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4th TASK: REINFORCEMENT OF THE COLUMN

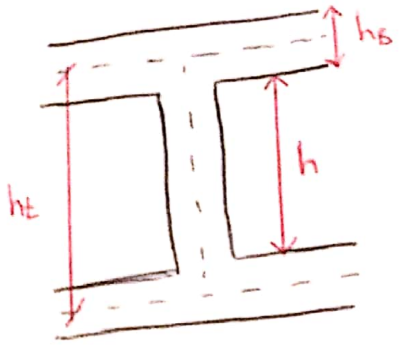
1. GEOMETRIC IMPERFECTIONS

$\theta_0 = 1/200 \rightarrow$ Basic value of imperfection

$$e_i = \theta_0 \cdot \alpha_h \cdot \alpha_m \cdot \frac{l_0}{2}$$

- $\alpha_h = \frac{2}{\sqrt{h}}$; $h = h_t - h_B$

h = clear lenght of the column



$h_t = 3'9\,m$
$h_B = 600\,mm$

$h = 3900 - 600$
$h = 3300\,mm$

$$\alpha_h = \frac{2}{\sqrt{3.3}} = 1'1$$

m = number of columns in one frame

- $\alpha_m = \sqrt{0'5\left(1 + \frac{1}{m}\right)}$ with $m = 3$

$$\alpha_m = \sqrt{0'5\left(1 + \frac{1}{3}\right)} = 0'8165$$

- $l_0 = 0'8 \cdot h = 0'8 \cdot 3'3 = 2'64\,m$

$\rightarrow e_i = \frac{1}{200} \cdot 1'1 \quad 0'8165 \cdot \frac{2'64}{2} = 0'0059\,m$

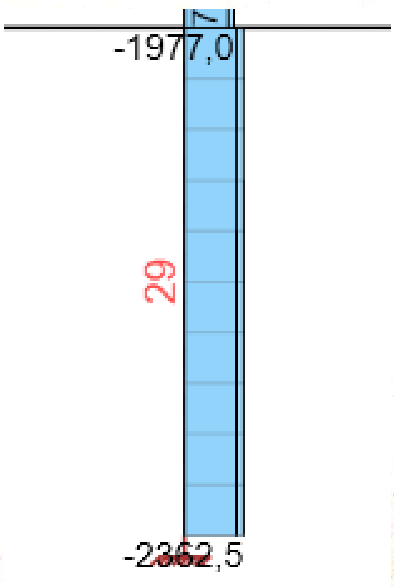
Additional moment due to geometric imperfection:

$M_{imp} = N_{Ed} \cdot e_i$

From task 2:

Ned in Head:
$N_{Ed} = -1977\,KN$

Ned in the Foot
$N_{Ed} = -2362'5\,KN$



Member	HEAD	FOOT
|Mmax|	11'7	13'9

		HEAD	FOOT
COMB1	Med	0	0
	Med,	11'7	13'9
COMB2	Med	4	-2'3
	Med,	15'7	16'2

COMB1

Member	Dx	Combination	N[kN]	Vz[kN]	My[kNm]
29	0,00	CO1(2)	**-2362,5**	**0,0**	**0,0**
29	3,90	CO1(2)	**-2354,5**	0,0	0,0

COMB2

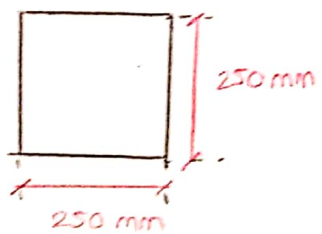
Member	Dx	Combination	N[kN]	Vz[kN]	My[kNm]
28	3,90	CO2(3)	-128,4	20,2	39,1
29	0,00	CO2(3)	**-2075,2**	1,6	**-2,3**
29	3,90	CO2(3)	**-2067,1**	**1,6**	**4,0**

2. SLENDERNESS OF THE COLUMN

$\lambda = \frac{l_0}{i}$; $i = \sqrt{\frac{I}{A_c}}$; $I = \frac{1}{12} b_{col} \cdot h_{col}^3$

$I = \frac{1}{12} \cdot 0'25 \cdot 0'25^3$

Section of my column: (TASK 1)



- $I = 3'25\, e^{-4}\ m^4$
- $A_c = 0'25 \cdot 0'25 = 6'25\, e^{-2}$
- $i = \sqrt{\frac{3'25 e^{-4}}{6'25 e^{-2}}} = 7'5\, e^{-2}\ m^2$

$\rightarrow \lambda = \frac{2'64\ m}{7'5 e^{-2}\ m^2} = 35'2\ m^{-1}$

LIMITING SLENDERNESS

$\lambda_{lim} = \frac{20 \cdot A \cdot B \cdot C}{\sqrt{n}} \leq 75$; $n = \frac{N_{Ed}}{A_c \cdot f_{cd}}$

A = 0'7 → Effect of creep
B = 1'1 → Effect of reinforc

$f_{cd} = 16'67$ MPa
[C25/30]

$16'67\ MPa = 16'67 e^3\ kN/m^2$

COMB 1

$n = \frac{2362'5\, e^3}{6'25 e^{4} \cdot 16'67}$

$n = 2'26$

$C = 0'7$ (no moments from Internal forces)

COMB 2

$n = \frac{2075'2 e^3}{6'25 e^{4} \cdot 16'67}$

$n = 1'99$

$C = 1'7 - r_m$

$r_m = \frac{M_{01}}{M_{02}} = \frac{-2'3}{4} = -0'575$

$C = 2'275$

For COMB 1:

$$\lambda_{lim} = \frac{20 \cdot 0'7 \cdot 1'1 \cdot 0'7}{\sqrt{2'26}} = 7'17 \leq 75$$

For COMB2:

$$\lambda_{lim} = \frac{20 \cdot 0'7 \cdot 1'1 \cdot 2'275}{\sqrt{1'99}} = 24'83 \leq 75$$

In both cases, $\lambda = 35'2 > \lambda_{limt} = 7'17$ (the lowest) so my column is slender, so it is supposed we need to increase the bending moment. a 30 %

$M_{Ed,I(COMB1)} = 18'07$ KN·m $\quad M_{Ed,I,COMB2} = 21'06$ KN·m

3. DESING OF REINFORCEMENT

1st METHOD

$$A_{s,req,1} = \frac{N_{Ed} - 0'8 \cdot A_c \cdot f_{cd}}{\sigma_s} \; ; \; \sigma_s \begin{cases} = 400 \text{ MPa if } f_{yd} \geq 400 \text{ MPa} \\ = f_{yd} \text{ if } f_{yd} < 400 \text{ MPa} \end{cases}$$

In my case, for B500, $f_{yd} = 434'78$ MPa > 400 MPa

so: $\sigma_s = 400$ MPa.

COMB 1

$$A_{s,req,1} = \frac{2362'5 - 0'8 \cdot 6'25 e^{-2} \cdot 16'67 e^3}{400 e^3}$$

$$A_{s,req,1} = 0'0038 \; m^2 = 3800 \; mm^2$$

COMB 2

$$A_{s,req,1} = \frac{2075'2 - 0'8 \cdot 6'25 e^{-2} \cdot 16'67 e^3}{400 e^3} = 0'0031 \; m^2$$

2nd METHOD

$$\mu = \frac{M_{Ed,I}}{b_{col} \cdot h_{col}^2 \cdot f_{cd}} \; ; \; \nu = \frac{N_{Ed}}{b_{col} \cdot h_{col} \cdot f_{cd}}$$ with μ and $\nu \rightarrow \omega$ in chart.

COMB 1

$$\mu = \frac{18'07}{0'25 \cdot 0'25^2 \cdot 16'67 e^3} = 0'069$$

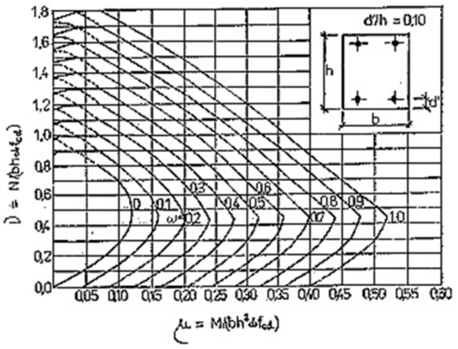
$$\nu = \frac{2362'5}{0'25 \cdot 0'25 \cdot 16'67 e^3} = 2'26$$

COMB 2

$$\mu = \frac{21'06}{0'25^3 \cdot 16'67 e^3} = 0'08$$

$$\nu = \frac{2075'2}{0'25^2 \cdot 16'67 e^3} = 1'99$$

$\omega = 0$ in both cases (out of the graph)



So, in both cases: $A_{s,req,2} = \dfrac{\omega \cdot A_c \cdot f_{cd}}{f_{yd}} = 0\ mm^2$

For $A_{s,req} < 0 \rightarrow 4\ \phi 12mm\ (452\ mm^2)$

So, finally: $A_{s,req} = \max(A_{s,req,1};\ A_{s,req2})$

$A_{s,req} = \max(3800;\ 452)\ mm^2$

$A_{s,req} = 3800\ mm^2 \rightarrow 8 \cdot \phi 25\ [A_{s,prov} = 3927\ mm^2]$

CHECK DETAILING RULES

- $A_{s,prov} \geq A_{s,min} = \max\left(0'1 \cdot \dfrac{N_{ed}}{f_{yd}};\ 0'002 \cdot A_c\right)$

$A_{s,min} = \max\left(0'1 \cdot \dfrac{2362'5}{434'78e^3};\ 0'002 \cdot 6'25e^{-2}\right)$

$A_{s,min} = \max(0'00054\ m^2;\ 0'000125\ m^2)$

$A_{s,min} = 540\ mm^2 < A_{s,prov} = 3927\ mm^2$ ✓

- $A_{s,max} = 0'04 \cdot A_c \geq A_{s,prov}$

$0'04 \cdot 6'25e^{-2} = 0'0025\ m^2 = 2500\ mm^2$

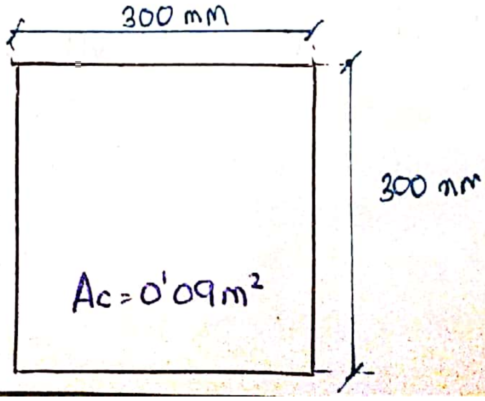
$A_{s,max} = 2500\ mm^2 \ngeq A_{s,prov} = 3927\ mm^2$

So, I will increase the cross-section of my column and change the concrete class to a C35/45. And the cross-section to 300 mm x 300 mm.

C35/45

$f_{ck} = 35\ MPa$

$f_{cd} = \dfrac{35}{1'5} = 23'3\ MPa$



So, we restart with the calculation of the REINFORCEMENT (I assume with this new section it will be also a slender column.

3.(1) DESING OF REINFORCEMENT

1st METHOD $A_c = 0'09 m^2 = 9e^4 mm^2$

COMB 1

$$A_{s,req,1} = \frac{2362'5 - 0'8 \cdot 0'09 \cdot 23'3e^3}{400\,e^3} = 0'00171\,m^2$$

$$A_{s,req,1} = 1712'2\ mm^2$$

COMB 2

$$A_{s,req,1} = \frac{2075'2 - 0'8 \cdot 0'09 \cdot 23'3e^3}{400\,e^3} = 0'00099\,m^2$$

$$A_{s,req,1} = 994\ mm^2$$

2nd METHOD

COMB 1

$$\mu = \frac{18'07}{0'3^3 \cdot 23'3e^3} = 0'028$$

$$\nu = \frac{2362'5}{0'3^2 \cdot 23'3e^3} = 1'12$$

$\omega = 0'1$

$$A_{s,req,2} = \frac{0'1 \cdot 0'09 \cdot 23'3e^3}{434'78e^3}$$

$$A_{s,req,2} = 0'00048\,m^2 = 482'3\,mm^2$$

COMB 2

$$\mu = \frac{21'06}{0'3^3 \cdot 23'3e^3} = 0'033$$

$$\nu = \frac{2075'2}{0'3^2 \cdot 16'67e^3} = 0'989$$

$\omega = 0$

$A_{s,req,2} = 0$

$$A_{s,req} = \max(1712'2\,mm^2 ; 482'3\,mm^2) = 1712'2\,mm^2$$

with **6 Ø 20** ($A_{s,prov} = 1885\ mm^2$)

CHECK DETAILING RULES

- $A_{s,min} = \max\left(0'1 \cdot \frac{2362'5}{434'78e^3} ; 0'002 \cdot 0'09\right) = \max(543'4 ; 180)\,mm$

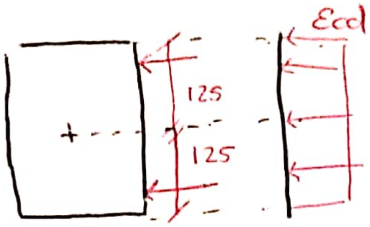
  $A_{s,min} = 543'4 < A_{s,prov} = 1885\,mm^2$ ✓

- $A_{s,max} = 0'04 \cdot A_c = 0'04 \cdot 0'09 = 3600\,mm^2$

  $A_{s,max} > A_{s,prov} = 1885\,mm^2$ ✓

4. INTERATION DIAGRAM

POINT 0 : maximum normal force resistance.



$N_{Rd,0} = b_{col} \cdot h_{col} f_{cd} + A_{s1} \sigma_s + A_{s2} \sigma_s$

$M_{Rd,0} = (A_{s2} z_2 - A_{s1} z_{s1}) \sigma_s$

$A_{s1} = A_{s2}$ and $z_{s1} = z_{s2}$

$N_{Rd,0} = 0'3^2 \cdot 23'3e^3 + 2 \cdot 1885 e^{-6} \cdot 400 e^3 =$

$N_{Rd,0} = 3605$ KN

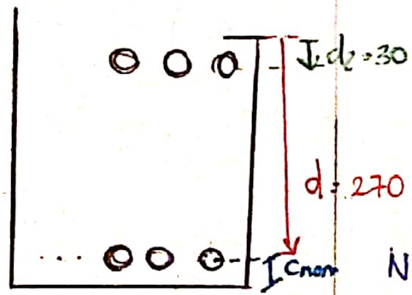
$M_{Rd,0} = 0$ KN·m

$N_{Rd,0} = 3605$ KN
$M_{Rd,0} = 0$ KN·m

POINT 1 : whole cross-section is compressed

$N_{Rd,1} = 0'8 \cdot b_{col}\, d \cdot f_{cd} + A_{s2} f_{yd}$

$M_{Rd,1} = 0'8\, b_{col}\, d \cdot f_{cd} \left(\frac{h}{2} - 0'4 d\right) + A_s f_{yd} \cdot z_{s2}$



$M_{Rd,1} = 0'8 \cdot 0'3 \cdot 0'27 \cdot 23'3 e^3 \left(\frac{0'3}{2} - 0'4 \cdot 0'27\right) + 1885 \cdot 434'74 e^{-3} \cdot 0'15$

$M_{Rd,1} = 186'12$ KN

$N_{Rd,1} = 0'8 \cdot 0'3 \cdot 0'27 \cdot 23'3 e^3 + 1885 e^{-6} \cdot 434'78 e^3$

$N_{Rd,1} = 2329'4$ KN

$C_{nom} = c + \phi/2$

$c = 20$ mm

$d = h - C_{nom} = 300 - 20 - \frac{20}{2}$

$d = 270$

POINT 2 : maximum bending moment resistance

$N_{Rd,2} = 0'8 \cdot b_{col} \cdot x_{bal,1} \cdot f_{cd} + A_{s2} \cdot \sigma_{s2} - A_{s1} \cdot f_{yd}$

$M_{Rd,2} = 0'8 \cdot b_{col} \cdot x_{bal,1} \cdot f_{cd} \left(\frac{h}{2} - 0'4 x_{bal,1}\right) + A_{s2} \cdot \sigma_{s2} z_{s2} + A_{s1} f_{yd} z_{s1}$

$N_{Rd,1} = 2329'4$ KN
$M_{Rd,1} = 186'12$ KN·m

$x_{bal,1} = \frac{700}{700 + f_{yd}} \cdot d = \frac{700}{700 + 434'78} \cdot 0'27 = 0'1665$ m

* σ_{s2} = f_{yd} if $\varepsilon_{s2} \geq \varepsilon_{yd}$
  = $\varepsilon_{s2} E_s$

$\varepsilon_{cd} = 3'5$ ‰

$\varepsilon_{s2} = \varepsilon_{cd}\left(1 - \frac{d_2}{x_{bal,1}}\right) = 0'0035\left(1 - \frac{0'03}{0'1665}\right) = 2'8$ ‰

$\varepsilon_y = \frac{f_{yd}}{E_s} = \frac{434'78}{210\,000} = 2'07$ ‰

$\varepsilon_{s2} > \varepsilon_y \rightarrow \sigma_{s2} = f_{yd} = 434'78 \text{ MPa}$

$N_{Rd,2} = 0'8 \cdot 0'3 \cdot 0'1665 \cdot 23'3e^3 + 1885e^{-6} \cdot 434'78e^3 - 1885e^{-6} \cdot 434'78e^3$

$N_{Rd,2} = 931 \text{ KN}$

$M_{Rd,2} = 0'8 \cdot 0'3 \cdot 0'1665 \cdot 23'3e^3 \left(\frac{0'3}{2} - 0'4 \cdot 0'1665\right) + 1885e^{-6} \cdot 434'78e^3 \cdot 0'15 \cdot 2$

$M_{Ed,2} = 323'5 \text{ KN} \cdot m$

$N_{Rd,2} = 931 \text{ KN}$
$M_{Ed,2} = 323'5 \text{ KN} \cdot m$

POINT 3: Pure bending

$N_{Rd,3} = 0 \text{ KN}$

$M_{Ed,3} = 0'8 \cdot b_{col} \cdot x \cdot f_{cd} \cdot \left(\frac{h}{2} - 0'4x\right) + A_{s2}\sigma_{s2} \cdot z_{s2} + A_{s1} f_{yd} \cdot z_{s1}$

For σ_{s2}:

$\sigma_{s2}^2 \cdot A_{s2} - \sigma_{s2}(A_{s1} f_{yd} + A_{s2}\varepsilon_{cd} E_s) + \varepsilon_{cd} E_s (A_{s1} f_{yd} - 0'8 b_{col} f_{cd} d_2) = 0$

$1885e^{-6}\sigma_{s2}^2 - 820'9\,\sigma_{s2} - 630659 = 0$

$\sigma_{s2,1} = 436257 \text{ N/m}^2$
$\sigma_{s2,2} = -776'9 \text{ N/m}^2$

$\sigma_{s2} = 776'9 \text{ N/m}^2$

$x = \frac{A_{s1} f_{yd} - A_{s2} \cdot \sigma_{s2}}{0'8 \cdot b_{col} \cdot f_{cd}} = \frac{1885e^{-6} \cdot 434'78e^3 - 1885e^{-6} \cdot 776'9}{0'8 \cdot 0'3 \cdot 23'3e^3}$

$x = 0'146 \text{ m}$

$M_{Rd,3} = 0'8 \cdot 0'3 \cdot 0'146 \cdot 23'3e^3 \left(\frac{0'3}{2} - 0'4 \cdot 0'146\right) + 1885e^{-6} \cdot 0'15 (776'9 + 434'78e^3) = 197'9 \text{ KN} \cdot m$

$N_{Ed,3} = 0 \text{ KN}$
$M_{Ed,3} = 197'9 \text{ KN} \cdot m$

POINT 4: whole cross section is in tension

$N_{Rd,4} = A_{s1} f_{yd} = 1885e^{-6} \cdot 434'78e^3 = 819'56 \text{ KN}$

$M_{Rd,4} = A_{s1} f_{yd} z_{s1} = 1885e^{-6} \cdot 434'78e^3 \cdot 0'15 = 122'9 \text{ KN} \cdot m$

$N_{Ed,4} = 819'56 \text{ KN}$
$M_{Ed,4} = 122'9 \text{ KN} \cdot m$

POINT 5: Pure tension

$N_{Rd,5} = (A_{s1} + A_{s2}) f_{yd} = 2 \cdot 1885e^{-6} \cdot 434'78e^3 = 1639'12 \text{ KN}$

$M_{Ed,5} = (A_{s1} z_{s1} - A_{s2} z_{s2}) \cdot f_{yd} = 0 \text{ KN} \cdot m$

$N_{Ed,5} = 1639'12 \text{ KN}$
$M_{Ed,5} = 0 \text{ KN} \cdot m$

5. RESTRICTION OF COMPRESSIVE RESISTANCE

MINIMUM EXCENTRICITY

$$e_0 = max\left(\frac{h_{col}}{30} ; 20\,mm\right)$$

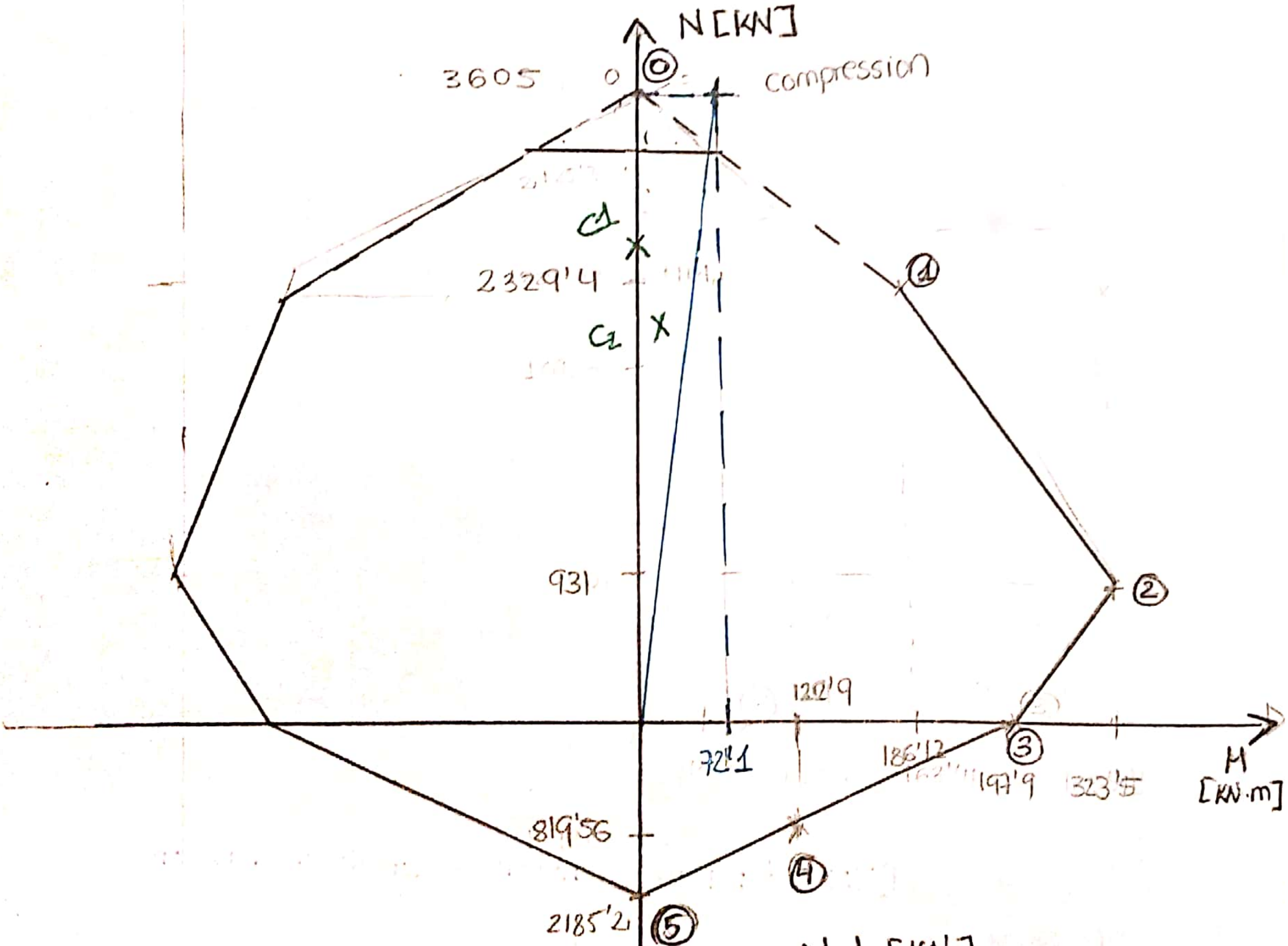
$$e_0 = max\left(\frac{300}{30} ; 20\right)$$

$$e_0 = max(10 ; 20)$$

$$e_0 = 20\,mm$$

MINIMUN BENDING MOMENT

$$M_0 = N_{Rd,0} \cdot e_0 = 3605 \cdot 0'02 \simeq 72'1\ KN \cdot m$$



COMB	Ned [KN]	Med [KN]
C1	2362'5	0
C2	2075'2	4

Column is checked, all extreme values of the internal forces are inside the interaction diagram.

CONCLUSION

It is needed rebars 6 ϕ 20.