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# Design of Cantilever Retaining Wall with 4m Height

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***Abstract*: Retaining structures hold back soil or other loose material where an abrupt change in ground elevation occurs. The retained material or backfill exerts a push on the structure and thus tends to overturn or slide it, or both. The cantilever is the most common type of retaining wall and is used for walls in the range of 3to 6m in height. This study presents analyses and design of cantilever retaining wall which is made from an internal stem of steel-reinforced, cast-in-place concrete (often in the shape of an inverted T). In this work a detailed analyses and design for this type of walls which include estimation of primary dimensions of the wall, then these dimensions were checked.The factor of safety against sliding, overturning and bearing were calculated.the shear resistance for the base,the tension stresses in the stem andthe tension stresses for the base were checked. Calculation of reinforcement for each part of the wall were done. All analysis and design are based on the ACI code**

***Keywords*: retaining, cantilever, wall, sliding, shear, reinforcement.**

## I. INTRODUCTION

**R**etaining walls are usually built to hold back soil mass to retail soil which is unable to stand vertically by themselves. However, retaining walls can also be constructed for aesthetic landscaping purposes. They are also provided to maintain the grounds at two different levels. Retaining walls shall be designed to withstand lateral earth and water pressures, the effects of surcharge loads, the self-weight of the wall.There are many types of retaining walls; following are the different types of retaining walls, based on the shape and the mode of resisting the pressure:

a. Gravity wall-Masonry or Plain concrete.

b. Cantilever retaining wall.

**c.** Counter fort retaining wall.

d. Buttress retaining wall.

Cantilever retaining walls are constructed of reinforced concrete. They consist of a relatively thin stem and a base slab. The base is also divided into two parts, theheel and toe. The heel is the part of the base under the backfill. The toe is the other part of the base. The analysis and design of retaining walls includes the following:

a. Estimation of primary dimensions of the wall, then these dimensions should be checked.

b. Checking external stabilityof the walls (sliding of retaining walls, overturning stability and bearing stability)

c. For reinforced concrete retaining walls main and secondary reinforcement must be calculated.

## II. OBJECTIVE OF THE STUDY

This paper shows the analysis and design of the cantilever retaining wall.The design involves two major steps: the first one is the evaluation of the stability of the whole structure under the service loads, which includes the overturning , sliding and bearing failure modes, and the second one is the design of the different components, such as the stem, heel and toe for bending and shear, under the combined factored loads.All analysis and design are based on the ACI code.

1. **The design procedure:** All design parameters are shown in table 1.

**TABLE 1.The design parameters**

| Parameter | Notation | Value |
|---|---|---|
| The height of wall | h | 4m |
| The density of back fill soil | $\gamma s$ | 17.5 kN/$m^3$ |
| the angle of internal friction of back fill soil | Ø | $30^0$ |
| Density of concerte | $\gamma c$ | 25 kN/$m^3$ |
| the assumed surcharge load | q | 50 kN/$m^2$ |
| The bearing capacity of soil under the wall | qa | 200 kN/$m^2$ |
| the angle of internal friction of fondation soil | Ø | 32 |
| The cohesion of foundation soil | C | 10 kN/$m^2$ |
| Compressive strength of concrete | $fc'$ | 21Mpa |
| The yield stress of steel | $fy$ | 347Mpa |

**1.1 The dimensions of the retaining wall will be assumed as follow refer to figure1:**

a. The width of the wall base

B= 0.4H to 0.7H = 0.4 * 4 to 0.7 * 4

B = 2.8m to1.6m ,the width of the base will be assumed as 3.2m

b. The thickness of the stem at the top

$t = \frac{H}{12}$ to $\frac{H}{10}$

$t = \frac{H}{10} = \frac{4}{10} = 0.4$ m

$t = \frac{H}{12} = \frac{4}{12} = 0.3$ m, use 0.3m as thickness of the stem at the top and 0.4m at the base

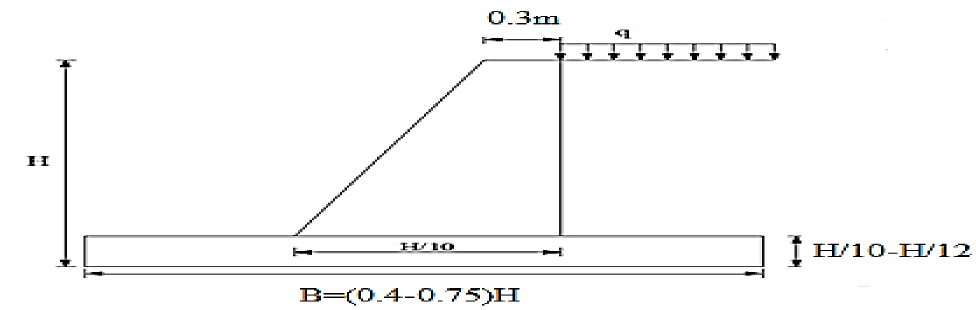


**Fig.1 The primary dimension of the wall**

c. Length of toe = $\frac{B}{3} = \frac{3.2}{3} = 1.067$ m

d. The thickness of the stem at the top will be assumed equal to 0.3m and its thickness at the base $= \frac{H}{10} = 0.4$m

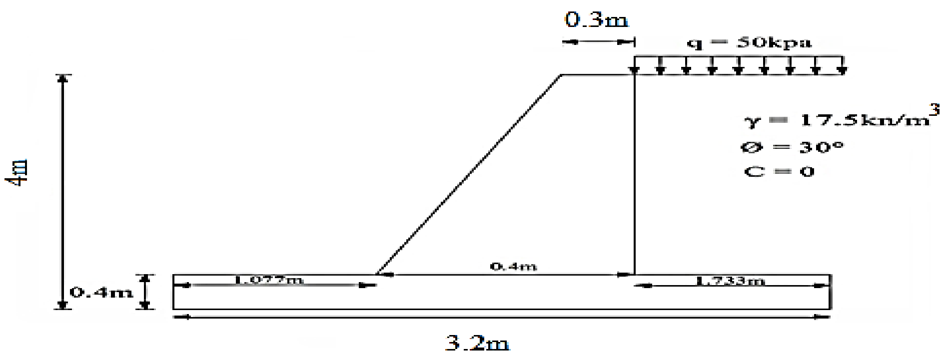


**Fig.2 the assumed dimension of the wall**

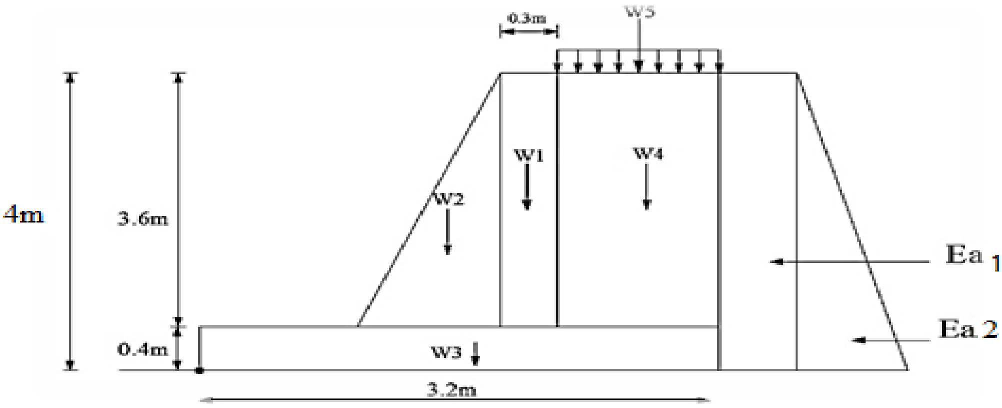


**Fig.3. loads and earth pressures acting on the wall**

**1.2 the loads and earth pressures acting on the wall:**

**a. The loads:**

W1 = 0.3 * 3.6 * 1 * 25 = 27 KN

$W_2$ = 0.5 * 0.1 * 3.6 * 1 * 25 = 4.5KN

$W_3$ = 0.4 * 3.2 * 1 * 25 = 32KN

$W_4$ = 3.6 * 1.733 * 1 * 17.5 = 109.179 KN

$W_5$ = 50 * 1.733 * 1 = 86.65 KN

The sum of these weights

Rv = $\sum w$ = 259.329 KN

**b. The active earth pressures:**

ka = $\frac{1-\sin 30°}{1+\sin 30°}$ = 0.33

$\sigma_1$= ka * q

$\sigma_1$= 0.33 * 50 = 16.5 kpa

$\sigma_2$ = ( q + γ H ) ka = ( 50 + (17.5 * 4 ) 0.33 = 39.6 kpa

$Ea_1$ = $\sigma_1$* H * 1

$Ea_{1\,=}$ 16.5 * 4 * 1 = 66 KN

$Ea_2$= 0.5($\sigma_2 - \sigma_1$) H * 1

$Ea_2$= 0.5 * (39.6 – 16.5) 4 * 1 = 46.21 KN

**1.3 The stability analysis:**

**a. Checking the factor of safety against sliding:**

F.S= $\frac{c' * B + Rv tan\emptyset}{Ea1+Ea1}$

$c' = c * 0.8 = 8kpa$

F.S = $\frac{8 * 3.2 + 259.329 * tan32}{66+46.21}$ = 1.67, F.S > 1.5 ∴ ok , The wall is safe against sliding

**b. Checking the factor of safety against overturning:**

F.S= $\frac{\text{resisting moment}}{\text{overturning moment}}$

The resisting moment and the overturning moment are shown in the following tables.

**TABLE 1. The resisting moments**

| Force KN | Arm m | Moment around point O OKN.m |
|---|---|---|
| $W_1$= 27 | 1.317 | 35.559 |
| $W_2$ = 4.5 | 1.13 | 5.085 |
| $W_3$ = 32 | 1.6 | 1.2 |
| $W_4$ = 109.179 | 2.3335 | 254.78 |
| $W_5$ = 86.65 | 2.3335 | 202.19 |
| | | $M_1$ = 548.814kN.m |

**TABLE 2. The overturning moments**

| Force KN | Arm m | Moment around point O |
|---|---|---|
| $Ea_1 = 66$ | 2 | 132 |
| $Ea_2 = 46.2$ | 1.33 | 61.446 |
| | | $M_2$= 193.446kN.m |

F.S = $\frac{M1}{M2} = \frac{548.814}{193.446}$= 2.8 >1.5 the wall is safe against overturning.

**c. Checking the pressure under the base of the wall:**

Rv * $x'$ = $M_1 - M_2$

$x'$= 1.37 m

$e = \frac{B}{2} - x'$

e = $\frac{3.2}{2} - 1.37$ = 0.23 m

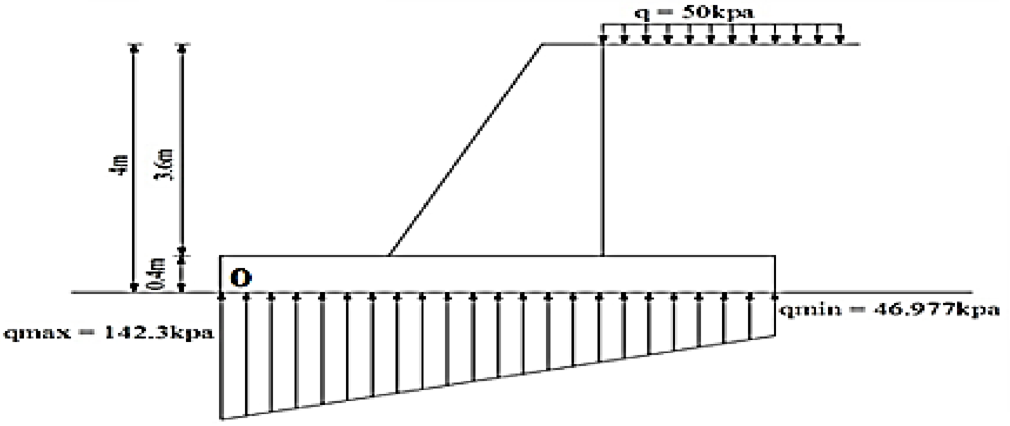


**Fig.4. the pressure distribution under the wall**

$B' = B - 2e$

$B'$ = 3.2 - 2 * 0.23 = 2.74 m

$q_{max} = \frac{Rv}{Af'}\left(1 + \frac{6e}{B'}\right)$

$q_{max}= \frac{259.329}{2.74 * 1} ( 1 + \frac{6*0.23}{2.74} ) = 142.3$ kpa

$q_{min}= \frac{Rv}{Af'} ( 1 - \frac{6e}{B'} )$

$q_{min}= \frac{259.329}{2.74*1} ( 1 - \frac{6*0.23}{2.74} ) = 46.977$ kpa

$q_a > q_{max} \therefore ok$

**1.4 Design of stem reinforcement:**

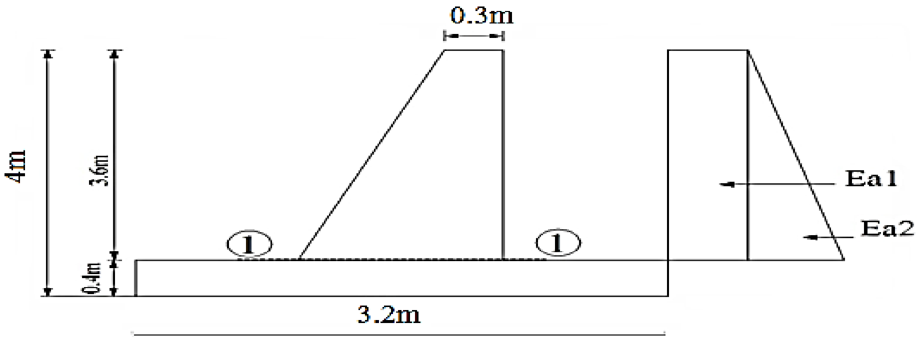


**Fig. 5. Shear force on the steam.**

The critical section for moment in the stem is at section (1-1) see figure 5 .

Moment in Section (1-1).

$M = Ea_1 * \frac{h}{2} + Ea_2 * \frac{h}{3}$

$M = \sigma_1 h * \frac{h}{2} + ( (\sigma_2 - \sigma_1) \, 0.5 * h * \frac{h}{3} )$

$M = (16.5 * 3.6 * \frac{3.6}{2} ) + ((37.29 - 16.5) \, 0.5 * 3.6 * \frac{3.6}{3}) = 151.83$kn.m

$Mu = M * 1.6 = 151.83 * 1.6 = 242.928$ KN.m

$Ru = \frac{Mu*10^6}{0.9*b*d^2}$

$Ru = \frac{242.928*10^6}{0.9* 1000*(315)^2} = 2.7$

$$\rho = \frac{0.85 \, fc'}{fy} \left( 1 - \sqrt{1 - \frac{2Ru}{0.85 * fc'}} \right)$$

$$\rho = \frac{0.85 \; 21}{347} \left( 1 - \sqrt{1 - \frac{2 * 2.7}{0.85 * 21}} \right) = 0.0084$$

$\rho_{min} = 0.002$

$\rho_{max} = 0.75 \, \rho d$

$\rho_{max} = 0.75 \, (0.85 * 0.85 * \frac{fc'}{fy} ( \frac{600}{600+fy}) )$

$\rho_{max} = 0.75 \, (0.85 * 0.85 * \frac{21}{347} ( \frac{600}{600+347}) ) = 0.021$

$\rho_{max} > \rho > \rho_{min}$

As = $\rho$ b d = 0.0084 * 1000 * 315 = 2646mm$^2$

Use Ø 20 ∴ Ab = 314 mm$^2$

No .of bars = $\frac{As}{Ab} = \frac{2646}{314}$ = 8.4 = 9 Ø 20/ m

The Secondary longitudinal reinforcement

As = $\frac{t1+t2}{2}$ * 1000 * 0.002

As = $\frac{300+400}{2}$ * 1000 * 0.002

Use Ø 10 , Ab = 78.5 mm$^2$

No .of bars = $\frac{As}{Ab}$ = 11 Ø 10 /m

Transverse temperature and shrinkage reinforcement

$As_{min} = \frac{t1+t2}{2}$ * h * 0.002

$As_{min} = \frac{300+400}{2}$ * 3600 * 0.002 = 2520mm$^2$

Use Ø 10 , Ab = 79mm$^2$

No .of bars = $\frac{2520}{A79b}$ = 32.08

Use 33Ø10

One third for inside face of the wall and two – third for outside face of the wall.

**1.6 Design of the base of the wall:**

**a.** The shear force for the base

$q_1$ = q * 1.6

$q_1$ = 50 * 1.6 = 80 kpa

$q_2 = \gamma soil$ * h * 1.2 = 17.5 x 3.6 x 1.2 = 75.6 kpa

$q_3 = \gamma c$ * t * 1.2 = 25 * 0.4 * 1.2 = 12 kpa

$\sum q$ = 169.6 kpa

$qu_1 = q_{max}$ * 1.6 = 142.3 * 1.6 = 227.68 kpa

$qu_2 = q_{min}$ * 1.6 = 46.977 * 1.6 = 75.1632 kpa

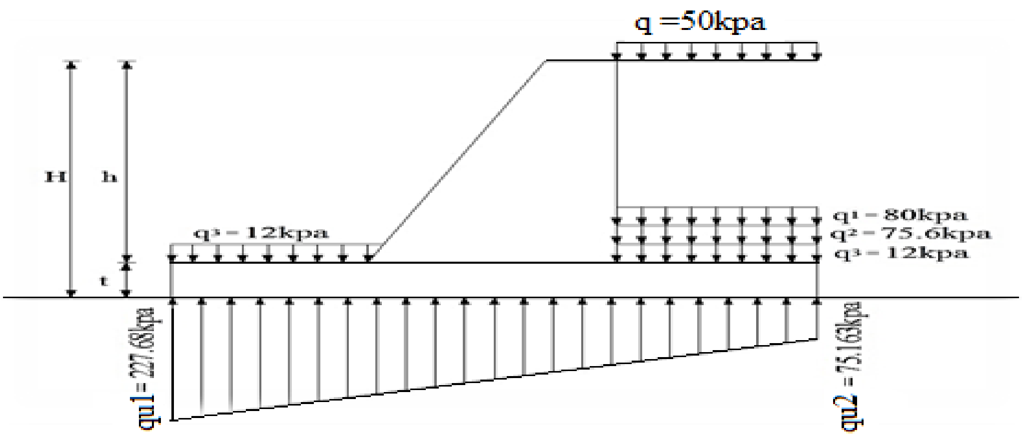


**Fig.6. the pressures on the base**

The ultimate shear force on the base:

$Vu = \frac{q'+qd}{2} * L = \frac{94.44 + 26.85}{2} * 1.418 = 85.99$ KN

$d = 400 - 75 - \frac{20}{2} = 315$ mm

The shear resistance:

$Vc = vc * b * d$

$vc = 0.17 * 0.85 * \sqrt{21} * 1000 * 1 * 0.315 = 208.5$ KN

$Vc > Vu$ ∴the thickness of the base is ok

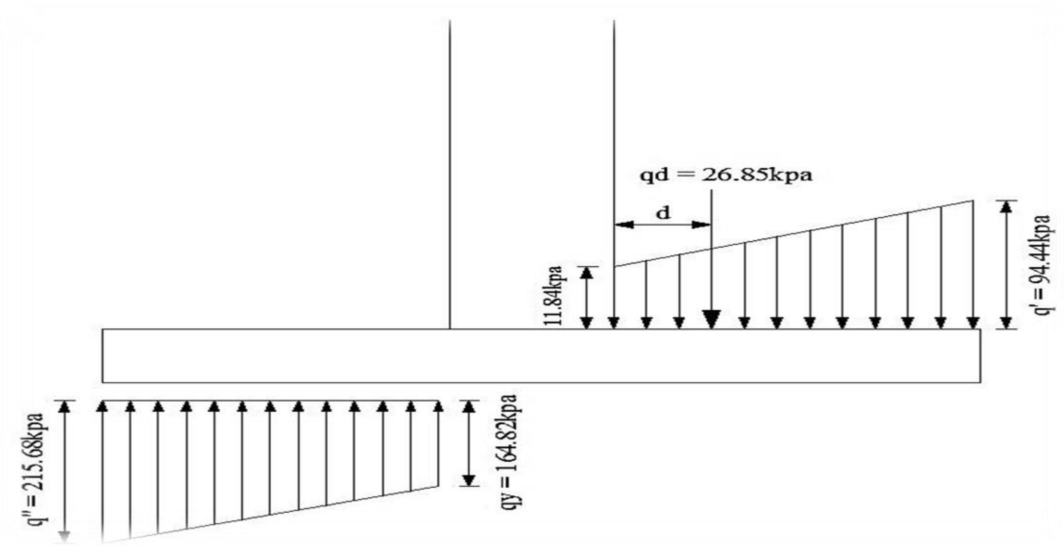


**Fig. 7 the net pressure on the base**

**b. The reinforcement of the heel:**

Dived the pressure which acts on the heel to rectangular and triangular shape and take the moment of these shapes around the face of the stem see figure 9,

$M = (11.84 * 1.733) * (\frac{1.733}{2}) + (0.5 * 1.733 * 82.6) \times (\frac{2}{3} * 1.733)$

$M = 17.77 + 82.69 = 100.46$KN.m

$Mu = 100.46 * 1.6 = 160.736$KN.m

$Ru = \frac{Mu*10^6}{0.9*b*d^2} = \frac{160.736*10^6}{0.9*1000*315^2} = 1.79$

$$\rho = \frac{0.85\, fc'}{fy} \left(1 - \sqrt{1 - \frac{2Ru}{0.85 * fc'}}\right)$$

$$\rho = \frac{0.85*21}{347} \left(1 - \sqrt{1 - \frac{2*4.2}{0.85*21}}\right) = 0.0054$$

$\rho_{min} = 0.002$

$\rho_{max} > \rho > \rho_{min}$

$As = \rho\, b\, d = 0.0054 * 1000 * 315 = 1701\ mm^2$

Use Ø 20 ∴ $Ab = 314\ mm^2$

No .of bars $= \frac{As}{Ab} = \frac{1701}{314} = 5.41$

Use 6Ø 20/ m top.

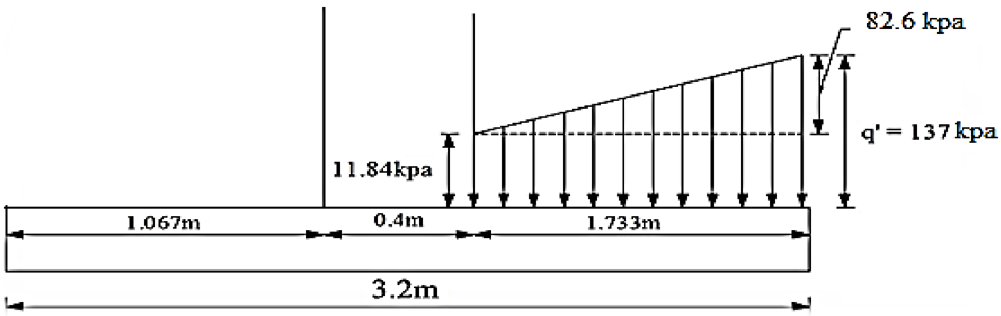


**Fig. 8 The pressure on the heel**

**c. The shear force on the toe:**

$Vu = \frac{q''+qd}{2} * L$

$q''$= 215.68kpa, $qd$ = 179.88kpa and L = 0.752m

$Vu = \frac{215.68 + 179.88}{2} * 0.752 = 148.731kN$

Vc = 208.5 kN

Vc> Vu∴ t is ok

**d. the reinforcement of the toe:**

$M = [(164.82 * 1.067) * \frac{1.06}{2}] + [(0.5 * 1.067 * 50.86) * (\frac{2}{3} * 1.067)] = 112.5KN.m$

Mu= M * 1.6 = 180KN.m

$Ru = \frac{Mu*10^6}{0.9*b*d^2} = \frac{180*10^6}{0.9*1000*315^2} = 2.01$

$$\rho = \frac{0.85\, fc'}{fy} \left(1 - \sqrt{1 - \frac{2Ru}{0.85 * fc'}}\right)$$

$\rho = \frac{0.85*21}{347} \left(1 \sqrt{1 - \frac{2*1.85}{0.85*21}}\right) = 0.0061 > \rho_{min}$

As = $\rho$ b d = 0.0061 * 1000 * 315 = 1921.5mm$^2$

Use Ø 20 ∴ Ab = 314 mm$^2$

7 Ø 20 /m bottom

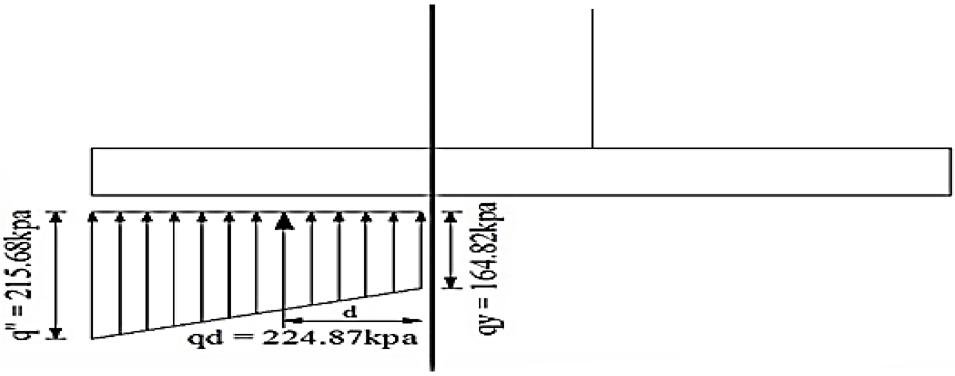


**Fig .9 Pressure on the toe**

The secondary reinforcement .

$As_{min}$= 0.002 x b x t = 0.002 x 3200 x 400 = $2560/_2$ = 1280 mm$^2$

Use Ø 10 , Ab = 79 mm$^2$

The spacing S = $\frac{79}{1280}$ * 1000 = 61.7 mm

$\emptyset 10@60mm$top and bottom.

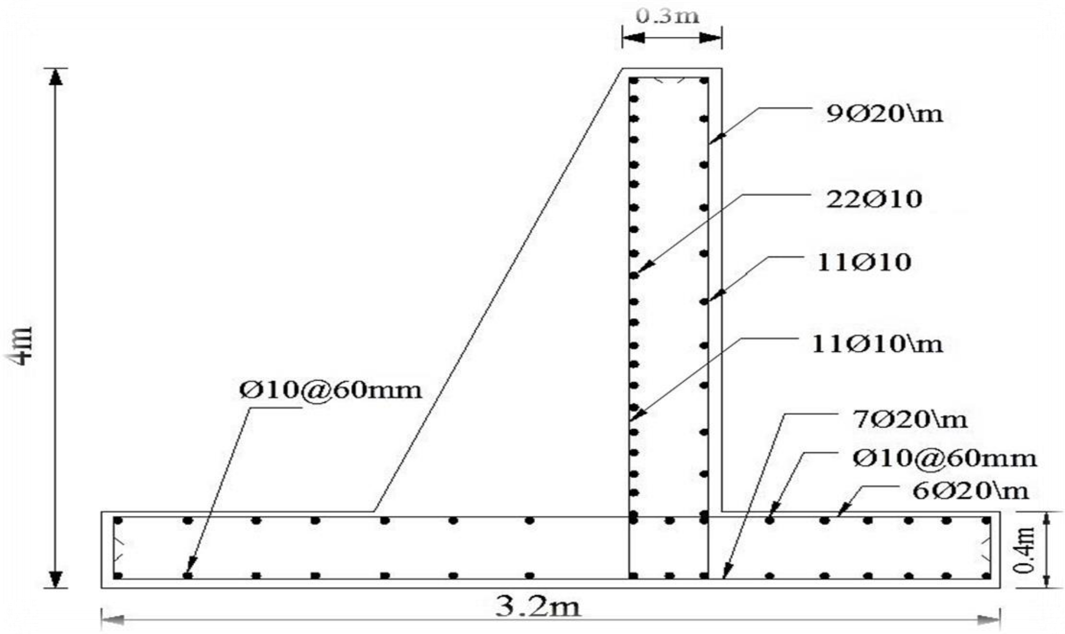


**Fig.10 The reinforcement of the cantilever R.W**

## REFERENCES

[1] ACI – code 318 – 1989 manual of reinforced concrete.

[2] Alam Singh and B.C. pumpia; soil mechanics and foundations; standard book house, Delhi, 1970.

[3] Clarence W. dunham; the theory and practice of reinforced concrete. Mc. Graw-Hill book company, New York.

[4] E. w. Brooker and H.O. Ireland; earth pressure at rest related to stress history, Canadian geotechnical journal , vol. II, No.1 ,1965.

[5] G.P.T Shebotaroiff, soil mechanics and earth structures. Mc. Graw-Hill book company, New York, USA.

[6] Joseph E. Bowles; Foundation analysis and design fifth edition. Mc-Graw-Hill book company, New York.