REFERENCES	CALCULATIONS	RESULTS

MEMBER #1 (SECTION POSITION 0.0 mm) BEAM DESIGN REPORT

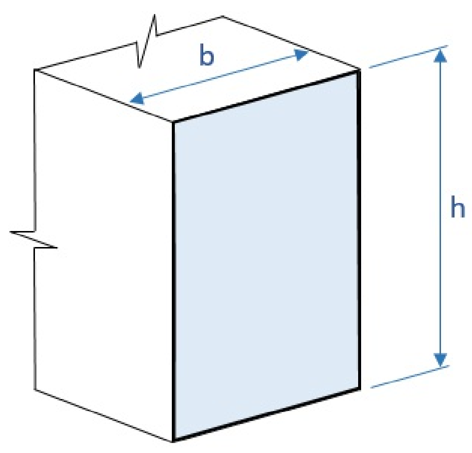
Code: ENV 1992-1-1 :1991

Project details

Project Name: Not Provided
Project ID: Not Provided
Company: Not Provided
Designer: Not Provided
Client: Not Provided
Project Notes: Not Provided
Project Units: Metric

General member design information

Dimentions:



Height $h = 560\ \mathrm{mm}$
Width $b = 280\ \mathrm{mm}$
Member length = $5000\ \mathrm{mm}$

Material properties:
Concrete strength $f_{ck} = 25\ \mathrm{MPa}$
Steel strength of longitudinal rebar $f_{yk} = 500\ \mathrm{MPa}$
Steel strength of shear rebar $f_{ywk} = 500\ \mathrm{MPa}$
Limiting crack width $\omega_{max} = 0.3\ \mathrm{mm}$

Design Factors and Settings:
Partial safety factor for concrete $\gamma_c = 1.50$
Partial safety factor for rebar $\gamma_s = 1.15$
Long term and unfavorable effects for concrete $\alpha_{cc} = 0.85$

Load Combinations (Ultimate Limit State)

For axial force in section:
LC1: USER = $0\ \mathrm{kN}$

For bending moment in section:
LC1: USER = $0\ \mathrm{kN\text{-}m}$

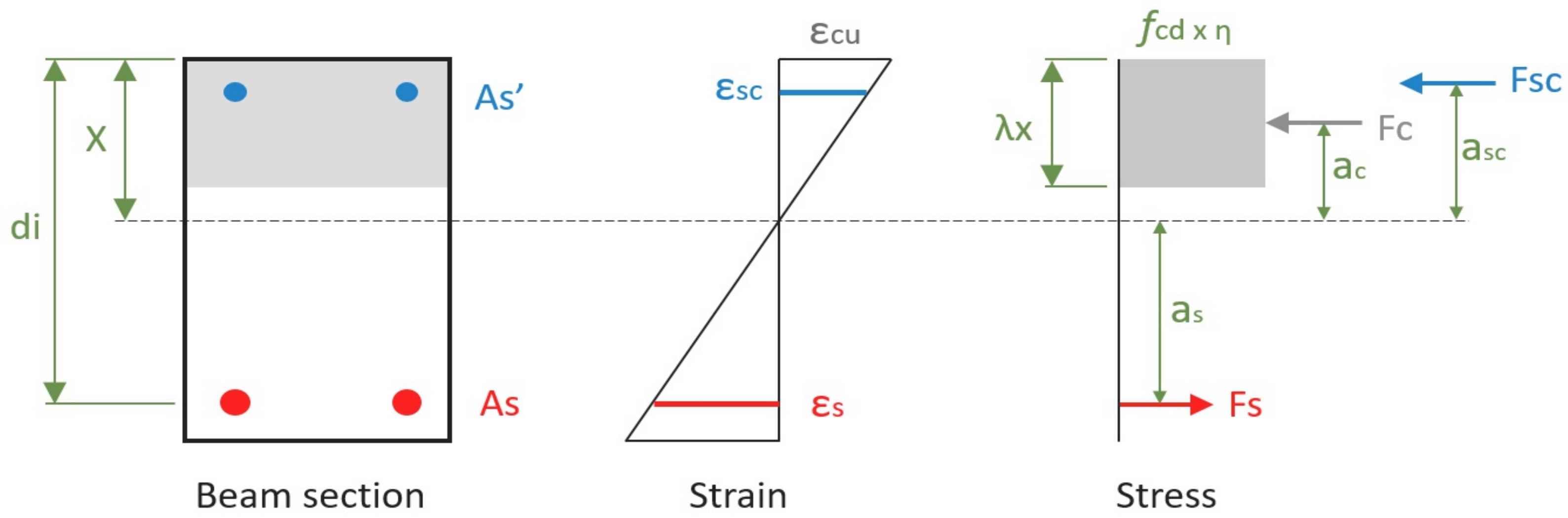
For shear force in section:
LC1: USER = $0\ \mathrm{kN}$

Load Combinations (Serviceability Limit State)

For bending moment in section:
LC1: USER = $0\ \mathrm{kN\text{-}m}$

Flexure check (Positive bending moment case)

BENDING MOMENT CAPACITY



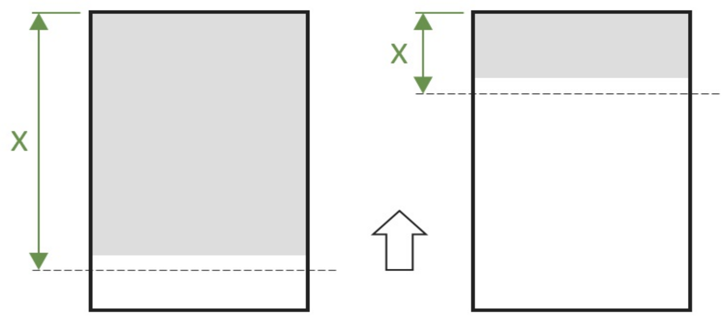
Section input data:
Section concrete area $A_c = 156800\ \mathrm{mm}^2$
Design compressive strength of concrete $f_{cd} = \alpha_{cc} \cdot f_{ck}/\gamma_c = 0.85 \cdot 25/1.5 = 14.17\ \mathrm{MPa}$
Design strength of rebar $f_{yd} = f_{yk}/\gamma_s = 500/1.15 = 434.78\ \mathrm{MPa}$
Design yield strain of rebar $e_y = f_{yd}/E_s = 434.78/200000 = 0.00217$
Ultimate strain in concrete (Table 3) $e_{cu} = 0.00350$
Effective height of the compression zone factor (3.1.7(3)) $\lambda = 0.80$

Effective strength of concrete factor (3.1.7(3)) $\eta = 1.00$
Given bending moment $M_{Ed} = 0.00$ kN-m

Section Rebar

Depth di (mm)	bar diameter (mm)	bar area Asi (mm2)
510	39.179	1205.58
510	39.179	1205.58
50	20	314.16
50	20	314.16

1. Calculation of neutral axis depth x



Calculation is based on iterative process:
- Assume x
- Calculate concrete force $F_c = \eta \cdot f_{cd} \cdot \int_{dA} \cdot \lambda \cdot x$
- Calculate compression force in steel $F_{cs} = \sum A'_{s,i} \cdot f_{s,i}$
- Calculate tensioning force in steel $F_s = \sum A_{s,i} \cdot f_{s,i}$
- Check equilibrium $F_c + F_{cs} = F_s$

Reinforcement stresses $f_s = \{e_s E_s \ (e_s \leq e_y), \ e_y \ (e_s > e_y)\}$
Reinforcement strains above axis $e_s = e_{cu} \cdot (x - d)/x$
Reinforcement strains below axis $e_s = e_{cu} \cdot (d - x)/x$

Searching of neutral axis x (from 510 to 0 mm)

Iter.	x (mm)	As (mm2)	Fc (kN)	Fcs (kN)	Fc + Fcs (kN)	Fs (kN)	Ratio
1	510.0	0.0	1618.40	273.18	1891.58	0.00	Infinity
2	499.8	2411.2	1586.03	273.18	1859.21	34.45	53.976
3	489.6	2411.2	1553.66	273.18	1826.85	70.33	25.977
4	479.4	2411.2	1521.30	273.18	1794.48	107.73	16.657
5	469.2	2411.2	1488.93	273.18	1762.11	146.77	12.006
6	459.0	2411.2	1456.56	273.18	1729.74	187.53	9.224
7	448.8	2411.2	1424.19	273.18	1697.37	230.16	7.375
8	438.6	2411.2	1391.82	273.18	1665.01	274.76	6.060
9	428.4	2411.2	1359.46	273.18	1632.64	321.49	5.078
10	418.2	2411.2	1327.09	273.18	1600.27	370.50	4.319
11	408.0	2411.2	1294.72	273.18	1567.90	421.95	3.716
12	397.8	2411.2	1262.35	273.18	1535.53	476.05	3.226
13	387.6	2411.2	1229.98	273.18	1503.17	532.99	2.820
14	377.4	2411.2	1197.62	273.18	1470.80	593.02	2.480
15	367.2	2411.2	1165.25	273.18	1438.43	656.37	2.191
16	357.0	2411.2	1132.88	273.18	1406.06	723.35	1.944
17	346.8	2411.2	1100.51	273.18	1373.69	794.26	1.730
18	336.6	2411.2	1068.14	273.18	1341.33	869.48	1.543
19	326.4	2411.2	1035.78	273.18	1308.96	949.39	1.379
20	316.2	2411.2	1003.41	273.18	1276.59	1034.47	1.234
21	306.0	2411.2	971.04	273.18	1244.22	1048.33	1.187
22	295.8	2411.2	938.67	273.18	1211.85	1048.33	1.156
23	285.6	2411.2	906.30	273.18	1179.49	1048.33	1.125
24	275.4	2411.2	873.94	273.18	1147.12	1048.33	1.094
25	265.2	2411.2	841.57	273.18	1114.75	1048.33	1.063
26	255.0	2411.2	809.20	273.18	1082.38	1048.33	1.032
27	244.8	2411.2	776.83	273.18	1050.01	1048.33	1.002
(Fc + Fcs) < Fs. Updating of iterations							
1	234.6	2411.2	744.46	273.18	1017.65	1048.33	0.971
2	244.6	2411.2	776.18	273.18	1049.37	1048.33	1.001
3	244.4	2411.2	775.54	273.18	1048.72	1048.33	1.000
4	244.2	2411.2	774.89	273.18	1048.07	1048.33	1.000

Final value of x is 244.19 mm and tensioning rebar area is 2411.16 mm2
Working depth of reinforcement $d = 510.00 \text{ mm}$

2. Calculation moment resistance M_{Rd}

$$M_{Rd} = F_c \cdot a_c + F_{cs} \cdot a_{cs} + F_s \cdot a_s = 113.53 + 53.05 + 278.66 = 445.24 \text{ kN-m}$$

$$M_{Ed} = 0.00 \text{ kN-m} \leq M_{Rd} = 445.24 \text{ kN-m}$$

STATUS OK!

9.2.1.1 (3)
9.2.1.1(1)

3. Calculation of maximum allowed longitudinal reinforcement (9.2.1.1 (3))

$$f_{ck} = 25 \text{ MPa} \leq 50 \text{ MPa}$$

$$f_{ctm} = 0.3 \cdot f_{ck}^{2/3} = 0.3 \cdot 25^{2/3} = 2.56 \text{ MPa}$$

$$A_{s,max} = 0.04 \cdot A_c = 0.04 \cdot 156800 = 6272 \text{ mm}^2$$

4. Calculation of minimum allowed longitudinal reinforcement (9.2.1.1(1))

$$A_{s,min1} = 0.26 \cdot \frac{f_{ctm}}{f_{yk}} \cdot b_t \cdot d = 0.26 \cdot \frac{2.56}{500} \cdot 280 \cdot 510.00 = 190.46 \text{ mm}^2$$

$$A_{s,min2} = 0.0013 \cdot b_t \cdot d = 0.0013 \cdot 280 \cdot 510.00 = 214.200 \text{ mm}^2$$

$$A_{s,min} = max\left[A_{s,min1}, A_{s,min2}\right] = 214.20 \text{ mm}^2$$

Check of allowed longitudinal reinforcement

$$A_s = 2411.16 \text{ mm}^2 \leq A_{s,max} = 6272.00 \text{ mm}^2$$

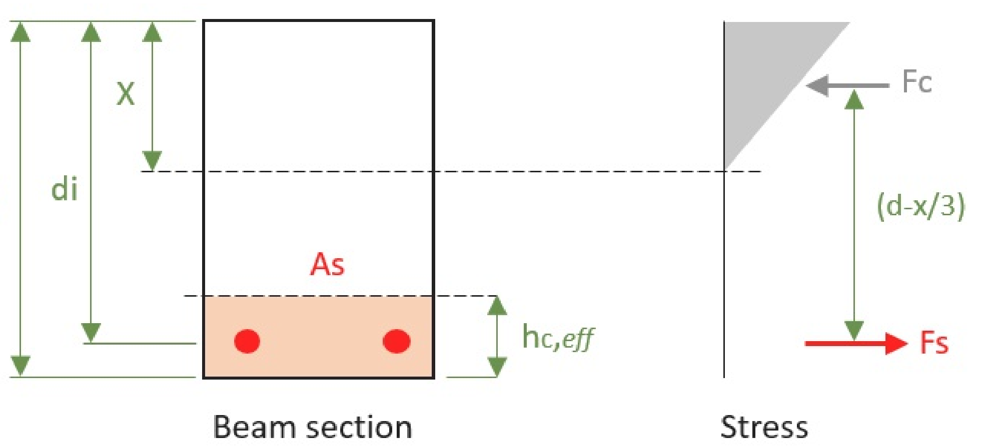
STATUS OK!

$$A_s = 2411.16 \text{ mm}^2 \geq A_{s,min} = 214.20 \text{ mm}^2$$

STATUS OK!

Crack width check (Positive bending moment case)

7.3.4(2) CRACK WIDTH CAPACITY



Section input data:
Depth to the outermost tension side of reinforcement $d_t = 510 \text{ mm}$
Section concrete area $A_c = 156800 \text{ mm}^2$
Age of concrete at loading $t_0 = 3 \text{ days}$
Age of concrete at the moment considered $t = 10000 \text{ days}$
Relative humidity $RH = 70 \%$
Given bending moment $M = 0.00 \text{ kN-m}$

1. Creep coefficient $\phi(t, t_0)$ (ANNEX B)

$$f_{cm} = f_{ck} + 8 = 25 + 8 = 33 \text{ MPa}$$

$$E_{cm} = 22 \cdot \frac{f_{cm}}{10}^{0.3} \cdot 1000 = 22 \cdot \frac{33}{10}^{0.3} \cdot 1000 = 31475.81 \text{ MPa}$$

Notional size of the member

$$h_0 = \frac{2 \cdot A_c}{u} = \frac{2 \cdot 156800.00}{1680} = 186.67 \text{ mm}$$

Factor to allow for the effect of relative humidity on the notional creep coefficient

$$f_{cm} \leq 35\text{MPa} \rightarrow \phi_{RH} = 1 + \frac{1 - \frac{RH}{100}}{0.1 \cdot \sqrt[3]{h_0}} = 1 + \frac{1 - \frac{70}{100}}{0.1 \cdot \sqrt[3]{186.67}} = 1.52$$

Factor to allow for the effect of concrete strength on the notional creep coefficient

$$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{33}} = 2.92$$

Factor to allow for the effect of concrete age at loading on the notional creep coefficient

$$\beta(t_0) = \frac{1}{0.1 + t_0^{0.2}} = \frac{1}{0.1 + 3^{0.2}} = 0.74$$

Notional creep coefficient

$$\phi_0 = \phi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0) = 1.52 \cdot 2.92 \cdot 0.74 = 3.31$$

Coefficient depending on the relative humidity and the notional member size

$$\beta_H = 1.5 \cdot \left[1 + (0.012 \cdot RH)^{18}\right] \cdot h_0 + 250 = 1.5 \cdot \left[1 + (0.012 \cdot 70)^{18}\right] \cdot 186.67 + 250 = 542.14$$

$$\beta_H \leq 1500$$

Coefficient to describe the development of creep with time after loading

$$\beta_c(t, t_0) = \left[\frac{(t - t_0)}{(\beta_H + t - t_0)}\right]^{0.3} = \left[\frac{(10000 - 3)}{(542.14 + 10000 - 3)}\right]^{0.3} = 0.98$$

Creep coefficient

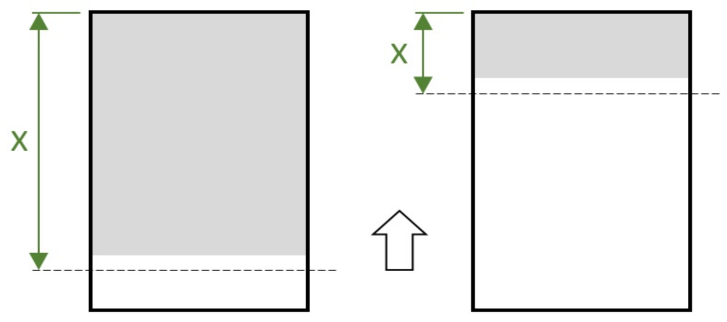
$$\phi(t, t_0) = \phi_0 \cdot \beta_c(t, t_0) = 3.31 \cdot 0.98 = 3.26$$

Effective modulus

$$E_{eff} = \frac{E_{cm}}{1 + \phi(t, t_0)} = \frac{31475.81}{1 + 3.26} = 7385.50 \text{ MPa}$$

$$a_e = \frac{E_s}{E_{eff}} = \frac{200000}{7385.50} = 27.08$$

2. Calculation of neutral axis depth x



Calculation is based on iterative process:
- Assume x
- Calculate left part of force equilibrium $A_{comp.} \cdot \frac{x}{2} + \sum a_e \cdot A_s \cdot \acute{d_i} + \sum a_e \cdot A_s \cdot d_i$
- Calculate right part of force equilibrium $A_{comp.} + a_e \cdot A_s + a_e \cdot \acute{A_s}$

Searching of neutral axis x (from 510 to 0 mm)

Iter.	x (mm)	As (mm2)	Asc (mm2)	Left force equil. part (kN)	Right force equil. part (kN)	Ratio
1	510.00	0.00	628.32	70564.91	114805.80	1.627
2	499.80	2411.16	628.32	69122.92	111082.25	1.607
3	489.60	2411.16	628.32	67710.06	107416.97	1.586
4	479.40	2411.16	628.32	66326.32	103809.95	1.565
5	469.20	2411.16	628.32	64971.72	100261.19	1.543
6	459.00	2411.16	628.32	63646.25	96770.70	1.520
7	448.80	2411.16	628.32	62349.91	93338.46	1.497
8	438.60	2411.16	628.32	61082.71	89964.49	1.473
9	428.40	2411.16	628.32	59844.63	86648.79	1.448
10	418.20	2411.16	628.32	58635.69	83391.34	1.422
11	408.00	2411.16	628.32	57455.87	80192.16	1.396
12	397.80	2411.16	628.32	56305.19	77051.24	1.368
13	387.60	2411.16	628.32	55183.64	73968.58	1.340
14	377.40	2411.16	628.32	54091.22	70944.18	1.312
15	367.20	2411.16	628.32	53027.93	67978.05	1.282
16	357.00	2411.16	628.32	51993.77	65070.18	1.251
17	346.80	2411.16	628.32	50988.75	62220.57	1.220
18	336.60	2411.16	628.32	50012.85	59429.22	1.188
19	326.40	2411.16	628.32	49066.09	56696.14	1.156

20	316.20	2411.16	628.32	48148.45	54021.32	1.122
21	306.00	2411.16	628.32	47259.95	51404.76	1.088
22	295.80	2411.16	628.32	46400.58	48846.46	1.053
23	285.60	2411.16	628.32	45570.34	46346.43	1.017
left part < right part. Updating of iterations						
1	275.40	2411.16	628.32	44769.24	43904.66	0.981
2	285.40	2411.16	628.32	45554.04	46297.02	1.016
3	285.19	2411.16	628.32	45537.74	46247.64	1.016
4	284.99	2411.16	628.32	45521.46	46198.28	1.015
5	284.78	2411.16	628.32	45505.18	46148.94	1.014
6	284.58	2411.16	628.32	45488.92	46099.63	1.013
7	284.38	2411.16	628.32	45472.67	46050.34	1.013
8	284.17	2411.16	628.32	45456.43	46001.07	1.012
9	283.97	2411.16	628.32	45440.21	45951.83	1.011
10	283.76	2411.16	628.32	45423.99	45902.61	1.011
11	283.56	2411.16	628.32	45407.79	45853.41	1.010
12	283.36	2411.16	628.32	45391.60	45804.24	1.009
13	283.15	2411.16	628.32	45375.42	45755.09	1.008
14	282.95	2411.16	628.32	45359.25	45705.96	1.008
15	282.74	2411.16	628.32	45343.10	45656.86	1.007
16	282.54	2411.16	628.32	45326.95	45607.78	1.006
17	282.34	2411.16	628.32	45310.82	45558.72	1.005
18	282.13	2411.16	628.32	45294.70	45509.69	1.005
19	281.93	2411.16	628.32	45278.59	45460.68	1.004
20	281.72	2411.16	628.32	45262.49	45411.69	1.003
21	281.52	2411.16	628.32	45246.40	45362.73	1.003
22	281.32	2411.16	628.32	45230.33	45313.79	1.002
23	281.11	2411.16	628.32	45214.27	45264.87	1.001
24	280.91	2411.16	628.32	45198.22	45215.98	1.000
25	280.70	2411.16	628.32	45182.18	45167.11	1.00

Value of x is 280.70 mm
Tensioning rebar area $A_s = 2411.16\ \mathrm{mm}^2$
Compression rebar area $A_{sc} = 628.32\ \mathrm{mm}^2$
Working depth of reinforcement $d = 510.00\ \mathrm{mm}$

3. Calculation of effective strain

$$\sigma_s = \frac{M}{A_s \cdot (d - x/3)} = \frac{0}{2411.16 \cdot (510 - 280.70/3)} = 0.00\ \mathrm{MPa}$$

$$k_t = 0.4 \text{ as long term loading}$$

$$f_{ck} = 25\ \mathrm{MPa} \leq 50\ \mathrm{MPa}$$

$$f_{ctm} = 0.3 \cdot f_{ck}^{2/3} = 0.3 \cdot 25^{2/3} = 2.56\ \mathrm{MPa}$$

$$f_{ct,eff} = f_{ctm}$$

$$a_e = \frac{E_s}{E_{cm}} = \frac{200000}{31475.81} = 6.35$$

$$h_{eff} = max\left[2.5 \cdot (h-d), \frac{h-x}{3}, \frac{h}{2}\right] = max\,[125.00, 93.10, 280.00] = 93.10 \text{ mm}$$

$$A_{c,eff} = b_w \cdot h_{eff} = 280 \cdot 93.10 = 26067.63 \text{ mm}^2$$

$$\rho_{eff} = \frac{A_s}{A_{c,eff}} = \frac{2411.16}{26067.63} = 0.09250$$

$$e_{sm} - e_{cm} = \frac{\sigma_s - k_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}} \cdot (1 + a_e \cdot \rho_{p,eff})}{E_s} =$$

$$= \frac{0.00 - 0.4 \cdot \frac{2.56}{0.09250} \cdot (1 + 6.35 \cdot 0.09250)}{200000} = -0.00009$$

$$e_{sm} - e_{cm} < 0.6 \cdot \frac{\sigma_s}{E_s} = 0.6 \cdot \frac{0.00}{200000} = 0.00000 \rightarrow e_{sm} - e_{cm} = 0.00000$$

4. Calculation of maximum crack spacing

$$\text{cover } c = 30.4105 \text{ mm}$$

$$k_1 = 0.8$$

$$k_2 = 0.5$$

$$s_{r,max} = 3.4 \cdot c \cdot \frac{0.425 \cdot k_1 \cdot k_2 \cdot diameter}{\rho_{p,eff}} = 3.4 \cdot 30.4105 \cdot \frac{0.425 \cdot 0.8 \cdot 0.5 \cdot 39.179}{0.09250} = 175.40 \text{ mm}$$

$$s_{r,max} \leq 5 \cdot (c + 0.5 \cdot diameter) = 5 \cdot (30.4105 + 0.5 \cdot 39.179) = 250.00 \text{ mm}$$

5. Calculation of crack width

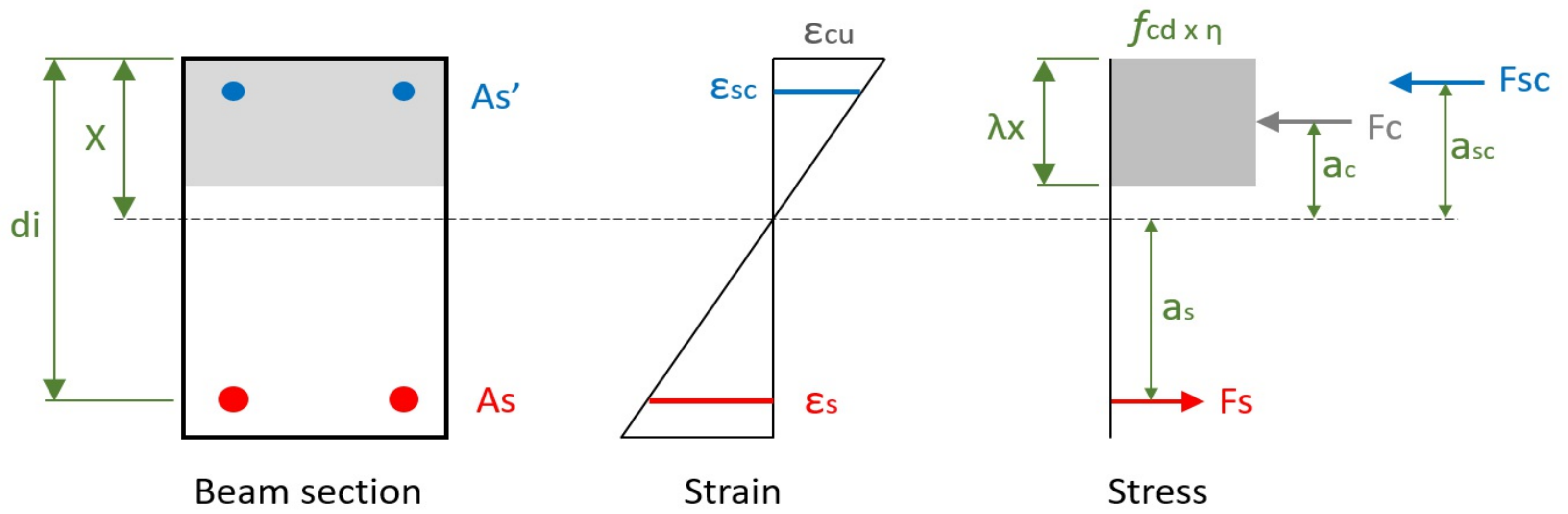
$$w_k = (e_{sm} - e_{cm}) \cdot s_{r,max} = 0.00000 \cdot 175.40 = 0.00 \text{ mm}$$

$$w_k = 0.00 \text{ mm} \leq w_{lim} = 0.3 \text{ mm}$$

STATUS OK!

Flexure check (Negative bending moment case)

BENDING MOMENT CAPACITY



Section input data:
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Design strength of rebar $f_{yd} = f_{yk}/\gamma_s = 500/1.15 = 434.78 \text{ MPa}$
Design yield strain of rebar $e_y = f_{yd}/E_s = 434.78/200000 = 0.00217$
Ultimate strain in concrete (Table 3) $e_{cu} = 0.00350$
Effective height of the compression zone factor (3.1.7(3)) $\lambda = 0.80$
Effective strength of concrete factor (3.1.7(3)) $\eta = 1.00$
Given bending moment $M_{Ed} = 0.00 \text{ kN-m}$

Section Rebar

Depth di (mm)	bar diameter (mm)	bar area Asi (mm2)
510	20	314.16
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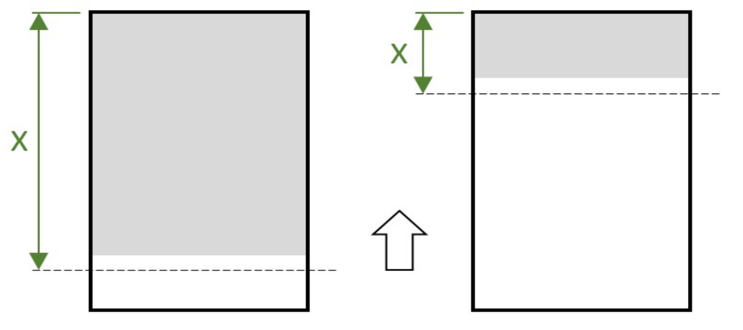
1. Calculation of neutral axis depth x



Calculation is based on iterative process:
- Assume x
- Calculate concrete force $F_c = \eta \cdot f_{cd} \cdot \int_{dA} \cdot \lambda \cdot x$
- Calculate compression force in steel $F_{cs} = \sum A_{s,i}^{'} \cdot f_{s,i}$
- Calculate tensioning force in steel $F_s = \sum A_{s,i} \cdot f_{s,i}$
- Check equilibrium $F_c + F_{cs} = F_s$

Reinforcement stresses $f_s = \{e_s E_s\ (e_s \le e_y),\ e_y\ (e_s > e_y)\}$
Reinforcement strains above axis $e_s = e_{cu} \cdot (x - d)/x$
Reinforcement strains below axis $e_s = e_{cu} \cdot (d - x)/x$

Searching of neutral axis x (from 510 to 0 mm)

Iter.	x (mm)	As (mm2)	Fc (kN)	Fcs (kN)	Fc + Fcs (kN)	Fs (kN)	Ratio
1	510.0	0.0	1618.40	1048.33	2666.73	0.00	Infinity
2	499.8	628.3	1586.03	1048.33	2634.36	8.98	293.490
3	489.6	628.3	1553.66	1048.33	2601.99	18.33	141.984
4	479.4	628.3	1521.30	1048.33	2569.63	28.07	91.531
5	469.2	628.3	1488.93	1048.33	2537.26	38.25	66.341
6	459.0	628.3	1456.56	1048.33	2504.89	48.87	51.257
7	448.8	628.3	1424.19	1048.33	2472.52	59.98	41.225
8	438.6	628.3	1391.82	1048.33	2440.15	71.60	34.081
9	428.4	628.3	1359.46	1048.33	2407.79	83.78	28.741
10	418.2	628.3	1327.09	1048.33	2375.42	96.55	24.604
11	408.0	628.3	1294.72	1048.33	2343.05	109.96	21.309
12	397.8	628.3	1262.35	1048.33	2310.68	124.05	18.627
13	387.6	628.3	1229.98	1048.33	2278.31	138.89	16.404
14	377.4	628.3	1197.62	1048.33	2245.95	154.53	14.534
15	367.2	628.3	1165.25	1048.33	2213.58	171.04	12.942
16	357.0	628.3	1132.88	1048.33	2181.21	188.50	11.572
17	346.8	628.3	1100.51	1048.33	2148.84	206.98	10.382
18	336.6	628.3	1068.14	1048.33	2116.47	226.58	9.341
19	326.4	628.3	1035.78	1048.33	2084.11	247.40	8.424
20	316.2	628.3	1003.41	1048.33	2051.74	269.57	7.611
21	306.0	628.3	971.04	1048.33	2019.37	273.18	7.392
22	295.8	628.3	938.67	1048.33	1987.00	273.18	7.274
23	285.6	628.3	906.30	1048.33	1954.63	273.18	7.155
24	275.4	628.3	873.94	1048.33	1922.27	273.18	7.037
25	265.2	628.3	841.57	1048.33	1889.90	273.18	6.918

26	255.0	628.3	809.20	1048.33	1857.53	273.18	6.800
27	244.8	628.3	776.83	1048.33	1825.16	273.18	6.681
28	234.6	628.3	744.46	1048.33	1792.79	273.18	6.563
29	224.4	628.3	712.10	1048.33	1760.43	273.18	6.444
30	214.2	628.3	679.73	1048.33	1728.06	273.18	6.326
31	204.0	628.3	647.36	1048.33	1695.69	273.18	6.207
32	193.8	628.3	614.99	1048.33	1663.32	273.18	6.089
33	183.6	628.3	582.62	1048.33	1630.95	273.18	5.970
34	173.4	628.3	550.26	1048.33	1598.59	273.18	5.852
35	163.2	628.3	517.89	1048.33	1566.22	273.18	5.733
36	153.0	628.3	485.52	1048.33	1533.85	273.18	5.615
37	142.8	628.3	453.15	1048.33	1501.48	273.18	5.496
38	132.6	628.3	420.78	1048.33	1469.11	273.18	5.378
39	122.4	628.3	388.42	998.35	1386.76	273.18	5.076
40	112.2	628.3	356.05	935.67	1291.72	273.18	4.728
41	102.0	628.3	323.68	860.45	1184.13	273.18	4.335
42	91.8	628.3	291.31	768.52	1059.84	273.18	3.880
43	81.6	628.3	258.94	653.61	912.56	273.18	3.340
44	71.4	628.3	226.58	505.87	732.45	273.18	2.681
45	61.2	628.3	194.21	308.88	503.09	273.18	1.842
(Fc + Fcs) < Fs. Updating of iterations							
1	51.0	628.3	161.84	33.09	194.93	273.18	0.714
2	61.0	628.3	193.56	304.27	497.83	273.18	1.822
3	60.8	628.3	192.91	299.63	492.54	273.18	1.803
4	60.6	628.3	192.27	294.95	487.22	273.18	1.783
5	60.4	628.3	191.62	290.25	481.86	273.18	1.764
6	60.2	628.3	190.97	285.51	476.48	273.18	1.744
7	60.0	628.3	190.32	280.74	471.06	273.18	1.724
8	59.8	628.3	189.68	275.94	465.61	273.18	1.704
9	59.6	628.3	189.03	271.10	460.13	273.18	1.684
10	59.4	628.3	188.38	266.23	454.62	273.18	1.664
11	59.2	628.3	187.73	261.33	449.07	273.18	1.644
12	59.0	628.3	187.09	256.40	443.48	273.18	1.623
13	58.8	628.3	186.44	251.43	437.86	273.18	1.603
14	58.5	628.3	185.79	246.42	432.21	273.18	1.582
15	58.3	628.3	185.14	241.38	426.53	273.18	1.561
16	58.1	628.3	184.50	236.31	420.80	273.18	1.540
17	57.9	628.3	183.85	231.19	415.04	273.18	1.519
18	57.7	628.3	183.20	226.05	409.25	273.18	1.498
19	57.5	628.3	182.56	220.86	403.42	273.18	1.477
20	57.3	628.3	181.91	215.64	397.55	273.18	1.455
21	57.1	628.3	181.26	210.39	391.65	273.18	1.434
22	56.9	628.3	180.61	205.09	385.70	273.18	1.412
23	56.7	628.3	179.97	199.76	379.72	273.18	1.390

24	56.5	628.3	179.32	194.38	373.70	273.18	1.368
25	56.3	628.3	178.67	188.97	367.64	273.18	1.346
26	56.1	628.3	178.02	183.52	361.55	273.18	1.323
27	55.9	628.3	177.38	178.03	355.41	273.18	1.301
28	55.7	628.3	176.73	172.50	349.23	273.18	1.278
29	55.5	628.3	176.08	166.93	343.01	273.18	1.256
30	55.3	628.3	175.43	161.32	336.75	273.18	1.233
31	55.1	628.3	174.79	155.67	330.45	273.18	1.210
32	54.9	628.3	174.14	149.97	324.11	273.18	1.186
33	54.7	628.3	173.49	144.23	317.72	273.18	1.163
34	54.5	628.3	172.85	138.45	311.30	273.18	1.140
35	54.3	628.3	172.20	132.63	304.82	273.18	1.116
36	54.1	628.3	171.55	126.76	298.31	273.18	1.092
37	53.9	628.3	170.90	120.84	291.75	273.18	1.068
38	53.7	628.3	170.26	114.89	285.14	273.18	1.044
39	53.4	628.3	169.61	108.88	278.49	273.18	1.019
40	53.2	628.3	168.96	102.83	271.79	273.18	0.995

Final value of x is 53.24 mm and tensioning rebar area is 628.32 mm2
Working depth of reinforcement $d = 510.00\ \mathrm{mm}$

2. Calculation moment resistance M_{Rd}

$$M_{Rd} = F_c \cdot a_c + F_{cs} \cdot a_{cs} + F_s \cdot a_s = 5.40 + 0.33 + 124.78 = 130.51\ \text{kN-m}$$

STATUS OK!

$$M_{Ed} = 0.00\ \text{kN-m} \leq M_{Rd} = 130.51\ \text{kN-m}$$

9.2.1.1 (3)
9.2.1.1(1)

3. Calculation of maximum allowed longitudinal reinforcement (9.2.1.1 (3))

$$f_{ck} = 25\ \mathrm{MPa} \leq 50\ \mathrm{MPa}$$

$$f_{ctm} = 0.3 \cdot f_{ck}^{2/3} = 0.3 \cdot 25^{2/3} = 2.56\ \mathrm{MPa}$$

$$A_{s,max} = 0.04 \cdot A_c = 0.04 \cdot 156800 = 6272\ \mathrm{mm}^2$$

4. Calculation of minimum allowed longitudinal reinforcement (9.2.1.1(1))

$$A_{s,min1} = 0.26 \cdot \frac{f_{ctm}}{f_{yk}} \cdot b_t \cdot d = 0.26 \cdot \frac{2.56}{500} \cdot 280 \cdot 510.00 = 190.46\ \mathrm{mm}^2$$

$$A_{s,min2} = 0.0013 \cdot b_t \cdot d = 0.0013 \cdot 280 \cdot 510.00 = 214.200\ \mathrm{mm}^2$$

$$A_{s,min} = max\left[A_{s,min1}, A_{s,min2}\right] = 214.20\ \mathrm{mm}^2$$

Check of allowed longitudinal reinforcement

$$A_s = 628.32\ \mathrm{mm}^2 \leq A_{s,max} = 6272.00\ \mathrm{mm}^2$$

STATUS OK!

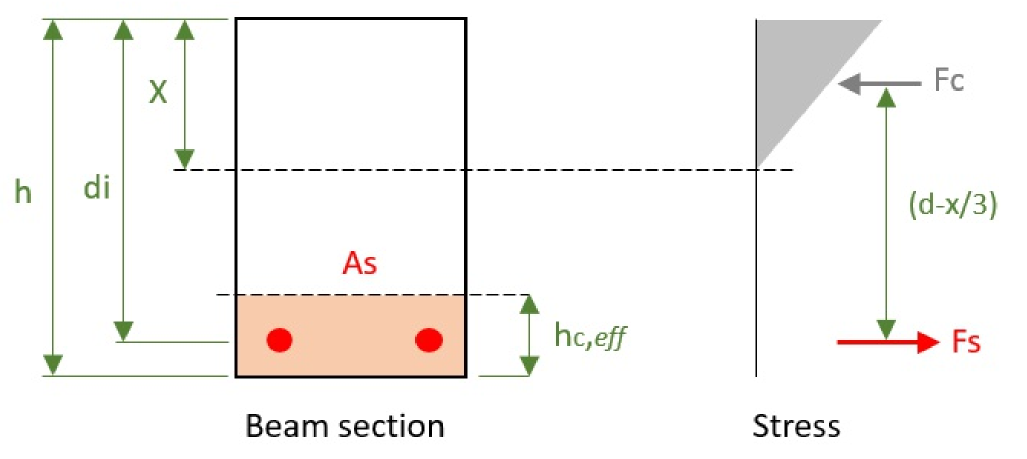
$$A_s = 628.32\ \mathrm{mm}^2 \geq A_{s,min} = 214.20\ \mathrm{mm}^2$$

STATUS OK!

Crack width check (Negative bending moment case)

7.3.4(2)

CRACK WIDTH CAPACITY



Section input data:
Depth to the outermost tension side of reinforcement $d_t = 510 \text{ mm}$
Section concrete area $A_c = 156800 \text{ mm}^2$
Age of concrete at loading $t_0 = 3 \text{ days}$
Age of concrete at the moment considered $t = 10000 \text{ days}$
Relative humidity $RH = 70\ \%$
Given bending moment $M = 0.00 \text{ kN-m}$

1. Creep coefficient $\phi(t, t_0)$ (ANNEX B)

$$f_{cm} = f_{ck} + 8 = 25 + 8 = 33 \text{ MPa}$$

$$E_{cm} = 22 \cdot \frac{f_{cm}}{10}^{0.3} \cdot 1000 = 22 \cdot \frac{33}{10}^{0.3} \cdot 1000 = 31475.81 \text{ MPa}$$

Notional size of the member

$$h_0 = \frac{2 \cdot A_c}{u} = \frac{2 \cdot 156800.00}{1680} = 186.67 \text{ mm}$$

Factor to allow for the effect of relative humidity on the notional creep coefficient

$$f_{cm} \leq 35\text{MPa} \rightarrow \phi_{RH} = 1 + \frac{1 - \frac{RH}{100}}{0.1 \cdot \sqrt[3]{h_0}} = 1 + \frac{1 - \frac{70}{100}}{0.1 \cdot \sqrt[3]{186.67}} = 1.52$$

Factor to allow for the effect of concrete strength on the notional creep coefficient

$$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{33}} = 2.92$$

Factor to allow for the effect of concrete age at loading on the notional creep coefficient

$$\beta(t_0) = \frac{1}{0.1 + t_0^{0.2}} = \frac{1}{0.1 + 3^{0.2}} = 0.74$$

Notional creep coefficient

$$\phi_0 = \phi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0) = 1.52 \cdot 2.92 \cdot 0.74 = 3.31$$

Coefficient depending on the relative humidity and the notional member size

$$\beta_H = 1.5 \cdot \left[1 + (0.012 \cdot RH)^{18}\right] \cdot h_0 + 250 = 1.5 \cdot \left[1 + (0.012 \cdot 70)^{18}\right] \cdot 186.67 + 250$$
$$= 542.14$$

$$\beta_H \leq 1500$$

Coefficient to describe the development of creep with time after loading

$$\beta_c(t, t_0) = \left[\frac{(t - t_0)}{(\beta_H + t - t_0)}\right]^{0.3} = \left[\frac{(10000 - 3)}{(542.14 + 10000 - 3)}\right]^{0.3} = 0.98$$

Creep coefficient

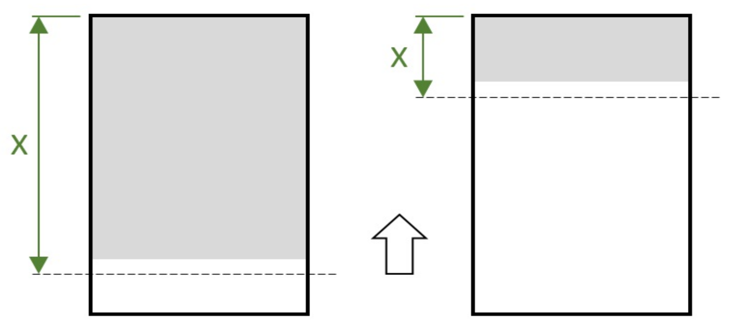
$$\phi(t, t_0) = \phi_0 \cdot \beta_c(t, t_0) = 3.31 \cdot 0.98 = 3.26$$

Effective modulus

$$E_{eff} = \frac{E_{cm}}{1 + \phi(t, t_0)} = \frac{31475.81}{1 + 3.26} = 7385.50 \text{ MPa}$$

$$a_e = \frac{E_s}{E_{eff}} = \frac{200000}{7385.50} = 27.08$$

2. Calculation of neutral axis depth x



Calculation is based on iterative process:
- Assume x
- Calculate left part of force equilibrium $A_{comp.} \cdot \frac{x}{2} + \sum a_e \cdot A_s \cdot \acute{d_i} + \sum a_e \cdot A_s \cdot d_i$
- Calculate right part of force equilibrium $A_{comp.} + a_e \cdot A_s + a_e \cdot \acute{A_s}$

Searching of neutral axis x (from 510 to 0 mm)

Iter.	x (mm)	As (mm2)	Asc (mm2)	Left force equil. part (kN)	Right force equil. part (kN)	Ratio
1	510.00	0.00	2411.16	48356.35	114805.80	2.374
2	499.80	628.32	2411.16	46914.36	111082.25	2.368
3	489.60	628.32	2411.16	45501.50	107416.97	2.361
4	479.40	628.32	2411.16	44117.76	103809.95	2.353
5	469.20	628.32	2411.16	42763.16	100261.19	2.345
6	459.00	628.32	2411.16	41437.69	96770.70	2.335
7	448.80	628.32	2411.16	40141.36	93338.46	2.325
8	438.60	628.32	2411.16	38874.15	89964.49	2.314
9	428.40	628.32	2411.16	37636.07	86648.79	2.302
10	418.20	628.32	2411.16	36427.13	83391.34	2.289
11	408.00	628.32	2411.16	35247.31	80192.16	2.275
12	397.80	628.32	2411.16	34096.63	77051.24	2.260
13	387.60	628.32	2411.16	32975.08	73968.58	2.243
14	377.40	628.32	2411.16	31882.66	70944.18	2.225
15	367.20	628.32	2411.16	30819.37	67978.05	2.206
16	357.00	628.32	2411.16	29785.21	65070.18	2.185
17	346.80	628.32	2411.16	28780.19	62220.57	2.162
18	336.60	628.32	2411.16	27804.29	59429.22	2.137
19	326.40	628.32	2411.16	26857.53	56696.14	2.111
20	316.20	628.32	2411.16	25939.90	54021.32	2.083
21	306.00	628.32	2411.16	25051.39	51404.76	2.052
22	295.80	628.32	2411.16	24192.02	48846.46	2.019
23	285.60	628.32	2411.16	23361.78	46346.43	1.984
24	275.40	628.32	2411.16	22560.68	43904.66	1.946
25	265.20	628.32	2411.16	21788.70	41521.15	1.906
26	255.00	628.32	2411.16	21045.85	39195.90	1.862
27	244.80	628.32	2411.16	20332.14	36928.91	1.816
28	234.60	628.32	2411.16	19647.56	34720.19	1.767
29	224.40	628.32	2411.16	18992.10	32569.73	1.715
30	214.20	628.32	2411.16	18365.78	30477.53	1.659
31	204.00	628.32	2411.16	17768.59	28443.60	1.601
32	193.80	628.32	2411.16	17200.54	26467.93	1.539
33	183.60	628.32	2411.16	16661.61	24550.52	1.473
34	173.40	628.32	2411.16	16151.81	22691.37	1.405

35	163.20	628.32	2411.16	15671.15	20890.48	1.333
36	153.00	628.32	2411.16	15219.61	19147.86	1.258
37	142.80	628.32	2411.16	14797.21	17463.50	1.180
38	132.60	628.32	2411.16	14403.94	15837.40	1.100
39	122.40	628.32	2411.16	14039.80	14269.56	1.016
left part < right part. Updating of iterations						
1	112.20	628.32	2411.16	13704.79	12759.99	0.931
2	122.20	628.32	2411.16	14032.81	14238.80	1.015
3	121.99	628.32	2411.16	14025.84	14208.06	1.013
4	121.79	628.32	2411.16	14018.88	14177.35	1.011
5	121.58	628.32	2411.16	14011.93	14146.65	1.010
6	121.38	628.32	2411.16	14004.99	14115.98	1.008
7	121.18	628.32	2411.16	13998.06	14085.34	1.006
8	120.97	628.32	2411.16	13991.15	14054.72	1.005
9	120.77	628.32	2411.16	13984.24	14024.12	1.003
10	120.56	628.32	2411.16	13977.35	13993.54	1.001
11	120.36	628.32	2411.16	13970.47	13962.99	1.00

Value of x is 120.36 mm
Tensioning rebar area $A_s = 628.32\ \mathrm{mm}^2$
Compression rebar area $A_{sc} = 2411.16\ \mathrm{mm}^2$
Working depth of reinforcement $d = 510.00\ \mathrm{mm}$

3. Calculation of effective strain

$$\sigma_s = \frac{M}{A_s \cdot (d - x/3)} = \frac{0}{628.32 \cdot (510 - 120.36/3)} = 0.00\ \mathrm{MPa}$$

$$k_t = 0.4 \text{ as long term loading}$$

$$f_{ck} = 25\ \mathrm{MPa} \leq 50\ \mathrm{MPa}$$

$$f_{ctm} = 0.3 \cdot f_{ck}^{2/3} = 0.3 \cdot 25^{2/3} = 2.56\ \mathrm{MPa}$$

$$f_{ct,eff} = f_{ctm}$$

$$a_e = \frac{E_s}{E_{cm}} = \frac{200000}{31475.81} = 6.35$$

$$h_{eff} = max\left[2.5 \cdot (h - d), \frac{h - x}{3}, \frac{h}{2}\right] = max\,[125.00, 146.55, 280.00] = 125.00\ \mathrm{mm}$$

$$A_{c,eff} = b_w \cdot h_{eff} = 280 \cdot 125.00 = 35000.00\ \mathrm{mm}^2$$

$$\rho_{eff} = \frac{A_s}{A_{c,eff}} = \frac{628.32}{35000.00} = 0.01795$$

$$e_{sm} - e_{cm} = \frac{\sigma_s - k_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}} \cdot (1 + a_e \cdot \rho_{p,eff})}{E_s} =$$

$$= \frac{0.00 - 0.4 \cdot \frac{2.56}{0.01795} \cdot (1 + 6.35 \cdot 0.01795)}{200000} = -0.00032$$

$$e_{sm} - e_{cm} < 0.6 \cdot \frac{\sigma_s}{E_s} = 0.6 \cdot \frac{0.00}{200000} = 0.00000 \rightarrow e_{sm} - e_{cm} = 0.00000$$

4. Calculation of maximum crack spacing

$$\text{cover } c = 40 \text{ mm}$$

$$k_1 = 0.8$$

$$k_2 = 0.5$$

$$s_{r,max} = 3.4 \cdot c \cdot \frac{0.425 \cdot k_1 \cdot k_2 \cdot diameter}{\rho_{p,eff}} = 3.4 \cdot 40 \cdot \frac{0.425 \cdot 0.8 \cdot 0.5 \cdot 20}{0.01795} = 325.39 \text{ mm}$$

$$s_{r,max} > 5 \cdot (c + 0.5 \cdot diameter) = 5 \cdot (40 + 0.5 \cdot 20) = 250.00 \text{ mm} \rightarrow s_{r,max} = 250.00$$

5. Calculation of crack width

$$w_k = (e_{sm} - e_{cm}) \cdot s_{r,max} = 0.00000 \cdot 250.00 = 0.00 \text{ mm}$$

$$w_k = 0.00 \text{ mm} \leq w_{lim} = 0.3 \text{ mm}$$

STATUS OK!

6.2.3(4)
6.2.3(3)
9.2.2(5)
9.2.2(6)

Shear check

SHEAR FORCE CAPACITY (Members with shear reinforcement)

Section input data:
Design compressive strength of concrete $f_{cd} = \alpha_{cc} \cdot f_{ck}/\gamma_c = 0.85 \cdot 25/1.5 = 14.17 \text{ MPa}$
Design strength of shear rebar $f_{ywd} = f_{ywk}/\gamma_s = 500/1.15 = 434.78 \text{ MPa}$
Mean width of web $b_w = 280 \text{ mm}$
Section concrete area $A_c = 156800 \text{ mm}^2$
Tensioning rebar area $A_{sl} = 2411.16 \text{ mm}^2$
Cross-sectional area of the shear reinforcement $A_{sw} = 157.08 \text{ mm}^2$
Spacing of stirrups $s = 250.00 \text{ mm}$
Working depth of reinforcement $d = 510.00 \text{ mm}$
Angle between strut and the beam axis $\theta = 45 \text{ deg}$
Given shear force $V_{Ed} = 0.00 \text{ kN}$

1. Calculation of shear resistance with reinforcement (6.2.3(3),6.2.3(4))

$$\sigma_{cp} = 0 \text{ as } N_{ed} = 0$$

Coefficient taking account of the state of the stress in the compression chord:

$$a_{cw} = 1.0 \text{ as } \sigma_{cp} \leq 0.0 \text{ MPa}$$

Strength reduction factor for concrete cracked in shear

$$v_1 = 0.6 \cdot (1 - \frac{f_{ck}}{250}) = 0.6 \cdot (1 - \frac{25}{250}) = 0.54 \text{ as } f_{ywd} = 434.78 \text{ MPa} \geq 0.8 \cdot f_{ywk} = 400.00 \text{ MPa}$$

$$V_{Rd,max} = \frac{f_{cd} \cdot 0.9 \cdot d \cdot b_w \cdot a_{cw} \cdot v_1}{cot(\theta) + tan(\theta)} = \frac{14.17 \cdot 0.9 \cdot 510.00 \cdot 280 \cdot 1.00 \cdot 0.54}{1.00 + 1.00} = 491.59 \text{ kN}$$

2. Shear Reinforcement detailing (9.2.2(5), 9.2.2(6))
Shear reinforcement ratio

$$\rho_w = \frac{A_{sw}}{b_w \cdot s} = \frac{157.08}{280 \cdot 250} = 0.00224$$

Minimum shear reinforcement ratio

$$\rho_{w,min} = 0.08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} = 0.08 \cdot \frac{\sqrt{25}}{500} = 0.00080$$

Minimum vertical links longitudinal spacing

$$s_{max} = 0.75 \cdot d = 0.75 \cdot 510.00 = 382.50 \text{ mm}$$

Maximum shear reinforcement

$$A_{sw,max} = \frac{0.5 \cdot a_{cw} \cdot v_1 \cdot f_{cd} \cdot b_w \cdot s}{f_{ywd}} = \frac{0.5 \cdot 1.00 \cdot 0.54 \cdot 14.17 \cdot 280 \cdot 250}{434.78} = 615.82 \text{ mm}^2$$

	$V_{Ed} = 0.00 \text{ kN} \leq V_{Rd,max} = 491.59 \text{ kN}$ $\rho_w = 0.00224 \geq \rho_{w,min} = 0.00080$ $A_{sw} = 157.08 \text{ mm}^2 \leq A_{sw,max} = 615.82 \text{ mm}^2$ $s = 250.00 \text{ mm} \leq s_{max} = 382.50 \text{ mm}$	**STATUS OK!** **STATUS OK!** **STATUS OK!** **STATUS OK!**