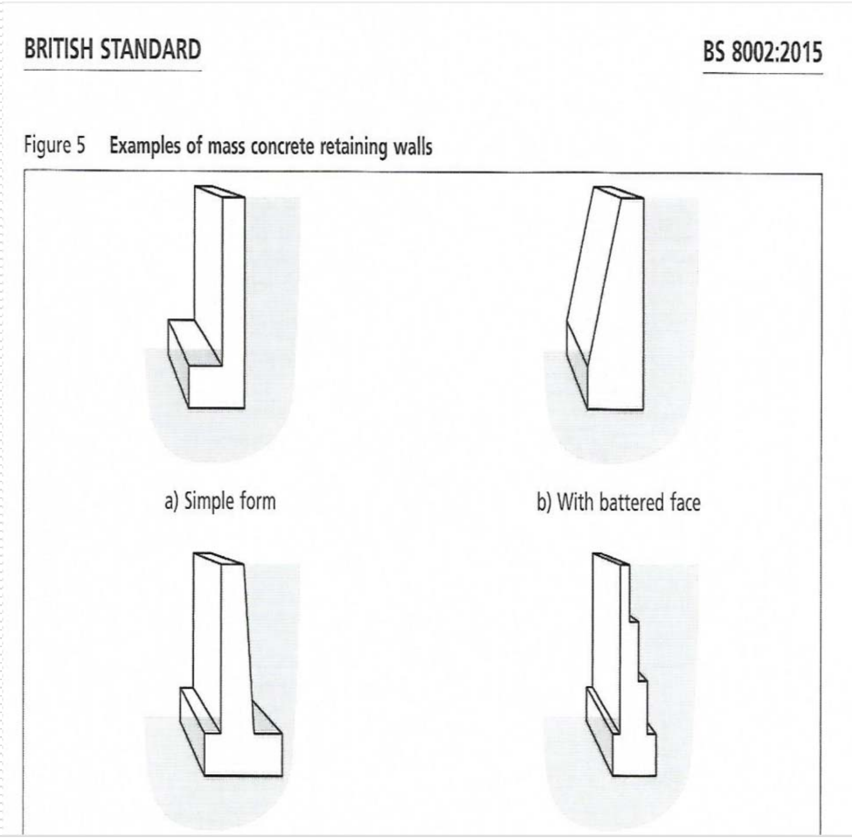
Earth Pressure and retaining walls

Lecture 1-2016

- Retaining walls are structures designed to restrain soil.
- A retaining wall is designed and constructed to resist the lateral pressure of the soil
- Basement walls is one kind of retaining wall
- Retaining wall must resist lateral pressures generated by soils and in some cases water pressures

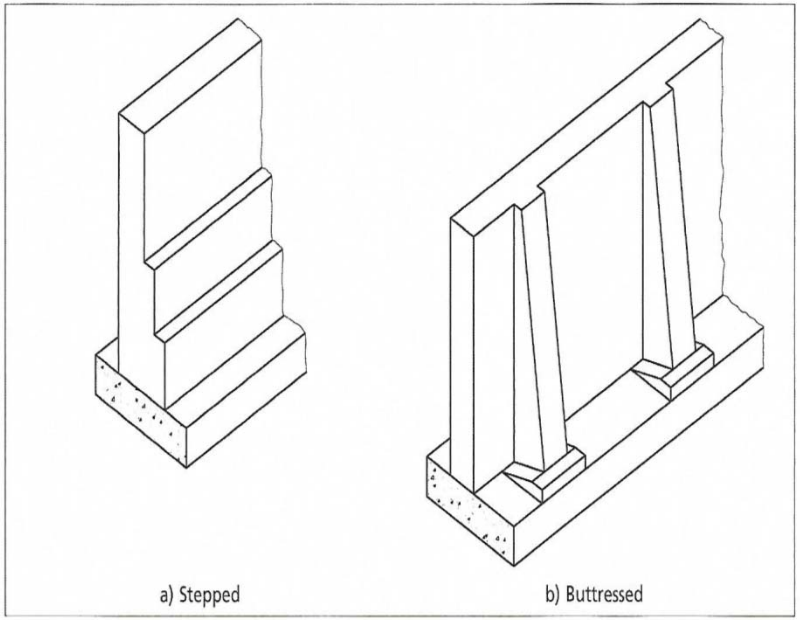
Earth Pressure and Retaining wall Lecture 1

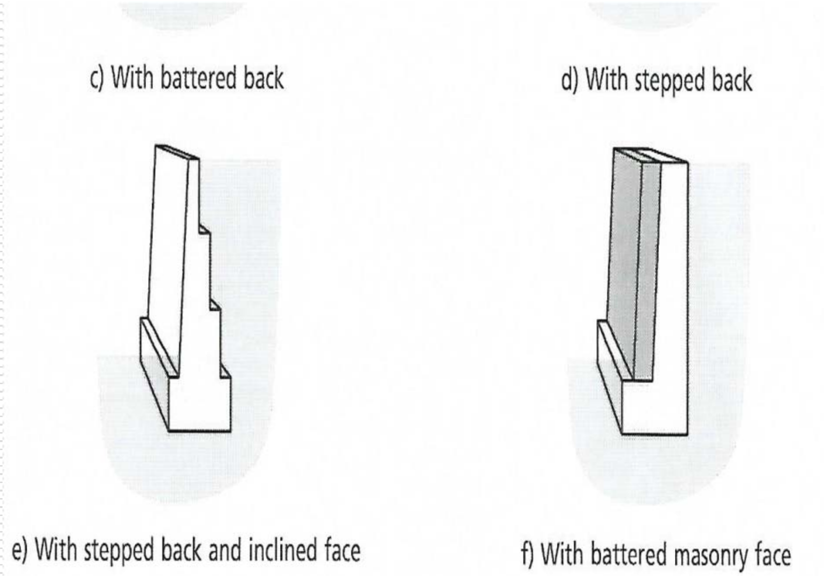
- Main types of retaining walls
  - Gravity walls
  - Reinforced concrete walls
    - a. Cantilever
    - b. Counterfort
  - Crib walls
  - Gabion Walls
  - Diaphragm walls
  - Reinforced earth walls
  - Anchored earth walls
  - Contigious pile walls



- Gravity Walls

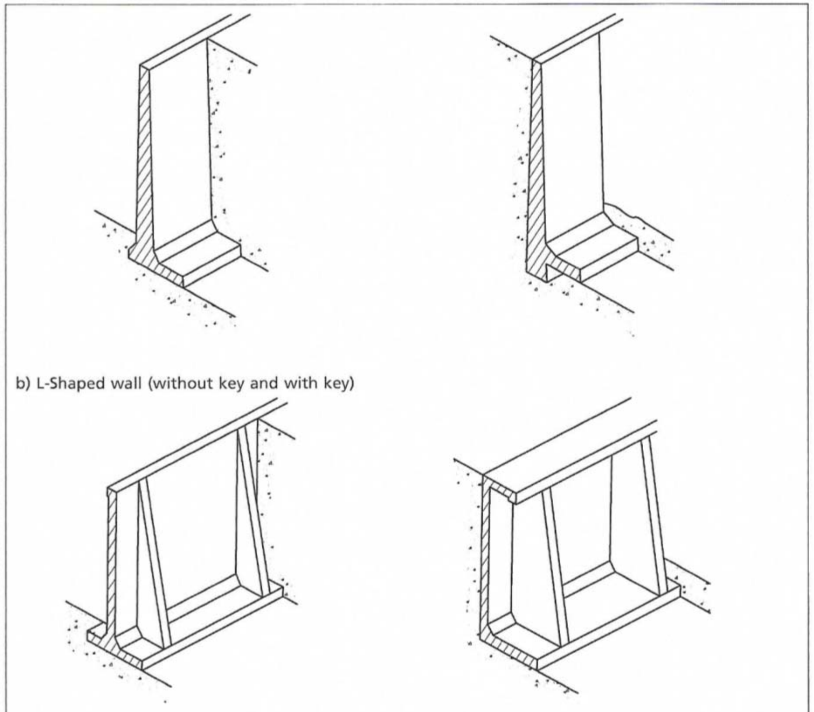
Figure 6 Examples of unreinforced masonry retaining walls





Earth Pressure and Retaining wall Lecture 1

Figure 11 **Examples of reinforced concrete retaining walls** (2 of 2)

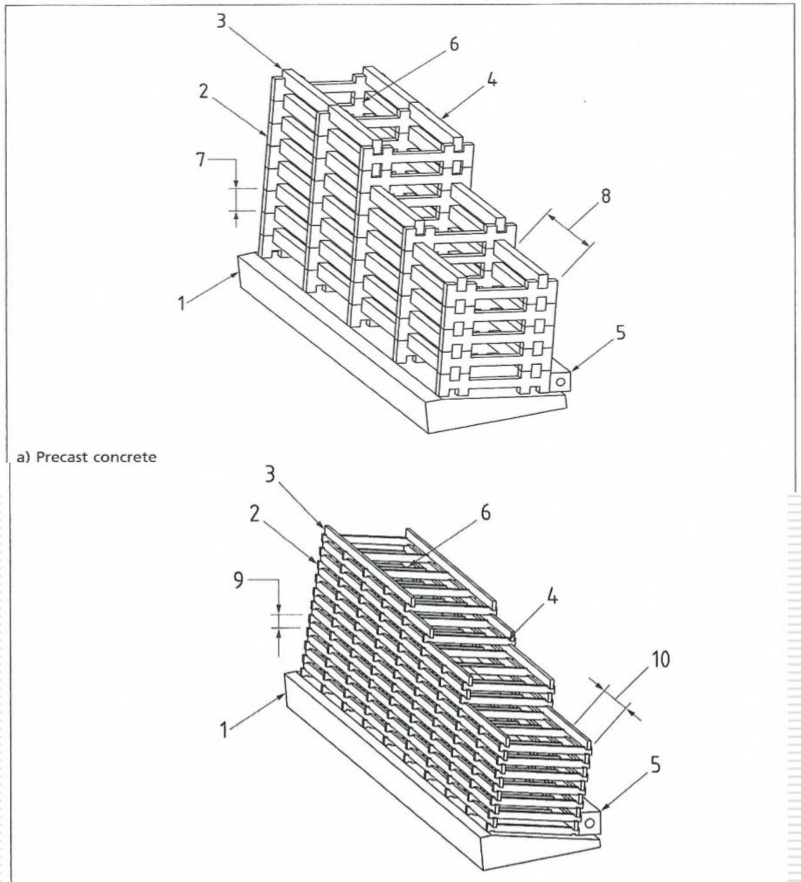


b) L-Shaped wall (without key and with key)

c) Reinforced concrete wall with counterforts

d) Reinforced concrete wall with buttresses

Figure 8 **Examples of crib walls**

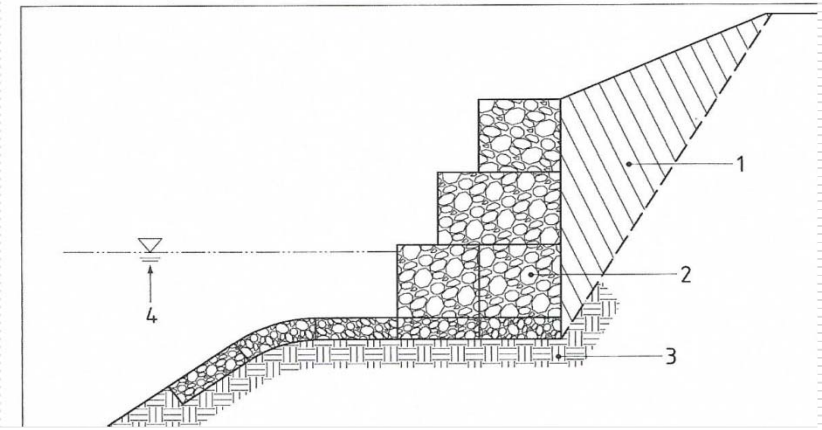


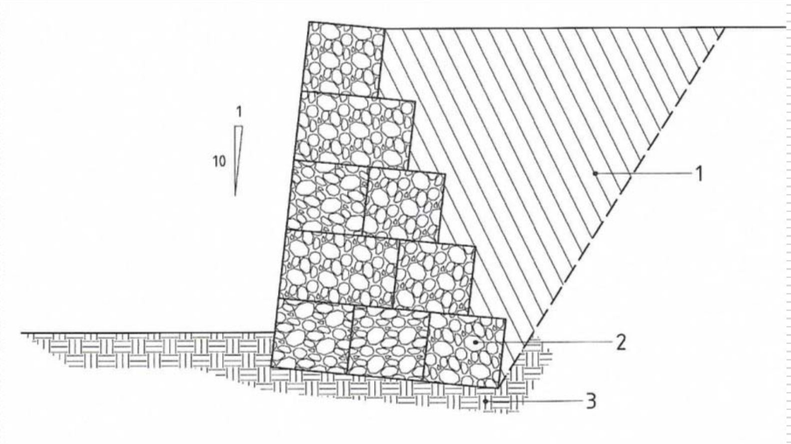
a) Precast concrete

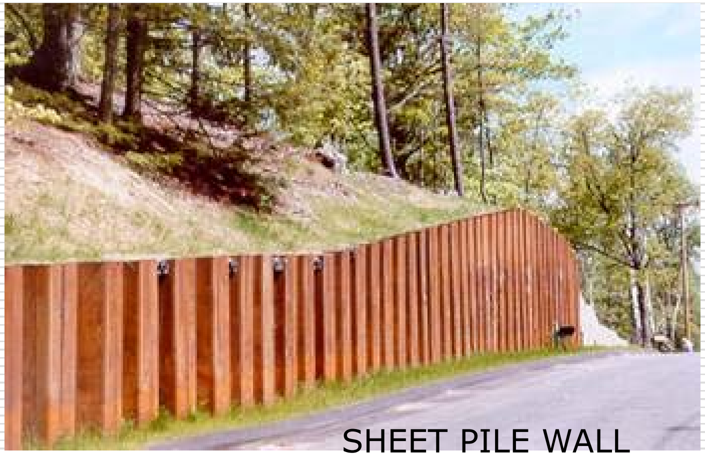
b) Timber

Earth Pressure and Retaining wall Lecture 1

Figure 7 **Examples of gabion retaining walls** (1 of 2)

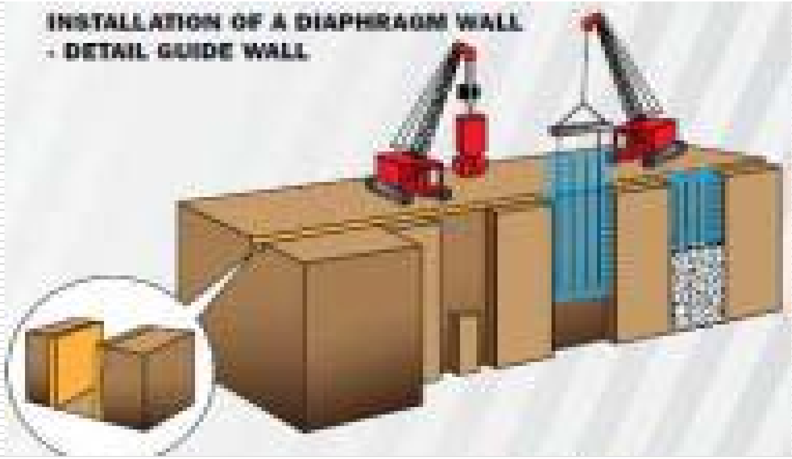


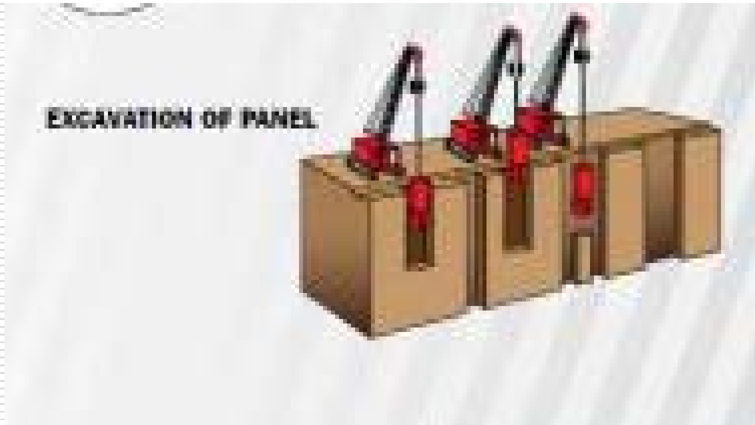


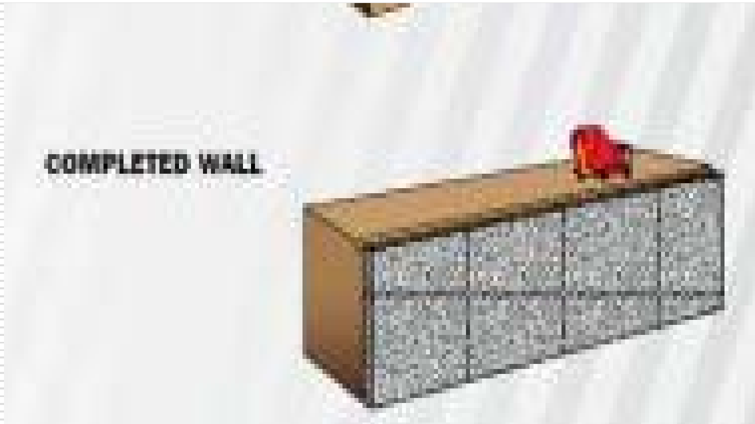


SHEET PILE WALL

Earth Pressure and Retaining wall Lecture 1

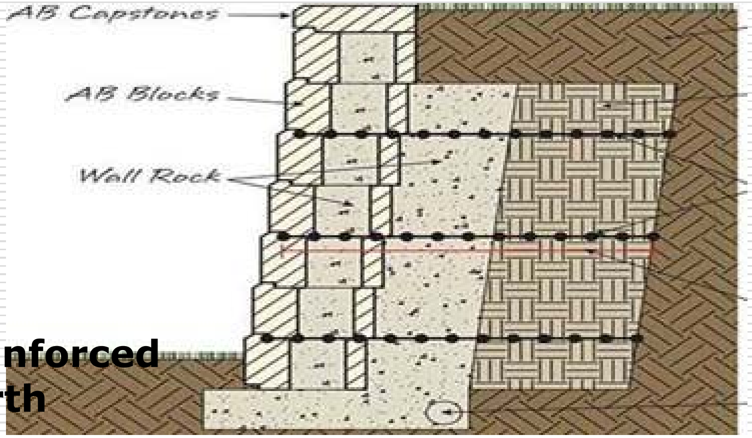




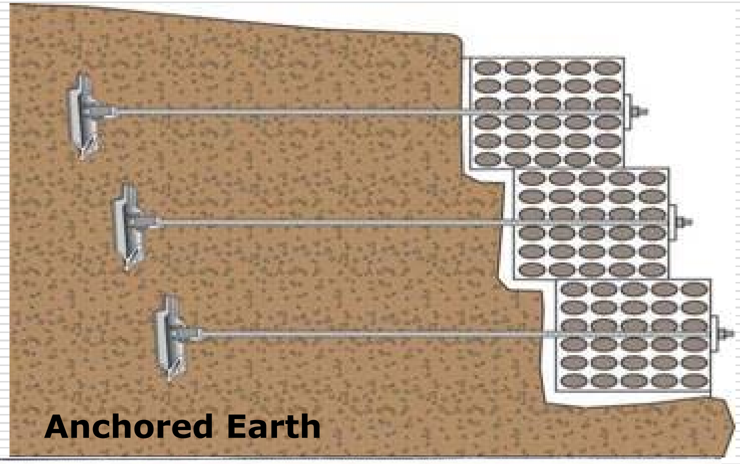


Installation of diaphragm wall

Earth Pressure and Retaining wall Lecture 1

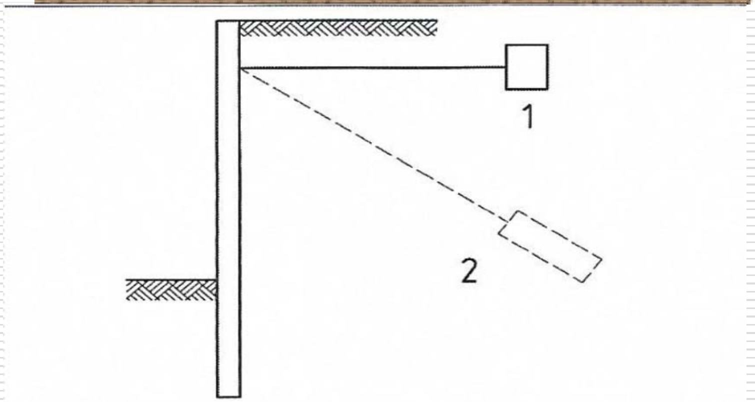


Reinforced Earth



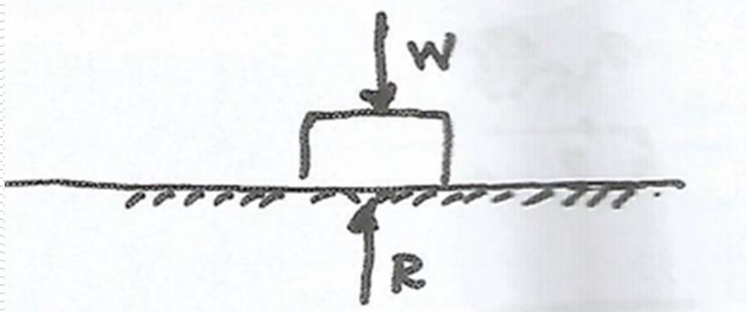
Anchored Earth

Contigious Pile Wall



b) Anchored wall

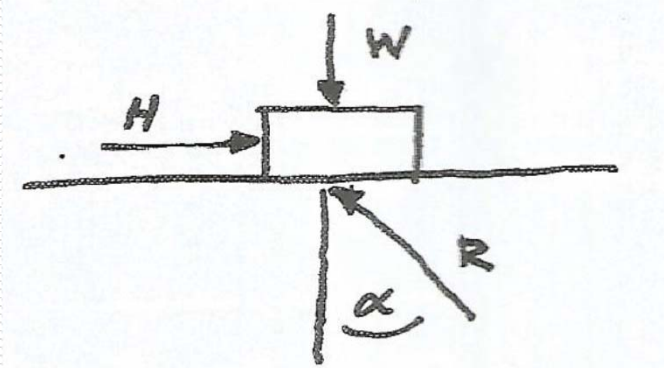
- **BASIC CONCEPTS**
  - Shear strength of soils



No Horizontal force applied

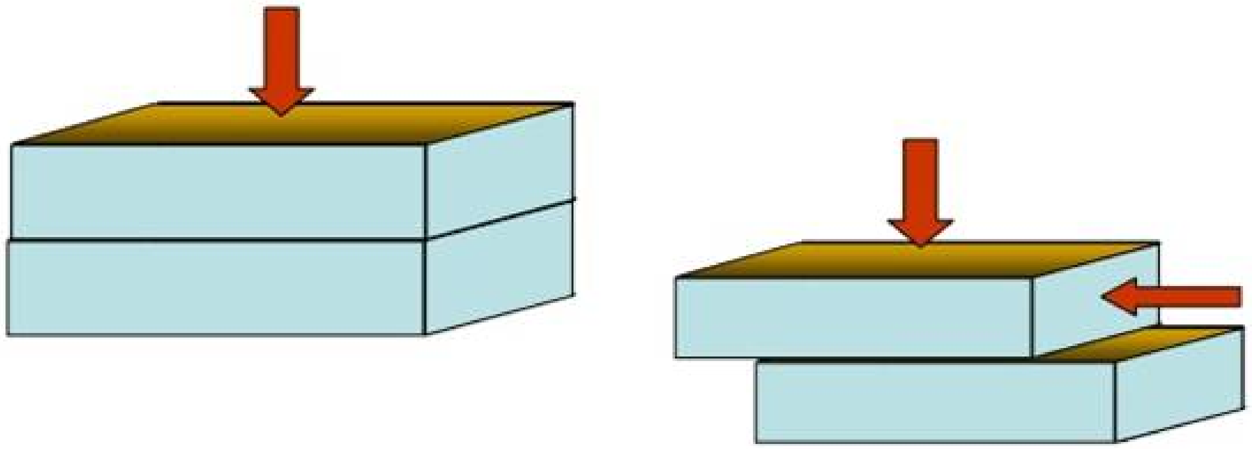
- Reaction **R=H=Rsinα**
- Vertical component **W=Rcosα**
- **H=Rsinα =shear strength**
- **W=Rcosα = Normal strength**
- **Where α = angle of obliquity**
- **When sliding starts**

  α = φ = angle of friction



Horizontal Force applied

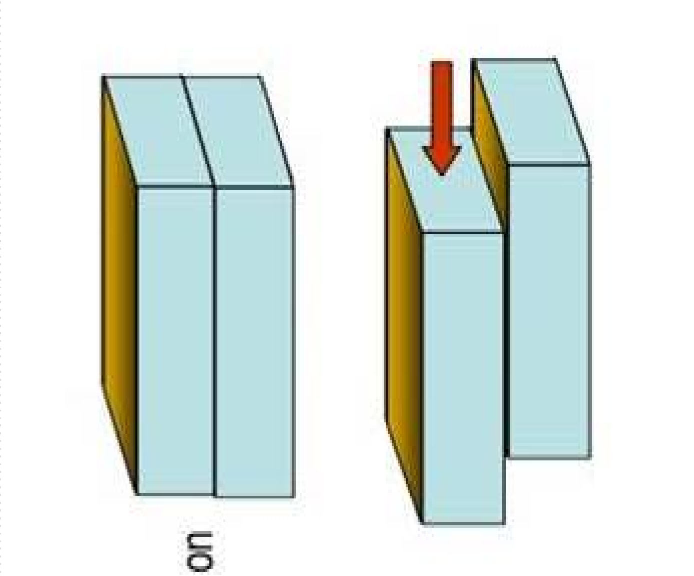
- Internal Friction angle (ϕ), is the measure of the shear strength of soils due to friction



- **Shear strength of soils-**
  Cohesion (C)

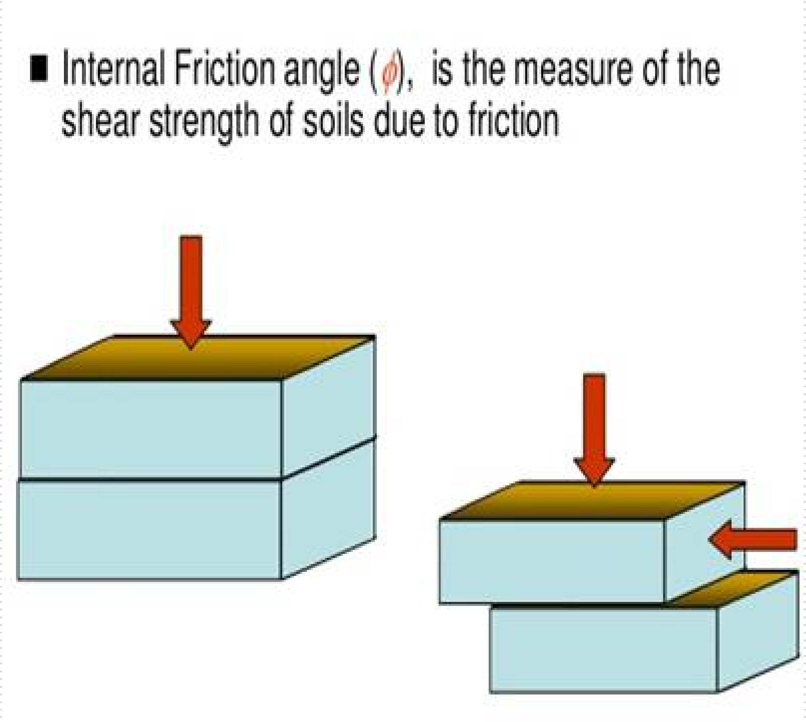
It is possible to make vertical 'cut ' in silts and clays and for this 'cut' to remain standing and unsupported for some time. This is due to 'cohesion'. In other words is a measure of the forces that cement of particles of soil

Cohesion is influenced by the grain size the state of packing of the soil particles and the water content.



Shear strength of soils- Friction angle (φ)

Friction is the internal friction between the soil grains. The soil friction angle is the angle of inclination with respect to the horizontal axis of the Mohr-Coulomb shear resistance line.



- The relationship between the shearing resistance, the friction and the cohesion is known as Coulomb's Low:

$$T_f = c + \sigma \tan\varphi$$

Where τ= shear strength,

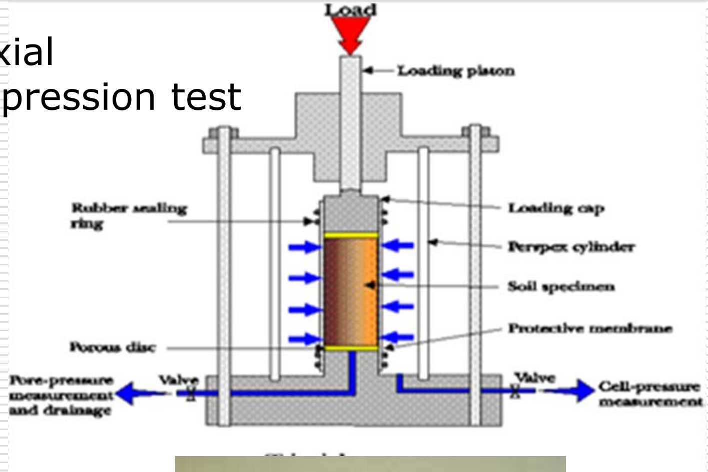
c= cohesion

σ = effective or normal stress

φ = angle of friction

Tests used to measure the shear strength properties of soil

Triaxial compression test



Types of shear tests

Untrained tests

Consolidated-untrained

Drained tests

The test are:

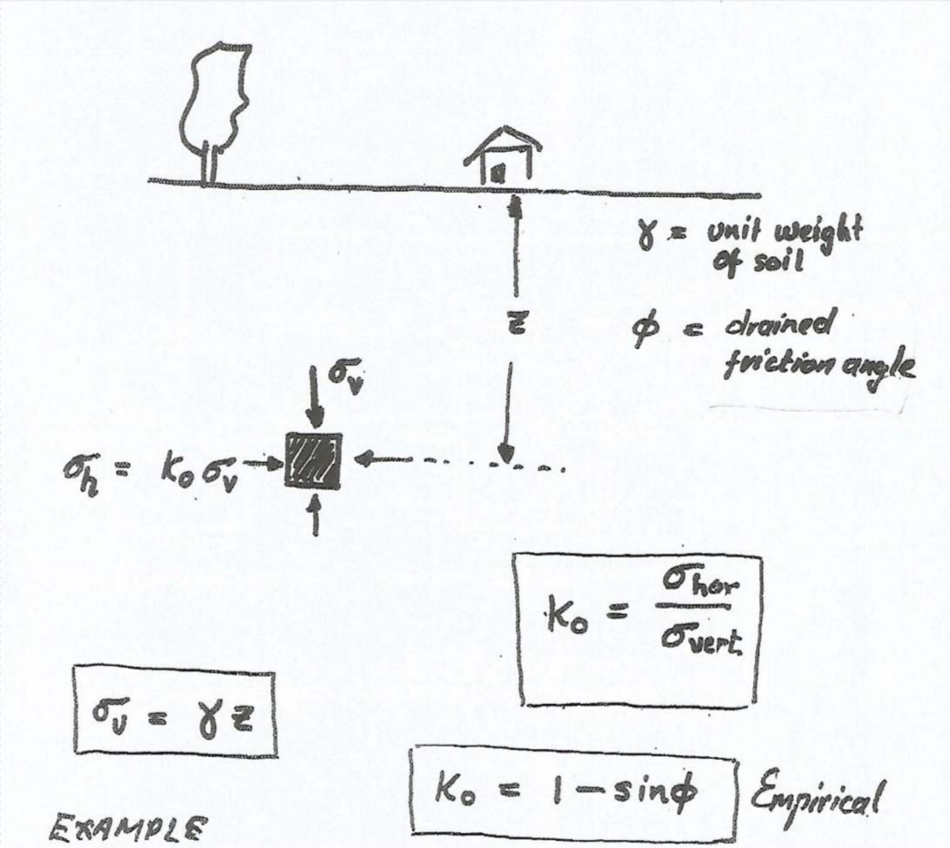
The shear box

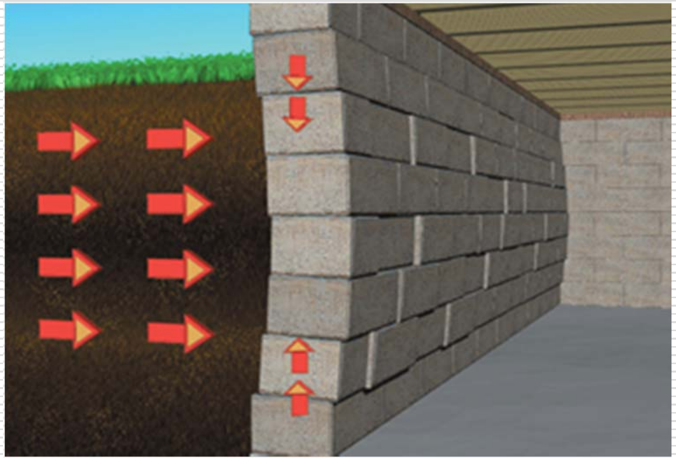
Triaxial Compression Test

Vane test

Vane test

- **Lateral Earth Pressure-Earth pressure at rest**
- Lateral earth pressure is the pressure that soil extents in the horizontal direction.
- The coefficient of lateral earth pressure, K_o, is defined as the ratio of the horizontal effective stress, σ_h, to the vertical effective stress, σ_v





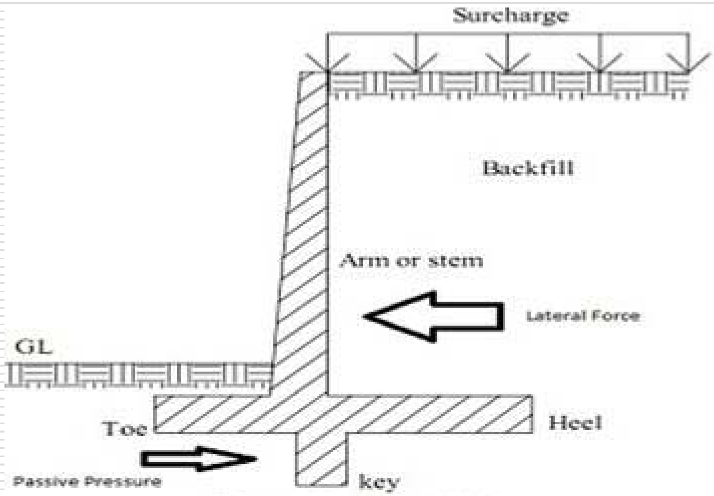
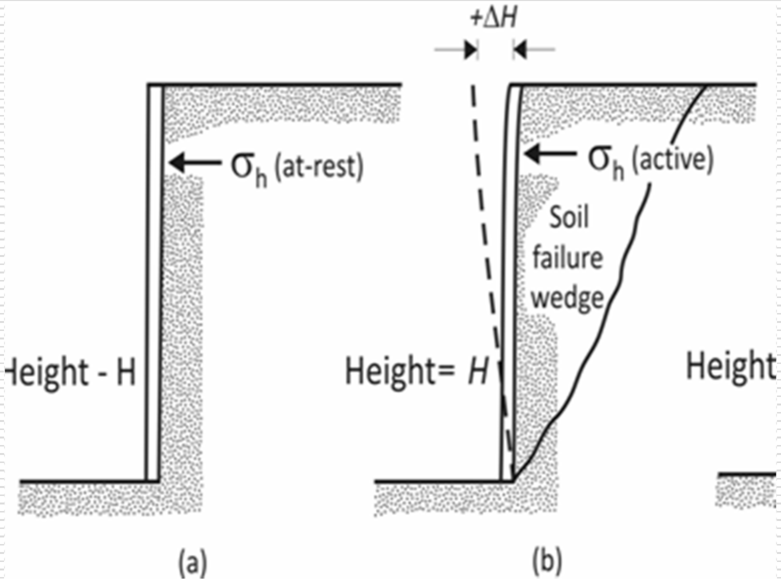


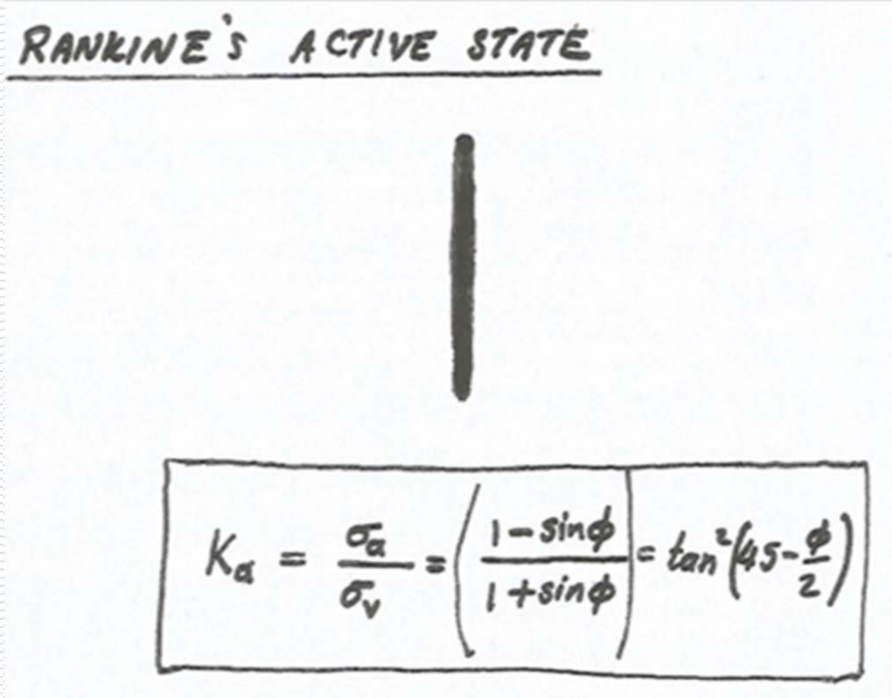
Figure 1: Retaining Wall

- **Active earth pressure**

- The minimum stable value of K is called the active earth pressure coefficient, Ka

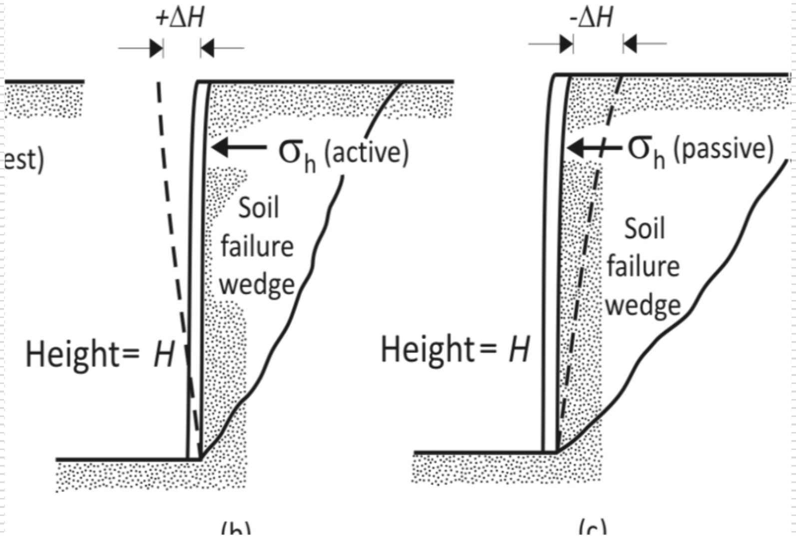
  The active earth pressure is obtained, for example, when a retaining wall moves away from the soil.

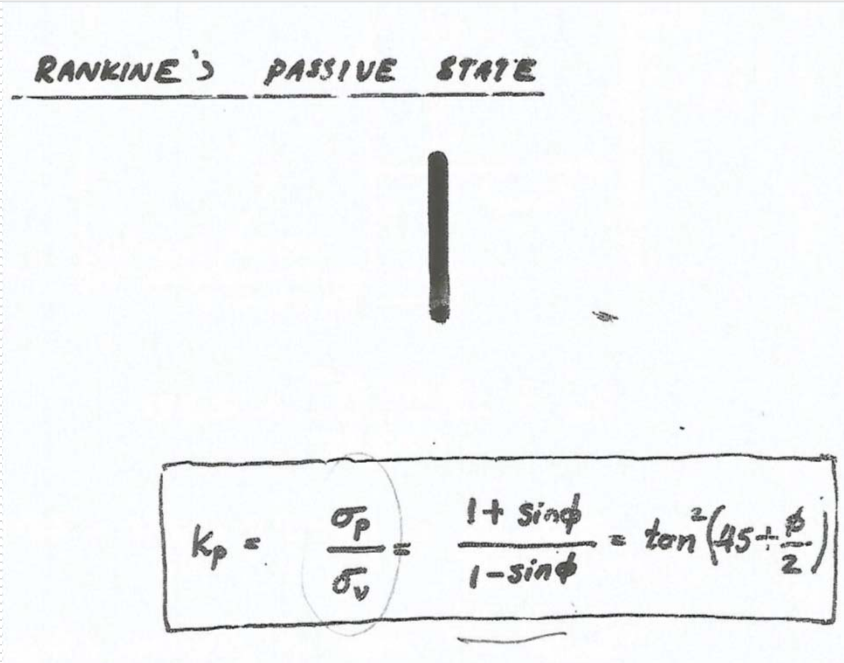


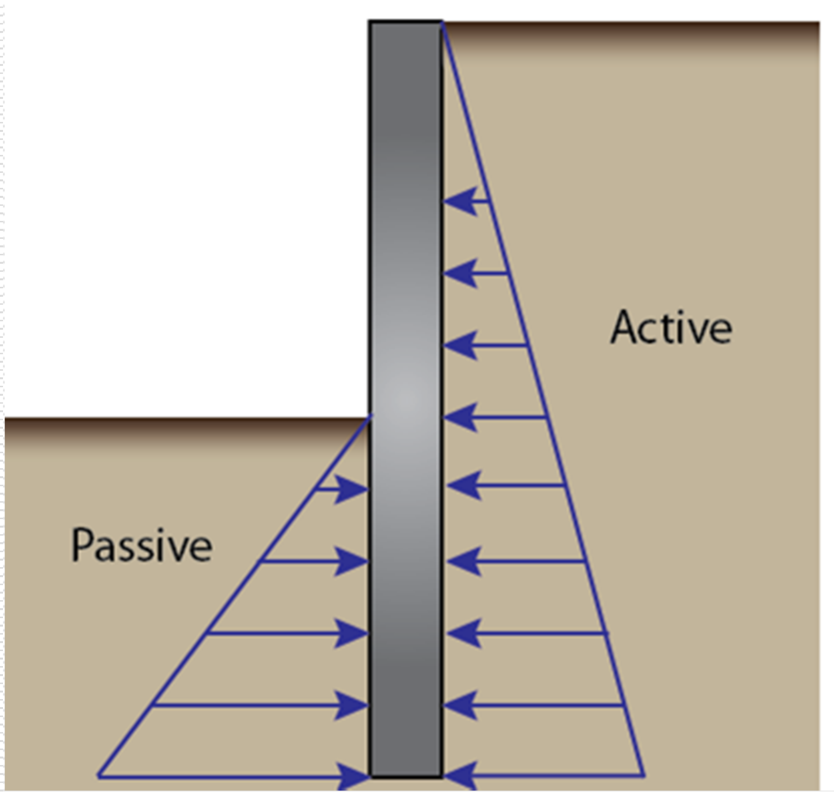


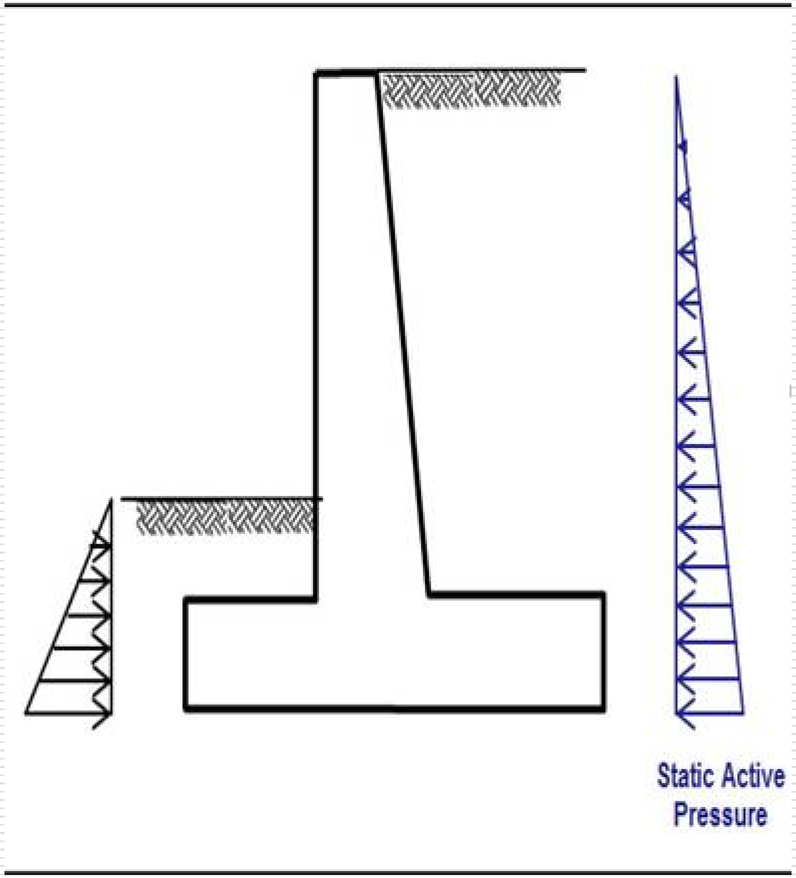
Passive earth pressure

- The maximum stable value of K is called the passive earth pressure coefficient, Kp
  The passive earth pressure would develop, for example against a vertical wall that is pushing soil horizontally.






Active
Passive


Static Active
Pressure

Earth Pressure and retaining walls

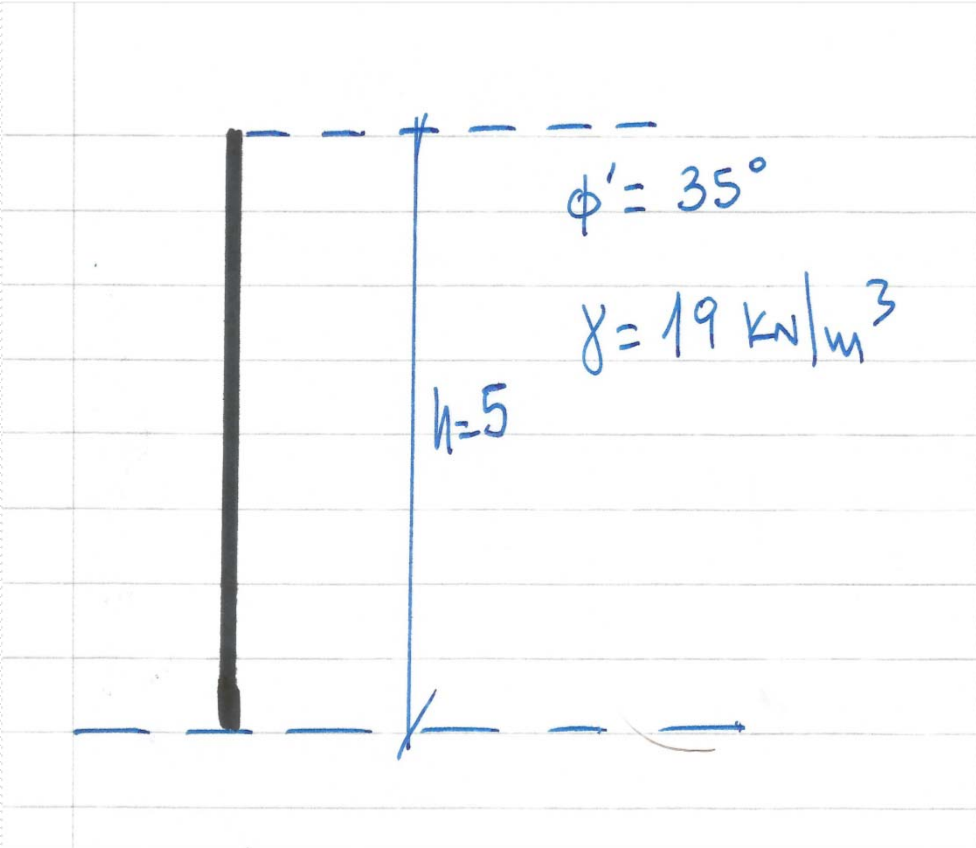
Lecture 2-2016

EXAMPLE 1

Using the Rankine theory determine the total active thrust on vertical retaining wall 5 m high, if the soil retained is cohesionless (granular) and has the following properties

(Note: Thrust force is kN/m^2 and pressure is in kN)

$\varphi' = 35^o$, $\gamma = 19$ kN/m^3



Earth Pressure and Retaining wall Lecture 2

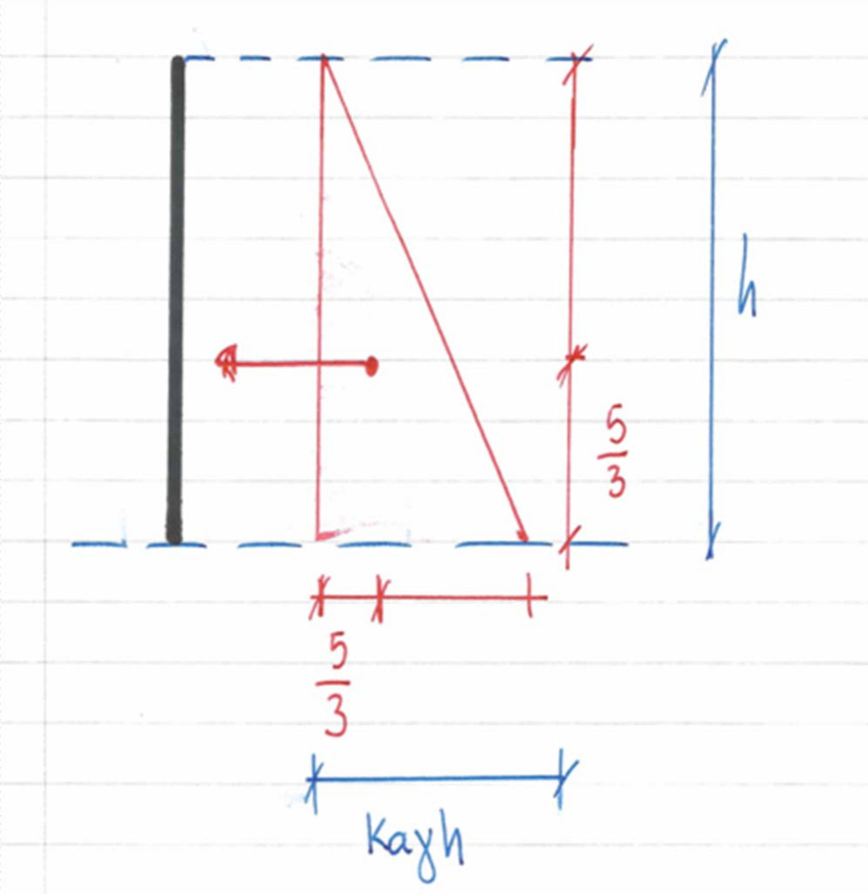
- First we calculate the active pressure K_a

  $K_a = (1-\sin 35 / 1 + \sin 35) = 0.271$

  Max earth pressure p_a =

  $19 \times 5 \times 0.271 = 25.75$ kN/m^2

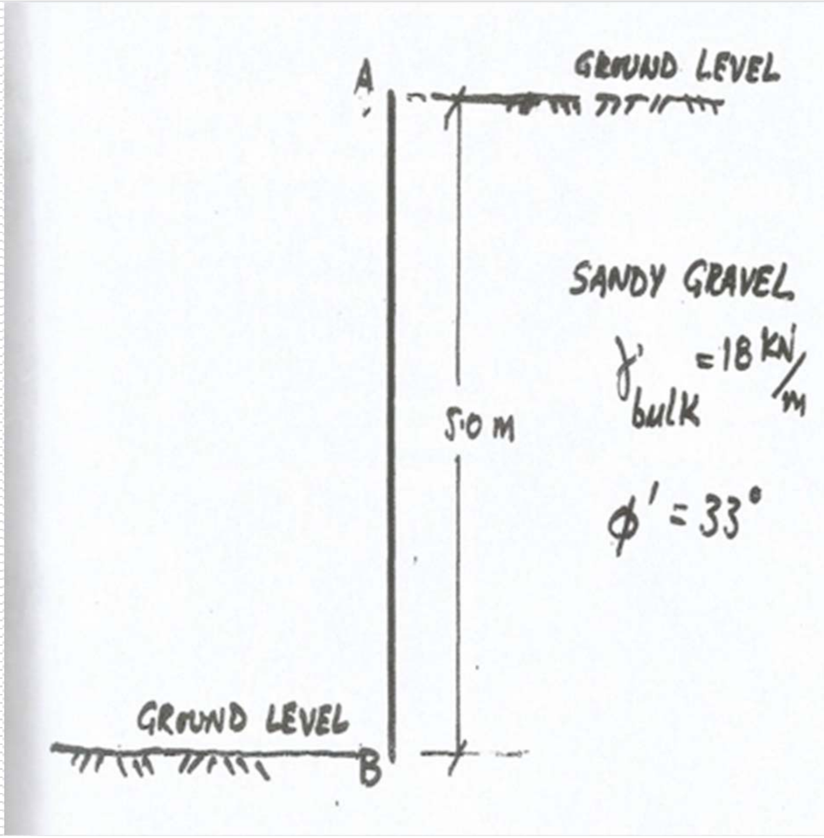
  max pressure per meter run =
  Area of pressure diagram =
  $\frac{1}{2} \times p_a \times h$ =
  $0.5 \times 25.75 \times 5$ =
  64 kN (per meter run)



TUTORIAL EXAMPLE
(page 13 of the book-part C)

Solution:

66.15 kN (per meter run)



SOLUTION

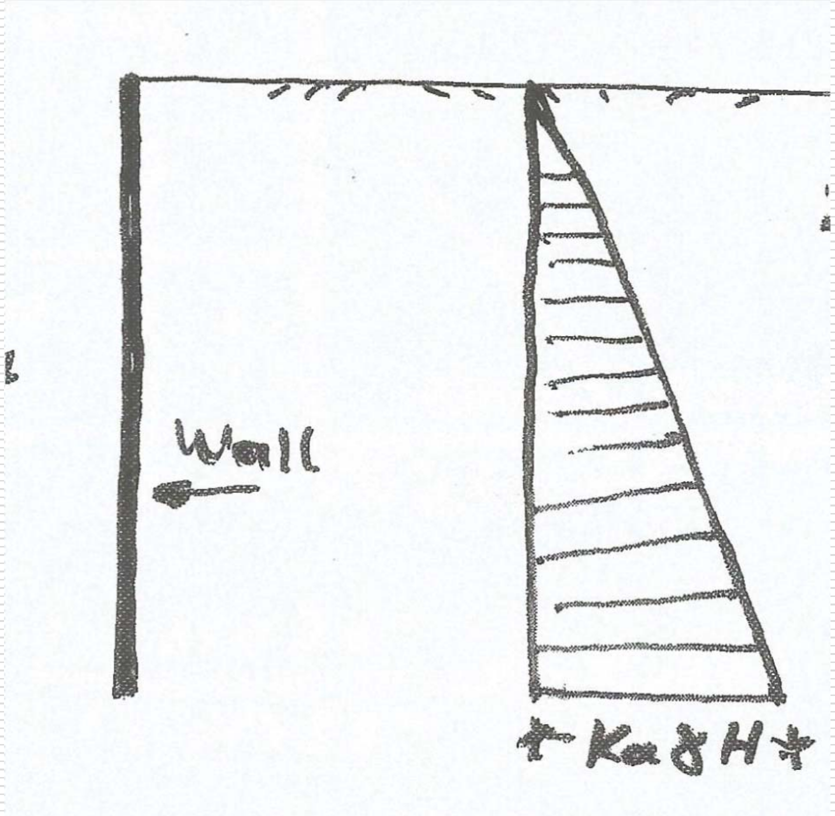
First we calculate the active pressure K_a

K_a= (1-sin33) /(1 + sin33) = 0.294

Max earth pressure p_a =

18 X 5 X 0.294 = 26.46 kN/m^2

max pressure per meter run =
Area of pressure diagram =
½ x p_a x h =
0.5 x 26.46 x 5 =
66.15 kN (per meter run)

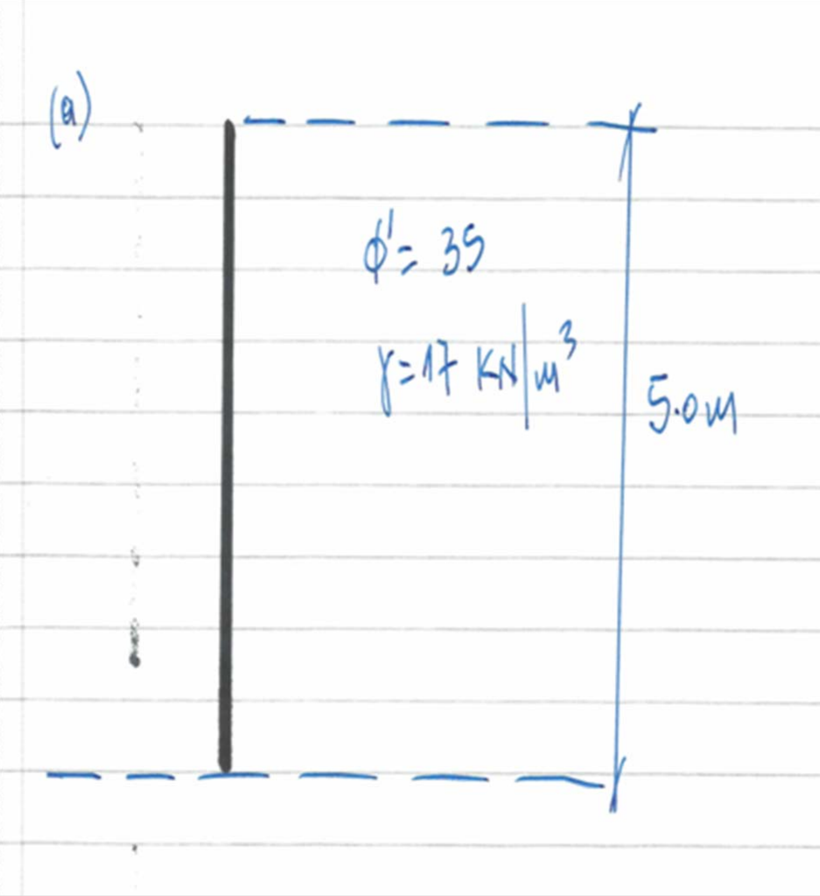


EXAMPLE 2

(page 17 of the book-part C)

Calculate the total active thrust on a vertical wall 5 m high, retaining a sand of unit weight 17 kN/m^3 for which $\varphi' = 35^o$ The surface of sand is horizontal and the water table is below the bottom of the wall

(b) Determine the thrust of the wall if the water table rises to the level 2 m below the surface of the sand. Note the saturated unit of the sand is $\gamma = 20$ kN/m^3. Water density $\gamma = 9.8$ kN/m^3



SOLUTION (a)

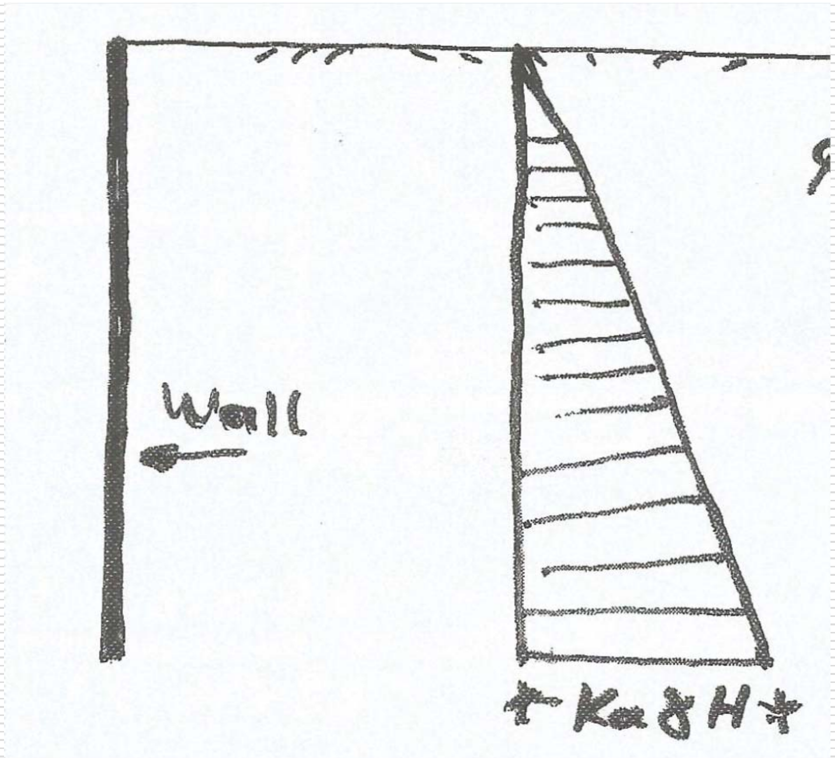
First we calculate the active pressure K_a

$K_a = (1-\sin 35)/(1+\sin 35) = 0.271$

Max earth pressure p_a =

17 X 5 X 0.271 = 23.03 kN/m^2

max pressure per meter run =
Area of pressure diagram =
½ x p_a x h =
0.5 x 23.03 x 5 =
57.58 kN (per meter run)



SOLUTION (b)

Pressure F_1 above the water table:

F_1= ½ x (0.271 x 17 x h) x h =

½ x 0.271 x 17 x 2^2 = 9.2 kN /m

Pressure F_2 surcharge of soil above w.t.

F_2= (0.271 x 17 x b) x h =

0.271 x 17 x 2 X 3 = 27.6 kN /m

Pressure F_3 below the water table:

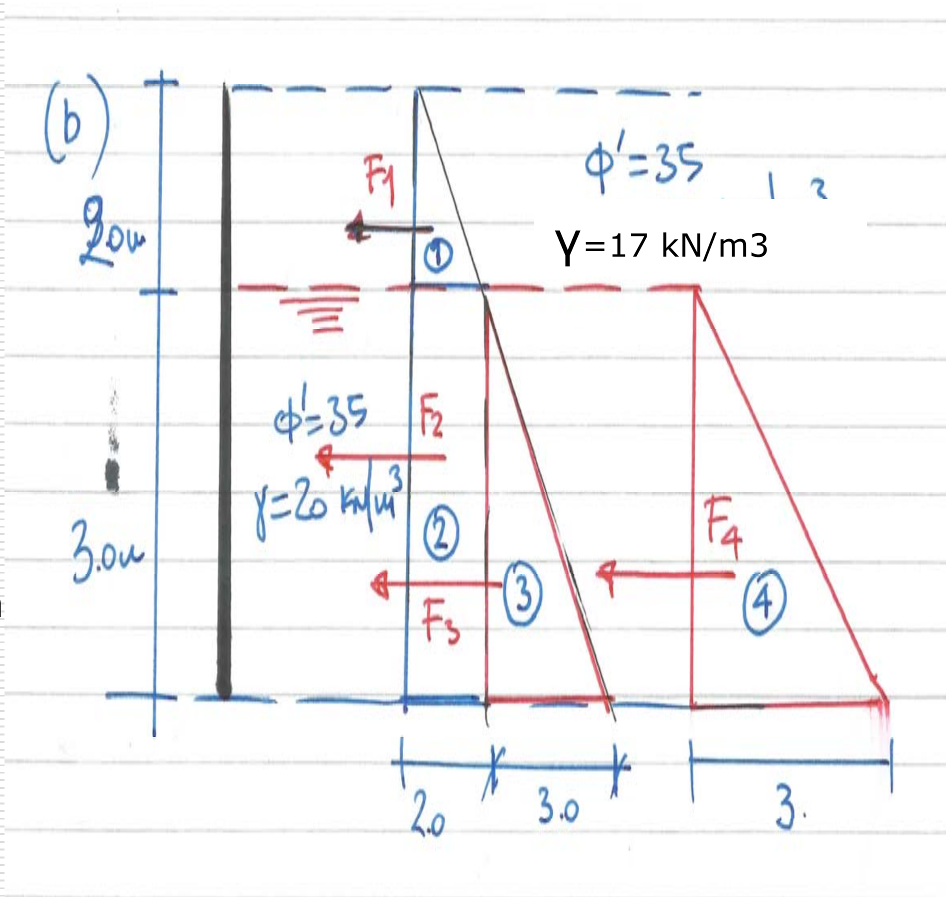
F_3= ½ x [0.271 x (20-9.8) x h) x h =

½ x 0.271 x 10.2 x 3^2 = 12.4 kN /m

Pressure F_4 of the water :

F_4= ½ x (9.8 x h) x h =

½ x 9.8 x 3^2 = 44.1 kN /m



Calculate a concrete wall section in order to support the above pressures. (Concrete 24 kN/m^3)

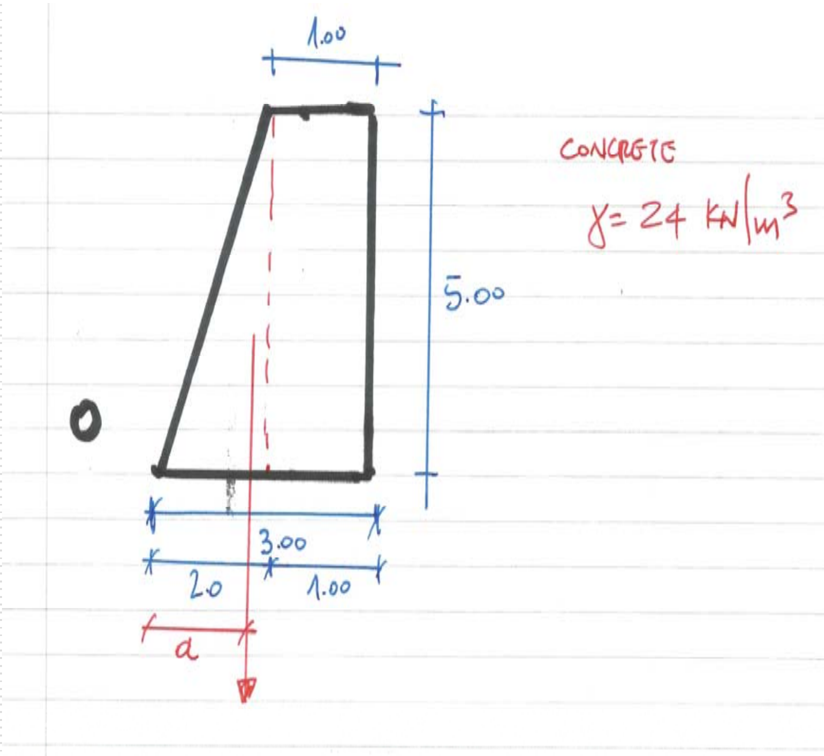
Calculate the ground pressure of the wall using the effective base **B′ = B – 2 e**

(where B = the base of the wall

B′ = effective width

e= eccentricity of the central of gravity)

Also check sliding and overturning



Sliding resistance :

(weigth x friction coefficient)

Wtanδ

Where W is the weight of the wall

δ = 2/3φ′

1. Assume a concrete wall with dimensions as per the adjacent figure.

2. Calculate the position of the central of gravity for the wall

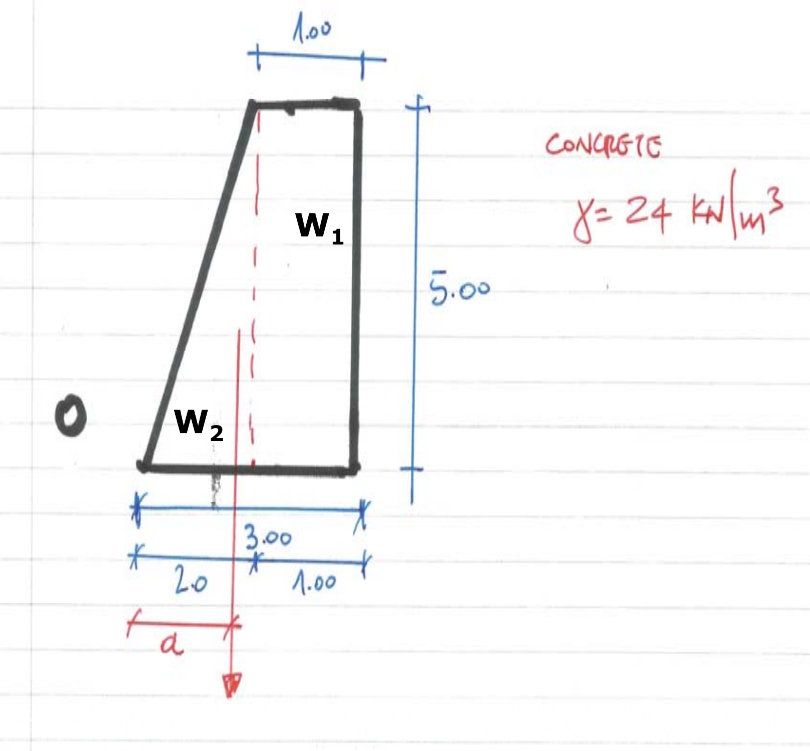
First we calculate the total self weight.

W_1 = 1.0 x 5 x 24 = 120 kN (per metre)
W_2 = ½ x 5 x 2 x 24 =120 kN (per metre)

Total 240 kN (per metre wall)

240 x a =120 x (2 + 1/2) + 120 x 2/3 x 2 =>
240 x a = 120 x 2.5 + 120 x 1.33 =>
a= 1.92

Therefore the eccentricity will be
e= 1.92 – B/2= 1.92 – 3 /2 => e= 0.42 m



Calculation the ground bearing pressure of the wall:

From previous calculations

e = 0.42 m

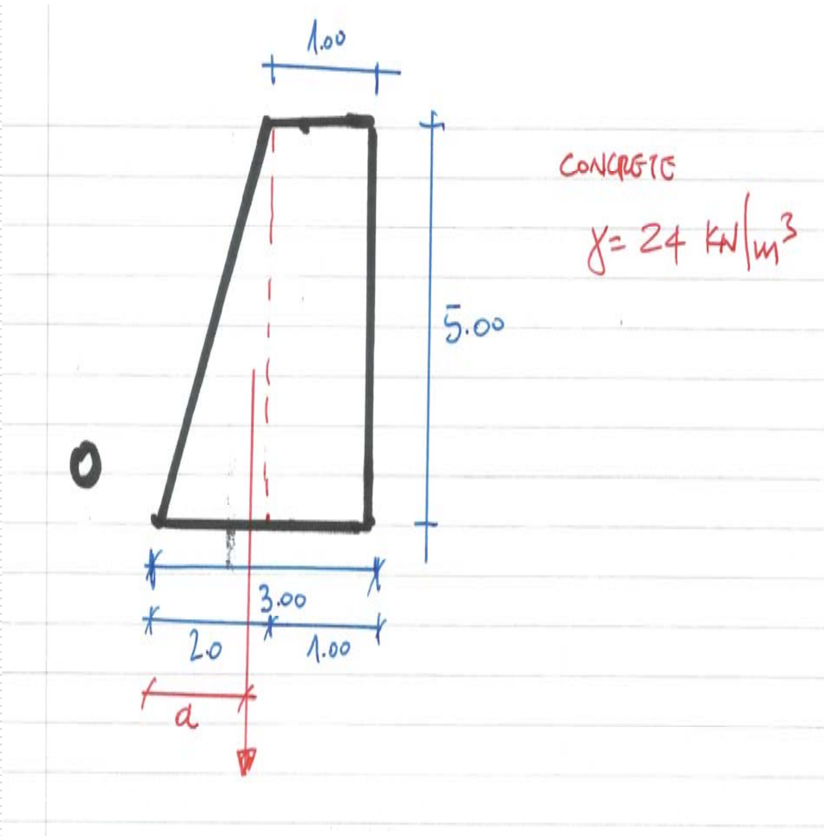
Effective base B′ = B – 2 e

Where B= 3 m

B′ = 3 – 2 x 0. 42 = 2.16 m

Pressure from wall per metre run:

240 /(2.16 x 1) = <u>111. 1 kN/m²</u>



Calculate the friction resistance:

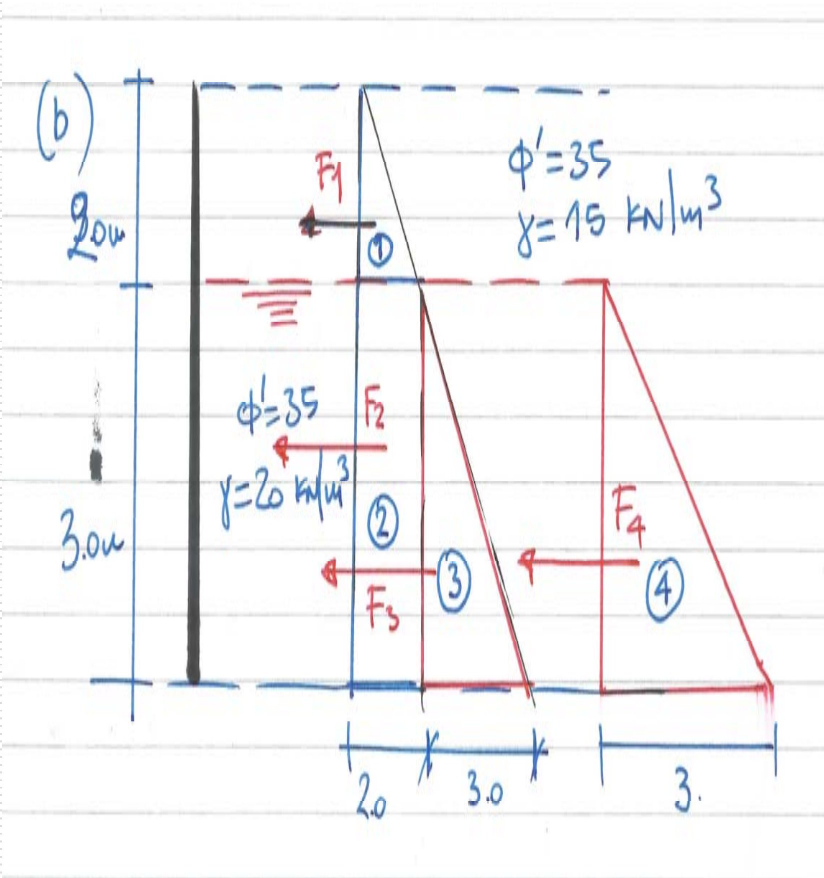
Total forces due to soil/water

$F_1 + F_2 + F_3 + F_4 =$
9.2 + 27.6 + 12.4 + 44.1 = 93.3 kN /m

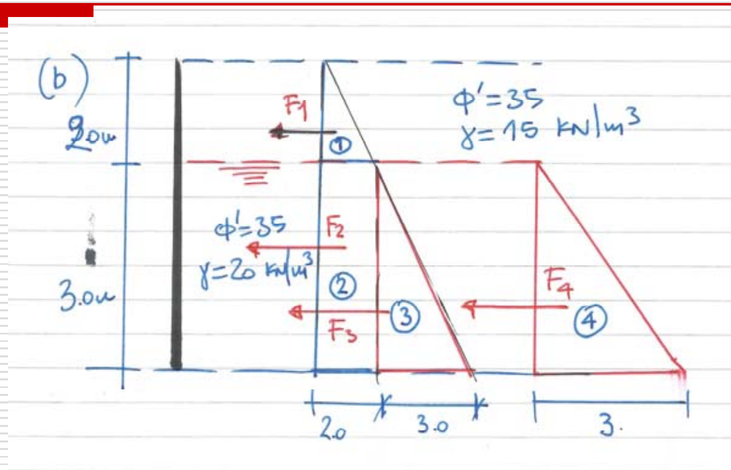
Friction resistance:
W x tan2/3 φ′ = 240 tan2/3 35= 103.51

Factor of safety: 103.51 /93.3 = 1.1

Too low and wall should change dimensions or introduce a shear key inside foundation
Usually friction factor to be between
1.2 to 1.5



- Check overturning



Overturning Moment due to pressures:
(kNm per metre run)

All moments to O

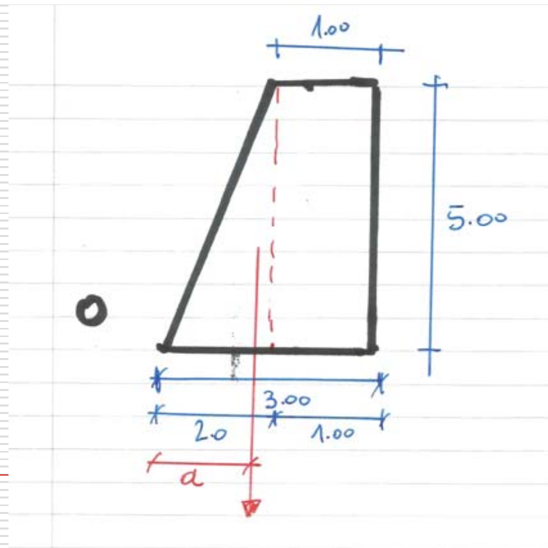
F_1 x (2 x 1/3 +3 =9.2 x 3. 66 = 33.67

F_2= 27.6 x 3/2 = 41.4

F_3 = 12.4 x 3 x 1/3 = 12.4

F_4 = 44.10 x 3 x 1/3 = 44.10

Total : 131.60 kNm
(per meter run)



Restoring moments due to self weight of the wall:

(moment to O)

W x a = 240 x 1.92 = 460.8 kNm

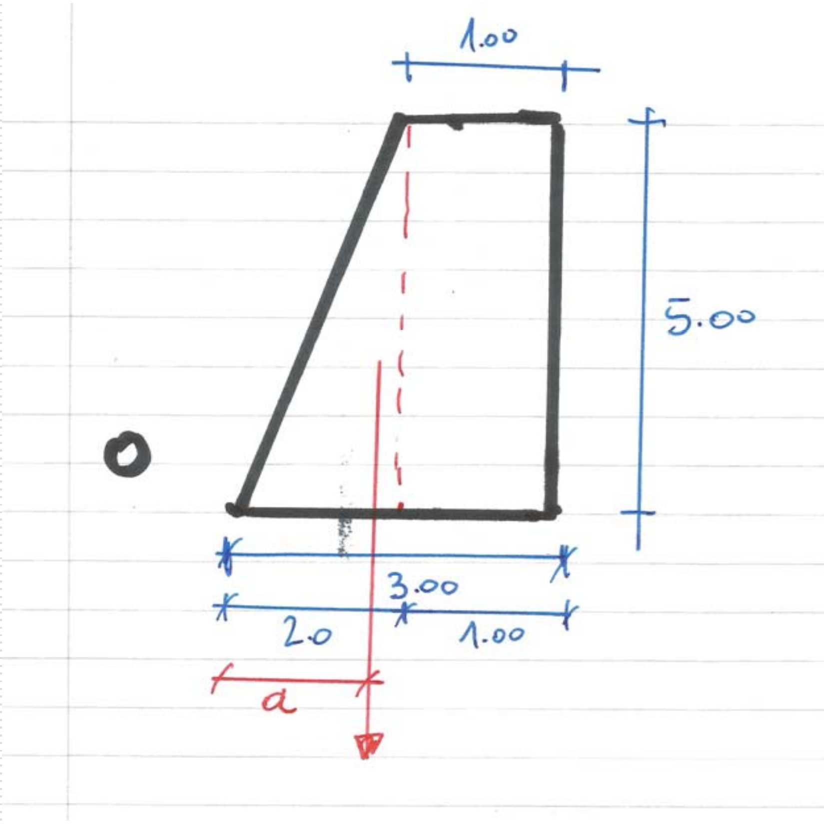
(pre meter run)

Wall ok because restoring moments are greater than overturning moments

Factor of safety:

FOS = 460.8/ 131.6 = 3.5 ok

Usually the moment factor of safety is between **1.2 and 1.5**



Tutorial example 2

Calculate the bearing pressure, sliding resistance and moment resistance of the concrete wall of the adjacent figure

(Concrete $\gamma=24\ kN/m^3$)

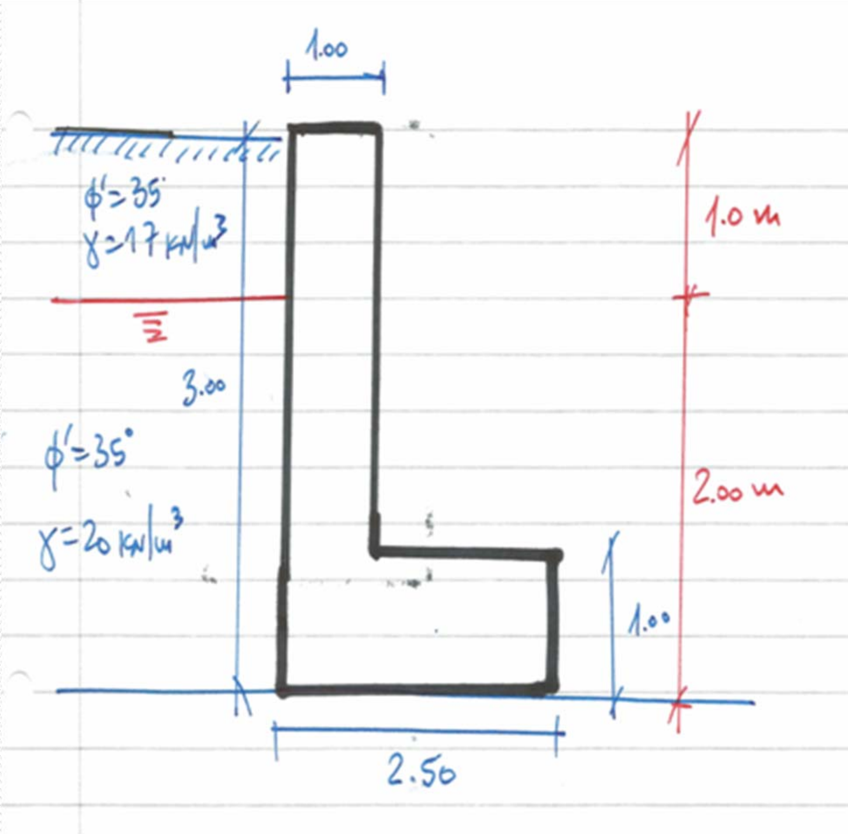
Note the saturated unit of the sand is $\gamma=20\ kN/m^3$. Water density $\gamma=9.8\ kN/m^3$

Solution:

Bearing pressure= $58.70\ kN/m^2$

Friction resistance-FOS = 1.27

Moment resistance FOS =5.45



K_a= (1-sin35) /(1 + sin35) = 0.271

Pressure F_1 above the water table:

F_1= ½ x (0.271 x 17 x h) x h =

½ x 0.271 x 17 x 1^2 = 2.30 kN /m

Pressure F_2 surcharge of soil above w.t.

F_2= (0.271 x 17 x b) x h =

0.271 x 17 x 1 X 2 = 9.21 kN /m

Pressure F_3 below the water table:

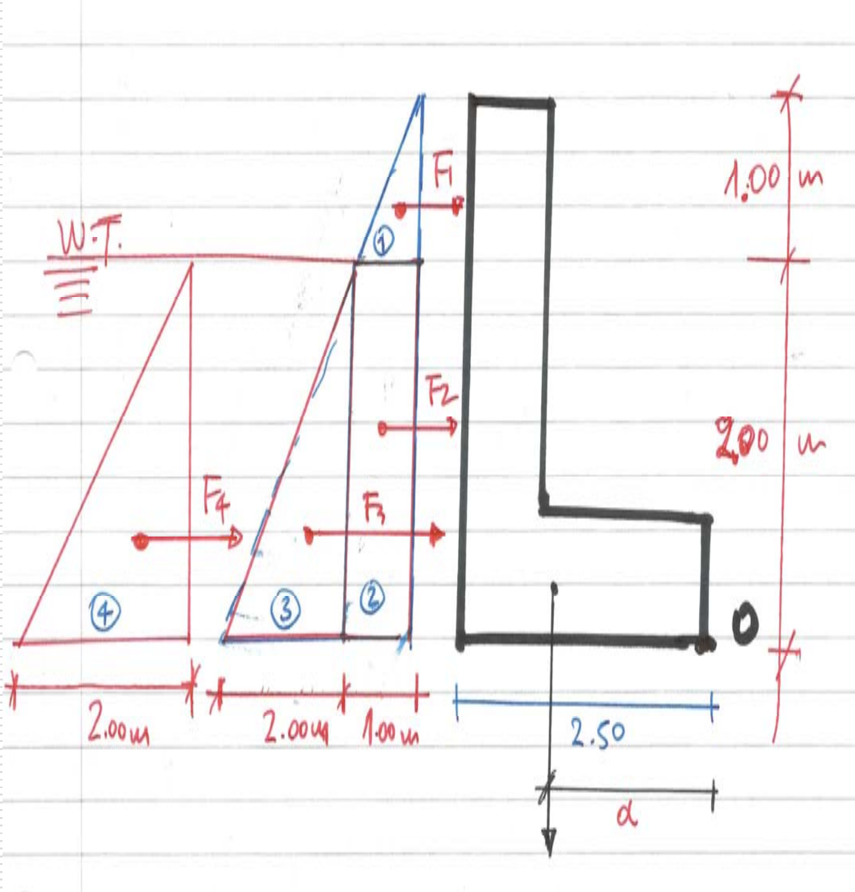
F_3= ½ x [0.271 x (20-9.8) x h) x h =

½ x 0.271 x 10.2 x 2^2 = 5.53 kN /m

Pressure F_4 of the water :

F_4= ½ x (9.8 x h) x h =

½ x 9.8 x 2^2 = 19.60 kN /m



Calculate the position of the central of gravity for the wall

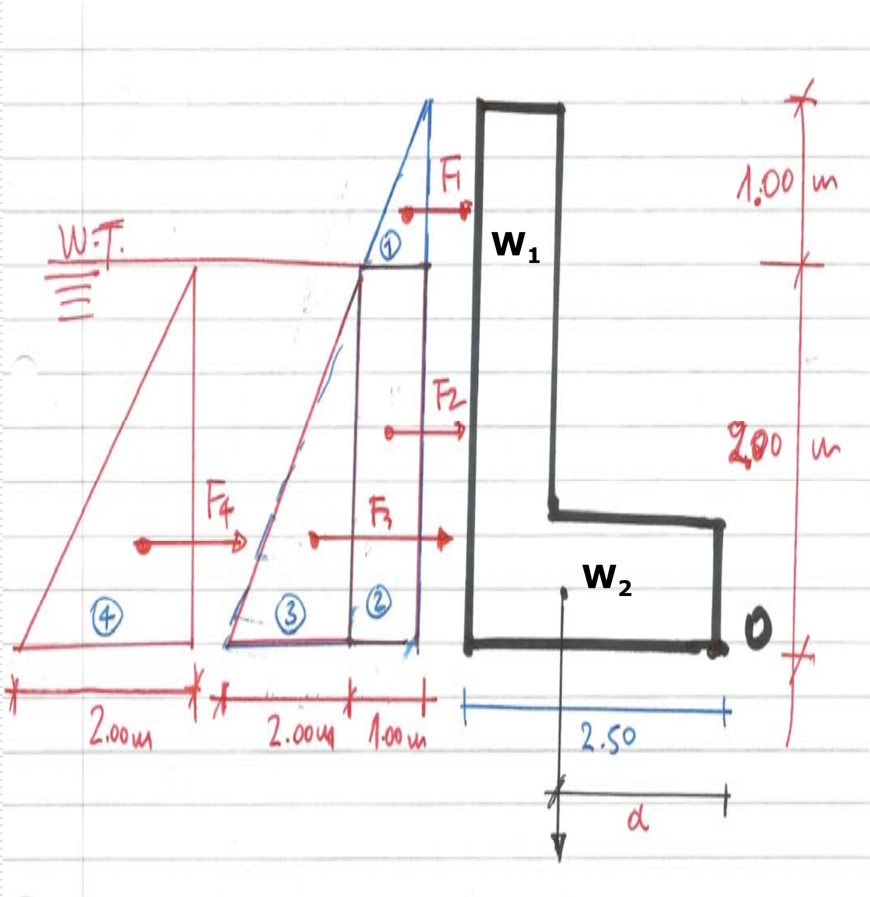
First we calculate the total self weight.

W_1 = 1.0 x 3 x 24 = 72 kN (per metre)
W_2 = 1.5 x 1 x 24 =36 kN (per metre)

Total 108 kN (per metre wall)

108 x a =72 x (1/2 + 1.5) + 36 x 1.5/2 =>
108 x a = 72 x 2 + 36 x 0.75 =>
a= 1.583

Therefore the eccentricity will be
e= 1.583 – B/2= 1.583 – 2.50/2 =><u>e= 0.33 m</u>



Calculation the ground bearing pressure of the wall:

From previous calculations

e = 0.33 m

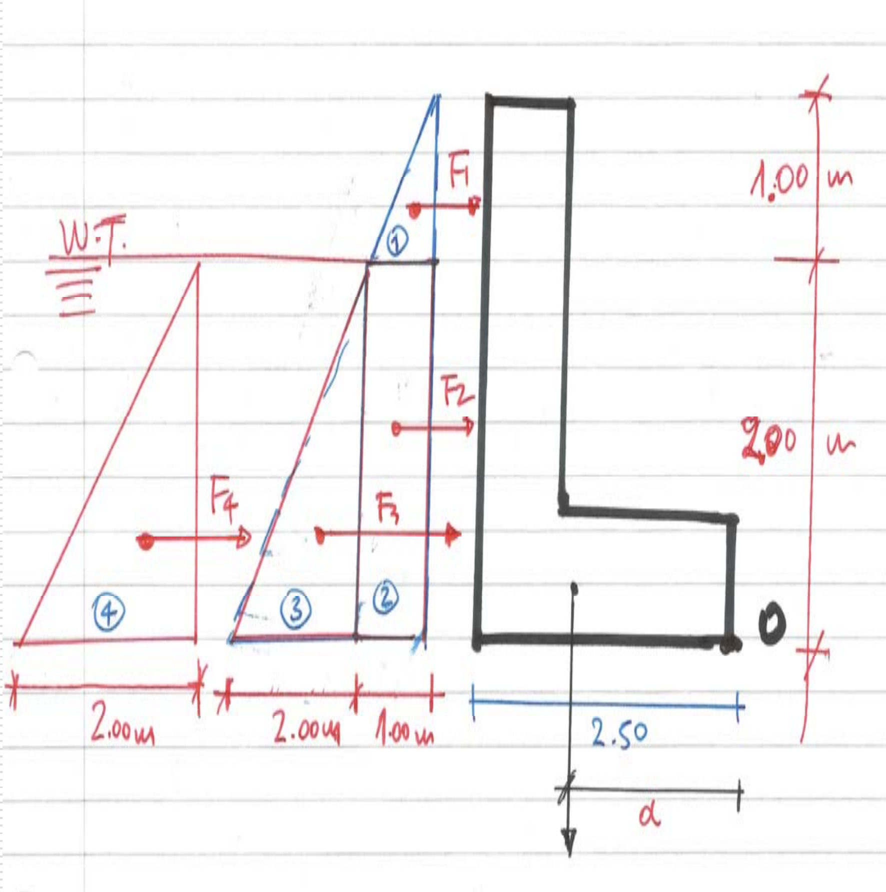
Effective base B′ = B – 2 e

Where B= 3 m

B′ = 2.5 – 2 x 0. 33 = 1.84 m

Pressure from wall per metre run:

108 /(1.84 x 1) = <u>58.70 kN/m²</u>



Calculate the friction resistance:

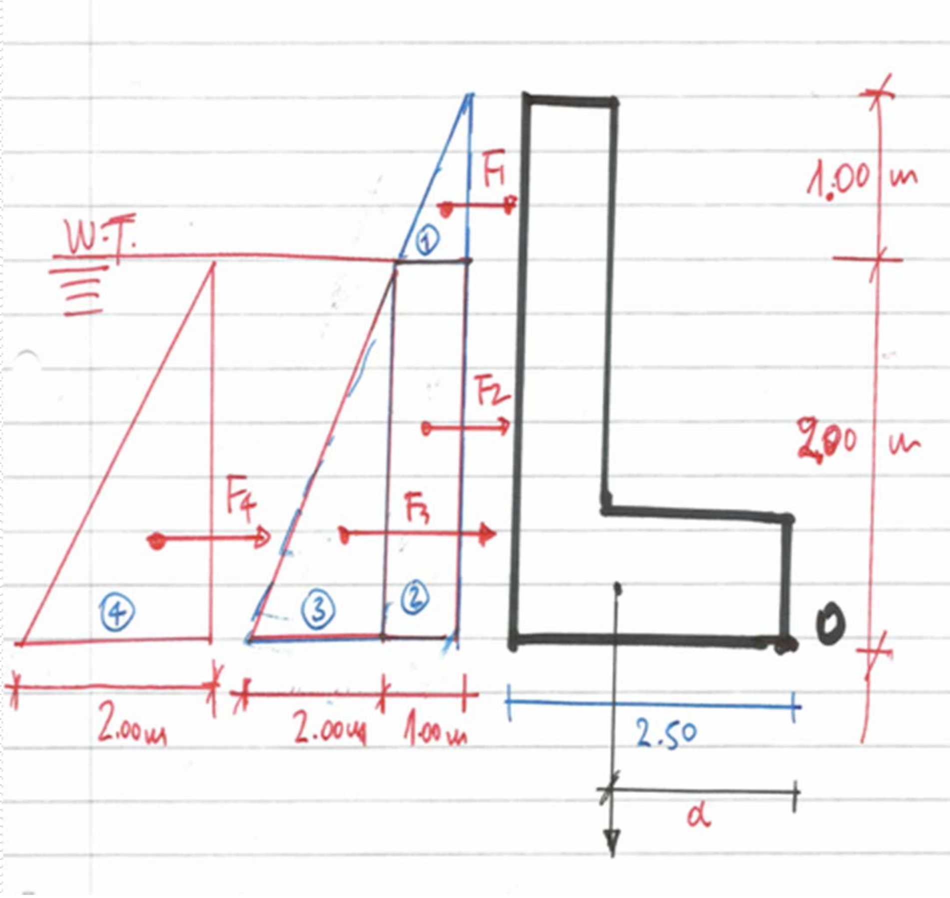
Total forces due to soil/water

$F_1 + F_2 + F_3 + F_4 =$
$2.30+9.21 + 5.53 +19.60 =36.64$ kN /m

Friction resistance:
$W \times \tan 2/3\ \varphi' = 108 \tan 2/3\ 35=$
46.59 KN/m

Factor of safety: 46.59 /36.64 = 1.27

Less than 1.5 and the wall should change dimensions or introduce a shear key inside foundation

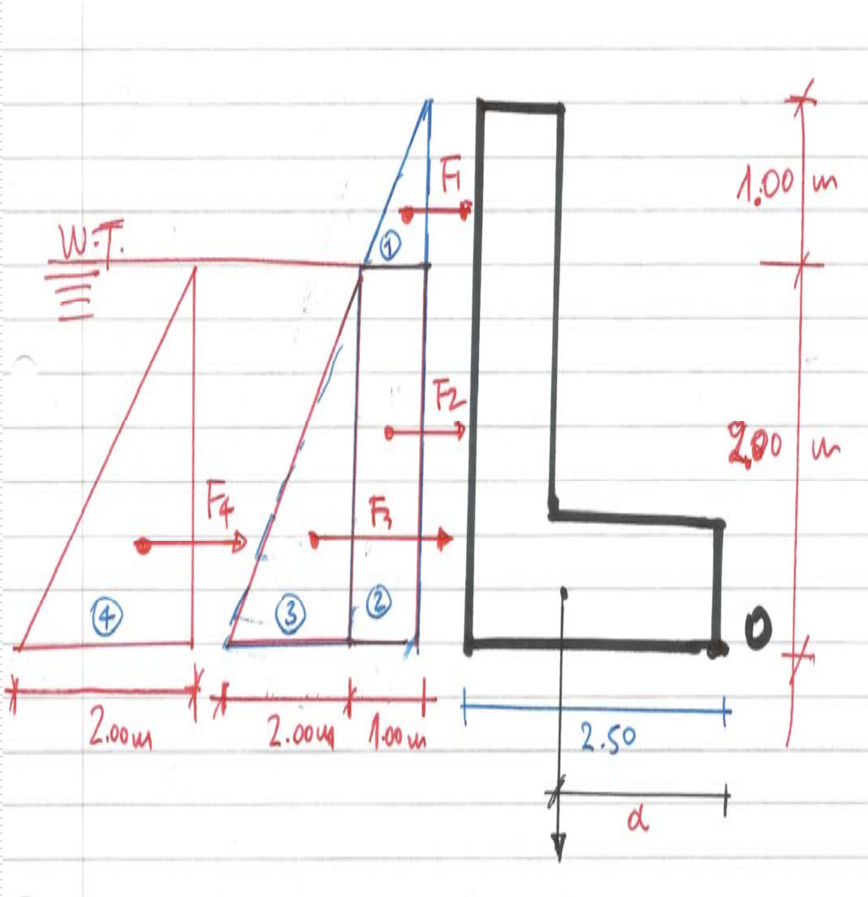


- Check overturning

Overturning Moment due to pressures:
(kNm per metre run)
All moments to O

F_1 x (1 x 1/3 +2) =2.30 x 2.33 = 5.36
F_2= 9.21 x 2/2 = 9.21
F_3 = 5.53 x 2 x 1/3 = 3.69
F_4 = 19.60 x 2 x 1/3 = 13.06

Total : 31.32 kNm
(per meter run)



Restoring moments due to self weight of the wall:

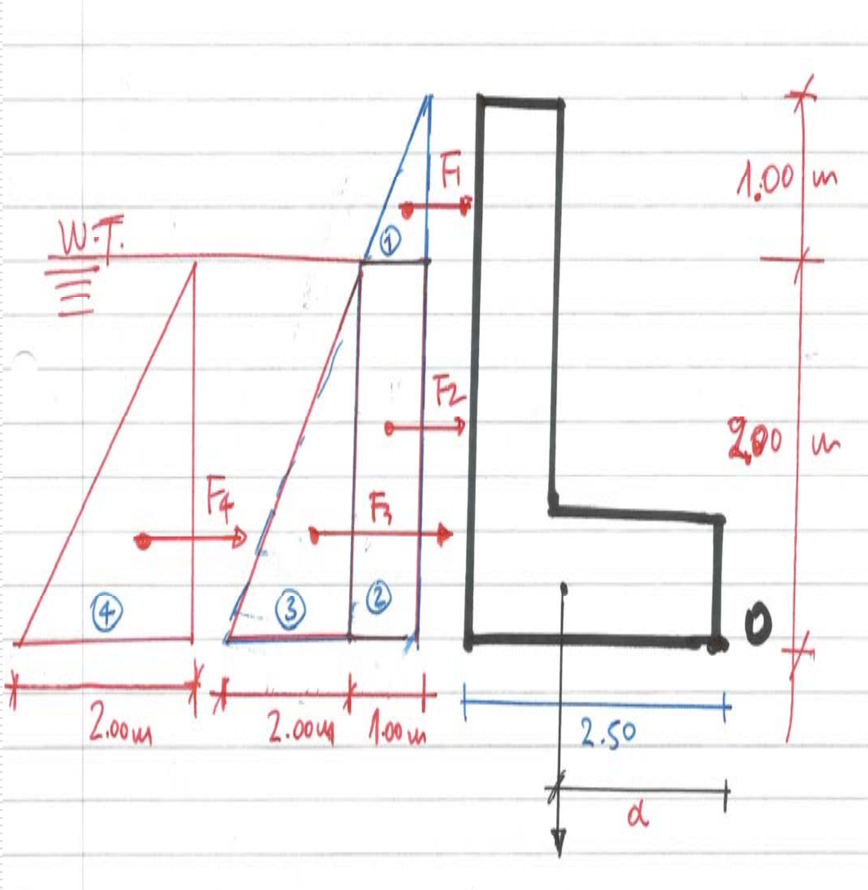
(moment to O)

W x a = 108 x 1.583 = 170.96 kNm (pre meter run)

<u>Wall ok because restoring moments are greater than overturning moments</u>

Factor of safety:

FOS = 170.96 / 31.32 = 5.45 ok



Earth Pressure and retaining walls

Lecture 3-2016

BEARING PRESSURE OF SOIL

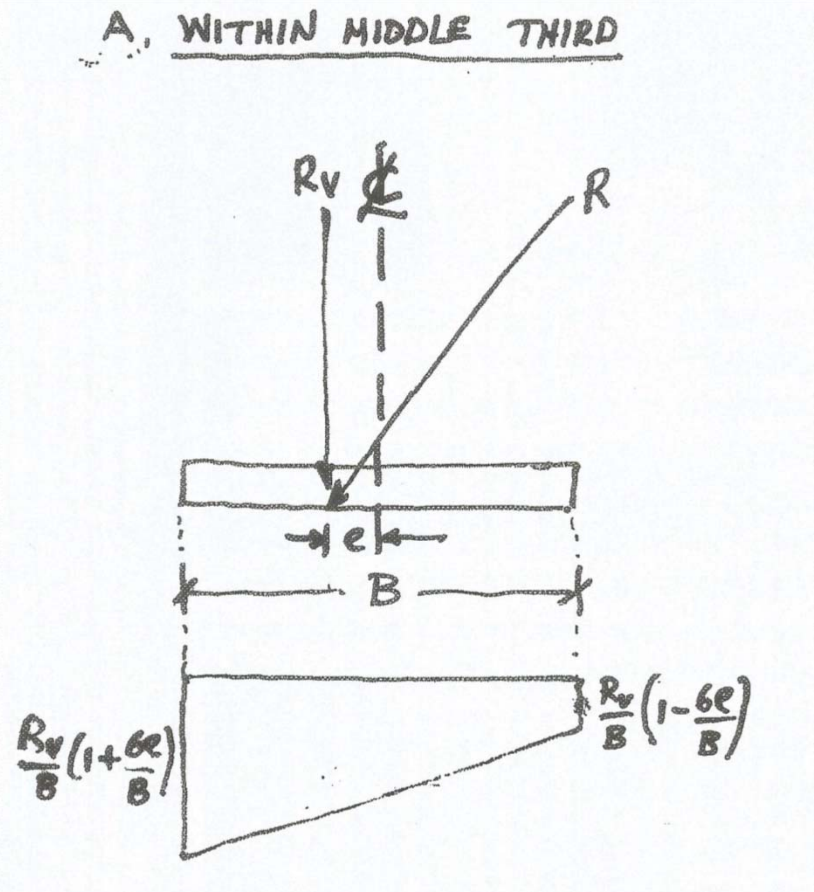
GENERAL CASE

Lets assume that **R** is the resultant force on the wall and let $\mathbf{R_v}$ be its vertical component. (Considering unit length of the wall.)

R_v is on the centroid
(only direct pressure no moment)

Maximum pressure on the base is:

$\mathbf{R_v}$ **/ (B** x 1) (per meter run)

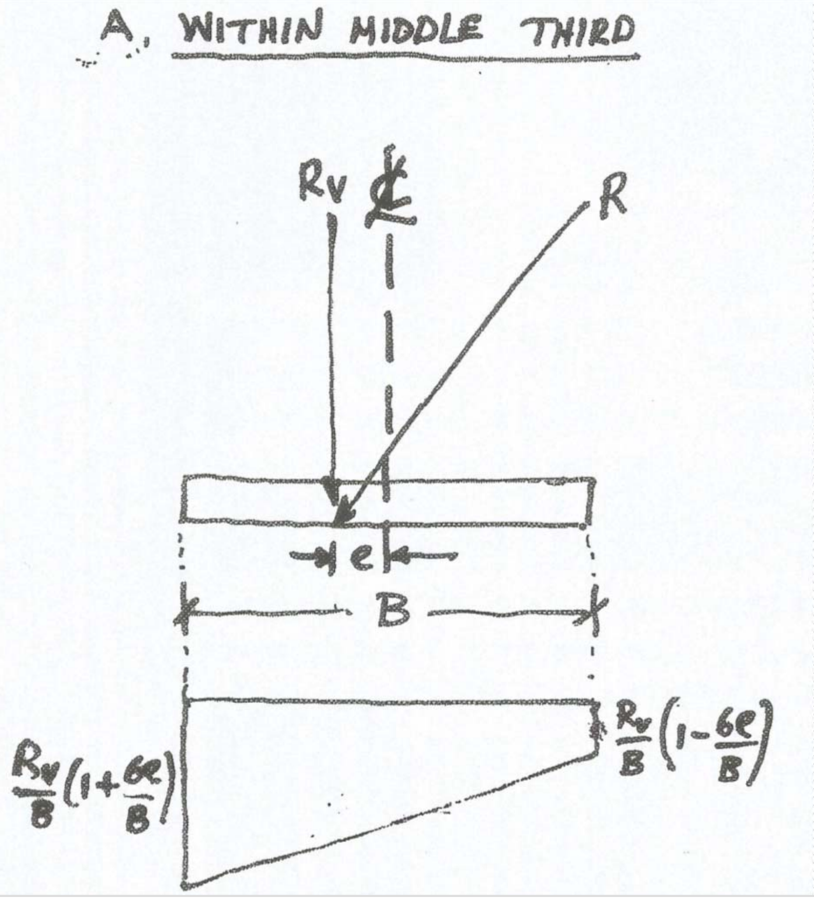


BEARING PRESSURE OF SOIL

Lets assume that **R** is the resultant force on the wall and let $\mathbf{R_v}$ be its vertical component. (Considering unit length of the wall.)

Section modulus of foundations

$Z = bh^2/6$ or $B^2 \times 1/6 = \mathbf{B^2/6}$
(per meter run)



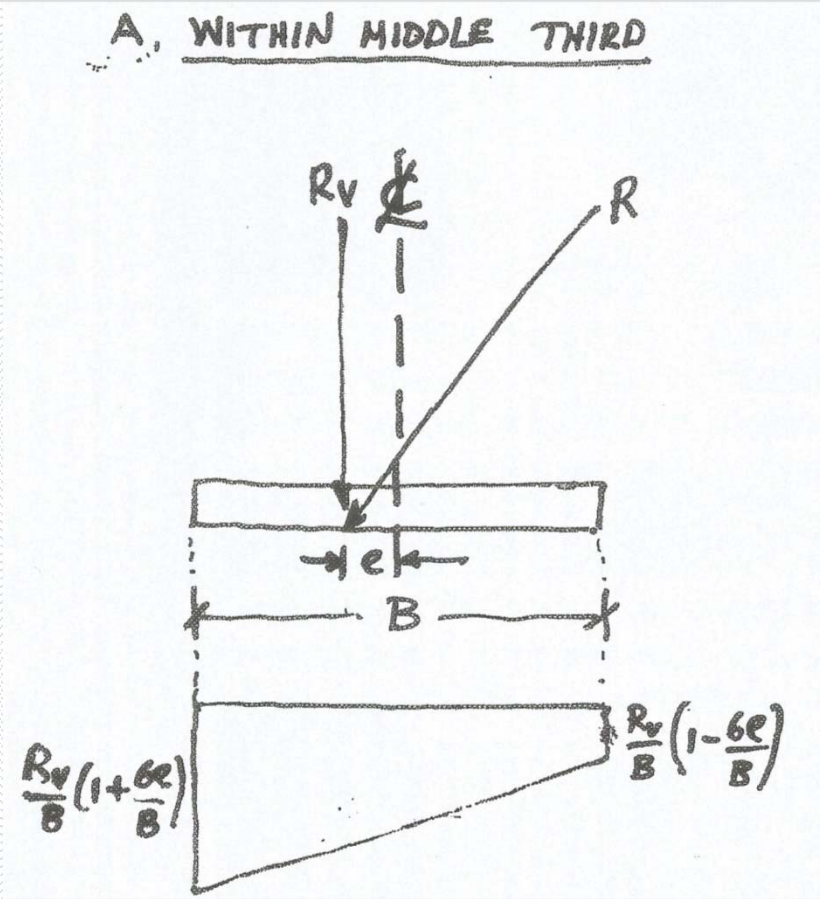
Maximum pressure on the base is:

(direct Pressure + pressure due bending)

R_v /B + 6 R_v e/B^2 =

R_v / B x [1 + (6 x e) /B]

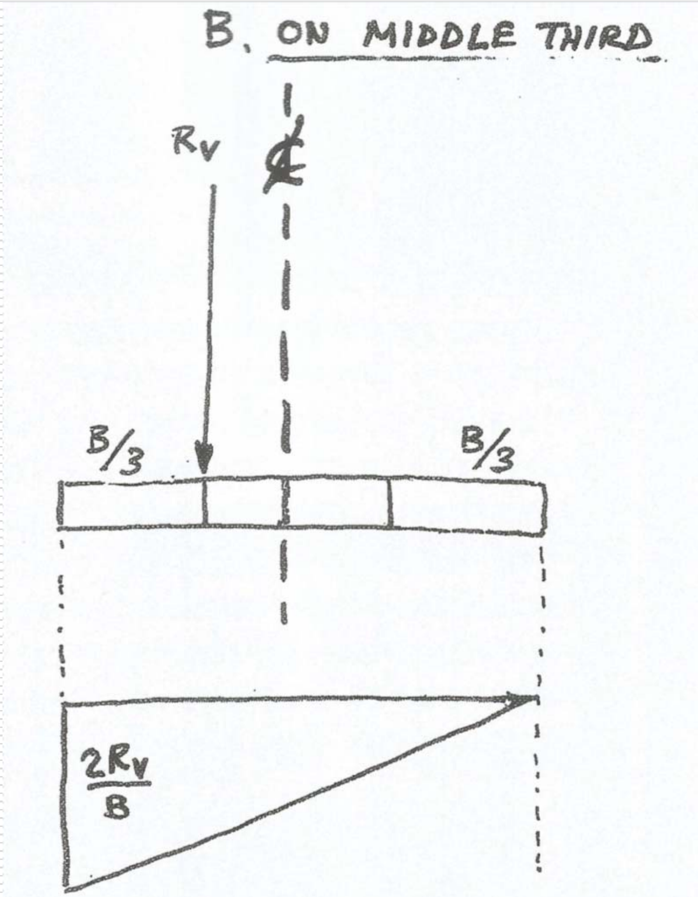
Note: The above formula applys when R_v is within middle third



Case B when $\mathbf{R_v}$ **is on the middle third**

Maximum pressure:

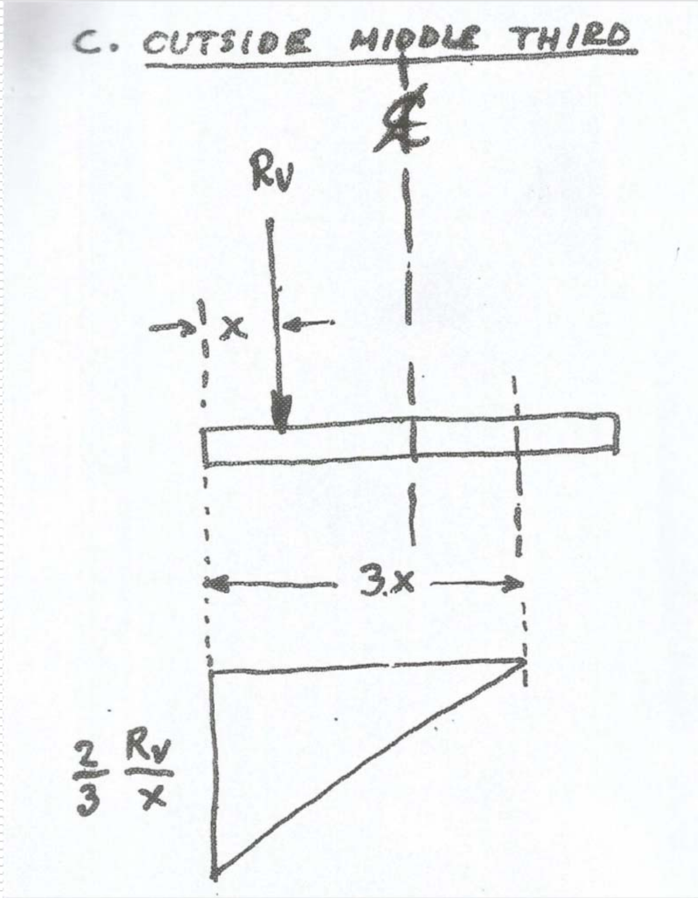
$\mathbf{(2 \times R_v) / B}$



Case C when $\mathbf{R_v}$ **is outside the middle third**

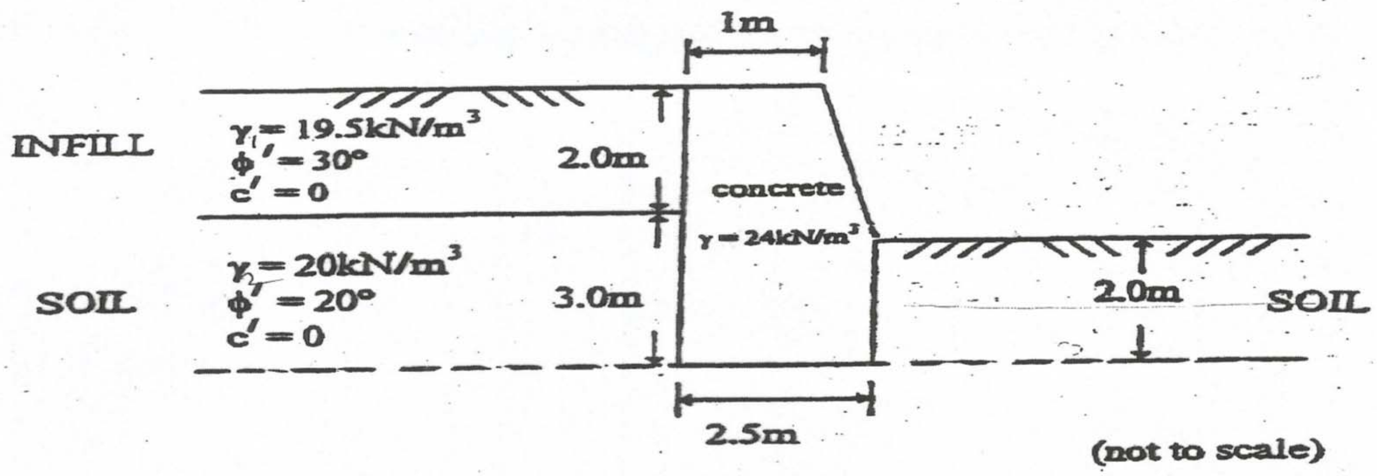
Maximum pressure:

$(2 \times 3) \times (R_v / x)$

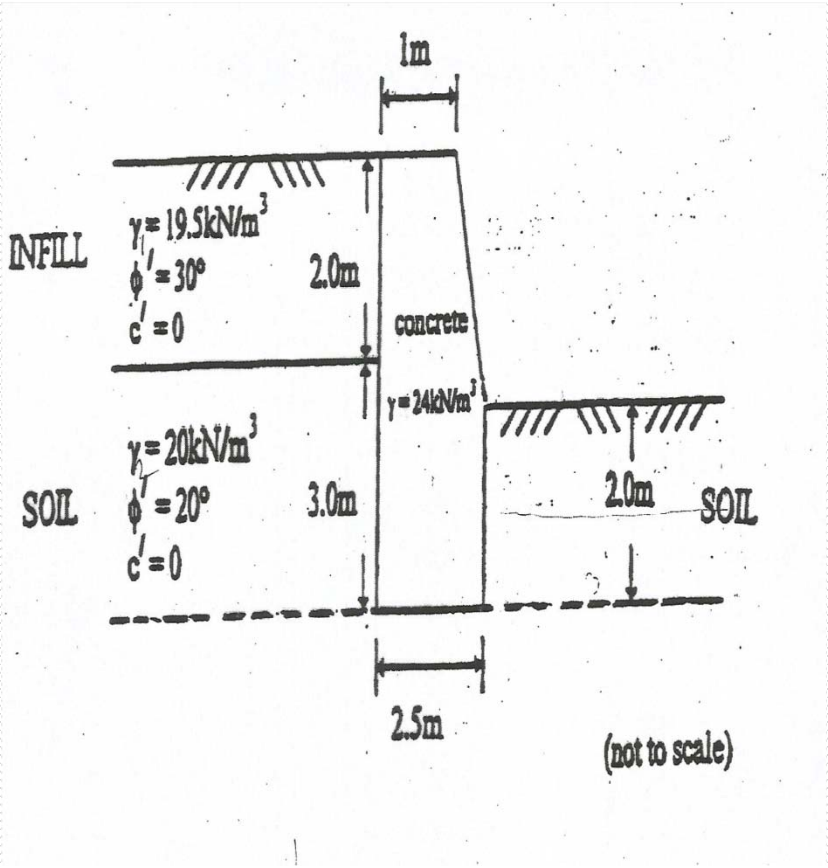


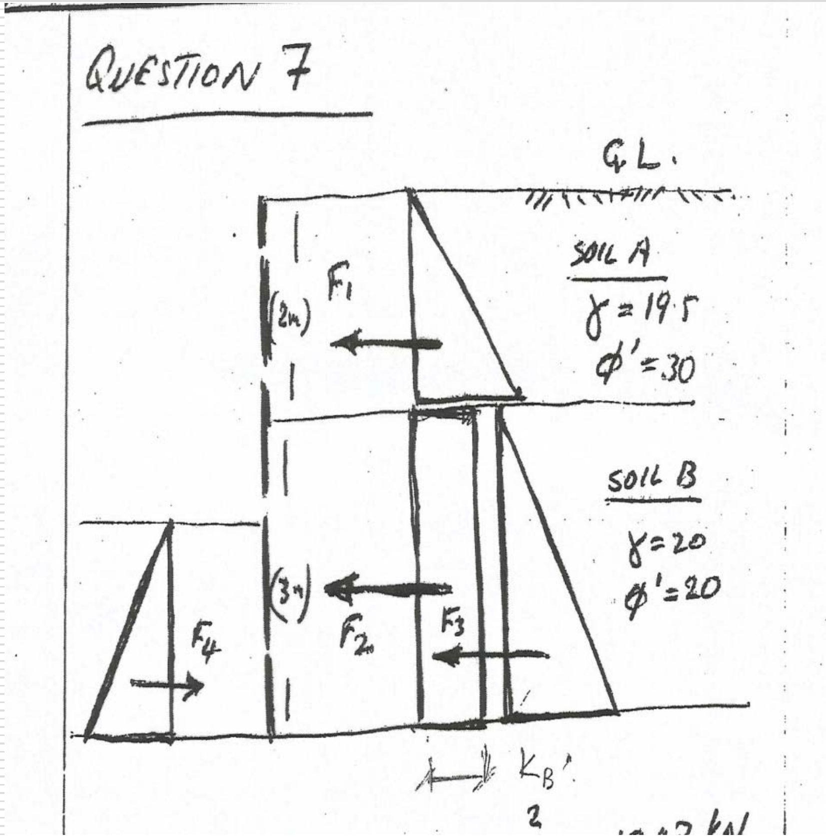
A mass concrete wall with the cross-section shown in Figure is constructed in a granular soil. After construction of the wall, infill compacted to a unit weight of 19.5 kN/m^3 and angle of shearing resistance of 30°, is placed to a height of 2.0mm behind the wall. For the wall, determine the factor of safety against sliding, overturning and bearing.

Take the angle of friction (i.e. the angle of obliquity) between the base of the concrete and the soil as equal to the angle of internal friction of soil. Assume the ultimate bearing capacity of the ground to be 400kN/m^2. The Meyerhof's stress distribution at the base of the wall (not the Trapezoidal one).



Note: Reverse diagrams only for this example





SOLUTION

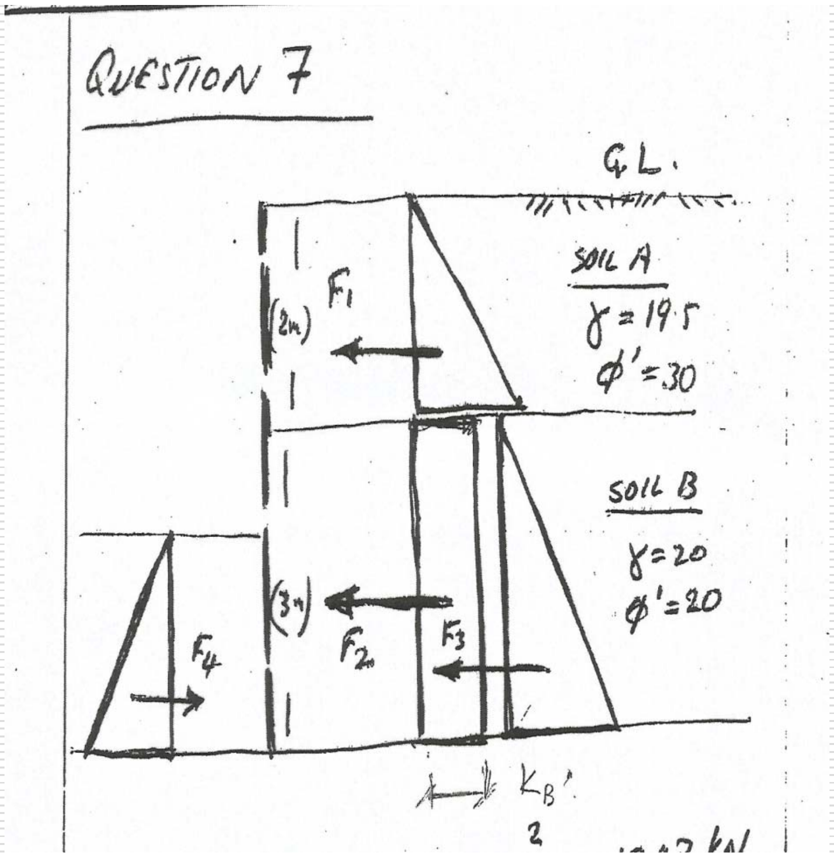
Soil A ground:

K_a = (1-sinφ)/(1+sinφ) =
(1-sin30)/(1+sin30)= 0.33

Soil B

K_a = (1-sinφ)/(1+sinφ) =
(1-sin20)/(1+sin20)= 0.49

Passive $\mathbf{K_p = 1 / K_a}$ = 1/0.49 = 2.04



- Ground pressures:

(all per meter run of wall)

Active pressures

Soil A:

F_1 =1/2 (0.33 x 19.5 x 2 x2)= 12.87 kN

F_2 = (0.49 x 19.5 x 2) x3 = 57.33 kN

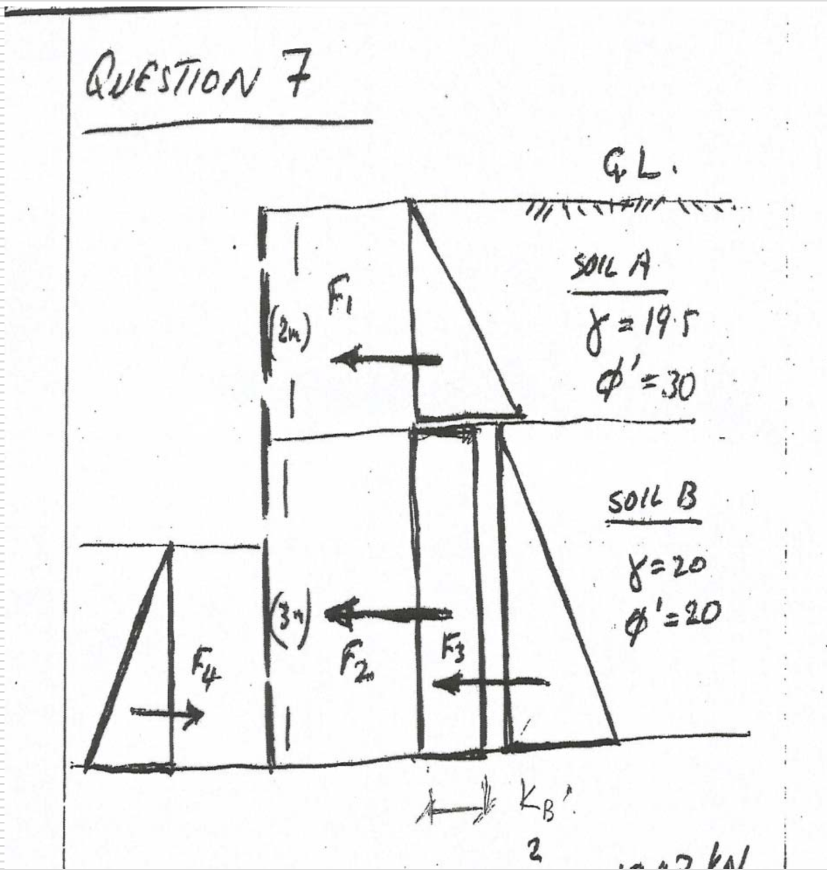
Soil B :

F_3 = 1/2 (0.49 x 20 x 3 x 3) =44.1 kN

Passive pressures:

Soil B

F_4= 1/2 (2.04 X 20 x 2 x 2) = 81.6 kN



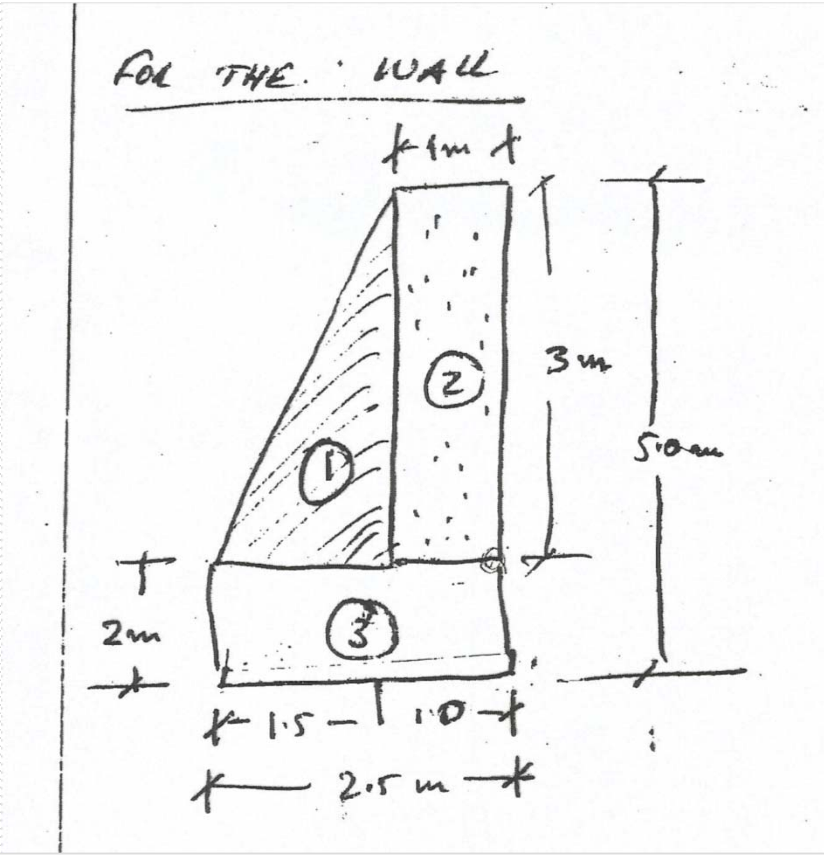
Dead weight of the wall:
(per meter run of wall)

Area 1: 1/2 x 1.5 x 3 x 24 x 1 = 54 kN

Area 2 : 1 x 3 x 24 x 1 = 72 kN

Area 3 : 2.5 x 2 x 24 x 1 = 120 kN

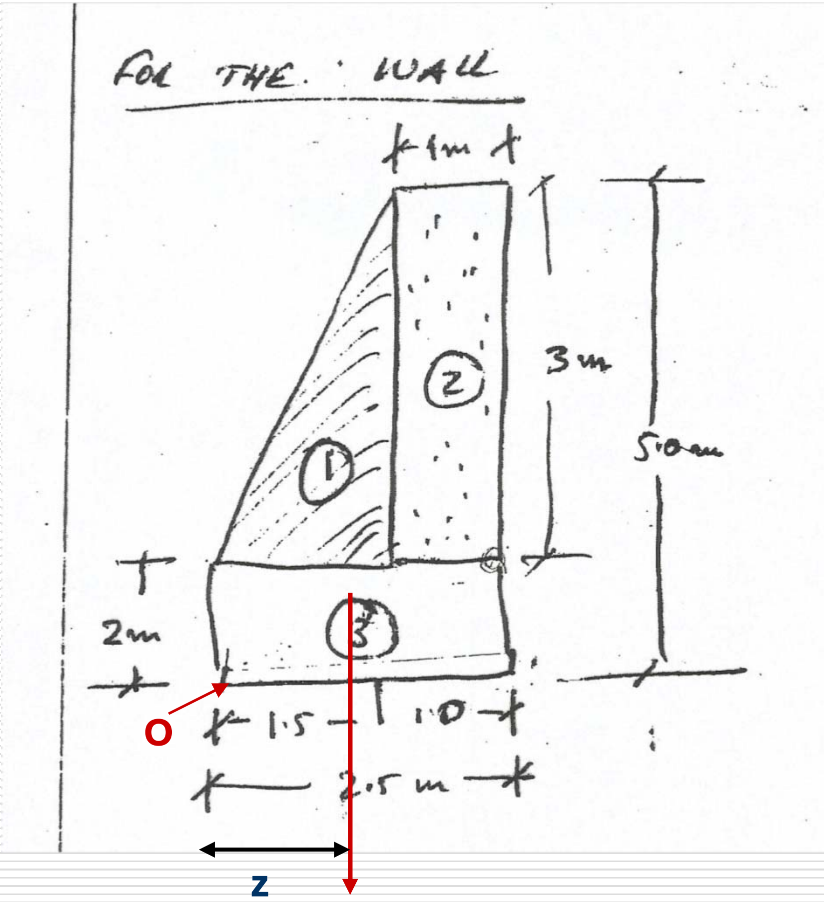
Total <u>246 kN</u>



- The central of gravity position is:

  (Moments about O)

  246 z = 54 x(2/3) x 1.5 +
  + 72 x (1/2 +1.5)+
  + 120 x 2.5/2 =>
  z= 1.414 m



A. Check stability:

Overturning moments (F_1 , $F_{2,}$ F_3)
All kNm per meter run

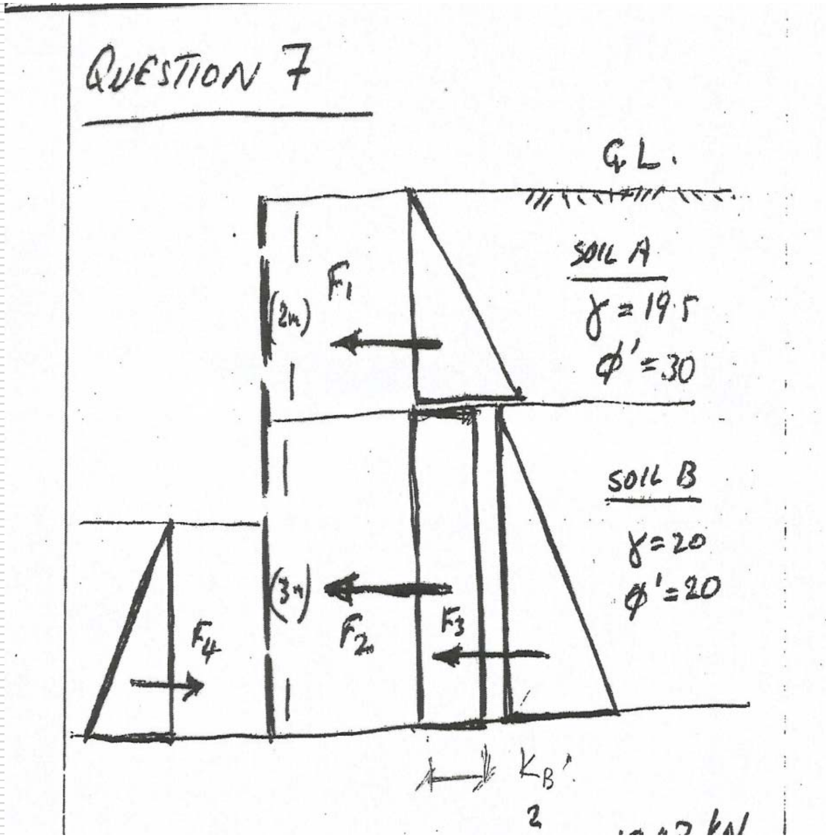
Moments to O

F_1 x [(1/3) x 2] +3 =12.97 x 3.67 =47.23

F_2 x 57.33 x 3/2 = 86

F_3 x 44. 1 x [(1/3) x 3] = 44.1

Total overturning moment 177.33 kNm
(per meter run)



- Restoring moments:

  (All kNm per meter run of wall)

  (dead weigh and passive F_4)

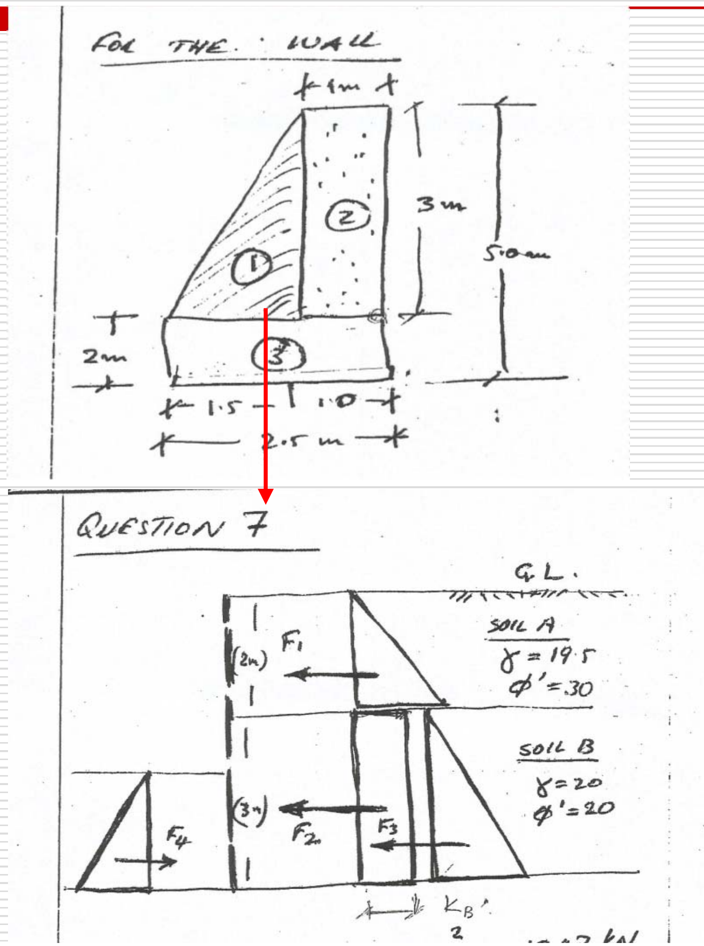
Dead weight: 246 x 1.414 = 347 .84

Passive F_4 = 81.6 x [(1/3) x 2] =54.67

Total restoring moment 402.51 kNm
(per meter run of wall)

Wall stable as the restoring moment is larger than overturning moment.

Factor of Safety: 402.51 / 177. 33 = 2.57
Greater than 1.5 OK



SLIDING CHECK

F acting (F_1 , F_2, F_3) = 114.3 kN

F resisting : Friction + passive F_4

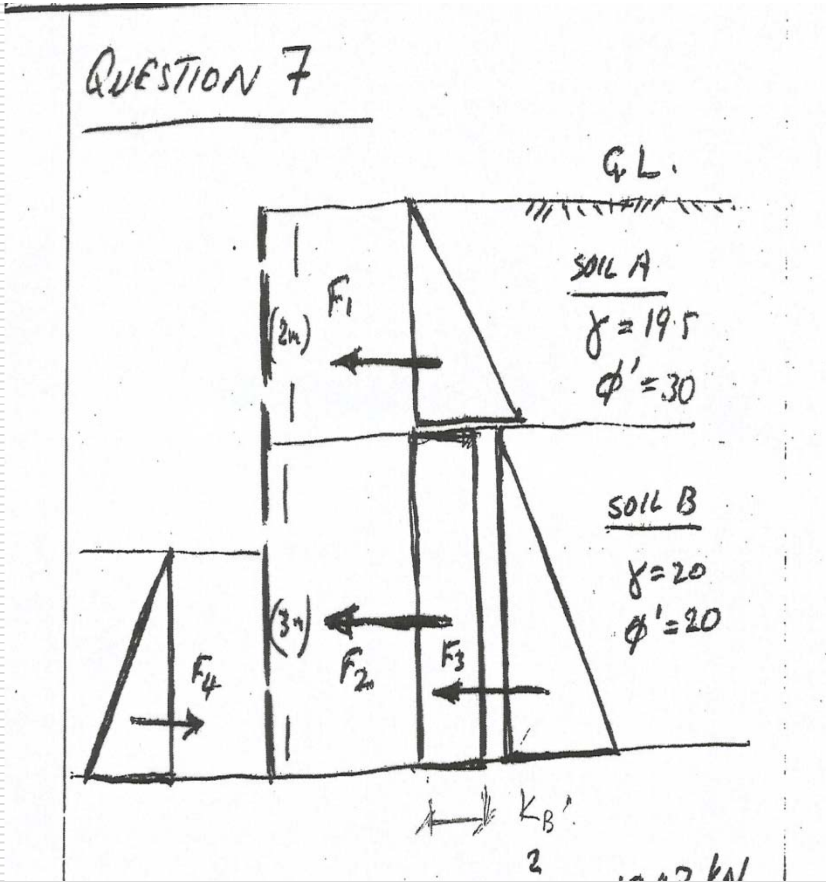
246tanδ + 81.6

246 x tan 20 +81.6 =

246 x 0.364 + 81.6 = 171.1 kN

Resisting force iis greater than acting and therefore the wall is passing

Factor of safety 171.1 /114.3 = 1.5 OK



Check bearing pressure

Eccentricity e= 1.414- 2.5/2 = 0.164

From Mayhorfs stress disribussion:

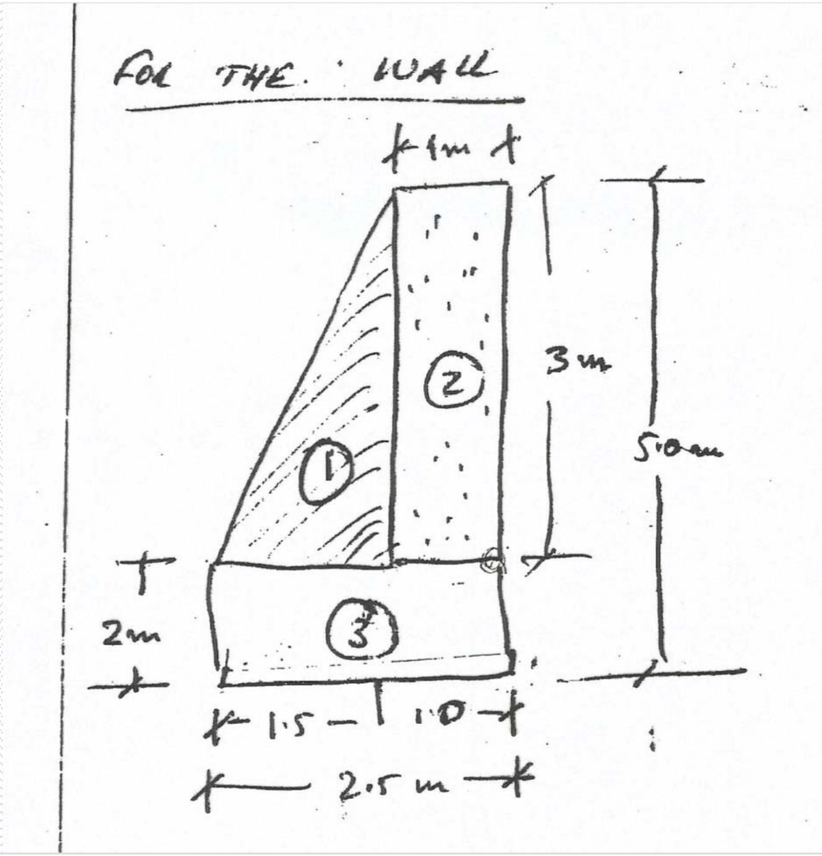
Area (B-2x e) x 1 meter run =
(2.5 -2 x0.164) x 1 = 2.172 m^2

Pressure : 246 / 2.172 = 113.kN/m^2

Less than 400 kn/m^2 and therefore is passing

Factor of safety: 400/ 113.26 = 3.53

3.53 > 3 therefore OK



Earth Pressure and retaining walls

Lecture 4-2016

RETAINING WALL-WORKING EXAMPLE

Calculate the Factors of safety against overturning and sliding

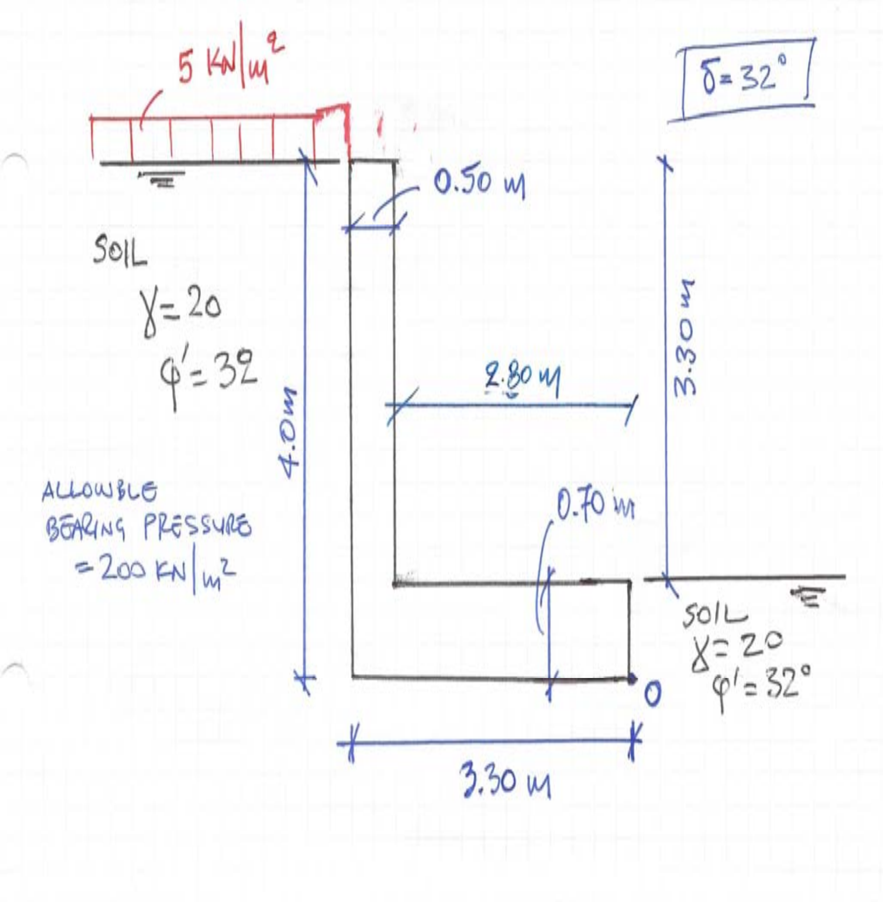
Calculate the factor of safety of ground bearing pressure.

SOLUTIONS:

FOS (moments): 2.78 (approx)

FOS (Sliding): 1.36 (approx)

FOS (bearing pressure): 4.50 (approx)

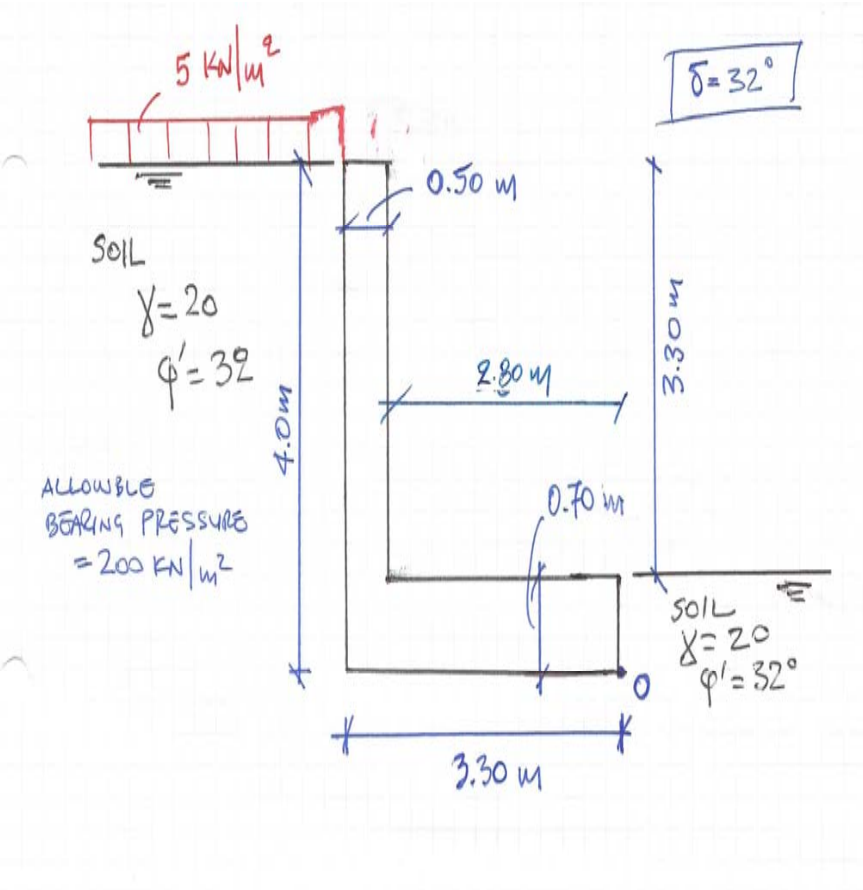


SOLUTION

Soil A ground:

$K_a = (1-\sin\varphi)/(1+\sin\varphi) =$
$(1-\sin 32)/(1+\sin 32) = \underline{0.307}$

Passive $K_p = 1/K_a = 1/0.307 = 3.26$



- Ground pressures:

(all per meter run of wall)

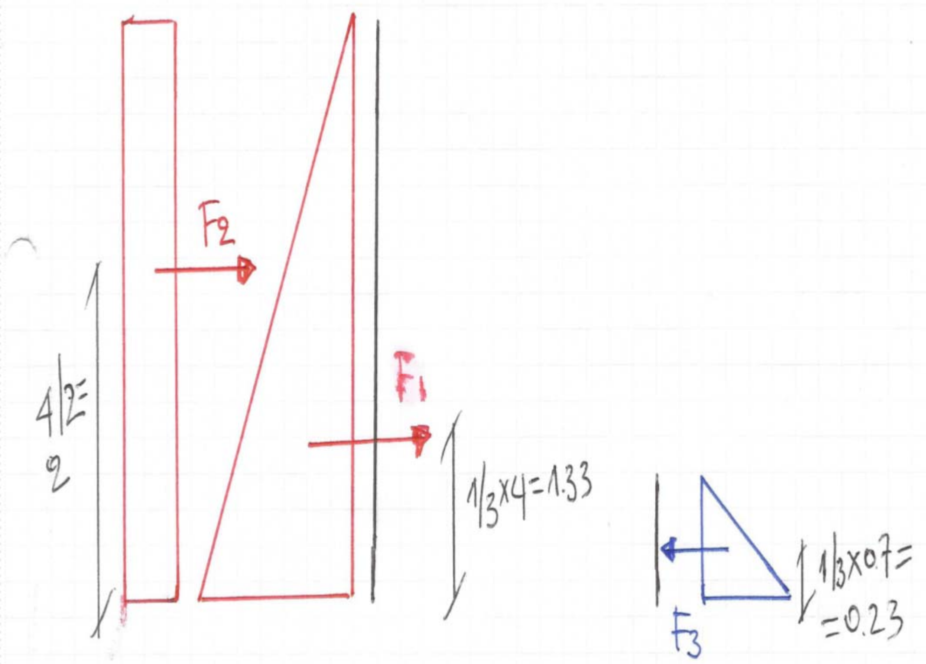
Active pressures

F_1 =1/2 (0.307 x 20 x 4 x4)= 49.12 kN

F_2 = 0.307 x 1 x 4 x 5 = 6.14 kN

Passive pressures:

F_3= 1/2 (3.26 X 20 x 0.7 x 0.7) = 15.97 kN

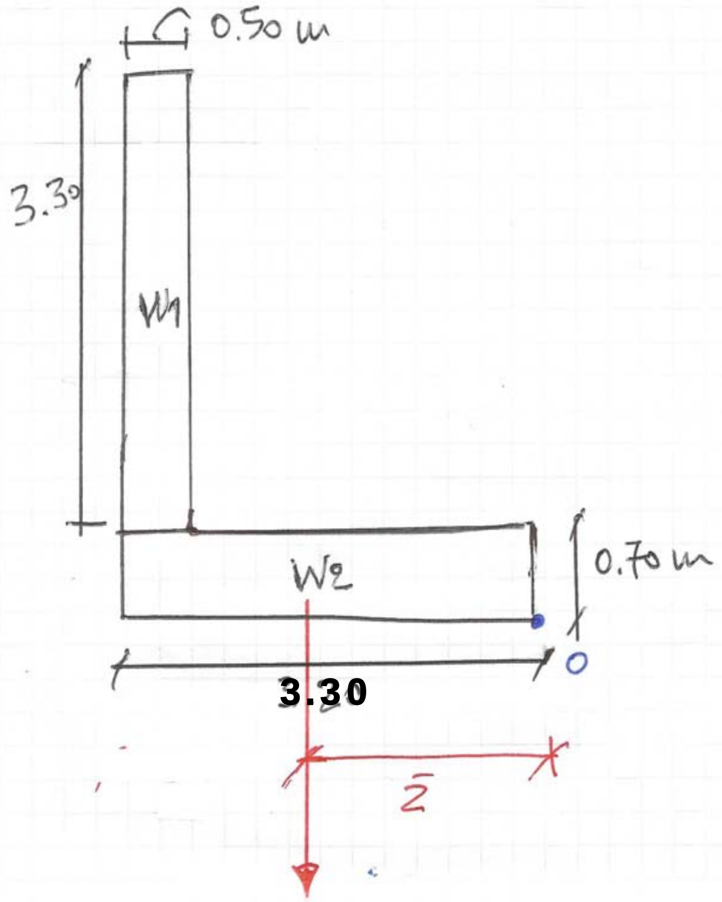


Dead weight of the wall:
(per meter run of wall)

Area 1: 0.5 x 3.30 x 24 x 1 = 39.60 kN

Area 2 :0.70 x 3.30 x 24 x 1 = 55.44 kN

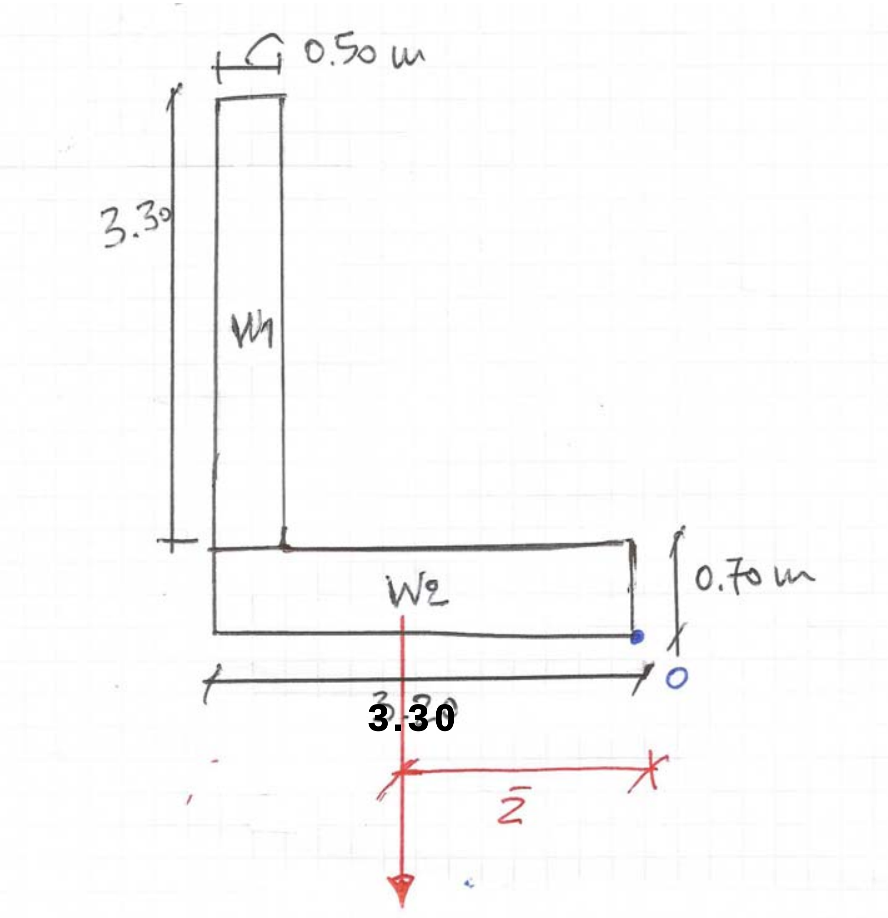
Total <u>95.04 kN</u>



- The central of gravity position is:

(Moments about O)

95.04 z = 39.60 x [(0.5/2) +2.80] +
+ 55.44 x 3.30/2 =>
95.04 z = 39.60 x 3.05 + 55.44 x 1.65
=> z= (120.78 + 91.48) /95.04
z= 2.23 m



A. Check stability:

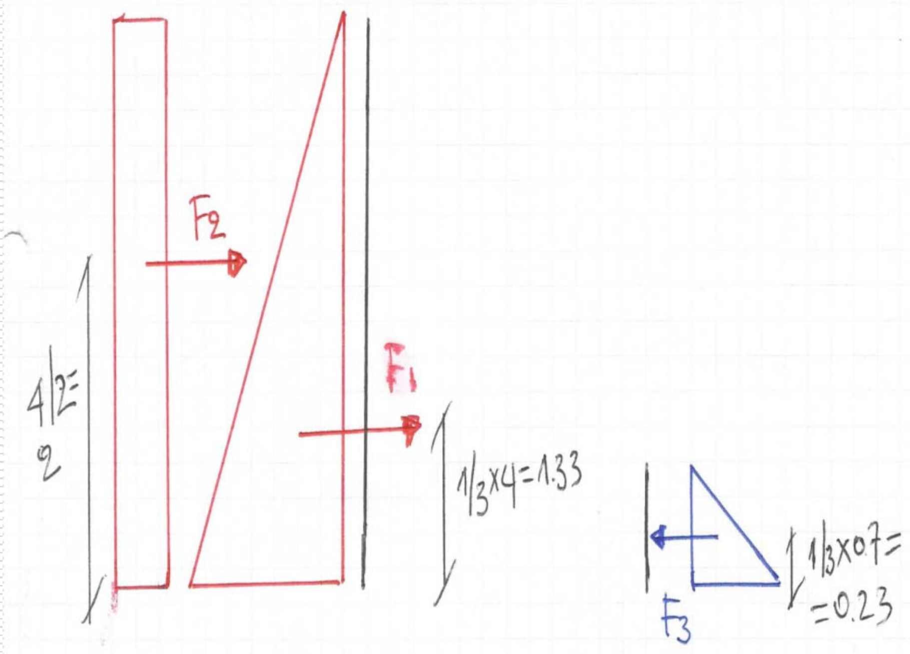
Overturning moments (F_1 , $F_{2,}$)
All kNm per meter run

Moments to O

F_1 x [(1/3) x 4] + 3 =49.12 x 1.33 = 65.33 kNm (per meter)

F_2 x 4/2 = 6.12 x 2 =12.24 kNm (per meter)

Total overturning moment 77.57 kNm (per meter run)



Earth Pressure and Retaining wall Lecture 4

- Restoring moments:

  (All kNm per meter run of wall)

  (dead weigh and passive F_3)

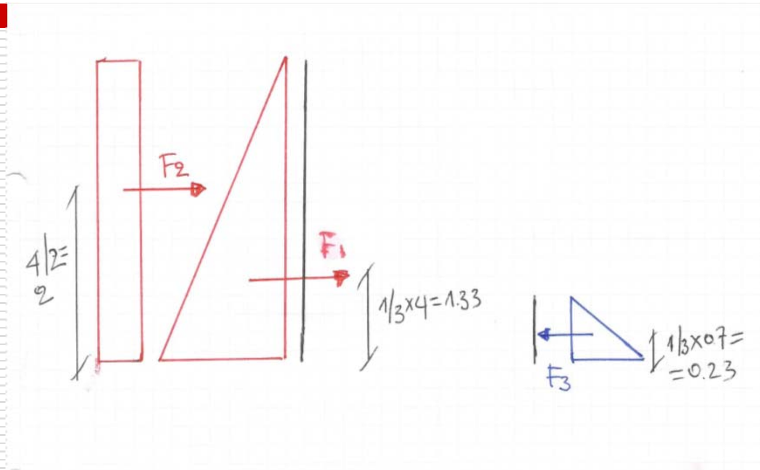
Dead weight: 95.04 x 2.23 = 211.94

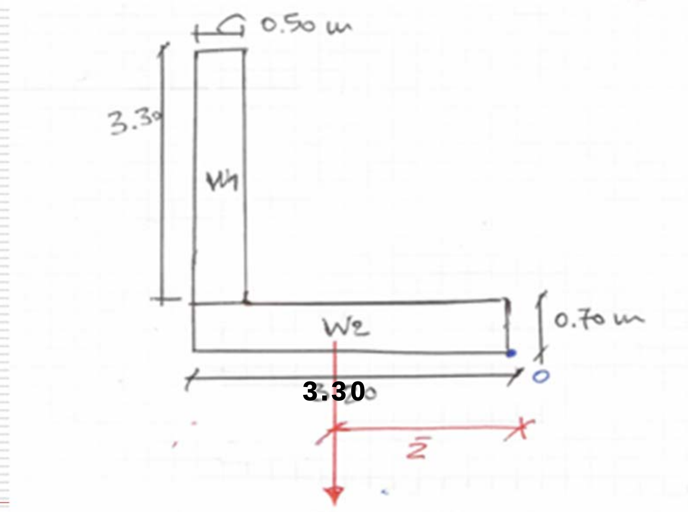
Passive F_3 = 15.97 x [(1/3) x 0.7] =3.73

Total restoring moment 215.67 kNm
(per meter run of wall)

Wall stable as the restoring moment is larger than overturning moment.

Factor of Safety: 215.67 / 77.57 = 2.78
Greater than 1.5 OK





SLIDING CHECK

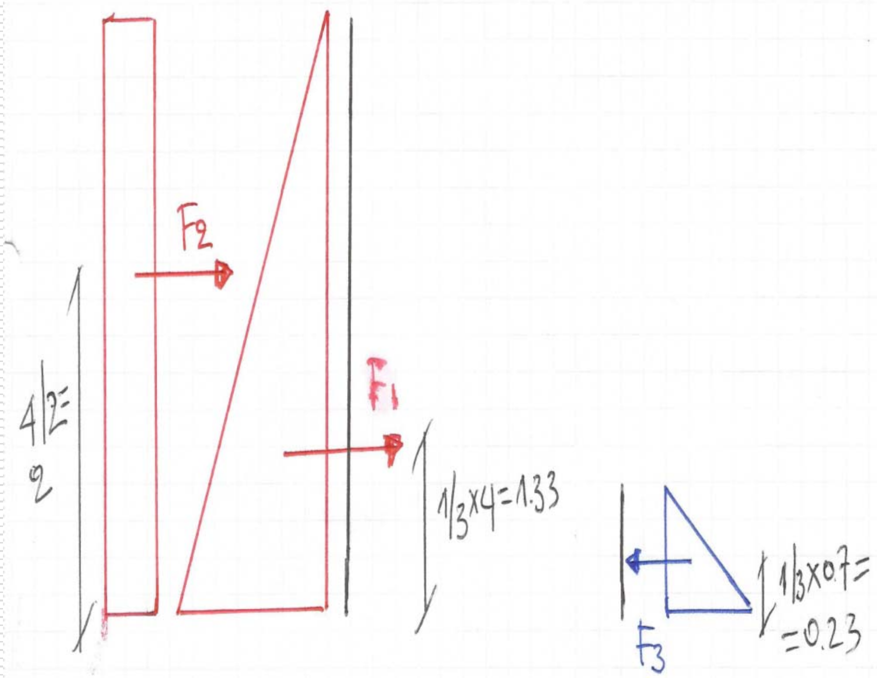
F acting (F_1 , F_2) = 55.26 kN

F resisting : Friction + passive F_3

95.04tanδ + 15.97
95.04 x tan 32 +15.97 =
95.04 x 0.625 + 15.97 = 75.37 kN

Resisting force iis greater than acting and therefore the wall is passing

Factor of safety 75.37 /55.26 = 1.36 OK



Check bearing pressure

Eccentricity e=2.23 – 3.3/2 = 0.58 m

From Mayhorfs stress disribussion:

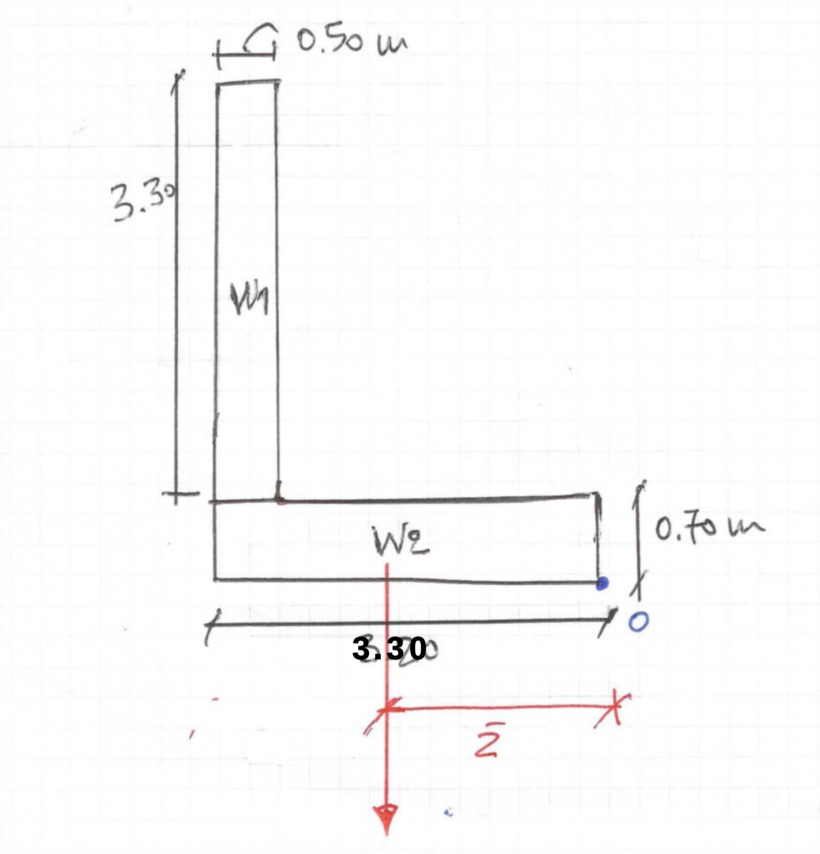
Area (B-2x e) x 1 meter run =
(3.3 -2 x0.58) x 1 = 2.14 m^2

Pressure : 95.04 / 2.14 = 44.41 kN/m^2

Less than 200 kN/m^2 and therefore is passing

Factor of safety: 200/ 44.41 =

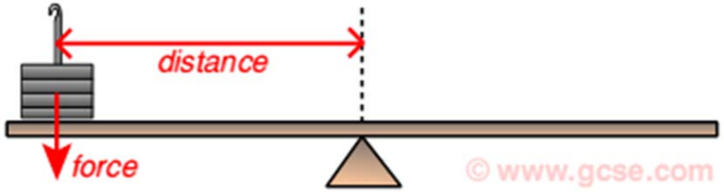
4.50 > 3 therefore OK

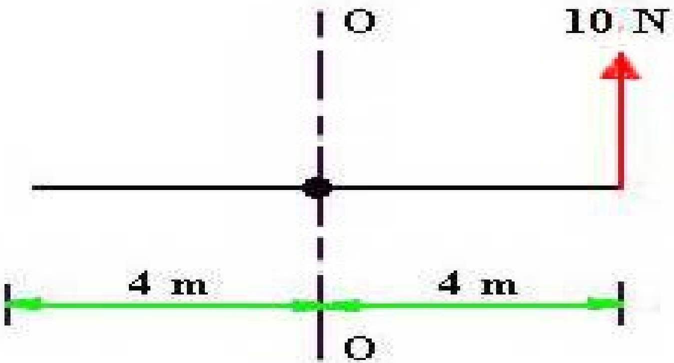


General Information

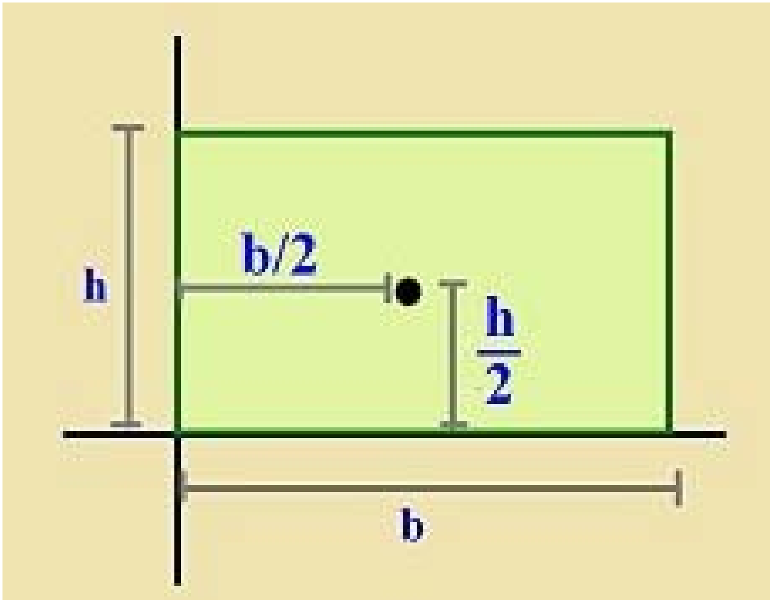
moment

moment

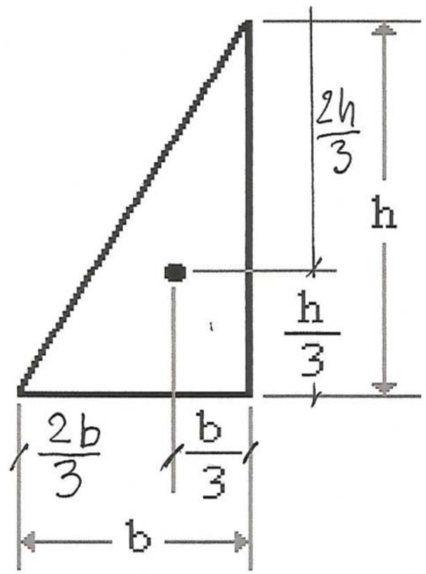




Useful formulas-centroids

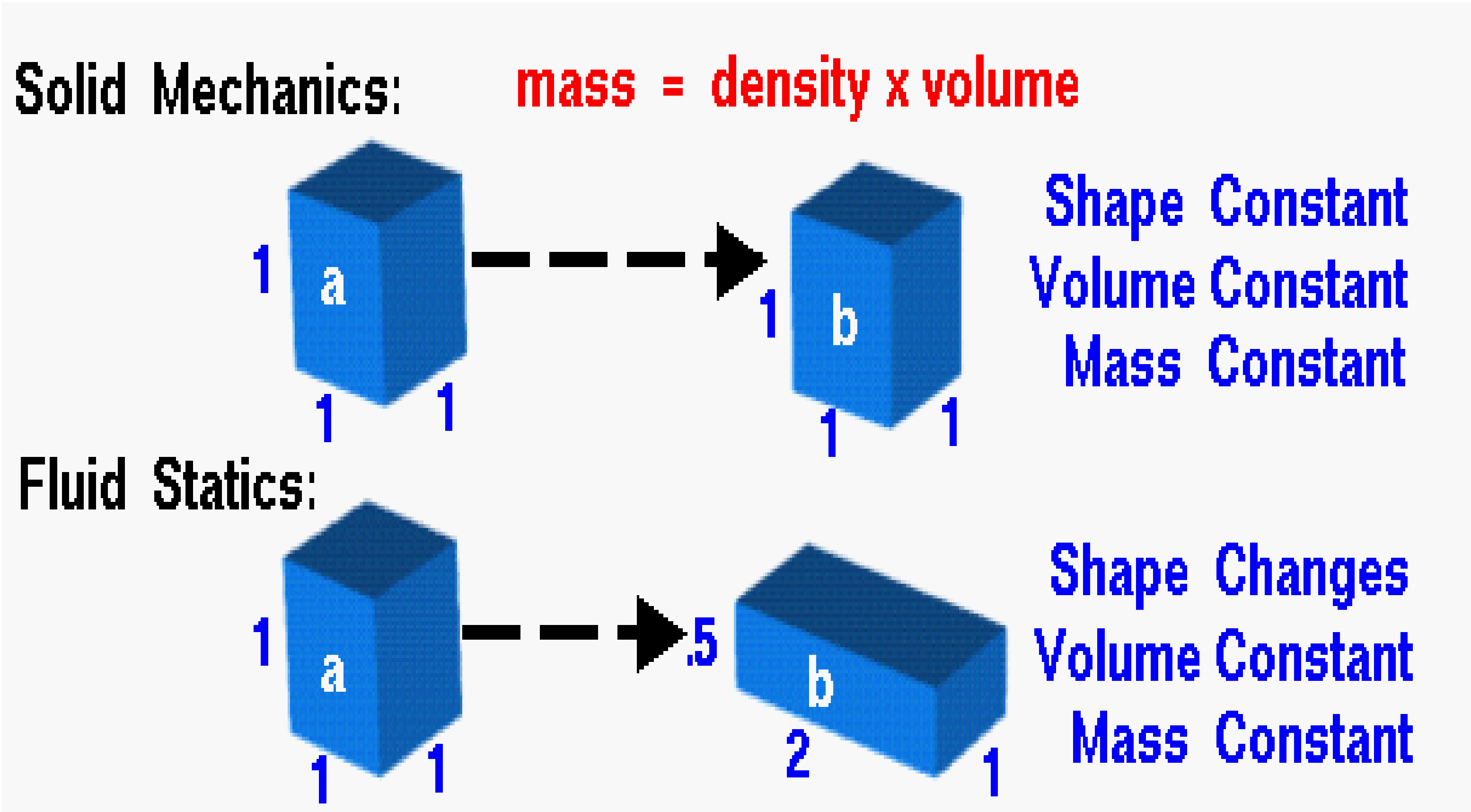


Centroid of rectangular

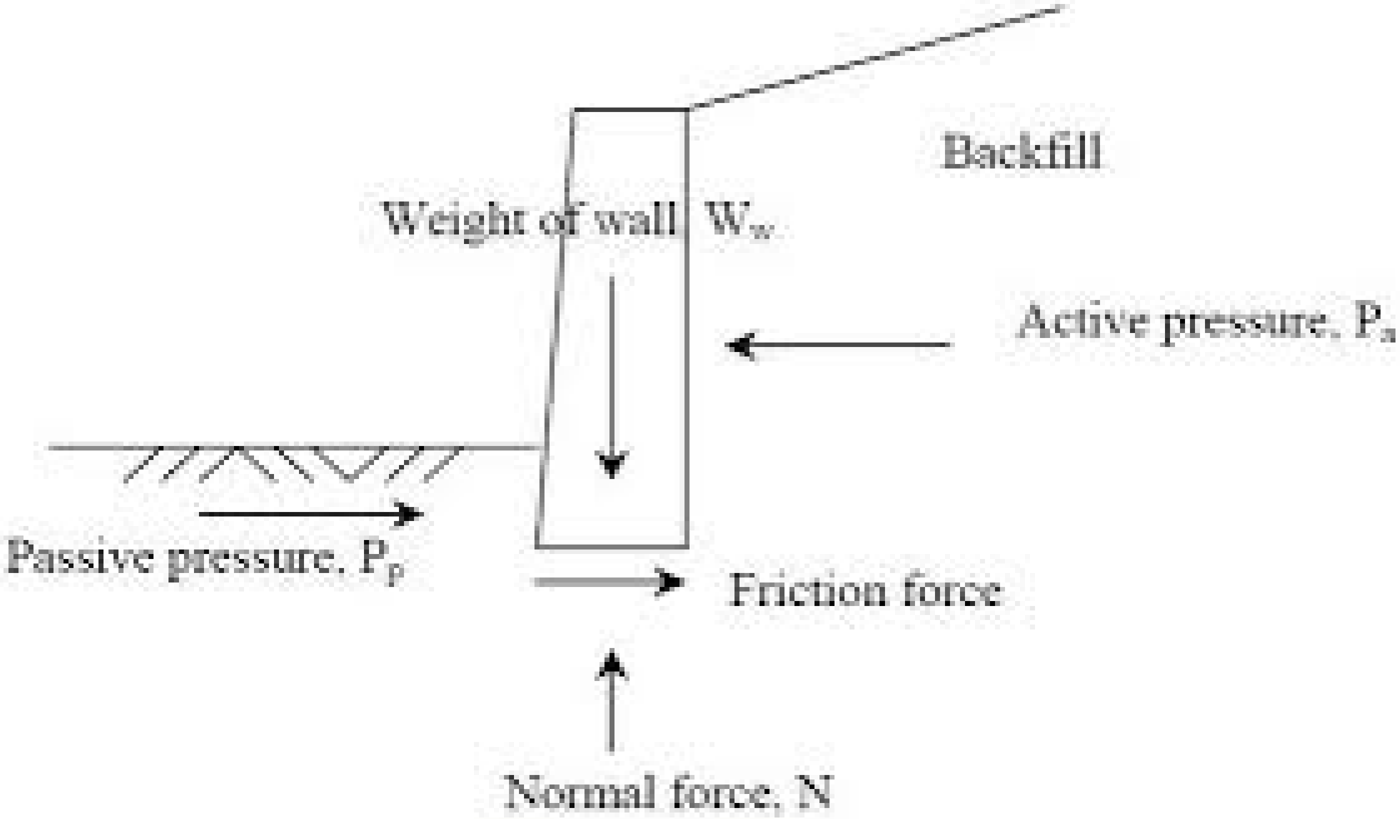


Centroid of triangle

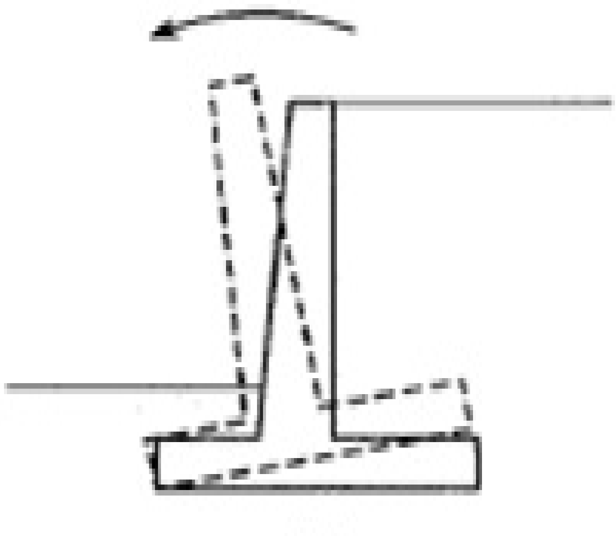
General information-mass



Retaining walls –Moments and forces



Retaining walls –Moments and forces



(a)