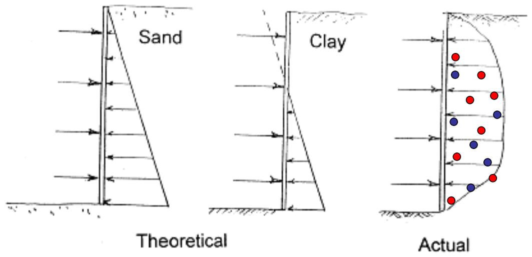
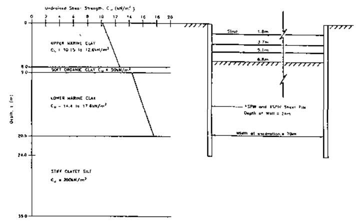
Lateral Earth Pressure in Braced Excavations

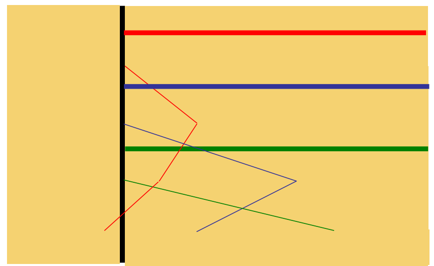


- Redistribution of earth pressure due to arching
- Preloading
- Incremental excavation and strut installation

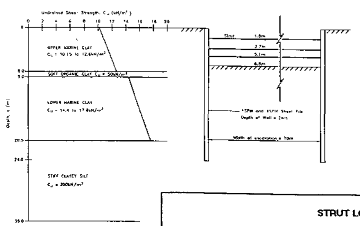
1



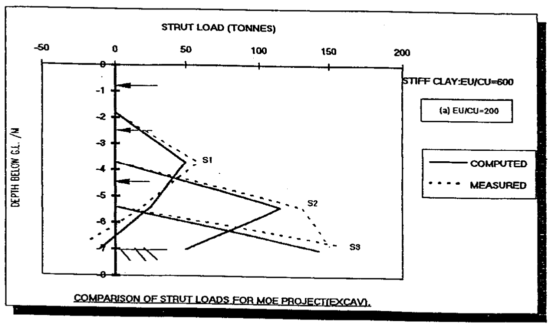
Development of Strut Forces during Excavation



2

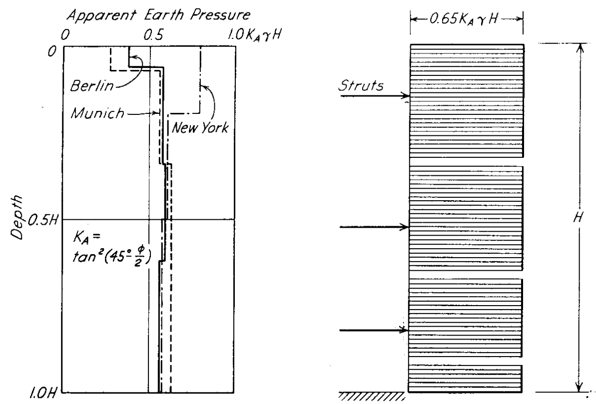


Development of Strut Forces during Excavation



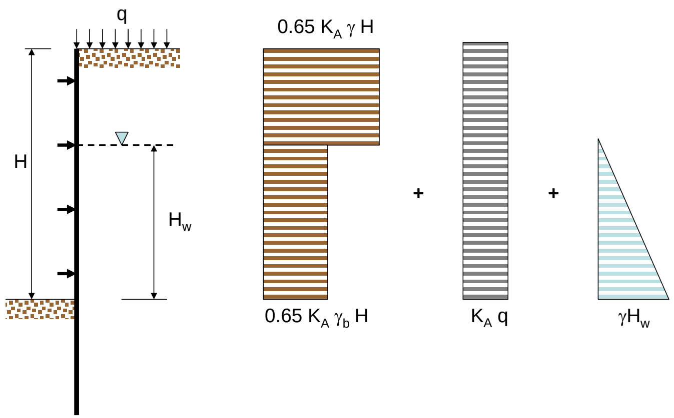
Apparent Pressure Diagram for Sand

(Peck, 1972)



4

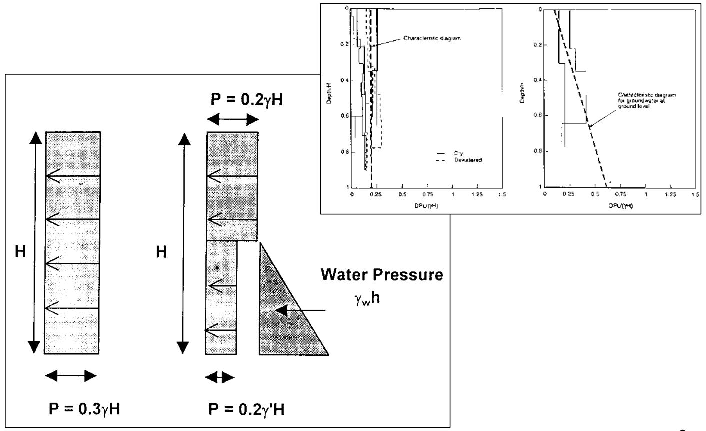
Apparent Pressure Diagram for Sand



5

CIRIA's Characteristic Pressure Diagram for Sand

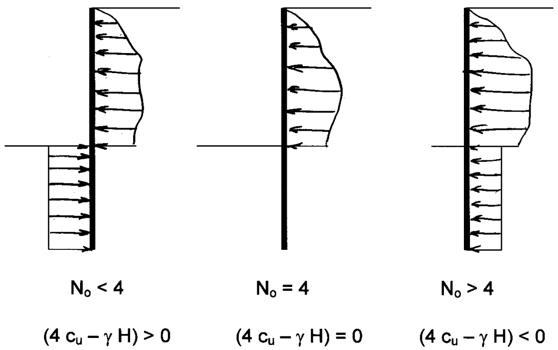
(CIRIA, 1996)



6

Strut Forces in Clay

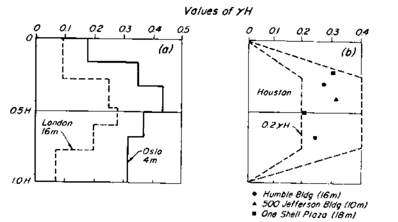
Stability Number, $N_o = (\gamma H + q) / c_u$



7

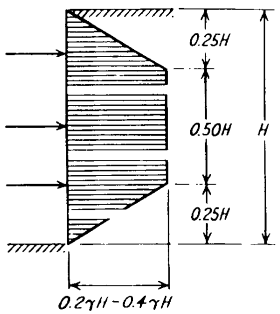
Strut Forces in Stiff Clay (N_o<4)

(Peck, 1972)



Fissured clays in London and Oslo

stiff slickensided clays in Houston

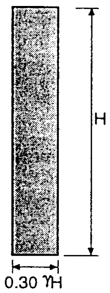


Tentative diagram for stiff-fissured clays, lower pressure if justified by experience; otherwise do not go below 0.3 γH.

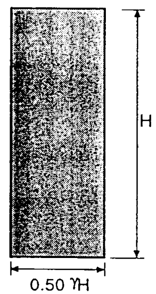
Strut Forces in Stiff to Very Stiff Clay

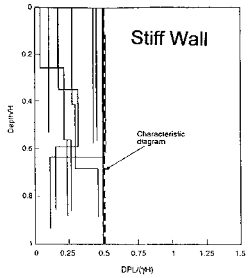
(CIRIA, 1996)

Flexible Wall



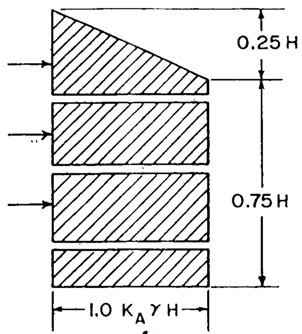
Stiff Wall





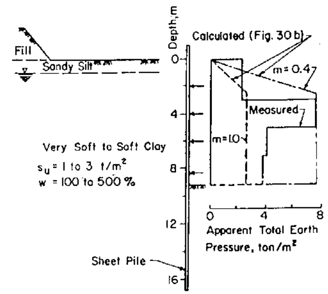
Strut Forces in Soft Clay (N_o>4)

(Peck, 1972)



$K_A = 1 - m \frac{4 s_u}{\gamma H}$

Why is m=0.4?



Use m=0.4 for excavation in deep clay deposit; otherwise use m=1.

Strut Forces in Soft Clay (N_o>4)

(Terzaghi,Peck & Mesri, 1996)

$$K_A = 1 - \frac{4c_u}{\gamma H}$$

$$\Delta K = 2.83 \frac{T}{H} \left(1 - \frac{5.14\, c_{ub}}{\gamma H}\right)$$

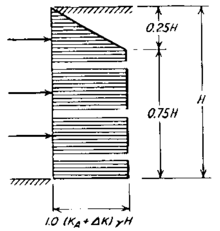
H = depth of excavation

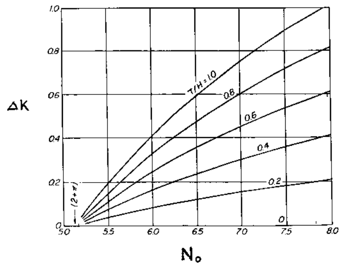
T = clay thickness below formation Level, i.e. depth to hard stratum or 0.7B whichever is small

c_u = average c_u above formation level

c_{ub} = average c_u below formation level down to 0.7B

γ = average total unit weight above formation level

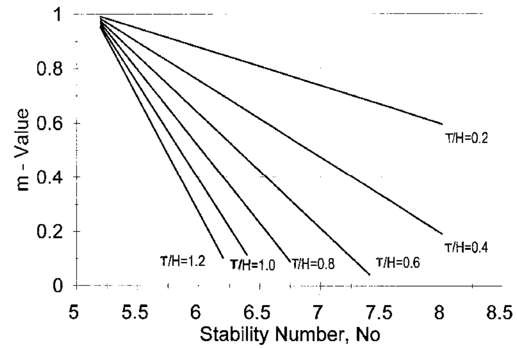


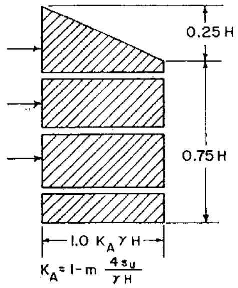


Strut Forces in Soft Clay (N_o>4)

(Terzaghi,Peck & Mesri, 1996)

$N_o = (\gamma H + q) / c_{ub}$



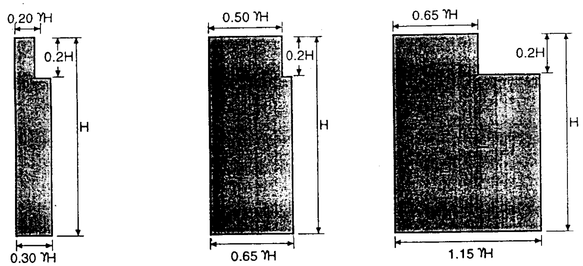


c_{ub} = c_u below excavation down to 0.7B

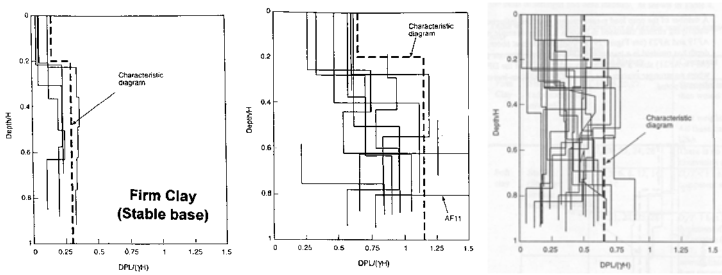
CIRIA's Characteristic Pressure Diagram for Soft Clay
(CIRIA, 1996)

- 81 cases from 77 sites in 12 countries
- 5% probability of being exceeded
- Applicable to flexible walls only
- Preload not exceeding 25%

Firm Clay (Stable base) **Soft Clay (Stable base)** **Soft clay (Unstable base)**



CIRIA's Characteristic Pressure Diagram for Soft Clay
(CIRIA, 1996)



Soft Clay (Stable base) Soft Clay (Unstable base)

14

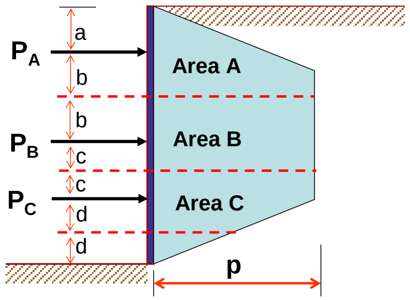
CIRIA's Characteristic Pressure Diagram for Soft Clay
(CIRIA, 1996)

Base condition	Case history	Comment
Stable (adequate soil strength) Firm Clay (stable)	10,15,20,27	Strengths and unit weights are greater than would be expected for a NC clay. Unit weights are greater than 19kN/m^3. All these case histories are in Chicago, USA
Stable (Stronger stratum at or near base) Soft Clay (stable)	7, 18, 23, 24, 26	There is no soft clay beneath the excavation (T=0)
	2b, 5, 6, 8, 12, 14, 16, 17	$D_e/T < 1$ i.e. wall does not extend to the competent stratum
	19, 21, 22, 25, 28	D_e/T 1 but $T/H < 0.33$, i.e. only small thickness of soft clay beneath the excavation (T/B of between 0.04 and 0.37)

CIRIA's Characteristic Pressure Diagram for Soft Clay
(CIRIA, 1996)

Soft Clay (unstable base)	1a	Intermediate (5.3m) dig stage of 11.5m deep excavation with sheet pile walls driven to rock at 12.5m (T/B = 0.65; D_e/T = 1.0 but T/H = 1.36)). This shallow dig is assumed to have enhanced base stability
	2a	Intermediate (5.8m) dig stage of 11.5m excavation with 16.5m long sheet piles and rock at 28m depth. (T/B = 1.5; T/H = 1.4)
Enhanced (wall contributes to base stability)	1b, 3, 11, 16, 13	Reported as driven to rock for stability (T/H = 0.41 to 0.72 except 0.13 for AF1b; T/B = 0.13 to 0.5)
	4 and 9	T/H of 2.4 and 0.6 respectively T/B of 0.2 and 0.4 respectively

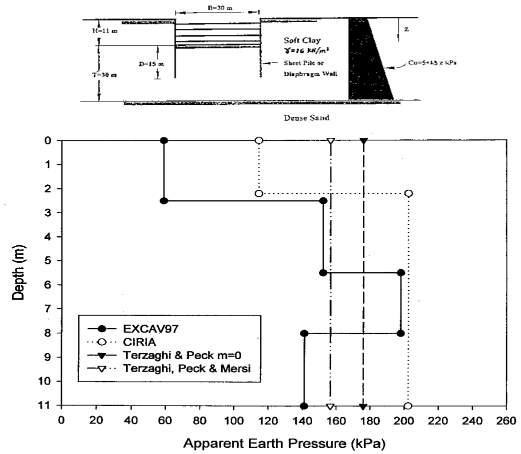
Strut Forces by Tributary area method



e.g. $P_B = (b + c) p$ in kN/m run

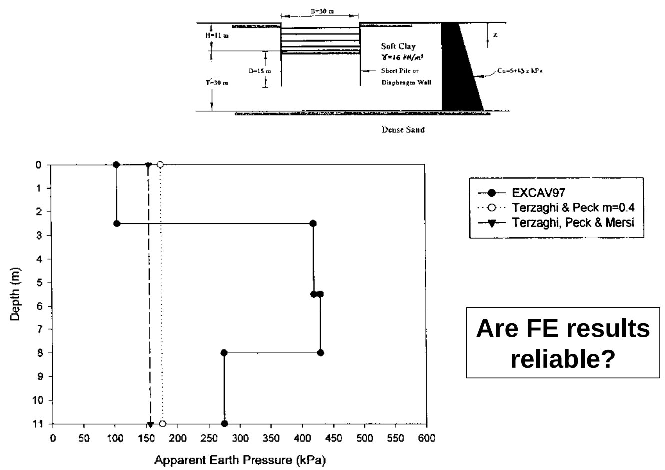
17

Comparison of APD – Sheetpile Wall



18

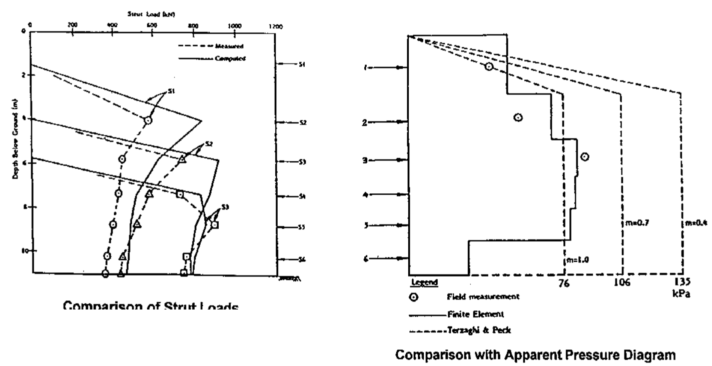
Comparison of APD – Diaphragm Wall



Are FE results reliable?

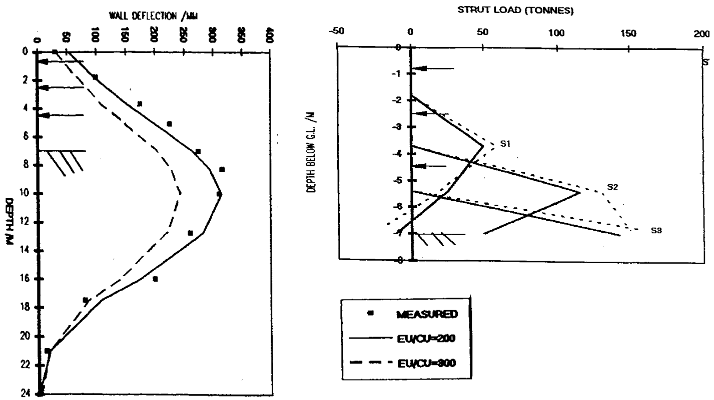
19

Validation of FEM for Determination of Strut Load Telecom Building, Singapore



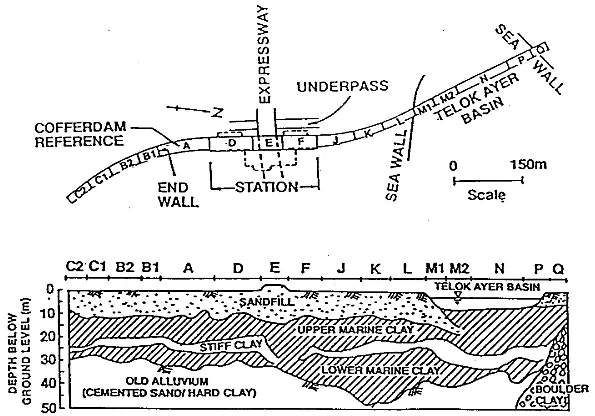
20

Validation of FEM for Determination of Strut Load MOE Building, Singapore



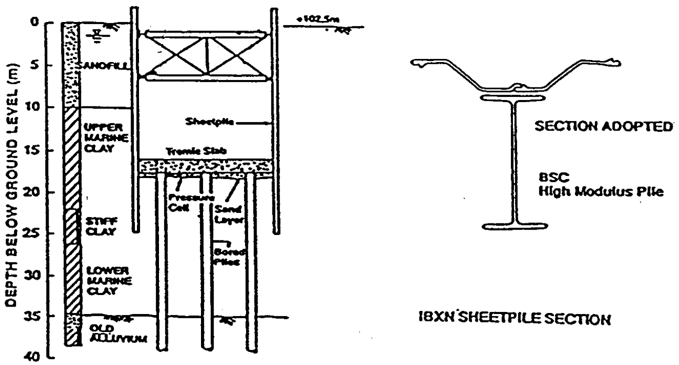
21

Marina South MRT Station



22

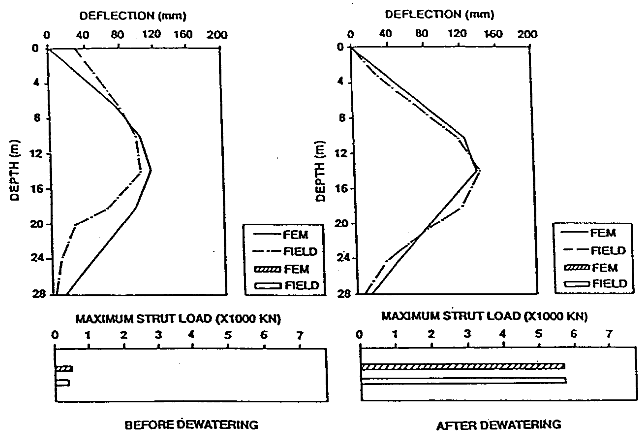
Marina South MRT Station



TYPICAL COFFERDAM SECTION

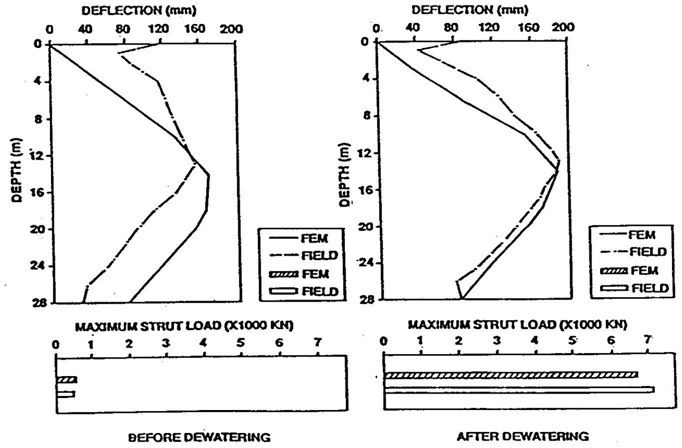
23

Comparison of Wall Deflections & Strut Forces at Cofferdam D

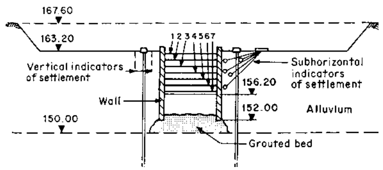


24

Comparison of Wall Deflections & Strut Forces at Cofferdam J



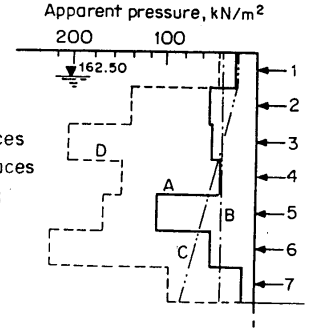
25



Strut Forces on Diaphragm Wall in Sand

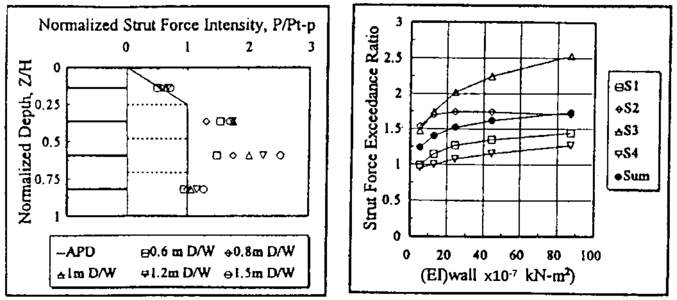
(Kastner & Lareal, 1974)

A mean of measured stresses in strut braces
D maximum measured stresses in strut braces
C values given by Peck's modified method
B values given by Peck's method

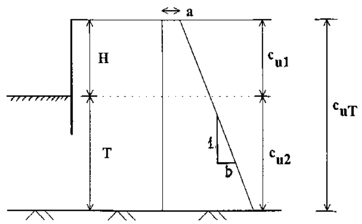


Effect of Wall Stiffness on Strut Forces

(Chang & Wong, 1996)



27



Effect of Wall Stiffness on Strut Forces

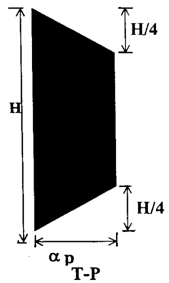
(Chang & Wong, 1996)

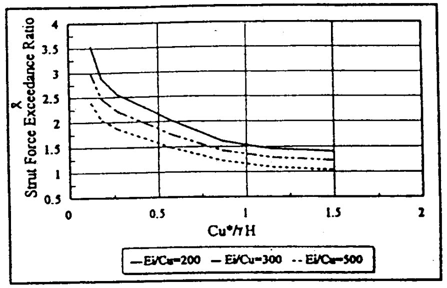
c_{u1} = upper average = $(2a + bH)/2$

c_{u2} = lower average = $[2a + b(2H + T)]/2$

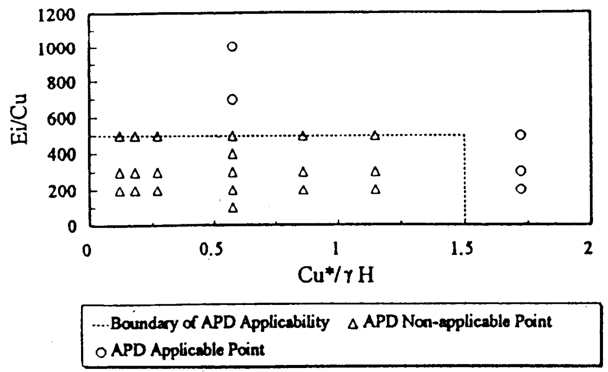
c_{uT} = total average = $[2a + b(H+T)]/2$

$c_u^* = (c_{u2} / c_{u1})\, c_{uT}$





APD for Diaphragm Wall in Soft Clay
(Chang & Wong, 1996)



29

Struts will expand or contract according to

Effect of Temperature on Strut Forces

$$\Delta L = \alpha \Delta t L$$

where L = strut length
Δt = change in strut temperature
α = thermal coefficient of expansion
~ 1.2×10^{-5} per °C for steel

If fully restrained (i.e. $\Delta L = 0$),

$$\Delta P_{temp} = \Delta\sigma A = (\Delta L / L) E A = \alpha \Delta t A E$$

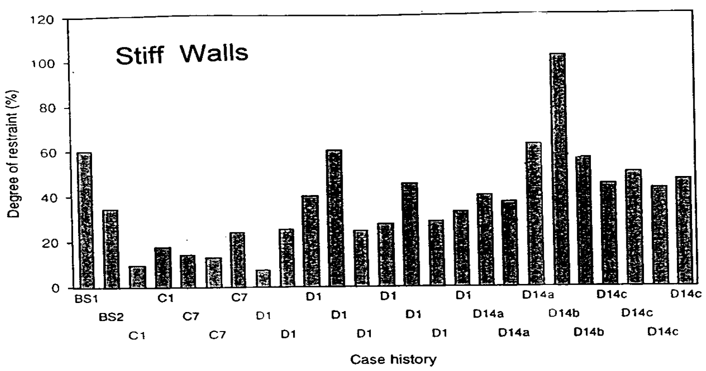
The actual ΔP_{field} measured in the field are much less than ΔP_{temp}, because of wall yielding.

$$\text{Degree of Restraint (\%)} = \frac{\Delta P_{field}}{\Delta P_{temp}} \times 100\%$$

30

Degree of Restraint
(CIRIA, 1996)

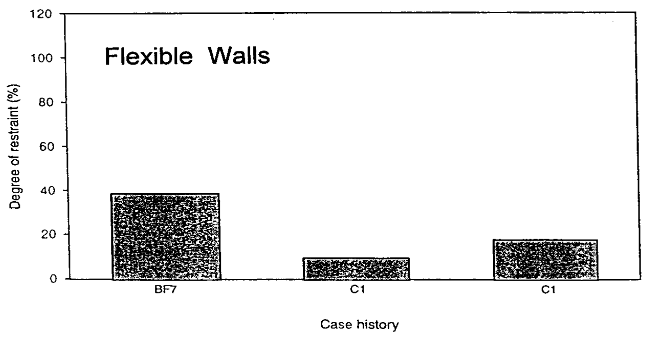
$$\frac{\Delta P_{field}}{\Delta P_{temp}} \times 100\%$$



B = Stiff Clay C = Granular Soils D = Mixed Soils

Degree of Restraint
(CIRIA, 1996)

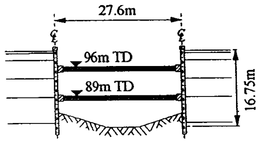
$$\frac{\Delta P_{field}}{\Delta P_{temp}} \times 100\%$$

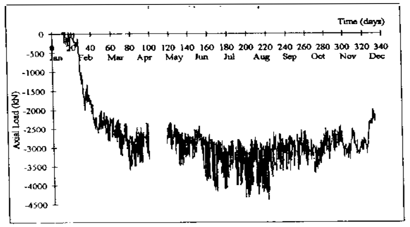


B = Stiff Clay C = Granular Soils D = Mixed Soils

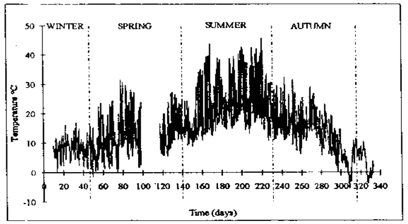
Temperature Effect on Strut Forces

(Batten et al., 1996)





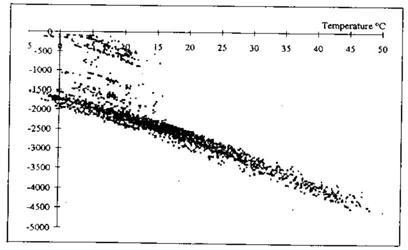
Axial load in upper props



Seasonal variation in prop temperature

Temperature Effect on Strut Forces

(Batten et al., 1996)



Tubular steel props

Diameter = 1067 mm

Thickness = 14.3 mm

Length = 24.1 m

$\alpha = 1.13 \times 10^{-5}$ per ^{o}C

If unrestrained, $\Delta L = \alpha \, \Delta t \, L = 13.6$ mm

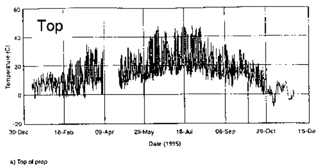
If fully restrained with $\Delta t = 50\ ^{o}C$, $\Delta P_{temp} = 5318$ kN

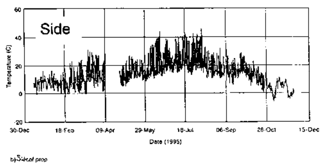
The actual ΔP_{field} measured in the field ~ 3000 kN

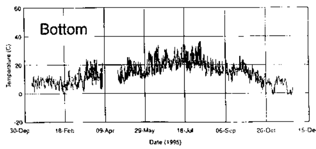
$$\text{Degree of Restraint (\%)} = \frac{\Delta P_{field}}{\Delta P_{temp}} \times 100\% = 56\%$$

Temperature Effect on Top, Side & Bottom of Strut

(Batten et al., 1996)



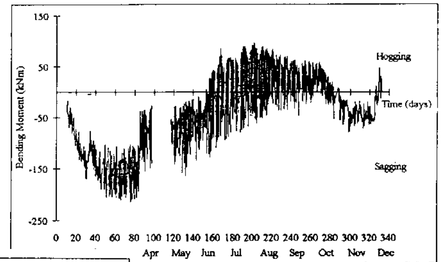




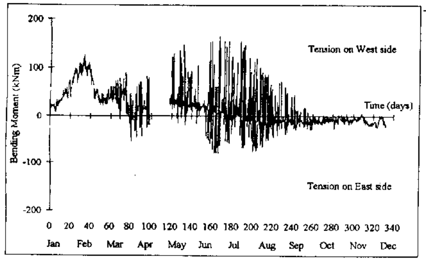
35

Temperature Induced Bending Moment in Strut

(Batten et al., 1996)



Bending moments about xx axis



Bending moment about the yy axis

36

Preloading of Struts

Taking up slack in support system

- Typically around 10% of the design (working) Load (CIRIA, 1996).
- In Singapore, 20 to 50% is commonly used.

Stiffen the support system

- Higher preload has been used in an attempt to reduce wall deflections and ground settlements. The wall may be pushed back under this load.
- Professor Broms advocated 100%.
- Singapore Post Centre used 100% preload.
- Most MRT stations along the NEL required a minimum of 50%.
- Some (O'Rourke, 1974) consider little benefit in introducing the additional load.

Avoid excessive preload

- Excessive preload can cause passive failure of the soil behind the wall.
- Large bending moment can be induced in the wall.

37

Other Factors Affecting Strut Forces

Unbalanced Horizontal Reactions

- Sloping ground
- River on one side
- Different ground conditions at opposite sides
- Large surcharge on one side
- Excavation on adjacent site
- Unbalanced groundwater level

Strut Removal

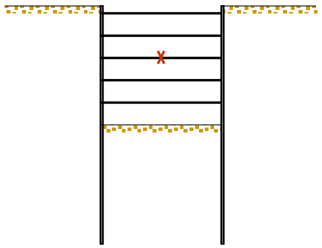
- Can increase load by 30% or more
- Should be simulated in analysis

Poor Workmanship

- Over-excavation
- Time delay
  - Dissipation of excess pore pressure
  - Stress relief

38

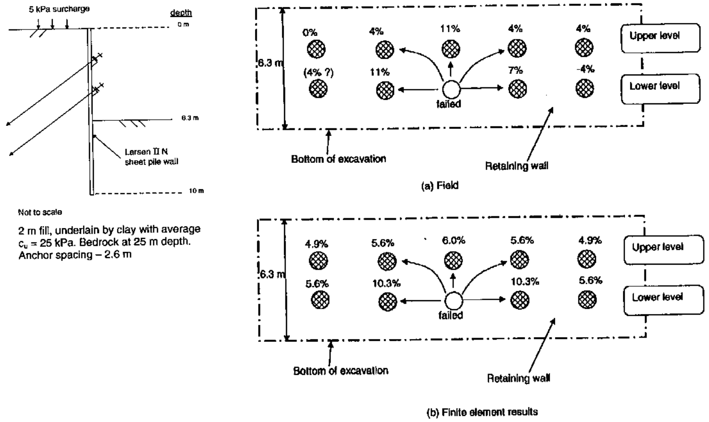
1-Strut Failure



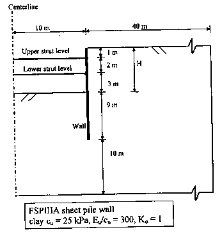
39

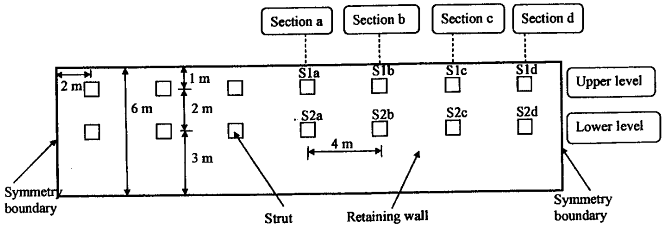
Case History from Manfred, Sweden

(Stille & Broms, 1976)

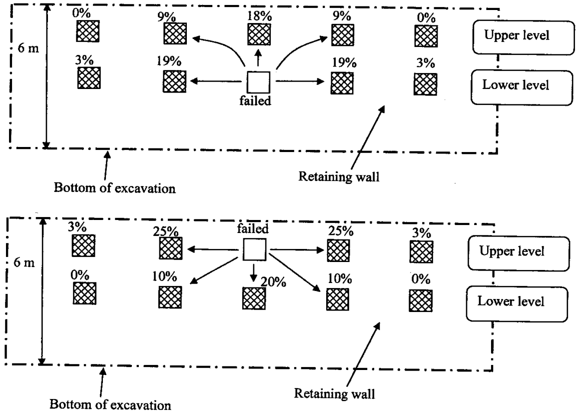


3-D FEA of Single Strut Failure
(Goh & Wong, 2003)



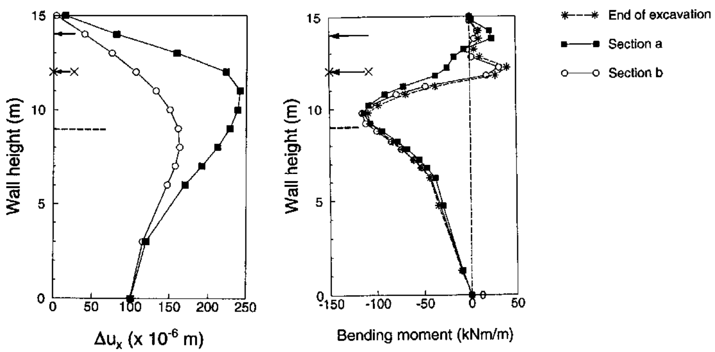


3-D FEA of Single Strut Failure
(Goh & Wong, 2003)



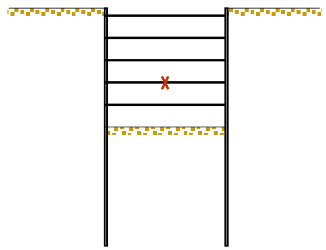
42

3-D FEA of Single Strut Failure
(Goh & Wong, 2003)



43

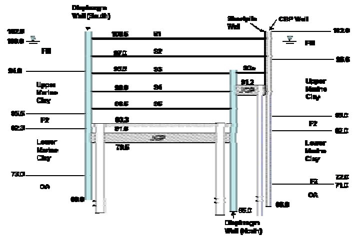
Analysis of One-Strut Failure

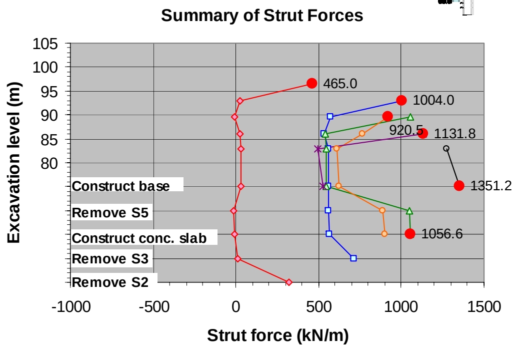


Option 1:	Failure of all struts on one level
Option 2:	Failure of alternate struts on one level Use reduced stiffness i.e. ½ EA

44

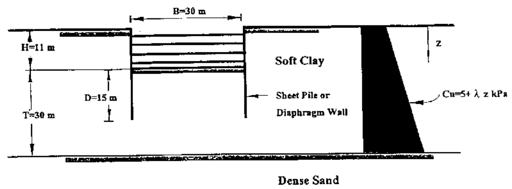
How many analyses should we conduct for 1-strut failure?

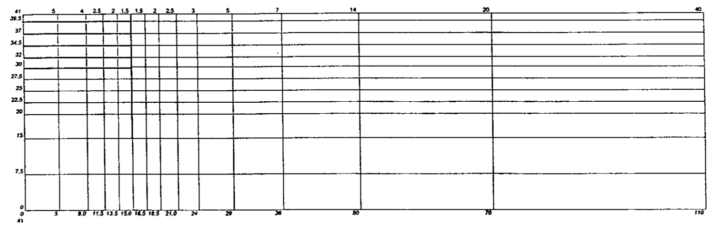




45

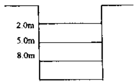
Parametric Study of a Hypothetical Problem



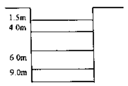


46

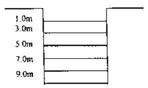
Effect of Number of Strut Level – Diaphragm Wall (1m)



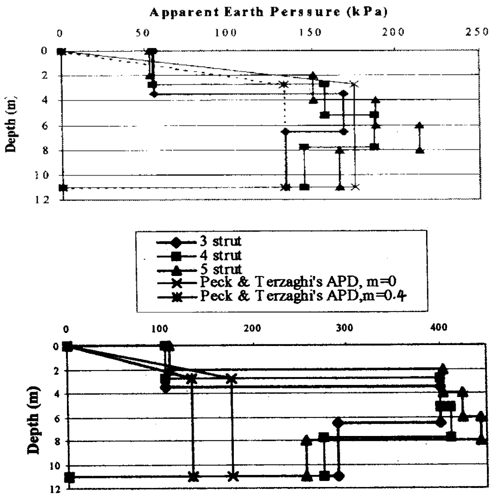
3 struts



4 struts

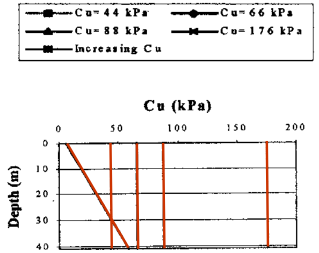


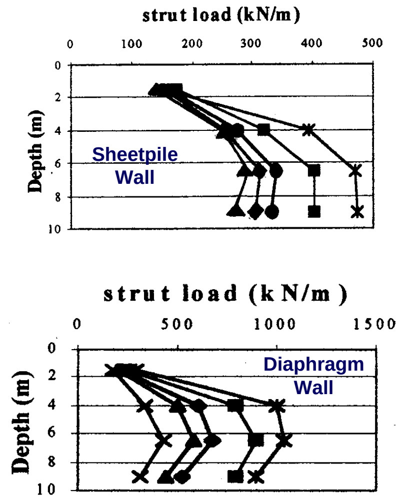
5 struts

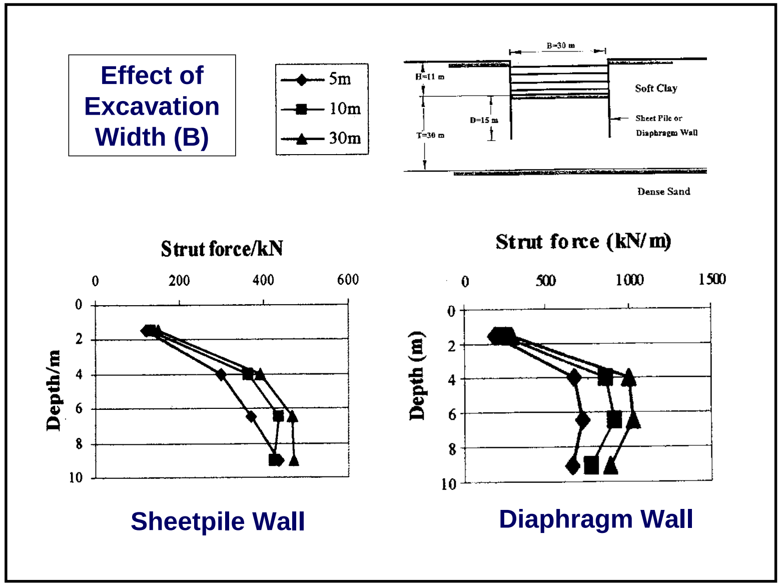


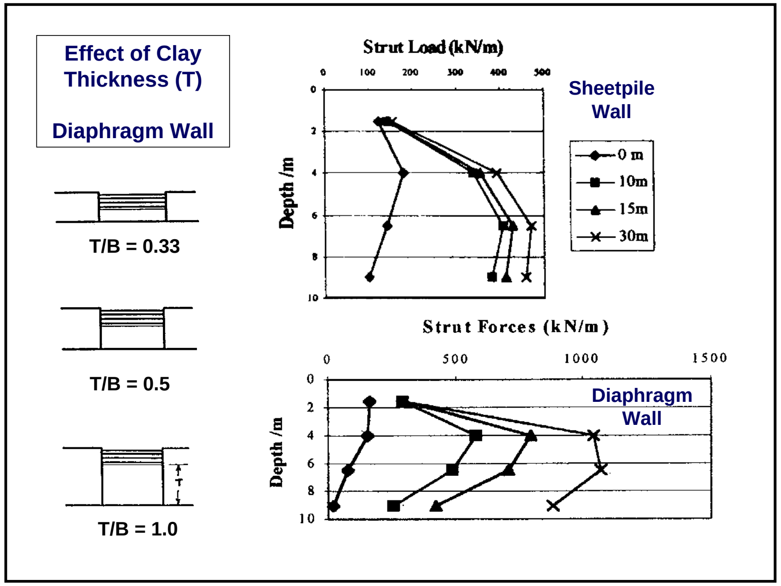
Effect of Undrained Shear Strength

(Sheetpile Wall)






Effect of Excavation Width (B)
5m
10m
30m
B=30 m
H=11 m
D=15 m
T=30 m
Soft Clay
Sheet Pile or Diaphragm Wall
Dense Sand
Strut force/kN
Depth/m
Sheetpile Wall
Strut force (kN/m)
Depth (m)
Diaphragm Wall


Effect of Clay Thickness (T)
Diaphragm Wall
T/B = 0.33
T/B = 0.5
T/B = 1.0
Strut Load (kN/m)
Depth /m
Sheetpile Wall
0 m
10m
15m
30m
Strut Forces (kN/m)
Depth /m
Diaphragm Wall