

SPR HOOPER

CONSULTING CIVIL AND STRUCTURAL ENGINEERS

STRUCTURAL CALCULATIONS

PROPOSED CAR PARKING AREA

RETAINING WALL

LAND OFF TABERNACLE TERRACE

CWMAVON

NEATH PORT TALBOT

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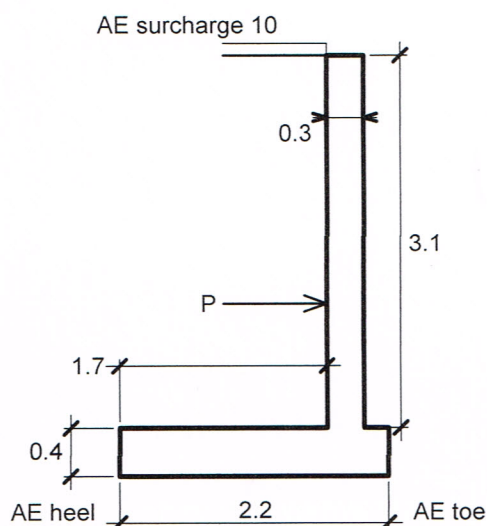
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Tbernacle Terrace Cwmavon
General components



Reinforced concrete retaining wall

Rankine & Coulomb Assumptions :

- * Failure surface is a plane
- * Resultant earth pressure P is $h/3$ up from the base

Coulomb Assumptions :

- * Line of action of P taken as $2/3$ the angle of internal friction

Rankine Assumptions :

- * Line of action of P is parallel to the retained surface

Analysis by Rankine's theory

Further Assumptions:

- * Friction between the retained soil and the back of the wall is to be ignored

Angle of slope of retained soil

$$\theta = 0 \text{ degrees}$$

Unit weight of retained soil

$$w = 20 \text{ kN/m}^3$$

Self weight of concrete

$$\begin{aligned} WT &= RC_WT \\ &= 23.6 \text{ kN/m}^3 \end{aligned}$$

Internal friction angle of soil

$$\phi = 40 \text{ degrees}$$

Retained soil is cohesionless

Surcharge pressure

$$p = 10 \text{ kN/m run}$$

Equivalent depth of surcharge

$$\begin{aligned} ds &= \text{press}/w \\ &= 10/20 \\ &= 0.5 \text{ m} \end{aligned}$$

Load above wall supported on stem

$$Va = 0 \text{ kN/m run}$$

Height of back of wall

$$h = 3.1 \text{ m}$$

Thickness of wall

$$tw = 0.3 \text{ m}$$

Thickness of base

$$d = 0.4 \text{ m}$$

Length of base

$$L = 2.2 \text{ m}$$

Distance heel to back of wall

$$xb = 1.7 \text{ m}$$

Distance toe to face of wall

$$\begin{aligned} xf &= L - xb - tw \\ &= 2.2 - 1.7 - 0.3 \\ &= 0.2 \text{ m} \end{aligned}$$

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Tbernacle Terrace Cwmavon
General components

Depth of soil over base at toe

$$db = 0 \text{ m}$$

Allowable bearing pressure

$$p = 150 \text{ kN/m}^2$$

Depth of soil for passive resist

$$dp = 0.4 \text{ m}$$

With a vertical wall, Rankine's theory assumes that the line of action of P is parallel to the surface slope of the retained soil

Angle of P (parallel to surface)

$$\begin{aligned}\delta &= \theta \\ &= 0 \text{ degrees}\end{aligned}$$

Friction factor under base

$$ff = 0.4$$

Cohesion, allowing for softening

$$\begin{aligned}fc' &= fc/2 \\ &= 100/2 \\ &= 50 \text{ kN/m}^2\end{aligned}$$

Pressure on wall from retained soil

Rankine gives the formula for resultant earth pressure on the back of the wall as $P = C_e \cdot w \cdot h^2/2$ where C_e is a pressure coefficient

Intermediate factor

$$\begin{aligned}fi &= \sqrt{\cos(\theta)^2 - \cos(\phi)^2} \\ &= \sqrt{\cos(0)^2 - \cos(40)^2} \\ &= 0.64\end{aligned}$$

Pressure coefficient

$$\begin{aligned}C_e &= \cos(\theta) \cdot (\cos(\theta) - fi) / (\cos(\theta) + fi) \\ &= \cos(0) \cdot (\cos(0) - 0.64) / (\cos(0) + 0.64) \\ &= 0.22\end{aligned}$$

Resultant (active) soil force

$$\begin{aligned}P &= C_e \cdot w \cdot h^2/2 \\ &= 0.22 \cdot 20 \cdot (3.1)^2/2 \\ &= 20.9 \text{ kN/m run}\end{aligned}$$

Horizontal component

$$\begin{aligned}Ph &= P \cdot \cos(\theta) \\ &= 20.9 \cdot \cos(0) \\ &= 20.9 \text{ kN/m run}\end{aligned}$$

Vertical component ignored

$$Pv = 0 \text{ kN/m run}$$

The lateral pressure corresponding to the surcharge is assumed uniform throughout the height and calculated as the vertical surcharge $\cdot (1 - \sin(\phi)) / (1 + \sin(\phi))$

Pressure coefficient (surcharge)

$$\begin{aligned}Ca &= (1 - \sin(\phi)) / (1 + \sin(\phi)) \\ &= (1 - \sin(40)) / (1 + \sin(40)) \\ &= 0.22\end{aligned}$$

Resultant soil force (surcharge)

$$\begin{aligned}Ps &= Ca \cdot w \cdot ds \cdot h \\ &= 0.22 \cdot 20 \cdot 0.5 \cdot 3.1 \\ &= 6.74 \text{ kN/m run}\end{aligned}$$

Horizontal component

$$\begin{aligned}Psh &= Ps \cdot \cos(\theta) \\ &= 6.74 \cdot \cos(0) \\ &= 6.74 \text{ kN/m run}\end{aligned}$$

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Tbernacle Terrace Cwmavon
General components

Vertical component ignored

$$P_{sv} = 0 \text{ kN/m run}$$

Forces and moments on wall and base

Maximum B.M. at base of wall

$$\begin{aligned} M &= P_h \cdot h/3 + P_{sh} \cdot h/2 \\ &= 20.9 \cdot 3.1/3 + 6.74 \cdot 3.1/2 \\ &= 32.04 \text{ kNm/m} \end{aligned}$$

Maximum S.F. at base of wall

$$\begin{aligned} S &= P_h + P_{sh} \\ &= 20.9 + 6.74 \\ &= 27.64 \text{ kN/m} \end{aligned}$$

Weight of wall

$$\begin{aligned} V_w &= h \cdot t_w \cdot W_T \\ &= 3.1 \cdot 0.3 \cdot 23.6 \\ &= 21.95 \text{ kN/m run} \end{aligned}$$

Total load wall to base

$$\begin{aligned} V &= V_w + P_v + P_{sv} \\ &= 21.95 + 0 + 0 \\ &= 21.95 \text{ kN/m run} \end{aligned}$$

Self weight of base

$$\begin{aligned} S_w &= L \cdot d \cdot W_T \\ &= 2.2 \cdot 0.4 \cdot 23.6 \\ &= 20.77 \text{ kN/m run} \end{aligned}$$

Weight of retained soil

$$\begin{aligned} w_{be} &= (h + d_s) \cdot x_b \cdot w \\ &= (3.1 + 0.5) \cdot 1.7 \cdot 20 \\ &= 122.4 \text{ kN/m run} \end{aligned}$$

Weight of retained soil (slope)

$$\begin{aligned} w_{bs} &= w \cdot x_b^2 \cdot \tan(\theta)/2 \\ &= 20 \cdot (1.7)^2 \cdot \tan(0)/2 \\ &= 0 \text{ kN/m run} \end{aligned}$$

Total weight of soil above base

$$\begin{aligned} w_b &= w_{be} + w_{bs} \\ &= 122.4 + 0 \\ &= 122.4 \text{ kN/m run} \end{aligned}$$

Weight of soil at front of wall

$$\begin{aligned} w_f &= d_b \cdot x_f \cdot w \\ &= 0 \cdot 0.2 \cdot 20 \\ &= 0 \text{ kN/m run} \end{aligned}$$

Total soil pressure (active)

$$\begin{aligned} P_{ab} &= C_e \cdot w \cdot (h + d)^2/2 \\ &= 0.22 \cdot 20 \cdot (3.1 + 0.4)^2/2 \\ &= 26.64 \text{ kN/m run} \end{aligned}$$

Horizontal component

$$\begin{aligned} P_{abh} &= P_{ab} \cdot \cos(\theta) \\ &= 26.64 \cdot \cos(0) \\ &= 26.64 \text{ kN/m run} \end{aligned}$$

Vertical component ignored

$$P_{abv} = 0 \text{ kN/m run}$$

Total soil pressure (surcharge)

$$\begin{aligned} P_{sb} &= C_a \cdot w \cdot d_s \cdot (h + d) \\ &= 0.22 \cdot 20 \cdot 0.5 \cdot (3.1 + 0.4) \\ &= 7.61 \text{ kN/m run} \end{aligned}$$

Horizontal component

$$\begin{aligned} P_{sbh} &= P_{sb} \cdot \cos(\theta) \\ &= 7.61 \cdot \cos(0) \\ &= 7.61 \text{ kN/m run} \end{aligned}$$

Vertical component ignored

$$P_{sbv} = 0 \text{ kN/m run}$$

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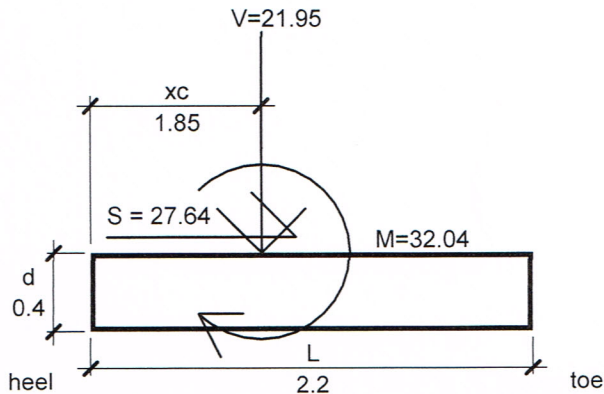
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Tbernacle Terrace Cwmavon
General components

Loads at base of wall



Total load on foundation strata

$$\begin{aligned} T &= V_w + S_w + w_b + w_f + P_{abv} + P_{sbv} \\ &= 21.95 + 20.77 + 122.4 + 0 + 0 + 0 \\ &= 165.12 \text{ kN/m run} \end{aligned}$$

Overturning moment

$$\begin{aligned} M_t &= P_{abh} \cdot (h+d)/3 + P_{sbh} \cdot (h+d)/2 \\ &= 26.64 \cdot (3.1+0.4)/3 + 7.61 \cdot (3.1+0.4)/2 \\ &= 44.39 \text{ kNm/m run} \end{aligned}$$

Sliding force

$$\begin{aligned} S_t &= P_{abh} + P_{sbh} \\ &= 26.64 + 7.61 \\ &= 34.25 \text{ kN/m run} \end{aligned}$$

Clockwise moments about heel resulting from weight of soil behind wall

$$\begin{aligned} M_{cb} &= w_b \cdot x_b/2 + 2 \cdot w_{bs} \cdot x_b/6 \\ &= 122.4 \cdot 1.7/2 + 2 \cdot 0 \cdot 1.7/6 \\ &= 104.04 \text{ kNm/m} \end{aligned}$$

Clockwise moments about heel resulting from vertical component of earth pressure

$$\begin{aligned} M_{cbv} &= (P_{abv} + P_{sbv}) \cdot x_b \\ &= (0+0) \cdot 1.7 \\ &= 0 \text{ kNm/m} \end{aligned}$$

Total clockwise moments about heel

$$\begin{aligned} M_c &= V_w \cdot (x_b + t_w/2) + M_t + S_w \cdot L/2 + M_{cb} + M_{cbv} + w_f \cdot (L - x_f/2) \\ &= 21.95 \cdot (1.7 + 0.3/2) + 44.39 + 20.77 \cdot 2.2/2 + 104.04 + 0 + 0 \cdot (2.2 - 0.2/2) \\ &= 211.88 \text{ kNm/m} \end{aligned}$$

Distance to centroid of load

$$\begin{aligned} x_c &= M_c / T \\ &= 211.88 / 165.12 \\ &= 1.28 \text{ m} \end{aligned}$$

Eccentricity

$$\begin{aligned} ecc &= x_c - L/2 \\ &= 1.28 - 2.2/2 \\ &= 0.18 \text{ m} \end{aligned}$$

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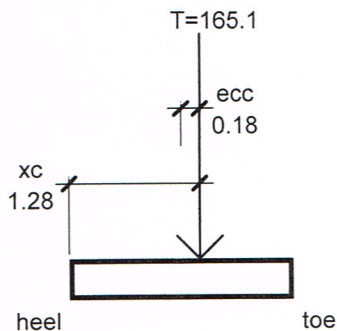
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Thernacle Terrace Cwmavon
General components



The load centroid lies within middle third

The pressure varies from p_h at the heel to p_t at the toe

Modulus of the base

$$\begin{aligned} z &= 1 \cdot L^2 / 6 \\ &= 1 \cdot (2.2)^2 / 6 \\ &= 0.81 \text{ m}^3/\text{m run} \end{aligned}$$

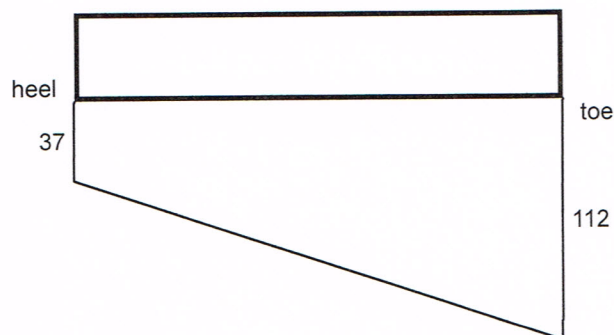
Pressure at heel

$$\begin{aligned} p_h &= T / (L \cdot 1) - T \cdot ecc / z \\ &= 165.12 / (2.2 \cdot 1) - 165.12 \cdot 0.18 / 0.81 \\ &= 37.55 \text{ kN/m}^2 \end{aligned}$$

Pressure at toe

$$\begin{aligned} p_t &= T / (L \cdot 1) + T \cdot ecc / z \\ &= 165.12 / (2.2 \cdot 1) + 165.12 \cdot 0.18 / 0.81 \\ &= 112.56 \text{ kN/m}^2 \end{aligned}$$

Pressure diagram (kN/m²)



Pressure beneath base; 112.56 < allowable; 150 - OK

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Shear forces and bending moments on base

Pressure under back of wall	$pwa = ph + (pt - ph) * xb / L$ $= 37.55 + (112.56 - 37.55) * 1.7 / 2.2$ $= 95.51 \text{ kN/m}^2$
Pressure under front of wall	$pwb = ph + (pt - ph) * (xb + tw) / L$ $= 37.55 + (112.56 - 37.55) * (1.7 + 0.3) / 2.2$ $= 105.74 \text{ kN/m}^2$
Downward S.F. on heel	$Sad = WT * d * xb + wb$ $= 23.6 * 0.4 * 1.7 + 122.4$ $= 138.45 \text{ kN/m}$
Upward S.F. on heel	$Sau = (ph + pwa) * xb / 2$ $= (37.55 + 95.51) * 1.7 / 2$ $= 113.1 \text{ kN/m}$
Downward B.M. on toe	$Mbd = (WT * d * xf + wf) * xf / 2$ $= (23.6 * 0.4 * 0.2 + 0) * 0.2 / 2$ $= 0.19 \text{ kNm/m}$
Downward B.M. on heel	$Mad = (3 * wbe + 4 * wbs + 3 * WT * d * xb) * xb / 6$ $= (3 * 122.4 + 4 * 0 + 3 * 23.6 * 0.4 * 1.7) * 1.7 / 6$ $= 117.68 \text{ kNm/m}$
Total S.F. on toe (+ve up)	$Swb = ((pwb + pt) / 2 - WT * d) * xf - wf$ $= ((105.74 + 112.56) / 2 - 23.6 * 0.4) * 0.2 - 0$ $= 19.94 \text{ kN/m}$
Total S.F. on heel	$Swa = Sau - Sad$ $= 113.1 - 138.45$ $= -25.35 \text{ kN/m}$
Total B.M. on toe (+ve up)	$Mwb = (2 * pt + pwb) * xf^2 / 6 - Mbd$ $= (2 * 112.56 + 105.74) * (0.2)^2 / 6 - 0.19$ $= 2.02 \text{ kNm/m}$
Total B.M. on heel	$Mwa = (2 * ph + pwa) * xb^2 / 6 - Mad$ $= (2 * 37.55 + 95.51) * (1.7)^2 / 6 - 117.68$ $= -35.51 \text{ kNm/m}$

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Check Sliding

Frictional resistance	F	$= ff \cdot T$ $= 0.4 \cdot 165.12$ $= 66.05 \text{ kN/m run}$
Rankine coeff.of passive pressure	Kp	$= (\tan(45 + \phi/2))^2$ $= (\tan(45 + 40/2))^2$ $= 4.6$
Passive resistance	R	$= 0.5 \cdot Kp \cdot w \cdot dp^2$ $= 0.5 \cdot 4.6 \cdot 20 \cdot (0.4)^2$ $= 7.36 \text{ kN/m}$
FS sliding (excluding passive)	FSf	$= F/St$ $= 66.05/34.25$ $= 1.93$

FS against sliding (excluding passive resistance); 1.93 > 1.5 - OK

FS sliding (including passive)	FSs	$= (F+R)/St$ $= (66.05+7.36)/34.25$ $= 2.14$
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FS against sliding (including passive resistance); 2.14 > 2 - OK

Check Overturning

Rotation is assumed to occur about the toe, restraining moments:

Due to soil behind wall	Mre	$= wbe \cdot (L-xb/2) + wbs \cdot (L-xb/3)$ $= 122.4 \cdot (2.2-1.7/2) + 0 \cdot (2.2-1.7/3)$ $= 165.24 \text{ kNm/m}$
Due to base, wall and soil on toe	Mrw	$= Vw \cdot (xf+tw/2) + Sw \cdot L/2 + wf \cdot xf/2$ $= 21.95 \cdot (0.2+0.3/2) + 20.77 \cdot 2.2/2 + 0 \cdot 0.2/2$ $= 30.53 \text{ kNm/m}$
Due to vert.comp. of earth press.	Mrv	$= (Pabv+Psbv) \cdot (xf+tw)$ $= (0+0) \cdot (0.2+0.3)$ $= 0 \text{ kNm/m}$
Total restraining moment	Mr	$= Mre+Mrw+Mrv$ $= 165.24+30.53+0$ $= 195.77 \text{ kNm/m}$
Total overturning moment	Mot	$= Mt$ $= 44.39 \text{ kNm/m}$
Factors of Safety against overturning:		
FS against overturning	FSot	$= Mr/Mot$ $= 195.77/44.39$ $= 4.41$

FS against overturning; 4.41 > 2 - OK

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Tbernacle Terrace Cwmavon
General components

CONSIDER RETAINING WALL ADJACENT TO CAR PARKING BAYS

BENDING MOMENT AT BASE OF WALL = 32.04 kNm/m

ULTIMATE BENDING MOMENT = $32.04 \times 1.4 = 44.86 \text{ kNm/m}$

$$k = \frac{M}{f_{cu} b d^2} = \frac{44.86 \times 10^6}{35 \times 10^3 \times 250^2} = 0.020$$

$$z = 250 \left[0.5 + \sqrt{0.25 - \frac{0.020}{0.9}} \right] = 244 \text{ mm}$$

$$\begin{aligned} \text{AREA OF REINFORCEMENT} - A_s &= \frac{M}{0.87 f_y z} \\ &= \frac{44.86 \times 10^6}{0.87 \times 500 \times 244} = 423 \text{ mm}^2/\text{m} \end{aligned}$$

$$\text{MIN } A_s = \frac{0.13 b h}{100} = \frac{0.13 \times 10^3 \times 300}{100} = 390 \text{ mm}^2/\text{m}$$

USE FOR DISTRIBUTION REINFORCEMENT

FOR MAIN WALL REINFORCEMENT USE:- B12 DIA BARS @ 150 C/C

GIVING $754 \text{ mm}^2/\text{m}$.

FOR DISTRIBUTION REINFORCEMENT USE:- B12 DIA BARS @ 150 C/C

GIVING $754 \text{ mm}^2/\text{m}$.

CONSIDER BASE

MAXIMUM BENDING MOMENT ON BASE = 35.51 kNm/m

ULTIMATE MOMENT = $35.51 \times 1.4 = 49.71 \text{ kNm/m}$

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$$k = \frac{M}{f_{mb} b d^2} = \frac{49.71 \times 10^6}{35 \times 10^3 \times 350^2} = 0.012$$

$$z = 350 \left[0.5 + \sqrt{0.25 - \frac{0.012}{0.9}} \right] = 345 \text{ mm}$$

$$\begin{aligned} \text{AREA OF REINFORCEMENT} - A_s &= \frac{M}{0.87 f_{yk} z} \\ &= \frac{49.71 \times 10^6}{0.87 \times 500 \times 345} = 331 \text{ mm}^2/\text{m} \end{aligned}$$

$$\text{MIN } A_s = \frac{0.13 b h}{100} = \frac{0.13 \times 10^3 \times 400}{100} = 520 \text{ mm}^2/\text{m}$$

USE:- B12 DIA BARS @ 150 %s FOR MAIN REINFORCEMENT
PROVIDING - 754 mm²/m

USE:- B12 DIA BARS @ 150 %s FOR DISTRIBUTION REINFORCEMENT
PROVIDING - 754 mm²/m.

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CONSIDER THE WALL WITH A HIGHWAY CONTAINMENT FACILITY.

USING RECOMMENDED LOAD OF 25kN/m

AS THE LOADING IS A SHORT TERM IMPACT LOADING

$$\gamma_f = 1.05$$

$$\text{ULTIMATE LOAD} = 25 \times 1.05 = 26.25 \text{ kN/m}$$

$$k = \frac{M}{f_{cu} b d^2} = \frac{27 \times 10^6}{35 \times 10^3 \times 250^2} = 0.012$$

$$z = 250 \left[0.5 + \sqrt{0.25 - \frac{0.012}{0.9}} \right] = 246.5 \text{ mm}$$

$$\begin{aligned} \text{AREA OF REINFORCEMENT} - A_s &= \frac{M}{0.87 f_y z} \\ &= \frac{27 \times 10^6}{0.87 \times 500 \times 246.5} = 252 \text{ mm}^2/\text{m} \end{aligned}$$

$$\text{AREA OF REINFORCEMENT FROM DESIGN} = 423 \text{ mm}^2/\text{m}$$

$$\text{AREA OF REINFORCEMENT REQUIRED FOR IMPACT} = 252 \text{ mm}^2/\text{m}$$

$$\text{AREA OF REINFORCEMENT PROVIDED} = 754 \text{ mm}^2/\text{m}$$

∴ THE MAIN STEM OF THE WALL CAN RESIST HIGHWAY IMPACT LOADING.

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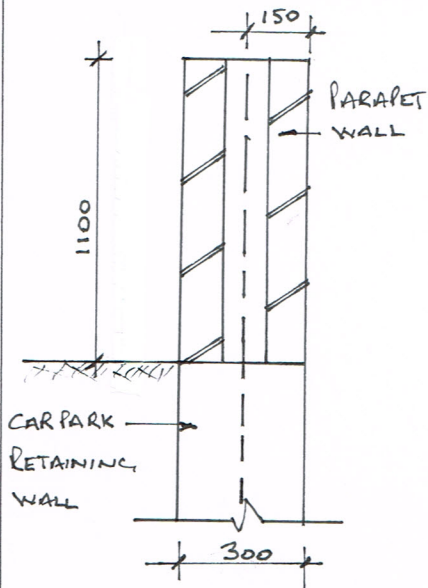
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Tbernacle Terrace Cwmavon
General components



HIGHWAY PARAPET WALL

USING RECOMMENDED LOAD OF 25 kN/m

AS THE LOADING IS A SHORT TERM IMPACT

LOAD $\gamma_f = 1.05$

ULTIMATE LOAD = $27 \times 1.05 = 27 \text{ kN/m}$

$$k = \frac{M}{f_{cu} b d^2} = \frac{27 \times 10^6}{35 \times 10^3 \times 150^2} = 0.034$$

$$z = 150 \left[0.5 + \sqrt{0.25 - \frac{0.034}{0.9}} \right] = 144 \text{ mm}$$

$$\text{AREA OF REINFORCEMENT} - A_s = \frac{M}{0.87 f_y z}$$

$$= \frac{27 \times 10^6}{0.87 \times 500 \times 144} = 431 \text{ mm}^2/\text{m}$$

USE: B785 MESH IN CENTRE CORE OF WALL.

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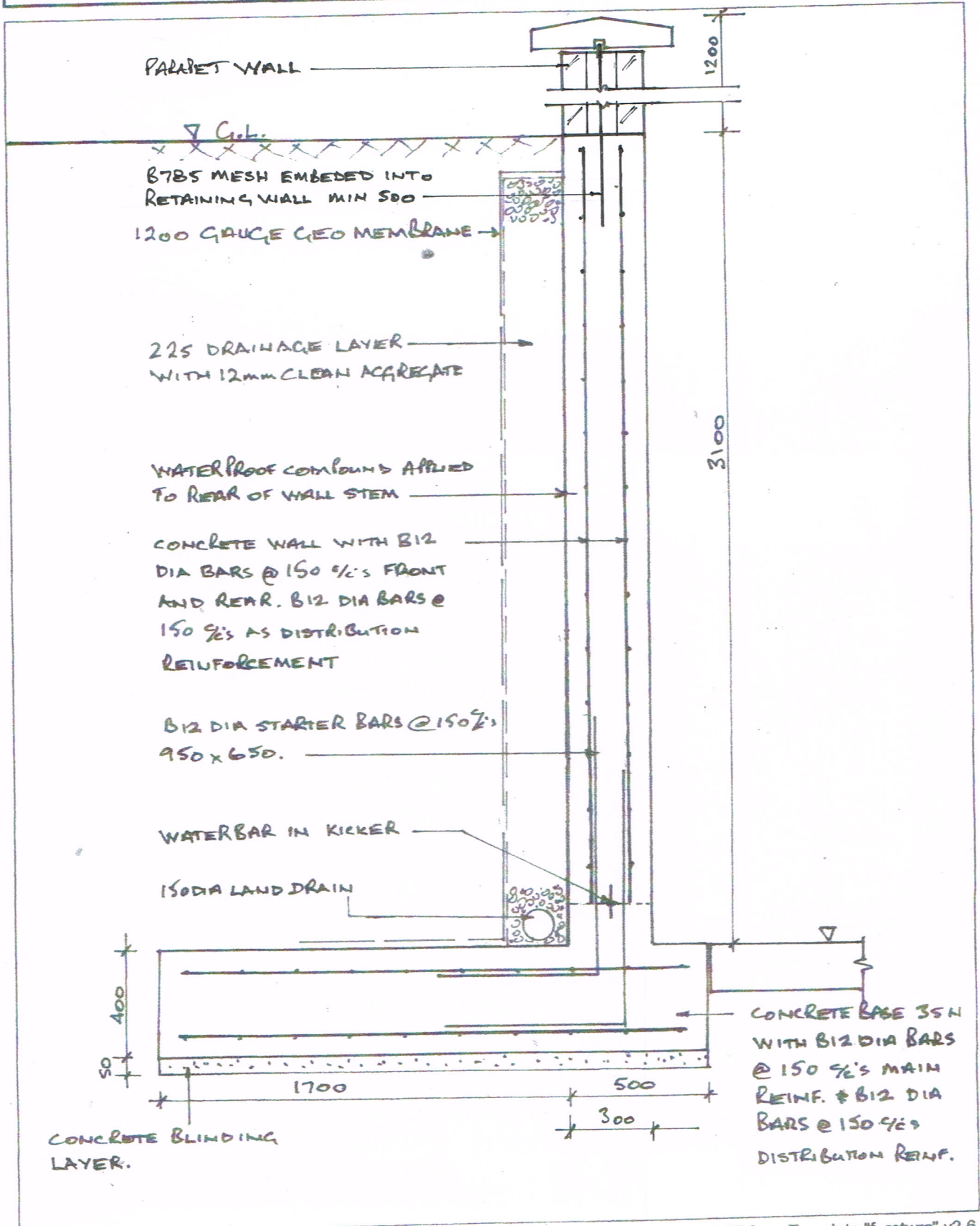
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Tbernacle Terrace Cwmavon
General components

DETAIL OF 1200 HIGH PARAPET WALL.

