



Vale Consultancy
CONSULTING CIVIL & STRUCTURAL ENGINEERS

Title: Retaining wall Structural Package

Project: Greenwood Close

Client: MVH

Document No: 001
Project No: 11969
Prepared By: JM
Checked By: MNJ

Revision: -

Date: 01.04.21

DESIGN STATEMENT

The design has been done in accordance with British Standards BS6399, & EuroCodes

Information for this has been provided by architectural drawings, topographical survey and site investigation report.

The retaining walls have been designed as cavity reinforced masonry walls, for three different heights, with the retained element being mainly landscaping embankments, but sometimes garden areas and parking bays.

Surcharge loading taken for these areas is 1.5kn/m^2 , except for parking bay areas which is 2.5kn/m^2 .

Please refer to Vale Consultancy drawing 11969_01 for reference.

The client and contractor are to check the drawings supplied, and thus the layout above is correct, and report any discrepancies to the engineer prior to fabrication.

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RETAINING WALL ANALYSIS & DESIGN (EN1992/EN1996/EN1997)

RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.9.07

Retaining wall details

Stem type	Cantilever
Stem height	$h_{\text{stem}} = 1650 \text{ mm}$
Stem thickness	$t_{\text{stem}} = 325 \text{ mm}$
Angle to rear face of stem	$\alpha = 90 \text{ deg}$
Stem density	$\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
Toe length	$l_{\text{toe}} = 725 \text{ mm}$
Heel length	$l_{\text{heel}} = 250 \text{ mm}$
Base thickness	$t_{\text{base}} = 300 \text{ mm}$
Base density	$\gamma_{\text{base}} = 25 \text{ kN/m}^3$
Height of retained soil	$h_{\text{ret}} = 1500 \text{ mm}$
Angle of soil surface	$\beta = 17 \text{ deg}$
Depth of cover	$d_{\text{cover}} = 150 \text{ mm}$

Retained soil properties

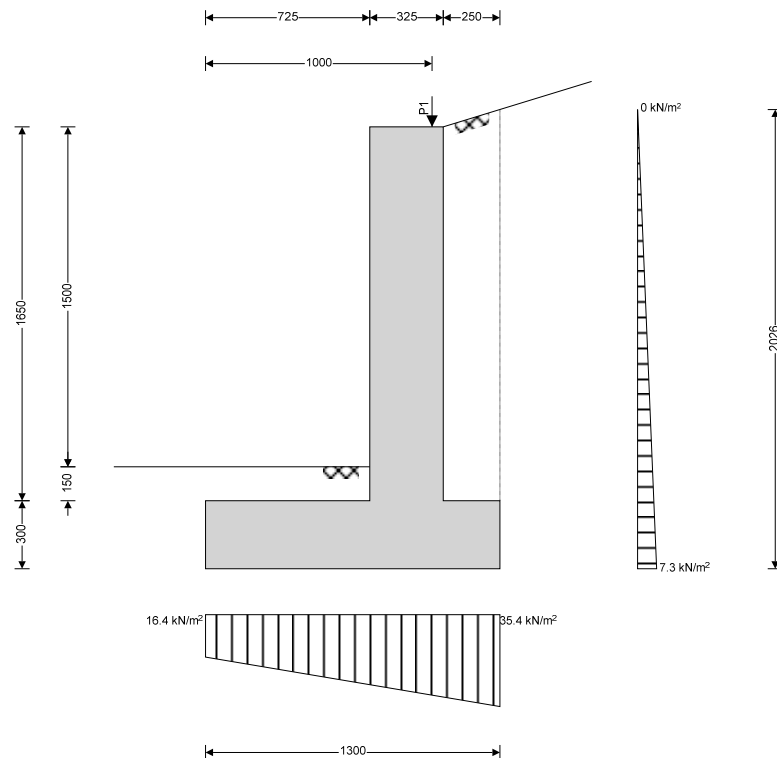
Soil type	Dense gravel
Moist density	$\gamma_{\text{mr}} = 17.5 \text{ kN/m}^3$
Saturated density	$\gamma_{\text{sr}} = 20.8 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{r.k}} = 42 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{r.k}} = 18 \text{ deg}$

Base soil properties

Soil type	Stiff clay
Soil density	$\gamma_{\text{b}} = 19 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{b.k}} = 24 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{b.k}} = 9 \text{ deg}$
Characteristic base friction angle	$\delta_{\text{bb.k}} = 24 \text{ deg}$
Presumed bearing capacity	$P_{\text{bearing}} = 100 \text{ kN/m}^2$

Loading details

Vertical line load at 1000 mm	$P_{\text{G1}} = 1 \text{ kN/m}$
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General arrangement

Calculate retaining wall geometry

Base length

$$l_{\text{base}} = l_{\text{toe}} + t_{\text{stem}} + l_{\text{heel}} = \mathbf{1300 \text{ mm}}$$

Moist soil height

$$h_{\text{moist}} = h_{\text{soil}} = \mathbf{1650 \text{ mm}}$$

Retained surface length

$$l_{\text{sur}} = l_{\text{heel}} = \mathbf{250 \text{ mm}}$$

Effective height of wall

$$h_{\text{eff}} = h_{\text{base}} + d_{\text{cover}} + h_{\text{ret}} + l_{\text{sur}} \times \tan(\beta) = \mathbf{2026 \text{ mm}}$$

Area of wall stem

$$A_{\text{stem}} = h_{\text{stem}} \times t_{\text{stem}} = \mathbf{0.536 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{stem}} = l_{\text{toe}} + t_{\text{stem}} / 2 = \mathbf{887 \text{ mm}}$$

Area of wall base

$$A_{\text{base}} = l_{\text{base}} \times t_{\text{base}} = \mathbf{0.39 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{base}} = l_{\text{base}} / 2 = \mathbf{650 \text{ mm}}$$

Area of moist soil

$$A_{\text{moist}} = h_{\text{moist}} \times l_{\text{heel}} + \tan(\beta) \times l_{\text{heel}}^2 / 2 = \mathbf{0.422 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{moist}_v} = l_{\text{base}} - (h_{\text{moist}} \times l_{\text{heel}}^2 / 2 + \tan(\beta) \times l_{\text{heel}}^3 / 6) / A_{\text{moist}} = \mathbf{1176 \text{ mm}}$$

- Distance to horizontal component

$$x_{\text{moist}_h} = h_{\text{eff}} / 3 = \mathbf{675 \text{ mm}}$$

Area of base soil

$$A_{\text{pass}} = d_{\text{cover}} \times l_{\text{toe}} = \mathbf{0.109 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{pass}_v} = l_{\text{base}} - (d_{\text{cover}} \times l_{\text{toe}} \times (l_{\text{base}} - l_{\text{toe}} / 2)) / A_{\text{pass}} = \mathbf{363 \text{ mm}}$$

- Distance to horizontal component

$$x_{\text{pass}_h} = (d_{\text{cover}} + h_{\text{base}}) / 3 = \mathbf{150 \text{ mm}}$$

Area of excavated base soil

$$A_{\text{exc}} = h_{\text{pass}} \times l_{\text{toe}} = \mathbf{0.109 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{exc}_v} = l_{\text{base}} - (h_{\text{pass}} \times l_{\text{toe}} \times (l_{\text{base}} - l_{\text{toe}} / 2)) / A_{\text{exc}} = \mathbf{363 \text{ mm}}$$

- Distance to horizontal component

$$x_{\text{exc}_h} = (h_{\text{pass}} + h_{\text{base}}) / 3 = \mathbf{150 \text{ mm}}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times [1 + \sqrt{(\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.217}$$

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Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,k})^2 / (\sin(90 + \delta_{b,k}) \times [1 - \sqrt{[\sin(\phi'_{b,k} + \delta_{b,k}) \times \sin(\phi'_{b,k}) / (\sin(90 + \delta_{b,k}))]}])^2 = \mathbf{3.049}$$

Bearing pressure check

Vertical forces on wall

Wall stem

$$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{13.4 \text{ kN/m}}$$

Wall base

$$F_{base} = A_{base} \times \gamma_{base} = \mathbf{9.8 \text{ kN/m}}$$

Line loads

$$F_{P_v} = P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = A_{moist} \times \gamma_{mr} = \mathbf{7.4 \text{ kN/m}}$$

Base soil

$$F_{pass_v} = A_{pass} \times \gamma_b = \mathbf{2.1 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{pass_v} = \mathbf{33.6 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = K_A \times \cos(\delta_{r,k}) \times \gamma_{mr} \times h_{eff}^2 / 2 = \mathbf{7.4 \text{ kN/m}}$$

Base soil

$$F_{pass_h} = -K_P \times \cos(\delta_{b,k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-5.8 \text{ kN/m}}$$

Total

$$F_{total_h} = \max(F_{moist_h} + F_{pass_h} - F_{total_v} \times \tan(\delta_{bb,k}), 0 \text{ kN/m}) = \mathbf{0 \text{ kN/m}}$$

Moments on wall

Wall stem

$$M_{stem} = F_{stem} \times x_{stem} = \mathbf{11.9 \text{ kNm/m}}$$

Wall base

$$M_{base} = F_{base} \times x_{base} = \mathbf{6.3 \text{ kNm/m}}$$

Line loads

$$M_P = P_{G1} \times p_1 = \mathbf{1 \text{ kNm/m}}$$

Moist retained soil

$$M_{moist} = F_{moist_v} \times x_{moist_v} - F_{moist_h} \times x_{moist_h} = \mathbf{3.7 \text{ kNm/m}}$$

Base soil

$$M_{pass} = F_{pass_v} \times x_{pass_v} - F_{pass_h} \times x_{pass_h} = \mathbf{1.6 \text{ kNm/m}}$$

Total

$$M_{total} = M_{stem} + M_{base} + M_P + M_{moist} + M_{pass} = \mathbf{24.5 \text{ kNm/m}}$$

Check bearing pressure

Distance to reaction

$$\bar{x} = M_{total} / F_{total_v} = \mathbf{730 \text{ mm}}$$

Eccentricity of reaction

$$e = \bar{x} - l_{base} / 2 = \mathbf{80 \text{ mm}}$$

Loaded length of base

$$l_{load} = l_{base} = \mathbf{1300 \text{ mm}}$$

Bearing pressure at toe

$$q_{toe} = F_{total_v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{16.4 \text{ kN/m}^2}$$

Bearing pressure at heel

$$q_{heel} = F_{total_v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{35.4 \text{ kN/m}^2}$$

Factor of safety

$$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{2.829}$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

Partial factors on actions - Table A.3 - Combination 1

Partial factor set

$$A1$$

Permanent unfavourable action

$$\gamma_G = \mathbf{1.35}$$

Permanent favourable action

$$\gamma_{Gf} = \mathbf{1.00}$$

Variable unfavourable action

$$\gamma_Q = \mathbf{1.50}$$

Variable favourable action

$$\gamma_{Qf} = \mathbf{0.00}$$

Partial factors for soil parameters – Table A.4 - Combination 1

Soil parameter set

$$M1$$

Angle of shearing resistance

$$\gamma_{\phi'} = \mathbf{1.00}$$

Effective cohesion

$$\gamma_{c'} = \mathbf{1.00}$$

Weight density

$$\gamma_{\gamma} = \mathbf{1.00}$$

Library item Partial factors output

Retained soil properties

Design moist density

$$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = \mathbf{17.5 \text{ kN/m}^3}$$

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Design saturated density

$$\gamma_{sr}' = \gamma_{sr} / \gamma_f = \mathbf{20.8 \text{ kN/m}^3}$$

Design effective shear resistance angle

$$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_\phi) = \mathbf{42 \text{ deg}}$$

Design wall friction angle

$$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_\phi) = \mathbf{18 \text{ deg}}$$

Base soil properties

Design soil density

$$\gamma_b' = \gamma_b / \gamma_f = \mathbf{19 \text{ kN/m}^3}$$

Design effective shear resistance angle

$$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_\phi) = \mathbf{24 \text{ deg}}$$

Design wall friction angle

$$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_\phi) = \mathbf{9 \text{ deg}}$$

Design base friction angle

$$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_\phi) = \mathbf{24 \text{ deg}}$$

Design effective cohesion

$$c'_{b,d} = c'_{b,k} / \gamma_c = \mathbf{0 \text{ kN/m}^2}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.217}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d} / (\sin(90 + \delta_{b,d}))}]^2) = \mathbf{3.049}$$

Sliding check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma G_f \times A_{stem} \times \gamma_{stem} = \mathbf{13.4 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma G_f \times A_{base} \times \gamma_{base} = \mathbf{9.8 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma G_f \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma G_f \times A_{moist} \times \gamma_{mr}' = \mathbf{7.4 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma G_f \times A_{exc} \times \gamma_b' = \mathbf{2.1 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{33.6 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{10 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} = \mathbf{10 \text{ kN/m}}$$

Check stability against sliding

Base soil resistance

$$F_{exc_h} = \gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{5.8 \text{ kN/m}}$$

Base friction

$$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = \mathbf{15 \text{ kN/m}}$$

Resistance to sliding

$$F_{rest} = F_{exc_h} + F_{friction} = \mathbf{20.8 \text{ kN/m}}$$

Factor of safety

$$FoS_{sl} = F_{rest} / F_{total_h} = \mathbf{2.07}$$

PASS - Resistance to sliding is greater than sliding force

Overtuning check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma G_f \times A_{stem} \times \gamma_{stem} = \mathbf{13.4 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma G_f \times A_{base} \times \gamma_{base} = \mathbf{9.8 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma G_f \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma G_f \times A_{moist} \times \gamma_{mr}' = \mathbf{7.4 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma G_f \times A_{exc} \times \gamma_b' = \mathbf{2.1 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{33.6 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{10 \text{ kN/m}}$$

Base soil

$$F_{exc_h} = -\gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-5.8 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} + F_{exc_h} = \mathbf{4.2 \text{ kN/m}}$$

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Overturning moments on wall

Moist retained soil $M_{\text{moist_OT}} = F_{\text{moist_h}} \times X_{\text{moist_h}} = \mathbf{6.8 \text{ kNm/m}}$

Total $M_{\text{total_OT}} = M_{\text{moist_OT}} = \mathbf{6.8 \text{ kNm/m}}$

Restoring moments on wall

Wall stem $M_{\text{stem_R}} = F_{\text{stem}} \times X_{\text{stem}} = \mathbf{11.9 \text{ kNm/m}}$

Wall base $M_{\text{base_R}} = F_{\text{base}} \times X_{\text{base}} = \mathbf{6.3 \text{ kNm/m}}$

Line loads $M_{\text{P_R}} = \text{abs}(\gamma_{\text{Gf}} \times P_{\text{G1}}) \times p_1 = \mathbf{1 \text{ kNm/m}}$

Moist retained soil $M_{\text{moist_R}} = F_{\text{moist_v}} \times X_{\text{moist_v}} = \mathbf{8.7 \text{ kNm/m}}$

Base soil $M_{\text{exc_R}} = F_{\text{exc_v}} \times X_{\text{exc_v}} - F_{\text{exc_h}} \times X_{\text{exc_h}} = \mathbf{1.6 \text{ kNm/m}}$

Total $M_{\text{total_R}} = M_{\text{stem_R}} + M_{\text{base_R}} + M_{\text{P_R}} + M_{\text{moist_R}} + M_{\text{exc_R}} = \mathbf{29.5 \text{ kNm/m}}$

Check stability against overturning

Factor of safety $\text{FoS}_{\text{ot}} = M_{\text{total_R}} / M_{\text{total_OT}} = \mathbf{4.36}$

PASS - Maximum restoring moment is greater than overturning moment

Design approach 1

Partial factors on actions - Table A.3 - Combination 2

Partial factor set	A2
Permanent unfavourable action	$\gamma_{\text{G}} = \mathbf{1.00}$
Permanent favourable action	$\gamma_{\text{Gf}} = \mathbf{1.00}$
Variable unfavourable action	$\gamma_{\text{Q}} = \mathbf{1.30}$
Variable favourable action	$\gamma_{\text{Qf}} = \mathbf{0.00}$

Partial factors for soil parameters – Table A.4 - Combination 2

Soil parameter set	M2
Angle of shearing resistance	$\gamma_{\phi'} = \mathbf{1.25}$
Effective cohesion	$\gamma_{c'} = \mathbf{1.25}$
Weight density	$\gamma_{\gamma} = \mathbf{1.00}$

Library item Partial factors output

Retained soil properties

Design moist density	$\gamma_{\text{mr}}' = \gamma_{\text{mr}} / \gamma_{\gamma} = \mathbf{17.5 \text{ kN/m}^3}$
Design saturated density	$\gamma_{\text{sr}}' = \gamma_{\text{sr}} / \gamma_{\gamma} = \mathbf{20.8 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{\text{r,d}} = \text{atan}(\tan(\phi'_{\text{r,k}}) / \gamma_{\phi'}) = \mathbf{35.8 \text{ deg}}$
Design wall friction angle	$\delta_{\text{r,d}} = \text{atan}(\tan(\delta_{\text{r,k}}) / \gamma_{\phi'}) = \mathbf{14.6 \text{ deg}}$

Base soil properties

Design soil density	$\gamma_{\text{b}}' = \gamma_{\text{b}} / \gamma_{\gamma} = \mathbf{19 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{\text{b,d}} = \text{atan}(\tan(\phi'_{\text{b,k}}) / \gamma_{\phi'}) = \mathbf{19.6 \text{ deg}}$
Design wall friction angle	$\delta_{\text{b,d}} = \text{atan}(\tan(\delta_{\text{b,k}}) / \gamma_{\phi'}) = \mathbf{7.2 \text{ deg}}$
Design base friction angle	$\delta_{\text{bb,d}} = \text{atan}(\tan(\delta_{\text{bb,k}}) / \gamma_{\phi'}) = \mathbf{19.6 \text{ deg}}$
Design effective cohesion	$c'_{\text{b,d}} = c'_{\text{b,k}} / \gamma_{c'} = \mathbf{0 \text{ kN/m}^2}$

Using Coulomb theory

Active pressure coefficient	$K_{\text{A}} = \sin(\alpha + \phi'_{\text{r,d}})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{\text{r,d}}) \times [1 + \sqrt{[\sin(\phi'_{\text{r,d}} + \delta_{\text{r,d}}) \times \sin(\phi'_{\text{r,d}} - \beta) / (\sin(\alpha - \delta_{\text{r,d}}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.295}$
Passive pressure coefficient	$K_{\text{P}} = \sin(90 - \phi'_{\text{b,d}})^2 / (\sin(90 + \delta_{\text{b,d}}) \times [1 - \sqrt{[\sin(\phi'_{\text{b,d}} + \delta_{\text{b,d}}) \times \sin(\phi'_{\text{b,d}}) / (\sin(90 + \delta_{\text{b,d}}))]}]^2) = \mathbf{2.409}$

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Sliding check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma G_f \times A_{\text{stem}} \times \gamma_{\text{stem}} = 13.4 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma G_f \times A_{\text{base}} \times \gamma_{\text{base}} = 9.8 \text{ kN/m}$
Line loads	$F_{P_v} = \gamma G_f \times P_{G1} = 1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma G_f \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 7.4 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma G_f \times A_{\text{exc}} \times \gamma_b' = 2.1 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{P_v} + F_{\text{moist}_v} + F_{\text{exc}_v} = 33.6 \text{ kN/m}$

Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 10.3 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} = 10.3 \text{ kN/m}$

Check stability against sliding

Base soil resistance	$F_{\text{exc}_h} = \gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = 4.6 \text{ kN/m}$
Base friction	$F_{\text{friction}} = F_{\text{total}_v} \times \tan(\delta_{bb,d}) = 12 \text{ kN/m}$
Resistance to sliding	$F_{\text{rest}} = F_{\text{exc}_h} + F_{\text{friction}} = 16.6 \text{ kN/m}$
Factor of safety	$F_{\text{oSsl}} = F_{\text{rest}} / F_{\text{total}_h} = 1.612$
PASS - Resistance to sliding is greater than sliding force	

Overtuning check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma G_f \times A_{\text{stem}} \times \gamma_{\text{stem}} = 13.4 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma G_f \times A_{\text{base}} \times \gamma_{\text{base}} = 9.8 \text{ kN/m}$
Line loads	$F_{P_v} = \gamma G_f \times P_{G1} = 1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma G_f \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 7.4 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma G_f \times A_{\text{exc}} \times \gamma_b' = 2.1 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{P_v} + F_{\text{moist}_v} + F_{\text{exc}_v} = 33.6 \text{ kN/m}$

Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 10.3 \text{ kN/m}$
Base soil	$F_{\text{exc}_h} = -\gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = -4.6 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} + F_{\text{exc}_h} = 5.7 \text{ kN/m}$

Overtuning moments on wall

Moist retained soil	$M_{\text{moist}_OT} = F_{\text{moist}_h} \times X_{\text{moist}_h} = 6.9 \text{ kNm/m}$
Total	$M_{\text{total}_OT} = M_{\text{moist}_OT} = 6.9 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = 11.9 \text{ kNm/m}$
Wall base	$M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = 6.3 \text{ kNm/m}$
Line loads	$M_{P_R} = \text{abs}(\gamma G_f \times P_{G1}) \times p_1 = 1 \text{ kNm/m}$
Moist retained soil	$M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = 8.7 \text{ kNm/m}$
Base soil	$M_{\text{exc}_R} = F_{\text{exc}_v} \times X_{\text{exc}_v} - F_{\text{exc}_h} \times X_{\text{exc}_h} = 1.4 \text{ kNm/m}$
Total	$M_{\text{total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{P_R} + M_{\text{moist}_R} + M_{\text{exc}_R} = 29.4 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$F_{\text{oSot}} = M_{\text{total}_R} / M_{\text{total}_OT} = 4.23$
PASS - Maximum restoring moment is greater than overturning moment	

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RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1 and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the UK National Annex

Tedds calculation version 2.9.07

Concrete details - Table 3.1 - Strength and deformation characteristics for concrete

Concrete strength class	C28/35
Characteristic compressive cylinder strength	$f_{ck} = 28 \text{ N/mm}^2$
Characteristic compressive cube strength	$f_{ck,cube} = 35 \text{ N/mm}^2$
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 36 \text{ N/mm}^2$
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = 2.8 \text{ N/mm}^2$
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} = 1.9 \text{ N/mm}^2$
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = 32308 \text{ N/mm}^2$
Partial factor for concrete - Table 2.1N	$\gamma_C = 1.50$
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{cc} = 0.85$
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = 15.9 \text{ N/mm}^2$
Maximum aggregate size	$h_{agg} = 20 \text{ mm}$
Ultimate strain - Table 3.1	$\epsilon_{cu2} = 0.0035$
Shortening strain - Table 3.1	$\epsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$
Bending coefficient k_1	$K_1 = 0.40$
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$
Bending coefficient k_3	$K_3 = 0.40$
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$

Reinforcement details

Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement	$E_s = 200000 \text{ N/mm}^2$
Partial factor for reinforcing steel - Table 2.1N	$\gamma_S = 1.15$
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S = 435 \text{ N/mm}^2$

Cover to reinforcement

Top face of base	$c_{bt} = 40 \text{ mm}$
Bottom face of base	$c_{bb} = 40 \text{ mm}$

Masonry details - Section 3.1

Masonry type	Aggregate concrete - Group 1
Normalised mean compressive strength	$f_b = 7.3 \text{ N/mm}^2$
Characteristic flexural strength - cl.6.3.4(1)	$f_{xk} = 0 \text{ N/mm}^2$
Initial shear strength - Table NA.5	$f_{vko} = 0.15 \text{ N/mm}^2$

Mortar details - Section 3.2

Mortar type	General purpose - M6, prescribed mix
Compressive strength of mortar	$f_m = 6 \text{ N/mm}^2$

Ultimate limit states - Table NA.1

Class of execution control	1
Category of manufacture control	1
Partial factor for direct or flexural compression	$\gamma_{Mc} = 2.0$

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Partial factor for flexural tension

$$\gamma_{Mt} = 2.3$$

Partial factor for shear

$$\gamma_{Mv} = 2.0$$

Characteristic strengths of concrete infill - Table 3.2

Concrete infill strength class

C28/35

Characteristic compressive strength

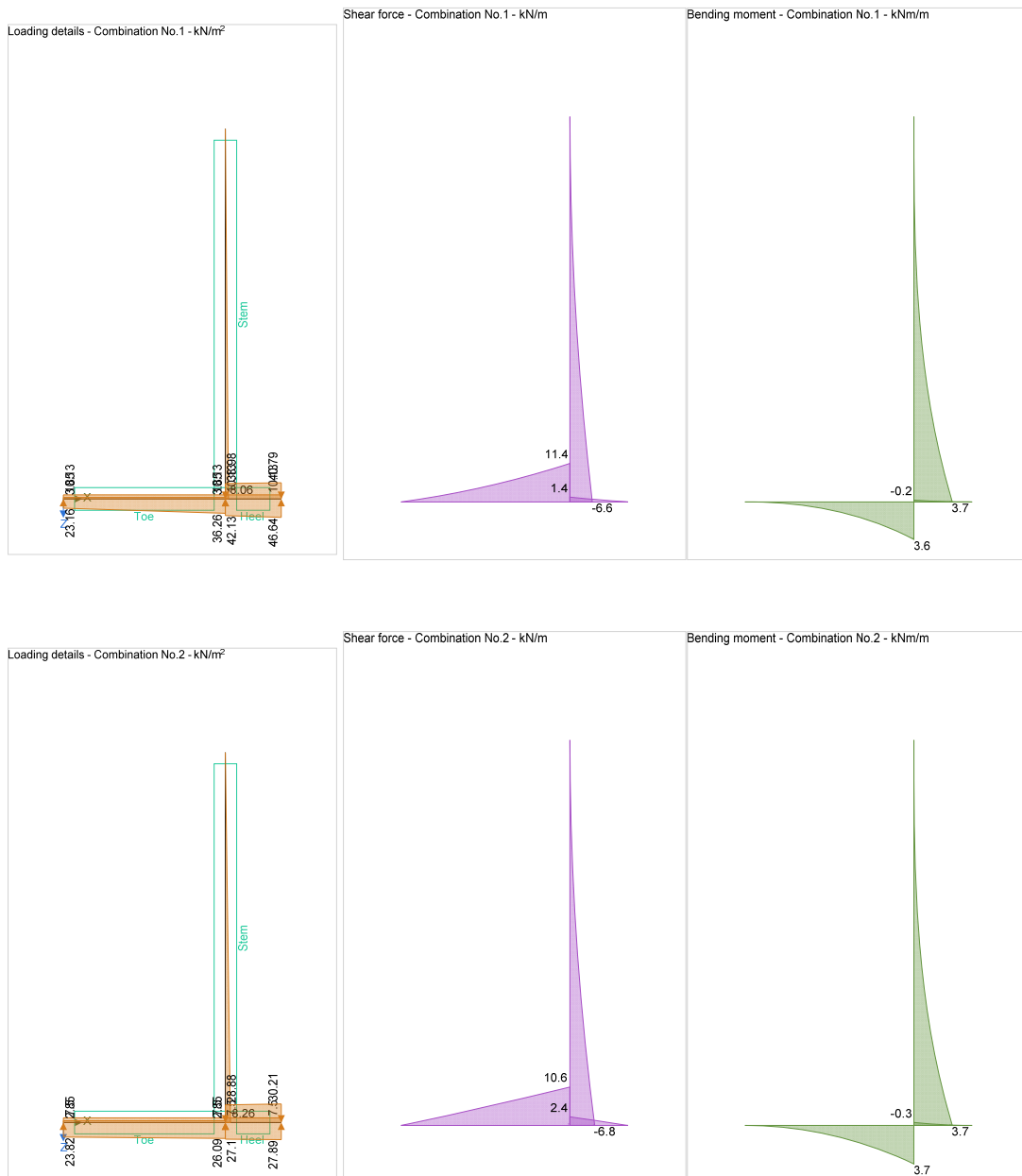
$$f_{ck, \text{infill}} = 25 \text{ N/mm}^2$$

Characteristic shear strength

$$f_{cvk, \text{infill}} = 0.45 \text{ N/mm}^2$$

Design shear strength

$$f_{cvd, \text{infill}} = f_{cvk, \text{infill}} / \gamma_{Mv} = 0.225 \text{ N/mm}^2$$



Check stem design at base of stem

Depth of section

$$t = 325 \text{ mm}$$

Cavity wall details

Front leaf thickness

$$t_f = 100 \text{ mm}$$

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Rear leaf thickness $t_r = 100$ mm

Masonry characteristics

Compressive strength constants - Table NA.4

$$K = 0.550$$

Characteristic compressive strength - cl.3.6.1.2(1)

$$f_k = K \times f_b^{0.7} \times f_m^{0.3} = 3.786 \text{ N/mm}^2$$

Design compressive strength

$$f_d = \min(f_k, f_{ck, \text{infill}}) / \gamma_{Mc} = 1.893 \text{ N/mm}^2$$

Design flexural strength

$$f_{xd} = f_{xk} / \gamma_{Mt} = 0 \text{ N/mm}^2$$

Height of masonry

$$h_{wt} = h_{stem} = 1650 \text{ mm}$$

Compressive axial force combination 0

$$F_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1}) = 14.4 \text{ kN/m}$$

Moment combination 0

$$M_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t^2 / 2 + P_{G1} \times (p_1 - l_{toe})) + \gamma_{Qf} \times P_{Q1} \times (p_1 - l_{toe})) = 2.5 \text{ kNm/m}$$

Eccentricity of axial load

$$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = 16.3 \text{ mm}$$

Capacity reduction factor - exp.6.4

$$\Phi = 1 - 2 \times e / t = 0.9$$

Design vertical resistance - exp.6.2

$$N_{Rd} = \Phi \times t \times f_d = 553.6 \text{ kN/m}$$

Design vertical compressive stress

$$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = 0.044 \text{ N/mm}^2$$

Apparent design flexural strength - exp.6.16

$$f_{xd, \text{app}} = f_{xd} + \sigma_d = 0.044 \text{ N/mm}^2$$

Limit of charact. shear strength - exp. 3.1

$$f_{vk, \text{lim}} = 0.065 \times f_b = 0.475 \text{ N/mm}^2$$

Characteristic shear strength - exp.3.5

$$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk, \text{lim}}) = 0.168 \text{ N/mm}^2$$

Design shear strength

$$f_{vd} = f_{vk} / \gamma_{Mv} = 0.084 \text{ N/mm}^2$$

Library item: Masonry characteristics output

Reinforced masonry members subjected to bending, bending and axial loading, or axial loading - Section 6.6

Design bending moment combination 2

$$M = 3.7 \text{ kNm/m}$$

Tension reinforcement provided

$$10 \text{ dia. bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{sr, \text{prov}} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 393 \text{ mm}^2/\text{m}$$

Depth to tension reinforcement

$$d = 175 \text{ mm}$$

Minimum area of reinforcement - cl.8.2.3(1)

$$A_{sr, \text{min}} = 0.0005 \times d = 88 \text{ mm}^2/\text{m}$$

Lever arm - exp.6.23

$$z = d \times \min(1 - 0.5 \times A_{sr, \text{prov}} \times f_{yd} / (d \times f_d), 0.95) = 130 \text{ mm}$$

Moment of resistance - exp.6.22 and exp.6.24a

$$M_{Rd} = \min(A_{sr, \text{prov}} \times f_{yd} \times z, 0.4 \times f_d \times d^2) = 22.2 \text{ kNm/m}$$

$$M / M_{Rd} = 0.169$$

PASS - Moment of resistance exceeds applied design moment

Reinforced masonry members subjected to shear loading - Section 6.7

Design shear force

$$V = 6.813 \text{ kN/m}$$

Design shear resistance - exp.6.40

$$V_{Rd} = \min(f_{vd}, f_{cvd, \text{infill}}) \times d = 14.676 \text{ kN/m}$$

$$V / V_{Rd} = 0.464$$

PASS - Design shear resistance exceeds applied design shear force

Horizontal reinforcement parallel to face of stem

Minimum area of reinforcement - cl.8.2.3(4)

$$A_{sx, \text{req}} = 0.0005 \times d = 88 \text{ mm}^2/\text{m}$$

Transverse reinforcement provided

$$10 \text{ dia. bars @ } 200 \text{ c/c}$$

Area of transverse reinforcement provided

$$A_{sx, \text{prov}} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = 393 \text{ mm}^2/\text{m}$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Check base design at toe

Depth of section

$$h = 300 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 2

$$M = 3.7 \text{ kNm/m}$$

Depth to tension reinforcement

$$d = h - c_{bb} - \phi_{bb} / 2 = 255 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.002$$

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$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$$

$$K' = \mathbf{0.207}$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr,prov} \times f_{yd} / (d \times f_d), 0.95) = \mathbf{210 \text{ mm}}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = \mathbf{113 \text{ mm}}$$

Area of tension reinforcement required

$$A_{bb,req} = M / (f_{yd} \times z) = \mathbf{41 \text{ mm}^2/\text{m}}$$

Tension reinforcement provided

$$\mathbf{10 \text{ dia.bars @ } 200 \text{ c/c}}$$

Area of tension reinforcement provided

$$A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{393 \text{ mm}^2/\text{m}}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{367 \text{ mm}^2/\text{m}}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bb,max} = 0.04 \times h = \mathbf{12000 \text{ mm}^2/\text{m}}$$

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = \mathbf{0.934}$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = \mathbf{0.3 \text{ mm}}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = \mathbf{0.6}$$

Serviceability bending moment

$$M_{sls} = \mathbf{2.5 \text{ kNm/m}}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bb,prov} \times z) = \mathbf{30.4 \text{ N/mm}^2}$$

Load duration

Long term

Load duration factor

$$k_t = \mathbf{0.4}$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = \mathbf{62415 \text{ mm}^2/\text{m}}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = \mathbf{2.8 \text{ N/mm}^2}$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bb,prov} / A_{c,eff} = \mathbf{0.006}$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = \mathbf{6.19}$$

Bond property coefficient

$$k_1 = \mathbf{0.8}$$

Strain distribution coefficient

$$k_2 = \mathbf{0.5}$$

$$k_3 = \mathbf{3.4}$$

$$k_4 = \mathbf{0.425}$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times C_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = \mathbf{406 \text{ mm}}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = \mathbf{0.037 \text{ mm}}$$

$$w_k / w_{max} = \mathbf{0.123}$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = \mathbf{11.4 \text{ kN/m}}$$

$$C_{Rd,c} = 0.18 / \gamma_c = \mathbf{0.120}$$

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.886}$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bb,prov} / d, 0.02) = \mathbf{0.002}$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.480 \text{ N/mm}^2}$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = \mathbf{122.3 \text{ kN/m}}$$

$$V / V_{Rd,c} = \mathbf{0.093}$$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section

$$h = \mathbf{300 \text{ mm}}$$

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Rectangular section in flexure - Section 6.1

Design bending moment combination 2

Depth to tension reinforcement

$$M = 0.3 \text{ kNm/m}$$

$$d = h - c_{bt} - \phi_{bt} / 2 = 255 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.000$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$$

$$K' = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr,prov} \times f_{yd} / (d \times f_d), 0.95) = 210 \text{ mm}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = 113 \text{ mm}$$

Area of tension reinforcement required

$$A_{bt,req} = M / (f_{yd} \times z) = 3 \text{ mm}^2/\text{m}$$

Tension reinforcement provided

$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = 393 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 367 \text{ mm}^2/\text{m}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bt,max} = 0.04 \times h = 12000 \text{ mm}^2/\text{m}$$

$$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = 0.934$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = 0.6$$

Serviceability bending moment

$$M_{sls} = 0.1 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = 1.2 \text{ N/mm}^2$$

Load duration

$$\text{Long term}$$

Load duration factor

$$k_t = 0.4$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 62415 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = 0.006$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = 6.19$$

Bond property coefficient

$$k_1 = 0.8$$

Strain distribution coefficient

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = 406 \text{ mm}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.001 \text{ mm}$$

$$w_k / w_{max} = 0.005$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 2.4 \text{ kN/m}$$

$$C_{Rd,c} = 0.18 / \gamma_c = 0.120$$

$$k = \min(1 + \sqrt{200 \text{ mm} / d}, 2) = 1.886$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bt,prov} / d, 0.02) = 0.002$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.480 \text{ N/mm}^2$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = 122.3 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.020$$

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PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

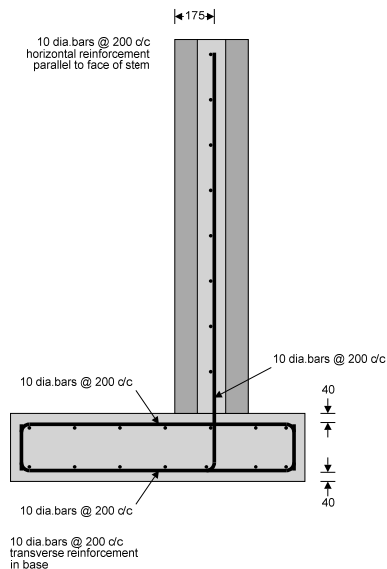
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx,req} = 0.2 \times A_{bb,prov} = 79 \text{ mm}^2/\text{m}$

Maximum spacing of reinforcement – cl.9.3.1.1(3) $S_{bx,max} = 450 \text{ mm}$

Transverse reinforcement provided 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided $A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times S_{bx}) = 393 \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required



Reinforcement details

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RETAINING WALL ANALYSIS & DESIGN (EN1992/EN1996/EN1997)

RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.9.07

Retaining wall details

Stem type	Cantilever
Stem height	$h_{\text{stem}} = 2400 \text{ mm}$
Stem thickness	$t_{\text{stem}} = 325 \text{ mm}$
Angle to rear face of stem	$\alpha = 90 \text{ deg}$
Stem density	$\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
Toe length	$l_{\text{toe}} = 900 \text{ mm}$
Heel length	$l_{\text{heel}} = 250 \text{ mm}$
Base thickness	$t_{\text{base}} = 300 \text{ mm}$
Base density	$\gamma_{\text{base}} = 25 \text{ kN/m}^3$
Height of retained soil	$h_{\text{ret}} = 2250 \text{ mm}$
Angle of soil surface	$\beta = 17 \text{ deg}$
Depth of cover	$d_{\text{cover}} = 150 \text{ mm}$

Retained soil properties

Soil type	Dense gravel
Moist density	$\gamma_{\text{mr}} = 17.5 \text{ kN/m}^3$
Saturated density	$\gamma_{\text{sr}} = 20.8 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{r.k}} = 42 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{r.k}} = 18 \text{ deg}$

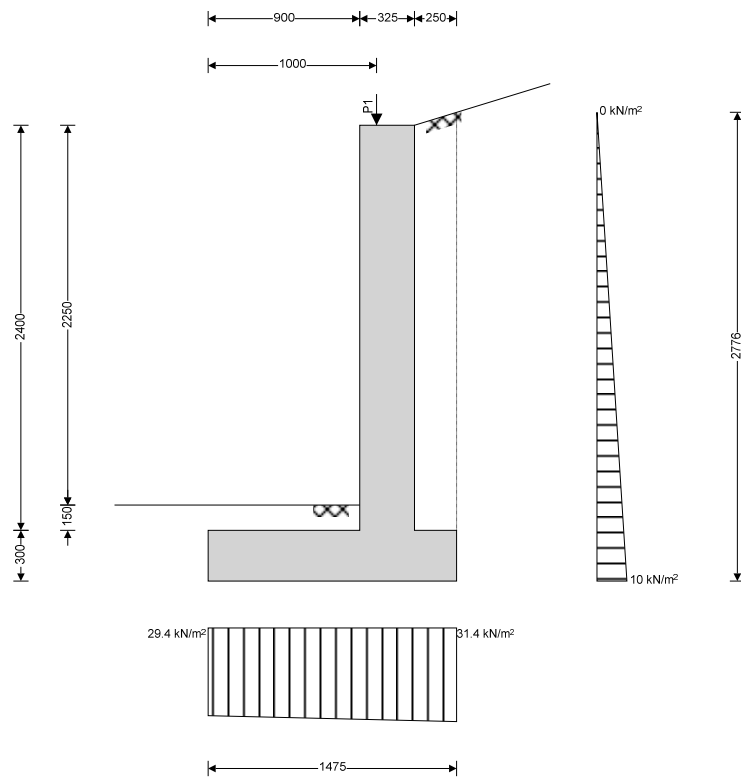
Base soil properties

Soil type	Stiff clay
Soil density	$\gamma_{\text{b}} = 19 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{b.k}} = 24 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{b.k}} = 9 \text{ deg}$
Characteristic base friction angle	$\delta_{\text{bb.k}} = 24 \text{ deg}$
Presumed bearing capacity	$P_{\text{bearing}} = 100 \text{ kN/m}^2$

Loading details

Vertical line load at 1000 mm	$P_{\text{G1}} = 1 \text{ kN/m}$
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General arrangement

Calculate retaining wall geometry

Base length

$$l_{base} = l_{toe} + t_{stem} + l_{heel} = 1475 \text{ mm}$$

Moist soil height

$$h_{moist} = h_{soil} = 2400 \text{ mm}$$

Retained surface length

$$l_{sur} = l_{heel} = 250 \text{ mm}$$

Effective height of wall

$$h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = 2776 \text{ mm}$$

Area of wall stem

$$A_{stem} = h_{stem} \times t_{stem} = 0.78 \text{ m}^2$$

- Distance to vertical component

$$x_{stem} = l_{toe} + t_{stem} / 2 = 1063 \text{ mm}$$

Area of wall base

$$A_{base} = l_{base} \times t_{base} = 0.443 \text{ m}^2$$

- Distance to vertical component

$$x_{base} = l_{base} / 2 = 738 \text{ mm}$$

Area of moist soil

$$A_{moist} = h_{moist} \times l_{heel} + \tan(\beta) \times l_{heel}^2 / 2 = 0.61 \text{ m}^2$$

- Distance to vertical component

$$x_{moist_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2 + \tan(\beta) \times l_{heel}^3 / 6) / A_{moist} = 1351 \text{ mm}$$

- Distance to horizontal component

$$x_{moist_h} = h_{eff} / 3 = 925 \text{ mm}$$

Area of base soil

$$A_{pass} = d_{cover} \times l_{toe} = 0.135 \text{ m}^2$$

- Distance to vertical component

$$x_{pass_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = 450 \text{ mm}$$

- Distance to horizontal component

$$x_{pass_h} = (d_{cover} + h_{base}) / 3 = 150 \text{ mm}$$

Area of excavated base soil

$$A_{exc} = h_{pass} \times l_{toe} = 0.135 \text{ m}^2$$

- Distance to vertical component

$$x_{exc_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{exc} = 450 \text{ mm}$$

- Distance to horizontal component

$$x_{exc_h} = (h_{pass} + h_{base}) / 3 = 150 \text{ mm}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times [1 + \sqrt{(\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}]^2) = 0.217$$

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Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,k})^2 / (\sin(90 + \delta_{b,k}) \times [1 - \sqrt{[\sin(\phi'_{b,k} + \delta_{b,k}) \times \sin(\phi'_{b,k}) / (\sin(90 + \delta_{b,k}))]}]^2) = \mathbf{3.049}$$

Bearing pressure check

Vertical forces on wall

Wall stem

$$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{19.5 \text{ kN/m}}$$

Wall base

$$F_{base} = A_{base} \times \gamma_{base} = \mathbf{11.1 \text{ kN/m}}$$

Line loads

$$F_{P_v} = P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = A_{moist} \times \gamma_{mr}' = \mathbf{10.7 \text{ kN/m}}$$

Base soil

$$F_{pass_v} = A_{pass} \times \gamma_b' = \mathbf{2.6 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{pass_v} = \mathbf{44.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{14.2 \text{ kN/m}}$$

Base soil

$$F_{pass_h} = -K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-5.8 \text{ kN/m}}$$

Total

$$F_{total_h} = \max(F_{moist_h} + F_{pass_h} - F_{total_v} \times \tan(\delta_{bb,k}), 0 \text{ kN/m}) = \mathbf{0 \text{ kN/m}}$$

Moments on wall

Wall stem

$$M_{stem} = F_{stem} \times x_{stem} = \mathbf{20.7 \text{ kNm/m}}$$

Wall base

$$M_{base} = F_{base} \times x_{base} = \mathbf{8.2 \text{ kNm/m}}$$

Line loads

$$M_P = P_{G1} \times p_1 = \mathbf{1 \text{ kNm/m}}$$

Moist retained soil

$$M_{moist} = F_{moist_v} \times x_{moist_v} - F_{moist_h} \times x_{moist_h} = \mathbf{1.3 \text{ kNm/m}}$$

Base soil

$$M_{pass} = F_{pass_v} \times x_{pass_v} - F_{pass_h} \times x_{pass_h} = \mathbf{2 \text{ kNm/m}}$$

Total

$$M_{total} = M_{stem} + M_{base} + M_P + M_{moist} + M_{pass} = \mathbf{33.2 \text{ kNm/m}}$$

Check bearing pressure

Distance to reaction

$$\bar{x} = M_{total} / F_{total_v} = \mathbf{741 \text{ mm}}$$

Eccentricity of reaction

$$e = \bar{x} - l_{base} / 2 = \mathbf{3 \text{ mm}}$$

Loaded length of base

$$l_{load} = l_{base} = \mathbf{1475 \text{ mm}}$$

Bearing pressure at toe

$$q_{toe} = F_{total_v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{30 \text{ kN/m}^2}$$

Bearing pressure at heel

$$q_{heel} = F_{total_v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{30.8 \text{ kN/m}^2}$$

Factor of safety

$$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{3.251}$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

Partial factors on actions - Table A.3 - Combination 1

Partial factor set

$$A1$$

Permanent unfavourable action

$$\gamma_G = \mathbf{1.35}$$

Permanent favourable action

$$\gamma_{Gf} = \mathbf{1.00}$$

Variable unfavourable action

$$\gamma_Q = \mathbf{1.50}$$

Variable favourable action

$$\gamma_{Qf} = \mathbf{0.00}$$

Partial factors for soil parameters – Table A.4 - Combination 1

Soil parameter set

$$M1$$

Angle of shearing resistance

$$\gamma_{\phi'} = \mathbf{1.00}$$

Effective cohesion

$$\gamma_{c'} = \mathbf{1.00}$$

Weight density

$$\gamma_{\gamma} = \mathbf{1.00}$$

Library item Partial factors output

Retained soil properties

Design moist density

$$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = \mathbf{17.5 \text{ kN/m}^3}$$

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Design saturated density

$$\gamma_{sr}' = \gamma_{sr} / \gamma_f = \mathbf{20.8 \text{ kN/m}^3}$$

Design effective shear resistance angle

$$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_\phi) = \mathbf{42 \text{ deg}}$$

Design wall friction angle

$$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_\phi) = \mathbf{18 \text{ deg}}$$

Base soil properties

Design soil density

$$\gamma_b' = \gamma_b / \gamma_f = \mathbf{19 \text{ kN/m}^3}$$

Design effective shear resistance angle

$$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_\phi) = \mathbf{24 \text{ deg}}$$

Design wall friction angle

$$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_\phi) = \mathbf{9 \text{ deg}}$$

Design base friction angle

$$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_\phi) = \mathbf{24 \text{ deg}}$$

Design effective cohesion

$$c'_{b,d} = c'_{b,k} / \gamma_c = \mathbf{0 \text{ kN/m}^2}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.217}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d} / (\sin(90 + \delta_{b,d}))}]^2) = \mathbf{3.049}$$

Sliding check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma G_f \times A_{stem} \times \gamma_{stem} = \mathbf{19.5 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma G_f \times A_{base} \times \gamma_{base} = \mathbf{11.1 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma G_f \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma G_f \times A_{moist} \times \gamma_{mr}' = \mathbf{10.7 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma G_f \times A_{exc} \times \gamma_b' = \mathbf{2.6 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{44.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{18.8 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} = \mathbf{18.8 \text{ kN/m}}$$

Check stability against sliding

Base soil resistance

$$F_{exc_h} = \gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{5.8 \text{ kN/m}}$$

Base friction

$$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = \mathbf{19.9 \text{ kN/m}}$$

Resistance to sliding

$$F_{rest} = F_{exc_h} + F_{friction} = \mathbf{25.7 \text{ kN/m}}$$

Factor of safety

$$FoS_{sl} = F_{rest} / F_{total_h} = \mathbf{1.367}$$

PASS - Resistance to sliding is greater than sliding force

Overtuning check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma G_f \times A_{stem} \times \gamma_{stem} = \mathbf{19.5 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma G_f \times A_{base} \times \gamma_{base} = \mathbf{11.1 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma G_f \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma G_f \times A_{moist} \times \gamma_{mr}' = \mathbf{10.7 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma G_f \times A_{exc} \times \gamma_b' = \mathbf{2.6 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{44.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{18.8 \text{ kN/m}}$$

Base soil

$$F_{exc_h} = -\gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-5.8 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} + F_{exc_h} = \mathbf{13 \text{ kN/m}}$$

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Overturning moments on wall

Moist retained soil $M_{\text{moist_OT}} = F_{\text{moist_h}} \times X_{\text{moist_h}} = 17.4 \text{ kNm/m}$

Total $M_{\text{total_OT}} = M_{\text{moist_OT}} = 17.4 \text{ kNm/m}$

Restoring moments on wall

Wall stem $M_{\text{stem_R}} = F_{\text{stem}} \times X_{\text{stem}} = 20.7 \text{ kNm/m}$

Wall base $M_{\text{base_R}} = F_{\text{base}} \times X_{\text{base}} = 8.2 \text{ kNm/m}$

Line loads $M_{\text{P_R}} = \text{abs}(\gamma_{\text{Gf}} \times P_{\text{G1}}) \times p_1 = 1 \text{ kNm/m}$

Moist retained soil $M_{\text{moist_R}} = F_{\text{moist_v}} \times X_{\text{moist_v}} = 14.4 \text{ kNm/m}$

Base soil $M_{\text{exc_R}} = F_{\text{exc_v}} \times X_{\text{exc_v}} - F_{\text{exc_h}} \times X_{\text{exc_h}} = 2 \text{ kNm/m}$

Total $M_{\text{total_R}} = M_{\text{stem_R}} + M_{\text{base_R}} + M_{\text{P_R}} + M_{\text{moist_R}} + M_{\text{exc_R}} = 46.3 \text{ kNm/m}$

Check stability against overturning

Factor of safety $\text{FoS}_{\text{ot}} = M_{\text{total_R}} / M_{\text{total_OT}} = 2.658$

PASS - Maximum restoring moment is greater than overturning moment

Design approach 1

Partial factors on actions - Table A.3 - Combination 2

Partial factor set	A2
Permanent unfavourable action	$\gamma_{\text{G}} = 1.00$
Permanent favourable action	$\gamma_{\text{Gf}} = 1.00$
Variable unfavourable action	$\gamma_{\text{Q}} = 1.30$
Variable favourable action	$\gamma_{\text{Qf}} = 0.00$

Partial factors for soil parameters – Table A.4 - Combination 2

Soil parameter set	M2
Angle of shearing resistance	$\gamma_{\phi'} = 1.25$
Effective cohesion	$\gamma_{c'} = 1.25$
Weight density	$\gamma_{\gamma} = 1.00$

Library item Partial factors output

Retained soil properties

Design moist density $\gamma_{\text{mr}}' = \gamma_{\text{mr}} / \gamma_{\gamma} = 17.5 \text{ kN/m}^3$

Design saturated density $\gamma_{\text{sr}}' = \gamma_{\text{sr}} / \gamma_{\gamma} = 20.8 \text{ kN/m}^3$

Design effective shear resistance angle $\phi'_{\text{r,d}} = \text{atan}(\tan(\phi'_{\text{r,k}}) / \gamma_{\phi'}) = 35.8 \text{ deg}$

Design wall friction angle $\delta_{\text{r,d}} = \text{atan}(\tan(\delta_{\text{r,k}}) / \gamma_{\phi'}) = 14.6 \text{ deg}$

Base soil properties

Design soil density $\gamma_{\text{b}}' = \gamma_{\text{b}} / \gamma_{\gamma} = 19 \text{ kN/m}^3$

Design effective shear resistance angle $\phi'_{\text{b,d}} = \text{atan}(\tan(\phi'_{\text{b,k}}) / \gamma_{\phi'}) = 19.6 \text{ deg}$

Design wall friction angle $\delta_{\text{b,d}} = \text{atan}(\tan(\delta_{\text{b,k}}) / \gamma_{\phi'}) = 7.2 \text{ deg}$

Design base friction angle $\delta_{\text{bb,d}} = \text{atan}(\tan(\delta_{\text{bb,k}}) / \gamma_{\phi'}) = 19.6 \text{ deg}$

Design effective cohesion $c'_{\text{b,d}} = c'_{\text{b,k}} / \gamma_{c'} = 0 \text{ kN/m}^2$

Using Coulomb theory

Active pressure coefficient $K_{\text{A}} = \sin(\alpha + \phi'_{\text{r,d}})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{\text{r,d}}) \times [1 + \sqrt{[\sin(\phi'_{\text{r,d}} + \delta_{\text{r,d}}) \times \sin(\phi'_{\text{r,d}} - \beta) / (\sin(\alpha - \delta_{\text{r,d}}) \times \sin(\alpha + \beta))]}]^2) = 0.295$

Passive pressure coefficient $K_{\text{P}} = \sin(90 - \phi'_{\text{b,d}})^2 / (\sin(90 + \delta_{\text{b,d}}) \times [1 - \sqrt{[\sin(\phi'_{\text{b,d}} + \delta_{\text{b,d}}) \times \sin(\phi'_{\text{b,d}}) / (\sin(90 + \delta_{\text{b,d}}))]}]^2) = 2.409$

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Sliding check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma G_f \times A_{\text{stem}} \times \gamma_{\text{stem}} = 19.5 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma G_f \times A_{\text{base}} \times \gamma_{\text{base}} = 11.1 \text{ kN/m}$
Line loads	$F_{P_v} = \gamma G_f \times P_{G1} = 1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma G_f \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 10.7 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma G_f \times A_{\text{exc}} \times \gamma_b' = 2.6 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{P_v} + F_{\text{moist}_v} + F_{\text{exc}_v} = 44.8 \text{ kN/m}$

Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 19.3 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} = 19.3 \text{ kN/m}$

Check stability against sliding

Base soil resistance	$F_{\text{exc}_h} = \gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = 4.6 \text{ kN/m}$
Base friction	$F_{\text{friction}} = F_{\text{total}_v} \times \tan(\delta_{bb,d}) = 16 \text{ kN/m}$
Resistance to sliding	$F_{\text{rest}} = F_{\text{exc}_h} + F_{\text{friction}} = 20.6 \text{ kN/m}$
Factor of safety	$F_{\text{oSsl}} = F_{\text{rest}} / F_{\text{total}_h} = 1.065$
PASS - Resistance to sliding is greater than sliding force	

Overtuning check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma G_f \times A_{\text{stem}} \times \gamma_{\text{stem}} = 19.5 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma G_f \times A_{\text{base}} \times \gamma_{\text{base}} = 11.1 \text{ kN/m}$
Line loads	$F_{P_v} = \gamma G_f \times P_{G1} = 1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma G_f \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 10.7 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma G_f \times A_{\text{exc}} \times \gamma_b' = 2.6 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{P_v} + F_{\text{moist}_v} + F_{\text{exc}_v} = 44.8 \text{ kN/m}$

Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 19.3 \text{ kN/m}$
Base soil	$F_{\text{exc}_h} = -\gamma G_f \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = -4.6 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} + F_{\text{exc}_h} = 14.7 \text{ kN/m}$

Overtuning moments on wall

Moist retained soil	$M_{\text{moist}_OT} = F_{\text{moist}_h} \times X_{\text{moist}_h} = 17.9 \text{ kNm/m}$
Total	$M_{\text{total}_OT} = M_{\text{moist}_OT} = 17.9 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = 20.7 \text{ kNm/m}$
Wall base	$M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = 8.2 \text{ kNm/m}$
Line loads	$M_{P_R} = \text{abs}(\gamma G_f \times P_{G1}) \times p_1 = 1 \text{ kNm/m}$
Moist retained soil	$M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = 14.4 \text{ kNm/m}$
Base soil	$M_{\text{exc}_R} = F_{\text{exc}_v} \times X_{\text{exc}_v} - F_{\text{exc}_h} \times X_{\text{exc}_h} = 1.8 \text{ kNm/m}$
Total	$M_{\text{total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{P_R} + M_{\text{moist}_R} + M_{\text{exc}_R} = 46.1 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$F_{\text{OSot}} = M_{\text{total}_R} / M_{\text{total}_OT} = 2.584$
PASS - Maximum restoring moment is greater than overturning moment	

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RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1 and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the UK National Annex

Tedds calculation version 2.9.07

Concrete details - Table 3.1 - Strength and deformation characteristics for concrete

Concrete strength class	C28/35
Characteristic compressive cylinder strength	$f_{ck} = 28 \text{ N/mm}^2$
Characteristic compressive cube strength	$f_{ck,cube} = 35 \text{ N/mm}^2$
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 36 \text{ N/mm}^2$
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = 2.8 \text{ N/mm}^2$
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} = 1.9 \text{ N/mm}^2$
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = 32308 \text{ N/mm}^2$
Partial factor for concrete - Table 2.1N	$\gamma_C = 1.50$
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{cc} = 0.85$
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = 15.9 \text{ N/mm}^2$
Maximum aggregate size	$h_{agg} = 20 \text{ mm}$
Ultimate strain - Table 3.1	$\epsilon_{cu2} = 0.0035$
Shortening strain - Table 3.1	$\epsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$
Bending coefficient k_1	$K_1 = 0.40$
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$
Bending coefficient k_3	$K_3 = 0.40$
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$

Reinforcement details

Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement	$E_s = 200000 \text{ N/mm}^2$
Partial factor for reinforcing steel - Table 2.1N	$\gamma_S = 1.15$
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S = 435 \text{ N/mm}^2$

Cover to reinforcement

Top face of base	$c_{bt} = 40 \text{ mm}$
Bottom face of base	$c_{bb} = 40 \text{ mm}$

Masonry details - Section 3.1

Masonry type	Aggregate concrete - Group 1
Normalised mean compressive strength	$f_b = 7.3 \text{ N/mm}^2$
Characteristic flexural strength - cl.6.3.4(1)	$f_{xk} = 0 \text{ N/mm}^2$
Initial shear strength - Table NA.5	$f_{vko} = 0.15 \text{ N/mm}^2$

Mortar details - Section 3.2

Mortar type	General purpose - M6, prescribed mix
Compressive strength of mortar	$f_m = 6 \text{ N/mm}^2$

Ultimate limit states - Table NA.1

Class of execution control	1
Category of manufacture control	1
Partial factor for direct or flexural compression	$\gamma_{Mc} = 2.0$

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Partial factor for flexural tension

$\gamma_{Mt} = 2.3$

Partial factor for shear

$\gamma_{MV} = 2.0$

Characteristic strengths of concrete infill - Table 3.2

Concrete infill strength class

C28/35

Characteristic compressive strength

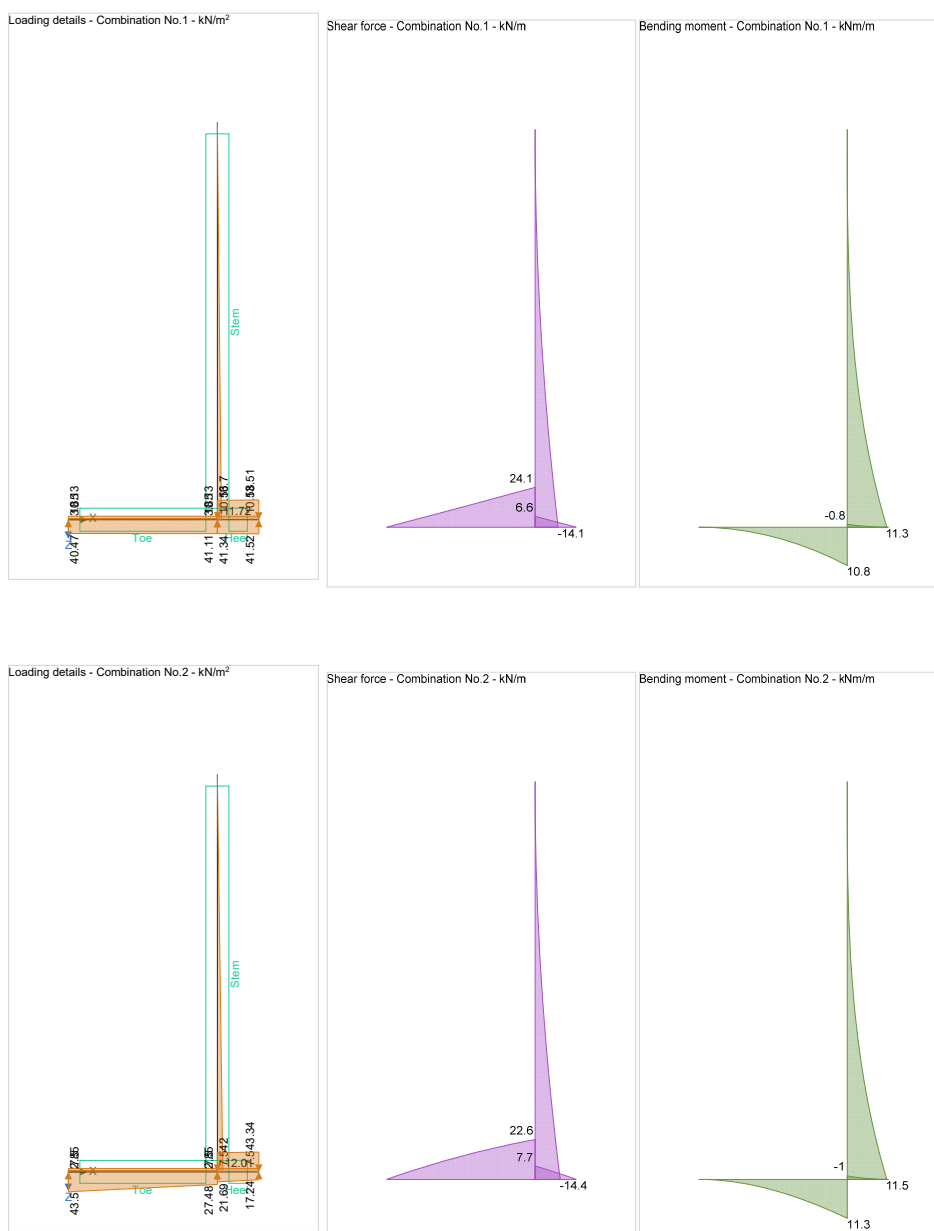
$$f_{ck,infill} = 25 \text{ N/mm}^2$$

Characteristic shear strength

$$f_{cvk,infll} = 0.45 \text{ N/mm}^2$$

Design shear strength

$$f_{cvd,infll} = f_{cvk,infll} / \gamma_{Mv} = \mathbf{0.225 \text{ N/mm}^2}$$



Check stem design at base of stem

Depth of section

t = 325 mm

Cavity wall details

Front leaf thickness

$$t_f = 100 \text{ mm}$$

Rear leaf thickness

$$t_r = 100 \text{ mm}$$

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Masonry characteristics

Compressive strength constants - Table NA.4	$K = 0.550$
Characteristic compressive strength - cl.3.6.1.2(1)	$f_k = K \times f_b^{0.7} \times f_m^{0.3} = 3.786 \text{ N/mm}^2$
Design compressive strength	$f_d = \min(f_k, f_{ck, \text{infill}}) / \gamma_{Mc} = 1.893 \text{ N/mm}^2$
Design flexural strength	$f_{xd} = f_{xk} / \gamma_{Mt} = 0 \text{ N/mm}^2$
Height of masonry	$h_{wt} = h_{stem} = 2400 \text{ mm}$
Compressive axial force combination 0	$F_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1}) = 20.5 \text{ kN/m}$
Moment combination 0	$M_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t^2 / 2 + P_{G1} \times (p_1 - l_{toe})) + \gamma_{Qf} \times P_{Q1} \times (p_1 - l_{toe})) = 3.3 \text{ kNm/m}$
Eccentricity of axial load	$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = 16.3 \text{ mm}$
Capacity reduction factor - exp.6.4	$\Phi = 1 - 2 \times e / t = 0.9$
Design vertical resistance - exp.6.2	$N_{Rd} = \Phi \times t \times f_d = 553.6 \text{ kN/m}$
Design vertical compressive stress	$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = 0.063 \text{ N/mm}^2$
Apparent design flexural strength - exp.6.16	$f_{xd, \text{app}} = f_{xd} + \sigma_d = 0.063 \text{ N/mm}^2$
Limit of charact. shear strength - exp. 3.1	$f_{vk, \text{lim}} = 0.065 \times f_b = 0.475 \text{ N/mm}^2$
Characteristic shear strength - exp.3.5	$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk, \text{lim}}) = 0.175 \text{ N/mm}^2$
Design shear strength	$f_{vd} = f_{vk} / \gamma_{Mv} = 0.088 \text{ N/mm}^2$

Library item: Masonry characteristics output

Reinforced masonry members subjected to bending, bending and axial loading, or axial loading - Section 6.6

Design bending moment combination 2	$M = 11.5 \text{ kNm/m}$
Tension reinforcement provided	10 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{sr, \text{prov}} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 393 \text{ mm}^2/\text{m}$
Depth to tension reinforcement	$d = 175 \text{ mm}$
Minimum area of reinforcement - cl.8.2.3(1)	$A_{sr, \text{min}} = 0.0005 \times d = 88 \text{ mm}^2/\text{m}$
Lever arm - exp.6.23	$z = d \times \min(1 - 0.5 \times A_{sr, \text{prov}} \times f_{yd} / (d \times f_d), 0.95) = 130 \text{ mm}$
Moment of resistance - exp.6.22 and exp.6.24a	$M_{Rd} = \min(A_{sr, \text{prov}} \times f_{yd} \times z, 0.4 \times f_d \times d^2) = 22.2 \text{ kNm/m}$
	$M / M_{Rd} = 0.520$

PASS - Moment of resistance exceeds applied design moment

Reinforced masonry members subjected to shear loading - Section 6.7

Design shear force	$V = 14.414 \text{ kN/m}$
Design shear resistance - exp.6.40	$V_{Rd} = \min(f_{vd}, f_{c, \text{vd}, \text{infill}}) \times d = 15.333 \text{ kN/m}$
	$V / V_{Rd} = 0.940$

PASS - Design shear resistance exceeds applied design shear force

Horizontal reinforcement parallel to face of stem

Minimum area of reinforcement - cl.8.2.3(4)	$A_{sx, \text{req}} = 0.0005 \times d = 88 \text{ mm}^2/\text{m}$
Transverse reinforcement provided	10 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{sx, \text{prov}} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = 393 \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Check base design at toe

Depth of section	$h = 300 \text{ mm}$
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Rectangular section in flexure - Section 6.1

Design bending moment combination 2	$M = 11.3 \text{ kNm/m}$
Depth to tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2 = 255 \text{ mm}$
	$K = M / (d^2 \times f_{ck}) = 0.006$
	$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$

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$$K' = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr,prov} \times f_{yd} / (d \times f_d), 0.95) = 210 \text{ mm}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = 113 \text{ mm}$$

Area of tension reinforcement required

$$A_{bb,req} = M / (f_{yd} \times z) = 123 \text{ mm}^2/\text{m}$$

Tension reinforcement provided

$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times S_{bb}) = 393 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 367 \text{ mm}^2/\text{m}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bb,max} = 0.04 \times h = 12000 \text{ mm}^2/\text{m}$$

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = 0.934$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = 0.6$$

Serviceability bending moment

$$M_{sls} = 7.9 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bb,prov} \times z) = 95.4 \text{ N/mm}^2$$

Load duration

Long term

Load duration factor

$$k_t = 0.4$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 62415 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bb,prov} / A_{c,eff} = 0.006$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = 6.19$$

Bond property coefficient

$$k_1 = 0.8$$

Strain distribution coefficient

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = 406 \text{ mm}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.116 \text{ mm}$$

$$w_k / w_{max} = 0.388$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 24.1 \text{ kN/m}$$

$$C_{Rd,c} = 0.18 / \gamma_C = 0.120$$

$$k = \min(1 + \sqrt{200 \text{ mm} / d}, 2) = 1.886$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bb,prov} / d, 0.02) = 0.002$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.480 \text{ N/mm}^2$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = 122.3 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.197$$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section

$$h = 300 \text{ mm}$$

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Rectangular section in flexure - Section 6.1

Design bending moment combination 2

$$M = 1 \text{ kNm/m}$$

Depth to tension reinforcement

$$d = h - c_{bt} - \phi_{bt} / 2 = 255 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.001$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$$

$$K' = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr,prov} \times f_{yd} / (d \times f_d), 0.95) = 210 \text{ mm}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = 113 \text{ mm}$$

Area of tension reinforcement required

$$A_{bt,req} = M / (f_{yd} \times z) = 11 \text{ mm}^2/\text{m}$$

Tension reinforcement provided

$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = 393 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 367 \text{ mm}^2/\text{m}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bt,max} = 0.04 \times h = 12000 \text{ mm}^2/\text{m}$$

$$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = 0.934$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = 0.6$$

Serviceability bending moment

$$M_{sls} = 0.6 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = 7.3 \text{ N/mm}^2$$

Load duration

Long term

Load duration factor

$$k_t = 0.4$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 62415 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = 0.006$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = 6.19$$

Bond property coefficient

$$k_1 = 0.8$$

Strain distribution coefficient

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = 406 \text{ mm}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.009 \text{ mm}$$

$$w_k / w_{max} = 0.029$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 7.7 \text{ kN/m}$$

$$C_{Rd,c} = 0.18 / \gamma_c = 0.120$$

$$k = \min(1 + \sqrt{200 \text{ mm} / d}, 2) = 1.886$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bt,prov} / d, 0.02) = 0.002$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.480 \text{ N/mm}^2$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = 122.3 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.063$$

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PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

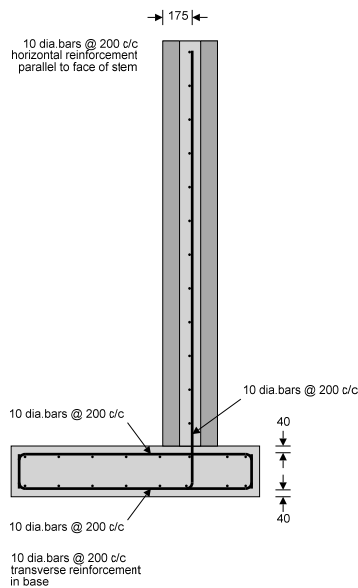
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx,req} = 0.2 \times A_{bb,prov} = 79 \text{ mm}^2/\text{m}$

Maximum spacing of reinforcement – cl.9.3.1.1(3) $S_{bx,max} = 450 \text{ mm}$

Transverse reinforcement provided 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided $A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times S_{bx}) = 393 \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required



Reinforcement details

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RETAINING WALL ANALYSIS & DESIGN (EN1992/EN1996/EN1997)

RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.9.07

Retaining wall details

Stem type	Cantilever
Stem height	$h_{\text{stem}} = 3350 \text{ mm}$
Stem thickness	$t_{\text{stem}} = 375 \text{ mm}$
Angle to rear face of stem	$\alpha = 90 \text{ deg}$
Stem density	$\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
Toe length	$l_{\text{toe}} = 1400 \text{ mm}$
Heel length	$l_{\text{heel}} = 250 \text{ mm}$
Base thickness	$t_{\text{base}} = 450 \text{ mm}$
Key position	$p_{\text{key}} = 0 \text{ mm}$
Key depth	$d_{\text{key}} = 500 \text{ mm}$
Key thickness	$t_{\text{key}} = 300 \text{ mm}$
Base density	$\gamma_{\text{base}} = 25 \text{ kN/m}^3$
Height of retained soil	$h_{\text{ret}} = 3200 \text{ mm}$
Angle of soil surface	$\beta = 22.5 \text{ deg}$
Depth of cover	$d_{\text{cover}} = 150 \text{ mm}$

Retained soil properties

Soil type	Dense gravel
Moist density	$\gamma_{\text{mr}} = 17.5 \text{ kN/m}^3$
Saturated density	$\gamma_{\text{sr}} = 20.8 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{r,k}} = 42 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{r,k}} = 21 \text{ deg}$

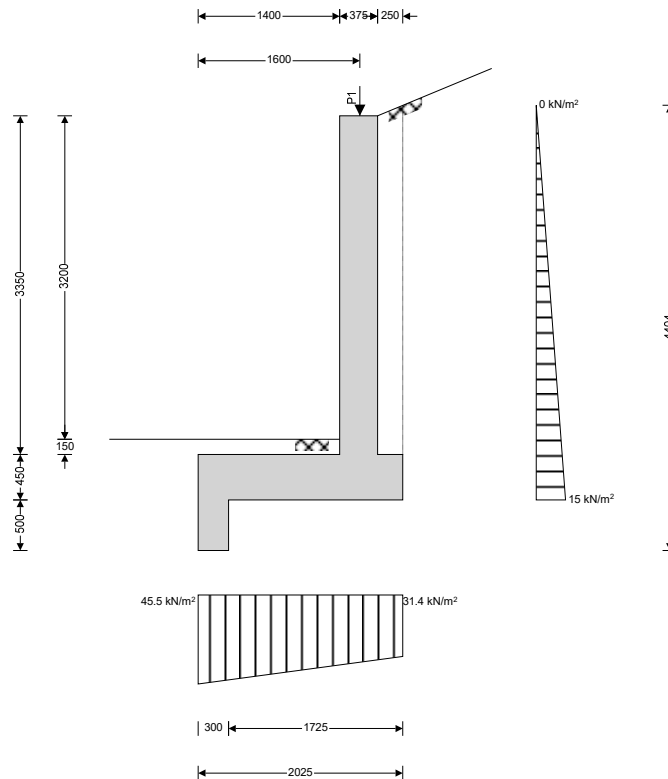
Base soil properties

Soil type	Stiff clay
Soil density	$\gamma_{\text{b}} = 19 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{\text{b,k}} = 24 \text{ deg}$
Characteristic wall friction angle	$\delta_{\text{b,k}} = 12 \text{ deg}$
Characteristic base friction angle	$\delta_{\text{bb,k}} = 24 \text{ deg}$
Presumed bearing capacity	$P_{\text{bearing}} = 100 \text{ kN/m}^2$

Loading details

Vertical line load at 1600 mm	$P_{\text{G1}} = 1 \text{ kN/m}$
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General arrangement

Calculate retaining wall geometry

Base length

$$l_{base} = l_{toe} + t_{stem} + l_{heel} = \mathbf{2025 \text{ mm}}$$

Base height

$$h_{base} = t_{base} + d_{key} = \mathbf{950 \text{ mm}}$$

Moist soil height

$$h_{moist} = h_{soil} = \mathbf{3350 \text{ mm}}$$

Retained surface length

$$l_{sur} = l_{heel} = \mathbf{250 \text{ mm}}$$

Effective height of wall

$$h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = \mathbf{4404 \text{ mm}}$$

Area of wall stem

$$A_{stem} = h_{stem} \times t_{stem} = \mathbf{1.256 \text{ m}^2}$$

- Distance to vertical component

$$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1588 \text{ mm}}$$

Area of wall base

$$A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = \mathbf{1.061 \text{ m}^2}$$

- Distance to vertical component

$$x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = \mathbf{891 \text{ mm}}$$

Area of moist soil

$$A_{moist} = h_{moist} \times l_{heel} + \tan(\beta) \times l_{heel}^2 / 2 = \mathbf{0.85 \text{ m}^2}$$

- Distance to vertical component

$$x_{moist_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2 + \tan(\beta) \times l_{heel}^3 / 6) / A_{moist} = \mathbf{1901 \text{ mm}}$$

- Distance to horizontal component

$$x_{moist_h} = h_{eff} / 3 - d_{key} = \mathbf{968 \text{ mm}}$$

- Distance to horizontal component above key

$$x_{moist_h_a} = (h_{eff} - d_{key}) / 3 = \mathbf{1301 \text{ mm}}$$

Area of base soil

$$A_{pass} = d_{cover} \times l_{toe} = \mathbf{0.21 \text{ m}^2}$$

- Distance to vertical component

$$x_{pass_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = \mathbf{700 \text{ mm}}$$

- Distance to horizontal component

$$x_{pass_h} = (d_{cover} + h_{base}) / 3 - d_{key} = \mathbf{-133 \text{ mm}}$$

Area of excavated base soil

$$A_{exc} = h_{pass} \times l_{toe} = \mathbf{0.21 \text{ m}^2}$$

- Distance to vertical component

$$x_{exc_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{exc} = \mathbf{700 \text{ mm}}$$

- Distance to horizontal component

$$x_{exc_h} = (h_{pass} + h_{base}) / 3 - d_{key} = \mathbf{-133 \text{ mm}}$$

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Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times [1 + \sqrt{\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.235}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,k})^2 / (\sin(90 + \delta_{b,k}) \times [1 - \sqrt{\sin(\phi'_{b,k} + \delta_{b,k}) \times \sin(\phi'_{b,k}) / (\sin(90 + \delta_{b,k}))}]^2) = \mathbf{3.337}$$

Bearing pressure check

Vertical forces on wall

Wall stem

$$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{31.4 \text{ kN/m}}$$

Wall base

$$F_{base} = A_{base} \times \gamma_{base} = \mathbf{26.5 \text{ kN/m}}$$

Line loads

$$F_{P_v} = P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = A_{moist} \times \gamma_{mr} = \mathbf{14.9 \text{ kN/m}}$$

Base soil

$$F_{pass_v} = A_{pass} \times \gamma_b = \mathbf{4 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{pass_v} = \mathbf{77.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = K_A \times \cos(\delta_{r,k}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 = \mathbf{29.2 \text{ kN/m}}$$

Base soil

$$F_{pass_h} = \max(-K_P \times \cos(\delta_{b,k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2, -(F_{moist_h})) = \mathbf{-29.2 \text{ kN/m}}$$

Total

$$F_{total_h} = \max(F_{moist_h} + F_{pass_h} - F_{total_v} \times \tan(\delta_{bb,k}), 0 \text{ kN/m}) = \mathbf{0 \text{ kN/m}}$$

Moments on wall

Wall stem

$$M_{stem} = F_{stem} \times x_{stem} = \mathbf{49.9 \text{ kNm/m}}$$

Wall base

$$M_{base} = F_{base} \times x_{base} = \mathbf{23.6 \text{ kNm/m}}$$

Line loads

$$M_P = P_{G1} \times p_1 = \mathbf{1.6 \text{ kNm/m}}$$

Moist retained soil

$$M_{moist} = F_{moist_v} \times x_{moist_v} - F_{moist_h} \times x_{moist_h} = \mathbf{0 \text{ kNm/m}}$$

Base soil

$$M_{pass} = F_{pass_v} \times x_{pass_v} - F_{pass_h} \times x_{pass_h} = \mathbf{-1.1 \text{ kNm/m}}$$

Total

$$M_{total} = M_{stem} + M_{base} + M_P + M_{moist} + M_{pass} = \mathbf{74 \text{ kNm/m}}$$

Check bearing pressure

Distance to reaction

$$\bar{x} = M_{total} / F_{total_v} = \mathbf{951 \text{ mm}}$$

Eccentricity of reaction

$$e = \bar{x} - l_{base} / 2 = \mathbf{-62 \text{ mm}}$$

Loaded length of base

$$l_{load} = l_{base} = \mathbf{2025 \text{ mm}}$$

Bearing pressure at toe

$$q_{toe} = F_{total_v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{45.5 \text{ kN/m}^2}$$

Bearing pressure at heel

$$q_{heel} = F_{total_v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{31.4 \text{ kN/m}^2}$$

Factor of safety

$$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{2.2}$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

Partial factors on actions - Table A.3 - Combination 1

Partial factor set

$$A1$$

Permanent unfavourable action

$$\gamma_G = \mathbf{1.35}$$

Permanent favourable action

$$\gamma_{Gf} = \mathbf{1.00}$$

Variable unfavourable action

$$\gamma_Q = \mathbf{1.50}$$

Variable favourable action

$$\gamma_{Qf} = \mathbf{0.00}$$

Partial factors for soil parameters – Table A.4 - Combination 1

Soil parameter set

$$M1$$

Angle of shearing resistance

$$\gamma_{\phi'} = \mathbf{1.00}$$

Effective cohesion

$$\gamma_{c'} = \mathbf{1.00}$$

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Weight density

$$\gamma_{\gamma} = 1.00$$

Library item Partial factors output

Retained soil properties

Design moist density

$$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = 17.5 \text{ kN/m}^3$$

Design saturated density

$$\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = 20.8 \text{ kN/m}^3$$

Design effective shear resistance angle

$$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi}') = 42 \text{ deg}$$

Design wall friction angle

$$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi}') = 21 \text{ deg}$$

Base soil properties

Design soil density

$$\gamma_b' = \gamma_b / \gamma_{\gamma} = 19 \text{ kN/m}^3$$

Design effective shear resistance angle

$$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi}') = 24 \text{ deg}$$

Design wall friction angle

$$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi}') = 12 \text{ deg}$$

Design base friction angle

$$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi}') = 24 \text{ deg}$$

Design effective cohesion

$$c'_{b,d} = c'_{b,k} / \gamma_{c'} = 0 \text{ kN/m}^2$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{[\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))]}]^2) = 0.235$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{[\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))]}]^2) = 3.337$$

Sliding check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = 31.4 \text{ kN/m}$$

Wall base

$$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = 26.5 \text{ kN/m}$$

Line loads

$$F_{P_v} = \gamma_{Gf} \times P_{G1} = 1 \text{ kN/m}$$

Moist retained soil

$$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = 14.9 \text{ kN/m}$$

Base soil

$$F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = 4 \text{ kN/m}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = 77.8 \text{ kN/m}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = 50.2 \text{ kN/m}$$

Total

$$F_{total_h} = F_{moist_h} = 50.2 \text{ kN/m}$$

Check stability against sliding

Base soil resistance

$$F_{exc_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = 37.5 \text{ kN/m}$$

Base friction

$$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = 34.6 \text{ kN/m}$$

Resistance to sliding

$$F_{rest} = F_{exc_h} + F_{friction} = 72.2 \text{ kN/m}$$

Factor of safety

$$FoS_{sl} = F_{rest} / F_{total_h} = 1.437$$

PASS - Resistance to sliding is greater than sliding force

Overtipping check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = 31.4 \text{ kN/m}$$

Wall base

$$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = 26.5 \text{ kN/m}$$

Line loads

$$F_{P_v} = \gamma_{Gf} \times P_{G1} = 1 \text{ kN/m}$$

Moist retained soil

$$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = 14.9 \text{ kN/m}$$

Base soil

$$F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = 4 \text{ kN/m}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = 77.8 \text{ kN/m}$$

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Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times (h_{\text{eff}} - d_{\text{key}})^2 / 2 = 39.5 \text{ kN/m}$
Base soil	$F_{\text{exc}_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = -37.5 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} + F_{\text{exc}_h} = 1.9 \text{ kN/m}$

Overtuning moments on wall

Moist retained soil	$M_{\text{moist}_OT} = F_{\text{moist}_h} \times X_{\text{moist}_h_a} = 51.3 \text{ kNm/m}$
Base soil	$M_{\text{exc}_OT} = F_{\text{exc}_h} \times X_{\text{exc}_h} = 5 \text{ kNm/m}$
Total	$M_{\text{total}_OT} = M_{\text{moist}_OT} + M_{\text{exc}_OT} = 56.3 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = 49.9 \text{ kNm/m}$
Wall base	$M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = 23.6 \text{ kNm/m}$
Line loads	$M_{P_R} = \text{abs}(\gamma_{Gf} \times P_{G1}) \times p_1 = 1.6 \text{ kNm/m}$
Moist retained soil	$M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = 28.3 \text{ kNm/m}$
Base soil	$M_{\text{exc}_R} = F_{\text{exc}_v} \times X_{\text{exc}_v} = 2.8 \text{ kNm/m}$
Total	$M_{\text{total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{P_R} + M_{\text{moist}_R} + M_{\text{exc}_R} = 106.2 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{\text{total}_R} / M_{\text{total}_OT} = 1.884$
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PASS - Maximum restoring moment is greater than overturning moment

Design approach 1

Partial factors on actions - Table A.3 - Combination 2

Partial factor set	A2
Permanent unfavourable action	$\gamma_G = 1.00$
Permanent favourable action	$\gamma_{Gf} = 1.00$
Variable unfavourable action	$\gamma_Q = 1.30$
Variable favourable action	$\gamma_{Qf} = 0.00$

Partial factors for soil parameters – Table A.4 - Combination 2

Soil parameter set	M2
Angle of shearing resistance	$\gamma_{\phi'} = 1.25$
Effective cohesion	$\gamma_{c'} = 1.25$
Weight density	$\gamma_{\gamma} = 1.00$

Library item Partial factors output

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = 17.5 \text{ kN/m}^3$
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = 20.8 \text{ kN/m}^3$
Design effective shear resistance angle	$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = 35.8 \text{ deg}$
Design wall friction angle	$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}) = 17.1 \text{ deg}$

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_{\gamma} = 19 \text{ kN/m}^3$
Design effective shear resistance angle	$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi'}) = 19.6 \text{ deg}$
Design wall friction angle	$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi'}) = 9.7 \text{ deg}$
Design base friction angle	$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = 19.6 \text{ deg}$
Design effective cohesion	$c'_{b,d} = c'_{b,k} / \gamma_{c'} = 0 \text{ kN/m}^2$

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Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.325}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{(\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))}]^2) = \mathbf{2.567}$$

Sliding check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{31.4 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{26.5 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma_{Gf} \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{14.9 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = \mathbf{4 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{77.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{52.8 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} = \mathbf{52.8 \text{ kN/m}}$$

Check stability against sliding

Base soil resistance

$$F_{exc_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{29.1 \text{ kN/m}}$$

Base friction

$$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = \mathbf{27.7 \text{ kN/m}}$$

Resistance to sliding

$$F_{rest} = F_{exc_h} + F_{friction} = \mathbf{56.8 \text{ kN/m}}$$

Factor of safety

$$FoS_{sl} = F_{rest} / F_{total_h} = \mathbf{1.077}$$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem

$$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{31.4 \text{ kN/m}}$$

Wall base

$$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{26.5 \text{ kN/m}}$$

Line loads

$$F_{P_v} = \gamma_{Gf} \times P_{G1} = \mathbf{1 \text{ kN/m}}$$

Moist retained soil

$$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{14.9 \text{ kN/m}}$$

Base soil

$$F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = \mathbf{4 \text{ kN/m}}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{P_v} + F_{moist_v} + F_{exc_v} = \mathbf{77.8 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times (h_{eff} - d_{key})^2 / 2 = \mathbf{41.5 \text{ kN/m}}$$

Base soil

$$F_{exc_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-29.1 \text{ kN/m}}$$

Total

$$F_{total_h} = F_{moist_h} + F_{exc_h} = \mathbf{12.4 \text{ kN/m}}$$

Overturning moments on wall

Moist retained soil

$$M_{moist_{OT}} = F_{moist_h} \times X_{moist_{h_a}} = \mathbf{54 \text{ kNm/m}}$$

Base soil

$$M_{exc_{OT}} = F_{exc_h} \times X_{exc_h} = \mathbf{3.9 \text{ kNm/m}}$$

Total

$$M_{total_{OT}} = M_{moist_{OT}} + M_{exc_{OT}} = \mathbf{57.8 \text{ kNm/m}}$$

Restoring moments on wall

Wall stem

$$M_{stem_R} = F_{stem} \times X_{stem} = \mathbf{49.9 \text{ kNm/m}}$$

Wall base

$$M_{base_R} = F_{base} \times X_{base} = \mathbf{23.6 \text{ kNm/m}}$$

Line loads

$$M_{P_R} = \text{abs}(\gamma_{Gf} \times P_{G1}) \times p_1 = \mathbf{1.6 \text{ kNm/m}}$$

Moist retained soil

$$M_{moist_R} = F_{moist_v} \times X_{moist_v} = \mathbf{28.3 \text{ kNm/m}}$$

Base soil

$$M_{exc_R} = F_{exc_v} \times X_{exc_v} = \mathbf{2.8 \text{ kNm/m}}$$

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Total $M_{total_R} = M_{stem_R} + M_{base_R} + M_{P_R} + M_{moist_R} + M_{exc_R} = 106.2 \text{ kNm/m}$

Check stability against overturning

Factor of safety

$$FoS_{ot} = M_{total_R} / M_{total_OT} = 1.836$$

PASS - Maximum restoring moment is greater than overturning moment

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1 and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the UK National Annex

Tedds calculation version 2.9.07

Concrete details - Table 3.1 - Strength and deformation characteristics for concrete

Concrete strength class	C28/35
Characteristic compressive cylinder strength	$f_{ck} = 28 \text{ N/mm}^2$
Characteristic compressive cube strength	$f_{ck,cube} = 35 \text{ N/mm}^2$
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 36 \text{ N/mm}^2$
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = 2.8 \text{ N/mm}^2$
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} = 1.9 \text{ N/mm}^2$
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = 32308 \text{ N/mm}^2$
Partial factor for concrete - Table 2.1N	$\gamma_C = 1.50$
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{cc} = 0.85$
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = 15.9 \text{ N/mm}^2$
Maximum aggregate size	$h_{agg} = 20 \text{ mm}$
Ultimate strain - Table 3.1	$\epsilon_{cu2} = 0.0035$
Shortening strain - Table 3.1	$\epsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$
Bending coefficient k_1	$K_1 = 0.40$
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$
Bending coefficient k_3	$K_3 = 0.40$
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$

Reinforcement details

Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement	$E_s = 200000 \text{ N/mm}^2$
Partial factor for reinforcing steel - Table 2.1N	$\gamma_S = 1.15$
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S = 435 \text{ N/mm}^2$

Cover to reinforcement

Top face of base	$C_{bt} = 40 \text{ mm}$
Bottom face of base	$C_{bb} = 40 \text{ mm}$

Masonry details - Section 3.1

Masonry type	Aggregate concrete - Group 1
Normalised mean compressive strength	$f_b = 7.3 \text{ N/mm}^2$
Characteristic flexural strength - cl.6.3.4(1)	$f_{xk} = 0 \text{ N/mm}^2$
Initial shear strength - Table NA.5	$f_{vko} = 0.3 \text{ N/mm}^2$

Mortar details - Section 3.2

Mortar type	Thin layer - M6, prescribed mix
Compressive strength of mortar	$f_m = 6 \text{ N/mm}^2$

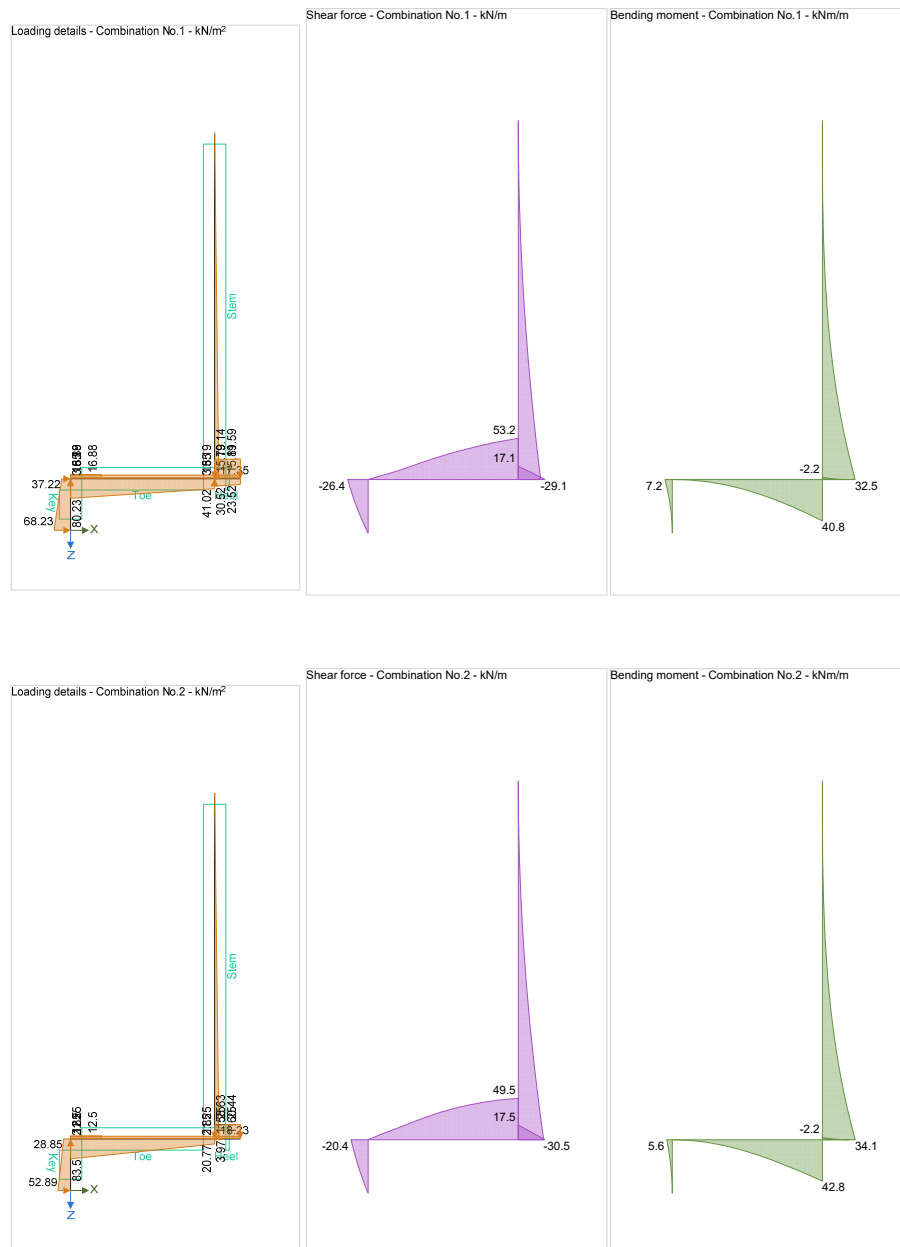
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Ultimate limit states - Table NA.1

Class of execution control	1
Category of manufacture control	1
Partial factor for direct or flexural compression	$\gamma_{Mc} = 2.0$
Partial factor for flexural tension	$\gamma_{Mt} = 2.3$
Partial factor for shear	$\gamma_{Mv} = 2.0$

Characteristic strengths of concrete infill - Table 3.2

Concrete infill strength class	C28/35
Characteristic compressive strength	$f_{ck, \text{infill}} = 25 \text{ N/mm}^2$
Characteristic shear strength	$f_{cvk, \text{infill}} = 0.45 \text{ N/mm}^2$
Design shear strength	$f_{cvd, \text{infill}} = f_{cvk, \text{infill}} / \gamma_{Mv} = 0.225 \text{ N/mm}^2$



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Check stem design at base of stem

Depth of section $t = 375$ mm

Cavity wall details

Front leaf thickness $t_f = 100$ mm

Rear leaf thickness $t_r = 100$ mm

Masonry characteristics

Compressive strength constants - Table NA.4 $K = 0.800$

Characteristic compressive strength - cl.3.6.1.2(1) $f_k = K \times f_b^{0.85} \times (1 \text{ N/mm}^2)^{0.15} = 4.334 \text{ N/mm}^2$

Design compressive strength $f_d = \min(f_k, f_{ck, \text{infill}}) / \gamma_{Mc} = 2.167 \text{ N/mm}^2$

Design flexural strength $f_{xd} = f_{xk} / \gamma_{Mt} = 0 \text{ N/mm}^2$

Height of masonry $h_{wt} = h_{stem} = 3350$ mm

Compressive axial force combination 0 $F_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1}) = 32.4 \text{ kN/m}$

Moment combination 0 $M_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t^2 / 2 + P_{G1} \times (p_1 - l_{toe})) + \gamma_{Qf} \times P_{Q1} \times (p_1 - l_{toe})) = 6.1 \text{ kNm/m}$

Eccentricity of axial load $e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = 18.8$ mm

Capacity reduction factor - exp.6.4 $\Phi = 1 - 2 \times e / t = 0.9$

Design vertical resistance - exp.6.2 $N_{Rd} = \Phi \times t \times f_d = 731.4 \text{ kN/m}$

Design vertical compressive stress $\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = 0.086 \text{ N/mm}^2$

Apparent design flexural strength - exp.6.16 $f_{xd, app} = f_{xd} + \sigma_d = 0.086 \text{ N/mm}^2$

Limit of charact. shear strength - exp. 3.1 $f_{vk, lim} = 0.065 \times f_b = 0.475 \text{ N/mm}^2$

Characteristic shear strength - exp.3.5 $f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk, lim}) = 0.335 \text{ N/mm}^2$

Design shear strength $f_{vd} = f_{vk} / \gamma_{Mv} = 0.167 \text{ N/mm}^2$

Library item: Masonry characteristics output

Reinforced masonry members subjected to bending, bending and axial loading, or axial loading - Section 6.6

Design bending moment combination 2 $M = 34.1 \text{ kNm/m}$

Tension reinforcement provided 16 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{sr, prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 1005 \text{ mm}^2/\text{m}$

Depth to tension reinforcement $d = 225$ mm

Minimum area of reinforcement - cl.8.2.3(1) $A_{sr, min} = 0.0005 \times d = 113 \text{ mm}^2/\text{m}$

Lever arm - exp.6.23 $z = d \times \min(1 - 0.5 \times A_{sr, prov} \times f_{yd} / (d \times f_d), 0.95) = 124$ mm

Moment of resistance - exp.6.22 and exp.6.24a $M_{Rd} = \min(A_{sr, prov} \times f_{yd} \times z, 0.4 \times f_d \times d^2) = 43.9 \text{ kNm/m}$

$M / M_{Rd} = 0.777$

PASS - Moment of resistance exceeds applied design moment

Reinforced masonry members subjected to shear loading - Section 6.7

Design shear force $V = 30.537 \text{ kN/m}$

Design shear resistance - exp.6.40 $V_{Rd} = \min(f_{vd}, f_{c, vd, \text{infill}}) \times d = 37.639 \text{ kN/m}$

$V / V_{Rd} = 0.811$

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 400 mm

Depth of section $t = 375$ mm

Cavity wall details

Front leaf thickness $t_f = 100$ mm

Rear leaf thickness $t_r = 100$ mm

Masonry characteristics

Compressive strength constants - Table NA.4 $K = 0.800$

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Characteristic compressive strength - cl.3.6.1.2(1)	$f_k = K \times f_b^{0.85} \times (1 \text{ N/mm}^2)^{0.15} = 4.334 \text{ N/mm}^2$
Design compressive strength	$f_d = \min(f_k, f_{ck, \text{infill}}) / \gamma_{Mc} = 2.167 \text{ N/mm}^2$
Design flexural strength	$f_{xd} = f_{xk} / \gamma_{Mt} = 0 \text{ N/mm}^2$
Height of masonry	$h_{wt} = h_{stem} - 400 \text{ mm} = 2950 \text{ mm}$
Compressive axial force combination 0	$F_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1}) = 28.7 \text{ kN/m}$
Moment combination 0	$M_x = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t^2 / 2 + P_{G1} \times (p_1 - l_{toe})) + \gamma_{Qf} \times P_{Q1} \times (p_1 - l_{toe})) = 5.4 \text{ kNm/m}$
Eccentricity of axial load	$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = 18.8 \text{ mm}$
Capacity reduction factor - exp.6.4	$\Phi = 1 - 2 \times e / t = 0.9$
Design vertical resistance - exp.6.2	$N_{Rd} = \Phi \times t \times f_d = 731.4 \text{ kN/m}$
Design vertical compressive stress	$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = 0.076 \text{ N/mm}^2$
Apparent design flexural strength - exp.6.16	$f_{xd, \text{app}} = f_{xd} + \sigma_d = 0.076 \text{ N/mm}^2$
Limit of charact. shear strength - exp. 3.1	$f_{vk, \text{lim}} = 0.065 \times f_b = 0.475 \text{ N/mm}^2$
Characteristic shear strength - exp.3.5	$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk, \text{lim}}) = 0.331 \text{ N/mm}^2$
Design shear strength	$f_{vd} = f_{vk} / \gamma_{Mv} = 0.165 \text{ N/mm}^2$

Library item: Masonry characteristics output

Reinforced masonry members subjected to bending, bending and axial loading, or axial loading - Section 6.6

Design bending moment combination 2	$M = 23.3 \text{ kNm/m}$
Tension reinforcement provided	10 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{sr1, \text{prov}} = \pi \times \phi_{sr1}^2 / (4 \times s_{sr1}) = 393 \text{ mm}^2/\text{m}$
Depth to tension reinforcement	$d = 225 \text{ mm}$
Minimum area of reinforcement - cl.8.2.3(1)	$A_{sr, \text{min}} = 0.0005 \times d = 113 \text{ mm}^2/\text{m}$
Lever arm - exp.6.23	$z = d \times \min(1 - 0.5 \times A_{sr1, \text{prov}} \times f_{yd} / (d \times f_d), 0.95) = 186 \text{ mm}$
Moment of resistance - exp.6.22 and exp.6.24a	$M_{Rd} = \min(A_{sr1, \text{prov}} \times f_{yd} \times z, 0.4 \times f_d \times d^2) = 31.7 \text{ kNm/m}$
	$M / M_{Rd} = 0.735$

PASS - Moment of resistance exceeds applied design moment

Reinforced masonry members subjected to shear loading - Section 6.7

Design shear force	$V = 23.68 \text{ kN/m}$
Design shear resistance - exp.6.40	$V_{Rd} = \min(f_{vd}, f_{c, \text{vd}, \text{infill}}) \times d = 37.189 \text{ kN/m}$
	$V / V_{Rd} = 0.637$

PASS - Design shear resistance exceeds applied design shear force

Horizontal reinforcement parallel to face of stem

Minimum area of reinforcement - cl.8.2.3(4)	$A_{sx, \text{req}} = 0.0005 \times d = 113 \text{ mm}^2/\text{m}$
Transverse reinforcement provided	10 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{sx, \text{prov}} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = 393 \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Check base design at toe

Depth of section	$h = 450 \text{ mm}$
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Rectangular section in flexure - Section 6.1

Design bending moment combination 2	$M = 42.8 \text{ kNm/m}$
Depth to tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2 = 405 \text{ mm}$
	$K = M / (d^2 \times f_{ck}) = 0.009$
	$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$
	$K' = 0.207$

K' > K - No compression reinforcement is required

Lever arm	$z = d \times \min(1 - 0.5 \times A_{sr1, \text{prov}} \times f_{yd} / (d \times f_d), 0.95) = 366 \text{ mm}$
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Depth of neutral axis	$x = 2.5 \times (d - z) = 98 \text{ mm}$
Area of tension reinforcement required	$A_{bb,req} = M / (f_{yd} \times z) = 269 \text{ mm}^2/\text{m}$
Tension reinforcement provided	10 dia.bars @ 100 c/c
Area of tension reinforcement provided	$A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times S_{bb}) = 785 \text{ mm}^2/\text{m}$
Minimum area of reinforcement - exp.9.1N	$A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 583 \text{ mm}^2/\text{m}$
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bb,max} = 0.04 \times h = 18000 \text{ mm}^2/\text{m}$
	$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = 0.742$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width	$w_{max} = 0.3 \text{ mm}$
Variable load factor - EN1990 – Table A1.1	$\psi_2 = 0.6$
Serviceability bending moment	$M_{sls} = 22.9 \text{ kNm/m}$
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb,prov} \times z) = 79.6 \text{ N/mm}^2$
Load duration	Long term
Load duration factor	$k_t = 0.4$
Effective area of concrete in tension	$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ $A_{c,eff} = 112500 \text{ mm}^2/\text{m}$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$
Reinforcement ratio	$\rho_{p,eff} = A_{bb,prov} / A_{c,eff} = 0.007$
Modular ratio	$\alpha_e = E_s / E_{cm} = 6.19$
Bond property coefficient	$k_1 = 0.8$
Strain distribution coefficient	$k_2 = 0.5$ $k_3 = 3.4$ $k_4 = 0.425$
Maximum crack spacing - exp.7.11	$s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = 380 \text{ mm}$
Maximum crack width - exp.7.8	$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$ $w_k = 0.091 \text{ mm}$ $w_k / w_{max} = 0.302$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = 53.2 \text{ kN/m}$ $C_{Rd,c} = 0.18 / \gamma_c = 0.120$ $k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.703$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb,prov} / d, 0.02) = 0.002$ $v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.411 \text{ N/mm}^2$
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$ $V_{Rd,c} = 166.7 \text{ kN/m}$ $V / V_{Rd,c} = 0.319$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section	$h = 450 \text{ mm}$
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Rectangular section in flexure - Section 6.1

Design bending moment combination 2	$M = 2.2 \text{ kNm/m}$
Depth to tension reinforcement	$d = h - c_{bt} - \phi_{bt} / 2 = 405 \text{ mm}$ $K = M / (d^2 \times f_{ck}) = 0.000$

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$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$$

$$K' = \mathbf{0.207}$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr1,prov} \times f_{yd} / (d \times f_d), 0.95) = \mathbf{366 \text{ mm}}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = \mathbf{98 \text{ mm}}$$

Area of tension reinforcement required

$$A_{bt,req} = M / (f_{yd} \times z) = \mathbf{14 \text{ mm}^2/\text{m}}$$

Tension reinforcement provided

$$10 \text{ dia.bars @ } 100 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = \mathbf{785 \text{ mm}^2/\text{m}}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{583 \text{ mm}^2/\text{m}}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bt,max} = 0.04 \times h = \mathbf{18000 \text{ mm}^2/\text{m}}$$

$$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = \mathbf{0.742}$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = \mathbf{0.3 \text{ mm}}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = \mathbf{0.6}$$

Serviceability bending moment

$$M_{sls} = \mathbf{1.2 \text{ kNm/m}}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = \mathbf{4.3 \text{ N/mm}^2}$$

Load duration

Long term

Load duration factor

$$k_t = \mathbf{0.4}$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = \mathbf{112500 \text{ mm}^2/\text{m}}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = \mathbf{2.8 \text{ N/mm}^2}$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = \mathbf{0.007}$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = \mathbf{6.19}$$

Bond property coefficient

$$k_1 = \mathbf{0.8}$$

Strain distribution coefficient

$$k_2 = \mathbf{0.5}$$

$$k_3 = \mathbf{3.4}$$

$$k_4 = \mathbf{0.425}$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times C_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = \mathbf{380 \text{ mm}}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = \mathbf{0.005 \text{ mm}}$$

$$w_k / w_{max} = \mathbf{0.016}$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = \mathbf{17.5 \text{ kN/m}}$$

$$C_{Rd,c} = 0.18 / \gamma_c = \mathbf{0.120}$$

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.703}$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bt,prov} / d, 0.02) = \mathbf{0.002}$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.411 \text{ N/mm}^2}$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = \mathbf{166.7 \text{ kN/m}}$$

$$V / V_{Rd,c} = \mathbf{0.105}$$

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section

$$h = \mathbf{300 \text{ mm}}$$

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Rectangular section in flexure - Section 6.1

Design bending moment combination 1

Depth to tension reinforcement

$$M = 7.2 \text{ kNm/m}$$

$$d = h - c_{bb} - \phi_k / 2 = 255 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.004$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$$

$$K' = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = d \times \min(1 - 0.5 \times A_{sr1,prov} \times f_{yd} / (d \times f_d), 0.95) = 216 \text{ mm}$$

Depth of neutral axis

$$x = 2.5 \times (d - z) = 98 \text{ mm}$$

Area of tension reinforcement required

$$A_{k,req} = M / (f_{yd} \times z) = 77 \text{ mm}^2/\text{m}$$

Tension reinforcement provided

$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{k,prov} = \pi \times \phi_k^2 / (4 \times s_k) = 393 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N

$$A_{k,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 367 \text{ mm}^2/\text{m}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{k,max} = 0.04 \times h = 12000 \text{ mm}^2/\text{m}$$

$$\max(A_{k,req}, A_{k,min}) / A_{k,prov} = 0.934$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width

$$w_{max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = 0.6$$

Serviceability bending moment

$$M_{sls} = 5.6 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{k,prov} \times z) = 66.6 \text{ N/mm}^2$$

Load duration

Long term

Load duration factor

$$k_t = 0.4$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 67173 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Reinforcement ratio

$$\rho_{p,eff} = A_{k,prov} / A_{c,eff} = 0.006$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = 6.19$$

Bond property coefficient

$$k_1 = 0.8$$

Strain distribution coefficient

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p,eff} = 427 \text{ mm}$$

Maximum crack width - exp.7.8

$$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.085 \text{ mm}$$

$$w_k / w_{max} = 0.284$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 26.4 \text{ kN/m}$$

$$C_{Rd,c} = 0.18 / \gamma_c = 0.120$$

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.886$$

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{k,prov} / d, 0.02) = 0.002$$

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.480 \text{ N/mm}^2$$

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = 122.3 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.216$$

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PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

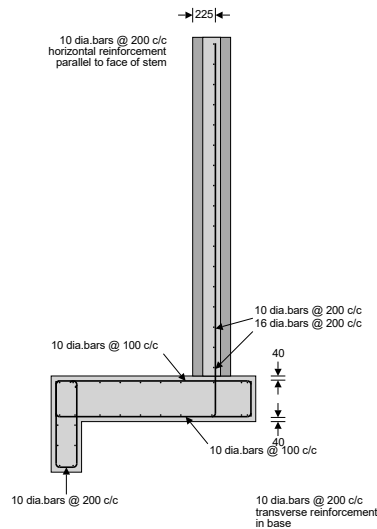
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx,req} = 0.2 \times A_{bb,prov} = 157 \text{ mm}^2/\text{m}$

Maximum spacing of reinforcement – cl.9.3.1.1(3) $S_{bx,max} = 450 \text{ mm}$

Transverse reinforcement provided 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided $A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times S_{bx}) = 393 \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required



Reinforcement details