2)
  - Practical considerations and limitations.
  - Fully implemented in RCB and RCC software
- Eurocode 2
  - 500°C Isotherm Method
  - Theory and example
  - Coming early 2023 to RCB and RCC

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Fire Design of Column to AS 3600

- 5.3 Design Performance Criteria
  - 5.3.1 General Performance Criteria
    - A) determined using tabulated data and figures
    - B) predicted by methods of calculation
      - Eurocode 2 Part 1.2
        - 500°C Isotherm Method – **coming to INDUCTA RCC and RCB in early 2023!**
        - Zone Method
- 5.6 Fire Resistance Periods (FRPs) For Columns
    - Table 5.6.3
      - Eqn. 5.6.3(2) as an alternative (2018)
    - Table 5.6.4
    - Table 5.7.2 – if aspect ratio > 4:1 – wall

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AS 3600 – Tabulated Fire Data

- AS 3600 – 2009 and AS 3600 2018: Tables 5.6.3, 5.6.4, 5.7.2
- Deemed to comply approach
- Derived from empirical tests
  - Limiting Criteria to use these clauses represents the scope of the tests.
- Key Limiting Criteria:
  - Braced Column
  - Effective length under fire: $l_{o.fi} < 3$ m – Table 5.6.3
  - Eccentricity under fire conditions (e)
    - $e \leq 0.15b$ – Table 5.6.3
    - $e/b < 0.25$ and $e \leq 100$ mm – Table 5.6.4
    - Slenderness under fire condition $\lambda_f \leq 30$ – Table 5.6.4
  - Aspect Ratio ≥ 4 – Table 5.7.2

Difficult to get fix-fix columns working using the tables due to eccentricity limits

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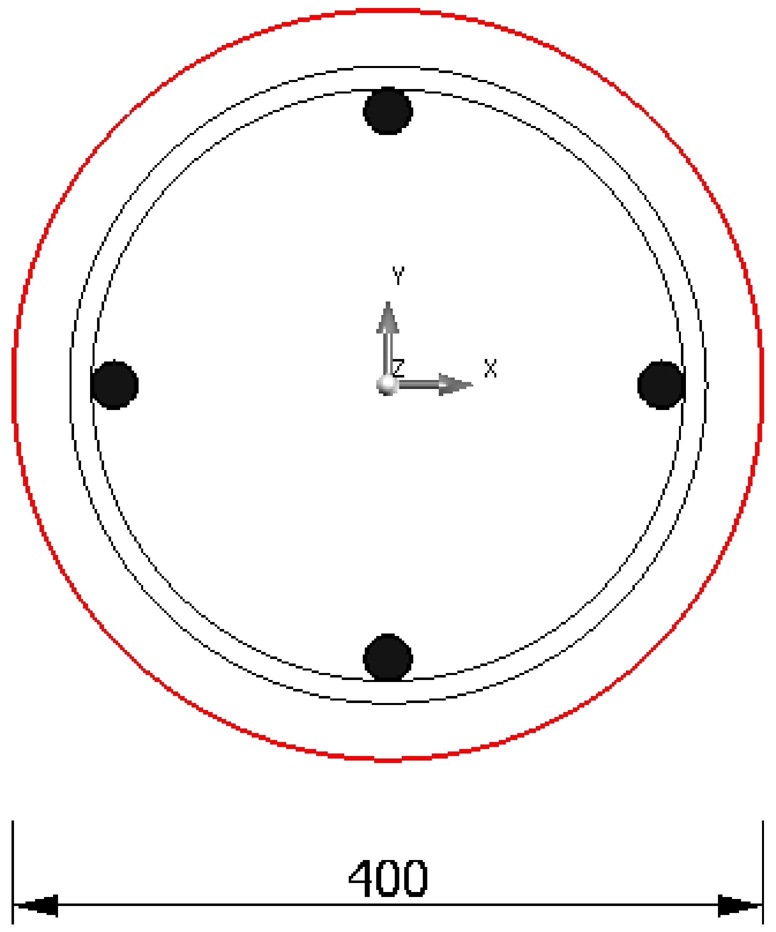
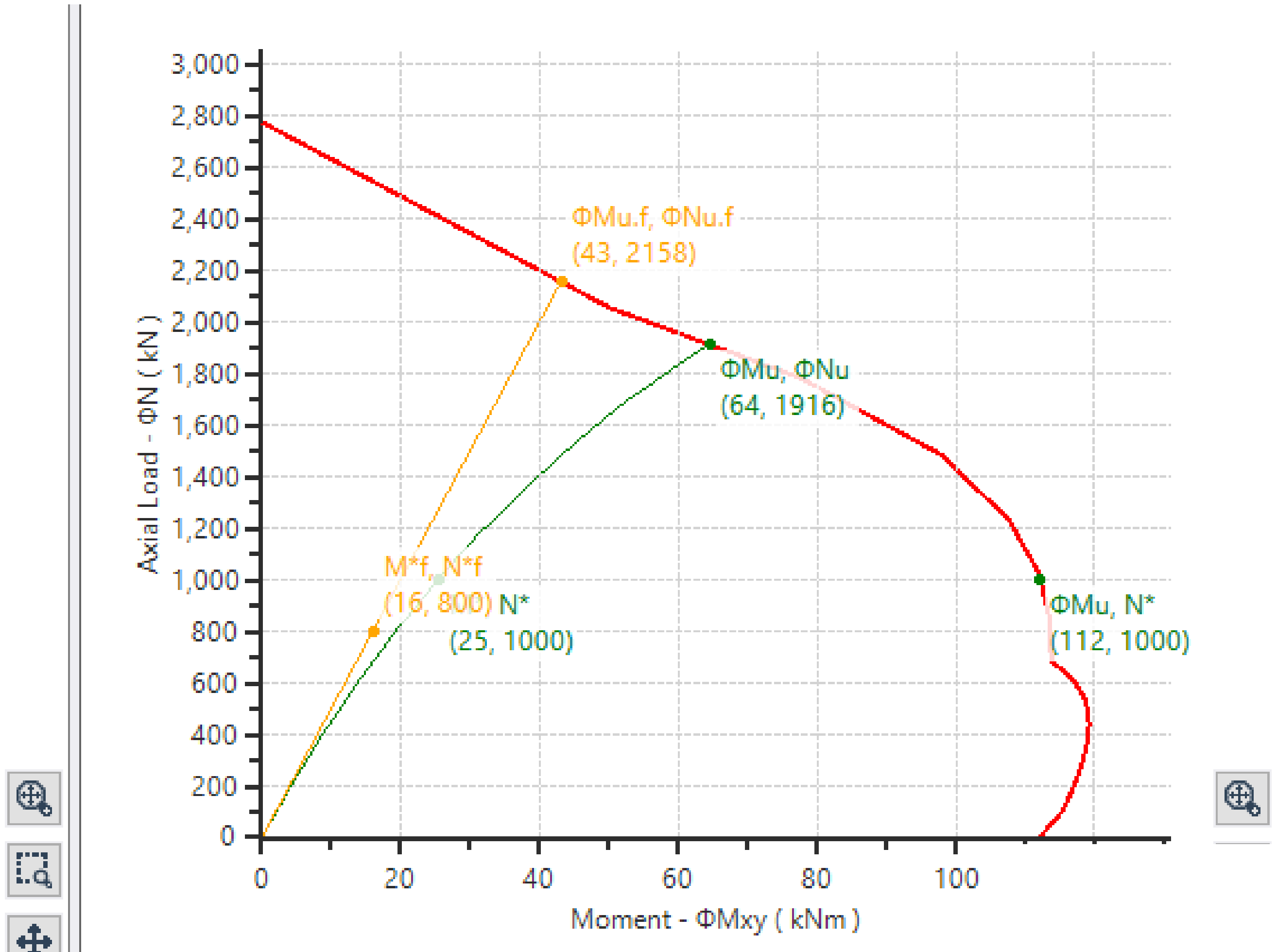
Table 5.6.3 - Example





- FRP = 90 min
- a_s = 54 mm
- L_u = 3 m
- $l_{o.fi}$ = 1.5 m < 3 m
- N^*_f = 800 kN
- $\phi N_{u.f}$ = 2,158 kN
- μ_{fi} = 0.37
- e = 20 mm < 0.15b

Required Min. Dimensions:

b_{min}: 257 mm $a_{s,min}$: 39 mm or

b_{min}: 357 mm $a_{s,min}$: 32 mm

b = 400 mm, a_s = 54 mm … **PASS**

TABLE 5.6.3

FIRE RESISTANCE PERIODS (FRPs) FOR STRUCTURAL ADEQUACY OF COLUMNS

FRP for structural adequacy	Minimum dimensions, mm					
	Combinations for column exposed on more than one side					
	μ_{fi} = 0.2		μ_{fi} = 0.5		μ_{fi} = 0.7	
min	a_s	b	a_s	b	a_s	b
90	31 25	200 300	45 38	300 400	53 40(1)	350 450(1)

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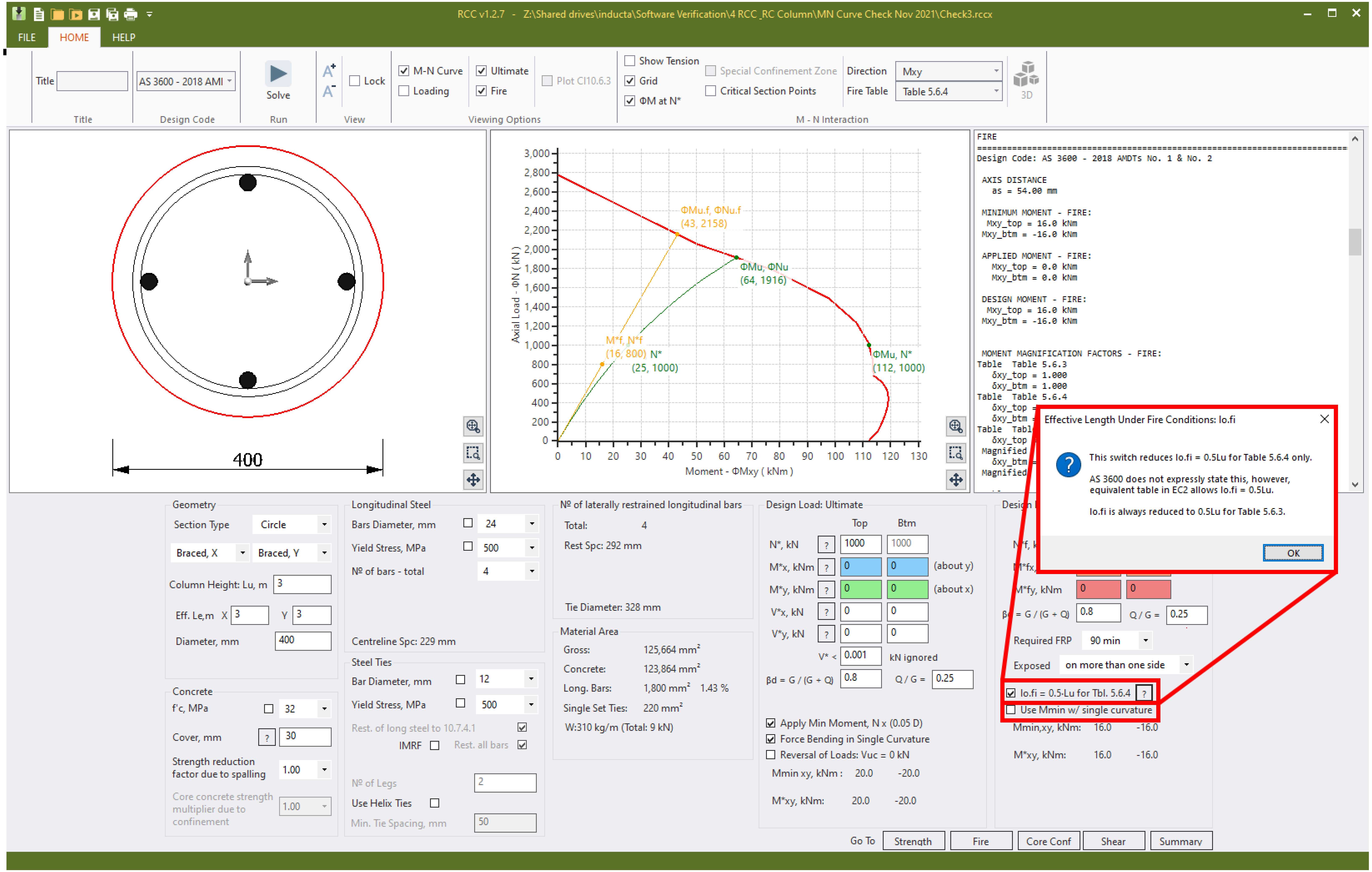
RCC v1.2.7 - Z:\Shared drives\inducta\Software Verification\4 RCC _RC Column\MN Curve Check Nov 2021\Check3.rccx
FILE
HOME
HELP
Title
AS 3600 - 2018 AMI
Solve
Lock
M-N Curve
Loading
Ultimate
Fire
Plot Cl10.6.3
Show Tension
Grid
ΦM at N*
Special Confinement Zone
Critical Section Points
Direction
Mxy
Fire Table
Table 5.6.4
3D
Title
Design Code
Run
View
Viewing Options
M - N Interaction
400
ΦMu.f, ΦNu.f
(43, 2158)
ΦMu, ΦNu
(64, 1916)
M*f, N*f
(16, 800)
N*
(25, 1000)
ΦMu, N*
(112, 1000)
Axial Load - ΦN (kN)
Moment - ΦMxy (kNm)
FIRE
Design Code: AS 3600 - 2018 AMDTS No. 1 & No. 2
AXIS DISTANCE
as = 54.00 mm
MINIMUM MOMENT - FIRE:
Mxy_top = 16.0 kNm
Mxy_btm = -16.0 kNm
APPLIED MOMENT - FIRE:
Mxy_top = 0.0 kNm
Mxy_btm = 0.0 kNm
DESIGN MOMENT - FIRE:
Mxy_top = 16.0 kNm
Mxy_btm = -16.0 kNm
MOMENT MAGNIFICATION FACTORS - FIRE:
Table Table 5.6.3
δxy_top = 1.000
δxy_btm = 1.000
Table Table 5.6.4
Effective Length Under Fire Conditions: lo.fi
This switch reduces lo.fi = 0.5Lu for Table 5.6.4 only.
AS 3600 does not expressly state this, however, equivalent table in EC2 allows lo.fi = 0.5Lu.
lo.fi is always reduced to 0.5Lu for Table 5.6.3.
OK
Geometry
Section Type
Circle
Braced, X
Braced, Y
Column Height: Lu, m
3
Eff. Le,m X
3
Y
3
Diameter, mm
400
Concrete
f'c, MPa
32
Cover, mm
30
Strength reduction factor due to spalling
1.00
Core concrete strength multiplier due to confinement
1.00
Longitudinal Steel
Bars Diameter, mm
24
Yield Stress, MPa
500
№ of bars - total
4
Centreline Spc: 229 mm
Steel Ties
Bar Diameter, mm
12
Yield Stress, MPa
500
Rest. of long steel to 10.7.4.1
IMRF
Rest. all bars
№ of Legs
2
Use Helix Ties
Min. Tie Spacing, mm
50
№ of laterally restrained longitudinal bars
Total: 4
Rest Spc: 292 mm
Tie Diameter: 328 mm
Material Area
Gross: 125,664 mm²
Concrete: 123,864 mm²
Long. Bars: 1,800 mm² 1.43 %
Single Set Ties: 220 mm²
W:310 kg/m (Total: 9 kN)
Design Load: Ultimate
Top
Btm
N*, kN
1000
1000
M*x, kNm
0
0
(about y)
M*y, kNm
0
0
(about x)
V*x, kN
0
0
V*y, kN
0
0
V* < 0.001 kN ignored
βd = G / (G + Q) 0.8
Q / G = 0.25
Apply Min Moment, N x (0.05 D)
Force Bending in Single Curvature
Reversal of Loads: Vuc = 0 kN
Mmin xy, kNm : 20.0 -20.0
M*xy, kNm: 20.0 -20.0
M*fy, kNm
0
0
βd = G / (G + Q) 0.8
Q / G = 0.25
Required FRP
90 min
Exposed
on more than one side
lo.fi = 0.5·Lu for Tbl. 5.6.4
Use Mmin w/ single curvature
Mmin,xy, kNm: 16.0 -16.0
M*xy, kNm: 16.0 -16.0
Go To
Strength
Fire
Core Conf
Shear
Summary

AS 3600 – Eqn. 5.6.3(2)

- Introduced to 2018 version of AS 3600
  - Has been amended twice since release.
- Provided as an alternative to the tabulated data
- No limits on eccentricity
- Limits on effective length (lo.fi) and dimensions.
- Provides more flexibility than tables
  - Can cap values to back limits (conservative)
    - $l_{o.fi}$ can be taken as 2 m when $_{lo.fi}$ < 2m
    - b′ taken as 450 mm when b′ > 450 mm

The FRP for structural adequacy for columns outside the limits defined for Table 5.6.3 and within the limits defined in the variables below may be assessed using Equation 5.6.3(2):

$$FRP = 120\left(\left(R_{\eta.fi} + R_a + R_l + R_b + R_n\right)/120\right)^{1.8} \quad \ldots 5.6.3(2)$$

where

$R_{\eta.fi}$ = $83(1.0 - \mu_{fi}\,(1 + \omega)/(.945 + \omega))$

R_a = $1.60\,(a_s - 30)$

R_l = $9.60\,(5 - lo_{.fi})$

R_b = $0.09\,b'$

R_n = 0 for 4 (corner bars only)

= 12 for greater than 4 bars

a_s = the axis distance to the longitudinal steel bars (mm); $25\text{ mm} \le a_s \le 80\text{ mm}$

$l_{o.fi}$ = the effective length of the column under fire conditions; 2 metres $\le l_{o.fi} \le$ 6 metres

When $l_{o.fi} < 2$ m, it is conservative to take $l_{o.fi} = 2$ m in Equation 5.6.3(2)

b' = $2A_g / (y + x)$ for rectangular cross-sections

= the diameter of circular cross-sections within the limits

$200\text{ mm} \le b' \le 450\text{ mm}$ and $y \le 1.5x$

ω = $1.3\,A_s f_{sy} / A_g f'_c$ denotes the mechanical reinforcement ratio at normal temperature conditions

- INDUCTA would treat these as "hard" limits and stop calculations if they were violated.
- $l_{o.fi}$ limit was clarified with AMDT No. 2
- b' geometry limit capped in a recent update to RCC and RCB

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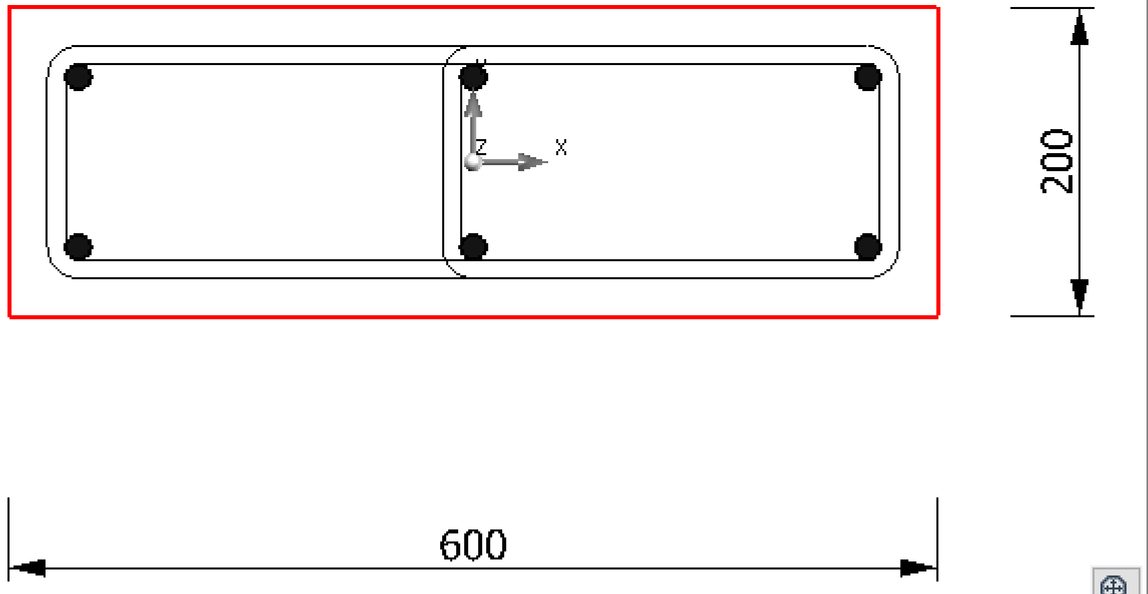
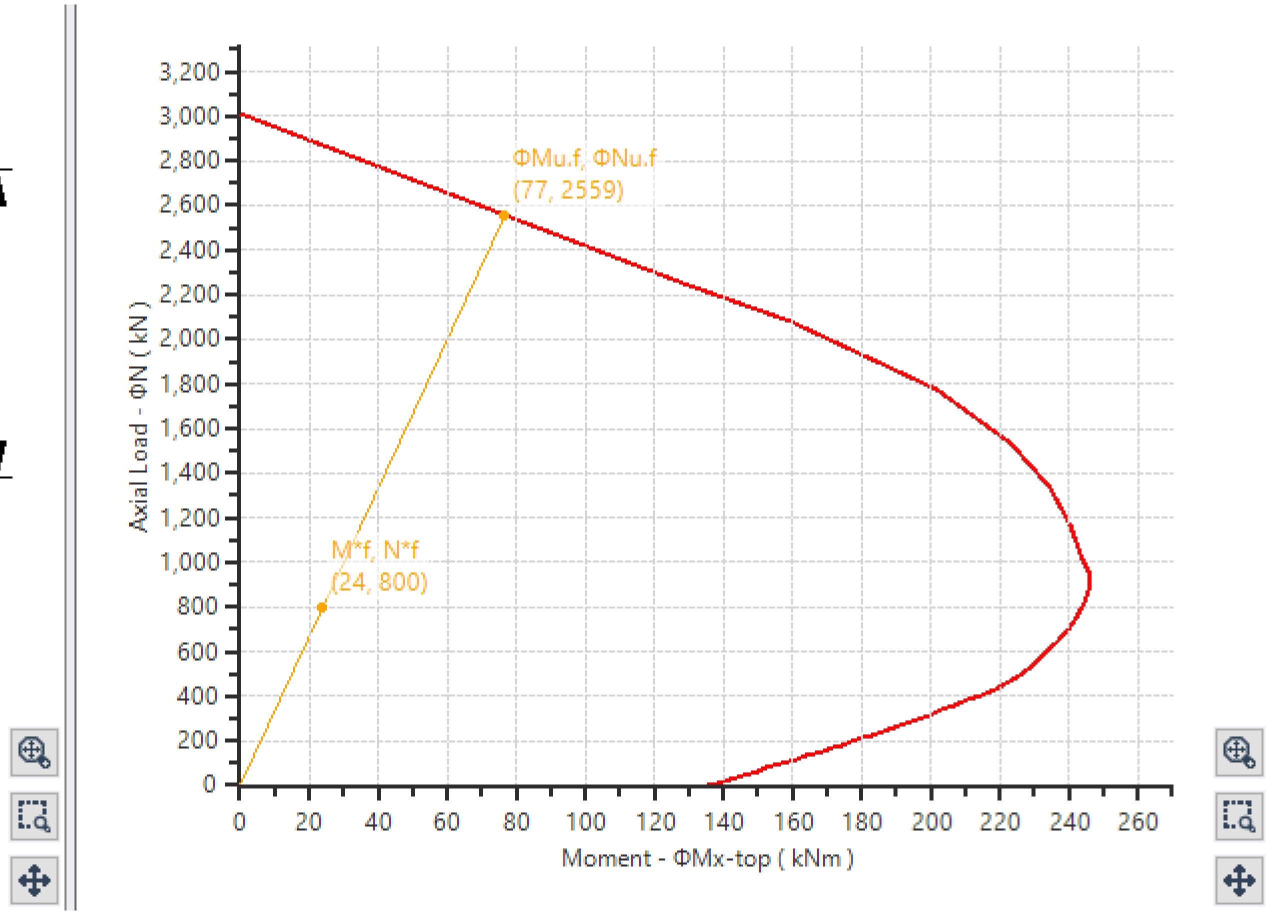




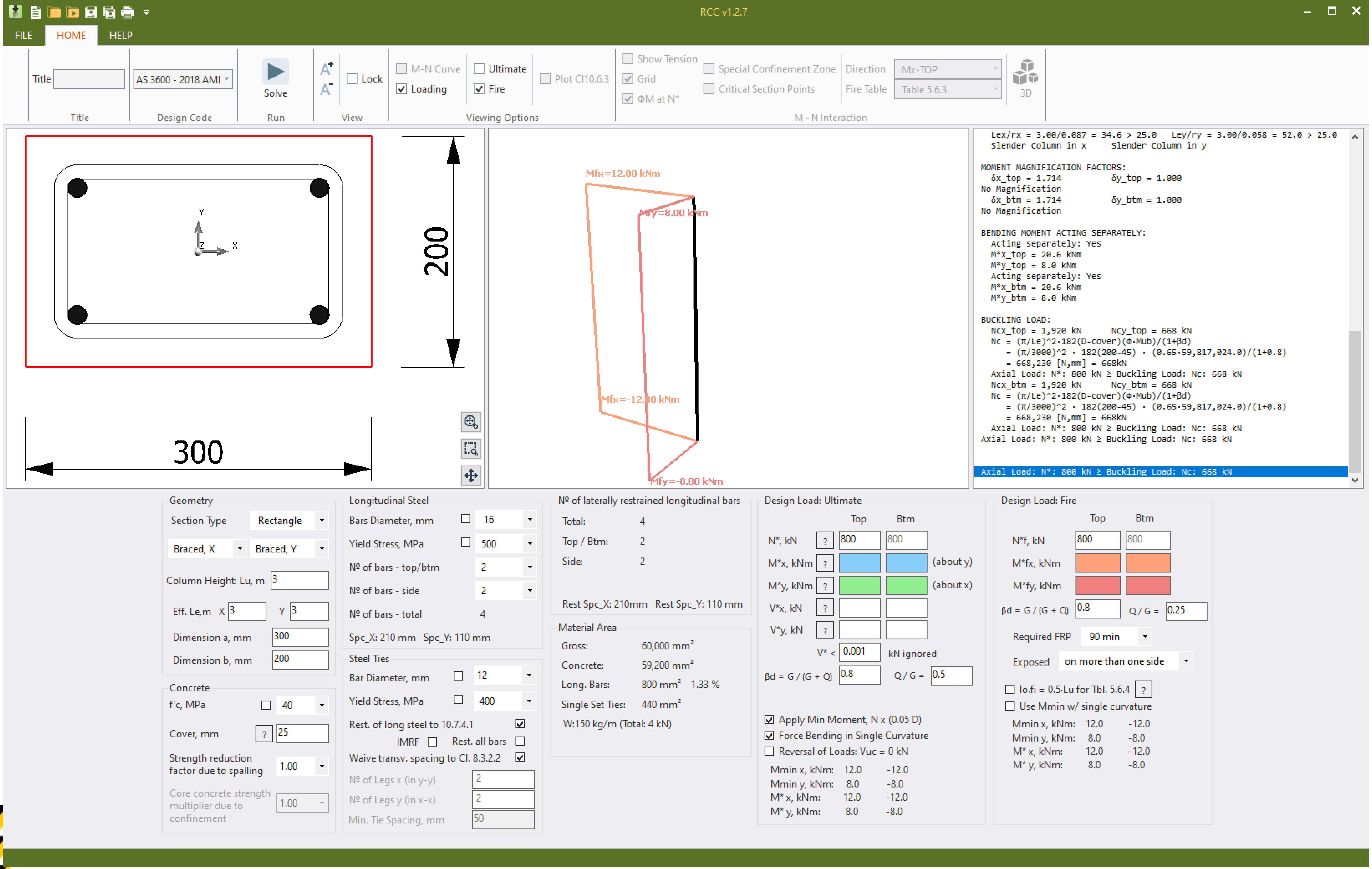
N^*f = 800 kN
M^*fx unmagnified = -24 kNm
Effective length under fire (lo.fi_x): 2000 mm
Reinf. ratio: 0.01
Min. Dimension (b): 200 mm
Axis distance (as): 45 mm

ΦN_{ux} = 2,559 kN
$\mu_{fi} = N^*_f / \Phi N_u = 0.31$
A_{gross}: 120,000 mm²
$\omega = 1.3 A_s f_{sy} / A_g f'_c = 0.162$
b' = 240 mm
x = 200 mm
y = 300 mm - capped to y = 1.5x

$R_{\eta.fi}$ = 55.76
R_a = 24.00
R_1 = 28.80
R_b = 21.60
R_n = 12

FRP = 163 min ...Eqn 5.6.3(2)

- Tests have shown blade columns have larger FRP than columns of same thickness but less width.
- If y > 1.5 x then y should be limited to:
  - y = 1.5x ...then
  - b′ = 2x . 1.5x / (x + 1.5 x) = 1.2 x
- Similar for a circular columns
  - 500 mm column would fail b′ but 450 mm passes?
  - Makes sense to cap back to lower value (conservative)



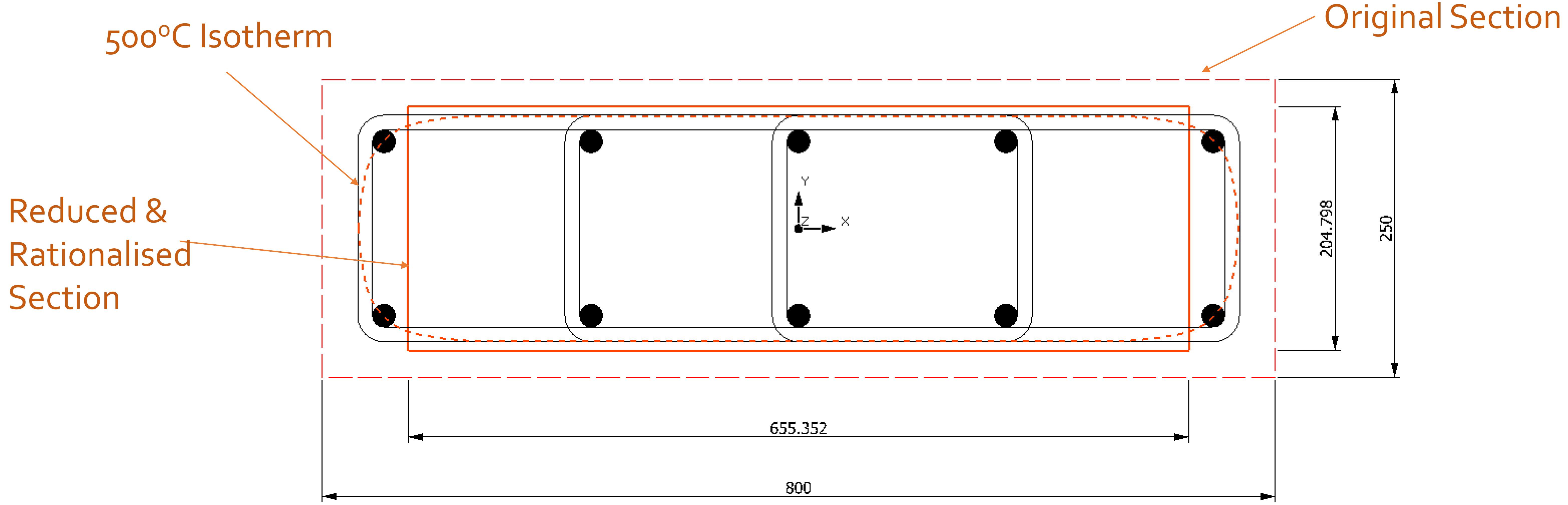
RCC v1.2.7
FILE HOME HELP
Title
AS 3600 - 2018 AMI
Solve
Lock
M-N Curve
Loading
Ultimate
Fire
Plot Cl10.6.3
Show Tension
Grid
ΦM at N*
Special Confinement Zone
Critical Section Points
Direction Mx-TOP
Fire Table Table 5.6.3
3D
Title Design Code Run View Viewing Options M - N Interaction
200
300
Y
X
Z
Mfx=12.00 kNm
Mfy=8.00 kNm
Mfx=-12.00 kNm
Mfy=-8.00 kNm
Lex/rx = 3.00/0.087 = 34.6 > 25.0 Ley/ry = 3.00/0.058 = 52.0 > 25.0
Slender Column in x Slender Column in y
MOMENT MAGNIFICATION FACTORS:
δx_top = 1.714 δy_top = 1.000
No Magnification
δx_btm = 1.714 δy_btm = 1.000
No Magnification
BENDING MOMENT ACTING SEPARATELY:
Acting separately: Yes
M*x_top = 20.6 kNm
M*y_top = 8.0 kNm
Acting separately: Yes
M*x_btm = 20.6 kNm
M*y_btm = 8.0 kNm
BUCKLING LOAD:
Ncx_top = 1,920 kN Ncy_top = 668 kN
Nc = (π/Le)^2·182(D-cover)(Φ·Mub)/(1+βd)
= (π/3000)^2 · 182(200-45) · (0.65·59,817,024.0)/(1+0.8)
= 668,230 [N,mm] = 668kN
Axial Load: N*: 800 kN ≥ Buckling Load: Nc: 668 kN
Ncx_btm = 1,920 kN Ncy_btm = 668 kN
Nc = (π/Le)^2·182(D-cover)(Φ·Mub)/(1+βd)
= (π/3000)^2 · 182(200-45) · (0.65·59,817,024.0)/(1+0.8)
= 668,230 [N,mm] = 668kN
Axial Load: N*: 800 kN ≥ Buckling Load: Nc: 668 kN
Axial Load: N*: 800 kN ≥ Buckling Load: Nc: 668 kN
Axial Load: N*: 800 kN ≥ Buckling Load: Nc: 668 kN
Geometry
Section Type Rectangle
Braced, X Braced, Y
Column Height: Lu, m 3
Eff. Le,m X 3 Y 3
Dimension a, mm 300
Dimension b, mm 200
Concrete
f'c, MPa 40
Cover, mm ? 25
Strength reduction factor due to spalling 1.00
Core concrete strength multiplier due to confinement 1.00
Longitudinal Steel
Bars Diameter, mm 16
Yield Stress, MPa 500
Nº of bars - top/btm 2
Nº of bars - side 2
Nº of bars - total 4
Spc_X: 210 mm Spc_Y: 110 mm
Steel Ties
Bar Diameter, mm 12
Yield Stress, MPa 400
Rest. of long steel to 10.7.4.1
IMRF Rest. all bars
Waive transv. spacing to Cl. 8.3.2.2
Nº of Legs x (in y-y) 2
Nº of Legs y (in x-x) 2
Min. Tie Spacing, mm 50
Nº of laterally restrained longitudinal bars
Total: 4
Top / Btm: 2
Side: 2
Rest Spc_X: 210mm Rest Spc_Y: 110 mm
Material Area
Gross: 60,000 mm²
Concrete: 59,200 mm²
Long. Bars: 800 mm² 1.33 %
Single Set Ties: 440 mm²
W:150 kg/m (Total: 4 kN)
Design Load: Ultimate
Top Btm
N*, kN ? 800 800
M*x, kNm ? (about y)
M*y, kNm ? (about x)
V*x, kN ?
V*y, kN ?
V* < 0.001 kN ignored
βd = G / (G + Q) 0.8 Q / G = 0.5
Apply Min Moment, N x (0.05 D)
Force Bending in Single Curvature
Reversal of Loads: Vuc = 0 kN
Mmin x, kNm: 12.0 -12.0
Mmin y, kNm: 8.0 -8.0
M* x, kNm: 12.0 -12.0
M* y, kNm: 8.0 -8.0
Design Load: Fire
Top Btm
N*f, kN 800 800
M*fx, kNm
M*fy, kNm
βd = G / (G + Q) 0.8 Q / G = 0.25
Required FRP 90 min
Exposed on more than one side
lo.fi = 0.5·Lu for Tbl. 5.6.4 ?
Use Mmin w/ single curvature
Mmin x, kNm: 12.0 -12.0
Mmin y, kNm: 8.0 -8.0
M* x, kNm: 12.0 -12.0
M* y, kNm: 8.0 -8.0

Fire Design of Columns to AS 3600

- 5.3.1 b) predicted by methods of calculation
  - Eurocode 2 Part 1-2
    - **500°C Isotherm Method – Annex B1**
    - Zone Method – Annex B2
  - **Zone Method**
    - More accurate but difficult to implement and check.
    - Concrete is divided into zones (at least 3) and considers reduced concrete strength.
    - There is also a zone of concrete that is ineffective.
    - Reduced reinforcement capacity is considered.
    - Section is checked using this cross section with varying concrete grades and reduced reinforcement.
    - Will not be done with the INDUCTA Software.

500°C Isotherm Method

- Assume concrete with temperature > 500°C is ineffective.
- Assume all other concrete has same properties normal temperature.
- Reinforcement has reduced strength even if outside the reduced section.
- Isotherm is rationalised to a rectangle with same area and aspect ratio or original section.



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500°C Isotherm Method

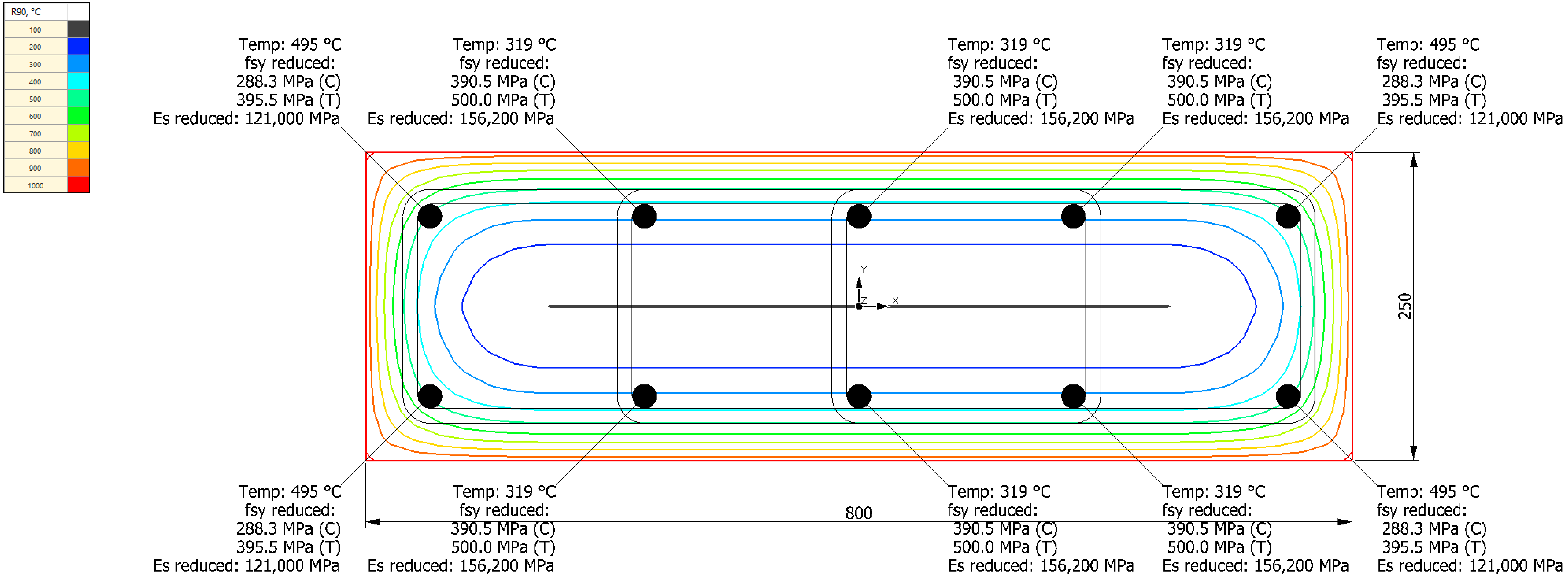

Figure A.13: Temperature profiles (°C) for a column - R90

Calculation Procedure

- Determine the 500°C isotherm for the chosen Fire Resistance Class (R or FRP)
  - Figure A.15 (rectangular) & Figure A.20 (circular and complex)
- Determine the reduced concrete section
  - Create an equivalent rectangle that has same area is reduced 5000C Isotherm but maintains aspect ratio of original section. (rect. only)
- Determine the temperature of the reinforcing bars for the relevant temperature profile
  - Figure A11 – A14 (rectangular) & Figure A16 – A 19 (circular and complex)
- Determine reduced strength of the reinforcement to 4.2.4.3
  - Reinforcement yield stress (f_{sy}) will vary for compression and for tension
  - Elastic Modulus (E_s) is reduced
- Check the section using conventional calculation methods
  - Reduced concrete section has normal, unreduced properties
  - Reinforcement has reduced properties.

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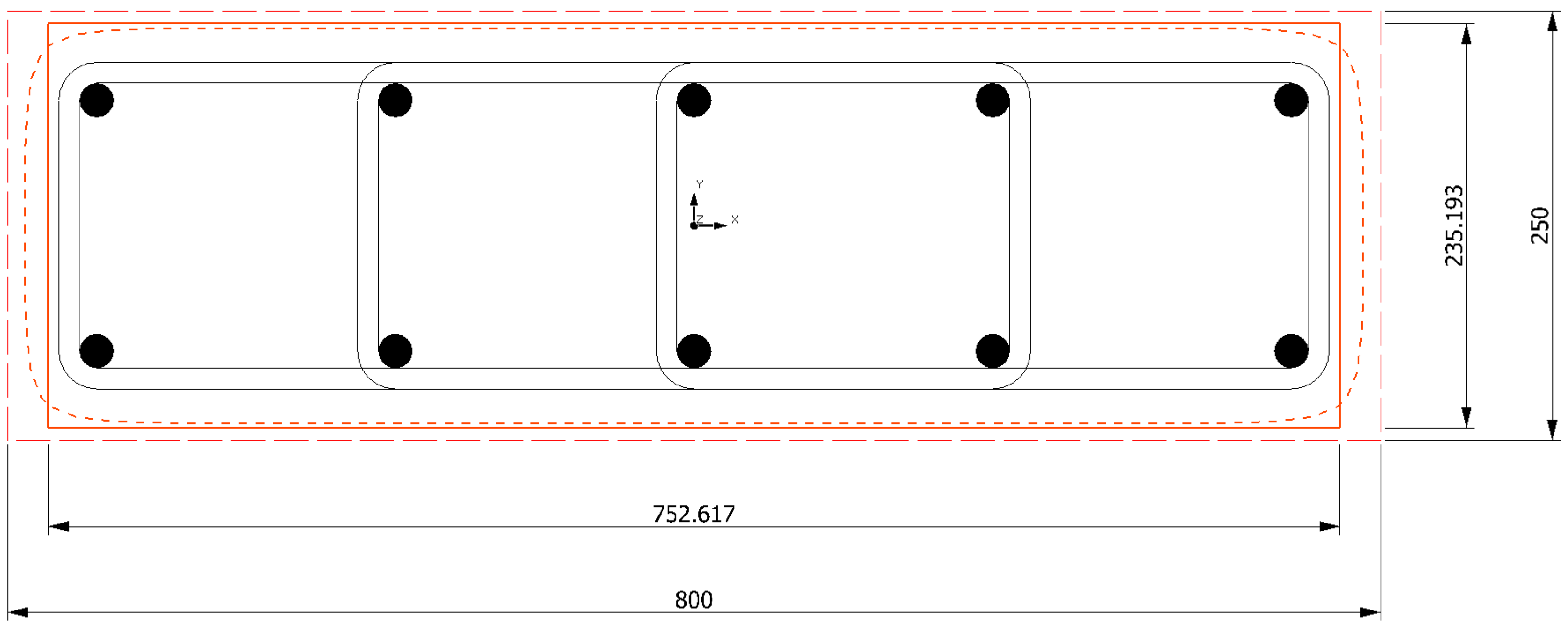
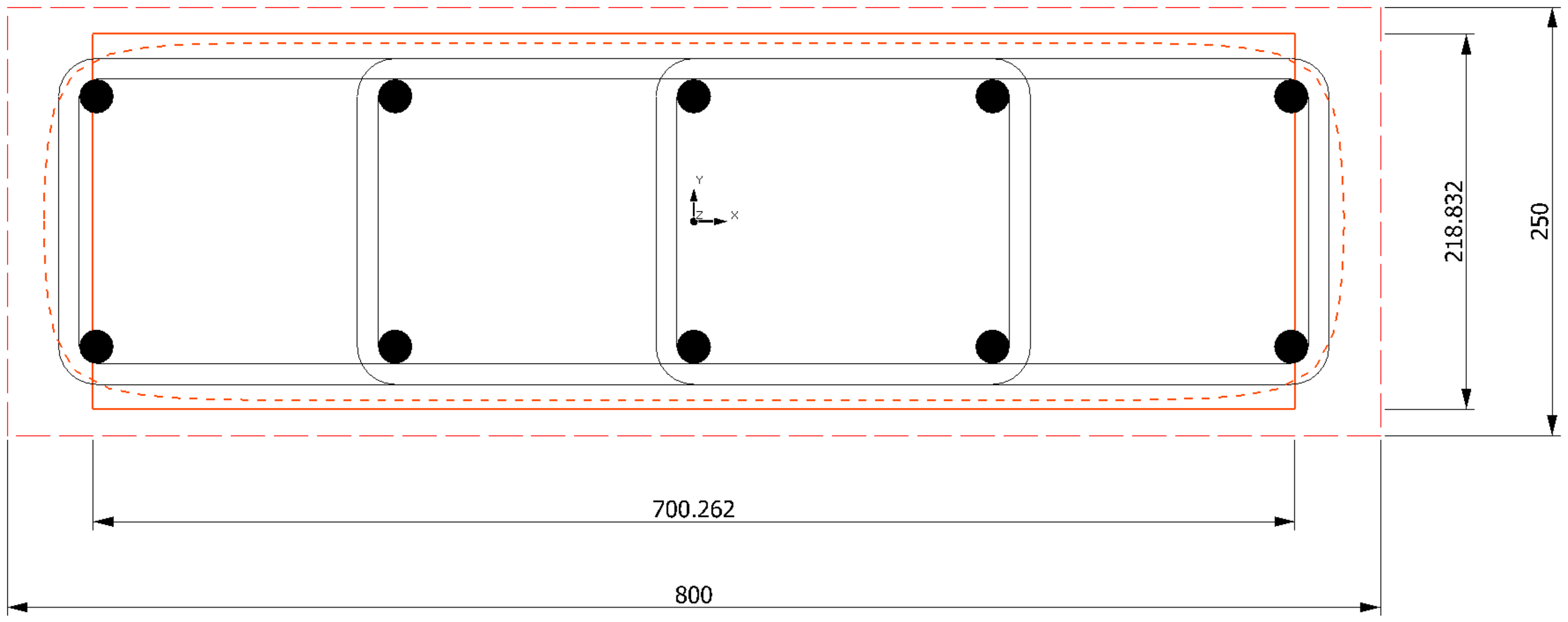
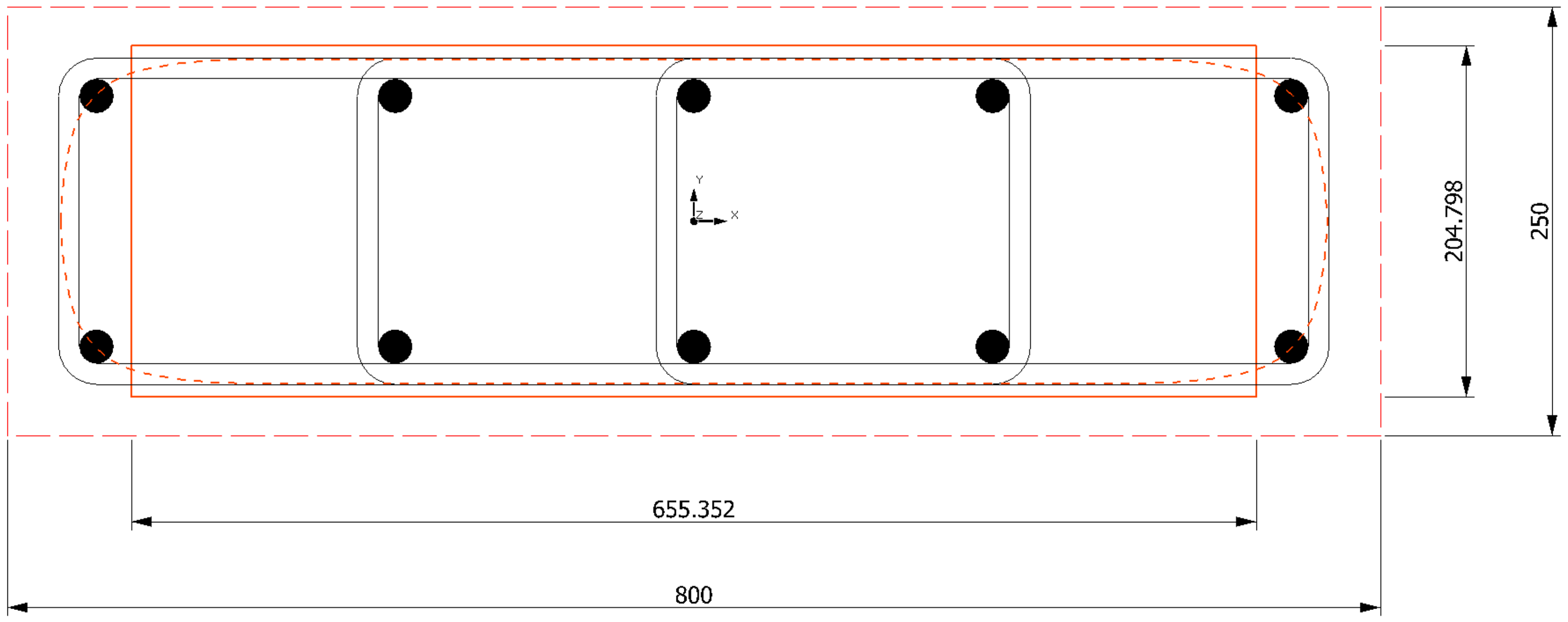


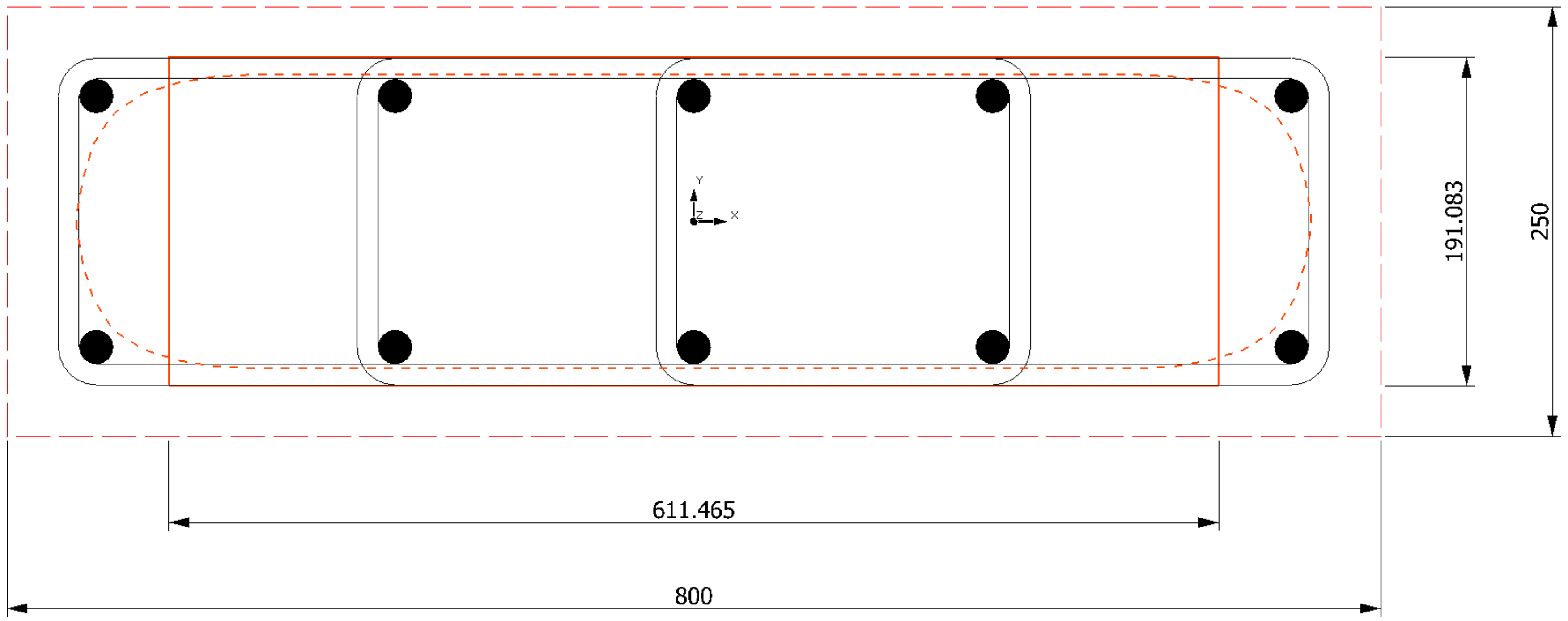
R = 30



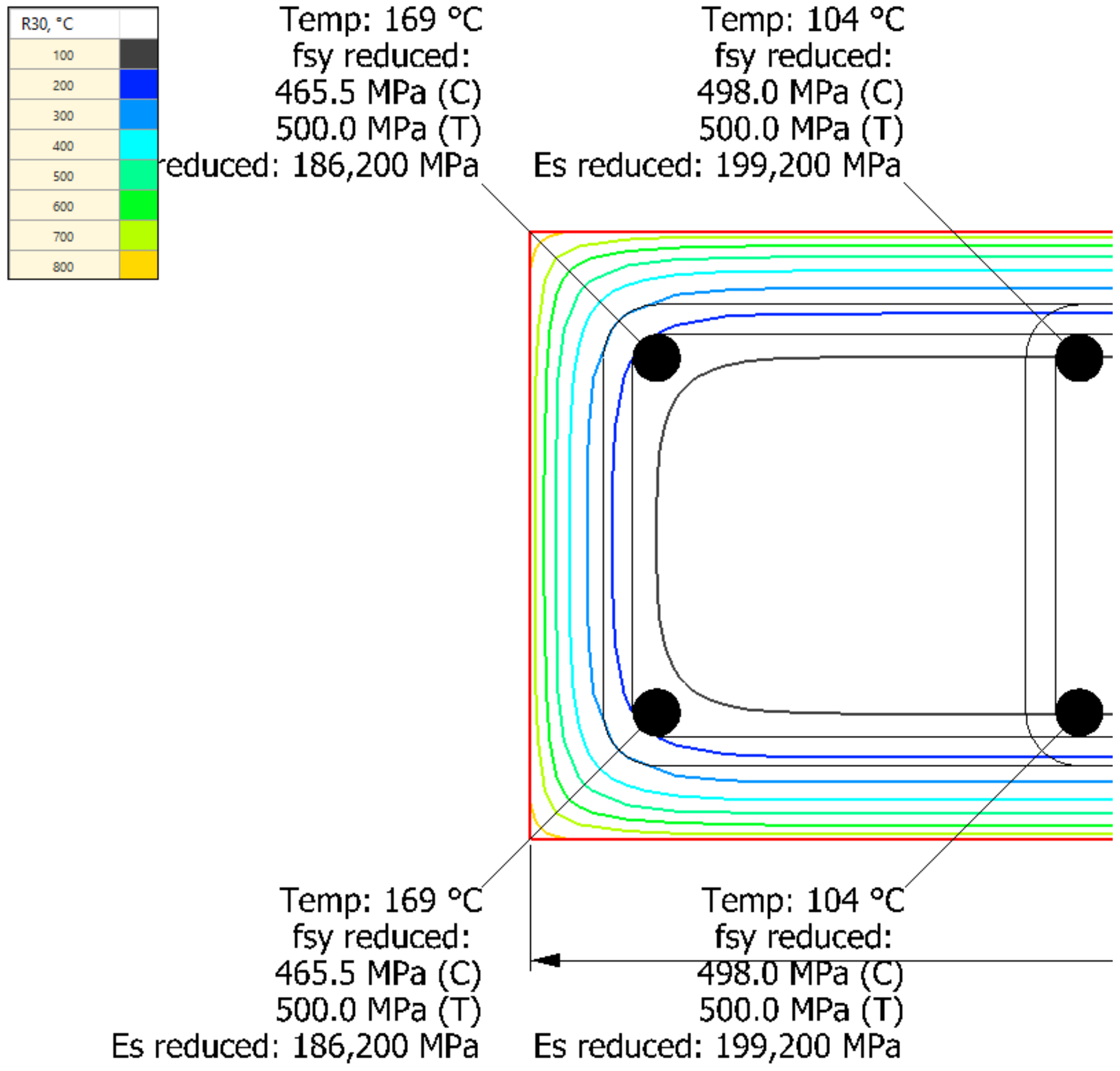
R = 60

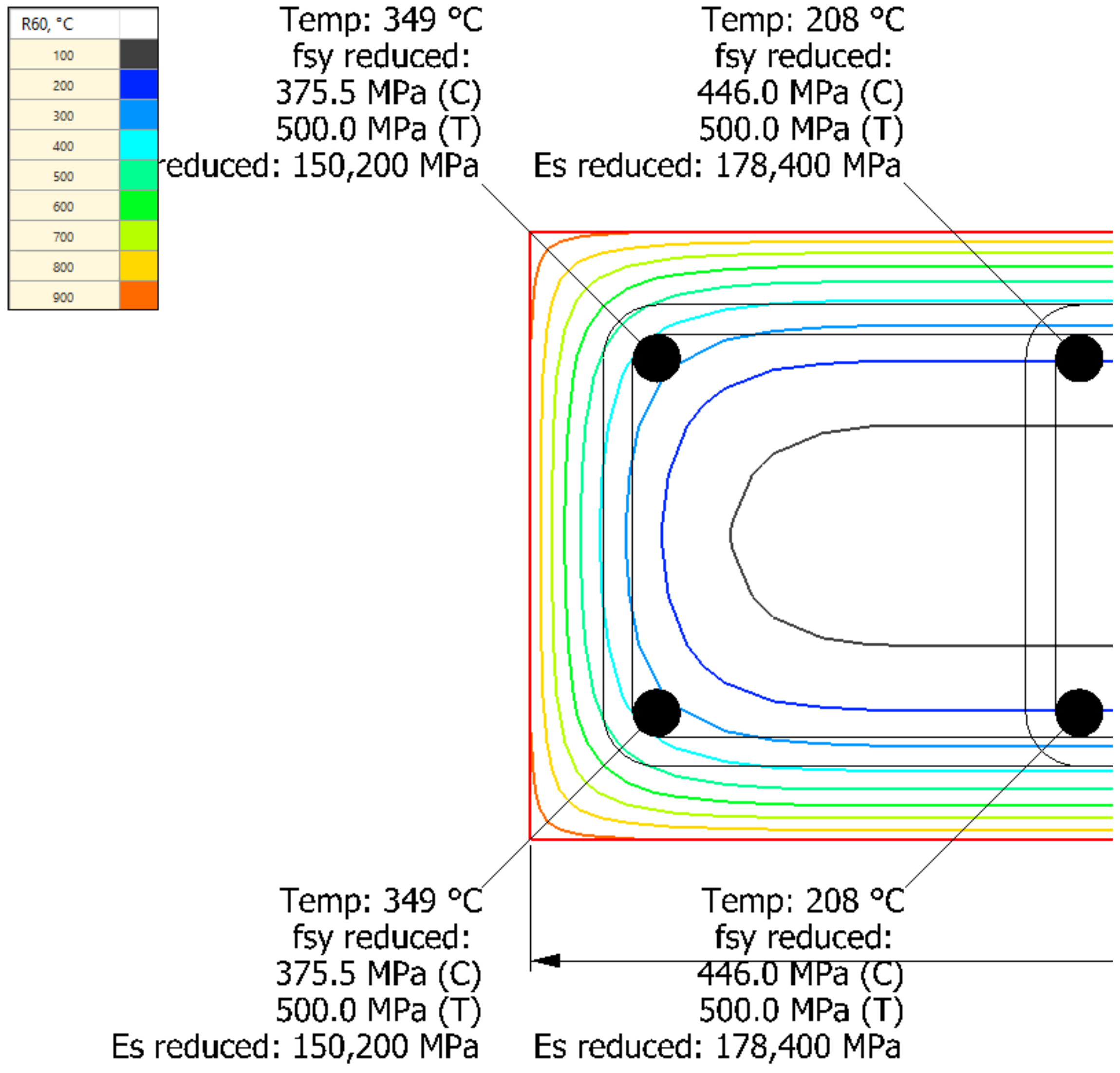


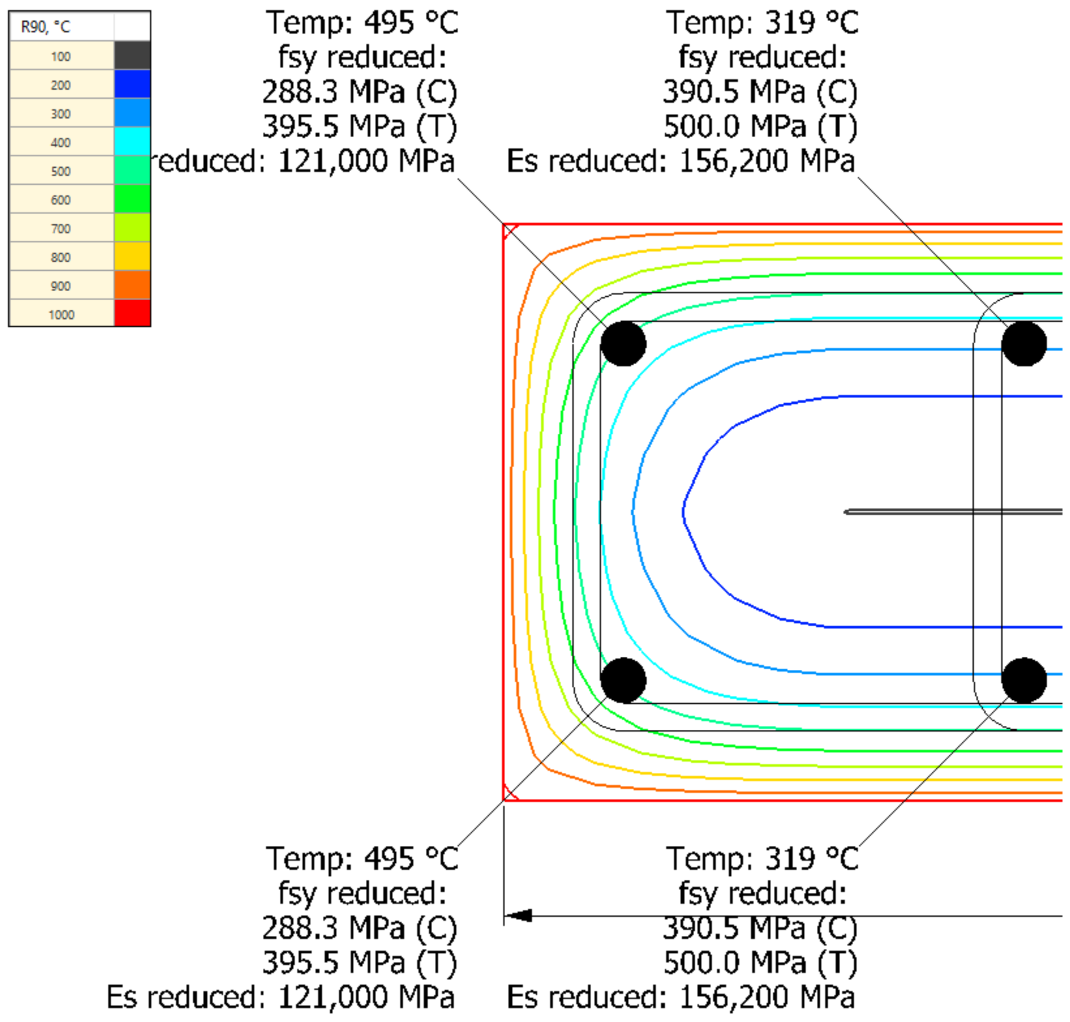
R = 90

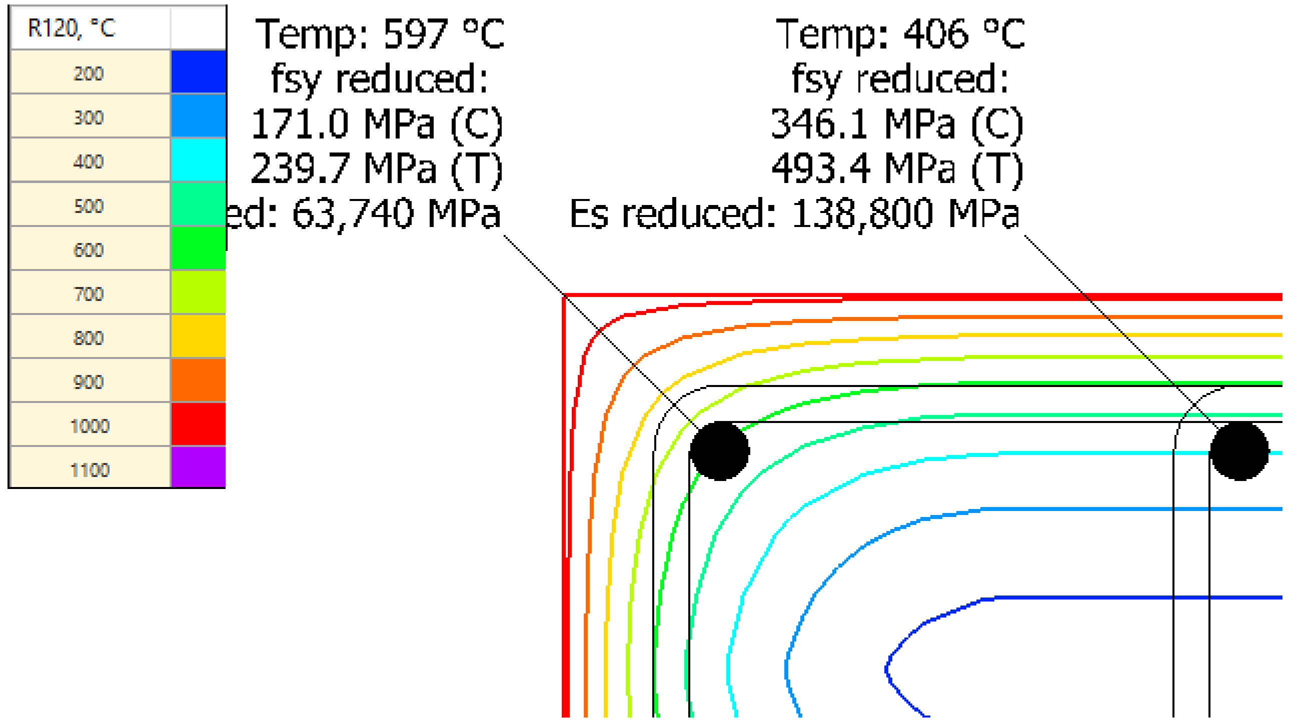


R = 120


R30, °C
100
200
300
400
500
600
700
800
Temp: 169 °C
fsy reduced:
465.5 MPa (C)
500.0 MPa (T)
reduced: 186,200 MPa
Temp: 104 °C
fsy reduced:
498.0 MPa (C)
500.0 MPa (T)
Es reduced: 199,200 MPa
Temp: 169 °C
fsy reduced:
465.5 MPa (C)
500.0 MPa (T)
Es reduced: 186,200 MPa
Temp: 104 °C
fsy reduced:
498.0 MPa (C)
500.0 MPa (T)
Es reduced: 199,200 MPa


R60, °C
100
200
300
400
500
600
700
800
900
Temp: 349 °C
fsy reduced:
375.5 MPa (C)
500.0 MPa (T)
reduced: 150,200 MPa
Temp: 208 °C
fsy reduced:
446.0 MPa (C)
500.0 MPa (T)
Es reduced: 178,400 MPa
Temp: 349 °C
fsy reduced:
375.5 MPa (C)
500.0 MPa (T)
Es reduced: 150,200 MPa
Temp: 208 °C
fsy reduced:
446.0 MPa (C)
500.0 MPa (T)
Es reduced: 178,400 MPa


R90, °C
100
200
300
400
500
600
700
800
900
1000
Temp: 495 °C
fsy reduced:
288.3 MPa (C)
395.5 MPa (T)
reduced: 121,000 MPa
Temp: 319 °C
fsy reduced:
390.5 MPa (C)
500.0 MPa (T)
Es reduced: 156,200 MPa
Temp: 495 °C
fsy reduced:
288.3 MPa (C)
395.5 MPa (T)
Es reduced: 121,000 MPa
Temp: 319 °C
fsy reduced:
390.5 MPa (C)
500.0 MPa (T)
Es reduced: 156,200 MPa


R120, °C
200
300
400
500
600
700
800
900
1000
1100
Temp: 597 °C
fsy reduced:
171.0 MPa (C)
239.7 MPa (T)
ed: 63,740 MPa
Temp: 406 °C
fsy reduced:
346.1 MPa (C)
493.4 MPa (T)
Es reduced: 138,800 MPa

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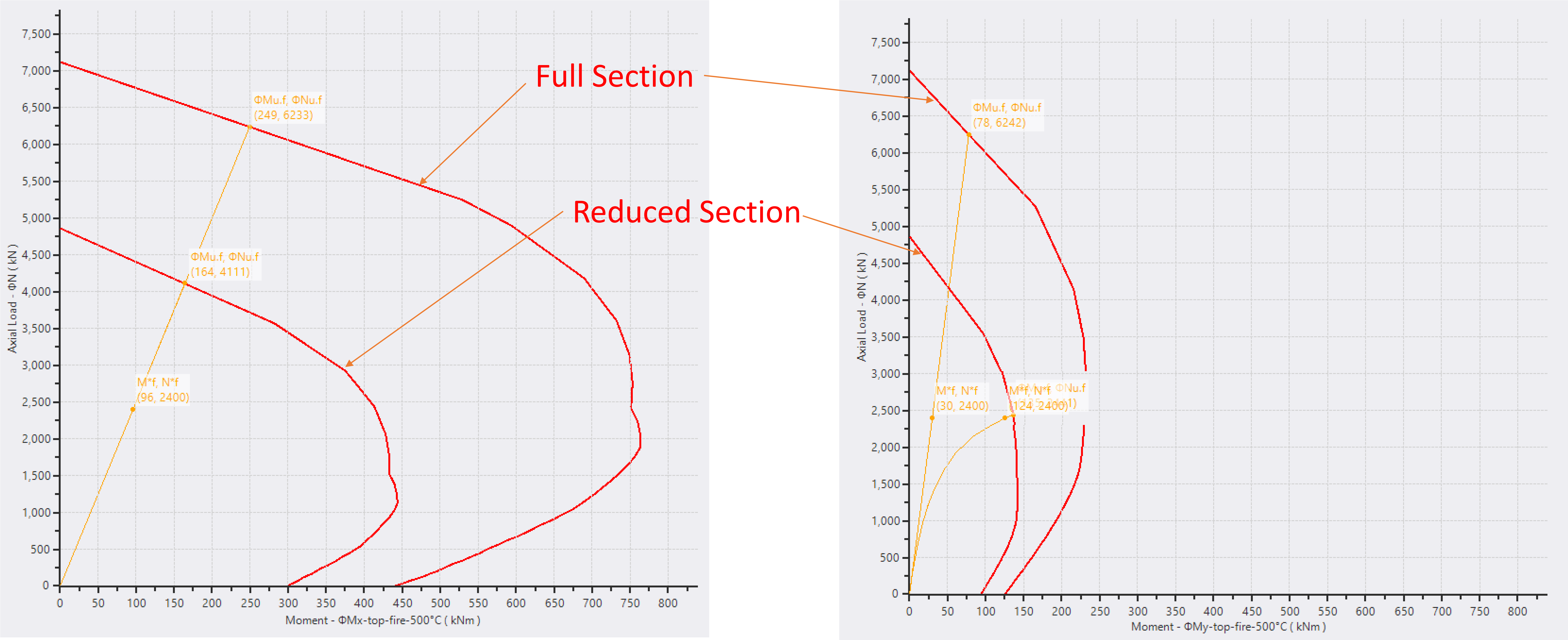
Section Capacity – R90



Circular Sections

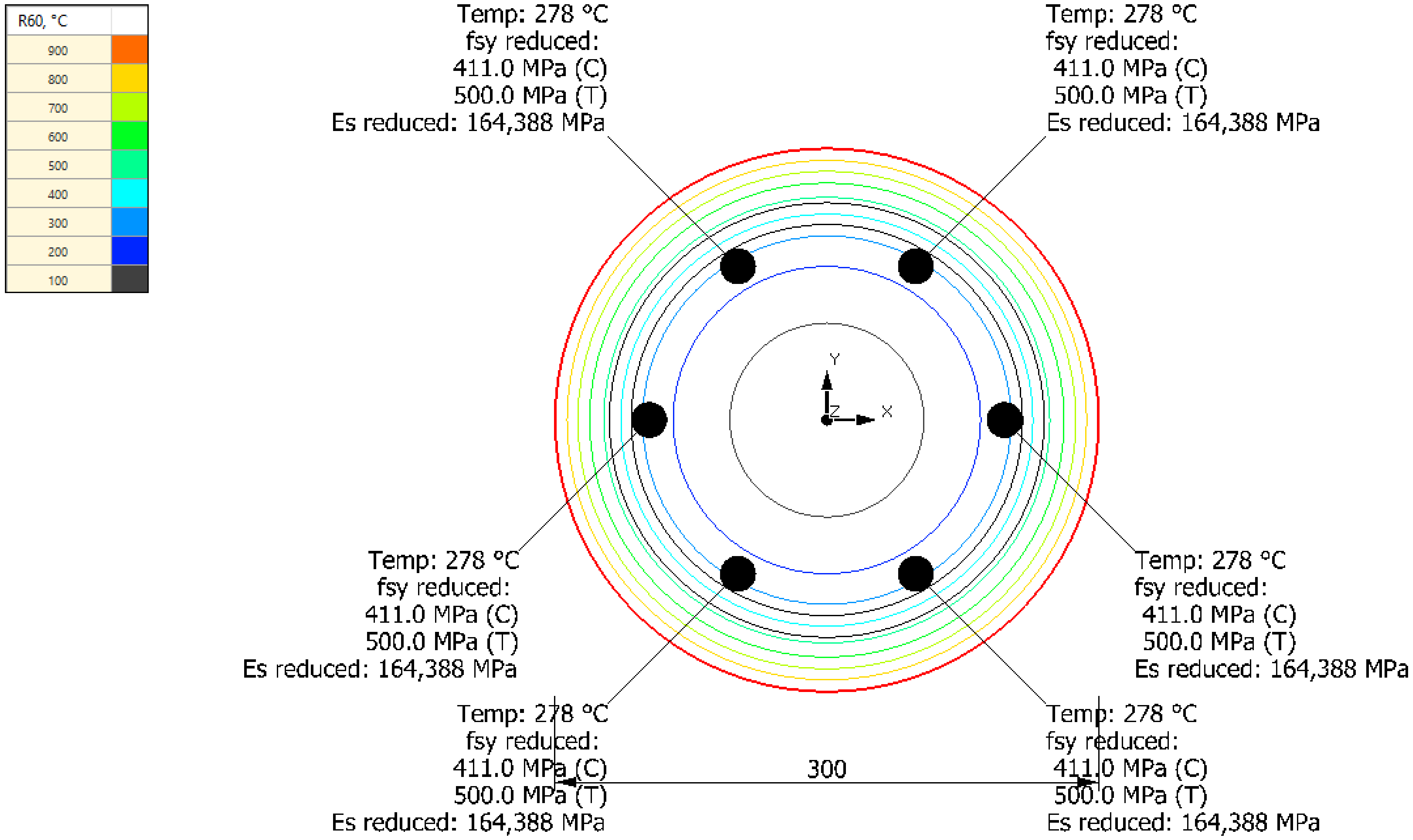


Figure A.17: Temperature profiles (°C) for a circular column - R60

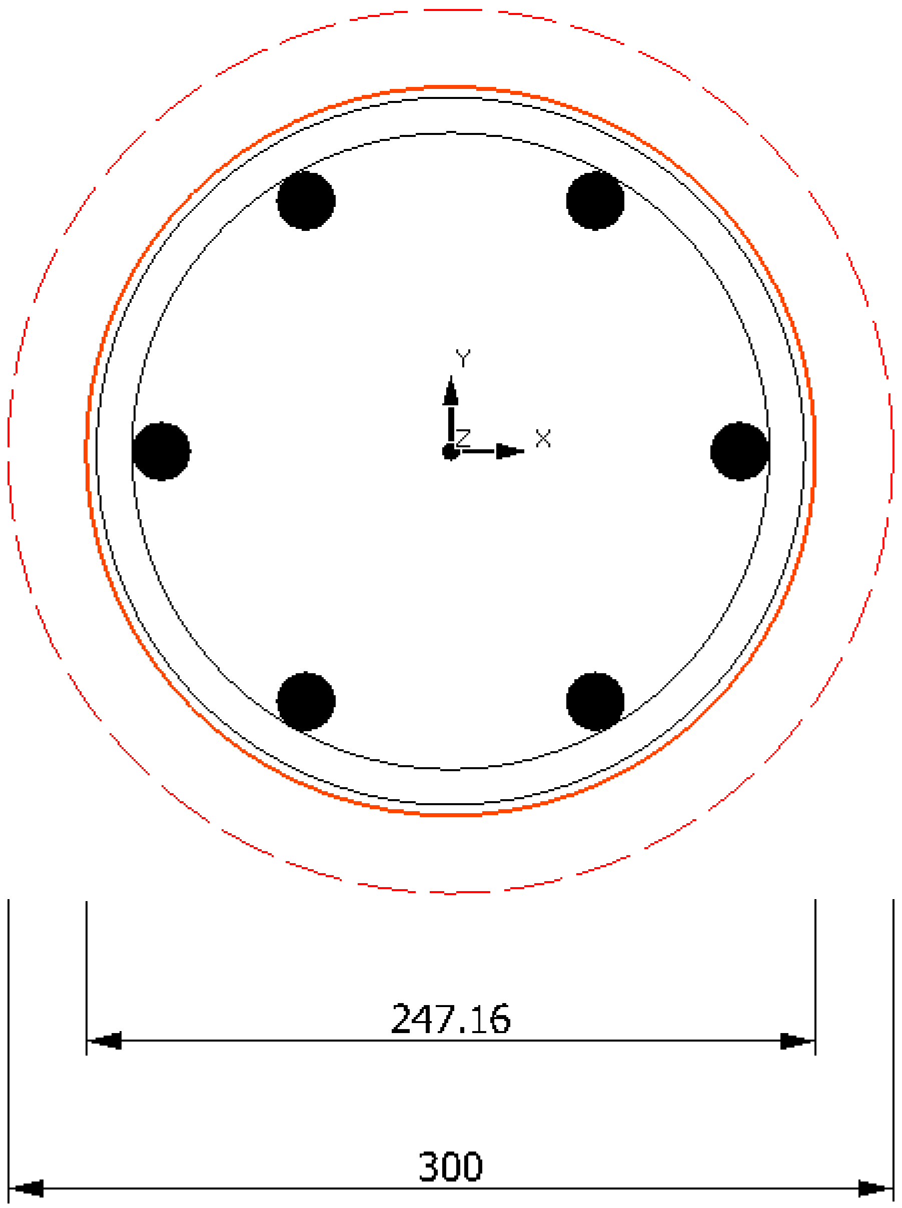


Figure A.20: 500 °C isotherms for a circular column

INDUCTA

Complex Sections

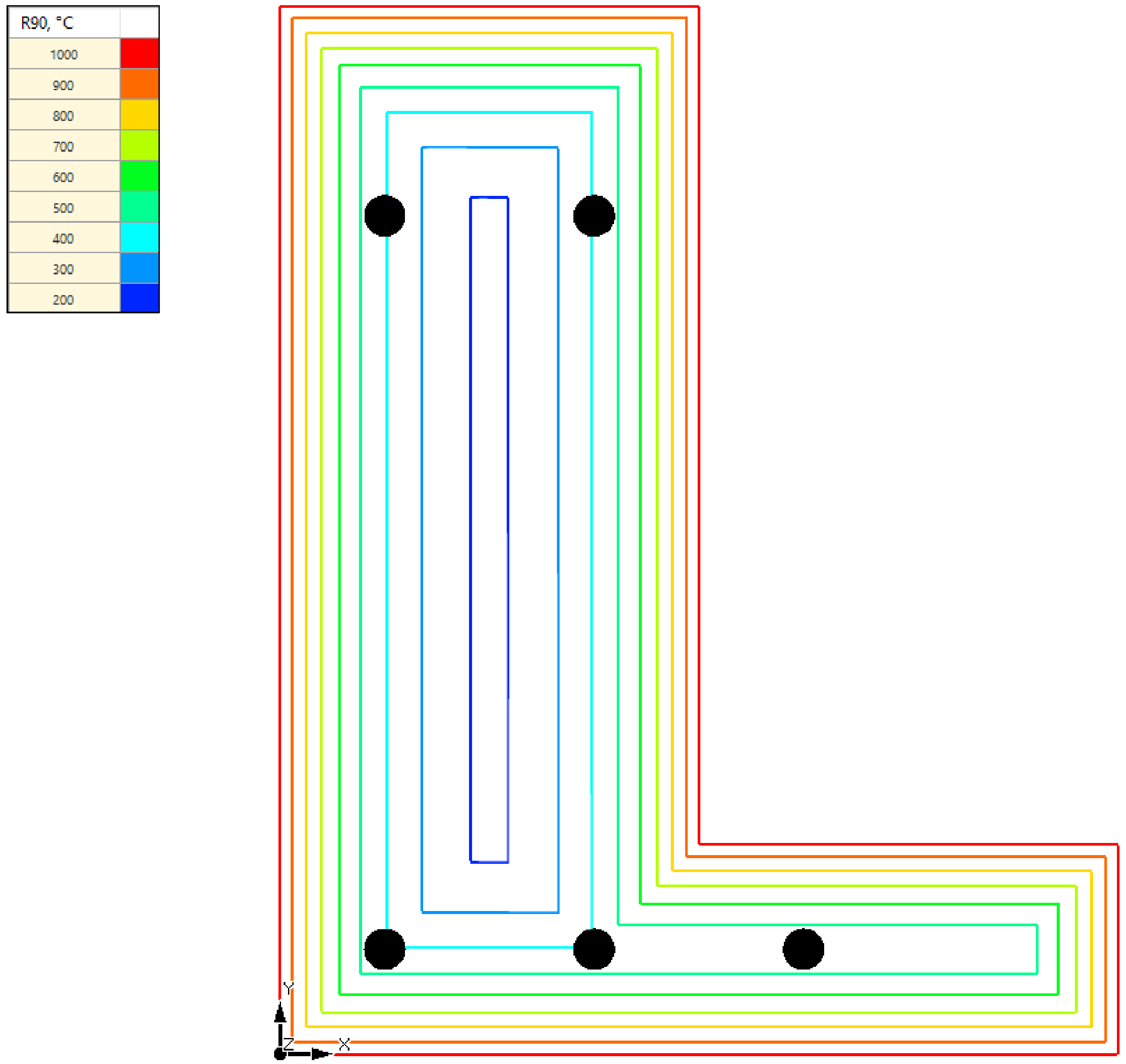
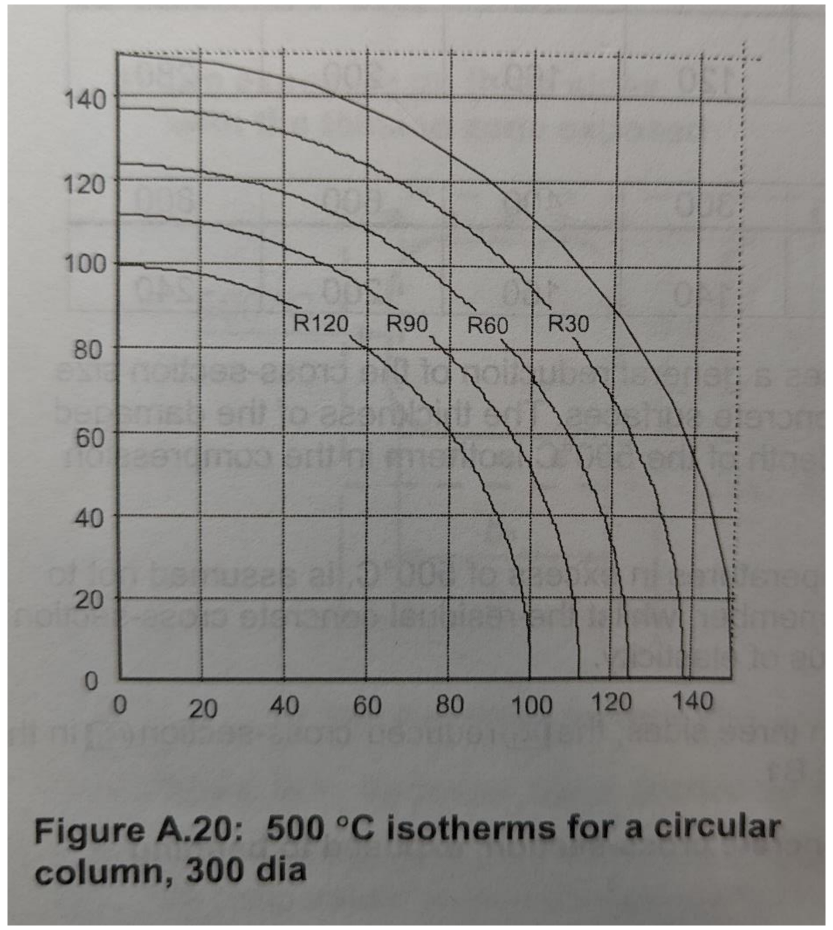


Figure A.18: Temperature profiles (°C) for a circular column - R90



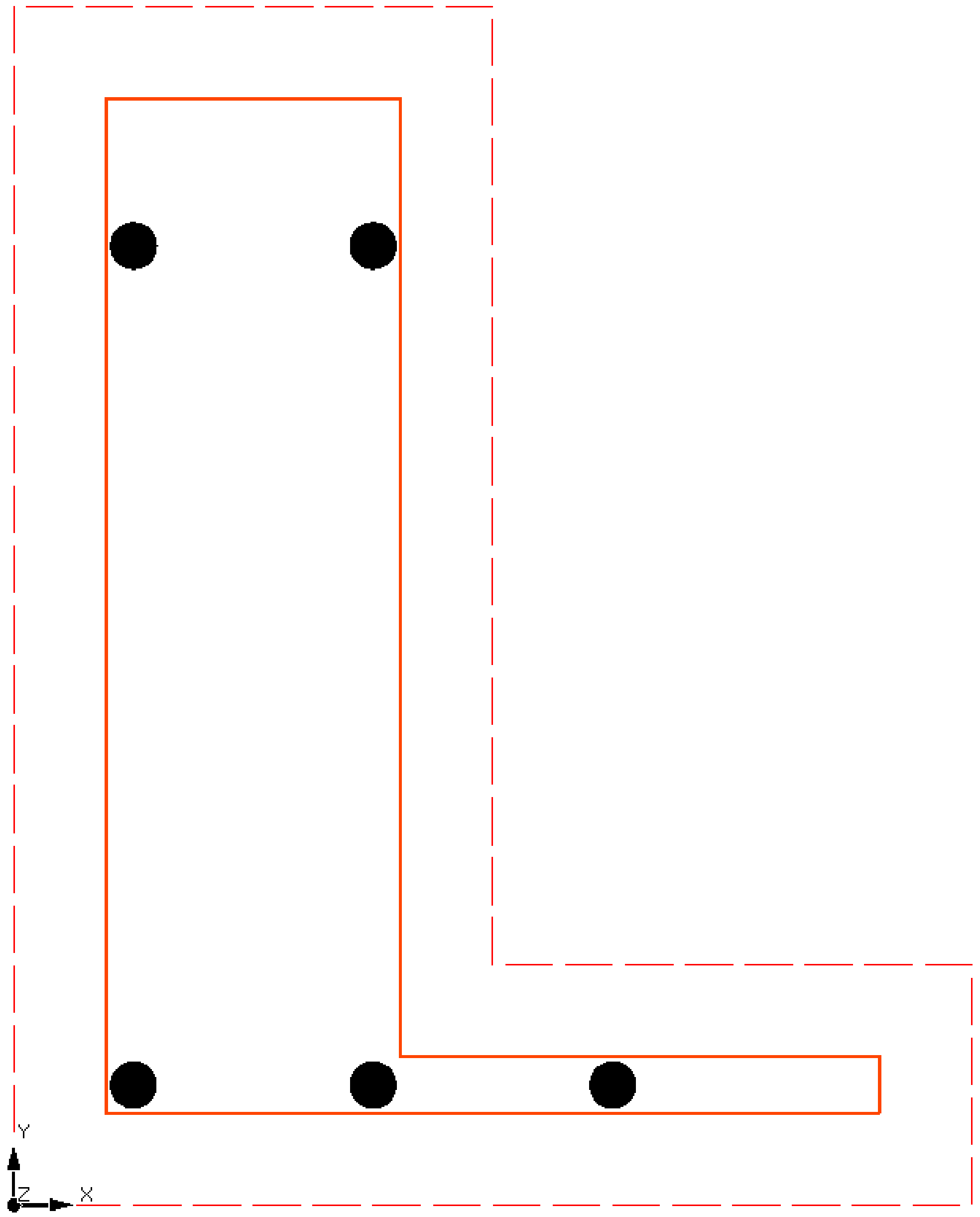


Figure A.20: 500 °C isotherms for a circular column

Closing Remarks

- EC2 500^{o}C Isotherm Method
  - Coming as a free update to INDUCTA RCB and RCC software early 2023.
- Fully automated as per existing column calculations.
- Will provide complete solution for column fire design using the INDUCTA Software.

References

- Concrete structures AS 3600 – 2018 Incl. AMDTs No 1 & No 2
- Concrete structure – commentary (supplement 1 to AS 3600:2018)
- Concrete Design Guide, No. 6: Fire design of concrete columns and walls to Eurocode 2
- Eurocode 2: Design on concrete structure – Part 1-2: General rules – Structural fire design

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