P2 PORTAL COLUMN 1.1 M DIAMETER

TOP

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of**
North Java Corridor Flyover Project

Calculation: **Balaraja Flyover**
Serviceability Check - Traffic Load Only
1100 mm Dia Circular RC Column - P2 Top Section

Reference: **Project Specific Design Criteria**

Section Data

MPa := 1000000·Pa

kN := 1000·N

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	30	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P21	Combination 1 - P + Traffic Load Only	3173.2	1877.2	100%
2	P21	Combination 1 - P + Traffic Load Only	3173.2	901.7	100%
3	P22	Combination 1 - P + Traffic Load Only	3177.7	1878.1	100%
4	P22	Combination 1 - P + Traffic Load Only	3177.7	900.9	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \quad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \left| \begin{array}{l} \frac{E_S}{E_C} \ \text{ if } \ E_C > 0 \\ 1 \ \text{ otherwise} \end{array} \right. \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \left| \begin{array}{l} 0.5 \cdot f_y \ \text{ if } \ 0.5 \cdot f_y \le 170MPa \\ 170MPa \ \text{ otherwise} \end{array} \right. \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \left| \begin{array}{l} 0.5 \cdot f_y \ \text{ if } \ 0.5 \cdot f_y \le 110MPa \\ f_y \ \text{ otherwise} \end{array} \right. \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$

$A_C = 0.94783\ m^2$

$$x_C := -\frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{y_{i+1} - y_i}{8} \cdot \left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3} \right] \right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{x_{i+1} - x_i}{8} \cdot \left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3} \right] \right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$

$I_x = 0.07149\ m^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$

$I_y = 0.07149\ m^4$

$$I_{xC} := I_x - A_C \cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ m^4$

$$I_{yC} := I_y - A_C \cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$ $A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$ $x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$ $y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

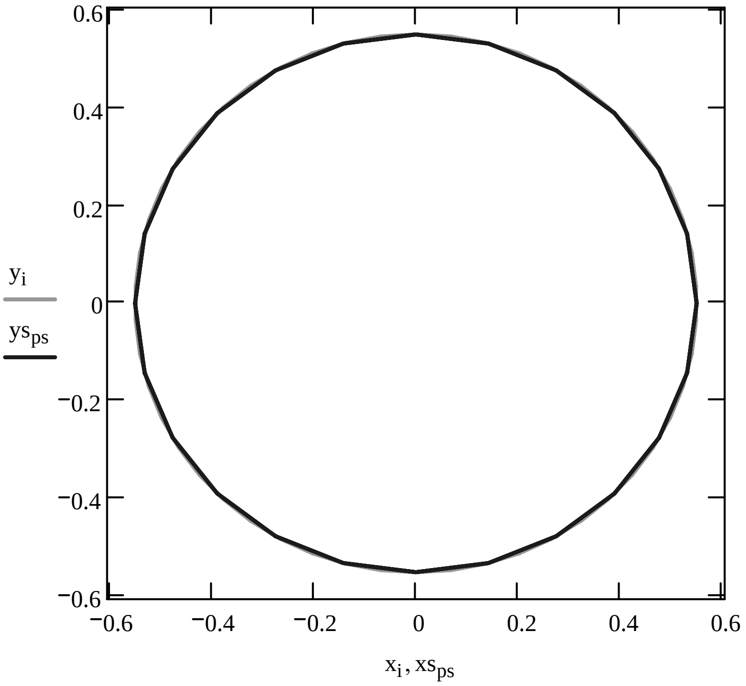
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-99	-464	**52**	0	0	0
3	804	-193	-433	**53**	0	0	0
4	804	-279	-383	**54**	0	0	0
5	804	-352	-317	**55**	0	0	0
6	804	-410	-237	**56**	0	0	0
7	804	-451	-146	**57**	0	0	0
8	804	-471	-50	**58**	0	0	0
9	804	-471	50	**59**	0	0	0
10	804	-451	146	**60**	0	0	0
11	804	-410	237	**61**	0	0	0
12	804	-352	317	**62**	0	0	0
13	804	-279	383	**63**	0	0	0
14	804	-193	433	**64**	0	0	0
15	804	-99	464	**65**	0	0	0
16	804	0	474	**66**	0	0	0
17	804	99	464	**67**	0	0	0
18	804	193	433	**68**	0	0	0
19	804	279	383	**69**	0	0	0
20	804	352	317	**70**	0	0	0
21	804	410	237	**71**	0	0	0
22	804	451	146	**72**	0	0	0
23	804	471	50	**73**	0	0	0
24	804	471	-50	**74**	0	0	0
25	804	451	-146	**75**	0	0	0
26	804	410	-237	**76**	0	0	0
27	804	352	-317	**77**	0	0	0
28	804	279	-383	**78**	0	0	0
29	804	193	-433	**79**	0	0	0
30	804	99	-464	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $\quad A2 := A2 \cdot mm^2$ $\quad A3 := A3 \cdot mm^2$ $\quad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $\quad X2 := X2 \cdot mm$ $\quad X3 := X3 \cdot mm$ $\quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $\quad Y2 := Y2 \cdot mm$ $\quad Y3 := Y3 \cdot mm$ $\quad Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $\quad A_{bar_k} := A1_k$ $\quad x_{bar_k} := X1_k$ $\quad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $\quad x_{bar_{k+50}} := X2_k$ $\quad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $\quad x_{bar_{k+100}} := X3_k$ $\quad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $\quad x_{bar_{k+150}} := X4_k$ $\quad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 24127\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0255$$

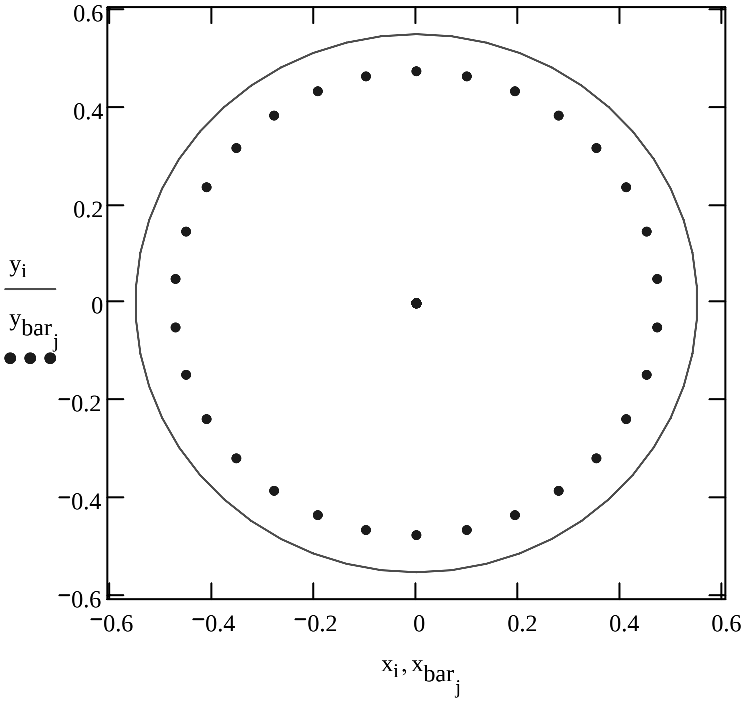
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

$$y_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00271\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00271\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1111154\,\mathrm{mm}^2$

Effective centroid $x_E := \frac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\,\mathrm{m}$

$y_E := \frac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\,\mathrm{m}$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {x_C}^2 + \rho \cdot {x_b}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot {x_{ST}}^2\right) \cdot \alpha$

$I_{EX} = 0\ \mathrm{m}^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {y_C}^2 + \rho \cdot {y_b}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot {y_{ST}}^2\right) \cdot \alpha$

$I_{EY} = 0\ \mathrm{m}^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ \mathrm{m}$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ \mathrm{m}$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

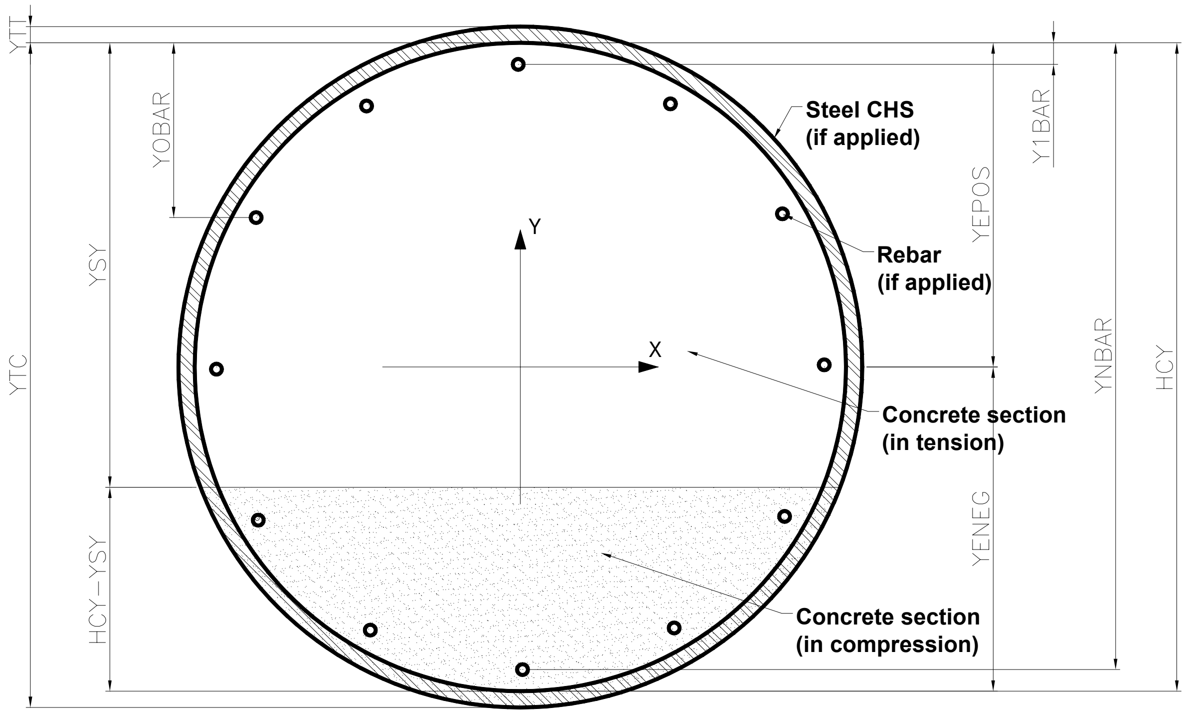
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns+1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \begin{vmatrix} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{vmatrix} \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \begin{vmatrix} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{vmatrix}$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array}\right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy \ \text{ if } f_c > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy \ \text{ if } f_c > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \left| \begin{array}{l} y_{nbar}\cdot\frac{q}{ns+1} \ \text{ if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} \ \text{ otherwise} \end{array} \right.$$

$$\varepsilon_{S_{j,q}} := \left| \begin{array}{l} -\frac{y_{SY_q}-y_{Obar_j}}{y_{nbar}-y_{SY_q}}\cdot\varepsilon cc\left(f_c,\sigma_{cd_q}\right) \ \text{ if } f_c = 0 \\ -\frac{y_{SY_q}-y_{Obar_j}}{H_{CY}-y_{SY_q}}\cdot\varepsilon cc\left(f_c,\sigma_{cd_q}\right) \ \text{ otherwise} \end{array} \right.$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \left| \begin{array}{l} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} \ \text{ if } A_{BAR} > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]dy$$

$$F_{TC} := \begin{cases} F_{TC1} - F_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS} := \begin{cases} M_{TS1} - M_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC}$$

$$F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC}$$

$$M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc},\varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc},\varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 26894.6\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17484.9\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

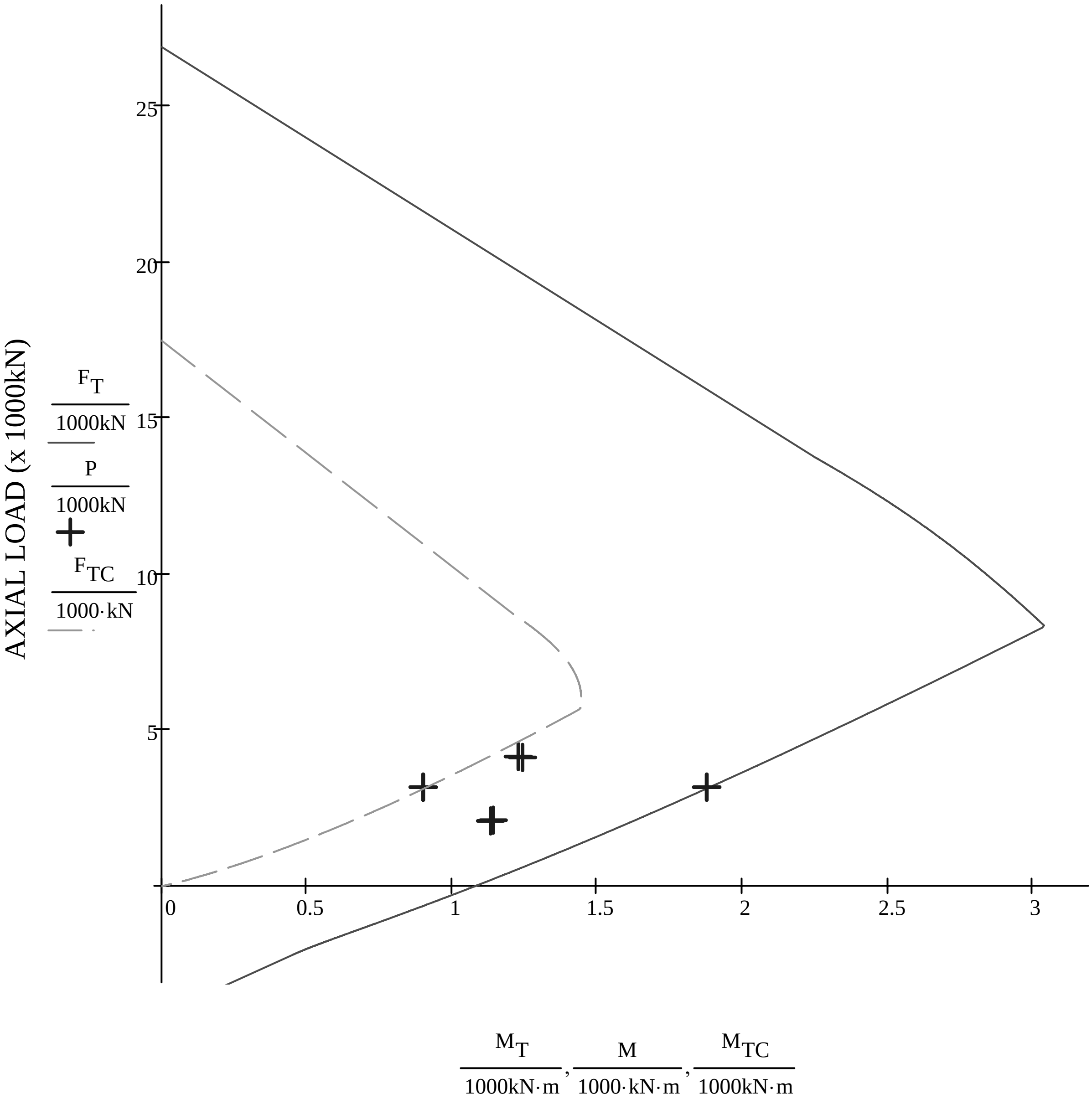
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -4101.7\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P,F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P,F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 2.55\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 0\,mm$	Yield Strength of CHS	$f_{ys} = 250\,MPa$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.0000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.0000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 3173 \\ 3173 \\ 3178 \\ 3178 \\ 2096 \\ 4131 \\ 2119 \\ 4157 \end{pmatrix} kN \qquad M = \begin{pmatrix} 1877 \\ 902 \\ 1878 \\ 901 \\ 1133 \\ 1243 \\ 1143 \\ 1229 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1884.6 \\ 1884.6 \\ 1884.6 \\ 1884.6 \\ 1624.7 \\ 2100.6 \\ 1624.7 \\ 2117.3 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.996 \\ 0.478 \\ 0.997 \\ 0.478 \\ 0.698 \\ 0.592 \\ 0.703 \\ 0.580 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column 1100 mm

Percentage of rebar 2.55 %

Load Case Ref	Pier	Applied Service Axial Load kN	Applied Service Bending Moment kNm	Service Limit State Bending Moment kNm	Allowable Stress Factor	Applied Stress Factor	Serviceability Limit State Design Result
1	**P21**	**3173**	**1877**	**1884.6**	**100%**	**100%**	OK
2	**P21**	**3173**	**902**	**1884.6**	**100%**	**48%**	OK
3	**P22**	**3178**	**1878**	**1884.6**	**100%**	**100%**	OK
4	**P22**	**3178**	**901**	**1884.6**	**100%**	**48%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P2 Top Section

Reference: **Project Specific Design Criteria**

Section Data

$\mathrm{MPa} := 1000000 \cdot \mathrm{Pa}$ $\mathrm{kN} := 1000 \cdot \mathrm{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	30	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P21	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3173.2	2269.3	140%
2	P21	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3173.2	1293.4	140%
3	P22	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3177.7	2270.8	140%
4	P22	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3177.7	1293.1	140%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \qquad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right]$$

$A_C = 0.94783\ m^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right]$$

$I_x = 0.07149\ m^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right]$$

$I_y = 0.07149\ m^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ m^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

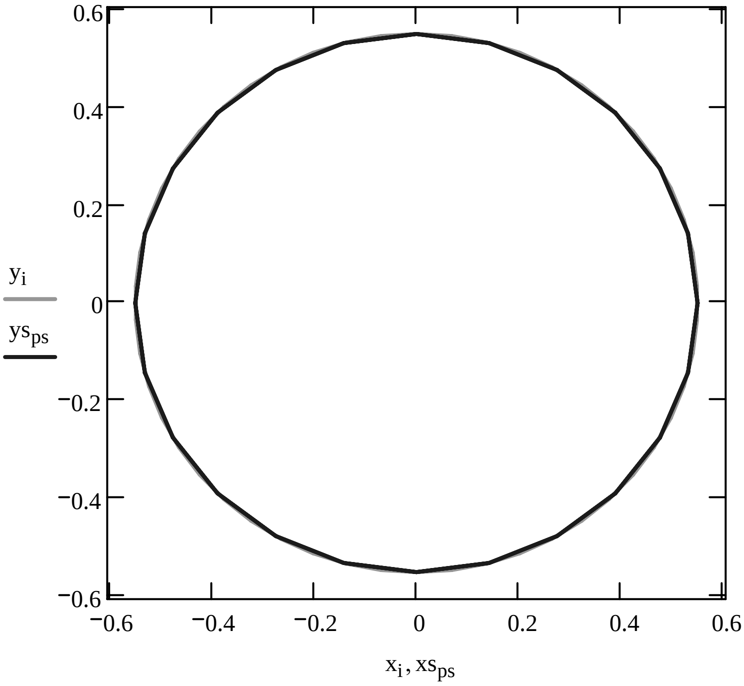
$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$

$I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$

$I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-99	-464	**52**	0	0	0
3	804	-193	-433	**53**	0	0	0
4	804	-279	-383	**54**	0	0	0
5	804	-352	-317	**55**	0	0	0
6	804	-410	-237	**56**	0	0	0
7	804	-451	-146	**57**	0	0	0
8	804	-471	-50	**58**	0	0	0
9	804	-471	50	**59**	0	0	0
10	804	-451	146	**60**	0	0	0
11	804	-410	237	**61**	0	0	0
12	804	-352	317	**62**	0	0	0
13	804	-279	383	**63**	0	0	0
14	804	-193	433	**64**	0	0	0
15	804	-99	464	**65**	0	0	0
16	804	0	474	**66**	0	0	0
17	804	99	464	**67**	0	0	0
18	804	193	433	**68**	0	0	0
19	804	279	383	**69**	0	0	0
20	804	352	317	**70**	0	0	0
21	804	410	237	**71**	0	0	0
22	804	451	146	**72**	0	0	0
23	804	471	50	**73**	0	0	0
24	804	471	-50	**74**	0	0	0
25	804	451	-146	**75**	0	0	0
26	804	410	-237	**76**	0	0	0
27	804	352	-317	**77**	0	0	0
28	804	279	-383	**78**	0	0	0
29	804	193	-433	**79**	0	0	0
30	804	99	-464	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2 \qquad A2 := A2 \cdot mm^2 \qquad A3 := A3 \cdot mm^2 \qquad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm \quad X2 := X2 \cdot mm \quad X3 := X3 \cdot mm \quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm \quad Y2 := Y2 \cdot mm \quad Y3 := Y3 \cdot mm \quad Y4 := Y4 \cdot mm$

$k := 1 .. 50 \qquad A_{bar_k} := A1_k \qquad x_{bar_k} := X1_k \qquad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k \qquad x_{bar_{k+50}} := X2_k \qquad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k \qquad x_{bar_{k+100}} := X3_k \qquad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k \qquad x_{bar_{k+150}} := X4_k \qquad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 24127\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0255$$

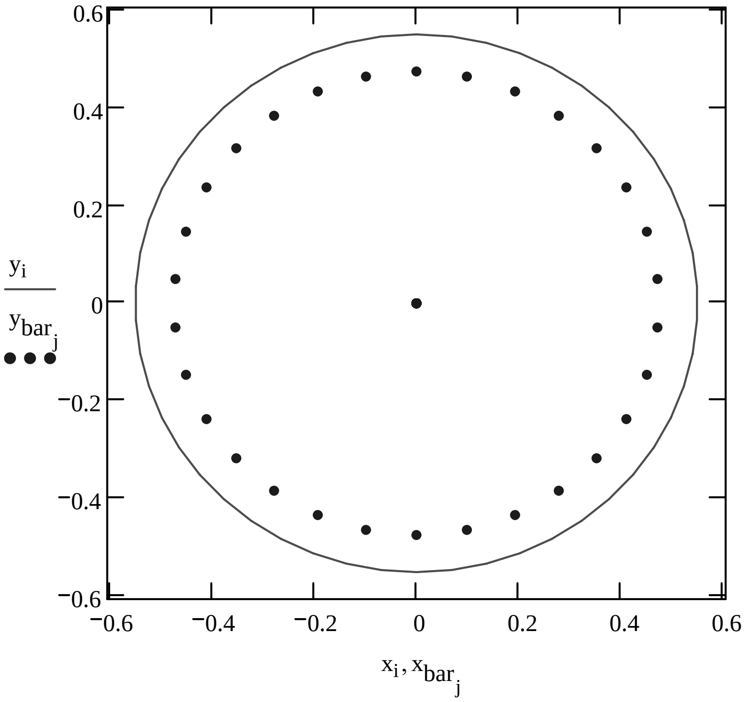
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00271\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00271\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1111154\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1 - \rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot [(1 - \rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\,m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

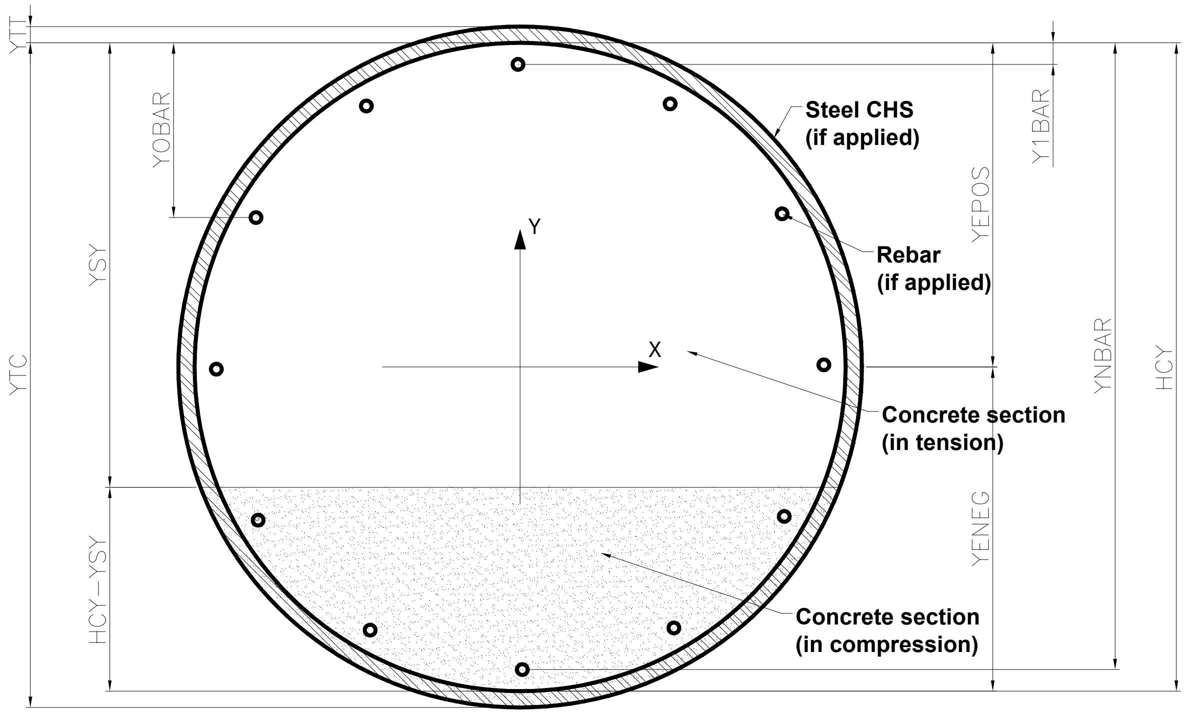
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2$ $\frac{\sigma_{cc}}{E_C} = 0.001165$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$\varepsilon_{cc} := \text{Find}(\varepsilon cc)$ $\varepsilon_{cc} = 0.003321$

$$\varepsilon_{cc} := \begin{array}{|l} \varepsilon_{tc} \ \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \ \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \ \text{otherwise} \end{array}$$

$\varepsilon_{cc} = 0.003321$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \begin{array}{|l} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \ \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \ \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \ \text{otherwise} \end{array}$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc}\cdot\frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc}\cdot\frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(ts = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array}\right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \left| \begin{array}{l} y_{nbar}\cdot\dfrac{q}{ns+1} \quad \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} \quad \text{otherwise} \end{array} \right.$$

$$\varepsilon_{S_{j,q}} := \left| \begin{array}{l} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{otherwise} \end{array} \right.$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \left| \begin{array}{l} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} \quad \text{if } A_{BAR} > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left| \begin{array}{ll} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left| \begin{array}{ll} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]dy$$

$$F_{TC} := \left| \begin{array}{l} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS} := \left| \begin{array}{l} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC}$$

$$F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC}$$

$$M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \left| \begin{array}{l} \min(\varepsilon_{cc}, \varepsilon_{tc}) \ \text{ if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) \ \text{ if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} \ \text{ if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} \ \text{ if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) \ \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cL} = 0.001950$$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \left| \begin{array}{l} \sigma_{cd_2} \ \text{ if } f_c > 0 \\ 0 \ \text{ otherwise} \end{array} \right. \qquad \sigma_{cL} = 18.93\,\text{MPa}$$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 26894.6\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17484.9\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

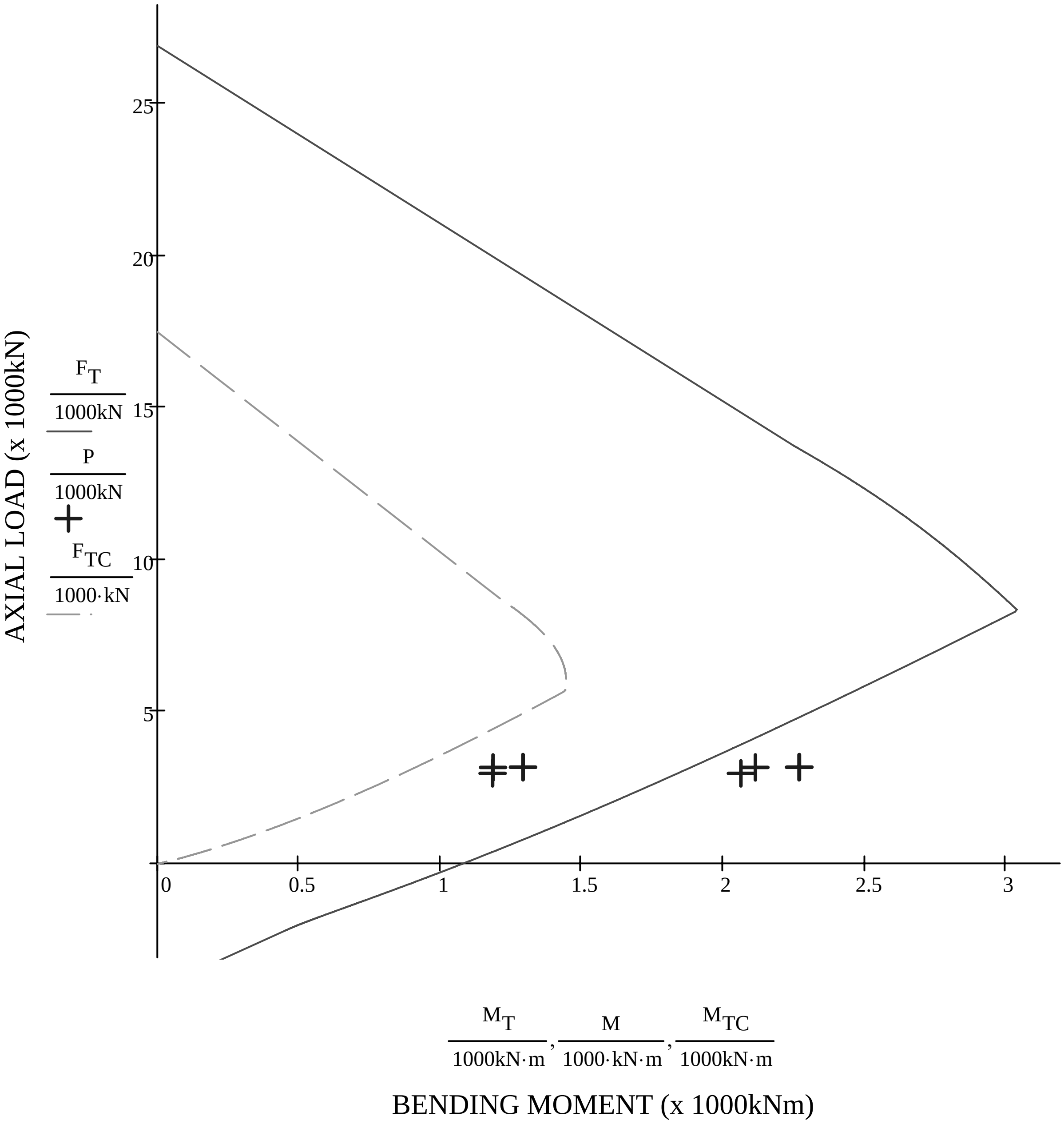
$$P_{MIN} := \left| \begin{array}{l} \varepsilon_{rs}\cdot E_S(A_{BAR}) \ \text{ if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) \ \text{ if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) \ \text{ otherwise} \end{array} \right.$$

$P_{MIN} = -4101.7\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \left| \begin{array}{l} \min(P, F_T)\cdot 0.75 \ \text{ if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 \ \text{ otherwise} \end{array} \right.$$

$P_{MINC} := 0\text{kN}$ $\qquad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 2.55\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r > F_{T_1}$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r < F_{T_{ns+1}}$
    $(P_r - c1) \cdot m1$  if  $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
    $(P_r - c2) \cdot m2$  if  $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
    otherwise
        $j \leftarrow 1$
        while  $F_{T_j} > P_r$
            $j \leftarrow j + 1$
        $M_{T_j}$
```

```
$StressFactor_r :=$
    "No Result"  if  $M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m$
    $\frac{M_r}{M_{SLS_r}}$  otherwise
```

$$P = \begin{pmatrix} 3173 \\ 3173 \\ 3178 \\ 3178 \\ 2974 \\ 2974 \\ 3172 \\ 3172 \end{pmatrix} kN \qquad M = \begin{pmatrix} 2269 \\ 1293 \\ 2271 \\ 1293 \\ 2063 \\ 1186 \\ 2115 \\ 1187 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1884.6 \\ 1884.6 \\ 1884.6 \\ 1884.6 \\ 1828.4 \\ 1828.4 \\ 1884.6 \\ 1884.6 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 1.204 \\ 0.686 \\ 1.205 \\ 0.686 \\ 1.129 \\ 0.649 \\ 1.122 \\ 0.630 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			2.55	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P21**	**3173**	**2269**	**1884.6**	**140%**	**120%**	OK
2	**P21**	**3173**	**1293**	**1884.6**	**140%**	**69%**	OK
3	**P22**	**3178**	**2271**	**1884.6**	**140%**	**120%**	OK
4	**P22**	**3178**	**1293**	**1884.6**	**140%**	**69%**	OK

BASE

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project:	**Detailed Design Study of** **North Java Corridor Flyover Project**
Calculation:	**Balaraja Flyover** **Serviceability Check - Traffic Load Only** **1100 mm Dia Circular RC Column - P2 Base Section**
Reference:	**Project Specific Design Criteria**

Section Data

$\mathrm{MPa} := 1000000 \cdot \mathrm{Pa}$ $\mathrm{kN} := 1000 \cdot \mathrm{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	12	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P21	Combination 1 - P + Traffic Load Only	3336.8	70.0	100%
2	P21	Combination 1 - P + Traffic Load Only	3336.8	322.1	100%
3	P22	Combination 1 - P + Traffic Load Only	3341.4	69.5	100%
4	P22	Combination 1 - P + Traffic Load Only	3341.4	322.6	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \qquad E_C := 4700\sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	**X**	**Y**	**Ref.**	**X**	**Y**
	mm	**mm**		**mm**	**mm**
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i \right) \cdot \frac{x_{i+1} + x_i}{2} \right] \qquad A_C = 0.94783\ \mathrm{m}^2$$

$$x_C := -\frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{y_{i+1} - y_i}{8} \cdot \left[\left(x_{i+1} + x_i \right)^2 + \frac{\left(x_{i+1} - x_i \right)^2}{3} \right] \right] \qquad x_C = 0\ \mathrm{m}$$

$$y_C := \frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{x_{i+1} - x_i}{8} \cdot \left[\left(y_{i+1} + y_i \right)^2 + \frac{\left(y_{i+1} - y_i \right)^2}{3} \right] \right] \qquad y_C = 0\ \mathrm{m}$$

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i \right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i \right)^2 + \left(y_{i+1} - y_i \right)^2 \right] \right] \qquad I_x = 0.07149\ \mathrm{m}^4$$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i \right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i \right)^2 + \left(x_{i+1} - x_i \right)^2 \right] \right] \qquad I_y = 0.07149\ \mathrm{m}^4$$

$$I_{xC} := I_x - A_C \cdot x_C^{\ 2} \qquad I_{xC} = 0.07149\ \mathrm{m}^4$$

$$I_{yC} := I_y - A_C \cdot y_C^{\ 2} \qquad I_{yC} = 0.07149\ \mathrm{m}^4$$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$ $A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$ $x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$ $y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

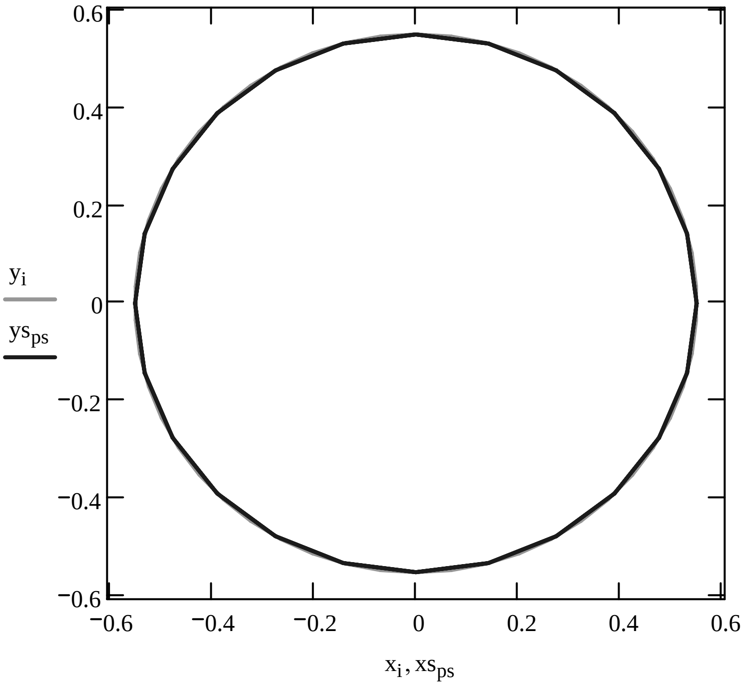
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^{\ 2}$ $I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^{\ 2}$ $I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-237	-410	**52**	0	0	0
3	804	-410	-237	**53**	0	0	0
4	804	-474	0	**54**	0	0	0
5	804	-410	237	**55**	0	0	0
6	804	-237	410	**56**	0	0	0
7	804	0	474	**57**	0	0	0
8	804	237	410	**58**	0	0	0
9	804	410	237	**59**	0	0	0
10	804	474	0	**60**	0	0	0
11	804	410	-237	**61**	0	0	0
12	804	237	-410	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1..50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 9651\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0102$$

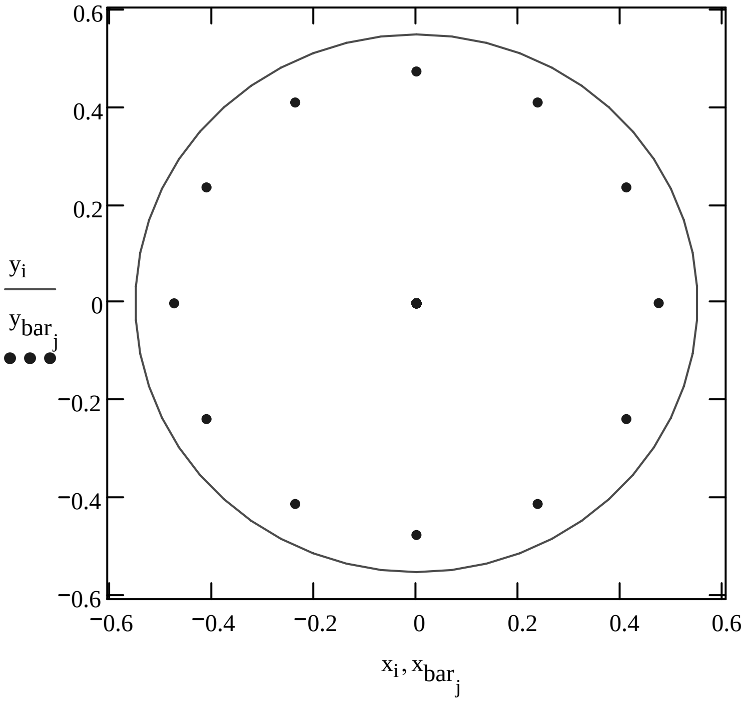
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\text{ m}$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\text{ m}$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^{\,2} \qquad I_{xb} = 0.00108\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^{\,2} \qquad I_{yb} = 0.00108\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot \left[1 + \rho \cdot (\alpha - 1)\right] + A_{ST} \cdot \alpha$ $\qquad A_E = 1013161\ \mathrm{mm}^2$

Effective centroid $x_E := \dfrac{A_C \cdot \left[(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha\right] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\qquad x_E = 0.000\ \mathrm{m}$

$y_E := \dfrac{A_C \cdot \left[(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha\right] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\qquad y_E = 0.000\ \mathrm{m}$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {x_C}^2 + \rho \cdot {x_b}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot {x_{ST}}^2\right) \cdot \alpha$

$I_{EX} = 0\ \mathrm{m}^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {y_C}^2 + \rho \cdot {y_b}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot {y_{ST}}^2\right) \cdot \alpha$

$I_{EY} = 0\ \mathrm{m}^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $\qquad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $\qquad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $\qquad H_{CX} = 1\ \mathrm{m}$

$H_{CY} := yF_{pos} - yF_{neg}$ $\qquad H_{CY} = 1\ \mathrm{m}$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

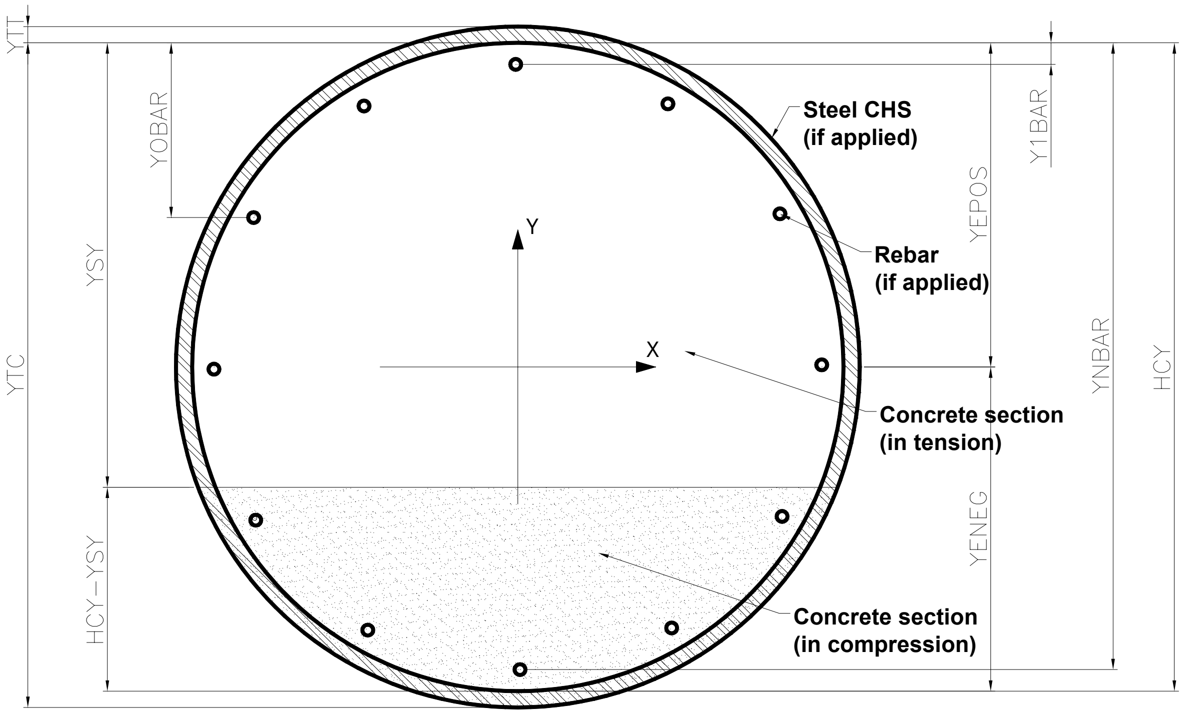
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $\quad ns := 500$

$q := 2\,..\,ns$

Distance of neutral axis from extreme fiber in tension $\quad y_{SY_q} := H_{CY}\cdot\frac{q}{ns+1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C}\cdot 2 \qquad\qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc\cdot\left(4700\sqrt{\frac{f_c\cdot 2}{MPa}} - \frac{4700^2}{2.68}\cdot\varepsilon cc\right)\cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad\qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left|\begin{array}{l} \varepsilon_{tc} \ \text{ if } \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\ \varepsilon_{rc} \ \text{ if } \left(f_c = 0\right)\cdot(ts = 0) \\ \varepsilon_{cc} \ \text{ otherwise} \end{array}\right. \qquad\qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc\left(f_c,\sigma_{cd}\right) := \left|\begin{array}{l} \frac{\sigma_{cd}}{\sigma_{tc}}\cdot\varepsilon_{tc} \ \text{ if } \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\ \frac{\sigma_{cd}}{\sigma_{rc}}\cdot\varepsilon_{rc} \ \text{ if } \left(f_c = 0\right)\cdot(ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}}\cdot\varepsilon_{cc} \ \text{ otherwise} \end{array}\right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\quad \varepsilon_{tcc_q} := \varepsilon_{cc}\cdot\frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\quad \varepsilon_{tct_q} := \varepsilon_{cc}\cdot\frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left| \begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\frac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\frac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\frac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left| \begin{array}{ll} \displaystyle\sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left| \begin{array}{ll} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{cases} F_{TC1} - F_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{cases} M_{TS1} - M_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$ $\qquad$ $F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$ $\qquad$ $M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc}, \varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21522.8\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17758.9\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

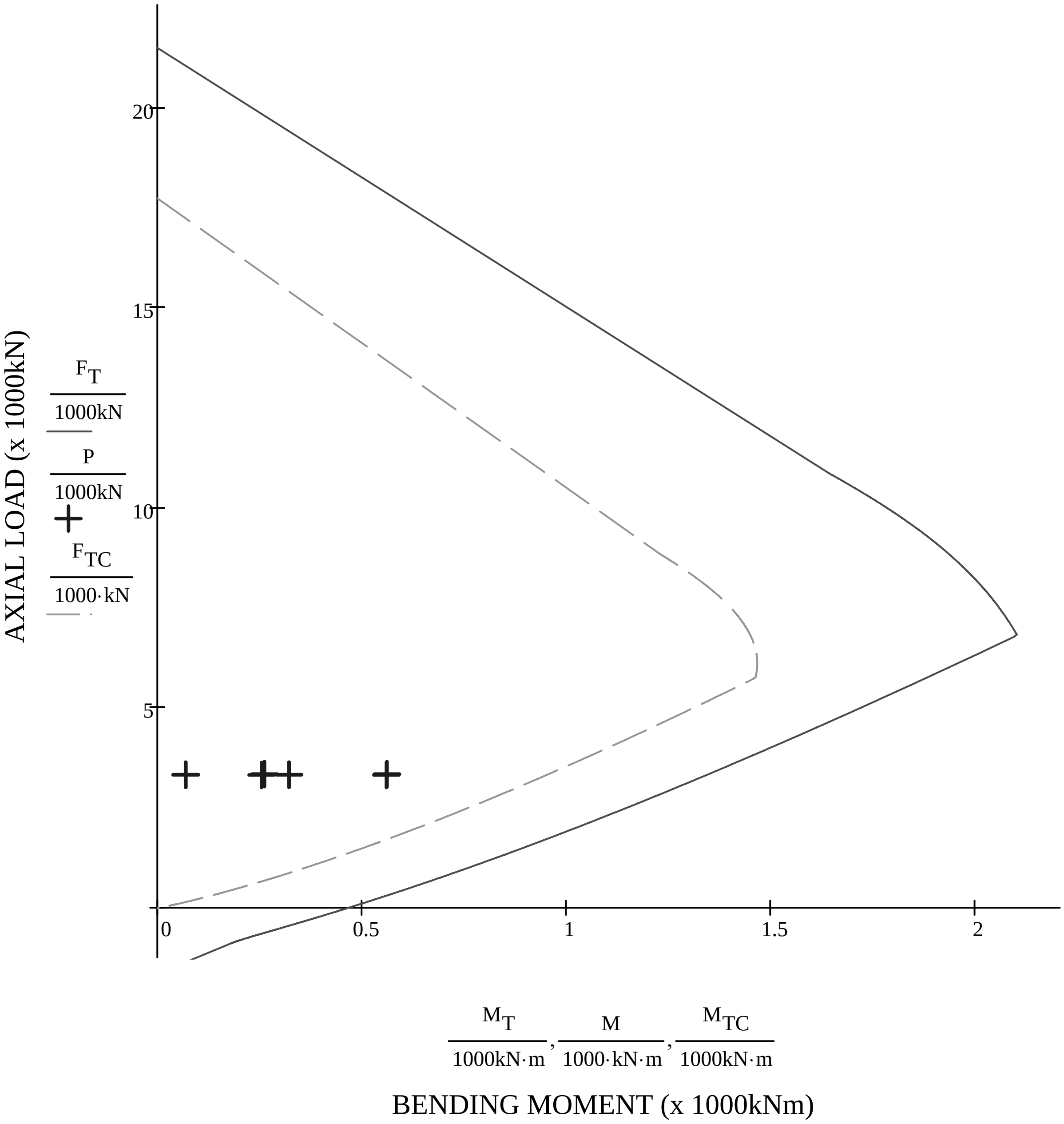
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -1640.7\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\mathrm{mm}$	Characteristic strength of concrete	$f_c = 30\,\mathrm{MPa}$
Percentage reinforcement	$\rho = 1.02\,\%$	Yield Strength of Rebar	$f_y = 390\,\mathrm{MPa}$
Thickness of CHS	$ts = 0\,\mathrm{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\mathrm{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \;\; \text{if} \;\; P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \;\; \text{if} \;\; P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \;\; \text{if} \;\; \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \;\; \text{if} \;\; \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while} \;\; F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \;\; \text{if} \;\; M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \;\; \text{otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 3337 \\ 3337 \\ 3341 \\ 3341 \\ 3355 \\ 3355 \\ 3335 \\ 3335 \end{pmatrix} kN \qquad M = \begin{pmatrix} 70 \\ 322 \\ 70 \\ 323 \\ 562 \\ 263 \\ 561 \\ 256 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.052 \\ 0.240 \\ 0.052 \\ 0.240 \\ 0.419 \\ 0.195 \\ 0.417 \\ 0.190 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			1.02	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P21**	**3337**	**70**	**1343.2**	**100%**	**5%**	OK
2	**P21**	**3337**	**322**	**1343.2**	**100%**	**24%**	OK
3	**P22**	**3341**	**70**	**1343.2**	**100%**	**5%**	OK
4	**P22**	**3341**	**323**	**1343.2**	**100%**	**24%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of**
North Java Corridor Flyover Project

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P2 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$MPa := 1000000 \cdot Pa$ $kN := 1000 \cdot N$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	12	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P21	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3336.8	287.0	140%
2	P21	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3336.8	544.2	140%
3	P22	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3341.4	286.7	140%
4	P22	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3341.4	544.8	140%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \quad D := D \cdot mm \quad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \quad dia2 := dia2 \cdot mm \quad cov1 := cov1 \cdot mm \quad cov2 := cov2 \cdot mm$

$P := P \cdot kN \quad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \quad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \quad \alpha = 7.77$

$E_C = 25743\, MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \quad \sigma_{ct} = 4.8\, MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \quad \sigma_{cc} = 30.0\, MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \quad \sigma_{rs} = 170\, MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \quad \sigma_{rc} = 390\, MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \quad \sigma_{ts} = -150\, MPa$

$\sigma_{tc} := 1 f_{ys} \quad \sigma_{tc} = 250\, MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \quad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \quad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \quad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \quad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1} - y_i\right)\cdot\frac{x_{i+1} + x_i}{2}\right] \qquad A_C = 0.94783\ m^2$$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1} - y_i}{8}\cdot\left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3}\right]\right] \qquad x_C = 0\ m$$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1} - x_i}{8}\cdot\left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3}\right]\right] \qquad y_C = 0\ m$$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1} - x_i\right)\cdot\frac{y_{i+1} + y_i}{24}\right]\cdot\left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2\right]\right] \qquad I_x = 0.07149\ m^4$$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1} - y_i\right)\cdot\frac{x_{i+1} + x_i}{24}\right]\cdot\left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2\right]\right] \qquad I_y = 0.07149\ m^4$$

$$I_{xC} := I_x - A_C\cdot x_C^{\ 2} \qquad I_{xC} = 0.07149\ m^4$$

$$I_{yC} := I_y - A_C\cdot y_C^{\ 2} \qquad I_{yC} = 0.07149\ m^4$$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

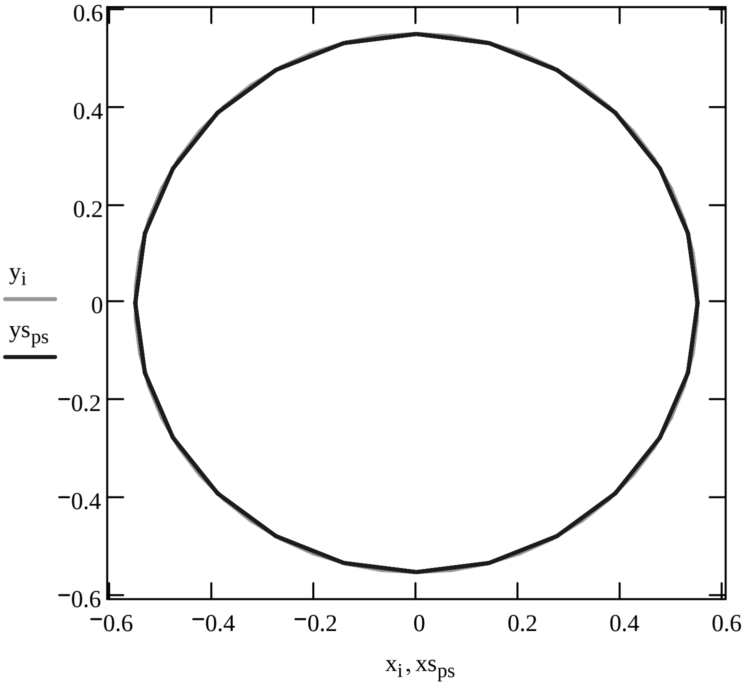
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\qquad I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\qquad I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	804	0	-474	**51**	0	0	0
2	804	-237	-410	**52**	0	0	0
3	804	-410	-237	**53**	0	0	0
4	804	-474	0	**54**	0	0	0
5	804	-410	237	**55**	0	0	0
6	804	-237	410	**56**	0	0	0
7	804	0	474	**57**	0	0	0
8	804	237	410	**58**	0	0	0
9	804	410	237	**59**	0	0	0
10	804	474	0	**60**	0	0	0
11	804	410	-237	**61**	0	0	0
12	804	237	-410	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2 \qquad A2 := A2 \cdot mm^2 \qquad A3 := A3 \cdot mm^2 \qquad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm \quad X2 := X2 \cdot mm \quad X3 := X3 \cdot mm \quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm \quad Y2 := Y2 \cdot mm \quad Y3 := Y3 \cdot mm \quad Y4 := Y4 \cdot mm$

$k := 1..50 \qquad A_{bar_k} := A1_k \qquad x_{bar_k} := X1_k \qquad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k \qquad x_{bar_{k+50}} := X2_k \qquad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k \qquad x_{bar_{k+100}} := X3_k \qquad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k \qquad x_{bar_{k+150}} := X4_k \qquad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 9651\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0102$$

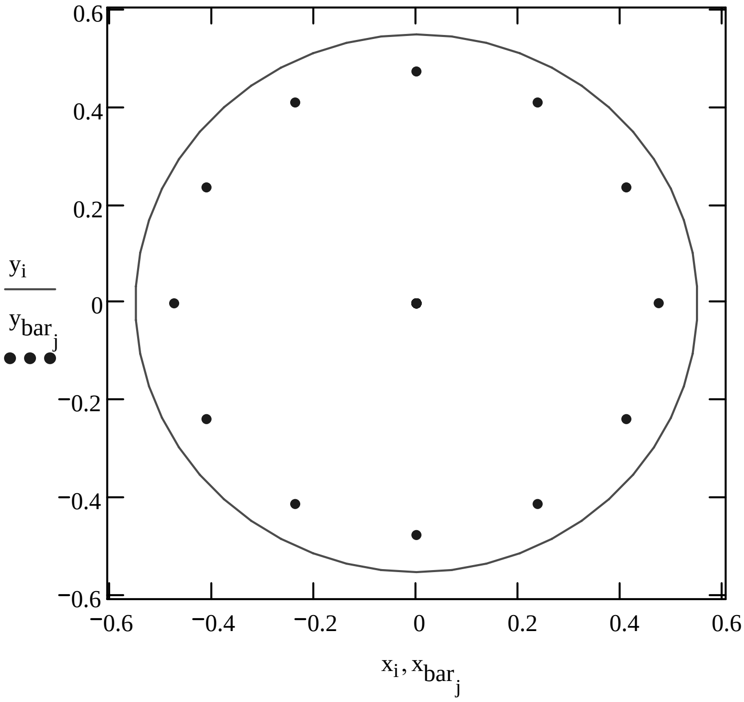
$$x_b := \begin{vmatrix} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{vmatrix} \qquad x_b = 0\text{ m}$$

$$y_b := \begin{vmatrix} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{vmatrix} \qquad y_b = 0\text{ m}$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00108\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00108\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1013161\ mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\ m$

$y_E := \dfrac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\ m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C^{\ 2} + \rho \cdot x_b^{\ 2} \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}^{\ 2}\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C^{\ 2} + \rho \cdot y_b^{\ 2} \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}^{\ 2}\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\mathrm{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\mathrm{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\mathrm{mm}$

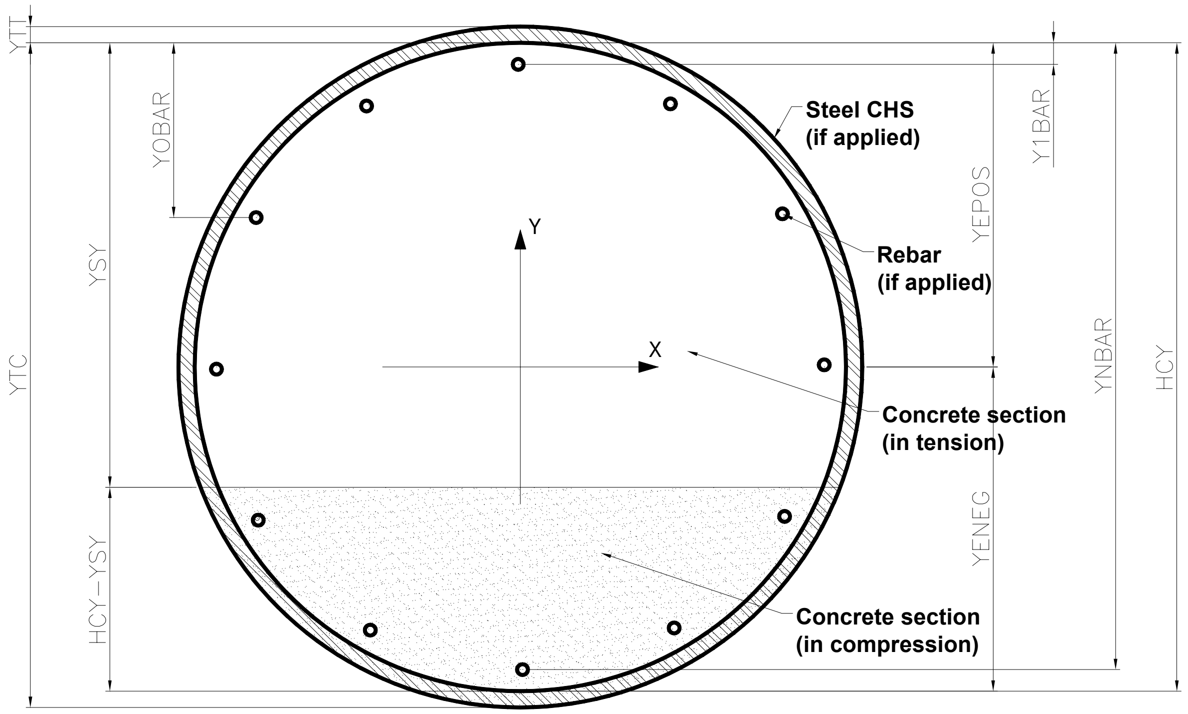
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\mathrm{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\mathrm{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\mathrm{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\mathrm{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{ll} \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} & \text{otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{ll} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \dfrac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left| \begin{array}{l} \sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\ \sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\ \sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cc} \ \text{ otherwise} \end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left| \begin{array}{l} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) \text{ if } A_{BAR} > 0 \\ 0 \text{ otherwise} \end{array} \right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left| \begin{array}{l} F_{TS1} - F_{TS2} \text{ if } ts > 0 \\ 0 \text{ otherwise} \end{array} \right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{array}{|l} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{array}{|l} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$ $\qquad$ $F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$ $\qquad$ $M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \left|\begin{array}{l} \min(\varepsilon_{cc}, \varepsilon_{tc}) \ \text{ if } \ (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) \ \text{ if } \ (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} \ \text{ if } \ (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} \ \text{ if } \ (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) \ \text{ otherwise} \end{array}\right.$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \left|\begin{array}{l} \sigma_{cd_2} \ \text{ if } \ f_c > 0 \\ 0 \ \text{ otherwise} \end{array}\right.$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21522.8\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17758.9\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

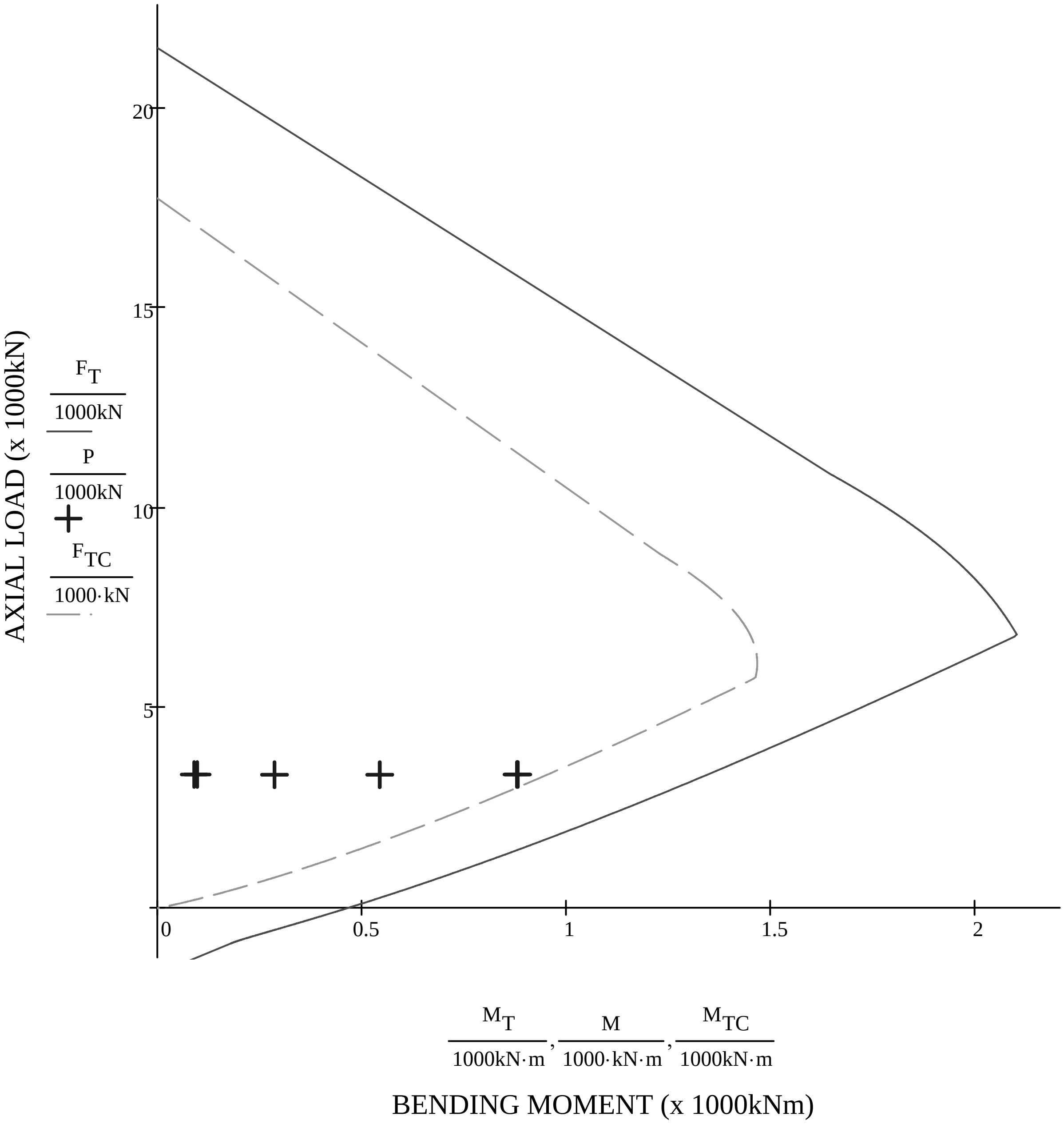
$$P_{MIN} := \left|\begin{array}{l} \varepsilon_{rs}\cdot E_S(A_{BAR}) \ \text{ if } \ ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) \ \text{ if } \ A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) \ \text{ otherwise} \end{array}\right.$$

$P_{MIN} = -1640.7\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \left|\begin{array}{l} \min(P, F_T)\cdot 0.75 \ \text{ if } \ \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 \ \text{ otherwise} \end{array}\right.$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\mathrm{mm}$	Characteristic strength of concrete	$f_c = 30\,\mathrm{MPa}$
Percentage reinforcement	$\rho = 1.02\,\%$	Yield Strength of Rebar	$f_y = 390\,\mathrm{MPa}$
Thickness of CHS	$ts = 0\,\mathrm{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\mathrm{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left|\begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \ \text{if } P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \ \text{if } P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \ \text{if } \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \ \text{if } \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left|\begin{array}{l} j \leftarrow 1 \\ \text{while } F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array}\right. \end{array}\right.$$

$$StressFactor_r := \left|\begin{array}{l} \text{"No Result"} \ \ \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \ \text{otherwise} \end{array}\right.$$

$$P = \begin{pmatrix} 3337 \\ 3337 \\ 3341 \\ 3341 \\ 3346 \\ 3346 \\ 3344 \\ 3344 \end{pmatrix} kN \qquad M = \begin{pmatrix} 287 \\ 544 \\ 287 \\ 545 \\ 880 \\ 90 \\ 883 \\ 98 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \\ 1343.2 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.214 \\ 0.405 \\ 0.213 \\ 0.406 \\ 0.655 \\ 0.067 \\ 0.657 \\ 0.073 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			1.02	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P21**	**3337**	**287**	**1343.2**	**140%**	**21%**	OK
2	**P21**	**3337**	**544**	**1343.2**	**140%**	**41%**	OK
3	**P22**	**3341**	**287**	**1343.2**	**140%**	**21%**	OK
4	**P22**	**3341**	**545**	**1343.2**	**140%**	**41%**	OK

P3 SINGLE COLUMN 1.7 M DIAMETER

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of**
North Java Corridor Flyover Project

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1700 mm Dia Circular RC Column - P3 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$MPa := 1000000 \cdot Pa$

$kN := 1000 \cdot N$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1700	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	64	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P30	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	5809.4	299.5	140%
2	P30	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	5809.4	277.2	140%

$f_c := f_c \cdot MPa$ $f_{ys} := f_{ys} \cdot MPa$ $f_y := f_y \cdot MPa$ $D := D \cdot mm$ $ts := ts \cdot mm$

$dia1 := dia1 \cdot mm$ $dia2 := dia2 \cdot mm$ $cov1 := cov1 \cdot mm$ $cov2 := cov2 \cdot mm$

$P := P \cdot kN$ $M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa$ $E_C := 4700\sqrt{\dfrac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \dfrac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases}$ $\alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\dfrac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa$ $\sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c$ $\sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases}$ $\sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases}$ $\sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys}$ $\sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys}$ $\sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\dfrac{\sigma_{rs}}{E_S}$ $\varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \dfrac{\sigma_{rc}}{E_S}$ $\varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \dfrac{\sigma_{ts}}{E_S}$ $\varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \dfrac{\sigma_{tc}}{E_S}$ $\varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-850	**26**	0	850
2	-107	-843	**27**	107	843
3	-211	-823	**28**	211	823
4	-313	-790	**29**	313	790
5	-409	-745	**30**	409	745
6	-500	-688	**31**	500	688
7	-582	-620	**32**	582	620
8	-655	-542	**33**	655	542
9	-718	-455	**34**	718	455
10	-769	-362	**35**	769	362
11	-808	-263	**36**	808	263
12	-835	-159	**37**	835	159
13	-848	-53	**38**	848	53
14	-848	53	**39**	848	-53
15	-835	159	**40**	835	-159
16	-808	263	**41**	808	-263
17	-769	362	**42**	769	-362
18	-718	455	**43**	718	-455
19	-655	542	**44**	655	-542
20	-582	620	**45**	582	-620
21	-500	688	**46**	500	-688
22	-409	745	**47**	409	-745
23	-313	790	**48**	313	-790
24	-211	823	**49**	211	-823
25	-107	843	**50**	107	-843

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right]$$

$A_C = 2.26383\ m^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right]$$

$I_x = 0.40783\ m^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right]$$

$I_y = 0.40783\ m^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.40783\ m^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.40783\ m^4$

Steel Tube Cross Section Data - generated from input

$\mathrm{ns} := 50$ Number of Points - 50 points maximum

$\mathrm{ps} := 1 .. \mathrm{ns} + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-850	**26**	0	-850
2	-220	-821	**27**	220	-821
3	-425	-736	**28**	425	-736
4	-601	-601	**29**	601	-601
5	-736	-425	**30**	736	-425
6	-821	-220	**31**	821	-220
7	-850	0	**32**	850	0
8	-821	220	**33**	821	220
9	-736	425	**34**	736	425
10	-601	601	**35**	601	601
11	-425	736	**36**	425	736
12	-220	821	**37**	220	821
13	0	850	**38**	0	850
14	220	821	**39**	-220	821
15	425	736	**40**	-425	736
16	601	601	**41**	-601	601
17	736	425	**42**	-736	425
18	821	220	**43**	-821	220
19	850	0	**44**	-850	0
20	821	-220	**45**	-821	-220
21	736	-425	**46**	-736	-425
22	601	-601	**47**	-601	-601
23	425	-736	**48**	-425	-736
24	220	-821	**49**	-220	-821
25	0	-850	**50**	0	-850

$\mathrm{XSS1} := \mathrm{XSS1} \cdot \mathrm{mm}$ $\mathrm{XSS2} := \mathrm{XSS2} \cdot \mathrm{mm}$ $\mathrm{YSS1} := \mathrm{YSS1} \cdot \mathrm{mm}$ $\mathrm{YSS2} := \mathrm{YSS2} \cdot \mathrm{mm}$

$z := 1 .. 25$ $\mathrm{xs}_z := \mathrm{XSS1}_z$ $\mathrm{ys}_z := \mathrm{YSS1}_z$

$z := 26 .. 50$ $\mathrm{xs}_z := \mathrm{XSS2}_{z-25}$ $\mathrm{ys}_z := \mathrm{YSS2}_{z-25}$

$\mathrm{xs}_{\mathrm{ns}+1} := \mathrm{XSS1}_1$ $\mathrm{ys}_{\mathrm{ns}+1} := \mathrm{YSS1}_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = -0.5\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.024\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

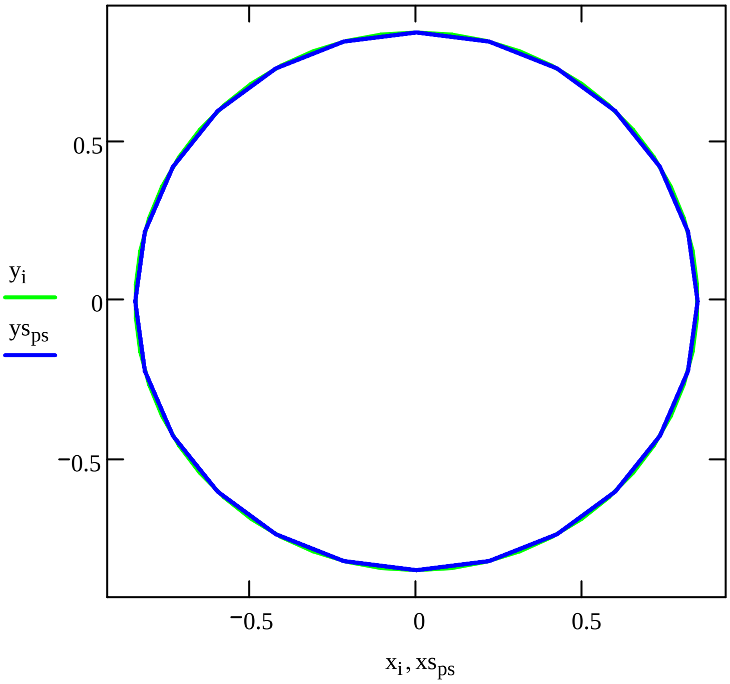
$I_{yS} = 0\ m^4$

$$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^{\,2}$$

$I_{xS} = 0\ m^4$

$$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^{\,2}$$

$I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-774	**51**	804	759	-151
2	804	-76	-770	**52**	804	741	-225
3	804	-151	-759	**53**	804	715	-296
4	804	-225	-741	**54**	804	683	-365
5	804	-296	-715	**55**	804	644	-430
6	804	-365	-683	**56**	804	598	-491
7	804	-430	-644	**57**	804	547	-547
8	804	-491	-598	**58**	804	491	-598
9	804	-547	-547	**59**	804	430	-644
10	804	-598	-491	**60**	804	365	-683
11	804	-644	-430	**61**	804	296	-715
12	804	-683	-365	**62**	804	225	-741
13	804	-715	-296	**63**	804	151	-759
14	804	-741	-225	**64**	804	76	-770
15	804	-759	-151	**65**	0	0	0
16	804	-770	-76	**66**	0	0	0
17	804	-774	0	**67**	0	0	0
18	804	-770	76	**68**	0	0	0
19	804	-759	151	**69**	0	0	0
20	804	-741	225	**70**	0	0	0
21	804	-715	296	**71**	0	0	0
22	804	-683	365	**72**	0	0	0
23	804	-644	430	**73**	0	0	0
24	804	-598	491	**74**	0	0	0
25	804	-547	547	**75**	0	0	0
26	804	-491	598	**76**	0	0	0
27	804	-430	644	**77**	0	0	0
28	804	-365	683	**78**	0	0	0
29	804	-296	715	**79**	0	0	0
30	804	-225	741	**80**	0	0	0
31	804	-151	759	**81**	0	0	0
32	804	-76	770	**82**	0	0	0
33	804	0	774	**83**	0	0	0
34	804	76	770	**84**	0	0	0
35	804	151	759	**85**	0	0	0
36	804	225	741	**86**	0	0	0
37	804	296	715	**87**	0	0	0
38	804	365	683	**88**	0	0	0
39	804	430	644	**89**	0	0	0
40	804	491	598	**90**	0	0	0
41	804	547	547	**91**	0	0	0
42	804	598	491	**92**	0	0	0
43	804	644	430	**93**	0	0	0
44	804	683	365	**94**	0	0	0
45	804	715	296	**95**	0	0	0
46	804	741	225	**96**	0	0	0
47	804	759	151	**97**	0	0	0
48	804	770	76	**98**	0	0	0
49	804	774	0	**99**	0	0	0
50	804	770	-76	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1..50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 51472\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0227$$

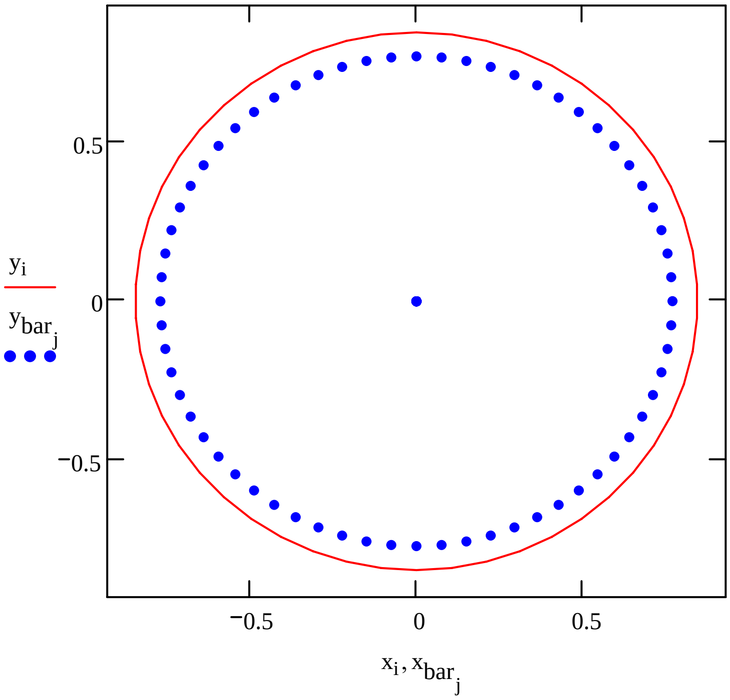
$$x_b := \begin{array}{|l} \left[\sum_{j=1}^{200}\left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \qquad x_b = 0\ m$$

$$y_b := \begin{array}{|l} \left[\sum_{j=1}^{200}\left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200}\left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.01542\,m^4$$

$$I_{yb} := \sum_{j=1}^{200}\left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.01542\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot \left[1 + \rho \cdot (\alpha - 1)\right] + A_{ST} \cdot \alpha$ $A_E = 2612250\ mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot \left[(1 - \rho) \cdot x_C + \rho \cdot x_b \cdot \alpha\right] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\ m$

$y_E := \dfrac{A_C \cdot \left[(1 - \rho) \cdot y_C + \rho \cdot y_b \cdot \alpha\right] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\ m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot x_C^2 + \rho \cdot x_b^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}^2\right) \cdot \alpha$

$I_{EX} = 1\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot y_C^2 + \rho \cdot y_b^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}^2\right) \cdot \alpha$

$I_{EY} = 1\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 2\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 2\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 850\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -850\,\text{mm}$

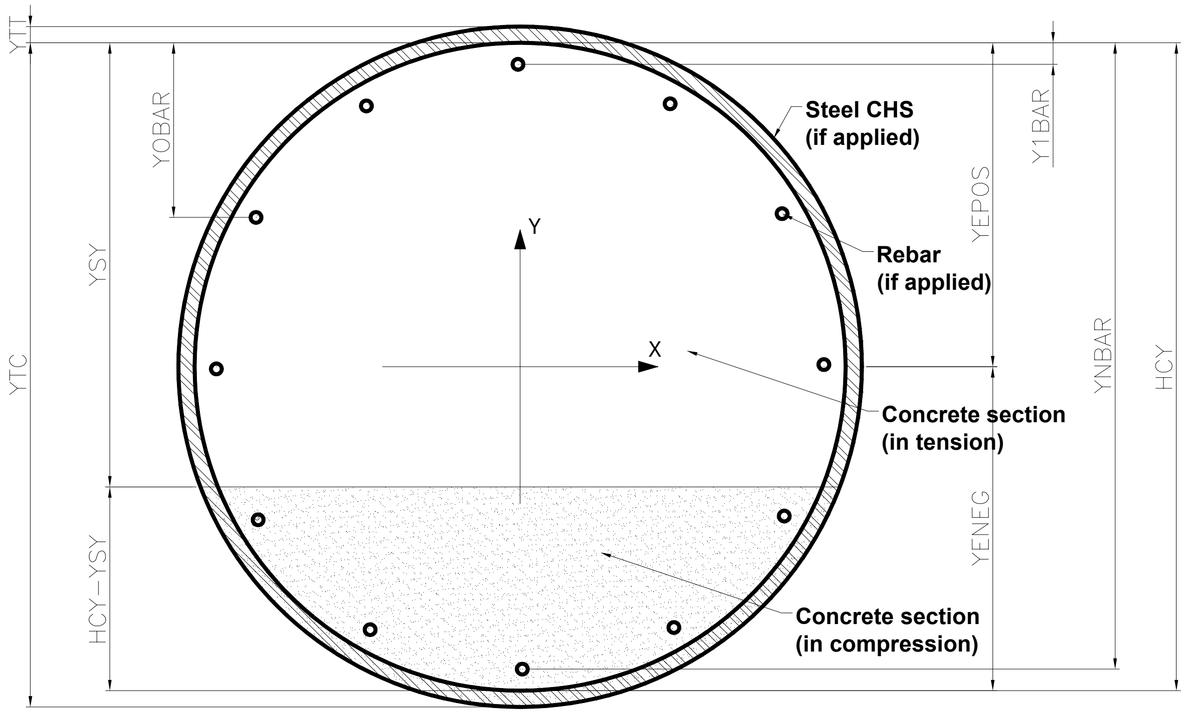
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min(y_{Epos} - y_{bar})$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max(y_{Epos} - y_{bar})$ $y_{nbar} = 1624\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1700\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \begin{vmatrix} \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} & \text{otherwise} \end{vmatrix} \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \begin{vmatrix} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} & \text{otherwise} \end{vmatrix}$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \dfrac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd(\varepsilon_{tcc}, q) := \left| \begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ (f_c = 0) \cdot (A_{BAR} = 0) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ (f_c = 0) \cdot (ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ (\varepsilon_{tcc} > \varepsilon_{tc}) \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc} \right) \cdot (A_{BAR} > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}} < \varepsilon_{ts} \right] \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{-(y_{SY_q} - y_{1bar})}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc(f_c, \sigma_{cd}) \cdot \dfrac{-(y_{SY_q} - y_{1bar})}{H_{CY} - y_{SY_q}} < \varepsilon_{rs} \right] \cdot (A_{BAR} > 0) \\
\sigma_{cc} \ \text{ otherwise}
\end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \left| \begin{array}{l} y_{nbar}\cdot\frac{q}{ns+1} \quad \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} \quad \text{otherwise} \end{array} \right.$$

$$\varepsilon_{S_{j,q}} := \left| \begin{array}{l} -\frac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{if } f_c = 0 \\ -\frac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{otherwise} \end{array} \right.$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \left| \begin{array}{l} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} \quad \text{if } A_{BAR} > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{cases} F_{TC1} - F_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{cases} M_{TS1} - M_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$

$F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$

$M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \left| \begin{array}{l} \min(\varepsilon_{cc}, \varepsilon_{tc}) \ \text{ if } \ (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) \ \text{ if } \ (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} \ \text{ if } \ (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} \ \text{ if } \ (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) \ \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cL} = 0.001950$$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \left| \begin{array}{l} \sigma_{cd_2} \ \text{ if } \ f_c > 0 \\ 0 \ \text{ otherwise} \end{array} \right. \qquad \sigma_{cL} = 18.44\,\text{MPa}$$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1 - \rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 60878.4\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1 - \rho)$$

$P_{MAXC} = 40804.4\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

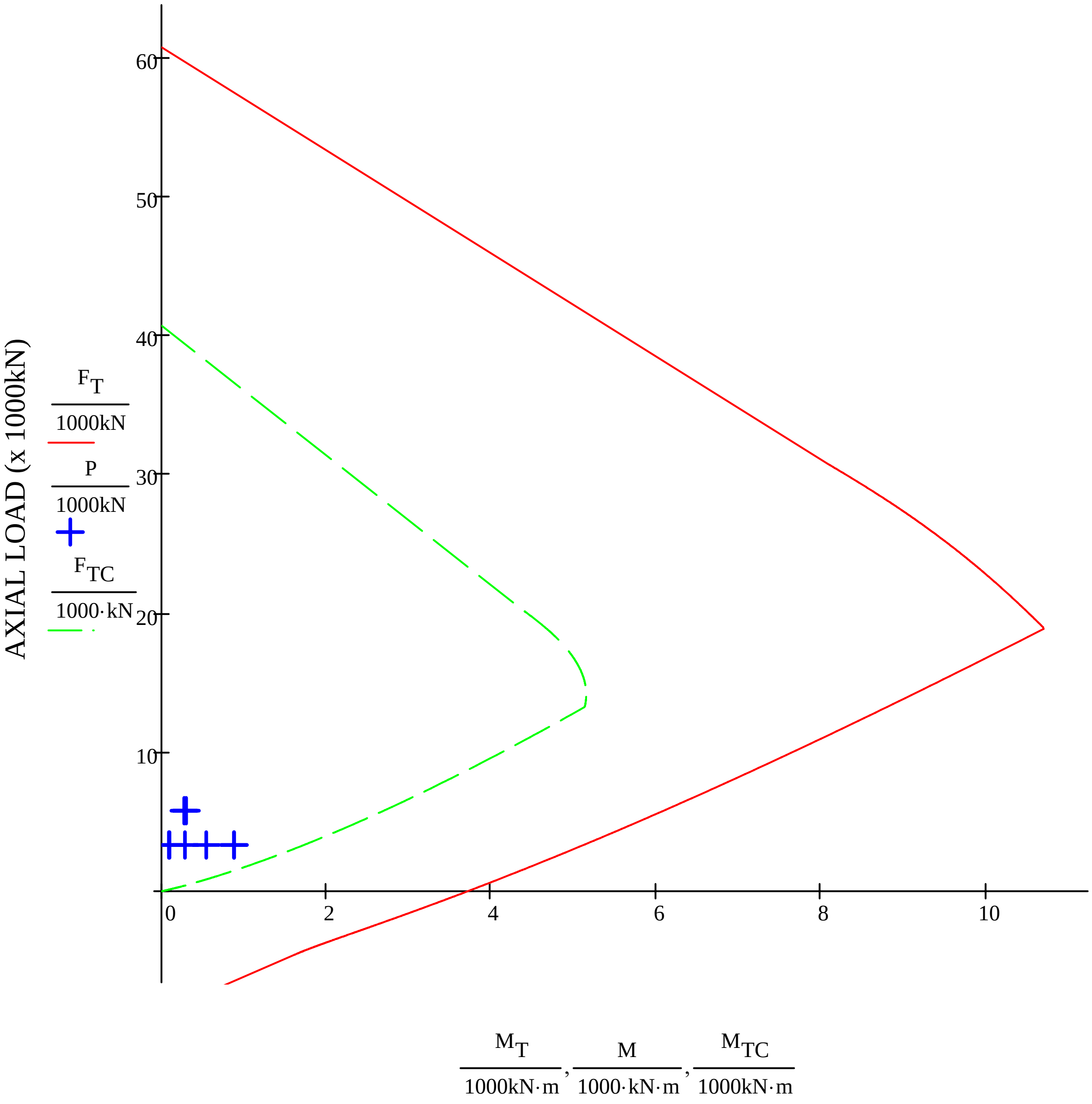
$$P_{MIN} := \left| \begin{array}{l} \varepsilon_{rs}\cdot E_S(A_{BAR}) \ \text{ if } \ ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) \ \text{ if } \ A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) \ \text{ otherwise} \end{array} \right.$$

$P_{MIN} = -8750.2\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \left| \begin{array}{l} \min(P, F_T)\cdot 0.75 \ \text{ if } \ \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 \ \text{ otherwise} \end{array} \right.$$

$P_{MINC} := 0\text{kN}$ $\qquad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1700\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 2.27\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



BENDING MOMENT (x 1000kNm)

INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r > F_{T_1}$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r < F_{T_{ns+1}}$
    $(P_r - c1) \cdot m1$  if  $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
    $(P_r - c2) \cdot m2$  if  $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
    otherwise
        $j \leftarrow 1$
        while  $F_{T_j} > P_r$
            $j \leftarrow j + 1$
        $M_{T_j}$
```

```
$StressFactor_r :=$
    "No Result"  if  $M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m$
    $\frac{M_r}{M_{SLS_r}}$  otherwise
```

$$P = \begin{pmatrix} 5809 \\ 5809 \\ 3341 \\ 3341 \\ 3346 \\ 3346 \\ 3344 \\ 3344 \end{pmatrix} kN \qquad M = \begin{pmatrix} 299 \\ 277 \\ 287 \\ 545 \\ 880 \\ 90 \\ 883 \\ 98 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 6075.0 \\ 6075.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.049 \\ 0.046 \\ 0.056 \\ 0.107 \\ 0.172 \\ 0.018 \\ 0.173 \\ 0.019 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1700	mm			
Percentage of rebar			2.27	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P30**	**5809**	**299**	**6075.0**	**140%**	**5%**	OK
2	**P30**	**5809**	**277**	**6075.0**	**140%**	**5%**	OK

KATAHIRA & ENGINEERS
INTERNATIONAL

Project:	**Detailed Design Study of** **North Java Corridor Flyover Project**
Calculation:	**Balaraja Flyover** **Serviceability Check - Traffic Load Only** **1700 mm Dia Circular RC Column - P3 Base Section**
Reference:	**Project Specific Design Criteria**

Section Data

$MPa := 1000000 \cdot Pa$ $kN := 1000 \cdot N$

Input Item			
Concrete Compressive Strength	f_c	30	MPa
Structural Steel Yield Strength	f_{ys}	250	MPa
Rebar Yield Strength	f_y	390	MPa
Diameter of reinforced concrete section	D	1700	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	$dia1$	32	mm
Diameter of rebar - layer 2	$dia2$	0	mm
Number bars - layer 1 (max 100)	$n1$	64	
Number bars - layer 2 (max 100)	$n2$	0	
Cover from face of section - layer 1	$cov1$	60	mm
Cover from face of section - layer 2	$cov2$	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P30	Combination 1 - P + Traffic Load Only	5278.4	2181.0	100%
2	P30	Combination 1 - P + Traffic Load Only	5278.4	2156.4	100%

$f_c := f_c \cdot MPa$ $f_{ys} := f_{ys} \cdot MPa$ $f_y := f_y \cdot MPa$ $D := D \cdot mm$ $ts := ts \cdot mm$

$dia1 := dia1 \cdot mm$ $dia2 := dia2 \cdot mm$ $cov1 := cov1 \cdot mm$ $cov2 := cov2 \cdot mm$

$P := P \cdot kN$ $M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa$ $E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \left| \begin{array}{ll} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{array} \right.$ $\alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa$ $\sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c$ $\sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \left| \begin{array}{ll} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{array} \right.$ $\sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \left| \begin{array}{ll} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{array} \right.$ $\sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys}$ $\sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys}$ $\sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S}$ $\varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S}$ $\varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S}$ $\varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S}$ $\varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-850	**26**	0	850
2	-107	-843	**27**	107	843
3	-211	-823	**28**	211	823
4	-313	-790	**29**	313	790
5	-409	-745	**30**	409	745
6	-500	-688	**31**	500	688
7	-582	-620	**32**	582	620
8	-655	-542	**33**	655	542
9	-718	-455	**34**	718	455
10	-769	-362	**35**	769	362
11	-808	-263	**36**	808	263
12	-835	-159	**37**	835	159
13	-848	-53	**38**	848	53
14	-848	53	**39**	848	-53
15	-835	159	**40**	835	-159
16	-808	263	**41**	808	-263
17	-769	362	**42**	769	-362
18	-718	455	**43**	718	-455
19	-655	542	**44**	655	-542
20	-582	620	**45**	582	-620
21	-500	688	**46**	500	-688
22	-409	745	**47**	409	-745
23	-313	790	**48**	313	-790
24	-211	823	**49**	211	-823
25	-107	843	**50**	107	-843

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right]$$

$A_C = 2.26383\ m^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right]$$

$I_x = 0.40783\ m^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right]$$

$I_y = 0.40783\ m^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.40783\ m^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.40783\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	**X**	**Y**	**Ref.**	**X**	**Y**
	mm	**mm**		**mm**	**mm**
1	0	-850	**26**	0	-850
2	-220	-821	**27**	220	-821
3	-425	-736	**28**	425	-736
4	-601	-601	**29**	601	-601
5	-736	-425	**30**	736	-425
6	-821	-220	**31**	821	-220
7	-850	0	**32**	850	0
8	-821	220	**33**	821	220
9	-736	425	**34**	736	425
10	-601	601	**35**	601	601
11	-425	736	**36**	425	736
12	-220	821	**37**	220	821
13	0	850	**38**	0	850
14	220	821	**39**	-220	821
15	425	736	**40**	-425	736
16	601	601	**41**	-601	601
17	736	425	**42**	-736	425
18	821	220	**43**	-821	220
19	850	0	**44**	-850	0
20	821	-220	**45**	-821	-220
21	736	-425	**46**	-736	-425
22	601	-601	**47**	-601	-601
23	425	-736	**48**	-425	-736
24	220	-821	**49**	-220	-821
25	0	-850	**50**	0	-850

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$

$A_{ST} = 0\ \mathrm{m}^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = -0.5\ \mathrm{m}$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.024\ \mathrm{m}$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

$I_{xS} = 0\ \mathrm{m}^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

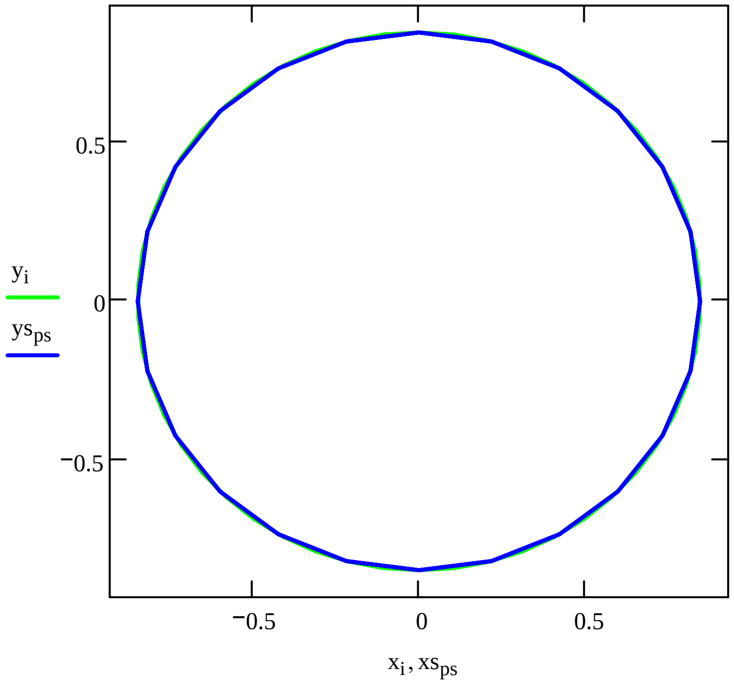
$I_{yS} = 0\ \mathrm{m}^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$

$I_{xS} = 0\ \mathrm{m}^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$

$I_{yS} = 0.00000\ \mathrm{m}^4$



Rebar Data Layer 1 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	804	0	-774	**51**	804	759	-151
2	804	-76	-770	**52**	804	741	-225
3	804	-151	-759	**53**	804	715	-296
4	804	-225	-741	**54**	804	683	-365
5	804	-296	-715	**55**	804	644	-430
6	804	-365	-683	**56**	804	598	-491
7	804	-430	-644	**57**	804	547	-547
8	804	-491	-598	**58**	804	491	-598
9	804	-547	-547	**59**	804	430	-644
10	804	-598	-491	**60**	804	365	-683
11	804	-644	-430	**61**	804	296	-715
12	804	-683	-365	**62**	804	225	-741
13	804	-715	-296	**63**	804	151	-759
14	804	-741	-225	**64**	804	76	-770
15	804	-759	-151	**65**	0	0	0
16	804	-770	-76	**66**	0	0	0
17	804	-774	0	**67**	0	0	0
18	804	-770	76	**68**	0	0	0
19	804	-759	151	**69**	0	0	0
20	804	-741	225	**70**	0	0	0
21	804	-715	296	**71**	0	0	0
22	804	-683	365	**72**	0	0	0
23	804	-644	430	**73**	0	0	0
24	804	-598	491	**74**	0	0	0
25	804	-547	547	**75**	0	0	0
26	804	-491	598	**76**	0	0	0
27	804	-430	644	**77**	0	0	0
28	804	-365	683	**78**	0	0	0
29	804	-296	715	**79**	0	0	0
30	804	-225	741	**80**	0	0	0
31	804	-151	759	**81**	0	0	0
32	804	-76	770	**82**	0	0	0
33	804	0	774	**83**	0	0	0
34	804	76	770	**84**	0	0	0
35	804	151	759	**85**	0	0	0
36	804	225	741	**86**	0	0	0
37	804	296	715	**87**	0	0	0
38	804	365	683	**88**	0	0	0
39	804	430	644	**89**	0	0	0
40	804	491	598	**90**	0	0	0
41	804	547	547	**91**	0	0	0
42	804	598	491	**92**	0	0	0
43	804	644	430	**93**	0	0	0
44	804	683	365	**94**	0	0	0
45	804	715	296	**95**	0	0	0
46	804	741	225	**96**	0	0	0
47	804	759	151	**97**	0	0	0
48	804	770	76	**98**	0	0	0
49	804	774	0	**99**	0	0	0
50	804	770	-76	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 51472\ mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0227$$

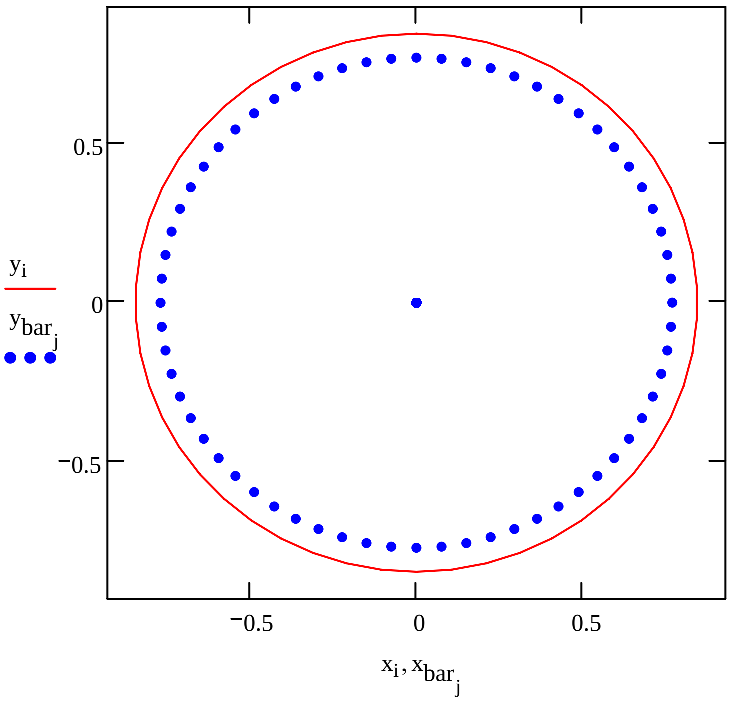
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \ \text{ if } A_{BAR} > 0 \\ 0m \ \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \ \text{ if } A_{BAR} > 0 \\ 0m \ \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.01542\ m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.01542\ m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\quad A_E = 2612250\ mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\quad x_E = 0.000\ m$

$y_E := \dfrac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\quad y_E = 0.000\ m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$I_{EX} = 1\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$

$I_{EY} = 1\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $\quad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $\quad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $\quad H_{CX} = 2\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $\quad H_{CY} = 2\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$ts := y_1 - ys_1$ $\qquad ts = 0\,mm$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $\quad y_{Epos} := \max(y) \quad y_{Epos} = 850\,mm$

Negative case - determine coord of extreme concrete fiber $\quad y_{Eneg} := \min(y) \quad y_{Eneg} = -850\,mm$

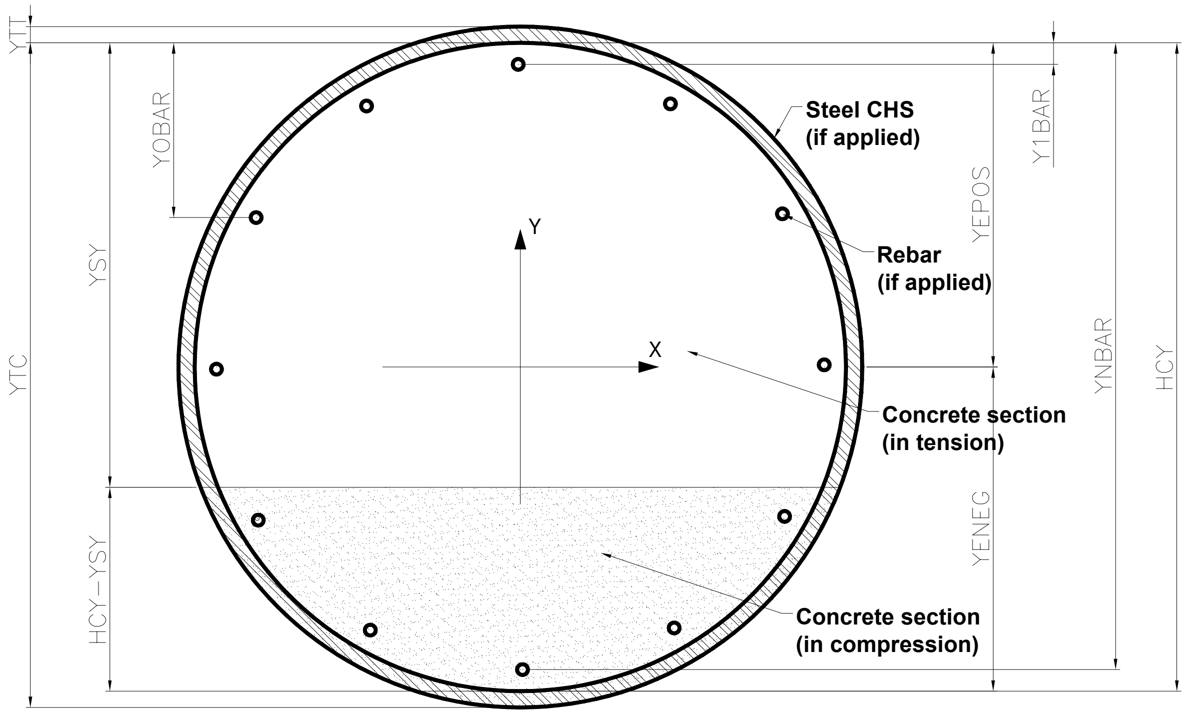
Offsets of rebar from extreme fiber $\quad y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $\quad y_{1bar} := \min\left(y_{Epos} - y_{bar}\right) \quad y_{1bar} = 76\,mm$

Determine most extreme rebar (maximum offset) $\quad y_{nbar} := \max\left(y_{Epos} - y_{bar}\right) \quad y_{nbar} = 1624\,mm$

Offsets of extreme steel tube fiber from extreme concrete fiber $\quad y_{tt} := ts \quad y_{tt} = 0\,mm$

$y_{tc} := H_{CY} + ts \quad y_{tc} = 1700\,mm$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2$ $\frac{\sigma_{cc}}{E_C} = 0.001165$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc)$ $\varepsilon_{cc} = 0.003321$

$$\varepsilon_{cc} := \left| \begin{array}{ll} \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} & \text{otherwise} \end{array} \right.$$

$\varepsilon_{cc} = 0.003321$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{ll} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \dfrac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$
\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|
\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array}
\right.
$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\frac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\frac{y_{SY_q}-y_{Obar_j}}{y_{nbar}-y_{SY_q}}\cdot\varepsilon cc\left(f_c,\sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\frac{y_{SY_q}-y_{Obar_j}}{H_{CY}-y_{SY_q}}\cdot\varepsilon cc\left(f_c,\sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \left|\begin{array}{l} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}\right.$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \left|\begin{array}{l} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}\right.$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$

$F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$

$M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc},\varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc},\varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.44\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 60878.4\,\text{kN}$ $F_{T_1} := P_{MAX}$ $M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 40804.4\,\text{kN}$ $F_{TC_1} := P_{MAXC}$ $M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

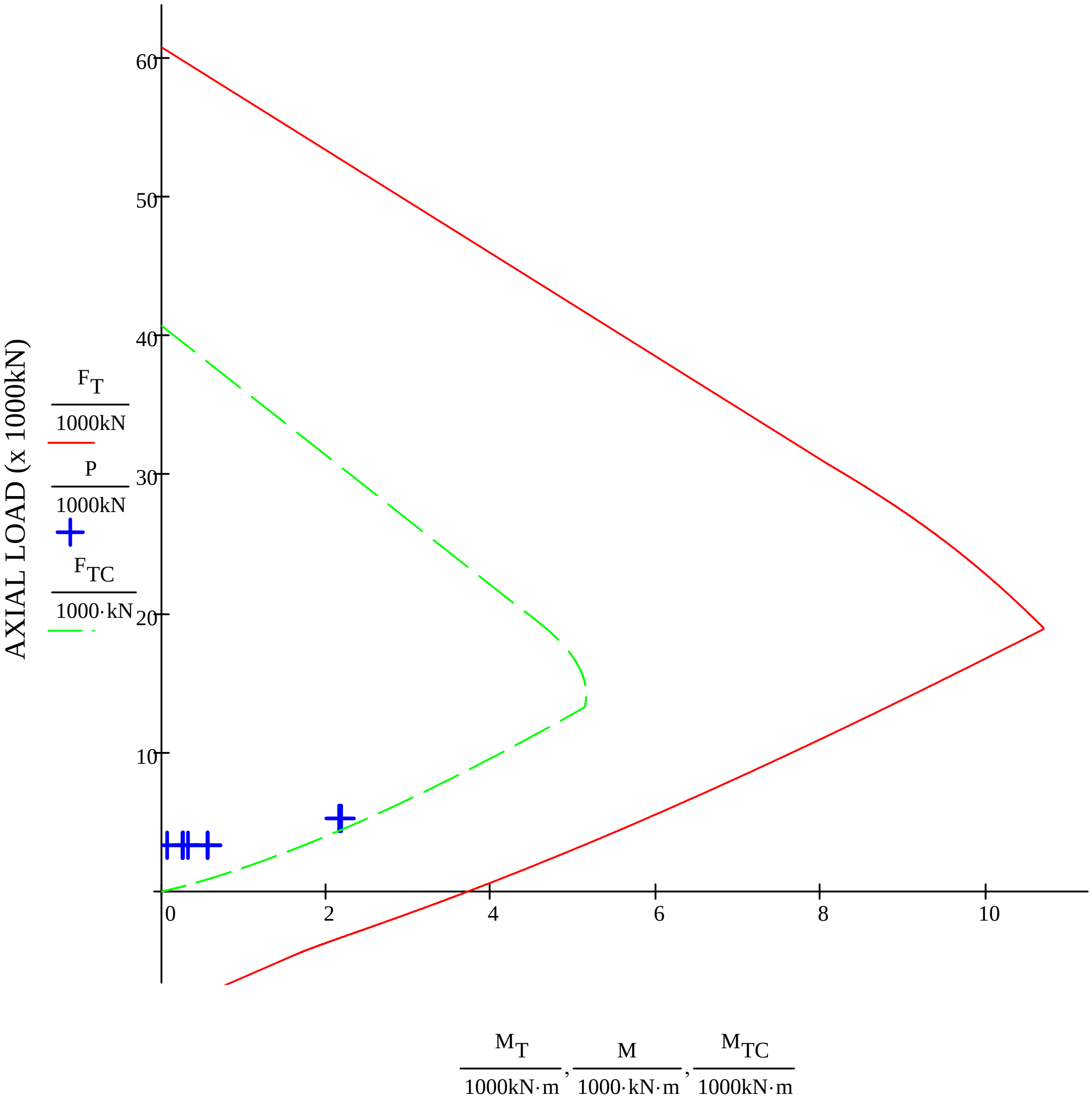
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -8750.2\,\text{kN}$ $F_{T_{ns+1}} := P_{MIN}$ $M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1700\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 2.27\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 0\,mm$	Yield Strength of CHS	$f_{ys} = 250\,MPa$



BENDING MOMENT (x 1000kNm)

INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r > F_{T_1}$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r < F_{T_{ns+1}}$
    $(P_r - c1) \cdot m1$  if  $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
    $(P_r - c2) \cdot m2$  if  $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
    otherwise
        $j \leftarrow 1$
        while  $F_{T_j} > P_r$
            $j \leftarrow j + 1$
        $M_{T_j}$
```

```
$StressFactor_r :=$
    "No Result"  if  $M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m$
    $\frac{M_r}{M_{SLS_r}}$  otherwise
```

$$P = \begin{pmatrix} 5278 \\ 5278 \\ 3341 \\ 3341 \\ 3355 \\ 3355 \\ 3335 \\ 3335 \end{pmatrix} kN \qquad M = \begin{pmatrix} 2181 \\ 2156 \\ 70 \\ 323 \\ 562 \\ 263 \\ 561 \\ 256 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 5863.3 \\ 5863.3 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \\ 5105.0 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.372 \\ 0.368 \\ 0.014 \\ 0.063 \\ 0.110 \\ 0.051 \\ 0.110 \\ 0.050 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1700	mm			
Percentage of rebar			2.27	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P30**	**5278**	**2181**	**5863.3**	**100%**	**37%**	OK
2	**P30**	**5278**	**2156**	**5863.3**	**100%**	**37%**	OK

P6 PORTAL COLUMN 1.1 M DIAMETER

TOP

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Traffic Load Only
1100 mm Dia Circular RC Column - P6 Top Section

Reference: **Project Specific Design Criteria**

Section Data

$\mathrm{MPa} := 1000000 \cdot \mathrm{Pa}$ $\quad \mathrm{kN} := 1000 \cdot \mathrm{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	24	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P61	Combination 1 - P + Traffic Load Only	2758.5	131.5	100%
2	P61	Combination 1 - P + Traffic Load Only	2758.5	12.8	100%
3	P62	Combination 1 - P + Traffic Load Only	2666.4	131.2	100%
4	P62	Combination 1 - P + Traffic Load Only	2666.4	12.6	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \quad E_C := 4700\sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right] \qquad A_C = 0.94783\ m^2$$

$$x_C := -\frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{y_{i+1} - y_i}{8} \cdot \left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3} \right] \right] \qquad x_C = 0\ m$$

$$y_C := \frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{x_{i+1} - x_i}{8} \cdot \left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3} \right] \right] \qquad y_C = 0\ m$$

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right] \qquad I_x = 0.07149\ m^4$$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right] \qquad I_y = 0.07149\ m^4$$

$$I_{xC} := I_x - A_C \cdot x_C^{\,2} \qquad I_{xC} = 0.07149\ m^4$$

$$I_{yC} := I_y - A_C \cdot y_C^{\,2} \qquad I_{yC} = 0.07149\ m^4$$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

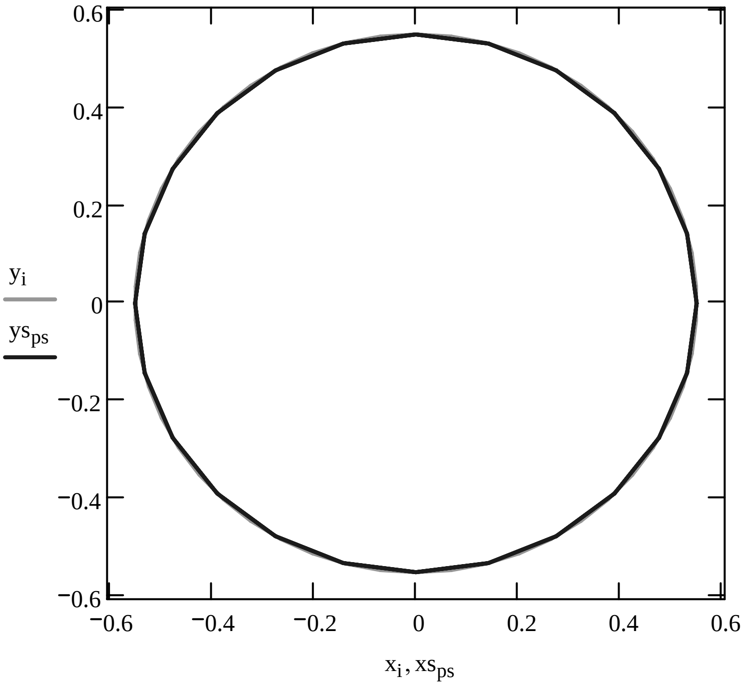
$I_{yS} = 0\ m^4$

$$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$$

$I_{xS} = 0\ m^4$

$$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$$

$I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	804	0	-474	**51**	0	0	0
2	804	-123	-458	**52**	0	0	0
3	804	-237	-410	**53**	0	0	0
4	804	-335	-335	**54**	0	0	0
5	804	-410	-237	**55**	0	0	0
6	804	-458	-123	**56**	0	0	0
7	804	-474	0	**57**	0	0	0
8	804	-458	123	**58**	0	0	0
9	804	-410	237	**59**	0	0	0
10	804	-335	335	**60**	0	0	0
11	804	-237	410	**61**	0	0	0
12	804	-123	458	**62**	0	0	0
13	804	0	474	**63**	0	0	0
14	804	123	458	**64**	0	0	0
15	804	237	410	**65**	0	0	0
16	804	335	335	**66**	0	0	0
17	804	410	237	**67**	0	0	0
18	804	458	123	**68**	0	0	0
19	804	474	0	**69**	0	0	0
20	804	458	-123	**70**	0	0	0
21	804	410	-237	**71**	0	0	0
22	804	335	-335	**72**	0	0	0
23	804	237	-410	**73**	0	0	0
24	804	123	-458	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $\quad A2 := A2 \cdot mm^2$ $\quad A3 := A3 \cdot mm^2$ $\quad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $\quad X2 := X2 \cdot mm$ $\quad X3 := X3 \cdot mm$ $\quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $\quad Y2 := Y2 \cdot mm$ $\quad Y3 := Y3 \cdot mm$ $\quad Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $\quad A_{bar_k} := A1_k$ $\quad x_{bar_k} := X1_k$ $\quad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $\quad x_{bar_{k+50}} := X2_k$ $\quad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $\quad x_{bar_{k+100}} := X3_k$ $\quad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $\quad x_{bar_{k+150}} := X4_k$ $\quad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 19302\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0204$$

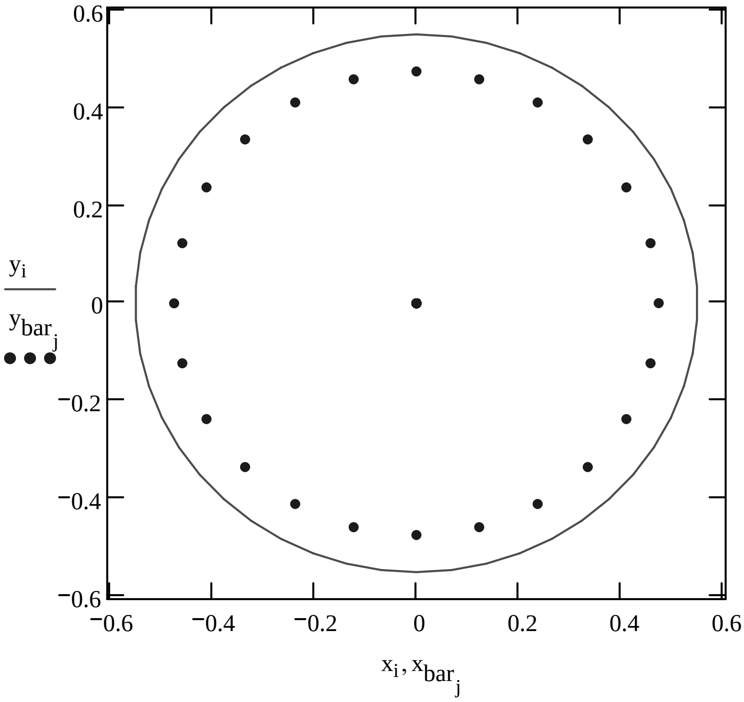
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00217\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00217\,m^4$$

$j := 1..200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\quad A_E = 1078490\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\quad x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\quad y_E = 0.000\,m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $\quad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $\quad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $\quad H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $\quad H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

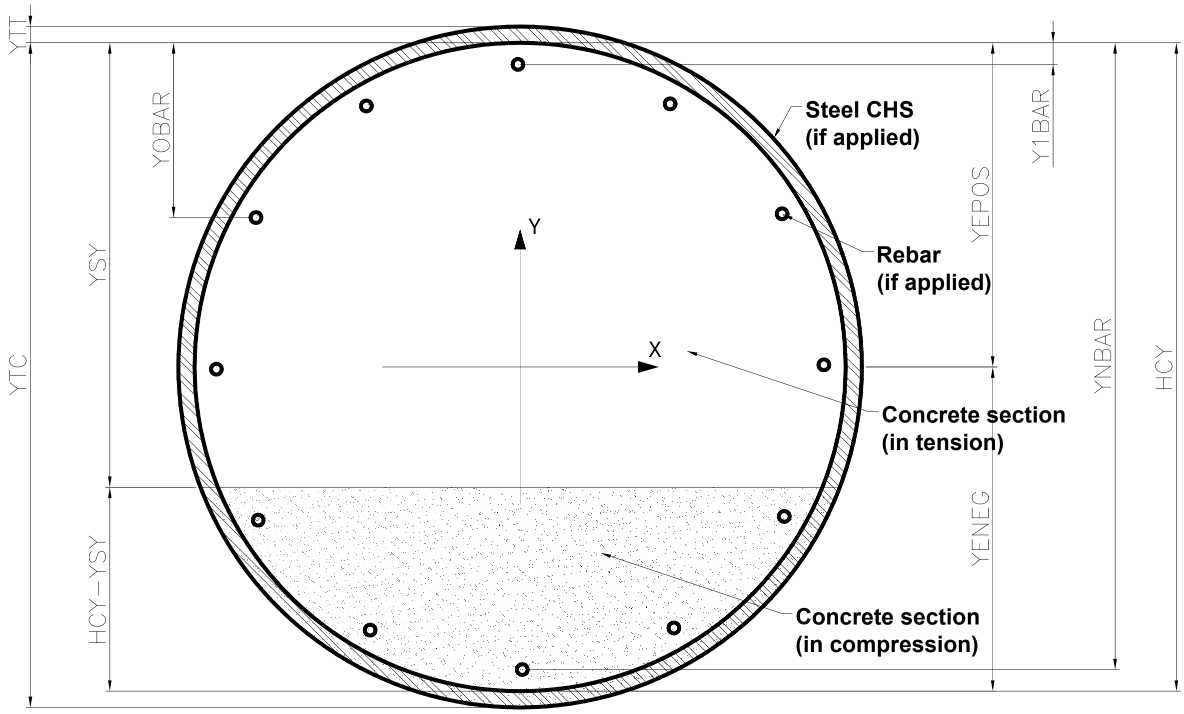
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min(y_{Epos} - y_{bar})$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max(y_{Epos} - y_{bar})$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns+1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{l} \varepsilon_{tc} \ \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \ \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \ \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{l} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \ \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \ \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \ \text{ otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc}\cdot\frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc}\cdot\frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right)\cdot(ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot(ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot(ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array}\right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left| \begin{array}{ll} \displaystyle\sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left| \begin{array}{ll} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{vmatrix} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{vmatrix} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC} \qquad F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC} \qquad M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc},\varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc},\varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 25104\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17576.2\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

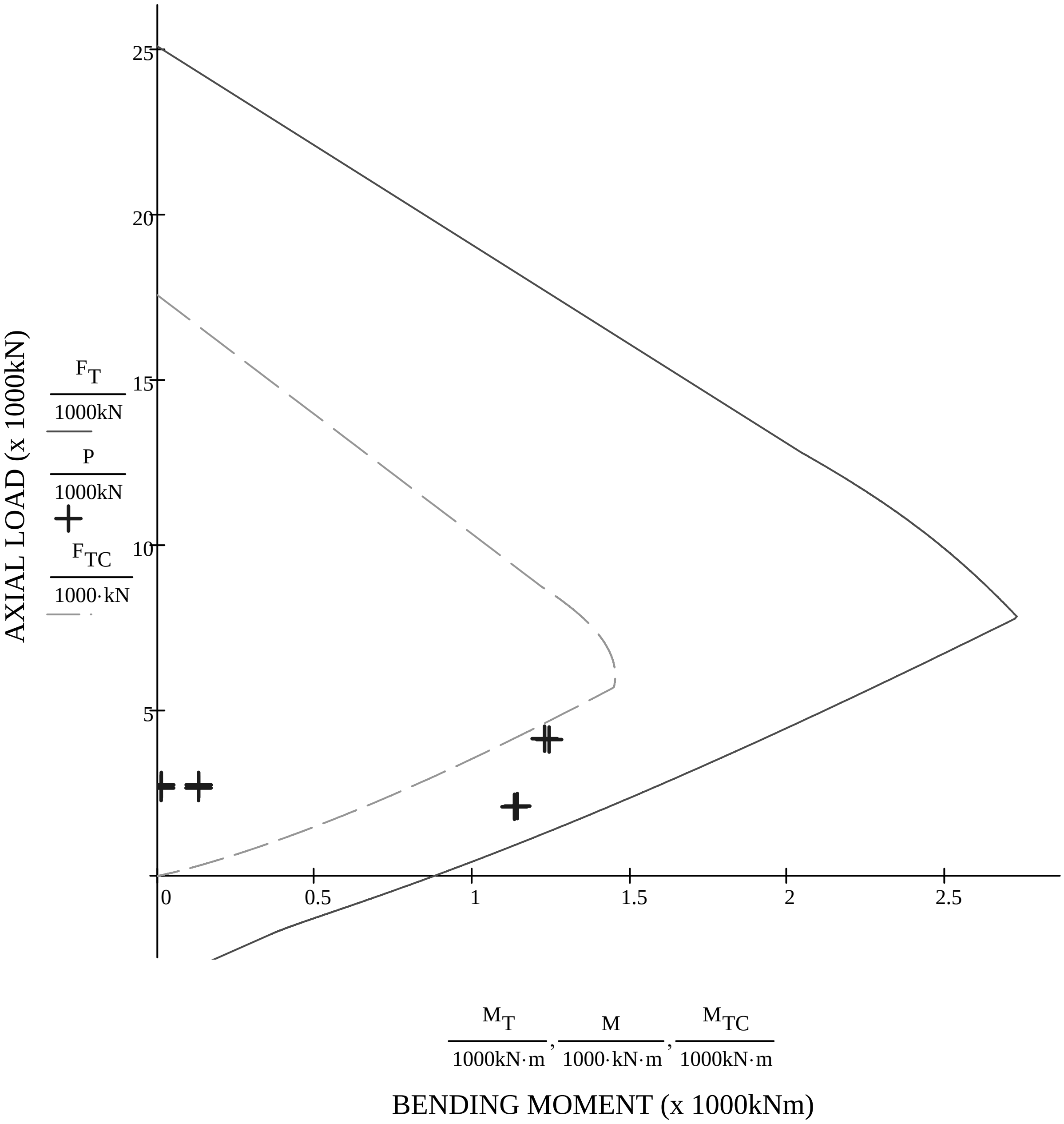
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -3281.3\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 2.04\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 2758 \\ 2758 \\ 2666 \\ 2666 \\ 2096 \\ 4131 \\ 2119 \\ 4157 \end{pmatrix} kN \qquad M = \begin{pmatrix} 132 \\ 13 \\ 131 \\ 13 \\ 1133 \\ 1243 \\ 1143 \\ 1229 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1589.0 \\ 1589.0 \\ 1564.4 \\ 1564.4 \\ 1426.5 \\ 1911.2 \\ 1437.4 \\ 1911.2 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.083 \\ 0.008 \\ 0.084 \\ 0.008 \\ 0.794 \\ 0.651 \\ 0.795 \\ 0.643 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column 1100 mm

Percentage of rebar 2.04 %

Load Case Ref	Pier	Applied Service Axial Load kN	Applied Service Bending Moment kNm	Service Limit State Bending Moment kNm	Allowable Stress Factor	Applied Stress Factor	Serviceability Limit State Design Result
1	**P61**	**2758**	**132**	**1589.0**	**100%**	**8%**	OK
2	**P61**	**2758**	**13**	**1589.0**	**100%**	**1%**	OK
3	**P62**	**2666**	**131**	**1564.4**	**100%**	**8%**	OK
4	**P62**	**2666**	**13**	**1564.4**	**100%**	**1%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P6 Top Section

Reference: **Project Specific Design Criteria**

Section Data

$\text{MPa} := 1000000 \cdot \text{Pa}$

$\text{kN} := 1000 \cdot \text{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	24	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P61	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2747.9	177.8	140%
2	P61	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2747.9	58.0	140%
3	P62	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2669.5	177.5	140%
4	P62	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2669.5	58.2	140%

$f_c := f_c \cdot \mathrm{MPa} \quad f_{ys} := f_{ys} \cdot \mathrm{MPa} \quad f_y := f_y \cdot \mathrm{MPa} \qquad D := D \cdot \mathrm{mm} \qquad ts := ts \cdot \mathrm{mm}$

$\mathrm{dia1} := \mathrm{dia1} \cdot \mathrm{mm} \qquad \mathrm{dia2} := \mathrm{dia2} \cdot \mathrm{mm} \qquad \mathrm{cov1} := \mathrm{cov1} \cdot \mathrm{mm} \qquad \mathrm{cov2} := \mathrm{cov2} \cdot \mathrm{mm}$

$P := P \cdot \mathrm{kN} \qquad M := M \cdot \mathrm{kN} \cdot \mathrm{m}$

$E_S := 200000 \cdot \mathrm{MPa} \qquad E_C := 4700 \sqrt{\frac{f_c}{\mathrm{MPa}}} \cdot \mathrm{MPa}$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,\mathrm{MPa}$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{\mathrm{MPa}}\right)^{\frac{2}{3}} \cdot \mathrm{MPa} \qquad \sigma_{ct} = 4.8\,\mathrm{MPa}$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,\mathrm{MPa}$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170\mathrm{MPa} \\ 170\mathrm{MPa} & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,\mathrm{MPa}$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110\mathrm{MPa} \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,\mathrm{MPa}$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,\mathrm{MPa}$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,\mathrm{MPa}$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	**X**	**Y**	**Ref.**	**X**	**Y**
	mm	**mm**		**mm**	**mm**
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right]$$

$A_C = 0.94783\ m^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right]$$

$I_x = 0.07149\ m^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right]$$

$I_y = 0.07149\ m^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ m^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

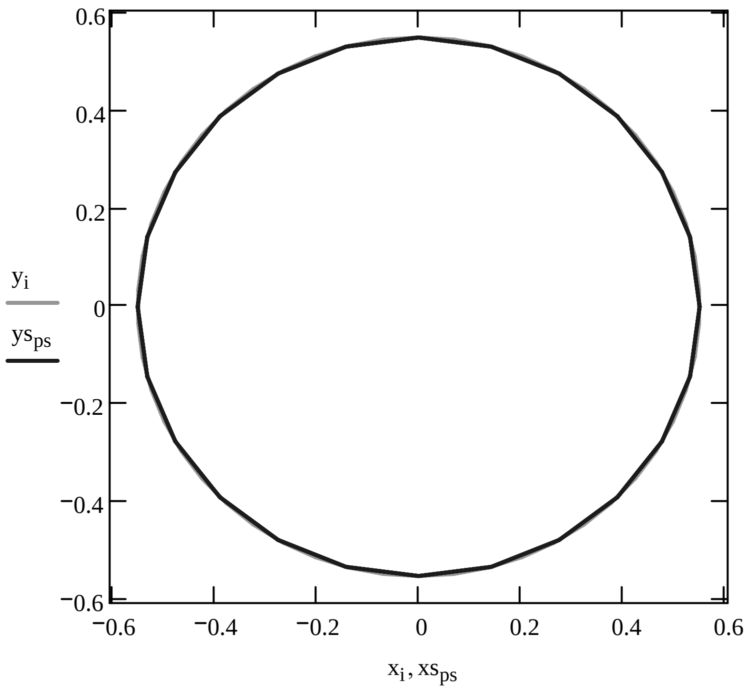
$I_{yS} = 0\ m^4$

$$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$$

$I_{xS} = 0\ m^4$

$$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$$

$I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-123	-458	**52**	0	0	0
3	804	-237	-410	**53**	0	0	0
4	804	-335	-335	**54**	0	0	0
5	804	-410	-237	**55**	0	0	0
6	804	-458	-123	**56**	0	0	0
7	804	-474	0	**57**	0	0	0
8	804	-458	123	**58**	0	0	0
9	804	-410	237	**59**	0	0	0
10	804	-335	335	**60**	0	0	0
11	804	-237	410	**61**	0	0	0
12	804	-123	458	**62**	0	0	0
13	804	0	474	**63**	0	0	0
14	804	123	458	**64**	0	0	0
15	804	237	410	**65**	0	0	0
16	804	335	335	**66**	0	0	0
17	804	410	237	**67**	0	0	0
18	804	458	123	**68**	0	0	0
19	804	474	0	**69**	0	0	0
20	804	458	-123	**70**	0	0	0
21	804	410	-237	**71**	0	0	0
22	804	335	-335	**72**	0	0	0
23	804	237	-410	**73**	0	0	0
24	804	123	-458	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1\cdot mm^2$ $\quad A2 := A2\cdot mm^2$ $\quad A3 := A3\cdot mm^2$ $\quad A4 := A4\cdot mm^2$

$X1 := X1\cdot mm$ $\quad X2 := X2\cdot mm$ $\quad X3 := X3\cdot mm$ $\quad X4 := X4\cdot mm$

$Y1 := Y1\cdot mm$ $\quad Y2 := Y2\cdot mm$ $\quad Y3 := Y3\cdot mm$ $\quad Y4 := Y4\cdot mm$

$k := 1 .. 50$ $\quad A_{bar_k} := A1_k$ $\quad x_{bar_k} := X1_k$ $\quad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $\quad x_{bar_{k+50}} := X2_k$ $\quad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $\quad x_{bar_{k+100}} := X3_k$ $\quad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $\quad x_{bar_{k+150}} := X4_k$ $\quad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 19302\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0204$$

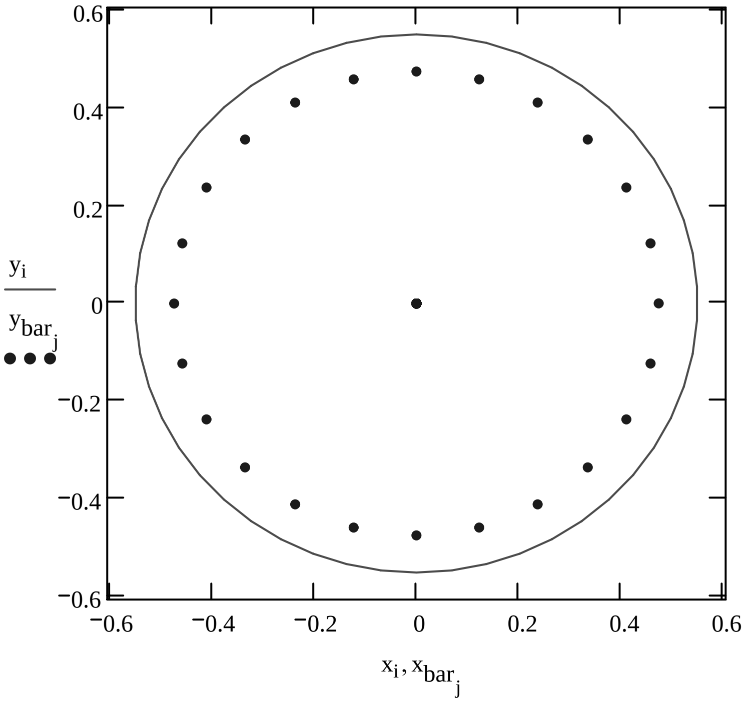
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j}\cdot x_{bar_j}\right)\right]\cdot\frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j}\cdot y_{bar_j}\right)\right]\cdot\frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j}\cdot\left(x_{bar_j}\right)^2\right] + A_{BAR}\cdot x_b^{\,2} \qquad I_{xb} = 0.00217\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j}\cdot\left(y_{bar_j}\right)^2\right] + A_{BAR}\cdot y_b^{\,2} \qquad I_{yb} = 0.00217\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1078490\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\,m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

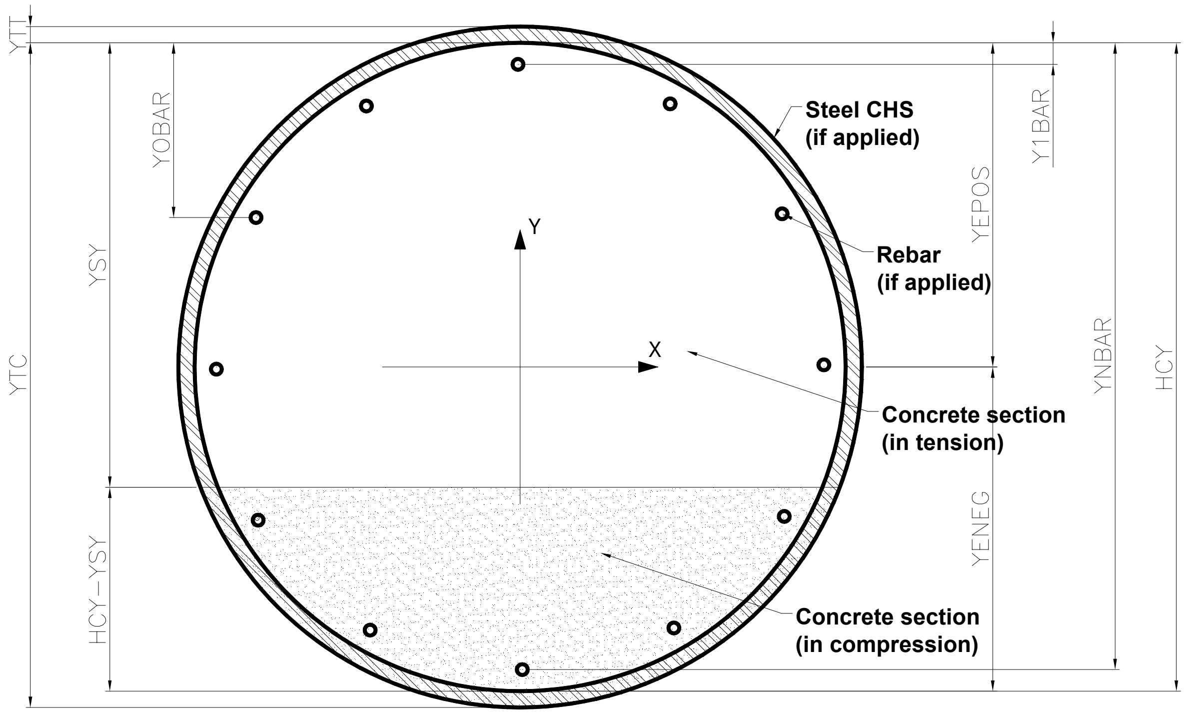
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns+1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{ll} \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} & \text{otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{ll} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \dfrac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$
\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|
\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \;\text{ if }\; f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \;\text{ if }\; \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \;\text{ if }\; \left(f_c = 0\right)\cdot(ts = 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \;\text{ if }\; \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot(ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot(ts > 0) \\
\sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cc} \;\text{ otherwise}
\end{array}
\right.
$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_{j} F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left| \begin{array}{ll} \displaystyle\sum_{j} -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left| \begin{array}{ll} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{array} \right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{vmatrix} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{vmatrix} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$ $F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$ $M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc}, \varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 25104\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17576.2\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

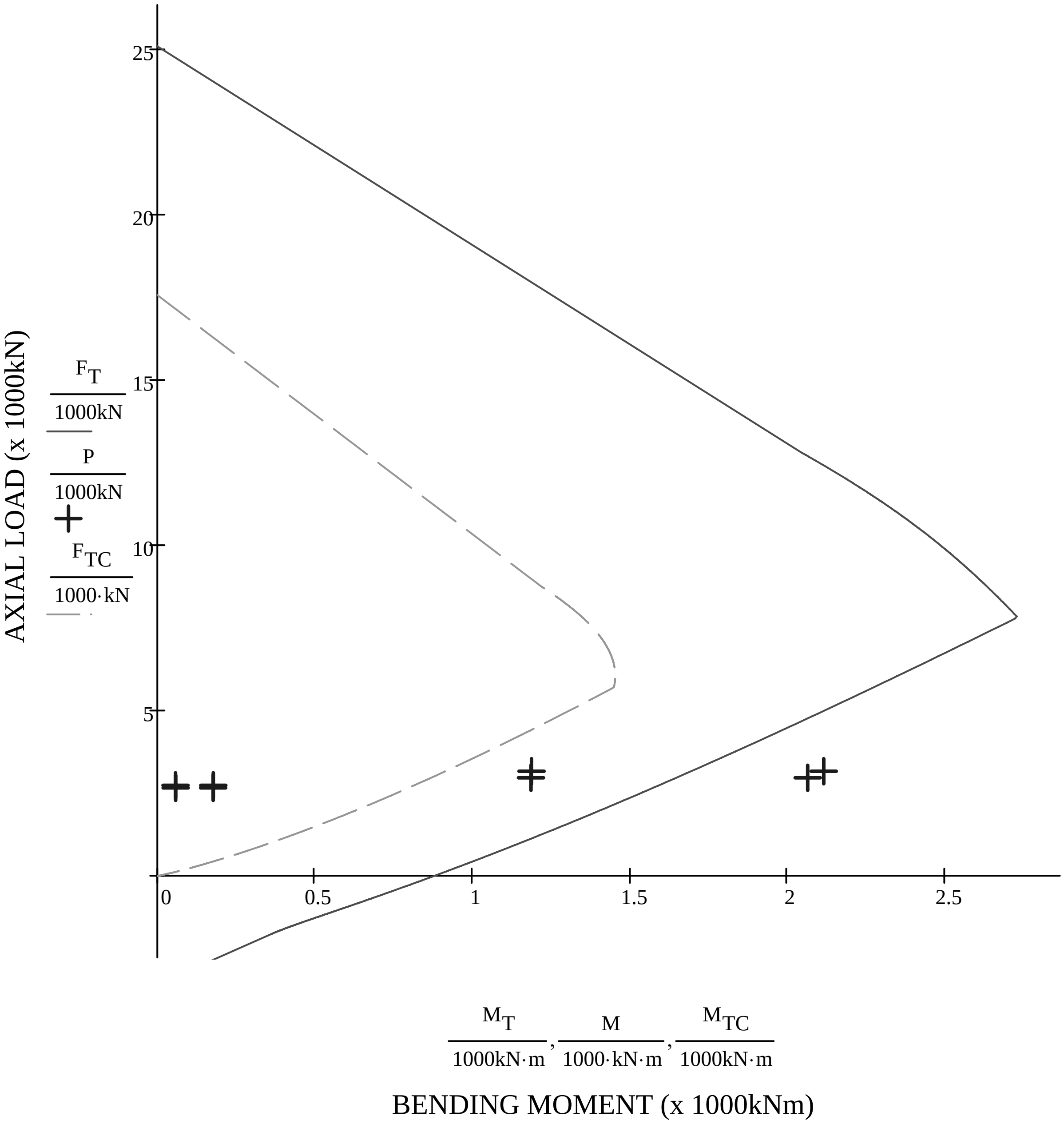
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -3281.3\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 2.04\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 2748 \\ 2748 \\ 2669 \\ 2669 \\ 2974 \\ 2974 \\ 3172 \\ 3172 \end{pmatrix} kN \qquad M = \begin{pmatrix} 178 \\ 58 \\ 178 \\ 58 \\ 2063 \\ 1186 \\ 2115 \\ 1187 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1589.0 \\ 1589.0 \\ 1564.4 \\ 1564.4 \\ 1639.7 \\ 1639.7 \\ 1692.4 \\ 1692.4 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.112 \\ 0.037 \\ 0.113 \\ 0.037 \\ 1.258 \\ 0.723 \\ 1.250 \\ 0.702 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			2.04	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P61**	**2748**	**178**	**1589.0**	**140%**	**11%**	OK
2	**P61**	**2748**	**58**	**1589.0**	**140%**	**4%**	OK
3	**P62**	**2669**	**178**	**1564.4**	**140%**	**11%**	OK
4	**P62**	**2669**	**58**	**1564.4**	**140%**	**4%**	OK

BASE

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of**
North Java Corridor Flyover Project

Calculation: **Balaraja Flyover**
Serviceability Check - Traffic Load Only
1100 mm Dia Circular RC Column - P6 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$\text{MPa} := 1000000 \cdot \text{Pa}$ $\text{kN} := 1000 \cdot \text{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	12	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P61	Combination 1 - P + Traffic Load Only	2904.0	2.7	100%
2	P61	Combination 1 - P + Traffic Load Only	2904.0	54.8	100%
3	P62	Combination 1 - P + Traffic Load Only	2812.0	2.7	100%
4	P62	Combination 1 - P + Traffic Load Only	2812.0	54.8	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \qquad E_C := 4700\sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1} - y_i\right)\cdot\frac{x_{i+1} + x_i}{2}\right]$$

$A_C = 0.94783\ m^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1} - y_i}{8}\cdot\left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1} - x_i}{8}\cdot\left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1} - x_i\right)\cdot\frac{y_{i+1} + y_i}{24}\right]\cdot\left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2\right]\right]$$

$I_x = 0.07149\ m^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1} - y_i\right)\cdot\frac{x_{i+1} + x_i}{24}\right]\cdot\left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2\right]\right]$$

$I_y = 0.07149\ m^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ m^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

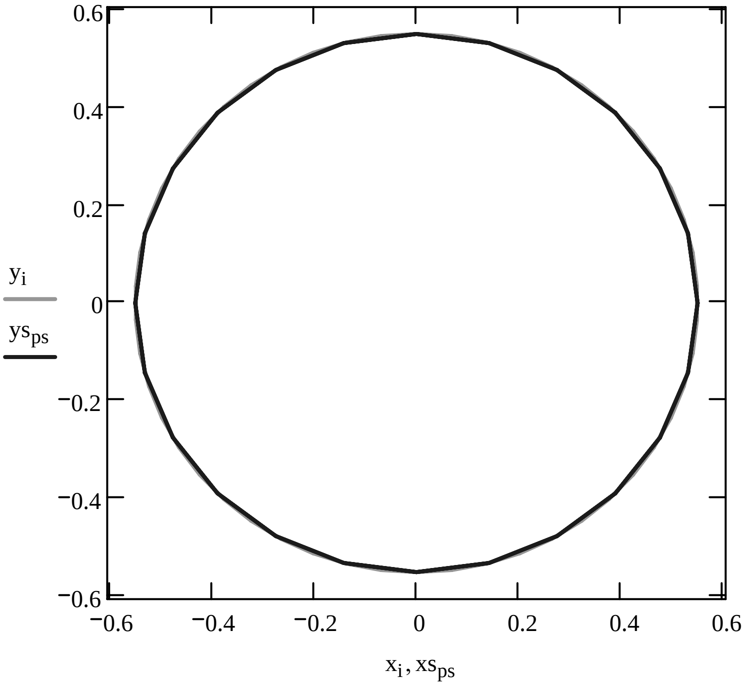
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\qquad I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\qquad I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-237	-410	**52**	0	0	0
3	804	-410	-237	**53**	0	0	0
4	804	-474	0	**54**	0	0	0
5	804	-410	237	**55**	0	0	0
6	804	-237	410	**56**	0	0	0
7	804	0	474	**57**	0	0	0
8	804	237	410	**58**	0	0	0
9	804	410	237	**59**	0	0	0
10	804	474	0	**60**	0	0	0
11	804	410	-237	**61**	0	0	0
12	804	237	-410	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1\cdot mm^2$ $A2 := A2\cdot mm^2$ $A3 := A3\cdot mm^2$ $A4 := A4\cdot mm^2$

$X1 := X1\cdot mm$ $X2 := X2\cdot mm$ $X3 := X3\cdot mm$ $X4 := X4\cdot mm$

$Y1 := Y1\cdot mm$ $Y2 := Y2\cdot mm$ $Y3 := Y3\cdot mm$ $Y4 := Y4\cdot mm$

$k := 1 .. 50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 9651\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0102$$

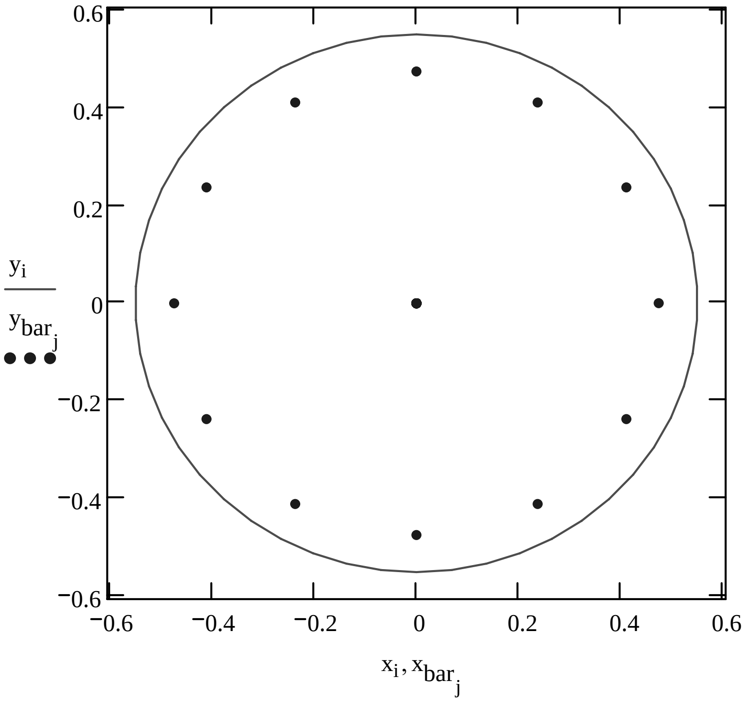
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j}\cdot x_{bar_j}\right)\right]\cdot\frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

$$y_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j}\cdot y_{bar_j}\right)\right]\cdot\frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j}\cdot\left(x_{bar_j}\right)^2\right] + A_{BAR}\cdot x_b^{\,2} \qquad I_{xb} = 0.00108\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j}\cdot\left(y_{bar_j}\right)^2\right] + A_{BAR}\cdot y_b^{\,2} \qquad I_{yb} = 0.00108\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\qquad A_E = 1013161\ \text{mm}^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1 - \rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\qquad x_E = 0.000\ \text{m}$

$$y_E := \frac{A_C \cdot [(1 - \rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E} \qquad y_E = 0.000\ \text{m}$$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$$I_{EX} = 0\ \text{m}^4$$

$$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$$

$$I_{EY} = 0\ \text{m}^4$$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E) \qquad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E) \qquad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg} \qquad H_{CX} = 1\ \text{m}$

$H_{CY} := yF_{pos} - yF_{neg} \qquad H_{CY} = 1\ \text{m}$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

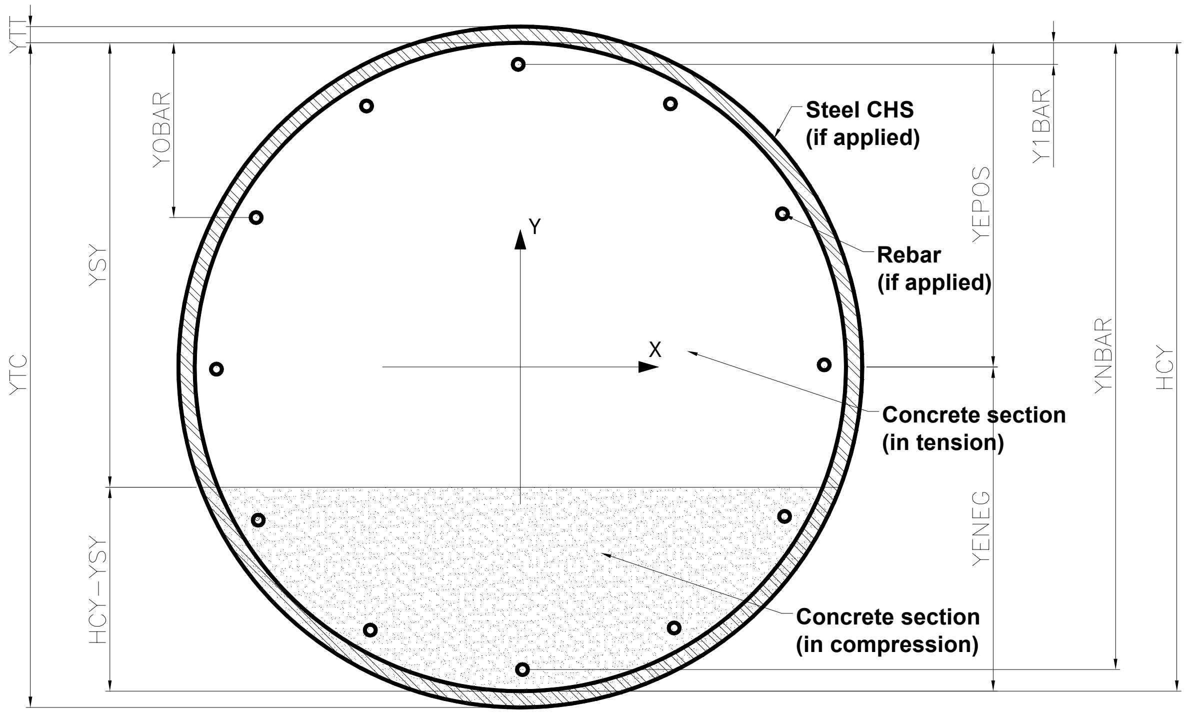
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{ll} \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} & \text{otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{ll} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} & \text{if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} & \text{if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} & \text{otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc}\cdot\frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc}\cdot\frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \;\text{ if }\; f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \;\text{ if }\; \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \;\text{ if }\; \left(f_c = 0\right)\cdot\left(ts = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \;\text{ if }\; \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left(\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \;\text{ if }\; \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cc} \;\text{ otherwise}
\end{array}\right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \begin{vmatrix} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \begin{vmatrix} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{vmatrix}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC}$$

$$F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC}$$

$$M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{array}{|l} \min(\varepsilon_{cc},\varepsilon_{tc}) \text{ if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc}) \text{ if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} \text{ if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} \text{ if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc},\varepsilon_{tc}) \text{ otherwise} \end{array}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{array}{|l} \sigma_{cd_2} \text{ if } f_c > 0 \\ 0 \text{ otherwise} \end{array}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21522.8\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17758.9\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

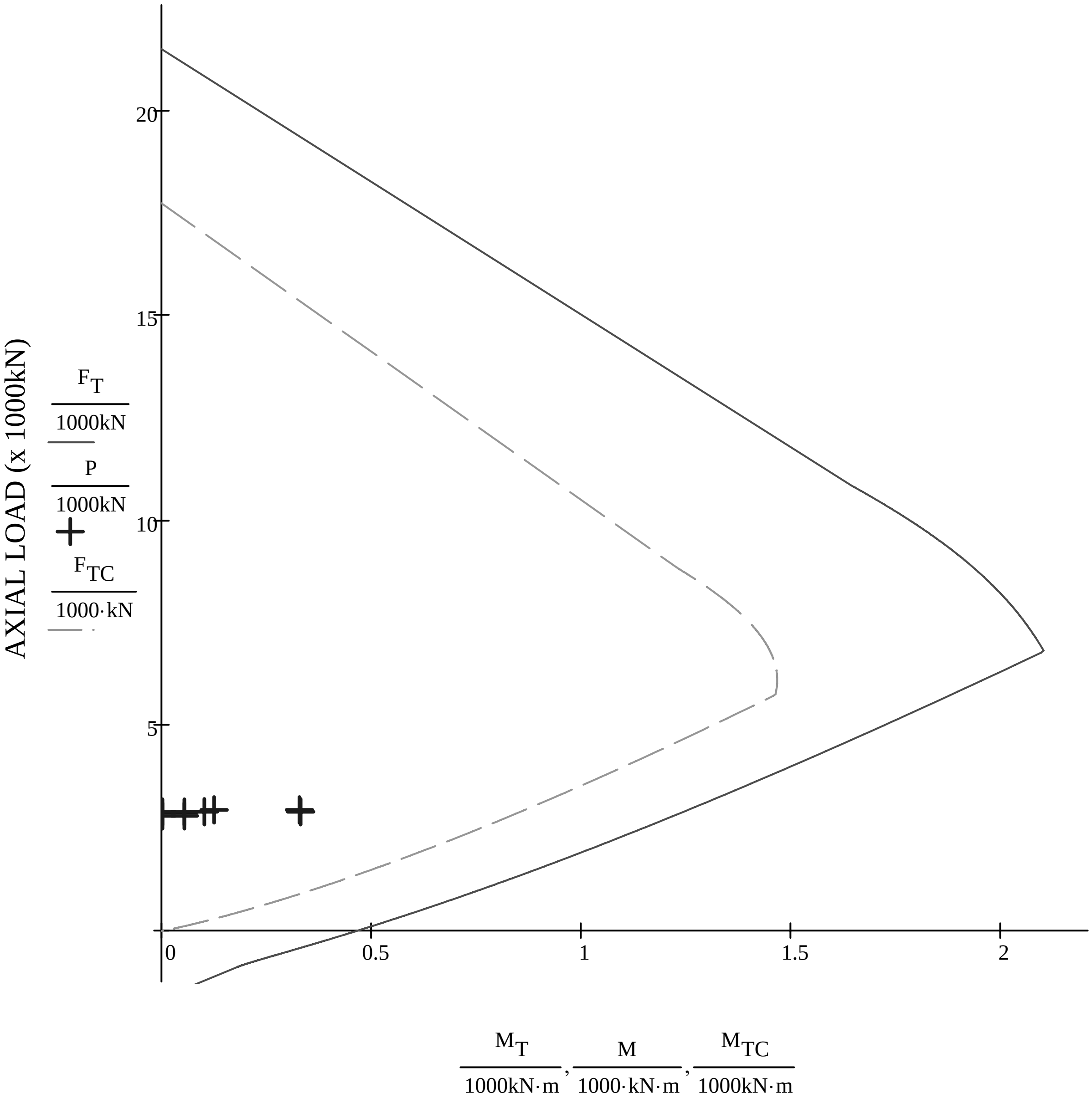
$$P_{MIN} := \begin{array}{|l} \varepsilon_{rs}\cdot E_S(A_{BAR}) \text{ if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) \text{ if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) \text{ otherwise} \end{array}$$

$P_{MIN} = -1640.7\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{array}{|l} \min(P, F_T)\cdot 0.75 \text{ if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 \text{ otherwise} \end{array}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 1.02\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 0\,mm$	Yield Strength of CHS	$f_{ys} = 250\,MPa$



BENDING MOMENT (x 1000kNm)

INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 2904 \\ 2904 \\ 2812 \\ 2812 \\ 2912 \\ 2912 \\ 2959 \\ 2959 \end{pmatrix} kN \qquad M = \begin{pmatrix} 3 \\ 55 \\ 3 \\ 55 \\ 332 \\ 102 \\ 329 \\ 126 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1239.2 \\ 1239.2 \\ 1217.4 \\ 1217.4 \\ 1239.2 \\ 1239.2 \\ 1250.3 \\ 1250.3 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.002 \\ 0.044 \\ 0.002 \\ 0.045 \\ 0.268 \\ 0.083 \\ 0.263 \\ 0.101 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			1.02	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P61**	**2904**	**3**	**1239.2**	**100%**	**0%**	OK
2	**P61**	**2904**	**55**	**1239.2**	**100%**	**4%**	OK
3	**P62**	**2812**	**3**	**1217.4**	**100%**	**0%**	OK
4	**P62**	**2812**	**55**	**1217.4**	**100%**	**5%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P6 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$\mathrm{MPa} := 1000000\cdot\mathrm{Pa}$ $\mathrm{kN} := 1000\cdot\mathrm{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	12	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P61	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2893.4	25.5	140%
2	P61	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2893.4	73.2	140%
3	P62	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2815.1	25.5	140%
4	P62	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2815.1	73.2	140%

$f_c := f_c \cdot MPa$ $f_{ys} := f_{ys} \cdot MPa$ $f_y := f_y \cdot MPa$ $D := D \cdot mm$ $ts := ts \cdot mm$

$dia1 := dia1 \cdot mm$ $dia2 := dia2 \cdot mm$ $cov1 := cov1 \cdot mm$ $cov2 := cov2 \cdot mm$

$P := P \cdot kN$ $M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa$ $E_C := 4700\sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases}$ $\alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa$ $\sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c$ $\sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases}$ $\sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases}$ $\sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys}$ $\sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys}$ $\sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S}$ $\varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S}$ $\varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S}$ $\varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S}$ $\varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right] \qquad A_C = 0.94783\ m^2$$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right] \qquad x_C = 0\ m$$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right] \qquad y_C = 0\ m$$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right] \qquad I_x = 0.07149\ m^4$$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right] \qquad I_y = 0.07149\ m^4$$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2} \qquad I_{xC} = 0.07149\ m^4$$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2} \qquad I_{yC} = 0.07149\ m^4$$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{2}\right]$$ $A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1}-ys_{ps}}{8}\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\frac{\left(xs_{ps+1}-xs_{ps}\right)^2}{3}\right]\right]$$ $x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1}-xs_{ps}}{8}\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\frac{\left(ys_{ps+1}-ys_{ps}\right)^2}{3}\right]\right]$$ $y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1}-xs_{ps}\right)\cdot\frac{ys_{ps+1}+ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1}+ys_{ps}\right)^2+\left(ys_{ps+1}-ys_{ps}\right)^2\right]\right]$$

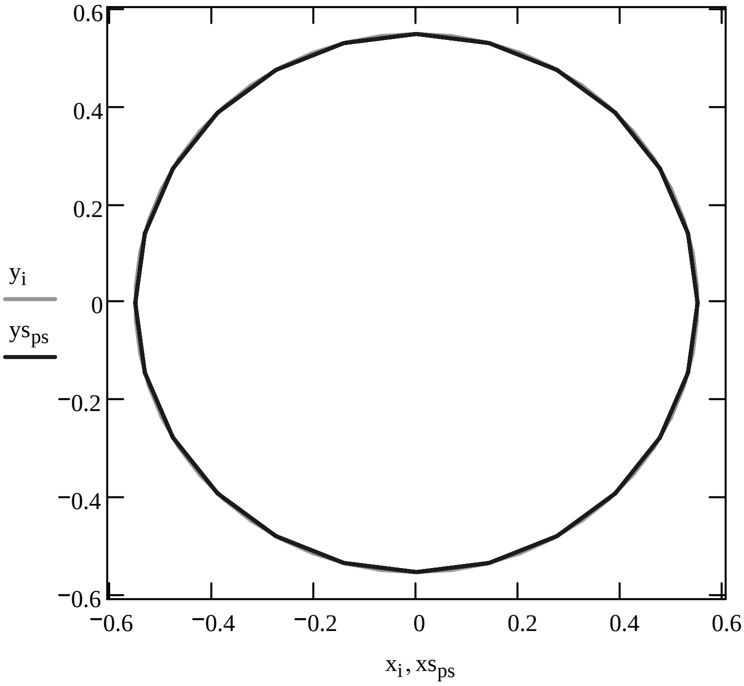
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1}-ys_{ps}\right)\cdot\frac{xs_{ps+1}+xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1}+xs_{ps}\right)^2+\left(xs_{ps+1}-xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-237	-410	**52**	0	0	0
3	804	-410	-237	**53**	0	0	0
4	804	-474	0	**54**	0	0	0
5	804	-410	237	**55**	0	0	0
6	804	-237	410	**56**	0	0	0
7	804	0	474	**57**	0	0	0
8	804	237	410	**58**	0	0	0
9	804	410	237	**59**	0	0	0
10	804	474	0	**60**	0	0	0
11	804	410	-237	**61**	0	0	0
12	804	237	-410	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $\quad A2 := A2 \cdot mm^2$ $\quad A3 := A3 \cdot mm^2$ $\quad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $\quad X2 := X2 \cdot mm$ $\quad X3 := X3 \cdot mm$ $\quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $\quad Y2 := Y2 \cdot mm$ $\quad Y3 := Y3 \cdot mm$ $\quad Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $\quad A_{bar_k} := A1_k$ $\quad x_{bar_k} := X1_k$ $\quad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $\quad x_{bar_{k+50}} := X2_k$ $\quad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $\quad x_{bar_{k+100}} := X3_k$ $\quad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $\quad x_{bar_{k+150}} := X4_k$ $\quad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 9651\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0102$$

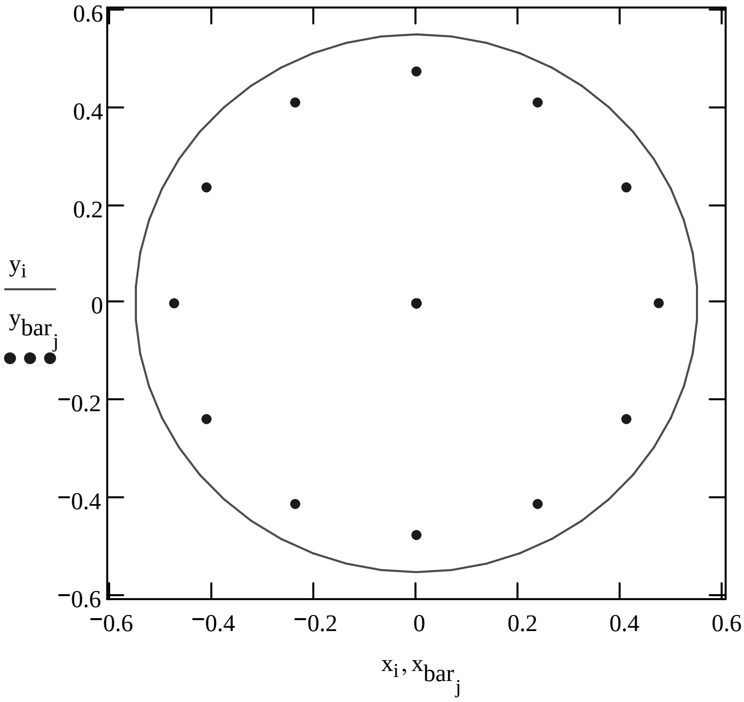
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \ \text{ if } A_{BAR} > 0 \\ 0m \ \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \ \text{ if } A_{BAR} > 0 \\ 0m \ \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^{\,2} \qquad I_{xb} = 0.00108\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^{\,2} \qquad I_{yb} = 0.00108\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1013161\ mm^2$

Effective centroid $x_E := \frac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\ m$

$y_E := \frac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\ m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\mathrm{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\mathrm{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\mathrm{mm}$

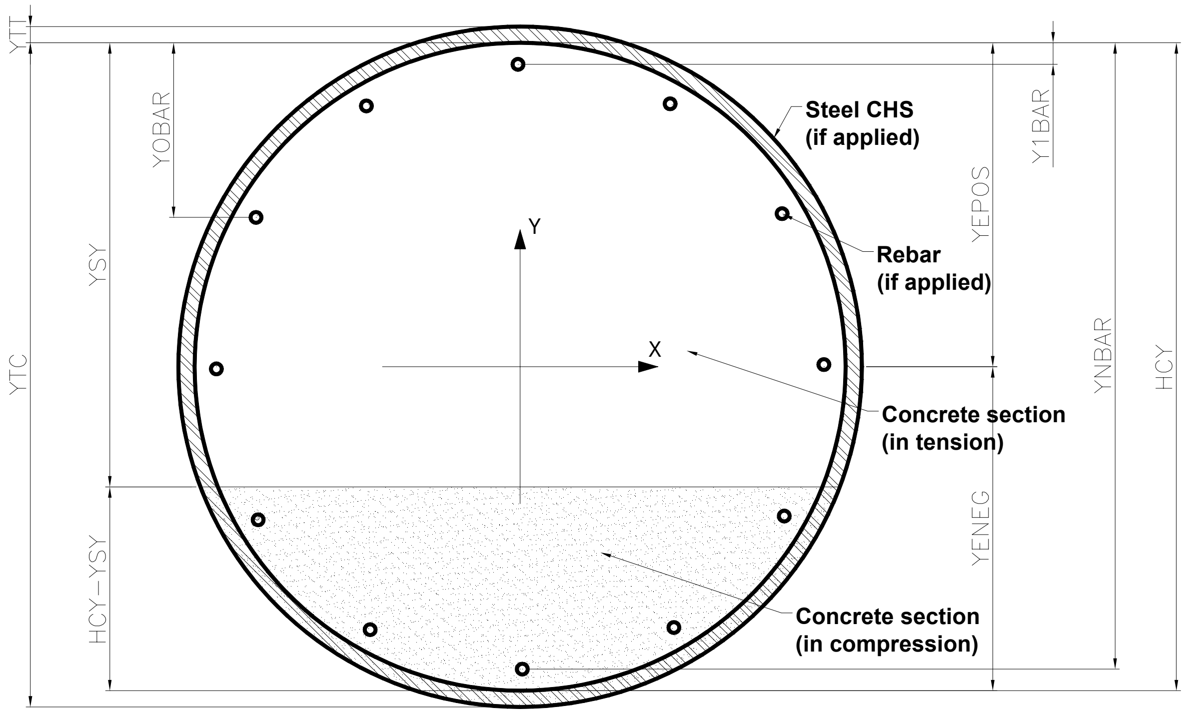
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 76\,\mathrm{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\mathrm{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\mathrm{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\mathrm{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700\sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{l} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{l} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \dfrac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left| \begin{array}{l} \sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\ \sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\ \sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cc} \ \text{ otherwise} \end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\frac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\frac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\frac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC} := \left| \begin{array}{l} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right]\cdot y \, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right]\cdot y \, dy$$

$$M_{TS} := \left| \begin{array}{l} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right]\cdot y \, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right]\cdot y \, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$F_T := F_C + F_R + F_{TS} + F_{TC}$ $F_{TC} := F_C$

Calculate total moment response from section:

$M_T := M_C + M_R + M_{TS} + M_{TC}$ $M_{TC} := M_C$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc}, \varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) & \text{otherwise} \end{cases} \qquad \varepsilon_{cL} = 0.001950$$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \sigma_{cL} = 18.93\,\text{MPa}$$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21522.8\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17758.9\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -1640.7\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\qquad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column $D = 1100\,\text{mm}$

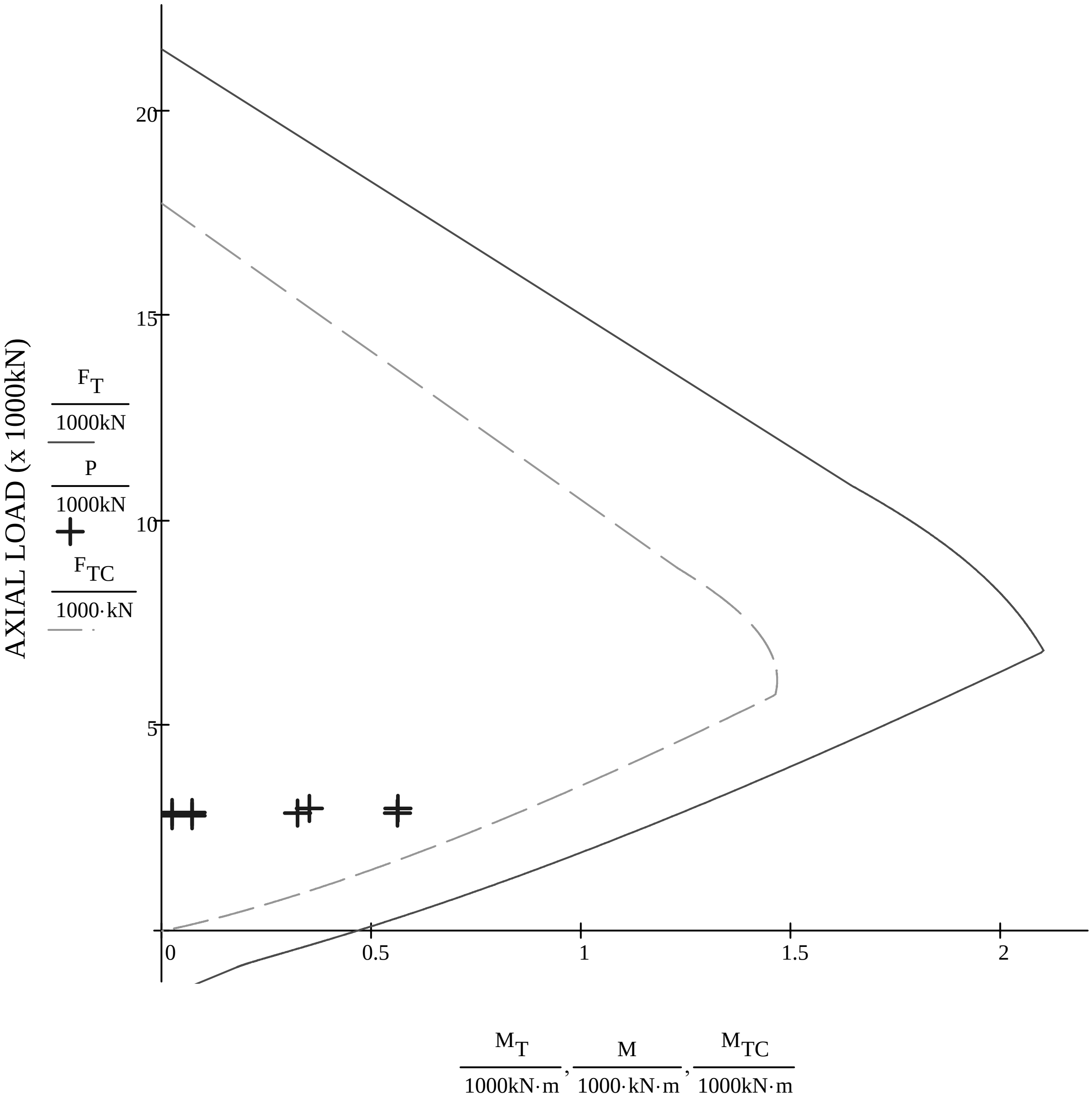
Characteristic strength of concrete $f_c = 30\,\text{MPa}$

Percentage reinforcement $\rho = 1.02\,\%$

Yield Strength of Rebar $f_y = 390\,\text{MPa}$

Thickness of CHS $ts = 0\,\text{mm}$

Yield Strength of CHS $f_{ys} = 250\,\text{MPa}$



BENDING MOMENT (x 1000kNm)

INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$
    $0.000000000000000001 \cdot kN \cdot m$   if $P_r > F_{T_1}$
    $0.000000000000000001 \cdot kN \cdot m$   if $P_r < F_{T_{ns+1}}$
    $(P_r - c1) \cdot m1$   if $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
    $(P_r - c2) \cdot m2$   if $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
    otherwise
        $j \leftarrow 1$
        while $F_{T_j} > P_r$
            $j \leftarrow j + 1$
        $M_{T_j}$
```

$$StressFactor_r := \begin{cases} \text{"No Result"} & \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} & \text{otherwise} \end{cases}$$

$$P = \begin{pmatrix} 2893 \\ 2893 \\ 2815 \\ 2815 \\ 2881 \\ 2881 \\ 2994 \\ 2994 \end{pmatrix} kN \qquad M = \begin{pmatrix} 26 \\ 73 \\ 26 \\ 73 \\ 563 \\ 325 \\ 564 \\ 353 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1239.2 \\ 1239.2 \\ 1217.4 \\ 1217.4 \\ 1228.2 \\ 1228.2 \\ 1261.5 \\ 1261.5 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.021 \\ 0.059 \\ 0.021 \\ 0.060 \\ 0.458 \\ 0.264 \\ 0.447 \\ 0.280 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			1.02	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P61**	**2893**	**26**	**1239.2**	**140%**	**2%**	OK
2	**P61**	**2893**	**73**	**1239.2**	**140%**	**6%**	OK
3	**P62**	**2815**	**26**	**1217.4**	**140%**	**2%**	OK
4	**P62**	**2815**	**73**	**1217.4**	**140%**	**6%**	OK

P7 PORTAL COLUMN 1.1 M DIAMETER

TOP

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of**
North Java Corridor Flyover Project

Calculation: **Balaraja Flyover**
Serviceability Check - Traffic Load Only
1100 mm Dia Circular RC Column - P7 Top Section

Reference: **Project Specific Design Criteria**

Section Data

MPa := 1000000·Pa

kN := 1000·N

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	39	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P71	Combination 1 - P + Traffic Load Only	3181.8	486.6	100%
2	P71	Combination 1 - P + Traffic Load Only	3181.8	2143.0	100%
3	P72	Combination 1 - P + Traffic Load Only	3161.5	496.5	100%
4	P72	Combination 1 - P + Traffic Load Only	3161.5	2127.7	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \quad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \quad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right]$$

$A_C = 0.94783\ \mathrm{m}^2$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right]$$

$x_C = 0\ \mathrm{m}$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right]$$

$y_C = 0\ \mathrm{m}$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right]$$

$I_x = 0.07149\ \mathrm{m}^4$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right]$$

$I_y = 0.07149\ \mathrm{m}^4$

$$I_{xC} := I_x - A_C\cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ \mathrm{m}^4$

$$I_{yC} := I_y - A_C\cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ \mathrm{m}^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$ $A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$ $x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$ $y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

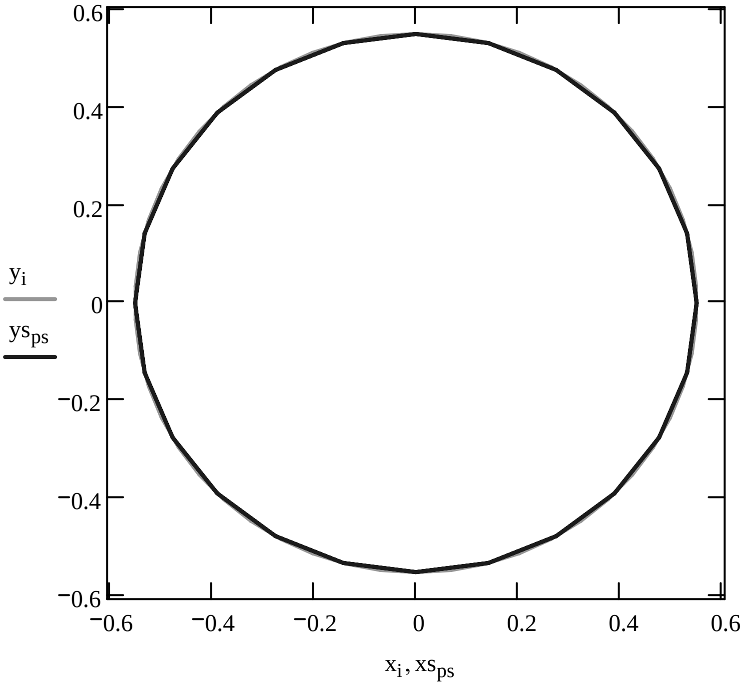
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-76	-468	**52**	0	0	0
3	804	-150	-450	**53**	0	0	0
4	804	-220	-420	**54**	0	0	0
5	804	-285	-379	**55**	0	0	0
6	804	-342	-328	**56**	0	0	0
7	804	-390	-269	**57**	0	0	0
8	804	-428	-203	**58**	0	0	0
9	804	-455	-132	**59**	0	0	0
10	804	-471	-57	**60**	0	0	0
11	804	-474	19	**61**	0	0	0
12	804	-464	95	**62**	0	0	0
13	804	-443	168	**63**	0	0	0
14	804	-410	237	**64**	0	0	0
15	804	-367	300	**65**	0	0	0
16	804	-314	355	**66**	0	0	0
17	804	-253	401	**67**	0	0	0
18	804	-186	436	**68**	0	0	0
19	804	-113	460	**69**	0	0	0
20	804	-38	472	**70**	0	0	0
21	804	38	472	**71**	0	0	0
22	804	113	460	**72**	0	0	0
23	804	186	436	**73**	0	0	0
24	804	253	401	**74**	0	0	0
25	804	314	355	**75**	0	0	0
26	804	367	300	**76**	0	0	0
27	804	410	237	**77**	0	0	0
28	804	443	168	**78**	0	0	0
29	804	464	95	**79**	0	0	0
30	804	474	19	**80**	0	0	0
31	804	471	-57	**81**	0	0	0
32	804	455	-132	**82**	0	0	0
33	804	428	-203	**83**	0	0	0
34	804	390	-269	**84**	0	0	0
35	804	342	-328	**85**	0	0	0
36	804	285	-379	**86**	0	0	0
37	804	220	-420	**87**	0	0	0
38	804	150	-450	**88**	0	0	0
39	804	76	-468	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2 \qquad A2 := A2 \cdot mm^2 \qquad A3 := A3 \cdot mm^2 \qquad A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm \quad X2 := X2 \cdot mm \quad X3 := X3 \cdot mm \quad X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm \quad Y2 := Y2 \cdot mm \quad Y3 := Y3 \cdot mm \quad Y4 := Y4 \cdot mm$

$k := 1 .. 50 \qquad A_{bar_k} := A1_k \qquad x_{bar_k} := X1_k \qquad y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k \qquad x_{bar_{k+50}} := X2_k \qquad y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k \qquad x_{bar_{k+100}} := X3_k \qquad y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k \qquad x_{bar_{k+150}} := X4_k \qquad y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 31366\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0331$$

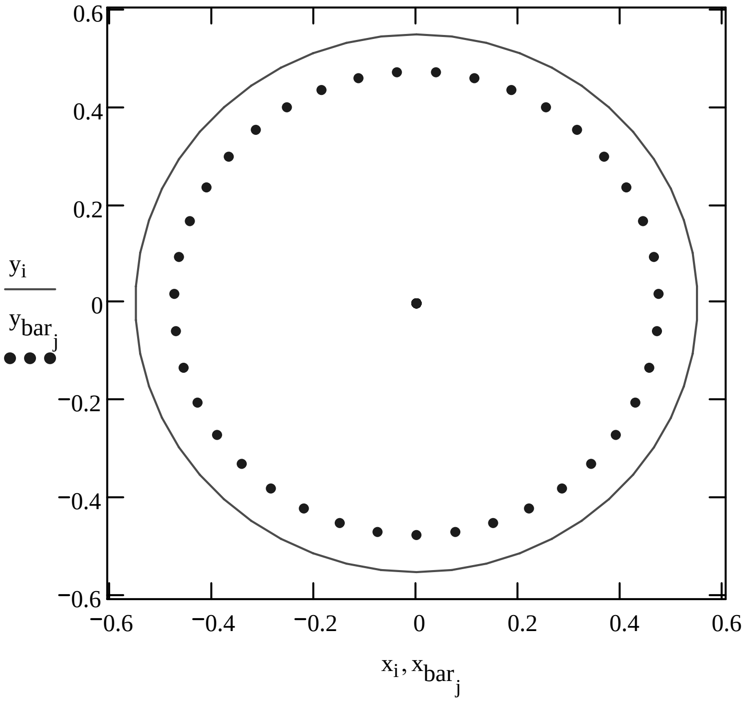
$$x_b := \begin{array}{|l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \qquad x_b = 0\ m$$

$$y_b := \begin{array}{|l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00352\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00352\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1160150\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\,m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {x_C}^2 + \rho \cdot {x_b}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot {x_{ST}}^2\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot {y_C}^2 + \rho \cdot {y_b}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot {y_{ST}}^2\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\mathrm{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\mathrm{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\mathrm{mm}$

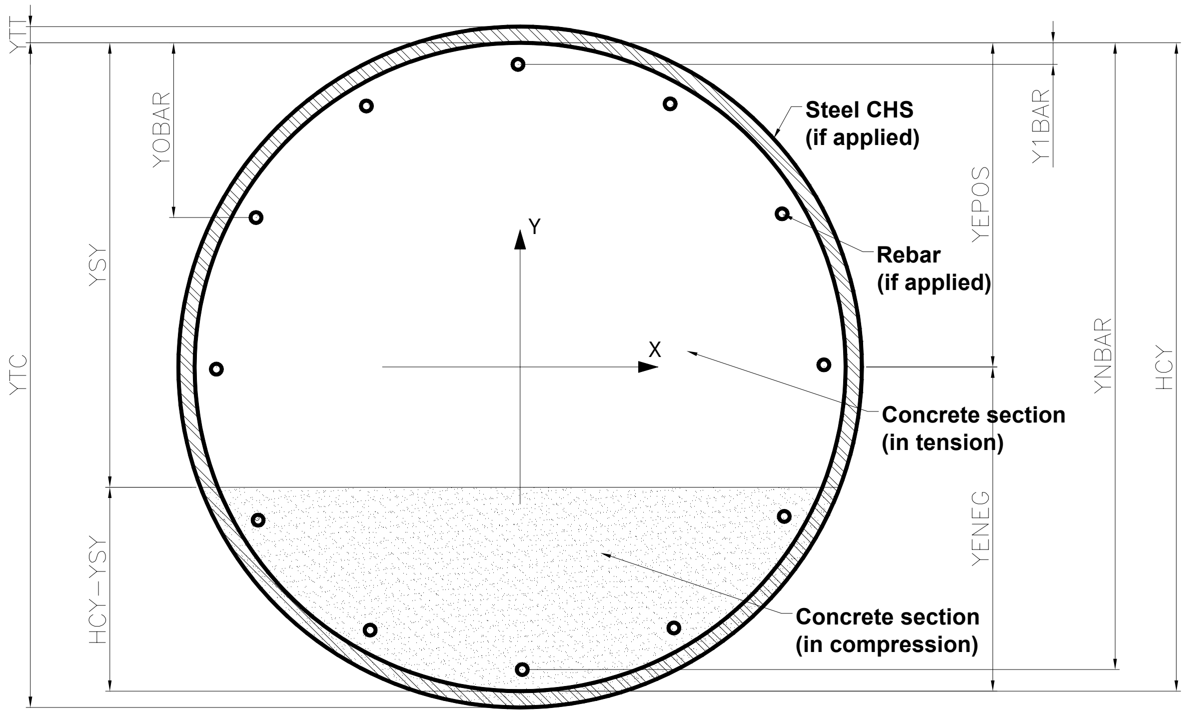
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min(y_{Epos} - y_{bar})$ $y_{1bar} = 78\,\mathrm{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max(y_{Epos} - y_{bar})$ $y_{nbar} = 1024\,\mathrm{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\mathrm{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\mathrm{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$$\varepsilon_{cc} := \text{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{l} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{l} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

```
$\sigma cd(\varepsilon_{tcc}, q) :=$
    $\sigma_{cd} \leftarrow \sigma_{cc}$  if  $f_c > 0$
    $\sigma_{cd} \leftarrow \sigma_{tc}$  if  $(f_c = 0) \cdot (A_{BAR} = 0)$
    $\sigma_{cd} \leftarrow \sigma_{rc}$  if  $(f_c = 0) \cdot (ts = 0)$
    $\sigma_{cd} \leftarrow \sigma_{cd} \cdot \frac{\varepsilon_{tc}}{\varepsilon_{tcc}}$  if  $(\varepsilon_{tcc} > \varepsilon_{tc}) \cdot (ts > 0)$
    $\sigma_{cd} \leftarrow \sigma_{cd} \cdot \frac{\varepsilon_{rc}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}}$  if  $\left(\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot (A_{BAR} > 0)$
    $\sigma_{cd} \leftarrow \sigma_{cd} \cdot \frac{\varepsilon_{ts}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}}}$  if  $\left[\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{-(y_{SY_q} + y_{tt})}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0)$
    $\sigma_{cd} \leftarrow \sigma_{cd} \cdot \frac{\varepsilon_{rs}}{\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{-(y_{SY_q} - y_{1bar})}{H_{CY} - y_{SY_q}}}$  if  $\left[\varepsilon cc(f_c, \sigma_{cd}) \cdot \frac{-(y_{SY_q} - y_{1bar})}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot (A_{BAR} > 0)$
    $\sigma_{cc}$  otherwise
```

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{vmatrix} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{vmatrix}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{vmatrix} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{vmatrix}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]dy$$

$$F_{TC} := \left|\begin{array}{l} F_{TC1}-F_{TC2} \ \text{ if } \ ts>0 \\ 0 \ \text{ otherwise} \end{array}\right.$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS} := \left|\begin{array}{l} M_{TS1}-M_{TS2} \ \text{ if } \ ts>0 \\ 0 \ \text{ otherwise} \end{array}\right.$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC} \qquad F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC} \qquad M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min\left(\varepsilon_{cc}, \varepsilon_{tc}\right) & \text{if } \left(A_{BAR} = 0\right)\cdot(ts \neq 0)\cdot\left(f_c \neq 0\right) \\ \min\left(\varepsilon_{cc}, \varepsilon_{rc}\right) & \text{if } (ts = 0)\cdot\left(A_{BAR} \neq 0\right)\cdot\left(f_c \neq 0\right) \\ \varepsilon_{tc} & \text{if } \left(A_{BAR} = 0\right)\cdot\left(f_c = 0\right) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot\left(f_c = 0\right) \\ \min\left(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}\right) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1 - \rho) + \varepsilon_{cL}\cdot E_S\left(A_{BAR} + A_{ST}\right)$$

$P_{MAX} = 29580.5\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1 - \rho)$$

$P_{MAXC} = 17347.9\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

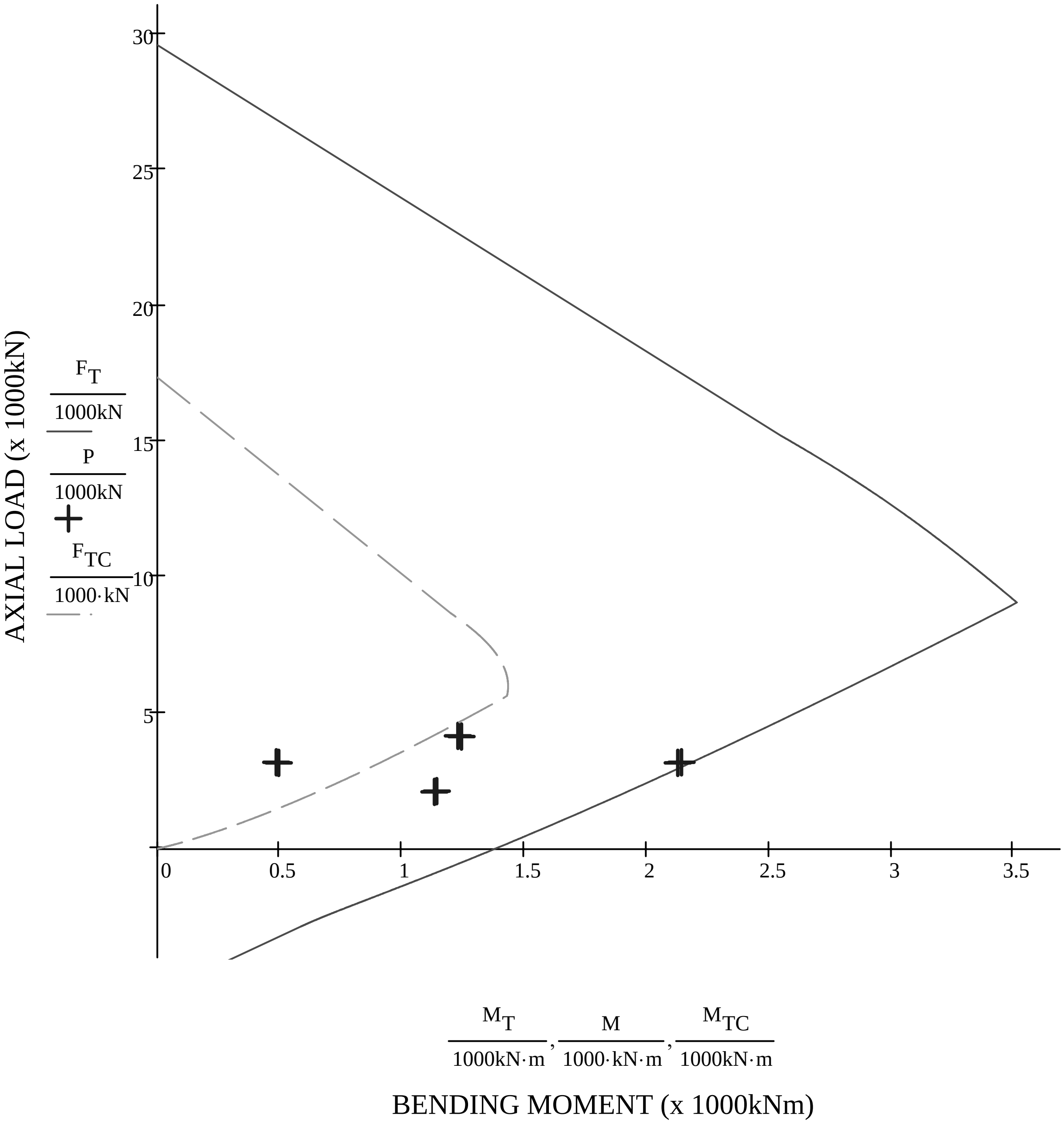
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S\left(A_{BAR}\right) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S\left(A_{ST}\right) & \text{if } A_{BAR} = 0 \\ \max\left(\varepsilon_{ts}, \varepsilon_{rs}\right)\cdot E_S\left(A_{BAR} + A_{ST}\right) & \text{otherwise} \end{cases}$$

$P_{MIN} = -5332.2\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min\left(P, F_T\right)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min\left(P, F_T\right)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 3.31\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left| \begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left| \begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array} \right. \end{array} \right.$$

$$StressFactor_r := \left| \begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array} \right.$$

$$P = \begin{pmatrix} 3182 \\ 3182 \\ 3162 \\ 3162 \\ 2096 \\ 4131 \\ 2119 \\ 4157 \end{pmatrix} kN \qquad M = \begin{pmatrix} 487 \\ 2143 \\ 497 \\ 2128 \\ 1133 \\ 1243 \\ 1143 \\ 1229 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 2173.3 \\ 2173.3 \\ 2173.3 \\ 2173.3 \\ 1915.3 \\ 2409.2 \\ 1915.3 \\ 2409.2 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.224 \\ 0.986 \\ 0.228 \\ 0.979 \\ 0.592 \\ 0.516 \\ 0.597 \\ 0.510 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			3.31	%			

Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P71**	**3182**	**487**	**2173.3**	**100%**	**22%**	OK
2	**P71**	**3182**	**2143**	**2173.3**	**100%**	**99%**	OK
3	**P72**	**3162**	**497**	**2173.3**	**100%**	**23%**	OK
4	**P72**	**3162**	**2128**	**2173.3**	**100%**	**98%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P7 Top Section

Reference: **Project Specific Design Criteria**

Section Data

$MPa := 1000000 \cdot Pa$ $kN := 1000 \cdot N$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	39	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P71	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp	3172.9	986.0	140%
2	P71	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp	3172.9	2646.7	140%
3	P72	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp	3171.2	1004.2	140%
4	P72	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp	3171.2	2639.7	140%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \qquad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n}\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{2}\right] \qquad A_C = 0.94783\ m^2$$

$$x_C := -\frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{y_{i+1}-y_i}{8}\cdot\left[\left(x_{i+1}+x_i\right)^2+\frac{\left(x_{i+1}-x_i\right)^2}{3}\right]\right] \qquad x_C = 0\ m$$

$$y_C := \frac{1}{A_C}\cdot\sum_{i=1}^{n}\left[\frac{x_{i+1}-x_i}{8}\cdot\left[\left(y_{i+1}+y_i\right)^2+\frac{\left(y_{i+1}-y_i\right)^2}{3}\right]\right] \qquad y_C = 0\ m$$

$$I_x := \sum_{i=1}^{n}\left[\left[\left(x_{i+1}-x_i\right)\cdot\frac{y_{i+1}+y_i}{24}\right]\cdot\left[\left(y_{i+1}+y_i\right)^2+\left(y_{i+1}-y_i\right)^2\right]\right] \qquad I_x = 0.07149\ m^4$$

$$I_y := -\sum_{i=1}^{n}\left[\left[\left(y_{i+1}-y_i\right)\cdot\frac{x_{i+1}+x_i}{24}\right]\cdot\left[\left(x_{i+1}+x_i\right)^2+\left(x_{i+1}-x_i\right)^2\right]\right] \qquad I_y = 0.07149\ m^4$$

$$I_{xC} := I_x - A_C\cdot x_C^2 \qquad I_{xC} = 0.07149\ m^4$$

$$I_{yC} := I_y - A_C\cdot y_C^2 \qquad I_{yC} = 0.07149\ m^4$$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

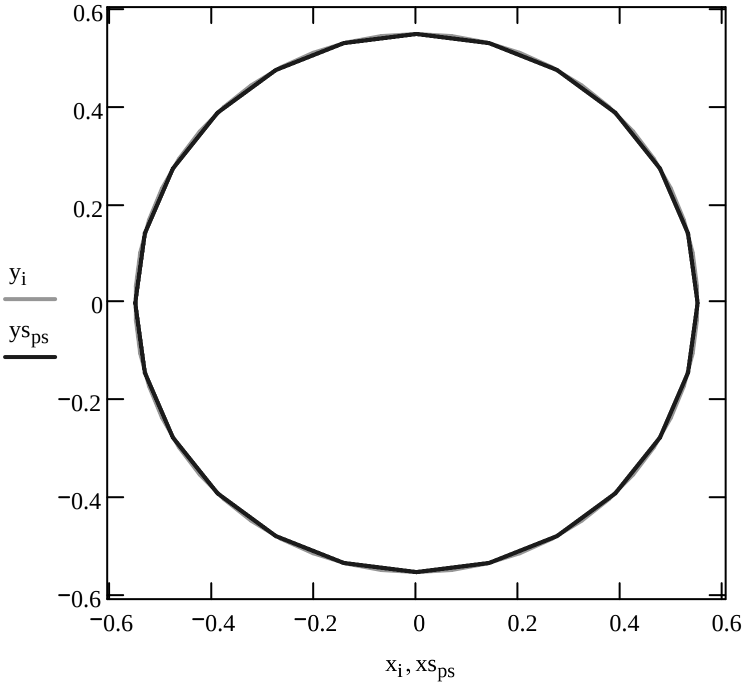
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\quad I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\quad I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area	X	Y	Ref	Area	X	Y
	mm2	mm	mm		mm2	mm	mm
1	804	0	-474	**51**	0	0	0
2	804	-76	-468	**52**	0	0	0
3	804	-150	-450	**53**	0	0	0
4	804	-220	-420	**54**	0	0	0
5	804	-285	-379	**55**	0	0	0
6	804	-342	-328	**56**	0	0	0
7	804	-390	-269	**57**	0	0	0
8	804	-428	-203	**58**	0	0	0
9	804	-455	-132	**59**	0	0	0
10	804	-471	-57	**60**	0	0	0
11	804	-474	19	**61**	0	0	0
12	804	-464	95	**62**	0	0	0
13	804	-443	168	**63**	0	0	0
14	804	-410	237	**64**	0	0	0
15	804	-367	300	**65**	0	0	0
16	804	-314	355	**66**	0	0	0
17	804	-253	401	**67**	0	0	0
18	804	-186	436	**68**	0	0	0
19	804	-113	460	**69**	0	0	0
20	804	-38	472	**70**	0	0	0
21	804	38	472	**71**	0	0	0
22	804	113	460	**72**	0	0	0
23	804	186	436	**73**	0	0	0
24	804	253	401	**74**	0	0	0
25	804	314	355	**75**	0	0	0
26	804	367	300	**76**	0	0	0
27	804	410	237	**77**	0	0	0
28	804	443	168	**78**	0	0	0
29	804	464	95	**79**	0	0	0
30	804	474	19	**80**	0	0	0
31	804	471	-57	**81**	0	0	0
32	804	455	-132	**82**	0	0	0
33	804	428	-203	**83**	0	0	0
34	804	390	-269	**84**	0	0	0
35	804	342	-328	**85**	0	0	0
36	804	285	-379	**86**	0	0	0
37	804	220	-420	**87**	0	0	0
38	804	150	-450	**88**	0	0	0
39	804	76	-468	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1..50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j}$$ $A_{BAR} = 31366\,mm^2$

$$\rho := \frac{A_{BAR}}{A_C}$$ $\rho = 0.0331$

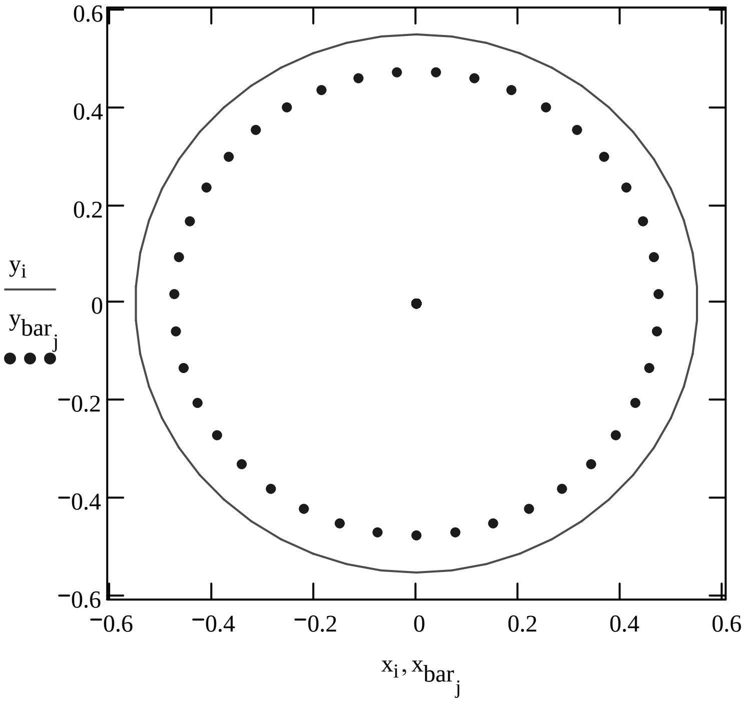
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases}$$ $x_b = 0\ m$

$$y_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases}$$ $y_b = 0\ m$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2$$ $I_{xb} = 0.00352\,m^4$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2$$ $I_{yb} = 0.00352\,m^4$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 1160150\ mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot [(1 - \rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $x_E = 0.000\ m$

$y_E := \dfrac{A_C \cdot [(1 - \rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $y_E = 0.000\ m$

Effective stiffness $I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot x_C^{\ 2} + \rho \cdot x_b^{\ 2} \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}^{\ 2}\right) \cdot \alpha$

$I_{EX} = 0\ m^4$

$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1 - \rho) \cdot y_C^{\ 2} + \rho \cdot y_b^{\ 2} \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}^{\ 2}\right) \cdot \alpha$

$I_{EY} = 0\ m^4$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

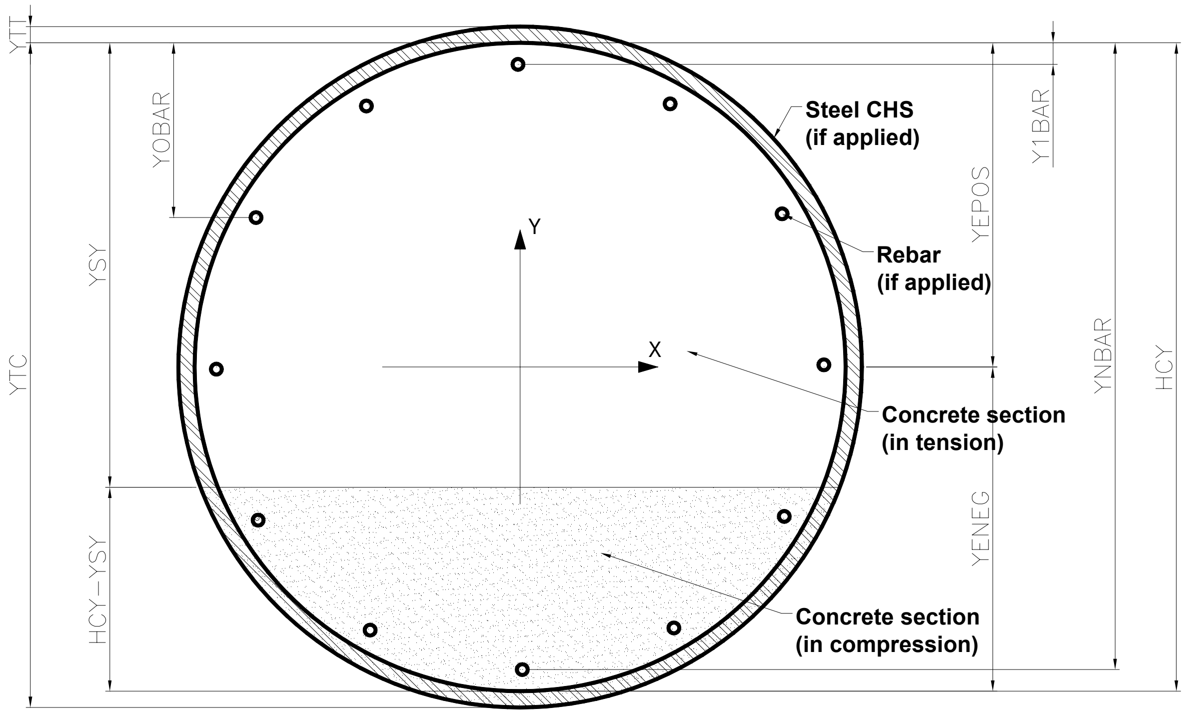
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min(y_{Epos} - y_{bar})$ $y_{1bar} = 78\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max(y_{Epos} - y_{bar})$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \left| \begin{array}{l} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{array} \right. \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \left| \begin{array}{l} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{array} \right.$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression
$$\varepsilon_{rcc_q} := \varepsilon_{cc}\cdot\frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension
$$\varepsilon_{rct_q} := \varepsilon_{cc}\cdot\frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left|\begin{array}{l}
\sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\
\sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(ts = 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot\left(ts > 0\right) \\
\sigma_{cd} \leftarrow \sigma_{cd}\cdot\dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right)\cdot\dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\
\sigma_{cc} \ \text{ otherwise}
\end{array}\right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right] dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \begin{cases} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right]\cdot y\, dy & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \begin{cases} y_{nbar}\cdot\dfrac{q}{ns+1} & \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} & \text{otherwise} \end{cases}$$

$$\varepsilon_{S_{j,q}} := \begin{cases} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) & \text{otherwise} \end{cases}$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \begin{cases} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_{j} F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \left|\begin{array}{ll} \displaystyle\sum_{j} -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{array}\right.$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \left|\begin{array}{ll} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{array}\right.$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC} := \begin{array}{|l} F_{TC1} - F_{TC2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] \cdot y \, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] \cdot y \, dy$$

$$M_{TS} := \begin{array}{|l} M_{TS1} - M_{TS2} \ \text{ if } \ ts > 0 \\ 0 \ \text{ otherwise} \end{array}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] \cdot y \, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] \cdot y \, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC} \qquad F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC} \qquad M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc}, \varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1 - \rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 29580.5\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1 - \rho)$$

$P_{MAXC} = 17347.9\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

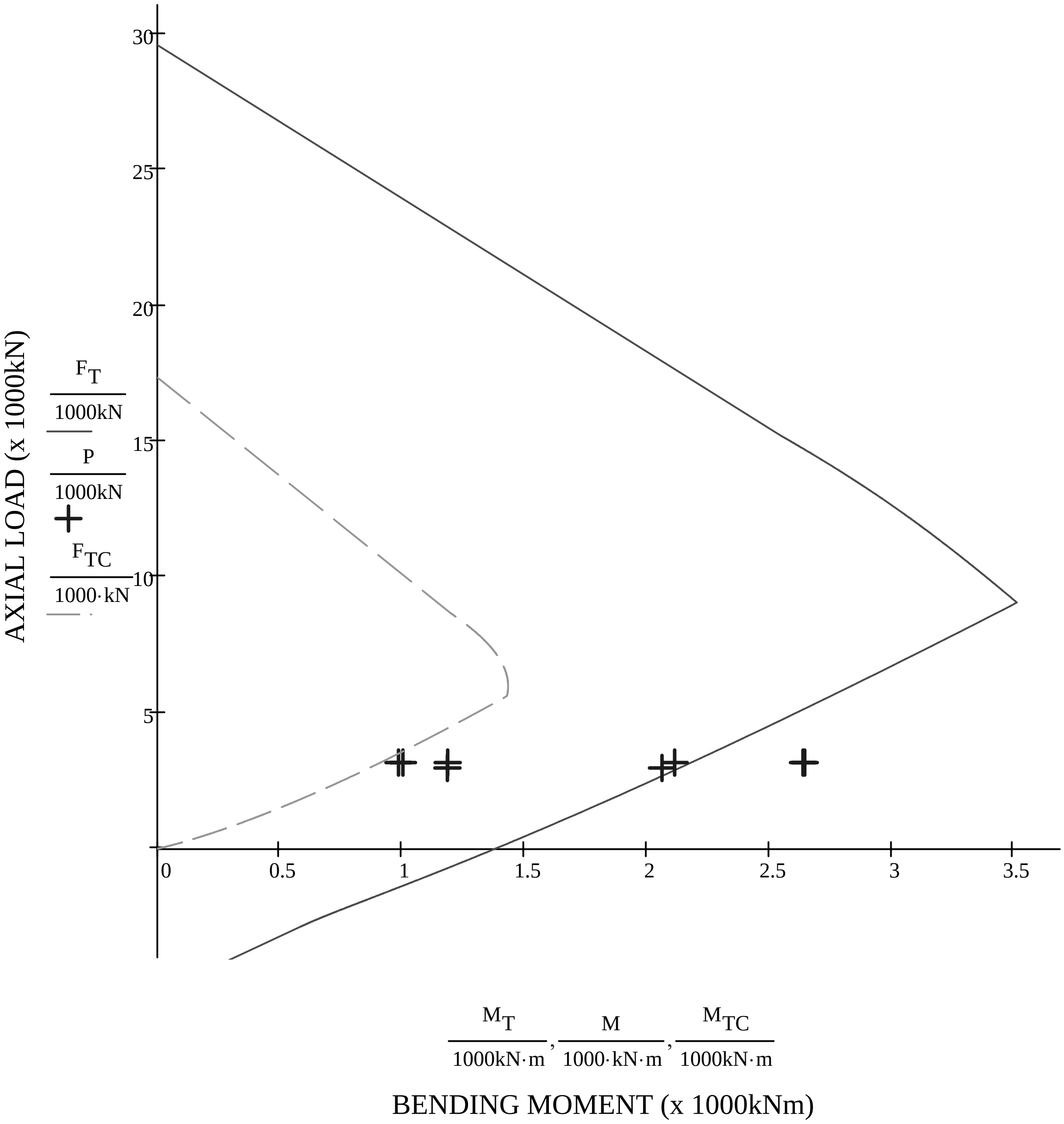
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -5332.2\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\qquad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 3.31\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 0\,mm$	Yield Strength of CHS	$f_{ys} = 250\,MPa$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

$$M_{SLS_r} := \left|\begin{array}{l} 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r > F_{T_1} \\ 0.000000000000000001 \cdot kN \cdot m \ \text{ if } \ P_r < F_{T_{ns+1}} \\ \left(P_r - c1\right) \cdot m1 \ \text{ if } \ \left(P_r > F_{T_2}\right) \cdot \left(P_r \le F_{T_1}\right) \\ \left(P_r - c2\right) \cdot m2 \ \text{ if } \ \left(P_r \ge F_{T_{ns+1}}\right) \cdot \left(P_r < F_{T_{ns}}\right) \\ \text{otherwise} \\ \quad \left|\begin{array}{l} j \leftarrow 1 \\ \text{while } \ F_{T_j} > P_r \\ \quad j \leftarrow j + 1 \\ M_{T_j} \end{array}\right. \end{array}\right.$$

$$StressFactor_r := \left|\begin{array}{l} \text{"No Result"} \ \text{ if } \ M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} \ \text{ otherwise} \end{array}\right.$$

$$P = \begin{pmatrix} 3173 \\ 3173 \\ 3171 \\ 3171 \\ 2974 \\ 2974 \\ 3172 \\ 3172 \end{pmatrix} kN \qquad M = \begin{pmatrix} 986 \\ 2647 \\ 1004 \\ 2640 \\ 2063 \\ 1186 \\ 2115 \\ 1187 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 2173.3 \\ 2173.3 \\ 2173.3 \\ 2173.3 \\ 2127.0 \\ 2127.0 \\ 2173.3 \\ 2173.3 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.454 \\ 1.218 \\ 0.462 \\ 1.215 \\ 0.970 \\ 0.558 \\ 0.973 \\ 0.546 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			3.31	%			
Load Case Ref	**Pier**	**Applied Service Axial Load kN**	**Applied Service Bending Moment kNm**	**Service Limit State Bending Moment kNm**	**Allowable Stress Factor**	**Applied Stress Factor**	**Serviceability Limit State Design Result**
1	**P71**	**3173**	**986**	**2173.3**	**140%**	**45%**	OK
2	**P71**	**3173**	**2647**	**2173.3**	**140%**	**122%**	OK
3	**P72**	**3171**	**1004**	**2173.3**	**140%**	**46%**	OK
4	**P72**	**3171**	**2640**	**2173.3**	**140%**	**121%**	OK

BASE

Serviceability Check - Traffic Load Only

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Traffic Load Only
1100 mm Dia Circular RC Column - P7 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$\text{MPa} := 1000000 \cdot \text{Pa}$ $\text{kN} := 1000 \cdot \text{N}$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	13	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P71	Combination 1 - P + Traffic Load Only	3368.0	655.1	100%
2	P71	Combination 1 - P + Traffic Load Only	3368.0	263.9	100%
3	P72	Combination 1 - P + Traffic Load Only	3347.8	653.3	100%
4	P72	Combination 1 - P + Traffic Load Only	3347.8	248.9	100%

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad f_y := f_y \cdot MPa \qquad D := D \cdot mm \qquad ts := ts \cdot mm$

$dia1 := dia1 \cdot mm \qquad dia2 := dia2 \cdot mm \qquad cov1 := cov1 \cdot mm \qquad cov2 := cov2 \cdot mm$

$P := P \cdot kN \qquad M := M \cdot kN \cdot m$

$E_S := 200000 \cdot MPa \qquad E_C := 4700 \sqrt{\frac{f_c}{MPa}} \cdot MPa$ Modular ratio $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases} \qquad \alpha = 7.77$

$E_C = 25743\,MPa$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\frac{f_c}{MPa}\right)^{\frac{2}{3}} \cdot MPa \qquad \sigma_{ct} = 4.8\,MPa$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c \qquad \sigma_{cc} = 30.0\,MPa$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170MPa \\ 170MPa & \text{otherwise} \end{cases} \qquad \sigma_{rs} = 170\,MPa$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \begin{cases} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110MPa \\ f_y & \text{otherwise} \end{cases} \qquad \sigma_{rc} = 390\,MPa$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys} \qquad \sigma_{ts} = -150\,MPa$

$\sigma_{tc} := 1 f_{ys} \qquad \sigma_{tc} = 250\,MPa$

Limiting strain of rebar $\varepsilon_{rs} := -\frac{\sigma_{rs}}{E_S} \qquad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \frac{\sigma_{rc}}{E_S} \qquad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \frac{\sigma_{ts}}{E_S} \qquad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \frac{\sigma_{tc}}{E_S} \qquad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$

$A_C = 0.94783 \text{ m}^2$

$$x_C := -\frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{y_{i+1} - y_i}{8} \cdot \left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3} \right] \right]$$

$x_C = 0 \text{ m}$

$$y_C := \frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{x_{i+1} - x_i}{8} \cdot \left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3} \right] \right]$$

$y_C = 0 \text{ m}$

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$

$I_x = 0.07149 \text{ m}^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$

$I_y = 0.07149 \text{ m}^4$

$$I_{xC} := I_x - A_C \cdot x_C^2$$

$I_{xC} = 0.07149 \text{ m}^4$

$$I_{yC} := I_y - A_C \cdot y_C^2$$

$I_{yC} = 0.07149 \text{ m}^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

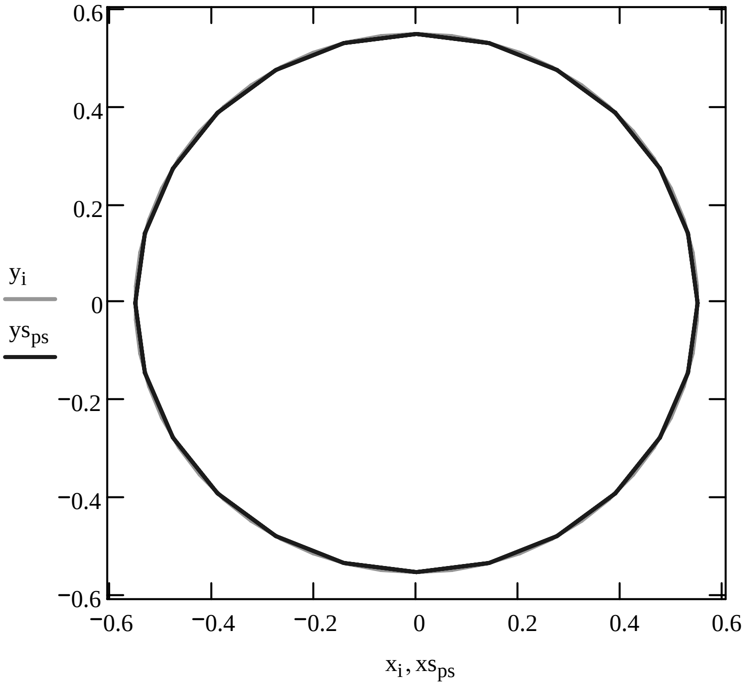
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\qquad I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\qquad I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-220	-420	**52**	0	0	0
3	804	-390	-269	**53**	0	0	0
4	804	-471	-57	**54**	0	0	0
5	804	-443	168	**55**	0	0	0
6	804	-314	355	**56**	0	0	0
7	804	-113	460	**57**	0	0	0
8	804	113	460	**58**	0	0	0
9	804	314	355	**59**	0	0	0
10	804	443	168	**60**	0	0	0
11	804	471	-57	**61**	0	0	0
12	804	390	-269	**62**	0	0	0
13	804	220	-420	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 10455\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.011$$

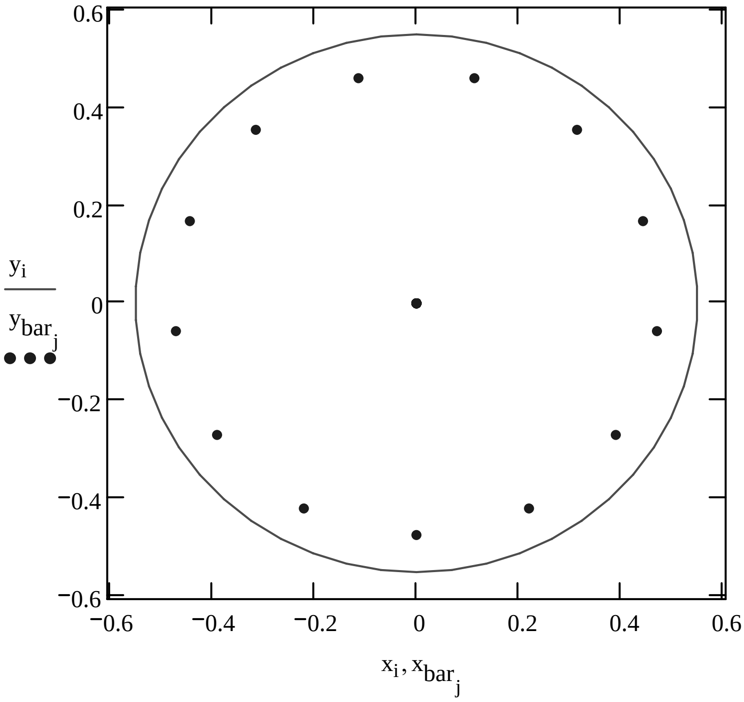
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^{\,2} \qquad I_{xb} = 0.00117\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^{\,2} \qquad I_{yb} = 0.00117\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\qquad A_E = 1018605\ \text{mm}^2$

Effective centroid $$x_E := \frac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E} \qquad x_E = 0.000\ \text{m}$$

$$y_E := \frac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E} \qquad y_E = 0.000\ \text{m}$$

Effective stiffness $$I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C^2 + \rho \cdot x_b^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}^2\right) \cdot \alpha$$

$$I_{EX} = 0\ \text{m}^4$$

$$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C^2 + \rho \cdot y_b^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}^2\right) \cdot \alpha$$

$$I_{EY} = 0\ \text{m}^4$$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E) \qquad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E) \qquad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg} \qquad H_{CX} = 1\ \text{m}$

$H_{CY} := yF_{pos} - yF_{neg} \qquad H_{CY} = 1\ \text{m}$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

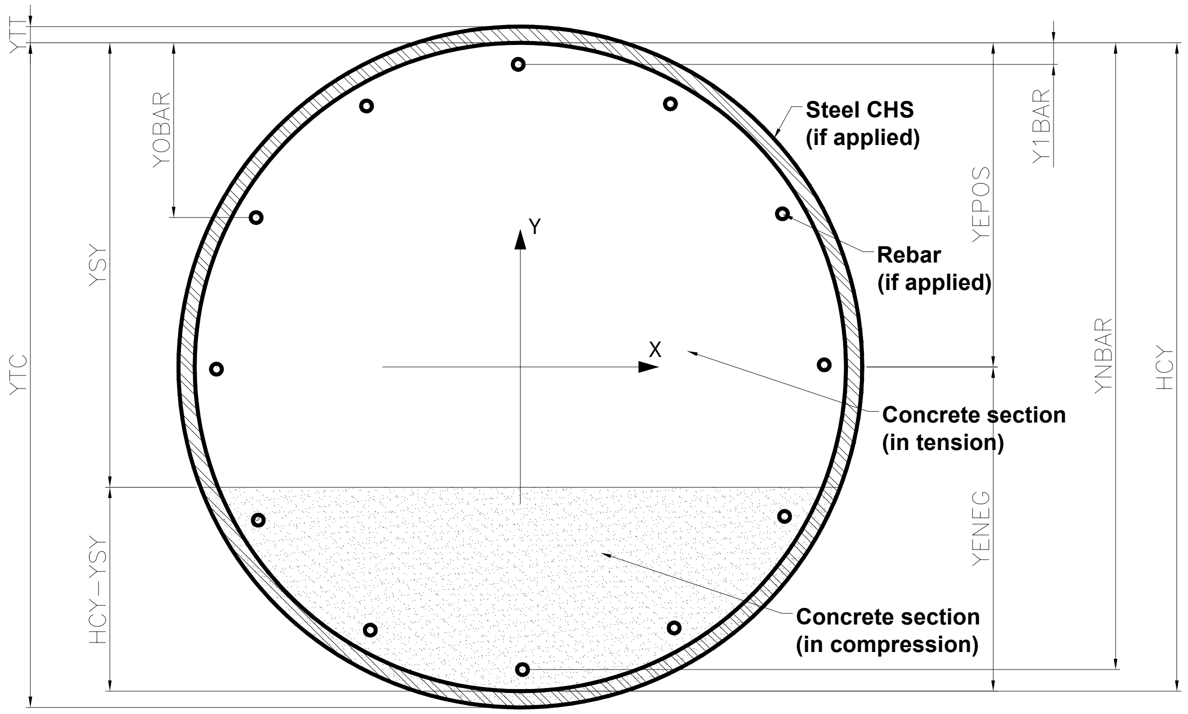
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 90\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $\mathrm{ns} := 500$

$q := 2 .. \mathrm{ns}$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{\mathrm{ns} + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{\mathrm{MPa}}} - \frac{4700^2}{2.68} \cdot \varepsilon cc\right) \cdot \mathrm{MPa}$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \begin{vmatrix} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{vmatrix} \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \begin{vmatrix} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{vmatrix}$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left| \begin{array}{l} \sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\ \sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right)\cdot\left(A_{BAR} = 0\right) \\ \sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right)\cdot(ts = 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right)\cdot(ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right)\cdot\left(A_{BAR} > 0\right) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right]\cdot(ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right]\cdot\left(A_{BAR} > 0\right) \\ \sigma_{cc} \ \text{ otherwise} \end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right] dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q}}\right]\cdot y\, dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \left| \begin{array}{l} y_{nbar}\cdot\dfrac{q}{ns+1} \quad \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} \quad \text{otherwise} \end{array} \right.$$

$$\varepsilon_{S_{j,q}} := \left| \begin{array}{l} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{otherwise} \end{array} \right.$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \left| \begin{array}{l} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} \quad \text{if } A_{BAR} > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_j F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_j -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]dy$$

$$F_{TC} := \begin{cases} F_{TC1} - F_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TS} := \begin{cases} M_{TS1} - M_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\,dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC}$$

$$F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC}$$

$$M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc}, \varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc}, \varepsilon_{rc}, \varepsilon_{tc}) & \text{otherwise} \end{cases} \qquad \varepsilon_{cL} = 0.001950$$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \sigma_{cL} = 18.93\,\text{MPa}$$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21821.2\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17743.7\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

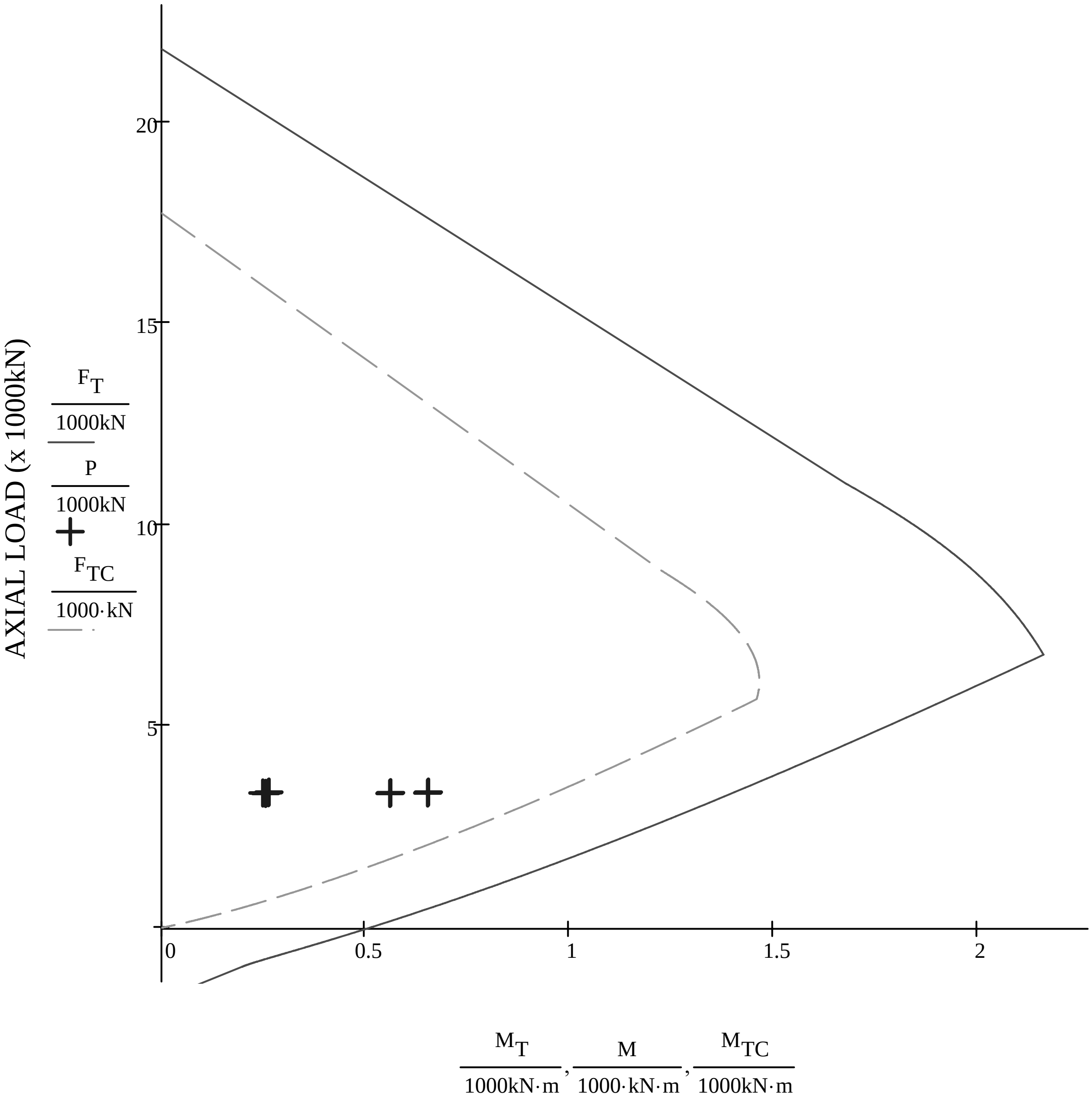
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -1777.4\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\qquad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 1.10\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 0\,mm$	Yield Strength of CHS	$f_{ys} = 250\,MPa$



BENDING MOMENT (x 1000kNm)

INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r > F_{T_1}$
    $0.000000000000000001 \cdot kN \cdot m$  if  $P_r < F_{T_{ns+1}}$
    $(P_r - c1) \cdot m1$  if  $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
    $(P_r - c2) \cdot m2$  if  $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
    otherwise
        $j \leftarrow 1$
        while  $F_{T_j} > P_r$
            $j \leftarrow j + 1$
        $M_{T_j}$
```

```
$StressFactor_r :=$
    "No Result"  if  $M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m$
    $\frac{M_r}{M_{SLS_r}}$  otherwise
```

$$P = \begin{pmatrix} 3368 \\ 3368 \\ 3348 \\ 3348 \\ 3355 \\ 3355 \\ 3335 \\ 3335 \end{pmatrix} kN \qquad M = \begin{pmatrix} 655 \\ 264 \\ 653 \\ 249 \\ 562 \\ 263 \\ 561 \\ 256 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1406.2 \\ 1406.2 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.466 \\ 0.188 \\ 0.469 \\ 0.179 \\ 0.403 \\ 0.188 \\ 0.402 \\ 0.183 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column 1100 mm

Percentage of rebar 1.10 %

Load Case Ref	Pier	Applied Service Axial Load kN	Applied Service Bending Moment kNm	Service Limit State Bending Moment kNm	Allowable Stress Factor	Applied Stress Factor	Serviceability Limit State Design Result
1	**P71**	**3368**	**655**	**1406.2**	**100%**	**47%**	OK
2	**P71**	**3368**	**264**	**1406.2**	**100%**	**19%**	OK
3	**P72**	**3348**	**653**	**1393.5**	**100%**	**47%**	OK
4	**P72**	**3348**	**249**	**1393.5**	**100%**	**18%**	OK

Serviceability Check - Full Live Load

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **Detailed Design Study of North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Serviceability Check - Full Live Load
1100 mm Dia Circular RC Column - P7 Base Section

Reference: **Project Specific Design Criteria**

Section Data

$MPa := 1000000 \cdot Pa$

$kN := 1000 \cdot N$

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fys	250	MPa
Rebar Yield Strength	fy	390	MPa
Diameter of reinforced concrete section	D	1100	mm
Thickness of CHS section	t	0	mm
Diameter of rebar - layer 1	dia1	32	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	13	
Number bars - layer 2 (max 100)	n2	0	
Cover from face of section - layer 1	cov1	60	mm
Cover from face of section - layer 2	cov2	115	mm

Load Data

Ref	Pier	Load Case	P	M	Stress
			kN	kNm	Allowance
1	P71	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3359.1	1000.9	140%
2	P71	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3359.1	115.2	140%
3	P72	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3357.5	1003.6	140%
4	P72	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	3357.5	130.6	140%

$f_c := f_c \cdot \mathrm{MPa}$ $\quad f_{ys} := f_{ys} \cdot \mathrm{MPa}$ $\quad f_y := f_y \cdot \mathrm{MPa}$ $\quad D := D \cdot \mathrm{mm}$ $\quad ts := ts \cdot \mathrm{mm}$

$dia1 := dia1 \cdot \mathrm{mm}$ $\quad dia2 := dia2 \cdot \mathrm{mm}$ $\quad cov1 := cov1 \cdot \mathrm{mm}$ $\quad cov2 := cov2 \cdot \mathrm{mm}$

$P := P \cdot \mathrm{kN}$ $\quad M := M \cdot \mathrm{kN} \cdot \mathrm{m}$

$E_S := 200000 \cdot \mathrm{MPa}$ $\quad E_C := 4700 \sqrt{\dfrac{f_c}{\mathrm{MPa}}} \cdot \mathrm{MPa}$ Modular ratio $\alpha := \left| \begin{array}{ll} \dfrac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{array} \right.$ $\quad \alpha = 7.77$

$E_C = 25743\,\mathrm{MPa}$

Calculate Basic Allowable Stresses

Calculate rupture stress: $\sigma_{ct} := 0.5 \cdot \left(\dfrac{f_c}{\mathrm{MPa}} \right)^{\frac{2}{3}} \cdot \mathrm{MPa}$ $\quad \sigma_{ct} = 4.8\,\mathrm{MPa}$

Calculate basic allowable stress of concrete $\sigma_{cc} := 1.0 \cdot f_c$ $\quad \sigma_{cc} = 30.0\,\mathrm{MPa}$

Calculate basic allowable tensile stress of rebar $\sigma_{rs} := \left| \begin{array}{ll} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 170\mathrm{MPa} \\ 170\mathrm{MPa} & \text{otherwise} \end{array} \right.$ $\quad \sigma_{rs} = 170\,\mathrm{MPa}$

Calculate basic allowable compressive stress of rebar $\sigma_{rc} := \left| \begin{array}{ll} 0.5 \cdot f_y & \text{if } 0.5 \cdot f_y \le 110\mathrm{MPa} \\ f_y & \text{otherwise} \end{array} \right.$ $\quad \sigma_{rc} = 390\,\mathrm{MPa}$

Calculate basic allowable stress of structural steel $\sigma_{ts} := -0.6 f_{ys}$ $\quad \sigma_{ts} = -150\,\mathrm{MPa}$

$\sigma_{tc} := 1 f_{ys}$ $\quad \sigma_{tc} = 250\,\mathrm{MPa}$

Limiting strain of rebar $\varepsilon_{rs} := -\dfrac{\sigma_{rs}}{E_S}$ $\quad \varepsilon_{rs} = -0.000850$

$\varepsilon_{rc} := \dfrac{\sigma_{rc}}{E_S}$ $\quad \varepsilon_{rc} = 0.001950$

Limiting strain of structural steel $\varepsilon_{ts} := \dfrac{\sigma_{ts}}{E_S}$ $\quad \varepsilon_{ts} = -0.000750$

$\varepsilon_{tc} := \dfrac{\sigma_{tc}}{E_S}$ $\quad \varepsilon_{tc} = 0.001250$

Concrete Cross Section Data - generated

$n := 50$ Number of Points - 50 points maximum

$i := 1 .. n + 1$ Range from 1 to n+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	550
2	-69	-546	**27**	69	546
3	-137	-533	**28**	137	533
4	-202	-511	**29**	202	511
5	-265	-482	**30**	265	482
6	-323	-445	**31**	323	445
7	-377	-401	**32**	377	401
8	-424	-351	**33**	424	351
9	-464	-295	**34**	464	295
10	-498	-234	**35**	498	234
11	-523	-170	**36**	523	170
12	-540	-103	**37**	540	103
13	-549	-35	**38**	549	35
14	-549	35	**39**	549	-35
15	-540	103	**40**	540	-103
16	-523	170	**41**	523	-170
17	-498	234	**42**	498	-234
18	-464	295	**43**	464	-295
19	-424	351	**44**	424	-351
20	-377	401	**45**	377	-401
21	-323	445	**46**	323	-445
22	-265	482	**47**	265	-482
23	-202	511	**48**	202	-511
24	-137	533	**49**	137	-533
25	-69	546	**50**	69	-546

$k := 1 .. 25$ $XS1 := XS1 \cdot mm$ $XS2 := XS2 \cdot mm$ $YS1 := YS1 \cdot mm$ $YS2 := YS2 \cdot mm$

$x_k := XS1_k$ $y_k := YS1_k$ $x_{k+25} := XS2_k$ $y_{k+25} := YS2_k$ $x_{n+1} := XS1_1$ $y_{n+1} := YS1_1$

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$

$A_C = 0.94783\ m^2$

$$x_C := -\frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{y_{i+1} - y_i}{8} \cdot \left[\left(x_{i+1} + x_i\right)^2 + \frac{\left(x_{i+1} - x_i\right)^2}{3} \right] \right]$$

$x_C = 0\ m$

$$y_C := \frac{1}{A_C} \cdot \sum_{i=1}^{n} \left[\frac{x_{i+1} - x_i}{8} \cdot \left[\left(y_{i+1} + y_i\right)^2 + \frac{\left(y_{i+1} - y_i\right)^2}{3} \right] \right]$$

$y_C = 0\ m$

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$

$I_x = 0.07149\ m^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$

$I_y = 0.07149\ m^4$

$$I_{xC} := I_x - A_C \cdot x_C^{\,2}$$

$I_{xC} = 0.07149\ m^4$

$$I_{yC} := I_y - A_C \cdot y_C^{\,2}$$

$I_{yC} = 0.07149\ m^4$

Steel Tube Cross Section Data - generated from input

$ns := 50$ Number of Points - 50 points maximum

$ps := 1 .. ns + 1$ Range from 1 to ns+1

Ref.	X	Y	Ref.	X	Y
	mm	mm		mm	mm
1	0	-550	**26**	0	-550
2	-142	-531	**27**	142	-531
3	-275	-476	**28**	275	-476
4	-389	-389	**29**	389	-389
5	-476	-275	**30**	476	-275
6	-531	-142	**31**	531	-142
7	-550	0	**32**	550	0
8	-531	142	**33**	531	142
9	-476	275	**34**	476	275
10	-389	389	**35**	389	389
11	-275	476	**36**	275	476
12	-142	531	**37**	142	531
13	0	550	**38**	0	550
14	142	531	**39**	-142	531
15	275	476	**40**	-275	476
16	389	389	**41**	-389	389
17	476	275	**42**	-476	275
18	531	142	**43**	-531	142
19	550	0	**44**	-550	0
20	531	-142	**45**	-531	-142
21	476	-275	**46**	-476	-275
22	389	-389	**47**	-389	-389
23	275	-476	**48**	-275	-476
24	142	-531	**49**	-142	-531
25	0	-550	**50**	0	-550

$XSS1 := XSS1 \cdot mm$ $XSS2 := XSS2 \cdot mm$ $YSS1 := YSS1 \cdot mm$ $YSS2 := YSS2 \cdot mm$

$z := 1 .. 25$ $xs_z := XSS1_z$ $ys_z := YSS1_z$

$z := 26 .. 50$ $xs_z := XSS2_{z-25}$ $ys_z := YSS2_{z-25}$

$xs_{ns+1} := XSS1_1$ $ys_{ns+1} := YSS1_1$

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right]$$

$A_{ST} = 0\ m^2$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right]$$

$x_{ST} = 0.2\ m$

$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right]$$

$y_{ST} = -0.011\ m$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right]$$

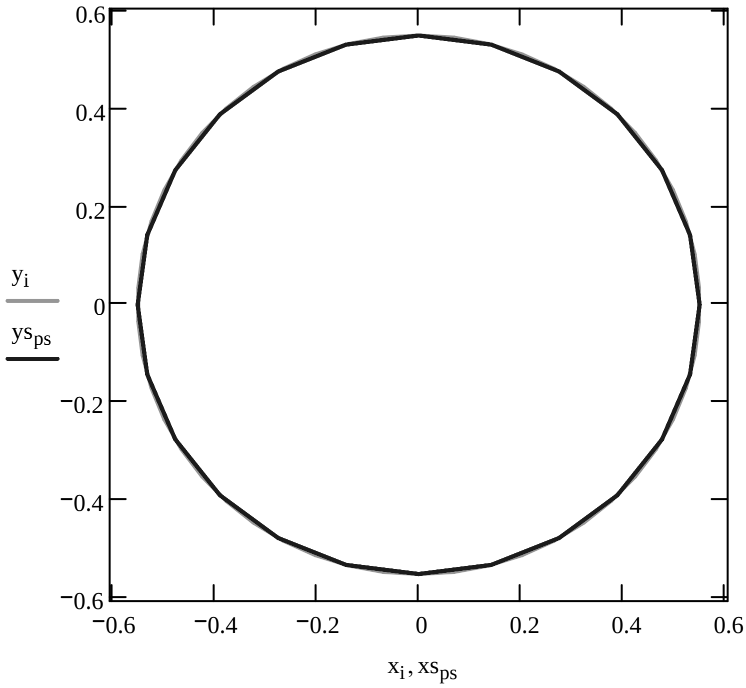
$I_{xS} = 0\ m^4$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right]$$

$I_{yS} = 0\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\quad I_{xS} = 0\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\quad I_{yS} = 0.00000\ m^4$



Rebar Data Layer 1 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	804	0	-474	**51**	0	0	0
2	804	-220	-420	**52**	0	0	0
3	804	-390	-269	**53**	0	0	0
4	804	-471	-57	**54**	0	0	0
5	804	-443	168	**55**	0	0	0
6	804	-314	355	**56**	0	0	0
7	804	-113	460	**57**	0	0	0
8	804	113	460	**58**	0	0	0
9	804	314	355	**59**	0	0	0
10	804	443	168	**60**	0	0	0
11	804	471	-57	**61**	0	0	0
12	804	390	-269	**62**	0	0	0
13	804	220	-420	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

Rebar Data Layer 2 - generated from input

Ref	Area mm2	X mm	Y mm	Ref	Area mm2	X mm	Y mm
1	0	0	0	**51**	0	0	0
2	0	0	0	**52**	0	0	0
3	0	0	0	**53**	0	0	0
4	0	0	0	**54**	0	0	0
5	0	0	0	**55**	0	0	0
6	0	0	0	**56**	0	0	0
7	0	0	0	**57**	0	0	0
8	0	0	0	**58**	0	0	0
9	0	0	0	**59**	0	0	0
10	0	0	0	**60**	0	0	0
11	0	0	0	**61**	0	0	0
12	0	0	0	**62**	0	0	0
13	0	0	0	**63**	0	0	0
14	0	0	0	**64**	0	0	0
15	0	0	0	**65**	0	0	0
16	0	0	0	**66**	0	0	0
17	0	0	0	**67**	0	0	0
18	0	0	0	**68**	0	0	0
19	0	0	0	**69**	0	0	0
20	0	0	0	**70**	0	0	0
21	0	0	0	**71**	0	0	0
22	0	0	0	**72**	0	0	0
23	0	0	0	**73**	0	0	0
24	0	0	0	**74**	0	0	0
25	0	0	0	**75**	0	0	0
26	0	0	0	**76**	0	0	0
27	0	0	0	**77**	0	0	0
28	0	0	0	**78**	0	0	0
29	0	0	0	**79**	0	0	0
30	0	0	0	**80**	0	0	0
31	0	0	0	**81**	0	0	0
32	0	0	0	**82**	0	0	0
33	0	0	0	**83**	0	0	0
34	0	0	0	**84**	0	0	0
35	0	0	0	**85**	0	0	0
36	0	0	0	**86**	0	0	0
37	0	0	0	**87**	0	0	0
38	0	0	0	**88**	0	0	0
39	0	0	0	**89**	0	0	0
40	0	0	0	**90**	0	0	0
41	0	0	0	**91**	0	0	0
42	0	0	0	**92**	0	0	0
43	0	0	0	**93**	0	0	0
44	0	0	0	**94**	0	0	0
45	0	0	0	**95**	0	0	0
46	0	0	0	**96**	0	0	0
47	0	0	0	**97**	0	0	0
48	0	0	0	**98**	0	0	0
49	0	0	0	**99**	0	0	0
50	0	0	0	**100**	0	0	0

$A1 := A1 \cdot mm^2$ $A2 := A2 \cdot mm^2$ $A3 := A3 \cdot mm^2$ $A4 := A4 \cdot mm^2$

$X1 := X1 \cdot mm$ $X2 := X2 \cdot mm$ $X3 := X3 \cdot mm$ $X4 := X4 \cdot mm$

$Y1 := Y1 \cdot mm$ $Y2 := Y2 \cdot mm$ $Y3 := Y3 \cdot mm$ $Y4 := Y4 \cdot mm$

$k := 1 .. 50$ $A_{bar_k} := A1_k$ $x_{bar_k} := X1_k$ $y_{bar_k} := Y1_k$

$A_{bar_{k+50}} := A2_k$ $x_{bar_{k+50}} := X2_k$ $y_{bar_{k+50}} := Y2_k$

$A_{bar_{k+100}} := A3_k$ $x_{bar_{k+100}} := X3_k$ $y_{bar_{k+100}} := Y3_k$

$A_{bar_{k+150}} := A4_k$ $x_{bar_{k+150}} := X4_k$ $y_{bar_{k+150}} := Y4_k$

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 10455\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.011$$

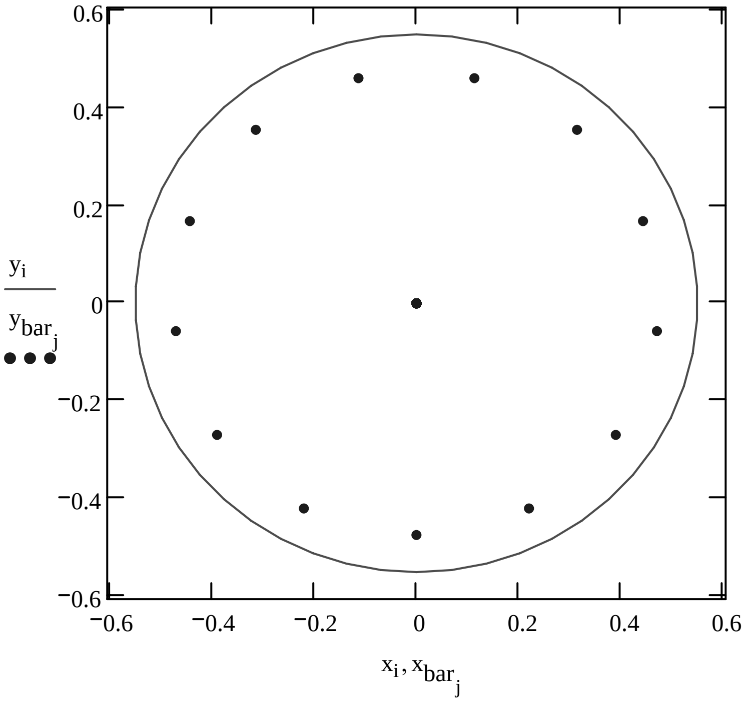
$$x_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad x_b = 0\ m$$

$$y_b := \left| \begin{array}{l} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot y_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} \text{ if } A_{BAR} > 0 \\ 0m \text{ otherwise} \end{array} \right. \qquad y_b = 0\ m$$

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00117\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00117\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\qquad A_E = 1018605\,mm^2$

Effective centroid

$$x_E := \frac{A_C \cdot [(1-\rho) \cdot x_C + \rho \cdot x_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E} \qquad x_E = 0.000\,m$$

$$y_E := \frac{A_C \cdot [(1-\rho) \cdot y_C + \rho \cdot y_b \cdot \alpha] + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E} \qquad y_E = 0.000\,m$$

Effective stiffness

$$I_{EX} := I_{xC} + I_{xb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot x_C{}^2 + \rho \cdot x_b{}^2 \cdot \alpha\right] + \left(I_{xS} + A_{ST} \cdot x_{ST}{}^2\right) \cdot \alpha$$

$$I_{EX} = 0\ m^4$$

$$I_{EY} := I_{yC} + I_{yb} \cdot (\alpha - 1) + A_C \cdot \left[(1-\rho) \cdot y_C{}^2 + \rho \cdot y_b{}^2 \cdot \alpha\right] + \left(I_{yS} + A_{ST} \cdot y_{ST}{}^2\right) \cdot \alpha$$

$$I_{EY} = 0\ m^4$$

Distance from extreme concrete fiber to centroid

$xF_{pos} := \max(x - x_E)$ $\qquad xF_{neg} := \min(x - x_E)$

$yF_{pos} := \max(y - y_E)$ $\qquad yF_{neg} := \min(y - y_E)$

Total depth of concrete section

$H_{CX} := xF_{pos} - xF_{neg}$ $\qquad H_{CX} = 1\ m$

$H_{CY} := yF_{pos} - yF_{neg}$ $\qquad H_{CY} = 1\ m$

Section modulus

$$Z_{Xpos} := \frac{I_{EX}}{xF_{pos}} \qquad Z_{Xneg} := \frac{I_{EX}}{xF_{neg}}$$

$$Z_{Ypos} := \frac{I_{EY}}{yF_{pos}} \qquad Z_{Yneg} := \frac{I_{EY}}{yF_{neg}}$$

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 0\,\text{mm}$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 550\,\text{mm}$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -550\,\text{mm}$

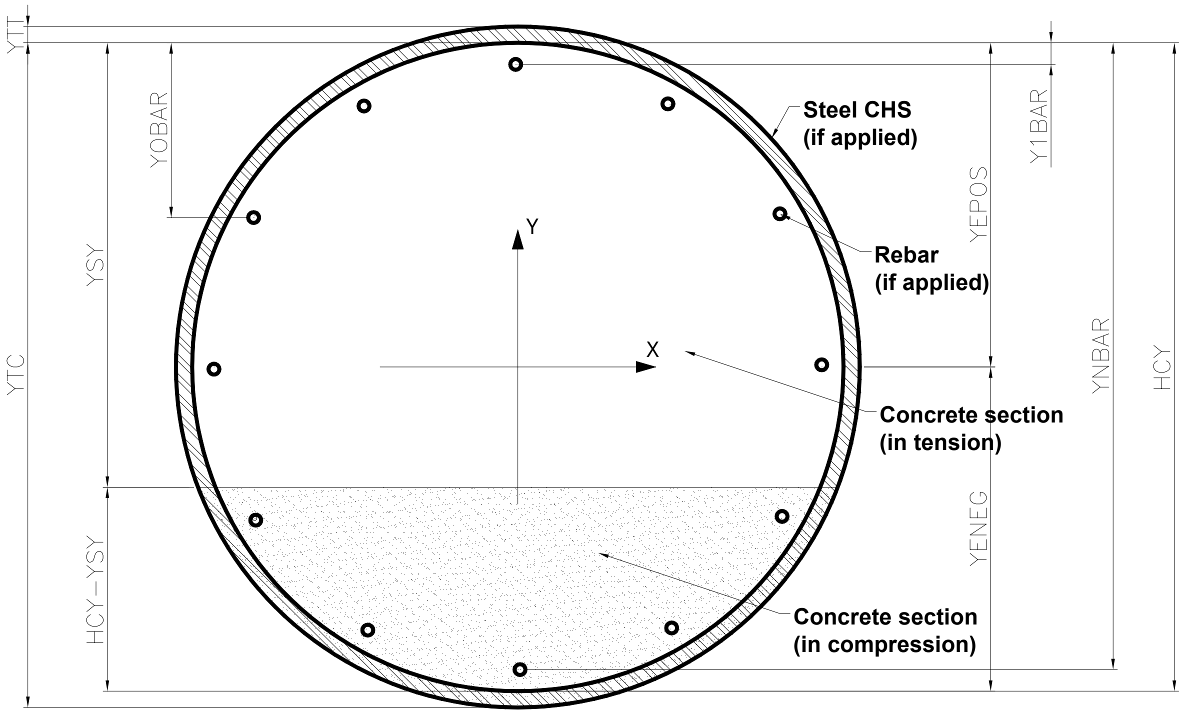
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min\left(y_{Epos} - y_{bar}\right)$ $y_{1bar} = 90\,\text{mm}$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max\left(y_{Epos} - y_{bar}\right)$ $y_{nbar} = 1024\,\text{mm}$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 0\,\text{mm}$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1100\,\text{mm}$



ASSIGN NEUTRAL AXIS VALUES

Number of sections to analysed $ns := 500$

$q := 2 .. ns$

Distance of neutral axis from extreme fiber in tension $y_{SY_q} := H_{CY} \cdot \frac{q}{ns + 1}$

Calculate stresses and strains in reinforcement and concrete at extreme fibers

Calculate strain at extreme compression fiber assuming max allowable stress in concrete:

Trial value of concrete strain

$$\varepsilon cc := \frac{\sigma_{cc}}{E_C} \cdot 2 \qquad \frac{\sigma_{cc}}{E_C} = 0.001165$$

Given

$$\sigma_{cc} = \varepsilon cc \cdot \left(4700 \sqrt{\frac{f_c \cdot 2}{MPa}} - \frac{4700^2}{2.68} \cdot \varepsilon cc \right) \cdot MPa$$

$$\varepsilon_{cc} := \mathrm{Find}(\varepsilon cc) \qquad \varepsilon_{cc} = 0.003321$$

$$\varepsilon_{cc} := \begin{vmatrix} \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \varepsilon_{cc} \text{ otherwise} \end{vmatrix} \qquad \varepsilon_{cc} = 0.003321$$

Strain at other stresses taken to be linear:

$$\varepsilon cc(f_c, \sigma_{cd}) := \begin{vmatrix} \frac{\sigma_{cd}}{\sigma_{tc}} \cdot \varepsilon_{tc} \text{ if } (f_c = 0) \cdot (A_{BAR} = 0) \\ \frac{\sigma_{cd}}{\sigma_{rc}} \cdot \varepsilon_{rc} \text{ if } (f_c = 0) \cdot (ts = 0) \\ \frac{\sigma_{cd}}{\sigma_{cc}} \cdot \varepsilon_{cc} \text{ otherwise} \end{vmatrix}$$

Calculate strain in steel tube assuming max allowable stress in concrete:

In compression $\varepsilon_{tcc_q} := \varepsilon_{cc} \cdot \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}}$

In tension $\varepsilon_{tct_q} := \varepsilon_{cc} \cdot \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}$

Calculate strain in rebar assuming max allowable stress in concrete:

In compression $$\varepsilon_{rcc_q} := \varepsilon_{cc} \cdot \frac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

In tension $$\varepsilon_{rct_q} := \varepsilon_{cc} \cdot \frac{y_{1bar} - y_{SY_q}}{H_{CY} - y_{SY_q}}$$

Calculate design max stress in compression taking account of other limits:

$$\sigma cd\left(\varepsilon_{tcc}, q\right) := \left| \begin{array}{l} \sigma_{cd} \leftarrow \sigma_{cc} \ \text{ if } \ f_c > 0 \\ \sigma_{cd} \leftarrow \sigma_{tc} \ \text{ if } \ \left(f_c = 0\right) \cdot \left(A_{BAR} = 0\right) \\ \sigma_{cd} \leftarrow \sigma_{rc} \ \text{ if } \ \left(f_c = 0\right) \cdot (ts = 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{tc}}{\varepsilon_{tcc}} \ \text{ if } \ \left(\varepsilon_{tcc} > \varepsilon_{tc}\right) \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rc}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left(\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{y_{nbar} - y_{SY_q}}{H_{CY} - y_{SY_q}} > \varepsilon_{rc}\right) \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{ts}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{ts}\right] \cdot (ts > 0) \\ \sigma_{cd} \leftarrow \sigma_{cd} \cdot \dfrac{\varepsilon_{rs}}{\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}}} \ \text{ if } \ \left[\varepsilon cc\left(f_c, \sigma_{cd}\right) \cdot \dfrac{-\left(y_{SY_q} - y_{1bar}\right)}{H_{CY} - y_{SY_q}} < \varepsilon_{rs}\right] \cdot \left(A_{BAR} > 0\right) \\ \sigma_{cc} \ \text{ otherwise} \end{array} \right.$$

$$\sigma_{cd_q} := \sigma cd\left(\varepsilon_{tcc_q}, q\right)$$

CALCULATE FORCES AND MOMENTS AT EACH NEUTRAL AXIS LOCATION

Calculate force in concrete:

$$F_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right] dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate moment from concrete about column centroid:

$$M_{C_q} := \left| \begin{array}{l} \displaystyle\int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot(1-\rho)\cdot\left[\frac{\sigma_{cd_q}\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}}\right]\cdot y\, dy \quad \text{if } f_c > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate strain in rebar assuming design max stress in concrete:

$$y_{SY_q} := \left| \begin{array}{l} y_{nbar}\cdot\dfrac{q}{ns+1} \quad \text{if } (f_c = 0)\cdot(A_{BAR} > 0) \\ y_{SY_q} \quad \text{otherwise} \end{array} \right.$$

$$\varepsilon_{S_{j,q}} := \left| \begin{array}{l} -\dfrac{y_{SY_q} - y_{Obar_j}}{y_{nbar} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{if } f_c = 0 \\ -\dfrac{y_{SY_q} - y_{Obar_j}}{H_{CY} - y_{SY_q}}\cdot\varepsilon cc\left(f_c, \sigma_{cd_q}\right) \quad \text{otherwise} \end{array} \right.$$

Calculate force in each rebar:

$$F_{S_{j,q}} := \left| \begin{array}{l} \varepsilon_{S_{j,q}} E_S\cdot A_{bar_j} \quad \text{if } A_{BAR} > 0 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Calculate total force in reinforcement:

$$F_{R_q} := \sum_{j} F_{S_{j,q}}$$

Calculate moment from reinforcement about section centroid:

$$M_{R_q} := \begin{cases} \sum_{j} -\left(\varepsilon_{S_{j,q}} E_S \cdot A_{bar_j} \cdot y_{bar_j}\right) & \text{if } A_{BAR} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate strain in steel tube at extreme tension fiber:

$$\varepsilon_{tds_q} := \frac{-\left(y_{SY_q} + y_{tt}\right)}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate strain in steel tube at extreme compression fiber:

$$\varepsilon_{tdc_q} := \frac{y_{tc} - y_{SY_q}}{H_{CY} - y_{SY_q}} \varepsilon cc\left(f_c, \sigma_{cd_q}\right)$$

Calculate tensile force in steel tube:

$$F_{TS1_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS2_q} := \int_{\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tds_q} \cdot E_S \cdot \left[y - \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TS} := \begin{cases} F_{TS1} - F_{TS2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calculate compressive force in steel tube:

$$F_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2} - y_{SY_q}\right)}^{\frac{H_{CY}}{2} + y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2} + y_{tt}\right)^2 - y^2} \cdot \left[\frac{\varepsilon_{tdc_q} \cdot E_S \cdot \left[y + \left(\frac{H_{CY}}{2} - y_{SY_q}\right)\right]}{H_{CY} - y_{SY_q} + y_{tt}}\right] dy$$

$$F_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right] dy$$

$$F_{TC} := \left|\begin{array}{l} F_{TC1} - F_{TC2} \ \ \text{if } \ ts > 0 \\ 0 \ \ \text{otherwise} \end{array}\right.$$

Calculate moment from tensile force in steel tube:

$$M_{TS1_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} -2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS2_q} := \int_{\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} -2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tds_q}\cdot E_S\cdot\left[y-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TS} := \left|\begin{array}{l} M_{TS1} - M_{TS2} \ \ \text{if } \ ts > 0 \\ 0 \ \ \text{otherwise} \end{array}\right.$$

Calculate moment from compressive force in steel tube:

$$M_{TC1_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}+y_{tt}} 2\sqrt{\left(\frac{H_{CY}}{2}+y_{tt}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC2_q} := \int_{-\left(\frac{H_{CY}}{2}-y_{SY_q}\right)}^{\frac{H_{CY}}{2}} 2\sqrt{\left(\frac{H_{CY}}{2}\right)^2 - y^2}\cdot\left[\frac{\varepsilon_{tdc_q}\cdot E_S\cdot\left[y+\left(\frac{H_{CY}}{2}-y_{SY_q}\right)\right]}{H_{CY}-y_{SY_q}+y_{tt}}\right]\cdot y\, dy$$

$$M_{TC} := \begin{cases} M_{TC1} - M_{TC2} & \text{if } ts > 0 \\ 0 & \text{otherwise} \end{cases}$$

Calate total axial response from section:

$$F_T := F_C + F_R + F_{TS} + F_{TC}$$

$$F_{TC} := F_C$$

Calculate total moment response from section:

$$M_T := M_C + M_R + M_{TS} + M_{TC}$$

$$M_{TC} := M_C$$

CALCULATE MAXIMUM ALLOWABLE AXIAL FORCE IN SECTION

Limiting strain in axial compression:

$$\varepsilon_{cL} := \begin{cases} \min(\varepsilon_{cc},\varepsilon_{tc}) & \text{if } (A_{BAR} = 0)\cdot(ts \neq 0)\cdot(f_c \neq 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc}) & \text{if } (ts = 0)\cdot(A_{BAR} \neq 0)\cdot(f_c \neq 0) \\ \varepsilon_{tc} & \text{if } (A_{BAR} = 0)\cdot(f_c = 0) \\ \varepsilon_{rc} & \text{if } (ts = 0)\cdot(f_c = 0) \\ \min(\varepsilon_{cc},\varepsilon_{rc},\varepsilon_{tc}) & \text{otherwise} \end{cases}$$

$\varepsilon_{cL} = 0.001950$

Limiting concrete stress in axial compression

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases}$$

$\sigma_{cL} = 18.93\,\text{MPa}$

$$P_{MAX} := \sigma_{cL}\cdot A_C(1-\rho) + \varepsilon_{cL}\cdot E_S(A_{BAR} + A_{ST})$$

$P_{MAX} = 21821.2\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

$$P_{MAXC} := \sigma_{cL}\cdot A_C\cdot(1-\rho)$$

$P_{MAXC} = 17743.7\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

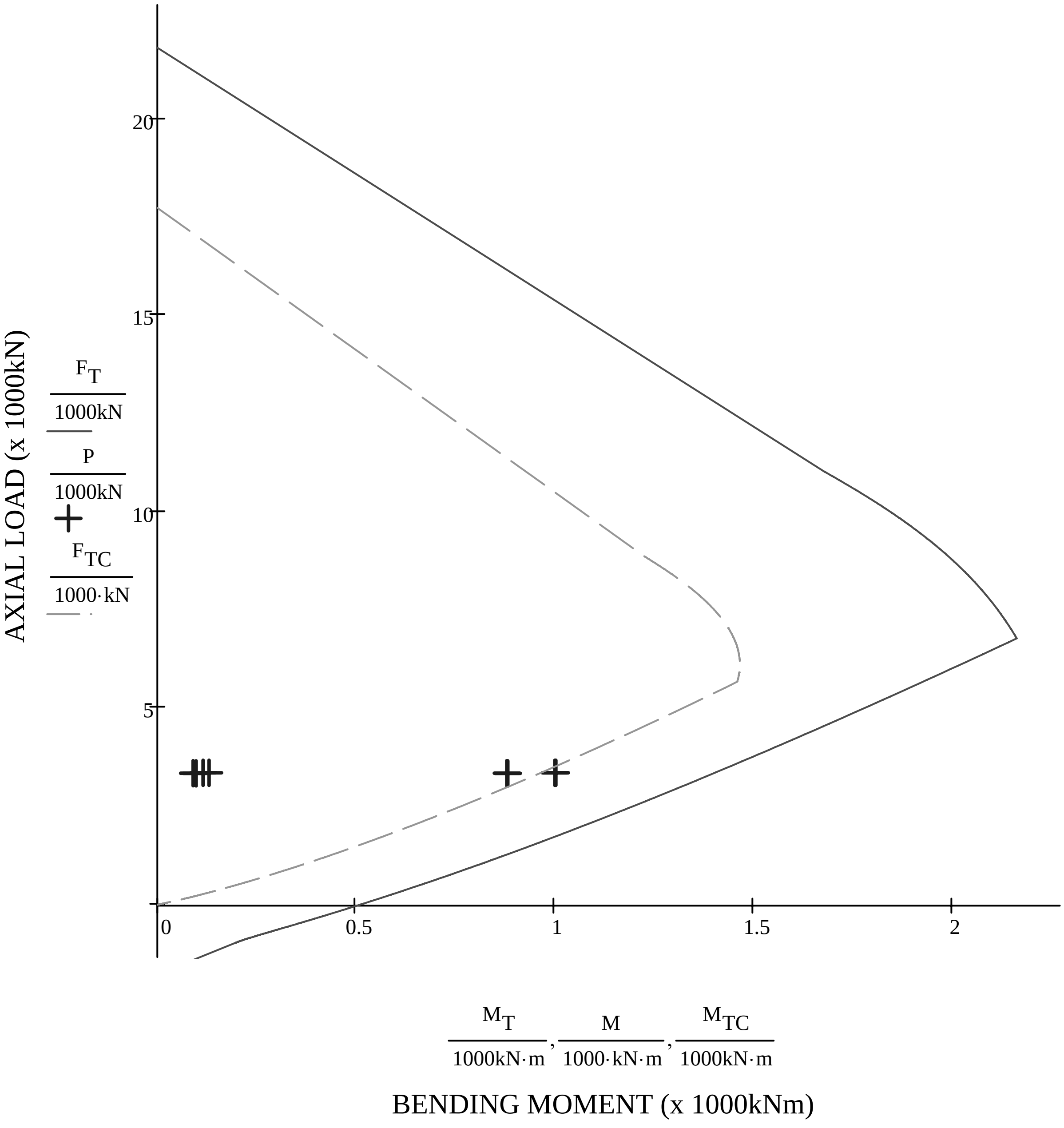
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -1777.4\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

$$\text{Limit} := \begin{cases} \min(P, F_T)\cdot 0.75 & \text{if } \min(P) > 0 \\ \min(P, F_T)\cdot 1.25 & \text{otherwise} \end{cases}$$

$P_{MINC} := 0\text{kN}$ $\quad M_{TC_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

Diameter of Column	$D = 1100\,\text{mm}$	Characteristic strength of concrete	$f_c = 30\,\text{MPa}$
Percentage reinforcement	$\rho = 1.10\,\%$	Yield Strength of Rebar	$f_y = 390\,\text{MPa}$
Thickness of CHS	$ts = 0\,\text{mm}$	Yield Strength of CHS	$f_{ys} = 250\,\text{MPa}$



INTERACTION CURVE AT SERVICEABILITY LIMIT STATE

Equation of interaction line - upper region (between 1 and 2 calculation points)

$$m1 := \frac{M_{T_2} - M_{T_1}}{F_{T_2} - F_{T_1}} \qquad c1 := F_{T_1}$$

Equation of interaction line - lower region (between ns and ns+1 calculation points)

$$m2 := \frac{M_{T_{ns}} - M_{T_{ns+1}}}{F_{T_{ns}} - F_{T_{ns+1}}} \qquad c2 := F_{T_{ns+1}}$$

$r := 1 .. 8$

```
$M_{SLS_r} :=$ | $0.000000000000000001 \cdot kN \cdot m$  if  $P_r > F_{T_1}$
               | $0.000000000000000001 \cdot kN \cdot m$  if  $P_r < F_{T_{ns+1}}$
               | $(P_r - c1) \cdot m1$  if  $(P_r > F_{T_2}) \cdot (P_r \le F_{T_1})$
               | $(P_r - c2) \cdot m2$  if  $(P_r \ge F_{T_{ns+1}}) \cdot (P_r < F_{T_{ns}})$
               | otherwise
               |    | $j \leftarrow 1$
               |    | while  $F_{T_j} > P_r$
               |    |    $j \leftarrow j + 1$
               |    | $M_{T_j}$
```

```
$StressFactor_r :=$ | "No Result"  if  $M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m$
                    | $\frac{M_r}{M_{SLS_r}}$  otherwise
```

$$P = \begin{pmatrix} 3359 \\ 3359 \\ 3357 \\ 3357 \\ 3346 \\ 3346 \\ 3344 \\ 3344 \end{pmatrix} kN \qquad M = \begin{pmatrix} 1001 \\ 115 \\ 1004 \\ 131 \\ 880 \\ 90 \\ 883 \\ 98 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \\ 1393.5 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.718 \\ 0.083 \\ 0.720 \\ 0.094 \\ 0.632 \\ 0.065 \\ 0.633 \\ 0.070 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1100	mm			
Percentage of rebar			1.10	%			

Load Case Ref	Pier	Applied Service Axial Load kN	Applied Service Bending Moment kNm	Service Limit State Bending Moment kNm	Allowable Stress Factor	Applied Stress Factor	Serviceability Limit State Design Result
1	**P71**	**3359**	**1001**	**1393.5**	**140%**	**72%**	OK
2	**P71**	**3359**	**115**	**1393.5**	**140%**	**8%**	OK
3	**P72**	**3357**	**1004**	**1393.5**	**140%**	**72%**	OK
4	**P72**	**3357**	**131**	**1393.5**	**140%**	**9%**	OK