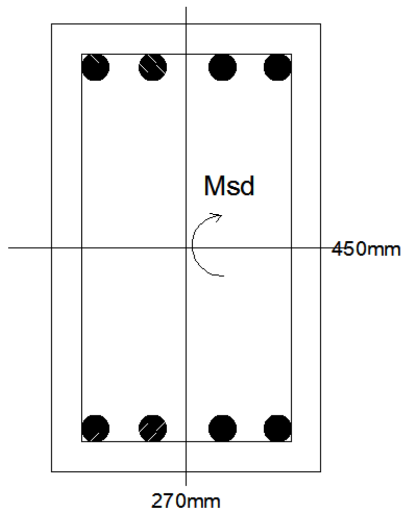
Example 4.1 [Uni-axial Column Design]

1. Design the braced short column to sustain a design load of 1100 KN and a design moment of 160KNm which include all other effects .Use C25/30 and S460.

   Take $\frac{d'}{H} = 0.1$ and section $270\ mm * 450\ mm$



Solution

Step 1- Material

$$f_{cd} = \frac{0.85 * 25}{1.5} = 14.16667\ mpa$$

$$f_{yd} = \frac{460}{1.15} = 400\ mpa$$

Step 2-Determine the normalized axial and bending moment value

$$v_{sd} = \frac{N_{sd}}{f_{cd}bh} = \frac{1100 * 10^3}{14.1667 * 270 * 450} = 0.639$$

$$\mu_{sd} = \frac{m_{sd}}{f_{cd}bd^2} = \frac{160 * 10^6}{14.1667 * 270 * 450^2} = 0.2065$$

Step 3-Using $\frac{d'}{H} = 0.1$ read the mechanical steel ratio from uniaxial interaction chart for

$$V_{sd} = 0.639 \quad \mu_{sd} = 0.2065$$

From interaction chart $\omega = 0.3$

$$A_{s,tot} = \frac{\omega f_{cd} bd}{f_{yd}} = \frac{0.3 * 14.166 * 270 * 450}{400} = 1290.937\ mm^2$$

$$A = \frac{A_{s,tot}}{2} = \frac{1290.937}{2} = 645.468\ mm^2$$

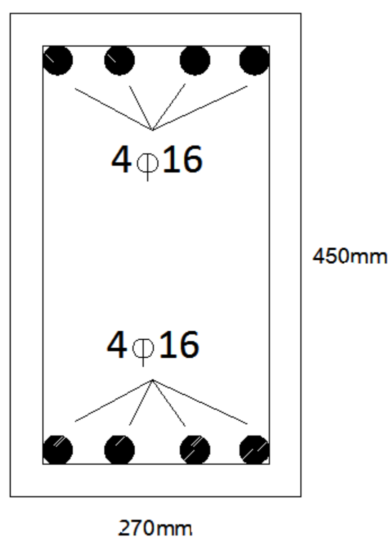
Check with maximum and minimum reinforcement limit

$$A_{s,min} = \ max \begin{cases} \frac{0.1\ N_{ED}}{f_{yd}} \\ 0.002 A_c \end{cases} = 275\ mm^2 \qquad OK!$$

$$A_{s,max} = 0.08\ A_c = 0.08 * 270 * 450 = \qquad\qquad OK!$$

Step 4- Detailing

$$Use\ 4\emptyset 16\ on\ each\ face$$



Example 4.2 [Biaxial column design]

Determine the longitudinal reinforcement for corner column of size 400*400 mm and the design factored moment and axial force of

$$P = 1360\ KN \quad M_{sd,h} = 200\ KNm \quad M_{sd,b} = 100\ KNm$$

Use C25/30 and S460 class 1 work take $\frac{h'}{h} = \frac{b'}{b} = 0.1$

Solution

Step 1- Material

$$f_{cd} = \frac{0.85 * 25}{1.5} = 14.16667\ mpa$$

$$f_{yd} = \frac{460}{1.15} = 400\ mpa$$

Step 2- Determine the normalized axial and bending moment value

$$v_{sd} = \frac{p}{f_{cd}bh} = \frac{1360*10^3}{14.1667*400*400} = 0.6$$

$$\mu_{sd,h} = \frac{m_{sd}}{f_{cd}bd^2} = \frac{200 * 10^6}{14.1667 * 400 * 400^2} = 0.2206$$

$$\mu_{sd,b} = \frac{m_{sd}}{f_{cd}db^2} = \frac{100 * 10^6}{14.1667 * 400 * 400^2} = 0.1103$$

Step 3- Find ω using $\frac{d'}{d} = \frac{b'}{B} = 0.1$, $V_{sd} = 0.6$,

$\mu_{sd,h} = 0.2206$,

$\mu_{sd,b} = 0.1103$

From biaxial chart $\omega = 0.6$

$$A_{s,tot} = \frac{\omega f_{cd}bd}{f_{yd}} = \frac{0.6 * 14.166 * 400 * 400}{400} = 3400\ mm^2$$

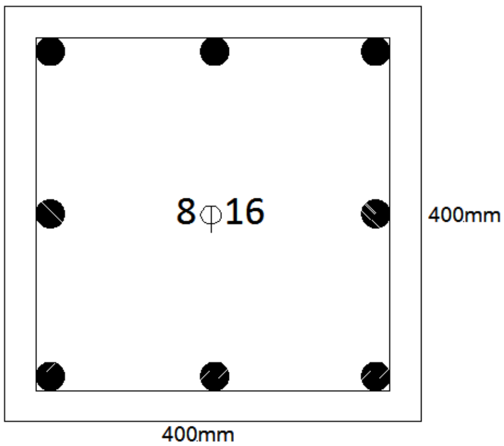
Check with maximum and minimum reinforcement limit

$$A_{s,min} = max\begin{cases}\dfrac{0.1\ N_{ED}}{f_{yd}} \\ 0.002A_c\end{cases} = 340\ mm^2 \qquad \boldsymbol{OK}!$$

$$A_{s,max} = 0.08\ A_c = 0.08 * 400 * 400 = 12800 \qquad \boldsymbol{OK}!$$

Step 4- Detailing

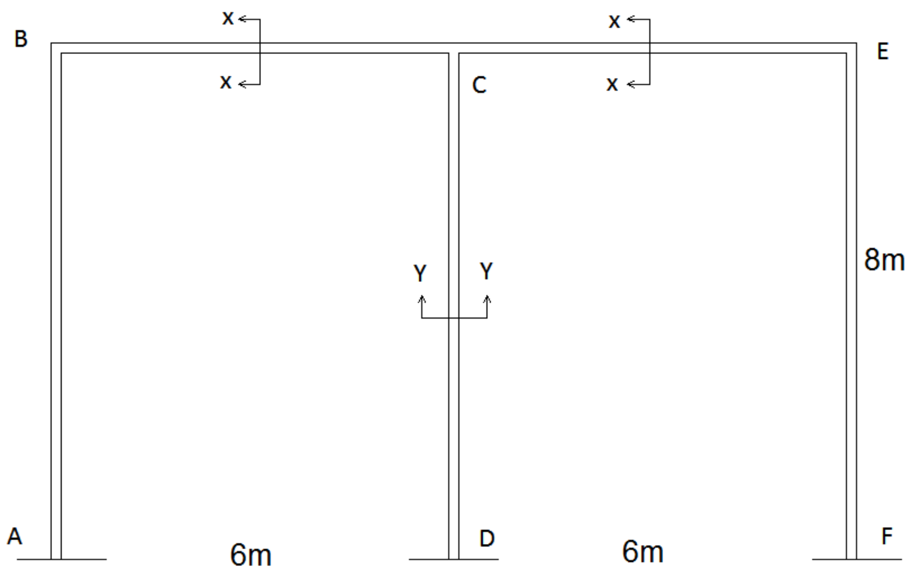
$$using\ \emptyset 24 \quad n = \frac{3400}{452.16} = 7.52 \quad so \quad Use\ 8\emptyset 24$$

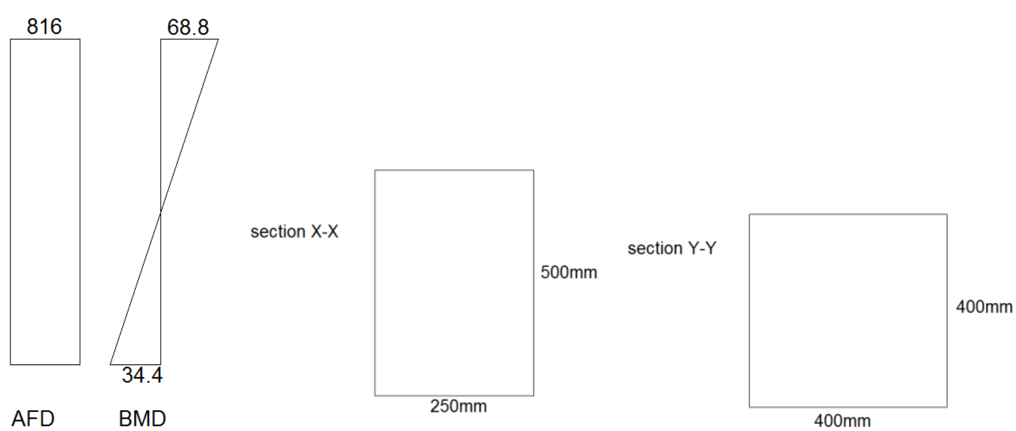


Example 4.3 [Column]

Determine whether the column CD is slender or not, if it is subjected t loads shown below. Consider the frame to be non-sway

Use C25/30 $f_{cd} = 14.1667\ mpa$





Solution

Step 1- Slenderness limit

$$\lambda_{lim} = {}^{20ABC}/_{\sqrt{n}} \quad take\ A = 0.7 \quad B = 1.1 \quad C = 1.7 - r_m$$

$$where\ r_m = \frac{m_{01}}{m_{02}} = \frac{-34.4}{68.8} = -0.5 \qquad C = 1.7 - (-0.5) = 2.2$$

$$n = \frac{N_{ed}}{A_c f_{cd}} = \frac{516 * 10^3}{14.1667 * 400 * 400} = 0.227647$$

$$\lambda_{lim} = \frac{20 * 0.7 * 1.1 * 2.2}{\sqrt{0.227647}} = 71.0088$$

Step 2-Find the slenderness of the column

2.1 Effective length

For Braced member

$$l_0 = 0.5l\sqrt{\left[1 + \frac{K_1}{0.5 + K_1}\right]\left[1 + \frac{K_2}{0.5 + K_2}\right]}$$

$$K = \frac{Column\ stiffness}{\sum beam\ stiffness}$$

$$K_i = \frac{\left(^{EI}/_{l}\right) column}{2\left(2\,^{EI}/_{l}\right) beam}$$

$$I_{column} = \frac{400 * 400^3}{12} = 2133333333\ mm^4$$

$$I_{beam} = \frac{250 * 500^3}{12} = 2604166667\ mm^4$$

$$K_1 = \frac{\frac{2133333333E}{8000}}{2(\frac{2 * 2604166667E}{6000})} = 0.1536$$

For fixed restraint K=0 but in reality we cannot provide a fully fixed support so use $K_2 = 0.1$

$$l_0 = 0.5 * 6000\sqrt{\left[1 + \frac{0.1536}{0.5 + 0.1536}\right]\left[1 + \frac{0.1}{0.5 + 0.1}\right]} = 3601.050\ mm$$

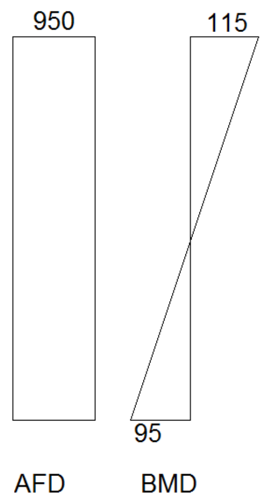
$$\lambda = \frac{l_o}{i} \qquad i = \sqrt{\frac{I}{A}} = \sqrt{\frac{2133333333}{160000}} = 115.470\ mm$$

$$\lambda = \frac{3601.0504}{115.470} = 31.186\ mm$$

$$\lambda < \lambda_{lim} \qquad Short\ column$$

Example 4.4 [Column Design]

Design the braced column to resist an axial load of 950 KN and a moment of M_{sd} =115 KNM at the top and M_{sd} =-95 KNM at the bottom as shown below .length of the column is 5.5 m and cross-section of 300*300 mm use C25/30 and S460 take L_e=0.66L



Solution

Step 1- Material

$$f_{cd} = \frac{0.85 * 25}{1.5} = 14.16667\ mpa$$

$$f_{yd} = \frac{460}{1.15} = 400\ mpa$$

Step 2- Check slenderness limit

$$\lambda_{lim} = {}^{20ABC}/_{\sqrt{n}} \quad take\ A = 0.7 \quad B = 1.1 \quad C = 1.7 - r_m$$

$$where\ r_m = \frac{m_{01}}{m_{02}} = \frac{-95}{115} = -0.826 \qquad C = 1.7 - (-0.826) = 2.526$$

$$n = \frac{N_{ed}}{A_c f_{cd}} = \frac{950 * 10^3}{14.1667 * 300 * 300} = 0.745$$

$$\lambda_{lim} = \frac{20 * 0.7 * 1.1 * 2.526}{\sqrt{0.745}} = 45.066$$

Step 3-Slenderess

$$\lambda = \frac{l_o}{i} \quad i = \sqrt{\frac{I}{A}} = \sqrt{\frac{675000000}{90000}} = 86.6025\ mm$$

$$ƛ = \frac{0.66 * 5500}{86.6025} = 41.915$$

$ƛ < ƛ_{lim}$ $\boldsymbol{Short\ column\ negelect\ second\ order\ effect}$

Step 4- accidental eccentricity

$$e_a = \frac{l_o}{400} = \frac{3630}{400} = 9.075\ mm$$

Step 5- Equivalent first order eccentricity

$$e_e = max \begin{cases} 0.6e_{02} + 0.4\ e_{01} \\ 0.4e_{02} \end{cases}$$

$$e_{02} = \frac{M_{02}}{N_{sd}} = \frac{115 * 10^6}{950 * 10^3} = 121.052\ mm$$

$$e_{01} = \frac{M_{01}}{N_{sd}} = \frac{95 * 10^6}{950 * 10^3} = 100\ mm$$

$$e_e = max \begin{cases} 0.6e_{02} + 0.4\ e_{01} \\ 0.4e_{02} \end{cases} = 48.4208\ \text{mm}$$

$$e_{tot} = e_o + e_e + e_2 = 9.075 + 48.4208 + 0 = 57.4958\ mm$$

$$check\ with\ \ e = e_{02} + e_a = 121.052 + 9.075 = 130.127\ mm$$

$$So\ take\ e_{tot} = 130.127\ mm$$

Step 6- Design

$$N_{sd} = 950\ KN \quad M_{sd} = N_{sd} * e_{tot} = 123.62\ KNm$$

$$v_{sd} = \frac{p}{f_{cd}bh} = \frac{950 * 10^3}{14.1667 * 300 * 300} = 0.745$$

$$\mu_{sd} = \frac{m_{sd}}{f_{cd}bd^2} = \frac{123.62 * 10^6}{14.1667 * 300 * 300^2} = 0.3232$$

Using $\frac{d'}{d} = 0.15$ read the mechanical steel ratio from uniaxial interaction chart for

$$V_{sd} = 0.745$$

$$\mu_{sd} = 0.3232$$

$$\omega = 0.79$$

$$A_{s,tot} = \frac{\omega f_{cd}bd}{f_{yd}} = \frac{0.79 * 14.166 * 300 * 300}{400} = 2518.125\ mm^2$$

$$A = \frac{A_{s,tot}}{2} = \frac{2518.125}{2} = 1259.0625\ mm^2$$

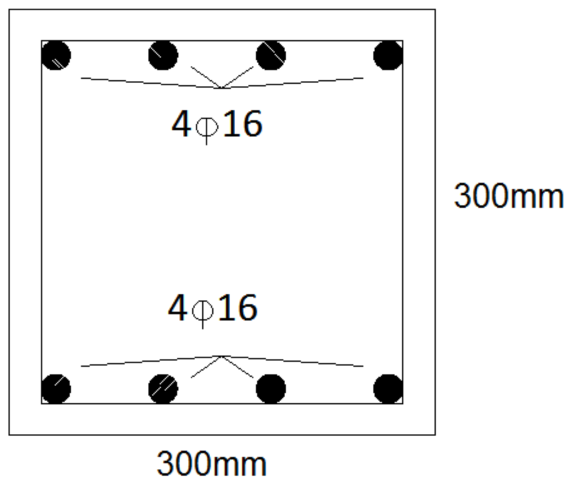
Check with maximum and minimum reinforcement limit

$$A_{s,min} = \; max\begin{cases}\dfrac{0.1\,N_{ED}}{f_{yd}} \\ 0.002A_c\end{cases} = 237.5\,mm^2 \qquad OK!$$

$$A_{s,max} = 0.08\,A_c = 0.08 * 300 * 300 = 7200\,mm^2 \qquad \boldsymbol{OK}!$$

Using Ø20 $\quad$ $provide\ 4Ø20\ on\ each\ face$

Step 7- Detailing



Example 4.5 [Column]

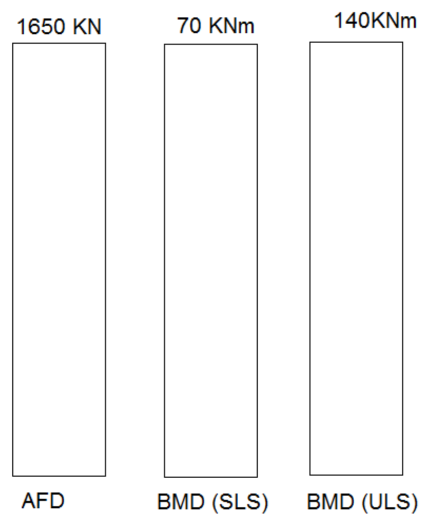
Design the braced column if it is subjected to the following loading .the column has total length of 6 m. L_e=0.7L

Use C25/30 and S460

If the column is slender .compute the total design moment using

a) Nominal curvature
b) Nominal stiffness

Use 400*400 mm section $\frac{d'}{d} = 0.1 \quad use\ \emptyset(\infty, t_o) = 2$



Solution

Step 1. Material data

$$f_{cd} = \frac{0.85 * 25}{1.5} = 14.16667\ mpa$$

$$f_{yd} = \frac{460}{1.15} = 400\ mpa$$

$$E_{cm} = 30\ Gpa$$

$$E_s = 200\ Gpa$$

Step 2- Check slenderness limit

$$\lambda_{lim} = {}^{20ABC}/_{\sqrt{n}} \quad take\ A = 0.7 \quad B = 1.1 \quad C = 1.7 - r_m$$

$$where\ r_m = \frac{m_{01}}{m_{02}} = \frac{140}{140} = 1 \qquad C = 1.7 - (1) = 0.7$$

$$n = \frac{N_{ed}}{A_c f_{cd}} = \frac{1650 * 10^3}{14.1667 * 400 * 400} = 0.72794$$

$$\lambda_{lim} = \frac{20 * 0.7 * 1.1 * 0.7}{\sqrt{0.72794}} = 12.63487$$

Step 3-slenderess

$$\lambda = \frac{l_o}{i} \qquad i = \sqrt{\frac{I}{A}} = \sqrt{\frac{2133333333}{160000}} = 115.470\ mm$$

$$\lambda = \frac{0.7 * 6000}{115.470} = 36.373$$

$$\lambda > \lambda_{lim} \qquad \boldsymbol{Slender\ column\ consider\ second\ order\ effect}$$

Step 4- accidental eccentricity

$$e_a = \frac{l_o}{400} = \frac{4200}{400} = 10.5\ mm$$

Step 5- Equivalent first order eccentricity

$$e_e = max\begin{cases} 0.6e_{02} + 0.4\ e_{01} \\ 0.4e_{02} \end{cases}$$

$$e_{02} = \frac{M_{02}}{N_{sd}} = \frac{140 * 10^6}{1650 * 10^3} = 84.848\ mm$$

$$e_{01} = \frac{M_{01}}{N_{sd}} = \frac{140 * 10^6}{1650 * 10^3} = 84.848\ mm$$

$$e_e = max\begin{cases} 0.6e_{02} + 0.4\ e_{01} \\ 0.4e_{02} \end{cases} = 84.848\ \text{mm}$$

Step 6- Calculate the second order moment

a) **Using Nominal curvature method**

$$e_2 = \frac{1}{r} {l_o}^2 / C \qquad \boldsymbol{C = 10 \quad For\ constant\ cross - section}$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_o} \qquad K_\emptyset = 1 + \beta \emptyset_{eff}$$

$$\emptyset_{eff} = 0 \quad if \quad \begin{cases} \emptyset(\infty, t_o) \le 2 & \boldsymbol{OK} \\ \lambda \le 75 & \boldsymbol{OK} \\ \frac{M_{oed}}{N_{ed}} \ge h & \boldsymbol{Not\ OK} \end{cases}$$

$$\emptyset_{eff} = \emptyset(\infty, t_o)\frac{M_{oeqp}}{M_{oed}}$$

$where \quad M_{oeqp} = first\ order\ moment\ i\ nquasi - permanent\ load(SLS)$

$M_{oed} = First\ order\ moment\ in\ design\ load\ combination\ (ULS)$

$$\emptyset_{eff} = \emptyset(\infty, t_o)\frac{M_{oeqp}}{M_{oed}} = 2 * \frac{70}{140} = 1$$

$$\beta = 0.35 + {}^{f_{ck}}/_{200} - {}^{\lambda}/_{150} = 0.35 + {}^{25}/_{200} - {}^{36.375}/_{150} = 0.2325$$

$$K_\emptyset = 1 + \beta\emptyset_{eff} = 1 + 0.2325 * 1 = 1.2325$$

$$\frac{1}{r_o} = \frac{\varepsilon_{yd}}{0.45d} = \frac{2 * 10^{-3}}{360} = 123456 * 10^{-5} \qquad d = effective\ depth$$

$$K_r = \frac{(n_u - n)}{(n_u - n_{bal})} \quad n_u = 1 + \omega \quad n = \frac{N_{ed}}{A_c f_{cd}} = \frac{1650 * 10^3}{14.166 * 400^2}$$

$$= 0.72974 \quad n_{bal} = 0.4$$

For first iteration take $\boldsymbol{e_2 = 0}$

$$e_{tot} = e_o + e_e + e_2 = 10.5 + 84.848 + 0 = 95.348\ mm$$

$$N_{sd} = 1650\ KN \qquad M_{sd} = N_{sd} * e_{tot} = 157.3242\ KNm$$

$$v_{sd} = \frac{N_{sd}}{f_{cd}bh} = \frac{1650 * 10^3}{14.1667 * 400 * 400} = 0.72794$$

$$\mu_{sd} = \frac{m_{sd}}{f_{cd}bd^2} = \frac{157.3242 * 10^6}{14.1667 * 400 * 400^2} = 0.17352$$

$$Using\ v_{sd} = 0.72794 \quad \mu_{sd} = 0.1752 \quad \frac{d'}{d} = 0.1 \qquad \omega = 0.25$$

So

$$n_u = 1 + \omega = 1.25 \quad K_r = \frac{(n_u - n)}{(n_u - n_{bal})} = \frac{(1.25 - 0.72794)}{(1.25 - 0.4)} = 0.614$$

$$\frac{1}{r} = 0.614 * 1.2325 * 1.23456 * 10^{-5} = 9.3456 * 10^{-6}$$

$$e_2 = \frac{1}{r}{}^{4200^2}/_{10} = 16.485\ mm$$

For Second iteration take $\boldsymbol{e_2 = 16.485\ mm}$

$$e_{tot} = e_o + e_e + e_2 = 10.5 + 84.848 + 16.485 = 111.833\ mm$$

$$N_{sd} = 1650\ KN \qquad M_{sd} = N_{sd} * e_{tot} = 184.525\ KNm$$

$$Using \quad v_{sd} = 0.72794 \quad and \quad \mu_{sd} = 0.2035 \qquad \omega = 0.35$$

$$n_u = 1 + \omega = 1.35 \quad K_r = \frac{(n_u - n)}{(n_u - n_{bal})} = \frac{(1.35 - 0.72794)}{(1.35 - 0.4)} = 0.6548$$

$$\frac{1}{r} = 0.6548 * 1.2325 * 1.23456 * 10^{-5} = 9.9634 * 10^{-6}$$

$$e_2 = \frac{1}{r} 4200^2 / 10 = 17.575\ mm$$

For their iteration take $\boldsymbol{e_2 = 17.575\ mm}$

$$e_{tot} = e_o + e_e + e_2 = 10.5 + 84.848 + 17.575 = 112.923\ mm$$

$$N_{sd} = 1650\ KN \quad M_{sd} = N_{sd} * e_{tot} = 186.323\ KNm$$

$$Using \quad v_{sd} = 0.72794 \quad and \quad \mu_{sd} = 0.2055 \qquad \omega = 0.35$$

The iteration **converges** with similar mechanical steel ratio $\boldsymbol{\omega = 0.35}$ **.**

$$A_{s,tot} = \frac{\omega f_{cd} bd}{f_{yd}} = \frac{0.35 * 14.166 * 400 * 400}{400} = 1983.33\ mm^2$$

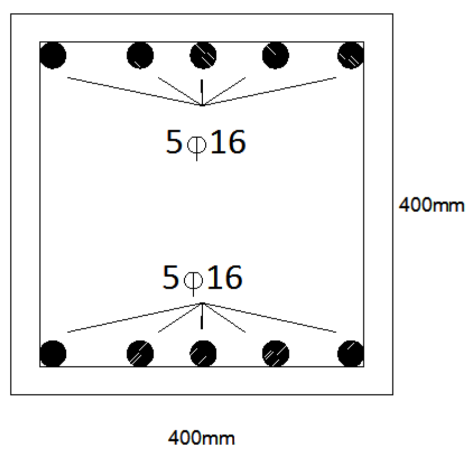
$$A = \frac{A_{s,tot}}{2} = \frac{1983.33}{2} = 991.666\ mm^2$$

Check with maximum and minimum reinforcement limit

$$A_{s,min} = \ max \begin{cases} \frac{0.1\ N_{ED}}{f_{yd}} \\ 0.002 A_c \end{cases} = 412.5\ mm^2 \qquad \boldsymbol{OK}!$$

$$A_{s,max} = 0.08\ A_c = 0.08 * 400 * 400 = 12800\ mm^2 \qquad \boldsymbol{OK}!$$

Using $\boldsymbol{\emptyset 16}$ $\quad \boldsymbol{provide\ 5\emptyset 16\ on\ each\ face}$



b) Using Nominal stiffness method

$$EI = K_c E_{cd} I_c + K_s E_s I_s$$

$$E_{cd} = \frac{E_{cm}}{\gamma_{ce}} = \frac{30}{1.2} = 25\ Gpa$$

Initially let us assume $\boldsymbol{\rho \geq 0.01}$ $\boldsymbol{to\ use\ the}$ **simplified** $\boldsymbol{method}$

$$K_s = 0 \quad K_c = {}^{0.3}/_{1 + 0.5\emptyset_{eff}}$$

$$\emptyset_{eff} = 1 \quad K_c = 0.2$$

$$I_c = \frac{bh^3}{12} = 2133333333\ mm^4$$

$$EI = K_c E_{cd} I_c + K_s E_s I_s = 0.2 * 25 * 10^3 * 2133333333 = 1.06667 * 10^{13}$$

$$N_b = \frac{\Pi^2 EI}{{l_o}^2} = \frac{\Pi^2 * 1.06667 * 10^{13}}{4200^2} = 5968.01475\ KN$$

N_b= Buckling load based on nominal stiffness

Design moment $M_{ed} = M_{oed}\left[1 + \frac{\beta}{\left({}^{N_b}/_{N_{ed}}\right) - 1}\right]$

$$\beta = {}^{\Pi^2}/_{c_o}$$

$$c_o = 8$$

$$M_{oed} = 140\ KNm$$

$$M_{ed} = M_{oed}\left[1 + \frac{\beta}{\left({}^{N_b}/_{N_{ed}}\right) - 1}\right] = 140 * \left[1 + \frac{1.2337}{\left({}^{5968.01475}/_{1650}\right) - 1}\right]$$

$$= 205.999\ KNm$$

For first iteration neglecting accidental eccentricity

$$v_{sd} = \frac{N_{sd}}{f_{cd} bh} = \frac{1650 * 10^3}{14.1667 * 400 * 400} = 0.72794$$

$$\mu_{sd} = \frac{m_{sd}}{f_{cd} bd^2} = \frac{205.999 * 10^6}{14.1667 * 400 * 400^2} = 0.2272$$

$$Using\ v_{sd} = 0.72794 \quad \mu_{sd} = 0.2272 \quad \frac{d'}{d} = 0.1 \qquad \omega = 0.4$$

$$A_{s,tot} = \frac{\omega f_{cd} bd}{f_{yd}} = \frac{0.4 * 14.166 * 400 * 400}{400} = 2266.666\ mm^2$$

$$A = \frac{A_{s,tot}}{2} = \frac{2266.666}{2} = 1133.333\ mm^2$$

$$\rho = \frac{A_s}{bd} = \frac{1133.333}{400 * 360} = 7.870 * 10^{-3} \quad \rho < 0.01$$

We cannot use the simplified method

$$for\ \rho > 0.002 \quad K_s = 1$$

$$K_c = {K_1 K_2}/{(1 + \emptyset_{eff})}$$

$$K_1 = \sqrt{{f_{ck}}/{20}} = 1.11803$$

$$K_2 = n\frac{\lambda}{170} \le 0.2$$

$$n = \frac{N_{ed}}{A_c f_{cd}} = 0.72794$$

$$K_2 = 0.2 \quad So \quad K_c = 0.111803$$

$$I_c = \frac{bh^3}{12} = 2133333333\ mm^4$$

$$I_s = 2 * [1133.333(360 - 200)^2] = 58026666.67\ mm^2$$

$$EI = K_c E_{cd} I_c + K_s E_s I_s = 0.111803 * 25 * 10^3 * 2133333333 + 1 * 200 * 10^3 * 58026666.6$$

$$EI = 1.756816 * 10^{13}$$

$$N_b = \frac{\Pi^2 EI}{{l_o}^2} = \frac{\Pi^2 * 1.756816 * 10^{13}}{4200^2} = 9829.40982\ KN$$

$$M_{ed} = M_{oed}\left[1 + \frac{\beta}{\left({N_b}/{N_{ed}}\right) - 1}\right] = 140 * \left[1 + \frac{1.2337}{\left({9829.40982}/{1650}\right) - 1}\right] = 174.842\ KNm$$

Design moment including accidental eccentricity is given by

$$M = 174.842 + 1650 * \left(\frac{10.5}{1000}\right) = 192.167\ KNM$$

$$v_{sd} = \frac{N_{sd}}{f_{cd} bh} = \frac{1650 * 10^3}{14.1667 * 400 * 400} = 0.72794$$

$$\mu_{sd} = \frac{m_{sd}}{f_{cd} bd^2} = \frac{192.167 * 10^6}{14.1667 * 400 * 400^2} = 0.212$$

$$Using\ v_{sd} = 0.72794 \quad \mu_{sd} = 0.212 \quad \frac{d'}{d} = 0.1 \qquad \omega = 0.35$$

$$A_{s,tot} = \frac{\omega f_{cd} bd}{f_{yd}} = \frac{0.35 * 14.166 * 400 * 400}{400} = 1983.333\ mm^2$$

$$A = \frac{A_{s,tot}}{2} = \frac{1983.33}{2} = 991.666\ mm^2$$

$$\rho = \frac{A_s}{bd} = \frac{991.666}{400 * 360} = 6.886 * 10^{-3} \quad \rho > 0.002$$

Second Iteration

$$I_c = \frac{bh^3}{12} = 2133333333\ mm^4$$
$$I_s = 2 * [991.666(360 - 200)^2] = 50773333.33\ mm^2$$
$$EI = K_c E_{cd} I_c + K_s E_s I_s$$
$$= 0.111803 * 25 * 10^3 * 2133333333 + 1 * 200 * 10^3 * 50773333.3$$
$$EI = 1.611749 * 10^{13}$$

$$N_b = \frac{\Pi^2 EI}{{l_o}^2} = \frac{\Pi^2 * 1.611749 * 10^{13}}{4200^2} = 9017.7598\ KN$$
$$M_{ed} = M_{oed}\left[1 + \frac{\beta}{\left(N_b/N_{ed}\right) - 1}\right] = 140 * \left[1 + \frac{1.2337}{\left(9017.7598/1650\right) - 1}\right]$$
$$= \mathbf{178.679\ KNm}$$

Design moment including accidental eccentricity is given by

$$M = 178.679 + 1650 * \left(\frac{10.5}{1000}\right) = 196.004\ KNM$$

$$v_{sd} = \frac{N_{sd}}{f_{cd}bh} = \frac{1650 * 10^3}{14.1667 * 400 * 400} = 0.72794$$
$$\mu_{sd} = \frac{m_{sd}}{f_{cd}bd^2} = \frac{196.004 * 10^6}{14.1667 * 400 * 400^2} = 0.216$$
$$Using\ v_{sd} = 0.72794 \quad \mu_{sd} = 0.216 \quad \frac{d'}{d} = 0.1 \qquad \omega = 0.35$$

The iteration converges with similar mechanical steel ratio $\omega = 0.35$.

$$A_{s,tot} = \frac{\omega f_{cd} bd}{f_{yd}} = \frac{0.35 * 14.166 * 400 * 400}{400} = 1983.33\ mm^2$$
$$A = \frac{A_{s,tot}}{2} = \frac{1983.33}{2} = 991.666\ mm^2$$

Check with maximum and minimum reinforcement limit

$$A_{s,min} = \ max\begin{cases}\dfrac{0.1\ N_{ED}}{f_{yd}} \\ 0.002A_c\end{cases} = 412.5\ mm^2 \qquad \boldsymbol{OK}!$$

$$A_{s,max} = 0.08\, A_c = 0.08 * 400 * 400 = 12800\; mm^2 \qquad \boldsymbol{OK}!$$

Using $\emptyset 16$ $\qquad$ $\boldsymbol{provide\ 5\emptyset 16\ on\ each\ face}$

Step 7- Detailing