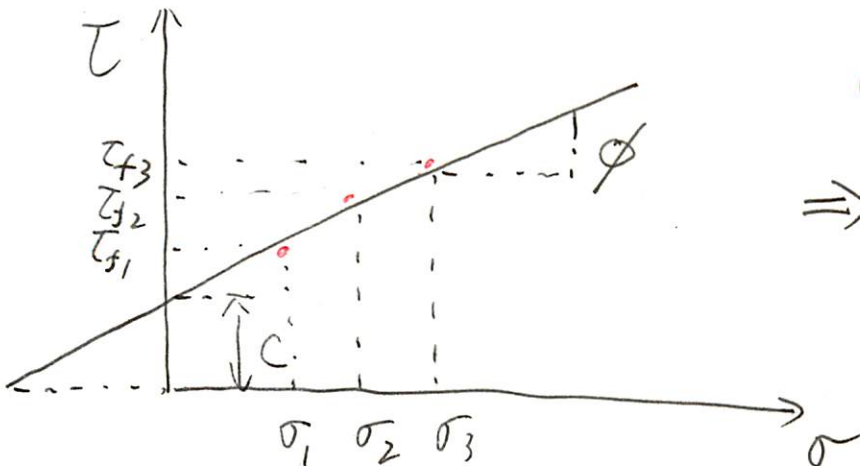
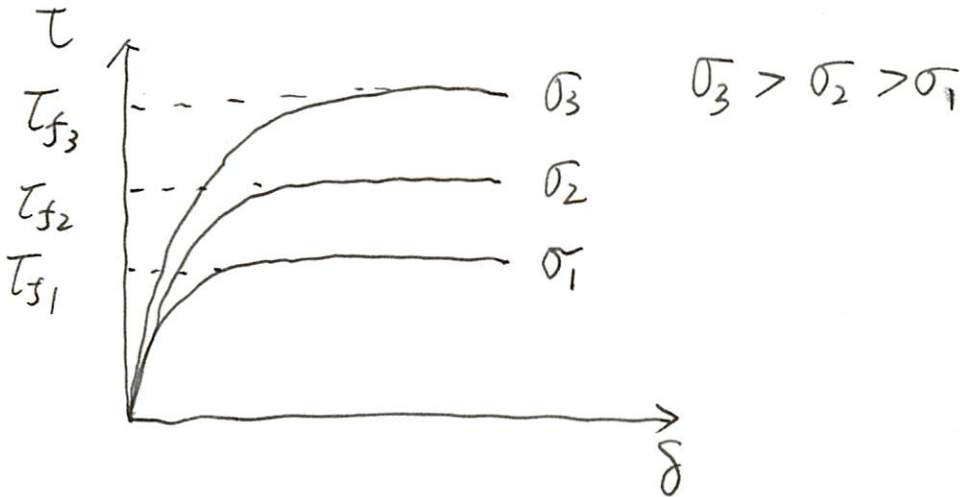
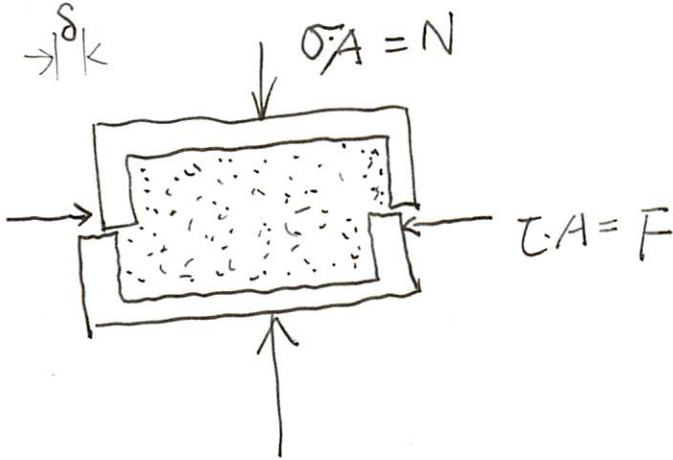




# 土断

## 1. 一面土断



$\phi$ : 摩擦角度

Coulomb 破壊標準

$$\Rightarrow \tau_f = \sigma \tan \phi + C$$

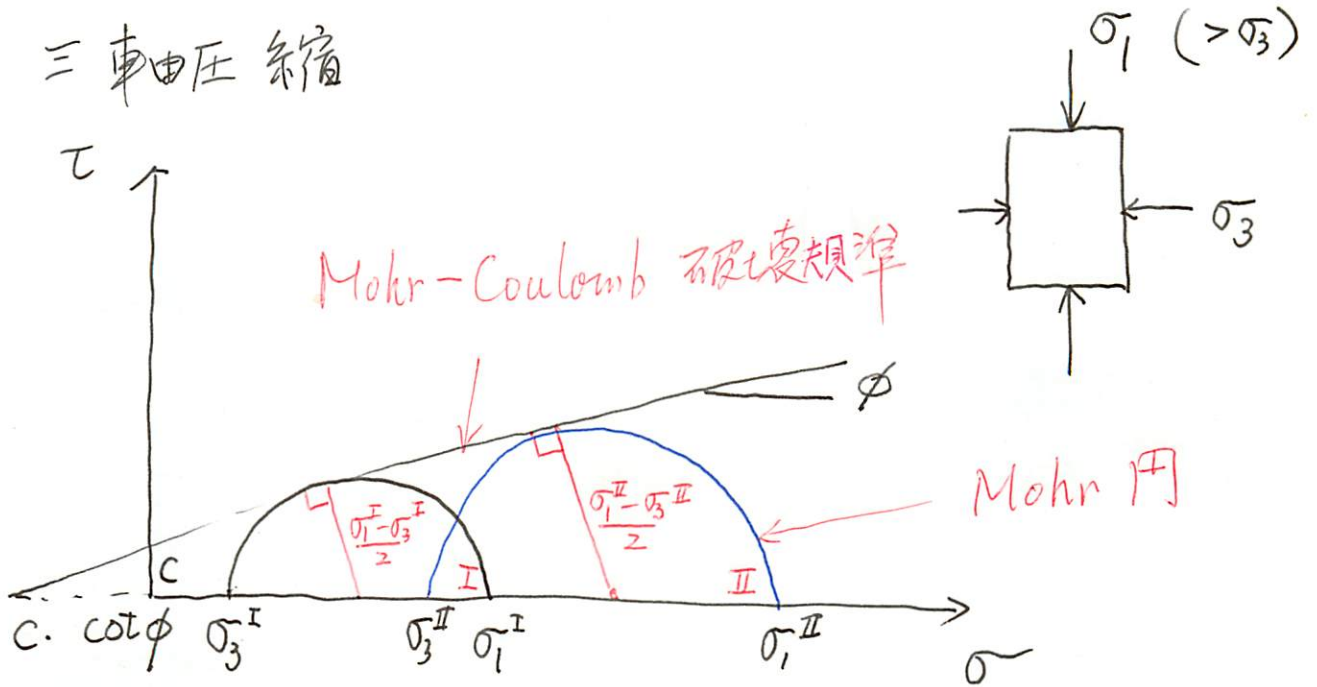


$$\sigma = 0, C = \tau_{f0}$$

粘着力  $\leftarrow C = \tau_{f0}$ : 抱束圧が0である時の土断強度.



## 2. 三軸圧縮



Mohr 円 2 :

$$\frac{\frac{\sigma_1^{\text{II}} - \sigma_3^{\text{II}}}{2}}{c \cdot \cot \phi + \frac{\sigma_1^{\text{II}} + \sigma_3^{\text{II}}}{2}} = \sin \phi$$

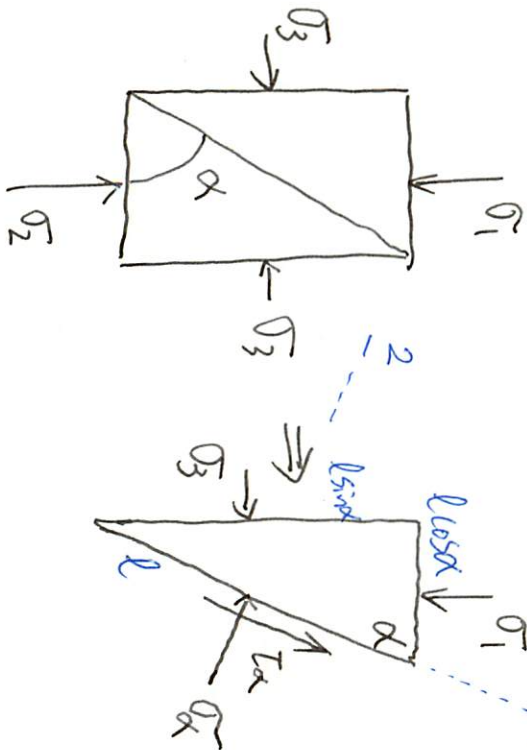
$$\Rightarrow \frac{\sigma_1^{\text{II}} - \sigma_3^{\text{II}}}{2} = \frac{\sigma_1^{\text{II}} + \sigma_3^{\text{II}}}{2} \sin \phi + c \cdot \cos \phi$$

$c$ : 粘着力;  $\phi$ : 内部摩擦角度.

$c, \phi$  を得るには最低 2 つの三軸圧縮試験が必要である。



### 3 Coulomb 破壊規準と Mohr - Coulomb 破壊規準の関係



(a) 1方向の力のつりあ式より:

$$\begin{aligned} \tau_\alpha \cdot l + \sigma_3 l \sin \alpha \cdot \cos \alpha \\ - \sigma_1 l \cos \alpha \cdot \sin \alpha = 0 \end{aligned}$$

$$\Rightarrow \tau_\alpha = \frac{\sigma_1 - \sigma_3}{2} \sin 2\alpha \quad \textcircled{1}$$

(b) 2方向の力のつりあ式より:

$$\sigma_\alpha l - \sigma_1 l \cos \alpha \cdot \cos \alpha - \sigma_3 l \sin \alpha \cdot \sin \alpha = 0$$

$$\Rightarrow \sigma_\alpha = \sigma_1 \cos^2 \alpha + \sigma_3 \sin^2 \alpha = \frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2} \cos 2\alpha \quad \textcircled{2}$$

Coulomb 破壊規準より

$$\tau_f = c + \sigma_\alpha \tan \phi$$

$$\tau_\alpha \leq \tau_f \Rightarrow f(\alpha) = \tau_\alpha - \tau_f \leq 0$$

従って,  $f(\alpha)$  が極限値を有する際,  $\frac{df(\alpha)}{d\alpha} = 0$   
を満たす  $\alpha$  が存在する。この時の  $\alpha = \alpha_{crit}$

$$f(\alpha) = \frac{\sigma_1 - \sigma_3}{2} \sin 2\alpha - \left[ c + \left( \frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2} \cos 2\alpha \right) \cdot \tan \phi \right]$$

③



$$\frac{df(\alpha)}{d\alpha} = 0 \Rightarrow (\sigma_1 - \sigma_3) \cos 2\alpha_{\text{cri}} + (\sigma_1 - \sigma_3) \sin 2\alpha_{\text{cri}} \cdot \tan \phi = 0$$

$$\Rightarrow \alpha_{\text{cri}} = \frac{\pi}{4} + \frac{\phi}{2} \quad \textcircled{4} \quad (\text{例} \textcircled{2} \text{ 取} \phi = 30^\circ \Rightarrow \alpha = 60^\circ)$$

式④を  $f(\alpha) = 0$  に代入すると

$$\frac{\sigma_1 - \sigma_3}{2} = \frac{\sigma_1 + \sigma_3}{2} \sin \phi + c \cdot \cos \phi \Rightarrow \text{Mohr-Coulomb 破壊規準を導く!}$$



#### 4. 有効応力

$$\sigma = \sigma' + u$$

or

$\sigma'$ : 有効応力  
 $u$ : 間隙水圧.

$$\begin{cases} \sigma_1 = \sigma'_1 + u \\ \sigma_3 = \sigma'_3 + u \end{cases}$$

$$\Rightarrow \sigma_1 - \sigma_3 = \sigma'_1 - \sigma'_3$$

$$\frac{\sigma_1 + \sigma_3}{2} = \frac{(\sigma'_1 + \sigma'_3)}{2} + u$$

#### 5. 間隙水圧を考慮した三軸試験

UU, CU, CD 試験

UU: 非圧密・非排水試験 ( $c_u, \phi_u$ )

CU: 圧密・非排水試験 ( $c_{cu}, \phi_{cu}; c', \phi'$ )

CD: 圧密・排水試験 ( $c_{cd}, \phi_{cd}$ )

目的: 上記の試験より, 材料パラメータである各種の  $c, \phi$  を求め, 土のせん断強度を把握する。



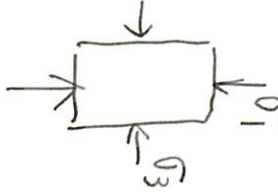


### UU 試験

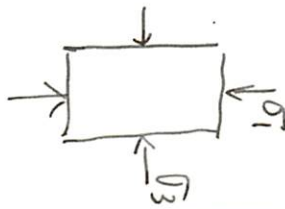
$$\phi_u = 0$$

$$c_u = \frac{1}{2}(\sigma_f - \sigma_{3f})$$

Sample 1



Sample 2



① 等方圧密

$$\sigma_{10}' = \sigma_{30}' = 2.0$$

$$\sigma_{10} = \sigma_{30} = 2.0$$

② 排水2...クを挿入,  
せん断可能

$$\sigma_{1f} = 3.9$$

$$\sigma_{3f} = 2.0$$

$$\Delta u_f = 1.0$$

① 等方圧密  
同様

同様

② 排水2...クを挿入,  
せん断可能

$$\sigma_{10}' = \sigma_{30}' = 2.0$$

$$\sigma_{10} = \sigma_{30} = 4.0$$

③ 排水2...クを挿入,  
せん断可能

$$\sigma_{1f} = 5.9$$

$$\sigma_{3f} = 4.0$$

$$\Delta u_f = 3.0$$

### CU 試験

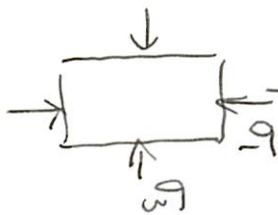
$$c_{cu} = 0 \quad c' = 0$$

$$\phi_{cu} < \phi'$$

Sample 1

UU

Sample 2



① 等方圧密

$$\sigma_{10}' = \sigma_{30}' = 2.0$$

$$\sigma_{10} = \sigma_{30} = 2.0$$

② 排水2...クを挿入,  
せん断可能

$$\sigma_{10}' = \sigma_{30}' = 4.0$$

$$\sigma_{10} = \sigma_{30} = 4.0$$

③ 排水2...クを挿入,  
せん断可能

$$\sigma_{1f} = 7.55$$

$$\sigma_{3f} = 4.0$$

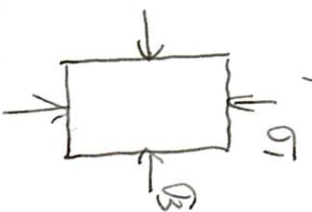
$$\Delta u_f = 2.45$$

### CD 試験

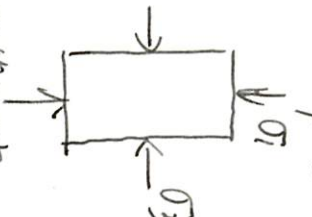
$$c_{cd} = 0 = c'$$

$$\phi_{cd} = \phi'$$

Sample 1



Sample 2



① 等方圧密

$$\sigma_{10}' = \sigma_{30}' = 2.0$$

$$\sigma_{10} = \sigma_{30} = 2.0$$

② 2...クを挿入,  
せん断可能

$$\sigma_{1f} = 6.0$$

$$\sigma_{3f} = 2.0$$

$$\Delta u_f = 0$$

① 等方圧密

$$\sigma_{10}' = \sigma_{30}' = 2.0$$

$$\sigma_{10} = \sigma_{30} = 2.0$$

② 排水2...クを挿入,  
せん断可能

$$\sigma_{10}' = \sigma_{30}' = 4.0$$

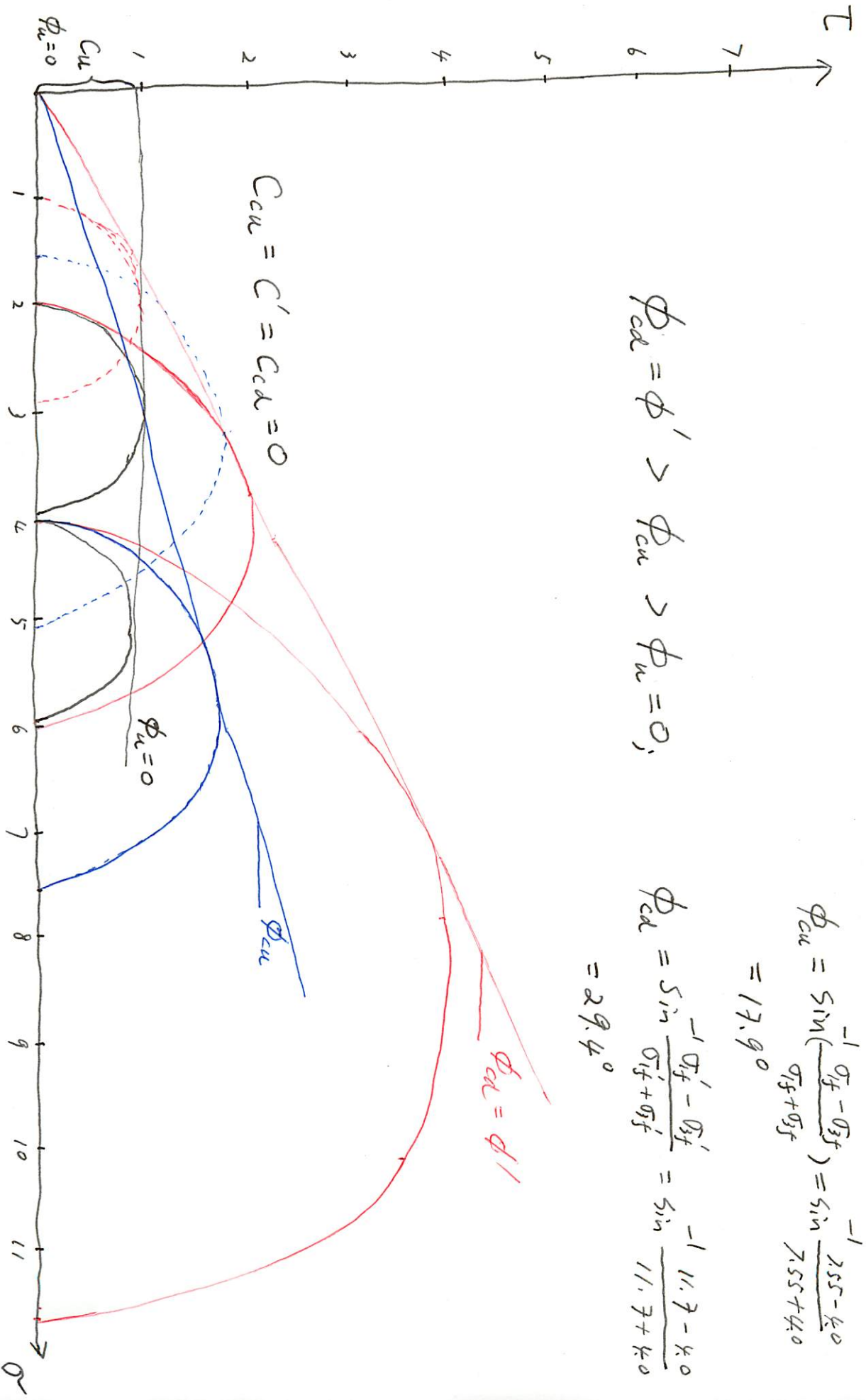
$$\sigma_{10} = \sigma_{30} = 4.0$$

③ 2...クを挿入,  
せん断可能

$$\sigma_{1f} = 11.7$$

$$\sigma_{3f} = 4.0$$

$$\Delta u_f = 0$$



$$\phi_{cd} = \phi' > \phi_{cu} > \phi_u = 0;$$

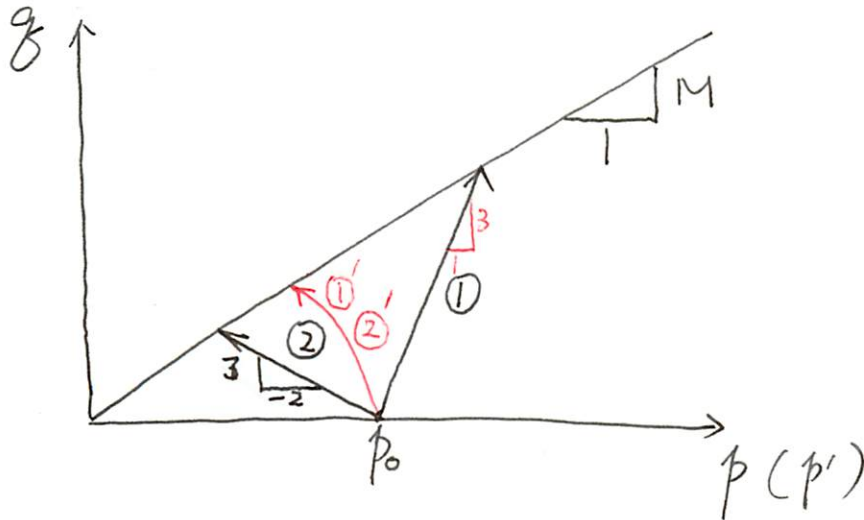
$$\phi_{cd} = \sin^{-1} \frac{\sigma'_{lf} - \sigma'_{bf}}{\sigma'_{lf} + \sigma'_{bf}} = \sin^{-1} \frac{11.7 - 4.0}{11.7 + 4.0} = 29.4^\circ$$

$$\phi_{cu} = \sin^{-1} \left( \frac{\sigma'_{lf} - \sigma'_{bf}}{\sigma'_{lf} + \sigma'_{bf}} \right) = \sin^{-1} \frac{25.5 - 4.0}{25.5 + 4.0} = 17.9^\circ$$

UU, CU, CD 試驗の結果は: Mohr 門に於て, 各種 C, phi を求めた。  
試験の種類は: かか物す" 一定の値を得るべき C, phi である。



## 7. 主応力経路



$$p = (\sigma_1 + 2\sigma_3) / 3$$

$$= (\sigma'_1 + 2\sigma'_3) / 3 + u = p' + u$$

$$\tau = \sigma_1 - \sigma_3$$

$$= \sigma'_1 - \sigma'_3$$

正根圧密粘土の場合:  $c' = 0$  より

Mohr-Coulomb 破壊規準:

$$\sin \phi' = \frac{\sigma'_{1f} - \sigma'_{3f}}{\sigma'_{3f} + \sigma'_{1f}} \Rightarrow \frac{\sigma'_{1f}}{\sigma'_{3f}} = \frac{1 + \sin \phi'}{1 - \sin \phi'}$$

“破壊”時のせん断応力比  $M$

$$M = \frac{\tau}{p'} \Big|_{\text{failure}} = \frac{3(\sigma'_{1f} - \sigma'_{3f})}{\sigma'_{1f} + \sigma'_{3f}} = \frac{6 \sin \phi'}{3 - \sin \phi'}$$

例えば  $\phi' = 30^\circ \Rightarrow M = 1.2$

全主応力経路①: 拘束圧  $\sigma_3$  一定の三軸圧縮試験

$$\left. \begin{aligned} \Delta \sigma_3 = 0, \quad \Delta \tau = \Delta \sigma_1 - \Delta \sigma_3 = \Delta \sigma_1 \\ \Delta p = (\Delta \sigma_1 + 2\Delta \sigma_3) / 3 = \frac{\Delta \sigma_1}{3} \end{aligned} \right\} \Rightarrow \frac{\Delta \tau}{\Delta p} = 3$$





全応力経路② 軸圧一定, 拘束圧減少の三軸圧縮試験

$$\Delta\sigma_1 = 0, \quad \Delta\sigma_3 \neq 0 (< 0)$$

$$\Delta q = -\Delta\sigma_3 > 0, \quad \Delta p = 2\Delta\sigma_3/3 < 0$$

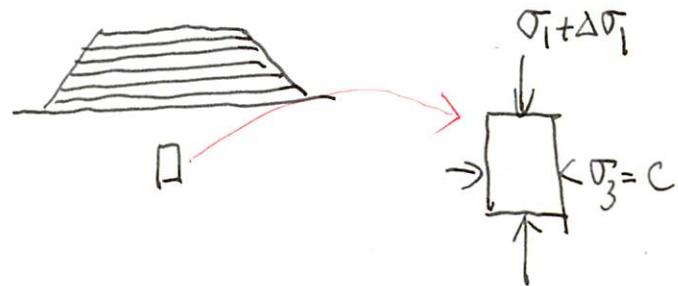
$$\frac{\Delta q}{\Delta p} = -\frac{3}{2}$$

有効応力経路①'②'は完全に一致する!(実験事実)

$$\lambda \ln \frac{p'}{p_0} + \frac{\lambda - k}{M} \cdot \frac{q}{p'} = 0 \quad \leftarrow \text{経路①'②'の軌跡}$$

8. 応用事例: 軟弱粘土地盤における載荷速度の影響

(1) 盛り土載荷



(2) 鉛直切り土載荷

