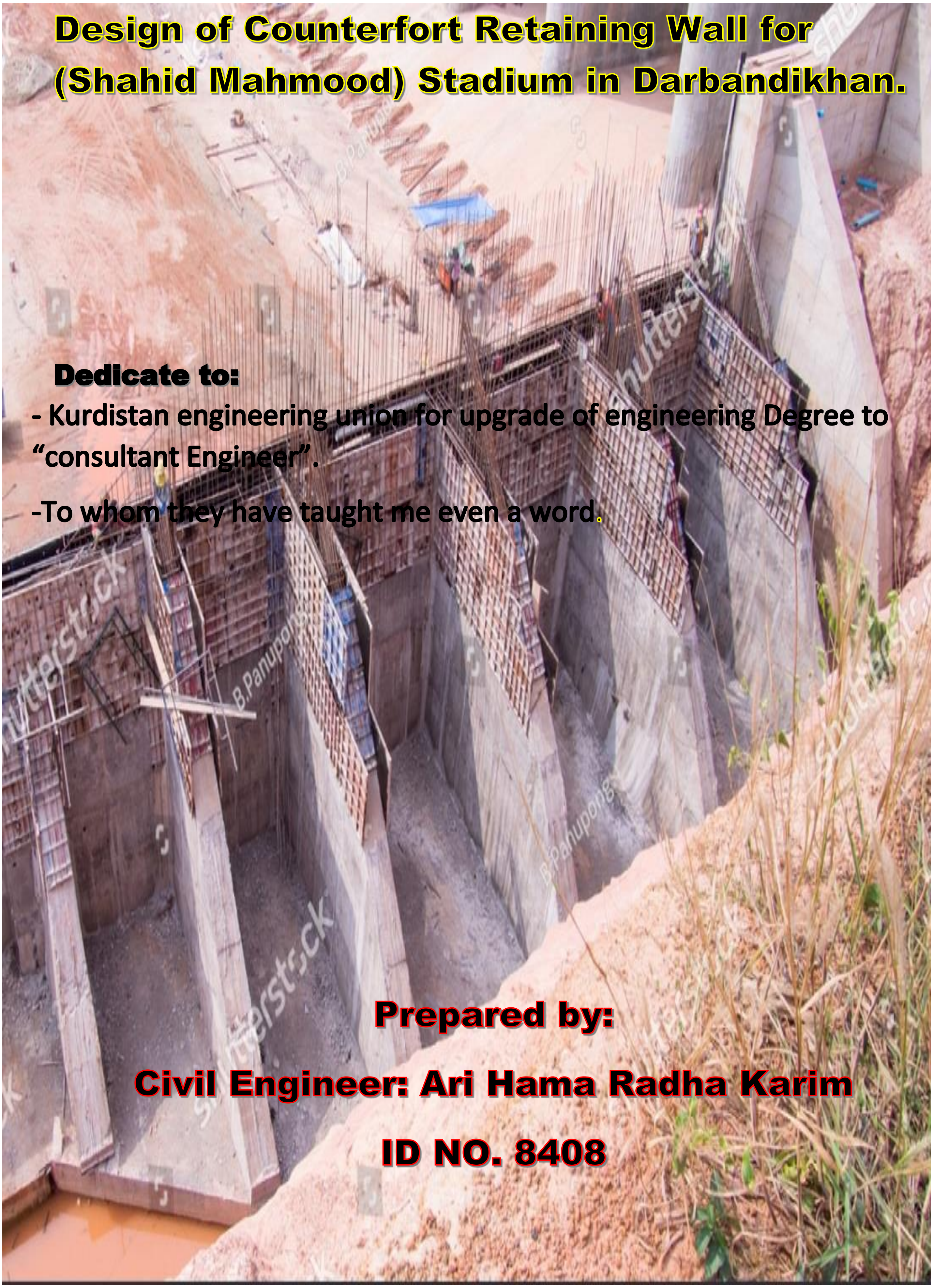


Design of Counterfort Retaining Wall for (Shahid Mahmood) Stadium in Darbandikhan.

Dedicate to:

- Kurdistan engineering union for upgrade of engineering Degree to "consultant Engineer".

-To whom they have taught me even a word.

Prepared by:

Civil Engineer: Ari Hama Radha Karim

ID NO. 8408

Index: -

Introduction

- Types of Retaining Walls (R.W), (Cantilever, Counterfort).
- Theories of forces acting on R.W.
- Types of failure of R.W.

-Design example on Counter fort R.W.

Introduction

Retaining walls are structures built to retain vertical or nearly vertical earth banks or any other material, where conditions disallow the mass to assume its slope, such conditions occur when the width of an embankment is restricted by conditions of ownerships, use of the structure, or economy. For example, in the railway or highway construction the width of the right of way is fixed, and the cut or embankment must be contained within that width. Similarly, the basement walls of buildings must be located within the property and must retain the soil surrounding the basement.

The earth of the side of the wall where ground level is higher is called backfill and the retaining wall is to retain this earth.

A retaining wall which supports the load of a bridge and also retains earth is called " Abutment ". The walls placed at an inclination to the normal to the direction of fill and used to retain the ends of an approach fill for a bridge are known as "Wing walls".

A properly designed retaining wall or abutment must satisfy two almost independent requirement; they are:

First:

To make the structure safe against failure by overturning so it requires for proper design an estimation of lateral earth pressure and excessive settlement, the pressure beneath the base must not exceed the allowable soil pressure, furthermore, the structure as a whole must have an adequate factor of safety with respect to sliding along its base or along some weak stratum below its base.

The structure is proportioned, for working loads and for earth pressure unmodified by load factors.

Second:

The entire structure as well as each of its parts must possess adequate strength. In this phase of design, load factors are ordinarily applied. The corresponding pressure and forces provide the basis for checking the ultimate structural strength at various critical sections.

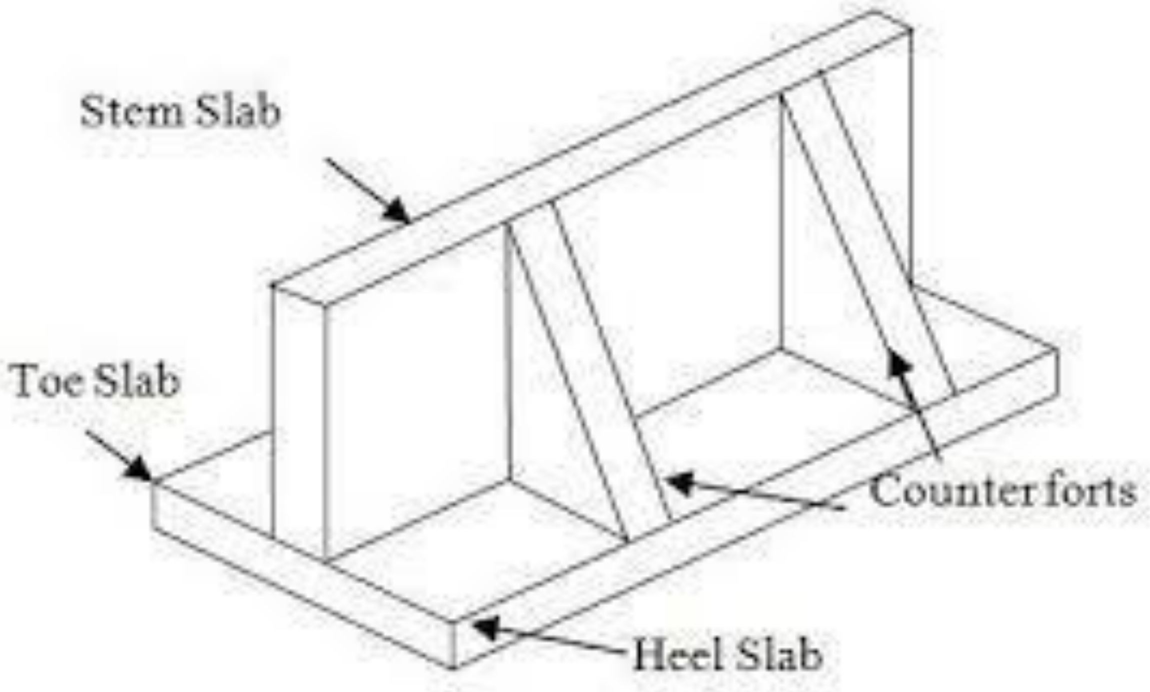
-Common uses of Retaining walls:

A retaining wall is a small constructed for the purpose of supporting a vertical or nearly vertical earth back which in turn, may support vertical loads.
It differs from other types of retaining structures, in much cases, because it doesn't require external bracing for stability.

For this reason, retaining walls have been widely used in variety of purposes.

Counterfort wall:

Looks something like a cantilever wall and likewise uses the weight of the soil together at intervals by **counter forts** or bracing walls. These act as tension ties and totally change the supports for stem and heel slabs.
The stem is a thin vertical slab becomes a slab spanning horizontally between counter forts
and the heel become as a slab supported on three sides. the counterfort is used to reduce shear and moments, this type of wall becomes more economical than the cantilever type for the height (greater than) > 6m.



Theories of forces acting on retaining wall

The forces acting on a retaining wall are customarily taken per unit of width for both gravity cantilever walls Counter fort walls may be considered as a unit between joints, or as a unit centered on two buttresses.

The forces,which act on the cantilever retaining wall, are:-

Vertical forces:

a) self-weight of the retaining wall

(1) Weight of rectangular portion of stem(w1)

(2)Weight of triangular portion of stem (w2)

(3) Base weight(w3)

b)Soil weight of backfill(w4)

Horizontal forces:

Lateral pressure on both sides

1- (Pp)which is passive pressure on the toe slab, which is neglected for safety.

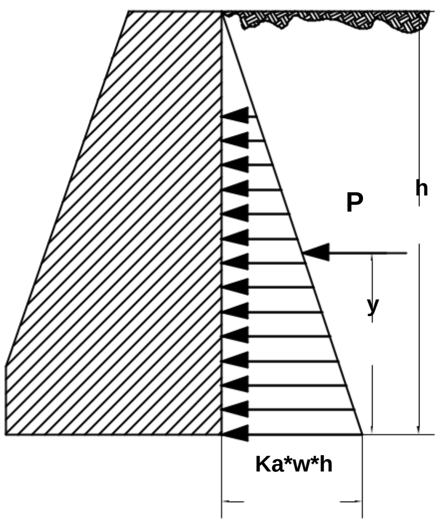
2-(pa) which is active earth pressure on the heel slab,which three types.

a) Horizontal surface.

b) Sloping surface.

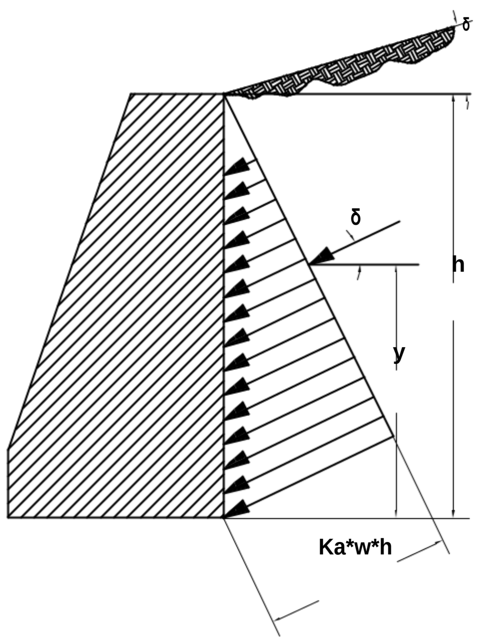
c) Horizontal surface with surcharge.

Note:
w = γ (soil)



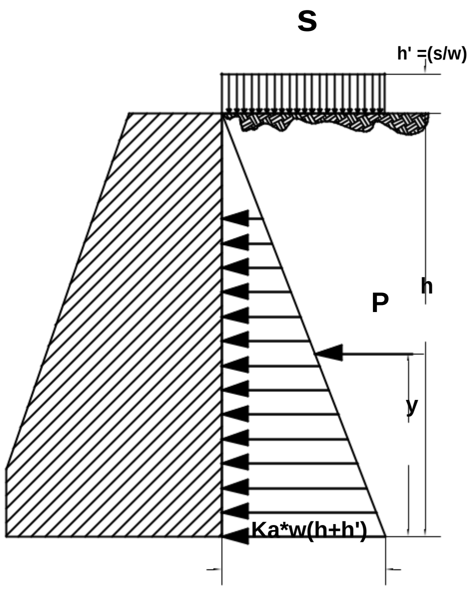
y= (h/3)

P = .5*Ka*w*h²



y =h/3 ; P =.5*Ka*w*h²

For δ = Ø ; Ka = cosØ



y= {(h²)+3*h*h'}/{3(h+2*h')}

P = .5*Ka*w*h*(h+2h')

.

Lateral pressure:

Earth pressure:

When an excavation is made in earth or when earth is piled up, the soil tends to slump and move side a way. Force is required to prevent this motion, the force exerted by the earth against any opposing structure is called the " active earth pressure " in order to differentiate it from the "passive earth pressure "; the resistance of the earth to being shoved aside by an outside force, the greatest angle at which the earth slope will remain in equilibrium is called " angle of repose " , and it is usually denoted by ° , it ordinarily varies from (30° to 40°) from the horizontal.

The magnitude of the active earth pressure; which is called "earth pressure ", is rather indeterminate.

The soil behind any wall may vary greatly in its characteristics from place to place ; when the back fill is deposited behind the wall it may exert a certain lateral pressure up on the structure ; but when the wall deforms slightly , it may tend to relive itself of some of the pressure because of the cohesion and friction of the earth upon itself ; if traffic or some other force causes vibrations that break down this internal frictional resistance , it may cause an increase of pressure upon the wall ; when the earth dried out , it may shrink and settle as it dries ; and when the soil is saturated by a rain , it may expand again.

-Types of earth pressure:

Passive earth pressure is exerted on a wall when it has a tendency to move towards the backfill. Such a condition may occur when the retaining wall supports an arch and is subjected to arch thrush, moving it towards hill.

Another condition of passive earth pressure may be when the wall supports soil of different heights on both sides.

If the soil has a tendency to move towards the wall is known as active earth pressure.

$Pa = (Ka * \gamma * h^2)/2$ $\quad$ $Ka = (1-\sin\Phi) / (1+\sin\Phi)$

$Pp = (Kp * \gamma * h^2)/2$ $\quad$ $Ka = (1+\sin\Phi) / (1-\sin\Phi)$

$$Kp= \cos\beta *\{(\cos\beta+((\cos\beta)^2-(\cos \Phi)^2) ^{0.5}) / \cos\beta-((\cos\beta)^2-(\cos \Phi)^2) ^{0.5})\}$$

$$Ka = \cos\beta *\{(\cos\beta-((\cos\beta)^2-(\cos \Phi)^2) ^{0.5}) / \cos\beta+((\cos\beta)^2-(\cos \Phi)^2) ^{0.5})\}$$

Pa: Active pressure $\quad$ Ka: coefficient active pressure

Pp: Passive pressure $\quad$ Kp: coefficient passive pressure

- Earth pressure theory:

Since the best backfill against a retaining wall structure is well-drained cohesion less material (sand and gravel), that is the condition usually specified in design. Although it is true that clay (cohesive material) will frequently exert, under ordinary moist conditions, less pressure against a wall than sand or gravel, under saturated condition becomes soft and behaves much as fluid .further more, some clays are expansive and exert greater pressure than cohesion less material. Drained granular material offers the most reliable situation.

Columb theory:

The columb theory considered that the active pressure against the surface to be the result of the tendency of a wedge of earth to slide against a wall. The failure plane assumes an angle such that the active pressure force required of the wall is maximum; Columb equation for active pressure.

$$K_a = \frac{\sin^2(\alpha+\Phi)}{\sin\alpha \cdot \sin(\alpha-\delta) \cdot \left\{1+\frac{(\sin(\Phi+\delta)\cdot\sin(\Phi-\beta))^{0.5}}{\sin(\alpha-\delta)\cdot\sin(\alpha+\delta))^{0.5}}\right\}^2}$$

a)

$$K_p = \frac{\sin^2(\alpha-\Phi)}{\sin\alpha_2 \cdot \sin(\alpha+\delta) \cdot \left\{1+\frac{(\sin(\Phi+\delta)\cdot\sin(\Phi+\beta))^{0.5}}{(\sin(\alpha+\delta)\cdot\sin(\alpha+\delta))^{0.5}}\right\}^2}$$

$P_a = (K_a \cdot \gamma \cdot h^2)/2$

$P_p = (K_p \cdot \gamma \cdot h^2)/2$

Rankine theory:

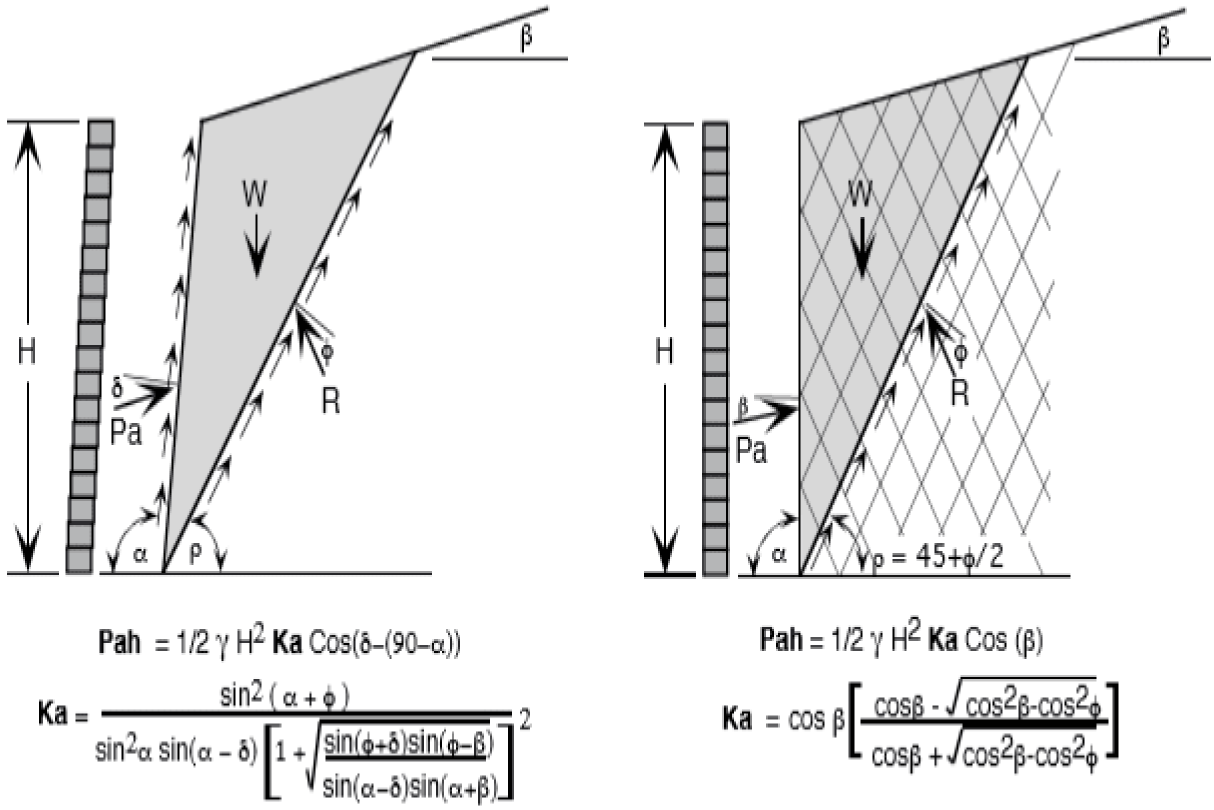
Rankine theory was presented a theory of earth pressure differing some what from of columb, Rankin's theory applied to a homogeneous in compressible cohesion less soil , the active pressure is brought about by consider a lateral expansion of elemental strips in the wedge which are parallel to the earth surface and surface and it's equation is :

Kp = (1+sinΦ) / (1-sin Φ)

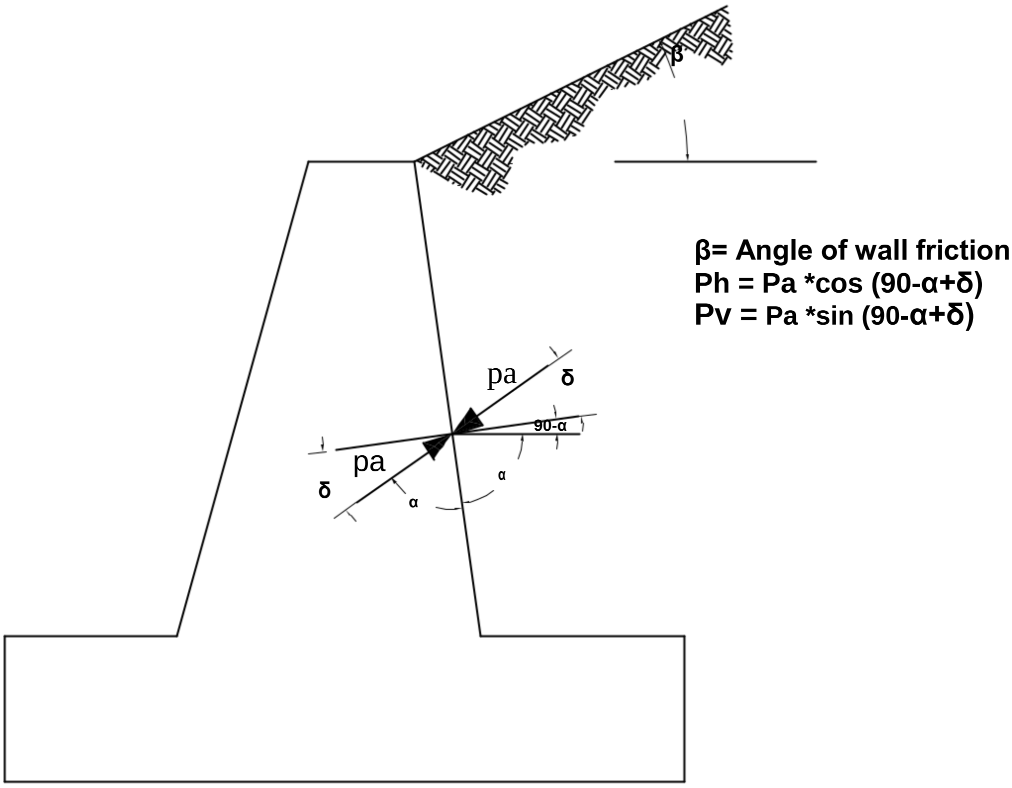
Ka = (1-sinΦ) / (1+sin Φ)

Kp= Cosβ *{(Cosβ+((Cosβ) ^2-(cos Φ)^2) ^0.5) / Cosβ-((Cosβ)^2-(cos Φ)^2) ^0.5)}

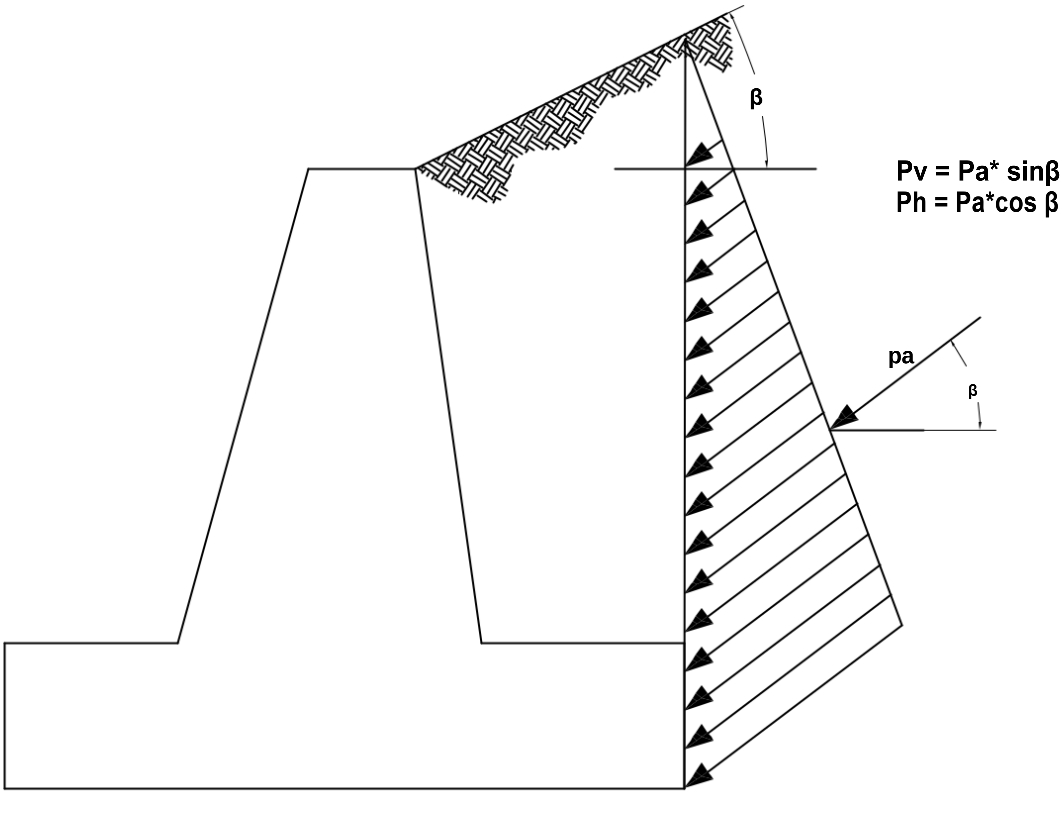
Ka = Cosβ *{(Cosβ-((Cosβ) ^2-(cos Φ)^2) ^0.5) / Cosβ+((Cosβ)^2-(cos Φ)^2) ^0.5)}



Coulomb Wedge Analysis **Rankine "state of stress" Analysis**



(a) - coulomb analysis



(b) - Rankine analysis

TYPES OF FAILURE OF RETAINING WALLS

(1) Sliding

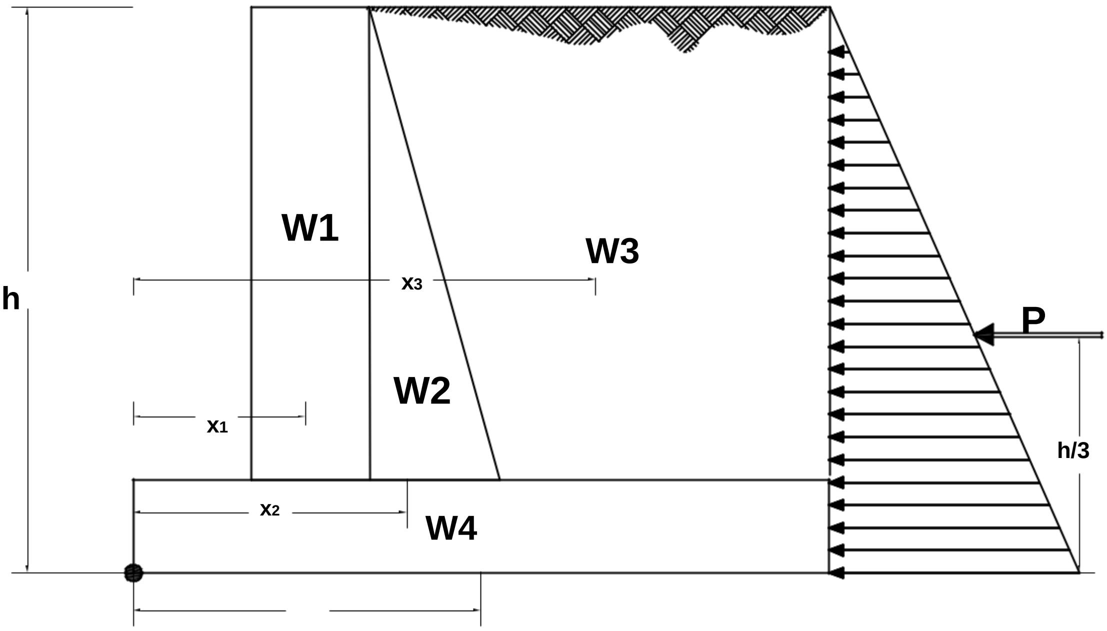
(2) Overturning

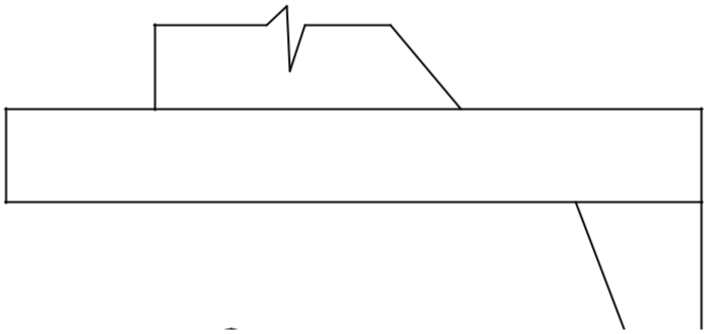
(3) Failure of soil due to excessive pressure (bearing capacity failure)

4)Shear failure of stem

5)excessive settlement

(1) Sliding failure





$\sum W = W1+W2+W3+W4$

$P = .5ka * \gamma s * h^2$

The coefficient of friction between the concrete &soil

Factor of safety against sliding $= \dfrac{\mu \sum w}{P}$ **Should be > 1.5**

Note: If factor of safety against sliding < 1.5 then sliding failure is controlled by construction of key under the end point of heel slab.

(2) Overturning Failure

$\sum Mr = \{(W1*X1) + (W2*X2) + (W3*X3) + (W4*X4)\}$

$\sum Mo = \{P*(h/3)\}$

Factor of safety against overturning $= \dfrac{\sum Mr}{\sum Mo}$ **should be >1.75**

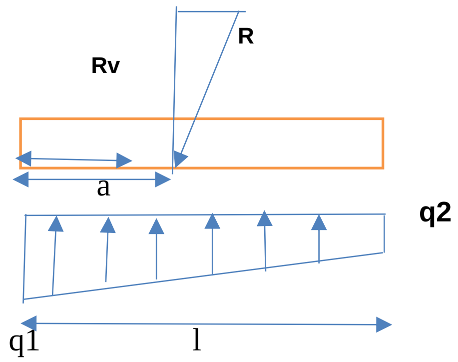
(3) Bearing Capacity Failure

If bearing capacity of soil < maximum pressure; failure in soil occur for control of this failure must be increase the length of the base.

Bearing capacity of soil:

For checking the bearing capacity of soil, we have three cases:

a) Resultant in middle third



q(all.) = (P/A) ± (MC/I)

(max.&min)

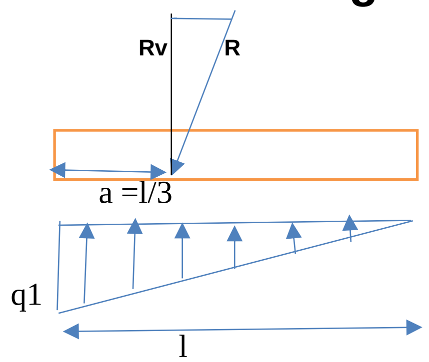
OR

$q1 = \{(4l - 6a) * Rv\} / l^2$

$q2 = \{(6a - 2l) * Rv\} / l^2$

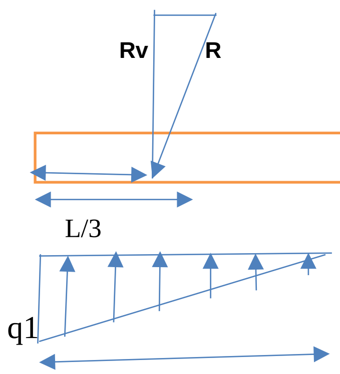
When a =l/2 ; q1 =q2 = (Rv/l)

(b) Resultant at edge of middle third.



q1= (2Rv/l)

q2=0



q1= (2Rv/3a)

(c) Resultant outside middle third.

$$q1=(2Rv/3a)$$

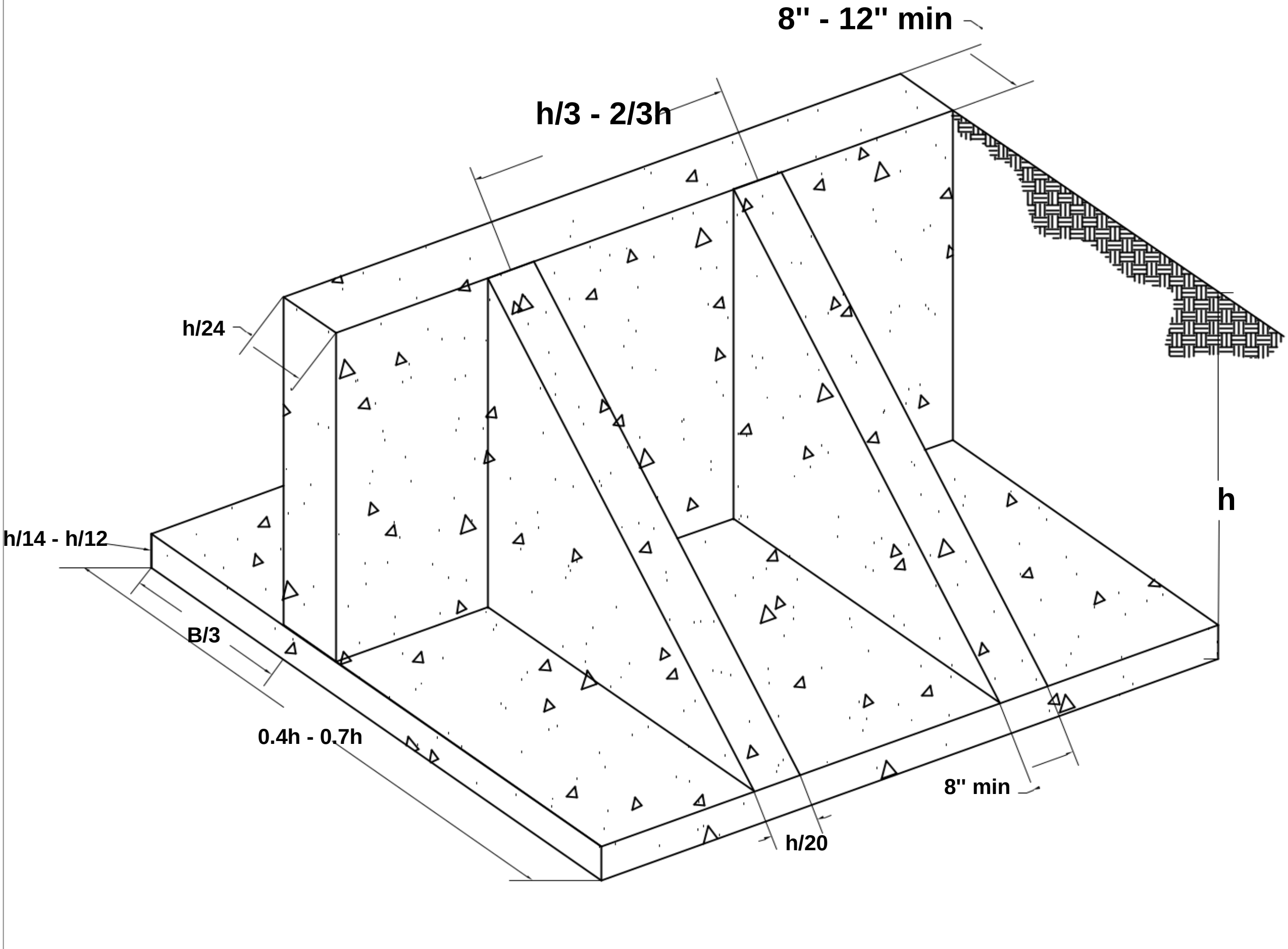
Common proportions of cantilever retaining wall - Counter fort walls :

The proportions of counter fort walls, vary to a greater extent than that of cantilever walls because the thickness of face and base slabs depends primarily on the spacing of counter forts.

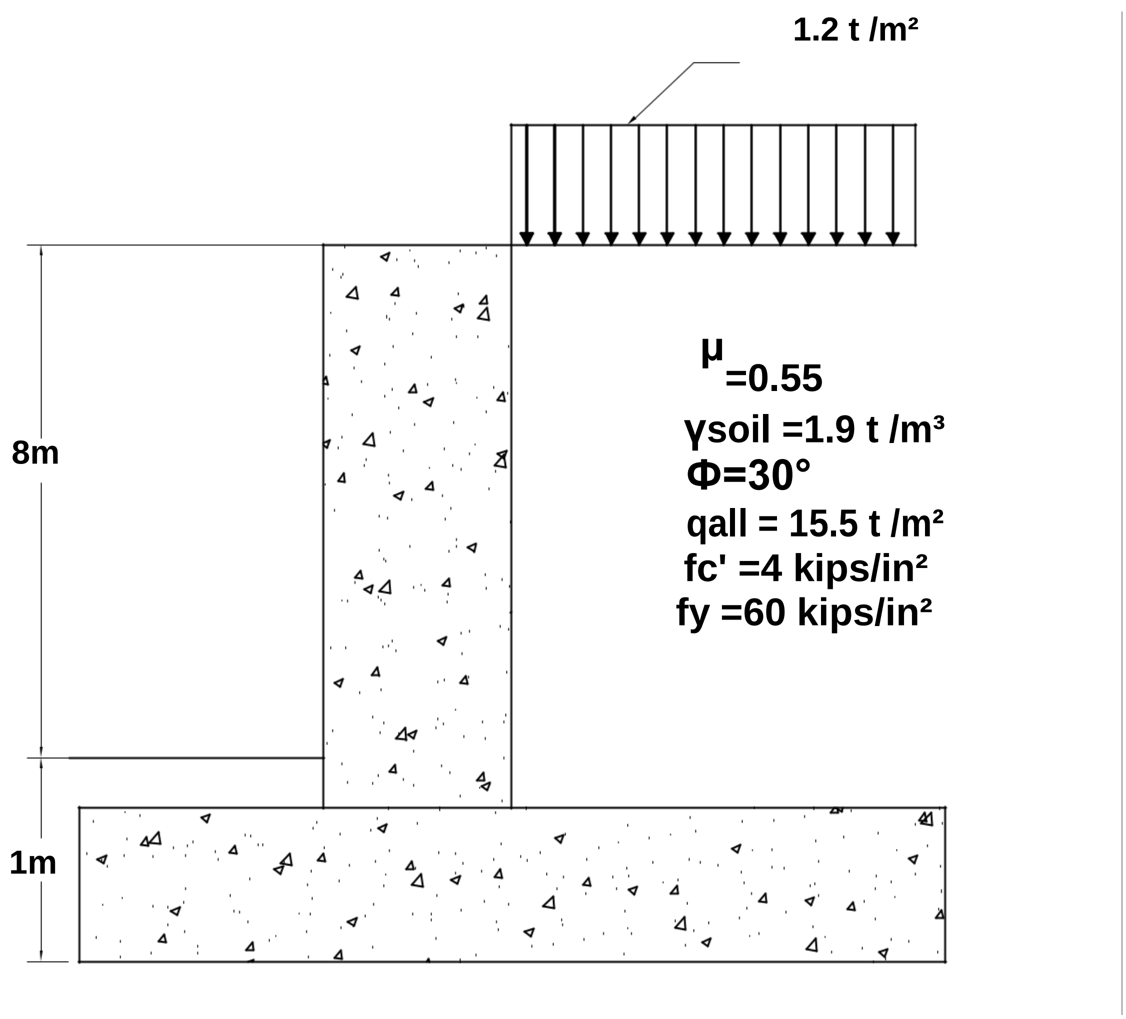
For walls of moderate height, the counter forts may be spaced as far as two-thirds of the height of the wall (2/3 h).

For walls higher than about (30 ft). The spacing may be reduced to less than one- third of the height

From the construction point of view, *counter forts* should not be placed on a spacing less than about (8 ft). The toe projection is generally smaller than that for cantilever walls.



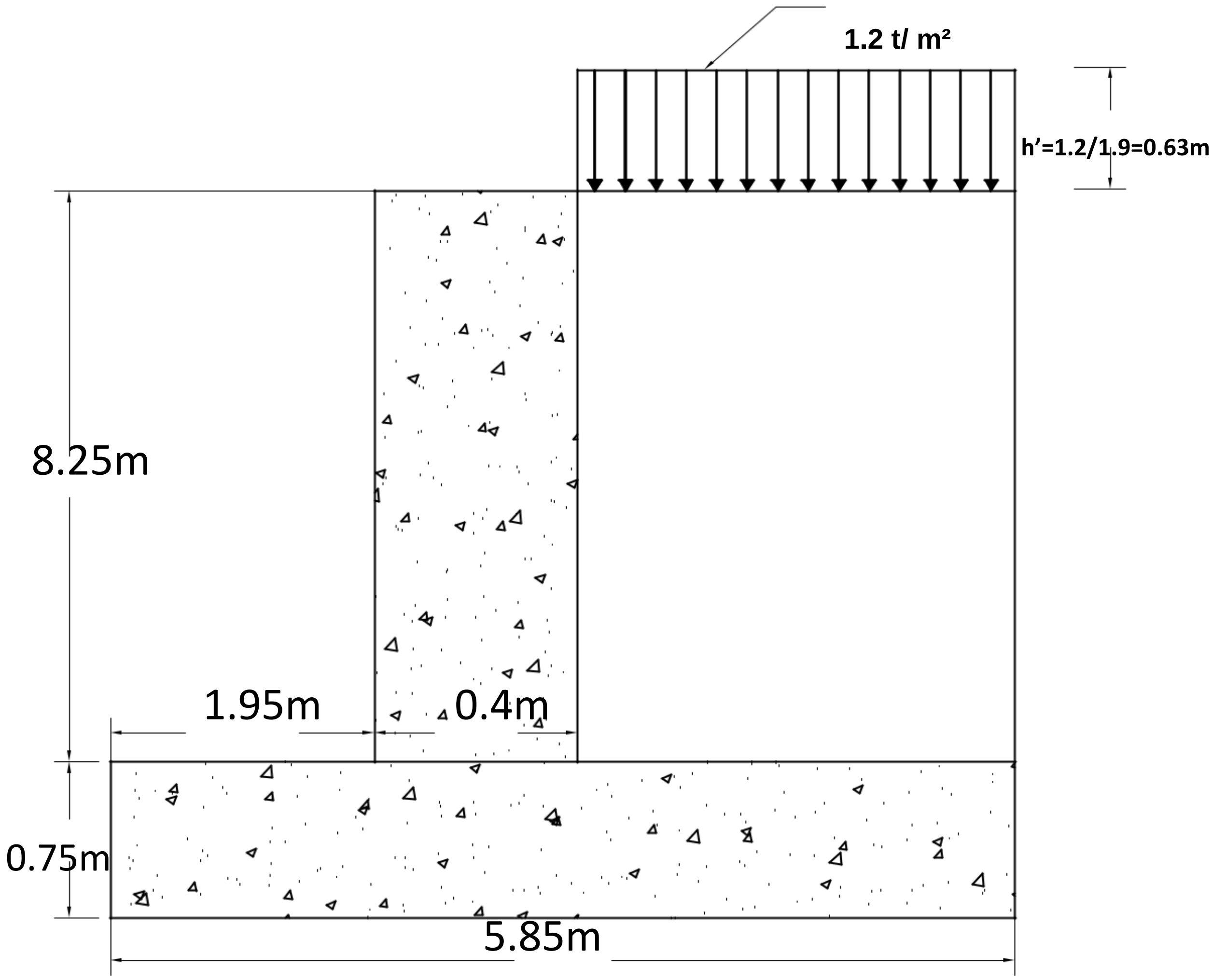
Design example on a counterfort retaining wall with surcharge.



b) $B=0.65h = 0.65*9 = 5.85$ m
c) Width of the stem $=h/24 = 9/24 = 0.375 \approx 0.4$ m
d) Length of the toe $= B/3 = 5.85 / 3 = 1.95$m
e) The width of forts$= h/20 = 9 / 20 = 0.45$m ≈ 60 cm
f) The distance between forts $= h/2.5 = 9 / 2.5 = 3.6$ m

$K_a = (1 - \sin 30°) / (1 + \sin 30°) = 0.33$

$f_c' = 4000 * 0.007 = 28$ Mpa $= 2800$ ton/m²
$f_y = 60000 * 0.007 = 420$ Mpa $= 42000$ ton/m²



a) horizontal force (p) = 0.5 Ka*γ*h(h+2h')

(1) 0.5*0.33*1.9*9*(9+2*0.63) = 28.95 ton

$y = (9^2 + 3*9*0.63)/(3(9+2*0.63)) = 3.18$ m

$M_{(overtuning)}$ = 28.95*3.18 = 92.06 t.m

Vertical forces and their moments about toe .

force (ton)	arm (m)	moment (t.m)
w1 = 5.85*0.75*2.4= 10.53	2.925	30.8
w2 = 0.4*8.25*2.4 = 7.92	2.15	17.03
w3 = 3.5*8.25*1.9 = 55	4.1	225.5
Σ f = 73.45		Σ M = 273.33

$a = x = (273.33 - 92.06)/ 73.45 = 2.46$ m which is in the middle third

$e = B/2 - x = 5.85 / 2 - 2.46 = 0.465$ m

$q_{all} = P/A - MC/I$

$P = 73.45$ t, $M = P*e = 4.15$ t .

$A = 1* 5.85 = 5.85\ m^2$, $I = (1*5.85^3) / 12 = 16.68\ m^4$

$q_{all} = (73.45 / 5.85) \pm ((34.15 * 2.925)/ 16.68) = 12.55 \pm 5.98$

$q_{max} = 18.33 > 10\ t/m^2$ not safe

$q_{min} = 6.57\ t / m^2$

Change the base length = 0.75*h = 0.75*9 = 6.75m ≈ 7 m

Length of toe = $B / 3 = {}^7/_3 = 2.33$ m ≈ 2.4 m

W (ton)	arm (m)	moment (t-m)
w1 = 7*.75*2.4 = 12.6	3.5	44.1
w2 = 0.4*8.25*2.4 = 7.92	2.6	20.59
w3 = 4.2*8.25*1.9 = 65.84	4.9	322.62
Σ f =86		Σm =387.31

P = 28.95 t

Mo = 92.06 t-m

$a = x = (387.31 - 92.06) / 86 = 3.43$ m which is in the middle third

$e = B/2 - x = 7 / 2 - 3.43 = 0.07$ m

$q_{all} = \Sigma f/A (1 \pm (6*e)/ B)$

$A = 1* 7 = 7\ m^2$

$q_{all} = (86 / 7) (1 \pm 6*0.07 / 7) = 12.28 (1 \pm 0.06)$

$q_{max} = 13.01 < 15\ t/m^2$ OK , $q_{max} = 11.54\ t/ m^2$

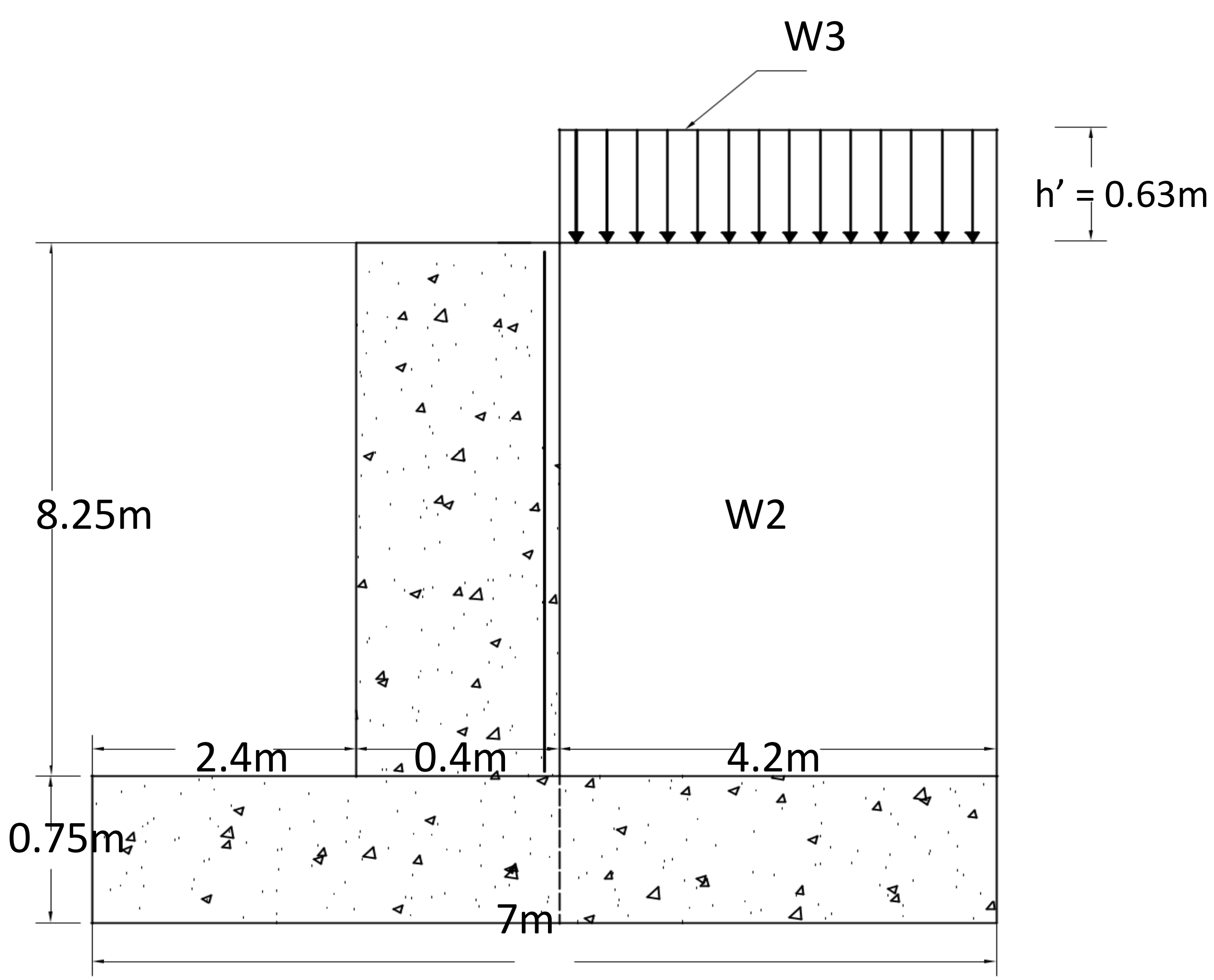
Checking for stability:

- F.S against sliding = μ Σf / P = (0.55*86) / 28.95 = 1.63 > 1.5 OK

-F.S against overturning = stabilizing moment / overturning moment

= 387.31 / 92.06 = 4.2 > 1.75

Check the thickness of base:



W 1 = 0.75*4.2*2.4 = 7.56 t

W 2 = 8.25*4.2*1.9 = 65.83 t

W 3 = 1.2*4.2 =
5.04 t

Vu =(1.7*5.04) +1.4 (7.56 + 65.83) = 111.31 t
Mu
= (1.7*5.04*2.164) + (1.4*65.83*2.164) + (1.4*7.56*2.132) = 240.54 t-m

Vu = ØVc 111.31 = 0.17*0.85*(28)^0.5*100*1*d

Mu= Ø*fy*ρ*b*d^2*{1-(0.59*ρact. *(fy/fc'))}

240.54 = 0.9*42000*0.014*1*d^2*{1-(0.59*.014*(420/28))}

d = 0.75 m ; dshear control ; h= 1.45 + 0.064 ≈ 1.5 m OK

- Design of stem:

P = Ka*γ*(h+h') = 0.33*1.9*(7.5 + 0.63) = 5.09 t /m
max. moment = (p*l²) / 12 = (5.09* 3.6²)*1.7 /12 = 9.34 t-m
Mu = Ø*As*fy*(d - (a/2)); d = 0.4 -0.064 = 0.336 m
9.34 = 0.9*As*42000*0.9*0.336
Asmin. = {(fc')^0.5 / 4*fy}*b*d = { (28)^0.5 / 4*420 }*1000*336 =1041.6 mm² > Asact. ; Asmin. control
use Ø 20 mm; Area Ø 20 mm = 314 mm²
1041.6 / 314 = 3.31 ; 100 / 3.31 = 30.14 cm
use Ø 20mm @ 25 cm c-c

- Design of heel:

Pressure on heel = γ*h(soil) + γ*h(concrete) = q = (1.4*1.9*7.5) + (1.4*2.4*1.5) + (1.7*1.2) = 27.03 t / m
max. moment = p*l² / 12 = (27.03* 3.6²) /12 = 29.19 t-m
Mu = Ø*As*fy*(d - (a/2)) ; dheel = 1.5 - 0.089 = 1.411m
29.19 = 0.9*As*42000*0.9*1.411
Asmin. = {(fc')^0.5 / 4*fy}*b*d = { (28)^0.5 / 4*420 }*1000*1.411 = 4374.1 mm² > Asact. ; Asmin. control
use Ø 25 mm ; Area Ø 25mm = 490 mm²
4374.1 / 490 = 8.926 ; 100 / 8.926 = 11.2 cm
use Ø 25mm @ 10 cm c-c

- Design of toe:

1.47 / 7 = y / 4.6   y = 0.966

Wf = 2.4*1.5*2.4*0.9 = 7.776 t

Mu = 1.7 {(0.51*0.5*2.4*0.66*2.4) + (12.5*2.4*2.4 / 2)} - (7.776*2.4 / 2) = 53.52 t-m

Mu = Ø*As*fy*(d - (a/2)); d = 1.411 m

53.52 = 0.9*As*42000*0.9*1.411   As = 1114.9 mm² < $As_{min.}$; $As_{min.}$ control

use Ø 25 mm ; Area Ø 25mm = 490 mm²

4374.1 / 490 = 8.92 ; 100 / 8.92 = 11.2 cm

use Ø 25mm @ 10 cm c-c

Secondary reinforcement:

a - Horizontal   for base ; As = 0.0025*b*h = 0.002*1000*1500 = 3750 mm²

use Ø 25 mm; Area Ø 25 mm = 490 mm²

3750 / 490 = 7.65; 100 / 7.65 = 13.06 cm   use Ø 25 mm @ 12 cm c-c

b - Vertical for stem ; As = 0.0012*b*h = 0.0012*1000*400 = 480 mm²

use Ø 16 mm; Area Ø 16 mm = 201mm²

480 / 201 = 2.388; 100 / 2.388 = 41.87 cm   use Ø 16 mm @ 40 cm c-c for rear face

use Ø 16 mm @ 35 cm c-c for front face

Design of counterforts:

ɵ = tan^-1 (7.5 / 4.2) = 60.75°

sinɵ = d / 4.2   d = 3.66 m; $d_{eff.}$ = 3.66 -0.076 = 3.58 m

Maximum hor. force (P) = 0.5*Ka*γ*h*(h+2h')*l = 0.5*0.33*1.9*7.5*(7.5 + 2*0.63)*3.6 = 74.15 t /m

Max. moment   = {P (h+h') / 3} = {74.15*1.7(7.5+0.63) / 3} = 341.6 t-m

Mu = Ø*As*fy*(d - (a/2)); d = 3.58 m

341.6 = 0.9*As*42000*0.9*3.58   As = 2804.8 mm²

d = h - 0.076 = 0.6 - 0.076 = 0.524

Asmin. = {(fc')^0.5 / 4*fy}*b*d = { (28)^0.5 / 4*420 }*3600*524 = 5847.84 mm² > Asact. ; Asmin. control

use Ø 25 mm; Area Ø 25mm = 490 mm²

5847.84 / 490 = 11.93; 100 /11.93 = 8.38 cm   use 12 Ø 25mm @ 8 cm c-c

Find As which prevent failure of counterforts in horizontal:

P = Ka*γ*(h+h')*l = 0.33*1.9*(7.5 + 0.63)*3.6 = 18.35 t

As = (18.35) / 42000 = 436.9 mm²

using Ø 10 mm as two legged stirrups; Area Ø 10 mm = 78.5 mm²

g) 436.9) / (78.5*2) = 2.78; 100 / 2.78 = 35.97
cm use Ø 10 mm @ 30 cm c-c

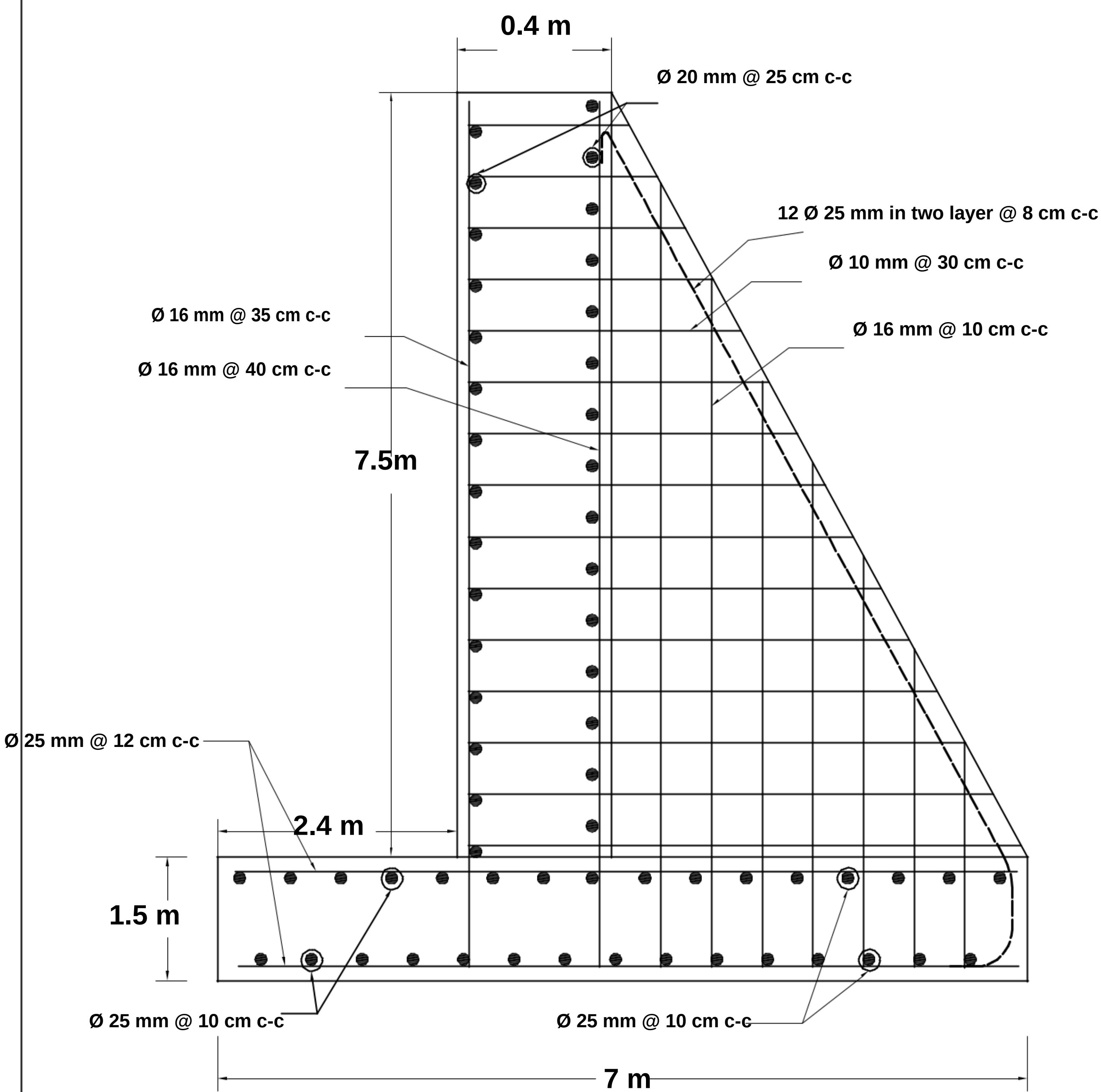
Find (As) which prevent failure of counterforts in horizontal:

As = (q*b*1.7)/ fy = (27.03*3.6*1.7) /42000 = 3938.65 mm²
using Ø 16 mm as two legged stirrups; Area Ø 16 mm = 210
mm² 3938.65 / (201*2) = 9.79; 100 / 9.79 = 10.2 cm use Ø 16 mm
@ 10 cm c-c

Check the counterforts for shear:

Ø Vc = 0.17*Ø*(fc')^0.5*b*d = 0.17* 0.85*(28)^0.5*100*0.536*3.6 = 147.54 t ; d = 0.6 - 0.064 = 0.536m Vu = 1.7*{ 0.5*Ka*γ*h*(h+2h')*l } = 1.7 { 0.5*0.33*1.9*7.5*(7.5 +2*0.63)*3.6 } = 126.055 t

Ø Vc = 147.54 t > Vu = 126.055 t OK



(Detail of reinforcement)

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