2) Shearing Conditions

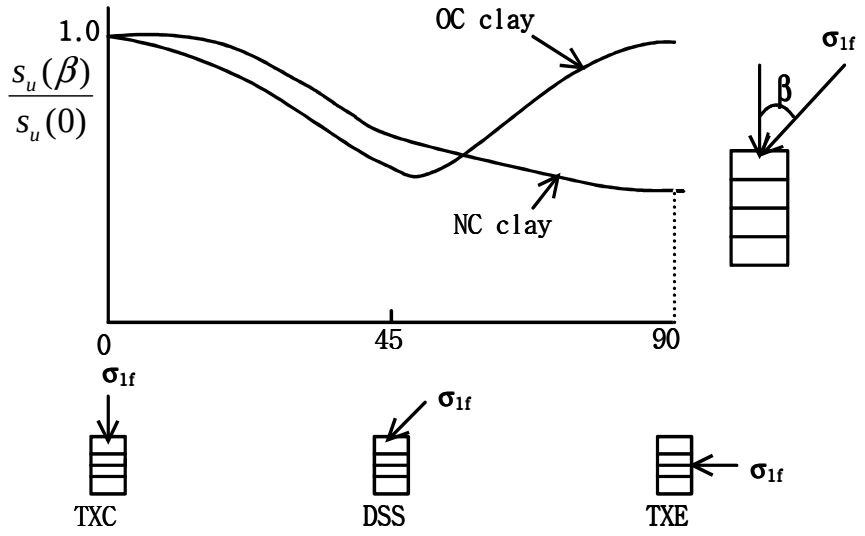
a) Anisotropy

2 types [1) Material → Inherent anisotropy
2) $K_0 \neq 1$ → Stress system anisotropy]

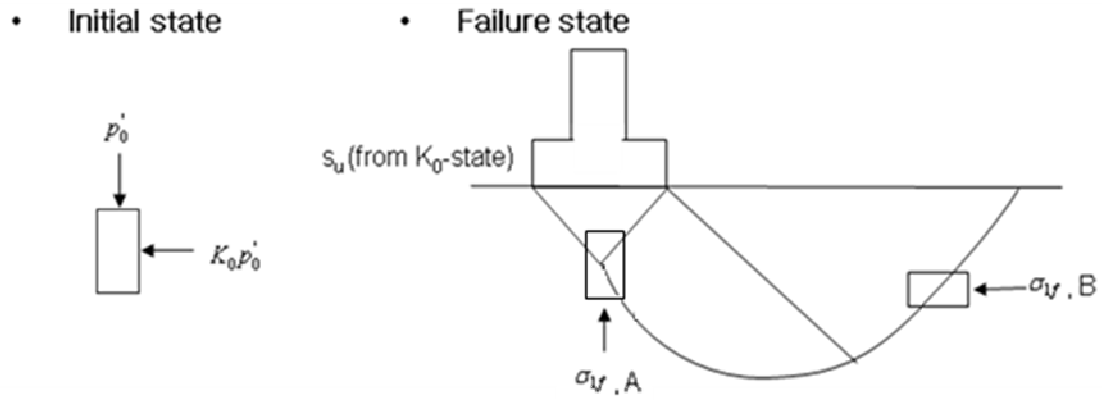
→ Caused by tendency of clay particles to become horizontally oriented during deposition (1 – D Compression)

Anisotropy will affect
→ ϕ' , c' ⇒ ϕ'_{ext} > ϕ'_{com} (?)
→ s_u
→ Deformation parameters (σ - ε response)
→ Pore pressure response

As the direction of major principal stress changes, anisotropy of undrained strength ($s_u(\beta)/s_u(0)$) is shown as,

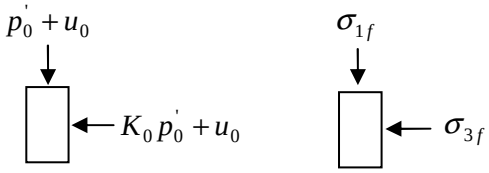


- Stress reorientation effects



We want to evaluate the change in strength caused by the rotation of principal stress direction (⇐ stress system induced anisotropy due to $K_0 \neq 1$).

Point A



Init. Fail.

$$s_u = \frac{\sigma_{1f} - \sigma_{3f}}{2} = \frac{(\sigma_1 - \sigma_3)_f}{2}$$

Look at N.C. clays (c'=0), based on Mohr-coulomb criteria to define failure,

$$\sin\phi' = \frac{(\sigma_1 - \sigma_3)_f}{\sigma_{1f}' + \sigma_{3f}'}$$

By Algebra,

$$(\sigma_1-\sigma_3)_f = \sigma'_{3f}\left(\frac{2\sin\phi'}{1-\sin\phi'}\right) \text{ ---------- ①}$$

Where $\sigma'_{3f} = \sigma_{3f} - \Delta u - u_0$

$= \sigma'_{3i} + u_0 + \Delta\sigma_3 - \Delta u - u_0 = \sigma'_{3i} + \Delta\sigma_3 - \Delta u$

We know : $\Delta\sigma_1 = \sigma_{1f} - p'_0 - u_0$

$\Delta\sigma_3 = \sigma_{3f} - K_0 p'_0 - u_0$

$\Delta u = B(\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3))$ (for saturated soil, B=1)

$$\sigma'_{3f} = \sigma'_{3i} + \Delta\sigma_3 - \Delta u$$
$$= K_0 p'_0 + (\sigma_{3f} - K_0 p'_0 - u_0)$$
$$-[\sigma_{3f} - K_0 p'_0 - u_0 + A(\sigma_{1f} - p'_0 - u_0 - \sigma_{3f} + K_0 p'_0 + u_0)]$$

$$\sigma'_{3f} = K_0 p'_0 - A(\sigma_{1f} - \sigma_{3f} - p'_0 + K_0 p'_0) \text{ ---------- ②}$$

Sub. ② → ①.

$$(\sigma_1-\sigma_3)_f = [K_0 p'_0 - A((\sigma_1-\sigma_3)_f - p'_0 + K_0 p'_0)]\left(\frac{2\sin\phi'}{1-\sin\phi'}\right)$$

$$(\sigma_1-\sigma_3)_f\left(1+\frac{2A\sin\phi'}{1-\sin\phi'}\right) = [K_0 p'_0 - A(-p'_0 + K_0 p'_0)]\left(\frac{2\sin\phi'}{1-\sin\phi'}\right)$$

$$\Rightarrow \frac{(\sigma_1-\sigma_3)_f}{2p'_0}\left(=\frac{s_u}{p'_0}\right) = [K_0 - A(K_0-1)]\left(\frac{\sin\phi'}{1-\sin\phi' + 2A\sin\phi'}\right)$$

NC clays (typical values)

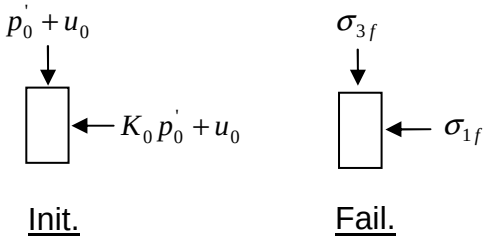
For ϕ' =30°

K_0 = 0.5

A_f=1

$$\Rightarrow \frac{s_u}{p'_0} = 0.3$$

Point B



$$\Delta\sigma_1 = \sigma_{1f} - K_0 p_0' - u_0$$

$$\Delta\sigma_3 = \sigma_{3f} - p_0' - u_0$$

$$\frac{s_u}{p_0'} = \frac{[1 - A(1 - K_0)]\sin\phi'}{1 - \sin\phi' + 2A\sin\phi'}$$

NC clays (typical values)

For ϕ' =30°

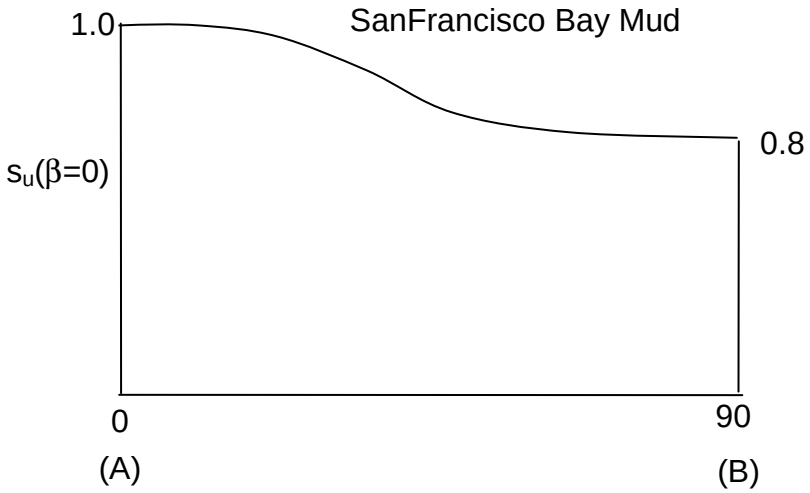
K_0 = 0.5

A_f=1

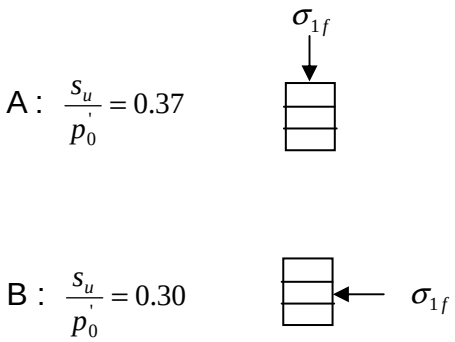
$$\Rightarrow \frac{s_u}{p_0'} = 0.17$$

Question : $\phi'_{com} = \phi'_{ext}$ (?), $(A_f)_{compression} = (A_f)_{extension}$ (?)

- Example of undrained strength anisotropy



$\Rightarrow$ Combined effect of inherent and stress system anisotropy



b) Plane strain tests vs. Triaxial tests

Plane strain test comparing to triaxial test gives;
(the effect of intermediate stress σ_2)

① Slight increase (5± %) in s_u

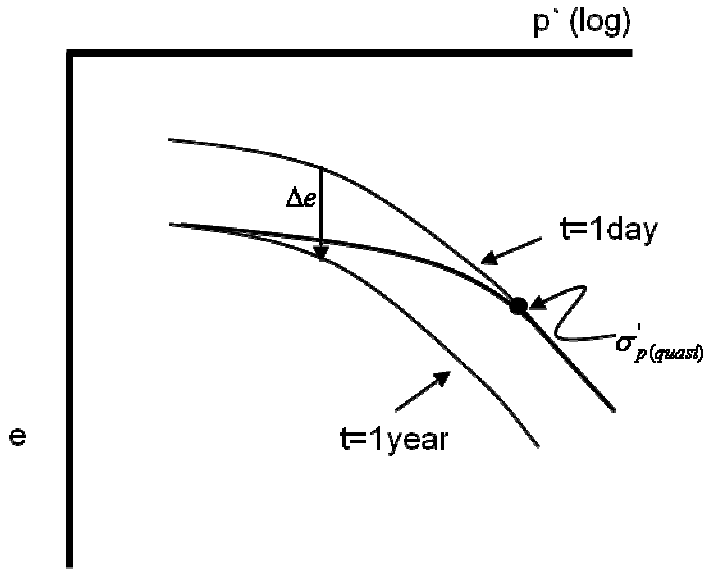
Loading direction	$s_u(TX)/s_u(PL)$
$\beta=0°$	0.92±0.05 (5 clays)
$\beta=90°$	0.82±0.02 (4 clays)

② Increase ϕ' by 2±2°

③ Lower strain at failure and increase tendency of the strain softening in plain strain tests, perhaps because of the more general formation of failure plane.

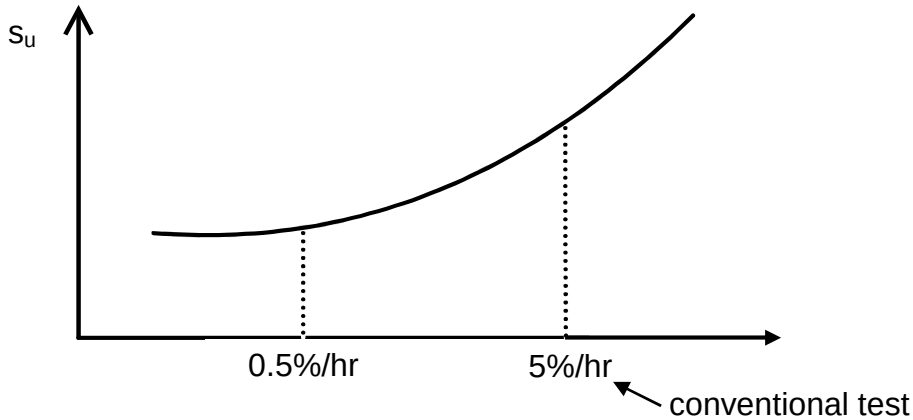
c) Aging effect

Aging → increase undrained strength, owing to decrease of e



In lab → one log cycle of time for secondary compression is required for aging.

d) Rate of shearing



$(s_u)_{\text{conventional test}} = 1.3\ s_{u(0.5\%/hr)}$