5. Deep Excavations

- Construction procedure greatly affects performance.

1) Support Systems

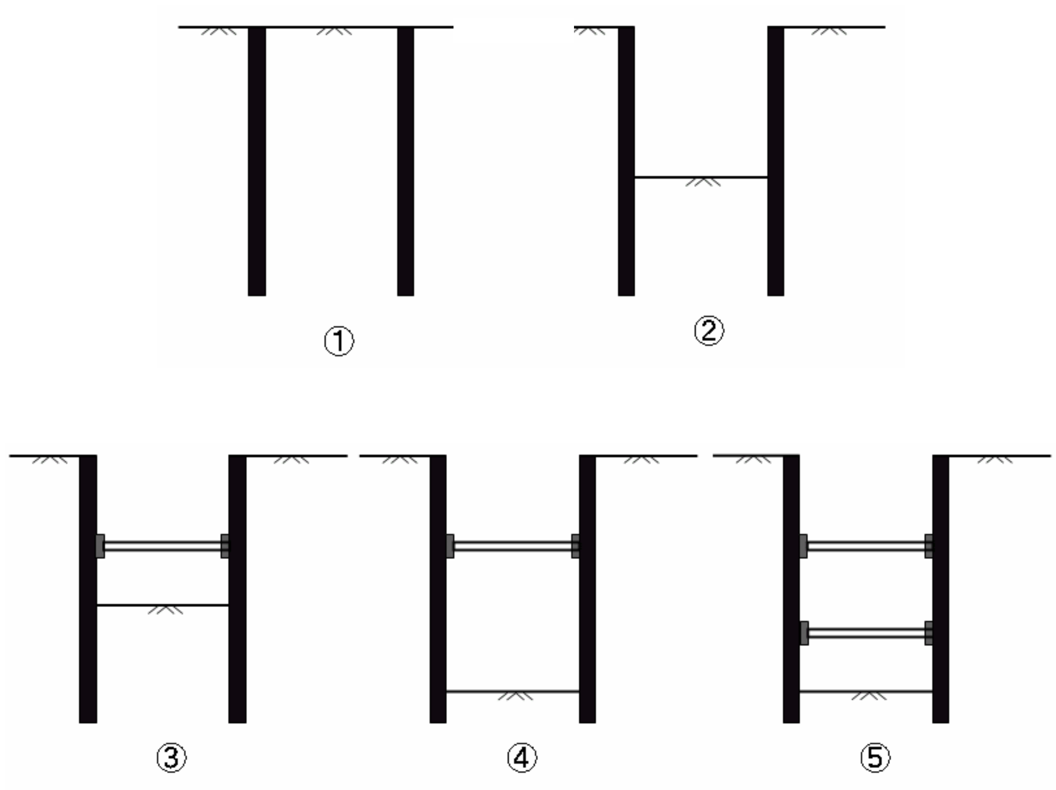
-

- Types
  - Cantilevered Walls (< 15 ~ 20 ft deep)
  - Braced Walls
    - Narrow (< 50 ~ 200 ft wide)
  - Rakers
    - Wide (No crosslot bracing is used)
  - Tied back (Tieback) Walls

a) Braced Walls (Narrow Cut)

i) Construction Procedure

① Install wall.
② Excavate to first strut level with the margin of working area.
③ Place wales and struts.
④ Excavate to second strut level with the margin of working area.
⑤ Place wales and struts.
⑥ Repeat ② and ⑤ until bottom of excavation.



ii) Notes

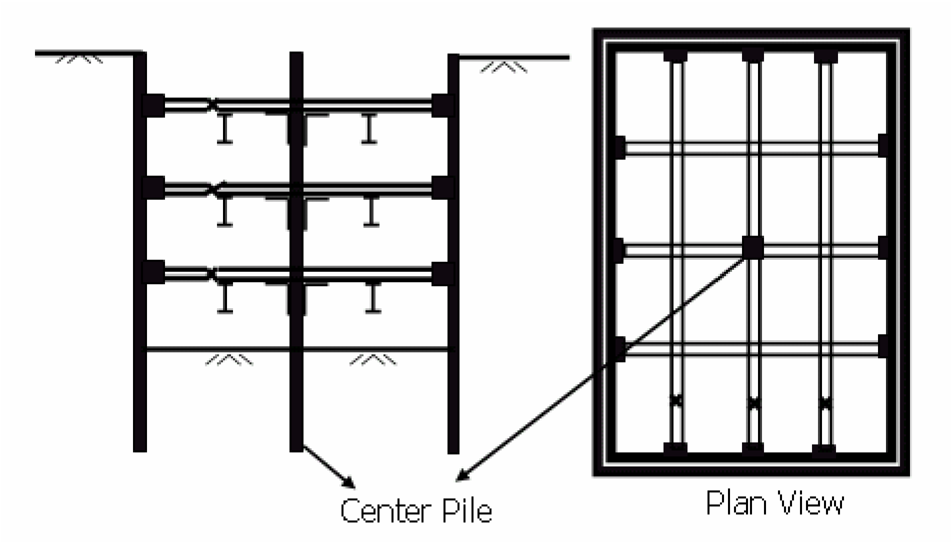
①

②

③
④

iii) Intermediate width

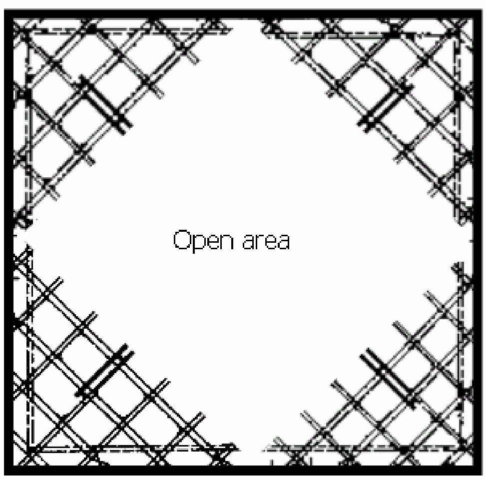
① Cross-lot bracing (center pile)



⇒ Difficult to construct or excavate with this system.

② Diagonal bracing

⇒ alternative way to increase access area for construction



b) Wide Excavation

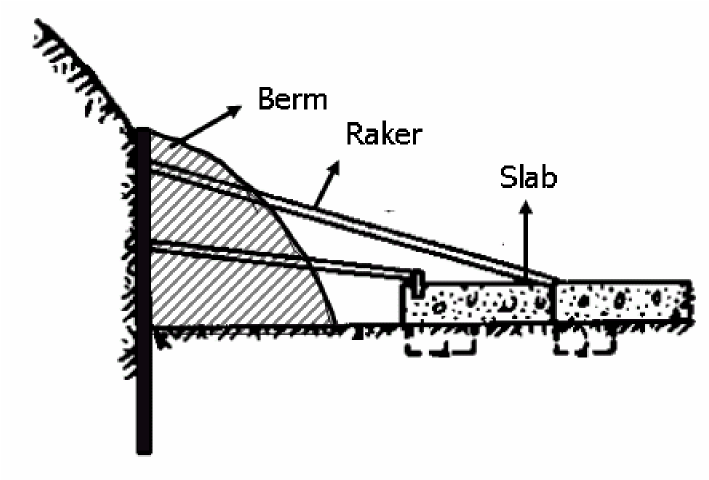
- Raker system

① Install wall.

② Excavate with berm.

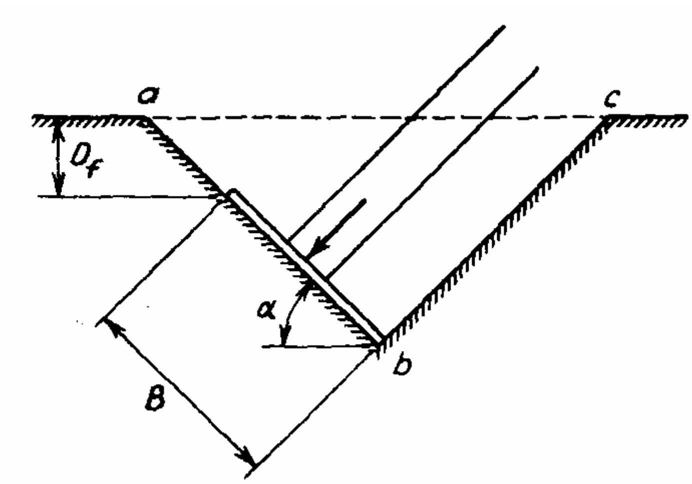
③ Pour bottom slab.

④ Remove berm and place rakers and wales in stage,



* Note

- one way to guarantee the raker support



c) Tied Back (Tieback) Walls

- Structural system that uses an anchor in the ground connected to the wall by tendons to secure a stability against earth pressure failure.
- Used in all soils without special treatments except soft clays and organic soils

i) Construction of tieback wall

(1) Procedure

① Install wall and excavate to 1st tieback level.

② Drill hole : a function of soil conditions.

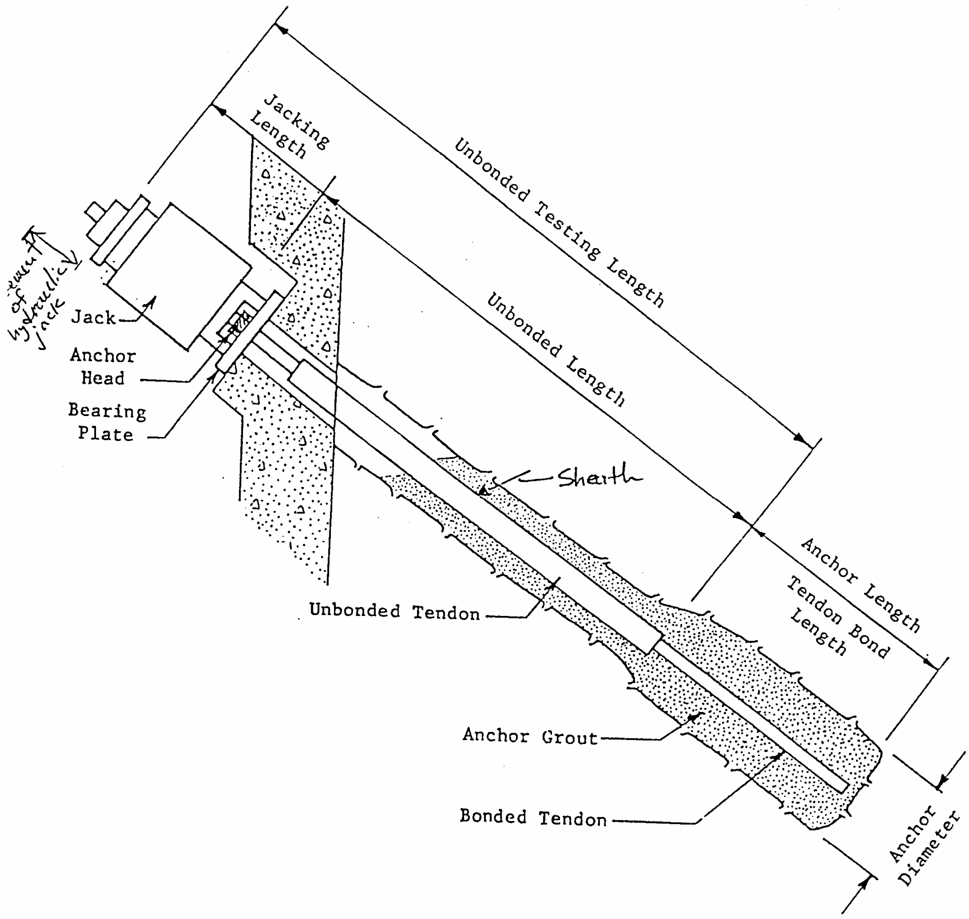
- Auger if 'good' soil conditions where hole will remain open for a period of time.
- Hollow stem auger if some support needed.
- Casing if total support is required.

③ Add sheath, insert tendon into hole, and grout hole.

- Pressure grout.
- Tremic grout.
- Just let it roll down hole.

④ Add connection and prestress system.

⑤ Excavate to 2nd tieback level and repeat ② ~ ④ until reaching the bottom of excavation.



Components of Tieback

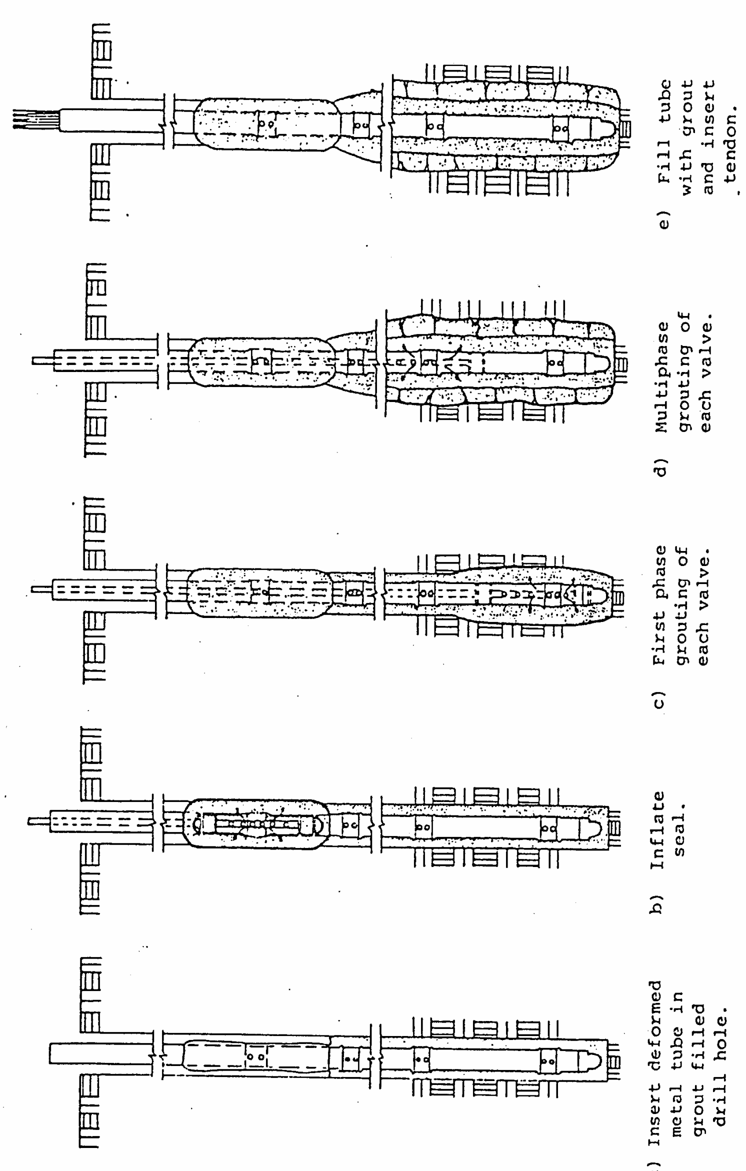


Figure 85. TMD tieback installation sequence.

another type of tieback
SIF Bachy

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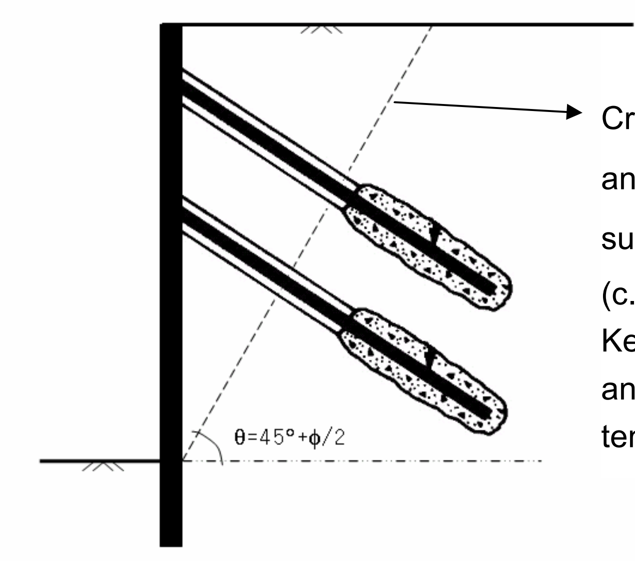
(2) How long



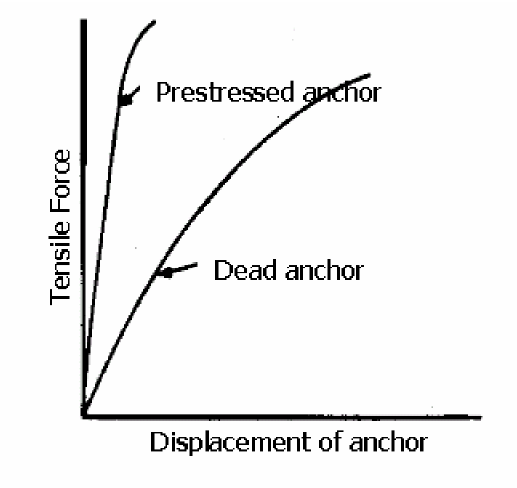
Critical failure surface without anchors (i.e. Rankine active failure surface)

(c.f. $\theta=\phi$ is alternative.)

Keep anchorage behind this surface and minimum length of unbonded tendon is 15ft.

(3) Prestressing

⇒ Take slack out of system ⇒ reduce movement.



2) Wall Systems

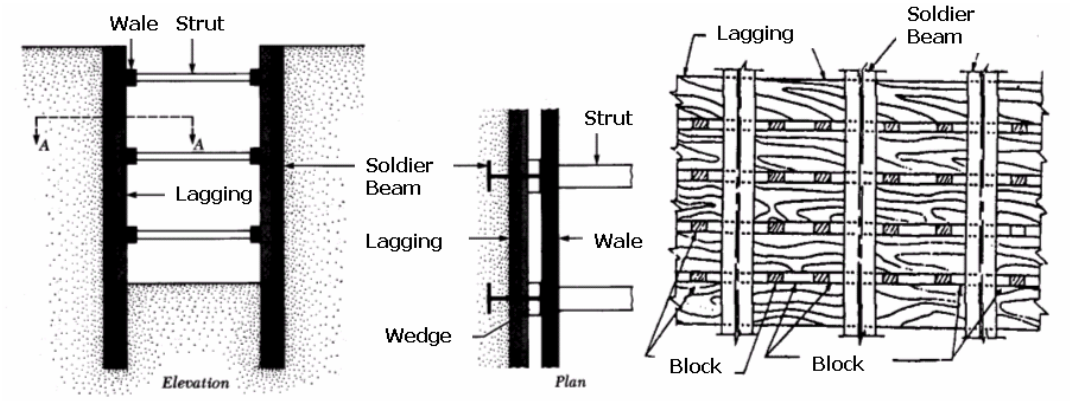
a) Types

i) Soldier beam and lagging

(1) Construction procedure

① Drive or auger in HP section piles.

② Excavate and place lagging, wales and struts.



(2) Advantages

①

②

③

(3) Disadvantages

①

②

③

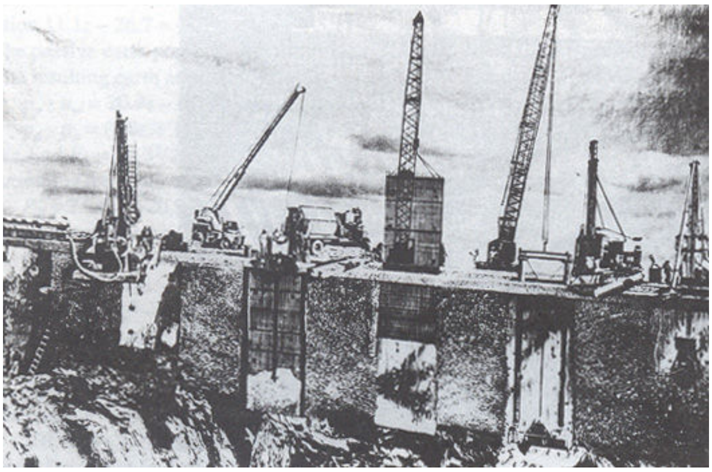
ii) Steel sheet piles

(1) Advantages
①
②

(2) Disadvantages
①
②
③
④

iii) Slurry wall (Diaphram wall)

- Useful for soft clays or loose sands



(Hansbo P.378 Fig.269, 270)

(1) Cast-in-place

- Advantages

①

②

③

- Disadvantages

①

(2) Precast slurry wall

- Advantages

①

②

- Disadvantages

①

iv) Cylinder pile walls

- Can be used for all ground types.

(Hansbo P.379 Fig.271)

- Advantages

  ①

  ②

- Disadvantages

  ①

3) Design of Braced Excavations

a) Design Requirements

- 2 basic requirements

① Design support systems to ensure stability.

⇒ Estimate earth pressure (+ water pressure).

⇒ Design structural systems.

⇒ Evaluate potential of basal heave and piping at the bottom of cut (determine embedded depth of wall).

② Ground movements

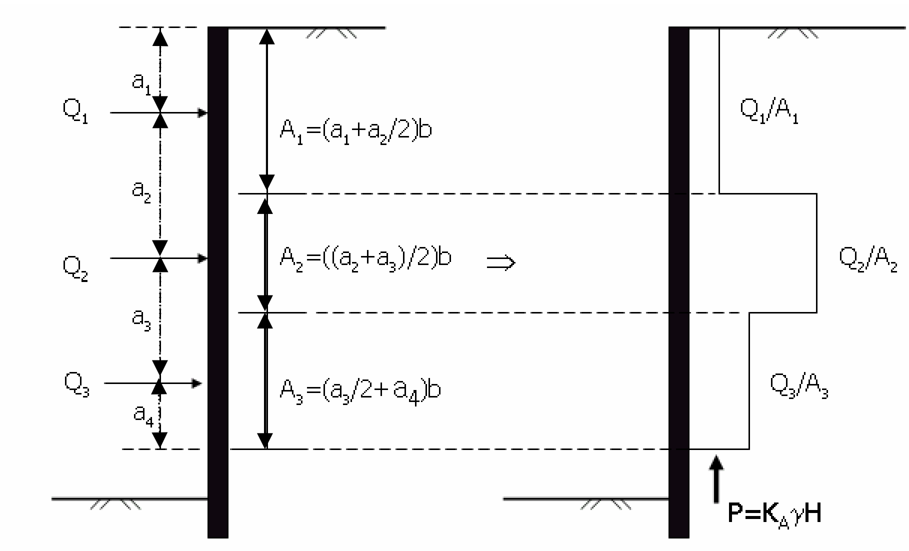
- The displacements (settlements) at various locations from the cut are predicted.

⇒ If inducing damages on nearby structures, structures of excavation should be redesigned to be stiffer or provide some treatments on backfill soils.

i) Determine earth pressure (+water pressure)

- Apparent earth pressures (to design struts)

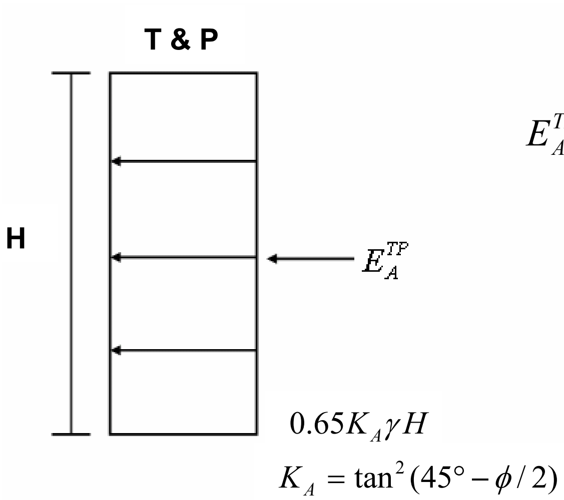
    - Empirically derived (based on strut load measurements)



P ≡ Apparent earth pressure against wall based on strut load measurements

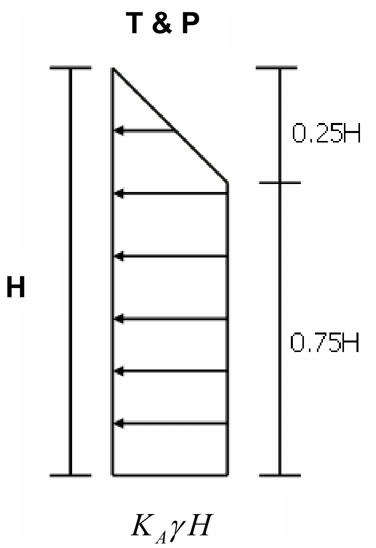
- Terzaghi and Peck apparent earth pressure diagrams
  ⇒ Envelops that encompass max. P values from available data for a given soil condition

① Dry and moist sand



$$E_A^{TP} = 0.65K_A\gamma H^2$$

② Soft to medium clays (N=$\frac{\gamma H}{c}$ > 4 (or 6))



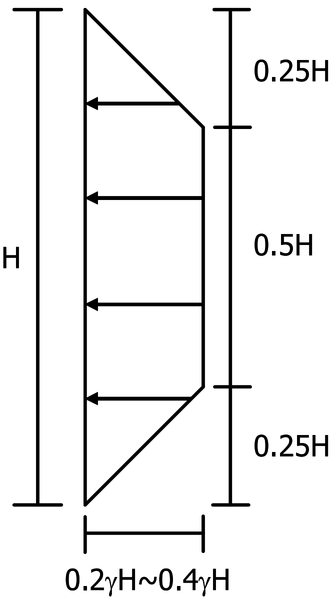
$$K_A = 1 - m(\frac{4c}{\gamma H})$$

c ≡ average undrained strength

m = 1 (or 0.4)

- m=1
  - unless (soft) clay (N>6) extending to a great depth below the bottom of cut (or when bottom heave is a problem, (1.0≤$(FS')_{SB}$≤1.5))
  - unless truly NC clays

③ Stiff clays ($N=\frac{\gamma H}{c}<4$)



⇑

Movements are small and short construction time.

- 4<N<6, use larger value of ② and ③ (DM. 7).

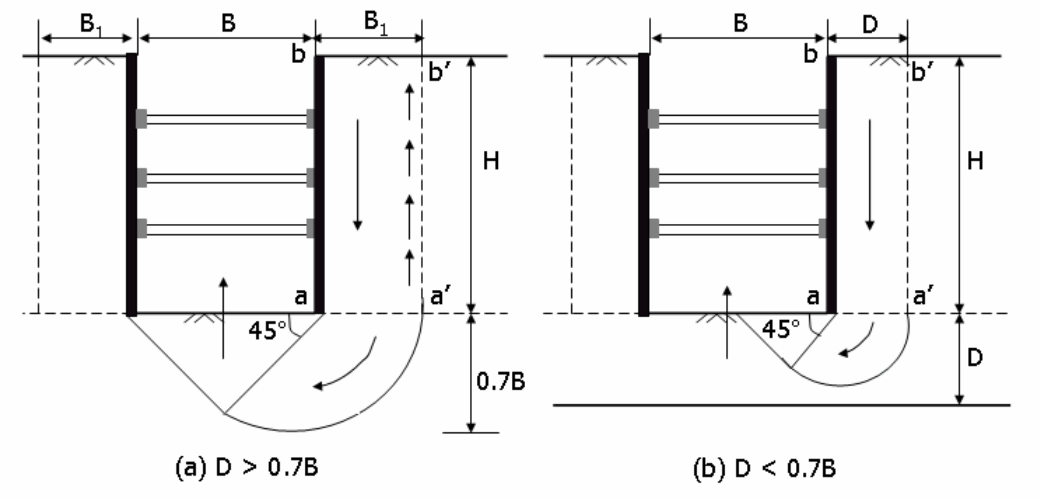
ii) Stability against basal heave and piping

(1) Basal heave

- Clays

① Shallow excavation (H/B<1)

- General case (Terzaghi, 1943)



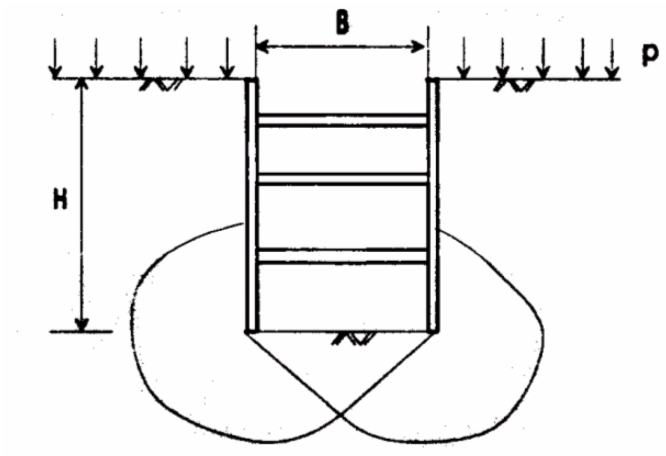
- $$FS = \frac{Q_u}{Q} = \frac{5.7c_u B_1}{\gamma H B_1 - Hc_u} = \frac{5.7c_u}{H(\gamma - \frac{c_u}{B_1})} = \frac{5.7c_u}{H(\gamma - \frac{c_u}{0.7B})}$$

if D < 0.7B,

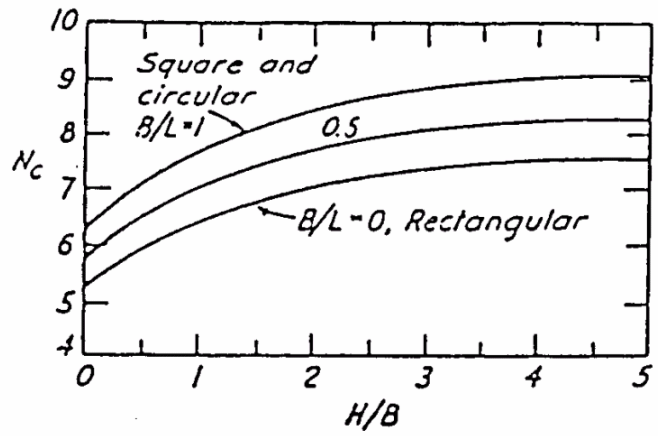
$$FS = \frac{5.7c_u}{H(\gamma - \frac{c_u}{D})}$$

② Deep excavation (H/B>1)

- General case (Bjerrun and Eide, 1956)



- $FS = \dfrac{c_u N_c}{\gamma H + p}$

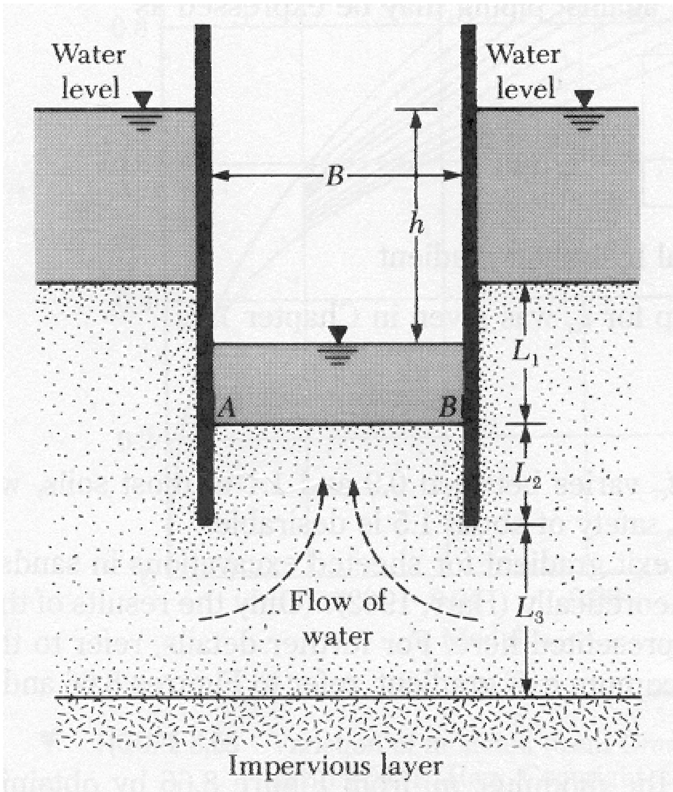


N_c for depth and shape of deep excavation

- F.S. > 1.5, then no bottom heave problems
- F.S. < 1.5, then bottom heave potential and must do something

In case of embedded sheeting, earth pressure P_H for embedded part should be estimated.

(2) Piping

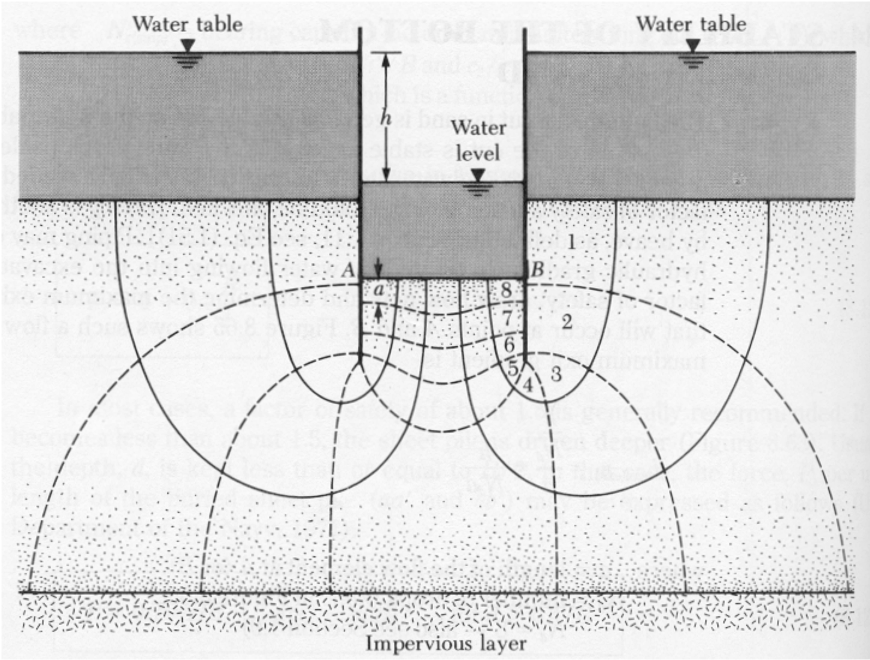


●

● Critical hydraulic gradient for piping

$$i_{crit} = \frac{(G_s - 1)}{(1+e)} = \frac{\gamma_{sub}}{\gamma_{water}} = 0.9 \sim 1.1\,(\approx 1.0)$$

- Determining the maximum exit gradient ($i_{\max(exit)}$)



$$i_{\max(exit)} = \frac{\Delta h}{a} = \frac{h / N_d}{a}$$

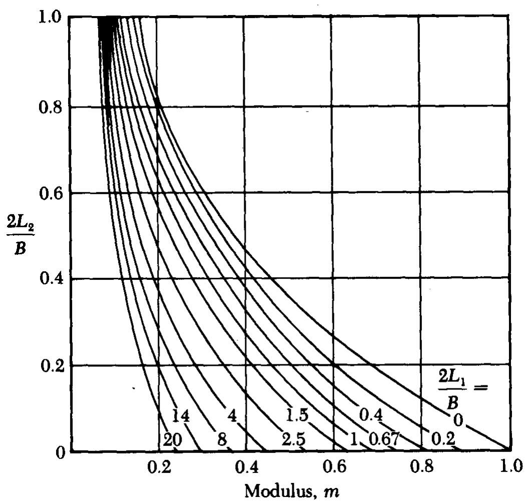
(N_d : number of drops in flow net)

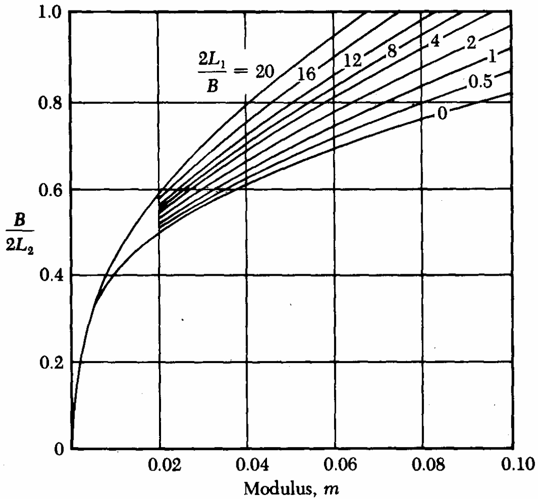
- $FS = \dfrac{i_{cr}}{i_{\max(exit)}} \; (= 1.5)$

- Alternative way to get FS against piping (by Harr(1962))

(Refer to Figure in page 212)

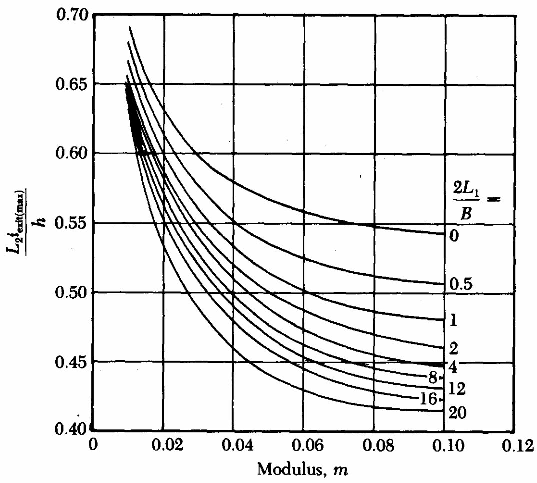
①Determine the modulus m from figures as shown below.

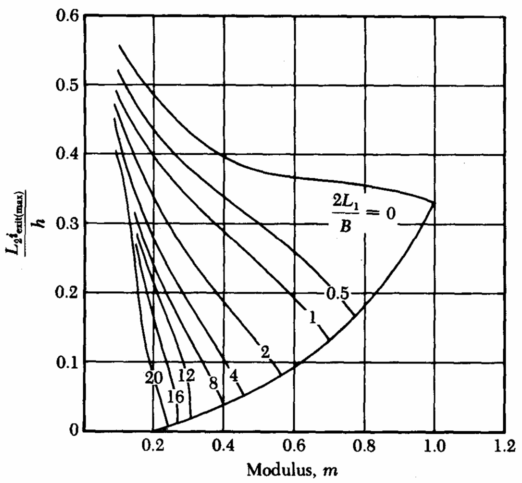




② With the known modulus m, determine $L_2 i_{exit(\max)} / h$.

$\Rightarrow$ $i_{exit(\max)}$ can be calculated.

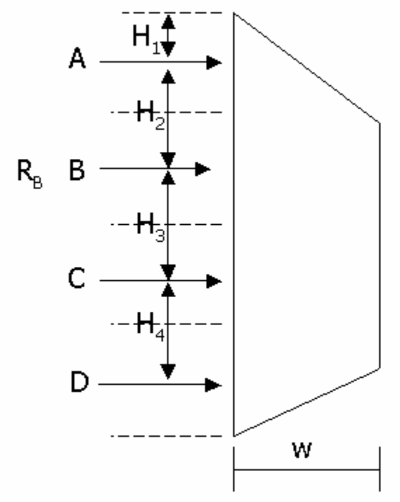




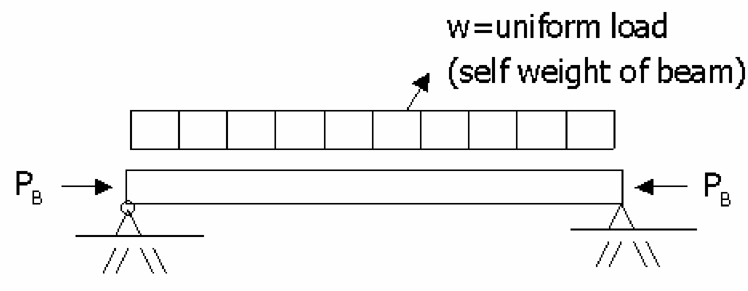
③ $FS = \dfrac{i_{cr}}{i_{\max(exit)}}$

iii) Designs of struts, wales and walls (Das 책 참조)

(1) Struts



$R_B = \frac{w}{2}(H_2 + H_3)$ ⇒ Use tributary areas to calculate strut loads and multiply strut horizontal spacing to get net strut loads (P_B).



⇒ Design for combined axial load and bending with steel construction manual.

(2) Walls

- Design for M_{max}.

  S=sectional modulus= $\frac{M_{max}}{\sigma_y}$

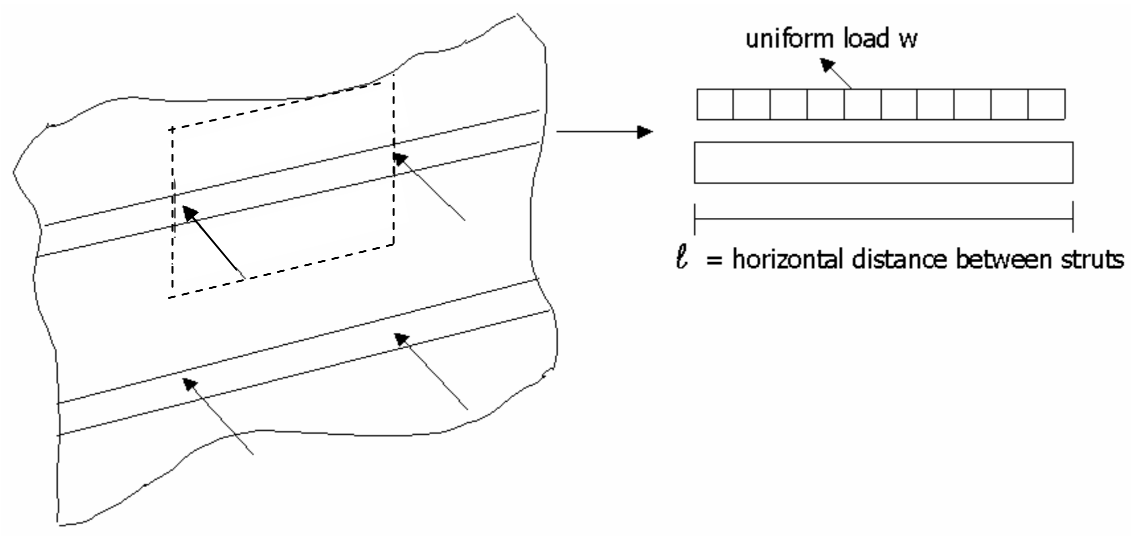
- Use M_{max} for all spans and construction sequence.

  $$M_{\max} = \frac{wl^2}{8} (or\ \frac{wl^2}{10})$$

  ⇓

  3 or more spans

(3) Wales



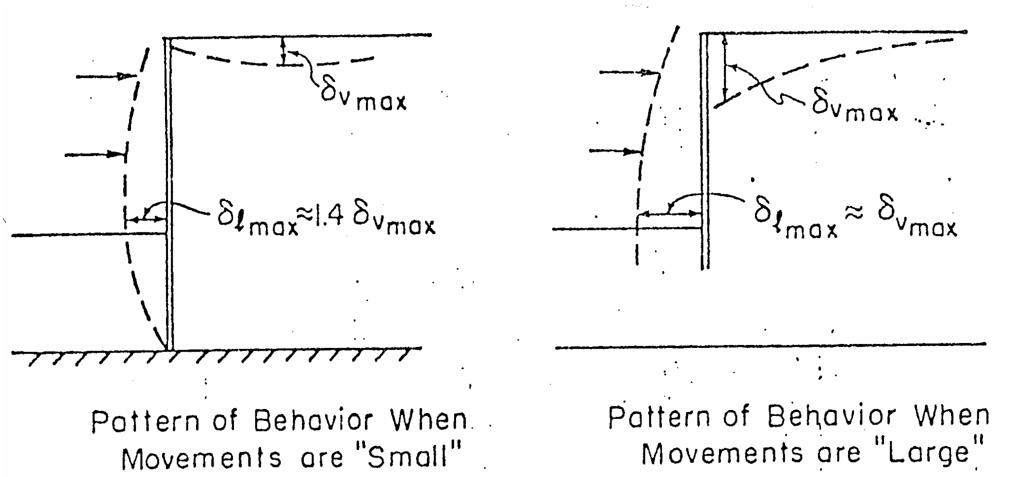
⇒ Can be simply supported ($M = \dfrac{wl^2}{8}$) or fixed supported ($M = \dfrac{wl^2}{12}$) depending on the conditions between strut-wales connections.

iv) Movements

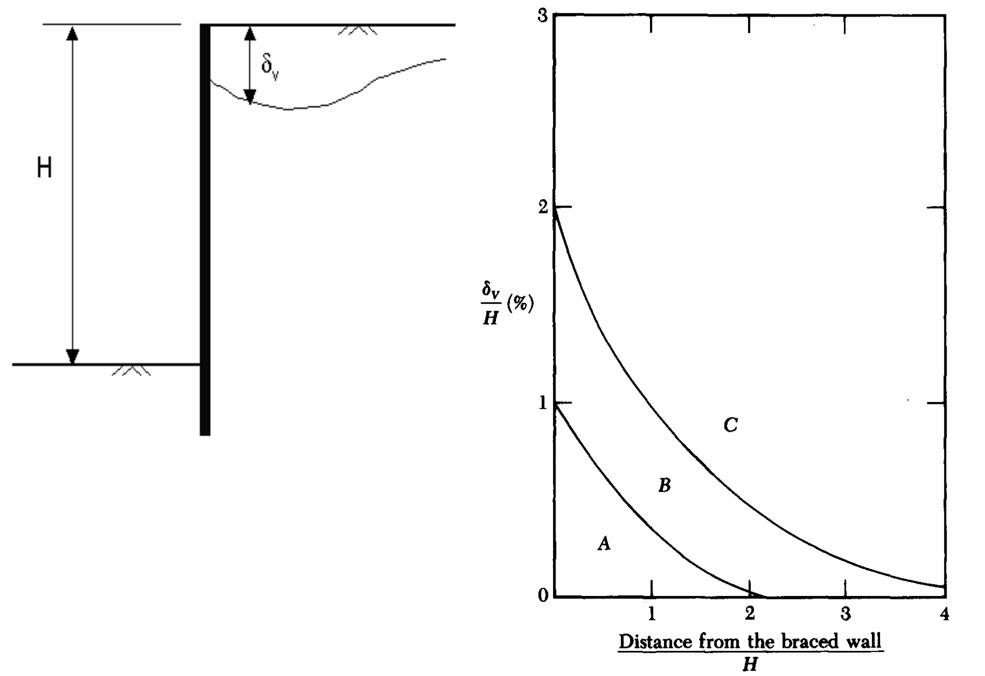
(1) Factors that affect movements.

-
-
-
-
-
-
-

(2) Estimations of movements associated with braced cuts



- Use peck chart (empirically)



A : sand and soft to hard clays and average workmanship

B : very soft to soft clays

$\Rightarrow$ limited depth of clay below bottom of excavation

and $N_b\,(=\dfrac{\gamma H}{c_b})<5.14$

C : very soft to soft clays

$\Rightarrow$ great depth of clay below excavation or $N_b>5.14$

(3) Lateral yielding of sheet piles and ground settlements

(Based on field records in clay)

* The maximum lateral wall movement, $\delta_{H(max)}$ has a definite relationship to the factor of safety against based heave (Mana and Clough, 1981)

→ Embed the sheet pile below the bottom of excavation

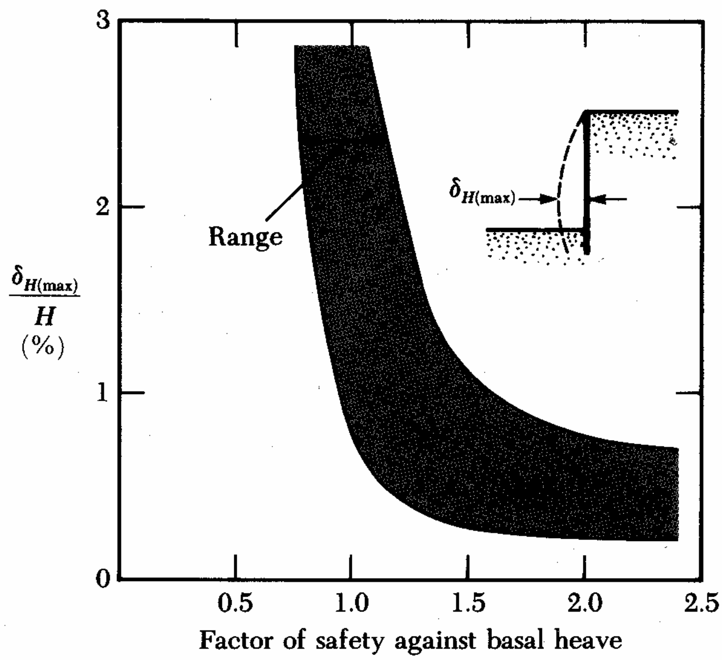


Figure 10.19 Range of variation of $\delta_{H(max)}/H$ with FS against basal heave from field observation (redrawn after Mana and Clough, 1981)

*The lateral movement of wall induces ground settlement around a braced cut.

The maximum ground settlement , $\delta_{V(max)}$

$$\delta_{V(max)} \approx 0.5\delta_{H(max)} \text{ to } 1.0\delta_{H(max)}$$

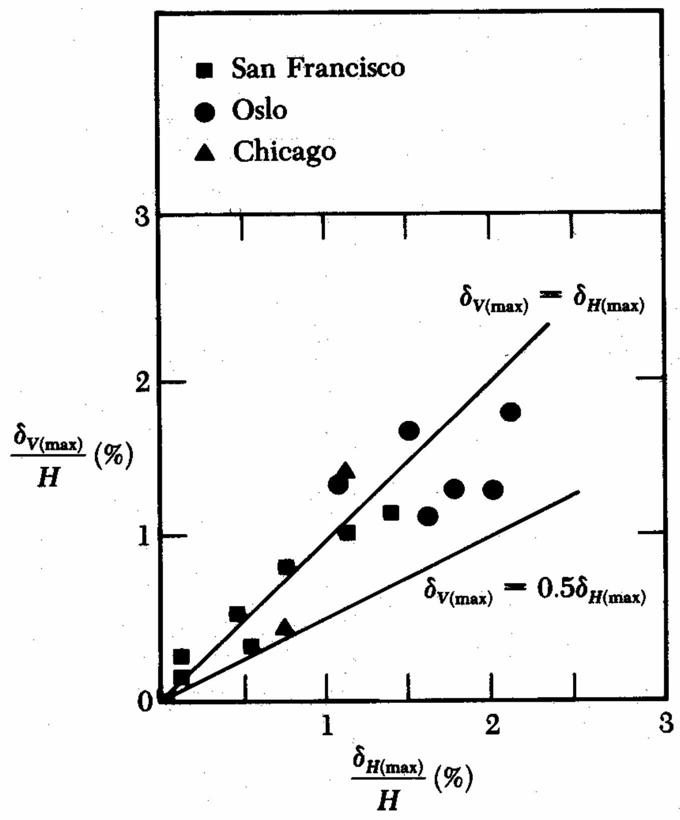


Figure 10.21 Variation of maximum lateral yield with maximum ground settlement (after Mana and Clough, 1981)