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Design of Retaining Wall

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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

1.1 GENERAL

Retaining 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, the heel 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 stability of the walls (sliding of retaining walls, overturning stability and bearing stability)
c. For reinforced concrete retaining walls main and secondary reinforcement must be calculated.

1.2 OBJECTIVES OF THE PROJECT

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.

Table 1.The design parameters

Parameter	Notation	Value
The height of wall	h	4m
The density of back fill soil	γs	17.5KN/m^2
The angle of internal friction of back fill soil	ϕ	30^0
Design of concrete	γc	25 KN/m^3
The assumed surcharge load	q	50KN/m^2
The bearing capacity of soil under the wall	qa	200KN/m^2
The angle of internal friction of foundation soil	ϕ	32
The cohesion of foundation soil	C	10KN/m^2
Compressive strength of concrete	Fc’	21Mpa
The yield stress of steel	fy	347Mpa

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 = H/12 to H/10

t = H/10 = 4/10 = 0.4 m

t =H/12 = 4/12 = 0.3 m, use 0.3m as thickness of the stem at the top and 0.4m at the base

c. Length of toe = B/3 = 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=H/10=0.4m

1.1 The dimensions of the retaining wall will be assumed as follow refer to figure.1:

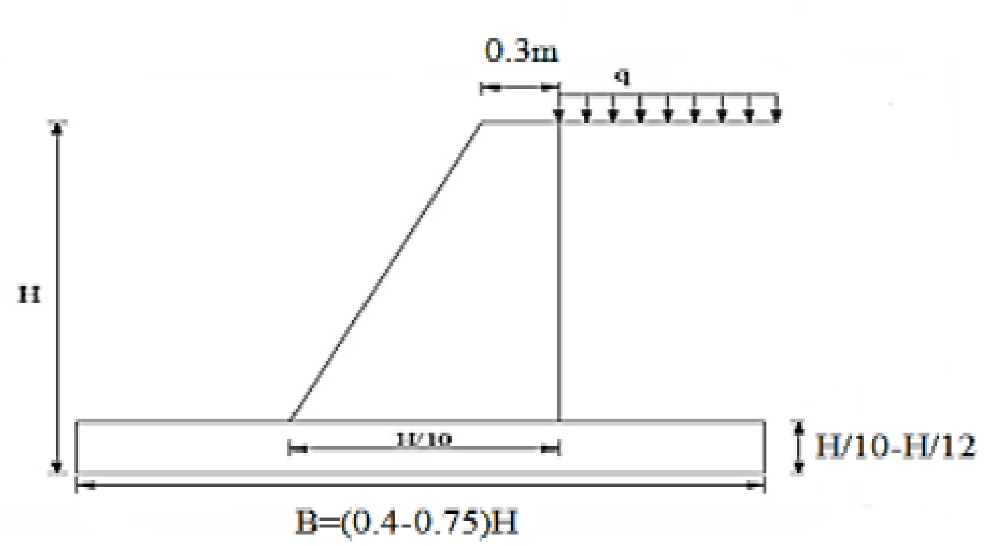

Fig.1 The primary dimension of the wall

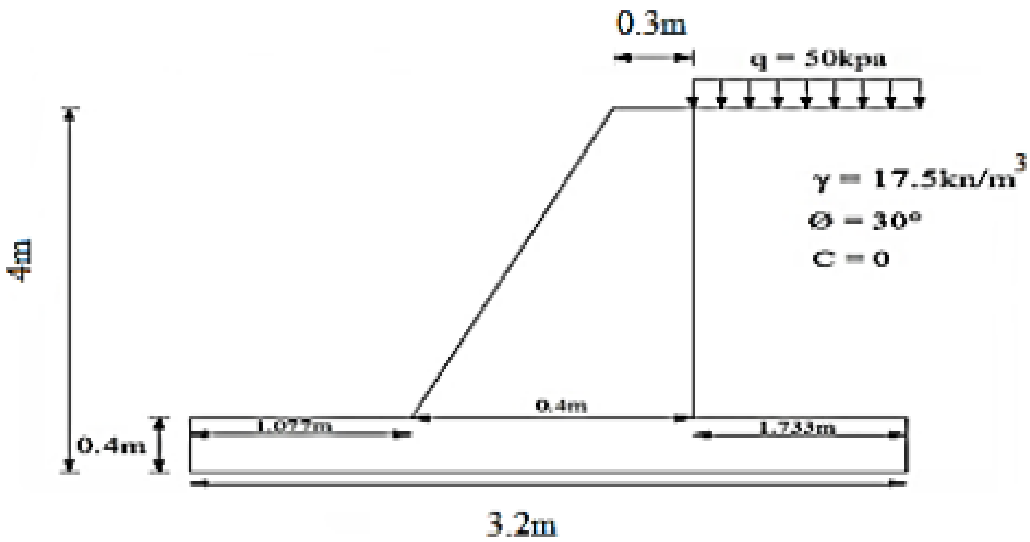

Fig.2 the assumed dimension of the wall

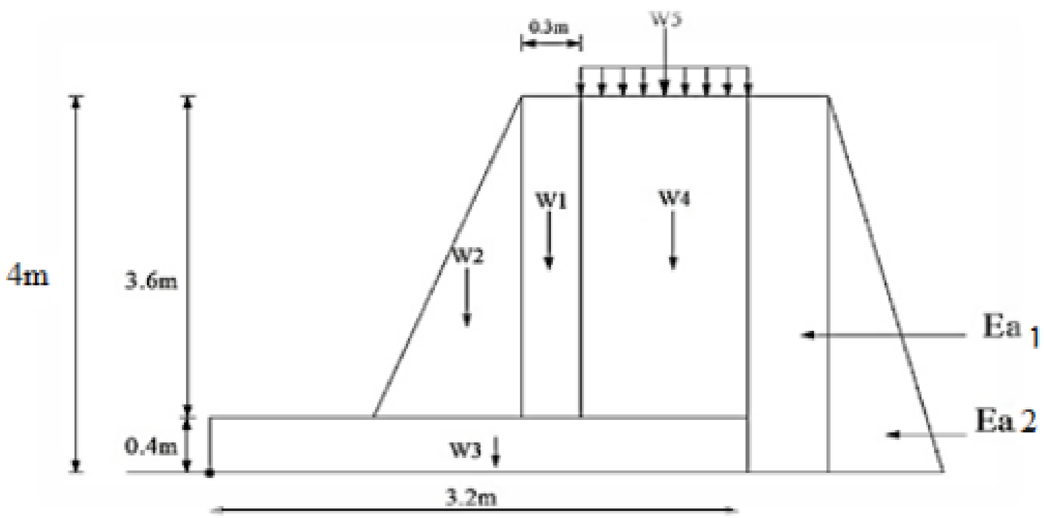

Fig.3. loads and earth pressures acting on the wall

1.2 the loads and earth pressures acting on the wall:

a. The loads:

W1 = 0.3 * 3.6 * 1 * 25 = 27 KN
W2 = 0.5 * 0.1 * 3.6 * 1 * 25 = 4.5KN
W3 = 0.4 * 3.2 * 1 * 25 = 32KN
W4 = 3.6 * 1.733 * 1 * 17.5 = 109.179 KN
W5 = 50 * 1.733 * 1 = 86.65 KN
The sum of these weights
Rv = ∑ 259.329 KN

b. The active earth pressures:

ka = 0.33
1= ka * q
1= 0.33 * 50 = 16.5 kpa
2 = (q + γ H) ka = (50 + (17.5 * 4) 0.33 = 39.6 kpa
Ea1 = 1* H * 1 Ea1 = 16.5 * 4 * 1 = 66 KN
Ea2= 0.5(2– 1) H * 1 Ea2= 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=(C'*B+Rvtan$^{\phi}$) ÷ (Ea1+Ea1)
C`= C*0.8= 8kpa
F.S=(8*3.2+259.329*tan32)÷(66+46.21) =1.67 , F.S >1.5
Hence ok, The wall safe against sliding.

b. Checking the factor of safety against overturning:

F.S=(Resisting moment)÷(Overturning moment)

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

Table 2. The resisting moments

Force KN	Arm m	Moment around point 0 0KN.m
W1 =27	1.317	35.559
W2 =4.5	1.13	5.085
W3 =32	1.6	1.2
W4 =109.179	2.3335	254.78
W5 =86.65	2.3335	202.19
		M1 =548.814KN.m

Table 3. The overturning moments

Force KN	Arm m	Moment around point 0
Ea1 =66	2	132
Ea2 =46.2	1.33	61.446
		M2 =193.446KN.m

F.S = (M1) ÷ (M2) = (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'= M1 – M2
X`= 1.37m
e = (B)÷(2) – X'
e = (3.2)÷ (2) -1.37 = 0.23m

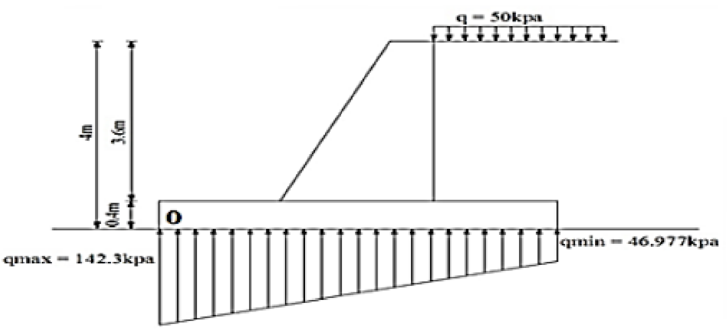

Fig.4. the pressure distribution under the wall

B` = B – 2e
B` = 3.2 – 2* 0.23 = 2.74m
qmax=(Rv/Af')x(1+ϵe/B')
qmax= 259.329/2.74+1 (1+(6+0.23/2.74)) = 142.3kpa
qmin = Rv/Af' (1-(6e/B'))
qmin = 259.329/2.74*1 (1-(6*0.23/2.74)) =46.977kpa
qa > qmax Hence ok.

1.4 Design of stem reinforcement:

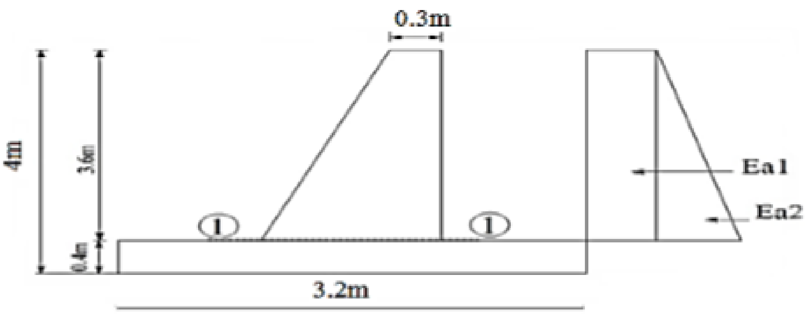

Fig. 5. Shear force on the steam.

The critical section for moment in the stem is at section (1-1) see figure 5 .
Moment in Section (1-1).
M =Ea1*h/2+Ea2*h/3
M =ϵ1h*h/2+((ϵ2-ϵ1)0.5*h*h/3)
M=(16.5*3.6*(3.6/2))+((37.29-16.5)0.5*3.6*(3.6/3))=151.83kn.m
Mu=M*1.6=151.83*1.6=242.928kn.m
Ru=Mu*10^6/0.9*b*d^2
Ru =Mu*10^6/0.9*1000*(315^2) =2.7
P = 0.85fc'/fy (1-√1-(2Ru/0.85*fc'))
P = 0.85*21/347 (1-√1-(2*2.7/0.85*21))=0.0084
Pmin =0.002
Pmax= 0.75 pd
Pmax =0.75(0.85*0.85*(fc'/fy)(600/600+347))=0.021
Pmax > p > pmin
As = p b d = 0.0084 * 1000 * 315 = 2646mm2
Use ϕ20 That Is, Ab = 314 mm2
No .of bars = As/Ab = 2646/314 = 8.4= 9ϕ20/m

The Secondary longitudinal reinforcement

As = t1+t2/2*h*0.002
As =300+400/2 * 1000 * 0.002
Use ϕ 10 , Ab = 78.5 mm2

No .of bars =As/Ab =11 ϕ 10 /m

Transverse temperature and shrinkage reinforcement

Asmin=t1+t2/2*h*0.002

Asmin= 300+400/2*3600*0.002 =2520mm2

Use ϕ 10 , Ab = 79mm2

No .of bars = 2520/79 = 32.08

Use 33 ϕ 10

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

q1 = q * 1.6

q1 = 50 * 1.6 = 80 kpa

q2 = γ soil * h * 1.2 = 17.5 x 3.6 x 1.2 = 75.6 kpa

q3 = γc * t * 1.2 = 25 * 0.4 * 1.2 = 12 kpa

∑q = 169.6 kpa

qu1=qmax*1.6=142.3*1.6 =227.68 kpa

qu2=qmin*1.6=46.977*1.6=75.1632 kpa

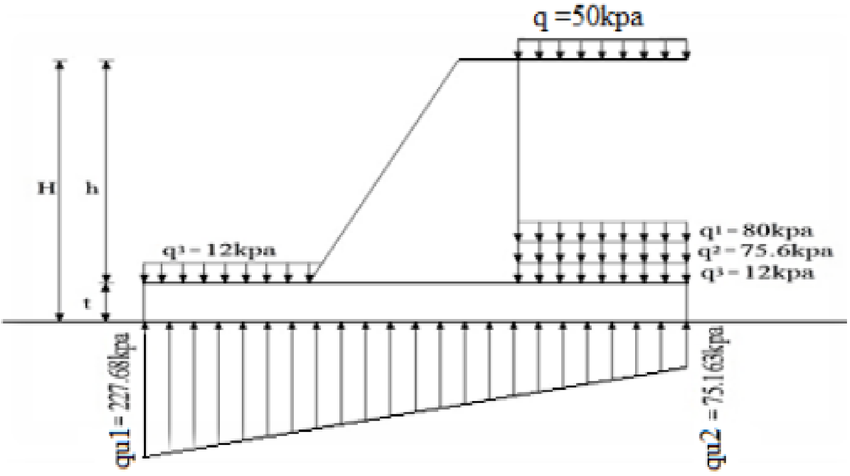

Fig.6. the pressures on the base

The ultimate shear force on the base:

Vu=(q'+qd/2)*L=(94.44+26.85)/2*1.418=85.99kn

D=400-75-(20/2) =315mm

The shear resistance:

Vc = Vc * b * d

Vc=0.17*0.85*√21*1000*1*0.315=208.5 KN

Vc > Vu Hence ,the thickness of the base is ok

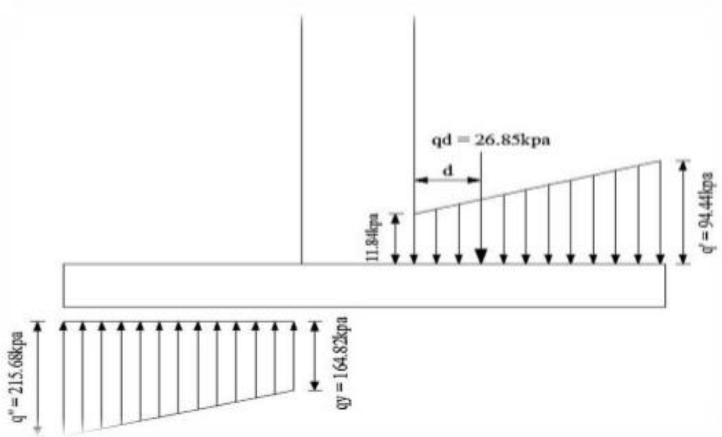

Fig. 7 the net pressure on the base

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) * (1.733/2)+ (0.5 * 1.733 * 82.6) x (2/3*1.733)

M = 17.77 + 82.69 = 100.46KN.m

Mu=100.46*1.6=160.736kn.m

Ru=(mu.10^6)÷0.9*b*d^2=160.736*10^6/0.9*1000*315^2 =1.79

P =(0.85fc'/fy)x(1-√1-2Ru/0.85*fc')

P=0.85*21/347(1-√1-2*4.2/0.85*21)=0.0054

pmin= 0.002

pmax > p>p min

As=p b d=0.0054*1000*315=1701mm2

Use ϕ 20 Hence , Ab=314mm2

No. of bars=(As/Ab)=1701/314=5.41

Use 6 ϕ20 / m top.

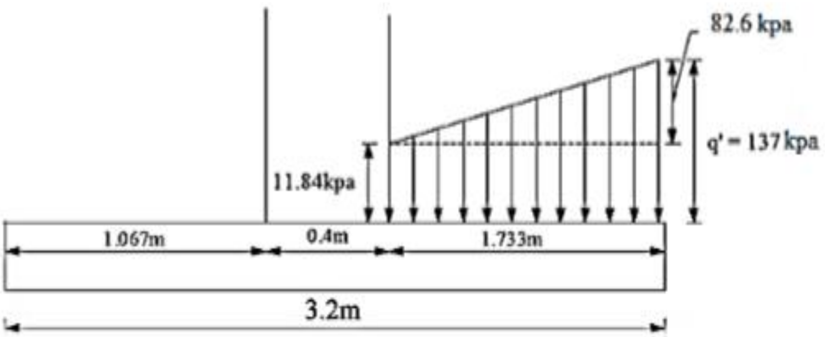

Fig. 8 The pressure on the heel

c. The shear force on the toe:

Vu=q"+qd/2*L

q"=215.68kpa, qd=179.88kpa and L=0.752m

Vu=215.68+179.88/2*0.752=148.731KN

Vc=208.5KN

Vc > Vu Hence t is ok

d. the reinforcement of the toe:

M=[(164.82*1.067)*1.06/2]+[(0.5*1.067*50.86)*(2/3*1.067)]=112.5KN.m

Mu=M*1.6=180KN.m

Ru=(mu.10^6)÷0.9*b*d^2=180*10^6/0.9*1000*315^2 =2.01

P =(0.85fc'/fy)x(1-√1-2Ru/0.85*fc')

P=0.85*21/347(1-√1-2*1.85/0.85*21)=0.0061>pmin

As=p b d=0.0061*1000*315=1921.5mm2

Use ϕ 20 Hence , Ab=314mm2

7 ϕ 20 /m bottom

Fig .9 Pressure on the toe

The secondary reinforcement :

Asmin=0.002*b*t=0.002*3200*400=2560/2=1280mm2

Use ϕ 10,Ab=79mm2

The spacing S=79/1280*1000=61.7mm

ϕ10@60mm top and bottom

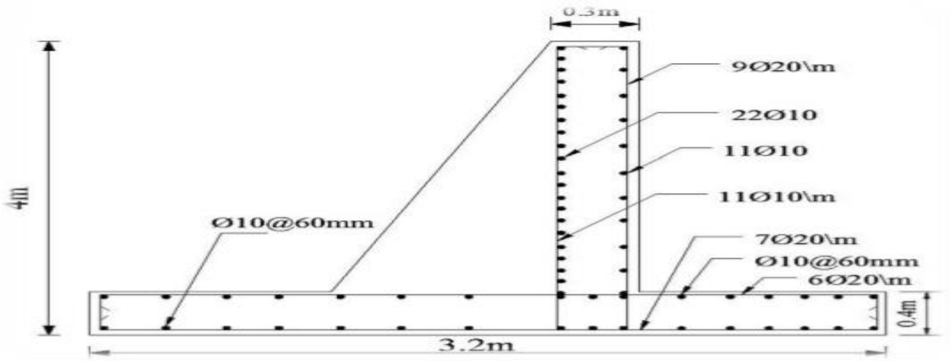

Fig.10 The reinforcement of the cantilever R.W

Design summary:

Height of wall: 4M
Width of wall: 3.2 M
Thickness Of base slab: 0.4 m
Thickness of stem: 0.3 m
R/F of toe slab: 10 mm dia @ 60 mm c/c
R/F of heel slab: 10 mm dia @ 60 mm c/c
R/F of stem: 22 mm dia @ 100 mm c/c

III. CONCLUSION

There is a little experience in physical modeling of reinforced soil structure. The existing shear stack was of great help in a designing the two models . both where set up as full scale model or prototype with accordingly adapted dimension to avoid the breakage of reinforcement during testing , the quantity of geogrids was a deliberately increase this way from the two limit state of internal stability ,only the pull out failure was allowed.

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