P8 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 - P8 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	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	P81	Combination 1 - P + Traffic Load Only	2749.1	1373.4	100%
2	P81	Combination 1 - P + Traffic Load Only	2749.1	1459.5	100%
3	P82	Combination 1 - P + Traffic Load Only	2795.8	1404.8	100%
4	P82	Combination 1 - P + Traffic Load Only	2795.8	1435.1	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 $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases}$ $\alpha = 7.77$

$E_C = 25743\,MPa$

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 $\sigma_{ts} := -0.6f_{ys}$ $\sigma_{ts} = -150\,MPa$

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

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

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

$A_C = 0.94783\ m^2$

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

$x_C = 0\ m$

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

$y_C = 0\ m$

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

$I_x = 0.07149\ m^4$

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

$I_y = 0.07149\ m^4$

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

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

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

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

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

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

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

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

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

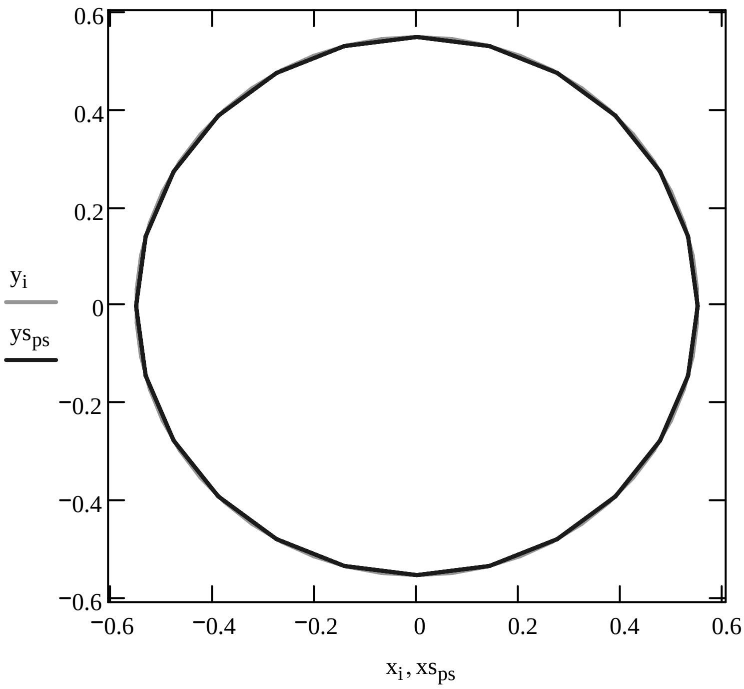
$I_{xS} = 0\ m^4$

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

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

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

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



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	-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

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

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

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

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

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

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

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

Calculate Section Properties of Reinforcement

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 19302\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0204$$

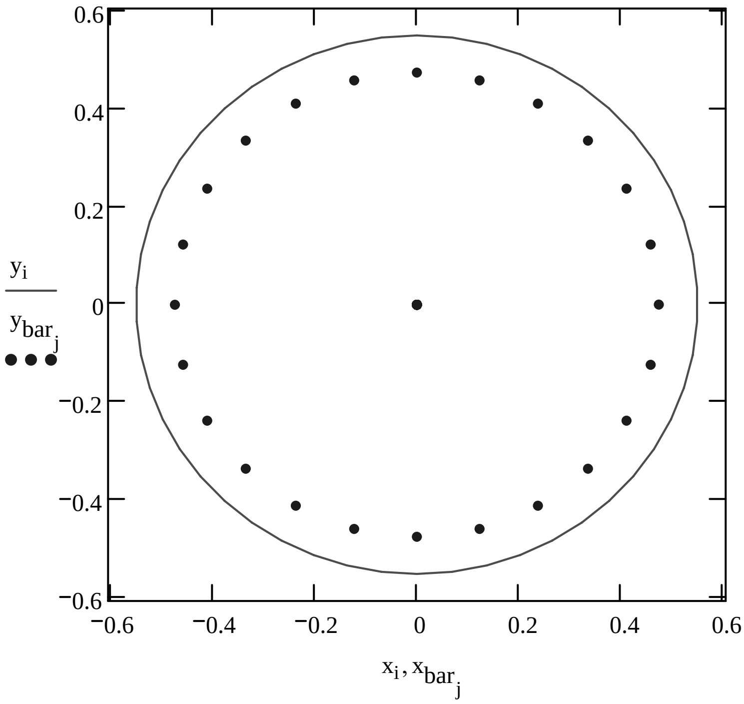
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

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

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00217\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00217\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $\qquad A_E = 1078490\ mm^2$

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

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

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:

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

Establish Section Dimensions

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

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

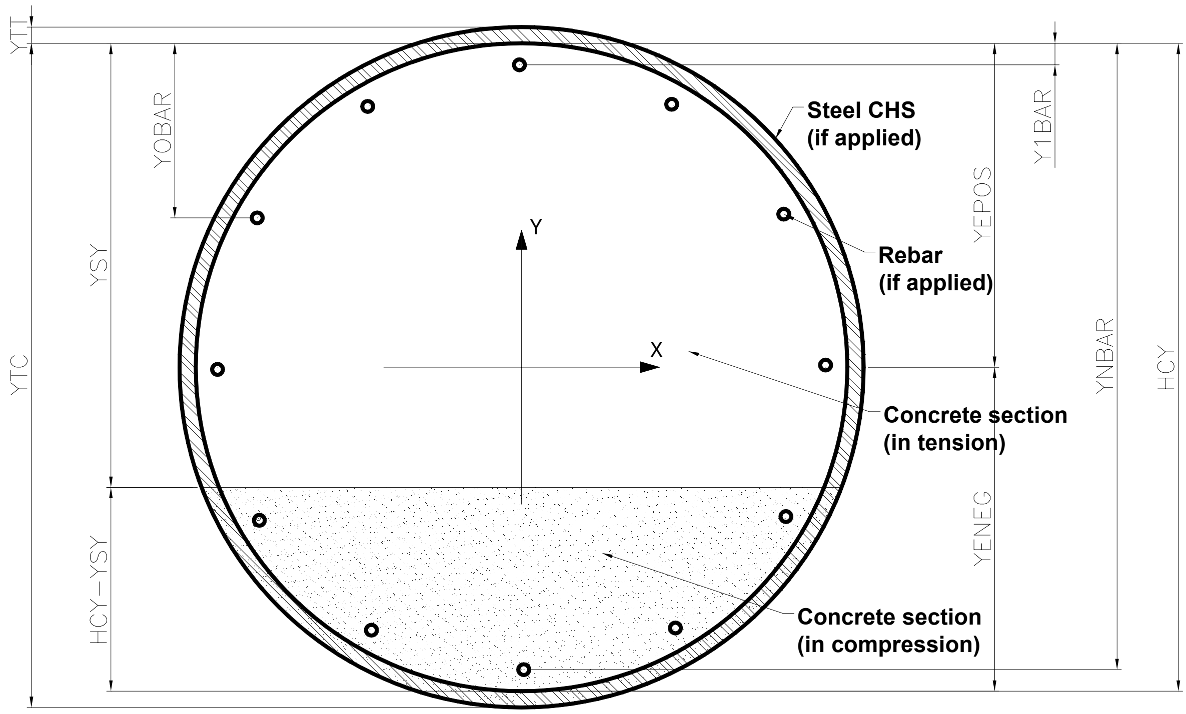
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

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

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

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

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



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

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:

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

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

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:

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

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

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

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

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \sigma_{cL} = 18.93\,\text{MPa}$$

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

$P_{MAX} = 25104\,\text{kN}$ $\qquad F_{T_1} := P_{MAX}$ $\qquad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

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

$P_{MAXC} = 17576.2\,\text{kN}$ $\qquad F_{TC_1} := P_{MAXC}$ $\qquad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

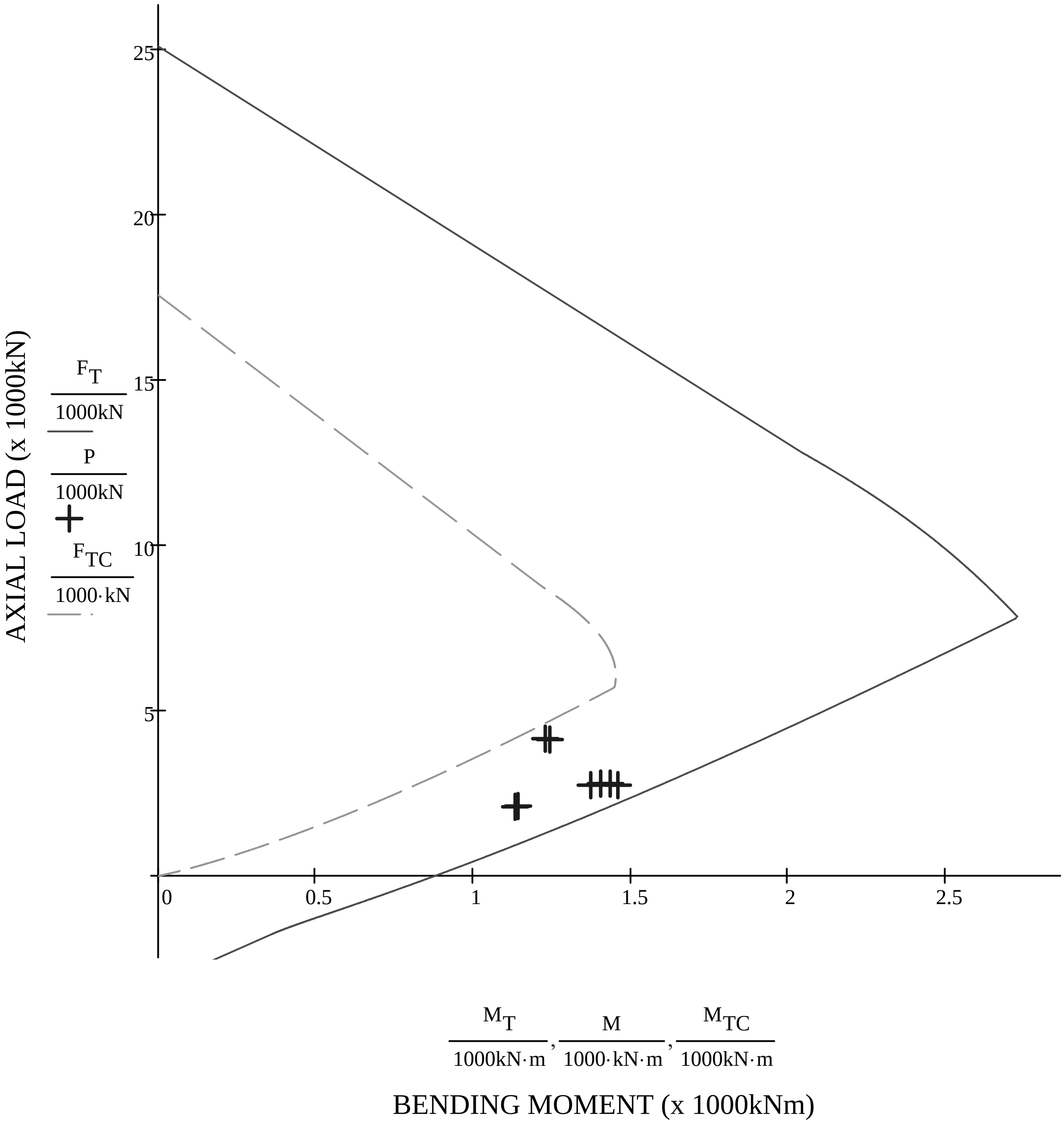
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -3281.3\,\text{kN}$ $\qquad F_{T_{ns+1}} := P_{MIN}$ $\qquad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

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

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

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 2.04\,\%$	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)

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

$r := 1 .. 8$

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

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

$$P = \begin{pmatrix} 2749 \\ 2749 \\ 2796 \\ 2796 \\ 2096 \\ 4131 \\ 2119 \\ 4157 \end{pmatrix} kN \quad M = \begin{pmatrix} 1373 \\ 1459 \\ 1405 \\ 1435 \\ 1133 \\ 1243 \\ 1143 \\ 1229 \end{pmatrix} kN \cdot m \quad M_{SLS} = \begin{pmatrix} 1589.0 \\ 1589.0 \\ 1601.5 \\ 1601.5 \\ 1426.5 \\ 1911.2 \\ 1437.4 \\ 1911.2 \end{pmatrix} kN \cdot m \quad StressFactor = \begin{pmatrix} 0.864 \\ 0.919 \\ 0.877 \\ 0.896 \\ 0.794 \\ 0.651 \\ 0.795 \\ 0.643 \end{pmatrix}$$

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	**P81**	**2749**	**1373**	**1589.0**	**100%**	**86%**	OK
2	**P81**	**2749**	**1459**	**1589.0**	**100%**	**92%**	OK
3	**P82**	**2796**	**1405**	**1601.5**	**100%**	**88%**	OK
4	**P82**	**2796**	**1435**	**1601.5**	**100%**	**90%**	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 - P8 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	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	P81	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2717.8	1759.1	140%
2	P81	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2717.8	1854.7	140%
3	P82	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2831.3	1799.2	140%
4	P82	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	2831.3	1839.1	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

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

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

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

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

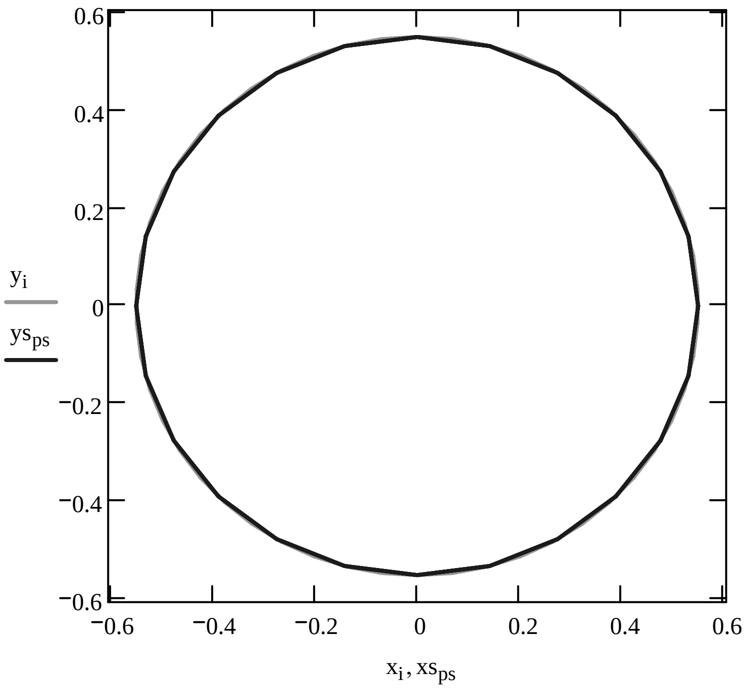
$I_{xS} = 0\ m^4$

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

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

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

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



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	-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

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 19302\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0.0204$$

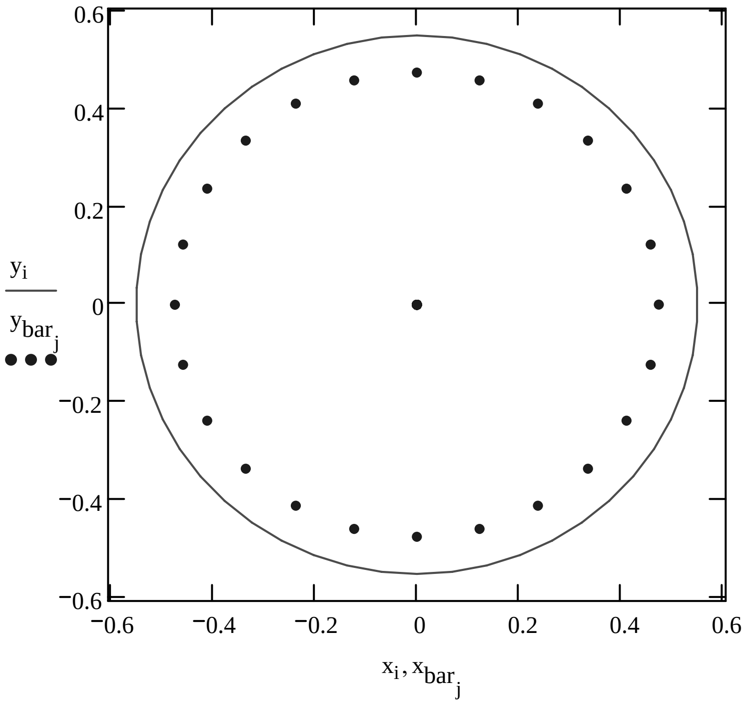
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

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

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0.00217\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0.00217\,m^4$$

$j := 1 .. 200$



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

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

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

Thickness of steel tube:

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

Establish Section Dimensions

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

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

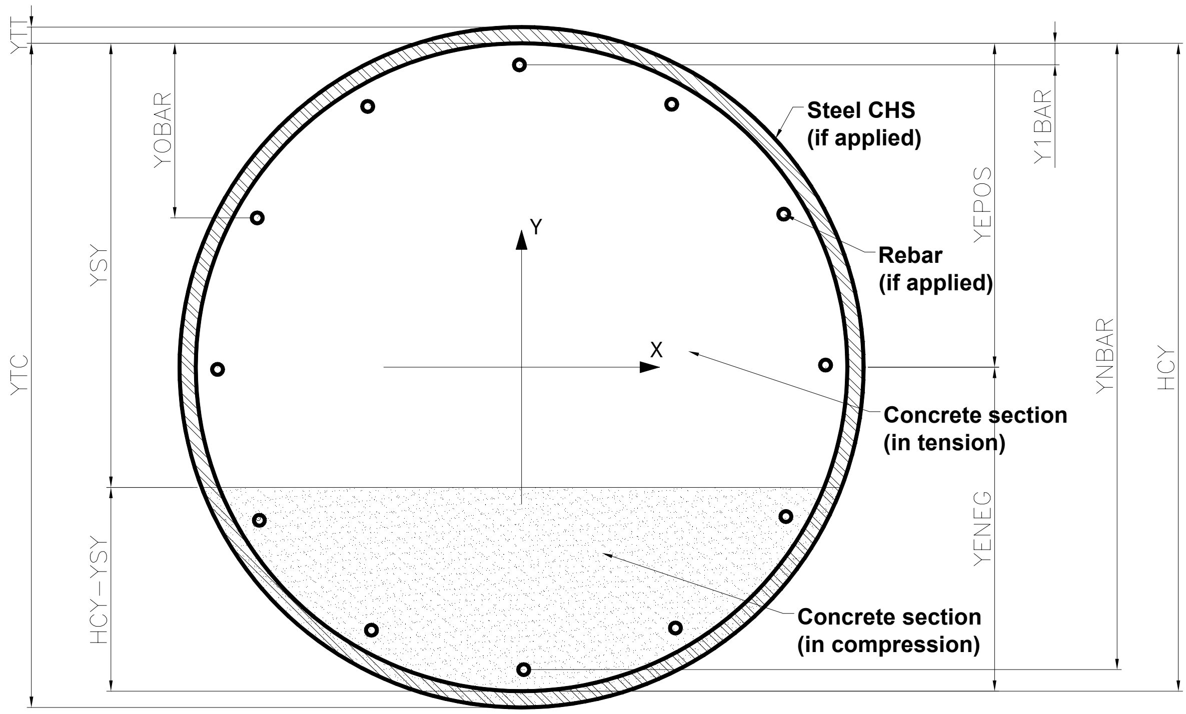
Offsets of rebar from extreme fiber $\quad$ $y_{Obar} := y_{Epos} - y_{bar}$

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

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

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

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



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

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

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

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

Strain at other stresses taken to be linear:

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

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

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:

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

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

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:

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

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

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

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

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

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

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

$P_{MAX} = 25104\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

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

$P_{MAXC} = 17576.2\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

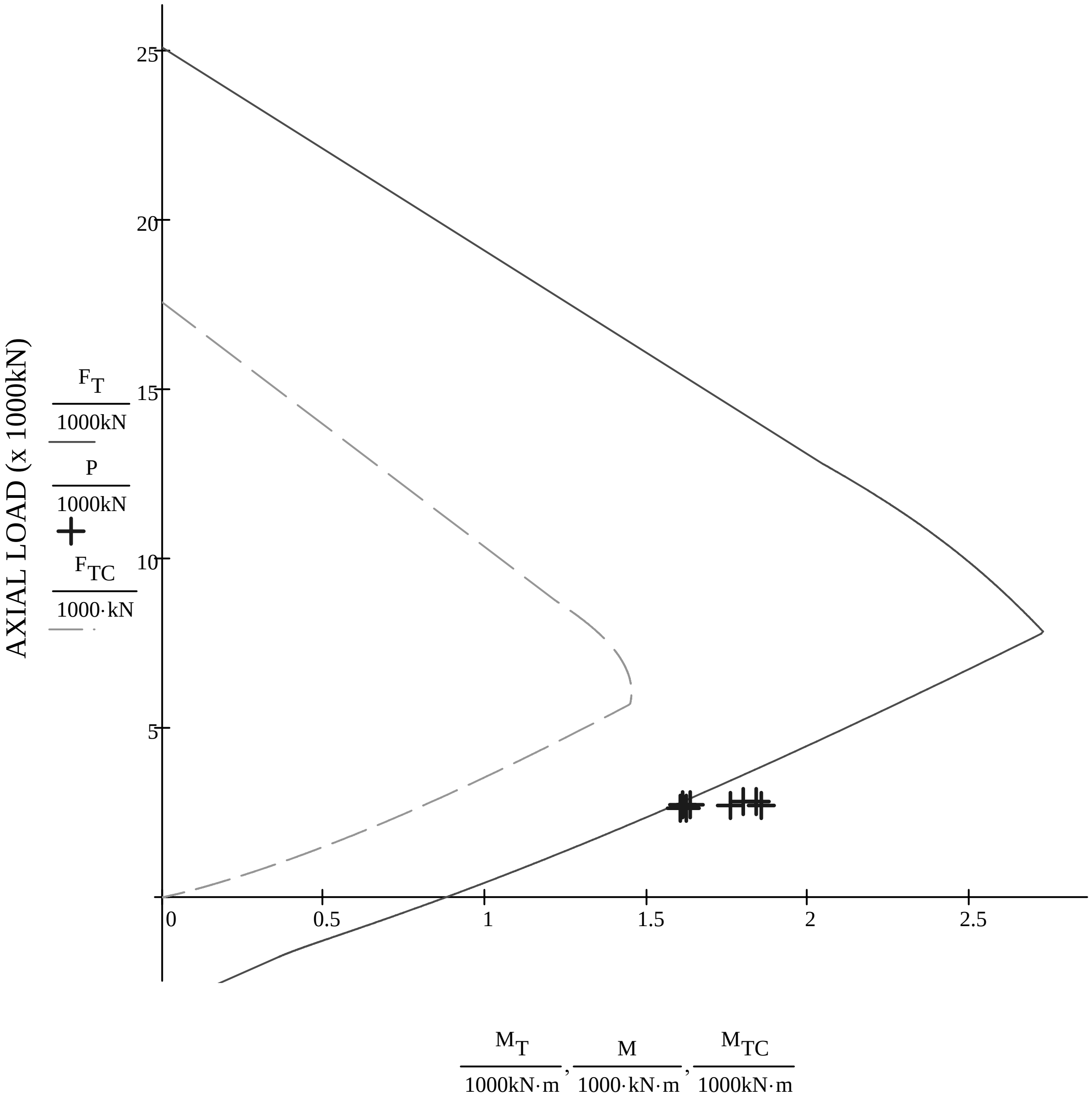
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -3281.3\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

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

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

Diameter of Column	$D = 1100\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 2.04\,\%$	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)

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

$r := 1 .. 8$

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

$$StressFactor_r := \begin{cases} \text{"No Result"} & \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} & \text{otherwise} \end{cases}$$

$$P = \begin{pmatrix} 2718 \\ 2718 \\ 2831 \\ 2831 \\ 2635 \\ 2635 \\ 2739 \\ 2739 \end{pmatrix} kN \qquad M = \begin{pmatrix} 1759 \\ 1855 \\ 1799 \\ 1839 \\ 1604 \\ 1623 \\ 1635 \\ 1611 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1576.6 \\ 1576.6 \\ 1601.5 \\ 1601.5 \\ 1564.4 \\ 1564.4 \\ 1589.0 \\ 1589.0 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 1.116 \\ 1.176 \\ 1.123 \\ 1.148 \\ 1.025 \\ 1.037 \\ 1.029 \\ 1.014 \end{pmatrix}$$

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	**P81**	**2718**	**1759**	**1576.6**	**140%**	**112%**	OK
2	**P81**	**2718**	**1855**	**1576.6**	**140%**	**118%**	OK
3	**P82**	**2831**	**1799**	**1601.5**	**140%**	**112%**	OK
4	**P82**	**2831**	**1839**	**1601.5**	**140%**	**115%**	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 - P8 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	P81	Combination 1 - P + Traffic Load Only	2912.0	332.0	100%
2	P81	Combination 1 - P + Traffic Load Only	2912.0	102.4	100%
3	P82	Combination 1 - P + Traffic Load Only	2958.7	329.0	100%
4	P82	Combination 1 - P + Traffic Load Only	2958.7	125.7	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 $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases}$ $\alpha = 7.77$

$E_C = 25743\,MPa$

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

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

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

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

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

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

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

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

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

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

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

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

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

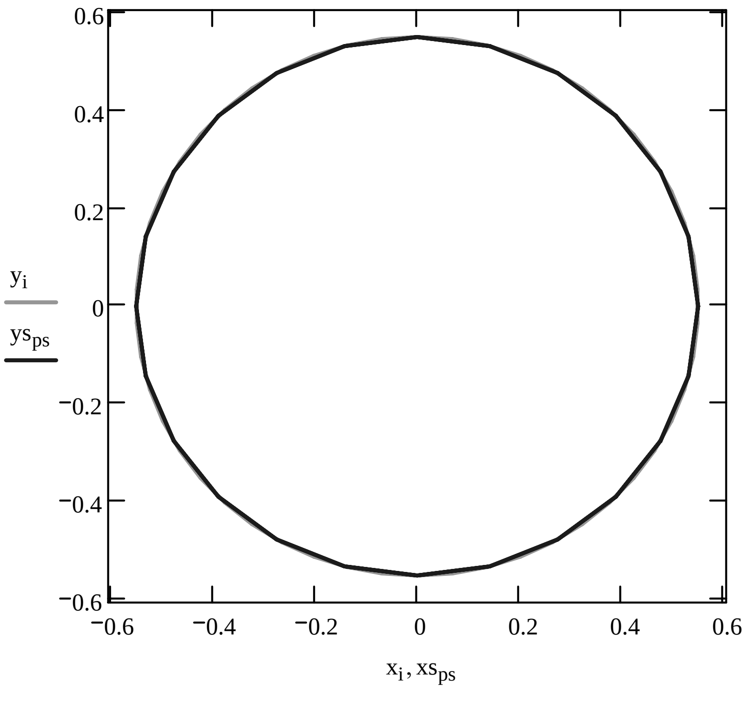
$I_{xS} = 0\ m^4$

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

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

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

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



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	-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

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

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

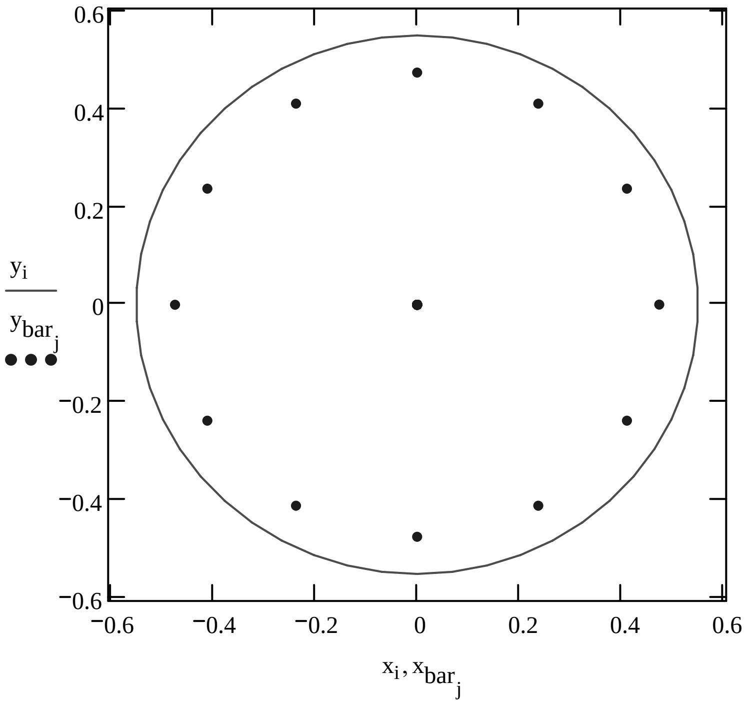
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases}$$ $x_b = 0\ m$

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

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

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

$j := 1..200$



Calculate Composite Section Properties (before cracking)

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

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

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

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:

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

Establish Section Dimensions

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

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

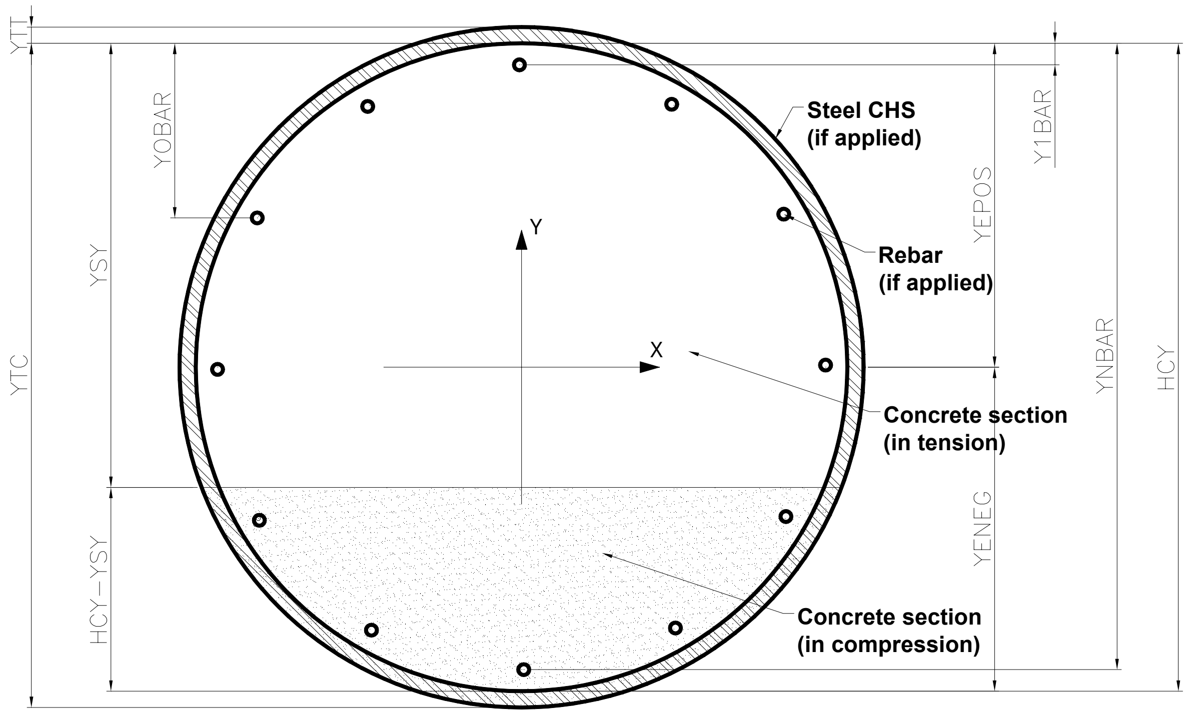
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

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

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

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

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



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

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

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

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

Strain at other stresses taken to be linear:

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

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:

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

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

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:

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

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

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

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

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

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

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

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

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

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

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

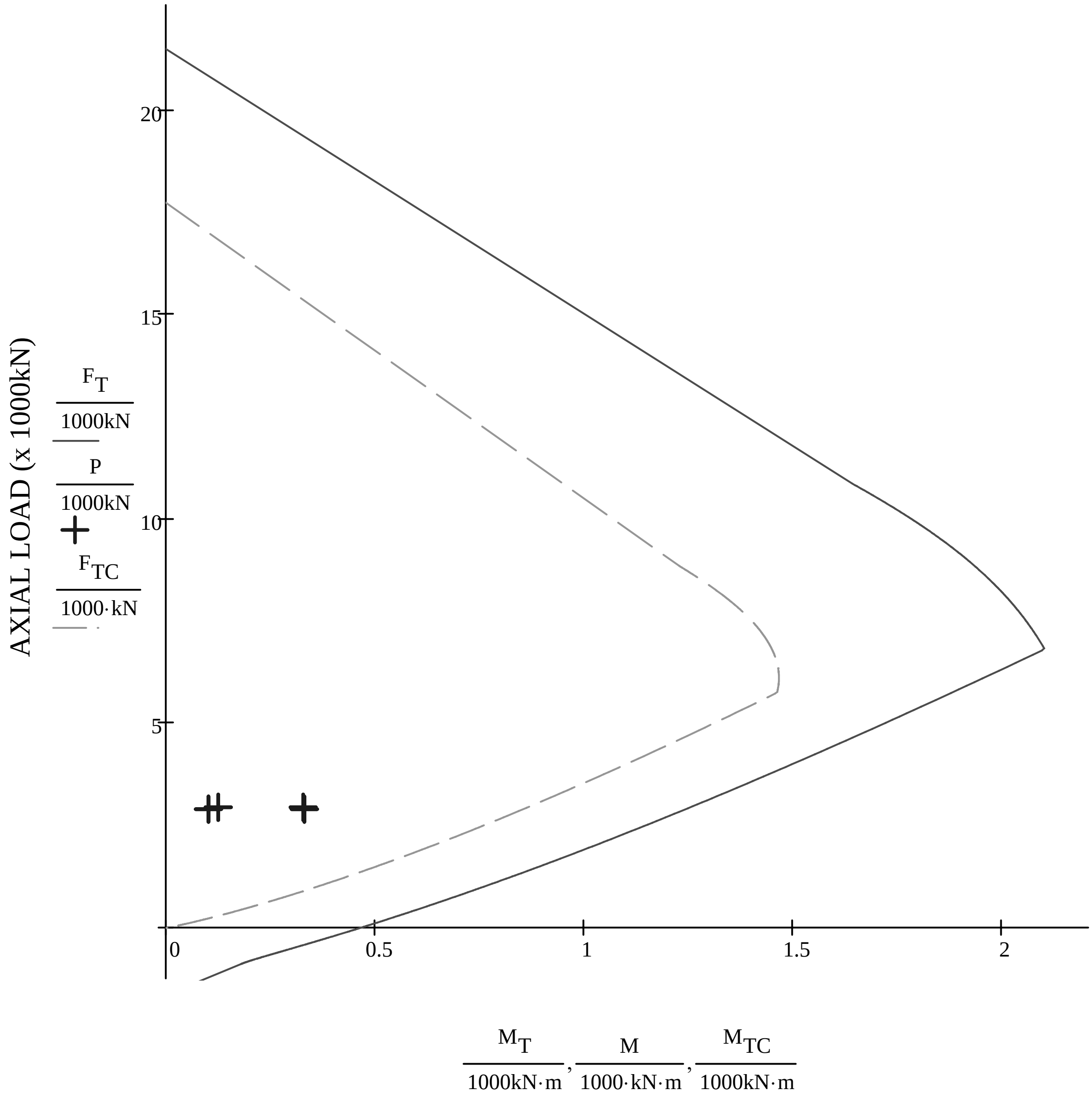
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

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

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

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

Diameter of Column	$D = 1100\,mm$	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	$f_{ys} = 250\,MPa$



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)

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

$r := 1 .. 8$

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

$$StressFactor_r := \begin{cases} \text{"No Result"} & \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} & \text{otherwise} \end{cases}$$

$$P = \begin{pmatrix} 2912 \\ 2912 \\ 2959 \\ 2959 \\ 2912 \\ 2912 \\ 2959 \\ 2959 \end{pmatrix} kN \qquad M = \begin{pmatrix} 332 \\ 102 \\ 329 \\ 126 \\ 332 \\ 102 \\ 329 \\ 126 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1239.2 \\ 1239.2 \\ 1250.3 \\ 1250.3 \\ 1239.2 \\ 1239.2 \\ 1250.3 \\ 1250.3 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.268 \\ 0.083 \\ 0.263 \\ 0.101 \\ 0.268 \\ 0.083 \\ 0.263 \\ 0.101 \end{pmatrix}$$

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	**P81**	**2912**	**332**	**1239.2**	**100%**	**27%**	OK
2	**P81**	**2912**	**102**	**1239.2**	**100%**	**8%**	OK
3	**P82**	**2959**	**329**	**1250.3**	**100%**	**26%**	OK
4	**P82**	**2959**	**126**	**1250.3**	**100%**	**10%**	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 - P8 Base 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	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	P81	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2880.7	562.9	140%
2	P81	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2880.7	324.7	140%
3	P82	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2994.2	564.0	140%
4	P82	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+SCSH	2994.2	352.9	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

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

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

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

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

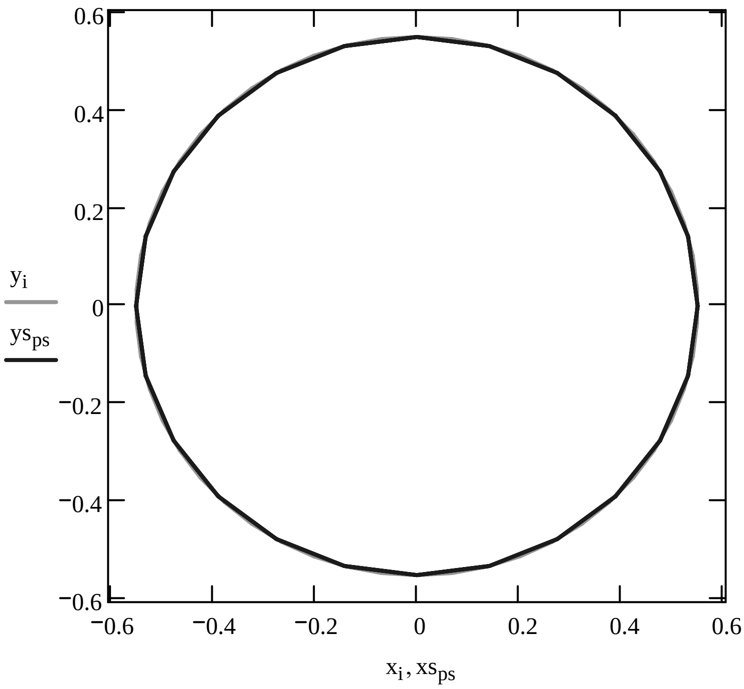
$$I_{xS} = 0\ m^4$$

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

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

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

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



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

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

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

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

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

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

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

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

Calculate Section Properties of Reinforcement

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

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

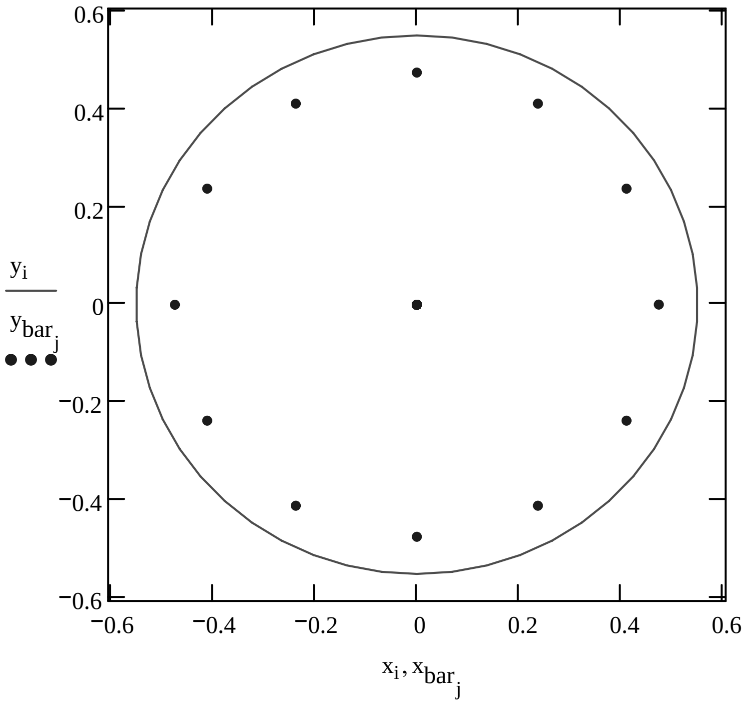
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

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

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

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

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

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

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

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

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:

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

Establish Section Dimensions

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

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

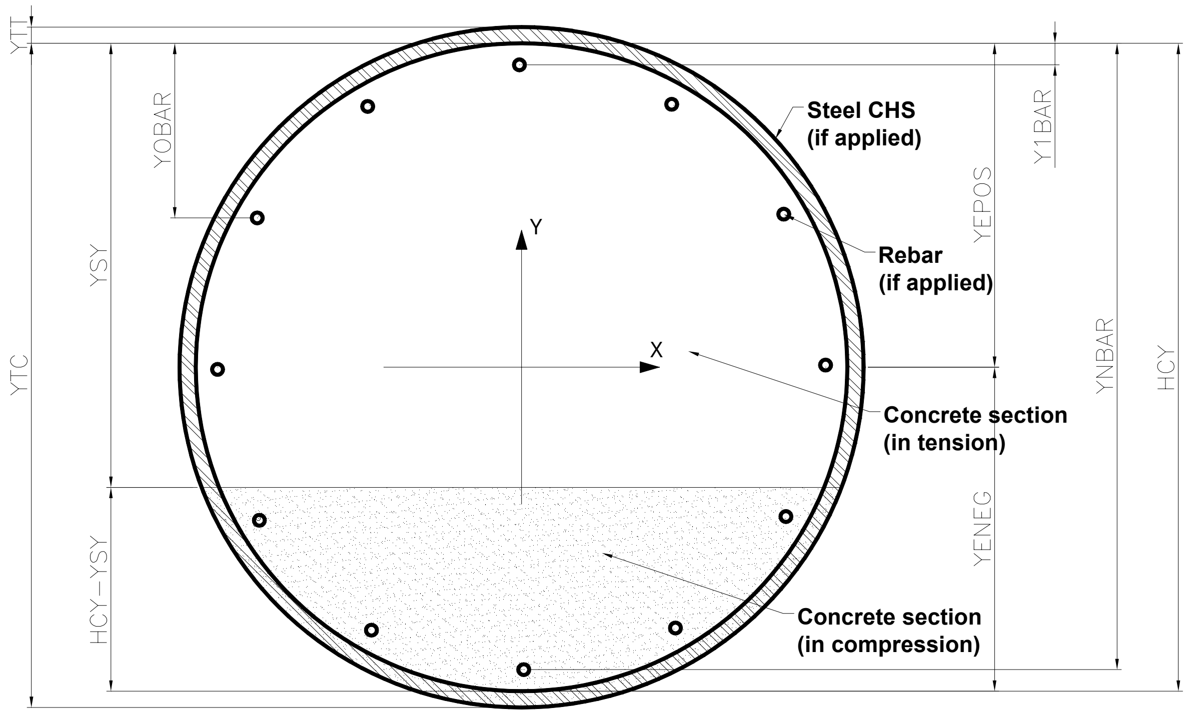
Offsets of rebar from extreme fiber $\quad y_{Obar} := y_{Epos} - y_{bar}$

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

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

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

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



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

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

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

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

Strain at other stresses taken to be linear:

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

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

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:

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

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

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:

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

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

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

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

$$\sigma_{cL} := \begin{cases} \sigma_{cd_2} & \text{if } f_c > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \sigma_{cL} = 18.93\,\text{MPa}$$

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

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

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

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

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

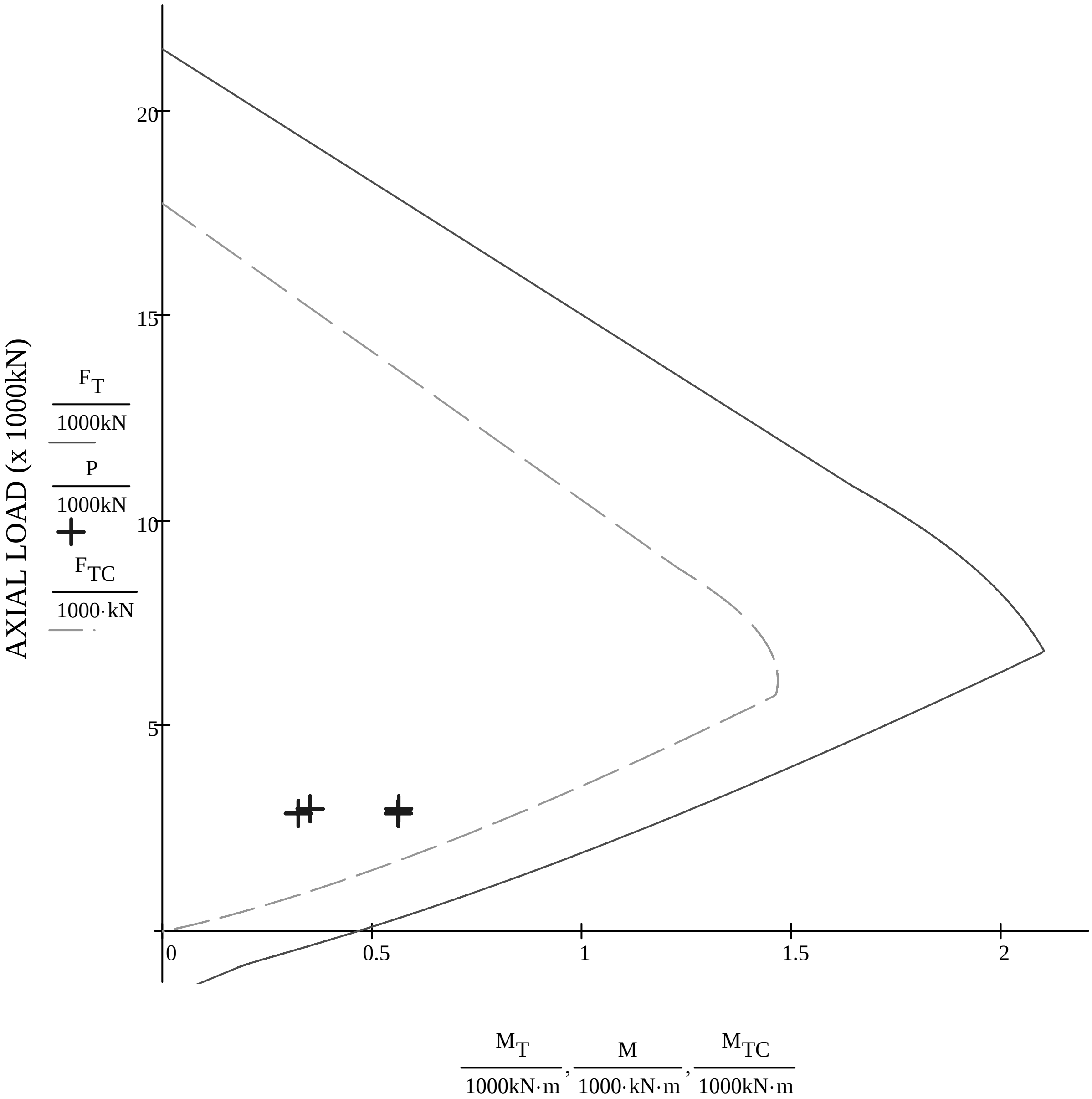
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

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

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

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

Diameter of Column	$D = 1100\,mm$	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	$f_{ys} = 250\,MPa$



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)

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

$r := 1 .. 8$

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

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

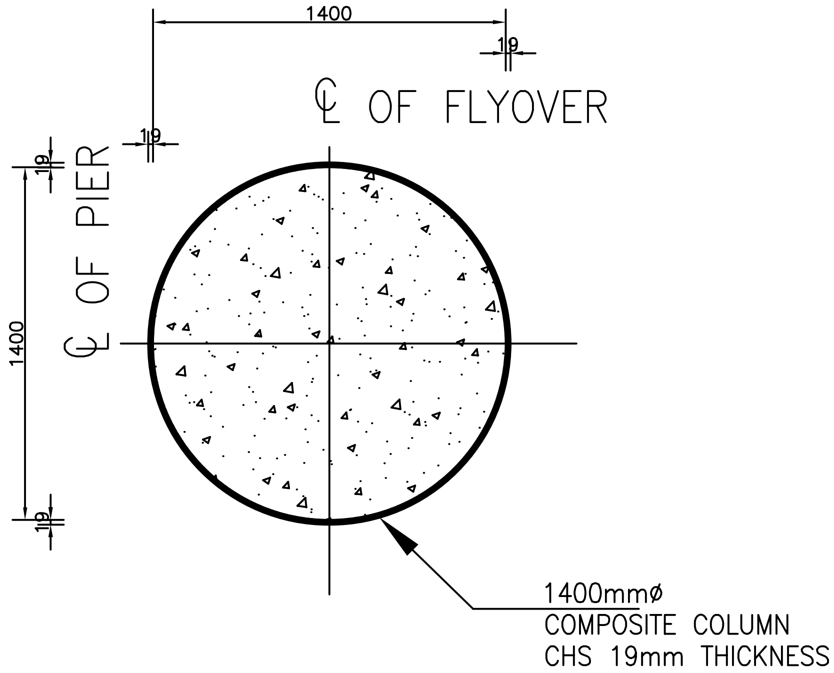
$$P = \begin{pmatrix} 2881 \\ 2881 \\ 2994 \\ 2994 \\ 2881 \\ 2881 \\ 2994 \\ 2994 \end{pmatrix} kN \qquad M = \begin{pmatrix} 563 \\ 325 \\ 564 \\ 353 \\ 563 \\ 325 \\ 564 \\ 353 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 1228.2 \\ 1228.2 \\ 1261.5 \\ 1261.5 \\ 1228.2 \\ 1228.2 \\ 1261.5 \\ 1261.5 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.458 \\ 0.264 \\ 0.447 \\ 0.280 \\ 0.458 \\ 0.264 \\ 0.447 \\ 0.280 \end{pmatrix}$$

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	**P81**	**2881**	**563**	**1228.2**	**140%**	**46%**	OK
2	**P81**	**2881**	**325**	**1228.2**	**140%**	**26%**	OK
3	**P82**	**2994**	**564**	**1261.5**	**140%**	**45%**	OK
4	**P82**	**2994**	**353**	**1261.5**	**140%**	**28%**	OK

7.1.2. COMPOSITE COLUMNS

SECTION


1400
19
℄ OF FLYOVER
19
19
℄ OF PIER
1400
19
1400mmø
COMPOSITE COLUMN
CHS 19mm THICKNESS

Ultimate Design

Notes on Ultimate Moment Design for Composite Columns

A check has been made only at Pier P4 and P5.

The design of composite columns is in accordance with 2.4.5(2) of the Design Criteria. The Design Criteria is based upon the provisions of Australian Standard AS 5100 which itself is closely aligned with the provisions of Eurocode 4.

The design criteria are re-presented here for ease of reference:

Composite Column Design

(a) Compression Members

The steel section shall be symmetrical, be fabricated from steel with a maximum yield stress of 350MPa and have a wall thickness such that the plate element slenderness λ_e is less than the limit given below:

$$\lambda_e = \frac{d_0}{t} \cdot \left(\frac{f_y}{250} \right) < 82 \quad \text{for circular hollow sections}$$

$$\lambda_e = \frac{h}{t} \cdot \left(\frac{f_y}{250} \right) < 45 \quad \text{for rectangular hollow sections}$$

where:

d_0 = outside diameter of the section

t = wall thickness of the section

h = outside depth of the section

Concrete shall be of normal density and strength and have a maximum aggregate size of 20mm.

Positive shear connection shall be provided between the concrete and the steel for that proportion of the shear stress at the strength limit state that exceeds 0.4MPa.

The steel contribution factor (α_s) shall lie within the following limits:

$$0.2 < \alpha_s \leq 0.9$$

where:

$$\alpha_s = \frac{\phi \cdot A_s \cdot f_y}{N_{us}}$$

ϕ = resistance factor of steel (= 0.9)

f_y = Cross-sectional area of steel section

N_{us} = Nominal section capacity of concentrically loaded composite compression member (given below)

In the design of composite columns, account will be taken of the confining effect of the steel tube, slenderness and imperfections.

For rectangular composite members, the ultimate section capacity is given as

$$N_{us} := \phi \cdot A_s \cdot f_y + \phi \cdot A_r \cdot f_{ry} + \phi_c \cdot A_c \cdot f_c$$

where:

	=	resistance factor for steel (= 0.9)
A_s	=	cross-sectional area of structural steel section
f_y	=	nominal yield strength of the structural steel
A_r	=	cross-sectional area of the reinforcement
f_{ry}	=	nominal yield stress of the reinforcement
$_c$	=	resistance factor for concrete in compression (=0.6)
A_c	=	area of concrete in cross-section
f_c	=	characteristic compressive strength of the concrete at 28 days

For circular composite members, the ultimate section capacity is given as

$$N_{us} := \phi \cdot A_s \cdot \eta_2 \cdot f_y + \phi \cdot A_r \cdot f_{ry} + \phi_c \cdot A_c \cdot f_c \cdot \left(1 + \eta_1 \cdot \frac{t \cdot f_y}{d_o \cdot f_c}\right)$$

where parameters are as above and where:

t	=	wall thickness of the steel tube
d_o	=	outside diameter of the circular hollow section
η_1, η_2	=	coefficients to account for the confining effect of the circular steel tube

The values of η_1 and η_2 for the case where the eccentricity of loading e=0, i.e. η_{10} and η_{20}, are calculated from the following equations:

$$\eta_{10} = 4.9 - 18.5\lambda_r + 17\lambda_r^2 \qquad \text{(but} \geq 0.0\text{)}$$

$$\eta_{20} = 0.25\,(3 + 2\lambda_r) \qquad \text{(but} \leq 1.0\text{)}$$

If the eccentricity of loading (e) lies in the range $0 < e \leq (d_o/10)$, η_1 and η_2 shall be calculated as follows:

$$\eta_1 := \eta_{10} \cdot \left(1 - \frac{10e}{d_o}\right)$$

$$\eta_2 := \eta_{20} + \left(1 - \eta_{20}\right) \cdot \frac{10e}{d_o}$$

The relative slenderness λ_r for a composite column in a given plane of bending is calculated as follows:

$$\lambda_r := \sqrt{\frac{N_s}{N_{cr}}}$$

where:

N_s = value of N_{us} determined above but taking values of and $_c$ to be 1.0

N_{cr} = elastic critical load

= $\left(\frac{\pi^2 \cdot (EI)_e}{L_e^2}\right)$

$(EI)_e$ = effective flexural stiffness

L_e = effective length of member

The effective flexural stiffness $(EI)_e$ of a composite member is calculated as follows:

$$(EI)_e = EI_s + EI_r + {}_c E_c I_c$$

where:

, $_c$ = resistance factor for steel and concrete

E = modulus of elasticity of structural steel section

I_s = second moment of area of structural steel section

I_r = second moment of area of the reinforcement

E_c = modulus of elasticity area of concrete

I_c = second moment of area of the un cracked concrete section

The effective length L_e of a compression member is calculated as follows:

$$L_e = k_e L$$

where:

k_e = member effective length factor

The ultimate member capacity shall be determined as follows:

$$N_{uc} := \alpha_c \cdot N_{us} \quad \leq N_{us}$$

where:

N_{us} = ultimate section capacity

α_c = compression member slenderness reduction factor, calculated as follows:

$$\alpha_c := \xi \cdot \left[1 - \sqrt{1 - \left(\frac{90}{\xi \cdot \lambda} \right)^2} \right]$$

$$\xi := \frac{\left(\frac{\lambda}{90} \right)^2 + 1 + \eta}{2 \cdot \left(\frac{\lambda}{90} \right)^2}$$

$$\lambda := \lambda_\eta + \alpha_a \cdot \alpha_b$$

$$\eta := 0.00326(\lambda - 13.5)$$

$$\lambda_\eta := 90 \cdot \lambda_r$$

$$\alpha_a := \frac{2100 \cdot (\lambda_\eta - 13.5)}{\lambda_\eta^2 - 15.3 \cdot \lambda_\eta + 2050}$$

$\alpha_b := -1.0$ For concrete filled RHS and CHS members

(b) Members Subject to Combined Compression and Bending

In the design of members subject to combined compression and uniaxial bending, the resistance of the cross-section will be determined assuming full plastic stress distribution for both steel and concrete components. The maximum concrete compressive stress is $_c f_c$ and the maximum steel compressive stress is f_y for the steel section and f_{yr} for the reinforcement.

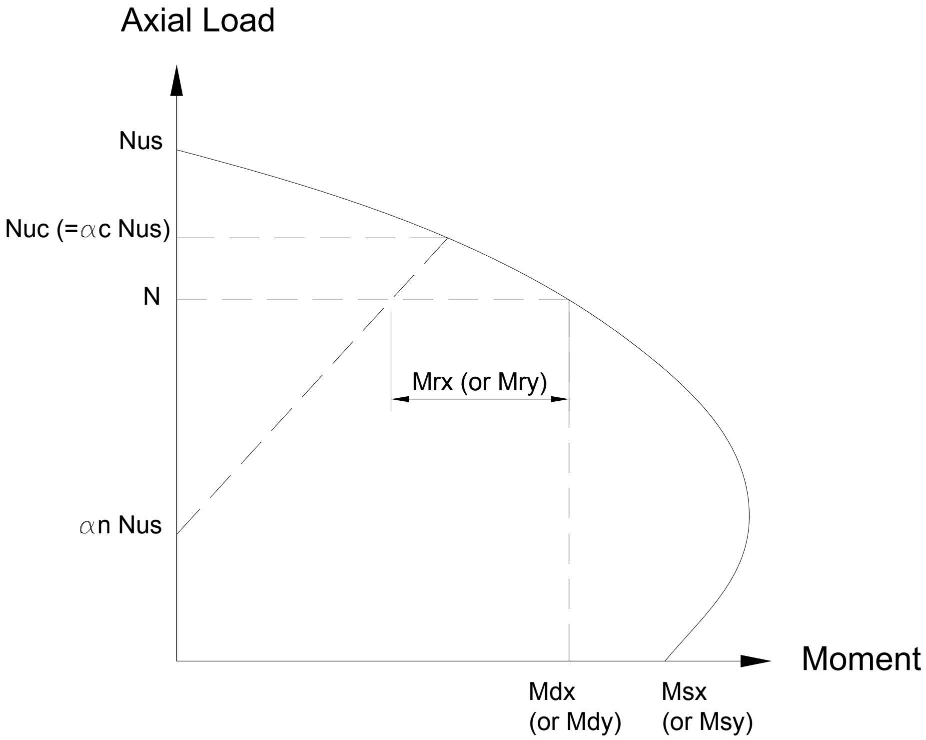
The section shall satisfy the following criterion:

$$M_x < 0.9 M_{rx}$$

$$M_y < 0.9 M_{ry}$$

where:

M_{rx} M_{ry}	=	section moment capacity, reduced by the effects of axial compression, slenderness and imperfections, determined from an interaction curve in the form of **FIGURE 2.4.5-1**
M_x M_y	=	design bending moments about the major and minor principal axes, respectively



INTERACTION CURVE OF COMPRESSION AND UNIAXIAL BENDING FOR COMPOSITE COMPRESSION MEMBERS

In Figure 2.4.5-1:

N_{us} = ultimate section capacity

N_{uc} = ultimate member capacity

= $\alpha_c N_{us}$

α_c = compression member slenderness reduction factor

$M_{dx,}$ = total moment capacity of the section when the design axial force N is acting on the section

M_{dx}

α_n = factor for interaction curve

= $\alpha_c\left(\frac{1+\beta_m}{4}\right)$

β_m = ratio of the smaller to the larger end bending moments taken as positive when the member is bent in reverse curvature

The reduced moment capacity, M_{rx} or M_{ry}, may not be taken to be larger than M_{sx} or M_{sy}, the ultimate section capacity, unless the design moment M_x or M_y is due only to the action of the eccentricity of the design axial force N.

(c) Members Subject to Combined Compression and Biaxial Bending

Members subject to combined compression and biaxial bending about both principal axes, shall satisfy items (i) and (ii) below.

(i) $M_x < 0.9M_{rx}$

$M_y < 0.9M_{ry}$

$$\frac{M_x}{M_{rx}} + \frac{M_y}{M_{ry}} \leq 1$$

(ii) $M_x < 0.9M_{dx}$

$M_y < 0.9M_{dy}$

P4-COMPOSITE COLUMN 1.4M DESIGN

KATAHIRA & ENGINEERS
INTERNATIONAL

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

Calculation: **Balaraja Flyover**
Detailed Design - Ultimate Moment Capacity Pier P4
Interaction Curve - 1.40m Dia Circular Composite Pier

Reference: **Project Specific Design Criteria**
Australian Bridge Design Standard AS 5100

Initial Data

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fy	235	MPa
Capacity factor - structural steel	∅	0.9	
Capacity factor - concrete	∅c	0.6	
Height of cantilever pier	LH	6.9	m
Diameter of concrete section	D	1362	mm
Thickness of CHS section	t	19	mm
Elastic modulus concrete	E_c	25743	MPa
Elastic modulus steel	E_s	200000	Mpa

NOTE: The steel section shall be symmetrical, be fabricated from steel with a maximum yield stress of 350MPa and have a wall thickness such that the plate element slenderness λ_e is less than the limit given below:

$$\lambda_e = \frac{d_0}{t} \cdot \left(\frac{f_y}{250} \right) < 82 \quad \text{for circular hollow sections}$$

where:

d_o = outside diameter of the section
t = wall thickness of the section

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad LH := LH \cdot m \quad D := D \cdot mm \quad ts := ts \cdot mm \quad E_C := E_c \cdot MPa \quad E_S := E_s \cdot MPa$

Modular ratio $\alpha := \frac{E_S}{E_C}$ $\alpha = 7.77$

Analysis Result

$k := 1 .. 16$

Location	Ultimate Load Case	P Axial kN	M_y Trans kNm	M_x Long kNm
Base	1. Comb 1 - Full Live Load	-8759.3	284.4	2257.3
Base	2. Comb 1 - Full Live Load	-15425.2	-322.9	-1981.4
Base	3. Comb 1 - Half Live Load (one side loaded)	-8991.0	2520.0	1331.8
Base	4. Comb 1 - Half Live Load (one side loaded)	-12361.2	-2565.6	-1161.1
Base	5. Comb 5 - EQX + 0.3 EQY	-6232.3	2845.8	4156.4
Base	6. Comb 5 - EQX + 0.3 EQY	-6970.9	-2856.8	-4115.1
Base	7. Comb 5 - 0.3 EQX + EQY	-6459.5	8633.1	1609.1
Base	8. Comb 5 - 0.3 EQX + EQY	-6743.7	-8644.0	-1567.8
Top	9. Comb 1 - Full Live Load	-8289.5	817.3	7873.6
Top	10. Comb 1 - Full Live Load	-14955.4	-826.0	-5653.5
Top	11. Comb 1 - Half Live Load (one side loaded)	-8521.2	6306.5	4373.1
Top	12. Comb 1 - Half Live Load (one side loaded)	-11891.4	-6316.7	-3086.7
Top	13. Comb 5 - EQX + 0.3 EQY	-5870.9	616.2	9531.1
Top	14. Comb 5 - EQX + 0.3 EQY	-6609.5	-618.7	-9241.9
Top	15. Comb 5 - 0.3 EQX + EQY	-6098.1	1869.3	3758.0
Top	16. Comb 5 - 0.3 EQX + EQY	-6382.3	-1871.8	-3468.7

$P := -P \cdot kN \qquad M_x := \sqrt{{M_x}^2} \cdot kN \cdot m \qquad M_y := \sqrt{{M_y}^2} \cdot kN \cdot m$

Check thickness of steel tube

$$\lambda_e := \frac{D + ts \cdot 2}{ts} \cdot \left(\frac{f_{ys}}{250 \cdot MPa} \right) \qquad \lambda_e = 69$$

$$PlateElementSlenderness := \begin{cases} \text{"OK"} & \text{if } \lambda_e < 82 \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

PlateElementSlenderness = "OK"

Concrete Cross Section Data - generated

$n := 24$ Number of Points - 50 points maximum

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

Ref.	X mm	Y mm	Ref.	X mm
1	0	-681	26	
2	-176	-658	27	
3	-341	-590	28	
4	-482	-482	29	
5	-590	-341	30	
6	-658	-176	31	
7	-681	0	32	
8	-658	176	33	
9	-590	341	34	
10	-482	482	35	
11	-341	590	36	
12	-176	658	37	
13	0	681	38	
14	176	658	39	
15	341	590	40	
16	482	482	41	
17	590	341	42	
18	658	176	43	
19	681	0	44	
20	658	-176	45	
21	590	-341	46	
22	482	-482	47	
23	341	-590	48	
24	176	-658	49	
25			50	

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

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

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$ $A_C = 1.44036\ m^2$

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

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

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$ $I_x = 0.1651\ m^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$ $I_y = 0.1651\ m^4$

$$I_{xC} := I_x - A_C \cdot x_C^{\ 2}$$ $I_{xC} = 0.1651\ m^4$

$$I_{yC} := I_y - A_C \cdot y_C^{\ 2}$$ $I_{yC} = 0.16510\ m^4$

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
	mm	mm		mm
1	0	-700	**26**	0
2	-181	-676	**27**	176
3	-350	-606	**28**	341
4	-495	-495	**29**	482
5	-606	-350	**30**	590
6	-676	-181	**31**	658
7	-700	0	**32**	681
8	-676	181	**33**	658
9	-606	350	**34**	590
10	-495	495	**35**	482
11	-350	606	**36**	341
12	-181	676	**37**	176
13	0	700	**38**	0
14	181	676	**39**	-176
15	350	606	**40**	-341
16	495	495	**41**	-482
17	606	350	**42**	-590
18	676	181	**43**	-658
19	700	0	**44**	-681
20	676	-181	**45**	-658
21	606	-350	**46**	-590
22	495	-495	**47**	-482
23	350	-606	**48**	-341
24	181	-676	**49**	-176
25	0	-700	**50**	0

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

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

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

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

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right] \qquad A_{ST} = 0.08149\ m^2$$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right] \qquad x_{ST} = 0.0\ m$$

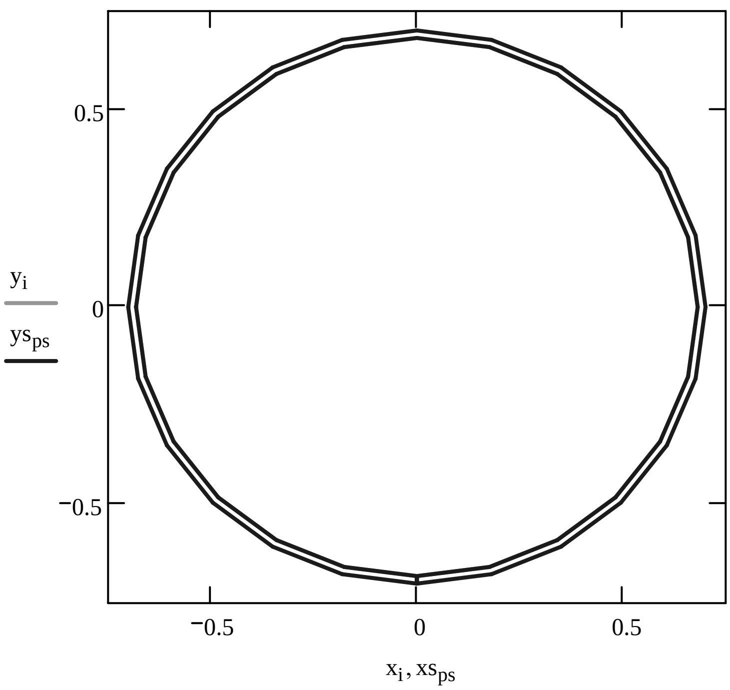
$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right] \qquad y_{ST} = 0\ m$$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right] \qquad I_{xS} = 0.01921\ m^4$$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right] \qquad I_{yS} = 0.01921\ m^4$$

$$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2 \qquad I_{xS} = 0.01921\ m^4$$

$$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2 \qquad I_{yS} = 0.01921\ m^4$$



Calculate Composite Section Properties (before cracking) - with respect to concrete modulus

Effective area $A_E := A_C + A_{ST} \cdot \alpha$ $\qquad A_E = 2073497\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot x_C + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\qquad x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot y_C + A_{ST} \cdot \alpha \cdot y_{ST}}{A_E}$ $\qquad y_E = 0.000\,m$

Effective stiffness

$$I_{EX} := I_{xC} + A_C \cdot \left(x_C^{\,2}\right) + \left(I_{xS} + A_{ST} \cdot x_{ST}^{\,2}\right) \cdot \alpha \qquad I_{EX} = 0\ m^4$$

$$I_{EY} := I_{yC} + A_C \cdot \left(y_C^{\,2}\right) + \left(I_{yS} + A_{ST} \cdot y_{ST}^{\,2}\right) \cdot \alpha \qquad I_{EY} = 0\ m^4$$

Distance from extreme concete fiber to centroid

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

Total depth of concrete section

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

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 19\,mm$$

Outside diameter of the circular hollow section:

$$d_o := H_{CY}$$

Section modulus

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

Calculate relative slenderness of column (10.6.2.4)

Effective length factor of cantilever column (10.3.2):

$k_e := 2.2$

$L_e := k_e \cdot LH$

Calculate the elastic critical load, N_{cr}:

$$N_{cr} := \frac{E_C \cdot I_{EY} \cdot \pi^2}{L_e^2} \qquad N_{cr} = 346599\,\text{kN}$$

Slenderness parameter

$$\lambda_r := \sqrt{\frac{A_{ST} \cdot f_{ys} + 0.85 \cdot A_C \cdot f_c}{N_{cr}}} \qquad \lambda_r = 0$$

Calculate Ultimate Section Capacity (10.6.2)

For a circular column calculate the confinement coefficients:

$$\eta_{10} := \left(\begin{array}{|l} \eta \leftarrow 4.9 - 18.5 \cdot \lambda_r + 17 \cdot \lambda_r^2 \\ \eta \;\text{ if }\; \eta \geq 0 \\ 0 \;\text{ otherwise} \end{array} \right) \qquad \eta_{10} = 0$$

$$\eta_{20} := \begin{array}{|l} \eta \leftarrow 0.25 \cdot (3 + 2 \cdot \lambda_r) \\ \eta \;\text{ if }\; \eta \leq 1.0 \\ 1.0 \;\text{ otherwise} \end{array} \qquad \eta_{20} = 1$$

$$\eta_1(e) := \begin{array}{|l} \eta \leftarrow \eta_{10} \cdot \left(1 - \frac{10e}{d_o}\right) \\ \eta \;\text{ if }\; \eta \geq 0 \\ 0 \;\text{ otherwise} \end{array}$$

$$\eta_2(e) := \begin{array}{|l} \eta \leftarrow \eta_{20} + (1 - \eta_{20}) \cdot \frac{10e}{d_o} \\ \eta \;\text{ if }\; \eta \leq 1.0 \\ 1.0 \;\text{ otherwise} \end{array}$$

$$N_{us}(e) := \phi \cdot A_{ST} \cdot \eta_2(e) \cdot f_{ys} + \phi_c \cdot A_C \cdot f_c \cdot \left(1 + \eta_1(e) \cdot \frac{ts \cdot f_{ys}}{d_o \cdot f_c}\right)$$

In the worst case, eccentricity is at least equal to do/10: $\eta_2\left(\frac{d_o}{10}\right) = 1 \qquad \eta_1\left(\frac{d_o}{10}\right) = 0$

$$N_{us} := N_{us}\left(\frac{d_o}{10}\right) \qquad N_{us} = 43162\,\text{kN}$$

Check Steel Contribution Factor (10.6.1.4)

$$\alpha_s := \frac{\phi \cdot A_{ST} \cdot f_{ys}}{N_{us}} \qquad \alpha_s = 0$$

$$SteelContribution_{Factor} := \begin{cases} \text{"OK"} & \text{if } (\alpha_s > 0.2)\cdot(\alpha_s \le 0.9) \\ \text{"SECTION NOT APPLICABLE"} & \text{otherwise} \end{cases}$$

$SteelContribution_{Factor} = \text{"OK"}$

Calculate Ultimate Member Capacity (10.6.3)

Compression member slenderness reduction factor α_c:

$$\lambda_\eta := 90 \cdot \lambda_r \qquad \lambda_\eta = 36$$

$$\alpha_a := \frac{2100 \cdot (\lambda_\eta - 13.5)}{\lambda_\eta^2 - 15.3 \cdot \lambda_\eta + 2050} \qquad \alpha_a = 17$$

$\alpha_b := -0.5$ Table 10.3.3(A) RHS and CHS section

$$\lambda := \lambda_\eta + \alpha_a \cdot \alpha_b \qquad \lambda = 28$$

$$\eta := \begin{vmatrix} \eta \leftarrow 0.00326 \cdot (\lambda - 13.5) \\ 0 \ \text{ if } \eta < 0 \\ \eta \ \text{ otherwise} \end{vmatrix} \qquad \eta = 0$$

$$\xi := \frac{\left(\frac{\lambda}{90}\right)^2 + 1 + \eta}{2 \cdot \left(\frac{\lambda}{90}\right)^2} \qquad \xi = 6$$

$$\alpha_c := \xi \cdot \left[1 - \sqrt{1 - \left(\frac{90}{\xi \cdot \lambda}\right)^2}\right] \qquad \alpha_c = 1$$

Nominal member capacity:

$$N_{uc} := \alpha_c \cdot N_{us} \qquad N_{uc} = 41079\,\text{kN}$$

Establish Section Dimensions

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

Positive case - determine coord of extreme steel fiber $y_{Espos} := \max(ys)$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{Etube} := y_{Espos} - y_{Epos}$

$y_{Etube} = 19\,mm$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT B (N=0)

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := (H_{CY} - y_{CB})\cdot\beta_1 \qquad Y_C = 359\,mm$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEB} := H_{CY} - Y_C \qquad Y_{CEB} = 1003\,mm$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1..n+1$

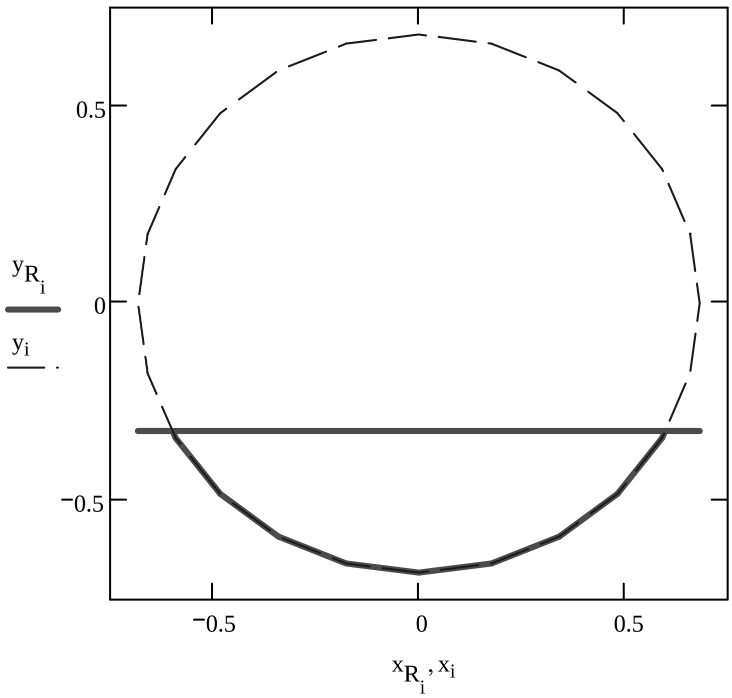
$x_R := x \qquad y_R := y$

$i := 2..n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1})\cdot\left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEB})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEB})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEB})\right] \\ x_i + (x_{i-1} - x_i)\cdot\left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEB})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEB})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEB})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1})\cdot\left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEB})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEB})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEB})\right] \\ y_i + (y_{i-1} - y_i)\cdot\left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEB})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEB})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEB})\right] \\ y_{Epos} - (Y_{CEB}) & \text{if } (y_{Epos} - y_i) < (Y_{CEB}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1..n+1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.3007\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 9021\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CB} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 118\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -12583\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 6568\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$y_{CB} \equiv 1003.48 \cdot mm$

$N_{uB} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$

$N_{uB} = -0\ kN$ **Balanced conditions apply**

Calculate offset of concrete force from centroid:

$x_{CG} := y_C - y_{CR}$ $x_{CG} = 468\ mm$

Calculate moment at first yield in concrete about centroid :

$$M_{syB} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$M_{syB} = 9207\ kN \cdot m$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT C (same moment capacity as POINT B)

Depth to neutral axis from extreme tensile fiber:

$y_{CC} := H_{CY} - y_{CB} \qquad y_{CC} = 0\ \text{m}$

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := (H_{CY} - y_{CC}) \cdot \beta_1 \qquad Y_C = 1003.48\ \text{mm}$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEC} := H_{CY} - Y_C \qquad Y_{CEC} = 359\ \text{mm}$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

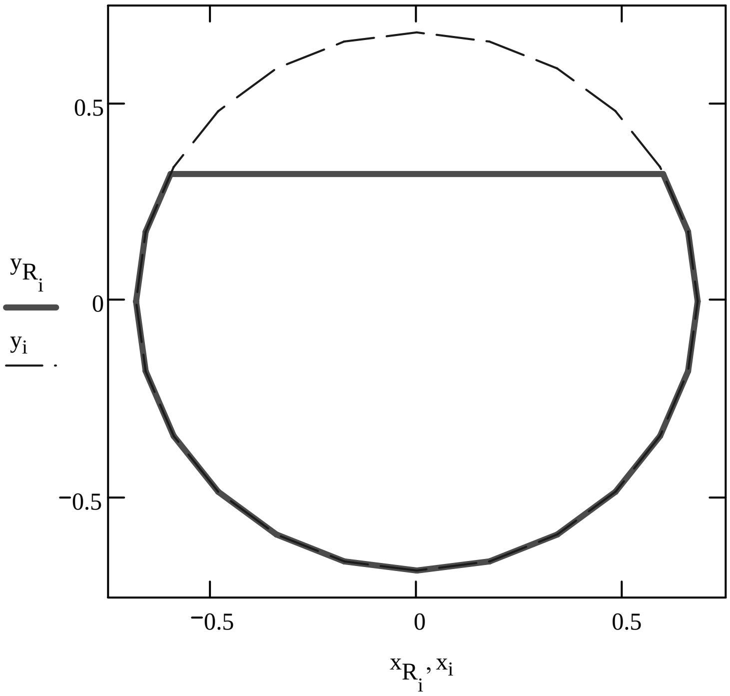
$x_R := x \qquad y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEC})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEC})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEC})\right] \\ x_i + (x_{i-1} - x_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEC})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEC})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEC})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEC})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEC})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEC})\right] \\ y_i + (y_{i-1} - y_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEC})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEC})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEC})\right] \\ y_{Epos} - (Y_{CEC}) & \text{if } (y_{Epos} - y_i) < (Y_{CEC}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 1.13967\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 34190\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CC} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 62\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -6568\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 12583\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uC} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uC} = 25927\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 123\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syC} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syC} = 9207\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT D (Max moment capacity)

Depth to neutral axis from extreme tensile fiber:

$$y_{CD} := \frac{H_{CY}}{2} \qquad y_{CD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CD}\right)\cdot\beta_1 \qquad Y_C = 681\ \text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CED} := H_{CY} - Y_C \qquad Y_{CED} = 681\ \text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

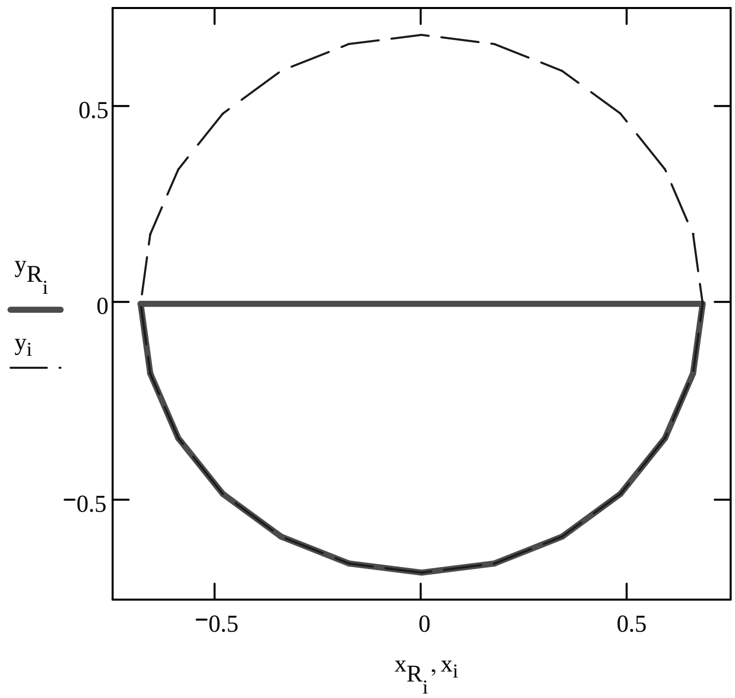
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CED}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CED}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CED}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CED}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CED}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CED}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CED}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CED}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CED}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CED}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CED}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CED}\right)\right] \\ y_{Epos} - \left(Y_{CED}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CED}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n} \left[\left(y_{R_{i+1}} - y_{R_i} \right) \cdot \frac{x_{R_{i+1}} + x_{R_i}}{2} \right] \qquad A_{CR} = 0.72018\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}} \cdot \sum_{i=1}^{n} \left[\frac{y_{R_{i+1}} - y_{R_i}}{8} \cdot \left[\left(x_{R_{i+1}} + x_{R_i} \right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i} \right)^2}{3} \right] \right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}} \cdot \sum_{i=1}^{n} \left[\frac{x_{R_{i+1}} - x_{R_i}}{8} \cdot \left[\left(y_{R_{i+1}} + y_{R_i} \right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i} \right)^2}{3} \right] \right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR} \cdot \left(f_c \right) \qquad F_C = 21605\, kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90 \cdot deg + asin\left(\frac{y_{CD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}} \right) \qquad \theta = 90\, deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -9576\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 9576\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uD} = 12963\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 287\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syD} = 11302\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBD} := \frac{y_{CB} + y_{CD}}{2} \qquad y_{CBD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CBD}\right)\cdot\beta_1 \qquad Y_C = 519.76\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBD} := H_{CY} - Y_C \qquad Y_{CEBD} = 842\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

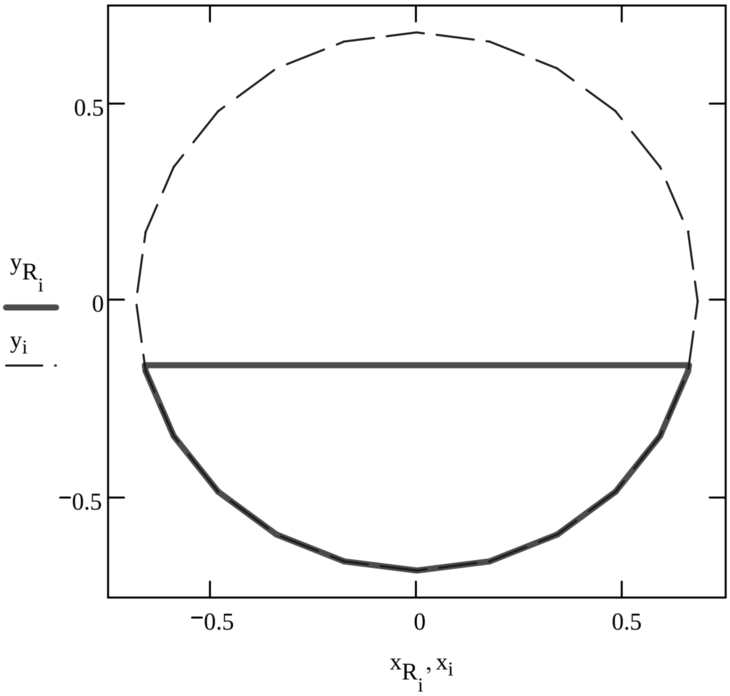
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ y_{Epos} - \left(Y_{CEBD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEBD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.50399\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 15120\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CBD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 104\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -11033\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 8118\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBD} = 6449\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 376\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBD} = 10775\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BBD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBBD} := \frac{y_{CBD} + y_{CB}}{2} \qquad y_{CBBD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CBBD}\right)\cdot\beta_1 \qquad Y_C = 439.14\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBBD} := H_{CY} - Y_C \qquad Y_{CEBBD} = 923\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

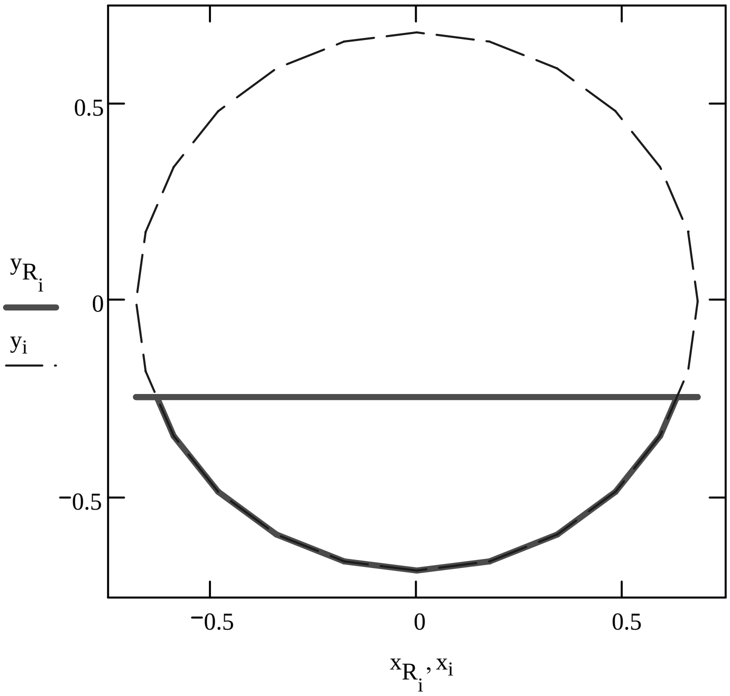
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right)\right. \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right)\right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right)\right. \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right)\right. \\ y_{Epos} - \left(Y_{CEBBD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEBBD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.39969\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 11991\ kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CBBD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 111\ deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -11789\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 7362\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBBD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBBD} = 3210\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 422\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBBD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBBD} = 10119\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BDD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBDD} := \frac{y_{CBD} + y_{CD}}{2} \qquad y_{CBDD} = 1 \text{ m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := (H_{CY} - y_{CBDD}) \cdot \beta_1 \qquad Y_C = 600.38 \text{ mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBDD} := H_{CY} - Y_C \qquad Y_{CEBDD} = 762 \text{ mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

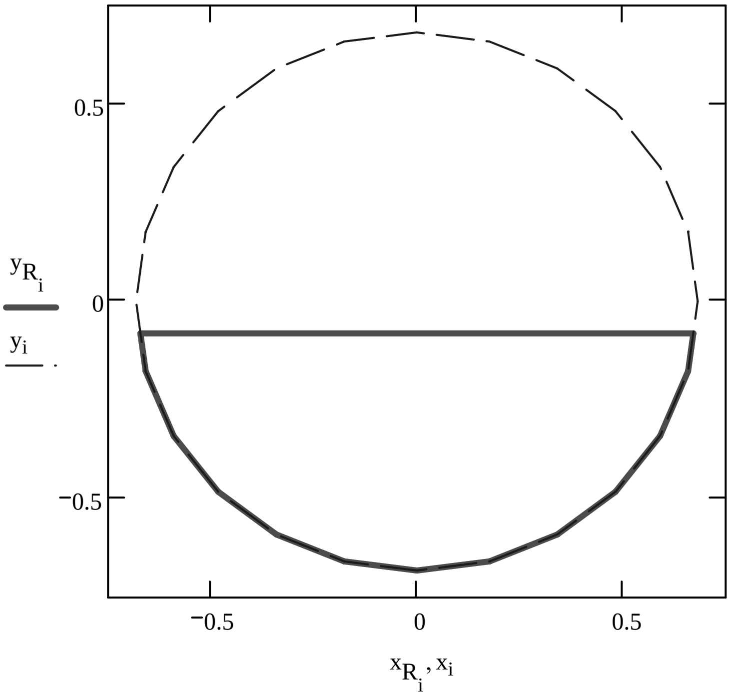
$x_R := x \qquad y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEBDD})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEBDD})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEBDD} \right. \\ x_i + (x_{i-1} - x_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEBDD})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEBDD})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEBDD} \right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEBDD})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEBDD})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEBDD} \right. \\ y_i + (y_{i-1} - y_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEBDD})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEBDD})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEBDD} \right. \\ y_{Epos} - (Y_{CEBDD}) & \text{if } (y_{Epos} - y_i) < (Y_{CEBDD}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n} \left[\left(y_{R_{i+1}} - y_{R_i} \right) \cdot \frac{x_{R_{i+1}} + x_{R_i}}{2} \right] \qquad A_{CR} = 0.61123\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}} \cdot \sum_{i=1}^{n} \left[\frac{y_{R_{i+1}} - y_{R_i}}{8} \cdot \left[\left(x_{R_{i+1}} + x_{R_i} \right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i} \right)^2}{3} \right] \right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}} \cdot \sum_{i=1}^{n} \left[\frac{x_{R_{i+1}} - x_{R_i}}{8} \cdot \left[\left(y_{R_{i+1}} + y_{R_i} \right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i} \right)^2}{3} \right] \right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR} \cdot \left(f_c \right) \qquad F_C = 18337\ kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90 \cdot deg + asin\left(\frac{y_{CBDD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}} \right) \qquad \theta = 97\ deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -10299\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 8852\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBDD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBDD} = 9700\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 331\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBDD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBDD} = 11170\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT CD (Max moment capacity)

Depth to neutral axis from extreme tensile fiber:

$$y_{CCD} := \frac{y_{CC} + y_{CD}}{2} \qquad y_{CCD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CCD}\right)\cdot\beta_1 \qquad Y_C = 842.24\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CECD} := H_{CY} - Y_C \qquad Y_{CECD} = 520\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1..n+1$$

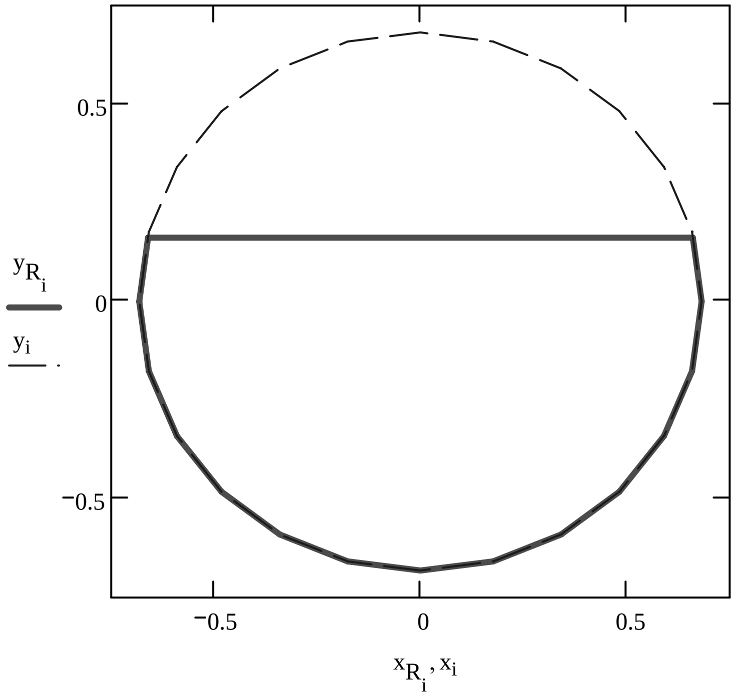
$$x_R := x \qquad y_R := y$$

$$i := 2..n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ y_{Epos} - \left(Y_{CECD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CECD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1..n+1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.93637\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 28091\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CCD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 76\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -8118\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 11033\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uCD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uCD} = 19478\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 203\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syCD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syCD} = 10775\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT CDD

Depth to neutral axis from extreme tensile fiber:

$$y_{CCDD} := \frac{y_{CCD} + y_{CD}}{2} \qquad y_{CCDD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CCDD}\right)\cdot\beta_1 \qquad Y_C = 761.62\ \text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CECDD} := H_{CY} - Y_C \qquad Y_{CECDD} = 600\ \text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

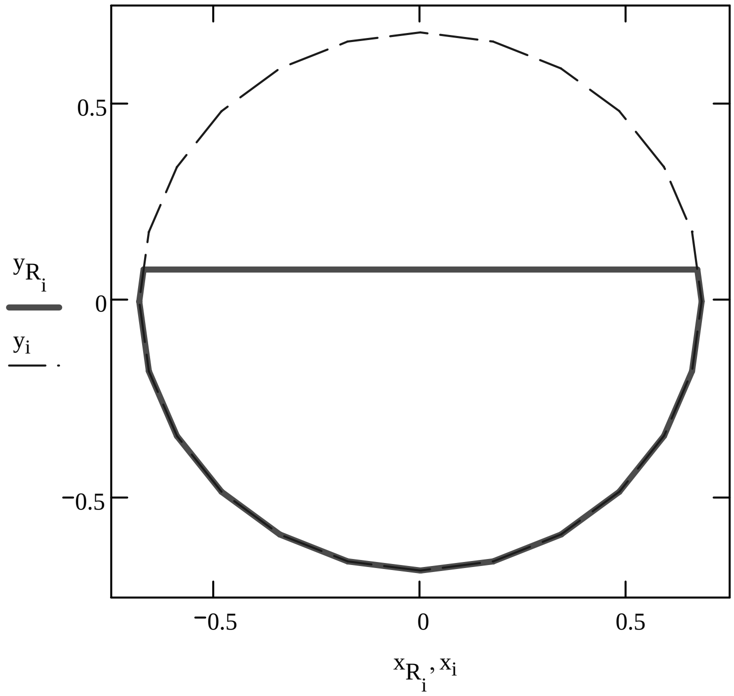
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right)\right. \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right)\right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right)\right. \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right)\right. \\ y_{Epos} - \left(Y_{CECDD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CECDD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.82913\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 24874\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CCDD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 83\,deg$$

Radius of steel tube to utside face $$Rd := \frac{H_{CY}}{2} + ts$$

Area of steel tube in tension: $$A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$$

Area of steel tube in compression: $$A_{STC} := A_{ST} - A_{STT}$$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $\qquad F_{STT} = -8852\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $\qquad F_{STC} = 10299\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uCDD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uCDD} = 16226\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 244\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syCDD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syCDD} = 11170\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT E (Intermediate)

Depth to neutral axis from extreme tensile fiber:

$y_{CE} := \frac{y_{CC}}{2}$ $\qquad y_{CE} = 0\ \text{m}$

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := (H_{CY} - y_{CE})\cdot\beta_1$ $\qquad Y_C = 1182.74\,\text{mm}$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEE} := H_{CY} - Y_C$ $\qquad Y_{CED} = 681\,\text{mm}$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

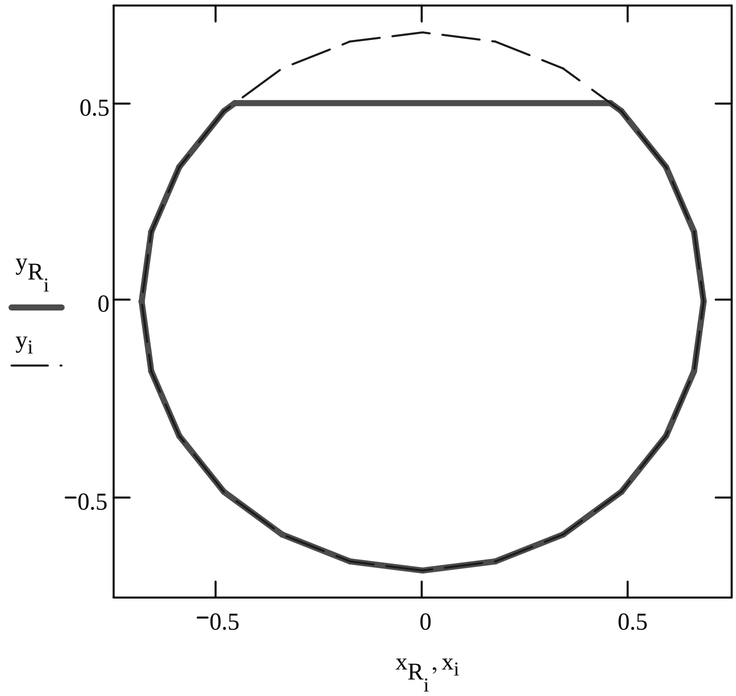
$x_R := x \qquad y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1})\cdot\left[1 - \frac{(y_{Epos} - y_{i+1}) - (Y_{CEE})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEE})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEE})\right] \\ x_i + (x_{i-1} - x_i)\cdot\left[1 - \frac{(y_{Epos} - y_{i-1}) - (Y_{CEE})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEE})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEE})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1})\cdot\left[1 - \frac{(y_{Epos} - y_{i+1}) - (Y_{CEE})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEE})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEE})\right] \\ y_i + (y_{i-1} - y_i)\cdot\left[1 - \frac{(y_{Epos} - y_{i-1}) - (Y_{CEE})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEE})\right]\cdot\left[y_{Epos} - y_i < (Y_{CEE})\right] \\ y_{Epos} - (Y_{CEE}) & \text{if } (y_{Epos} - y_i) < (Y_{CEE}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 1.33107\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 39932\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CE} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 43\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 1\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -4526\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 14625\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uE} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uE} = 33048\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 47\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syE} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syE} = 6250\,kN \cdot m$$

DETERMINE MOMENT- AXIAL LOAD RELATION FOR SECTION

$k := 1..10$

$M_{SY_k} :=$

$0 \cdot kN \cdot m$
M_{syE}
M_{syC}
M_{syCD}
M_{syCDD}
M_{syD}
M_{syBDD}
M_{syBD}
M_{syBBD}
M_{syB}

$N_{S_k} :=$

N_{us}
N_{uE}
N_{uC}
N_{uCD}
N_{uCDD}
N_{uD}
N_{uBDD}
N_{uBD}
N_{uBBD}
N_{uB}

$N_{uc_k} := N_{uc}$

$N_{SD_k} := N_{uc_k}$

$N_{UC} := N_{uc}$

$MS := \frac{M_{SY}}{1000kN \cdot m}$ $\quad NS := \frac{N_S}{1000kN}$ $\quad NUC := \frac{N_{UC}}{1000kN}$

MS =

	1
1	0.000
2	6.250
3	9.207
4	10.775
5	11.170
6	11.302
7	11.170
8	10.775
9	10.119
10	9.207

NS =

	1
1	43.162
2	33.048
3	25.927
4	19.478
5	16.226
6	12.963
7	9.7
8	6.449
9	3.21
10	-0

NUC =

	1
1	41.079
2	41.079
3	41.079
4	41.079
5	41.079
6	41.079
7	41.079
8	41.079
9	41.079
10	41.079

For cantilever columns: $\beta_m := 0$ $\quad \alpha_n := \alpha_c \cdot \left(\frac{1 + \beta_m}{4}\right)$ $\quad \alpha_n = 0$

Coordinates of αn line: $N_{uc} := N_{uc_1}$

$Coord1 := 0 \cdot kN \cdot m$

$$Coord2 := \begin{cases} M_{syE} \cdot \left(1 - \frac{N_{uc} - N_{uE}}{N_{us} - N_{uE}}\right) & \text{if } N_{uc} > N_{uE} \\ M_{syE} + \left(M_{syC} - M_{syE}\right) \cdot \left(1 - \frac{N_{uc} - N_{uC}}{N_{uE} - N_{uC}}\right) & \text{if } \left(N_{uc} \le N_{uE}\right) \cdot \left(N_{uc} > N_{uC}\right) \\ M_{syC} + \left(M_{syCD} - M_{syC}\right) \cdot \left(1 - \frac{N_{uc} - N_{uCD}}{N_{uC} - N_{uCD}}\right) & \text{if } \left(N_{uc} \le N_{uC}\right) \cdot \left(N_{uc} > N_{uCD}\right) \\ M_{syCD} + \left(M_{syCDD} - M_{syCD}\right) \cdot \left(1 - \frac{N_{uc} - N_{uCDD}}{N_{uCD} - N_{uCDD}}\right) & \text{if } \left(N_{uc} \le N_{uCD}\right) \cdot \left(N_{uc} > N_{uCDD}\right) \\ M_{syCDD} + \left(M_{syCD} - M_{syCDD}\right) \cdot \left(1 - \frac{N_{uc} - N_{uD}}{N_{uCDD} - N_{uD}}\right) & \text{if } \left(N_{uc} \le N_{uCDD}\right) \cdot \left(N_{uc} > N_{uD}\right) \\ M_{syD} - \left(M_{syD} - M_{syBDD}\right) \cdot \left(1 - \frac{N_{uc} - N_{uBDD}}{N_{uD} - N_{uBDD}}\right) & \text{if } \left(N_{uc} \le N_{uD}\right) \cdot \left(N_{uc} > N_{uBDD}\right) \\ M_{syBDD} - \left(M_{syBDD} - M_{syBD}\right) \cdot \left(1 - \frac{N_{uc} - N_{uBD}}{N_{uBDD} - N_{uBD}}\right) & \text{if } \left(N_{uc} \le N_{uBDD}\right) \cdot \left(N_{uc} > N_{uBD}\right) \\ M_{syBD} - \left(M_{syBD} - M_{syBBD}\right) \cdot \left(1 - \frac{N_{uc} - N_{uBBD}}{N_{uBD} - N_{uBBD}}\right) & \text{if } \left(N_{uc} \le N_{uBD}\right) \cdot \left(N_{uc} > N_{uBBD}\right) \\ M_{syBBD} - \left(M_{syBBD} - M_{syB}\right) \cdot \left(1 - \frac{N_{uc} - N_{uB}}{N_{uBBD} - N_{uB}}\right) & \text{otherwise} \end{cases}$$

$Coord2 = 1287 \, kN \cdot m$

$$line_{\alpha n} := \frac{N_{uc} - \alpha_n \cdot N_{us}}{Coord2 - Coord1} \cdot MS \cdot m + \frac{\alpha_n \cdot N_{us}}{1000kN}$$

Coordinates of moment capacity:

$$\mathrm{Coord3}(N_{ult},k) := \begin{cases} M_{syE}\cdot\left(1-\dfrac{N_{ult_k}-N_{uE}}{N_{us}-N_{uE}}\right) & \text{if } N_{ult_k} > N_{uE} \\ M_{syE}+(M_{syC}-M_{syE})\cdot\left(1-\dfrac{N_{ult_k}-N_{uC}}{N_{uE}-N_{uC}}\right) & \text{if } (N_{ult_k} \le N_{uE})\cdot(N_{ult_k} > N_{uC}) \\ M_{syC}+(M_{syCD}-M_{syC})\cdot\left(1-\dfrac{N_{ult_k}-N_{uCD}}{N_{uC}-N_{uCD}}\right) & \text{if } (N_{ult_k} \le N_{uC})\cdot(N_{ult_k} > N_{uCD}) \\ M_{syCD}+(M_{syCDD}-M_{syCD})\cdot\left(1-\dfrac{N_{ult_k}-N_{uCDD}}{N_{uCD}-N_{uCDD}}\right) & \text{if } (N_{ult_k} \le N_{uCD})\cdot(N_{ult_k} > N_{uCDD}) \\ M_{syCDD}+(M_{syCD}-M_{syCDD})\cdot\left(1-\dfrac{N_{ult_k}-N_{uCD}}{N_{uCDD}-N_{uCD}}\right) & \text{if } (N_{ult_k} \le N_{uCDD})\cdot(N_{ult_k} > N_{uCD}) \\ M_{syD}-(M_{syD}-M_{syBDD})\cdot\left(1-\dfrac{N_{ult_k}-N_{uBDD}}{N_{uD}-N_{uBDD}}\right) & \text{if } (N_{ult_k} \le N_{uD})\cdot(N_{ult_k} > N_{uBDD}) \\ M_{syBDD}-(M_{syBDD}-M_{syBD})\cdot\left(1-\dfrac{N_{ult_k}-N_{uBD}}{N_{uBDD}-N_{uBD}}\right) & \text{if } (N_{ult_k} \le N_{uBDD})\cdot(N_{ult_k} > N_{uBD}) \\ M_{syBD}-(M_{syBD}-M_{syBBD})\cdot\left(1-\dfrac{N_{ult_k}-N_{uBBD}}{N_{uBD}-N_{uBBD}}\right) & \text{if } (N_{ult_k} \le N_{uBD})\cdot(N_{ult_k} > N_{uBBD}) \\ M_{syBBD}-(M_{syBBD}-M_{syB})\cdot\left(1-\dfrac{N_{ult_k}-N_{uB}}{N_{uBBD}-N_{uB}}\right) & \text{otherwise} \end{cases}$$

$$\mathrm{Coord4}(N_{ult},k) := (N_{ult_k}-\alpha_n\cdot N_{us})\cdot\frac{1}{\dfrac{N_{uc}-\alpha_n\cdot N_{us}}{\mathrm{Coord2}-\mathrm{Coord1}}}$$

Design Moment Capacity

$$M_{ULTCAP}(N_{ULT},k) := \begin{cases} \mathrm{Coord3}(N_{ULT},k) & \text{if } N_{ULT_k} < \alpha_n\cdot N_{us} \\ \mathrm{Coord3}(N_{ULT},k)-\mathrm{Coord4}(N_{ULT},k) & \text{otherwise} \end{cases}$$

$k := 1 .. 16$

$M_{ULT_k} :=$

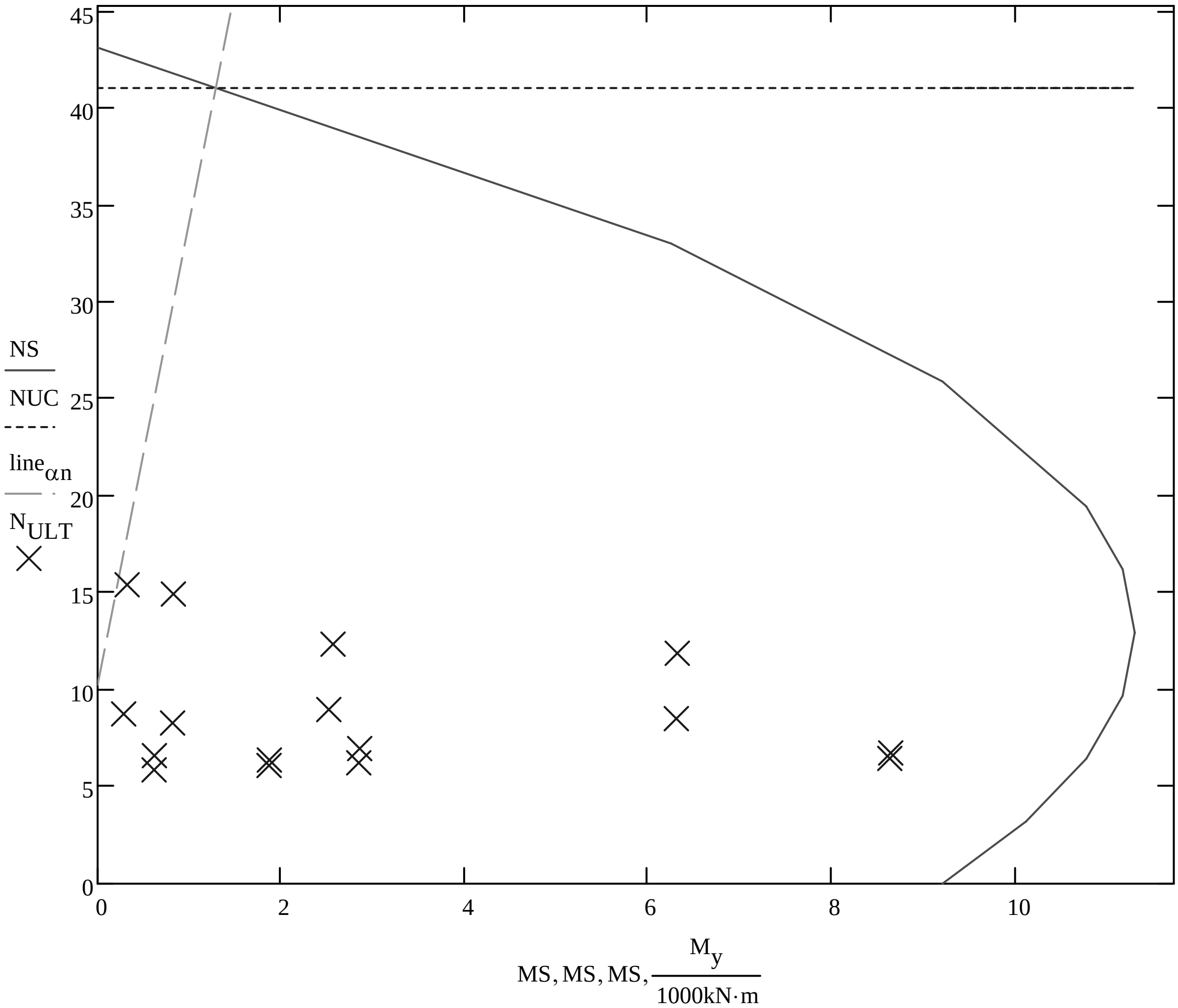
$M_{ULTCAP}(P,1)$
$M_{ULTCAP}(P,2)$
$M_{ULTCAP}(P,3)$
$M_{ULTCAP}(P,4)$
$M_{ULTCAP}(P,5)$
$M_{ULTCAP}(P,6)$
$M_{ULTCAP}(P,7)$
$M_{ULTCAP}(P,8)$
$M_{ULTCAP}(P,9)$
$M_{ULTCAP}(P,10)$
$M_{ULTCAP}(P,11)$
$M_{ULTCAP}(P,12)$
$M_{ULTCAP}(P,13)$
$M_{ULTCAP}(P,14)$
$M_{ULTCAP}(P,15)$
$M_{ULTCAP}(P,16)$

$M_{ULT} =$ (kN·m)

	1
1	11056
2	13371
3	11084
4	11191
5	10731
6	10838
7	10776
8	10811
9	10999
10	13257
11	11027
12	11191
13	10658
14	10794
15	10704
16	10761

$N_{ULT} := \frac{P}{1000kN}$

INTERACTION DIAGRAM - TRANSVERSE MOMENT M_y
COMPOSITE COLUMN (Steel Grade SM400)



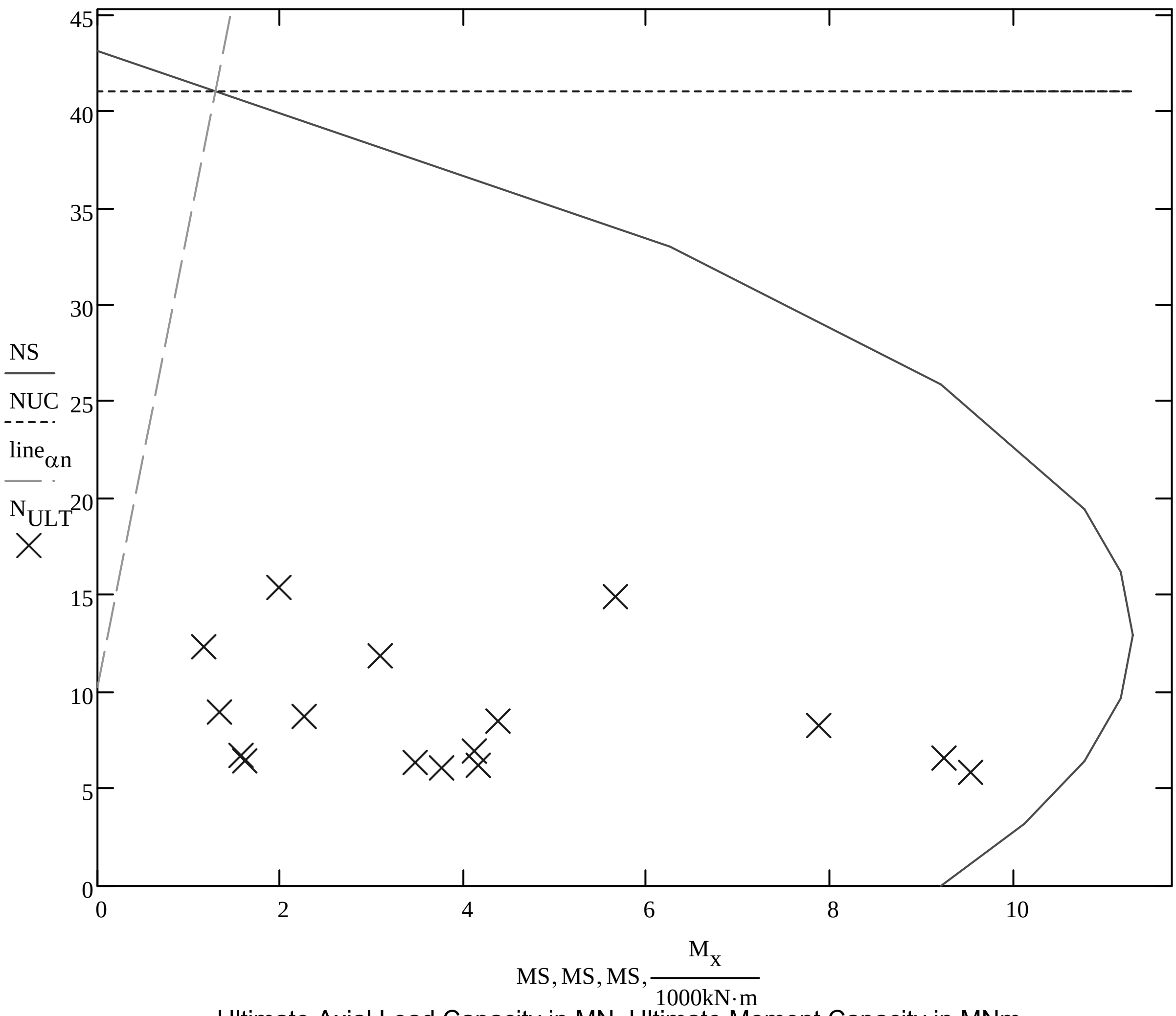
Ultimate Axial Load Capacity in MN. Ultimate Moment Capacity in MNm

PlateElementSlenderness = "OK"

$SteelContribution_{Factor}$ = "OK"

Concrete strength		$f_c = 30\,MPa$	
Yield Strength of Steel		$f_{ys} = 235\,MPa$	
Diameter of concrete section		$D = 1362\,mm$	
Thickness of steel tube		$ts = 19\,mm$	
Strength Reduction Factors	-	Steel	$\phi = 0.9$
	-	Concrete	$\phi_c = 0.6$

INTERACTION DIAGRAM - LONGITUDINAL MOMENT M_x
COMPOSITE COLUMN (Steel Grade SM400)



Ultimate Axial Load Capacity in MN. Ultimate Moment Capacity in MNm

PlateElementSlenderness = "OK"

$SteelContribution_{Factor}$ = "OK"

Concrete strength		$f_c = 30\,MPa$
Yield Strength of Steel		$f_{ys} = 235\,MPa$
Diameter of concrete section		$D = 1362\,mm$
Thickness of steel tube		$ts = 19\,mm$
Strength Reduction Factors	- Steel	$\phi = 0.9$
	- Concrete	$\phi_c = 0.6$

DESIGN SUMMARY

Location	Load Case	Longitudinal Moment			Transverse Moment			Biaxial Moment	
		M_x	0.9 M_{rx}	Result	M_y	0.9 M_{ry}	Result	$\frac{M_x}{M_{rx}} + \frac{M_y}{M_{ry}} \le 1.0$	Result
		kNm	kNm		kNm	kNm			
Base	1	2257.3	9950	OK	284.4	9950	OK	0.23	OK
Base	2	1981.4	12034	OK	322.9	12034	OK	0.17	OK
Base	3	1331.8	9976	OK	2520.0	9976	OK	0.35	OK
Base	4	1161.1	10072	OK	2565.6	10072	OK	0.33	OK
Base	5	4156.4	9658	OK	2845.8	9658	OK	0.65	OK
Base	6	4115.1	9755	OK	2856.8	9755	OK	0.64	OK
Base	7	1609.1	9699	OK	8633.1	9699	OK	0.95	OK
Base	8	1567.8	9730	OK	8644.0	9730	OK	0.94	OK
Top	9	7873.6	9899	OK	817.3	9899	OK	0.79	OK
Top	10	5653.5	11932	OK	826.0	11932	OK	0.49	OK
Top	11	4373.1	9924	OK	6306.5	9924	OK	0.97	OK
Top	12	3086.7	10072	OK	6316.7	10072	OK	0.84	OK
Top	13	9531.1	9592	OK	616.2	9592	OK	0.95	OK
Top	14	9241.9	9715	OK	618.7	9715	OK	0.91	OK
Top	15	3758.0	9633	OK	1869.3	9633	OK	0.53	OK
Top	16	3468.7	9685	OK	1871.8	9685	OK	0.50	OK

Note :

Members subject to combined compression and biaxial bending shall satisfy the items below:

$M_x \le 0.9\ M_{rx}$

$M_y \le 0.9\ M_{ry}$

$M_x/M_{rx} + M_y/M_{ry} \le 1.0$

PlateElementSlenderness = "OK"

$\text{SteelContribution}_{\text{Factor}}$ = "OK"

Concrete strength		$f_c = 30\,\text{MPa}$	
Yield Strength of Steel		$f_{ys} = 235\,\text{MPa}$	
Diameter of concrete section		$D = 1362\,\text{mm}$	
Thickness of steel tube		$ts = 19\,\text{mm}$	
Strength Reduction Factors	-	Steel	$\phi = 0.9$
	-	Concrete	$\phi_c = 0.6$

DESIGN SUMMARY - 2

Vectorial addition of biaxial moments: $M_d := \sqrt{M_x^2 + M_y^2}$

Clause 11.5.3, Biaxial Bending, of Australian Standard AS5100, states that if it is clear which is the critical plane only one item below need be considered:

$M_x \leq 0.9\ M_{rx}$

$M_y \leq 0.9\ M_{ry}$

$M_x/M_{rx} + M_y/M_{ry} \leq 1.0$

In the case of circular columns it is clear that the critical plane occurs in the direction of the vector addition of the biaxial moments. In this direction the section will be subject to the design moment M_d as determined above. The section shall therefore be checked to ensure the following:

$M_d \leq 0.9\ M_r$

Given that the section is circular M_r may be taken as either M_{rx} or M_{ry} for the given applied ultimate load.

Location	Load Case	Combined Moment			Moment Capacity
		M_d	0.9 M_r	Result	M_r
		kNm	kNm		kNm
Base	1	2275.1	9950	OK	11056
Base	2	2007.5	12034	OK	13371
Base	3	2850.2	9976	OK	11084
Base	4	2816.1	10072	OK	11191
Base	5	5037.3	9658	OK	10731
Base	6	5009.5	9755	OK	10838
Base	7	8781.8	9699	OK	10776
Base	8	8785.1	9730	OK	10811
Top	9	7915.9	9899	OK	10999
Top	10	5713.5	11932	OK	13257
Top	11	7674.3	9924	OK	11027
Top	12	7030.6	10072	OK	11191
Top	13	9551.0	9592	OK	10658
Top	14	9262.6	9715	OK	10794
Top	15	4197.2	9633	OK	10704
Top	16	3941.5	9685	OK	10761

DESIGN CONCLUSION

SECTION IS ADEQUATE

P5-COMPOSITE COLUMN 1.4M DESIGN

KATAHIRA & ENGINEERS
INTERNATIONAL

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

Calculation: **Balaraja Flyover**
Detailed Design - Ultimate Moment Capacity Pier P5
Interaction Curve - 1.40m Dia Circular Composite Pier

Reference: **Project Specific Design Criteria**
Australian Bridge Design Standard AS 5100

Initial Data

Input Item			
Concrete Compressive Strength	fc	30	MPa
Structural Steel Yield Strength	fy	235	MPa
Capacity factor - structural steel	∅	0.9	
Capacity factor - concrete	∅c	0.6	
Height of cantilever pier	LH	6.9	m
Diameter of concrete section	D	1362	mm
Thickness of CHS section	t	19	mm
Elastic modulus concrete	E_c	25743	MPa
Elastic modulus steel	E_s	200000	Mpa

NOTE: The steel section shall be symmetrical, be fabricated from steel with a maximum yield stress of 350MPa and have a wall thickness such that the plate element slenderness λ_e is less than the limit given below:

$$\lambda_e = \frac{d_0}{t} \cdot \left(\frac{f_y}{250} \right) < 82 \quad \text{for circular hollow sections}$$

where:

d_o = outside diameter of the section
t = wall thickness of the section

$f_c := f_c \cdot MPa \quad f_{ys} := f_{ys} \cdot MPa \quad LH := LH \cdot m \quad D := D \cdot mm \quad ts := ts \cdot mm \quad E_C := E_c \cdot MPa \quad E_S := E_s \cdot MPa$

Modular ratio $\alpha := \frac{E_S}{E_C} \qquad \alpha = 7.77$

Analysis Result

$k := 1 .. 16$

Location	Ultimate Load Case	P Axial kN	M_y Trans kNm	M_x Long kNm
Base	1. Comb 1 - Full Live Load	-8763.8	217.1	1987.0
Base	2. Comb 1 - Full Live Load	-15433.6	-339.9	-2248.1
Base	3. Comb 1 - Half Live Load (one side loaded)	-8997.6	1806.7	1166.1
Base	4. Comb 1 - Half Live Load (one side loaded)	-12367.5	-1952.0	-1323.5
Base	5. Comb 5 - EQX + 0.3 EQY	-6236.1	2845.6	4120.9
Base	6. Comb 5 - EQX + 0.3 EQY	-6976.3	-2880.3	-4154.2
Base	7. Comb 5 - 0.3 EQX + EQY	-6462.8	7063.6	1573.0
Base	8. Comb 5 - 0.3 EQX + EQY	-6749.6	-7098.3	-1606.2
Top	9. Comb 1 - Full Live Load	-8294.0	768.8	5668.0
Top	10. Comb 1 - Full Live Load	-14963.8	-767.3	-7870.5
Top	11. Comb 1 - Half Live Load (one side loaded)	-8527.8	5721.9	3097.7
Top	12. Comb 1 - Half Live Load (one side loaded)	-11897.7	-5720.1	-4369.4
Top	13. Comb 5 - EQX + 0.3 EQY	-5874.7	303.8	9241.7
Top	14. Comb 5 - EQX + 0.3 EQY	-6614.9	-303.4	-9523.1
Top	15. Comb 5 - 0.3 EQX + EQY	-6101.4	745.8	3467.8
Top	16. Comb 5 - 0.3 EQX + EQY	-6388.2	-745.4	-3749.1

$P := -P \cdot kN$ $\quad M_x := \sqrt{{M_x}^2} \cdot kN \cdot m$ $\quad M_y := \sqrt{{M_y}^2} \cdot kN \cdot m$

Check thickness of steel tube

$$\lambda_e := \frac{D + ts \cdot 2}{ts} \cdot \left(\frac{f_{ys}}{250 \cdot MPa} \right) \qquad \lambda_e = 69$$

$$PlateElementSlenderness := \begin{cases} \text{"OK"} & \text{if } \lambda_e < 82 \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

PlateElementSlenderness = "OK"

Concrete Cross Section Data - generated

$n := 24$ Number of Points - 50 points maximum

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

Ref.	X mm	Y mm	Ref.	X mm
1	0	-681	26	
2	-176	-658	27	
3	-341	-590	28	
4	-482	-482	29	
5	-590	-341	30	
6	-658	-176	31	
7	-681	0	32	
8	-658	176	33	
9	-590	341	34	
10	-482	482	35	
11	-341	590	36	
12	-176	658	37	
13	0	681	38	
14	176	658	39	
15	341	590	40	
16	482	482	41	
17	590	341	42	
18	658	176	43	
19	681	0	44	
20	658	-176	45	
21	590	-341	46	
22	482	-482	47	
23	341	-590	48	
24	176	-658	49	
25			50	

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

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

Calculate Section Properties of Concrete Section

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

$A_C = 1.44036\ m^2$

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

$x_C = 0\ m$

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

$y_C = 0\ m$

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

$I_x = 0.1651\ m^4$

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

$I_y = 0.1651\ m^4$

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

$I_{xC} = 0.1651\ m^4$

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

$I_{yC} = 0.16510\ m^4$

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 mm	Y mm	Ref.	X mm
1	0	-700	**26**	0
2	-181	-676	**27**	176
3	-350	-606	**28**	341
4	-495	-495	**29**	482
5	-606	-350	**30**	590
6	-676	-181	**31**	658
7	-700	0	**32**	681
8	-676	181	**33**	658
9	-606	350	**34**	590
10	-495	495	**35**	482
11	-350	606	**36**	341
12	-181	676	**37**	176
13	0	700	**38**	0
14	181	676	**39**	-176
15	350	606	**40**	-341
16	495	495	**41**	-482
17	606	350	**42**	-590
18	676	181	**43**	-658
19	700	0	**44**	-681
20	676	-181	**45**	-658
21	606	-350	**46**	-590
22	495	-495	**47**	-482
23	350	-606	**48**	-341
24	181	-676	**49**	-176
25	0	-700	**50**	0

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

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

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

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

Calculate Section Properties of Steel Tube Section

$$A_{ST} := -\sum_{ps=1}^{ns}\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{2}\right] \qquad A_{ST} = 0.08149\ m^2$$

$$x_{ST} := -\frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{ys_{ps+1} - ys_{ps}}{8}\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \frac{\left(xs_{ps+1} - xs_{ps}\right)^2}{3}\right]\right] \qquad x_{ST} = 0.0\ m$$

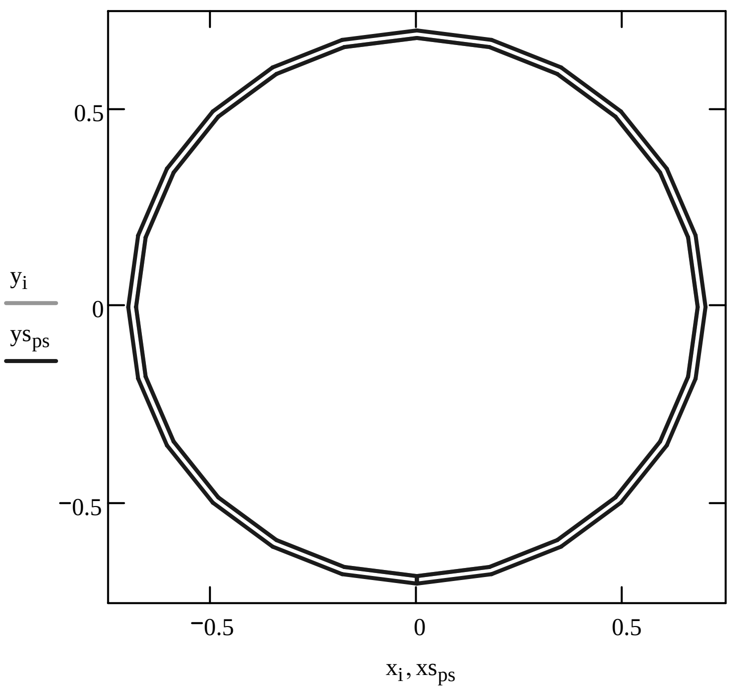
$$y_{ST} := \frac{1}{A_{ST}}\cdot\sum_{ps=1}^{ns}\left[\frac{xs_{ps+1} - xs_{ps}}{8}\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \frac{\left(ys_{ps+1} - ys_{ps}\right)^2}{3}\right]\right] \qquad y_{ST} = 0\ m$$

$$I_{xS} := \sum_{ps=1}^{ns}\left[\left[\left(xs_{ps+1} - xs_{ps}\right)\cdot\frac{ys_{ps+1} + ys_{ps}}{24}\right]\cdot\left[\left(ys_{ps+1} + ys_{ps}\right)^2 + \left(ys_{ps+1} - ys_{ps}\right)^2\right]\right] \qquad I_{xS} = 0.01921\ m^4$$

$$I_{yS} := -\sum_{ps=1}^{ns}\left[\left[\left(ys_{ps+1} - ys_{ps}\right)\cdot\frac{xs_{ps+1} + xs_{ps}}{24}\right]\cdot\left[\left(xs_{ps+1} + xs_{ps}\right)^2 + \left(xs_{ps+1} - xs_{ps}\right)^2\right]\right] \qquad I_{yS} = 0.01921\ m^4$$

$$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2 \qquad I_{xS} = 0.01921\ m^4$$

$$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2 \qquad I_{yS} = 0.01921\ m^4$$



Calculate Composite Section Properties (before cracking) - with respect to concrete modulus

Effective area $A_E := A_C + A_{ST} \cdot \alpha$ $\qquad A_E = 2073497\,mm^2$

Effective centroid $x_E := \dfrac{A_C \cdot x_C + A_{ST} \cdot \alpha \cdot x_{ST}}{A_E}$ $\qquad x_E = 0.000\,m$

$y_E := \dfrac{A_C \cdot y_C + A_{ST} \cdot \alpha \cdot y_{ST}}{A_E}$ $\qquad y_E = 0.000\,m$

Effective stiffness

$$I_{EX} := I_{xC} + A_C \cdot \left(x_C^{\,2}\right) + \left(I_{xS} + A_{ST} \cdot x_{ST}^{\,2}\right) \cdot \alpha \qquad I_{EX} = 0\ m^4$$

$$I_{EY} := I_{yC} + A_C \cdot \left(y_C^{\,2}\right) + \left(I_{yS} + A_{ST} \cdot y_{ST}^{\,2}\right) \cdot \alpha \qquad I_{EY} = 0\ m^4$$

Distance from extreme concete fiber to centroid

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

Total depth of concrete section

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

Thickness of steel tube:

$$ts := y_1 - ys_1 \qquad ts = 19\,mm$$

Outside diameter of the circular hollow section:

$$d_o := H_{CY}$$

Section modulus

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

Calculate relative slenderness of column (10.6.2.4)

Effective length factor of cantilever column (10.3.2):

$$k_e := 2.2$$

$$L_e := k_e \cdot LH$$

Calculate the elastic critical load, N_{cr}:

$$N_{cr} := \frac{E_C \cdot I_{EY} \cdot \pi^2}{L_e^2} \qquad N_{cr} = 346599\,\text{kN}$$

Slenderness parameter

$$\lambda_r := \sqrt{\frac{A_{ST} \cdot f_{ys} + 0.85 \cdot A_C \cdot f_c}{N_{cr}}} \qquad \lambda_r = 0$$

Calculate Ultimate Section Capacity (10.6.2)

For a circular column calculate the confinement coefficients:

$$\eta_{10} := \left(\begin{array}{l} \eta \leftarrow 4.9 - 18.5 \cdot \lambda_r + 17 \cdot \lambda_r^2 \\ \eta \ \text{ if } \ \eta \geq 0 \\ 0 \ \text{ otherwise} \end{array} \right) \qquad \eta_{10} = 0$$

$$\eta_{20} := \left| \begin{array}{l} \eta \leftarrow 0.25 \cdot (3 + 2 \cdot \lambda_r) \\ \eta \ \text{ if } \ \eta \leq 1.0 \\ 1.0 \ \text{ otherwise} \end{array} \right. \qquad \eta_{20} = 1$$

$$\eta_1(e) := \left| \begin{array}{l} \eta \leftarrow \eta_{10} \cdot \left(1 - \frac{10e}{d_o}\right) \\ \eta \ \text{ if } \ \eta \geq 0 \\ 0 \ \text{ otherwise} \end{array} \right.$$

$$\eta_2(e) := \left| \begin{array}{l} \eta \leftarrow \eta_{20} + (1 - \eta_{20}) \cdot \frac{10e}{d_o} \\ \eta \ \text{ if } \ \eta \leq 1.0 \\ 1.0 \ \text{ otherwise} \end{array} \right.$$

$$N_{us}(e) := \phi \cdot A_{ST} \cdot \eta_2(e) \cdot f_{ys} + \phi_c \cdot A_C \cdot f_c \cdot \left(1 + \eta_1(e) \cdot \frac{ts \cdot f_{ys}}{d_o \cdot f_c}\right)$$

In the worst case, eccentricity is at least equal to do/10: $\eta_2\left(\frac{d_o}{10}\right) = 1$ $\quad \eta_1\left(\frac{d_o}{10}\right) = 0$

$$N_{us} := N_{us}\left(\frac{d_o}{10}\right) \qquad N_{us} = 43162\,\text{kN}$$

Check Steel Contribution Factor (10.6.1.4)

$$\alpha_s := \frac{\phi \cdot A_{ST} \cdot f_{ys}}{N_{us}} \qquad \alpha_s = 0$$

$$SteelContribution_{Factor} := \begin{cases} \text{"OK"} & \text{if } (\alpha_s > 0.2) \cdot (\alpha_s \le 0.9) \\ \text{"SECTION NOT APPLICABLE"} & \text{otherwise} \end{cases}$$

$$SteelContribution_{Factor} = \text{"OK"}$$

Calculate Ultimate Member Capacity (10.6.3)

Compression member slenderness reduction factor α_c:

$$\lambda_\eta := 90 \cdot \lambda_r \qquad \lambda_\eta = 36$$

$$\alpha_a := \frac{2100 \cdot (\lambda_\eta - 13.5)}{\lambda_\eta^2 - 15.3 \cdot \lambda_\eta + 2050} \qquad \alpha_a = 17$$

$$\alpha_b := -0.5$$ Table 10.3.3(A) RHS and CHS section

$$\lambda := \lambda_\eta + \alpha_a \cdot \alpha_b \qquad \lambda = 28$$

$$\eta := \begin{array}{|l} \eta \leftarrow 0.00326 \cdot (\lambda - 13.5) \\ 0 \ \text{ if } \eta < 0 \\ \eta \ \text{ otherwise} \end{array} \qquad \eta = 0$$

$$\xi := \frac{\left(\frac{\lambda}{90}\right)^2 + 1 + \eta}{2 \cdot \left(\frac{\lambda}{90}\right)^2} \qquad \xi = 6$$

$$\alpha_c := \xi \cdot \left[1 - \sqrt{1 - \left(\frac{90}{\xi \cdot \lambda}\right)^2}\right] \qquad \alpha_c = 1$$

Nominal member capacity:

$$N_{uc} := \alpha_c \cdot N_{us} \qquad N_{uc} = 41079\,kN$$

Establish Section Dimensions

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

Positive case - determine coord of extreme steel fiber $y_{Espos} := \max(ys)$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{Etube} := y_{Espos} - y_{Epos}$

$y_{Etube} = 19\,mm$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT B (N=0)

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := (H_{CY} - y_{CB}) \cdot \beta_1 \qquad Y_C = 359\,mm$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEB} := H_{CY} - Y_C \qquad Y_{CEB} = 1003\,mm$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

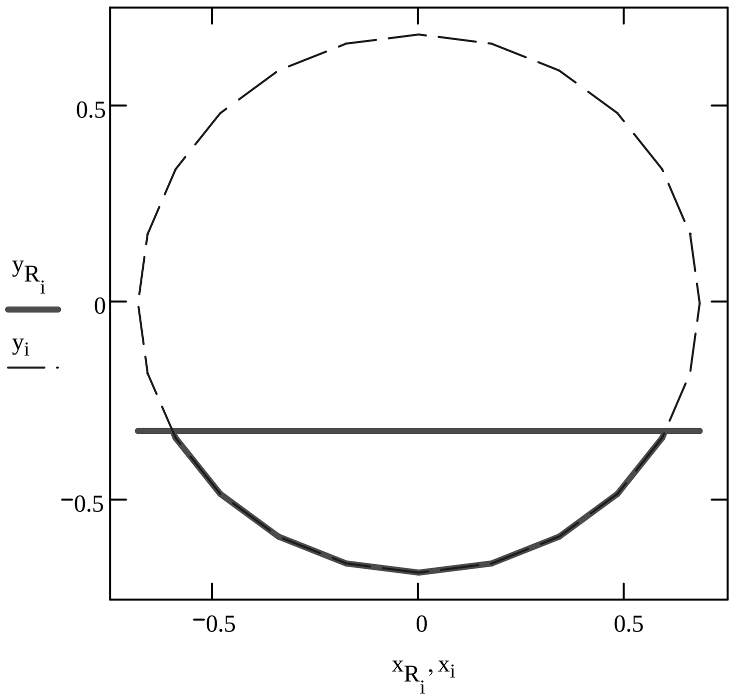
$x_R := x \qquad y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEB})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEB})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEB})\right] \\ x_i + (x_{i-1} - x_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEB})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEB})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEB})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1}) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CEB})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEB})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEB})\right] \\ y_i + (y_{i-1} - y_i) \cdot \left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CEB})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEB})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEB})\right] \\ y_{Epos} - (Y_{CEB}) & \text{if } (y_{Epos} - y_i) < (Y_{CEB}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.3007\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 9021\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CB} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 118\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -12583\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 6568\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$y_{CB} \equiv 1003.48 \cdot mm$

$N_{uB} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$

$N_{uB} = -0\,kN$ **Balanced conditions apply**

Calculate offset of concrete force from centroid:

$x_{CG} := y_C - y_{CR}$ $x_{CG} = 468\,mm$

Calculate moment at first yield in concrete about centroid :

$$M_{syB} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$M_{syB} = 9207\,kN \cdot m$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT C (same moment capacity as POINT B)

Depth to neutral axis from extreme tensile fiber:

$y_{CC} := H_{CY} - y_{CB}$ $\qquad y_{CC} = 0\ \text{m}$

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := \left(H_{CY} - y_{CC}\right)\cdot\beta_1$ $\qquad Y_C = 1003.48\ \text{mm}$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEC} := H_{CY} - Y_C$ $\qquad Y_{CEC} = 359\ \text{mm}$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

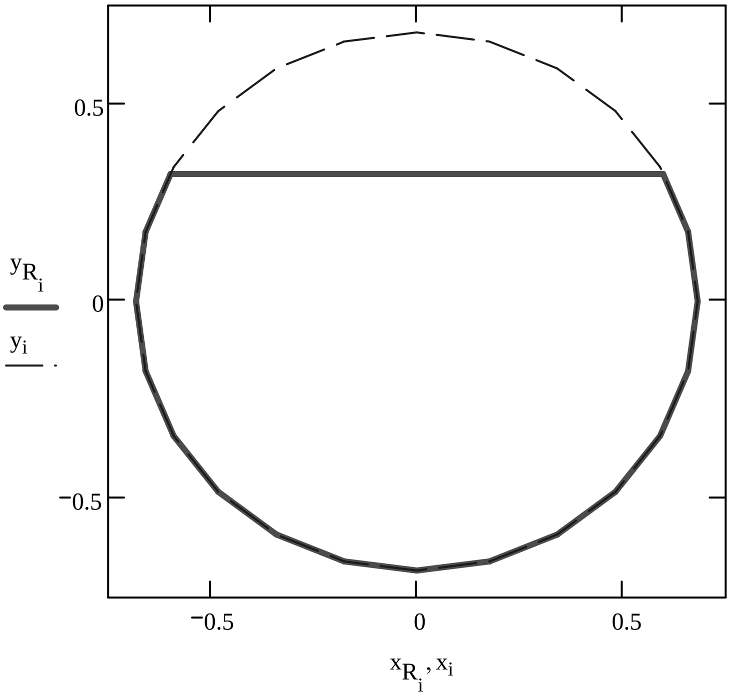
$x_R := x$ $\qquad y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEC}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEC}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEC}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEC}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEC}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEC}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEC}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEC}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEC}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEC}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEC}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEC}\right)\right] \\ y_{Epos} - \left(Y_{CEC}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEC}\right) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 1.13967\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 34190\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CC} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 62\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -6568\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 12583\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uC} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uC} = 25927\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 123\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syC} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syC} = 9207\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT D (Max moment capacity)

Depth to neutral axis from extreme tensile fiber:

$$y_{CD} := \frac{H_{CY}}{2} \qquad y_{CD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := (H_{CY} - y_{CD})\cdot\beta_1 \qquad Y_C = 681\ \text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CED} := H_{CY} - Y_C \qquad Y_{CED} = 681\ \text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1..n+1$$

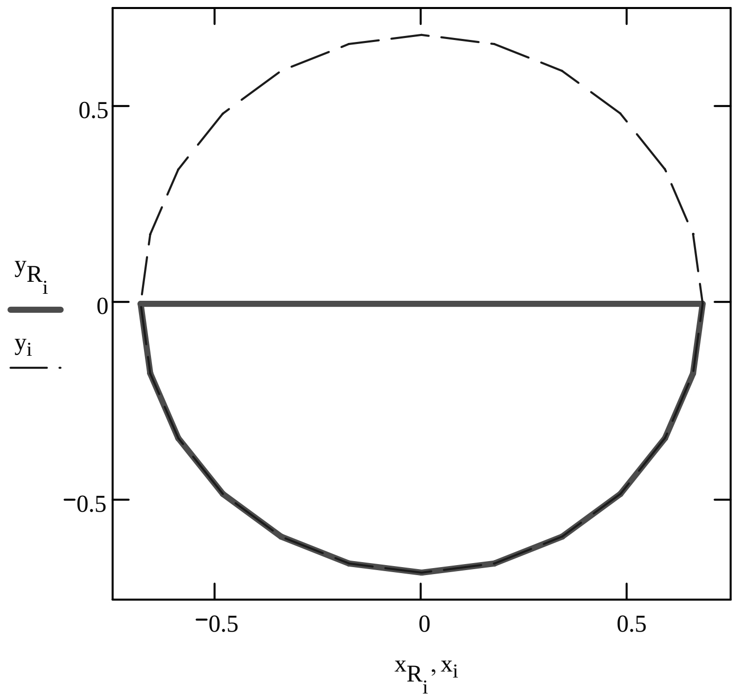
$$x_R := x \qquad y_R := y$$

$$i := 2..n$$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1})\cdot\left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CED})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CED})\right]\cdot\left[y_{Epos} - y_i < (Y_{CED})\right] \\ x_i + (x_{i-1} - x_i)\cdot\left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CED})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CED})\right]\cdot\left[y_{Epos} - y_i < (Y_{CED})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1})\cdot\left[1 - \dfrac{(y_{Epos} - y_{i+1}) - (Y_{CED})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CED})\right]\cdot\left[y_{Epos} - y_i < (Y_{CED})\right] \\ y_i + (y_{i-1} - y_i)\cdot\left[1 - \dfrac{(y_{Epos} - y_{i-1}) - (Y_{CED})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CED})\right]\cdot\left[y_{Epos} - y_i < (Y_{CED})\right] \\ y_{Epos} - (Y_{CED}) & \text{if } (y_{Epos} - y_i) < (Y_{CED}) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1..n+1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.72018\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 21605\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 90\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -9576\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 9576\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uD} = 12963\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 287\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot \left(Rd - ytube_T\right) + \phi \cdot F_{STC} \cdot \left(Rd - ytube_C\right)$$

$$M_{syD} = 11302\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBD} := \frac{y_{CB} + y_{CD}}{2} \qquad y_{CBD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CBD}\right)\cdot\beta_1 \qquad Y_C = 519.76\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBD} := H_{CY} - Y_C \qquad Y_{CEBD} = 842\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

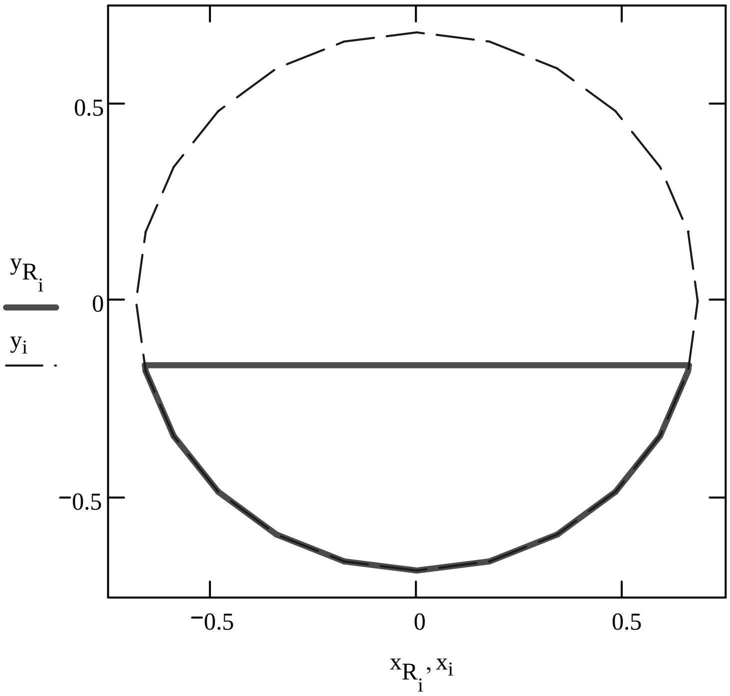
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBD}\right)\right] \\ y_{Epos} - \left(Y_{CEBD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEBD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.50399\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 15120\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CBD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 104\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -11033\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 8118\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBD} = 6449\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 376\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBD} = 10775\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BBD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBBD} := \frac{y_{CBD} + y_{CB}}{2} \qquad y_{CBBD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CBBD}\right)\cdot\beta_1 \qquad Y_C = 439.14\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBBD} := H_{CY} - Y_C \qquad Y_{CEBBD} = 923\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

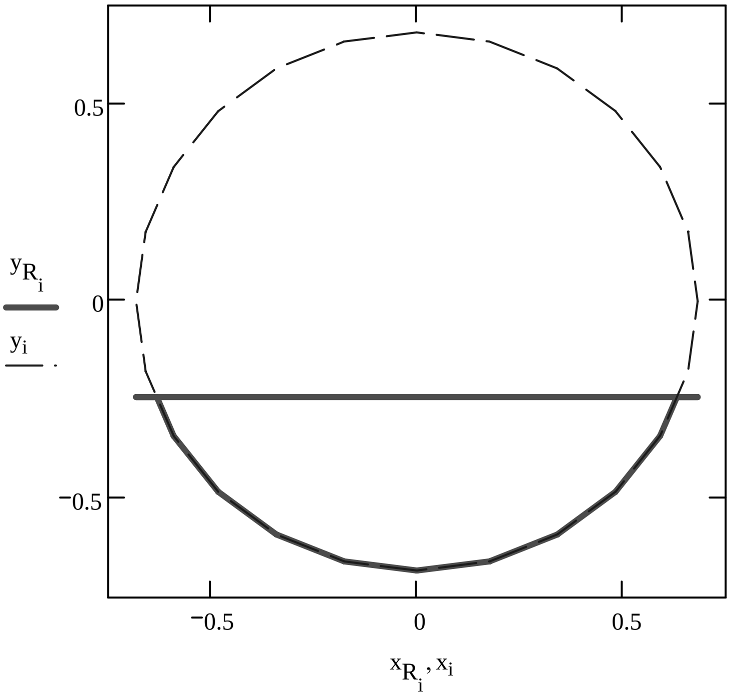
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right.\right. \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right.\right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right.\right. \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBBD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBBD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBBD}\right.\right. \\ y_{Epos} - \left(Y_{CEBBD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEBBD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.39969\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 11991\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CBBD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 111\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -11789\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 7362\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBBD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBBD} = 3210\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 422\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBBD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBBD} = 10119\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT BDD

Depth to neutral axis from extreme tensile fiber:

$$y_{CBDD} := \frac{y_{CBD} + y_{CD}}{2} \qquad y_{CBDD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CBDD}\right)\cdot\beta_1 \qquad Y_C = 600.38\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CEBDD} := H_{CY} - Y_C \qquad Y_{CEBDD} = 762\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

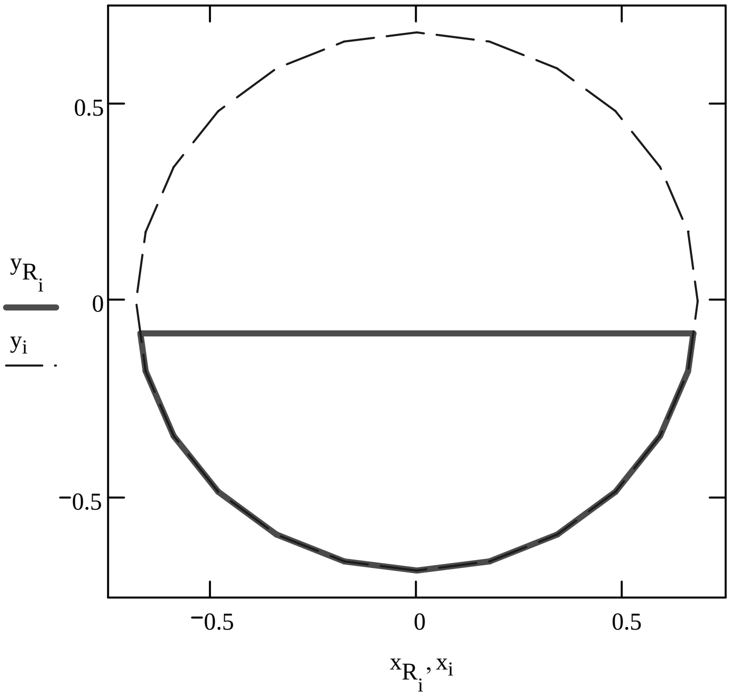
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBDD}\right.\right. \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBDD}\right.\right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CEBDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CEBDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBDD}\right.\right. \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CEBDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CEBDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CEBDD}\right.\right. \\ y_{Epos} - \left(Y_{CEBDD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CEBDD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.61123\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 18337\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CBDD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 97\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -10299\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 8852\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uBDD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uBDD} = 9700\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 331\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syBDD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syBDD} = 11170\ kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT CD (Max moment capacity)

Depth to neutral axis from extreme tensile fiber:

$$y_{CCD} := \frac{y_{CC} + y_{CD}}{2} \qquad y_{CCD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CCD}\right)\cdot\beta_1 \qquad Y_C = 842.24\,\text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CECD} := H_{CY} - Y_C \qquad Y_{CECD} = 520\,\text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

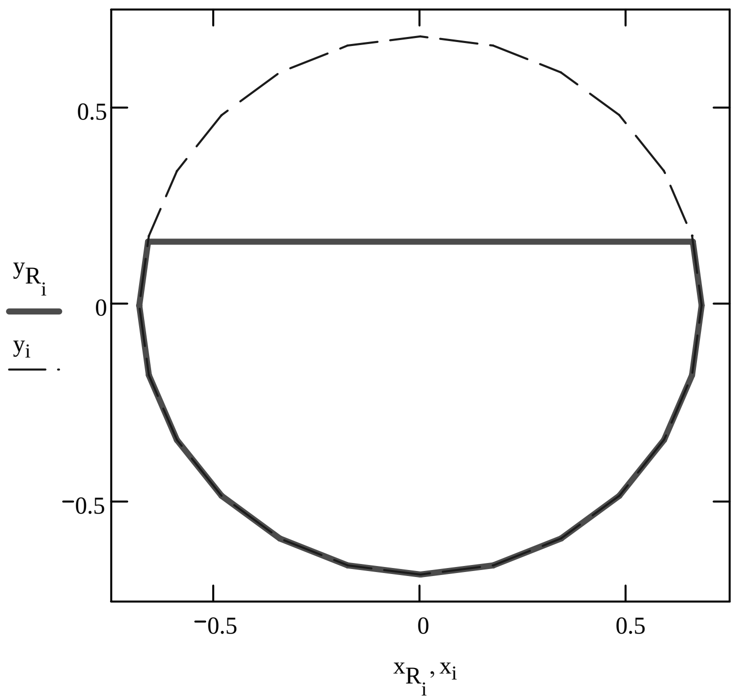
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECD}\right)\right] \\ y_{Epos} - \left(Y_{CECD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CECD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.93637\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 28091\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CCD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 76\,deg$$

Radius of steel tube to utside face $$Rd := \frac{H_{CY}}{2} + ts$$

Area of steel tube in tension: $$A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$$

Area of steel tube in compression: $$A_{STC} := A_{ST} - A_{STT}$$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0 \text{ m}$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0 \text{ m}$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $\qquad F_{STT} = -8118 \text{ kN}$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $\qquad F_{STC} = 11033 \text{ kN}$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uCD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uCD} = 19478 \text{ kN}$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 203 \text{ mm}$$

Calculate moment at first yield in concrete about centroid :

$$M_{syCD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syCD} = 10775 \text{ kN} \cdot \text{m}$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT CDD

Depth to neutral axis from extreme tensile fiber:

$$y_{CCDD} := \frac{y_{CCD} + y_{CD}}{2} \qquad y_{CCDD} = 1\ \text{m}$$

Calculate depth of equivalent rectangular stress block:

$$\beta_1 := 1$$

$$Y_C := \left(H_{CY} - y_{CCDD}\right)\cdot\beta_1 \qquad Y_C = 761.62\ \text{mm}$$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$$Y_{CECDD} := H_{CY} - Y_C \qquad Y_{CECDD} = 600\ \text{mm}$$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$$i := 1 .. n + 1$$

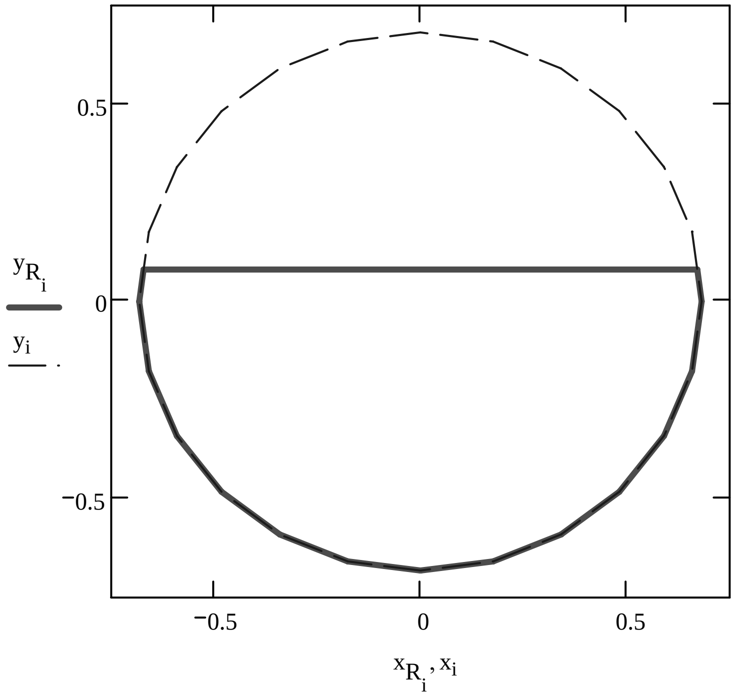
$$x_R := x \qquad y_R := y$$

$$i := 2 .. n$$

$$x_{R_i} := \begin{cases} x_i - \left(x_i - x_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right.\right. \\ x_i + \left(x_{i-1} - x_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right.\right. \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - \left(y_i - y_{i+1}\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i+1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right.\right. \\ y_i + \left(y_{i-1} - y_i\right)\cdot\left[1 - \dfrac{\left(y_{Epos} - y_{i-1}\right) - \left(Y_{CECDD}\right)}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > \left(Y_{CECDD}\right)\right]\cdot\left[y_{Epos} - y_i < \left(Y_{CECDD}\right.\right. \\ y_{Epos} - \left(Y_{CECDD}\right) & \text{if } \left(y_{Epos} - y_i\right) < \left(Y_{CECDD}\right) \\ y_i & \text{otherwise} \end{cases}$$

$$i := 1 .. n + 1$$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right] \qquad A_{CR} = 0.82913\ m^2$$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right] \qquad x_{CR} = 0\ m$$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right] \qquad y_{CR} = -0\ m$$

Calculate compressive force in concrete:

$$F_C := A_{CR}\cdot\left(f_c\right) \qquad F_C = 24874\,kN$$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CCDD} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right) \qquad \theta = 83\,deg$$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 0\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $\quad F_{STT} = -8852\,kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $\quad F_{STC} = 10299\,kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uCDD} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uCDD} = 16226\,kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 244\,mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syCDD} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syCDD} = 11170\,kN \cdot m$$

CALCULATE NOMINAL MOMENT SECTION CAPACITY, POINT E (Intermediate)

Depth to neutral axis from extreme tensile fiber:

$y_{CE} := \frac{y_{CC}}{2}$ $y_{CE} = 0\ m$

Calculate depth of equivalent rectangular stress block:

$\beta_1 := 1$

$Y_C := (H_{CY} - y_{CE}) \cdot \beta_1$ $Y_C = 1182.74\ mm$

Depth of equivalent rectangular stress block to extreme tensile fiber:

$Y_{CEE} := H_{CY} - Y_C$ $Y_{CED} = 681\ mm$

Calculate depth of concrete in compressive force linear response (concrete cracked in tension):

$i := 1 .. n + 1$

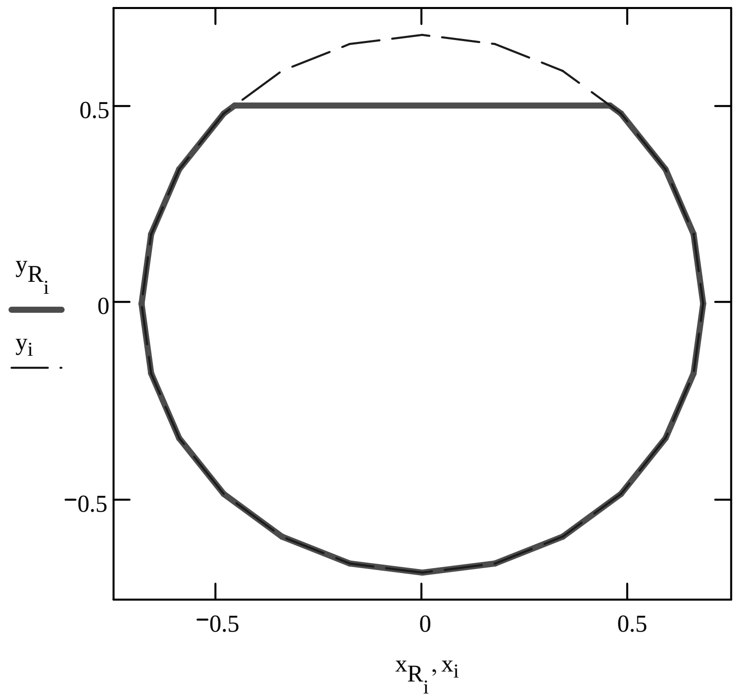
$x_R := x$ $y_R := y$

$i := 2 .. n$

$$x_{R_i} := \begin{cases} x_i - (x_i - x_{i+1}) \cdot \left[1 - \frac{(y_{Epos} - y_{i+1}) - (Y_{CEE})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEE})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEE})\right] \\ x_i + (x_{i-1} - x_i) \cdot \left[1 - \frac{(y_{Epos} - y_{i-1}) - (Y_{CEE})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEE})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEE})\right] \\ x_i & \text{otherwise} \end{cases}$$

$$y_{R_i} := \begin{cases} y_i - (y_i - y_{i+1}) \cdot \left[1 - \frac{(y_{Epos} - y_{i+1}) - (Y_{CEE})}{y_i - y_{i+1}}\right] & \text{if } \left[y_{Epos} - y_{i+1} > (Y_{CEE})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEE})\right] \\ y_i + (y_{i-1} - y_i) \cdot \left[1 - \frac{(y_{Epos} - y_{i-1}) - (Y_{CEE})}{y_i - y_{i-1}}\right] & \text{if } \left[y_{Epos} - y_{i-1} > (Y_{CEE})\right] \cdot \left[y_{Epos} - y_i < (Y_{CEE})\right] \\ y_{Epos} - (Y_{CEE}) & \text{if } (y_{Epos} - y_i) < (Y_{CEE}) \\ y_i & \text{otherwise} \end{cases}$$

$i := 1 .. n + 1$



$$A_{CR} := -\sum_{i=1}^{n}\left[\left(y_{R_{i+1}} - y_{R_i}\right)\cdot\frac{x_{R_{i+1}} + x_{R_i}}{2}\right]$$ $A_{CR} = 1.33107\ m^2$

$$x_{CR} := -\frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{y_{R_{i+1}} - y_{R_i}}{8}\cdot\left[\left(x_{R_{i+1}} + x_{R_i}\right)^2 + \frac{\left(x_{R_{i+1}} - x_{R_i}\right)^2}{3}\right]\right]$$ $x_{CR} = 0\ m$

$$y_{CR} := \frac{1}{A_{CR}}\cdot\sum_{i=1}^{n}\left[\frac{x_{R_{i+1}} - x_{R_i}}{8}\cdot\left[\left(y_{R_{i+1}} + y_{R_i}\right)^2 + \frac{\left(y_{R_{i+1}} - y_{R_i}\right)^2}{3}\right]\right]$$ $y_{CR} = -0\ m$

Calculate compressive force in concrete:

$F_C := A_{CR}\cdot\left(f_c\right)$ $F_C = 39932\ kN$

Calculate force in steel tube:

Angle subtended to neutral axis from centroid:

$$\theta := 90\cdot deg + asin\left(\frac{y_{CE} - \frac{H_{CY}}{2}}{\frac{H_{CY}}{2}}\right)$$ $\theta = 43\ deg$

Radius of steel tube to utside face $Rd := \frac{H_{CY}}{2} + ts$ $Rd = 1\ m$

Area of steel tube in tension: $A_{STT} := \frac{\theta}{\pi} \cdot A_{ST}$ $A_{STT} = 0\ m^2$

Area of steel tube in compression: $A_{STC} := A_{ST} - A_{STT}$ $A_{STC} = 0\ m^2$

Offset of centroid of steel tube in tension from extreme fiber in tension:

$$ytube_T := Rd \cdot \left[1 - \frac{2 \cdot \sin(\theta)}{3 \cdot \theta} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_T = 0\ m$$

Offset of centroid of steel tube in compression from extreme fiber in compression:

$$ytube_C := Rd \cdot \left[1 - \frac{2 \cdot \sin(\pi - \theta)}{3 \cdot (\pi - \theta)} \cdot \left(1 - \frac{ts}{Rd} + \frac{1}{2 - \frac{ts}{Rd}}\right)\right] \qquad ytube_C = 1\ m$$

Force in steel tube in tension: $F_{STT} := -A_{STT} \cdot f_{ys}$ $F_{STT} = -4526\ kN$

Force in steel tube in compression: $F_{STC} := A_{STC} \cdot f_{ys}$ $F_{STC} = 14625\ kN$

Define a distance of neutral axis from extreme fiber in tension to give balanced force conditions:

$$N_{uE} := \phi_c \cdot F_C + \phi \cdot F_{STT} + \phi \cdot F_{STC}$$

$$N_{uE} = 33048\ kN$$

Calculate offset of concrete force from centroid:

$$x_{CG} := y_C - y_{CR} \qquad x_{CG} = 47\ mm$$

Calculate moment at first yield in concrete about centroid :

$$M_{syE} := \phi_c \cdot F_C \cdot x_{CG} - \phi \cdot F_{STT} \cdot (Rd - ytube_T) + \phi \cdot F_{STC} \cdot (Rd - ytube_C)$$

$$M_{syE} = 6250\ kN \cdot m$$

DETERMINE MOMENT- AXIAL LOAD RELATION FOR SECTION

$k := 1 .. 10$

$M_{SY_k} :=$

$0 \cdot kN \cdot m$
M_{syE}
M_{syC}
M_{syCD}
M_{syCDD}
M_{syD}
M_{syBDD}
M_{syBD}
M_{syBBD}
M_{syB}

$N_{S_k} :=$

N_{us}
N_{uE}
N_{uC}
N_{uCD}
N_{uCDD}
N_{uD}
N_{uBDD}
N_{uBD}
N_{uBBD}
N_{uB}

$N_{uc_k} := N_{uc}$

$N_{SD_k} := N_{uc_k}$

$N_{UC} := N_{uc}$

$MS := \frac{M_{SY}}{1000kN \cdot m}$ $\quad NS := \frac{N_S}{1000kN}$ $\quad NUC := \frac{N_{UC}}{1000kN}$

MS =

	1
1	0.000
2	6.250
3	9.207
4	10.775
5	11.170
6	11.302
7	11.170
8	10.775
9	10.119
10	9.207

NS =

	1
1	43.162
2	33.048
3	25.927
4	19.478
5	16.226
6	12.963
7	9.7
8	6.449
9	3.21
10	-0

NUC =

	1
1	41.079
2	41.079
3	41.079
4	41.079
5	41.079
6	41.079
7	41.079
8	41.079
9	41.079
10	41.079

For cantilever columns: $\beta_m := 0$ $\quad \alpha_n := \alpha_c \cdot \left(\frac{1 + \beta_m}{4}\right)$ $\quad \alpha_n = 0$

Coordinates of αn line: $N_{uc} := N_{uc_1}$

$Coord1 := 0 \cdot kN \cdot m$

$$Coord2 := \begin{cases} M_{syE} \cdot \left(1 - \dfrac{N_{uc} - N_{uE}}{N_{us} - N_{uE}}\right) & \text{if } N_{uc} > N_{uE} \\ M_{syE} + \left(M_{syC} - M_{syE}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uC}}{N_{uE} - N_{uC}}\right) & \text{if } \left(N_{uc} \le N_{uE}\right) \cdot \left(N_{uc} > N_{uC}\right) \\ M_{syC} + \left(M_{syCD} - M_{syC}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uCD}}{N_{uC} - N_{uCD}}\right) & \text{if } \left(N_{uc} \le N_{uC}\right) \cdot \left(N_{uc} > N_{uCD}\right) \\ M_{syCD} + \left(M_{syCDD} - M_{syCD}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uCDD}}{N_{uCD} - N_{uCDD}}\right) & \text{if } \left(N_{uc} \le N_{uCD}\right) \cdot \left(N_{uc} > N_{uCDD}\right) \\ M_{syCDD} + \left(M_{syCD} - M_{syCDD}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uD}}{N_{uCDD} - N_{uD}}\right) & \text{if } \left(N_{uc} \le N_{uCDD}\right) \cdot \left(N_{uc} > N_{uD}\right) \\ M_{syD} - \left(M_{syD} - M_{syBDD}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uBDD}}{N_{uD} - N_{uBDD}}\right) & \text{if } \left(N_{uc} \le N_{uD}\right) \cdot \left(N_{uc} > N_{uBDD}\right) \\ M_{syBDD} - \left(M_{syBDD} - M_{syBD}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uBD}}{N_{uBDD} - N_{uBD}}\right) & \text{if } \left(N_{uc} \le N_{uBDD}\right) \cdot \left(N_{uc} > N_{uBD}\right) \\ M_{syBD} - \left(M_{syBD} - M_{syBBD}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uBBD}}{N_{uBD} - N_{uBBD}}\right) & \text{if } \left(N_{uc} \le N_{uBD}\right) \cdot \left(N_{uc} > N_{uBBD}\right) \\ M_{syBBD} - \left(M_{syBBD} - M_{syB}\right) \cdot \left(1 - \dfrac{N_{uc} - N_{uB}}{N_{uBBD} - N_{uB}}\right) & \text{otherwise} \end{cases}$$

$Coord2 = 1287\,kN \cdot m$

$$line_{\alpha n} := \frac{N_{uc} - \alpha_n \cdot N_{us}}{Coord2 - Coord1} \cdot MS \cdot m + \frac{\alpha_n \cdot N_{us}}{1000kN}$$

Coordinates of moment capacity:

$$\mathrm{Coord3}(N_{ult},k) := \begin{cases} M_{syE}\cdot\left(1-\dfrac{N_{ult_k}-N_{uE}}{N_{us}-N_{uE}}\right) & \text{if } N_{ult_k} > N_{uE} \\ M_{syE}+\left(M_{syC}-M_{syE}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uC}}{N_{uE}-N_{uC}}\right) & \text{if } \left(N_{ult_k}\le N_{uE}\right)\cdot\left(N_{ult_k}>N_{uC}\right) \\ M_{syC}+\left(M_{syCD}-M_{syC}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uCD}}{N_{uC}-N_{uCD}}\right) & \text{if } \left(N_{ult_k}\le N_{uC}\right)\cdot\left(N_{ult_k}>N_{uCD}\right) \\ M_{syCD}+\left(M_{syCDD}-M_{syCD}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uCDD}}{N_{uCD}-N_{uCDD}}\right) & \text{if } \left(N_{ult_k}\le N_{uCD}\right)\cdot\left(N_{ult_k}>N_{uCDD}\right) \\ M_{syCDD}+\left(M_{syCD}-M_{syCDD}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uCD}}{N_{uCDD}-N_{uCD}}\right) & \text{if } \left(N_{ult_k}\le N_{uCDD}\right)\cdot\left(N_{ult_k}>N_{uCD}\right) \\ M_{syD}-\left(M_{syD}-M_{syBDD}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uBDD}}{N_{uD}-N_{uBDD}}\right) & \text{if } \left(N_{ult_k}\le N_{uD}\right)\cdot\left(N_{ult_k}>N_{uBDD}\right) \\ M_{syBDD}-\left(M_{syBDD}-M_{syBD}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uBD}}{N_{uBDD}-N_{uBD}}\right) & \text{if } \left(N_{ult_k}\le N_{uBDD}\right)\cdot\left(N_{ult_k}>N_{uBD}\right) \\ M_{syBD}-\left(M_{syBD}-M_{syBBD}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uBBD}}{N_{uBD}-N_{uBBD}}\right) & \text{if } \left(N_{ult_k}\le N_{uBD}\right)\cdot\left(N_{ult_k}>N_{uBBD}\right) \\ M_{syBBD}-\left(M_{syBBD}-M_{syB}\right)\cdot\left(1-\dfrac{N_{ult_k}-N_{uB}}{N_{uBBD}-N_{uB}}\right) & \text{otherwise} \end{cases}$$

$$\mathrm{Coord4}(N_{ult},k) := \left(N_{ult_k}-\alpha_n\cdot N_{us}\right)\cdot\frac{1}{\dfrac{N_{uc}-\alpha_n\cdot N_{us}}{\mathrm{Coord2}-\mathrm{Coord1}}}$$

Design Moment Capacity

$$M_{ULTCAP}(N_{ULT},k) := \begin{cases} \mathrm{Coord3}(N_{ULT},k) & \text{if } N_{ULT_k} < \alpha_n\cdot N_{us} \\ \mathrm{Coord3}(N_{ULT},k)-\mathrm{Coord4}(N_{ULT},k) & \text{otherwise} \end{cases}$$

$k := 1 .. 16$

$M_{ULT_k} :=$

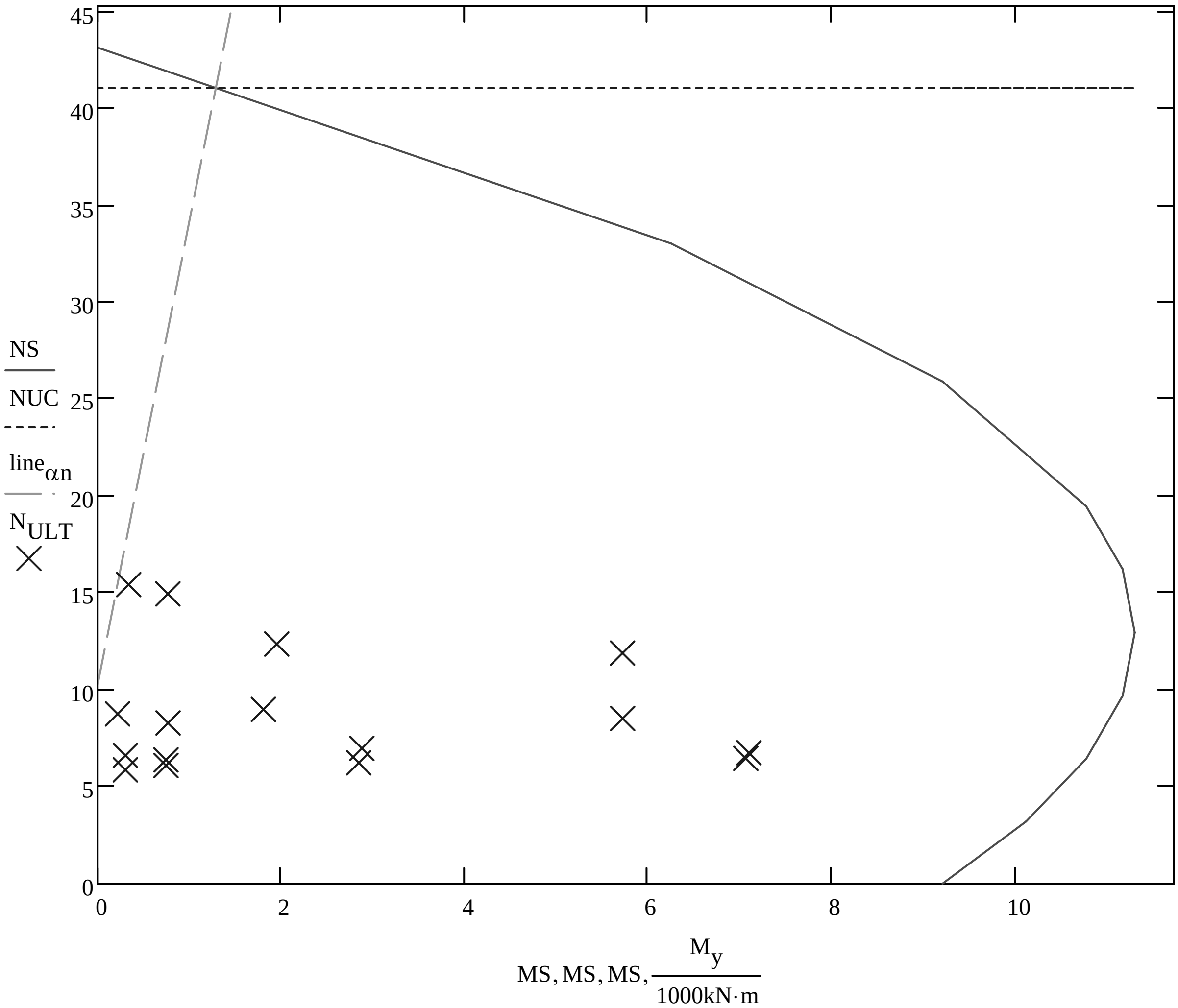
$M_{ULTCAP}(P,1)$
$M_{ULTCAP}(P,2)$
$M_{ULTCAP}(P,3)$
$M_{ULTCAP}(P,4)$
$M_{ULTCAP}(P,5)$
$M_{ULTCAP}(P,6)$
$M_{ULTCAP}(P,7)$
$M_{ULTCAP}(P,8)$
$M_{ULTCAP}(P,9)$
$M_{ULTCAP}(P,10)$
$M_{ULTCAP}(P,11)$
$M_{ULTCAP}(P,12)$
$M_{ULTCAP}(P,13)$
$M_{ULTCAP}(P,14)$
$M_{ULTCAP}(P,15)$
$M_{ULTCAP}(P,16)$

$M_{ULT} =$ (kN·m)

	1
1	11056
2	13373
3	11085
4	11191
5	10732
6	10839
7	10777
8	10811
9	10999
10	13259
11	11028
12	11191
13	10659
14	10795
15	10704
16	10763

$N_{ULT} := \frac{P}{1000kN}$

INTERACTION DIAGRAM - TRANSVERSE MOMENT M_y
COMPOSITE COLUMN (Steel Grade SM400)



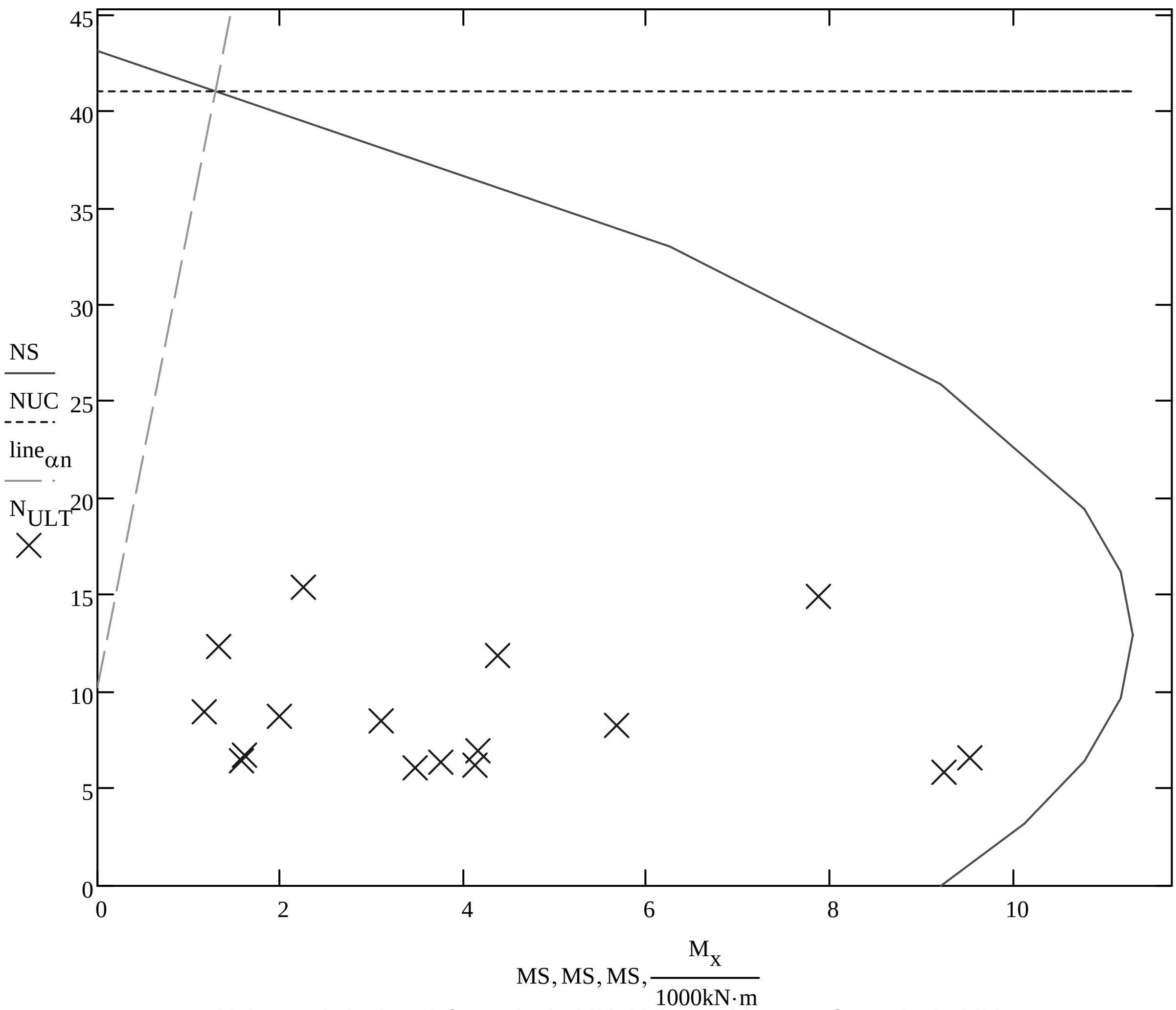
Ultimate Axial Load Capacity in MN. Ultimate Moment Capacity in MNm

PlateElementSlenderness = "OK"

$SteelContribution_{Factor}$ = "OK"

Concrete strength		$f_c = 30\,MPa$	
Yield Strength of Steel		$f_{ys} = 235\,MPa$	
Diameter of concrete section		$D = 1362\,mm$	
Thickness of steel tube		$ts = 19\,mm$	
Strength Reduction Factors	-	Steel	$\phi = 0.9$
	-	Concrete	$\phi_c = 0.6$

INTERACTION DIAGRAM - LONGITUDINAL MOMENT M_x
COMPOSITE COLUMN (Steel Grade SM400)



Ultimate Axial Load Capacity in MN. Ultimate Moment Capacity in MNm

PlateElementSlenderness = "OK"

$SteelContribution_{Factor}$ = "OK"

Concrete strength		$f_c = 30\,MPa$	
Yield Strength of Steel		$f_{ys} = 235\,MPa$	
Diameter of concrete section		$D = 1362\,mm$	
Thickness of steel tube		$ts = 19\,mm$	
Strength Reduction Factors	-	Steel	$\phi = 0.9$
	-	Concrete	$\phi_c = 0.6$

DESIGN SUMMARY

Location	Load Case	Longitudinal Moment			Transverse Moment			Biaxial Moment	
		M_x kNm	$0.9\ M_{rx}$ kNm	Result	M_y kNm	$0.9\ M_{ry}$ kNm	Result	$\frac{M_x}{M_{rx}}+\frac{M_y}{M_{ry}} \le 1.0$	Result
Base	1	1987.0	9951	OK	217.1	9951	OK	0.20	OK
Base	2	2248.1	12036	OK	339.9	12036	OK	0.19	OK
Base	3	1166.1	9976	OK	1806.7	9976	OK	0.27	OK
Base	4	1323.5	10072	OK	1952.0	10072	OK	0.29	OK
Base	5	4120.9	9659	OK	2845.6	9659	OK	0.65	OK
Base	6	4154.2	9755	OK	2880.3	9755	OK	0.65	OK
Base	7	1573.0	9699	OK	7063.6	9699	OK	0.80	OK
Base	8	1606.2	9730	OK	7098.3	9730	OK	0.81	OK
Top	9	5668.0	9899	OK	768.8	9899	OK	0.59	OK
Top	10	7870.5	11933	OK	767.3	11933	OK	0.65	OK
Top	11	3097.7	9925	OK	5721.9	9925	OK	0.80	OK
Top	12	4369.4	10072	OK	5720.1	10072	OK	0.90	OK
Top	13	9241.7	9593	OK	303.8	9593	OK	0.90	OK
Top	14	9523.1	9716	OK	303.4	9716	OK	0.91	OK
Top	15	3467.8	9634	OK	745.8	9634	OK	0.39	OK
Top	16	3749.1	9686	OK	745.4	9686	OK	0.42	OK

Note :

Members subject to combined compression and biaxial bending shall satisfy the items below:

$M_x \le 0.9\ M_{rx}$

$M_y \le 0.9\ M_{ry}$

$M_x/M_{rx} + M_y/M_{ry} \le 1.0$

PlateElementSlenderness = "OK"

$\text{SteelContribution}_{\text{Factor}}$ = "OK"

Concrete strength		$f_c = 30\ \text{MPa}$	
Yield Strength of Steel		$f_{ys} = 235\ \text{MPa}$	
Diameter of concrete section		$D = 1362\ \text{mm}$	
Thickness of steel tube		$ts = 19\ \text{mm}$	
Strength Reduction Factors	-	Steel	$\phi = 0.9$
	-	Concrete	$\phi_c = 0.6$

DESIGN SUMMARY - 2

Vectorial addition of biaxial moments: $M_d := \sqrt{M_x^2 + M_y^2}$

Clause 11.5.3, Biaxial Bending, of Australian Standard AS5100, states that if it is clear which is the critical plane only <u>one</u> item below need be considered:

$M_x \leq 0.9\ M_{rx}$

$M_y \leq 0.9\ M_{ry}$

$M_x/M_{rx} + M_y/M_{ry} \leq 1.0$

In the case of circular columns it is clear that the critical plane occurs in the direction of the vector addition of the biaxial moments. In this direction the section will be subject to the design moment M_d as determined above. The section shall therefore be checked to ensure the following:

$M_d \leq 0.9\ M_r$

Given that the section is circular M_r may be taken as either M_{rx} or M_{ry} for the given applied ultimate load.

Location	Load Case	Combined Moment			Moment Capacity
		M_d	$0.9\ M_r$	Result	M_r
		kNm	kNm		kNm
Base	1	1998.9	9951	OK	11056
Base	2	2273.6	12036	OK	13373
Base	3	2150.4	9976	OK	11085
Base	4	2358.3	10072	OK	11191
Base	5	5007.9	9659	OK	10732
Base	6	5055.0	9755	OK	10839
Base	7	7236.6	9699	OK	10777
Base	8	7277.7	9730	OK	10811
Top	9	5719.9	9899	OK	10999
Top	10	7907.9	11933	OK	13259
Top	11	6506.6	9925	OK	11028
Top	12	7198.0	10072	OK	11191
Top	13	9246.7	9593	OK	10659
Top	14	9527.9	9716	OK	10795
Top	15	3547.1	9634	OK	10704
Top	16	3822.5	9686	OK	10763

<u>DESIGN CONCLUSION</u>

SECTION IS
ADEQUATE

Serviceability Check

Notes on Serviceability Check for Composite Columns

For composite columns, AASHTO LRFD is silent regarding serviceability checks.

For the serviceability checks on composite concrete columns the following has therefore been assumed:

- Allowable tensile stress in structural steel is $0.6F_y$
- Allowable compressive stress in structural steel is taken as the yield stress of the steel (F_y)
- A linear stress-strain relation is assumed for the concrete up to the characteristic stress of the concrete with a limiting strain in the order of 0.002 used in the analysis.

Two (2) cases have been considered:

1. Analysis of section under full load, including braking and centrifugal forces and temperature effects, with an allowable overstress of 40% i.e. 140% allowable stress limit
2. Analysis of section under vertical live load and pedestrian loads only, with an allowable overstress of nil i.e. 100% allowable stress limit.

The above overstress allowance is given in the Design Criteria (Table 2.4.6-1).

TOP & 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
1400 mm Dia Circular Composite Column - P4 & P5 Top/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	1362	mm
Thickness of CHS section	t	19	mm
Diameter of rebar - layer 1	dia1	0	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	0	
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	P4T	Combination 1 - P + Traffic Load Only	7733.2	3963.1	100%
2	P4T	Combination 1 - P + Traffic Load Only	7733.2	2649.8	100%
3	P5T	Combination 1 - P + Traffic Load Only	7738.7	2651.6	100%
4	P5T	Combination 1 - P + Traffic Load Only	7738.7	3980.5	100%
5	P4B	Combination 1 - P + Traffic Load Only	8094.6	1009.8	100%
6	P4B	Combination 1 - P + Traffic Load Only	8094.6	747.2	100%
7	P4B	Combination 1 - P + Traffic Load Only	8100.1	732.9	100%
8	P4B	Combination 1 - P + Traffic Load Only	8100.1	1001.0	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 $\alpha := \begin{cases} \frac{E_S}{E_C} & \text{if } E_C > 0 \\ 1 & \text{otherwise} \end{cases}$ $\alpha = 7.77$

$E_C = 25743\,MPa$

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	-681	**26**	0	681
2	-85	-676	**27**	85	676
3	-169	-660	**28**	169	660
4	-251	-633	**29**	251	633
5	-328	-597	**30**	328	597
6	-400	-551	**31**	400	551
7	-466	-496	**32**	466	496
8	-525	-434	**33**	525	434
9	-575	-365	**34**	575	365
10	-616	-290	**35**	616	290
11	-648	-210	**36**	648	210
12	-669	-128	**37**	669	128
13	-680	-43	**38**	680	43
14	-680	43	**39**	680	-43
15	-669	128	**40**	669	-128
16	-648	210	**41**	648	-210
17	-616	290	**42**	616	-290
18	-575	365	**43**	575	-365
19	-525	434	**44**	525	-434
20	-466	496	**45**	466	-496
21	-400	551	**46**	400	-551
22	-328	597	**47**	328	-597
23	-251	633	**48**	251	-633
24	-169	660	**49**	169	-660
25	-85	676	**50**	85	-676

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

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

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$ $A_C = 1.45312\ m^2$

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

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

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$ $I_x = 0.16803\ m^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$ $I_y = 0.16803\ m^4$

$$I_{xC} := I_x - A_C \cdot x_C^2$$ $I_{xC} = 0.16803\ m^4$

$$I_{yC} := I_y - A_C \cdot y_C^2$$ $I_{yC} = 0.16803\ m^4$

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	-700	**26**	0	-681
2	-181	-676	**27**	176	-658
3	-350	-606	**28**	341	-590
4	-495	-495	**29**	482	-482
5	-606	-350	**30**	590	-341
6	-676	-181	**31**	658	-176
7	-700	0	**32**	681	0
8	-676	181	**33**	658	176
9	-606	350	**34**	590	341
10	-495	495	**35**	482	482
11	-350	606	**36**	341	590
12	-181	676	**37**	176	658
13	0	700	**38**	0	681
14	181	676	**39**	-176	658
15	350	606	**40**	-341	590
16	495	495	**41**	-482	482
17	606	350	**42**	-590	341
18	676	181	**43**	-658	176
19	700	0	**44**	-681	0
20	676	-181	**45**	-658	-176
21	606	-350	**46**	-590	-341
22	495	-495	**47**	-482	-482
23	350	-606	**48**	-341	-590
24	181	-676	**49**	-176	-658
25	0	-700	**50**	0	-681

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

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

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

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

Calculate Section Properties of Steel Tube Section

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

$A_{ST} = 0.08149\ m^2$

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

$x_{ST} = 0.0\ m$

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

$y_{ST} = 0\ m$

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

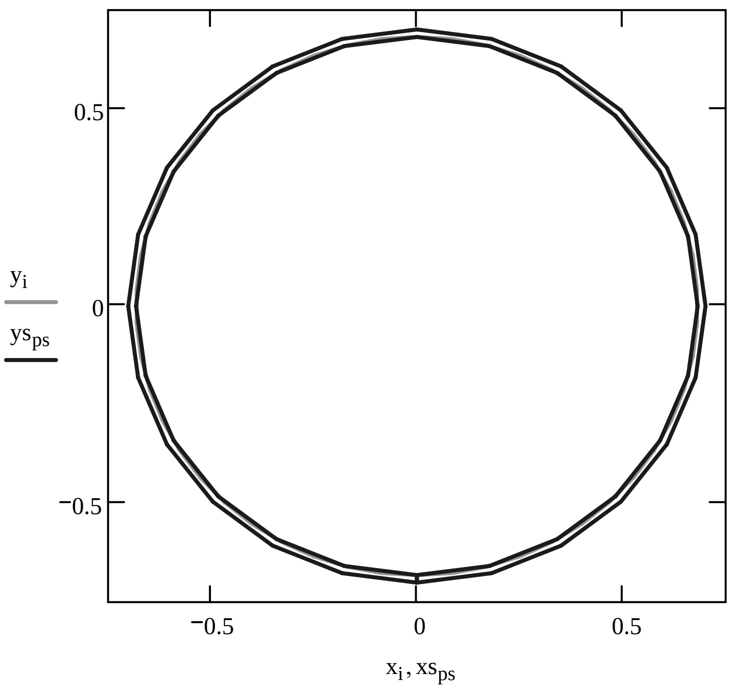
$I_{xS} = 0.01921\ m^4$

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

$I_{yS} = 0.01921\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ $\qquad I_{xS} = 0.01921\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ $\qquad I_{yS} = 0.01921\ m^4$



Rebar Data Layer 1 - 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

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

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 0\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0$$

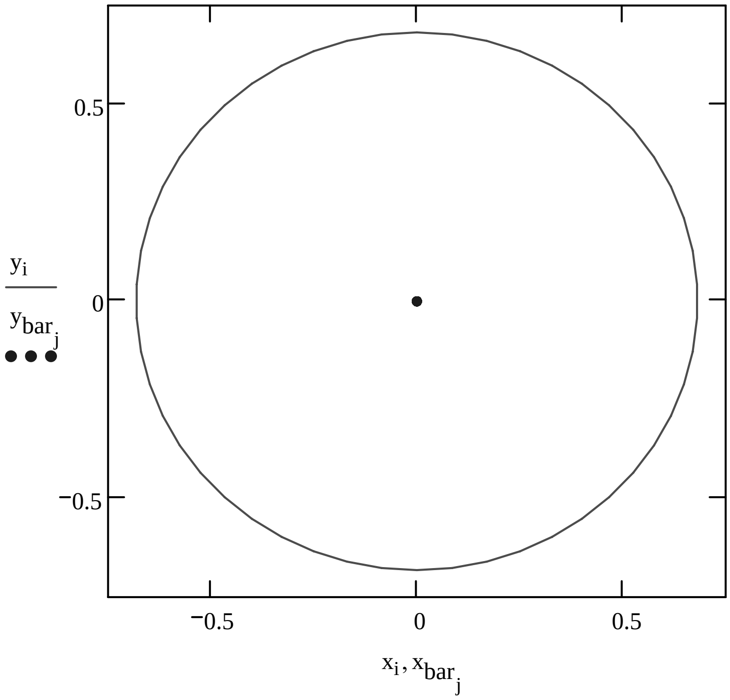
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

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

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 2086252\ mm^2$

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:

$$ts := y_1 - ys_1 \qquad ts = 19\,mm$$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $y_{Epos} := \max(y)$ $y_{Epos} = 681\,mm$

Negative case - determine coord of extreme concrete fiber $y_{Eneg} := \min(y)$ $y_{Eneg} = -681\,mm$

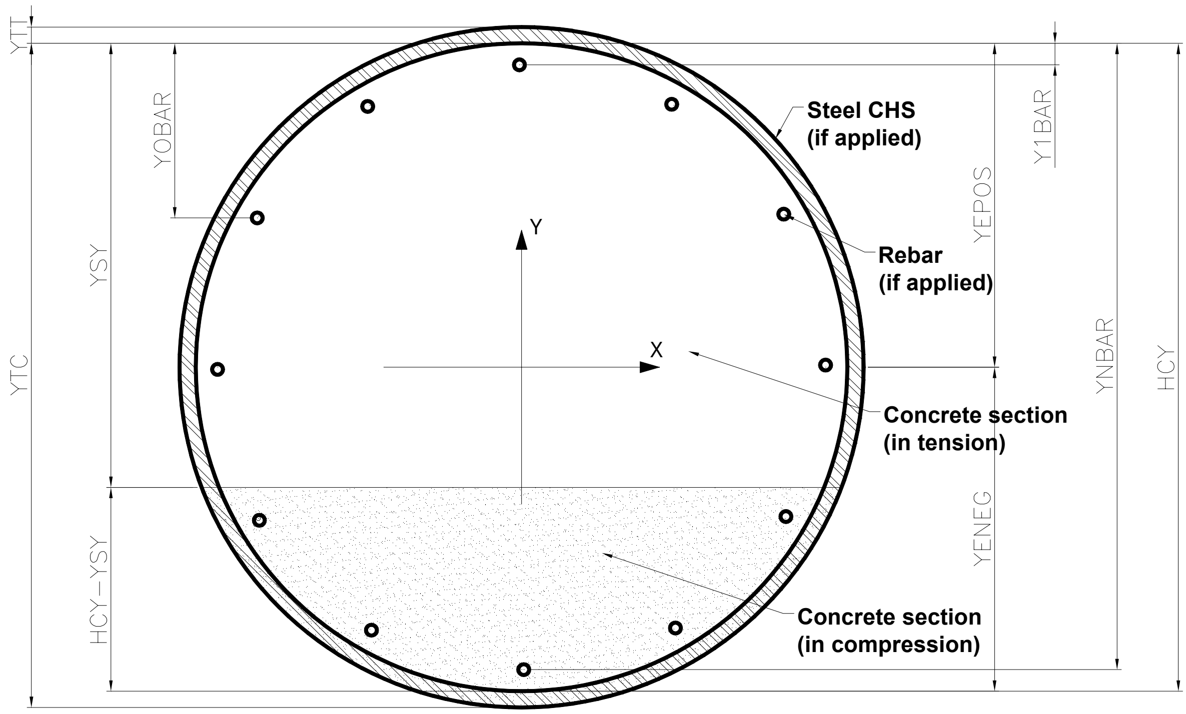
Offsets of rebar from extreme fiber $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $y_{1bar} := \min(y_{Epos} - y_{bar})$ $y_{1bar} = 681\,mm$

Determine most extreme rebar (maximum offset) $y_{nbar} := \max(y_{Epos} - y_{bar})$ $y_{nbar} = 681\,mm$

Offsets of extreme steel tube fiber from extreme concrete fiber $y_{tt} := ts$ $y_{tt} = 19\,mm$

$y_{tc} := H_{CY} + ts$ $y_{tc} = 1381\,mm$



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

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

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

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

Strain at other stresses taken to be linear:

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

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:

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

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

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:

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

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

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

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:

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

$\varepsilon_{cL} = 0.001250$

Limiting concrete stress in axial compression

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

$\sigma_{cL} = 11.14\,\text{MPa}$

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

$P_{MAX} = 36555.8\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

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

$P_{MAXC} = 16182.4\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

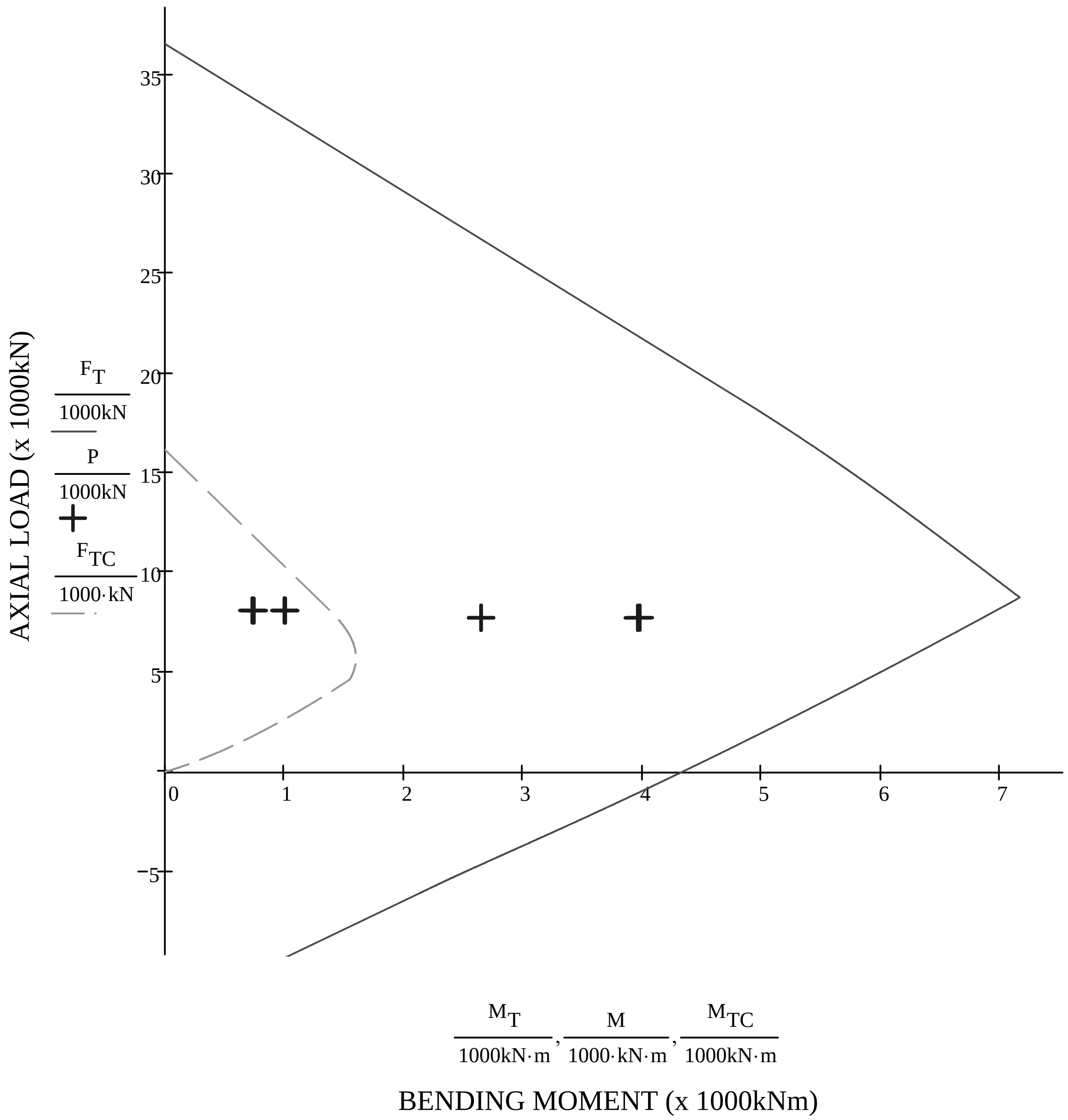
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts}, \varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -12224.1\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

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

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

Diameter of Column	$D = 1362\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 0.00\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 19\,mm$	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)

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

$r := 1 .. 8$

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

$$StressFactor_r := \begin{cases} \text{"No Result"} & \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} & \text{otherwise} \end{cases}$$

$$P = \begin{pmatrix} 7733 \\ 7733 \\ 7739 \\ 7739 \\ 8095 \\ 8095 \\ 8100 \\ 8100 \end{pmatrix} kN \qquad M = \begin{pmatrix} 3963 \\ 2650 \\ 2652 \\ 3980 \\ 1010 \\ 747 \\ 733 \\ 1001 \end{pmatrix} kN \cdot m \qquad M_{SLS} = \begin{pmatrix} 6834.0 \\ 6834.0 \\ 6834.0 \\ 6834.0 \\ 6957.5 \\ 6957.5 \\ 6957.5 \\ 6957.5 \end{pmatrix} kN \cdot m \qquad StressFactor = \begin{pmatrix} 0.580 \\ 0.388 \\ 0.388 \\ 0.582 \\ 0.145 \\ 0.107 \\ 0.105 \\ 0.144 \end{pmatrix}$$

RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1362	mm			
Percentage of rebar			0.00	%			
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	**P4T**	**7733**	**3963**	**6834.0**	**100%**	**58%**	OK
2	**P4T**	**7733**	**2650**	**6834.0**	**100%**	**39%**	OK
3	**P5T**	**7739**	**2652**	**6834.0**	**100%**	**39%**	OK
4	**P5T**	**7739**	**3980**	**6834.0**	**100%**	**58%**	OK
5	**P4B**	**8095**	**1010**	**6957.5**	**100%**	**15%**	OK
6	**P4B**	**8095**	**747**	**6957.5**	**100%**	**11%**	OK
7	**P4T**	**8100**	**733**	**6957.5**	**100%**	**11%**	OK
8	**P4T**	**8100**	**1001**	**6957.5**	**100%**	**14%**	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
1400 mm Dia Composite Column - P4 & P5 Top/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	1362	mm
Thickness of CHS section	t	19	mm
Diameter of rebar - layer 1	dia1	0	mm
Diameter of rebar - layer 2	dia2	0	mm
Number bars - layer 1 (max 100)	n1	0	
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	P4T	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	7733.2	5376.3	140%
2	P4T	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	7733.2	4056.4	140%
3	P5T	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	7738.7	4060.8	140%
4	P5T	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	7738.7	5395.1	140%
5	P4B	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	8094.6	1684.1	140%
6	P4B	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	8094.6	1415.4	140%
7	P5B	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	8100.1	1410.9	140%
8	P5B	Combination 1 - P + (TTD OR TTT) + (TTB or TTR) + Temp+CRSH	8100.1	1674.8	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	-681	26	0	681
2	-85	-676	27	85	676
3	-169	-660	28	169	660
4	-251	-633	29	251	633
5	-328	-597	30	328	597
6	-400	-551	31	400	551
7	-466	-496	32	466	496
8	-525	-434	33	525	434
9	-575	-365	34	575	365
10	-616	-290	35	616	290
11	-648	-210	36	648	210
12	-669	-128	37	669	128
13	-680	-43	38	680	43
14	-680	43	39	680	-43
15	-669	128	40	669	-128
16	-648	210	41	648	-210
17	-616	290	42	616	-290
18	-575	365	43	575	-365
19	-525	434	44	525	-434
20	-466	496	45	466	-496
21	-400	551	46	400	-551
22	-328	597	47	328	-597
23	-251	633	48	251	-633
24	-169	660	49	169	-660
25	-85	676	50	85	-676

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

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

Calculate Section Properties of Concrete Section

$$A_C := -\sum_{i=1}^{n} \left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{2} \right]$$ $A_C = 1.45312\ m^2$

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

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

$$I_x := \sum_{i=1}^{n} \left[\left[\left(x_{i+1} - x_i\right) \cdot \frac{y_{i+1} + y_i}{24} \right] \cdot \left[\left(y_{i+1} + y_i\right)^2 + \left(y_{i+1} - y_i\right)^2 \right] \right]$$ $I_x = 0.16803\ m^4$

$$I_y := -\sum_{i=1}^{n} \left[\left[\left(y_{i+1} - y_i\right) \cdot \frac{x_{i+1} + x_i}{24} \right] \cdot \left[\left(x_{i+1} + x_i\right)^2 + \left(x_{i+1} - x_i\right)^2 \right] \right]$$ $I_y = 0.16803\ m^4$

$$I_{xC} := I_x - A_C \cdot x_C^{\,2}$$ $I_{xC} = 0.16803\ m^4$

$$I_{yC} := I_y - A_C \cdot y_C^{\,2}$$ $I_{yC} = 0.16803\ m^4$

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	-700	**26**	0	-681
2	-181	-676	**27**	176	-658
3	-350	-606	**28**	341	-590
4	-495	-495	**29**	482	-482
5	-606	-350	**30**	590	-341
6	-676	-181	**31**	658	-176
7	-700	0	**32**	681	0
8	-676	181	**33**	658	176
9	-606	350	**34**	590	341
10	-495	495	**35**	482	482
11	-350	606	**36**	341	590
12	-181	676	**37**	176	658
13	0	700	**38**	0	681
14	181	676	**39**	-176	658
15	350	606	**40**	-341	590
16	495	495	**41**	-482	482
17	606	350	**42**	-590	341
18	676	181	**43**	-658	176
19	700	0	**44**	-681	0
20	676	-181	**45**	-658	-176
21	606	-350	**46**	-590	-341
22	495	-495	**47**	-482	-482
23	350	-606	**48**	-341	-590
24	181	-676	**49**	-176	-658
25	0	-700	**50**	0	-681

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

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

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

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

Calculate Section Properties of Steel Tube Section

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

$A_{ST} = 0.08149\ m^2$

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

$x_{ST} = 0.0\ m$

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

$y_{ST} = 0\ m$

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

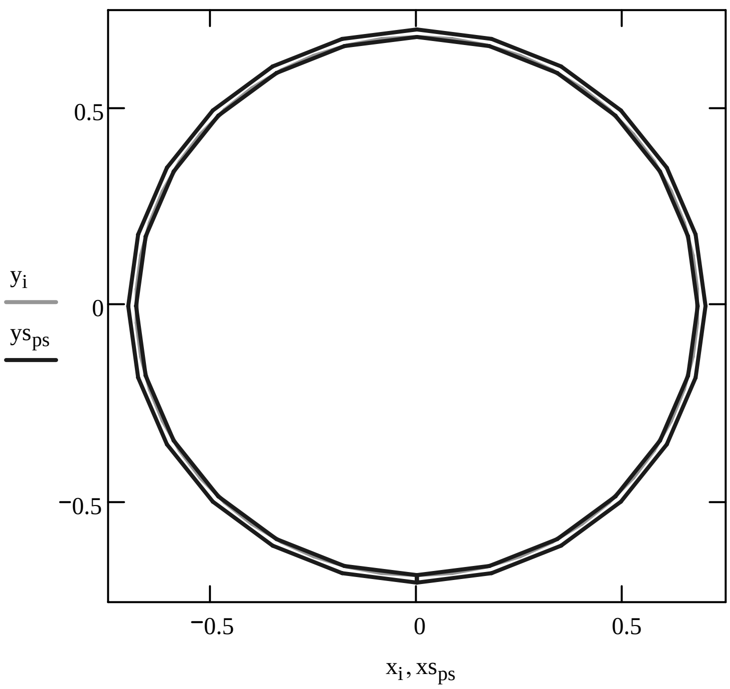
$I_{xS} = 0.01921\ m^4$

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

$I_{yS} = 0.01921\ m^4$

$I_{xS} := I_{xS} - A_{ST}\cdot x_{ST}^2$ — $I_{xS} = 0.01921\ m^4$

$I_{yS} := I_{yS} - A_{ST}\cdot y_{ST}^2$ — $I_{yS} = 0.01921\ m^4$



Rebar Data Layer 1 - 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

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

$$A_{BAR} := \sum_{j=1}^{200} A_{bar_j} \qquad A_{BAR} = 0\,mm^2$$

$$\rho := \frac{A_{BAR}}{A_C} \qquad \rho = 0$$

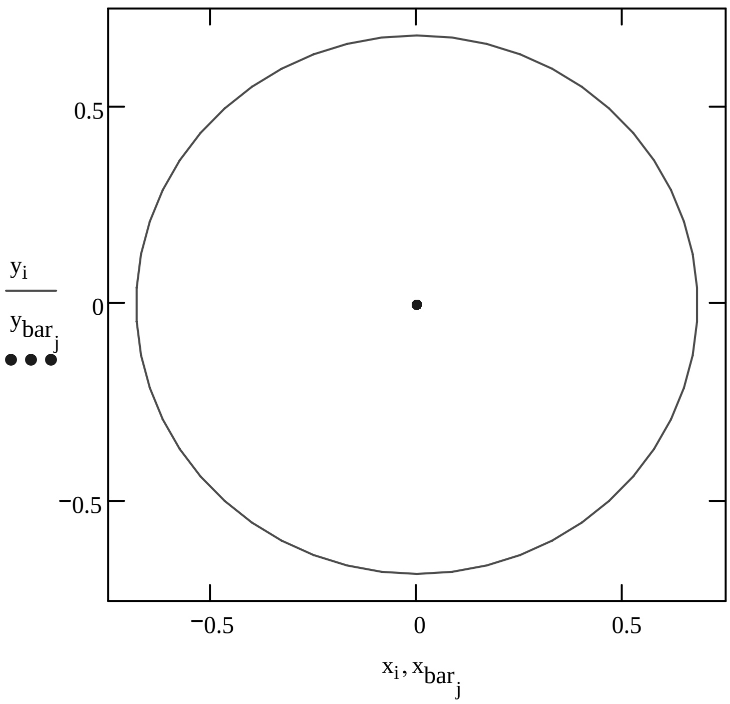
$$x_b := \begin{cases} \left[\sum_{j=1}^{200} \left(A_{bar_j} \cdot x_{bar_j}\right)\right] \cdot \frac{1}{A_{BAR}} & \text{if } A_{BAR} > 0 \\ 0m & \text{otherwise} \end{cases} \qquad x_b = 0\ m$$

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

$$I_{xb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(x_{bar_j}\right)^2\right] + A_{BAR} \cdot x_b^2 \qquad I_{xb} = 0\,m^4$$

$$I_{yb} := \sum_{j=1}^{200} \left[A_{bar_j} \cdot \left(y_{bar_j}\right)^2\right] + A_{BAR} \cdot y_b^2 \qquad I_{yb} = 0\,m^4$$

$j := 1 .. 200$



Calculate Composite Section Properties (before cracking)

Effective area $A_E := A_C \cdot [1 + \rho \cdot (\alpha - 1)] + A_{ST} \cdot \alpha$ $A_E = 2086252 \text{ mm}^2$

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

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

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

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

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

Total depth of concrete section

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

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

Section modulus

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

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

Thickness of steel tube:

$ts := y_1 - ys_1$ $\quad$ $ts = 19\,mm$

Establish Section Dimensions

Positive case - determine coord of extreme concrete fiber $\quad$ $y_{Epos} := \max(y)$ $\quad$ $y_{Epos} = 681\,mm$

Negative case - determine coord of extreme concrete fiber $\quad$ $y_{Eneg} := \min(y)$ $\quad$ $y_{Eneg} = -681\,mm$

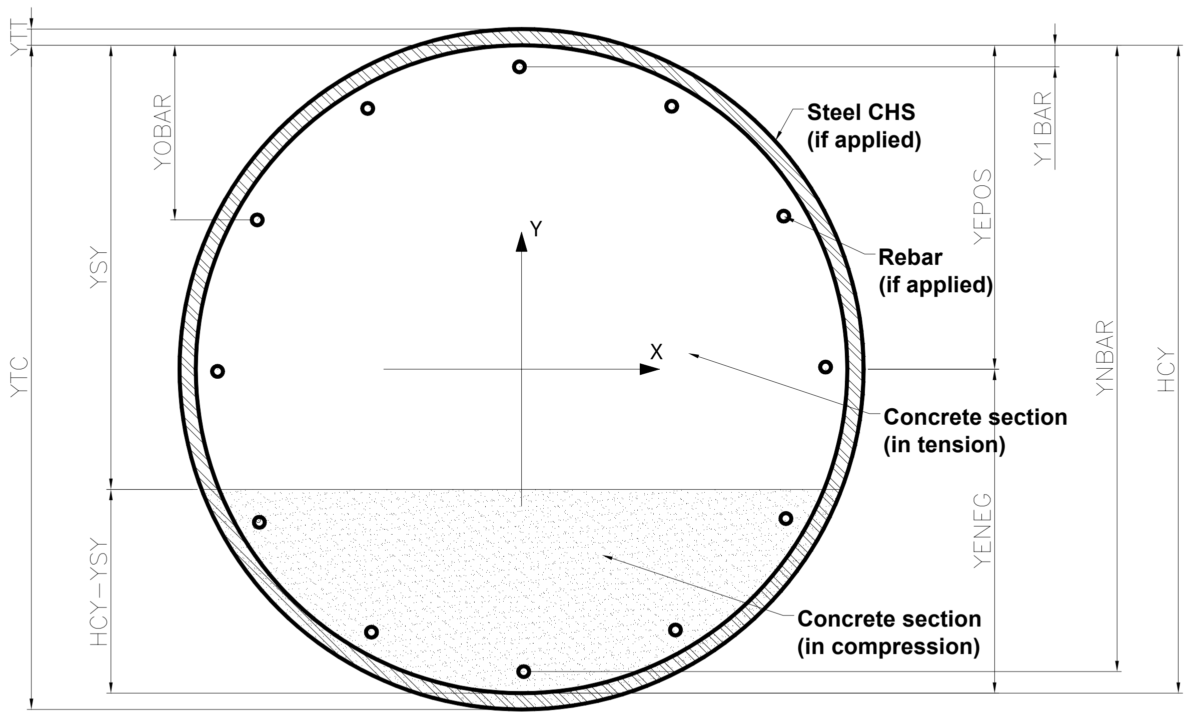
Offsets of rebar from extreme fiber $\quad$ $y_{Obar} := y_{Epos} - y_{bar}$

Determine most extreme rebar (minimum offset) $\quad$ $y_{1bar} := \min(y_{Epos} - y_{bar})$ $\quad$ $y_{1bar} = 681\,mm$

Determine most extreme rebar (maximum offset) $\quad$ $y_{nbar} := \max(y_{Epos} - y_{bar})$ $\quad$ $y_{nbar} = 681\,mm$

Offsets of extreme steel tube fiber from extreme concrete fiber $\quad$ $y_{tt} := ts$ $\quad$ $y_{tt} = 19\,mm$

$y_{tc} := H_{CY} + ts$ $\quad$ $y_{tc} = 1381\,mm$



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

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

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

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

Strain at other stresses taken to be linear:

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

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

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:

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

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

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:

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

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

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

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:

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

$\varepsilon_{cL} = 0.001250$

Limiting concrete stress in axial compression

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

$\sigma_{cL} = 11.14\,\text{MPa}$

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

$P_{MAX} = 36555.8\,\text{kN}$ $\quad F_{T_1} := P_{MAX}$ $\quad M_{T_1} := 0\cdot\text{kN}\cdot\text{m}$

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

$P_{MAXC} = 16182.4\,\text{kN}$ $\quad F_{TC_1} := P_{MAXC}$ $\quad M_{TC_1} := 0\cdot\text{kN}\cdot\text{m}$

CALCULATE MINIMUM ALLOWABLE AXIAL FORCE IN SECTION

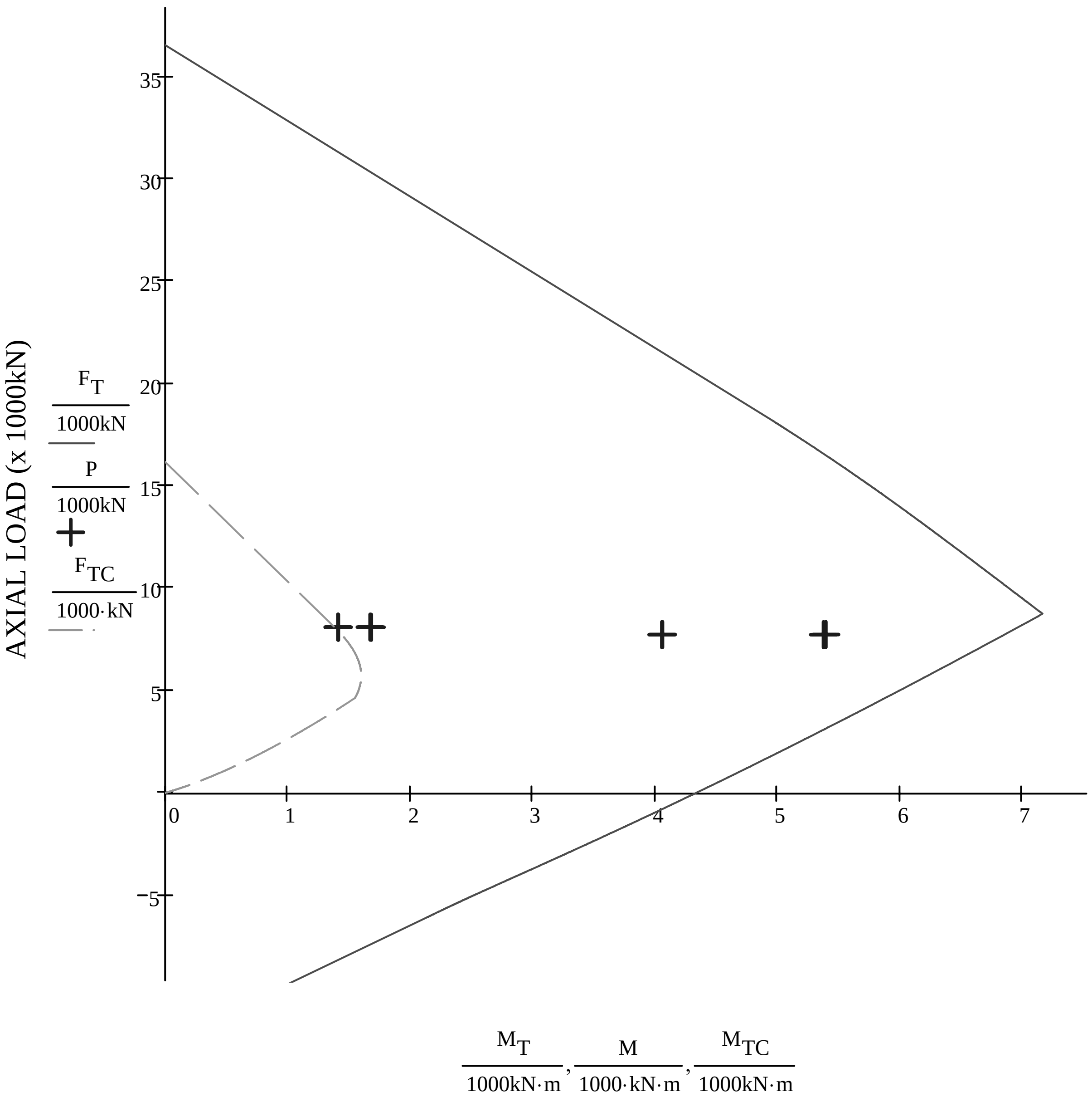
$$P_{MIN} := \begin{cases} \varepsilon_{rs}\cdot E_S(A_{BAR}) & \text{if } ts = 0 \\ \varepsilon_{ts}\cdot E_S(A_{ST}) & \text{if } A_{BAR} = 0 \\ \max(\varepsilon_{ts},\varepsilon_{rs})\cdot E_S(A_{BAR} + A_{ST}) & \text{otherwise} \end{cases}$$

$P_{MIN} = -12224.1\,\text{kN}$ $\quad F_{T_{ns+1}} := P_{MIN}$ $\quad M_{T_{ns+1}} := 0\cdot\text{kN}\cdot\text{m}$

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

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

Diameter of Column	$D = 1362\,mm$	Characteristic strength of concrete	$f_c = 30\,MPa$
Percentage reinforcement	$\rho = 0.00\,\%$	Yield Strength of Rebar	$f_y = 390\,MPa$
Thickness of CHS	$ts = 19\,mm$	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)

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

$r := 1 .. 8$

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

$$StressFactor_r := \begin{cases} \text{"No Result"} & \text{if } M_{SLS_r} < 0.00000000000000001 \cdot kN \cdot m \\ \dfrac{M_r}{M_{SLS_r}} & \text{otherwise} \end{cases}$$

$$P = \begin{pmatrix} 7733 \\ 7733 \\ 7739 \\ 7739 \\ 8095 \\ 8095 \\ 8100 \\ 8100 \end{pmatrix} kN \quad M = \begin{pmatrix} 5376 \\ 4056 \\ 4061 \\ 5395 \\ 1684 \\ 1415 \\ 1411 \\ 1675 \end{pmatrix} kN \cdot m \quad M_{SLS} = \begin{pmatrix} 6834.0 \\ 6834.0 \\ 6834.0 \\ 6834.0 \\ 6957.5 \\ 6957.5 \\ 6957.5 \\ 6957.5 \end{pmatrix} kN \cdot m \quad StressFactor = \begin{pmatrix} 0.787 \\ 0.594 \\ 0.594 \\ 0.789 \\ 0.242 \\ 0.203 \\ 0.203 \\ 0.241 \end{pmatrix}$$

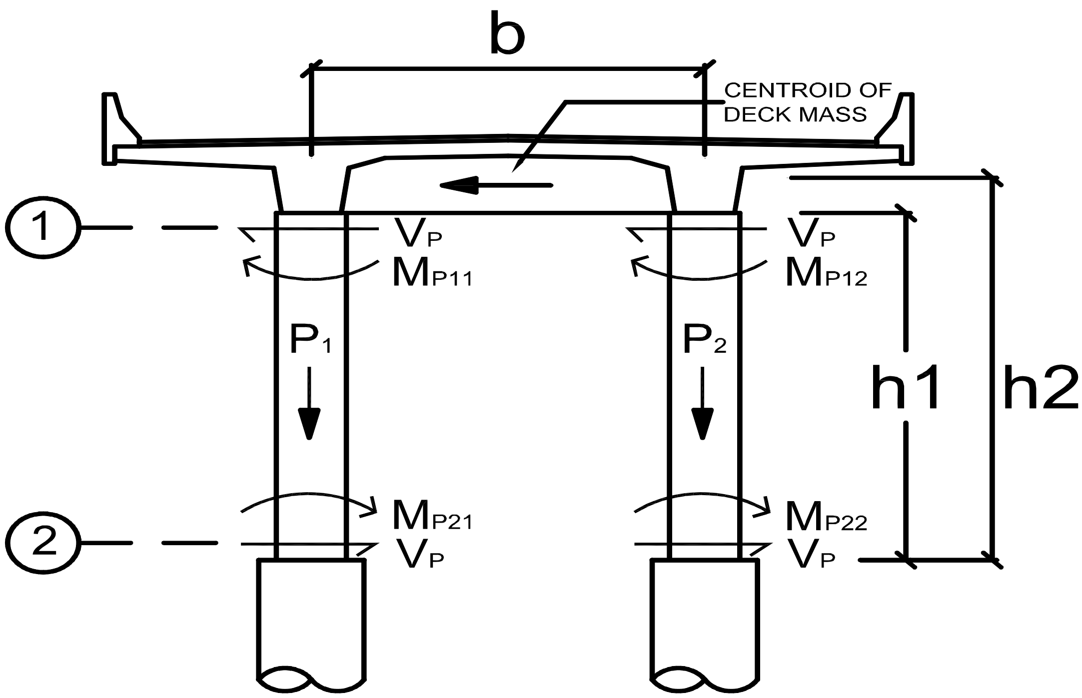
RESULTS SUMMARY
SERVICEABILITY LIMIT STATE ANALYSIS OF CIRCULAR BEAM COLUMN

Diameter of Column			1362	mm			
Percentage of rebar			0.00	%			
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	**P4T**	**7733**	**5376**	**6834.0**	**140%**	**79%**	OK
2	**P4T**	**7733**	**4056**	**6834.0**	**140%**	**59%**	OK
3	**P5T**	**7739**	**4061**	**6834.0**	**140%**	**59%**	OK
4	**P5T**	**7739**	**5395**	**6834.0**	**140%**	**79%**	OK
5	**P4B**	**8095**	**1684**	**6957.5**	**140%**	**24%**	OK
6	**P4B**	**8095**	**1415**	**6957.5**	**140%**	**20%**	OK
7	**P5B**	**8100**	**1411**	**6957.5**	**140%**	**20%**	OK
8	**P5B**	**8100**	**1675**	**6957.5**	**140%**	**24%**	OK

7.2. PLASTIC HINGING DEMAND ON SUPERSTRUCTURE AND FOUNDATIONS

RC TWIN COLUMN

PLASTIC HINGING EFFECTS AT TWIN COLUMN PIER



In the parallel direction with plane of portal, design forces due to plastic hinging are calculated as follows:

- Design of longitudinal reinforcement based on the design moment obtained based on requirements in design force for structure component and joint.
- Calculate plastic moment obtained based on both end of column section with a strength reduction factor is 1.3 for reinforced concrete and 1.25 for structural steel.
- Calculate design shear force on column based on plastic moment capacity.
- Determined total shear force placed to act on center of mass of superstructure, then calculate design axial force in the portal due to overturning.
- Using the design axial forces in the portal combined with dead load, determine the revised column overstrength plastic moments. With the revised plastic moments calculate the column shear forces and the maximum shear force on the portal. If the maximum shear force for the portal is not within 10% of the value previously determined, use the maximum portal shear force to recalculate axial force and plastic moments.

TABLE: Element Forces - Plastic Hinging

Frame	h1 m	h2 m	b m	Trial	P1 kN	P2 kN	MP11 kN-m	MP12 kN-m	MP21 kN-m	MP22 kN-m	VP kN	∆ P kN
P1	**7.029**	7.909	6.0	1st	2439.9	2440.3	5596.5	5596.5	3209.7	3209.7	1252.8	3302.9
				2nd	5742.8	-862.6	6362.2	4485.0	4218.5	1714.7	1193.7	3146.9
				3rd	5586.8	-706.6	6334.9	4542.2	4182.1	1800.5	1199.3	3161.7
				Test							OK	
P2	**7.029**	7.909	6.0	1st	2652.0	2653.1	5656.3	5656.3	3292.9	3294.2	1273.3	3356.8
				2nd	6008.8	-703.7	6407.7	4543.5	4280.9	1801.8	1211.7	3194.4
				3rd	5846.4	-541.3	6381.7	4602.0	4243.2	1888.9	1217.5	3209.8
				Test							OK	
P6	**6.25**	7.75	6.0	1st	2300.9	2281.8	4804.8	4799.6	3155.1	3147.3	1272.5	3287.4
				2nd	5588.3	-1005.6	5619.9	3552.9	4182.1	1636.7	1199.3	3098.3
				3rd	5399.2	-816.5	5584.8	3637.4	4135.3	1740.7	1207.9	3120.3
				Test							OK	
P7	**8**	8.88	6.0	1st	2678.6	2281.8	6806.8	6713.2	3432.0	3281.2	1264.6	3743.1
				2nd	6421.7	-1461.3	7462.0	5556.2	4479.8	1554.8	1190.8	3524.8
				3rd	6203.4	-1243.0	7436.0	5632.9	4434.3	1670.5	1198.4	3547.1
				Test							OK	
P8	**7**	7.88	6.0	1st	2298.8	2338.1	4804.8	4815.2	3153.8	3169.4	1138.8	2991.2
				2nd	5290.0	-653.1	5565.3	3710.2	4108.0	1829.1	1086.6	2854.2
				3rd	5153.0	-516.1	5538.0	3770.0	4072.9	1901.9	1091.6	2867.3
				Test							OK	
P9	**7**	7.88	6.0	1st	2491.5	2502.7	5610.8	5614.7	3230.5	3234.4	1263.6	3319.1
				2nd	5810.6	-816.4	6375.2	4501.9	4235.4	1740.7	1203.8	3162.0
				3rd	5653.5	-659.3	6346.6	4559.1	4197.7	1825.2	1209.2	3176.1
				Test							OK	

NOTES:

1 Plastic hinging determined based on the following reinforcement provisions:

Pier	Top	Base
P1	2.50%	1.00%
P2	2.50%	1.00%
P6	2.00%	1.00%
P7	3.25%	1.08%
P8	2.00%	1.00%
P9	2.50%	1.00%

2 Plastic hinge moments obtained using PCACol with strength reduction factors set to 1.0
Results then increased by a factor of 1.3 in the tabulations above.

RC COLUMN TWIN COLUMN PIER - PLASTIC HINGE EFFECTS
SUMMARY OF RESULTS

LOCATION PIER TOP - LOADING DECK

Pier	Transverse Case Axial Load kN max	Transverse Case Axial Load kN min	Transverse Case Moment kNm	Transverse Case Shear kN	Longitudinal Case Moment kNm	Longitudinal Case Shear kN
P1	5586.8	-706.6	6334.9	1199.3	5596.5	1252.8
P2	5846.4	-541.3	6381.7	1217.5	5656.3	1273.3
P6	5399.2	-816.5	5584.8	1207.9	4804.8	1272.5
P7	6203.4	-1243.0	7436.0	1198.4	6806.8	1264.6
P8	5153.0	-516.1	5538.0	1091.6	4815.2	1138.8
P9	5653.5	-659.3	6346.6	1209.2	5614.7	1263.6

LOCATION PIER BASE - LOADING PILES

Pier	Transverse Case Axial Load kN max	Transverse Case Axial Load kN min	Transverse Case Moment kNm	Transverse Case Shear kN	Longitudinal Case Moment kNm	Longitudinal Case Shear kN
P1	5586.8	-862.6	4182.1	1199.3	3209.7	1252.8
P2	5846.4	-541.3	4243.2	1217.5	3292.9	1273.3
P6	5399.2	-1005.6	4135.3	1207.9	3155.1	1272.5
P7	6203.4	-1461.3	4072.9	1198.4	3432.0	1264.6
P8	5153.0	-653.1	4072.9	1091.6	3153.8	1138.8
P9	5653.5	-816.4	4197.7	1209.2	3230.5	1263.6

RC SINGLE COLUMN

PLASTIC HINGING EFFECTS AT SINGLE COLUMN PIER

RC Column 1700 mm Diameter

TABLE: Element Forces - Plastic Hinging					
Frame	**h1** m	**P** kN	**MP2** kN-m	**MP1** kN-m	**VP** kN
P3	**5.662**	4451.8	14789.0	0.0	2612.0

Note:

1 MP1 Plastic Moment at Top of Column
MP2 Plastic Moment at Base of Column
VP Shear Force due to Plastic Hinging

2 Plastic hinge moments obtained from direct calculation using strength reduction factors set to 1.3 for concrete and 1.25 for structural steel

COMPOSITE SINGLE COLUMN

PLASTIC HINGING EFFECTS AT SINGLE COLUMN PIER

Thickness of CHS = 19 mm

TABLE: Element Forces - Plastic Hinging					
Frame	**h1** m	**P** kN	**MP2** kN-m	**MP1** kN-m	**VP** kN
~~P3~~	~~5.662~~	~~4451.8~~	~~15612.0~~	~~0.0~~	~~2757.3~~
P4	6.9	6743.7	16387.0	16387.0	4749.9
P5	6.9	6749.6	16389.0	16389.0	4750.4

Note:

1. MP1 Plastic Moment at Top of Column
   MP2 Plastic Moment at Base of Column
   VP Shear Force due to Plastic Hinging

2. Plastic hinge moments obtained from direct calculation using strength reduction factors set to 1.3 for concrete and 1.25 for structural steel

7.3. SHEAR DESIGN OF COLUMNS

7.3.1. RC COLUMNS

Notes on Shear Design – Reinforced Concrete

(1) General Design Provisions (AASHTO LRFD Article 5.8.3)

The nominal shear resistance, V_n, shall be determined as the lesser of:

$$V_n = V_c + V_s$$

$$V_n = 0.25 \cdot f_c^{'} \cdot b_v \cdot d_v$$

in which:

$V_c = 0.083 \cdot \beta \cdot \sqrt{f_c^{'}} \cdot b_v \cdot d_v = 0.166 \cdot \sqrt{f_c^{'}} \cdot b_v \cdot d_v$ in the case of reinforced concrete

$V_s = \dfrac{A_v \cdot f_y \cdot d_v \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}{s} = \dfrac{A_v \cdot f_y \cdot d_v}{s}$ in the case of θ = 45° and α = 90°

where:

b_v = effective web width (mm)

d_v = effective shear depth (mm)

s = spacing of stirrups (mm)

β = factor indicating ability of diagonally cracked concrete to transmit tension
(for reinforced concrete β may be taken as 2.0)

θ = angle of inclination of transverse reinforcement to longitudinal axis
(for reinforced concrete θ may be taken as 45°)

α = angle of inclination of transverse reinforcement to longitudinal axis
(for orthogonal reinforcement α = 90°)

A_v = area of shear reinforcement within a distance s (mm^2)

For the case of circular members, d_v can be determined as follows:

$$d_v = 0.9 \cdot d_e$$

where:

$$d_e = \frac{D}{2} + \frac{D_r}{\pi}$$

where:

D = external diameter of the circular member (mm)

D_r = diameter of the circle passing through the centers of the longitudinal Reinforcement

See figure below for an illustration of the above.

Circular members usually have the longitudinal reinforcement uniformly distributed around the perimeter of the section. When the member cracks, the highest shear stresses typically occur near the middepth of the section. It is for this reason that the effective web width can be taken as the diameter of the section.

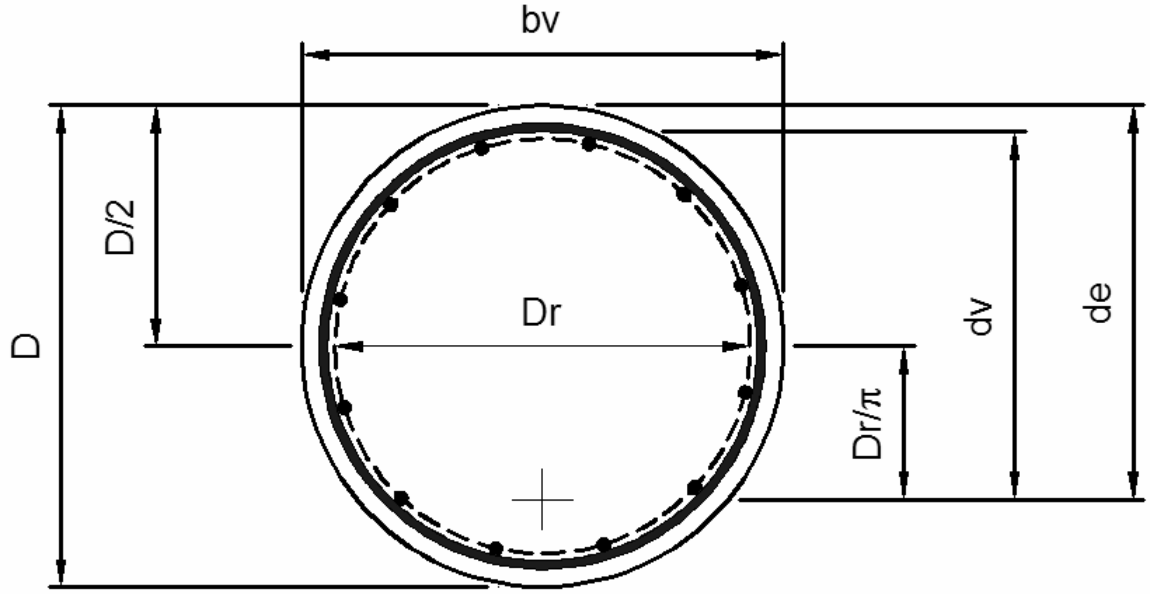


Illustration of terms bv, dv and de for Circular Sections

(2) Provisions for Seismic Design (AASHTO LRFD Article 5.10.11.4.1c)

The following provisions shall apply to the end regions of the top and bottom of the column:

- In the end regions, V_c, shall be taken as that specified in (1) above provided that the minimum axial factored compression force exceeds $0.10 \cdot f_c^{'} \cdot A_g$. For compression forces less than $0.10 \cdot f_c^{'} \cdot A_g$, V_c shall be taken to decrease linearly from the value given in (1) above to zero at zero compression force.
- The end regions shall be assumed to extend from the soffit of girders or cap beams at the top of columns or from the top of foundations at the bottom of columns, a distance taken as the greater of:
    - The maximum cross-sectional dimension of the column
    - One-sixth (1/6) of the clear height of the column, or
    - 450mm

(3) Transverse reinforcement for Confinement of Plastic Hinges (Design Criteria)

The cores of columns shall be sufficient confined by spiral or ties in the expected plastic hinge regions at the top and bottom of columns.

The transverse reinforcement for confinement shall have a yield strength not more than that of the longitudinal reinforcement.

The volumetric ratio of spiral reinforcement for a circular column shall be not less than as follows:

$$\rho_s = 0.45\left(\frac{A_g}{A_c} - 1\right)\frac{f_c^{'}}{f_{yh}} \text{ or } \rho_s = 0.12\frac{f_c^{'}}{f_{yh}}$$

whichever is greater.

where:

Ac = area of column core measured to the outside of the transverse spiral reinforcement

Ag = gross area of column

fc' = specified compressive strength of concrete

f_{yh} = yields strength of hoop or spiral reinforcement

ρ_s = ratio at volume of spiral reinforcement to total volume of concrete core.

Transverse hoop reinforcement may be provided by single or overlapping hoops or cross-ties. A crosstie is a continuous bar having a hook of not less than 135^0 with an extension of not less than six – diameters (but not less than 75 mm) at one end and a hook of not less than 90^0 with extension of not less than six – diameters at the other end.

Outside of the end region the volumetric ratio of spiral reinforcement for a circular column shall be not less than as follows:

$$\rho_s = 0.45\left(\frac{A_g}{A_c} - 1\right)\frac{f_c^{'}}{f_{yh}}$$

Within plastic hinge zones, splices in spiral reinforcement shall be made by full-welded splices.

(4) Spacing of transverse reinforcement for confinement (AASHTO LRFD Article 5.10.11.4.1e)

Transverse reinforcement for confinement shall be:

- Provided at the top and bottom of the column over a length not less than the greatest of the maximum cross-sectional column dimensions, one-sixth of the clear height of the column, or 450mm;
- Extended into the top and bottom connections as follows:
    - o The development length for all longitudinal steel shall be 1.25 times that required for the full yield strength of reinforcing
    - o Transverse reinforcement shall be continued for a distance not less than one-half the maximum column dimension or 380 mm from the face of the column connection into the adjoining member
- The maximum spacing for reinforcement shall not exceed the smaller of one- quarter of the minimum member dimension or 100 mm. Lapping of spiral reinforcement in the transverse confinement region shall not be permitted.

(5) Splices (AASHTO LRFD Article 5.10.11.4.1f)

Lap splices shall be permitted only within the center half of column height

The splices length shall not be less than 400 mm or 60 bar diameter, whichever is greater.

The maximum spacing of the transverse reinforcement over the length of the splice shall not exceed the smaller one-quarter of the minimum member dimension or 100 mm.

Full-welded or full-mechanical splices may be used provided that not more than alternate bars in each layer of longitudinal reinforcement are spliced at a section and the distance between splices of adjacent bars shall be greater than 600 mm.

(6) Requirements for Wall-Type Piers (AASHTO LRFD Article 5.10.11.4.2)

The provisions herein specified shall apply to the design for the strong direction of a pier.

The minimum reinforcement ratio, both horizontally ρ_h and vertically ρ_v in any pier shall not be less than 0.0025. The vertical reinforcement ratio shall not be less than the horizontal reinforcement ratio.

Reinforcement spacing, either horizontally or vertically, shall not exceed 450mm. The reinforcement required for shear shall be continuous and shall be distributed uniformly.

The factored shear resistance, V_r, in the pier shall be taken as the lesser of:

$V_r = 0.66\sqrt{f_c^{'}}bd$, and

$V_r = \phi V_n$

in which:

$$V_n = \left[0.165\sqrt{f_c^{'}} + \rho_h \cdot f_y\right] \cdot bd$$

Horizontal and vertical layers of reinforcement should be provided on each face of a pier. Splices in horizontal pier reinforcement shall be staggered, and splices in the two layers shall not occur at the same location.

TABLE: Ultimate Shear Capacity - Frames													
Column	Height	End Region Length	Vp PLASTIC HINGE SHEAR	P MIN AXIAL	Region	Vc factor	dv	Vc	Vs Required	Check Vc+Vs Limits	Link diameter	Required link spacing s	Design link spacing sd
Text	m	mm	KN	KN			mm	KN	KN		mm	mm	mm
P1	7.029	1289	1253	-707	End	0.00	767	0	1790	OK	19	95	**75**
					Center	1.00		767	1023	OK	19	166	**125**
P2	7.029	1172	1218	-541	End	0.00	767	0	1739	OK	19	97	***75***
					Center	1.00		767	973	OK	19	174	***150***
P6	6.250	1146	1208	-816	End	0.00	767	0	1726	OK	19	98	**75**
					Center	1.00		767	959	OK	19	177	**150**
P7	8.000	1467	1198	-1243	End	0.00	767	0	1712	OK	19	99	**75**
					Center	1.00		767	945	OK	19	179	**150**
P8	7.000	1167	1092	-516	End	0.00	767	0	1559	OK	19	109	**100**
					Center	1.00		767	793	OK	19	214	**150**
P9	7.000	1167	1209	-659	End	0.00	767	0	1727	OK	19	98	**75**
					Center	1.00		767	961	OK	19	176	**150**

f_c =	30	MPa
f_{yh} =	390	MPa
ϕ =	0.70	Strength Reduction Factor
D =	1100	mm
D_r =	948	mm

TABLE: Ultimate Shear Capacity - Frames

Column	Height	End Region Length	Vp PLASTIC HINGE SHEAR	P MIN AXIAL	Region	Vc factor	dv	Vc	Vs Required	Check Vc+Vs Limits	Link diameter	Required link spacing s	Design link spacing sd
Text	m	mm	KN	KN			mm	KN	KN		mm	mm	mm
P3	5.662	1700	2612	4452	End	0.65	1208	1221	2510	OK	19	106	**100**
					Center	1.00		1868	1863	OK	19	143	**125**

f_c = 30 MPa
f_{yh} = 390 MPa
ϕ = 0.70 Strength Reduction Factor
D = 1700 mm
D_r = 1548 mm

MINIMUM TRANVERSE SHEAR LINK REQUIREMENTS

AT END REGION (PLASTIC HINGE LOCATION)

For 1700 mm diameter column with 40 mm cover shall be not less than :

$$\rho_s := 0.45\left(\frac{A_g}{A_c} - 1\right)\cdot\frac{f_c}{f_{yh}} \qquad \rho_s = 0.0016883$$

OR

$$\rho_s := 0.12\frac{f_c}{f_{yh}} \qquad \rho_s = 0.009231$$

Given a minimum spriral link provision of 16 mm diameter at 100 mm spacing
Volumetric ratio of spiral reinforcement provided is : 0.0105

AT CENTER REGIONS

$$\rho_s := 0.45\left(\frac{A_g}{A_c} - 1\right)\cdot\frac{f_c}{f_{yh}} \qquad \rho_s = 0.0016883$$

7.3.2. COMPOSITE COLUMNS

Notes on Shear Design – Composite Columns

(1) Nominal Shear Resistance of Composite Members (AASHTO LRFD Article 6.12.3.2 and Australian Standard AS 5100 Article 5.10.4 and Article 5.11.3)

According to AASHTO LRFD the nominal shear resistance of a composite concrete filled tube may be taken as:

V_n = nominal shear resistance of the steel tube alone

The AASHTO LRFD code is silent regarding the determination of nominal shear resistance of steel tubes.

Australian Standard AS 5100 gives specific provisions for the nominal shear yield capacity of a circular hollow section as follows:

$$V_w = 0.36 \cdot F_y \cdot A_e$$

where

F_y = specified minimum yield strength of the structural steel (MPa)

A_e = effective area of the cross-section (mm^2)

In addition AS 5100 requires that the capacity reduction factor for webs in shear:

ϕ = 0.9

In the presence of bending moment, when the bending moment is assumed to be resisted by the whole cross-section, the member shall be designed for combined bending and shear and shall satisfy:

$$V^* \le \phi \cdot V_{vw}$$

where:

$$V_{vw} = V_w \cdot \left[2.2 - \left(\frac{1.6 \cdot M^*}{M_s} \right) \right]$$

V^* = Design shear force at the section

V_{vm} = Nominal shear capacity of a web in the presence of bending moment

M^* = Design bending moment

M_s = Nominal section moment capacity

In the extreme the design bending moment $M^* = \phi M_s$. and taking ϕ = 0.9 (the maximum strength reduction factor for the steel component used in the moment capacity design of composite columns) gives the following:

$$V_{vw} = V_w \cdot \left[2.2 - \left(\frac{1.6 \cdot \phi M_s}{M_s} \right) \right] = V_w \cdot [2.2 - 1.6 \times 0.9] = 0.76 \cdot V_w$$

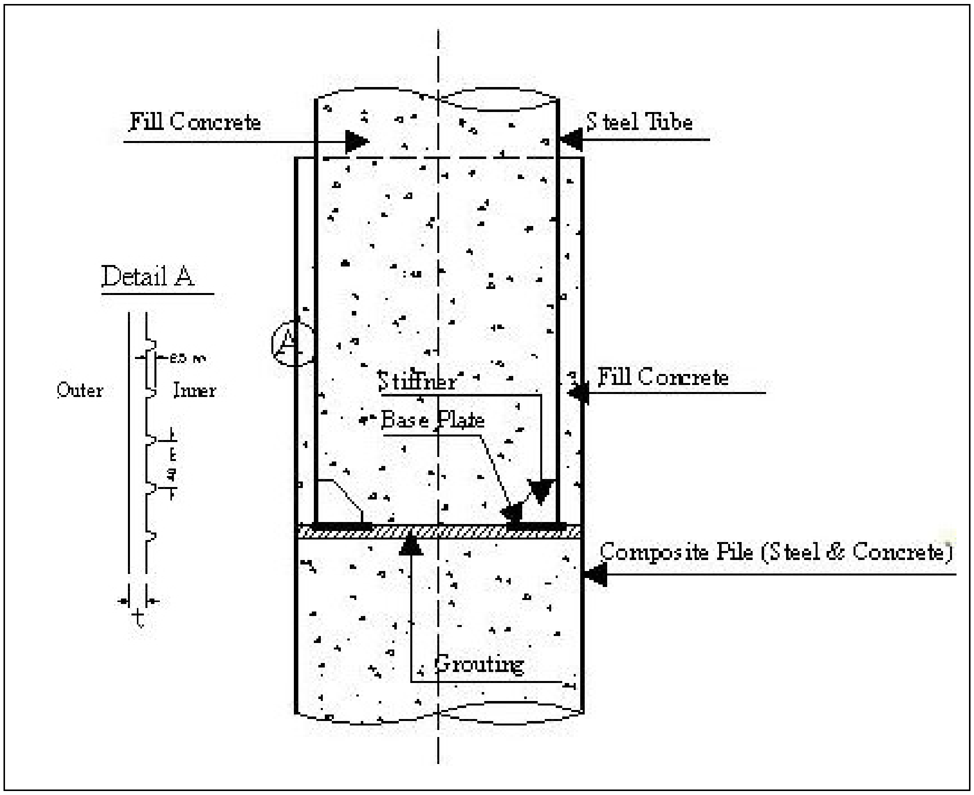
The member shall therefore be designed to satisfy the following:

$$V^* \le \phi \cdot 0.76 \cdot V_w = 0.24 \cdot F_y \cdot A_e$$

(2) Column-Pile Joints Made of Steel Pipes Filled with Concrete

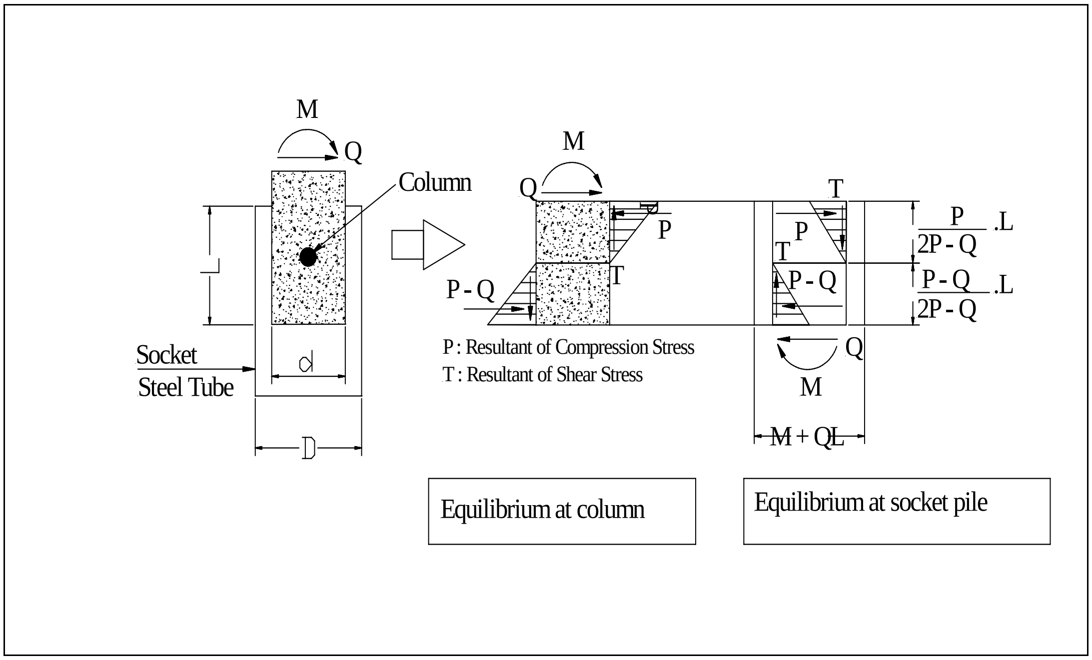
For the connection of composite columns to single large diameter bored pile foundation a socket type connection will be adopted. Socket type connections comprise the insertion of the composite column section into a larger diameter steel pipe pile with concrete filled between them. The arrangement has been tested in Japan and is approved by both JRA and Japan Railway Company.

A typical socket type connection is shown below.



TYPICAL SOCKET TYPE CONNECTION

The load carrying model for predicting the ultimate load capacity of the socket type connection is shown in the figure on the following page.



LOAD CARRYING MODEL FOR PREDICTING ULTIMATE LOAD CAPACITY

Proposed Method for Prediction of Ultimate Load Capacity of Connection

1) Balance of Moment

$$M - T \cdot \left(\frac{2\sqrt{2}}{\pi} \right) \cdot d = -\frac{LP^2}{3 \cdot (2P - Q)} + (P - Q) \cdot \frac{L \cdot (5P - 2Q)}{3 \cdot (2P - Q)} \quad \text{..........................(1)}$$

where M and Q are bending moment and shear force applied to the column respectively, and P and T are resultant forces of bearing pressure and frictional stresses developed on the column respectively. In the above equation, the friction is assumed to be developed on one-fourth the circumference of column on tensile and compressive sides respectively.

2) Frictional force at ultimate states

The frictional stresses developed between the column pipe and the concrete filled pipe pile are assumed to be subject to Coulomb's friction criteria. That is:

$$\tau_{\max} = c + \sigma_n \cdot \tan\phi \quad \text{..(2)}$$

where:

$\tau_{\max}$ = maximum frictional stress
c = cohesion of friction
σ_n = normal stress at interface
ϕ = friction angle

For the calculations, the cohesion c and friction angle ϕ are assumed as follows:

c = 0.7N/mm^2 ϕ = 20 degree for ordinary pipe
c = 8.0N/mm^2 ϕ = 0 degree for pipes with spiral ribs

Then, a resultant force of frictional stresses T is described as follows:

$$T = c\frac{\pi}{4}dL\frac{P-Q}{2P-Q} + \frac{\pi}{2\sqrt{2}}(P-Q)\tan\phi \text{ ....(3)}$$

3) Bearing pressure at ultimate states

The bearing pressure developed on the column is assumed to be determined by shear capacities of the shear panels which consist of the pile pipe and annular concrete in the overlapped part with length L. Therefore, the bearing pressure is described as follows:

$$P = V_s + V_c \text{ ....(4)}$$

where V_s is the shear capacity of the steel pipe and V_c is the shear capacity of the annular concrete.

The shear capacity of the steel pipe is calculated as follows:

$$V_s = f_y \cdot 2t \cdot \frac{D'}{\sqrt{\left(\frac{2}{3}L\right)^2 + \left(D'\right)^2}}\left(\frac{2}{3}L\right) \text{ ....(5)}$$

where $D' = \frac{\pi}{4}D$

The shear capacity of the concrete annulus is given by:

$$V_c = \frac{3\sqrt{2}}{\pi}\frac{D}{L}\left\{\frac{\pi}{4}D \cdot \left[L - {(D-d)}/{2}\right] \cdot c - \frac{\pi}{4}d\frac{L}{2}c\right\} \text{ ....(6)}$$

Consequently, the ultimate load can be calculated by solving equation (1) after substituting (3), (4), (5) and (6) into (1).

TABLE: Ultimate Shear Capacity - Frames

Column	Diameter of Concrete Section	CHS thickness	Effective Area of CHS Ae	Nominal Shear Capacity V_{vw}	Factored Shear Capacity ϕV_{vw}	Applied Shear Force V^*	Capacity Result
Text	mm	mm	mm^2	KN	KN	KN	
~~P3~~	~~1400~~	~~18~~	~~79168~~	~~5090~~	~~4581~~	~~2648~~	~~OK~~
P4	1400	19	83566	5373	4836	4560	OK
P5	1400	19	83566	5373	4836	4561	OK

F_y = 235 Minimum Yield Strength of Structural Steel MPa

ϕ = 0.90 Strength Reduction Factor

$V_{vw} = 0.76\, V_w$ Nominal shear capacity in the presence of bending moment

$V_w = 0.36\, F_y\, A_e$ Nominal shear yield capacity

$V^* \leq \phi\, V_{vw}$

KATAHIRA & ENGINEERS INTERNATIONAL

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

Calculation: **Detailed Design**
COMPOSITE COLUMN SOCKET CONNECTION TO PILE

Reference : **"Column-Pile Joints Made of Steel Pipes Filled with Concrete" Takano et al. Fourth World Congress on Joint Sealing and Bearing Systems for Concrete Structures**

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Input Data

Plastic Hinge Effects - Moment $M := 17000 \cdot kN \cdot m$

Shear Force $Q := 5000 \cdot kN$

Diameter of column $d := 1400 \cdot mm$

Diameter of pile $D := 2500 \cdot mm$

Length of embedment of column $L := 4.0m$

Thickness of pile pipe $t := 13 \cdot mm$

Characteristic yield strength of steel pipe $f_y := 235 \cdot MPa$

Ordinary pipe shear characteristics $c := 0.7 \cdot \frac{N}{mm^2}$ $\phi := 20 \cdot deg$

Shear capacity of pipe pile: $D_1 := \frac{\pi}{4} \cdot D$

$$V_s := f_y \cdot 2 \cdot t \cdot \frac{D_1}{\sqrt{\left(\frac{2}{3} \cdot L\right)^2 + D_1^{\,2}}} \cdot \left(\frac{2}{3} \cdot L\right) \qquad V_s = 9661\,kN$$

Shear capacity of concrete:

$$V_c := \frac{3 \cdot \sqrt{2}}{\pi} \cdot \frac{D}{L} \cdot \left[\frac{\pi}{4} \cdot D \cdot \left(L - \frac{D-d}{2}\right) \cdot c - \frac{\pi}{4} \cdot d \cdot \frac{L}{2} \cdot c\right] \qquad V_c = 2703\,kN$$

Bearing pressure at ultimate state

$$P := V_s + V_c \qquad P = 12364\,kN$$

Frictional force at ultimate limit state

$$T := c\cdot\frac{\pi}{4}\cdot d\cdot L\cdot\frac{P - Q}{2P - Q} + \frac{\pi}{2\cdot\sqrt{2}}\cdot(P - Q)\cdot\tan(\phi) \qquad T = 4126\,kN$$

Moment capacity of joint:

$$M_U := T\cdot\left(\frac{2\cdot\sqrt{2}}{\pi}\right)\cdot d - \frac{L\cdot P^2}{3\cdot(2\cdot P - Q)} + (P - Q)\cdot\frac{L\cdot(5\cdot P - 2\cdot Q)}{3(2P - Q)}$$

$$M_U = 20659\,kN\cdot m$$

Check capacity of joint against demand

$$CapacityCheck := \begin{cases} \text{"OK"} & \text{if } M_U \ge M \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

CapacityCheck = "OK"

CONCLUSION - 4m LONG SOCKET CONNECTION IS ADEQUATE

		Pile Diameter (mm)			
		1100	**1400**	**1700**	
A_g	mm^2	950332	1539380	2269801	
A_c	mm^2	708822	1227185	1886919	
ρ**(1)**		0.0118	0.0088	0.0070	
ρ**(2)**		0.0092	0.0092	0.0092	
ρ_s		**0.0118**	**0.0092**	**0.0092**	
		Required Steel Volume (mm^3)			
s(mm) =	75	840627	1065725	1571400	(Plastic Hinge Zone)
		Spiral Steel Volume (mm^3)			
d_b(mm) =	19	829271	1096491	1363710	
		Required ∅16mm Tie Steel Volume (mm^3)			
st (mm) =	150	22712	0	415380	(Plastic Hinge Zone)
st (mm) =	300	45425	0	830760	(Plastic Hinge Zone)
		Required Number of ∅16mmTies			
st (mm) =	150	0	0	2	(Plastic Hinge Zone)
st (mm) =	300	0	0	3	(Plastic Hinge Zone)

Note:

ρ**(1)** $$\rho_s = 0.45\left(\frac{A_g}{A_c} - 1\right)\frac{f_c'}{f_{yh}}$$

ρ**(2)** $$\rho_s = 0.12\frac{f_c'}{f_{yh}}$$

cover = 75 mm

f_c = 30 Mpa

f_y = 390 Mpa

s = spiral link spacing

st = tie link spacing

Take tie bar length to be 75% of pile diameter