Deep excavations

Dr Stephen Buttling

Resident Project Manager

Underground Train Station

Suvarnabhumi Airport, Bangkok, Thailand

EarthTech

A tyco International Ltd. Company

Mirny diamond mine
East Siberia

1200 m diameter
550 m deep

EarthTech
A tyco International Ltd. Company

A BETTER TOMORROW made possible

Deep excavations

- Some thoughts on soil investigation
  - Where did the soil come from?
  - Where did the rocks come from?
  - Where did the earth come from?

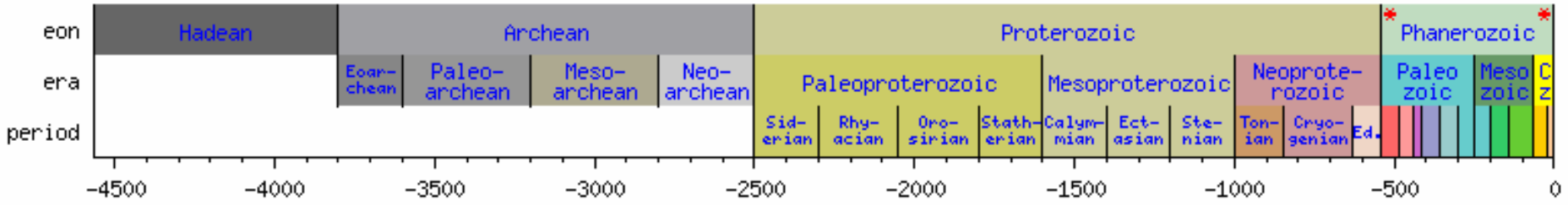
Deep excavations

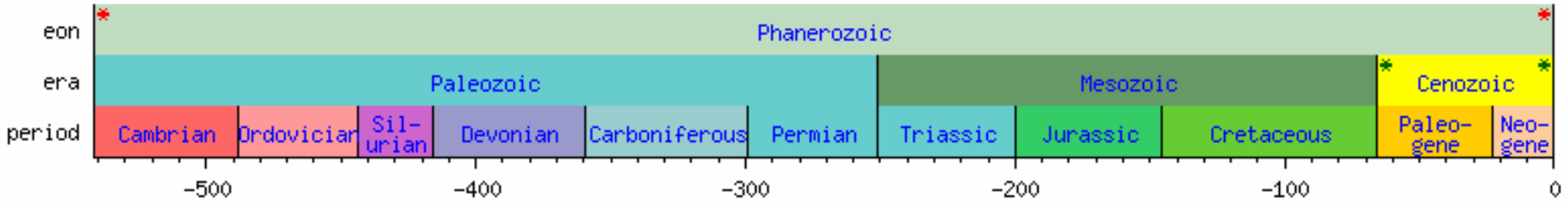
- Earth born about 4.5 billion years ago
- Solidified cloud of dust and gases left over from creation of the Sun
- For about 500 million years cooled down and core became about 2,000°C
- Oldest rocks on earth's surface about 4.4 billion years old – about 2.5 billion in North Australia
- Radioactive decay caused heating/melting. Iron moved to centre, forced silicates upwards

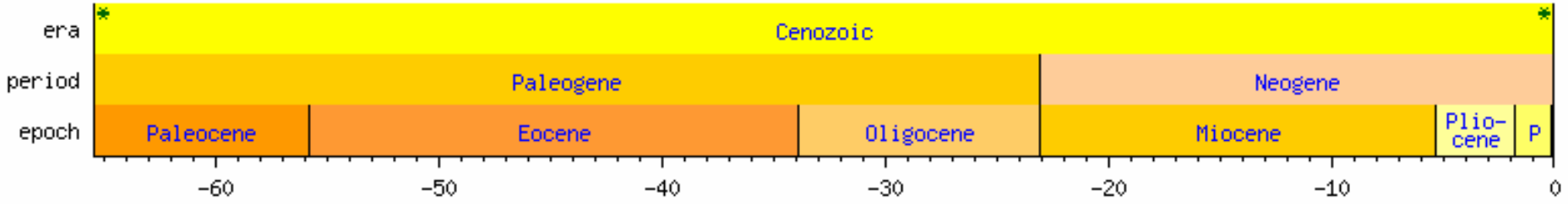
Deep excavations

- There would have been volcanoes and lava flows, but a thin fairly stable crust formed
- Depressions filled with water rising from within
- Water cycle started
- Weathering of the igneous and volcanic rocks followed
- Erosion through streams and rivers led to deposition as sediments

Deep excavations







Deep excavations

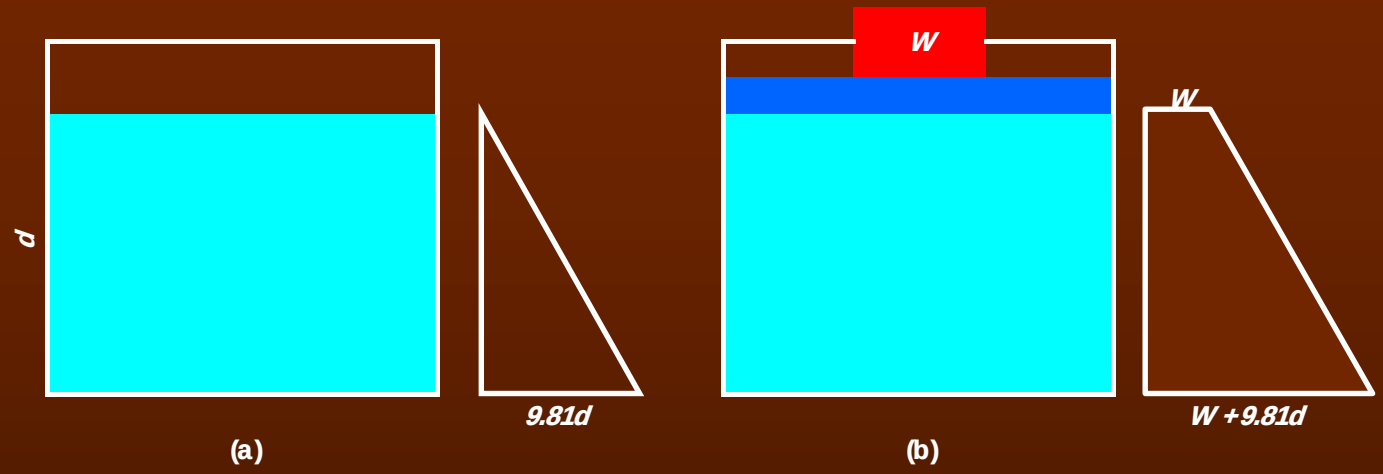
- Oldest rocks around Brisbane about 390 million years
- All soil sediments deposited in Pleistocene (last 2 million years)
- Current deposition is Holocene, about the same as man, last 10,000 years
- Deposition starts as boulders at stream heads, through gravels and sands within river to silts at estuary/delta and marine deposits beneath sea
- Subsequent layers lead to high vertical stresses and consolidation

Deep excavations

- Soil behaviour defined by stress history
- Loose sediments become denser/stiffer through consolidation
- Overconsolidation – caused by glaciation, erosion
- Lateral stresses of stiffened soils – tectonic action, folding, faulting

Deep excavations

Looking first at a tank full of water



Now considering soil, vertical stress is

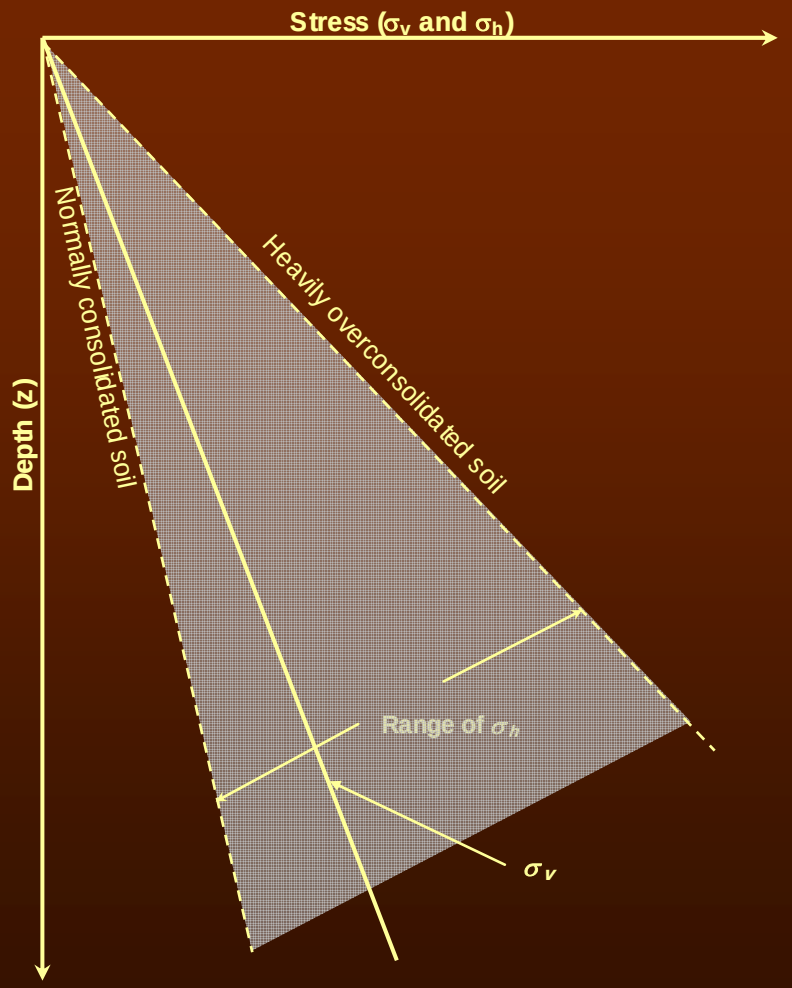
$$\sigma_v = \sum_{i=1}^{n} z_i \gamma_i$$

Deep excavations

- Assume $\sigma_h = K\sigma_v$
- K = coefficient of lateral earth pressure
- Not a constant – function of:
  - Soil properties – particle size and shape
  - Position – varies within a layer
  - Time – effects of excavation, loading etc
  - Therefore of stress history – effects of eg glaciation (London Clay)

Deep excavations

Overconsolidation ratios of up to about 100 have been measured



Deep excavations

- Define coefficient of lateral earth pressure at rest K_0
  - Normally consolidated soils < 1, maybe 0.4 to 0.5
  - Overconsolidated soils and decomposed rocks, maybe 3

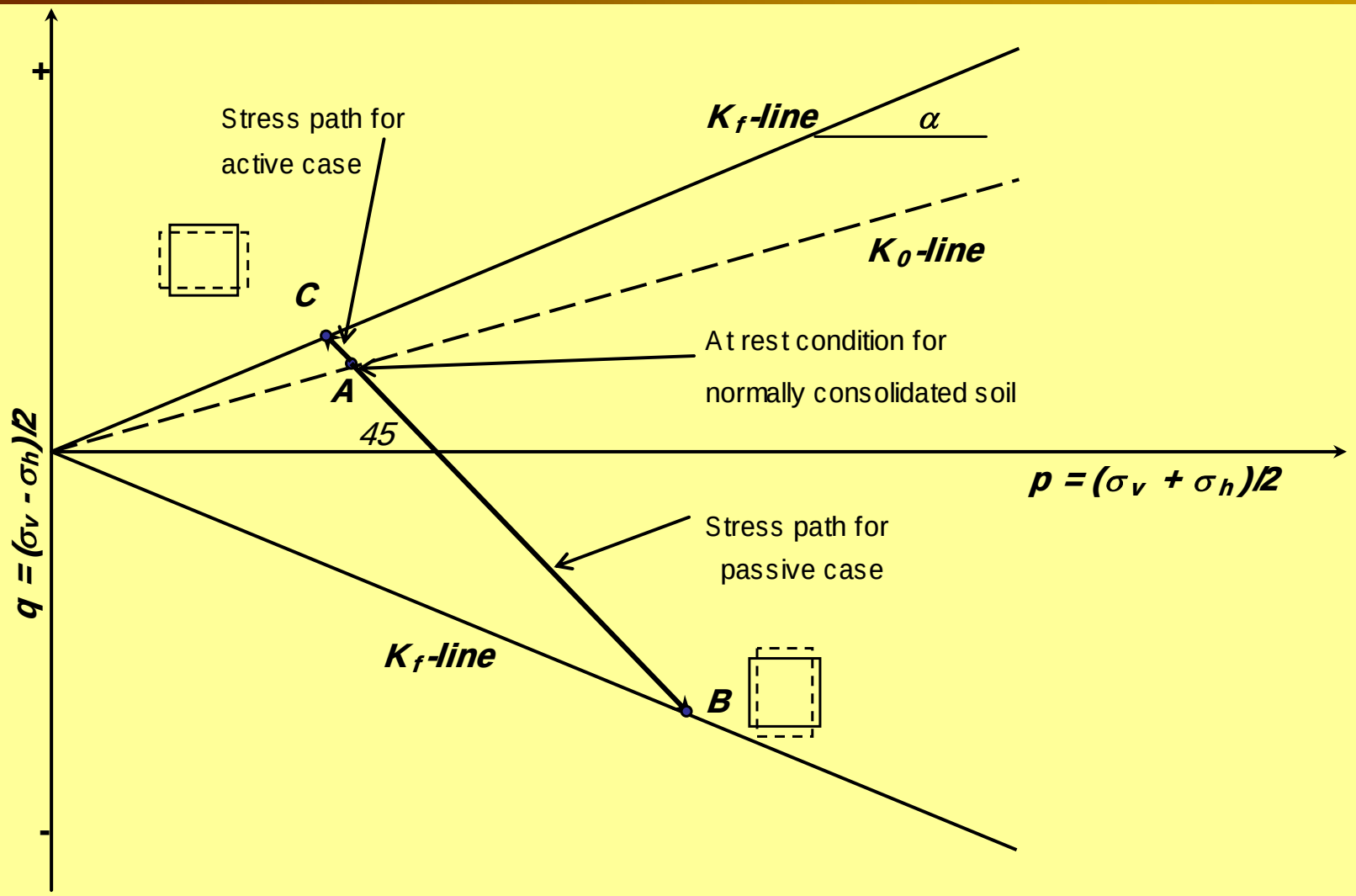
EarthTech

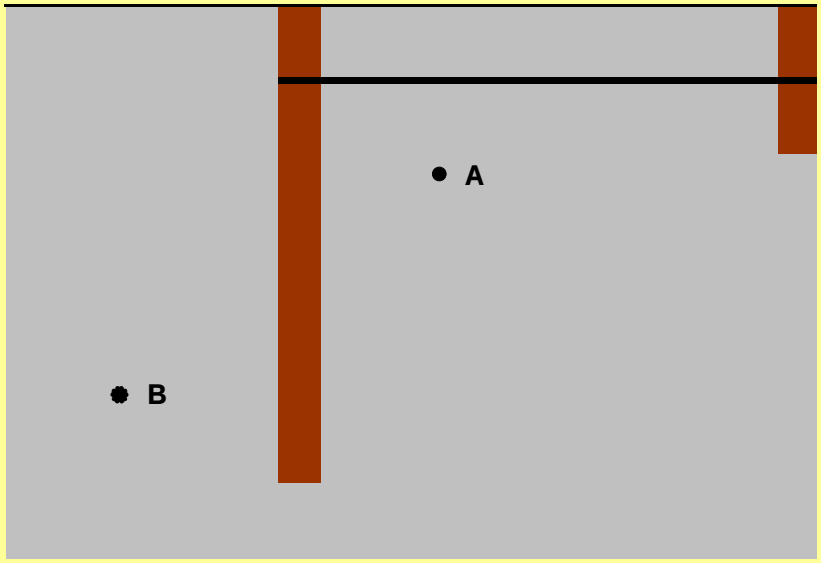
A tyco International Ltd. Company

A BETTER TOMORROW made possible

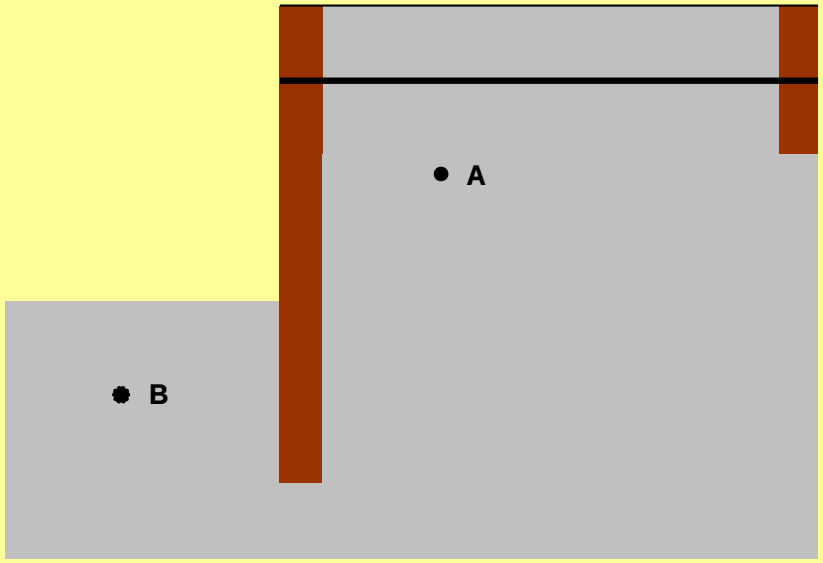
Deep excavations

- Rankine states
  - Active pressure limit K_a – ***as soil is stretched, e.g. upper part of wall moving towards excavation***
  - Passive pressure limit K_p – ***as soil is compressed horizontally, e.g. toe of wall moving towards excavation***


+
-
Stress path for
active case
K_f-line
α
K_0-line
C
A
At rest condition for
normally consolidated soil
45
$q = (\sigma_v - \sigma_h)/2$
$p = (\sigma_v + \sigma_h)/2$
Stress path for
passive case
K_f-line
B



(a)

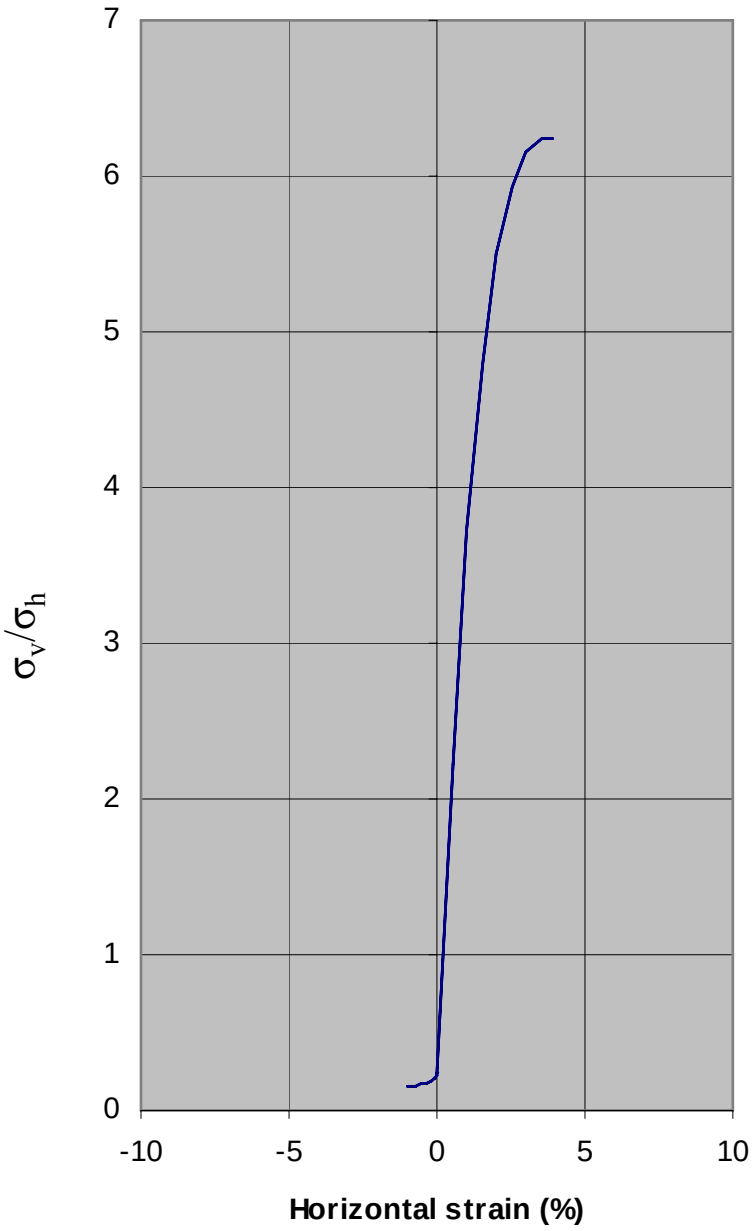


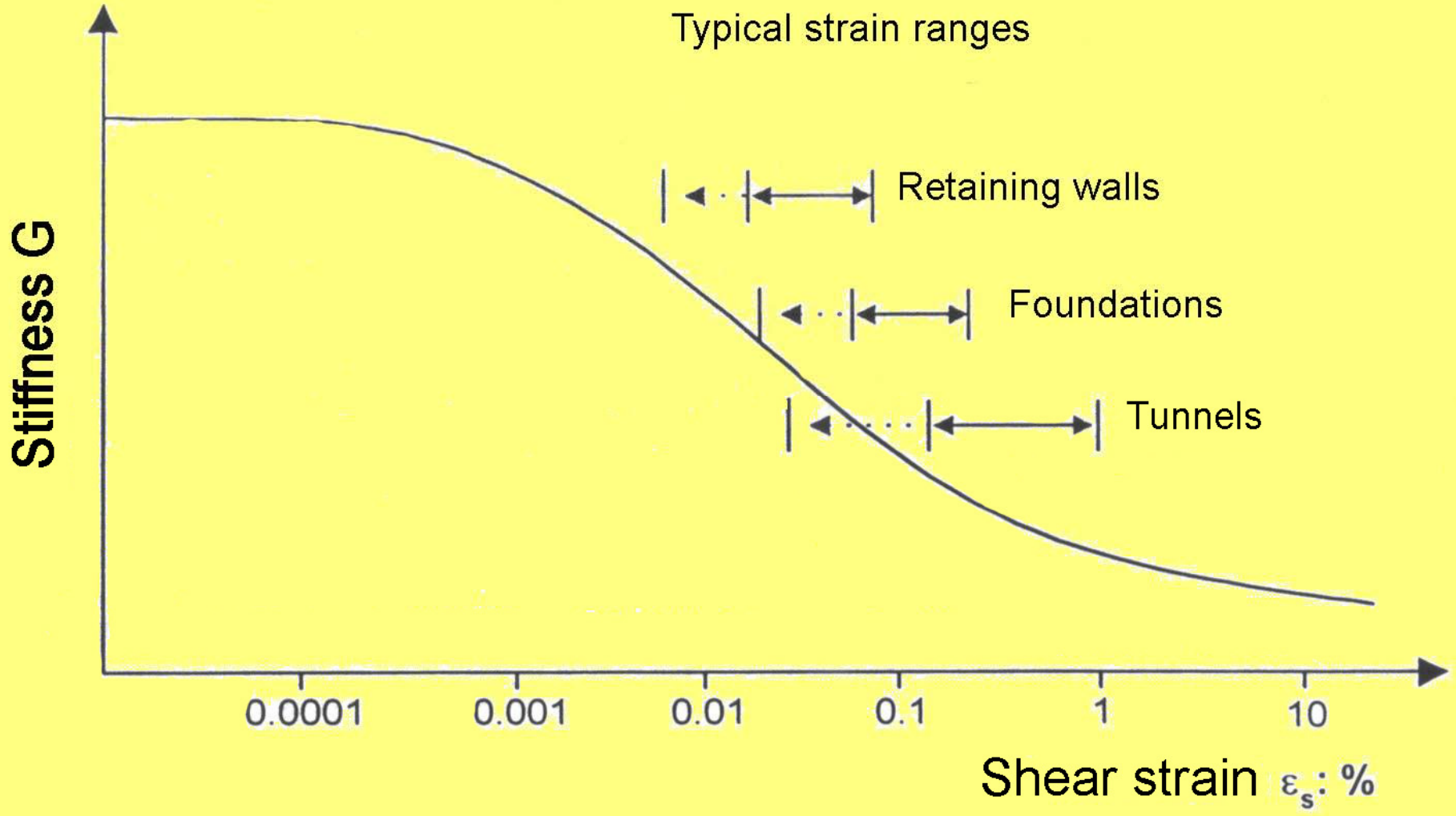
(b)

Compression Unloading test and Extension Loading test on dense sand. Note:

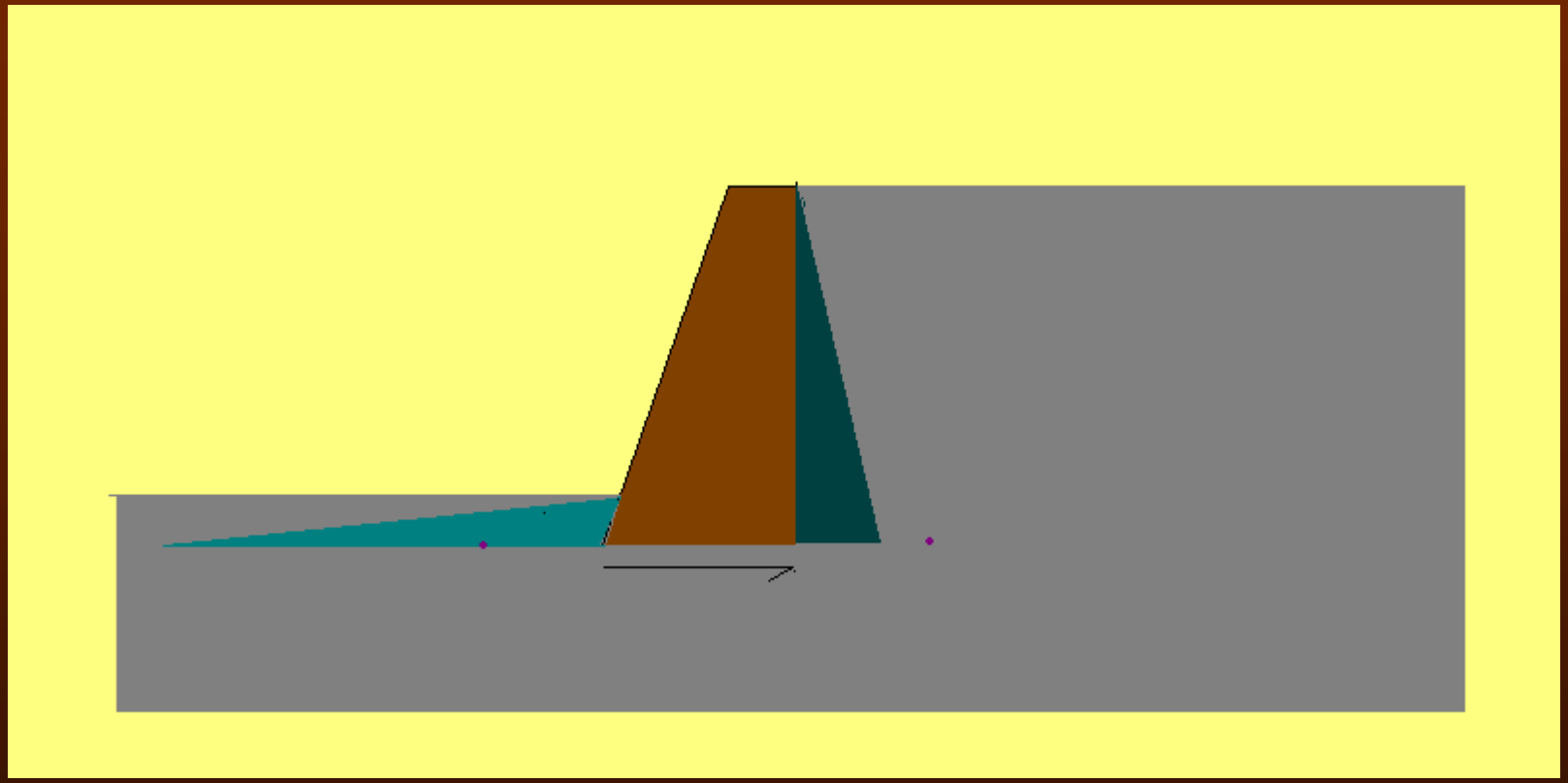
- Strain to active state ~ 0.5%
- Strain to half passive state ~ 0.5%
- Strain to full passive state ~ 3%

For loose sand strain to full passive state ~ 15%




Typical strain ranges
Stiffness G
Retaining walls
Foundations
Tunnels
0.0001
0.001
0.01
0.1
1
10
Shear strain ε_s: %

Gravity wall – large strains



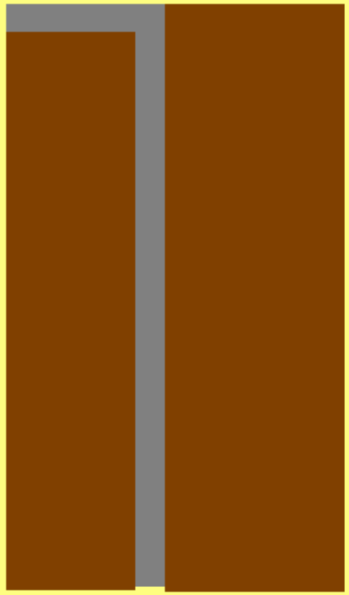
Deep excavations

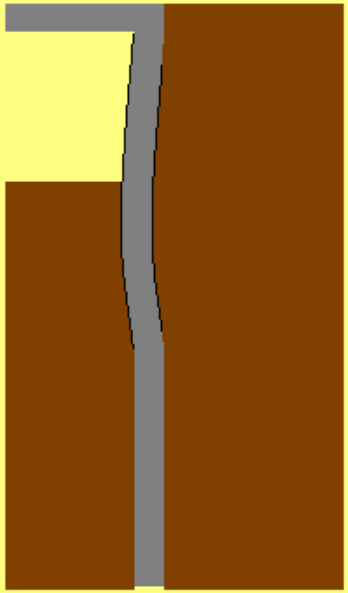
Sheet pile walls

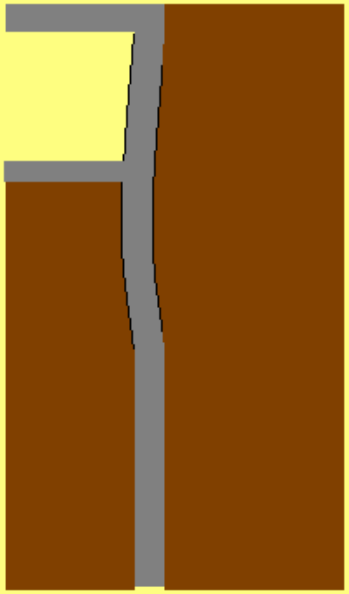
- Mana and Clough (1981) suggest 0.2 to 2%
- Baggett and Buttling (1977) ~ 1.4%

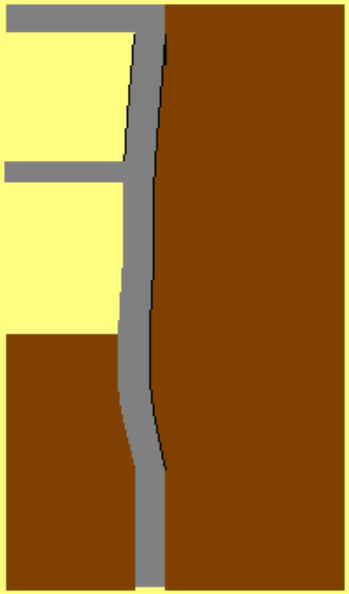
Diaphragm walls

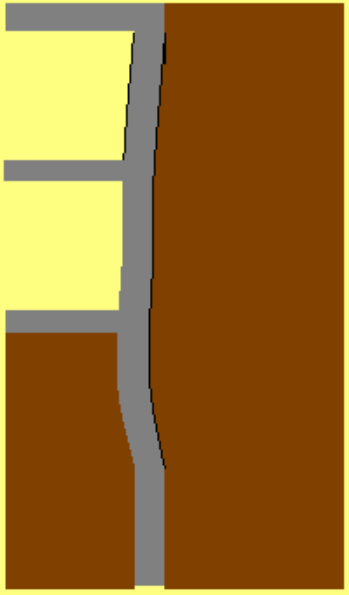
Small strains; ~ 0.1% for top down and 0.2% for strutted excavations











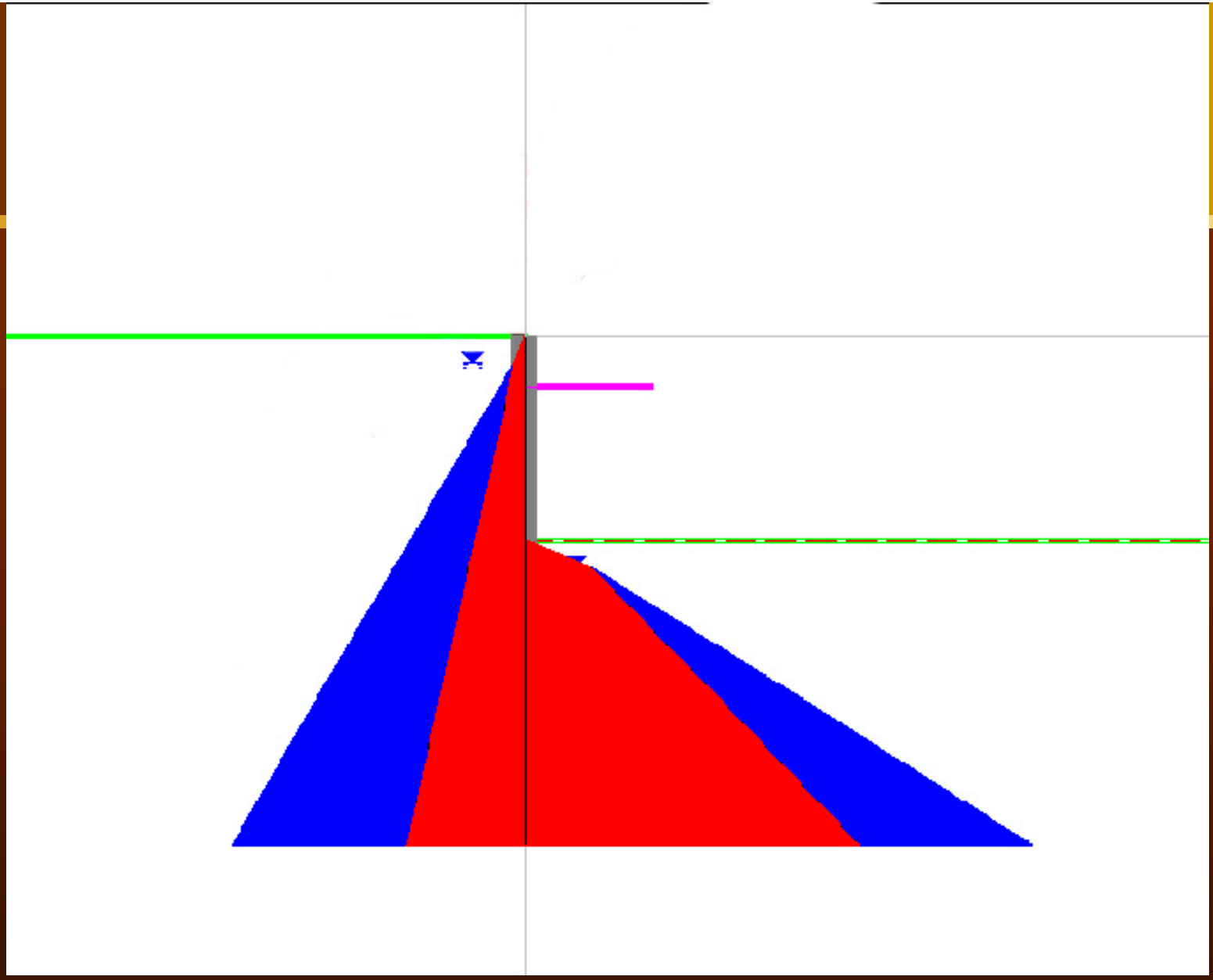
Horizontal movements increase progressively as excavation proceeds downwards. Typical values are about 0.1% of excavation depth for good workmanship in reasonable soil

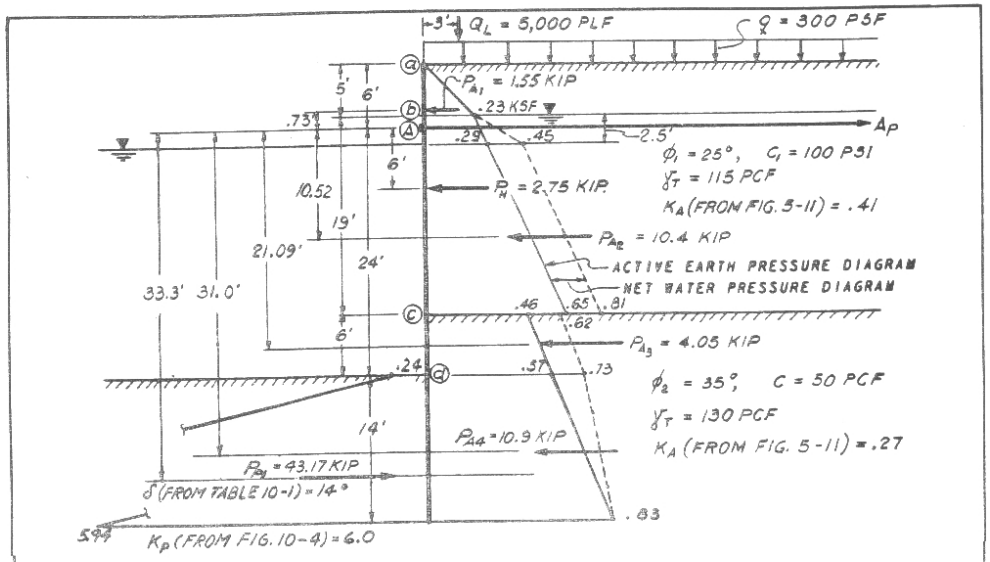
EarthTech

A tyco International Ltd. Company

Deep excavations

- Diaphragm walls – “Concurrent tunnelling and station excavation at Bangkok MRTA North” – Yeow, Gaba & Pillai – 15th SEAGC
  - Use of BRICK model and CamClay – very small strains = high stiffness = low soil pressure = low bending moment = low reinforcement requirement = cost saving.
  - After construction, wall stiffness is low, so IF error occurs, higher pressure = higher bending moment = greater deflection = lower stiffness = higher pressure = higher bending moment = greater deflection = lower stiffness = higher pressure = higher bending moment .....





ACTIVE EARTH PRESSURE (SEE FIG. 10-1) INCLUDING UNIFORM SURCHARGE q_x

$\sigma_H = \gamma Z K_A - 2C\sqrt{K_A}$

Ⓐ, $\sigma_H = .30 \times .41 - 2 \times .10\sqrt{.41} = 0$

Ⓑ, $\sigma_H = (.30+5\times.115).41 - 2\times.10\sqrt{.41} = .23$ KSF

Ⓒ, $\sigma_H = (.30+5\times.115+19\times.053).41 - 2\times.10\sqrt{.41} = .65$ KSF

Ⓒ, $\sigma_H = (.30+5\times.115+19\times.053).27 - 2\times.05\sqrt{.27} = .46$ KSF

Ⓓ, $\sigma_H = .46 + 6\times.068\times.27 = .57$ KSF

Ⓔ, $\sigma_H = .46 + (6+14)\times.068\times.27 = .83$ KSF

PRESSURE OF LINE LOAD SURCHARGE (SEE FIG. 10-6).

$m = \frac{x}{H} = \frac{3}{30} = 0.1$

$P_H = 0.55\,Q_L = 0.55 \times 5 = 2.75$ KIP

LOCATION OF RESULTANT:

$R = .60H = .60 \times 30 = 18'$

NET WATER PRESSURE

$\sigma_W = \gamma_W Z = .0625 \times 2.5 = .16$ KSF

PASSIVE PRESSURE

$\sigma_H = \gamma Z K_P + 2C\sqrt{K_P}$

Ⓓ, $\sigma_H = 0 + 2\times.05\sqrt{6.0} = .24$ KSF

Ⓔ, $\sigma_H = .068\times14\times6.0 + 2\times.05\sqrt{6.0} = 5.94$ KSF

SAFETY FACTOR AGAINST TOE FAILURE:

TAKE MOMENTS ABOUT Ⓐ

$F_S = \frac{\Sigma \text{ MOMENTS OF PASSIVE FORCES}}{\Sigma \text{ MOMENTS OF ACTIVE FORCES}}$

$= \frac{43.17\times33.3}{1.55\times0.73 + 2.75\times6 + 10.4\times10.52 + 4.05\times21.09 + 10.9\times31.0}$

$= 2.61 > 2.5$

ANCHOR PULL

$A_P = \Sigma P_A - \Sigma P_P / F_S$

$= 1.55 + 2.75 + 10.4 + 4.05 + 10.9 - \frac{43.17}{2.5} = 12.37$ IK

MAXIMUM BENDING MOMENT IN SHEETING

POINT OF ZERO SHEAR:

$12.37 - 1.55 - 2.75 - .45X - .022\times\frac{X^2}{2} = 0$

$X = 13.6'$ BELOW OUTSIDE WATER LEVEL

$M_{MAX} = 1.55\times15.7 + 12.37\times15.1 - 2.75\times9.1$

$- .45\times\frac{13.6^2}{2} - .022\times\frac{13.6^2}{2}\times4.52 = 86.9$ IK

MOMENT REDUCTION:

ASSUME: f_S = 27,000 PSI, E = 30,000,000 PSI

TRY ZP32, I = 385.7 IN^4, S = 38.3 IN^4

ρ = (FROM FIG. 10-13) $= \frac{(H+D)^4}{EI}$

$\rho = \frac{(30\times12+14\times12)^4}{30{,}000{,}000\times385.7} = 6.7 \frac{IN^2}{LB}$

$\frac{M_{DESIGN}}{M_{MAX}} = .83$; $M_{DESIGN} = .83\times86.9 = 72.1$ IK

$f_S = \frac{M}{S} = \frac{72.1\times1000\times12}{38.3} = 22{,}600$ PSI < 27,000

TRY A SMALLER SECTION

FIGURE 10-15
Example of Analysis of Anchored Bulkhead