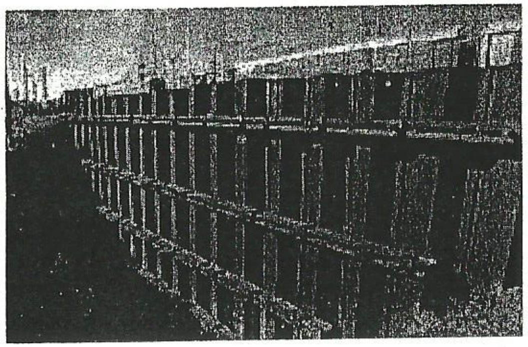
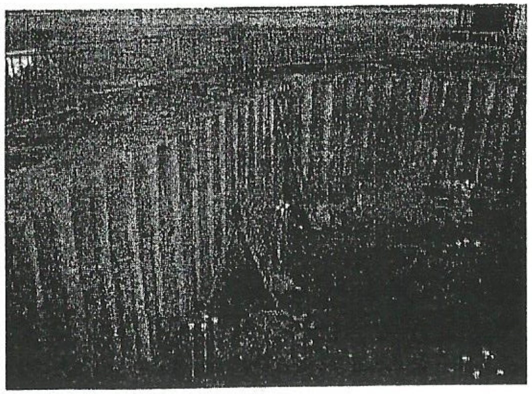
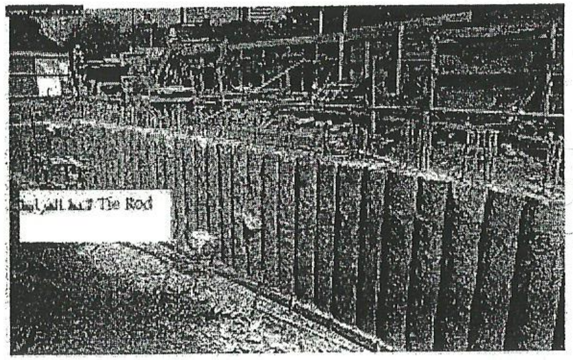
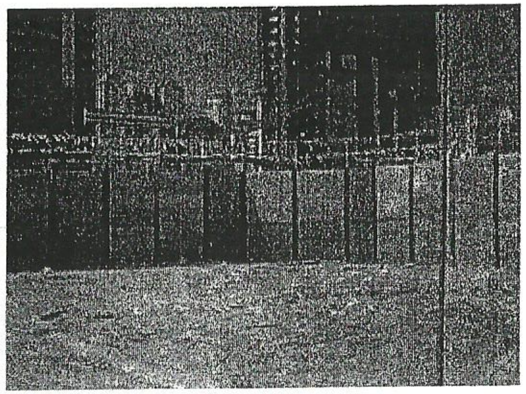
Supported Deep Excavation

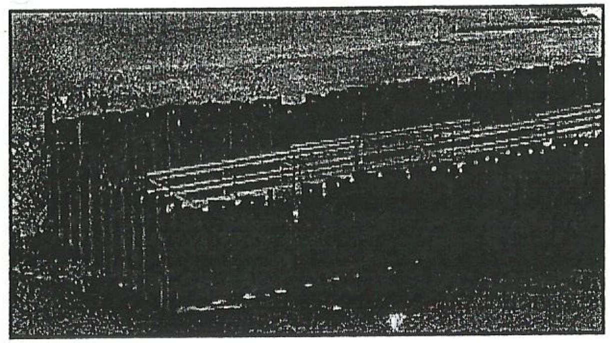
Lecture 4







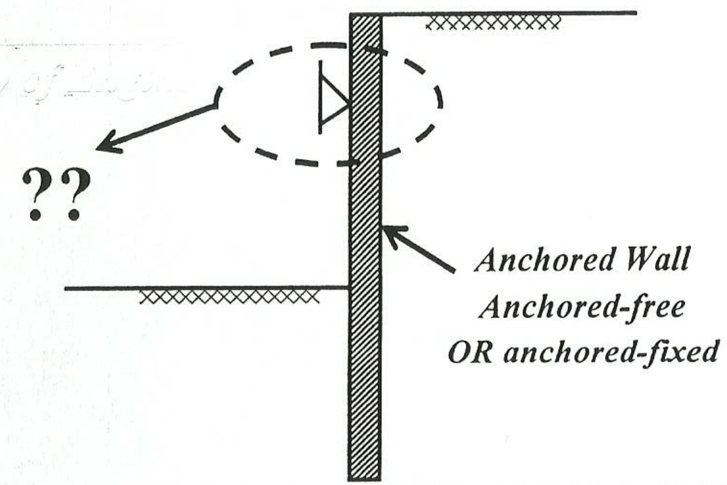




Anchoring of Shoring System

"Lateral Support of Anchored-Walls"

- ❑ **Design of walling beam and common types of lateral supports and anchors**



2

Lateral Support of Anchored-Walls

" Wale "

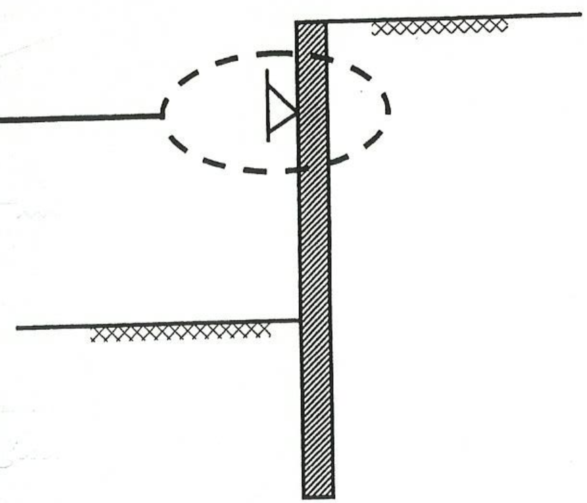
{Continuous Walling Beam}

+

" Lateral Support "

- Tieback (grouted anchor)
- Strut

Anchored Wall
Anchored-free
OR anchored-fixed

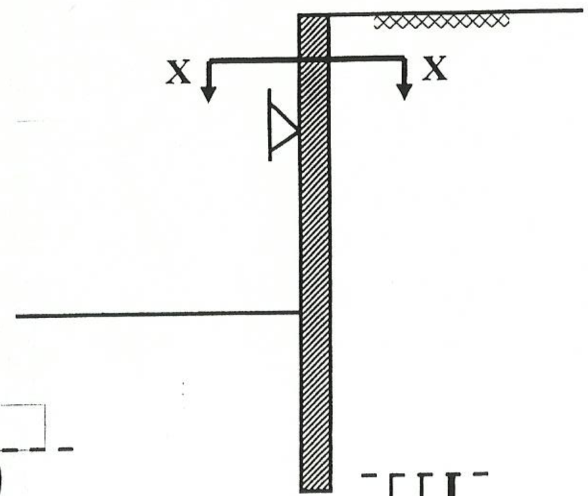


3

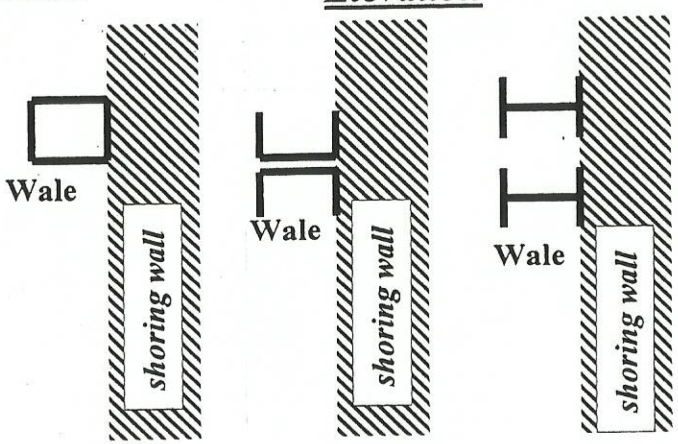
Lateral Support of Anchored-Walls

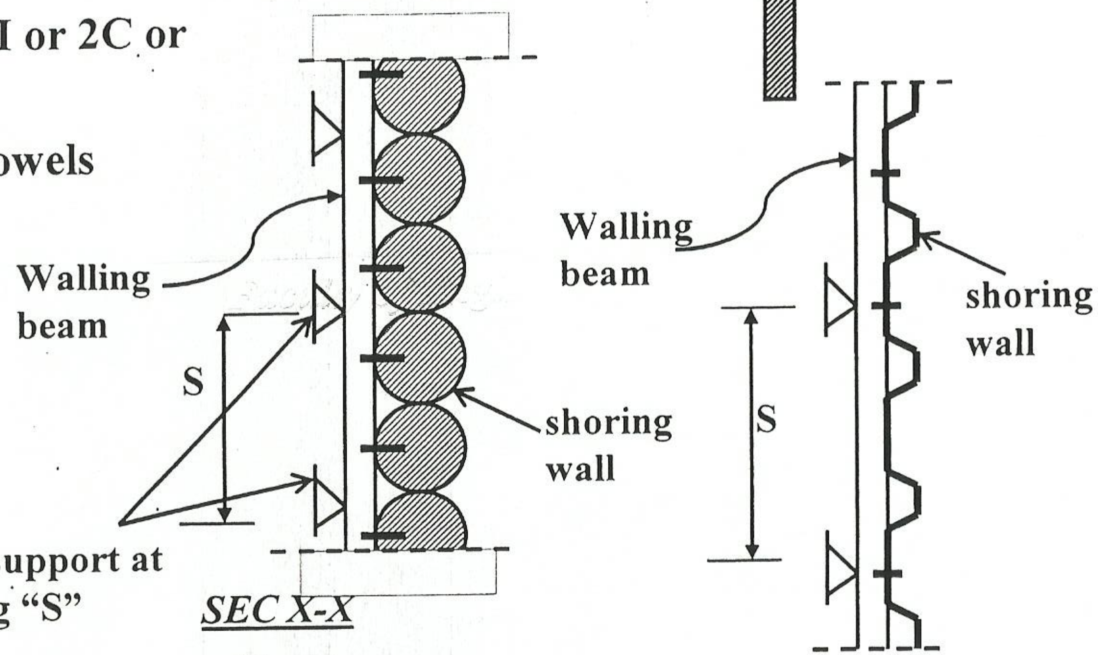
" Wale " {Continuous Walling Beam}

- The wale or (walling beam) is a continuous beam fixed onto the outer surface of the shoring wall (on the earth side) at the required level of lateral support
- It is usually of steel sections (e.g. 2I or 2C or box section)
- It is fixed with the wall by using dowels



Elevation





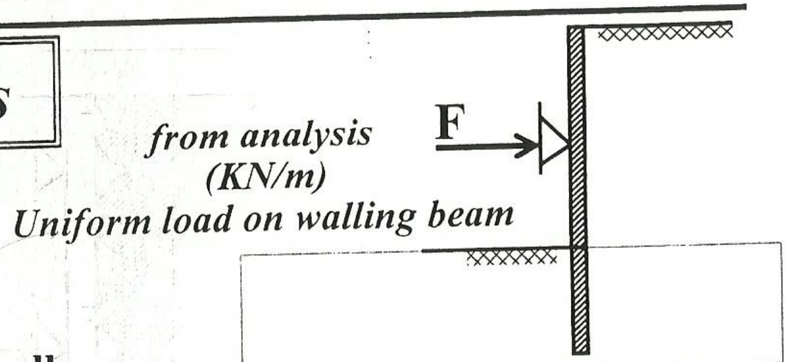
SEC X-X

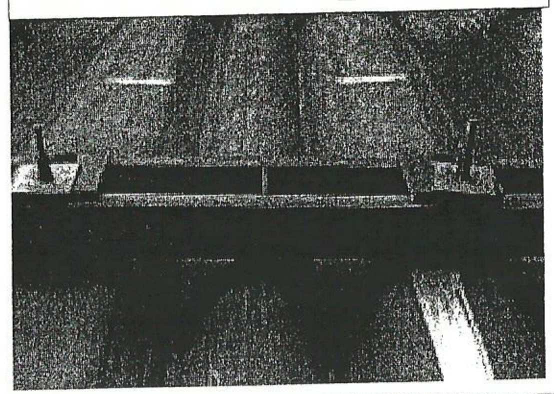
PLAN

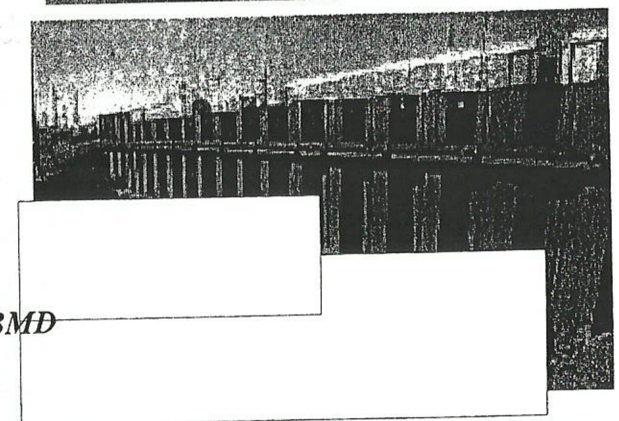
4

Lateral Support of Anchored-Walls

" Wale " {Continuous Walling Beam}

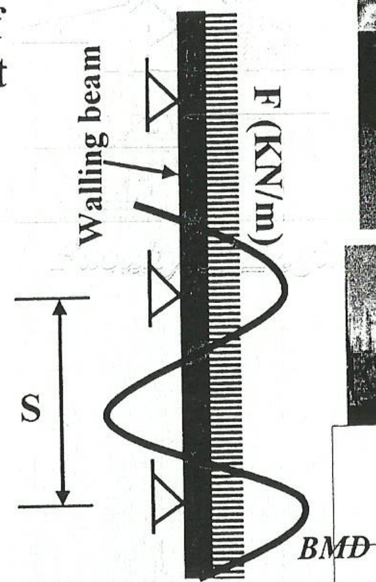






Functions of Wale:

1) Connecting the units (e.g. piles) of the shoring wall together to act as a one large continual unit
2) Facilitate the fixing of the lateral support on a continuous element (the wale) instead of fixing the lateral support in each wall unit
3) Transferring the reaction (F) from the shoring wall to the lateral support



Design of Wale:

$$M_{Max-walling} = \frac{F*(S)^2}{10}$$ *"as a continuous beam"*

Where:

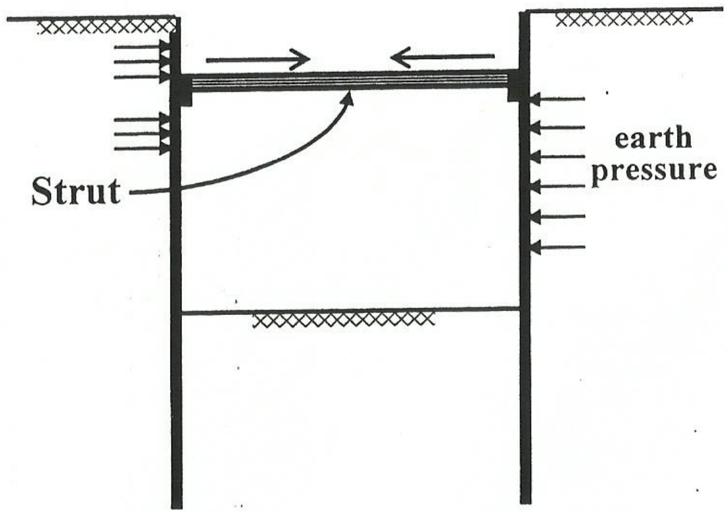
F = Reaction from analysis (KN/m)

S = typical spacing between lateral supports

Lateral Support of Anchored-Walls

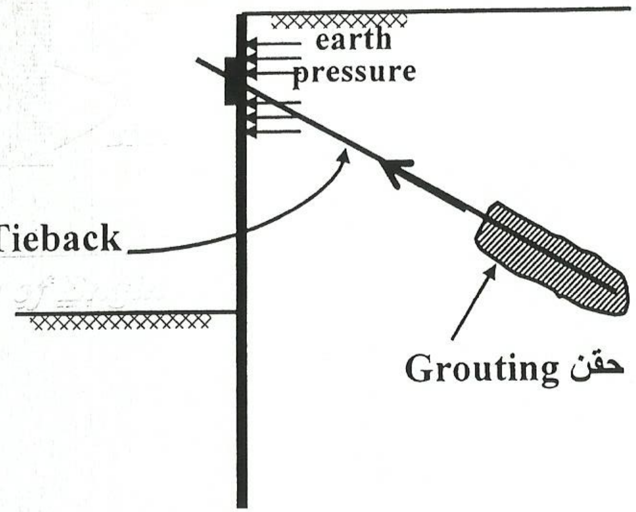
Fundamental Types of Lateral Support in Practice

[A] Strut



Compression element
{subjected to compression force}

[B] Tieback – Grouted Anchor

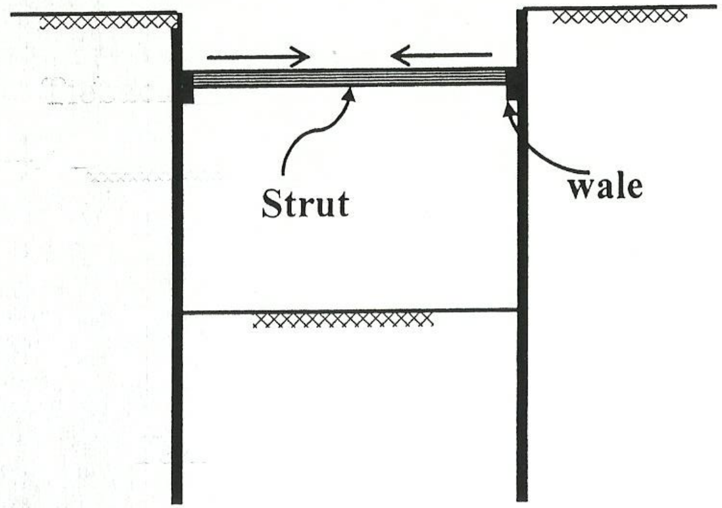


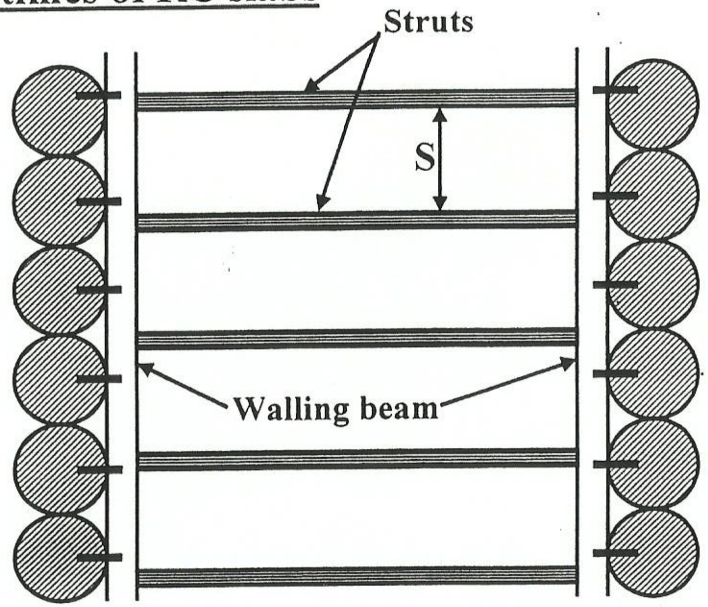
Tension element {subjected to tension/pullout force}

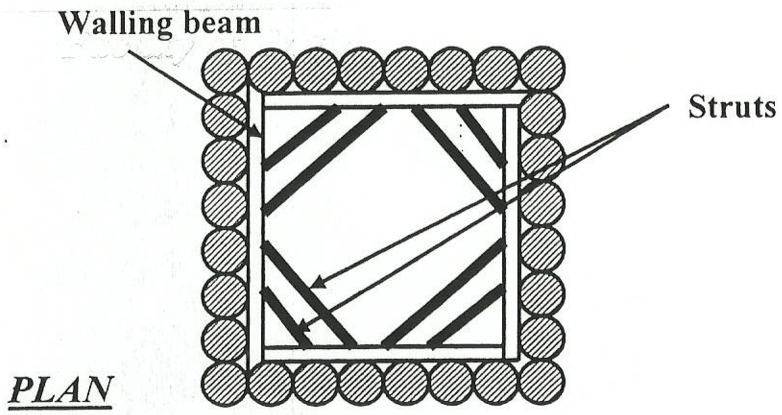
Fundamental Types of Lateral Support in Practice

[A] Strut

- Compression element between two shoring walls
- Spaced every spacing distance "S"
- Subjected to compression force from the earth pressure loads on the shoring wall
- Often from steel sections (such as steel pipes), <u>and some times of RC slabs</u>







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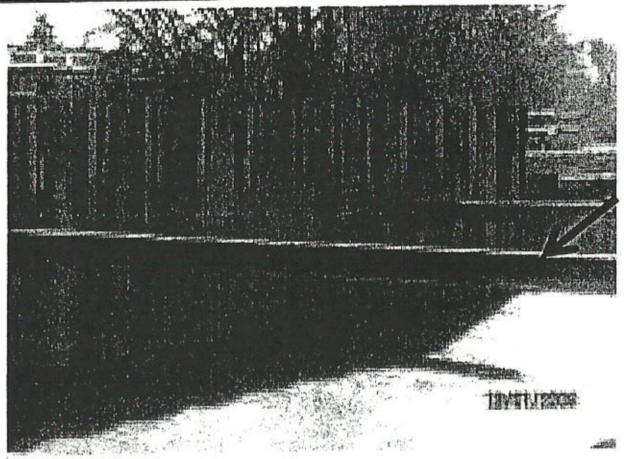
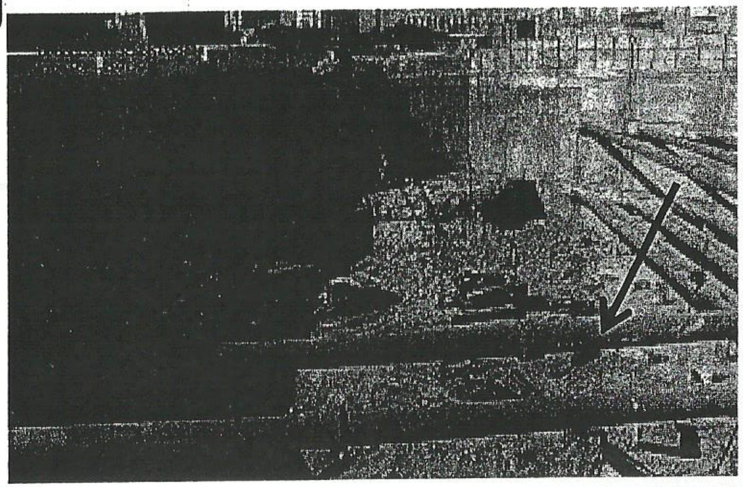
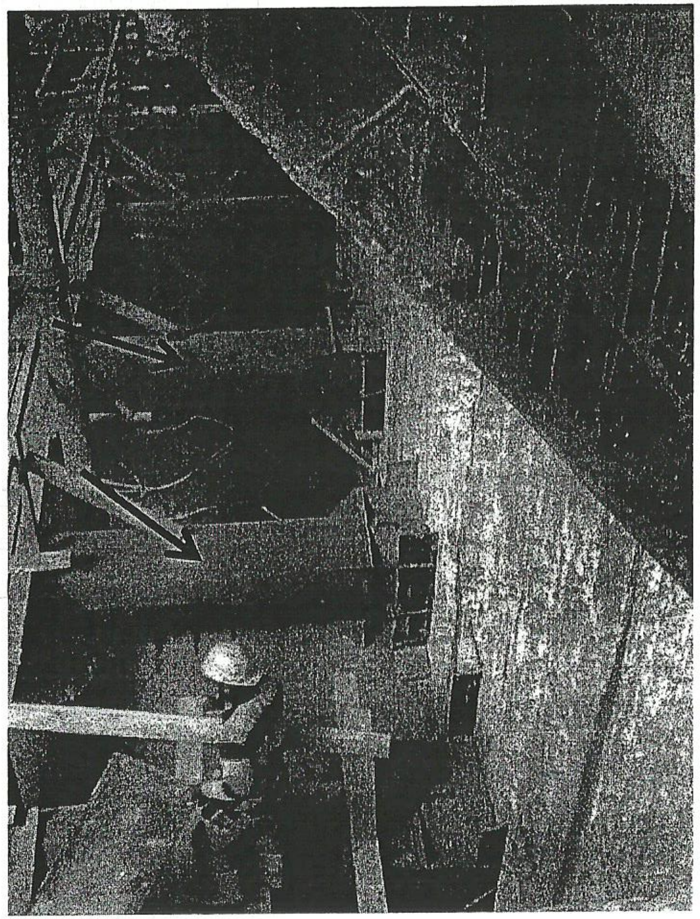
Fundamental Types of Lateral Support in Practice

[A] Strut







Fundamental Types of Lateral Support in Practice

[A] Strut

➢ **Design of Strut:**

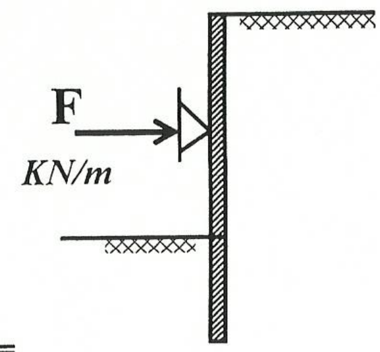
Compression force in each strut "C" = F * S

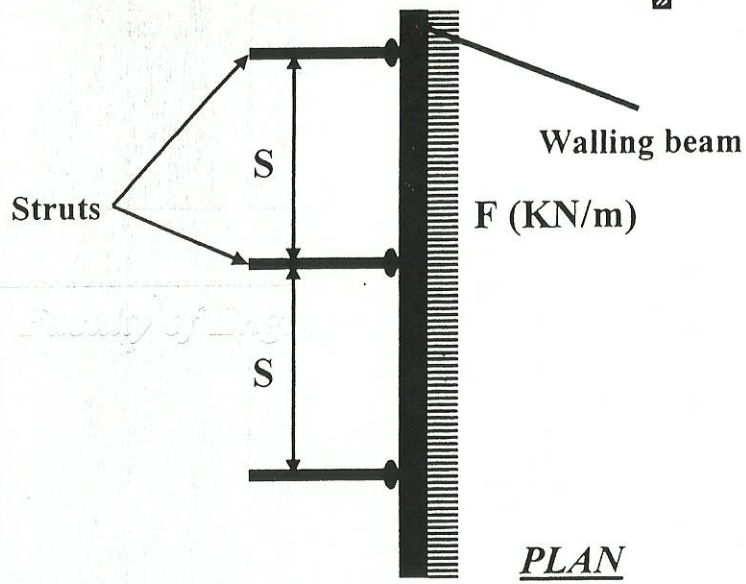
Where:

F = Reaction from analysis {uniform load on walling beam} (KN/m)

S = typical spacing between struts (2.0 m – 5.0 m)

➢ the main design aspect is the strut buckling



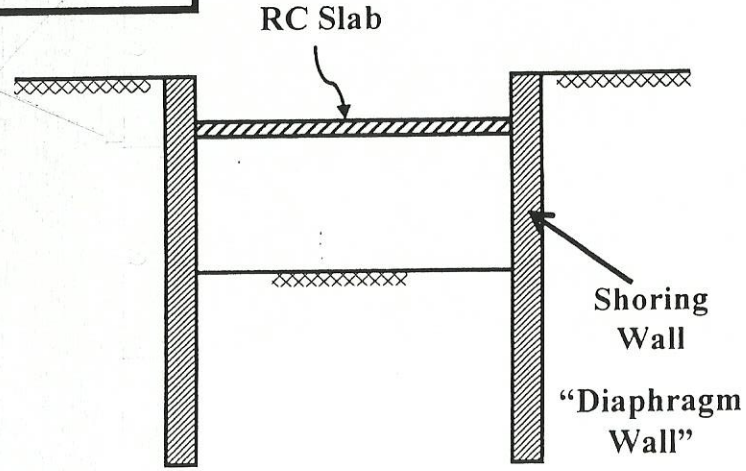


Fundamental Types of Lateral Support in Practice

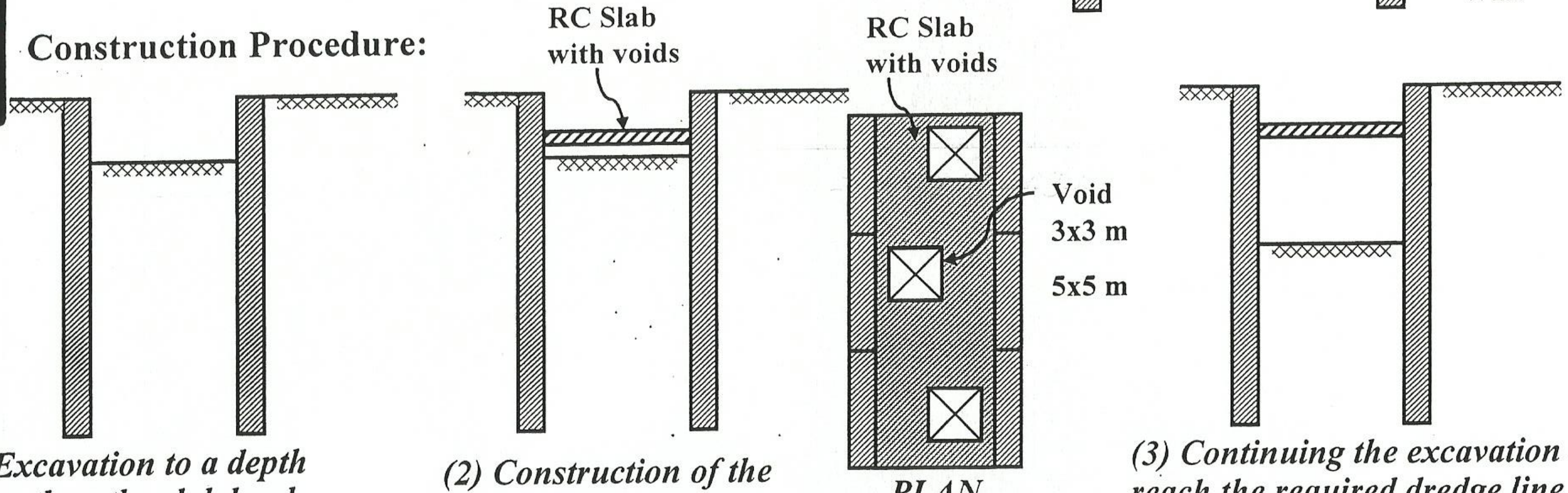
[A] Strut

➢ <u>RC Slab Strut:</u>

For applications of underground structures (such as underground metro station & underground parking area)



Construction Procedure:



(1) Excavation to a depth lower than the slab level

(2) Construction of the RC slab with voids

(3) Continuing the excavation to reach the required dredge line

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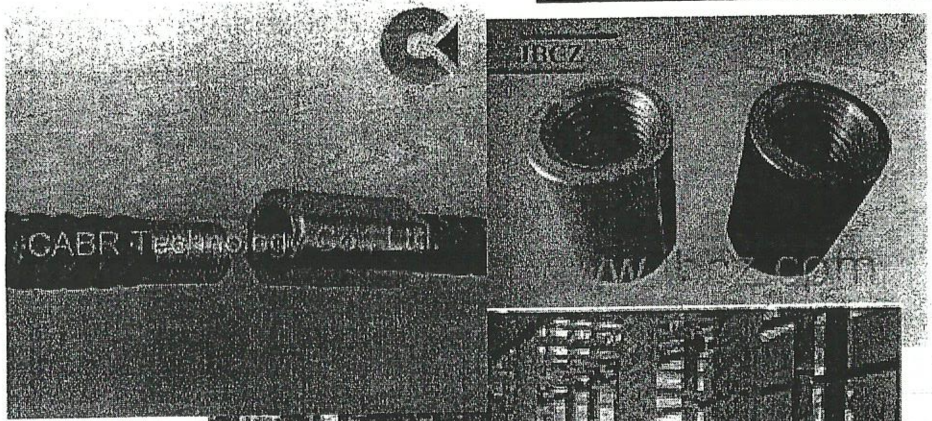
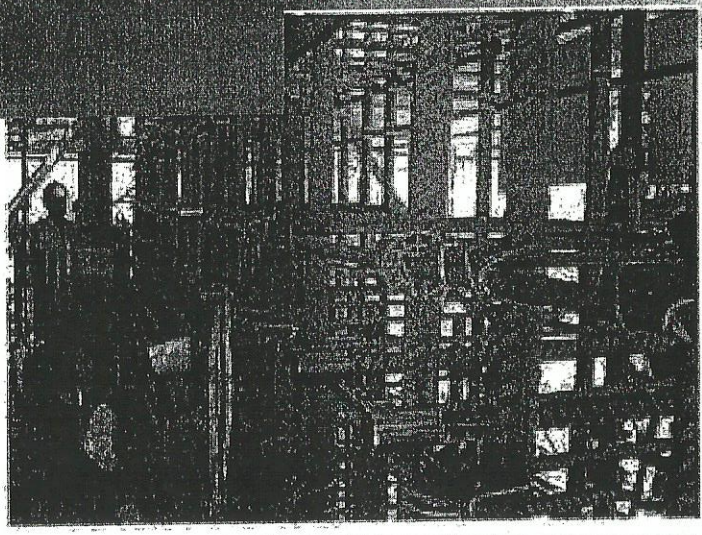
Fundamental Types of Lateral Support in Practice

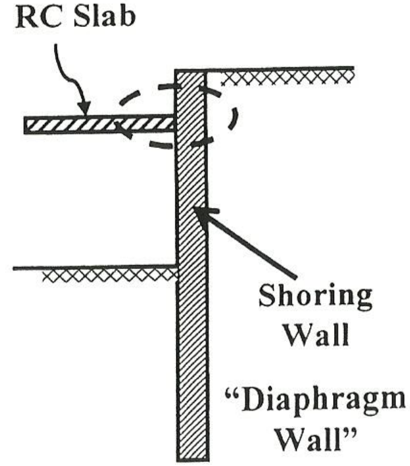
[A] Strut

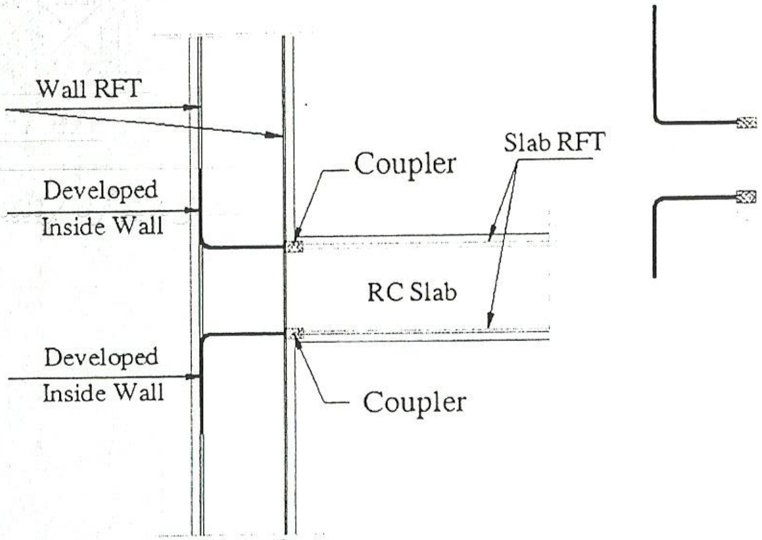
➢ **RC Slab Strut:** Connection between the RFT of the RC slab and the RFT of the diaphragm wall

Using Steel Coupler









Connection between Diaphragm wall and RC slab .

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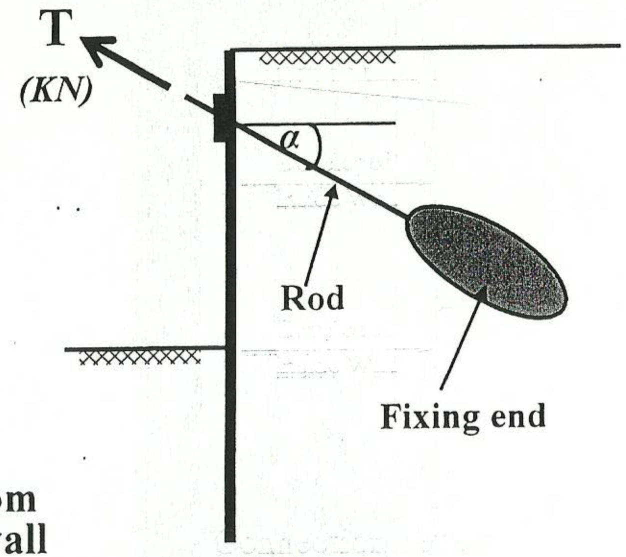
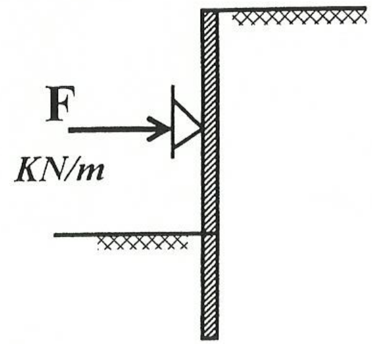
Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor

- Tension element ties the shoring wall from behind into the soil on the earth side
- Usually inclined on the horizontal direction with an angle "α" where α = 20° - 40 °
- Spaced every spacing distance "S"
- Subjected to tension (pullout) force from the earth pressure loads on the shoring wall





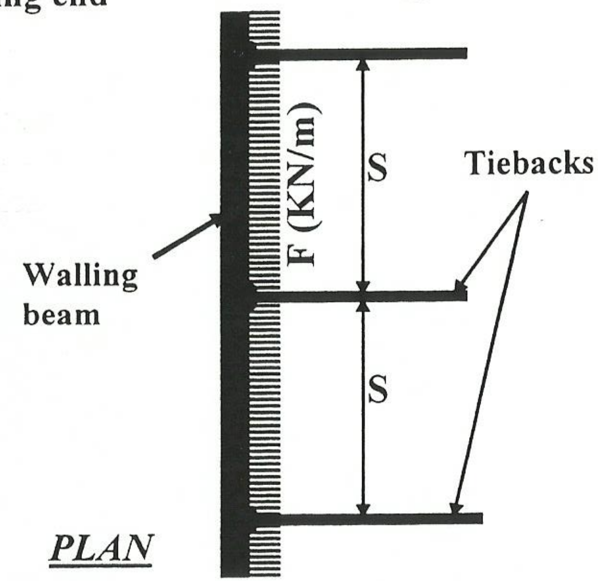
- Generally composed of steel rod connected to a fixing end (grouted body)

$$\text{Tension force in each Tieback "T"} = \frac{F * S}{\cos\alpha}$$

<u>*Where:*</u>

F = Reaction from analysis {uniform load on walling beam} (KN/m)

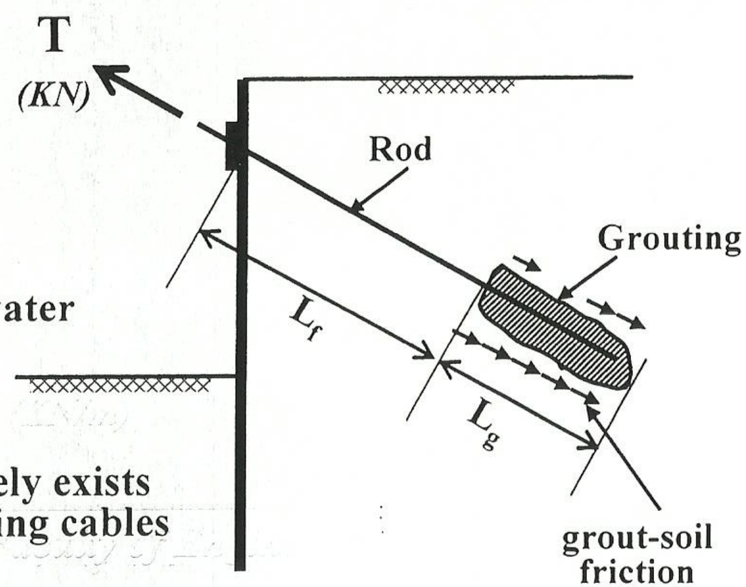
S = typical spacing between tiebacks (3.0 m – 5.0 m)



<u>*PLAN*</u>

Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor



❑ Rod:

➢ Steel rod or prestressing steel tendons

❑ Fixing End {Grouted Anchor}:

➢ grouted zone at the end of the anchor

➢ the grout material comprises cement + sand + water + admixtures

❑ Free Length & Grouted Length:

➢ L_f = free length of tieback along which the rod freely exists without grouting to allow for elongation of prestressing cables

➢ L_g = grouted length at the end of the tieback

➢ L_T = total inclined length of the tieback = $L_f + L_g$

❑ Resistance:

➢ The tieback system resists the tension force "T" by:

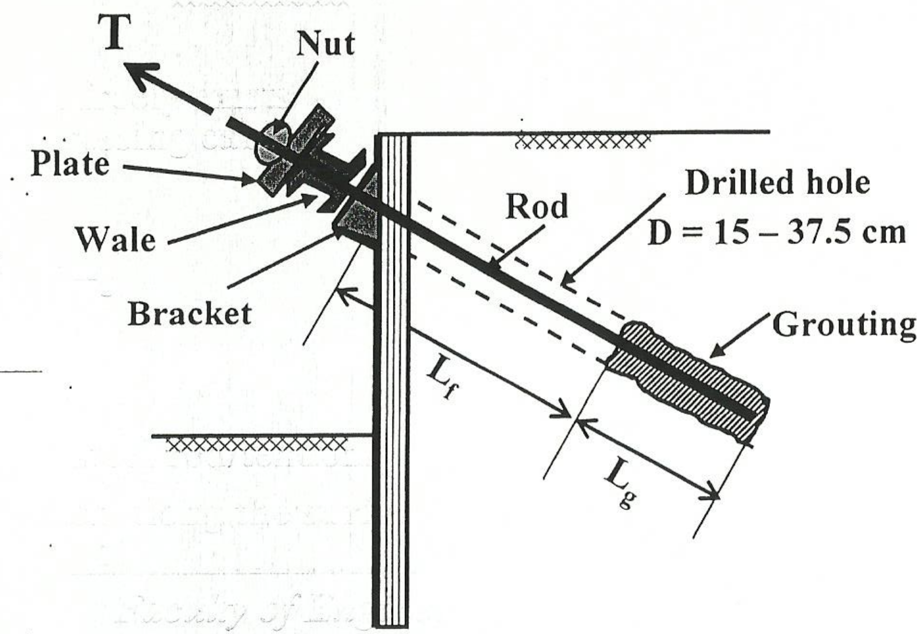
1) High tensile strength and prestreesing force of the steel rod/tendons

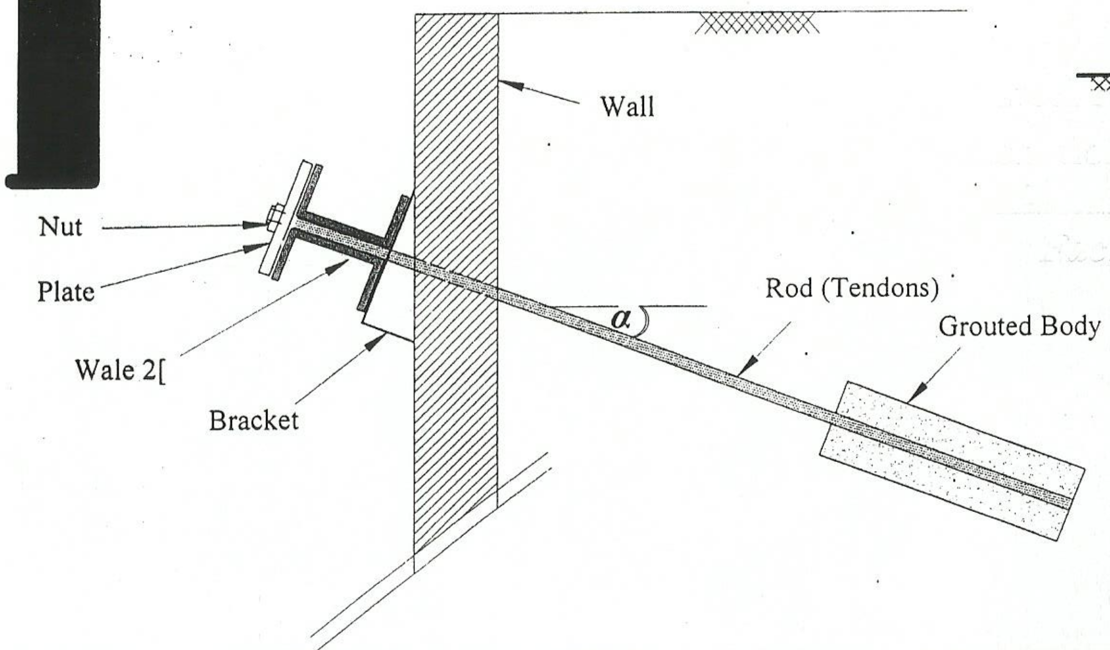
2) Bond between steel rod and grouting 3) Skin friction along the surface of the grouted body with the surrounding soil

Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor

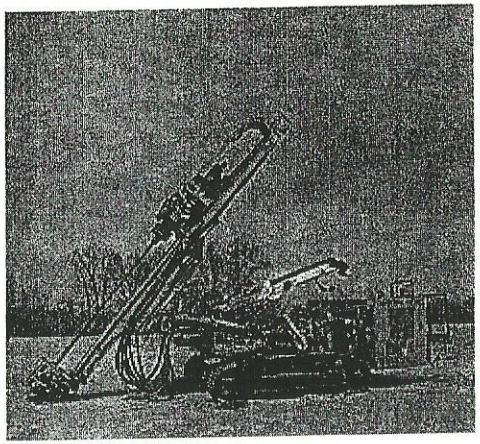
❑ **Typical Detail:**

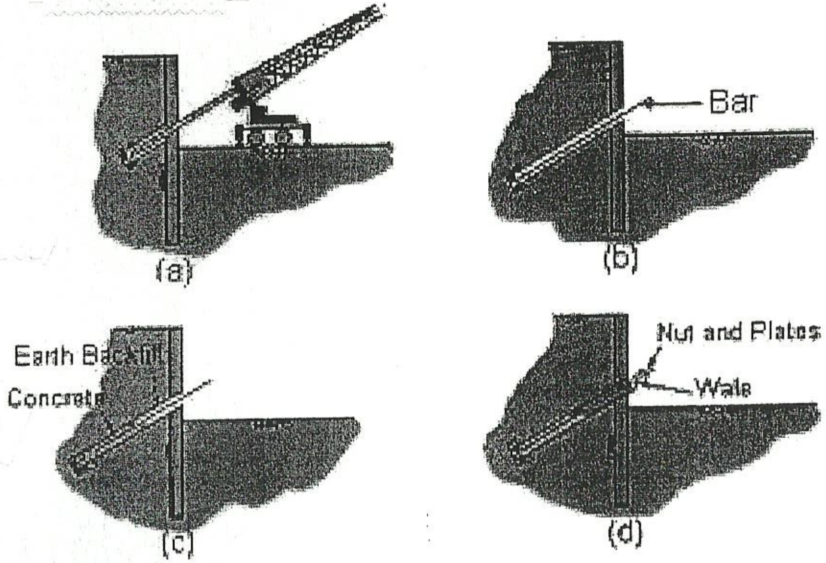


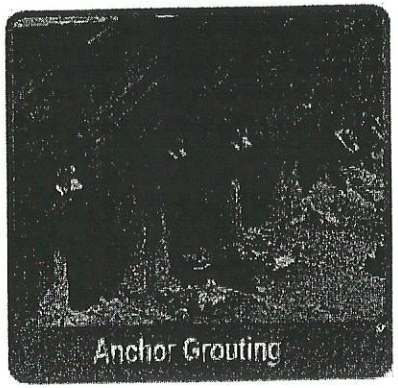


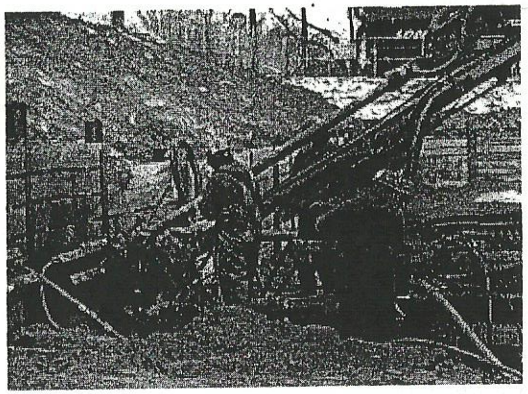
Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor









Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor

❑ Safe Zone for Grouting:

➢ Determination of the free length (L_f)

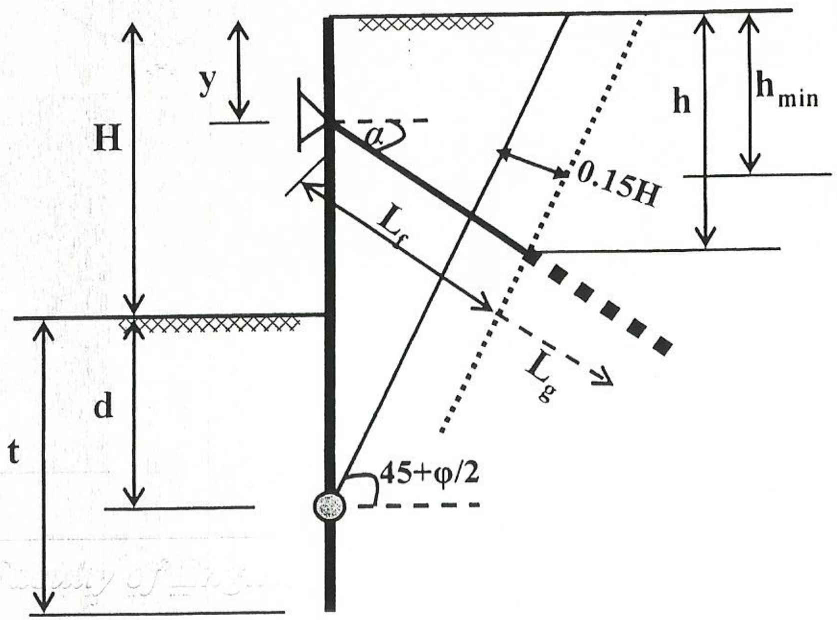
Graphical solution (draw to scale)

✓ determine the depth "h" at the safe start point of grouting

✓ check that $h > h_{min}$

where $h_{min} = 5.0$ m

✓Determine L_f from drawing



Anchored-free
OR anchored-fixed

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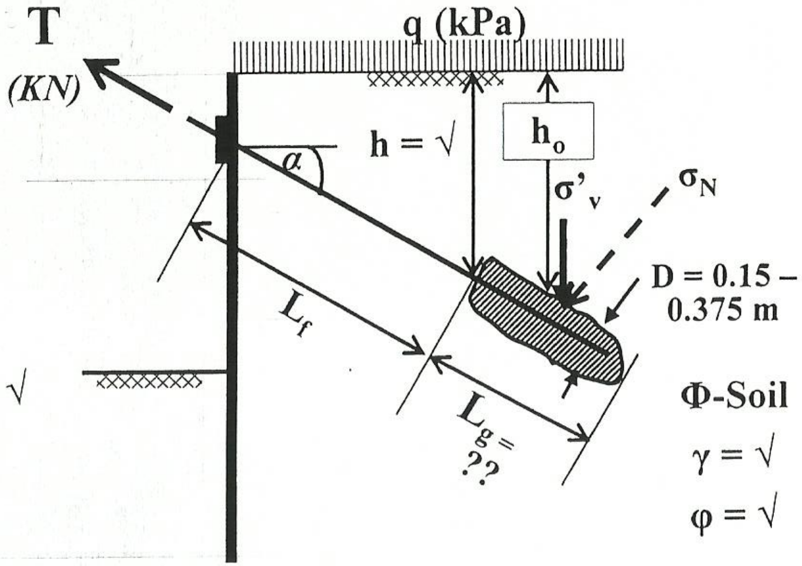
Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor

❑ Grouted Length (L_g):

$$T * FOS = \pi * D * L_g [\sigma_N * \tan\delta]$$



Where:

L_g = required grouted length of anchor = ????

T = Tension force in each tieback = $\frac{\text{wallingload*spacing}}{\cos\alpha}$ √

FOS = factor of safety ≈ 2.0

D = diameter of drilling "assumed" = 0.15 – 0.375 m √

$\delta = (3/4)\varphi$ (φ is the soil internal friction angle) √

σ_N = average normal stress on the surface of grouted body (kpa)

$$\sigma_N = \sigma'_v * \cos\alpha$$

α = inclination angle of tieback (given = 20° - 40°) √

σ'_v = effective vertical stress at the center of the grouted body = $[q + \gamma_{eff} * h_o]$

h_o = depth from ground surface to the center of the grouted body = $h + (L_g/2) * \sin\alpha$

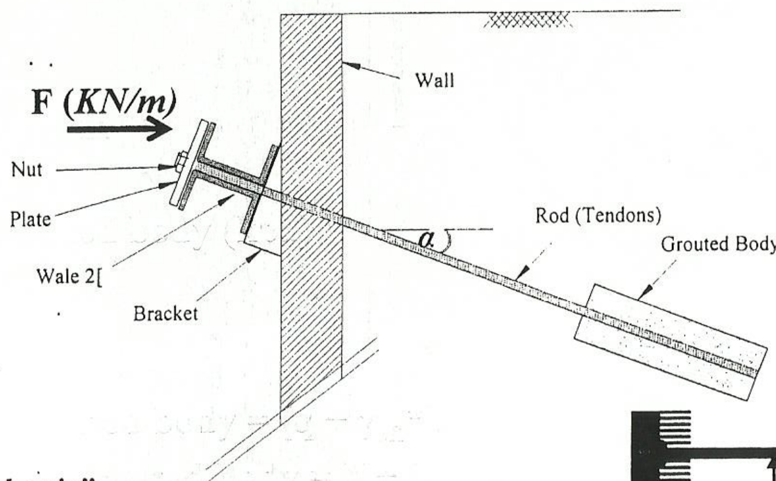
where "h" is obtained from the graphical solution for the free length of the tieback √

Fundamental Types of Lateral Support in Practice

[B] Tieback – Grouted Anchor

❑ **N.B:**

Maximum bending moment on inclined waling beam in case of grouted tie back:



"as a continuous beam"

$$M_{Max-walling} = \frac{F}{\cos\alpha} \times \frac{(S)^2}{10}$$

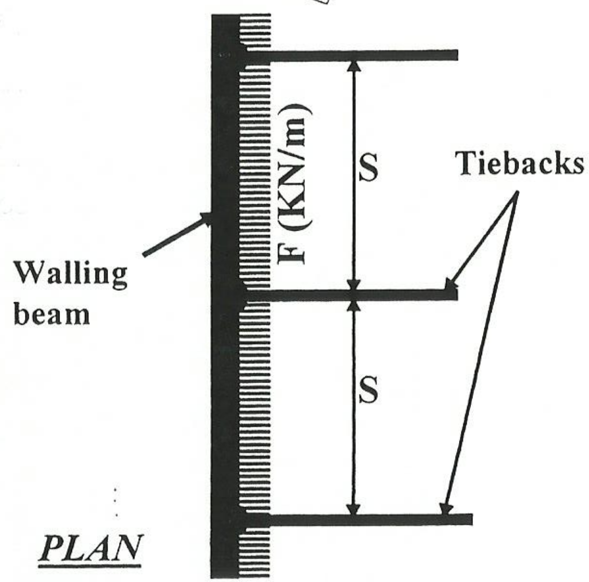
"about the principal axis"

Where:

F = Reaction from analysis (KN/m)

S = typical spacing between lateral supports

α = inclination angle of tieback



PLAN

[3] Analysis and Design of Braced Excavation System

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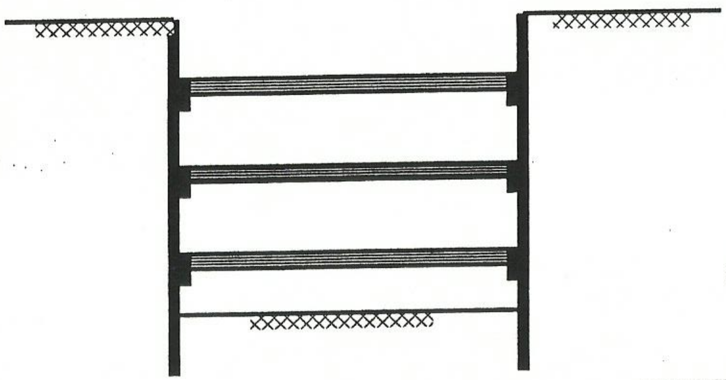
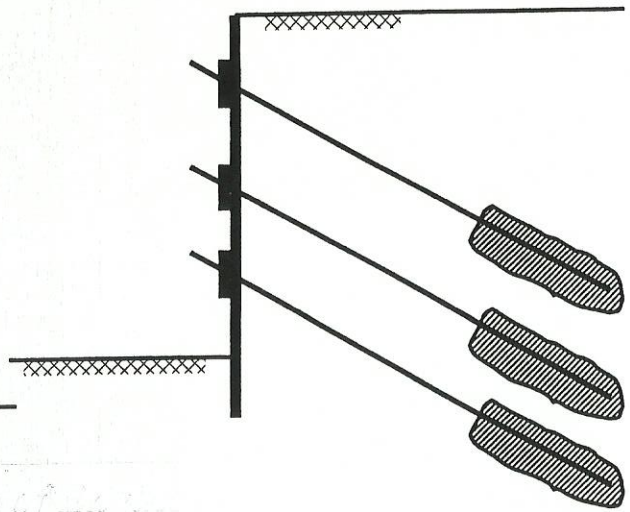
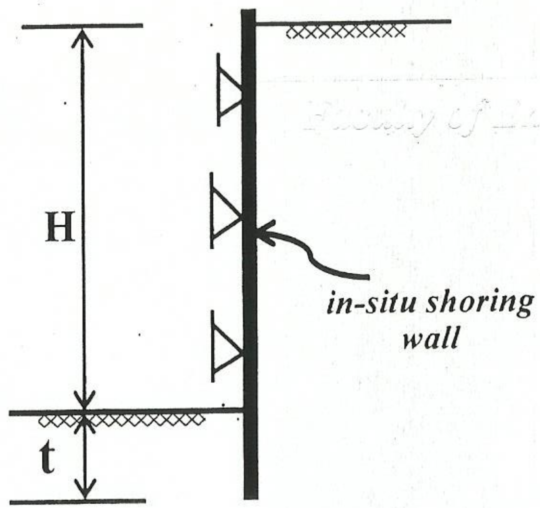
[3] Analysis and Design of Braced Excavation System

الحوائط الممسوكة جانبيا (الممنوعة من الحركة الجانبية) عند أكثر من نقطة





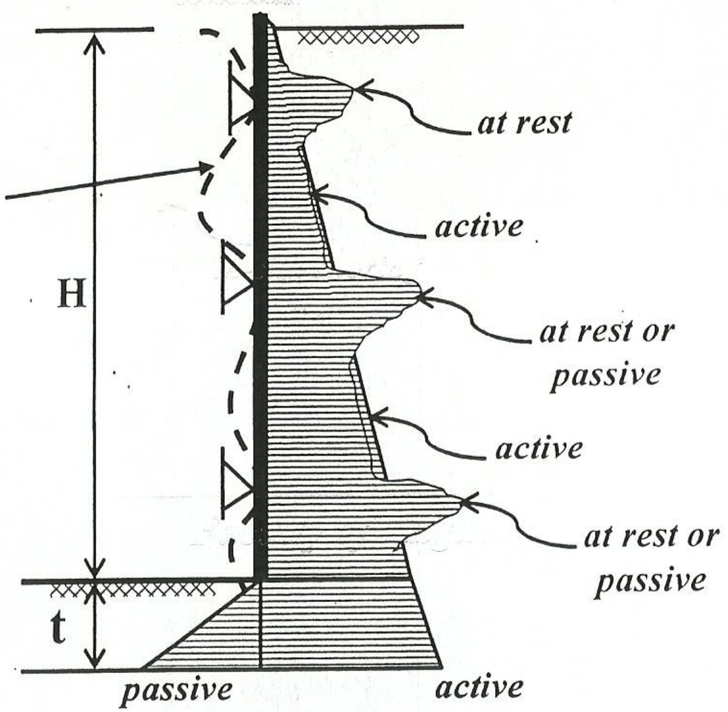
ELEVATION



➤ **The braced excavation system is a system of the in-situ shoring walls, in which the wall is anchored (prevented from horizontal movement) at more than one point (two or three, …) by means of a lateral support.**

[3] Analysis and Design of Braced Excavation System

❑ Lateral Earth Pressure on Braced Shoring Walls



- Complicated EP

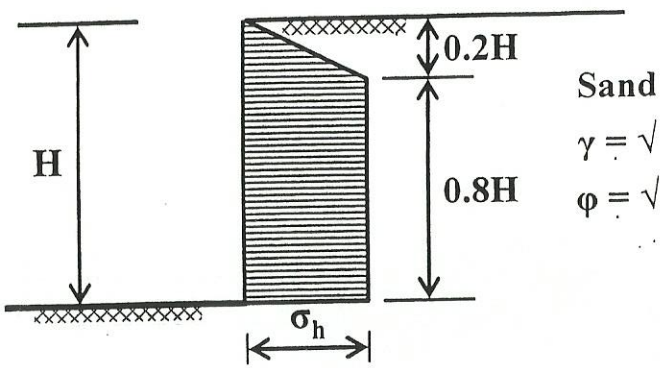
[3] Analysis and Design of Braced Excavation System

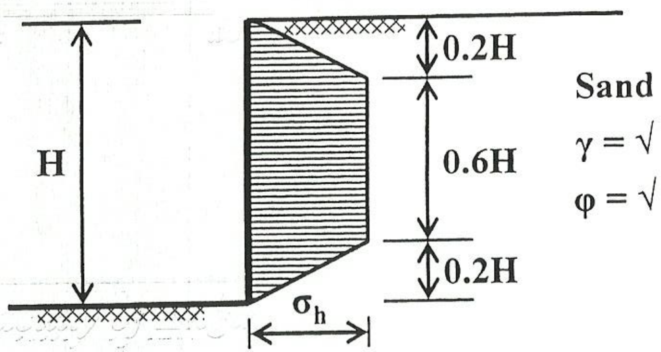
❑ Empirical Earth Pressure Diagrams on Braced Shoring Walls

Based on field measurements (Terzahgi & Peck, 1967)

Note that: these EP distributions are not dependent on the number or the locations of the lateral supports

➢ In Case of Sand Soil





For Loose Sand $\{\varphi \leq 32°\}$

$$\sigma_h = 0.8 * \gamma_{eff} * H * k_a$$

For Dense Sand $\{\varphi \geq 36°\}$

$$\sigma_h = 0.8 * \gamma_{eff} * H * k_a$$

Where: $k_a = \dfrac{1 - \sin\varphi}{1 + \sin\varphi}$

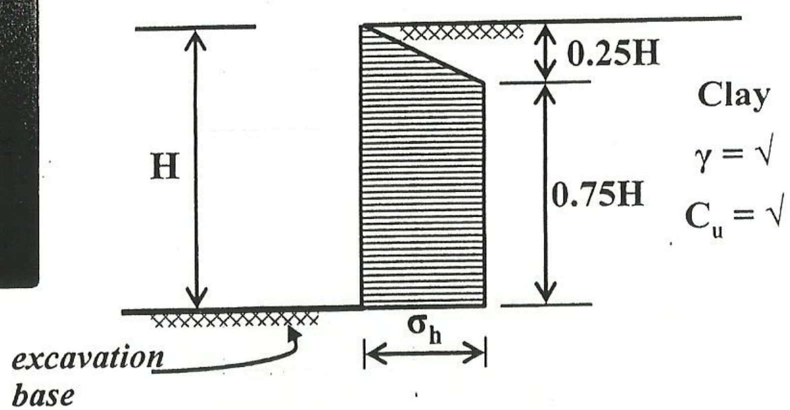
[3] Analysis and Design of Braced Excavation System

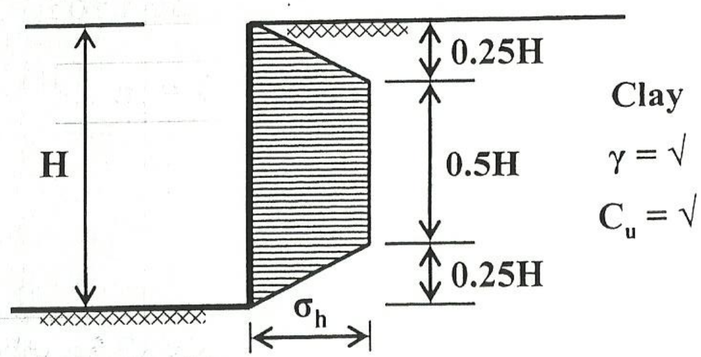
❑ Empirical Earth Pressure Diagrams on Braced Shoring Walls

Based on field measurements (Terzahgi & Peck, 1967)

Note that: these EP distributions are not dependent on the number or the locations of the lateral supports

➢ In Case of Clay Soil {undrained conditions}





For Soft to Medium Clay $\{C_u \leq 50\ kPa\}$

$$\sigma_h = \gamma_{eff} * H - 4m * C_u$$

❑ m = 0.4 for soft clay at the excavation base

❑ m = 1.0 for medium clay at the excavation base

For Stiff to Hard Clay $\{C_u = 50 - 200\ kPa\}$

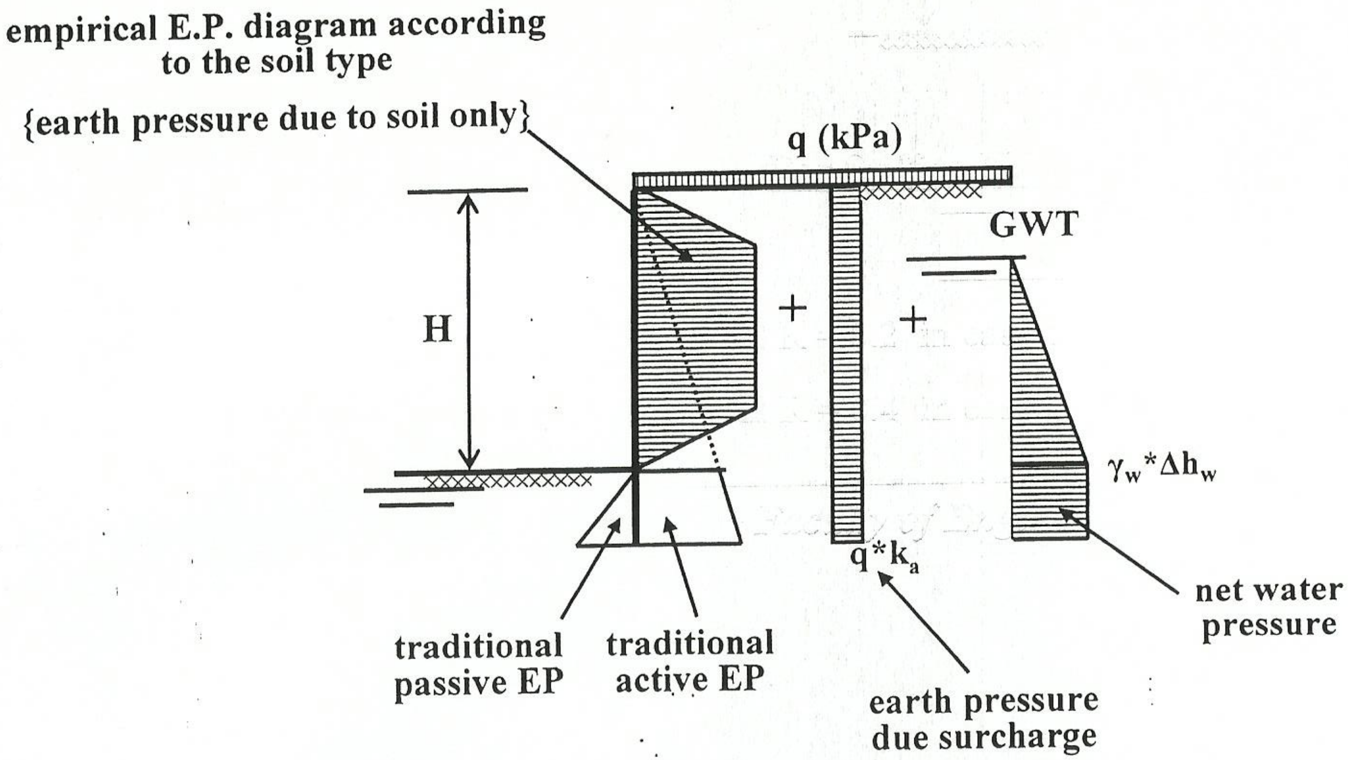
$$\sigma_h = R * \gamma_{eff} * H$$

❑ R = 0.2 in case of flexible wall (e.g. soldier piles)

❑ R = 0.4 in case of rigid wall (e.g. diaphragm wall)

[3] Analysis and Design of Braced Excavation System

❑ Lateral Earth Pressure on Braced Shoring Walls

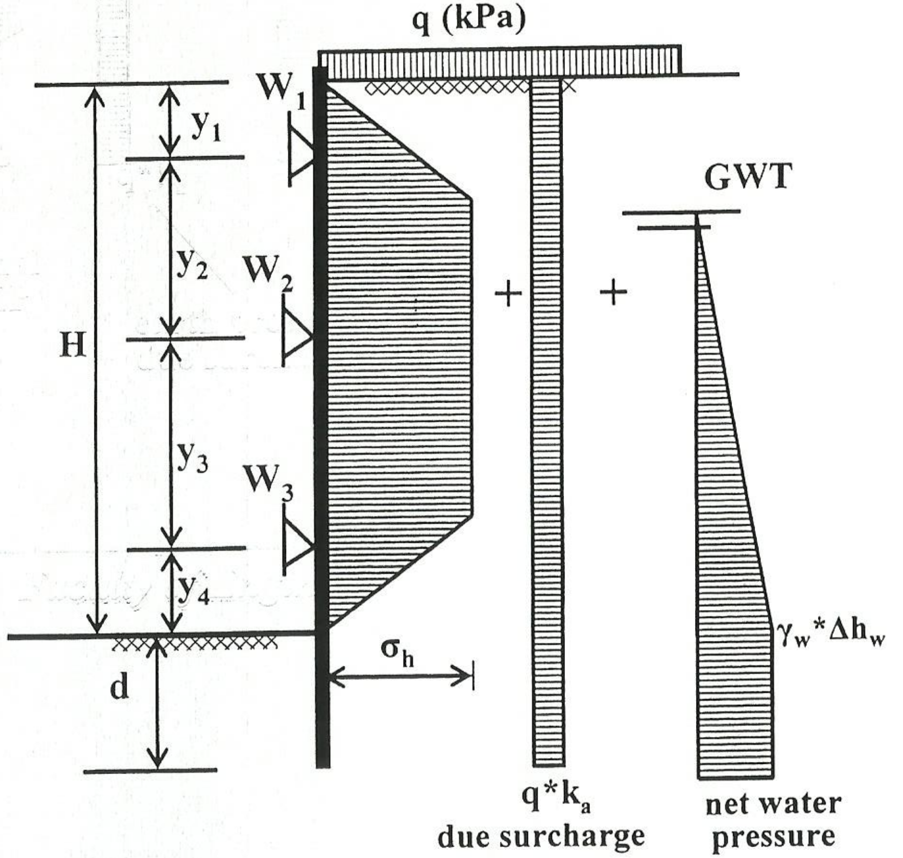


[3] Analysis and Design of Braced Excavation System

❑ Steps of Analysis and Design:

The fundamental requirements are: (1) the safe wall penetration depth "t", (2) the maximum bending moment on the wall "$M_{Max\text{-}wall}$", (3) the reactions on different wale beams, (4) the maximum bending moment on each wale beam and (5) the force in each lateral support

➢ Consider the wall end at a theoretical depth (d) below the dredge line "d is unknown"



[step 1] Determine the earth pressure due to soil (from the empirical distributions according to the soil type) + the earth pressure due to surcharge (if exists) + the net water pressure (if exists)

[3] Analysis and Design of Braced Excavation System

❑ Steps of Analysis and Design (cont.):

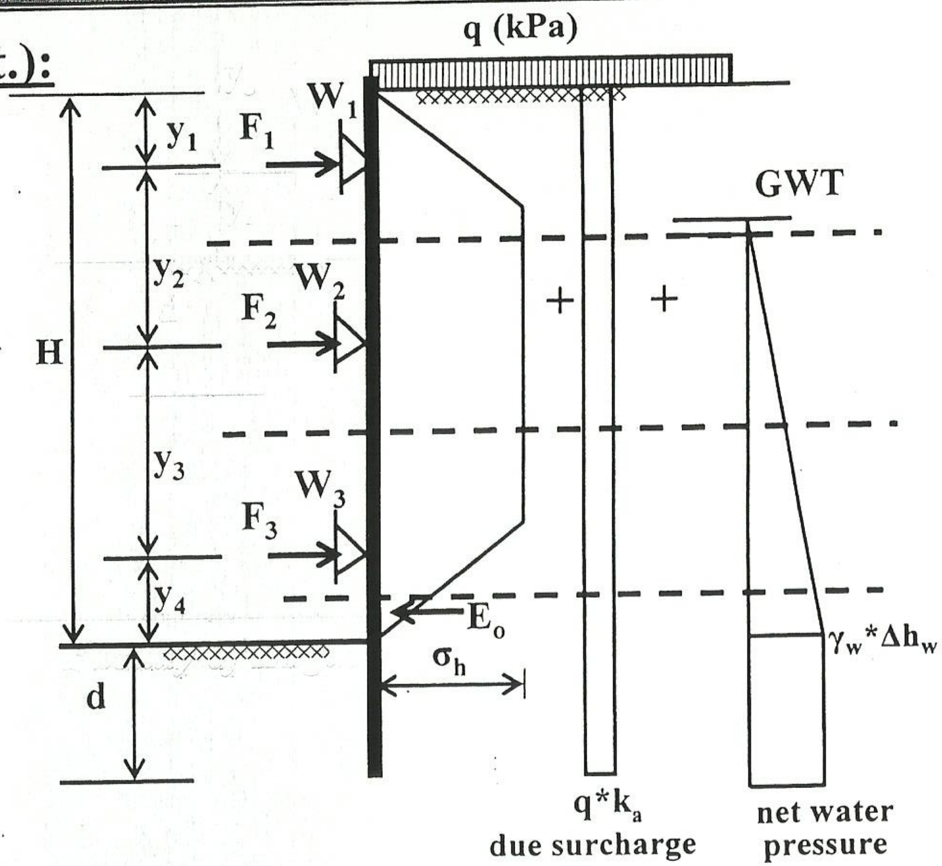
[step 2] Reactions on Supports

➢ F_1 (uniform load on walling beam W_1) = areas of pressure diagrams through the distance between ground surface to $y_2/2$ [KN/m]

➢ F_2 (uniform load on walling beam W_2) = areas of pressure diagrams through the distance between $y_2/2$ to $y_3/2$ [KN/m]

➢ F_3 (uniform load on walling beam W_3) = areas of pressure diagrams through the distance between $y_3/2$ to $y_4/2$ [KN/m]

➢ E_o (load carried on the embedded depth) = areas of pressure diagrams through the distance between $y_4/2$ to the dredge line[KN/m]



[3] Analysis and Design of Braced Excavation System

☐ Steps of Analysis and Design (cont.):

[step 3] Maximum moments on wales

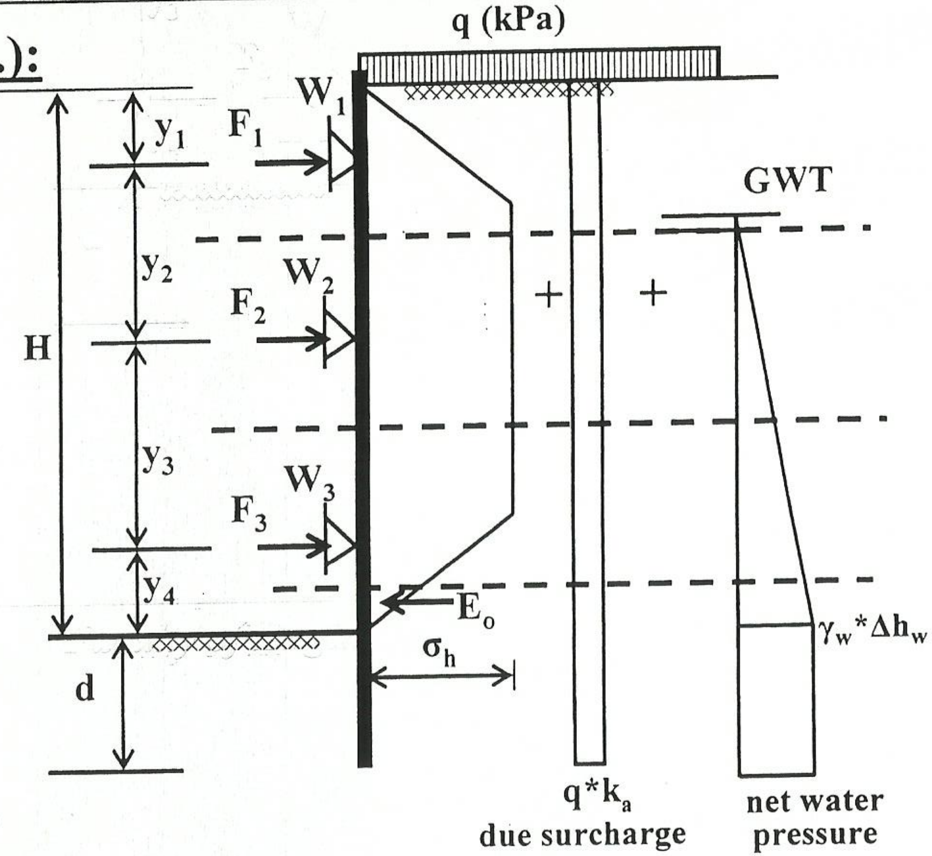
$$M_{Max-walling(1)} = \frac{F1*(S)^2}{10}$$

$$M_{Max-walling(2)} = \frac{F2*(S)^2}{10}$$

$$M_{Max-walling(3)} = \frac{F3*(S)^2}{10}$$

Where:

S = typical spacing between lateral supports



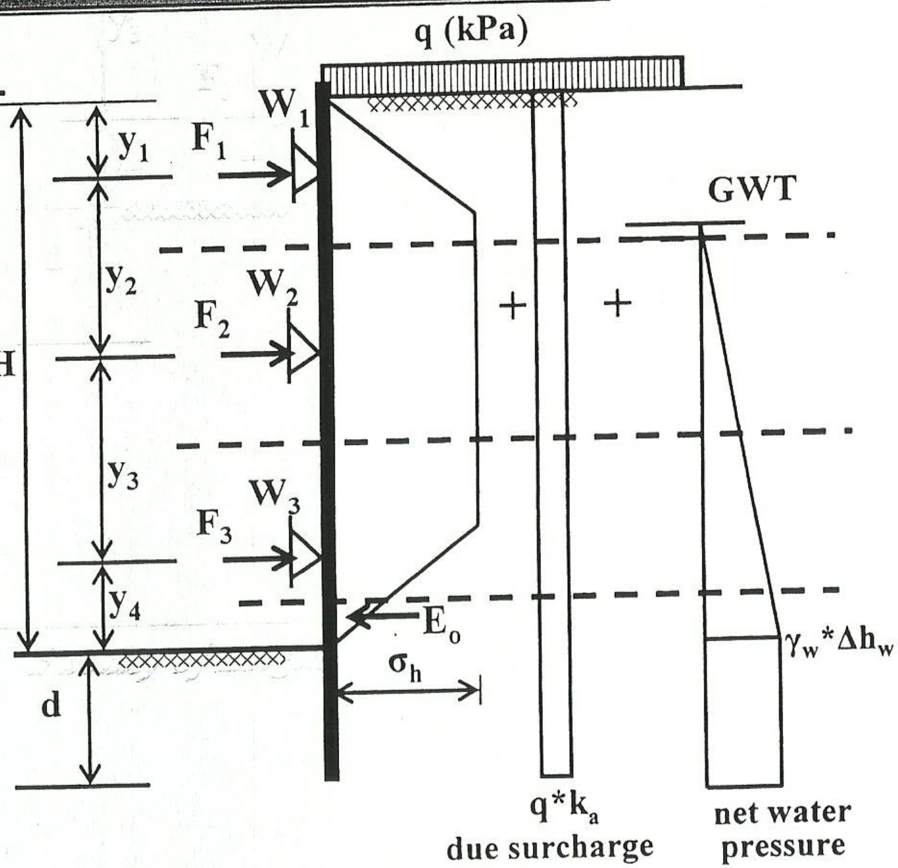
[3] Analysis and Design of Braced Excavation System

❑ Steps of Analysis and Design (cont.):

[step 4] **Forces on lateral supports**

Compression force in each strut "C" = F * S

Tension force in each Tieback "T" $= \dfrac{F*S}{\cos\alpha}$



[3] Analysis and Design of Braced Excavation System

❑ Steps of Analysis and Design (cont.):

[step 5] Maximum bending moment on wall

$M_{Max\text{-}wall}$ *KN.m/m*

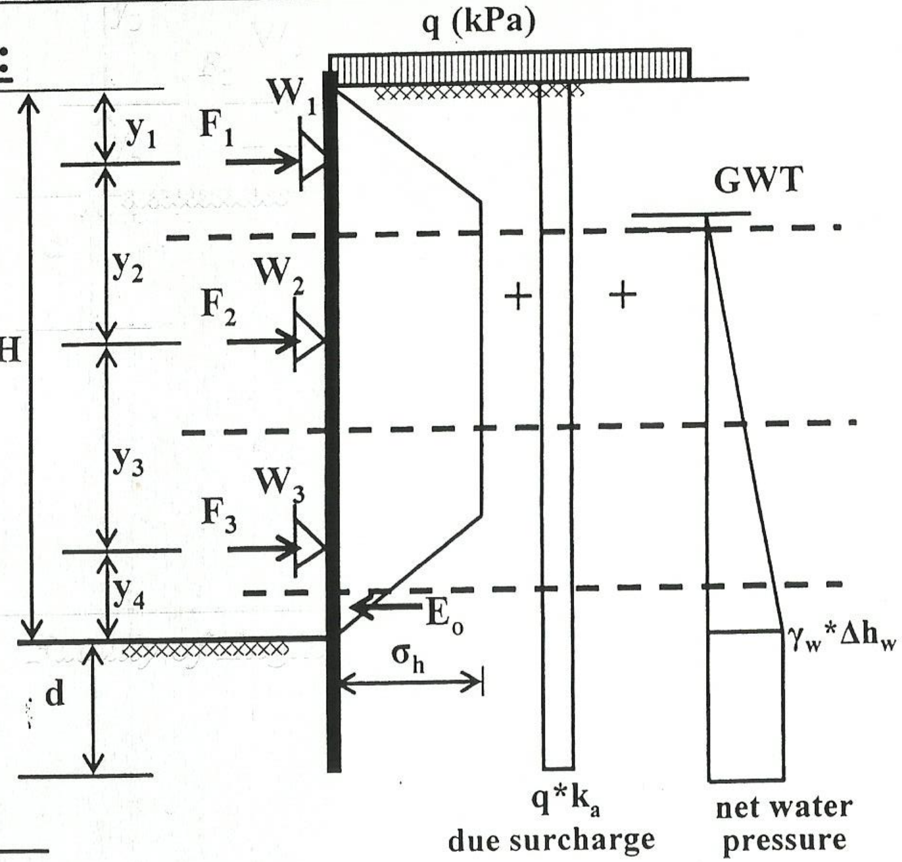
→ M_o الأكبر M_{cant}

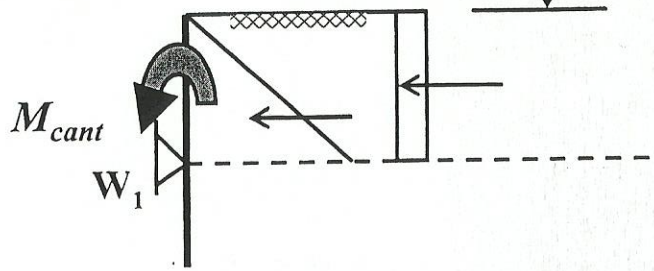
$$M_o = \frac{\sigma * (y_{max})^2}{10}$$ *Intermediate moment*

Where:

y_{max} = *the greater of* y_2 *or* y_3

$$\sigma = \sigma_h + q * k_a + \frac{\gamma_w * \Delta h_w}{2}$$





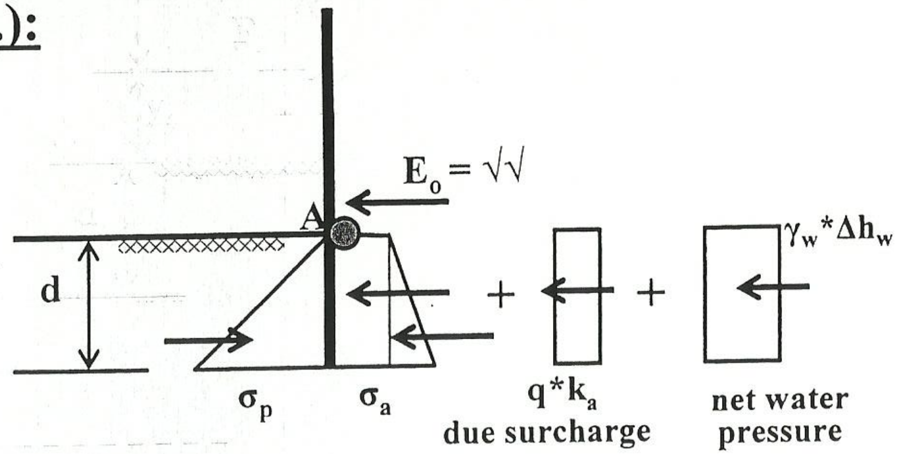
[3] Analysis and Design of Braced Excavation System

❑ Steps of Analysis and Design (cont.):

[step 6] Wall penetration depth

➢ calculate the active and passive earth pressure through the theoretical penetration depth "d"

➢ calculate the forces (all will be as a function of "d" or "d^2"; in addition to the force E_o from the upper braced wall



❖ Take $\sum Fx = 0$ along the depth "d"

an equation will result as a function of "d^2"

For example: $-(\ldots)d^2 + (\ldots)d + (\ldots) = 0$

❑ Solve the equation with respect to "d" get $d = \surd\surd$ m

❖ the safe penetration depth: get $t = 1.2 \times d = \surd\surd$ m وتقرب لاقرب ٥٠ سم بالزيادة

Not fixed

[3] Analysis and Design of Braced Excavation System

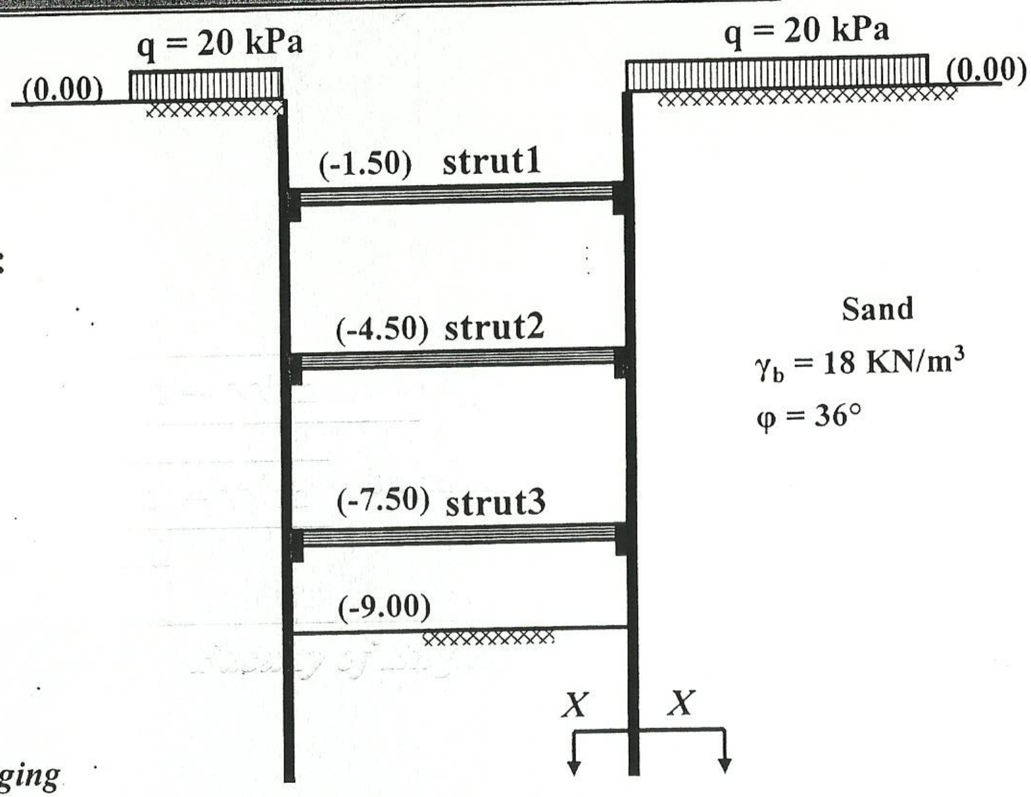
Example [4]:

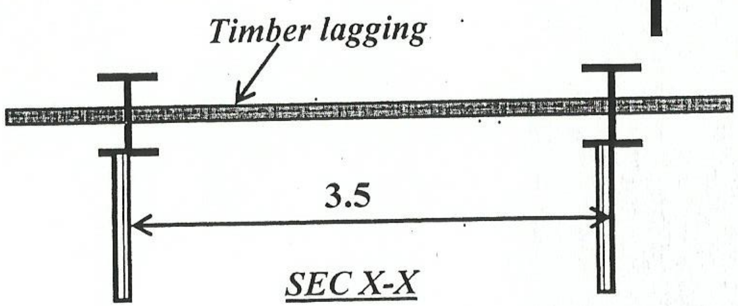
For the shown braced strutted soldier pile wall, the horizontal spacing between struts is 3.5 m, it is required to:

[1] Determine the force in each strut

[2] Determine the maximum bending moment per each soldier IB-pile

[3] Estimate the safe penetration depth of the wall

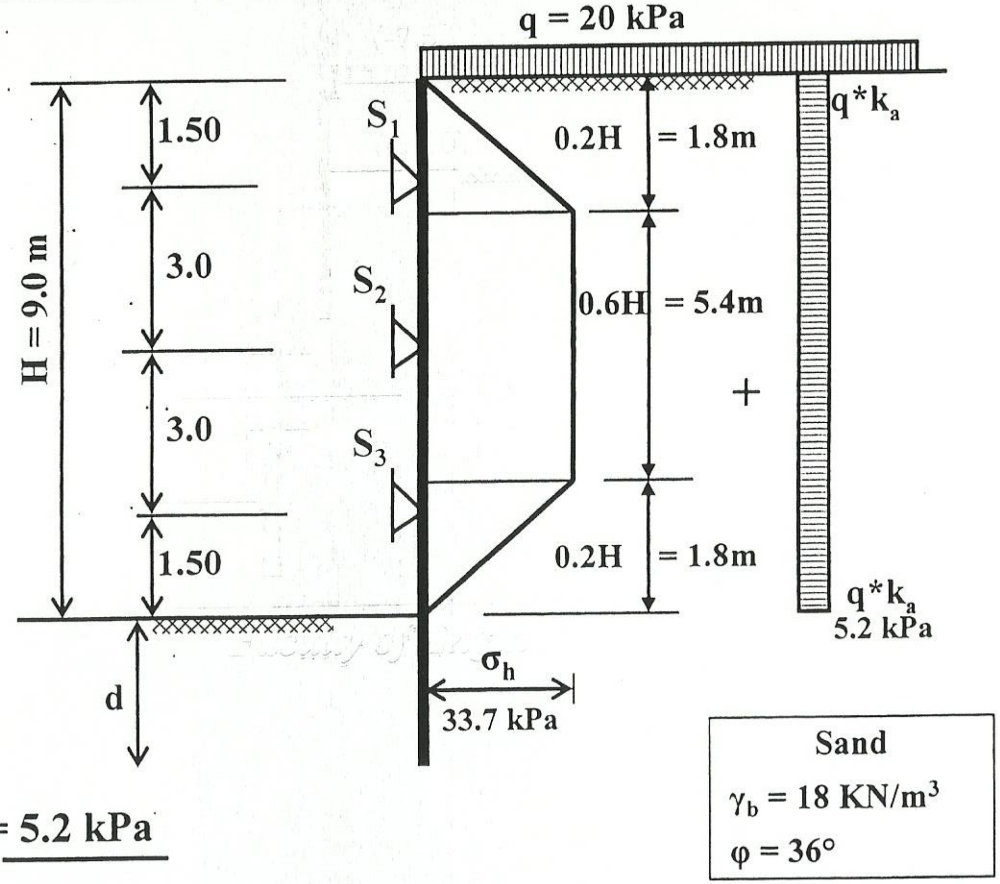




[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

> ➢ Consider the wall end at a theoretical depth (d) below the dredge line



Step (1): Calculations of EP :

➢ the soil is sand with $\varphi = 36°$ (Dense Sand)

$$\sigma_h = 0.8 * \gamma_{eff} * H * k_a$$ *due to soil only*

$$k_a = \frac{1 - \sin\varphi}{1 + \sin\varphi} = \frac{1 - \sin 36}{1 + \sin 36} = 0.26$$

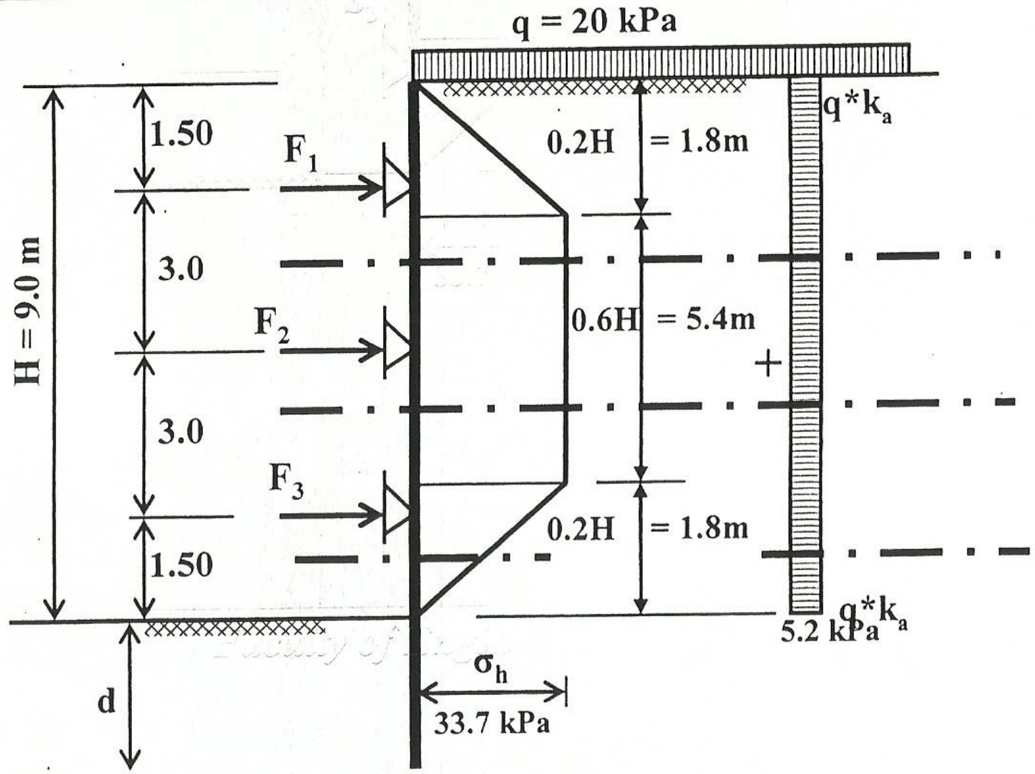
❖ $\sigma_h = 0.8 * \underset{\gamma_b}{18} * 9.0\ m * 0.26 = \underline{33.7\ kPa}$

➢ due to surcharge $= q * k_a = 20 * 0.26 = \underline{5.2\ kPa}$

[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

Step (2): Reactions



[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

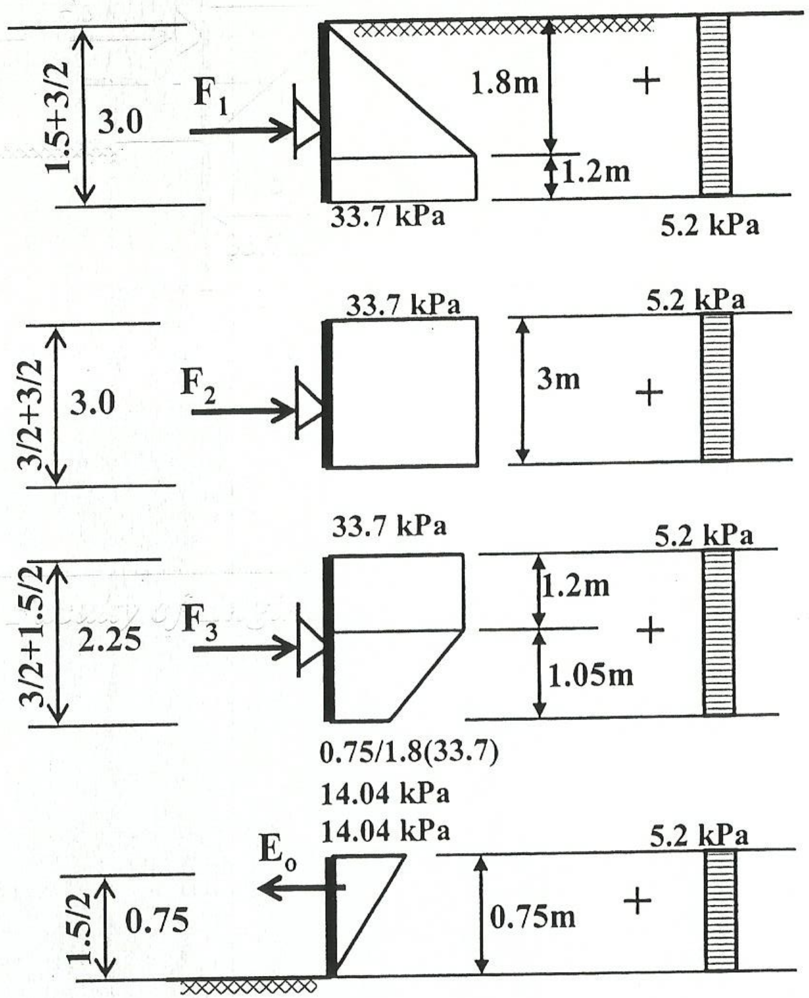
Step (2): Reactions

❖ $F_1 = 0.5*1.8m*33.7 + 1.2m*33.7 + 5.2*3.0m = 86.37$ KN/m

❖ $F_2 = 3.0m*33.7 + 3.0m*5.2 = 116.7$ KN/m

❖ $F_3 = 1.2m*33.7 + 0.5*1.05m*(33.7+14.04) + 2.25 * 5.2 = 77.2$ KN/m

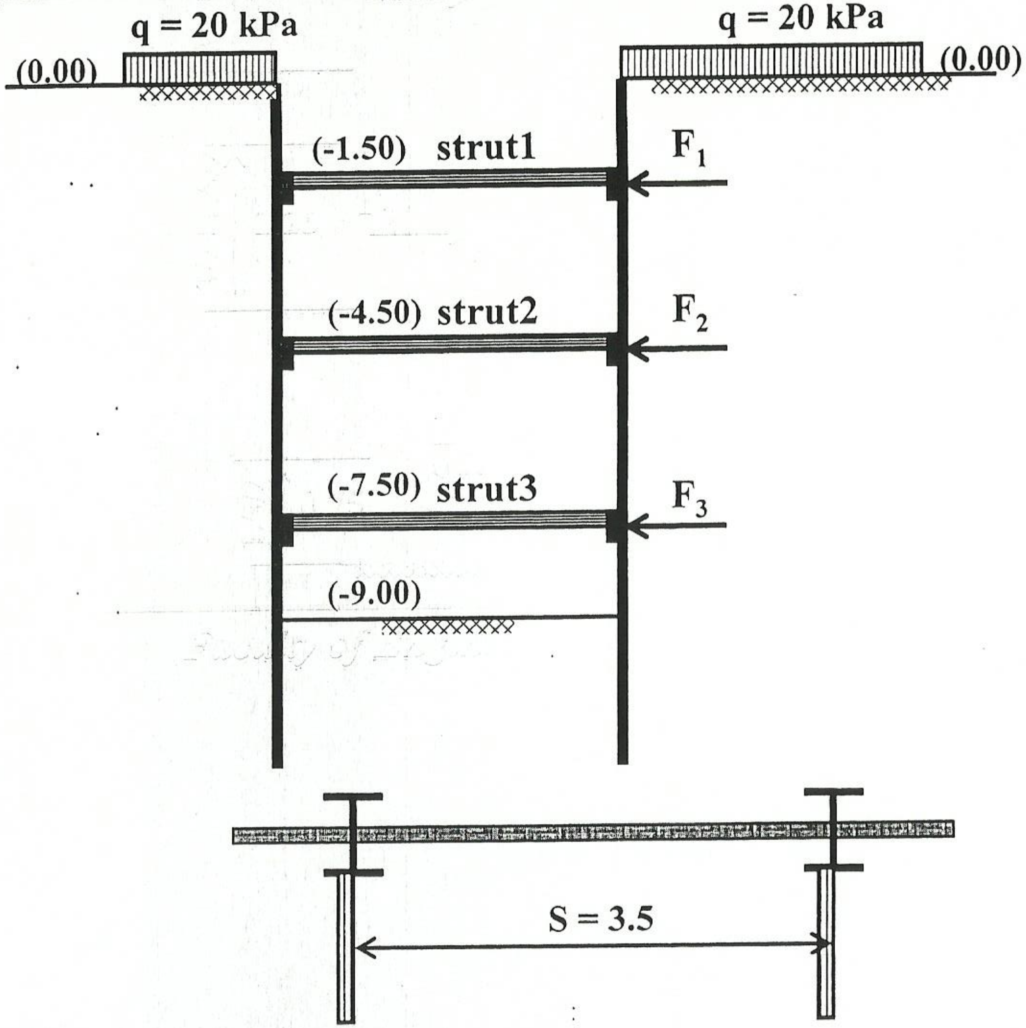
❖ $E_o = 0.5*0.75m*14.04 + 5.2*0.75m = 9.17$ KN/m



[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

Step (3): Forces in Struts



- Compression force in Strut 1 = F_1 * S

  = 86.37 * 3.5 m = 302.3 KN

- Compression force in Strut 2 = F_2 * S

  = 116.7 * 3.5 m = 408.5 KN

- Compression force in Strut 3 = F_3 * S

  = 77.2 * 3.5 m = 270.2 KN

[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

Step (4): Maximum moment on wall

$$M_o = \frac{\sigma * (y_{max})^2}{10}$$ *Intermediate moment*

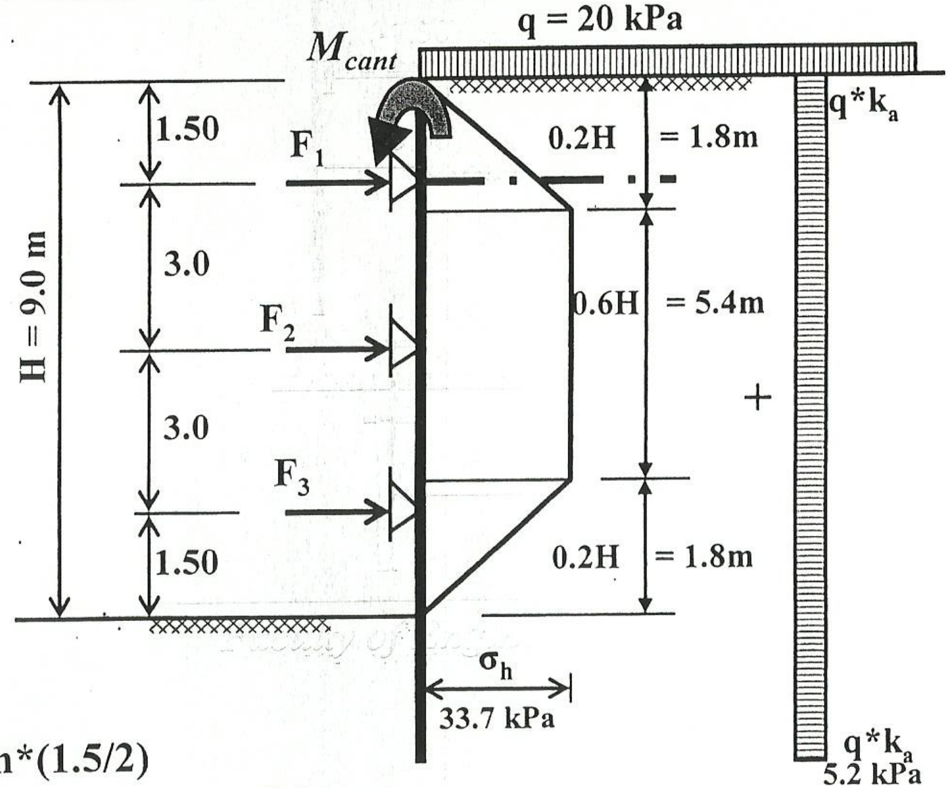
Where:

$y_{max} = 3.0\ m$

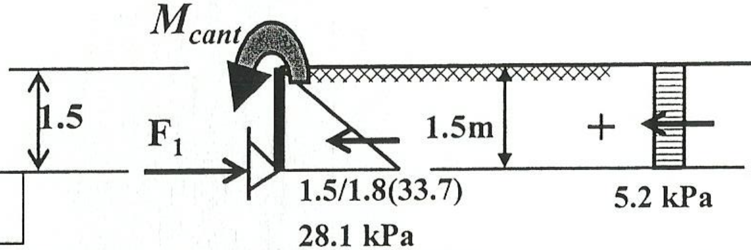
$\sigma = \sigma_h + q * k_a$

➢ $\sigma = 33.7 + 5.2 = 38.9$ kPa

❖ $M_o = \frac{38.9*(3.0)^2}{10}$ **= 35 KN.m/m**



❖ $M_{cant} = 0.5*28.1*1.5m*(1.5/3) + 5.2*1.5m*(1.5/2)$
= 16.4 KN.m/m



❖ $M_{Max\text{-}wall}$ = 35 KN.m/m نختار الاكبر

❖ $M_{Max\text{-}per\ soldier\ pile}$ = 35 * 3.5m = 122.5 KN.m

[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

Step (5): Wall penetration depth

❖ Within the penetration zone, use the traditional active and passive calculations

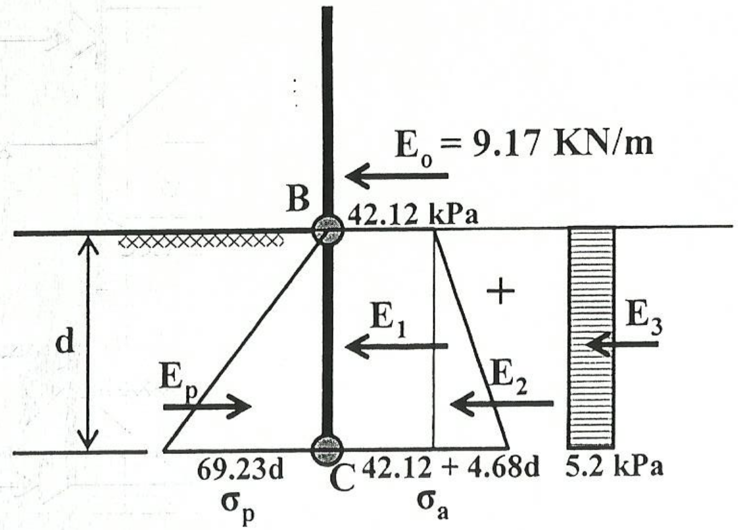
$$\sigma_{aB} = \underset{H}{9m} * \underset{\gamma_b}{18} * \underset{K_a}{0.26} - 0 = 42.12 \text{ kPa}$$ *Soil only without surcharge*

$$\sigma_{ac} = [42.12] + 18 * 0.26 * d = 42.12 + 4.68d$$

$$\sigma_{a-surcharge} = 20 * 0.26 = 5.2 \text{ kPa}$$

$$\sigma_{pB} = 0.0$$

$$\sigma_{pc} = d * \underset{\gamma_b}{18} * (1/\underset{K_p}{0.26}) = 69.23d$$



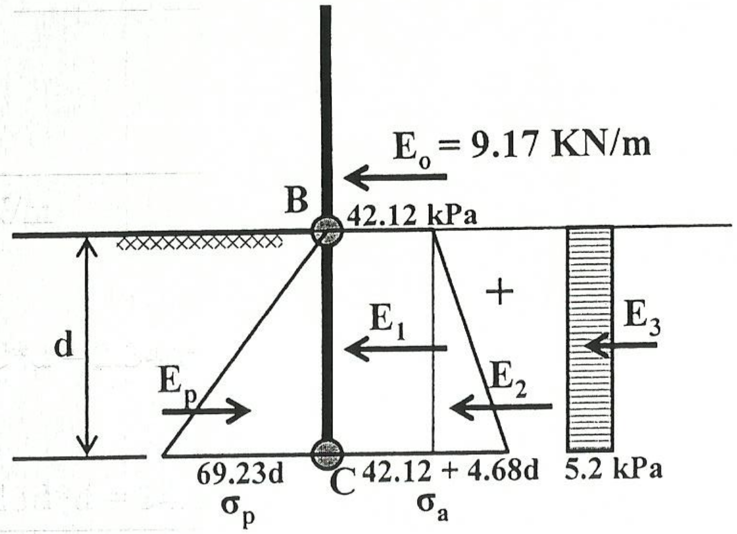
- $E_o = 9.17$ KN/m
- $E_1 = 42.12*d$
- $E_2 = 0.5*4.68*d = 2.34d^2$
- $E_3 = 5.2*d$
- $E_p = 0.5*69.23d*d = 34.62d^2$

[3] Analysis and Design of Braced Excavation System

Example [4]: *solution*

Step (5): Wall penetration depth

❑ Take $\sum Fx = 0$



❖ $E_o + E_1 + E_2 + E_3 - E_p = 0.0$

❖ $9.17 + 42.12(d) + 5.2(d) + 2.34(d)^2 - 34.62(d)^2 = 0.0$

$$-32.28(d)^2 + 47.32(Z) + 9.17 = 0$$

❖ **d = 1.64 m** *"theoretical penetration depth"*

❖ Safe penetration depth "t" = 1.2* d

= 1.2 * 1.64 m = 1.968 m-------- taken = 2.0 m

❖ **t = 2.0 m**