Praktikum Mekanika TANAH

Dosen : Sherly Meiwa ST., MT.

Jurusan Teknik Sipil
Universitas Komputer Indonesia
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Laboratory Test

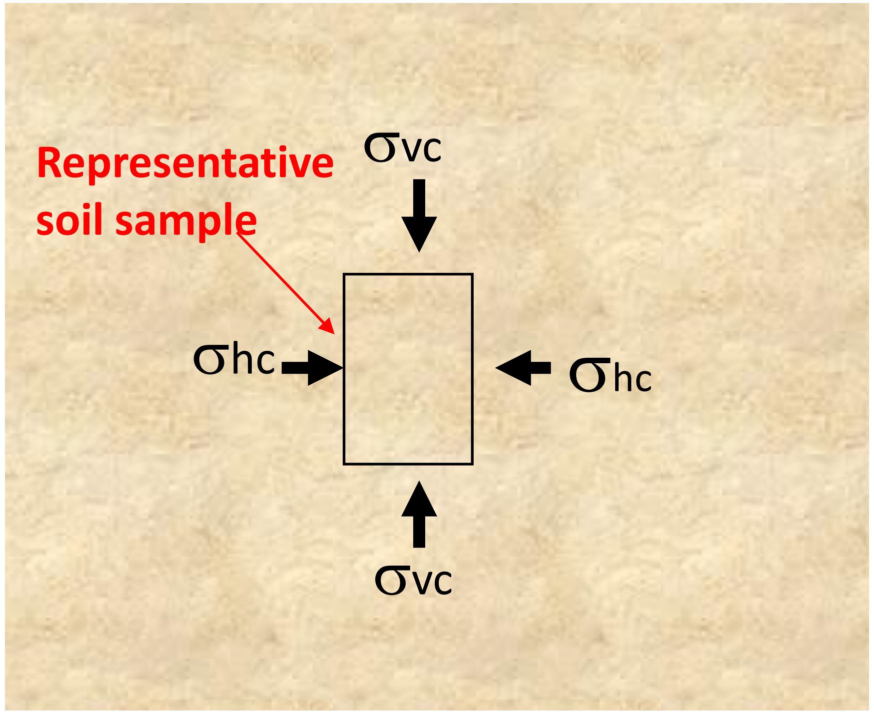
Index Properties

- Sieve Analysis & Hydrometer Analysis
- Water Content — ω
- Volumetric weight — γ
- Specific Gravity — Gs
- Atterberg Limit — PL, LL, PI

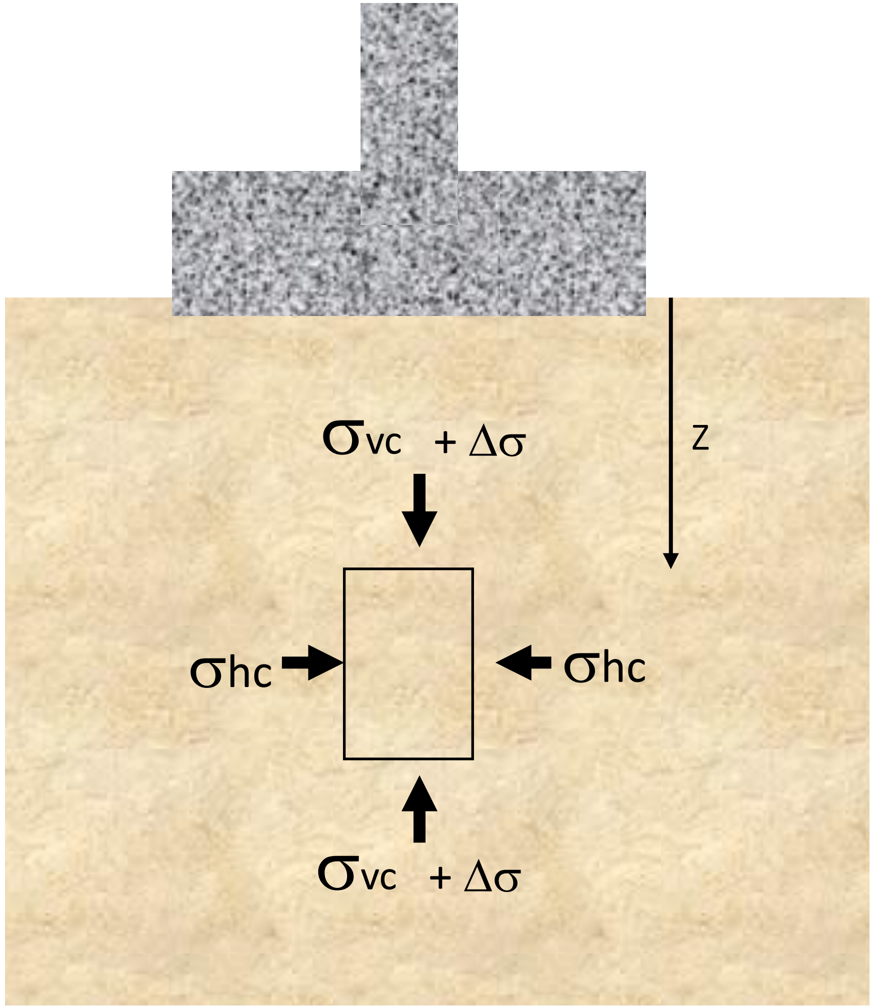
Engineering Properties

- Triaxial (UU, CU &CD) — ϕ, c, ϕ',c'
- Consolidation Test — Cc, Cr, Cv, Pc
- Direct Shear — ϕ and c
- UCS (Unconfined Compressive strength) — ϕ and cu
- Permeability (Constant Head & Falling Head) — Cc, Cr, Cv, Pc
- Compaction — γ maximum and ω optimum
- CBR (California Bearing Ratio) — CBR Ratio

Laboratory Test



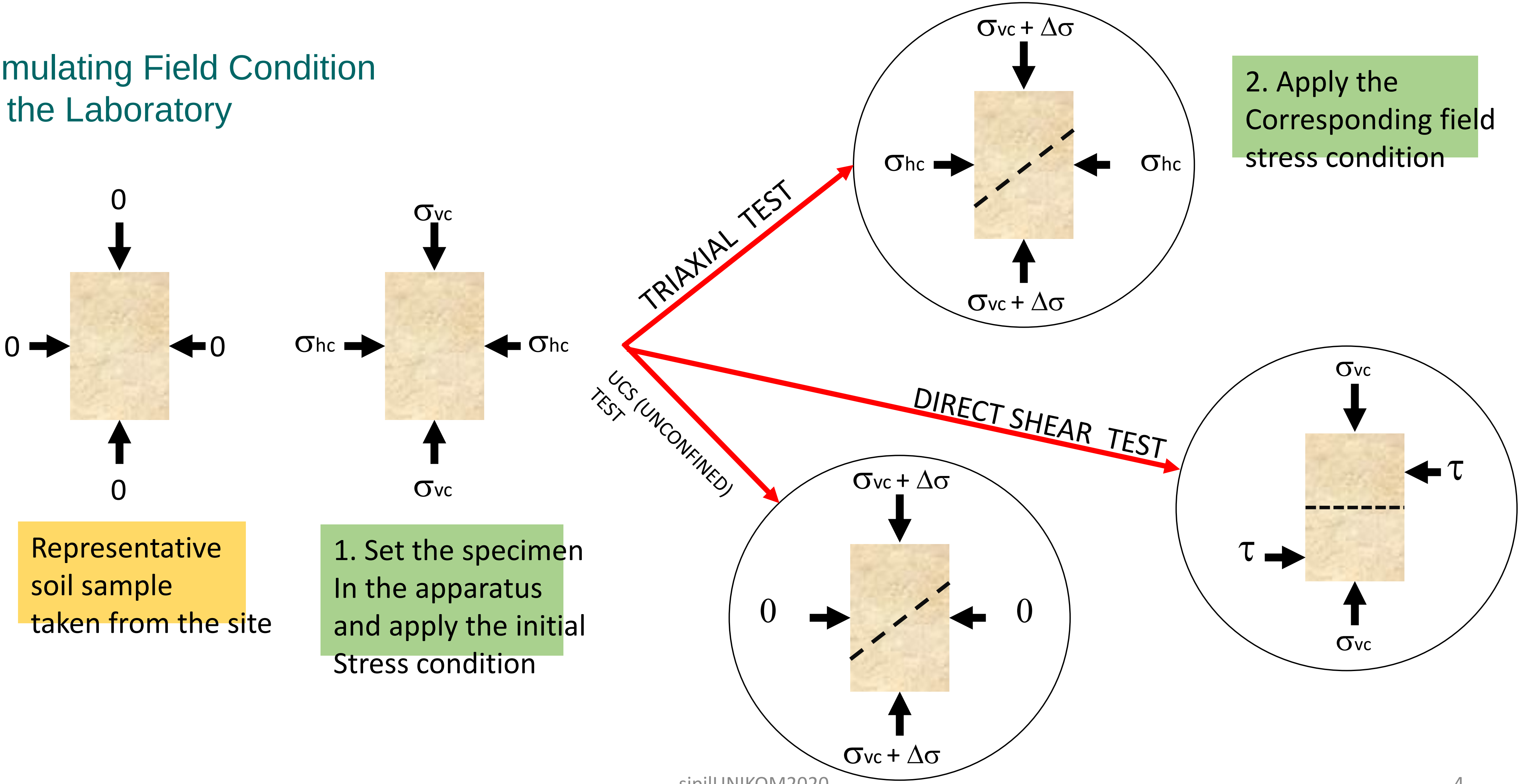
Before Construction



After and during Construction

Laboratory Test

Simulating Field Condition in the Laboratory

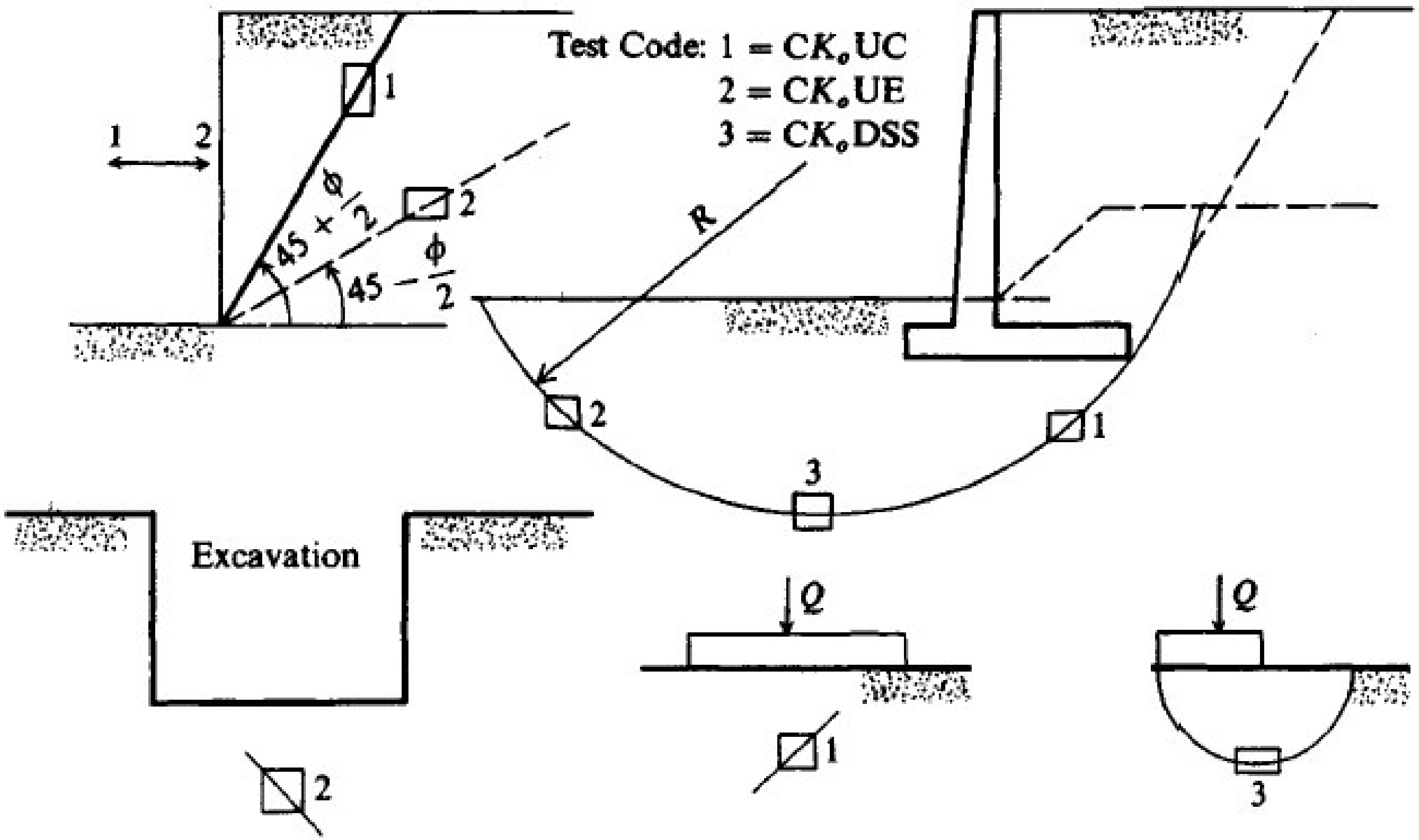


Representative soil sample taken from the site

1. Set the specimen In the apparatus and apply the initial Stress condition

2. Apply the Corresponding field stress condition

Penerapan Analisis Kuat Geser Tanah



Dasar Teori

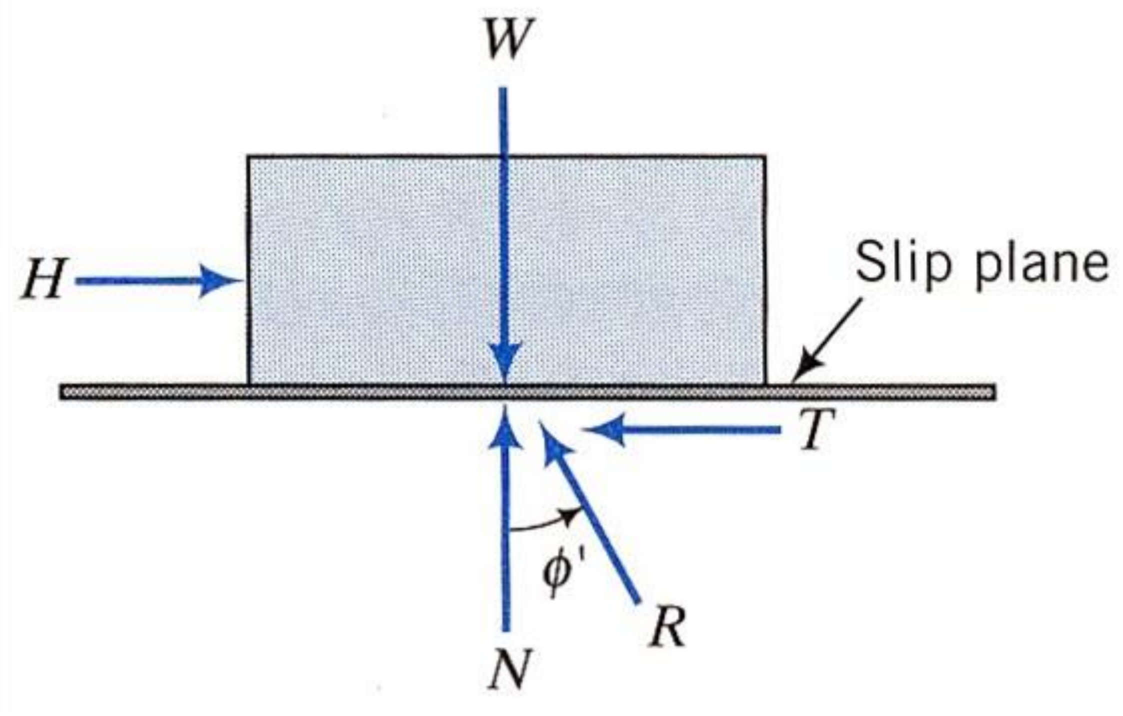
Hukum Gesekan Newton

H > μW	Geser
H < μW	Diam
H = μW	Labil

$$\frac{T}{W} = \tan \emptyset = \mu$$

$$dalam\ tegangan$$

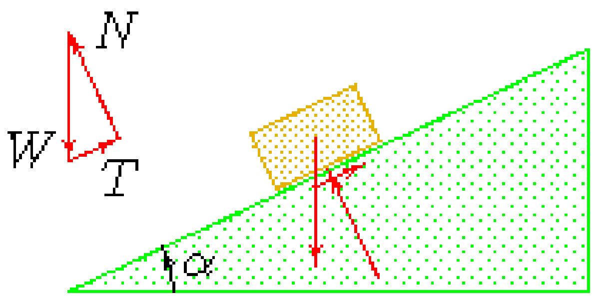
$$\frac{T/A}{W/A} = \frac{\tau}{\sigma} = \tan \emptyset = \mu$$



Kriteria Keruntuhan

Kriteria keruntuhan Coulomb

Keruntuhan pada Material diakibatkan oleh kombinasi kritis antara teg. Normal dan geser yang dinyatakan dalam bentuk:



T = *tegangan geser*
W = *berat tanah arah gravitasi*
N = *tegangan Normal*

$$\frac{T}{N} = \tan\alpha$$

Longsor terjadi manakala tegangan geser tanah lebih besar dari pada tegangan normal tanah

$$\tau_f = c + \sigma \tan\emptyset$$

σ = Teg. Normal

Kriteria keruntuhan Mohr-Coulomb

Keruntuhan pada Material diakibatkan oleh kombinasi kritis antara teg. normal dan geser serta sifat-sifat mekanis tanah yang dinyatakan dalam bentuk:

$$\tau_f = c + \sigma\ tan\emptyset$$

τ_f = Teg. Geser pada runtuh
c = Kohesi
$\emptyset$ = Sudut geser dalam
σ = Teg. Normal

Beberapa cara penentuan (pengujian kekuatan Geser Tanah:

1. Uji Geser Langsung (Direct Shear Test)
2. Uji Triaxial (Triaxial Test)
3. Uji Kuat Tekan Bebas (Unconfined Compressive Strength Test)
4. Uji Vane Shear

DIRECT SHEAR TEST

Uji Geser Langsung (Direct Shear Test)

Alat geser Langsung (Direct Shear)

Standar ASTM yang Berlaku

ASTM D3080 : Direct Shear Test of Soils Under Consolidated Drained Conditions.

Alat dan Bahan

a. Alat geser langsung (direct shear) terdiri dari
   - Stang penekan dan pemberi beban
   - Alat penggeser lengkap dengan cincin penguji (proving ring) dan dua buah arloji geser (ekstensiometer)
   - Cincin pemeriksa yang terbagi dua dengan penguncinya, terletak dalam kotak
   - Beban
   - Dua buah batu pori

b. Extruder dan sendok perata

c. Cincin cetak benda uji

d. Neraca ketelitian 0.01 gr

e. Stopwatch

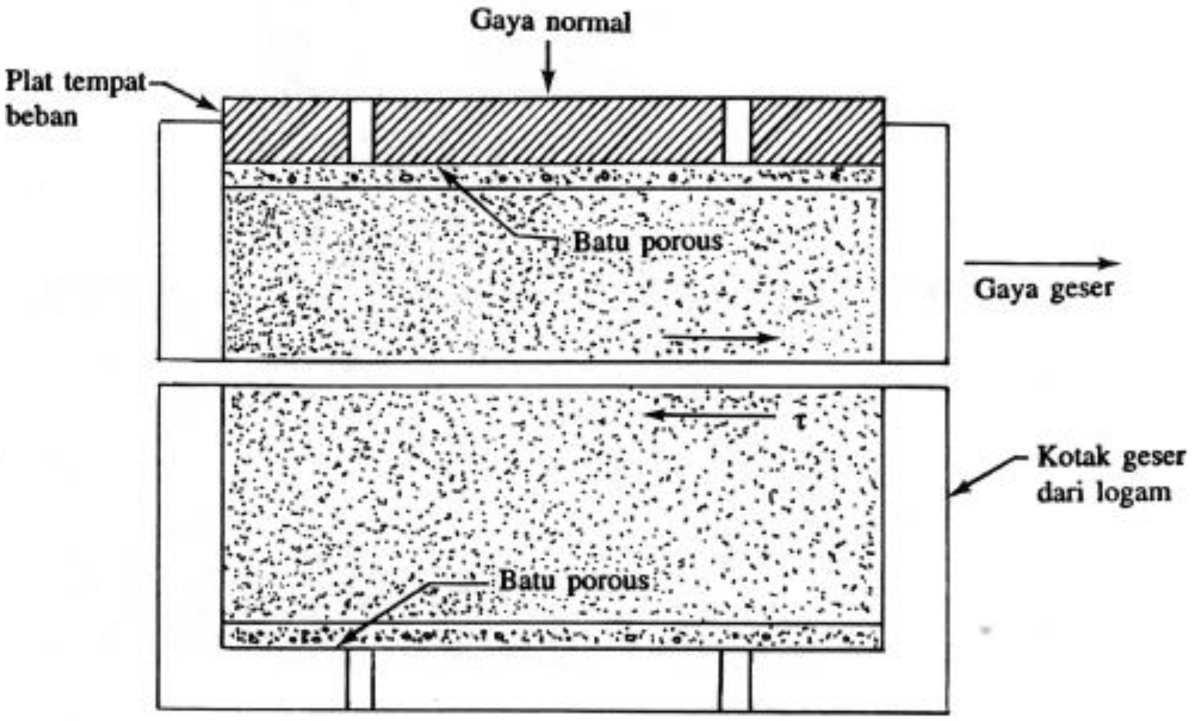
f. Kertas pori (whatman filter paper)

Prosedur

1. Timbang benda uji dengan cincinnya
2. Masukkan benda uji ke dalam kotak pemeriksaan yang telah terkunci menjadi satu dan pasang batu pori dan kertas pori pada permukaan atas dan permukaan bawah benda uji di dalam kotaknya. Kotak benda uji tersebut diletakkan pada alat *direct shear*. Masukkan air dan jenuhkan sampel.
3. Stang penekan dipasang pada arah vertikal untuk meberikan beban normal pada benda uji.
4. Penggeser benda uji dipasang pada arah mendatar untuk memberikan beban mendatar pada bagian atas cincin pemeriksaan. Atur pembacaan arloji geser sehingga menunjukkan angka nol.
5. Dengan beban normal yang ada, pembebanan geser pada kecepatan konstan diberikan dengan menyalakan mesin pada alat.
6. Lakukan pembacaan dial pada regangan tertentu (kelipatan 1%) sampai terjadi keruntuhan, dimana jarumnya berputar membalik.
7. Lakukan hal yang sama pada benda uji kedua sebesar 2x beban nirmal yang pertama dan lakukan juga untuk benda uji ketiga dengan beban 3x beban normal yang pertama.

NOTED:
Strain rate
For NC use 0.2 - 1 mm/min
OC use 0.1 - 0.2 mm/min

Uji Geser Langsung (Direct Shear Test)



Gambar 9-4 Diagram susunan alat uji geser langsung.

Ni : Beban Vertikal (normal)

Ti. : Gaya horisontal yang diperlukan untuk menggeser ring (tanah)

A : luas penampang tanah

Si : lintasan yang diperlukan sampai tanah tergeser

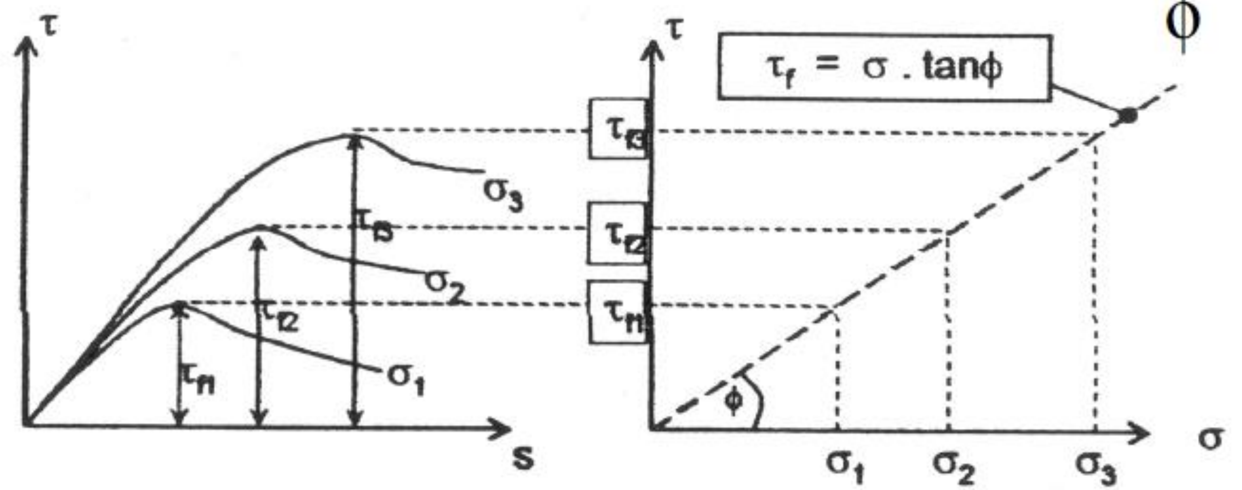
Direct Shear Test pada Tanah Pasir

Uji 1 : $\sigma_1 = \frac{N_1}{A}$: $\tau_1 = \frac{T_1}{A}$: S_1

Uji 1 : $\sigma_2 = \frac{N_2}{A}$: $\tau_2 = \frac{T_2}{A}$: S_2

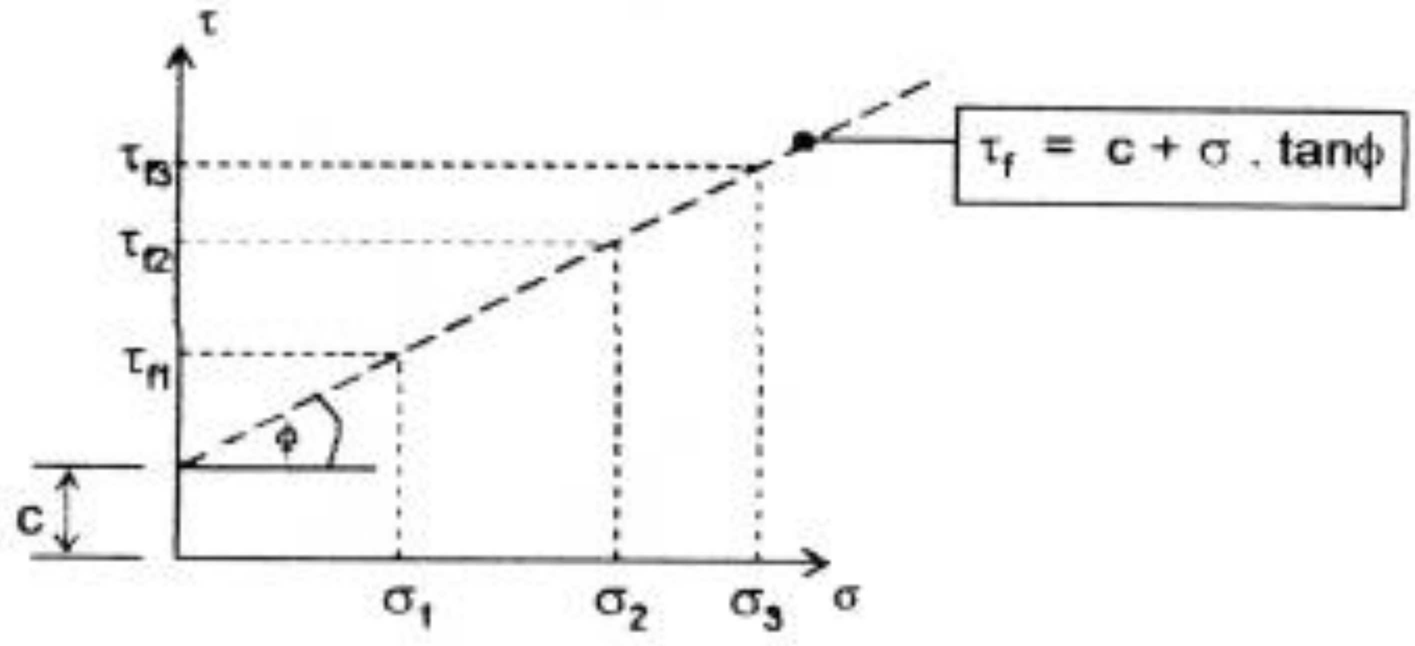
Uji 1 : $\sigma_3 = \frac{N_3}{A}$: $\tau_3 = \frac{T_3}{A}$: S_3

Hasil Uji



ϕ = sudut geser dalam

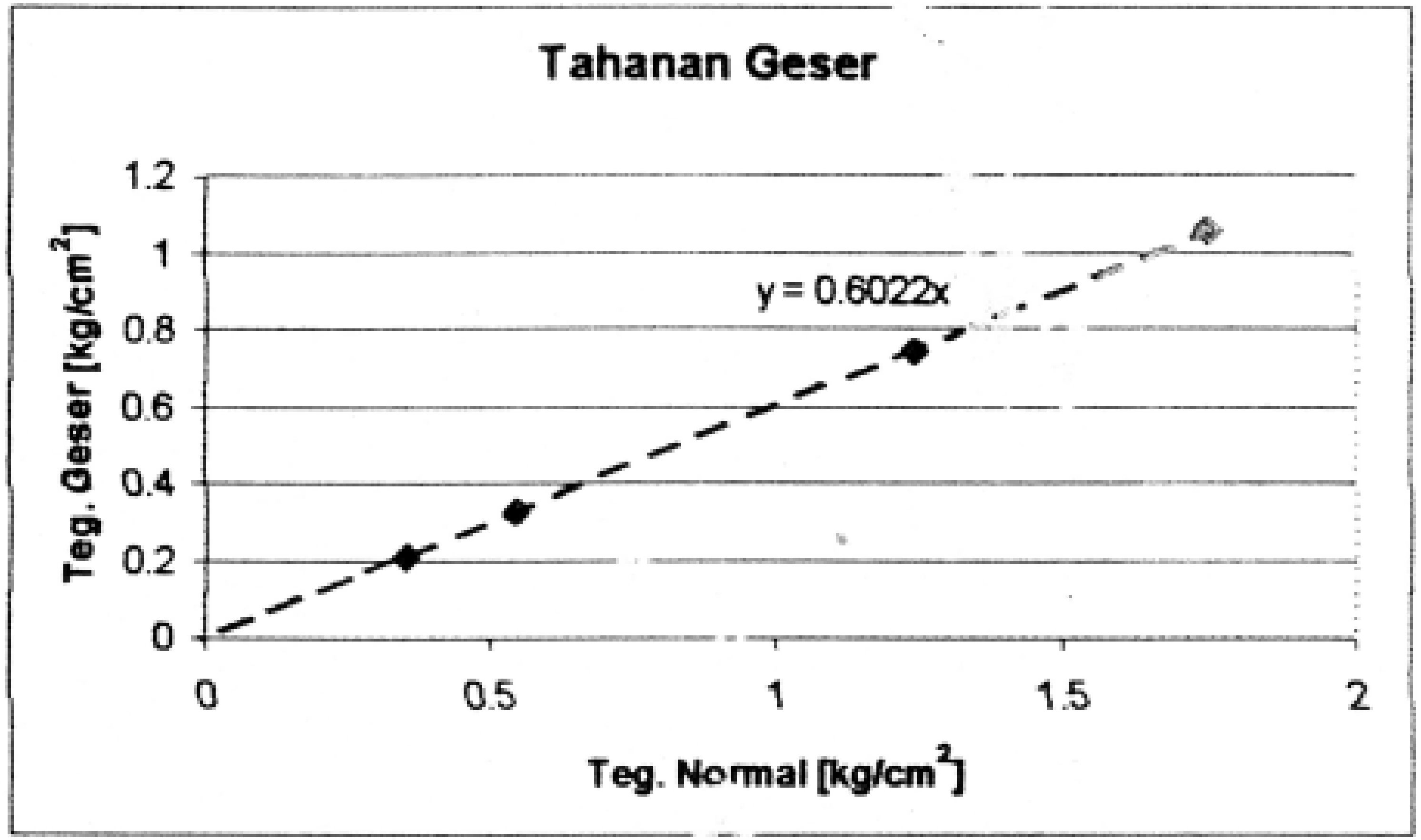
Direct Shear Test pada Tanah Lempung



ϕ : sudut geser dalam

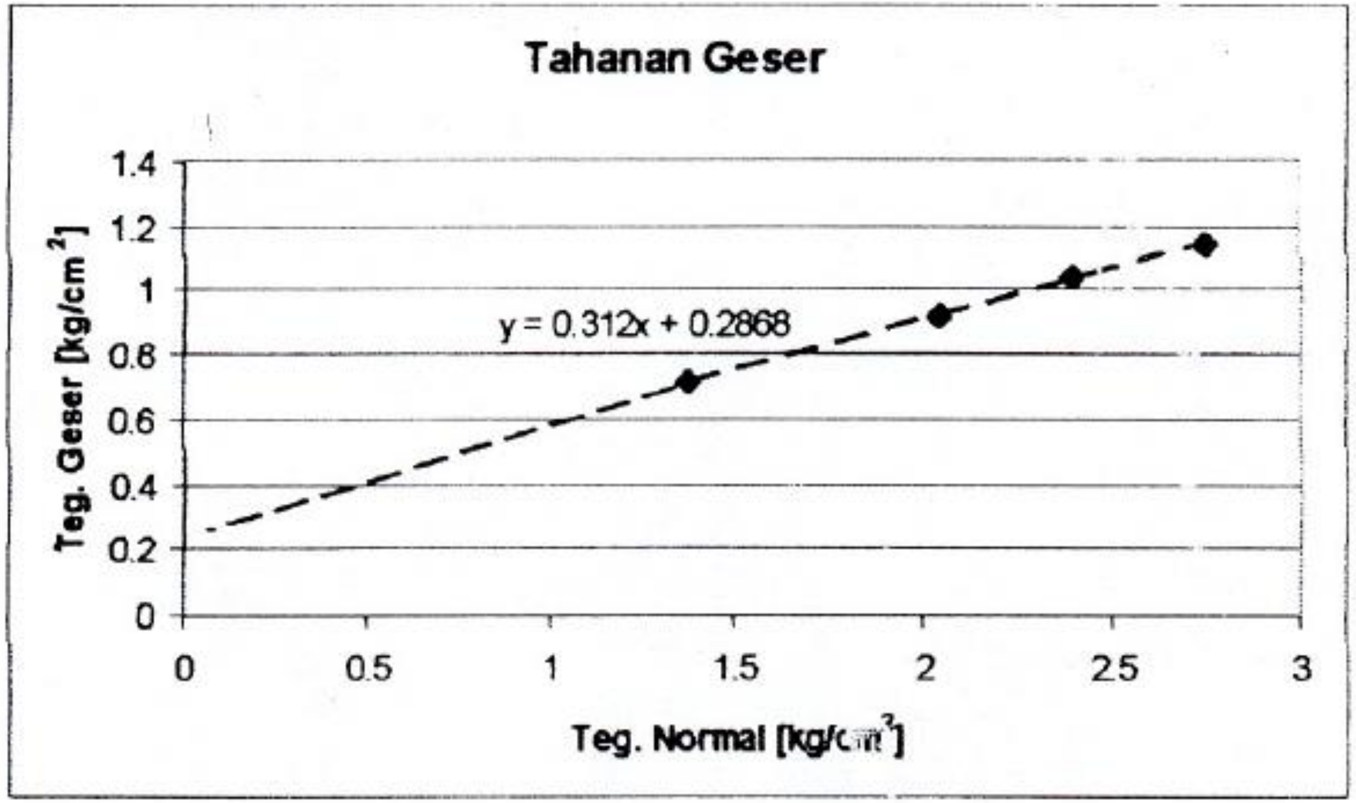
c : kohesi [kN/m^2]

Uji Geser Langsung (Direct Shear Test)



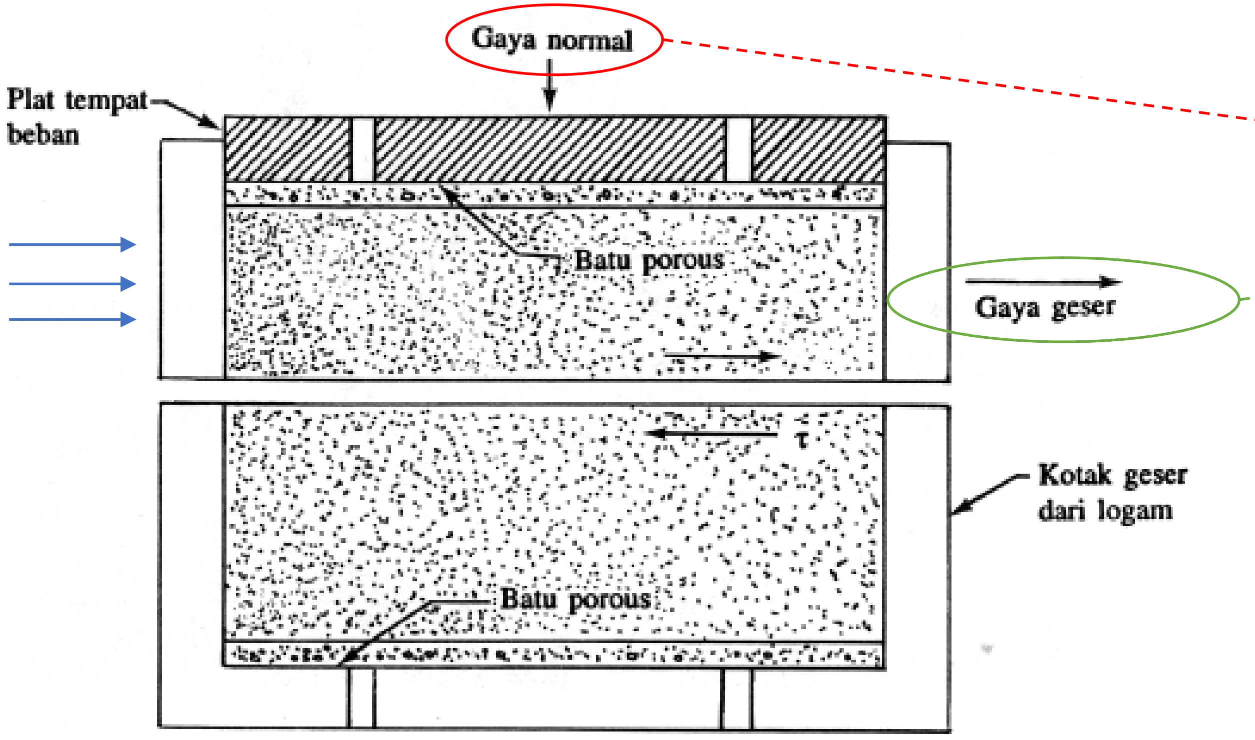
$\Phi = a \tan(0{,}6022) = 31^{o}$

$c = 0$



ϕ = atan(0.312) = 17.32^0
c = 0.2868 kg/cm^2

Uji Geser Langsung (Direct Shear Test)



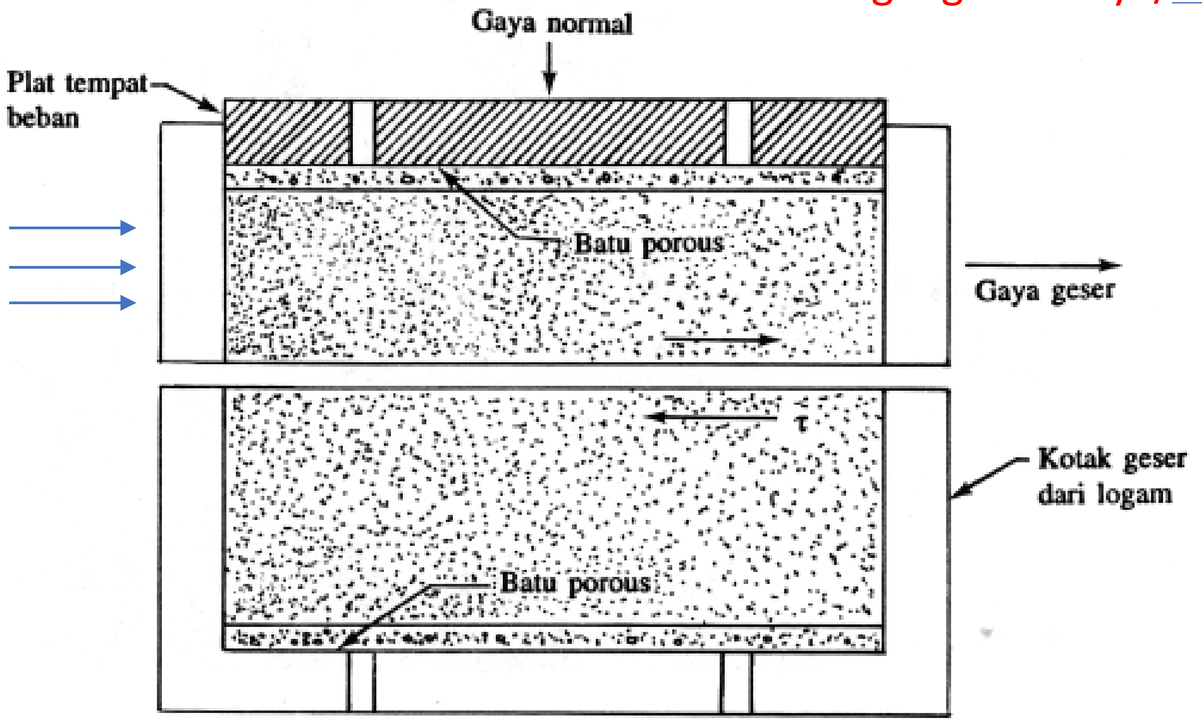
Gambar 9-4 Diagram susunan alat uji geser langsung.

Luas Sample: A = (5.08*5.08) cm^2

No. Uji	Arah Normal		Arah Geser	
	Gaya	Tegangan	Gaya	Tegangan
	kg	kg/cm^2	kg	kg/cm^2
1	9	0.348751	5.44	0.210924
2	14	0.542501	8.30	0.32166
3	32	1.240002	19.10	0.739993
4	45	1.743753	27.26	1.056638

Uji Geser Langsung (Direct Shear Test)

Tegangan = Gaya/area



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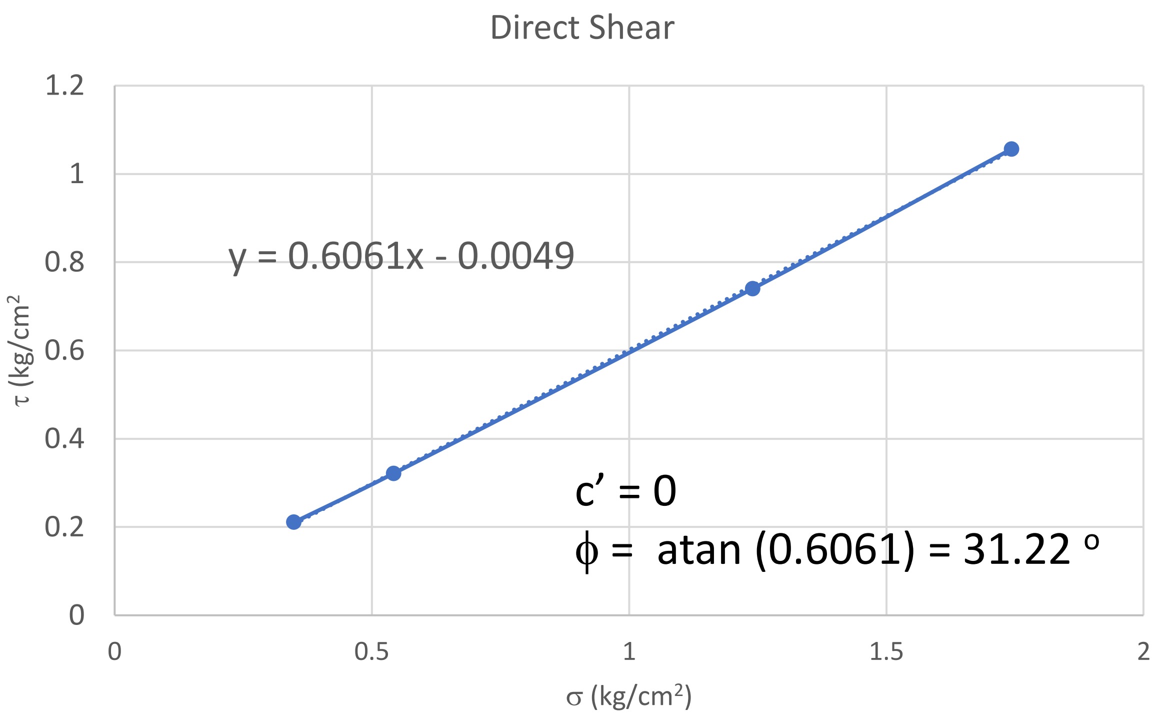

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Uji Geser Langsung (Direct Shear Test)

Contoh Tanah Pasir

Diameter Sample: D = 5.08 cm

No. Uji	Arah Normal		Arah Geser	
	Gaya	Tegangan	Gaya	Tegangan
	kg	kg/cm^2	kg	kg/cm^2
1	27	1.374545	14.06	0.715782
2	40	2.036363	18.06	0.919418
3	47	2.392727	20.41	1.039054
4	54	2.749091	22.43	1.141891

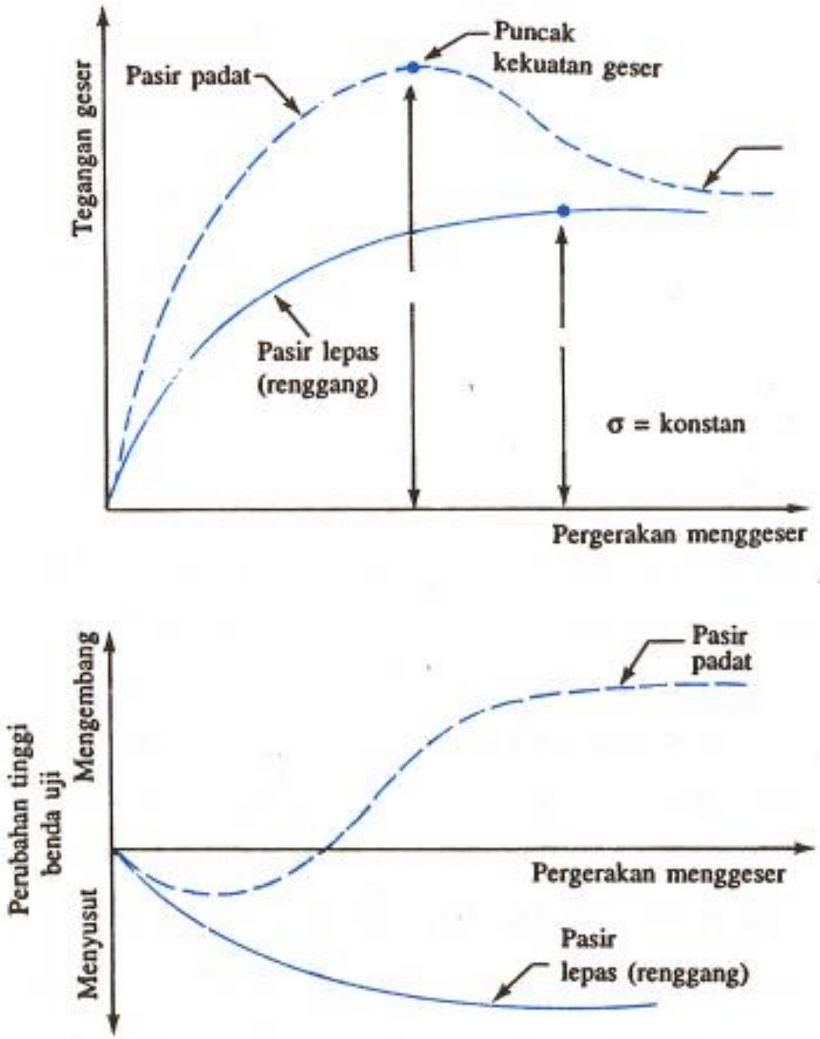


Diagram tegangan geser vs perubahan tinggi, benda uji karena pergerakan menggeser untuk tahan pasir padat dan lepas (uji geser langsung)

Hal umum yang dapat ditarik dari gambar di atas berkaitan dengan variasi tegangan geser penghambat dan perpindahan geser, yaitu:

1. Pada pasir lepas (renggang), tegangan geser penahan akan membesar sesuai dengan membesarnya perpindahan geser sampai tegangan tadi mencapai tegangan geser runtuh. Setelah itu, besar tegangan geser akan kira-kira konstan sejalan dengan bertambahnya perpindahan geser.

2. Pada pasir padat, tegangan penghambat akan naik sejalan dengan membesarnya perpindahan geser hingga tegangan geser runtuh (maksimum) τ_1 tercapai. Harga τ_1 ini disebut sebagai kekuatan geser puncak (peak shear strength). Bila tegangan runtuh telah dicapai, maka tegangan geser penghambat yang ada akan berkurang secara lambat laun dengan bertambahnya perpindahan geser sampai pada suatu saat mencapai harga konstan yang disebut kekuatan geser akhir maksimum (ultimate shear strength).

Contoh Laporan di Laboratorium

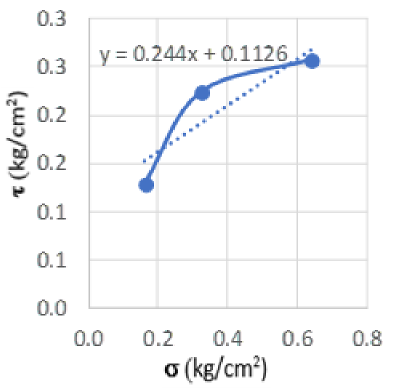
Pengujian Geser Langsung

Direct Shear Test(ASTM D3080)

calibration	0.5 kg	RPM :	0.5 mm/minute
Diameter	6.3 cm		

Dial	Normal Force (gr)	5040	Normal Force (gr)	10060	Normal Force (gr)	20030
	Dial Reading Stress Force	Stress Force (kg)	Dial Reading Stress Force	Stress Force (kg)	Dial Reading Stress Force	Stress Force (kg)
0	0	0	0	0	0	0
65	1.8	0.9	4.7	2.35	6.5	3.25
130	3.7	1.85	7.5	3.75	9.3	4.65
195	5.1	2.55	8.5	4.25	10.1	5.05
260	6.7	3.35	9.1	4.55	11.6	5.8
325	7.3	3.65	10.5	5.25	12.9	6.45
390	7.9	3.95	11.8	5.9	14.2	7.1
455	8.1	4.05	13.1	6.55	15.4	7.7
520	8	4	14	7	16.1	8.05
585	0	0	0	0	0	0
650	0	0	0	0	0	0
715	0	0	0	0	0	0
780	0	0	0	0	0	0
845	0	0	0	0	0	0
910	0	0	0	0	0	0
975	0	0	0	0	0	0
1040	0	0	0	0	0	0
1105	0	0	0	0	0	0
1170	0	0	0	0	0	0
1235	0	0	0	0	0	0
maximum shear strength		4.05		7		8.05

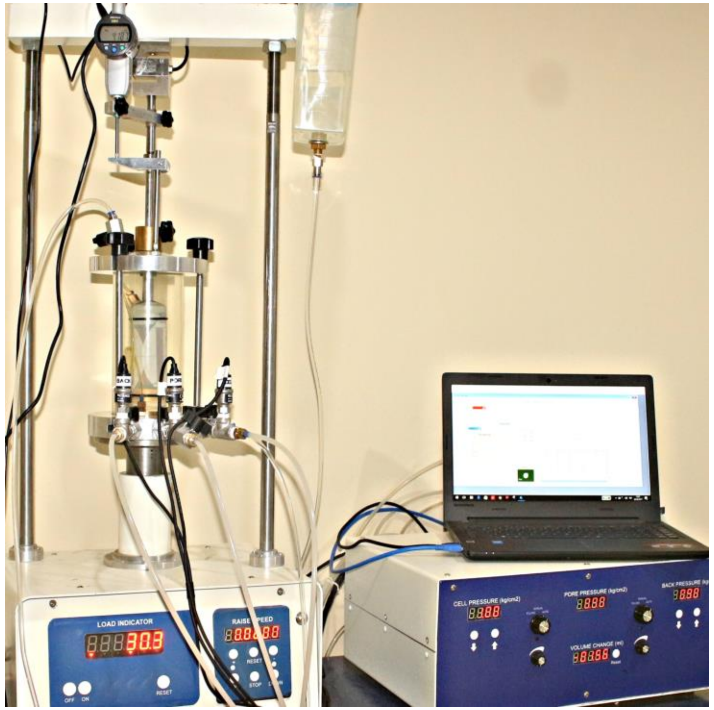
(σ) $\left[\frac{Normal\ force}{Area}\right]$ kg/cm^2	(τ) $\left[\frac{Shear\ force}{Area}\right]$ kg/cm^2
0.162	0.130
0.323	0.225
0.643	0.258
Kohesi (c)	0.1126 (kg/cm^2)
Sudut Geser (Ø) in degree	13.71 °



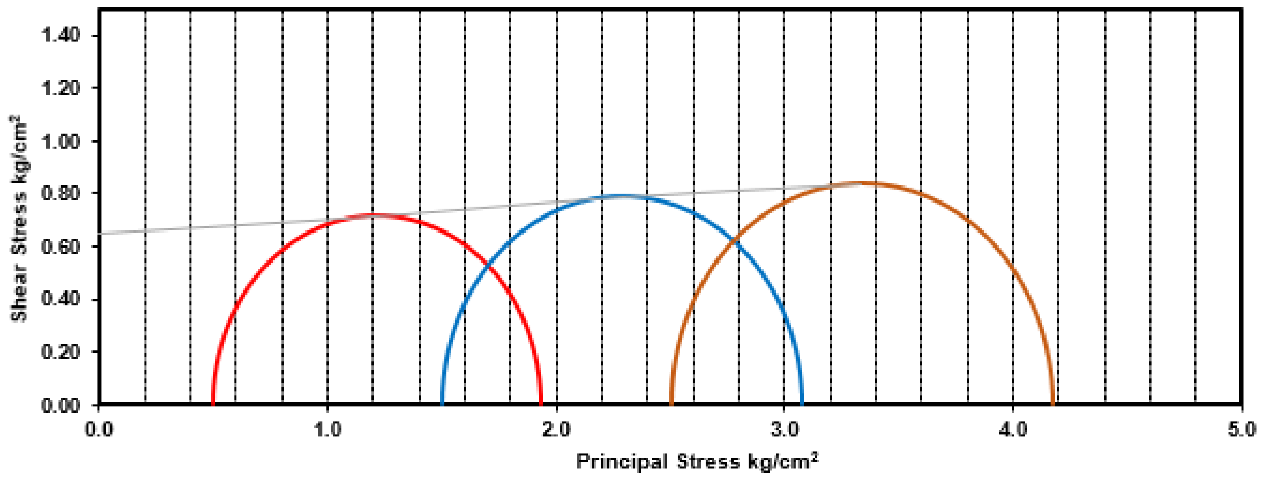
TRIAXIAL TEST

Triaxial Compression Test

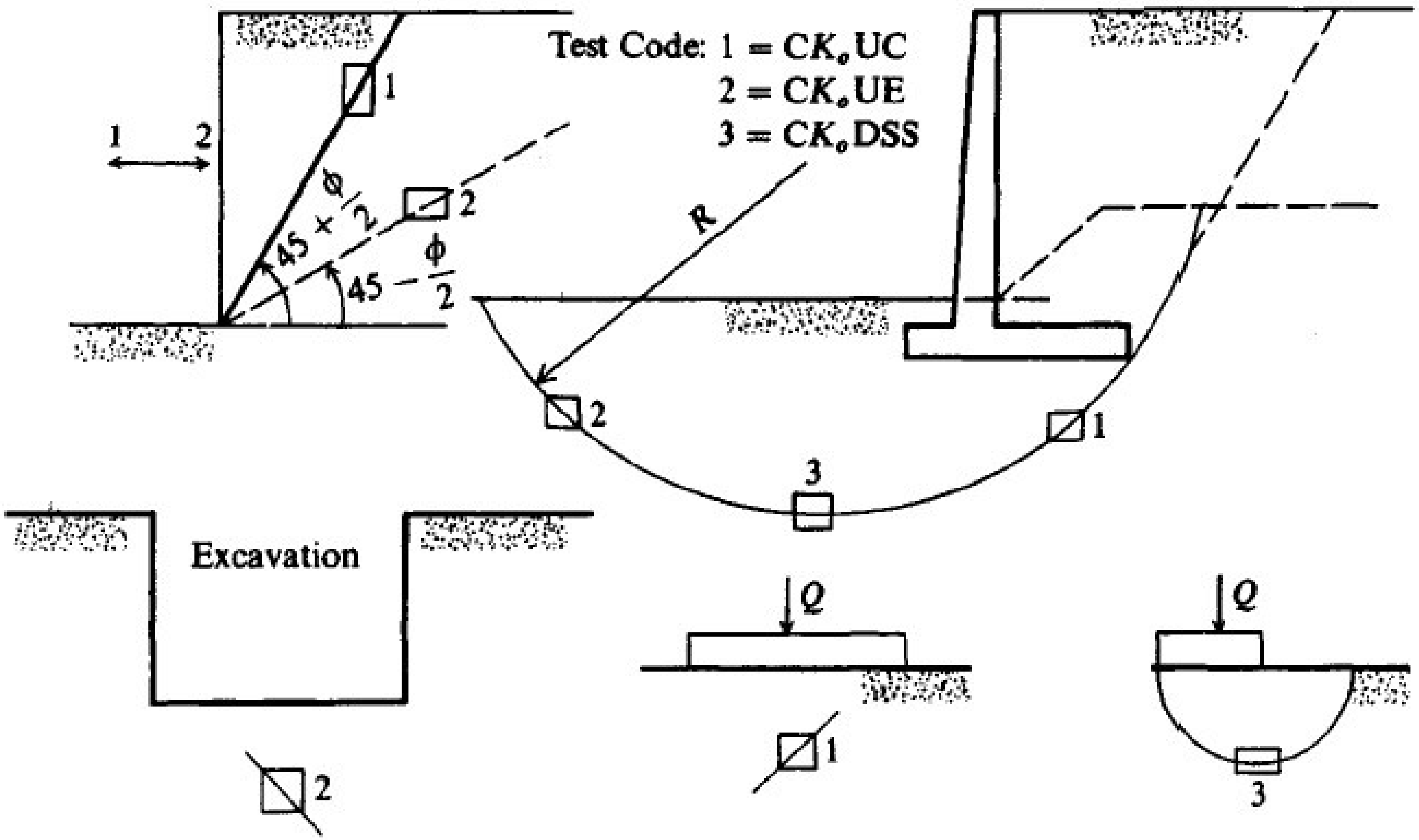
The triaxial compression test (ASTM D2850) is used for the determination of strength parameter of soil. The two parameters acquired are cohesion (c) and internal angle friction (ϕ).



Triaxial Compression Test

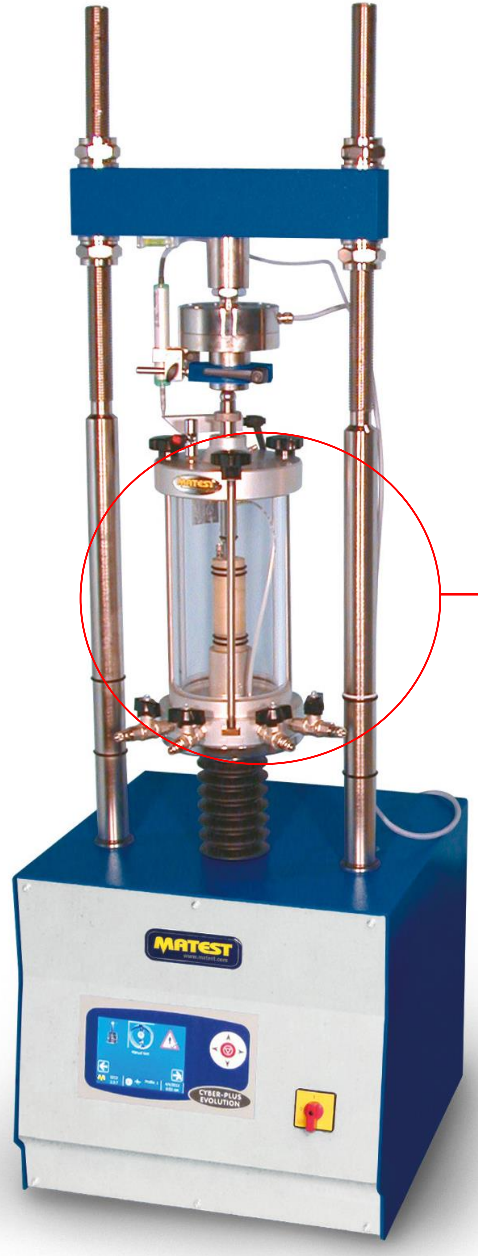


Aplikasi

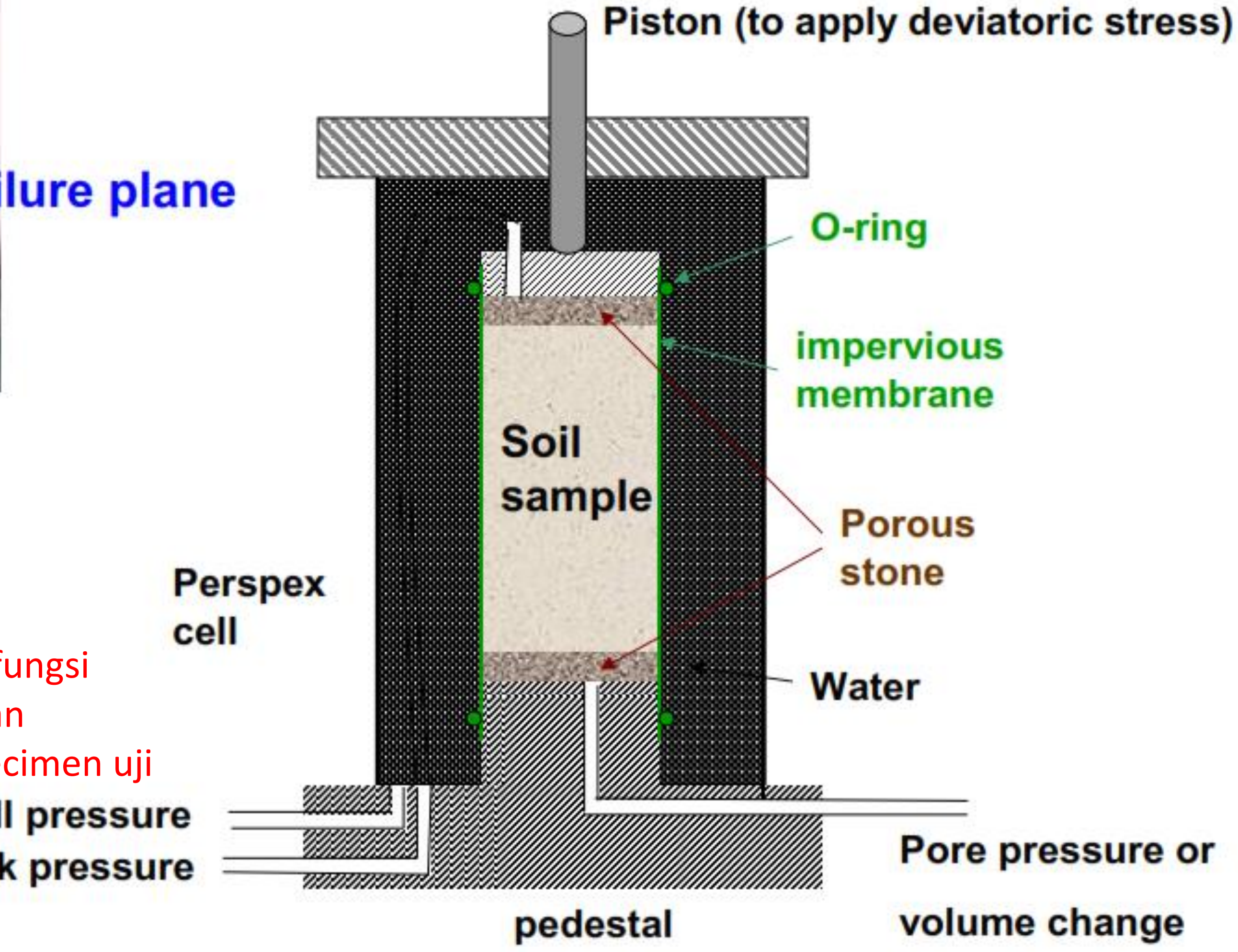


Test Code: 1 = CK$_o$UC
2 = CK$_o$UE
3 = CK$_o$DSS
1
2
1
2
45 + φ/2
45 − φ/2
2
R
2
1
3
Excavation
2
Q
1
Q
3

Uji Triaxial (Triaxial Test)



Soil sample at failure



Cell Pressure Berfungsi sebagai pemberian tekanan pada specimen uji

Uji Triaxial (Triaxial Test)

Tiga tipe standard dari uji triaxial yang biasanya dilakukan

1. Consolidated-drained test atau drained test (CD test)
2. Consolidated-undrained test (CU test)
3. Unconsolidated-undrained test atau undrained test (UU test)

Uji Triaxial (Triaxial Test)

Specimen Preparation (Undisturbed Sample)

Sampel dalam kondisi tidak terganggu (Undisturb) di siapkan dalam *Shelby tube*. *Shelby tube* seharusnya diletakkan dalam posisi vertical saat penyimpanan

Sample dikeluarkan dengan alat extruder

Uji Triaxial (Triaxial Test)

Specimen Preparation (Undisturbed Sample)

Sampel dicetak dengan tabung silinder untuk pengujian triaxial

Spesimen diletakkan di atas Bottomcap alat triaxial

Uji Triaxial (Triaxial Test)

Specimen Preparation (Undisturbed Sample)

Spesimen dibungkus dengan membrane karet diberi kertas filter diatas maupun bawah spesimen

Chamber alat triaxial diisi dengan air

Uji Triaxial (Triaxial Test)

Specimen Preparation (Undisturbed Sample)

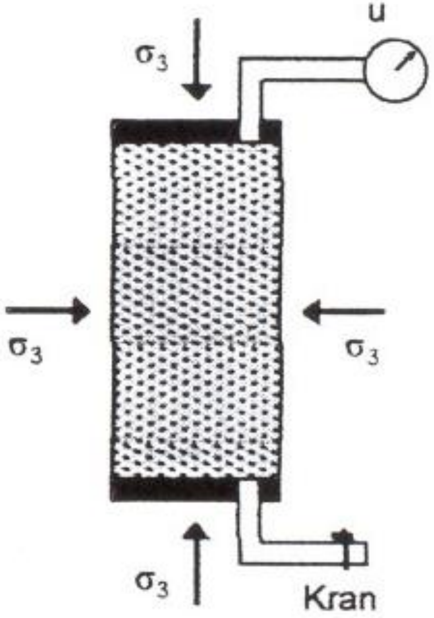
Proving Ring untuk mengukur deviatoric stress

Dial reading untuk mengukur penurunan vertikal

Prinsip Uji Triaxial

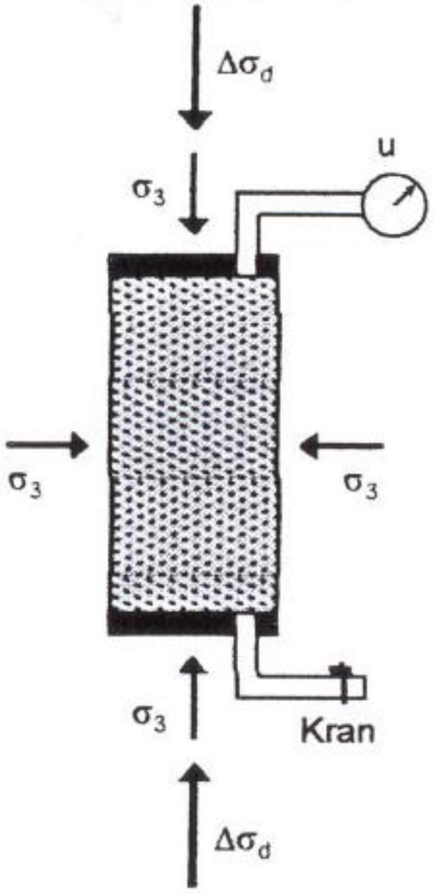
Tahap 1:
Confining Pressure

Tahap pemberian tegangan σ3



Tahap 2:
Shear Pressure

Tahap pemberian tegangan deviatorik



Pemberian Beban:

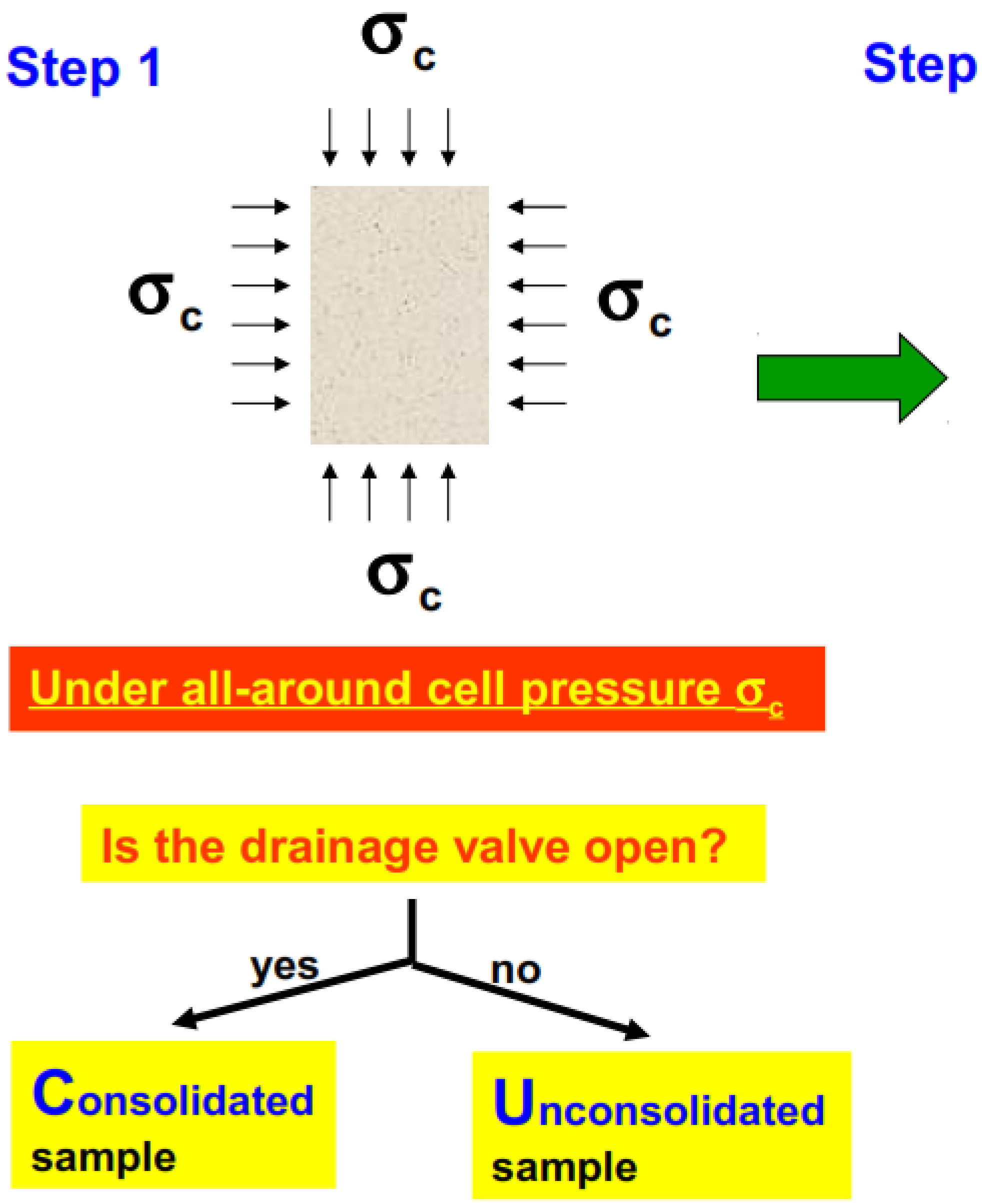
σ_3 : konstan

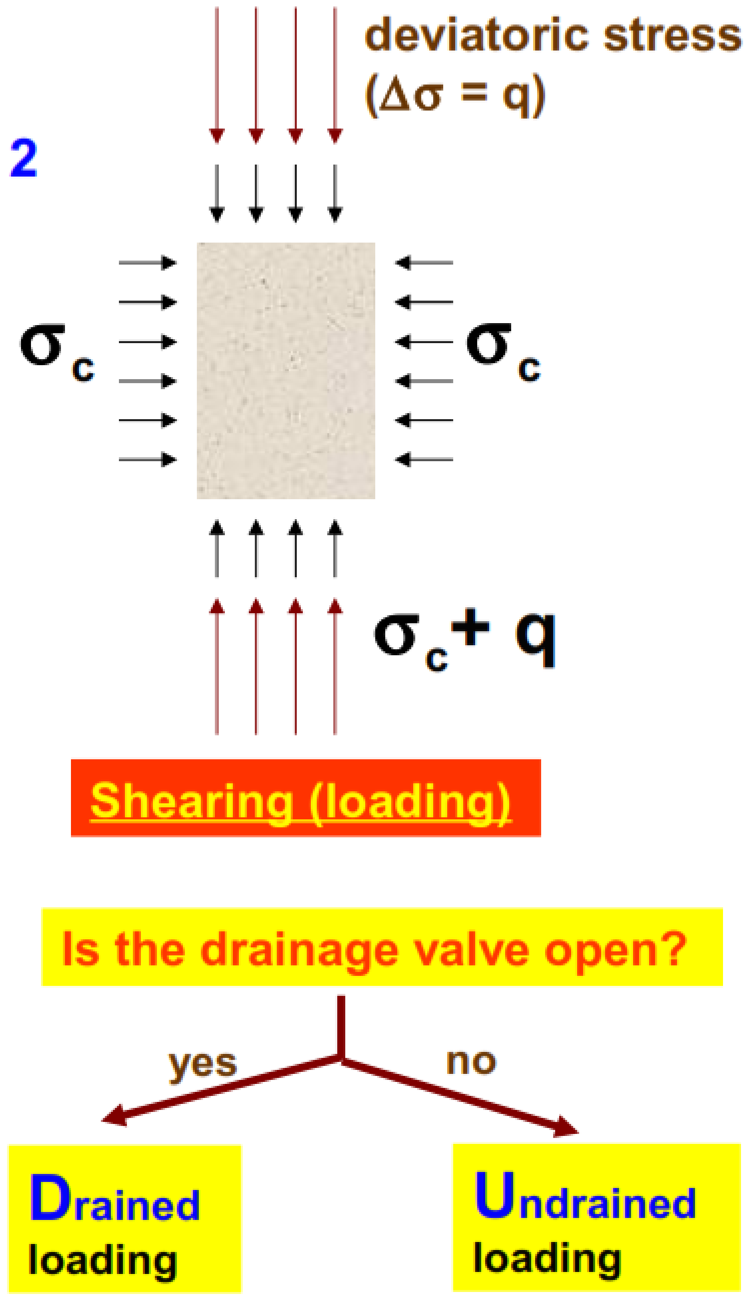
$\Delta\sigma_d$: bertahap sampai runtuh $(\Delta\sigma_d)_f$

Perbedaan Tipe Standard Pengujian Triaxial

Jenis Uji	Confining Pressure		Shear Pressure	
	Kran	Teg. Air Pori (u)	Kran	Teg. Air Pori (u)
CD	Buka	$u = u_c = 0$	Buka	$u = u_c + \Delta u_d = 0$
CU	Buka	$u = u_c = 0$	Tutup	$u = u_c + \Delta u_d = 0$
UU	Tutup	$u = u_c$	Tutup	$u = u_c + \Delta u_d$

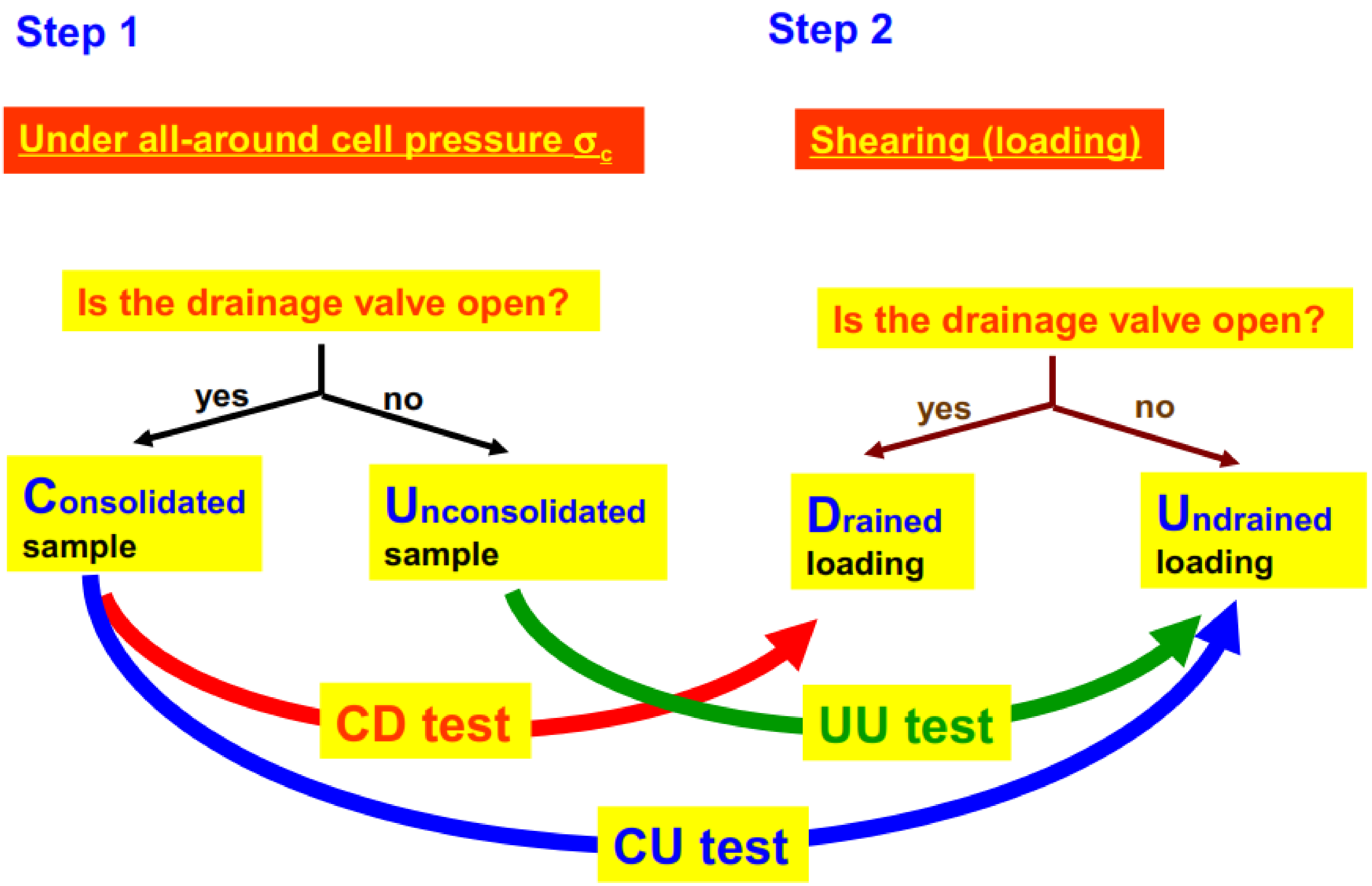
Types of Triaxial Tests





Triaxial Test : Consolidated Drained (CD)

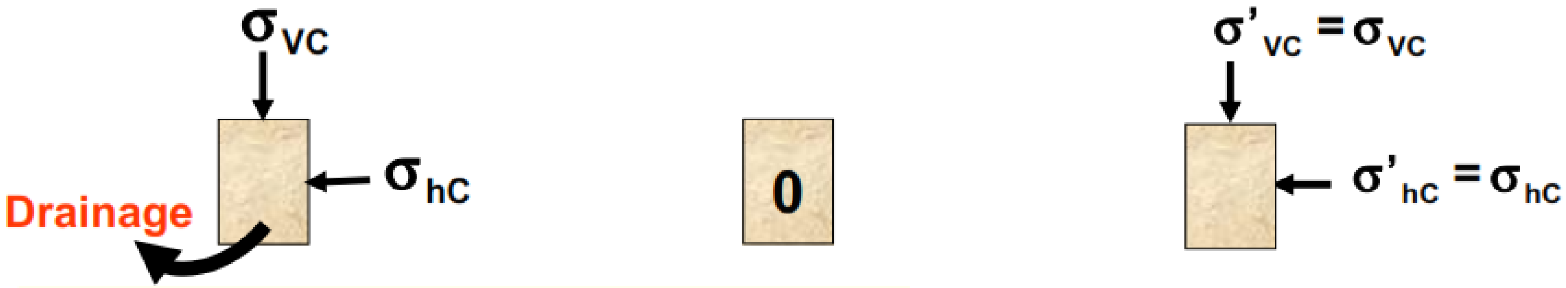
Types of Triaxial Tests



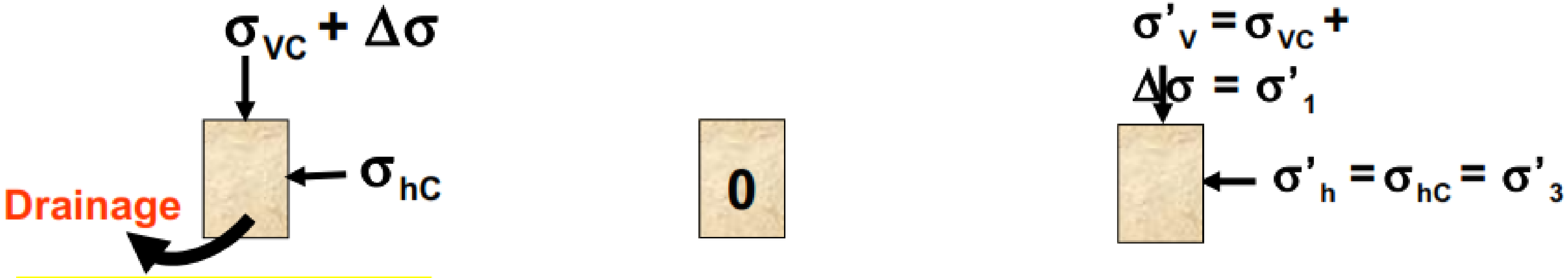
Consolidated- drained test (CD Test)

Total, σ = Neutral, u + Effective, σ'

Step 1: At the end of consolidation



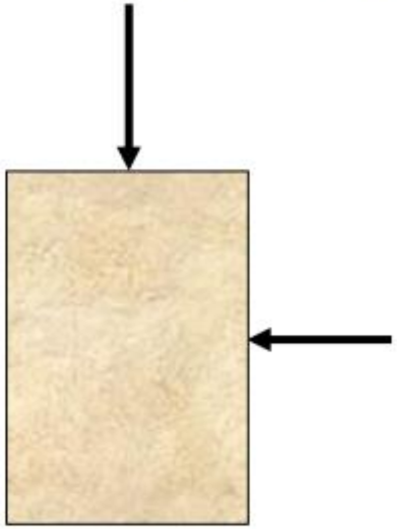
Step 2: During axial stress increase



Step 3: At failure

Consolidated- drained test (CD Test)

$$\sigma_1 = \sigma_{VC} + \Delta\sigma$$

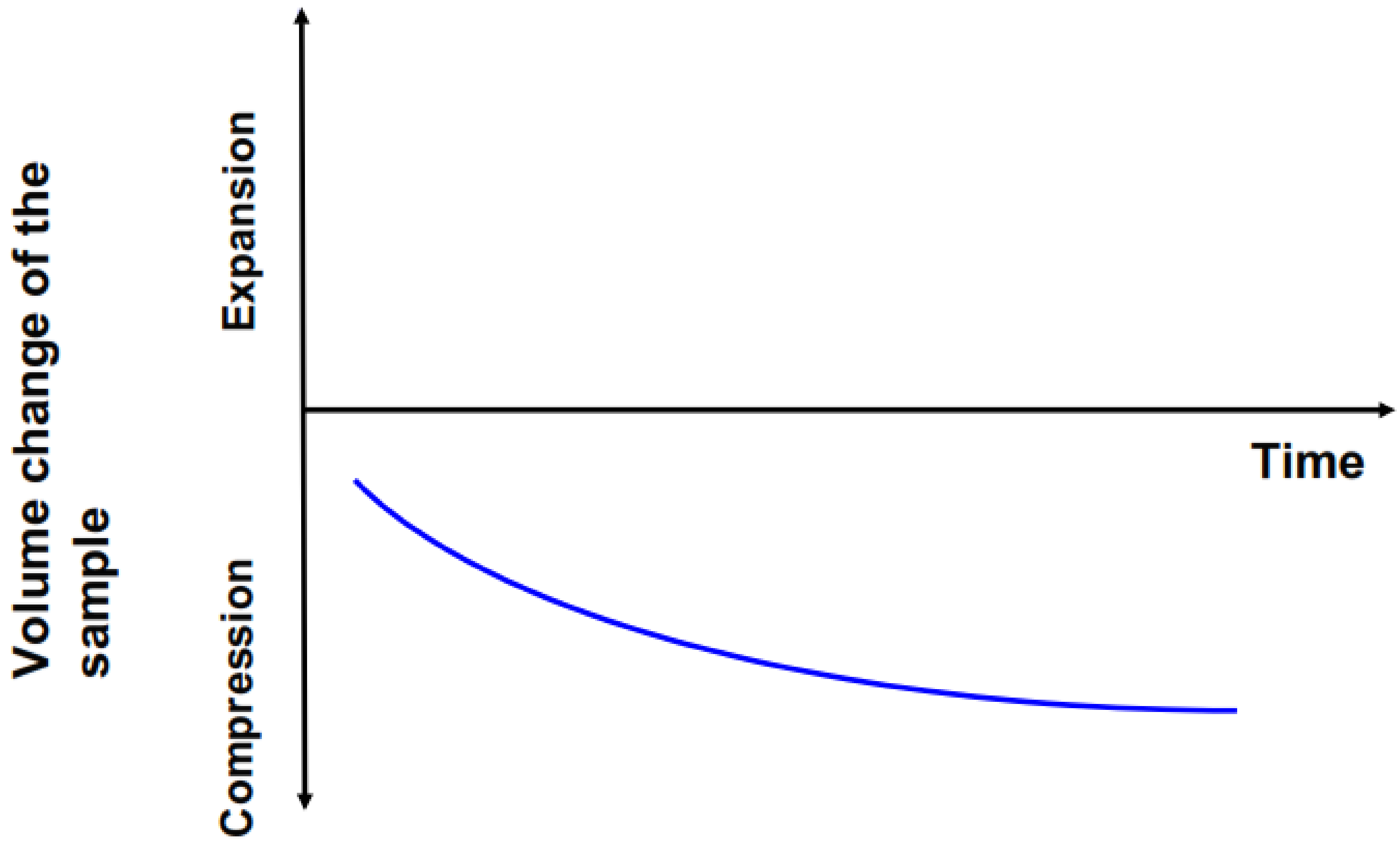


$$\sigma_3 = \sigma_{hC}$$

Deviator stress (q or $\Delta\sigma_d$) = $\sigma_1 - \sigma_3$

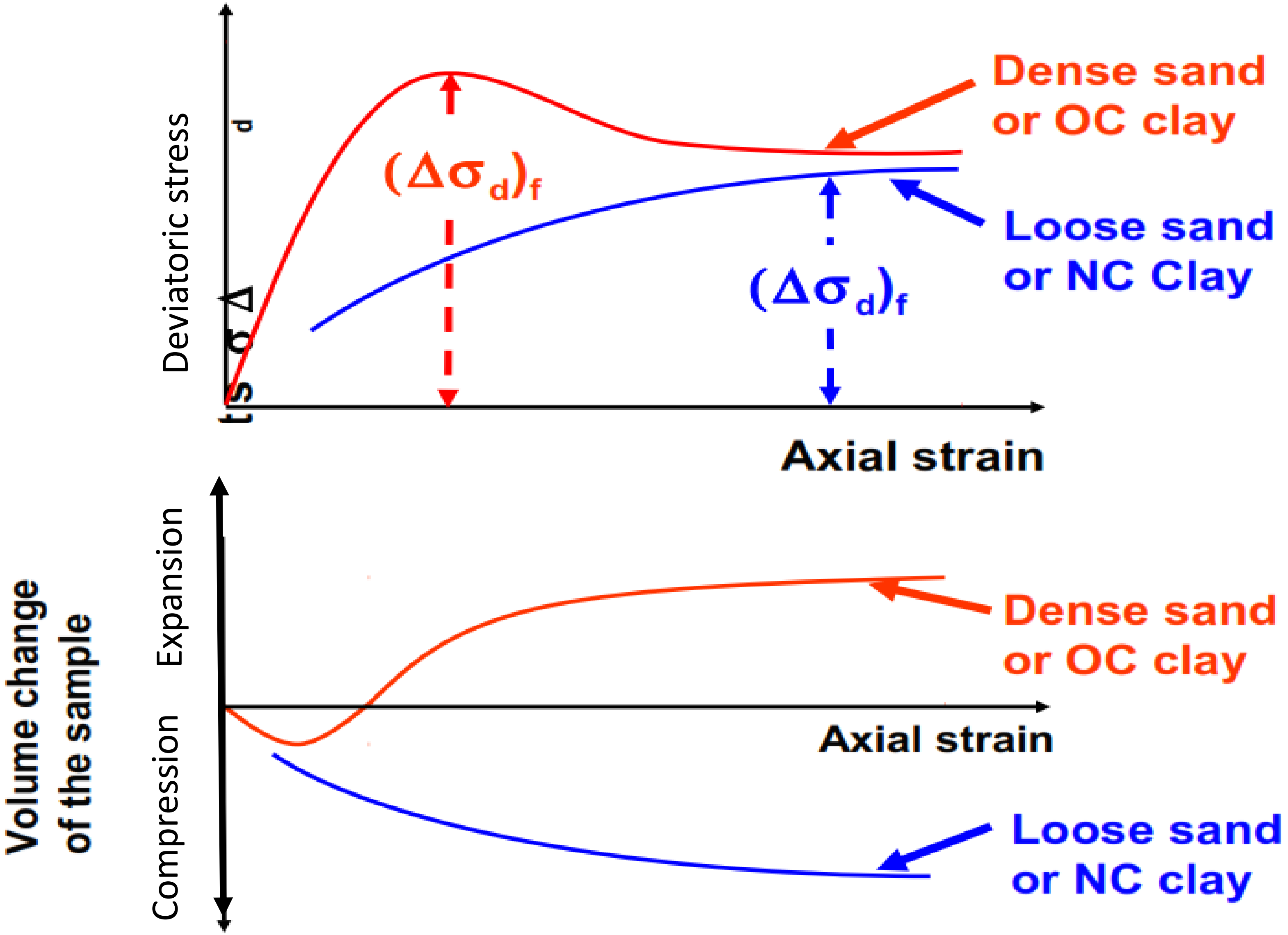
Consolidated- drained test (CD Test)

Volume change of sample during consolidation

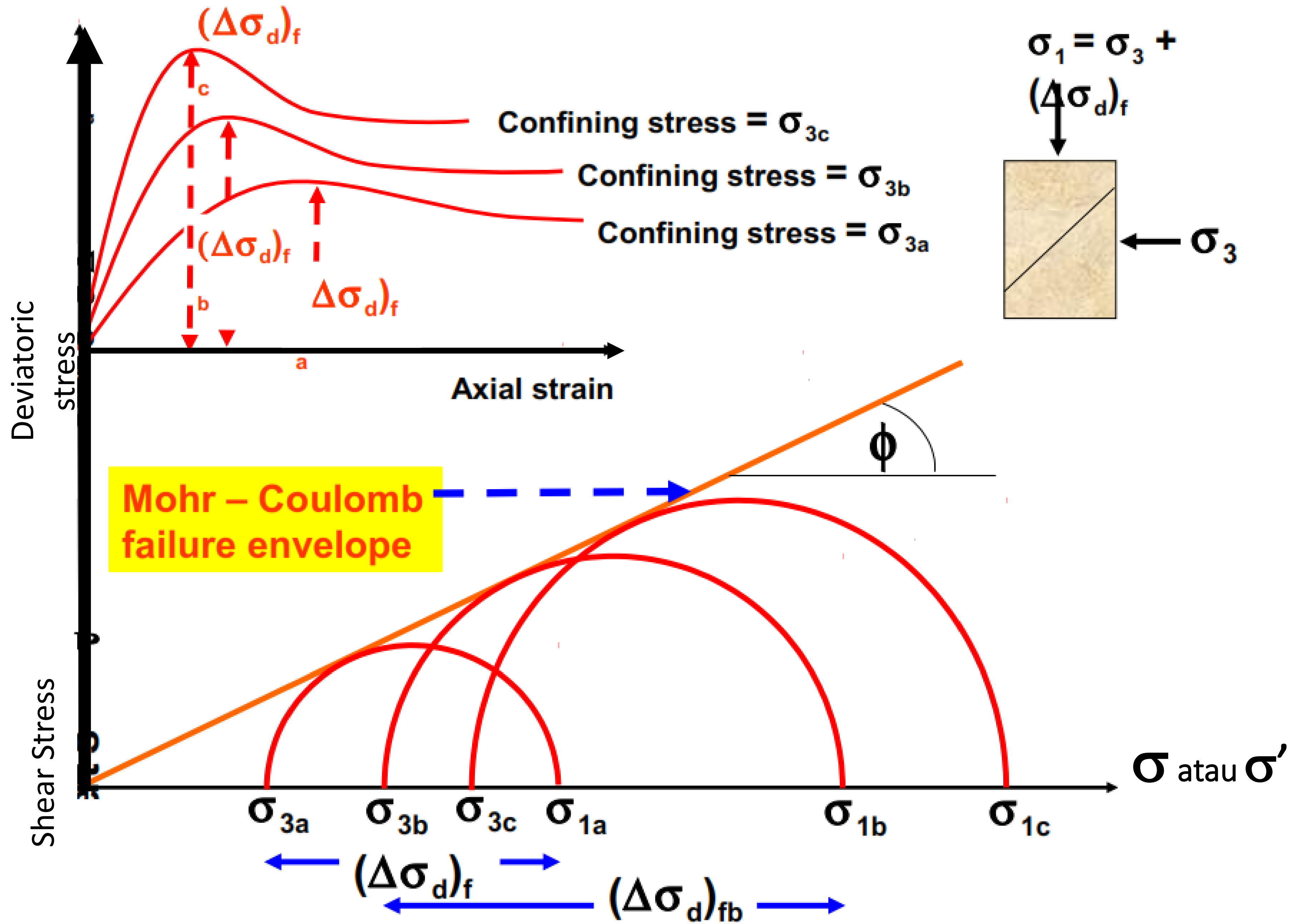


Consolidated- drained test (CD Test)

Stress-strain relationship during shearing

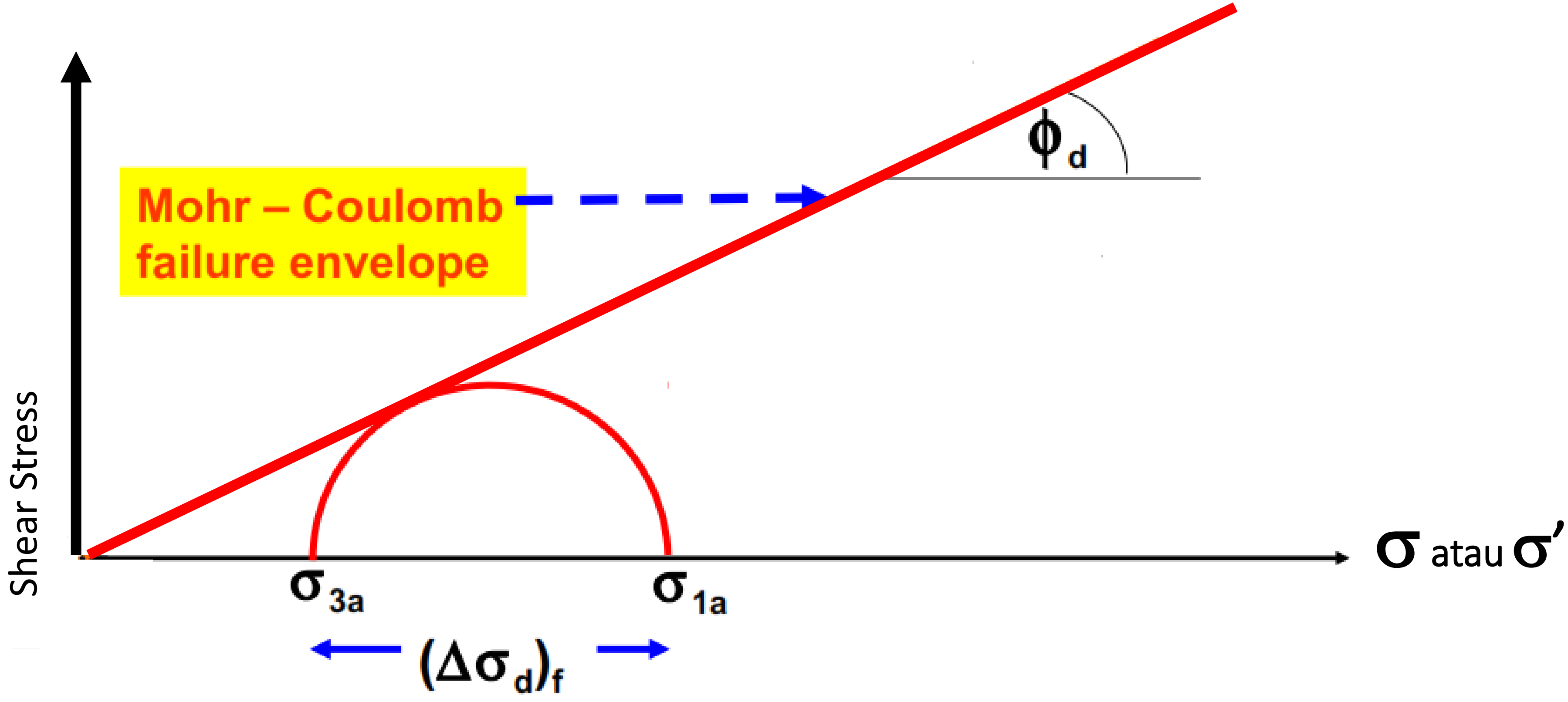


CD tests How to determine strength parameters c and ϕ



CD tests Failure envelopes

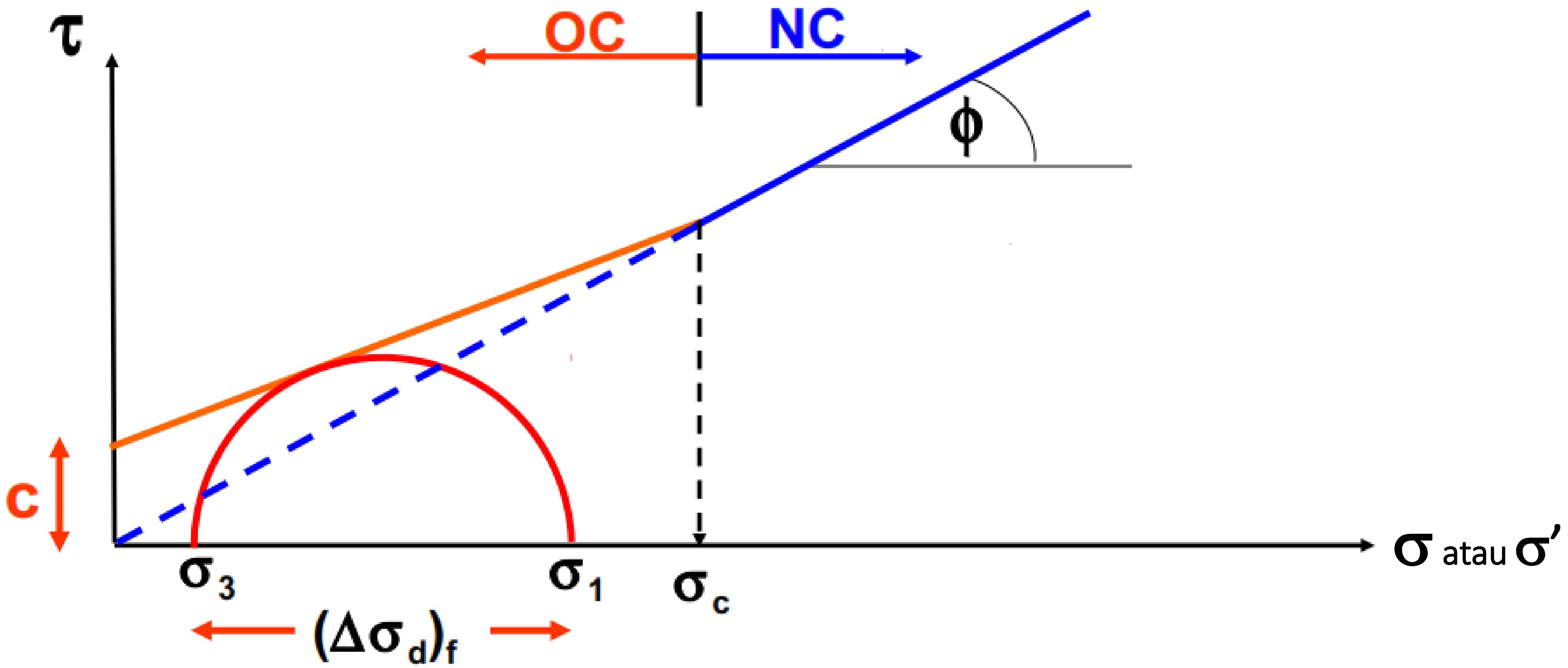
For sand and NC Clay, $c_d = 0$



Therefore, one CD test would be sufficient to determine ϕ_d of sand or NC clay

CD tests Failure envelopes

For OC Clay, $c_d \neq 0$



Triaxial Test : Consolidated Drained (CD)

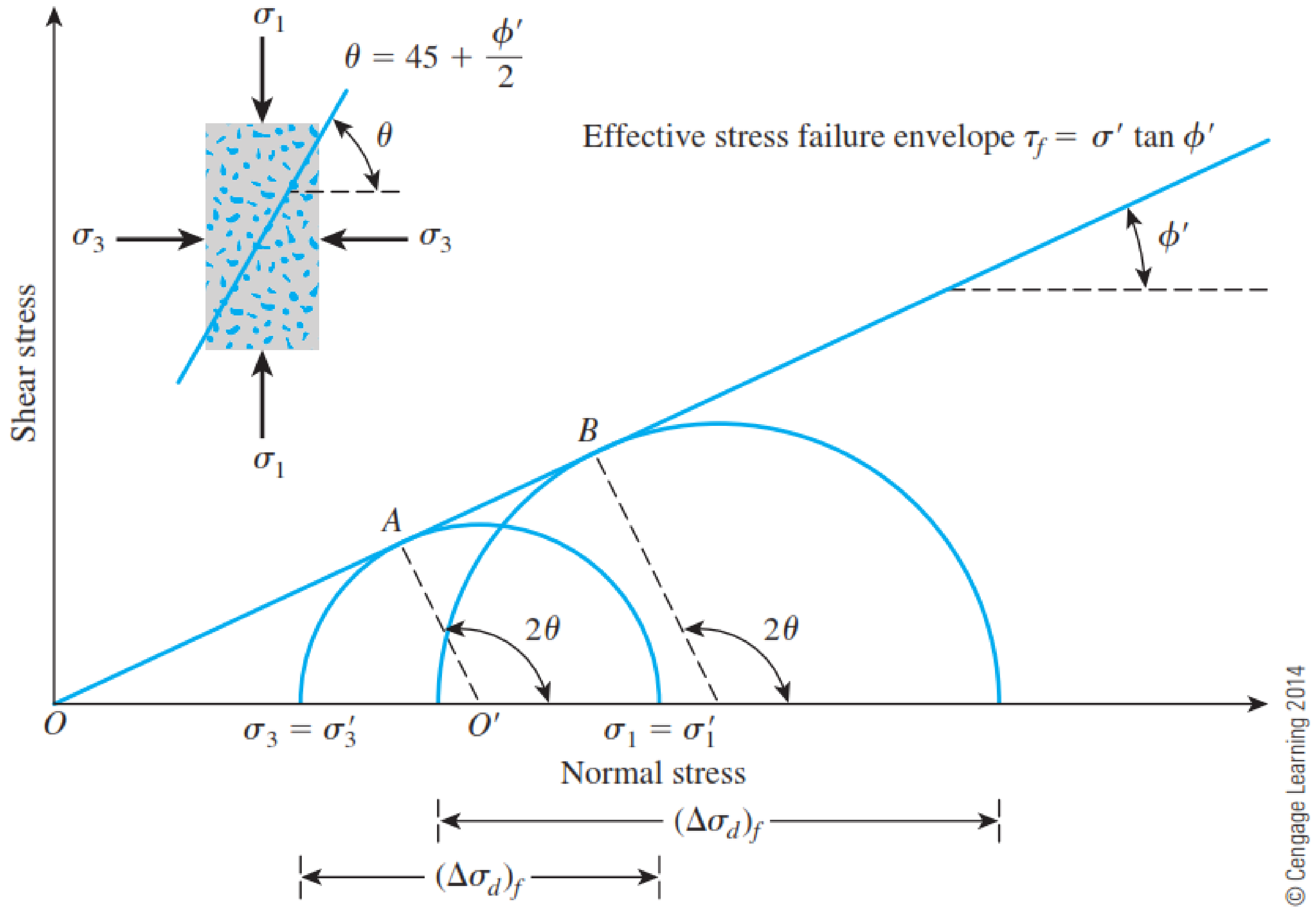


Figure 12.24 Effective stress failure envelope from drained tests on sand and normally consolidated clay

Normally Consolidated (NC)

Triaxial Test : Consolidated Drained (CD)

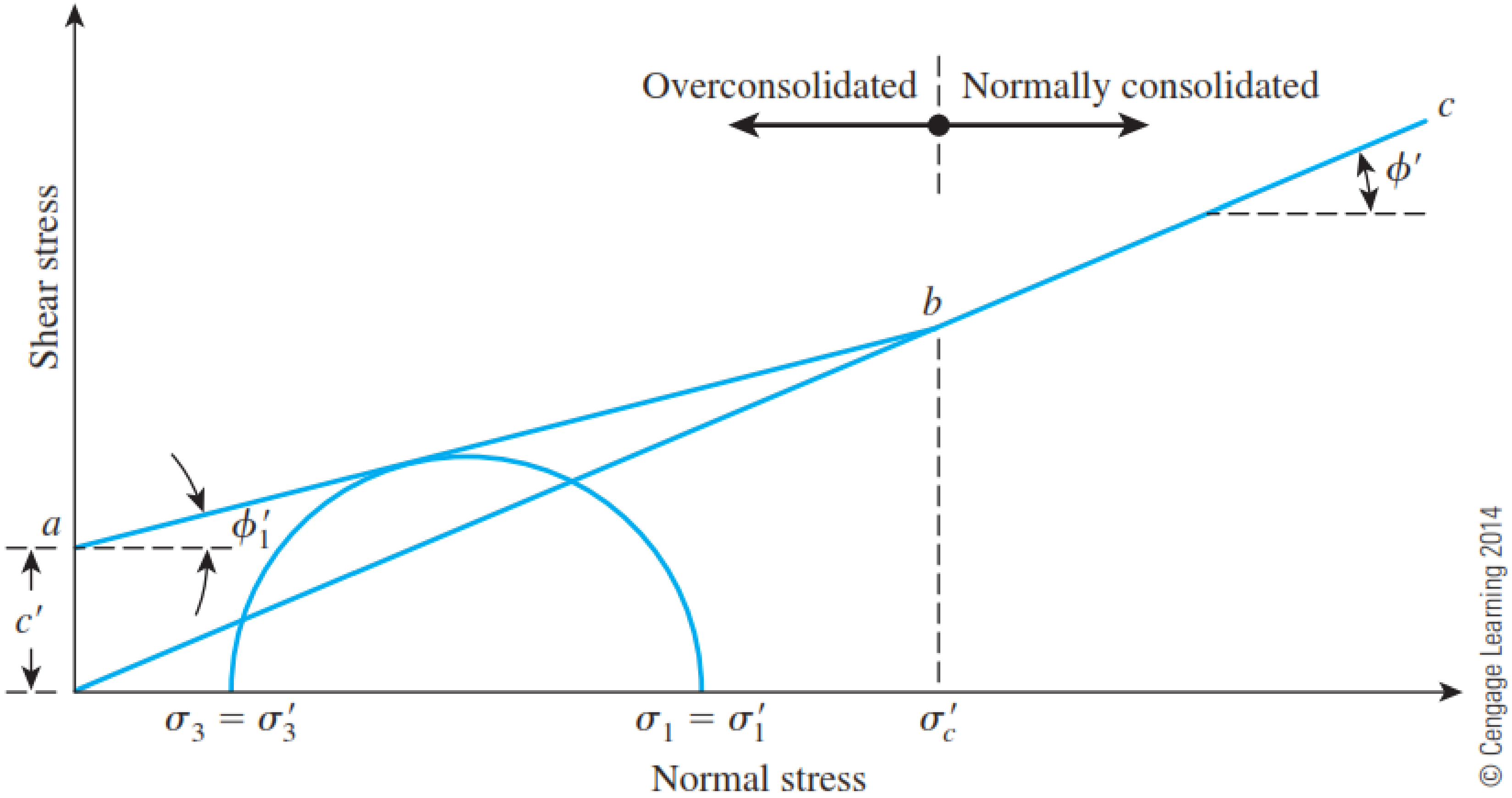


Figure 12.25 Effective stress failure envelope for overconsolidated clay

Overly Consolidated (OC)

Contoh Uji Triaxial 1

Hasil uji triaxial cara air teralirkan terkonsolidasi (CD) pada tanah lempung NC adalah sebagai berikut:

$\sigma 3$ = 276 kN/m^2

$(\Delta\sigma d)f$ = 276 kN/m^2

Tentukan:

a. Sudut Geser, Ø

b. Sudut θ (sudut antara bidang keruntuhan dengan bidang utama besar/major principal plane)

Penyelesaian:

Untuk tanah NC, persamaan garis keruntuhannya adalah:

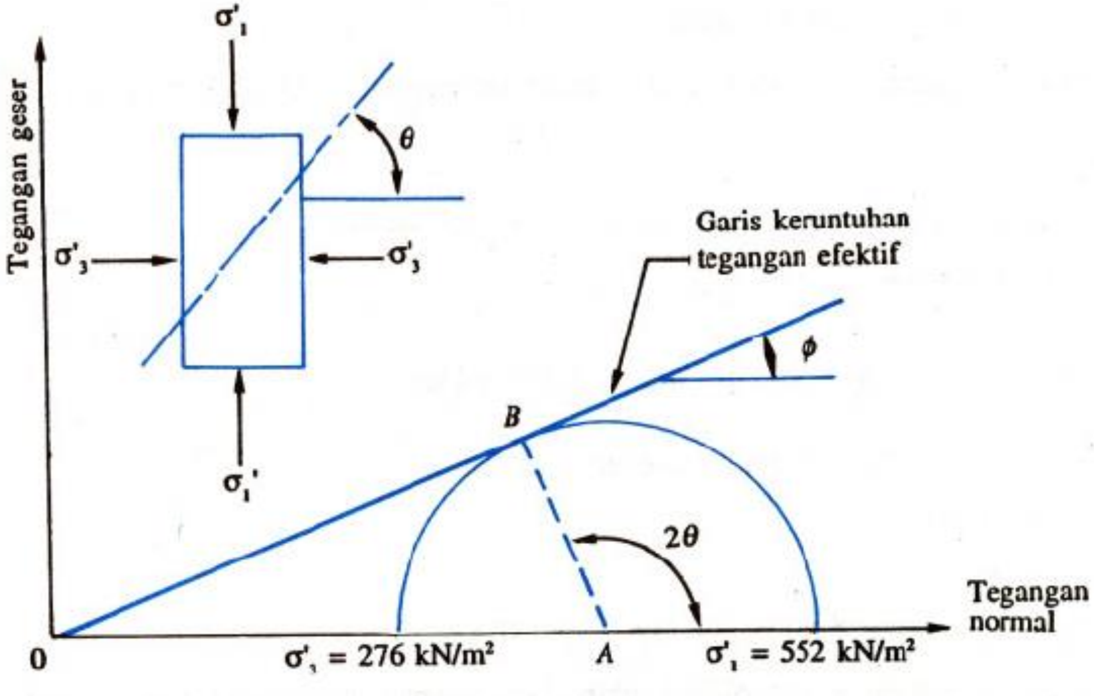
$\tau_1 = \sigma' tan\emptyset$

Pada uji triaxial baik tegangan utama besar maupun kecil pada saat terjadi keruntuhan adalah:

$\sigma_1' = \sigma_1 + \sigma_3 + \left((\Delta\sigma_d)\right)_f = 276 + 276 = 552$ kN/m^2

Dan

$\sigma_3 = \sigma_3 = 276$ kN/m^2



Gambar 9-16

Representative values for angle of internal friction ϕ

Soil	Type of test* Unconsolidated-undrained, U	Consolidated-undrained, CU	Consolidated-drained, CD
Gravel			
Medium size	40–55°		40–55°
Sandy	35–50°		35–50°
Sand			
Loose dry	28–34°		
Loose saturated	28–34°		
Dense dry	35–46°		43–50°
Dense saturated	1–2° less than dense dry		43–50°
Silt or silty sand			
Loose	20–22°		27–30°
Dense	25–30°		30–35°
Clay	0° if saturated	3–20°	20–42°

*See a laboratory manual on soil testing for a complete description of these tests, e.g., Bowles (1992).

Notes:

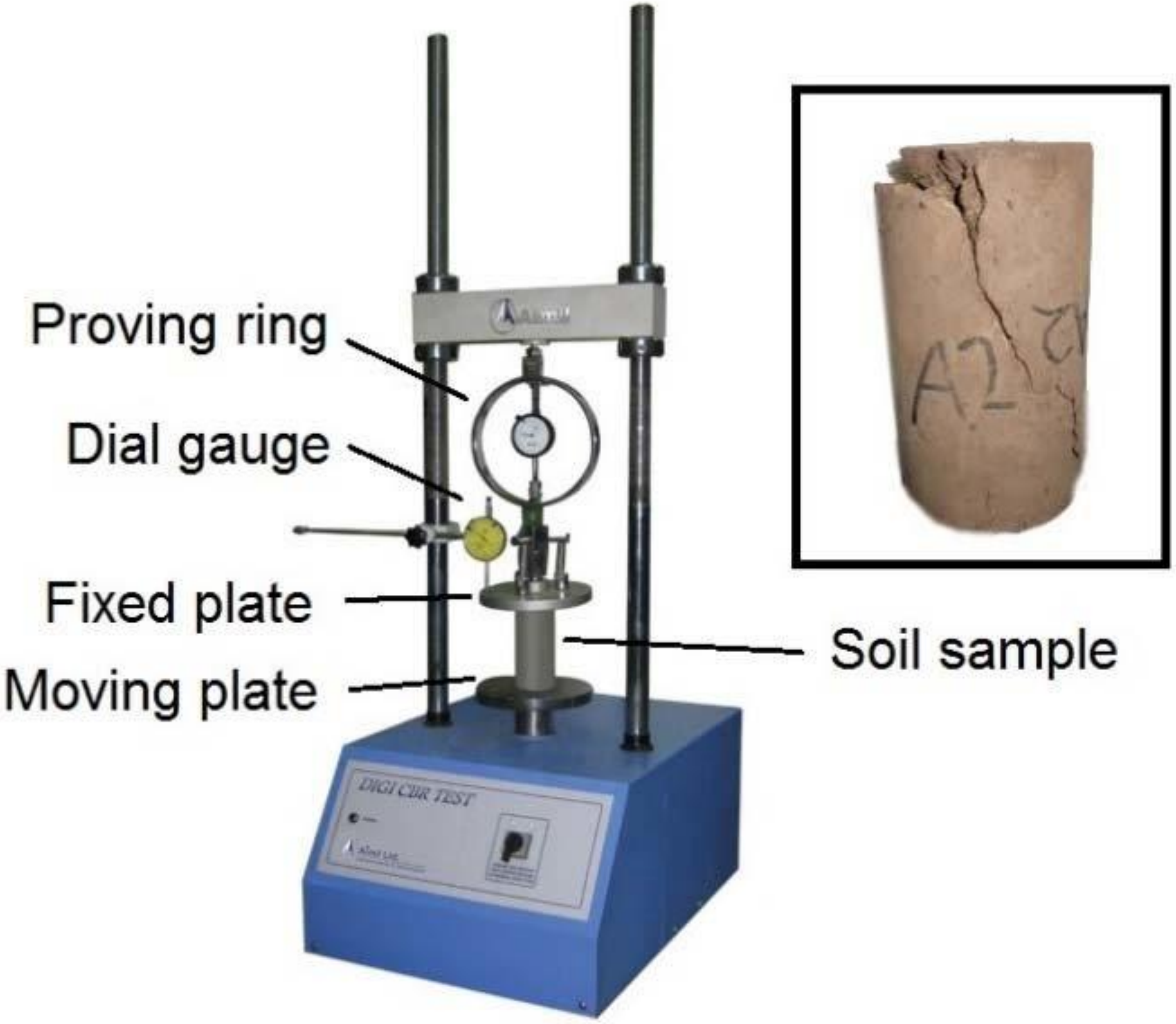
1. Use larger values as γ increases.
2. Use larger values for more angular particles.
3. Use larger values for well-graded sand and gravel mixtures (GW, SW).
4. Average values for gravels, 35–38°; sands, 32–34°.

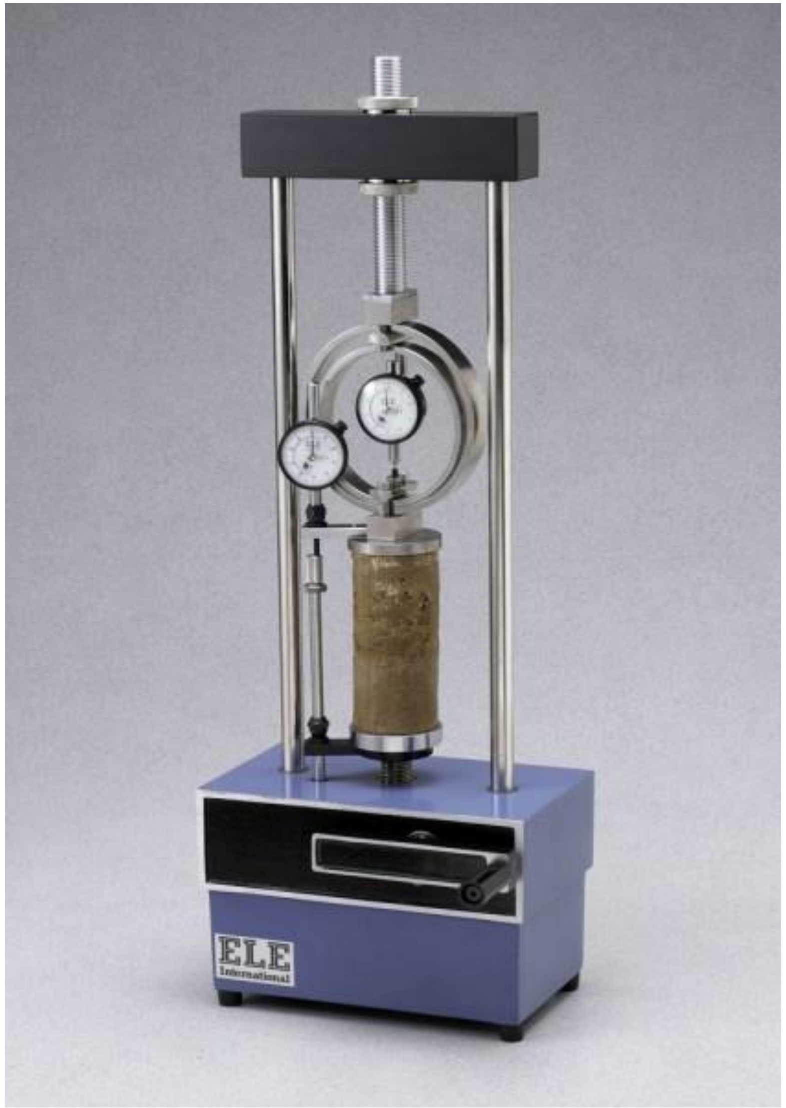
UNCONFINED COMPRESSION TEST

Unconfine Compression Test

The unconfined compression test (ASTM D2166), uses a tall, cylindrical sample of cohesive soil subjected to an axial load. This load applied quickly to maintain undrained condition. The test result are often expressed in terms of the compressive strength (Su).

Unconfine Compression Test





PERMEABILITY TEST

Permeability Test

Standar ASTM yang Berlaku

ASTM D5084 : Standard Test Methods forMeasurement of Hydraulic Conductivity of Saturated Porous Material Using aFlexible Wall Permeabemeter

Tujuan

Untuk menentukan koefisien permeabilitas (K) dari suatru contoh tanah berbutir halus seperti pasir halus, lanau, dan lempung.

ASTM : D5084-16a

Permeability Test

These test methods cover laboratory measurement of the hydraulic conductivity (also referred to as *coefficient of permeability*) of water-saturated porous materials with a flexible wall permeameter at temperatures between about 15 and 30°C

ASTM : D5084-16a

Contoh

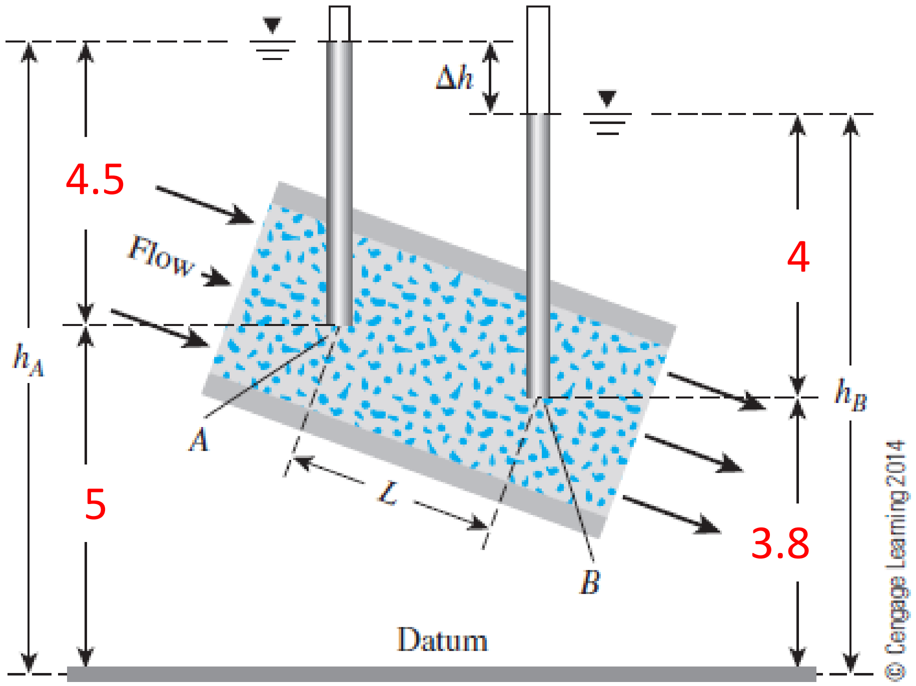


Figure 7.1 Pressure, elevation, and total heads for flow of water through soil

Perbedaan total Head dari titik A ke titik B

Δh dapat disebut juga kehilangan energi. Dapat dihitung dengan rumus berikut :

$$i = \frac{\Delta h}{L}$$

$i = gradien\ hidraulik$

L= jarak antara titik A ke B, atau Panjang aliran dimana kehilangan energi terjadi

Hukum Darcy

$$v = ki \tag{7.6}$$

where v = *discharge velocity*, which is the quanity of water flowing in unit time through a unit gross cross-sectional area of soil at right angles to the direction of flow

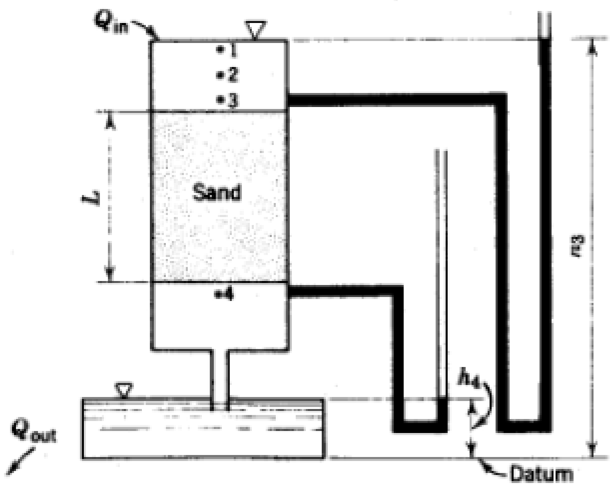
k = hydraulic conductivity (otherwise known as the coefficient of permeability)

$$q = vA = A_v v_s$$

where v_s = seepage velocity

A_v = area of void in the cross section of the specimen

Hukum Darcy



- Persamaan Darcy:

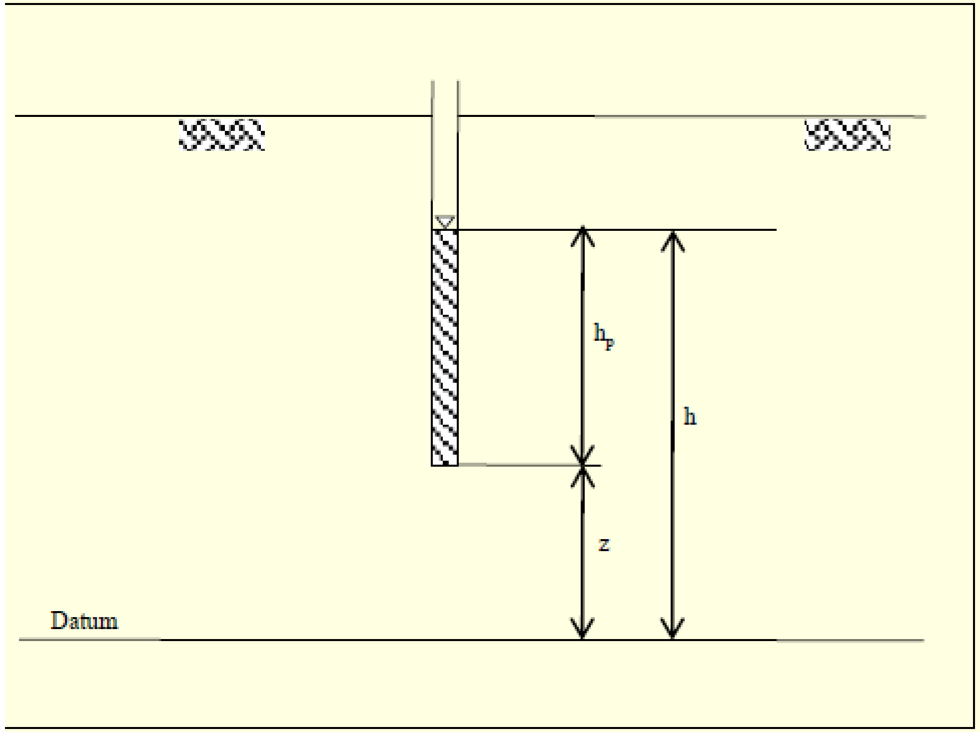
$$Q = k\frac{h_3 - h_4}{L}A = k\,i\,A \qquad Q = v\,A \;\; \text{dengan} \;\; v = k\frac{h_3 - h_4}{L} = k\,i$$

- Dimana:

v = kecepatan pengaliran,

i = hydraulic gradient

Hukum Darcy



$h = h_p + h_e + h_v = \text{constant}$

di mana:

- h = *total head*,
- $h_p = \dfrac{u}{\gamma_w}$ = *pressure head*,
- $h_e = z$ = *elevation head*,
- $h_v = \dfrac{v^2}{2g}$ = *velocity head*,
- u = tekanan air pori,
- z = elevasi dari suatu titik terhadap suatu datum,
- v = kecepatan pengaliran, dan
- g = percepatan gravitasi.

Uji Permeabilitas di laboratorium

Constant Head Test

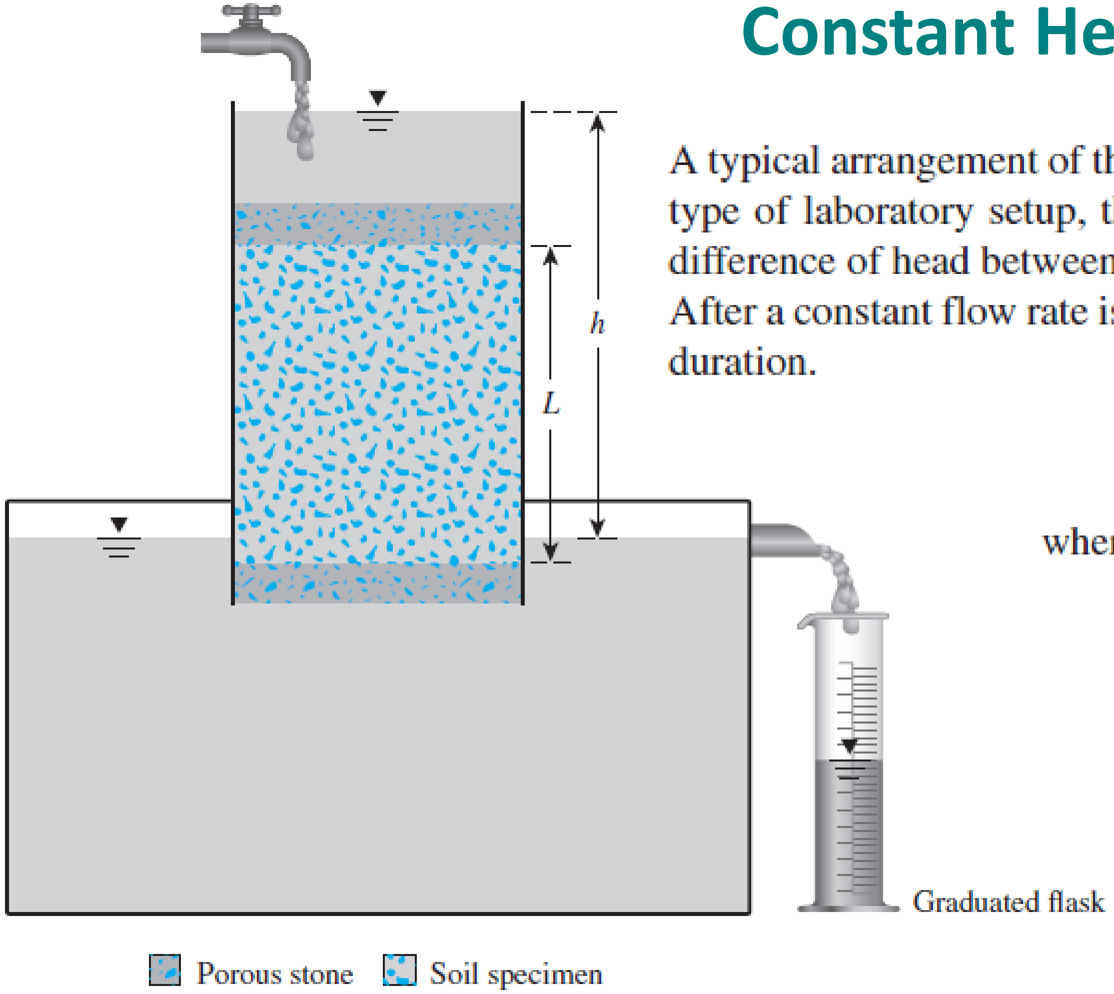


Figure 7.5 Constant-head permeability test

A typical arrangement of the constant-head permeability test is shown in Figure 7.5. In this type of laboratory setup, the water supply at the inlet is adjusted in such a way that the difference of head between the inlet and the outlet remains constant during the test period. After a constant flow rate is established, water is collected in a graduated flask for a known duration.

The total volume of water collected may be expressed as

$$Q = Avt = A(ki)t$$

where Q = volume of water collected
A = area of cross section of the soil specimen
t = duration of water collection

$$i = \frac{h}{L}$$ where L = length of the specimen,

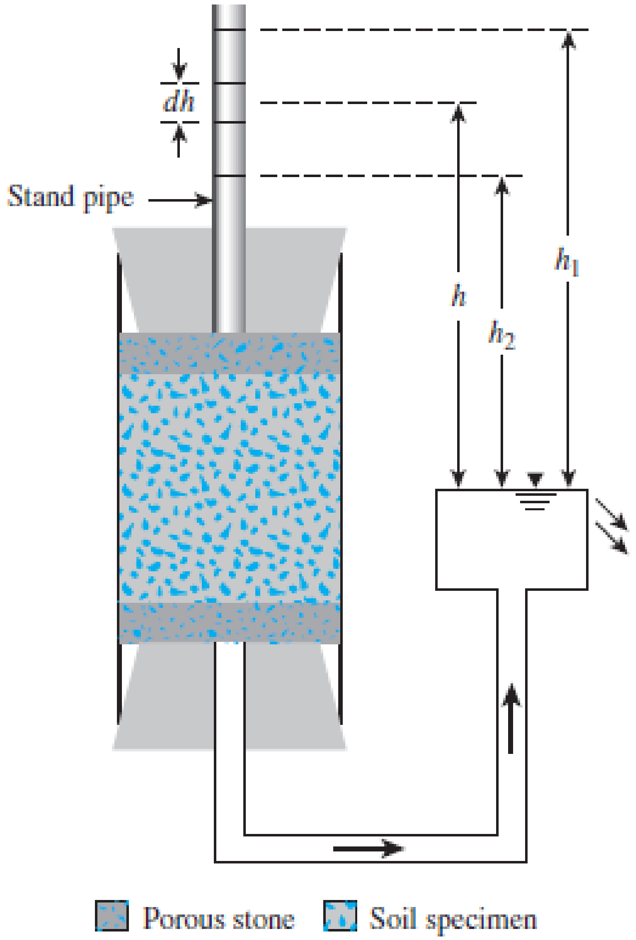
$$Q = A\left(k\frac{h}{L}\right)t$$

$$k = \frac{QL}{Aht}$$

a constant-head test arrangement in the laboratory for a test on a granular soil.

Uji Permeabilitas di laboratorium

Falling - Head Test



A typical arrangement of the falling-head permeability test is shown in Figure. Water from a standpipe flows through the soil. The initial head difference h_1 at time t=0 is recorded, and water is allowed to flow through the soil specimen such that the final head difference at time $t = t_2$ is h_2.

$$q = k\frac{h}{L}A$$

where q = flow rate
a = cross-sectional area of the standpipe
A = cross-sectional area of the soil specimen

$$k = 2.303\frac{aL}{At}\log_{10}\frac{h_1}{h_2}$$

Contoh

Constant Head Test

- $L = 30$ cm
- A = area of the specimen = 177 cm^2
- Constant-head difference, $h = 50$ cm
- Water collected in a period of 5 min = 350 cm^3

Calculate the hydraulic conductivity in cm/sec.

$$k = \frac{QL}{Aht}$$

Given $Q = 350$ cm^3, $L = 30$ cm, $A = 177$ cm^2, $h = 50$ cm, and $t = 5$ min, we have

$$k = \frac{(350)(30)}{(177)(50)(5)(60)} = \mathbf{3.95 \times 10^{-3}\ cm/sec}$$

Falling - Head Test

For a falling-head permeability test, the following values are given:

- Length of specimen = 200 mm.
- Area of soil specimen = 1000 mm^2.
- Area of standpipe = 40 mm^2.
- Head difference at time $t = 0$ = 500 mm.
- Head difference at time $t = 180$ sec = 300 mm.

Determine the hydraulic conductivity of the soil in cm/sec.

$$k = 2.303 \frac{aL}{At} \log_{10}\left(\frac{h_1}{h_2}\right)$$

We are given $a = 40$ mm^2, $L = 200$ mm, $A = 1000$ mm^2, $t = 180$ sec, $h_1 = 500$ mm, and $h_2 = 300$ mm,

$$k = 2.303 \frac{(40)(200)}{(1000)(180)} \log_{10}\left(\frac{500}{300}\right)$$
$$= \mathbf{2.27 \times 10^{-2}\ cm/sec}$$

note

Nilai **k** sering disebut sebagai koefisien permeabilitas atau konduktivitas hidraulik
k dibuat dalam satuan panjang per waktu

Rentang nilai koefisien permabilitas (k) berdasarkan tipe tanah

Soil type	*k* cm/sec
Clean gravel	100–1.0
Coarse sand	1.0–0.01
Fine sand	0.01–0.001
Silty clay	0.001–0.00001
Clay	<0.000001