Geopolymer cantilever concrete bench design

Part II

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List of symbols

DL	**Dead load/ self-weight**
LL	**Life load**
Q	**Snow load**
WL	**Wind load**
SLS	**Serviceability Limit State [KN; KN/m]**
ULS	**Ultimate Limit State [KN; KN/m]**
γ_G	**Safety factor for DL [1.2]**
γ_Q	**Safety factor for LL [1.5]**

Contents

1. Loads combinations

The important load combinations are calculated according to Eurocode 1 EN 1991.

Load combination	
Load combination 1:	Y_G DL + Y_Q LL
Load combination 2:	1.35 DL
Load combination 3:	1.35 DL + Y_Q ψ* WL
Load combination 4:	γ_G DL + Y_Q WL
Load combination 5:	γ_G DL + ψ* Y_Q LL + Y_Q WL

ψ: 0.4 factor for the life load [NEN-EN 1990]

γ_G: 1.2 Safety factor for DL

γ_Q: 1.5 Safety factor for LL

2. Loads on the cantilever bench

2.1 Life Load [LL]

Because there is no life load parameter for a bench, a governing life load chosen between a balcony, Living floor, stairs and a mass of 5 people. The loads are taken according to eurocode.

Life load		
Balcony Load	2.5 KN/m2	[2.5*0.4*3]= 3KN
Floor [Living]	1.75 KN/m2	[1.75*0.4*3]= 2.1 KN
Stairs vertical load	2 KN/m2	[2*0.4*3]= 2.4 KN
Average 5 People weight	420 kg	4.1201 KN → **Governing force**

2.2 Snow load [Q]

The snow load on the cantilever bench is calculated based on [NEN-EN 1991-1-3].

$$Q = \mu_i * C_e * C_t * S_k \left[\frac{KN}{m2}\right]$$

Ce: 1.0
Ct: 1.0
Sk: 0.70 [KN/m^2]
µi: [0.8-2.0] → 2.0 Maximum

$$Q = \mu_i * C_e * C_t * S_k = 2.0 * 1.0 * 1.0 * 0.7 = 1.4 \frac{KN}{m^2}$$

$$Q1_{\text{Sitting space}} = 1.4 * 0.4 = 0.56 \frac{KN}{m}$$

$$Q2_{\text{Back support}} = 1.4 * 0.15 = 0.21 \frac{KN}{m}$$

$$Q_{\text{snow total}}: Q1 + Q2 = 0.56 + 0.21 = \mathbf{0.77} \ \mathbf{\frac{KN}{m}}$$

2.3 Self-weight/ Dead load [DL]

The dead load on the structure is the self-weight of the geopolymer concrete bench that is calculated according to NEN-EN 1991-1-1. The volumetric weight of a normal cement based concrete $\gamma_c = 24\ \frac{KN}{m^3}$ is applied for the calculations.

DL1: $A_1 * \gamma_c = 0.08 * 24 = 1.92 \left[\frac{\mathrm{KN}}{\mathrm{m}}\right]$ $F_1 = 1.92 * 3[\mathrm{m}] = 5.76\ \mathrm{KN}$

DL2: $A_2 * \gamma_c = 0.105 * 24 = 2.52 \left[\frac{\mathrm{KN}}{\mathrm{m}}\right]$ $F_2 = 2.52 * 3[\mathrm{m}] = 7.56\ \mathrm{KN}$

A1: 0.4*0.2 = 0.08 m^2

A2: 0.7*0.15 =0.105 m^2

Total DL in SLS : F1+F2= 5.76+7.56 =13.32 KN

Total DL in ULS: $\gamma_G * F1 + \gamma_G * F2 = 1.2 * 5.76 + 1.2 * 7.56 = \mathbf{15.98\ KN}$

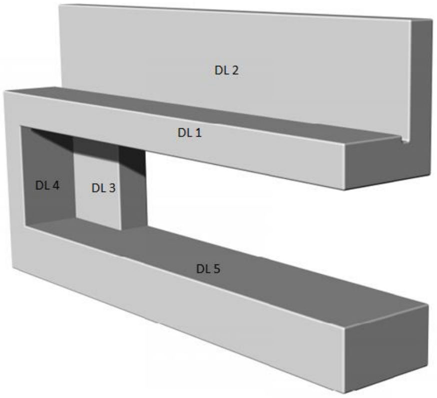

Figure 1: Dead load/self-weight of the cantilever geopolymer bench

2.4 Wind load [WL]

The wind load on the cantilever bench is calculated according to [NEN-EN 1991-1-4]. Wind is moving air with a density of 1.25 kg/m^3, whose speed and direction changes. The wind pressure $q_{p(ze)}$ is a function of the height (ze), the wind velocity and the air density.

$W_e = q_{p(ze)} * C_{pe}$ $\left[\frac{KN}{m^2}\right]$ (Wind pressure)

Cpe: 1.0 External pressure coefficient

qp(ze) $0.58 \left[\frac{KN}{m^2}\right]$ (extreme pressure)

$$W_e = q_{p(ze)} * C_{pe} = 0.58 * 1.0 = 0.58 \left[\frac{KN}{m^2}\right]$$

The wind force on the construction is calculated based on the following formula:

$$\mathbf{F_{wind}} = \mathbf{C_s C_d} * \sum\left(\mathbf{C_f} * \mathbf{q_{p(ze)}} * \mathbf{A_{ref}}\right) \text{ [KN]}$$

Cf: 0.02 (surface roughness)

CsCd: 1.0 (structural factor)

Aref: (Reference area):
A1: 200 *3000=600000 mm2= 0.6 m2
A2: 500 *3000=1500000 mm2=1.5 m2
A3: 300 *200=60000 mm2=0.06 m2
Fwind1: 6.96*10-3 KN ; Fwind2: 0.0174 KN; Fwind3: 6.96*10-4 KN
Fwind total= Fwind1+ Fwind2+Fwind3= 2.51 *10-2 KN (wind load on the construction is small).

3. Governing ULS load combination

Based on the loads in the previous chapters the governing load combination is load combination 1.

ULS Load combination	
Load combination 1:	Y_G DL + Y_Q LL= 1.2 DL + 1.5 LL= 1.2*15.98 + 1.5* 4.1201 = 25.36 KN → **Governing**
Load combination 2:	1.35 DL= 21.33 KN
Load combination 3:	1.35 DL + Y_Q ψ* WL =1.35 DL + 1.5 *0.4* WL= 1.35 *15.98 + 1.5 *0.4* 2.51*10^{-2} = 21.59 KN
Load combination 4:	γ_G DL + Y_Q WL= 1.2 DL + 1.5 WL=1.2*15.98 + 1.5*2.51*10^{-2}= 19.21 KN
Load combination 5:	γ_G DL + ψ* Y_Q LL + Y_Q WL=1.2 DL + 0.4* 1.5LL + 1.5 WL=1.2 *15.98 + 0.4* 1.5*4.1201 + 1.5 *2.51*10^{-2}= 21.69 KN

4. Tilting moment equilibrium

The tilting moment equilibrium is calculated based on a horizontal variable load and the self-weight of the cantilever bench. The horizontal load is based on horizontal stairs loads [$q_{horizontal}$].

$q_{horizontal}$= 0.5 KN/m

SLS: $F_{horizontal}$=0.5* 3(m)=1.5 KN

$M_{horizontal\ load}$:

∑ Moment/B [SLS]: 1.5*1.6 (m) = 2.4 KNm

ULS: $F_{horizontal}$=Y_Q *0.5* 3(m)=1.5*1.5= 2.25 KN

∑Moment/B [ULS]: 2.25*1.6 (m) = 3.6 KNm

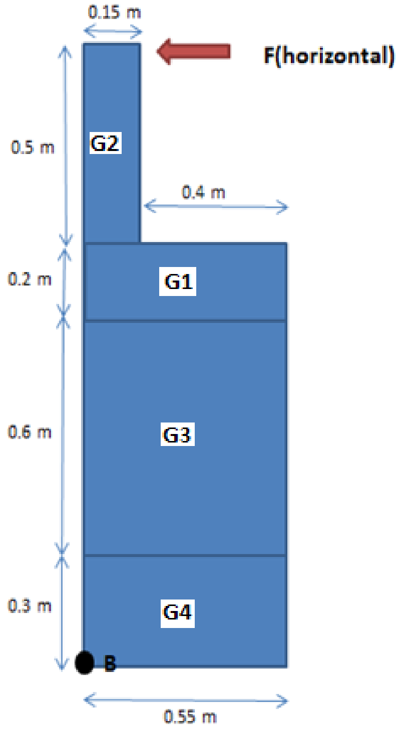

Figure 2: Cantilever bench cross-section

Self-weight:

G_1= Y_C*3 (m)*0.2 (m)=14.4 KN/m

G_2= Y_C*3 (m)*0.5 (m)=36 KN/m

G_3= Y_C*0.2 (m)*0.6(m)= 2.88 KN/m

G_4= Y_C*3 (m)*0.3 (m)= 21.6 KN/m

V1=G1*0.55 (m)= 14.4*0.55 (m)=7.92 KN

V2=G2*0.15 (m)= 5.4 KN

V3=G3* 0.55 (m)=1.584 KN

V4= 21.6*0.55 (m)=11.88 KN

Self-weight moment check:

Arm:

a_1= 0.275 meter

a_2= 0.075 meter

a_3= 0.275 meter

a_4= 0.275 meter

$M_{self-weight}$:

∑Moment/B [SLS]: V1*a_1+ V2*a_2+ V3*a_3+ V4*a_4= 6.29 KNm

Moment equilibrium check [SLS]: $M_{horizontal\ load} < M_{selfweight}$

2.4 KNm < 6.29 KNm (The cantilever bench is safe against tilting).

5. Structural Torsion

Due to the special design of the geopolymer concrete cantilever bench torsion moments and pure bending moments will occur. In this chapter the torsion moments on the cantilever bench is calculated according to NEN-EN 1992-1-1. To prevent collapse of the structure torsion reinforcement is required. In order not to exceed the resistance of the structure against torsion moment a design torsional moment (T_{ed}) is used as the maximum possible torsion moment that can occur in the structure.

$$\mathrm{UC:}\ \frac{\mathrm{T_{ed}}}{\mathrm{T_{rd,c}}} = 1.0$$

T_{ed}: design torsional moment [KNm]
$T_{rd,c}$: design torsional resistance moment [KNm]
For the calculations it is assumed that the design torsion moment is smaller that the design torsion resistance moment.

$$\mathrm{T_{rd,c}} = 2 * \mathrm{fctd} * \mathrm{t_{ef}} * \mathrm{A_k}$$

f_{ctd}: design concrete tensile strength= 1.77 [N/mm^2]
A_k: concrete cross-section area [mm^2]
t_{ef}: effective thickness of the cross-section [mm]

To calculate the effective thickness of the cross-section the following formula is required:

$$\mathrm{t_{ef}} = \frac{\mathrm{A}}{\mathrm{u}}$$

u: outer circumference of the cross-section $u = 2(b + h)$[mm]
A: total area of the cross-section [mm^2]

In figure the torsion moment reinforcement is calculated for section C1, C3 and C4.

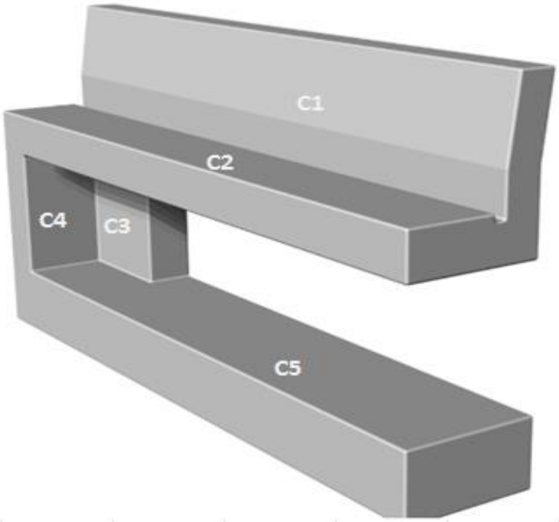

Figure 3: Torsion moment calculation on the cantilever concrete bench

5.1 Torsion reinforcement for section C1

The torsion reinforcement of the C1 is calculated by first calculating the effective thickness of the cross-section and assuming compression strut angle of maximum 45°.

The required cross-sectional area of the longitudinal reinforcement is calculated by the following formula:

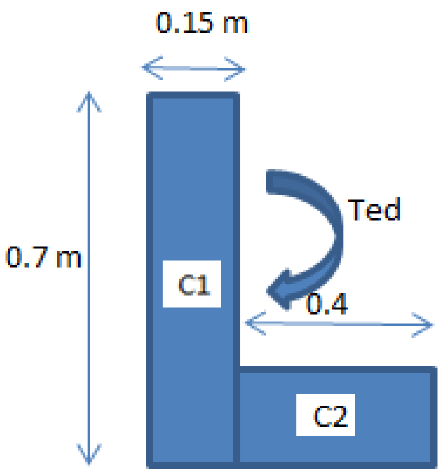

Figure 4: Torsion moment on section C1

$$A_{sl}=\frac{T_{ed}*u_k*\cot\theta}{f_{yd}*2*A_k}$$

The effective thickness of cross-section area C1:

$$t_{ef}=\frac{A}{u}=\frac{700*150}{2(700+150)}=61.76\ \mathrm{mm}$$

$$T_{ed}=T_{rd,c}=2*1.77*61.76*105000=22.96*10^6\mathrm{Nmm}$$
$$=22.96\ \mathrm{KNm}$$

$$A_{sl}=\frac{T_{ed}*u_k*\cot\theta}{f_{yd}*2*A_k}=\frac{22.96*10^6*\cot 45*\big(2(700+150)\big)}{435*2*105000}$$
$$=427.28\ \mathrm{mm}^2$$

$$\text{minimum longitudinal reinforcement of } \emptyset 10 \text{ is 6 in C1 cross} - \text{section} = 6\emptyset 10$$

5.2 Torsion reinforcement for section C3

The torsion moment on cross-section C3 is calculated by finding first the effective thickness.

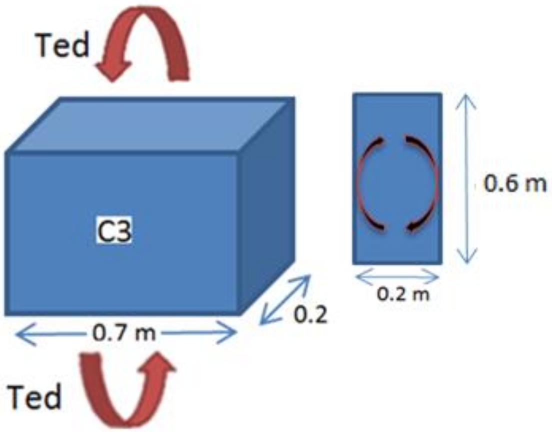

Figure 5: Torsion moment on section C3

$$t_{ef}=\frac{A}{u}=\frac{600*200}{2(600+200)}=75\ \mathrm{mm}$$

$$T_{ed}=T_{rd,c}=2*1.77*75*140000$$
$$=31.86*10^6\mathrm{Nmm}$$
$$=31.86\ \mathrm{KNm}$$

$$A_{sl}=\frac{T_{ed}*u_k*\cot\theta}{f_{yd}*2*A_k}$$
$$=\frac{31.86*10^6*\cot 45*\big(2(600+200)\big)}{435*2*120000}$$
$$=488.3\ \mathrm{mm}^2$$

Minimum 7 longitudinal reinforcement of Ø10 is required in section C3.

5.3 Torsion reinforcement for section C4

For cross-section C4 the same procedure is used for calculating the required torsion reinforcement.

$$t_{ef} = \frac{A}{u} = \frac{350 * 200}{2(350 + 200)} = 63.64\text{ mm}$$
$$T_{ed} = T_{rd,c} = 2 * 1.77 * 63.64 * 70000 = 15.77 * 10^6\text{Nmm} = 15.77\text{ KNm}$$
$$A_{sl} = \frac{T_{ed} * u_k * \cot\theta}{f_{yd} * 2 * A_k} = \frac{15.77 * 10^6 * \cot 45 * \big(2(350 + 200)\big)}{435 * 2 * 70000} = 284.84\text{ mm}^2$$

Minimum 4 longitudinal reinforcement of Ø10 is required in section C4.

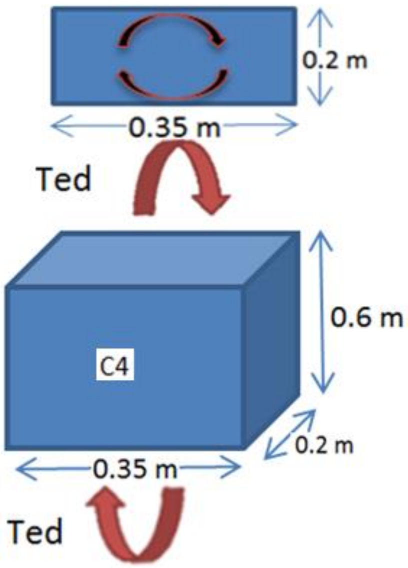

Figure 6: Torsion moment on section C4

To be able to have a clear view of the needed amount of reinforcement in section C1, C2, C3, C4 and C5 pure bending moments and reinforcement is calculated.

6. Reinforced concrete with pure bending

In this chapter the pure bending reinforcements are calculated on section C1, C2, C3, C4 and C5 according to the Eurocode 2 EN-1992.

6.1 Reinforcement calculation for section C2

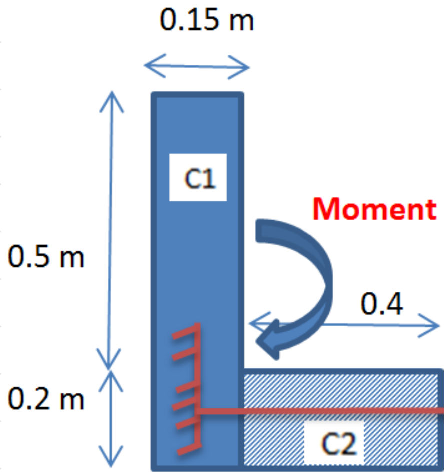

Figure 7: Reinforcement calculation against bending in section C2

Self-weight:

C2: γ_c*3 (m)*0.2 (m)=14.4 KN/m

Moment calculation due to self-weight of C2[ULS]:

$$\text{M1}: \gamma_g * \left(\frac{1}{2}\right) * 14.4 * 0.475^2 = 1.2 * \left(\frac{1}{2}\right) * 14.4 * 0.475^2 = 1.625 \text{ KNm}$$

Moment calculation due to the Life load [LL] [ULS]:

F_{LL}=4.1202 KN

$$\text{M2}: \gamma_Q * F_{LL} * 0.475 \text{ m} = 1.5 * 4.1202 * 0.475 \text{ m} = 2.94 \text{ KNm}$$

Total moment on C1:

$$\text{M1} + \text{M2} = 1.6245 + 2.94 = 4.56 \text{ KNm}$$

c_{cover}: concrete cover of 30 mm

b: 3 meter=3000 mm

h: 0.2 m= 200 mm

$$\text{d}: \text{h} - \emptyset 8 - \left(\frac{\emptyset 10}{2}\right) - c_{cover} = 200 - 8 - 5 - 30 = 157 \text{ mm}$$

Cylinder compression strength (f_{ck}): 45 Mpa

Design compression strength (f_{cd}): $\frac{f_{ck}}{\gamma_c} = \frac{45}{1.5} = 30 \text{ Mpa}$

Longitudinal reinforcement calculation in cross-section C2:

$$\frac{\text{M}}{\text{b} * \text{d}^2 * \text{fcd}} = \frac{4.56}{3 * 0.157^2 * 30} = 2.254$$

This gives reinforcement percentage less than 0.069%

This is much smaller than the minimum allowed for a slab height of 200 mm.

The minimum allowed reinforcement for a slab height of 200 mm is 0.22% .

$$\rho_{l,min} = 0.22\%$$

The longitudinal reinforcement area A_L:

$$A_L = \rho_{L,min} * \text{b} * \text{d} * 10^{-2} = 0.22 * 3000 * 157 * 10^{-2} = 1036.2 \text{ mm}^2$$

minimum longitudinal reinforcement of $\emptyset 10$ is 14 . $14\emptyset 10$. For section C2 $16\emptyset 10$ is applied in the final reinforcement bench design. See Appendix B and C.

The center to center distance of longitudinal the reinforcement bars:

$\text{c.t.c} = \frac{\text{b} * 2c_{cover} - 2\emptyset 8}{15} = \frac{3000\text{mm} - 60\text{mm} - 16\text{mm}}{15}$ =195 mm. The maximum distance between the reinforcement bars should be 195 mm. For the final bench design a c.t.c distance of 150 mm is chosen.

6.2 Reinforcement calculation for section C1

The reinforcement in cross-section C1 is calculated by finding the pure bending moment in point A (figure 8).

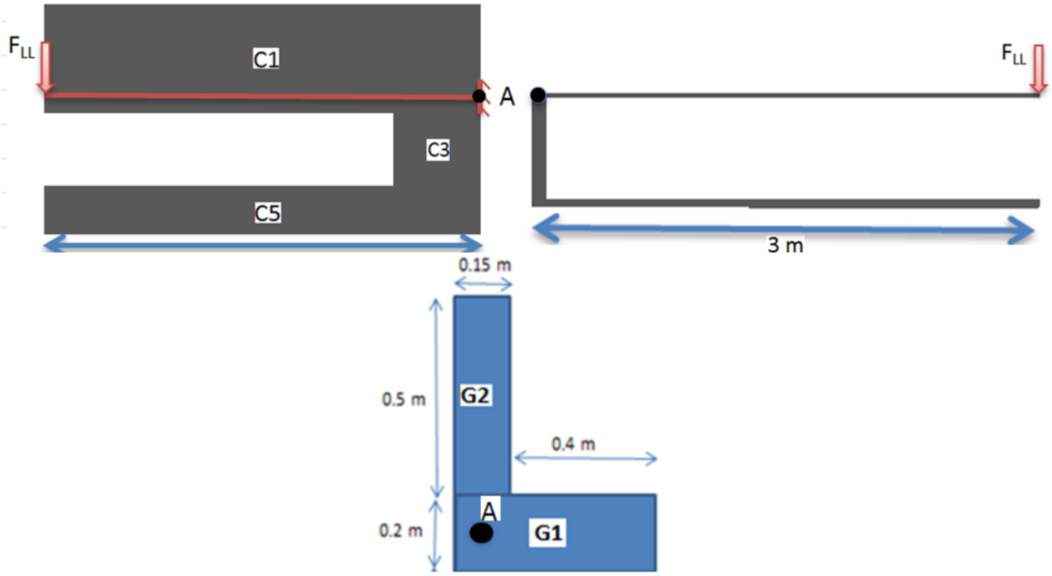

Figure 8: Longitudinal reinforcement calculation against bending in section C1

Self-weight:

$G_1 = \gamma_c * 0.55\ (m) * 0.2\ (m) = 2.64 \frac{KN}{m}$

$G_2 = \gamma_c * 0.15\ (m) * 0.5\ (m) = 1.8 \frac{KN}{m}$

Life load LL:

$F_{LL} = 4.1202\ KN$

Bending moment at point A [ULS]:

M1: $\frac{1}{2} * G_1 * l^2 * \gamma_G = \frac{1}{2} * 2.64 * 3^2 * 1.2 = 14.26\ KNm$

M2: $\frac{1}{2} * G_2 * l^2 * \gamma_G = \frac{1}{2} * 1.8 * 3^2 * 1.2 = 9.72\ KNm$

M3: $F_{LL} * l\ (m) * \gamma_Q = 4.1202 * 3\ (m) * 1.5 = 18.54\ KNm$

Total bending moment at point A [ULS]:

$M1 + M2 + M3 = 42.52\ KNm$

b: 0.15 m = 150 mm

h: 0.5 m= 500 mm

d: $h - \emptyset 8 - \left(\frac{\emptyset 10}{2}\right) - c_{cover} = 500 - 8 - 5 - 30 = 457\ mm$

Cylinder compression strength (f_{ck}): 45 Mpa

Design compression strength (f_{cd}): $\frac{f_{ck}}{\gamma_c} = \frac{45}{1.5} = 30$ Mpa

$\frac{M}{b * d^2 * fcd} = \frac{42.52}{0.15 * 0.457^2 * 30}$ =45.24 this gives a longitudinal reinforcement ratio of $\rho_{l,min} = 0.319\%$

$A_L = \rho_{L,min} * b * d * 10^{-2} = 0.319 * 150 * 457 * 10^{-2} = 218.67 mm^2$

Minimum 3 longitudinal reinforcement of Ø10. For section C1 3Ø10 is applied in the final bench design.

The total reinforcement design is given in appendix B and C.

6.3 Reinforcement calculation for section C3

Life load LL:

$F_{LL} = 4.1202 \text{ KN}$

Bending moment at point A [ULS]:

M1: $\frac{1}{2} * G_1 * l^2 * \gamma_G = \frac{1}{2} * 2.64 * 3^2 * 1.2 = 14.26 \text{ KNm}$

M2: $\frac{1}{2} * G_2 * l^2(m) * \gamma_G = \frac{1}{2} * 1.8 * 3^2 * 1.2 = 9.72 \text{ KNm}$

M3: $F_{LL} * l\,(m) * \gamma_Q = 4.1202 * 3\ (m) * 1.5 = 18.54 \text{ KNm}$

Total bending moment at point A [ULS]:

$M1 + M2 + M3 = 42.52 \text{ KNm}$

b= 0.2 m = 200 mm

h: 0.7 m= 700 mm

d: $h - \varnothing 8 - \left(\frac{\varnothing 10}{2}\right) - c_{cover} = 700 - 8 - 5 - 30 = 657 \text{ mm}$

Cylinder compression strength (f_{ck}): 45 Mpa

Design compression strength (f_{cd}): $\frac{f_{ck}}{\gamma_c} = \frac{45}{1.5} =$ 30 MPa

$\frac{M}{b*d^2*fcd} = \frac{42.52}{0.2*0.657^2*30} = 16.42$ this gives a longitudinal reinforcement ratio of $\rho_l = 0.114\%$

The minimum allowed reinforcement ratio for a height 600 mm and higher is 0.15%

$A_L = \rho_{L,min} * b * d * 10^{-2} = 0.15 * 200 * 657 * 10^{-2} = 197.1 mm^2$

Minimum 3 longitudinal reinforcement of Ø10. For the final reinforcement design of section C3 is given in appendix B and C.

6.4 Reinforcement calculation for section C4

Life load LL:

$F_{LL} = 4.1202\ KN$

Bending moment at point A [ULS]:

M1: $\frac{1}{2} * \mathrm{G}_1 * \mathrm{l}^2 * \gamma_\mathrm{G} = \frac{1}{2} * 2.64 * 3^2 * 1.2 = 14.26\ \mathrm{KNm}$

M2: $\frac{1}{2} * \mathrm{G}_2 * \mathrm{l}^2(\mathrm{m}) * \gamma_\mathrm{G} = \frac{1}{2} * 1.8 * 3^2 * 1.2 = 9.72\ \mathrm{KNm}$

M3: $\mathrm{F}_{\mathrm{LL}} * \mathrm{l}\ (\mathrm{m}) * \gamma_\mathrm{Q} = 4.1202 * 3\ (\mathrm{m}) * 1.5 = 18.54\ \mathrm{KNm}$

Total bending moment at point A [ULS]:

$M1 + M2 + M3 = 42.52\ KNm$

b= 0.35 m = 350 mm

h: 0.2 m= 200 mm

d: $h - Ø8 - \left(\frac{Ø10}{2}\right) - c_{cover} = 200 - 8 - 5 - 30 = 157\ mm$

Cylinder compression strength ($\mathrm{f_{ck}}$): 45 Mpa

Design compression strength ($\mathrm{f_{cd}}$): $\frac{\mathrm{f_{ck}}}{\gamma_\mathrm{c}} = \frac{45}{1.5} = 30\ \mathrm{Mpa}$

$\frac{\mathrm{M}}{\mathrm{b*d^2*fcd}} = \frac{42.52}{0.35*0.157^2*30} = 164.3$ this gives a longitudinal reinforcement ratio of $\rho_\mathrm{l} = 1.25\%$

$\mathrm{A_L} = \rho_\mathrm{L} * \mathrm{b} * \mathrm{d} * 10^{-2} = 1.25 * 350 * 157 * 10^{-2} = 686.9\ \mathrm{mm}^2$

Minimum 9 longitudinal reinforcement of Ø 10. For the final reinforcement design of section C3 is given in Appendix B and C.

6.5 Reinforcement calculation for section C5

The loads on the foundation of the cantilever concrete bench consist of soil load, self-weight of the upper part of the bench and the foundation self-weight.. The bending moment of the upper part of the bench goes further to the foundation.

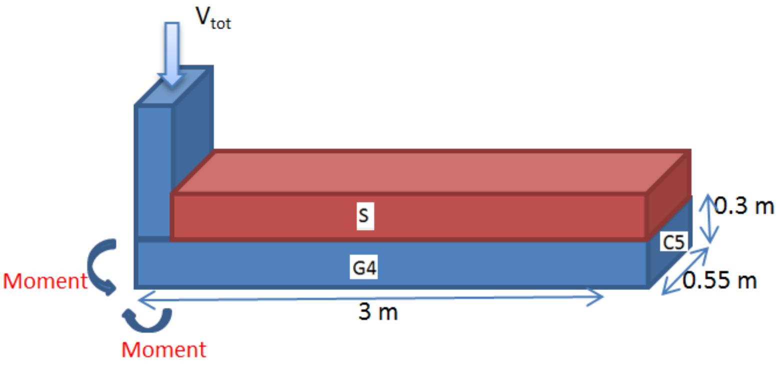

Figure 9: Loads on the foundation

$\gamma_{concrete} = 24\ \frac{KN}{m^3}$

b= 0.55 m =500 mm

h= 0.2 m= 200 mm

d: $\mathrm{h} - Ø8 - \left(\frac{Ø10}{2}\right) - \mathrm{c_{cover}} = 200 - 8 - 5 - 30 = 157\ \mathrm{mm}$

Loads on the foundation:

Soil load (S): $\gamma_{soil} * 0.3\ (m) * 0.55\ (m) = 18 * 0.3 * 0.55 = 2.97\,\frac{KN}{m}$

Self-weight the foundation (G4): $\gamma_c * h * b = 24 * 0.3\ (m) * 0.55\,(m) = 3.96\,\frac{KN}{m}$

G_1= Y_c*3 (m)*0.2 (m)=14.4 KN/m

G_2= Y_c*3 (m)*0.5 (m)=36 KN/m

G_3= Y_c*0.2 (m)*0.6 (m)= 2.88 KN/m

The self-weight of the upper part G1, G2 and G3

V1=G1*0.55 (m)= 14.4*0.55 (m)=7.92 KN

V2=G2*0.15 (m)= 5.4 KN

V3=G3* 0.55 (m)=1.584 KN

V_{tot} [ULS] :$(V_1 + V_2 + V_3) * \gamma_G + F_{LL} * \gamma_Q = (7.92 + 5.4 + 1.584) * 1.2 + 4.1202 * 1.5 = 24.1$ KN

To calculate the moment at point B we assume V_{tot} is located as given in figure 10.

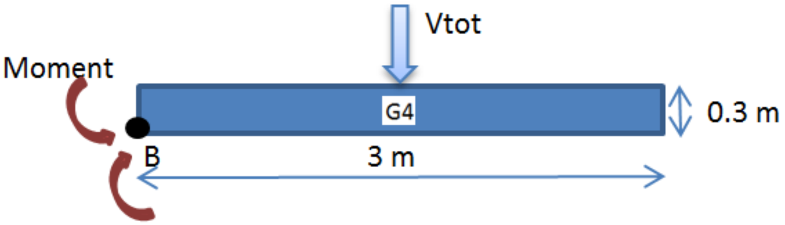

Figure 10: Loads and moment on the foundation

Moment/B: $V_{tot} * arm + ((\frac{1}{2}) * G_4 * l^2 * \gamma_G = 24.1 * 1.5 + ((\frac{1}{2}) * 3.96 * 3^2 * 1.2 = 57.53$ KNm

We assume no upward water load.

b= 0.55 m = 550 mm

h: 0.3 m= 300 mm

d: $h - \varnothing 8 - \left(\frac{\varnothing 10}{2}\right) - c_{cover} = 300 - 8 - 5 - 30 = 257\ mm$

Cylinder compression strength (f_{ck}): 45 Mpa

Design compression strength (f_{cd}): $\frac{f_{ck}}{\gamma_c} = \frac{45}{1.5} = 30$ Mpa

$$\frac{M}{b * d^2 * fcd} = \frac{57.53}{0.55 * 0.257^2 * 30} = 52.79$$

This gives a longitudinal reinforcement ratio of $\rho_l = 0.377\%$

$A_L = \rho_L * b * d * 10^{-2} = 0.377 * 550 * 257 * 10^{-2} = 532.9\ mm^2$

Minimum 7 longitudinal reinforcement of Ø 10. For the final reinforcement design of section C5 is given in Appendix B and C.

7. Shear capacity of the sections

In Eurocode 2 when checking the shear strength of an element without shear reinforcement, a maximum absorbable shear force is assumed to be equal to:

$$V_{Rd,c} = \left[\left(\frac{0.18}{\gamma_c}\right) * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}}\right] b * d$$

With a minimum value:

$$V_{Rd.c} = \nu_{min} * b_w * d$$

$$\nu_{min} = 0.035 * k^{\frac{3}{2}} * f_{ck}^{\frac{1}{2}}$$

$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$ With d in mm

$$\rho_l = \frac{A_{sl}}{b_w * d} \leq 0.02$$

A_{sl}: cross-section area of the longitudinal reinforcement

b_w: smallest width of the concrete cross-section in the tensile zone

d= 157 mm

b_w= 550 mm

$$\nu_{Ed} = \frac{V_{Ed}}{b_w * d} \leq \nu_{min}$$

$$V_{Ed} \leq 0.5 * b_w * d * \upsilon * f_{cd} = 0.5 * 550 * 157 * 0.492 * 30 = 637.3 \text{ KN}$$

$$\upsilon = 0.6\left[1 - \frac{f_{ck}}{250}\right] = 0.6\left[1 - \frac{45}{250}\right] = 0.492$$

$$k = 1 + \sqrt{\frac{200}{157}} = 2.1 \rightarrow 2.0$$

$$\nu_{min} = 0.035 * 2.0^{\frac{3}{2}} * 45^{\frac{1}{2}} = 0.664 \left[\frac{N}{mm^2}\right]$$

$$V_{Rd.c} = \nu_{min} * b_w * d = 0.664 * 550 * 157 = 57336.4\, N = 57.34\, KN$$

V_{Ed}= V_{tot}= 24.1 KN

$$UC: \frac{V_{Ed}}{V_{Rd,c}} = \frac{24.1}{57.34} = 0.42\, Safe$$

$\nu_{Ed} = \frac{24.1*10^3}{550*157} = 0.279 \left[\frac{N}{mm^2}\right] \leq \nu_{min}$ It is sufficient without shear reinforcement.

Appendix

A. Cantilever bench mould design

Dimensions are 3 meter of length and 1.5 meter of height

B. AutoCAD Reinforcement design

C. Final cantilever bench reinforcement design