100學年 實務專題(基礎與山坡地設計)

基本土壤力學知識

課程教師：蕭秋安 楊國鑫 謝佑明
日　　期：101.2.24

臺灣科技大學 營建工程系暨研究所
National Taiwan University of Science and Technology Department of Construction Engineering
TAIWAN TECH

內容大綱

一. 土壤性質與分類
二. 有效應力概念
三. 土壤壓縮性
四. 剪力強度
五. 側向土壓力

一、土壤性質與分類

地 質 鑽 探 及 土 壤 試 驗 一 覽 表
SOIL EXPLORATION AND TESTING REPORT

工程名稱：
Project
鑽孔編號： BH-1
Hole No. (總深度: 50.00 公尺)

鑽孔標高 4.637 M
Surface Elev.

地點：
Location
地下水位 -4.70 M
G. W. Depth

報告編號:
Test No.
頁次: 第 2 頁
Page.

深度 Depth (M)	柱狀圖 Log.	樣號 Sample No.	擊數 No. of Blows Per ft.	地質說明 Soil Description	分類 USCS Classi-fication	顆粒分析 Grain Sizes Analysis (%) 礫石 Gravel	砂 Sand	粉土黏土 Silt & Clay	自然含水量 Water Content W(%)	比重 Specific Gravity G	當地密度 Density γ_t (T/M^3)	空隙比 Void Ratio e	液性限度 Liquid Limit W_L(%)	塑性指數 Plasticity Index I_P(%)	單軸壓縮強度 Uniaxial Comp. Strength qu (kpa)	強度參數 Shear Strength Parameter ϕ (Degree)	C (kg/cm^2)	岩石品質指標 Rock Quality Design-ation R.Q.D.(%)	破碎指數 Fracture Index F.I.
2.00		S-1	2	棕黃色砂質粉土 2.30M	CL	0.0	0.2	99.8	31.8	2.71	1.91	0.87	33	14					
4.00		S-2	3	灰色砂質粉土夾薄層粉土質砂	SM	0.0	57.8	42.2	23.8	2.68	1.99	0.67	-	N.P.					
6.00		S-3	1.5		ML	0.0	43.3	56.7	23.0	2.68	2.00	0.65	-	N.P.					
7.30		T-1			CL-ML	0.0	3.2	96.8	29.9	2.72	1.94	0.83	23	5		27.4	0.10		
8.00		S-4	10		SM	1.2	78.5	20.3	20.1	2.68	2.09	0.54	-	N.P.					
10.00		S-5	4	10.50M	SM	0.0	70.9	29.1	24.2	2.68	1.98	0.68	-	N.P.					
12.00		S-6	22	灰色粉土質砂	SM	0.0	81.1	18.9	23.5	2.67	1.99	0.66	-	N.P.					
13.30		T-2		13.80M	SP-SM	0.0	89.0	11.0	23.4	2.67	1.96	0.68	-	N.P.		38.1	0.00		
14.00		S-7	26	灰色黏土夾薄層砂質粉土偶夾薄層粉土質砂	SM	0.0	86.8	13.2	22.5	2.68	1.97	0.66	-	N.P.					

15~30M

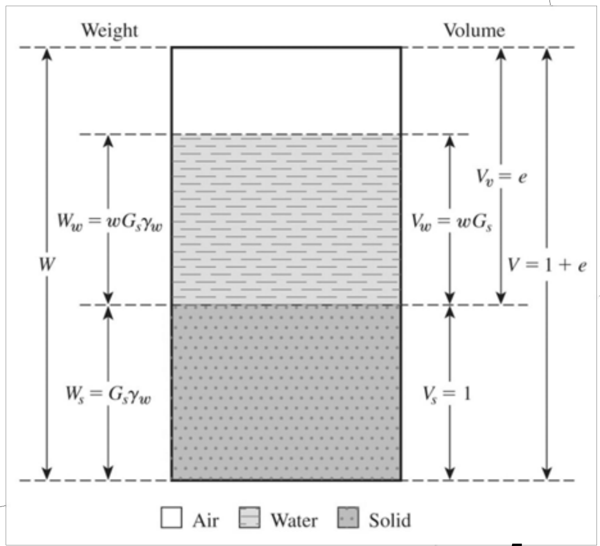
一、土壤性質與分類

- 工程性質
  1. 剪力強度 (c,ϕ)
  2. 壓縮性與回脹性 (Cv, Tv, Cr)
  3. 滲透性 (k)

一、土壤性質與分類

- 基本性質
  - n, e, ω, S, γ, Gs (重量、體積、定義、基本性質)
  - 公式：

1) $n = \frac{e}{1+e}$
2) $Se = \omega Gs$
3) $\gamma_d = \frac{\gamma_s}{1+e} = \frac{\gamma_m}{1+\omega}$
4) $\gamma_m = \frac{G_s+Se}{1+e} \cdot \gamma_w$



一、土壤性質與分類

- 指數性質
  - 指數性質試驗
    1) ω, γ_m, Gs
    2) 粒徑分析、Gs試驗
    3) 阿太保限度試驗 (液限LL, 塑限PL, 自然含水量)
  - 目的：土壤分類(統一土壤分類法)、概估工程性質

1) $\frac{C_u}{\sigma_v'} = 0.11 + 0.0037\,\mathrm{PI}$ *for NC clay*
2) $C_c = 0.009(LL - 10)$ *for NC clay*
3) $k = C_1 {D_{10}}^2$ *for Sand*

一、土壤性質與分類

- 統一土壤分類 (Unified soil classification system)
  - ASTM D-2487
    - 創始者：Casagrande (1948)
    - 二次大戰時為美國陸軍設立，支援軍用機場的設計及構築而訂
    - All purposes classification，基礎工程師常用
    - 1999 / 2004 最新修訂
  - 分類依據
    - 粒徑分佈曲線
    - 阿太保限度

一、土壤性質與分類

- 粒徑分佈曲線

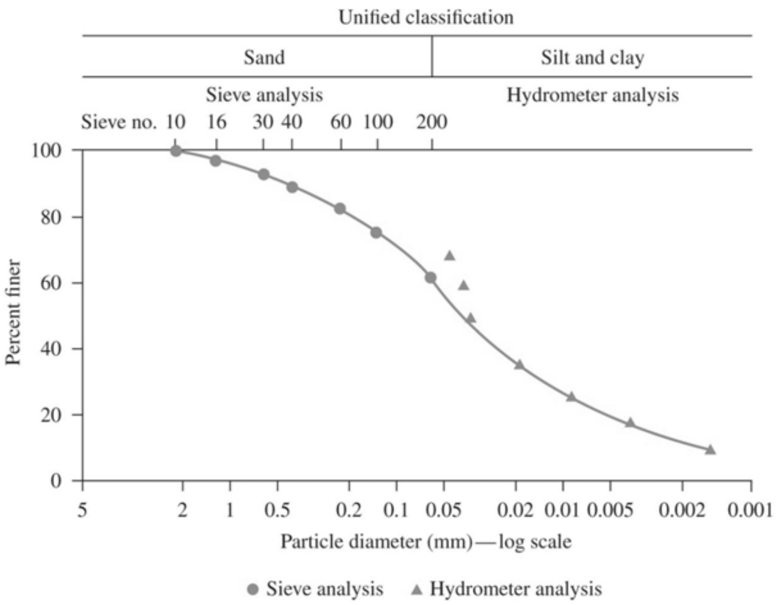
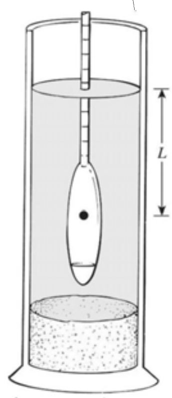


Figure 2.25 Particle-size distribution curve—sieve analysis and hydrometer analysis



Four major divisions

- Coarse-grained
- Fine-grained
- Organic soils
- Peat

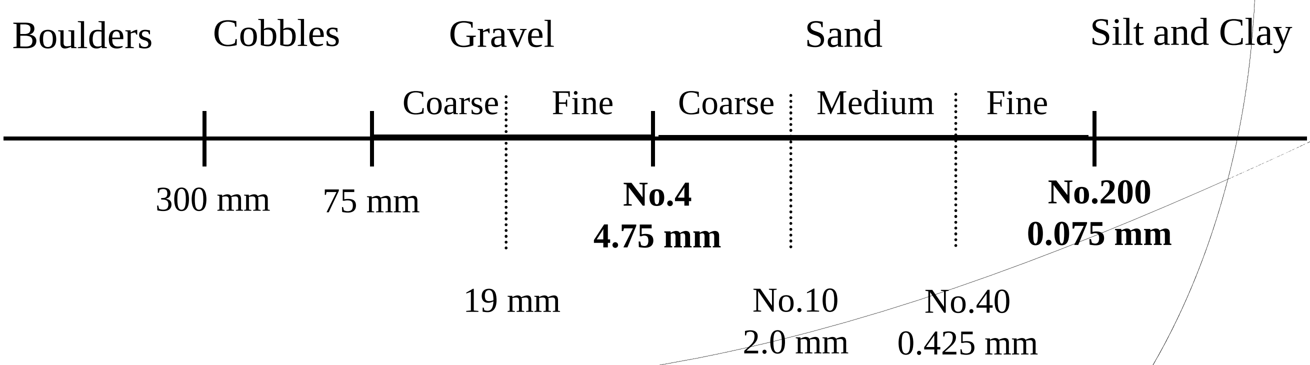


Table 5.2 Unified Soil Classification System (Based on Material Passing 76.2-mm Sieve)

Criteria for assigning group symbols				Group symbol
Coarse-grained soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c]	GW
			$C_u < 4$ and/or $1 > C_c > 3$[c]	GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 5.3)	GM
			$PI > 7$ and plots on or above "A" line (Figure 5.3)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c]	SW
			$C_u < 6$ and/or $1 > C_c > 3$[c]	SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 5.3)	SM
			$PI > 7$ and plots on or above "A" line (Figure 5.3)	SC
Fine-grained soils 50% or more passes No. 200 sieve	**Silts and clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 5.3)[e]	CL
			$PI < 4$ or plots below "A" line (Figure 5.3)[e]	ML
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 5.3)	CH
			PI plots below "A" line (Figure 5.3)	MH
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

No.4篩

No.200篩

LL

PI

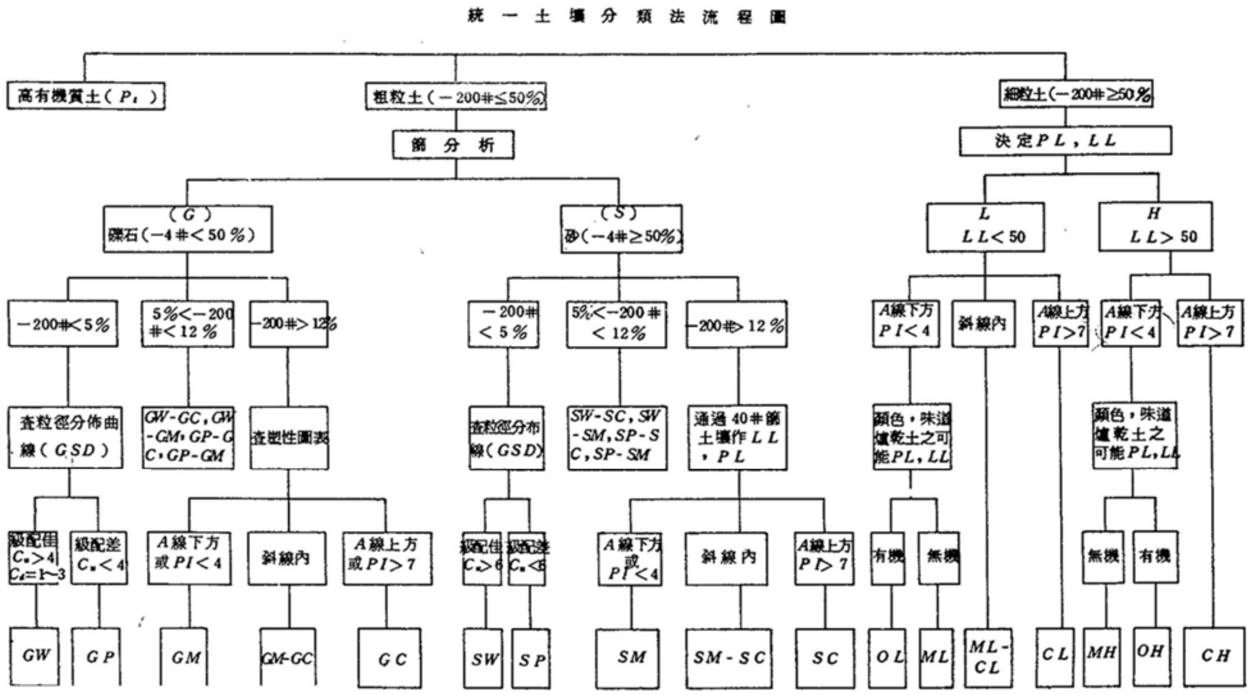
[a] Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

[b] Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

[c] $C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

[d] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol GC-GM or SC-SM.

[e] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol CL-ML.



抗剪強度：GW＞SM＞SC＞ML，CL

壓縮性：GW＜SM＜SC＜ML，CL

滲透性：GW＞SM＞SC＞ML，CL

台北縣中和市立言街39號
電話:(02)22228891傳真:(02)22256842

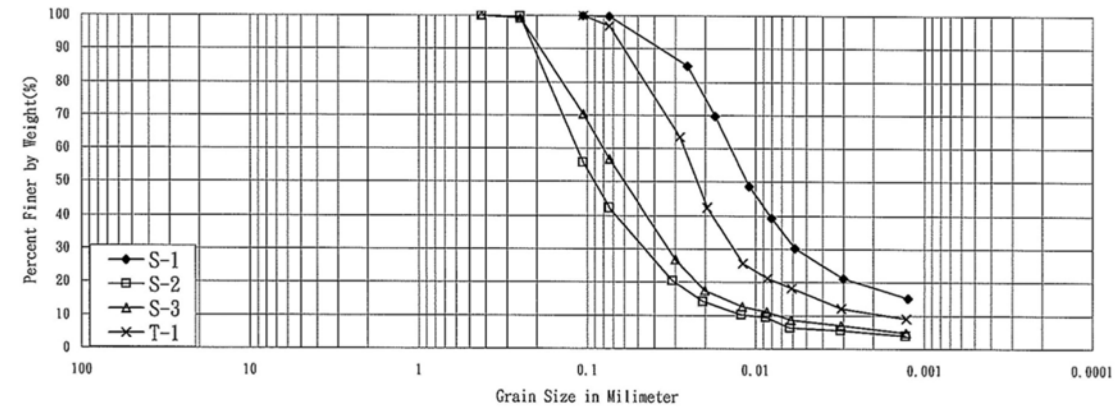
CNLA 0330

粒徑分佈曲線圖

報告編號:

試驗日期：95.10.14-10.27　　頁次:第 6 頁

試驗方法： CNS 11776(1986)



HOLE NO.	SAMPLE NO.	SYM.	DEPTH(m)	D10(mm)	D60(mm)	Cu	LL(%)	PI(%)	CLASSIFICATION
BH-1	S-1		1.55-2.00	-	-	-	33	14	CL
	S-2		3.55-4.00	-	-	-	-	N.P.	SM
	S-3		5.55-6.00	-	-	-	-	N.P.	ML
	T-1		6.50-7.30	-	-	-	23	5	CL-ML

$$C_u = D_{60}/D_{10} > 4(Gravel)$$
$$> 6(Sand)$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = 1 \sim 3$$

◉ Plasticity chart

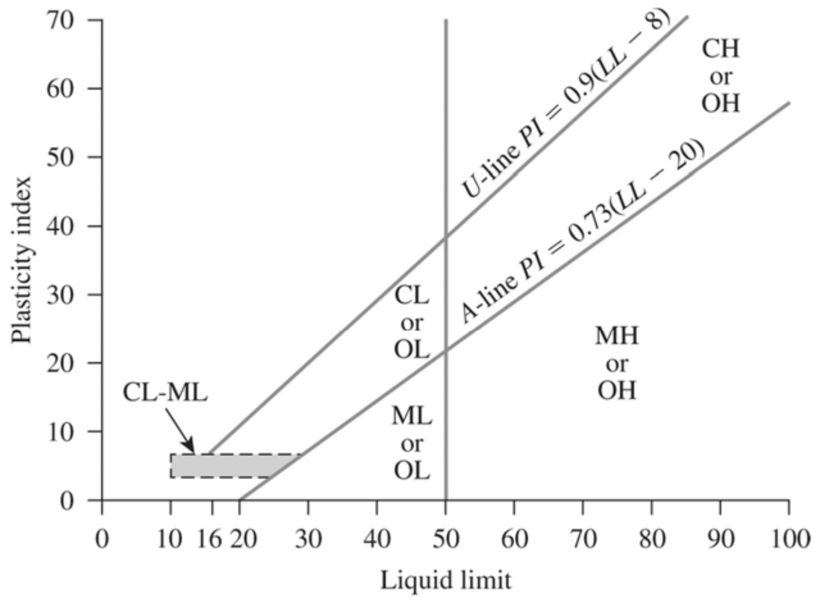


Figure 5.3 Plasticity chart

- A線 區分粘土與沉泥土
- U線 代表自然土之上限
- W_L=50%區分高、低塑性
  H L
- ML代表非塑性土壤(NP)

Major divisions (1)	Subdivisions (2)	USCS symbol (3)	Typical names (4)	Laboratory classification criteria (5)	
Coarse-grained soils (More than 50% retained on No. 200 sieve)	Gravels (More than 50% of coarse fraction retained on No. 4 sieve)	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	Less than 5% fines*	$C_u \geq 4$ and $1 \leq C_c \leq 3$
		GP	Poorly graded gravels or gravelly sands, little or no fines	Less than 5% fines*	$C_u < 4$ and/or $1 > C_c > 3$
		GM	Silty gravels, gravel-sand-silt mixtures	More than 12% fines*	Minus No. 40 soil plots below the *A*-line
		GC	Clayey gravels, gravel-sand-clay mixtures	More than 12% fines*	Minus No. 40 soil plots on or above the *A*-line
	Sands (50% or more of coarse fraction passes No. 4 sieve)	SW	Well-graded sands or gravelly sands, little or no fines	Less than 5% fines*	$C_u \geq 6$ and $1 \leq C_c \leq 3$
		SP	Poorly graded sands or gravelly sands, little or no fines	Less than 5% fines*	$C_u < 6$ and/or $1 > C_c > 3$
		SM	Silty sands, sand-silt mixtures	More than 12% fines*	Minus no. 40 soil plots below the *A*-line
		SC	Clayey sands, sand-clay mixtures	More than 12% fines*	Minus No. 40 soil plots on or above the *A*-line
Fine-grained soils (50% or more passes the No. 200 sieve)	Silts and clays (liquid limit less than 50)	ML	Inorganic silts, rock flour, silts of low plasticity	Inorganic soil	PI < 4 or plots below *A*-line**
		CL	Inorganic clays of low plasticity, gravelly clays, sandy clays, etc.	Inorganic soil	PI > 7 and plots on or above *A*-line**
		OL	Organic silts and organic clays of low plasticity	Organic soil	LL (oven dried)/LL (not dried) < 0.75
	Silts and clays (liquid limit 50 or more)	MH	Inorganic silts, micaceous silts, silts of high plasticity	Inorganic soil	Plots below *A*-line
		CH	Inorganic highly plastic clays, fat clays, silty clays, etc.	Inorganic soil	Plots on or above *A*-line
		OH	Organic silts and highly plastic organic clays	Organic soil	LL (oven dried)/LL (not dried) < 0.75
Peat	Highly organic	PT	Peat and other highly organic soils	Primarily organic matter, dark in colour, and organic odor	

C_u (coefficient of uniformity) = D_{60}/D_{10}; C_c (coefficient of curvature) = $(D_{30})^2/(D_{10} \times D_{60})$.
* "Fines" are those soil particles that pass the No. 200 sieve. For gravels and sands with between 5 and 12% fines, use of dual symbols is required (i.e., GW-GM, GW-GC, GP-GM, or GP-GC).
** If $4 \leq PI \leq 7$ and PI plots above *A*-line, then dual symbols (i.e., CL-ML) are required.

Figure 2.7 Unified Soil Classification System (USCS).

一、土壤性質與分類

- 例題：

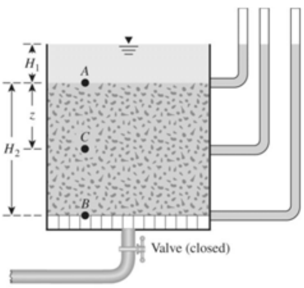
五種土壤，經篩分析後，其資料與塑性如下：

土樣＼篩號	通過4#(%)	10#	40#	100#	200#	*LL*	*PL*	*PI*
①	99	92	86	78	60	20	15	5
②	97	90	40	8	5	—	—	—
③	100	100	100	99	97	124	47	77
④	99	96	89	79	70	49	24	25
⑤	23	18	9	5	4	—	—	—

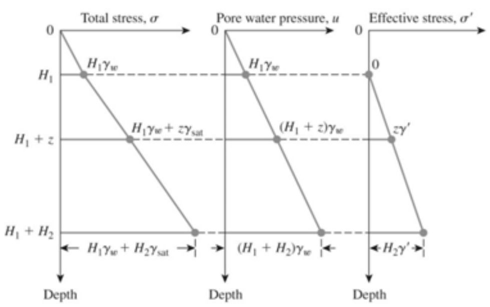
試以統一土壤分類法加以分類。

二、有效應力概念

- 總應力 σ = 有效應力 σ' + 水壓力 u

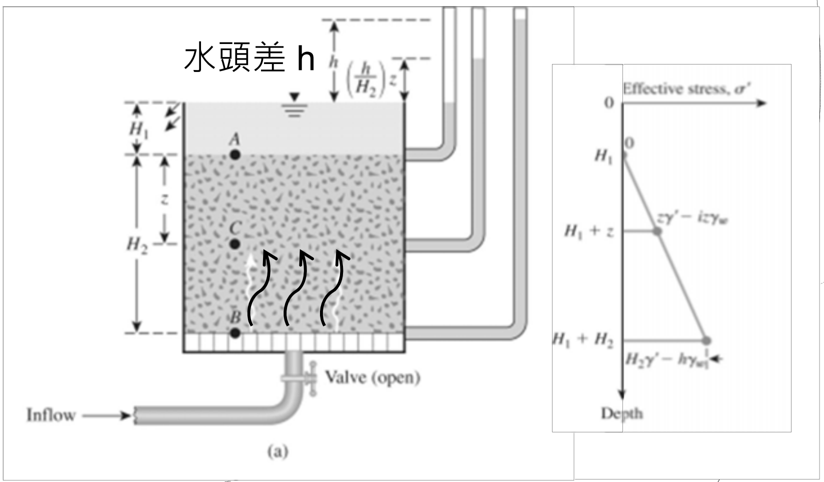


(a)



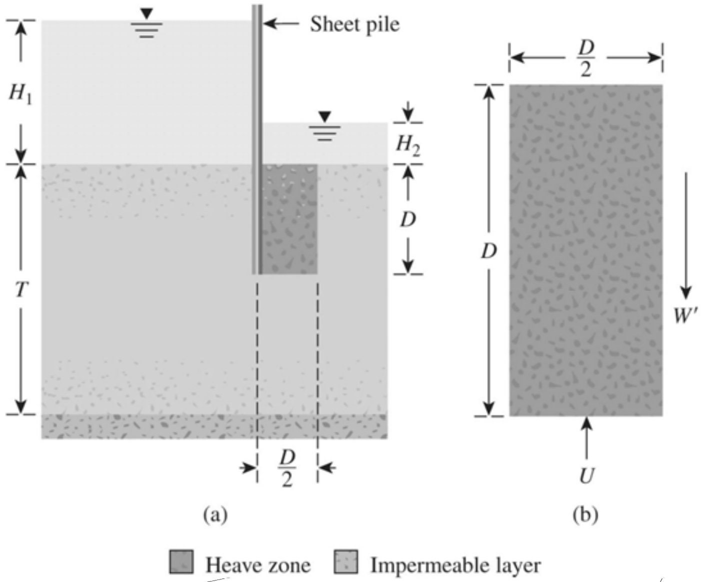
二、有效應力概念

- 流砂現象 & 臨界水力坡降
  - $\sigma_c' = z\gamma' - \frac{h}{H_2} z\gamma_w = z\gamma' - i_{cr} z\gamma_w = 0$
  - $i_{cr} = \frac{\gamma'}{\gamma_w}$



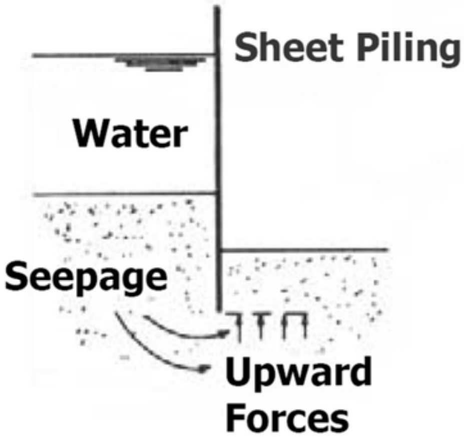
二、有效應力概念

- 流砂現象 & 臨界水力坡降
  - $FS = \frac{\gamma'}{i_{av}\gamma_w}$

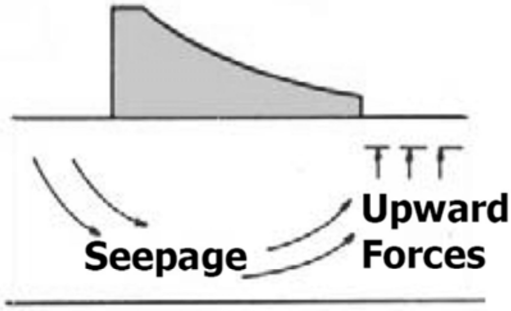


⊙ PIPING (管湧)

EXAMPLES OF PIPING

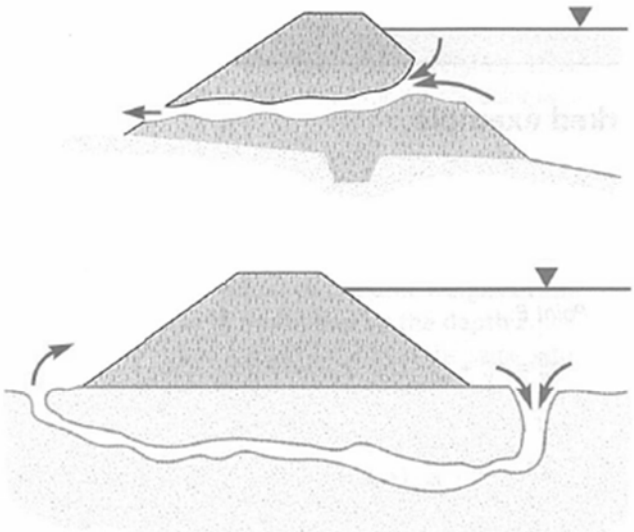


a. Sheet Piled excavation

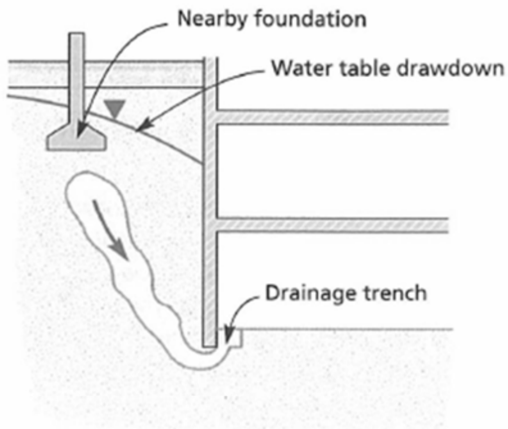


b. Downstream end of dam

⊙ PIPING (管湧)



(a)

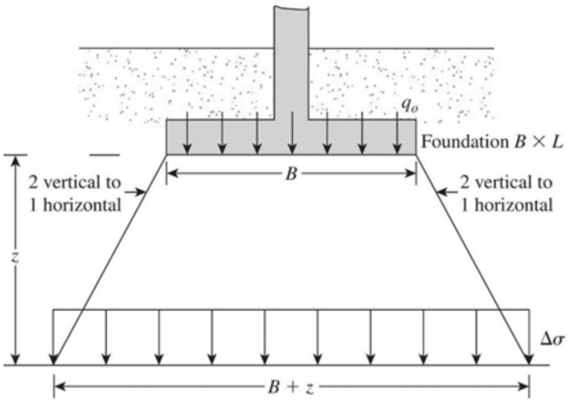


(b)

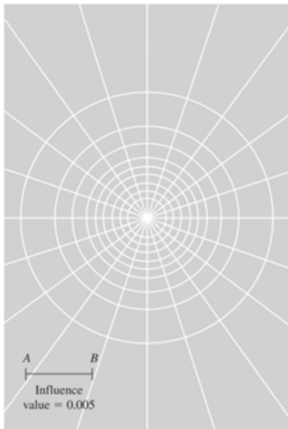
二、有效應力概念

◉ 外加載重造成之應力增量 Δσ

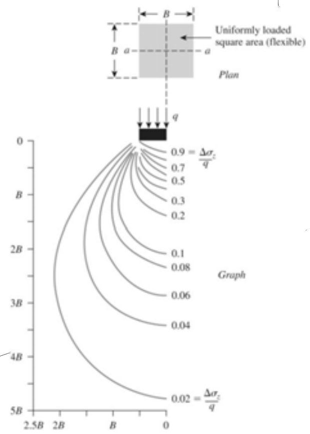
- 概算法 (2:1 method)
- Steinbrener法
- 壓力球根



2:1 method



Influence Chart

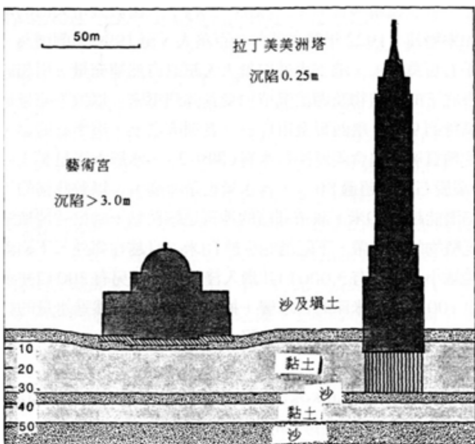


壓力球根

三、土壤壓縮性

◉ 沉陷

- 立即沉陷、主要壓密沉陷、二次壓密沉陷



墨西哥藝術宮

LEANING TOWER OF PISA

Factors - clays

- rate of construction

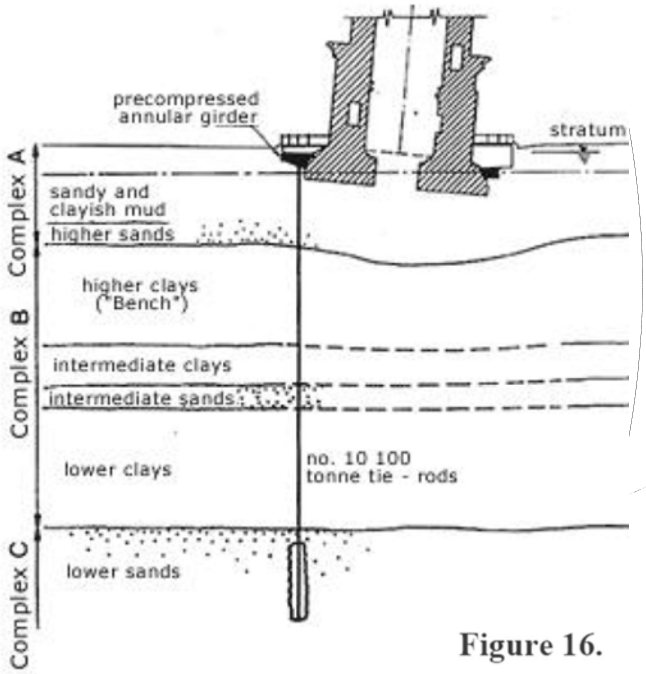
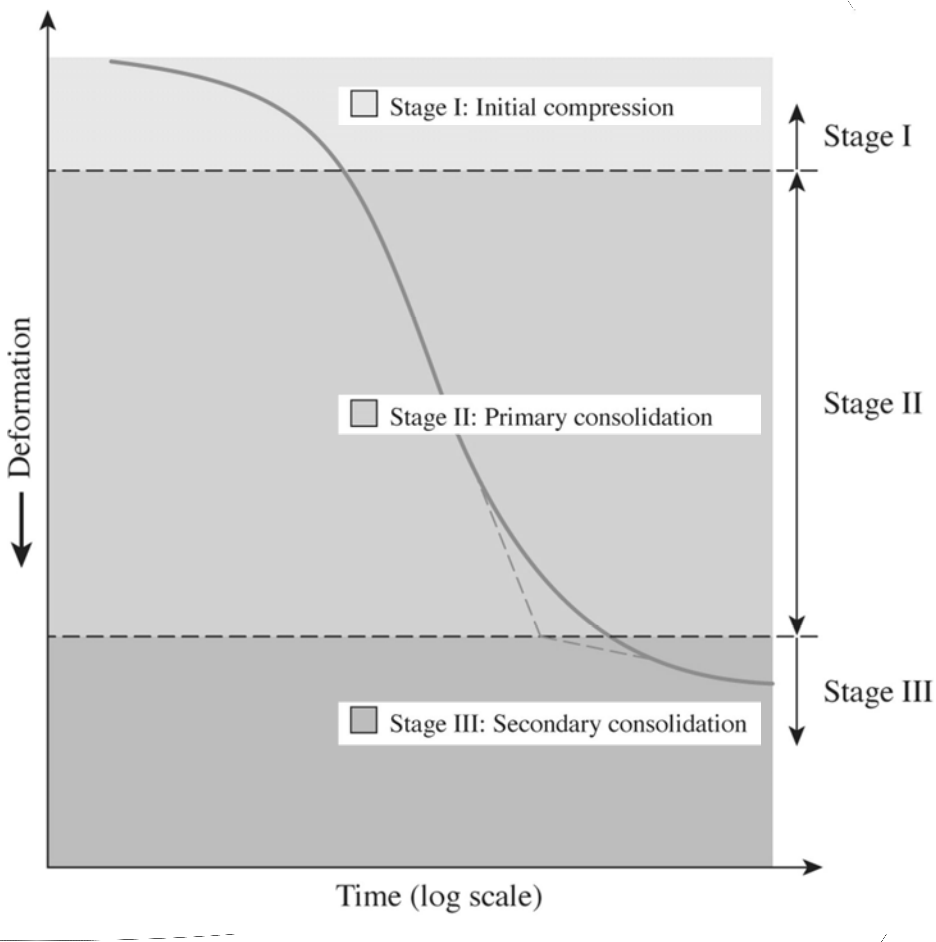


Figure 16.

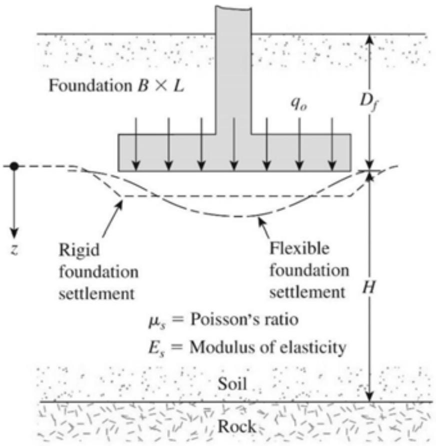
⊙ 沉陷

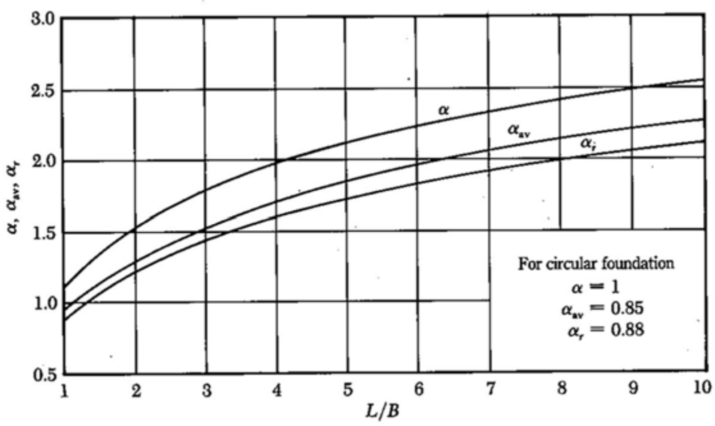


三、土壤壓縮性

⊙ 立即沉陷

- $S_e = \frac{Bq_0}{E_s}(1-\mu_s^2)\alpha_{av}$ *(average for flexible foundation)*
- $S_e = \frac{Bq_0}{E_s}(1-\mu_s^2)\alpha_r$ *(rigid foundation)*





⊙ 壓密沉陷

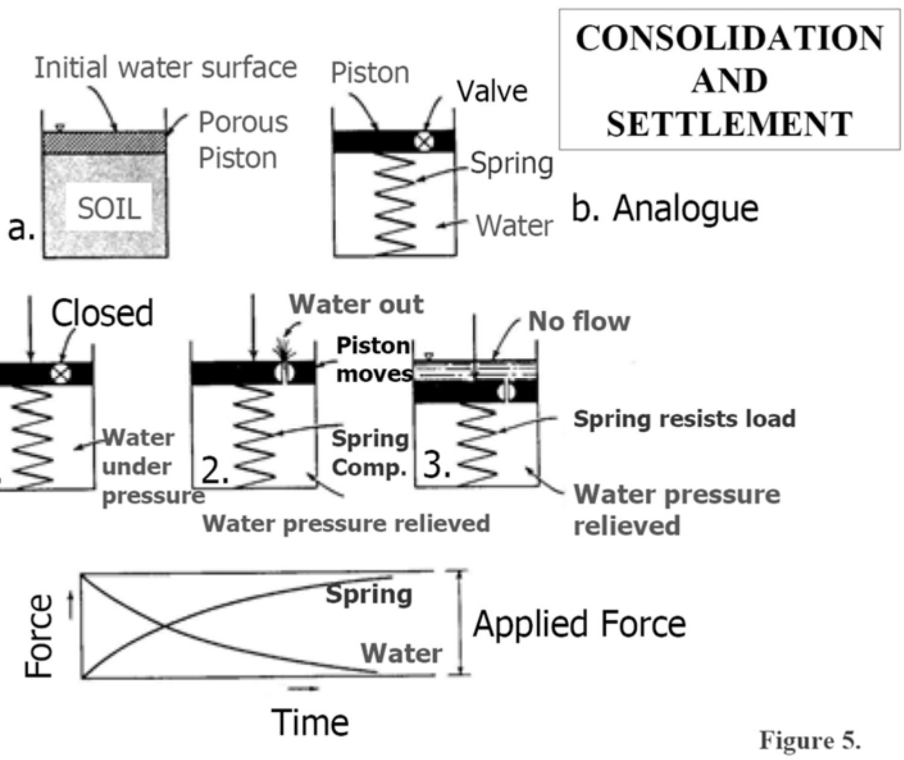


Figure 5.

三、土壤壓縮性

◉ 壓密沉陷

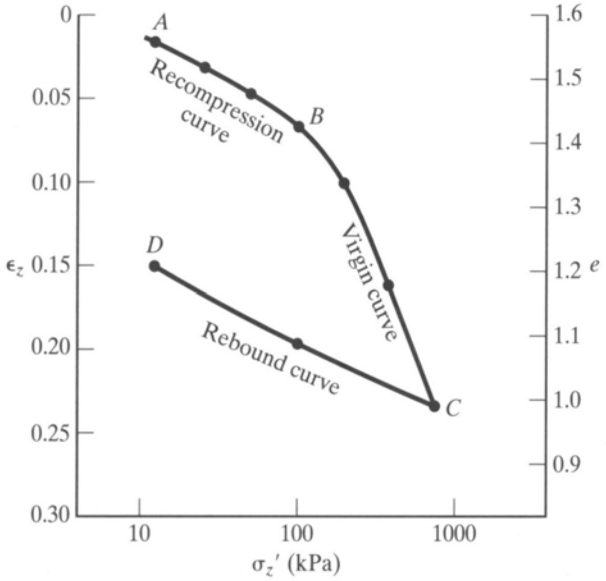
- $\frac{\Delta H}{H_0} = \frac{\Delta V}{V_0} = \frac{\Delta e V_s}{(1+e_0)V_s} = \frac{\Delta e}{1+e_0}$
- $\Delta H = H_0 \frac{\Delta e}{1+e_0}$

◉ 單向度壓密沉陷

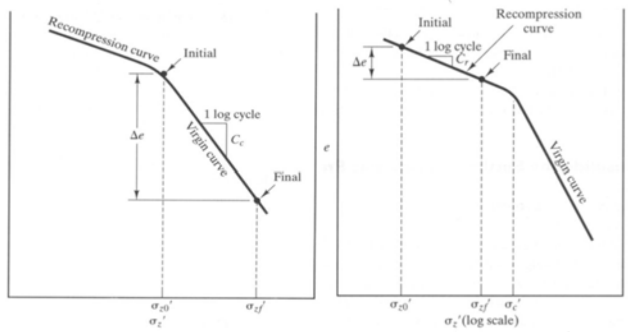
- $\Delta e = C_c log\left(\frac{p_0+\Delta p}{p_0}\right)$
- $\Delta H = \frac{C_c H_0}{1+e_0} log\left(\frac{p_0+\Delta p}{p_0}\right)$

◉ NC clay vs. OC clay

- C_c, C_r



三、土壤壓縮性



◉ NC clay

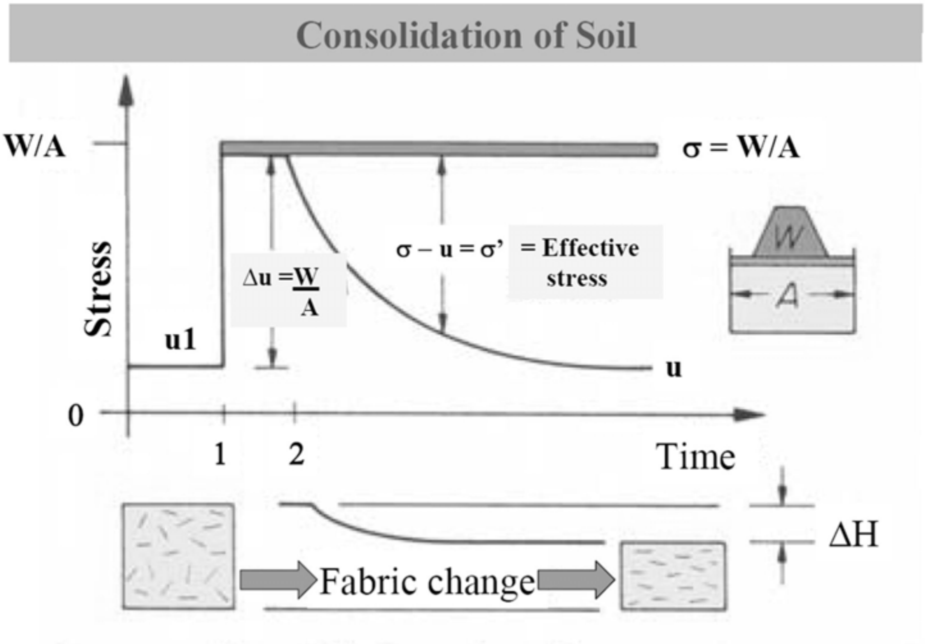
- $\Delta H = \frac{C_c H_0}{1+e_0} log\left(\frac{p_0+\Delta p}{p_0}\right)$ … ($p_c = p_0$)

◉ OC clay

- $\Delta H = \frac{C_r H_0}{1+e_0} log\left(\frac{p_0+\Delta p}{p_0}\right)$ … ($p_0 + \Delta p < p_c$)
- $\Delta H = \frac{C_r H_0}{1+e_0} log\left(\frac{p_c}{p_0}\right) + \frac{C_c H_0}{1+e_0} log\left(\frac{p_0+\Delta p}{p_c}\right)$ … ($p_0 + \Delta p > p_c$)

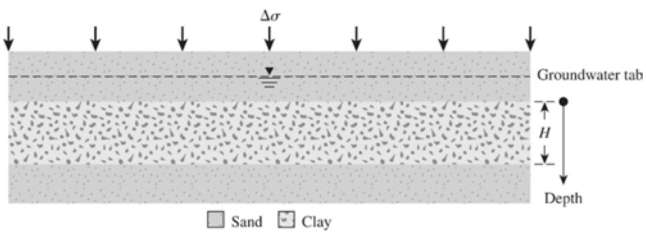
⊙ 壓密沉陷

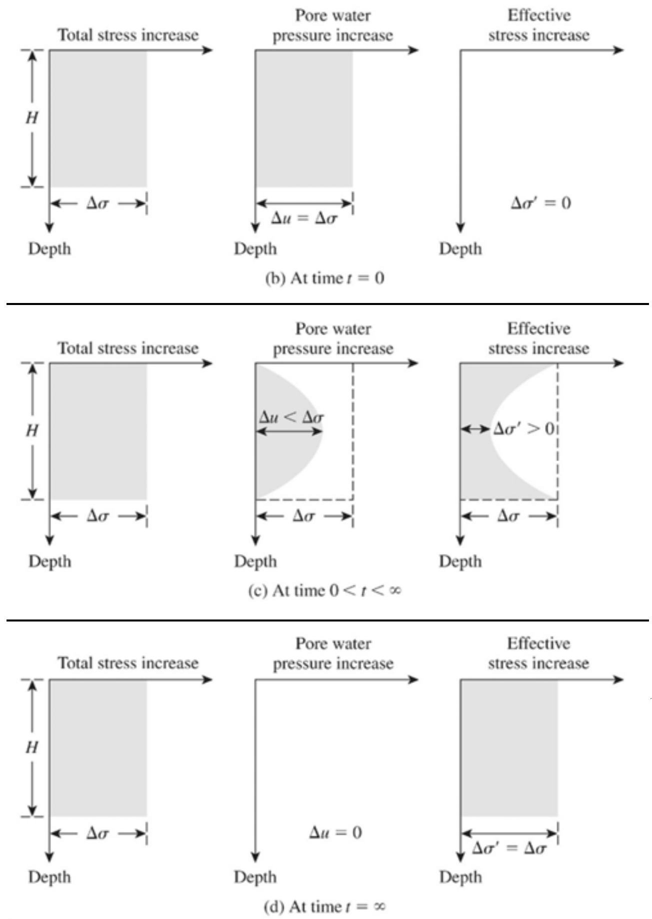
- 壓密是一種隨時間發展的作用



Consolidation of Soil
1 = application of load (W). 2 = start of pore fluid drainage

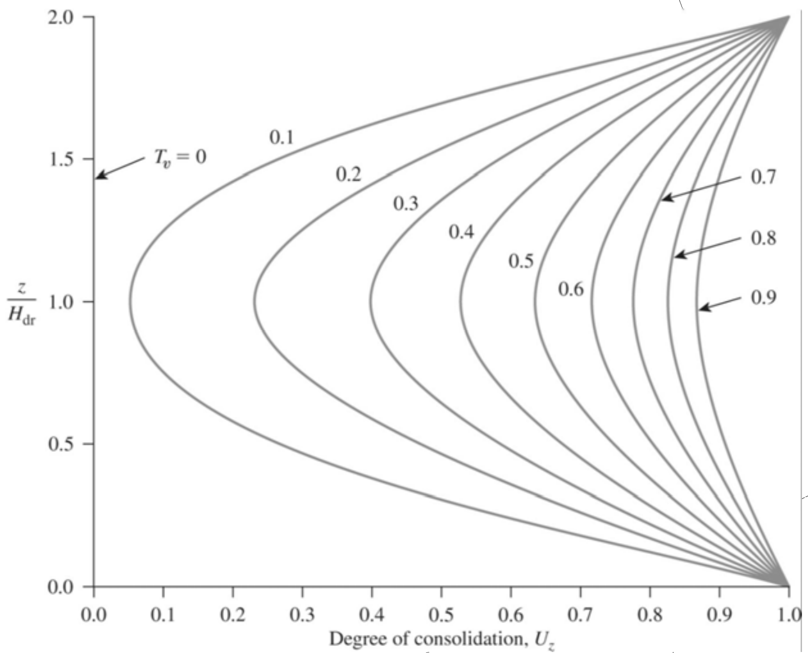
⊙ 壓密沉陷



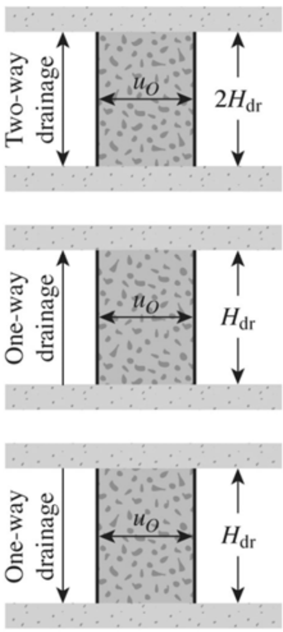


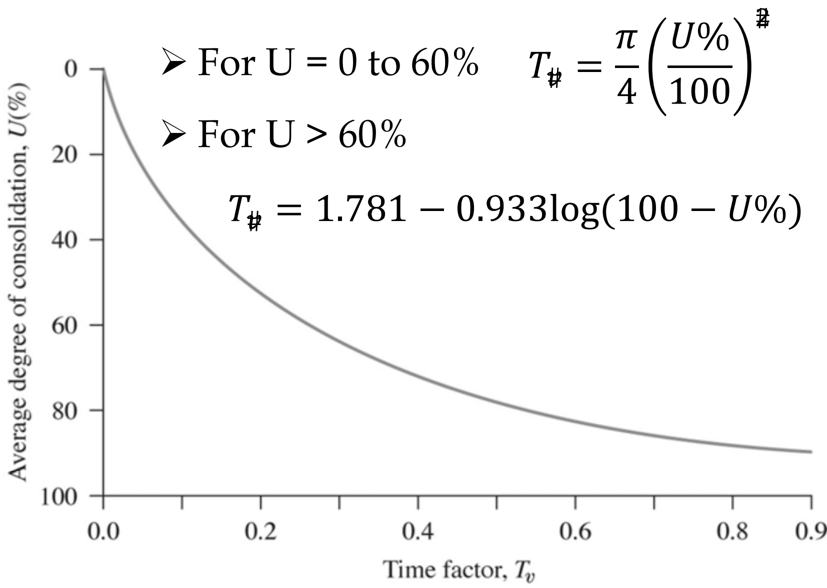
三、土壤壓縮性

- 壓密度
  - $U = 1 - \frac{\delta}{\delta_{[illegible]}}$
- time factor
  - $T_v = \frac{c_v t}{H_{dr}^2}$
  - 50%, T_v=0.197
  - 90%, T_v=0.848



- 平均壓密度 vs. Time Factor





- For U = 0 to 60% $\quad T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$
- For U > 60%

$$T_v = 1.781 - 0.933\log(100 - U\%)$$

Figure 11.24 Variation of average degree of consolidation with time factor, T_v (u_O constant with depth)

材料試驗部
MATERIAL TESTING DEPARTMENT
台北試驗室
TAIPEI LABORATORY

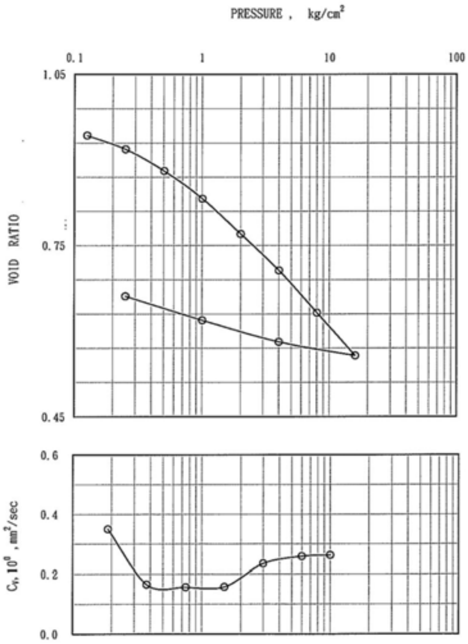
台北縣中和市立言街39號
電話:(02)22228801傳真:(02)22256842

CNLA 0330

單向度壓密試驗

孔號 :BH-2
樣號 :T-1-1
深度 :12.00~12.50m

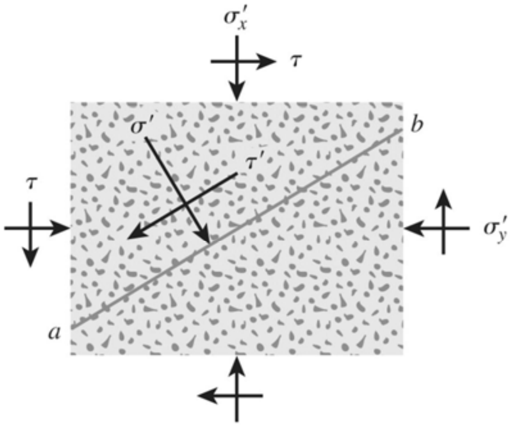
報告編號 :95417-P-060006Y
試驗日期 :95.10.16~10.26
試驗方法 : CNS 12239 A3270(1988)
頁　次 : 第 24 頁

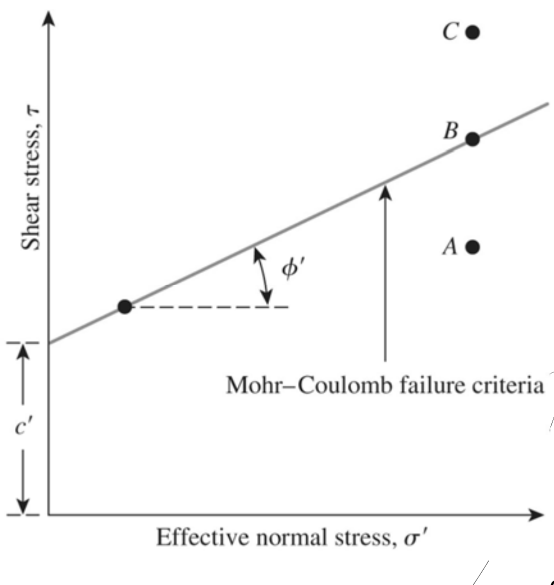


液性限度,LL(%)	40
塑性指數,PI(%)	21
比重,Gs	2.75
土壤分類,USCS	CL
壓縮指數,Cc	2.49E-01
預壓密應力,Pc(kgf/cm²)	1.50
試體狀況	浸水
試驗前	
含水量,w(%)	35.0
乾單位重,rd(g/cm³)	1.40
孔隙比,e	0.97
飽和度,S(%)	99.7
試體高度,H_0(cm)	2.02
試驗直徑,D(cm)	6.31
試驗後	
含水量,w(%)	25.8
乾單位重,rd(g/cm³)	1.61
孔隙比,e	0.71
飽和度,S(%)	100
試體高度,H_f(cm)	1.76

四、剪力強度

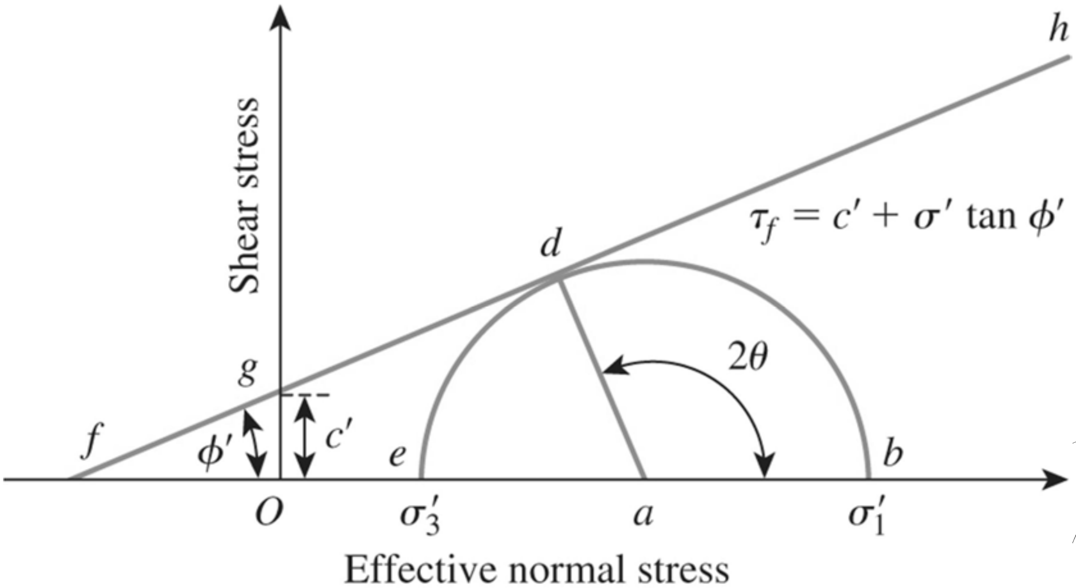
- Mohr-Coulomb Failure Criteria
  - $\tau_f = c + \sigma tan\phi$





四、剪力強度

- Mohr's circle & failure envelope



四、剪力強度

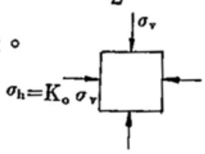
- 應力路徑 stress path

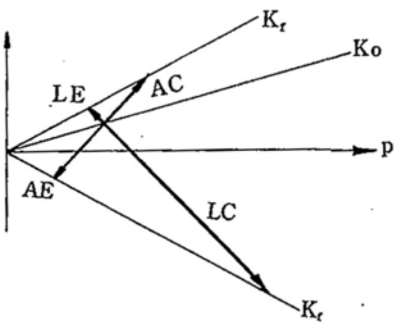
假設土壤起始應力狀態如右圖示：

正常壓密土壤$K_o < 1$，

取 $p = \frac{\sigma_v + \sigma_h}{2}$， $q = \frac{\sigma_v - \sigma_h}{2}$，則

K_o 線如下圖所示。

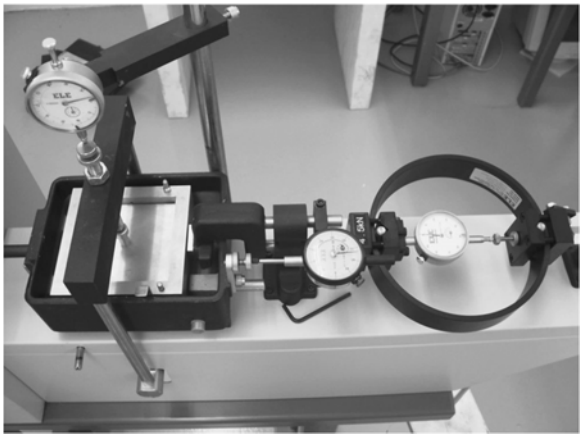




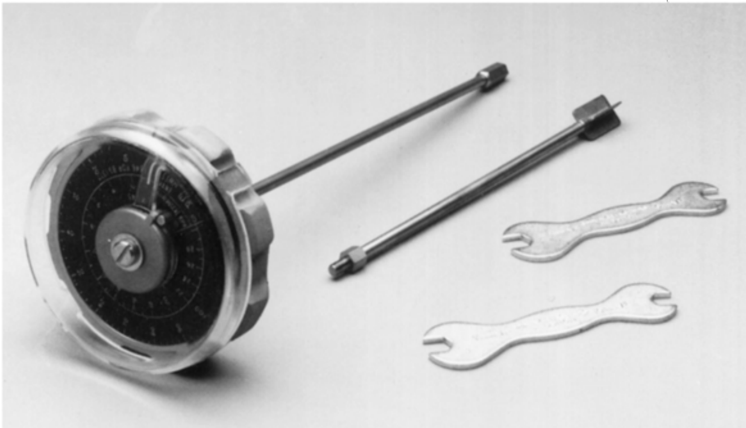
符號	工程例
AC： 軸向壓縮	σ_h 常數，σ_v 增加 （基礎載重情況）
LE： 側向拉伸	σ_v 常數，σ_h 減少 （主動土壓力）
AE： 軸向拉伸	σ_h 常數，σ_v 減少 （基礎開挖）
LC： 側向壓縮	σ_v 常數，σ_h 增加 （被動土壓力）

四、剪力強度

⊙ 剪力強度試驗



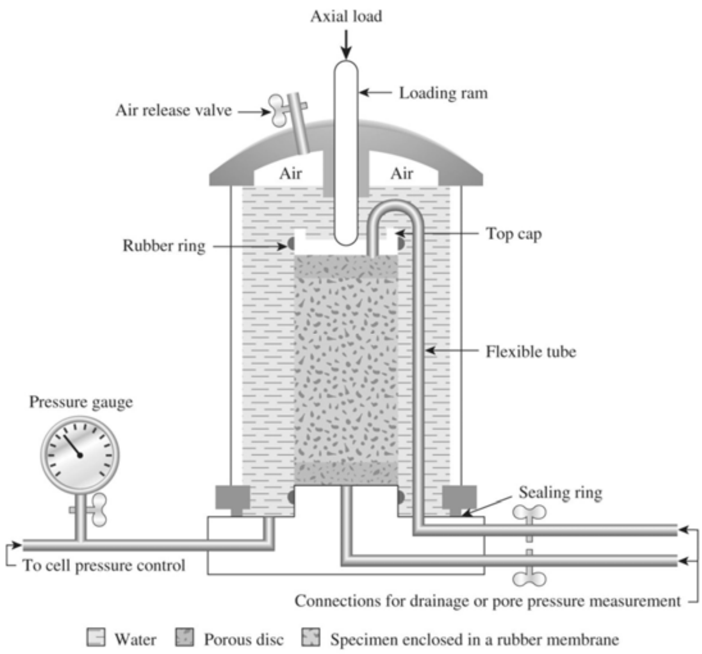
直接剪力試驗



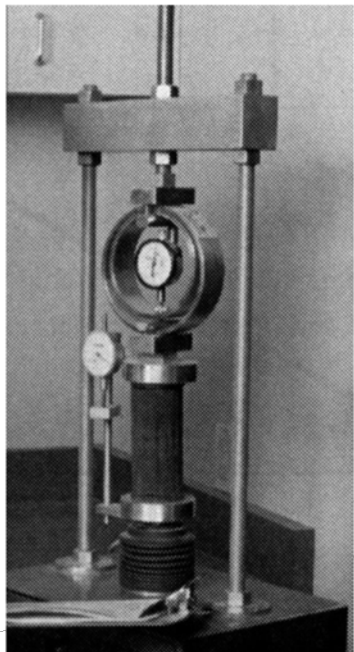
十字片剪儀

四、剪力強度

⊙ 剪力強度試驗



三軸壓縮試驗 (CU, CD, UU)



無圍壓縮試驗

四、剪力強度

◉ 經驗公式

Table 11.5 Empirical Equations Related to c_u and σ'_O

Reference	Relationship	Remarks
Skempton (1957)	$\frac{c_{u(\mathrm{VST})}}{\sigma'_O} = 0.11 + 0.0037(PI)$ PI = plasticity index (%) $c_{u(\mathrm{VST})}$ = undrained shear strength from vane shear test	For normally consolidated clay
Chandler (1988)	$\frac{c_{u(\mathrm{VST})}}{\sigma'_c} = 0.11 + 0.0037(PI)$ σ'_c = preconsolidation pressure	Can be used in overconsolidated soil; accuracy ±25%; not valid for sensitive and fissured clays
Jamiolkowski, *et al.* (1985)	$\frac{c_u}{\sigma'_c} = 0.23 \pm 0.04$	For lightly overconsolidated clays
Mesri (1989)	$\frac{c_u}{\sigma'_O} = 0.22$	
Bjerrum and Simons (1960)	$\frac{c_u}{\sigma'_O} = 0.45\left(\frac{PI\%}{100}\right)^{0.5}$ for $PI > 0.5$	Normally consolidated clay
	$\frac{c_u}{\sigma'_O} = 0.18(LI)^{0.15}$ for LI = liquidity index > 0.5	Normally consolidated clay
Ladd, *et al.* (1977)	$\frac{\left(\frac{c_u}{\sigma'_O}\right)_{\text{overconsolidated}}}{\left(\frac{c_u}{\sigma'_O}\right)_{\text{normally consolidated}}} = (OCR)^{0.8}$ OCR = overconsolidation ratio	

台北縣中和市立言街39號
電話:(02)22228891傳真:(02)22256842

材料試驗部
MATERIAL TESTING DEPARTMENT
台北試驗室
TAIPEI LABORATORY

CNLA 0330

土壤直接剪力試驗報告

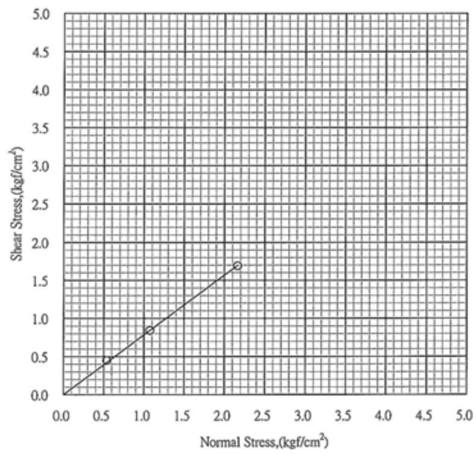
孔　號:BH-1
樣　號:T-2
深　度:12.50-13.30m

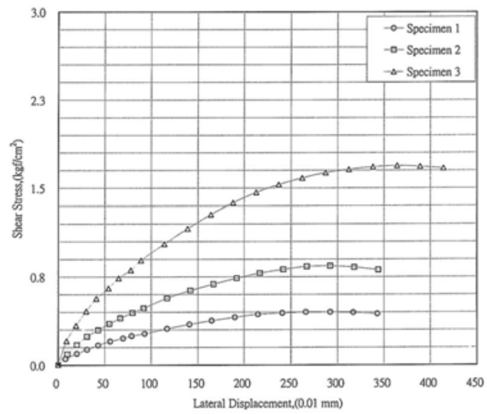
報告編號: 95417-P-060001Y
頁　次: 第 20 頁
試驗日期: 95.10.21~10.22
報告日期: 同首頁
試驗方法: CNS 11778(1986)

一、樣品一般物理性質

Soil Classification	Specific Gravity Gs	Liquid Limit W_l(%)	Plastic Index I_p (%)	C (kgf/cm^2)	ϕ (degree)
SP-SM	2.674	-	N.P.	0.00	38.1

Sample No.	1	2	3	Average
Initial Water Content,(%)	23.1	23.2	23.8	23.4
Initial Dry Density,(t/m^3)	1.57	1.62	1.59	1.59
Initial Thickness,(cm)	1.999	1.991	2.003	2.00
Initial Diameter,(cm)	5.952	5.963	5.944	5.953
Initial Void Ratio	0.70	0.65	0.69	0.68
Initial Degree of Saturation(%)	88.5	94.7	92.6	92.0
Final Water Content,(%)	24.5	22.1	22.1	
Final Dry Density,(t/m^3)	1.61	1.68	1.68	
Final Void Ratio	0.66	0.59	0.59	
Final Degree of Saturation,(%)	99.3	99.7	99.7	
Normal Stress,(kgf/cm^2)	0.54	1.07	2.16	
Rate of Deformation,(mm/min)	0.49	0.49	0.49	

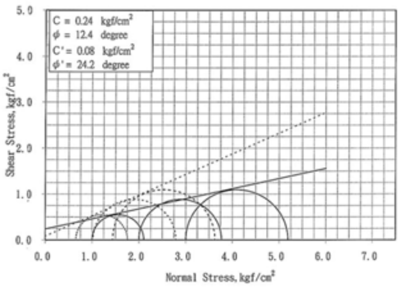




台 北 試 驗 室
Taipei Laboratory

Triaxial Compressive Test Report (CIU)

Hole No.: BH-4 Test Number: 95417-P-060003X
Sample No.: T-2 Page: 20
Depth: 12.50~13.30m Date Tested: 95.10.11~10.17
Soil Type: CL

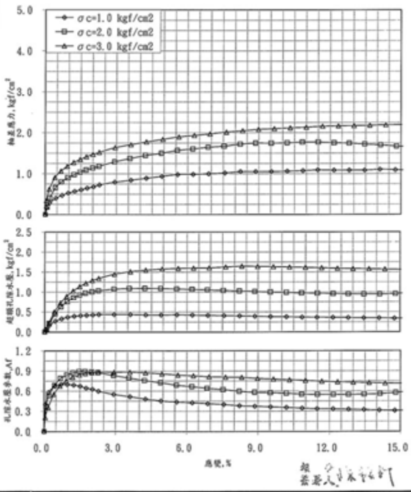


Specimen No.	Confining Pressure, σc kgf/cm2	Initial			Final		
		w %	e	rt t/m3	w %	e	rt t/m3
1	1.0	31.8	0.88	1.92	27.7	0.77	1.98
2	2.0	29.8	0.84	1.93	25.3	0.70	2.02
3	3.0	33.3	0.91	1.91	33.3	0.68	2.03
4	Average	31.6	0.88	1.92	-	-	-

台 北 試 驗 室
Taipei Laboratory

Triaxial Compressive Test Report (CIU)

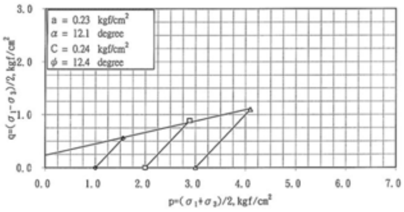
Hole No.: BH-4 Test Number: 95417-P-060003X
Sample No.: T-2 Page: 22
Depth: 12.50~13.30m Date Tested: 95.10.11~10.17
Soil Type: CL

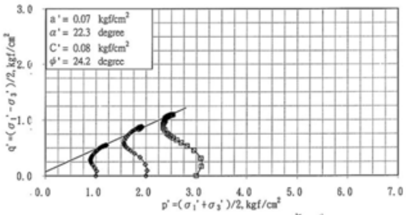


台 北 試 驗 室
Taipei Laboratory

Triaxial Compressive Test Report (CIU)

Hole No.: BH-4 Test Number: 95417-P-060003X
Sample No.: T-2 Page: 21
Depth: 12.50~13.30m Date Tested: 95.10.11~10.17
Soil Type: CL





台北縣中和市立言街39號
電話:(02)22228891傳真:(02)22256842
台 北 試 驗 室
TAIPEI LABORATORY
0330

凝聚性土壤無圍壓縮強度試驗報告

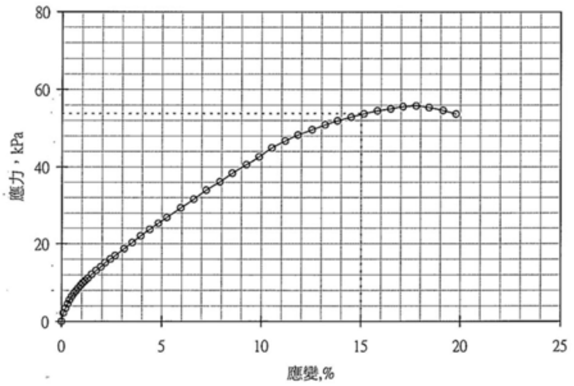
孔　號:BH-2　　試驗編號: 94208-P-060006Y
樣　號:T-1-1　　試驗日期: 95.10.12~10.13
深　度:12.00~12.50m　　試驗方法: CNS 12384(1988)
頁　次: 第 18 頁

一、樣品一般物理性質

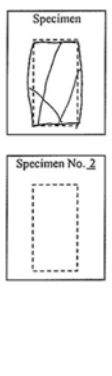
比重	2.75	液性限度 (%)	40	塑性指數 (%)	21	土壤分類 USCS	CL	樣品描述	灰色粉土質粘土

二、力學試驗結果

試體 Specimen	試體狀況	試驗前含水量 (%)	乾密度 γd (t/m³)	高度 (mm)	直徑 (mm)	長徑比 (L/D)	破壞應變 ε_f (%)	壓縮強度 kpa	靈敏度	應變速率 (%/min)	Symbols
1	不擾動	35.0	1.39	149.66	73.73	2.03	15.0	54	—	1.3	⊙
2											



破壞略面圖



四、剪力強度

⊙ 例題：

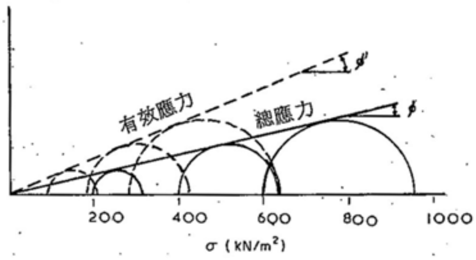
一 $\overline{CIU}$ 試驗記錄如下

圍壓，KN/m^2	破壞時軸差應力，KN/m^2	破壞時孔隙水壓
200	118	110
400	240	220
600	352	320

試分別畫出(1)總應力包絡線，(2)有效應力包絡線。

【解】CIU 試驗係指CU 試驗時所加圍壓爲各方向相同（即 isotropic，以 I 字代表），若試驗過程中兼測孔隙水壓時則以 $\overline{CIU}$ 代表之。

試 樣	σ_3	$\sigma_1 - \sigma_3$	σ_1	u	σ_1'	σ_3'	$\sigma_1' - \sigma_3'$
1	200	118	318	110	208	90	118
2	400	240	640	220	420	180	240
3	600	352	952	320	632	280	352

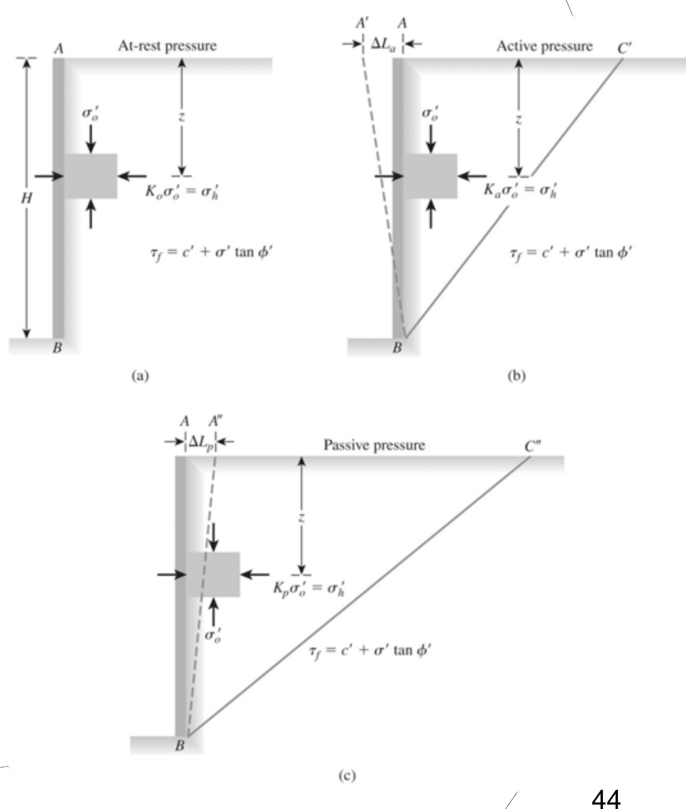


五、側向土壓力

- ⊙ 土壤結構互制
  - 作用力不是定值
- ⊙ 側向土壓力係數
  - K_0靜止土壓力係數
    - ○ $K_0 = 1 - sin\phi$

→ K_a (側向解壓至破壞)

→ K_p (側向加壓至破壞)

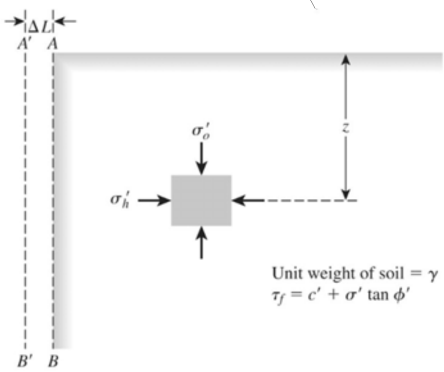


五、側向土壓力

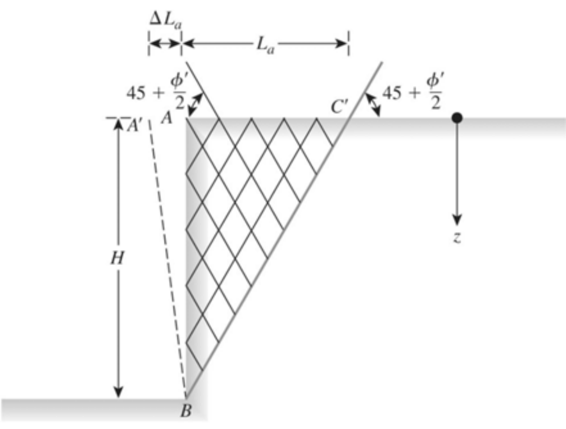
- Rankine's 土壓力理論，假設：
  - The soil is homogeneous and isotropic
  - The critical shear surface and ground surface are planes
  - The wall is infinitely long so that it can be analyzed in 2D
  - The wall moves sufficiently to develop the active or passive condition
  - The resultant of the normal and shear forces that act on the back of the wall is inclined at an angle parallel to the ground surface

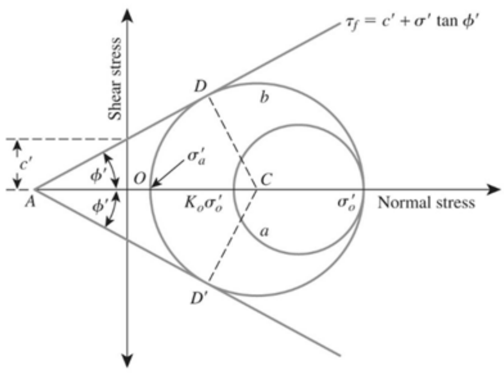
五、側向土壓力

- Rankine's 主動土壓力
  - $\sigma_a = \gamma z\, tan^2\left(45-\frac{\phi}{2}\right) - 2c\tan\left(45-\frac{\phi}{2}\right)$
  - $K_a = \frac{\sigma_a}{\sigma_v} = tan^2\left(45-\frac{\phi}{2}\right)$



(a)

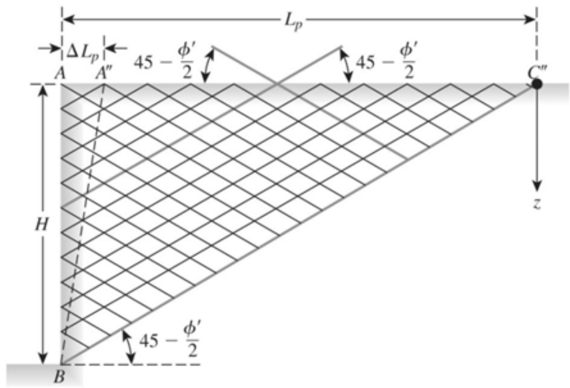


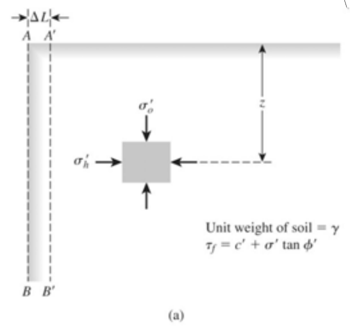


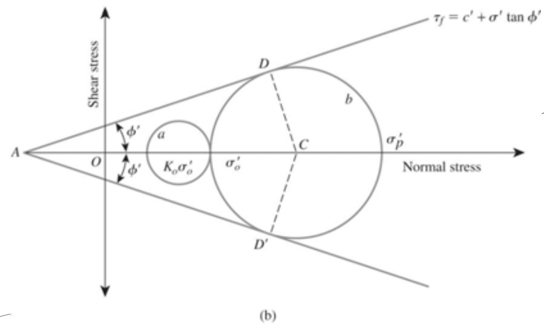
(b)

五、側向土壓力

- Rankine's 被動土壓力
  - $\sigma_p = \gamma z \tan^2\left(45+\frac{\phi}{2}\right) + 2c\tan\left(45+\frac{\phi}{2}\right)$
  - $K_p = \frac{\sigma_p}{\sigma_v} = \tan^2\left(45+\frac{\phi}{2}\right)$



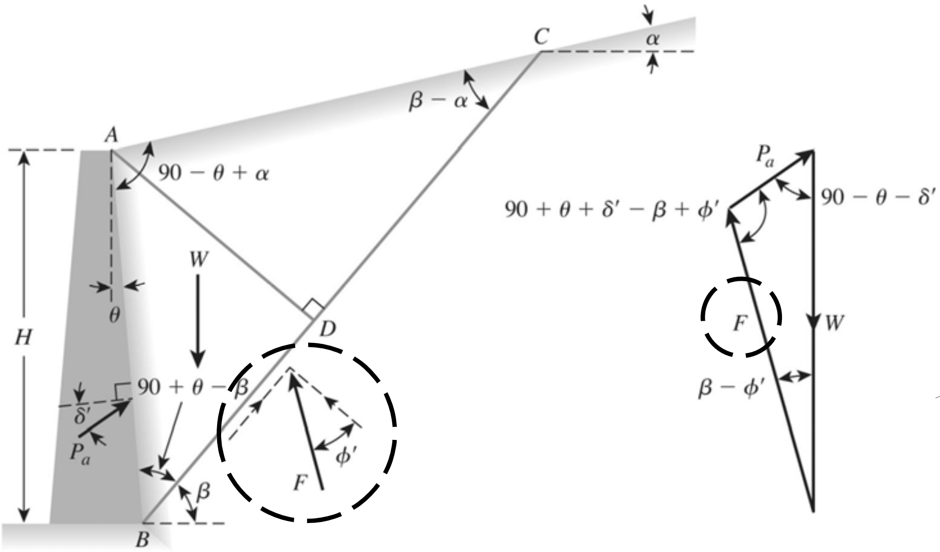




五、側向土壓力

- Coulomb's 主動土壓力
  - 考量牆身摩擦力

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos^2\theta\,\cos(\delta+\theta)\left[1+\sqrt{\frac{\sin(\delta+\phi)\,\sin(\phi-\alpha)}{\cos(\delta+\theta)\,\cos(\theta-\alpha)}}\right]^2}$$

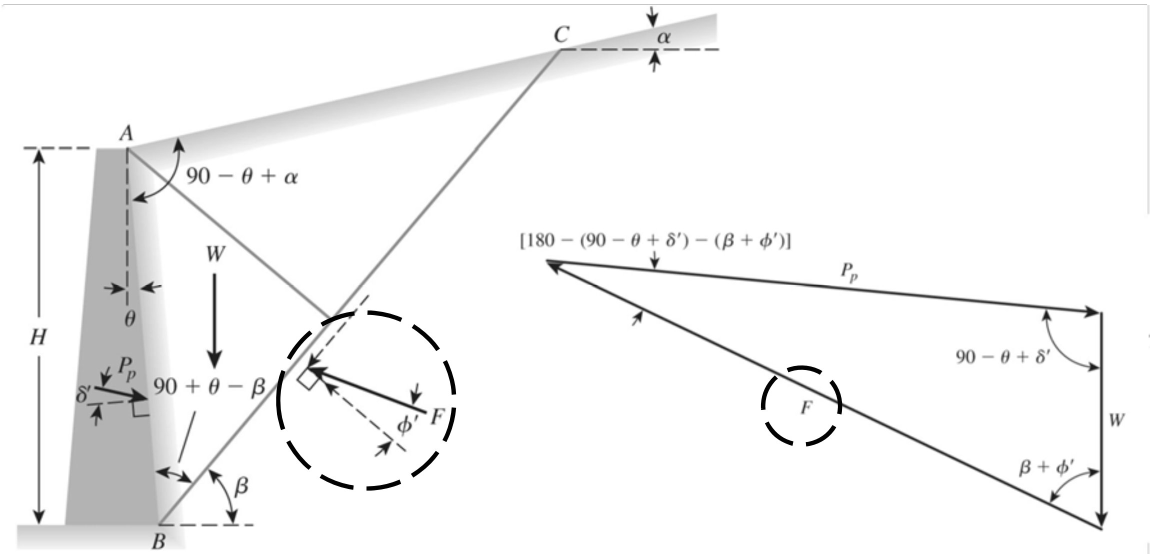


五、側向土壓力

◉ Coulomb's 被動土壓力

■ 考量牆身摩擦力

$$K_p = \frac{\cos^2(\phi+\theta)}{\cos^2\theta\,\cos(\delta-\theta)\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\,\sin(\phi+\alpha)}{\cos(\delta-\theta)\,\cos(\alpha-\theta)}}\right]^2}$$



五、側向土壓力

◉ 動態主動土壓力

■「建築物基礎構造設計規範」7.3.4節

地震時，擋土牆承受之主動土壓力合力 P_{AE}，依式(7.3-13)式計算。

$$P_{AE} = \frac{1}{2}\cdot\gamma\cdot H^2\cdot(1-k_v)\cdot K_{AE}$$ 式(7.3-13)

其中，K_{AE} 爲地震時之主動土壓力係數，可依下列方式計算：

$$K_{AE} = \frac{\cos^2(\phi-\theta-\varphi)}{\cos\varphi\cos^2\theta\cos(\delta+\varphi+\theta)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\varphi-\alpha)}{\cos(\delta+\varphi+\theta)\cos(\theta-\alpha)}}\right]^2}$$

式(7.3-14)

式內

P_{AE} = 地震時，牆背之主動土壓力合力（tf/m）

H = 擋土牆高度（m）

$\varphi = \tan^{-1}\left(\dfrac{k_h}{1-k_v}\right)$

k_v = 垂直向地震係數

k_h = 水平向地震係數

其餘符號與第7.3.2節之符號說明相同。

五、側向土壓力

⊙ 動態被動土壓力 ■「建築物基礎構造設計規範」7.3.5節

地震時，擋土牆承受之被動土壓力 P_{PE}，可依式(7.3-15)計算。

$$P_{PE}=\frac{1}{2}\cdot\gamma\cdot H^2\cdot(1-k_v)\cdot K_{PE}$$ 式(7.3-15)

其中，K_{PE} 爲地震時之被動土壓力係數，可依下列方式計算：

$$K_{PE}=\frac{\cos^2(\phi+\theta-\varphi)}{\cos\varphi\cos^2\theta\cos(\delta-\theta+\varphi)\left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\varphi+\alpha)}{\cos(\delta-\theta+\varphi)\cos(\alpha-\theta)}}\right]^2}$$ 式(7.3-16)

式內

P_{PE} = 地震時，牆背之被動土壓力合力（tf/m）

H = 擋土牆高度（m）

$\varphi=\tan^{-1}\left(\frac{k_h}{1-k_v}\right)$

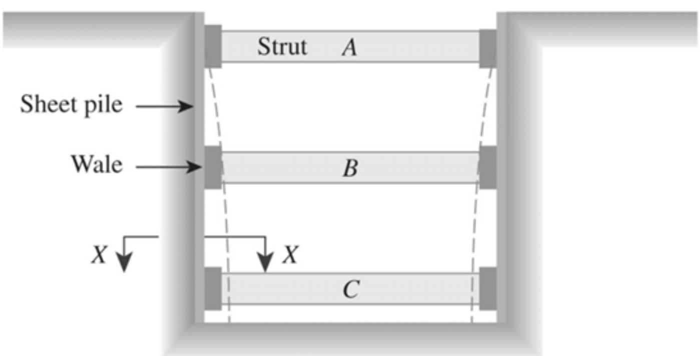
k_v = 垂直向地震係數

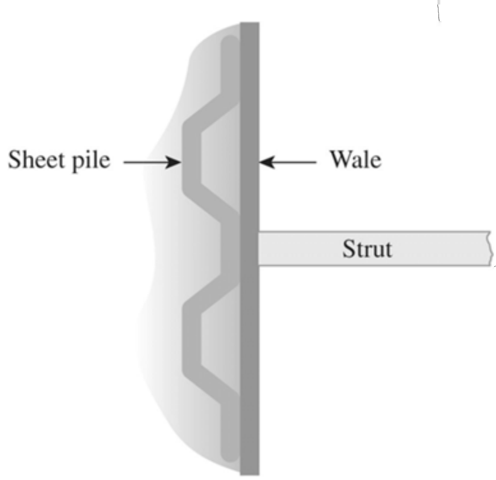
k_h = 水平向地震係數

其餘符號與第7.3.3節之符號說明相同。

五、側向土壓力

⊙ 擋土支撐視土壓力





五、側向土壓力

- 擋土支撐視土壓力
  - Peck's pressure diagrams