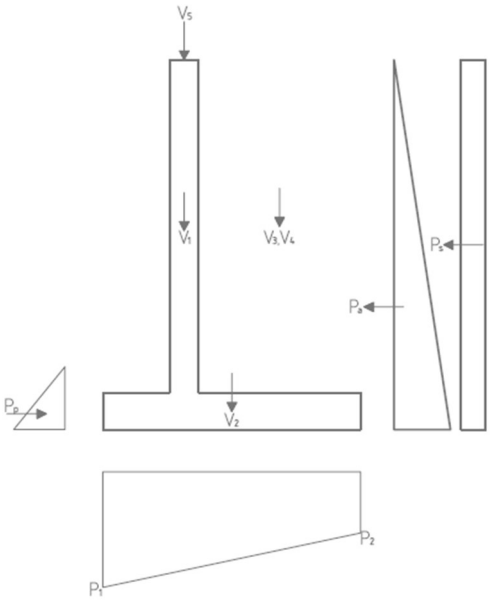
SOLUTION TO WORKED EXAMPLE

structurescentre@gmail.com

A Basement wall is required for a newly proposed residential development to retain a 4.0m height of granular material soil. A subsurface investigation has been carried out and results showed that the water table is below the retained soil. In addition to the lateral loads, from the granular soil and surcharges from moderate traffic, the wall is also required to also sustain actions transferred from floor slabs. Design this wall completely using C20/25 concrete and 460Mpa rebars.

Soil Properties	**Actions**
Soil unit weight = 18kN/m³	Surcharge Action = 10kN/m²
Shear resistance angle = 30°	Floor Slab $g_k = 45kN/m$; $q_k = 18kN/SLS$
Coefficient of friction = 0.55	



Proportioning Pointers

$Retained\ height\ =\ 4m$

$width\ of\ footing; w = 0.67\ \times 4 = 2.67; say\ 2.7m$

$stem\ thickness; h_s = 0.3m$

$footing\ thickness; h_s = 0.4m$

$toe\ width;\ w_1 = 0.7m$

$heel\ width;\ w_2 = (2.7 - 0.7 - 0.3) = 1.7m$

Pressure Coefficients

$$active\ pressure\ coefficient\ \ k_a = \frac{1 - sin\phi}{1 + sin\phi} = \frac{1 - sin30}{1 + sin30} = 0.33$$

$$passive\ pressure\ coefficient\ k_a = \frac{1 + sin\phi}{1 - sin\phi} = \frac{1 + sin30}{1 - sin30} = 3.0$$

$$at\ rest\ pressure\ coefficient\ k_0 = 1 - sin\phi = 1 - sin30 = 0.5$$

Actions

Lateral Actions

Active pressure $p_a = 0.5k_a\gamma_s h^2 = 0.5 \times 0.33 \times 18 \times 4^2 = 47.5kN/m$

Passive pressure $p_p = 0.5k_p\gamma_s h_1^2 = 0.5 \times 3 \times 18 \times 0.6^2 = 10.3kN/m$

At rest pressure $p_o = 0.5k_o\gamma_s h^2 = 0.5 \times 0.5 \times 19 \times 4^2 = 72kN/m$

Lateral pressure from surcharge (Active) $= \ \mathrm{p}_{s,1} = k_a qh = 0.33 \times 10 \times 4 = 13.2kN/m$

Lateral pressure from surcharge (Active) $= \ \mathrm{p}_{s,2} = k_o qh = 0.5 \times 10 \times 4 = 20kN/m$

Vertical Actions

Stem $V_1 = 0.3 \times (4 - 0.4) \times 25 = 27kN/m$

Footing $V_2 = 0.4 \times 2.7 \times 25 = 27kN/m$

Soil $V_3 = \gamma_s h w_2 = 18 \times 3.6 \times 1.7 = 110.16kN/m$

$Surcharge\ V_4 = qw_3 = 10 \times 1.7 = 17kN/m$

$Floor\ loads = 45 + 18 = 63kN$

Stability Check

Since this wall is a basement wall, two loading conditions must be considered with respect to load sequence. First at the temporary design stage where the wall is a free cantilever and the active earth pressure acts to topple or slide the wall and at the final design stage, where the wall is permanently propped by floor slab. For stability checks the latter condition is needless since overturning and sliding of the wall in the permanent condition is invariably impossible. Hence only the loading condition where the wall is a free cantilever is considered here.

a) Overturning

$$\gamma_g = 1.1 \ \& \gamma_q = 1.5 \ \text{(Unfavourable Actions)}$$

$$\gamma_g = 0.9 \ \& \gamma_q = 0 \ \text{(Favourable Actions)}$$

Taking moment about the toe of the section, overturning moment:

$$M_o = \left(47.5 \times \frac{4}{3} \times 1.1\right) + \left(13.2 \times \frac{4}{2} \times 1.5\right) - \left(10.3 \times \frac{0.6}{3} \times 0.9\right) = 107.4kN.m$$

Taking moment about the pivot, resisting moment:

$$M_r = (27 \times 0.85 \times 0.9) + (27 \times 1.35 \times 0.9) + (110.16 \times 1.85 \times 0.9) + (17 \times 1.85 \times 0) = 236.9kN.m$$

$$since \ M_o(107.4kN.m) < M_r(236.9kN.m) \ \mathbf{o.k}$$

b) Sliding

$$\gamma_g = 1.35 \ \& \gamma_q = 1.5 \ \text{(Unfavourable Actions)}$$

$$\gamma_g = 1.0 \ \& \gamma_q = 0 \ \text{(Favourable Actions)}$$

$$Sliding \ Force \ F_s = (47.5 \times 1.35) + (13.2 \times 1.5) = 72.16kN$$

$$Resisting \ Force \ F_R = (27 \times 0.9) + (27 \times 0.9) + (10.3 \times 1.0) + (110.16 \times 1.0 \times 0.55) + (17 \times 0) = 119.5kN$$

$$since \ F_s(72.2kN) < F_r(119.5kN) \ \mathbf{o.k}$$

c) Pressure

For the pressure verification, by inspection, the loading condition at the permanent condition of the wall would control.

$$\gamma_g = 1.35 \ \& \gamma_q = 1.5 \ \text{(Unfavourable Actions)}$$
$$\gamma_g = 0.9 \ \& \gamma_q = 0 \ \text{(Favourable Actions)}$$

Taking moment about the wall centerlines and applying the corresponding partial factors, out of balance moment:

$$\begin{aligned} \mathrm{M} = {} & (47.6 \times 1.33 \times 1.35) + (13.2 \times 2 \times 1.5) + (27 \times 0.5 \times 1.35) + (27 \times 0 \times 1.35) \\ & + (45 \times 0 \times 1.5) + (18 \times 0 \times 1.35) - (110.16 \times 0.5 \times 1.00) - (17 \times 0.5 \times 0) \\ & = 88.21 kN.m \end{aligned}$$

Vertical Actions

$$\begin{aligned} \mathrm{N} = {} & (27 \times 1.35) + (27 \times 1.35) + (110.16 \times 1.35) + (17 \times 1.5) + (45 \times 1.35) + (18 \times 1.5) \\ & = 335.9\mathrm{kN} \end{aligned}$$

$$\mathrm{e} = \frac{\mathrm{M}}{\mathrm{N}} = \frac{88.21}{335.9} = 0.26 < \left(\frac{2.7}{6} = 0.45\right)$$ The resultant is within middle third of the base

$$P = \frac{N}{B} \pm \frac{6Ne}{B^2} = \frac{335.9}{2.7} \pm \frac{6 \times 335.9 \times 0.26}{2.7^2} = 124.4 \pm 71.88$$

$$196.28 kN/m^2 \ \& 52.5 kN/m^2 \ \leq 200 kN/m^2 \ \boldsymbol{o.k}$$

Element Design

a) Stem

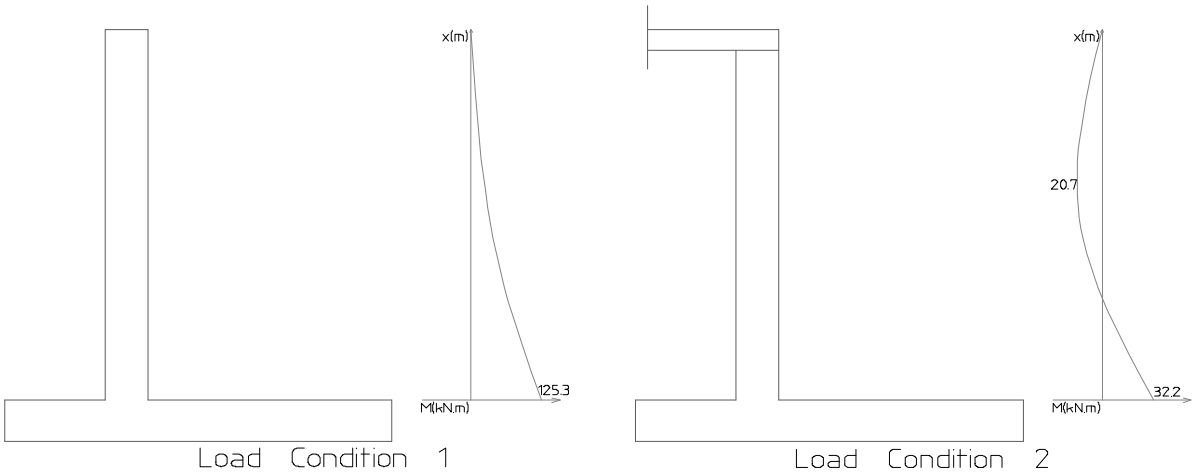
The two load conditions must be considered – the temporary condition wherein the stem is fixed at the base and free to rotate at the top and the permanent condition in which the wall is propped by the floor slabs and not free to rotate.

Flexural Design

i) Load condition one: (Free Cantilever) Negative moment at Stem- Base interface

ii) Load condition two: (Propped Cantilever) Negative moment at Stem- Base interface.

Moment & Shear force values under the above load conditions are presented below



Positive Moment in Front-face of Stem: Load combination two is critical

$$M_{Ed} = 20.7\text{kN.m}$$

Assuming cover to reinforcement of 40mm, 16mm bars

$$d = h - \left(c_{nom} + + \frac{\emptyset}{2}\right) = 300 - \left(40 + \frac{16}{2}\right) = 252\text{mm};\ b = 1000\text{mm}$$

$$k = \frac{M_{Ed}}{bd^2 f_{ck}} = \frac{20.7 \times 10^6}{1000 \times 252^2 \times 25} = 0.013$$

$$z = d\left[0.5 + \sqrt{0.25 - 0.882k}\right] \leq 0.95d$$

$$=d\left[0.5 + \sqrt{0.25 - 0.882(0.079)}\right] \leq 0.95d$$

$$=0.95d = 0.95 \times 252 = 239.4\text{mm}$$

$$A_s = \frac{M_{Ed}}{0.87 f_{yk} z} = \frac{20.7 \times 10^6}{0.87 \times 460 \times 239.4} = 216.1 mm^2/m$$

Try T12mm − 250mm centre As, prov = ***452mm²/m***

Negative moment in Back-face of Stem: Load combination one is critical

$$M_{Ed} = 125.3 kN.m$$

Assuming cover to reinforcement of 40mm, 16mm bars

$$d = h - \left(c_{nom} + + \frac{\emptyset}{2}\right) = 300 - \left(40 + \frac{16}{2}\right) = 252mm;\ b = 1000mm$$

$$k = \frac{M_{Ed}}{b d^2 f_{ck}} = \frac{125.3 \times 10^6}{1000 \times 252^2 \times 25} = 0.079$$

$$z = d\left[0.5 + \sqrt{0.25 - 0.882k}\right] \leq 0.95d$$

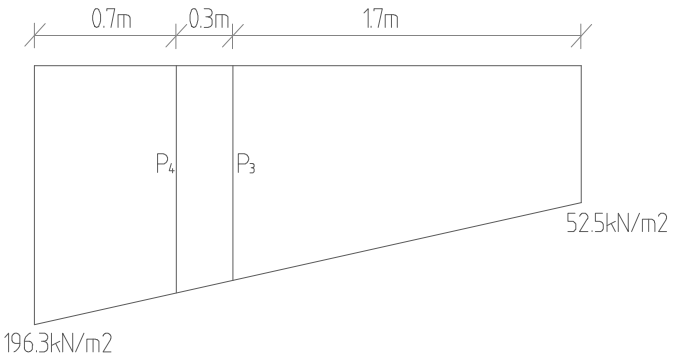
$$= d\left[0.5 + \sqrt{0.25 - 0.882(0.079)}\right] \leq 0.95d$$

$$= 0.92d = 0.92 \times 252 = 231.8mm$$

$$A_s = \frac{M_{Ed}}{0.87 f_{yk} z} = \frac{125.3 \times 10^6}{0.87 \times 460 \times 231.8} = 1350.71 mm^2/m$$

Try T16mm − 125mm centre As, prov = ***1608mm²/m***

b) Base



Heel

Pressure at the face of the wall from the heel side

$$P_3 = 52.5 + \frac{1.7}{2.7}(196.3 - 52.5) = 143kN/m^2$$

Taking moment about the centerline of the stem

$$\mathrm{M_{Ed}} = (27 \times 0.5 \times 1.35) + (110.16 \times 1.0 \times 1.35) + (17 \times 1.0 \times 1.5) - \left[(143 - 52.5)\left(\times \frac{1.7}{2} \times 0.72\right)\right] = 137.0kN.m$$

Assuming cover to reinforcement of 50mm, 16mm bars

$$\mathrm{d} = \mathrm{h} - \left(\mathrm{c_{nom}} + + \frac{\emptyset}{2}\right) = 400 - \left(50 + \frac{16}{2}\right) = 342\mathrm{mm};\ \mathrm{b} = 1000\mathrm{mm}$$

$$\mathrm{k} = \frac{\mathrm{M_{Ed}}}{\mathrm{bd^2 f_{ck}}} = \frac{137 \times 10^6}{1000 \times 342^2 \times 25} = 0.047$$

$$\mathrm{z} = \mathrm{d}\left[0.5 + \sqrt{0.25 - 0.882\mathrm{k}}\right] \leq 0.95\mathrm{d}$$

$$= \mathrm{d}\left[0.5 + \sqrt{0.25 - 0.882(0.047)}\right] \leq 0.95\mathrm{d}$$

$$= 0.95\mathrm{d} = 0.95 \times 344 = 326.8\mathrm{mm}$$

$$\mathrm{A_s} = \frac{\mathrm{M_{Ed}}}{0.87\mathrm{f_{yk}z}} = \frac{137 \times 10^6}{0.87 \times 460 \times 326.8} = 1047.5\mathrm{mm^2/m}$$

Try T16mm − 150mm centre $As_{,prov} = 1340mm^2/m$

Toe

Taking moment about the centerline of the stem

$$\mathrm{M_{Ed}} \approx 1.35 \times 27 \times 0.5 \times \frac{0.7}{2.7} - (197.3 \times 0.70 \times 0.5) = -64.3kN.m$$

Assuming cover to reinforcement of 50mm, 16mm bars

$$d = h - \left(c_{nom} + + \frac{\emptyset}{2}\right) = 400 - \left(50 + \frac{16}{2}\right) = 342mm;\ b = 1000mm$$

$$k = \frac{M_{Ed}}{bd^2 f_{ck}} = \frac{64.3 \times 10^6}{1000 \times 342^2 \times 25} = 0.022$$

$$z = d\left[0.5 + \sqrt{0.25 - 0.882k}\right] \leq 0.95d$$

$$= d\left[0.5 + \sqrt{0.25 - 0.882(0.022)}\right] \leq 0.95d$$

$$= 0.95d = 0.95 \times 344 = 326.8mm$$

$$A_s = \frac{M_{Ed}}{0.87 f_{yk} z} = \frac{64.3 \times 10^6}{0.87 \times 460 \times 326.8} = 491.6 mm^2/m$$

Try T12mm − 200mm centre As, prov = 565mm²/m

Detailing Verifications

Vertical Bars

$A_{s.min} = 0.002A_c = 0.002(1000 \times 300) = 600mm^2/m$

Hence Adopt T12-150mm Centers F.F of the Wall ($753\ mm^2/m$)

Horizontal Bars

$A_{s.min} = 0.002A_c = 0.002(1000 \times 300) \geq 0.25(1608) = 600mm^2/m$

Hence Adopt T12-150mm Centers Distribution bars (753 mm^2/m)

Base

$A_{s.min} = 0.0015bd = 0.0015(1000 \times 342) = 513mm^2/m$

Hence Adopt T12-200mm Centers Distribution bars (565 mm^2/m)

Summary

Stem

Back Face of Wall

- T16-125mm Centers Blackface of Wall
- T12-150mm Centers Distribution Bars

Front Face of Wall

- T12-150mm Centers Both ways

Footing

Heel

- T16-150mm Centers (Top)
- T12-150mm Centers Distribution Bars

Toe

- T12-250mm (Bottom)
- T12-150mm Centers Distribution Bars