

FOUNDATION DESIGN: Shallow and Deep Foundation

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17 Juli 2021



**HIMPUNAN AHLI TEKNIK TANAH INDONESIA
(HATTI)**



Materi Bahasan



- 1. Pengumpulan Data**
- 2. Teknik Fondasi**
- 3. Desain Fondasi Dangkal**
- 4. Desain Fondasi Dalam**
- 5. Verifikasi Desain**

1. PENGUMPULAN DATA



1.1 Informasi untuk Desain

- Deskripsi proyek
- Penyelidikan tanah di lapangan
- Uji laboratorium

1.2 Klasifikasi Tanah

1.3 Desain Muka Air

1.4 Parameter desain

Penyelidikan Tanah di Lapangan



SNI

Standar Nasional Indonesia

SNI 8460:2017

Persyaratan perancangan geoteknik

- Soil boring - SPT (Standard Penetration Test)
 - N-SPT & Undisturbed sampling (UDS)
- Mechanical CPT (Cone Penetration Test) / Sondir
 - q_c , friction ratio > jenis tanah
- Pengukuran muka air tanah (Piezometer)
- Pressuremeter test
- Vane Shear test (S_u soft clay)

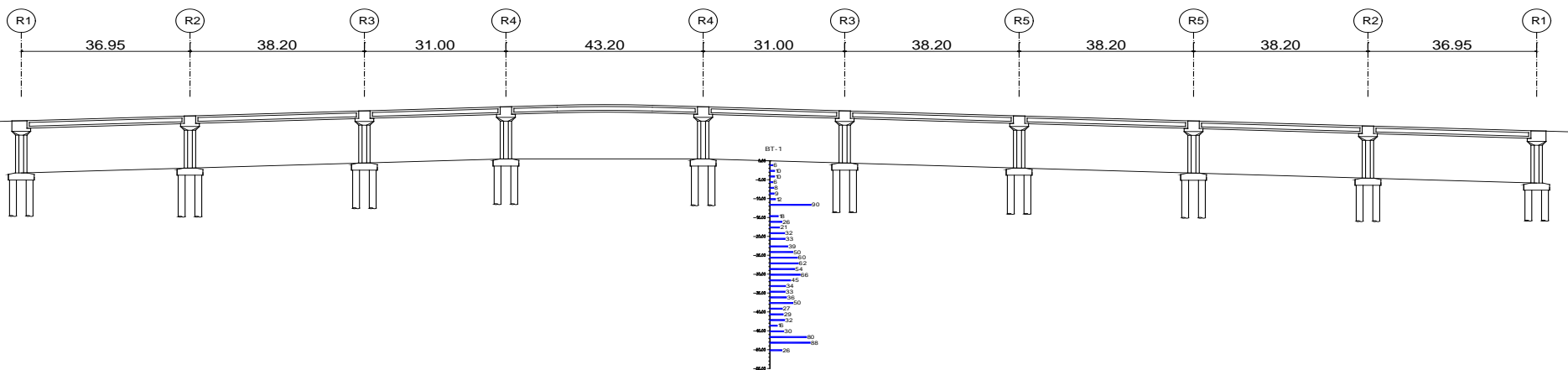
Lokasi dan Frekuensi Penyelidikan Tanah

SNI 8460:2017

Tabel 2 – Jumlah minimum penyelidikan tanah

Jenis struktur	Jumlah minimum penyelidikan tanah
Gedung tinggi 8 lantai ke atas	<ul style="list-style-type: none">- Satu titik setiap 300m² dalam pola grid dengan jarak 10 m sampai 30 m dengan minimum 3 titik per blok menara.- Dalam hal beberapa menara terletak berdekatan, dijadikan satu kesatuan dan digunakan kaidah yang sama.- Tambah titik apabila hasil investigasi menunjukkan anomali lapisan tanah
Gedung dengan 4 sampai dengan 7 lantai	<ul style="list-style-type: none">- Satu titik setiap 400m² dalam pola grid dengan jarak 15 m sampai 40 m dengan minimum 2 titik per gedung.- Dalam hal beberapa gedung terletak berdekatan, dijadikan satu kesatuan dan digunakan kaidah yang sama.- Tambah titik apabila hasil investigasi menunjukkan anomali lapisan tanah

"Hak cipta Badan Standardisasi Nasional, copy - right"



Uji Laboratorium



- Index properties

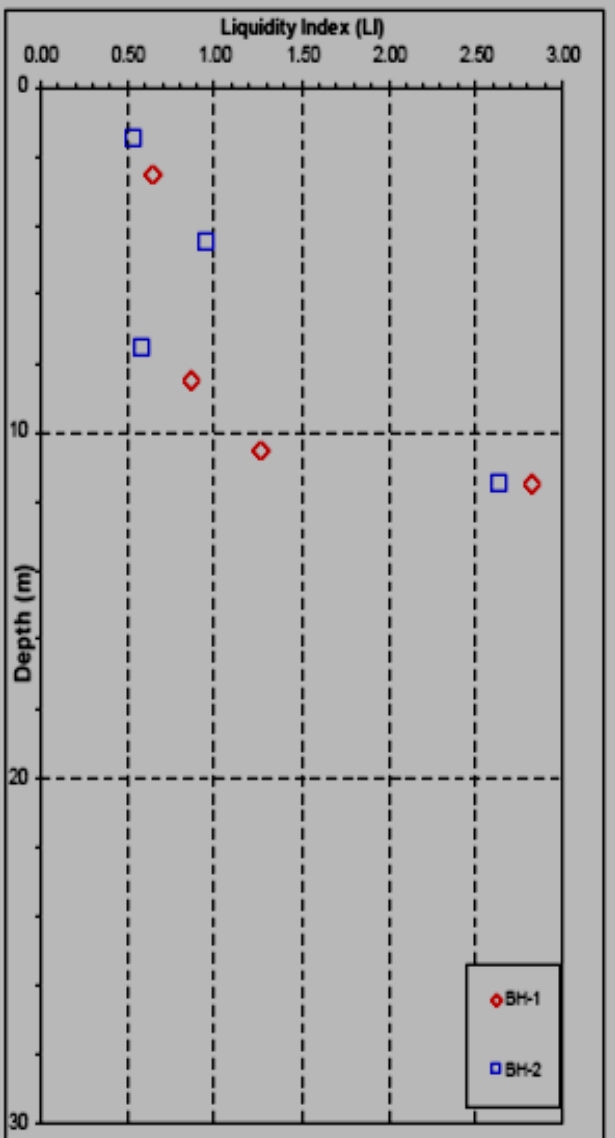
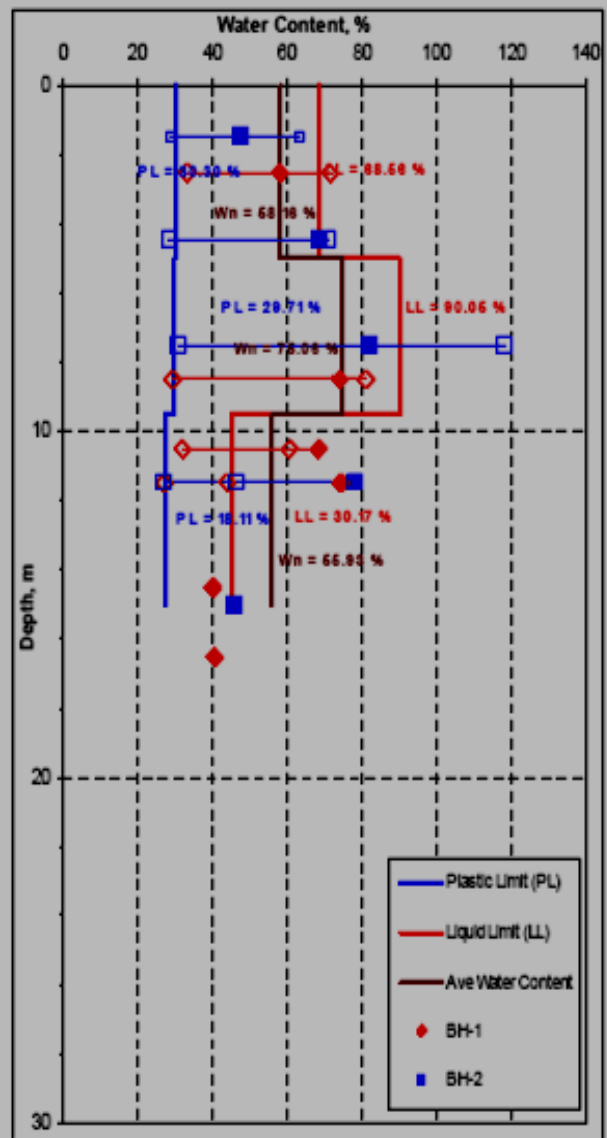
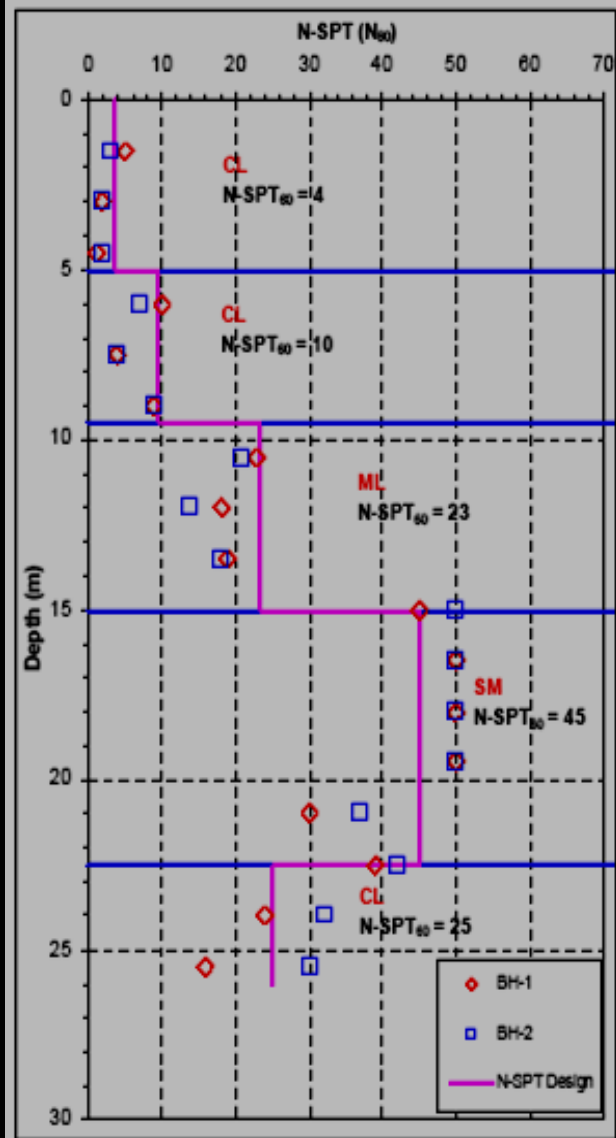
 - Sieve analysis, berat jenis, specific gravity, water content, Atterberg limit (PL & LL)

- Kuat geser tanah (S_u , c , ϕ)

- Parameter konsolidasi untuk tanah kohesif (p_c , e_0 , C_c , C_r)



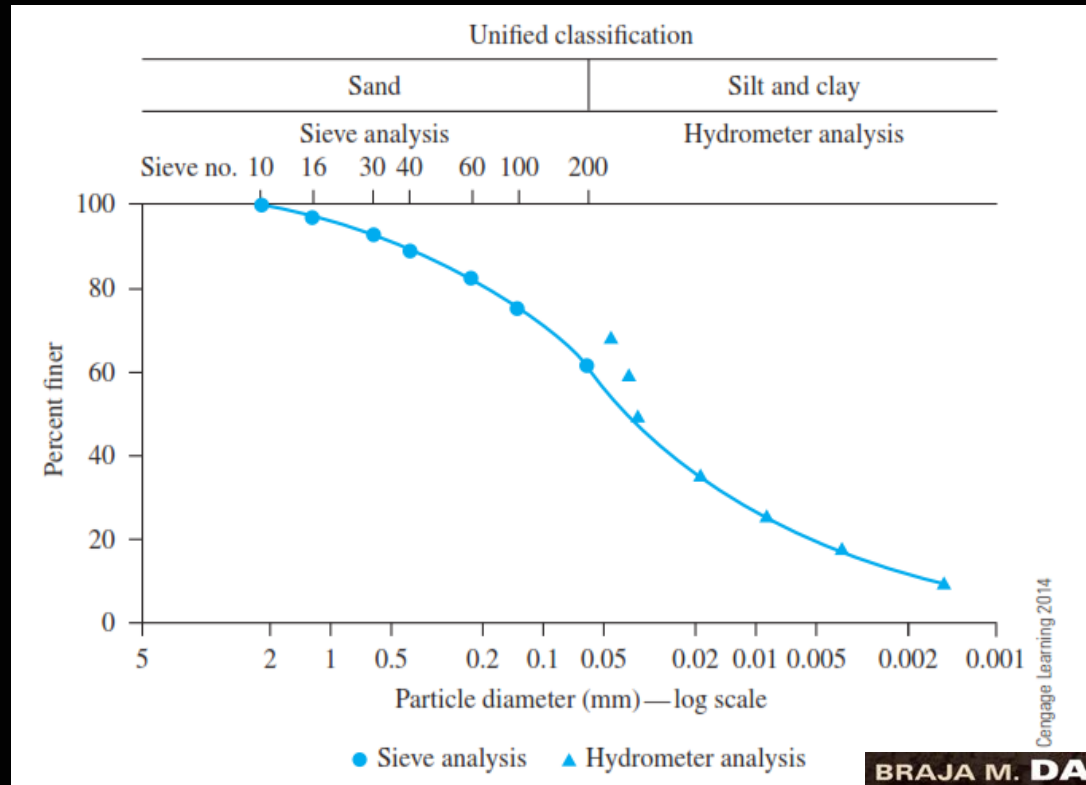
Contoh variasi parameter tanah





1.2 Klasifikasi Tanah

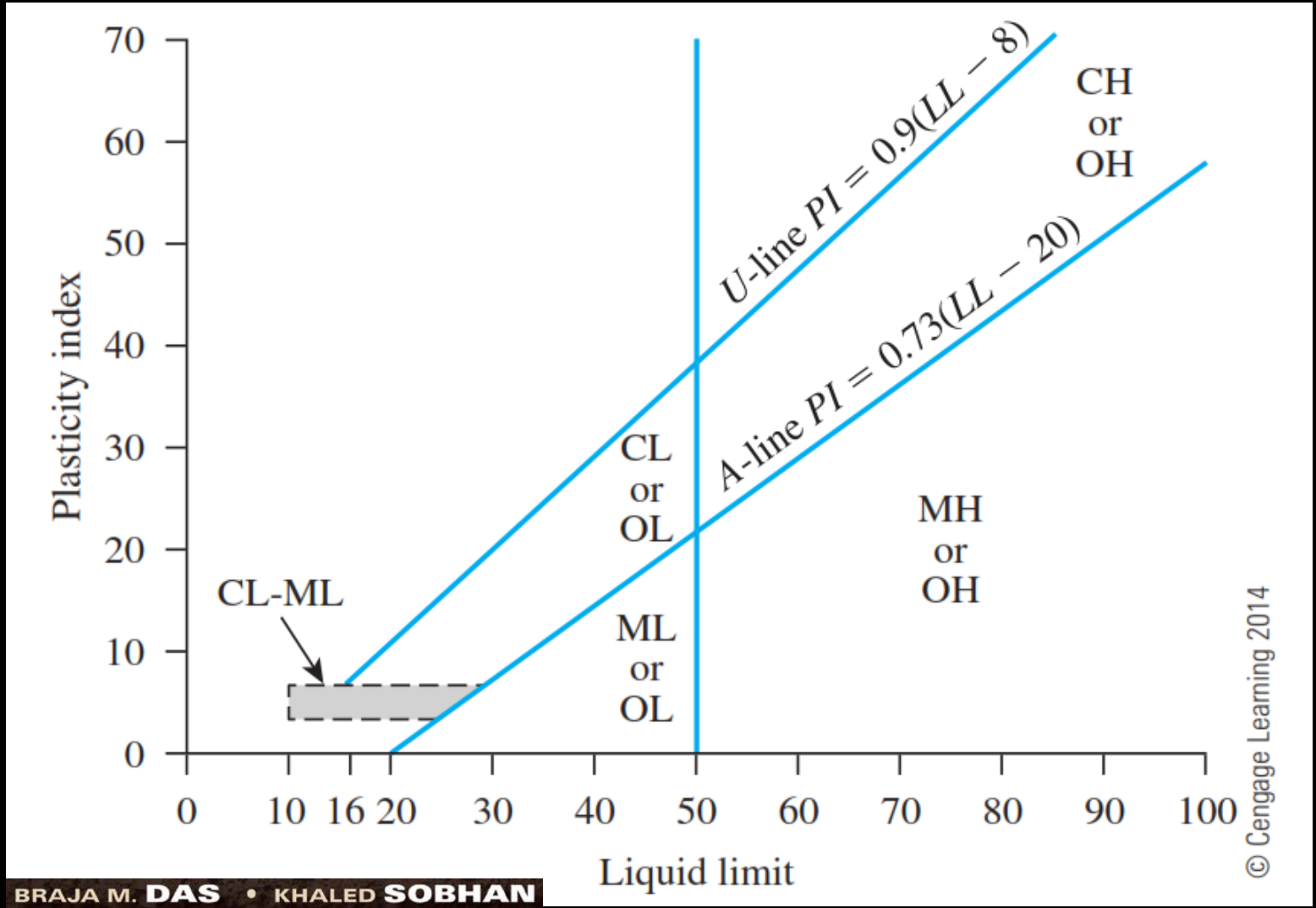
- Berdasarkan pengamatan visual saat boring test
- Berdasarkan tes laboratorium
 - Sieve analysis





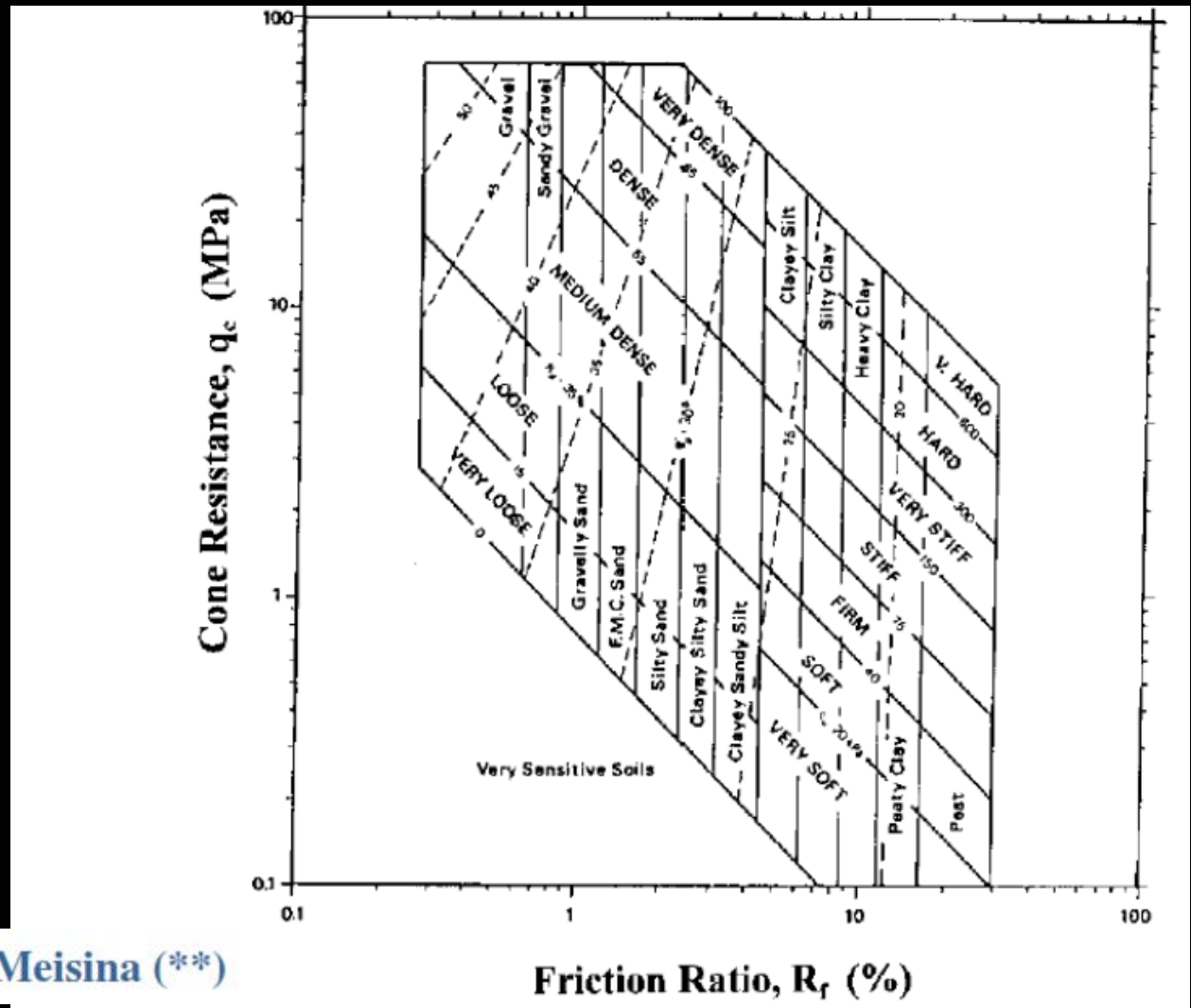
1.2 Klasifikasi Tanah

→ Atterberg limit



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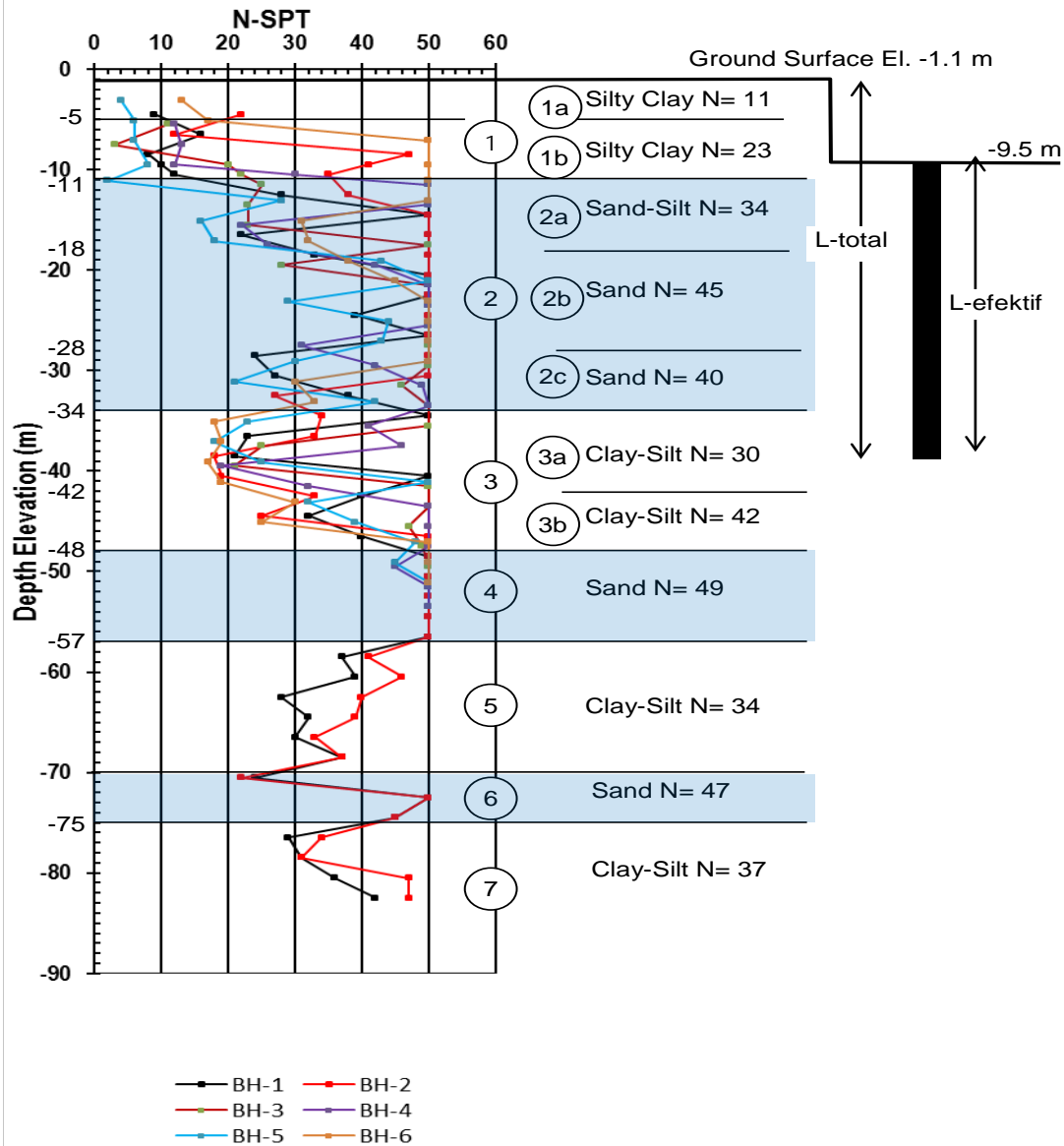
Klasifikasi tanah berdasarkan CPT



D. Lo Presti (*) and C. Meisina (**)

Figure 15. Soil classification chart (Searle, 1979)

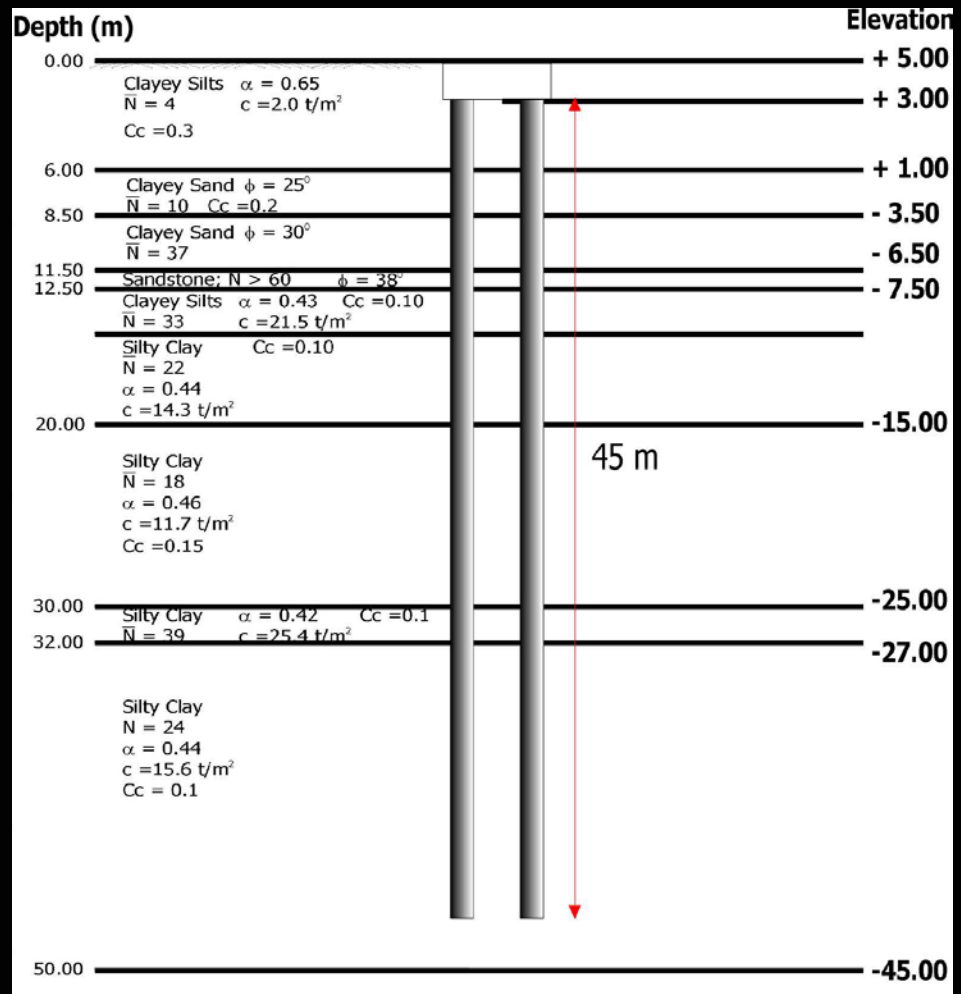
1.3 Desain Muka Air





1.4 Parameter desain

- Kuat geser
- Sifat deformasi (elastik, konsolidasi)
- DII



Kuat geser tanah (shear strength)



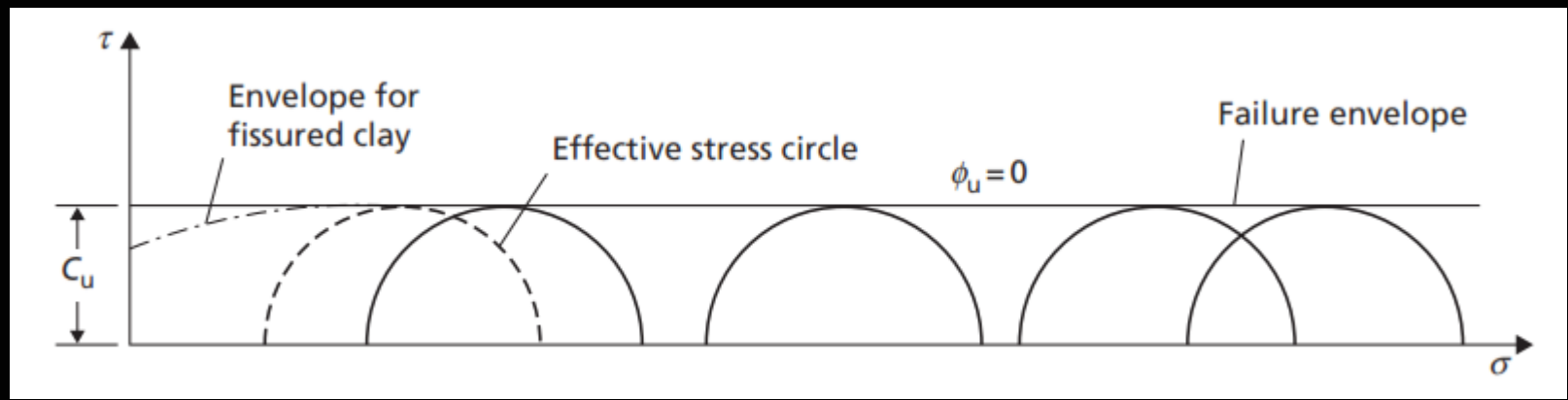
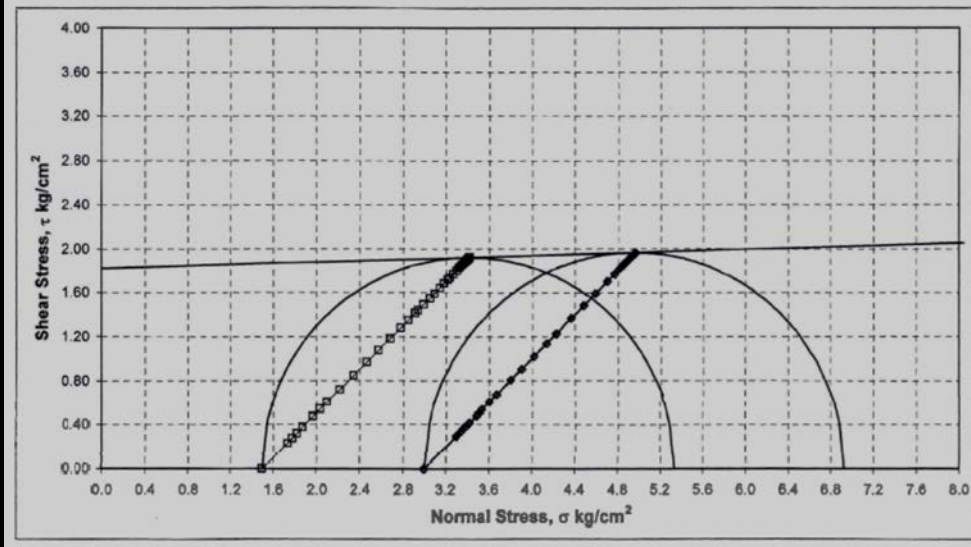
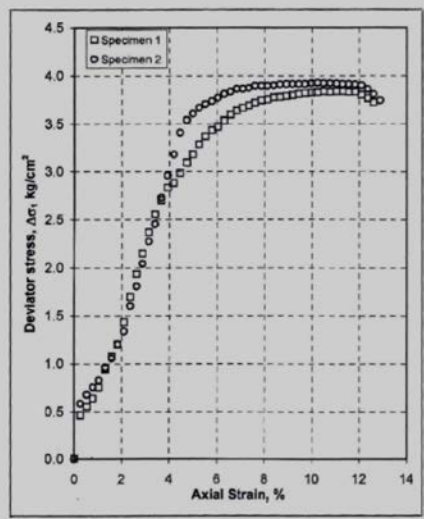
- Undrained shear strength (S_u) → UU triaxial, unconfined compression test (Lab test), atau **korelasi** dari N-SPT, Q_c sondir, pressuremeter
- Drained strength (c' , ϕ') diperoleh dari triaxial CU tests
- Korelasi empirik dari sifat fisik tanah

UU Triaxial Test Result

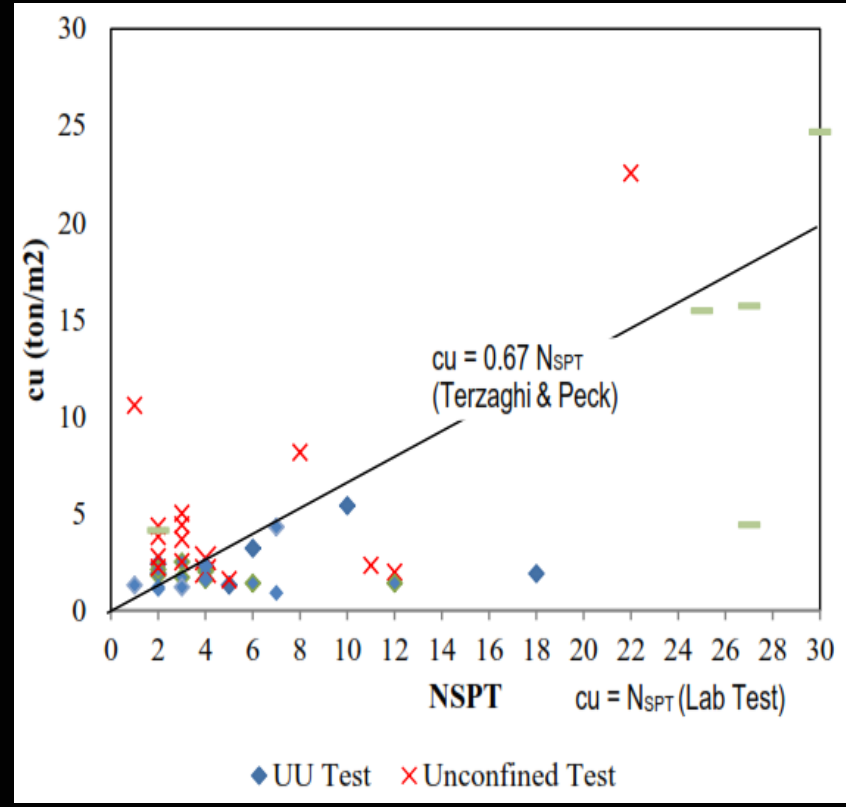
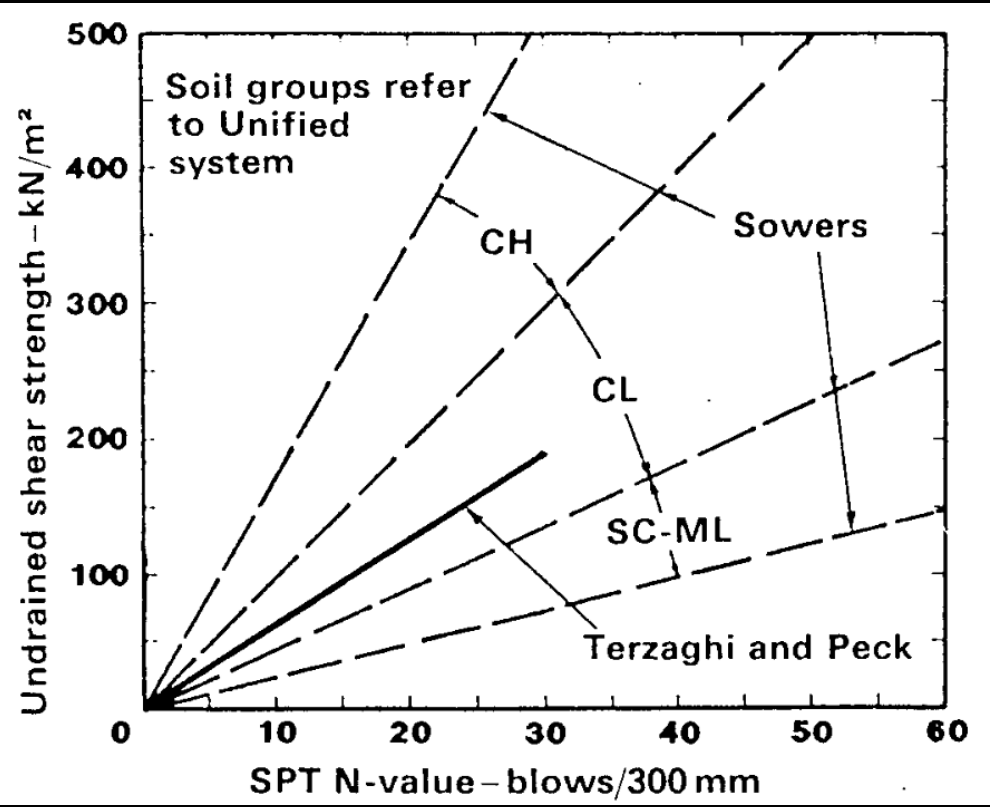


Soil Specimen No	1	2
Bulk Density (KN/m ³)	18.80	18.88
Moisture content (%)	29.76	29.73
Dry Density (KN/m ³)	14.48	14.55
Specific Gravity	2.64	2.64
Void Ratio	0.78	0.77
Degree of Saturation (%)	100.16	101.10
Lateral Pressure (KN/m ²)	150.00	300.00
Deviator Stress (KN/m ²)	383.48	392.41
Strain (%)	11.32	10.26

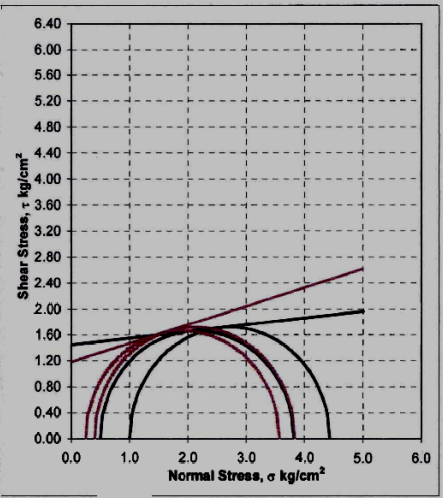
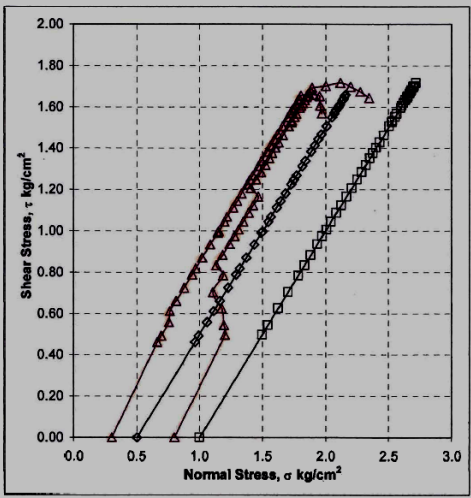
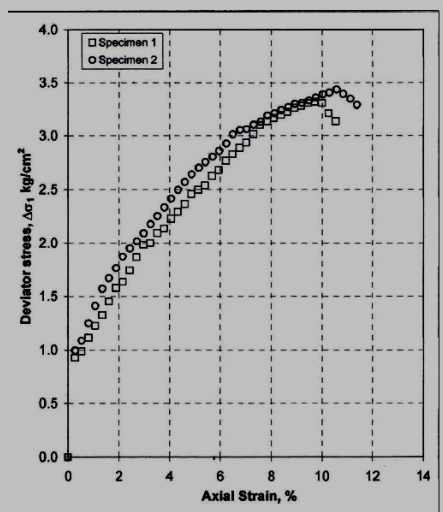
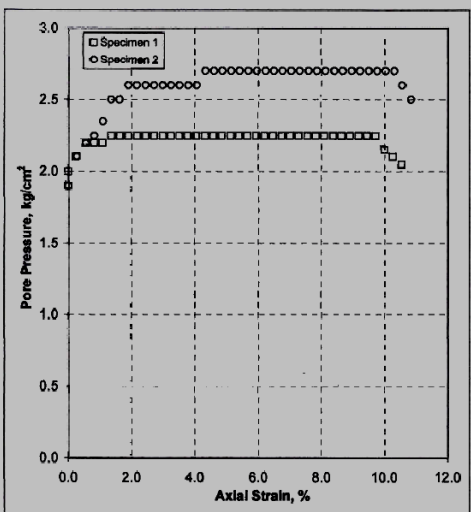
Cohesion, c (kg/cm ²)	1.819
Internal angle of friction, ϕ (°)	1.657



Korelasi kuat geser tanah (S_u) dengan N-SPT



CU Triaxial Test Result



STRENGTH PARAMETERS				
	Total Stress		Effective Stress	
φ (°)	5.943	φ' (°)	16.140	
Cu, kg/cm2	1.442	C', kg/cm2	1.174	



Korelasi PI & ϕ'

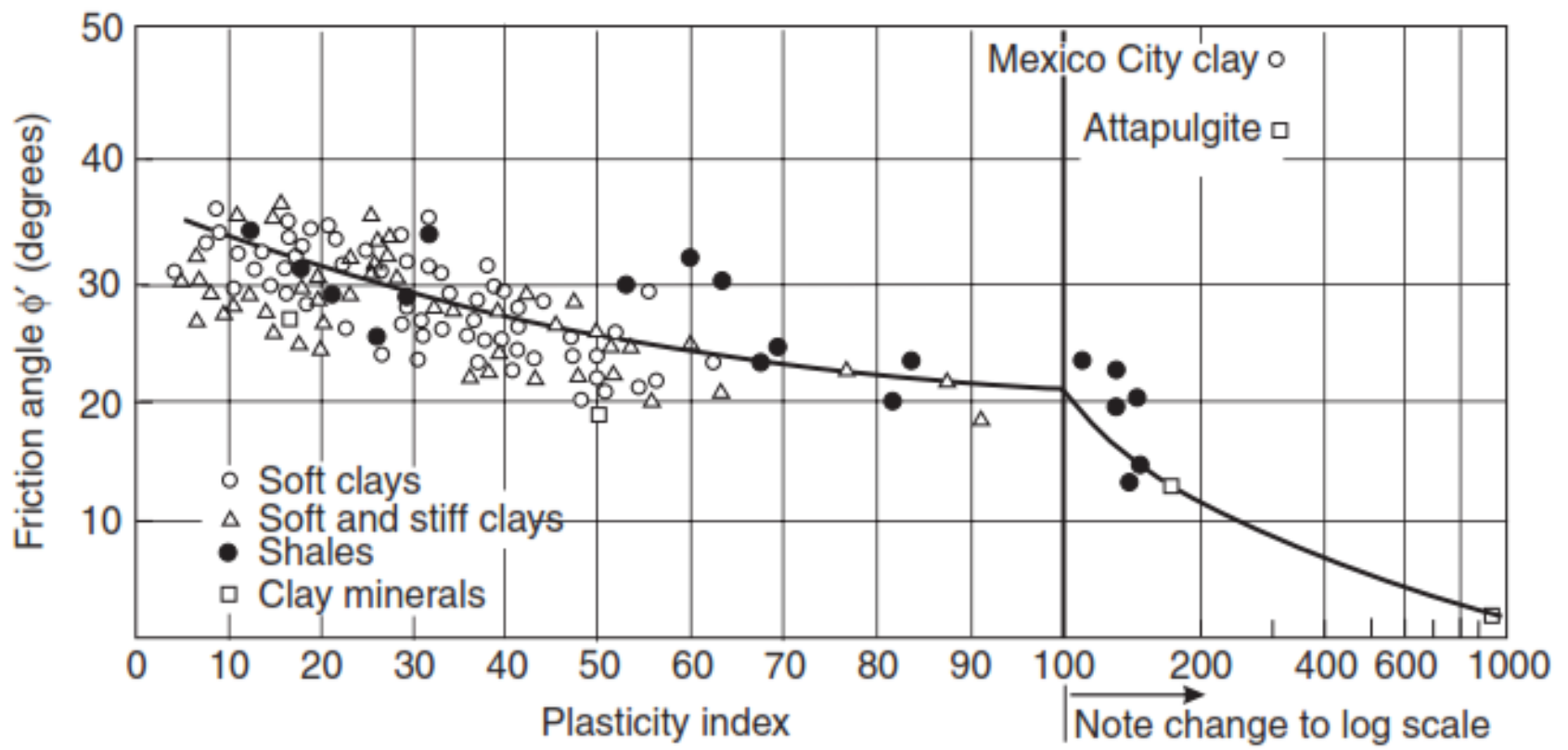
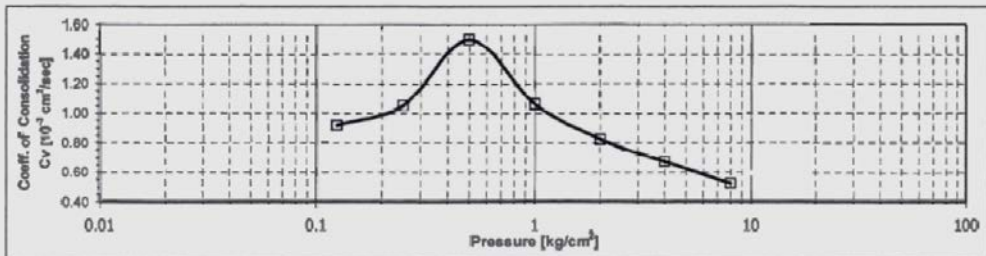
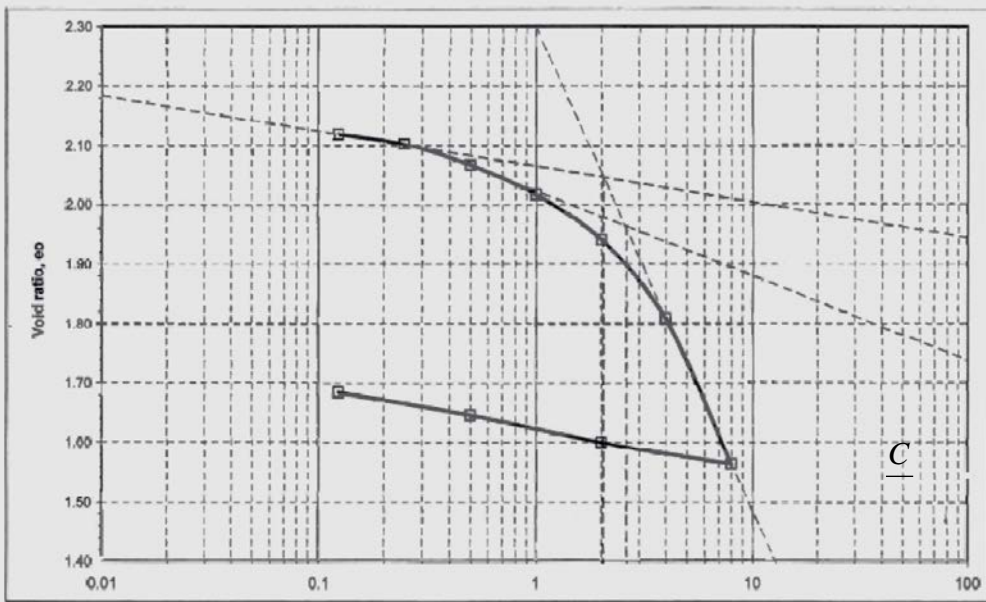


Figure 9.35 Values of the peak friction angle ϕ' for clay of various compositions plotted against their plasticity index. (After Terzaghi et al., 1996.)

Consolidation Test



Pressure (kg/cm ²)	0.125	0.25	0.5	1	2	4	8
Cv (10 ⁻³ cm ² /sec)	0.9164	1.0511	1.4959	1.0612	0.8224	0.6728	0.5258
mv (cm ² /kg)	3.76E-02	8.00E-02	8.60E-02	7.48E-02	6.18E-02	5.20E-02	4.55E-02
k (cm/second)	3.45E-05	8.41E-05	1.29E-04	7.94E-05	5.08E-05	3.50E-05	2.39E-05
Initial Moisture content	: 99.53 %		Initial degree of saturation : 100.00 %				
Final Moisture content	: 94.89 %		Final degree of saturation : 100.00 %				
Initial void ratio, e ₀	: 2.133		Preconsol. Pressure, P _c : 2.327 kg/cm ²				
Final void ratio, e _f	: 1.563		Range of P _c (kg/cm ²) : 2.033 to 2.621				
Unit weight of soil, γ	: 1.680 t/m ³		Compression index, C _c : 0.812				
			Swelling index, C _s : 0.060				
			Recompression Index, C _r : 0.055				

Consolidation parameter:

P_c

C_c

C_r

C_v

$$C_c' = C_c / (1 + e_0)$$

$$C_r' = C_r / (1 + e_0)$$

Korelasi empirik parameter konsolidasi



Table 5.3 SOME PUBLISHED CORRELATIONS FOR COMPRESSION INDICES (AFTER AZOUZ ET AL. 1976)

<i>Equation</i>	<i>Regions of applicability</i>
$C_c = 0.007 (LL - 7)$	Remoulded clays
$C_{cc} = 0.208e_0 + 0.0083$	Chicago clays
$C_c = 17.66 \times 10^{-5} w_n^2 + 5.93 \times 10^{-3} w_n - 1.35 \times 10^{-1}$	Chicago clays
$C_c = 1.15(e_0 - 0.35)$	All clays
$C_c = 0.30(e_0 - 0.27)$	Inorganic, cohesive soil; silt, some clay; silty clay; clay
$C_c = 1.15 \times 10^{-2} w_n$	Organic soils-meadow mats, peats, and organic silt and clay
$C_c = 0.75(e_0 - 0.50)$	Soils of very low plasticity
$C_{cc} = 0.156e_0 + 0.0107$	All clays
$C_c = 0.01 w_n$	Chicago clays

As summarised by Azzouz, Krizek, and Corotis (1976).

Note: w_n = natural water content.

SUMMARY



- Soil profile yang mewakili
- Parameter desain didasarkan pada hasil laboratorium, rumus empirik dan judgement
- Bandingkan dengan pengalaman lampau

2. Teknik Fondasi



2.1 Syarat Umum

2.2 Beban ke fondasi

2.3 Pemilihan tipe fondasi

2. Teknik Fondasi



2.1 Syarat Umum:

- Batas kapasitas/kekuatan
 - Kapasitas struktur
 - Kekuatan tanah (bearing capacity)
- Batas deformasi
 - Total settlement
 - Differential settlement

2. Teknik Fondasi



2.2 Beban-beban pada Fondasi

– Beban struktur atas

- Beban mati (DL)
- Beban hidup (LL)
- Beban angin
- Beban gempa
- Beban-beban lain

– Beban dalam tanah

- tekanan tanah
- tekanan air tanah
- gaya gempa
- Berat sendiri fondasi

2. Teknik Fondasi



2.3 Pemilihan Tipe Fondasi

– Tipe fondasi:

- Fondasi dangkal

- Fondasi dalam

 - o Fondasi tiang pancang

 - o Fondasi tiang bor

- Fondasi lain (raft foundation)

– Faktor-faktor yang mempengaruhi pemilihan tipe fondasi:

- Tipe struktur atas

- Kondisi tanah

- Pelaksanaan konstruksi

- Pertimbangan waktu dan ekonomi

3. Fondasi Dangkal



2.1 Jenis fondasi dangkal

2.2 Kedalaman minimum

2.3 Daya dukung (bearing capacity)

2.4 Settlement

2.5 Lateral resistance

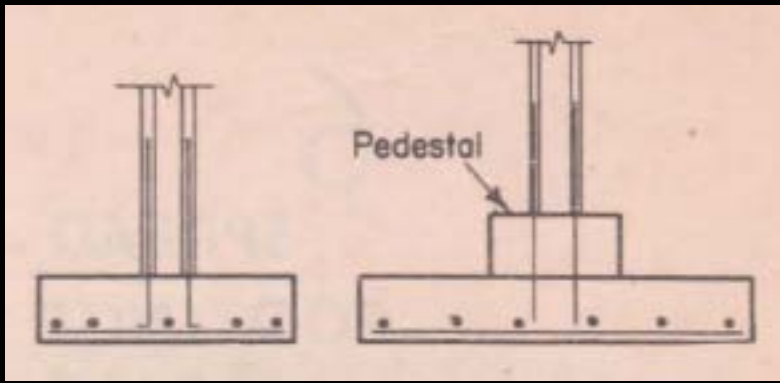
3. Fondasi Dangkal



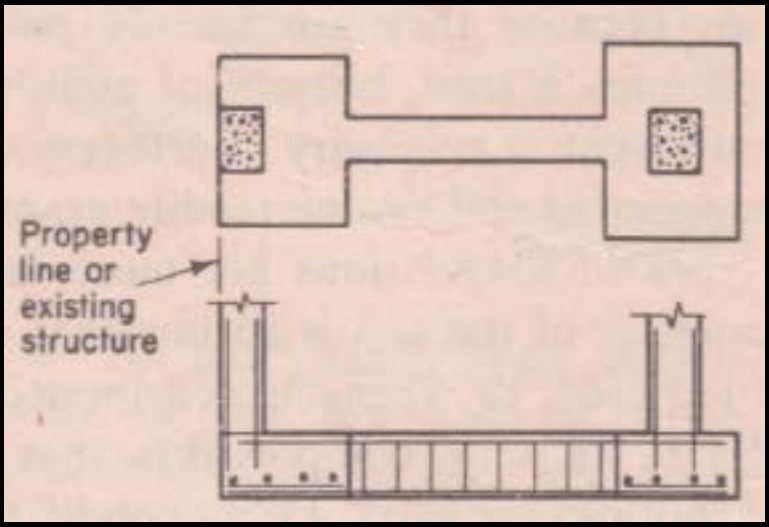
- Beban relatif kecil
- Tanah relatif baik
- Step desain:
 - Induced loads
 - Soil profile
 - Allowable bearing
 - Settlement



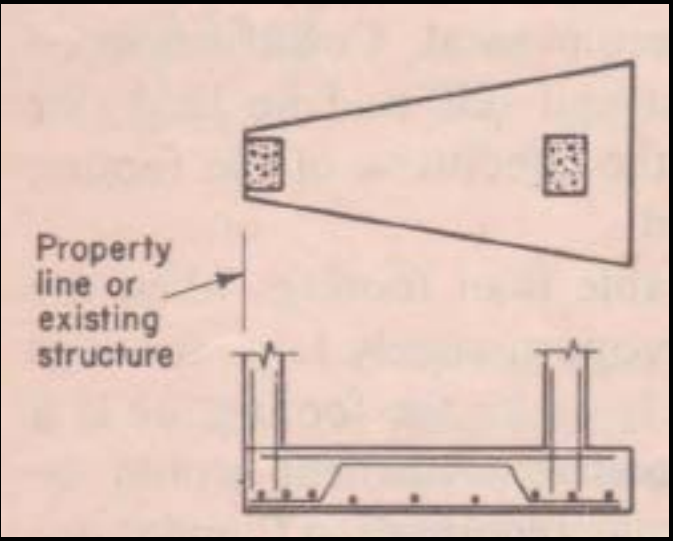
3.1 Jenis Fondasi Dangkal



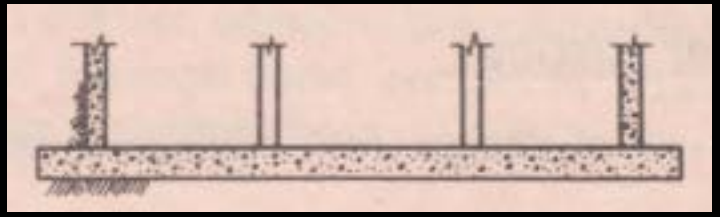
Spread footing



Strap footing



Combined footing

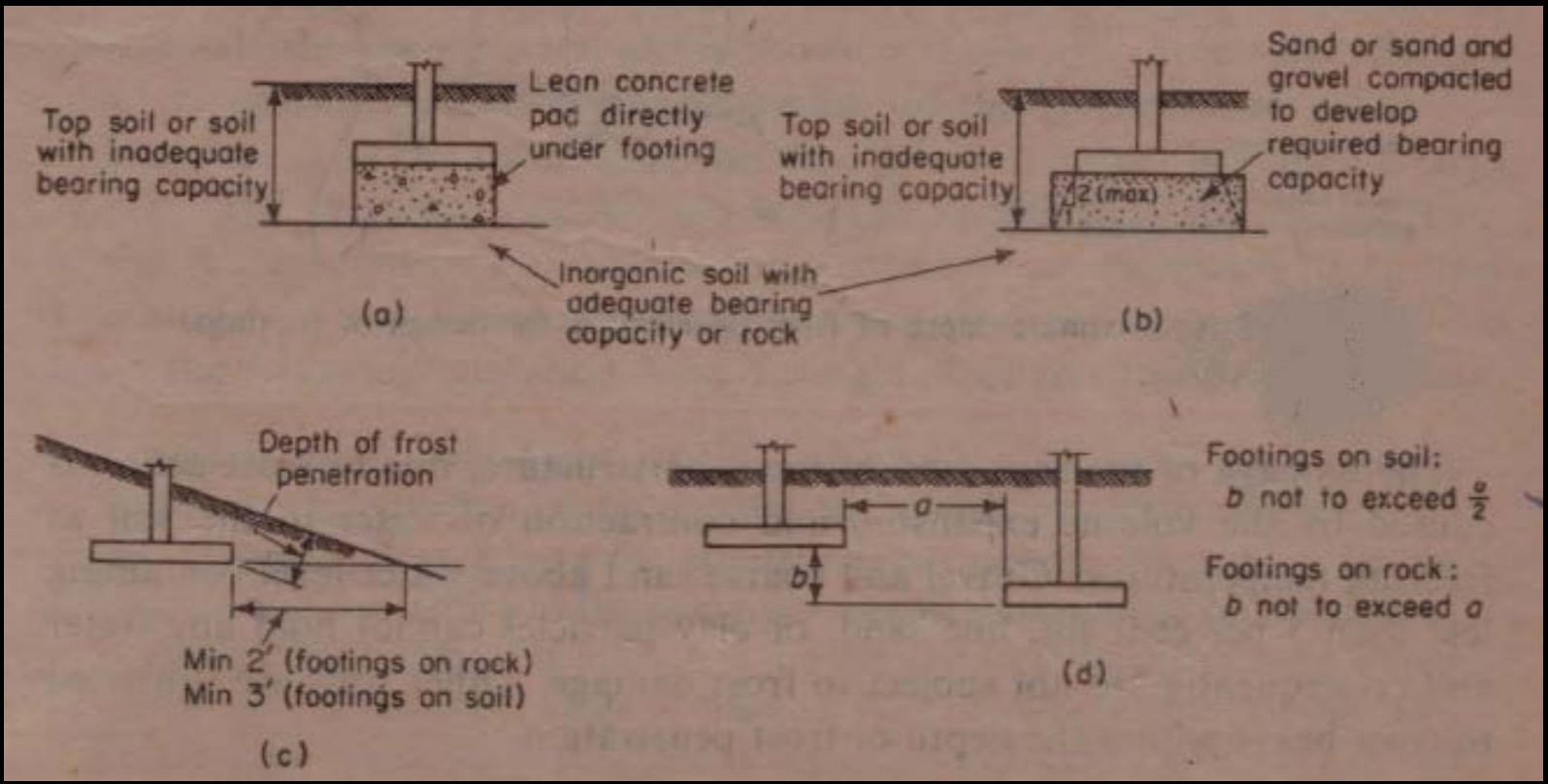


Mat foundation



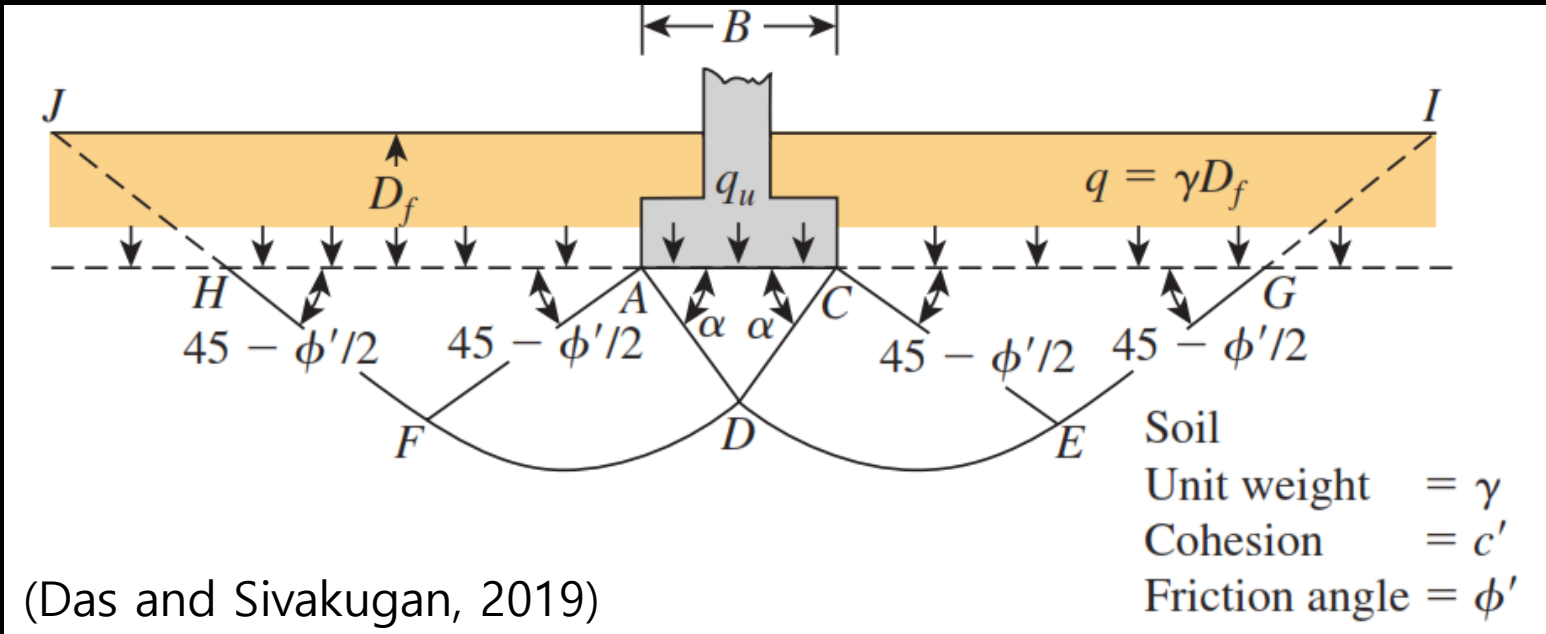
3.2 Minimum Depth of Footing

H & B ≥ 60-80 cm





3.3 Daya Dukung (Bearing Capacity)



(Das and Sivakugan, 2019)

$$q_u = c'N_c + qN_q + \frac{1}{2}\gamma BN_\gamma$$

$$q_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

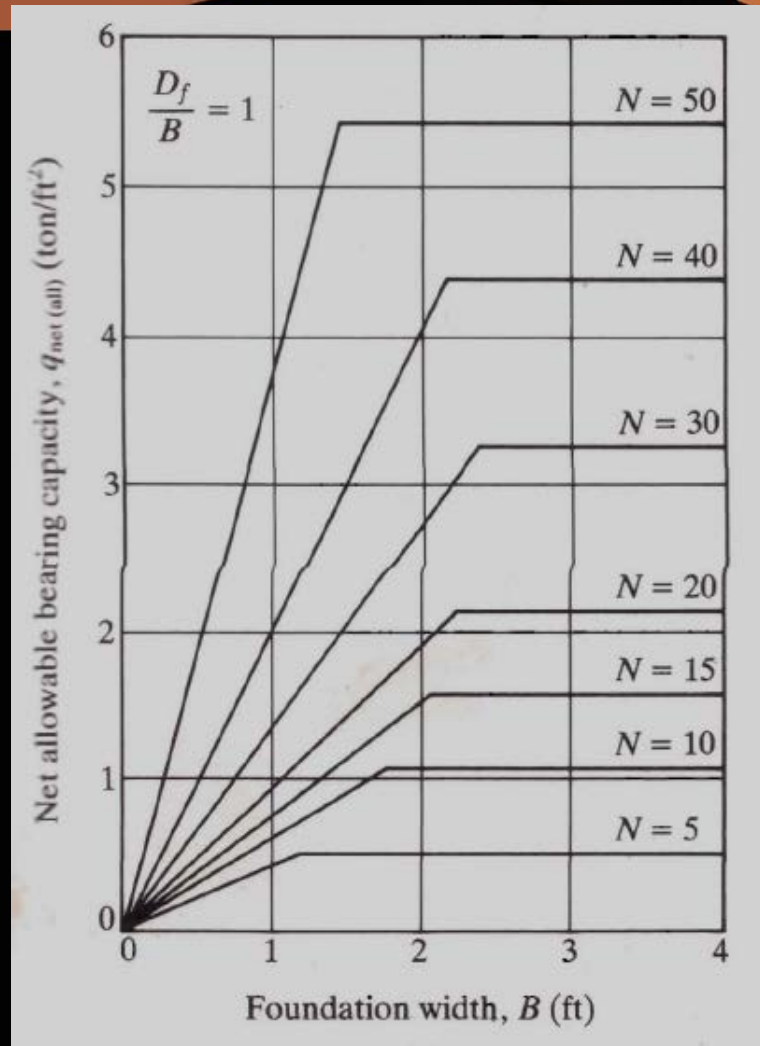


3.3 Daya Dukung (Bearing Capacity)

- Untuk pasir Meyerhof (1976)

$$q_{ult} = \frac{\bar{N}B}{10} (c_{w1} + c_{w2} \frac{D_f}{B})$$

- Peck, Hanson and Thornburn (1974) for Settlement = 25 mm



Net bearing capacity on sand (Peck, Hanson and Thornburn, 1974)

Rumus Meyerhof (pasir)

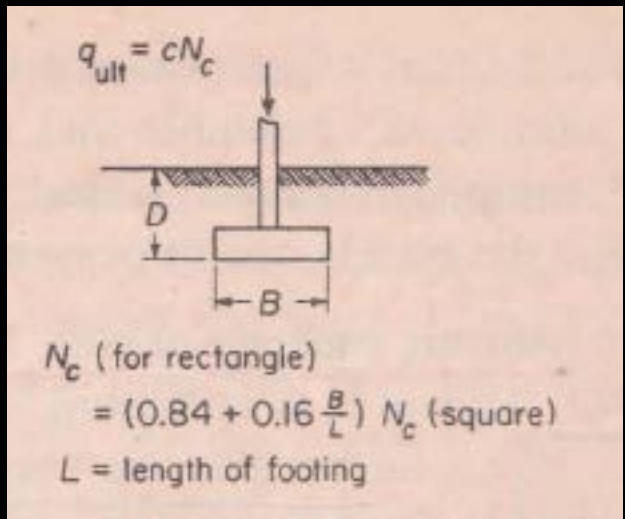


$$q_{ult} = \frac{\bar{N}B}{10} \left(c_{w1} + c_{w2} \frac{D_f}{B} \right)$$

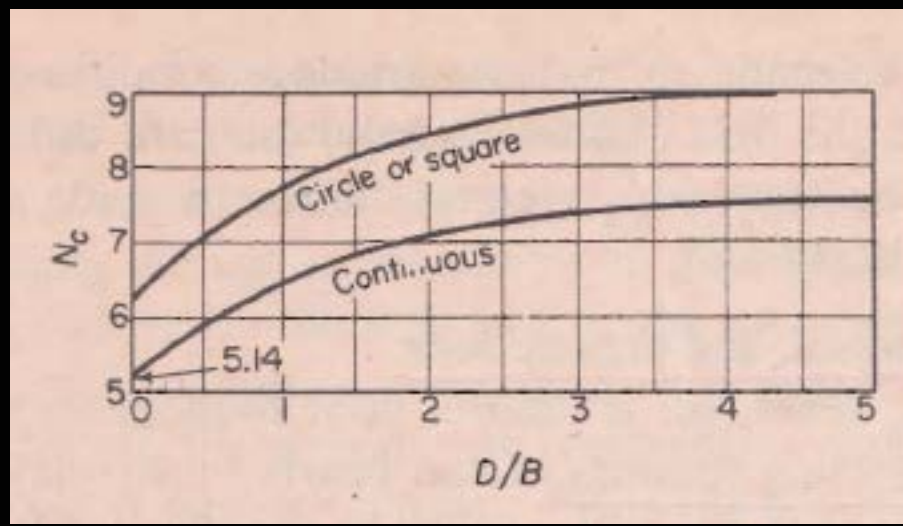
- q_{ult} (tsf) : ultimate bearing capacity
- B (ft) : footing width (least dimension)
- D_f (ft) : depth from ground surface to base of footing
- D_w (ft) : depth ground water level
- \bar{N} : average blow count, corrected for submerge effect;
for $N' > 15$ then correcting value $N_{cor} = 15 + 0.5(N - 15)$
where N = measured SPT blow count
- c_{w1}, c_{w2} : correction factors whose values depends on the position of the water table
for $D_w > D_f + 1.5B$, $c_{w1} = c_{w2} = 1.0$
for $D_w = D_f$ $c_{w1} = 0.5$ and $c_{w2} = 1.0$
for $D_w = 0$, $c_{w1} = 0.5$ and $c_{w2} = 0.5$
for other positions between $D_w = 0$ and $D_w = D_f + 1.5B$ can be determined by interpolation



Bearing Capacity (Clay)



$$q_u = c \cdot N_c$$



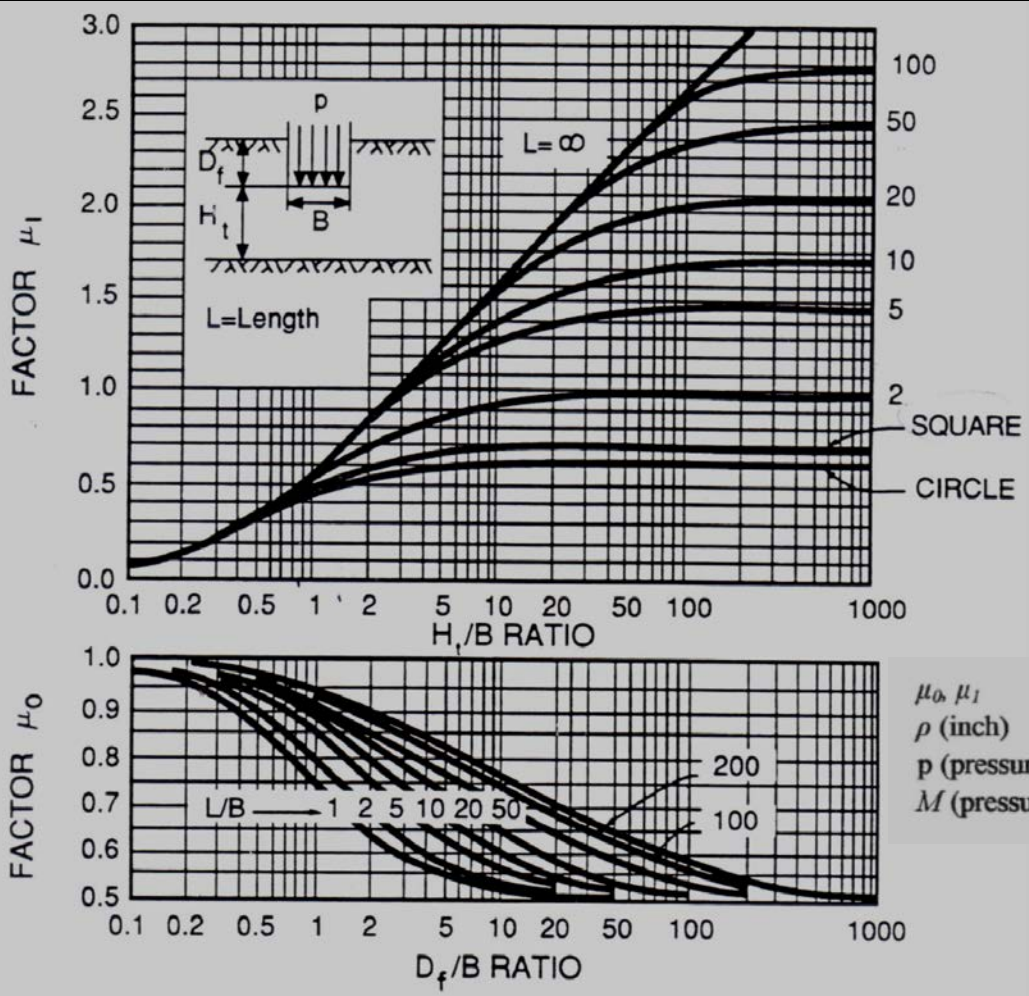
$$q_{all} = \frac{q_{ult}}{FK = 3}$$



3.4 Settlement

Pasir

• D'Appolonia et al. (1970)



$$\rho = \mu_0 \cdot \mu_1 \cdot \frac{p \cdot B}{M}$$

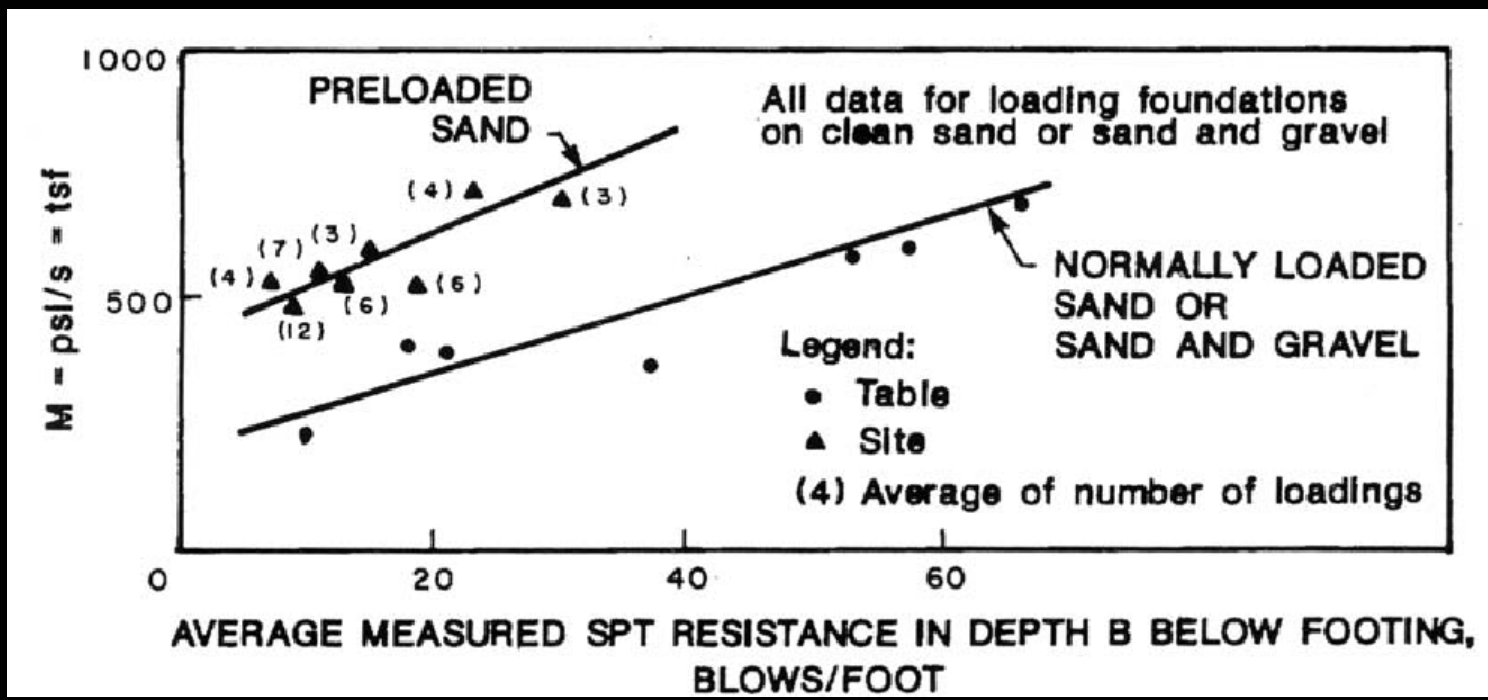
μ_0, μ_1 : settlement influence factors (Gambar C.1)
 ρ (inch) : settlement
 p (pressure unit) : average applied pressure under service loading condition
 M (pressure unit) : modulus compressibility (Gambar C.2)



Settlement untuk Pasir

• D'Appolonia et al. (1970)

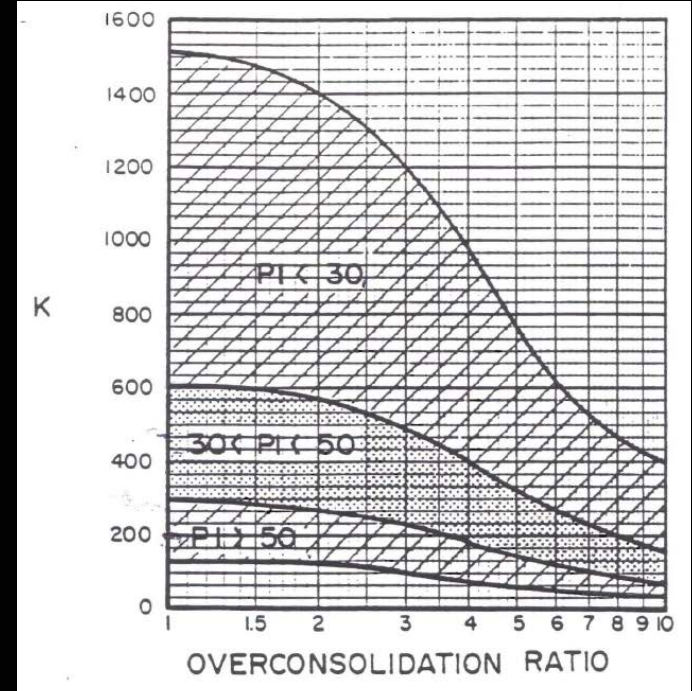
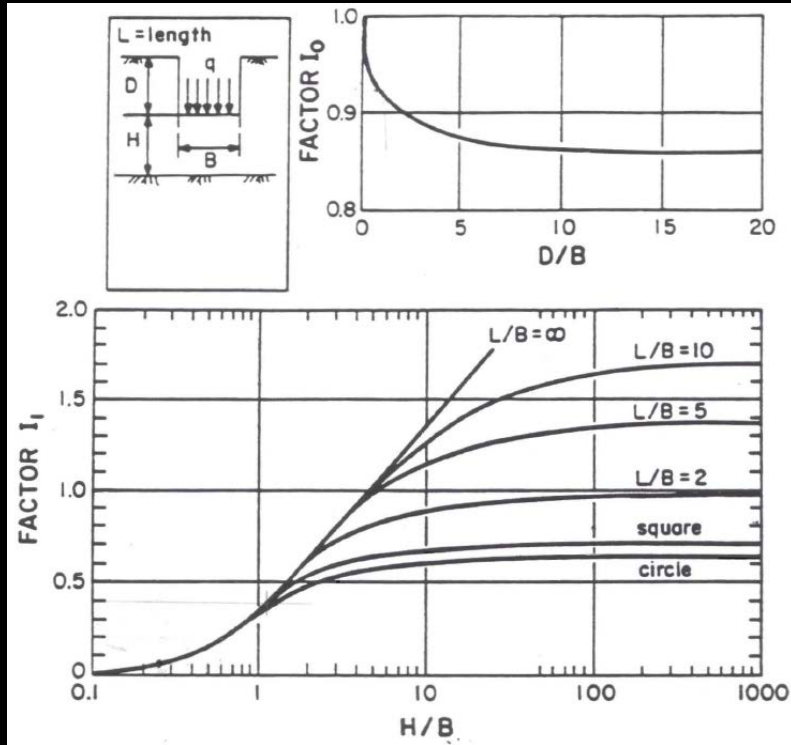
$$\rho = \mu_0 \cdot \mu_1 \cdot \frac{p \cdot B}{M}$$



Settlement for Clay



- Immediate Settlement



$$\rho_i = I_0 I_1 \frac{qB}{E} (1-\nu^2)$$
 ρ_i = IMMEDIATE SETTLEMENT (AVERAGE VALUE)
 q = AVERAGE BEARING PRESSURE
 B = FOUNDATION WIDTH
 E = YOUNG'S MODULUS OF FOUNDATION SOIL
 I_0 & I_1 = FACTORS FROM CHART ABOVE
 POISSON'S RATIO = 0.5

$E_u = K S_u$
 E_u = UNDRAINED MODULUS OF CLAY
 K = FACTOR FROM CHART ABOVE
 S_u = UNDRAINED SHEAR STRENGTH OF CLAY

Consolidation Settlement



- Overconsolidated Clay, $p_0 + \Delta p < P_c$

$$\delta = C_r'.H.\log\frac{p_0 + \Delta p}{p_0}$$

- Overconsolidated Clay, $p_0 < P_c < p_0 + \Delta p$

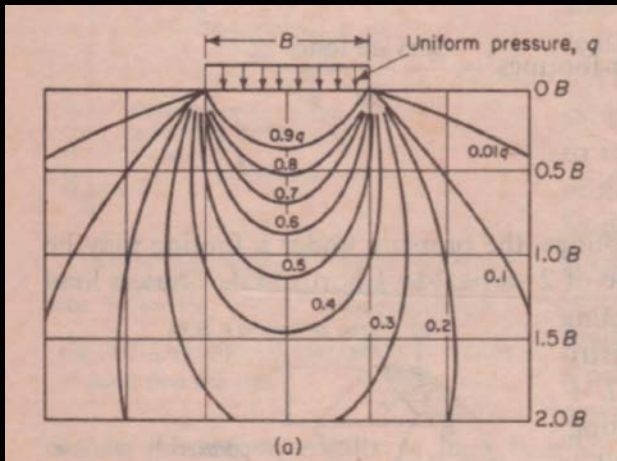
$$\delta = C_r'.H.\log\frac{p_c}{p_0} + C_c'.H.\log\frac{p_0 + \Delta p}{p_c}$$

- Normally Consolidated Clay, $p_0 = P_c$

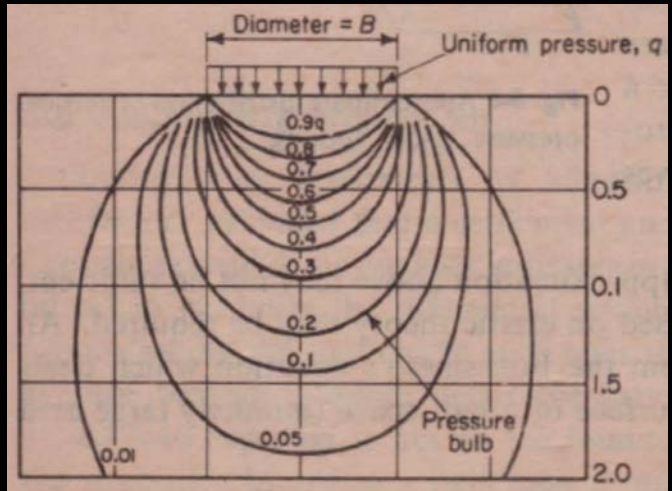
$$\delta = C_c'.H.\log\frac{p_0 + \Delta p}{p_0}$$



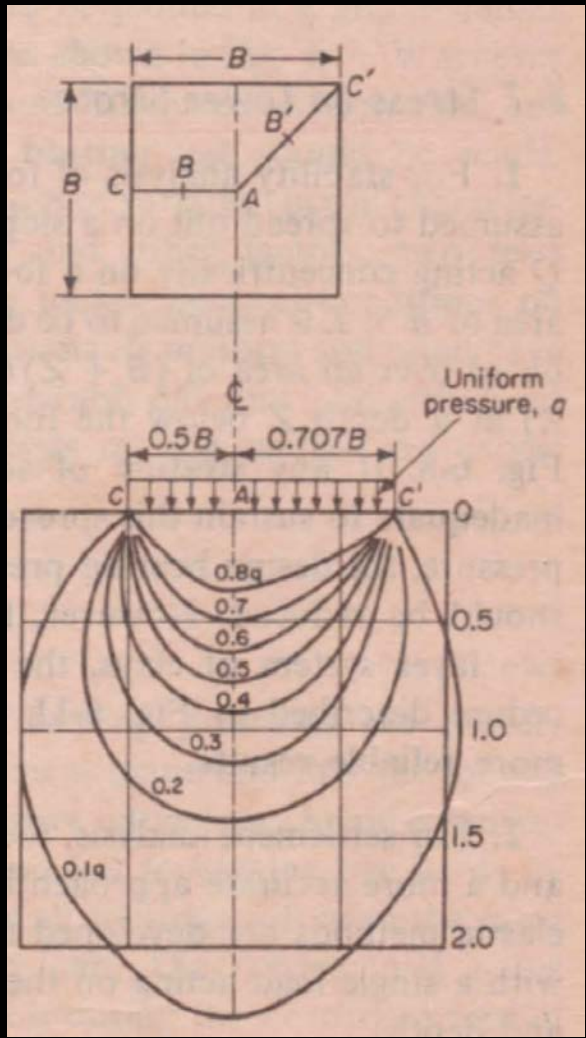
Vertical Stress Under Footing (Δp)



Under a continuous footing



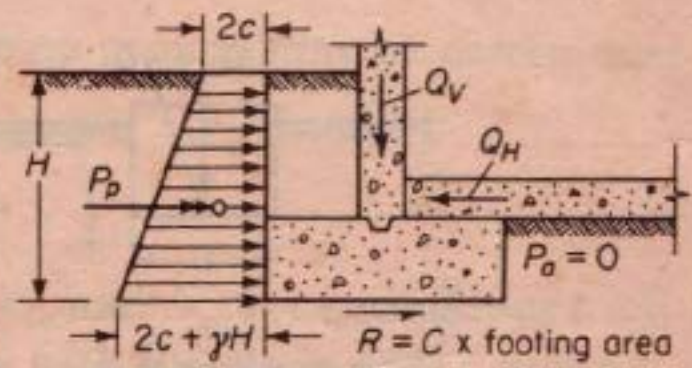
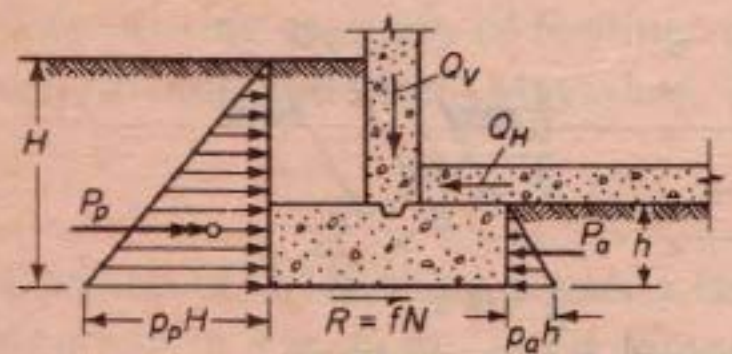
Under a circular footing



Under a squared footing



Lateral Resistance



N = total vertical force acting on the base of footing

$$\text{Factor of safety against sliding} = \frac{P_p - P_a + R}{Q_H}$$

Granular soils

Type of Soil	p_p psf		Coef. of Friction, f
	submerged	dry or moist	
Sand and/or gravel with less than 5% silt	210	350	0.55
Sand and/or gravel with 5% or more silt	180	250	0.45
Silt or soils containing more than 30% silt	120	150	0.35

Cohesive soils

Type of Soil	Cohesive Strength c = psf	Unit Weight, r pcf
Very soft clay	200	110
Soft clay	400	120
Medium, stiff, and hard clay	600	125

Hal-hal Lain



- ❖ Efek likuifaksi (loose sand).
- ❖ Efek settlement pada tanah urugan
- ❖ Pemadatan subgrade soil secara baik

4. Fondasi Dalam



4.1 Jenis fondasi dalam

4.2 Fondasi Tiang

- Tiang pancang
- Tiang bor

4.3 Daya dukung aksial

- Single Pile
- Pile Group

4.4 Daya dukung lateral

- Single Pile
- Pile Group

4.5 Settlement

4.1 Jenis Fondasi Dalam

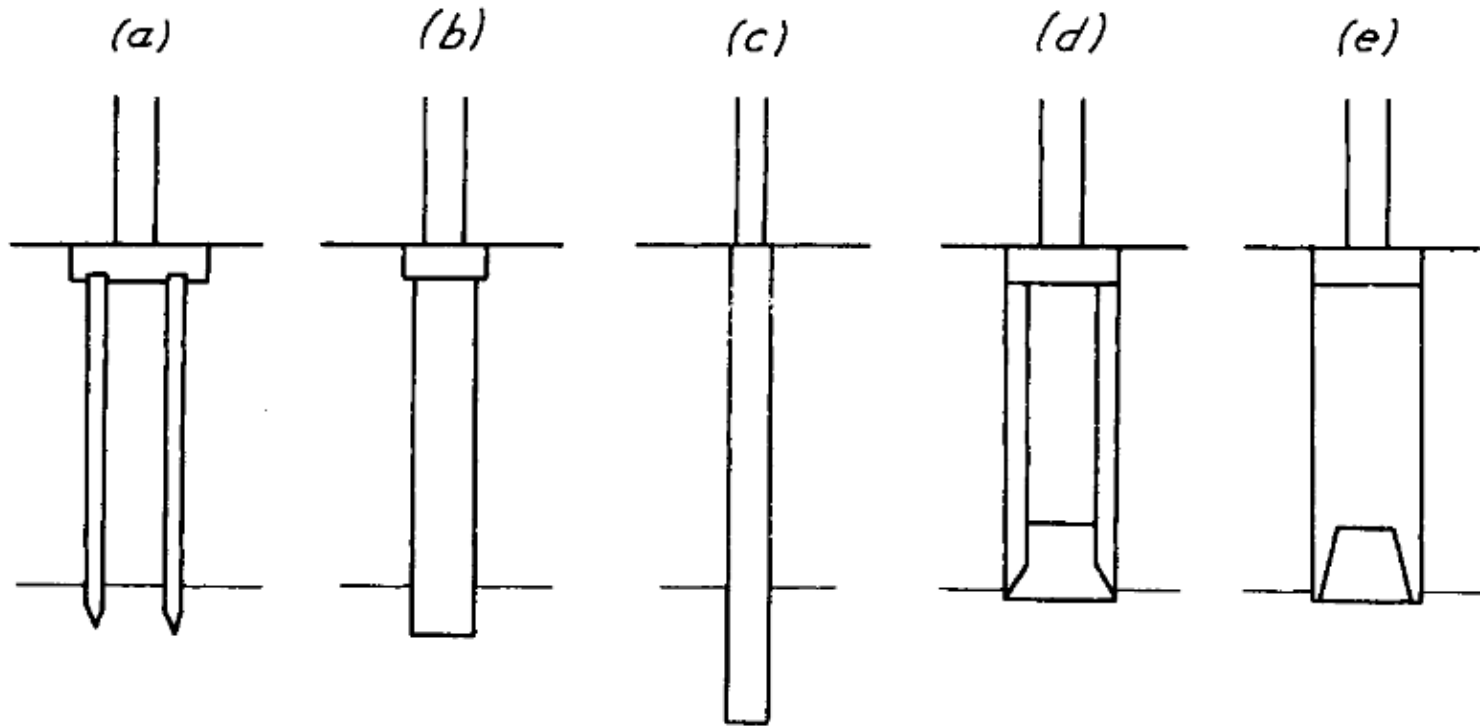


Fig. 1.2. Deep foundations: (a) piles, (b) piers, (c) diaphragm walls, (d) open caissons, (e) pneumatic caissons.

4.2 Fondasi Tiang



□ Jenis yang biasa digunakan:

- Fondasi bored pile
- Fondasi tiang pancang dengan hammer
- Fondasi tiang pancang tekan hidrolis
- Minipiles
- Franki pile

□ Daya Dukung Tiang

$$Q_{\text{tekan}} = [Q_{\text{shaft}} + Q_{\text{bearing}}] / FK$$

$$Q_{\text{tarik}} = [Q_{\text{shaft}} / FK] + W_{\text{pile}}$$

Karakteristik Fondasi Tiang



- Cara pelaksanaan
- Faktor pelaksanaan untuk desain
- Analisa dan desain disesuaikan dengan pelaksanaan

Pengaruh Pemancangan Tiang



- Pemancangan mendesak tanah ke samping dan ke bawah
- Tegangan air pori naik
- Pemancangan memadatkan tanah pasir lepas
- Pemancangan merusak tanah pasir padat
- Pengaruh pemancangan pada pasir

→ Kishida-Meyerhoff

$$\emptyset_2 = (\emptyset_1 + 40^0)/2$$

\emptyset_1 = \emptyset pasir sebelum dipancang

\emptyset_2 = \emptyset pasir sesudah pemancangan

Pengaruh alat pancang



- ❖ Berat hammer disesuaikan dengan berat tiang
- ❖ Tegangan tekan dan tegangan tarik dalam tiang
- ❖ Getaran pada tanah
- ❖ Polusi suara
- ❖ Energi pancang yang baik adalah hammer yang berat dengan tinggi jatuh kecil
- ❖ Hammer yang ringan dengan tinggi jatuh besar menyebabkan “efek cambuk” pada tiang

Pelaksanaan tiang bor



- ❑ Berpengaruh terhadap cara pelaksanaan
 - dengan casing atau tidak
 - dengan bentonite/polimer atau tidak
 - cor beton dalam air atau tidak

- ❑ Pengeboran menyebabkan “stress release”
 - “stress release” pada dinding lubang menyebabkan longsor
 - “stress release” pada dasar lubang menyebabkan “heaving”
 - Pada MAT tinggi dapat terjadi “boiling” dasar lubang

Mencegah longsor di lubang bor



- ❑ Longsor dinding lubang bor menyebabkan:
 - diameter lubang lebih besar
 - permukaan dinding tidak halus
 - menambah tahanan friksi tiang
 - menambah volume beton tiang bor
- ❑ Longsor pada pasir hanya dapat dicegah dengan “casing”
- ❑ Longsor pada tanah kohesif dapat dicegah dengan “bentonite” atau “polymer”
- ❑ Longsor tanah / lumpur di dasar lubang terisi air tidak bisa 100% dibersihkan.

4.3 Daya Dukung Aksial



1. Single Pile

- Tahanan geser selimut
- Tahanan ujung

2. Pile Group

Daya Dukung Aksial Tiang Tunggal



Rumus umum daya dukung aksial fondasi dalam:

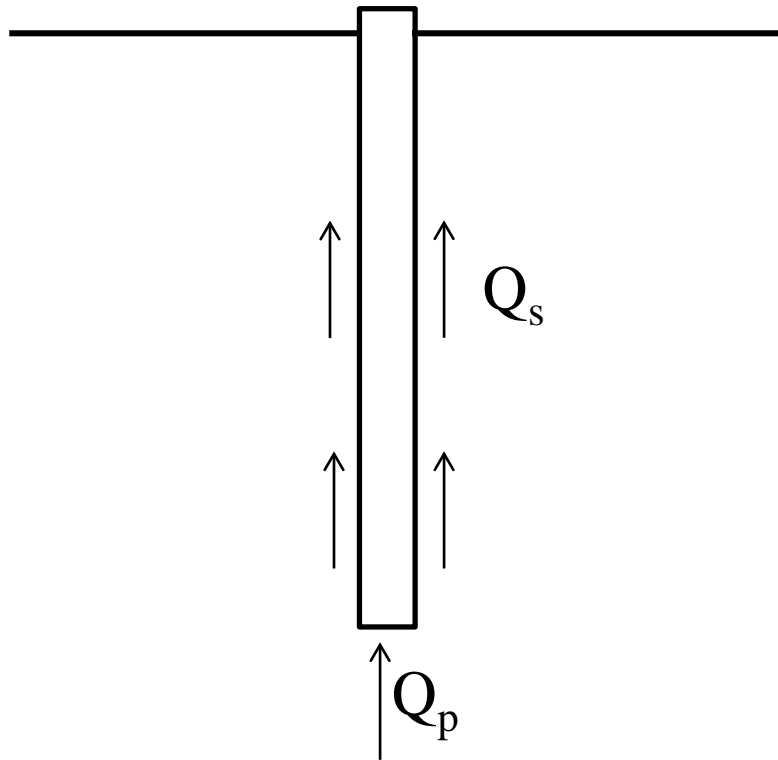
$$Q_{ult} = Q_s + Q_p$$

Q_s = *Tahanan Geser Selimut Tiang*

Q_p = *Tahanan Ujung Tiang*



Daya Dukung Umum



$$Q_u = Q_p + Q_s$$

$$Q_{all} = \frac{Q_u}{FS}$$

$$FS = 2.5$$

Tahanan Geser Selimut (Qs)



1. Tanah Kohesif

Tiang Pancang

Tiang Bor

2. Tanah Pasir

Tiang Pancang

Tiang Bor

1. Tahanan Geser Selimut Tiang Tanah Kohesif



Tahanan geser selimut tiang yang merupakan kontribusi dari kohesi tanah adalah:

$$Q_s = q_s \cdot L_j \cdot p \quad (q_s = \alpha \cdot c_u)$$

Dimana,

q_s = *unit gesekan kulit*

α = *Koefisien adhesi antara tanah dan tiang*

c_u = *Undrained cohesion*

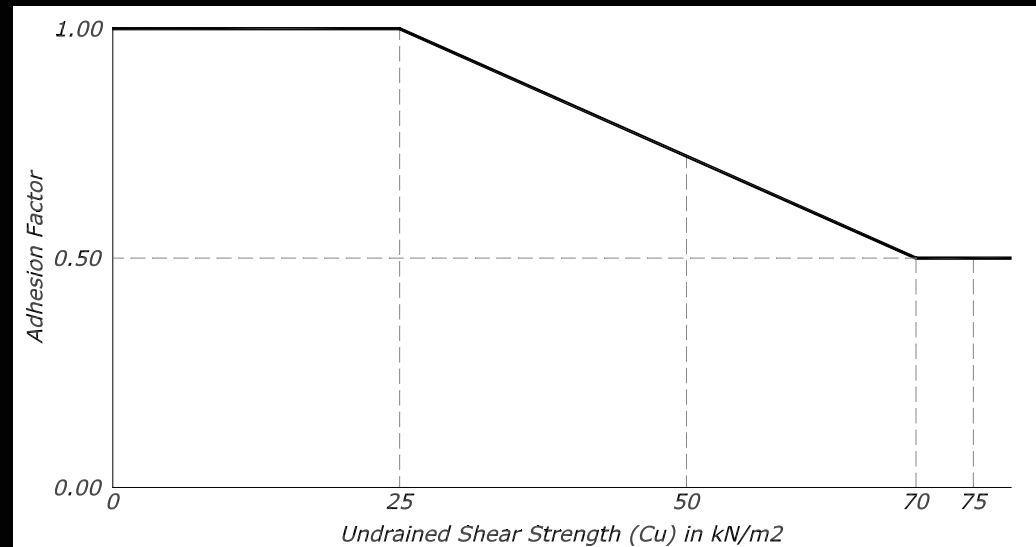
L_j = *Panjang lapisan tanah*

p = *keliling tiang*

Faktor Adhesi (α) pada Tanah Kohesif untuk “Tiang Pancang”



1. API Metode, 1986



2. API Metode, 2000

$$\alpha = 0.5 \Psi^{-0.5} \text{ untuk } \Psi \leq 1.0$$

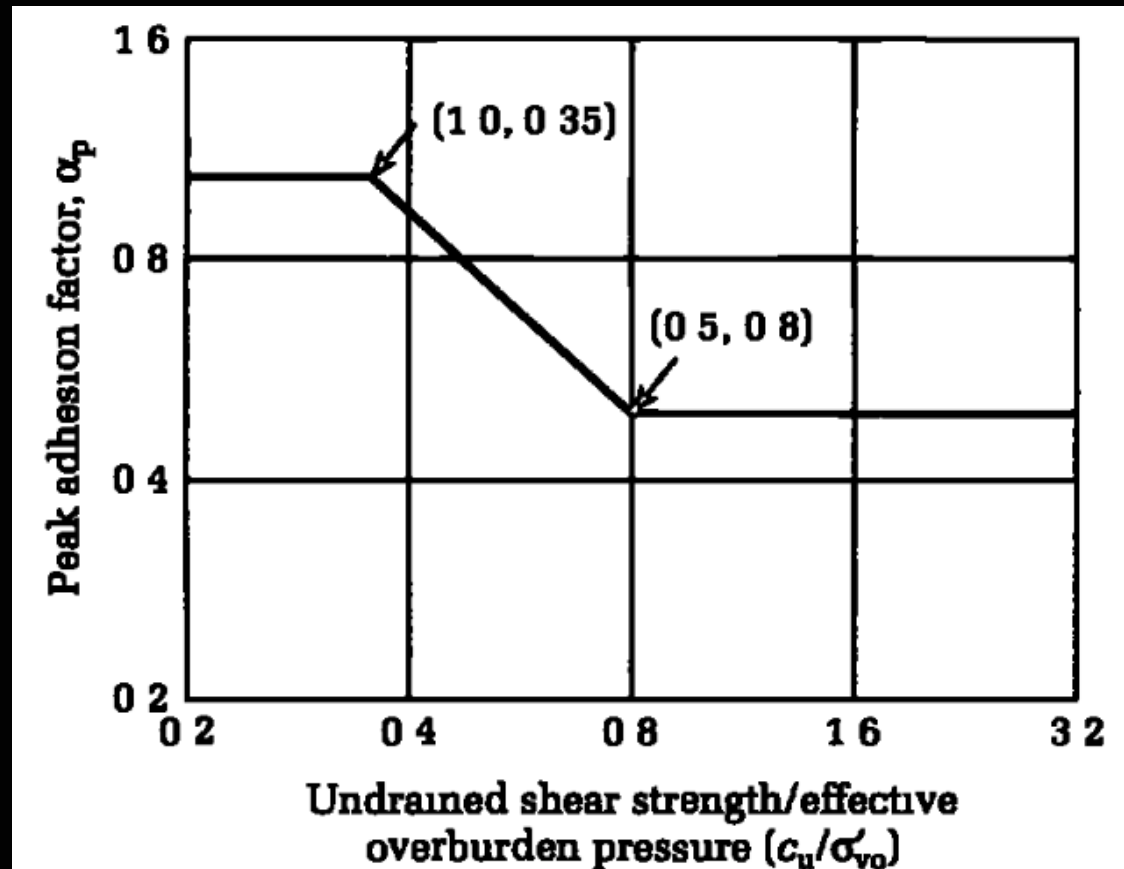
$$\alpha = 0.5 \Psi^{-0.25} \text{ untuk } \Psi > 1.0$$

$$\Psi = c_u / \sigma$$

Faktor Adhesi (α) pada Tanah Kohesif untuk “Tiang Pancang”



3. Tomlinson, 2001 :

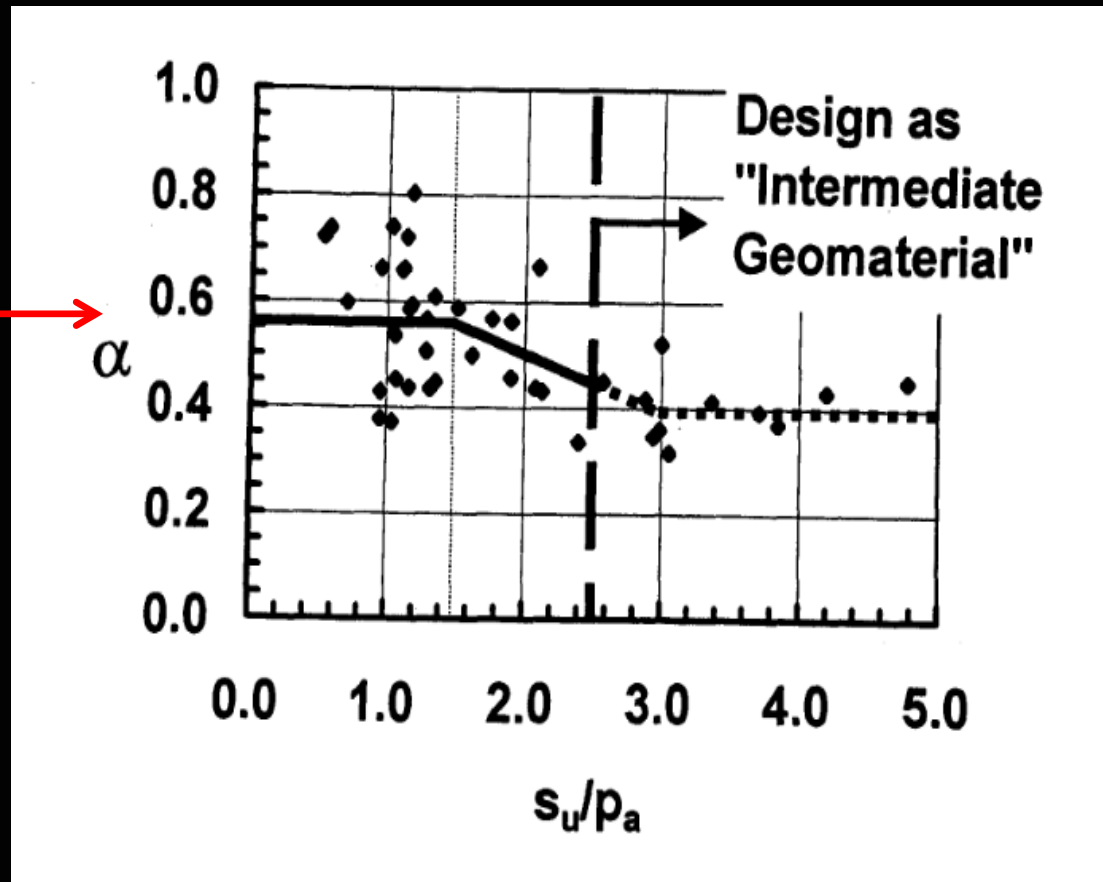


Faktor Adhesi (α) pada Tanah Kohesif untuk "Tiang Bor"



1. Reese and O'Neill, 1988

$$\alpha = 0.55$$



Batasan Tahanan Selimut pada Tanah Kohesif untuk “Tiang Bor”



Tahanan gesekan kulit tiang bor pada tanah kohesif perlu dibatasi sebagaimana dinyatakan oleh Tomlinson (2001),

$$q_s = \alpha c_u \leq q_{s(izin)} = 1.0 \text{ kg/cm}^2 \\ = 100 \text{ kN/m}^2$$

2. Tahanan Geser Selimut Tiang untuk tanah pasiran



Tahanan geser selimut tiang yang merupakan kontribusi dari sudut geser dalam (ϕ) adalah:

$$Q_s = q_s \cdot L_i \cdot p \qquad q_s = K\sigma \tan \delta$$

Dimana,

q_s = tahanan geser selimut per satuan luas

L_i = Tebal lapisan tanah

p = keliling tiang

Tahanan Geser Selimut “Tiang Pancang” untuk Tanah Berpasir



API, 2000

$$q_s = K\sigma \tan \delta$$

Density	Soil Description	Soil-Pile Friction Angle δ Degrees	Limiting Skin Friction Values kips/ft ² (kPa)	N_q	Limiting Unit End Bearing Values kips/ft ² (MPa)
Very Loose	Sand	15	1.0 (47.8)	8	40 (1.9)
Loose	Sand-Silt**				
Medium	Silt				
Loose	Sand	20	1.4 (67.0)	12	60 (2.9)
Medium	Sand-Silt**				
Dense	Silt				
Medium	Sand	25	1.7 (81.3)	20	100 (4.8)
Dense	Sand-Silt**				
Dense	Sand	30	2.0 (95.7)	40	200 (9.6)
Very Dense	Sand-Silt**				
Dense	Gravel	35	2.4 (114.8)	50	250 (12.0)
Very Dense	Sand				

*The parameters listed in this table are intended as guidelines only. Where detailed information such as in situ cone tests, strength tests on high quality samples, model tests, or pile driving performance is available, other values may be justified.

**Sand-Silt includes those soils with significant fractions of both sand and silt. Strength values generally increase with increasing sand fractions and decrease with increasing silt fractions.

K adalah tekanan tanah lateral

K = 0.8 (untuk tiang pipa ujung terbuka)

K = 1.0 (untuk full displacement)

σ adalah tegangan efektif overburden

δ = gesekan tiang dengan tanah

Tahanan Geser Selimut “Tiang Pancang” untuk Tanah Berpasir



Meyerhof (1976) dengan menggunakan nilai N-SPT

$$q_s = 0.1 N \text{ (t/m}^2\text{)} \text{ untuk displacement kecil}$$
$$q_s = 0.2 N \text{ (t/m}^2\text{)} \text{ untuk displacement besar}$$

Displacement kecil atau besar merupakan usaha pemancangan tiang. Displacement besar dapat diartikan sebagai pemancangan dengan menggunakan hammer. Kalau displacement kecil dapat diartikan bahwa usaha pemancangan kecil seperti pemancangan dengan menggunakan metode push-in atau jacking.

Tahanan Geser Selimut “Tiang Pancang” untuk Tanah Berpasir



Naval Engineering Facilities Command{

$$Q_s = 0.2 \times (N \text{ SPT}) \times L_i \times p \text{ (ton)}$$

Tahanan Geser Selimut “Tiang Bor” untuk Tanah Berpasir



Reese and Wright, 1977

$$q_s = 0.32 N \left(\text{t/m}^2 \right) \text{ untuk } N_{SPT} < 53$$

$$q_s = \frac{N - 53}{450} + 1.6 \left(\text{t/ft}^2 \right) \text{ untuk } 53 < N_{SPT} \leq 100$$

Catatan: $1 \text{ t/ft}^2 = 10.764 \text{ t/m}^2$

Naval Engineering Facilities Command{

$$Q_s = 0.1 \times (N \text{ SPT}) \times L_i \times p \text{ (ton)}$$

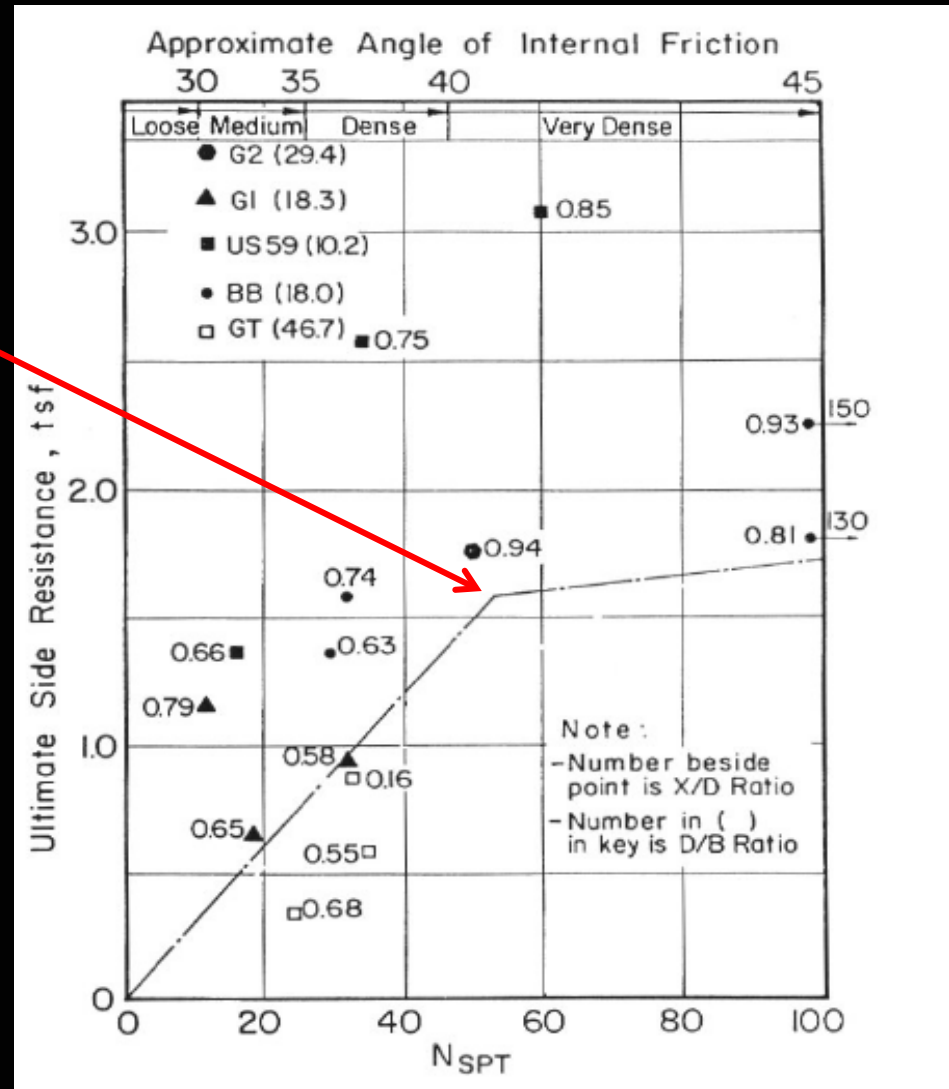
Batasan Tahanan Selimut pada Tanah Pasir untuk “Tiang Bor”



$$q_s = 1.6 \text{ tsf}$$

untuk $N_{SPT} < 53$

Nilai batas gesekan kulit tiang bor (Reese dan Wright, 1977)



Tahanan Ujung (Q_p)



1. Tanah Lempung
Tiang Pancang
Tiang Bor

2. Tanah Pasir
Tiang Pancang
Tiang Bor

Daya Dukung Ujung untuk Tanah Kohesif c_u



Tiang Pancang dan Tiang Bor:

$$Q_p = q_p \times A_p$$

$$q_p = 9 \times c_u$$

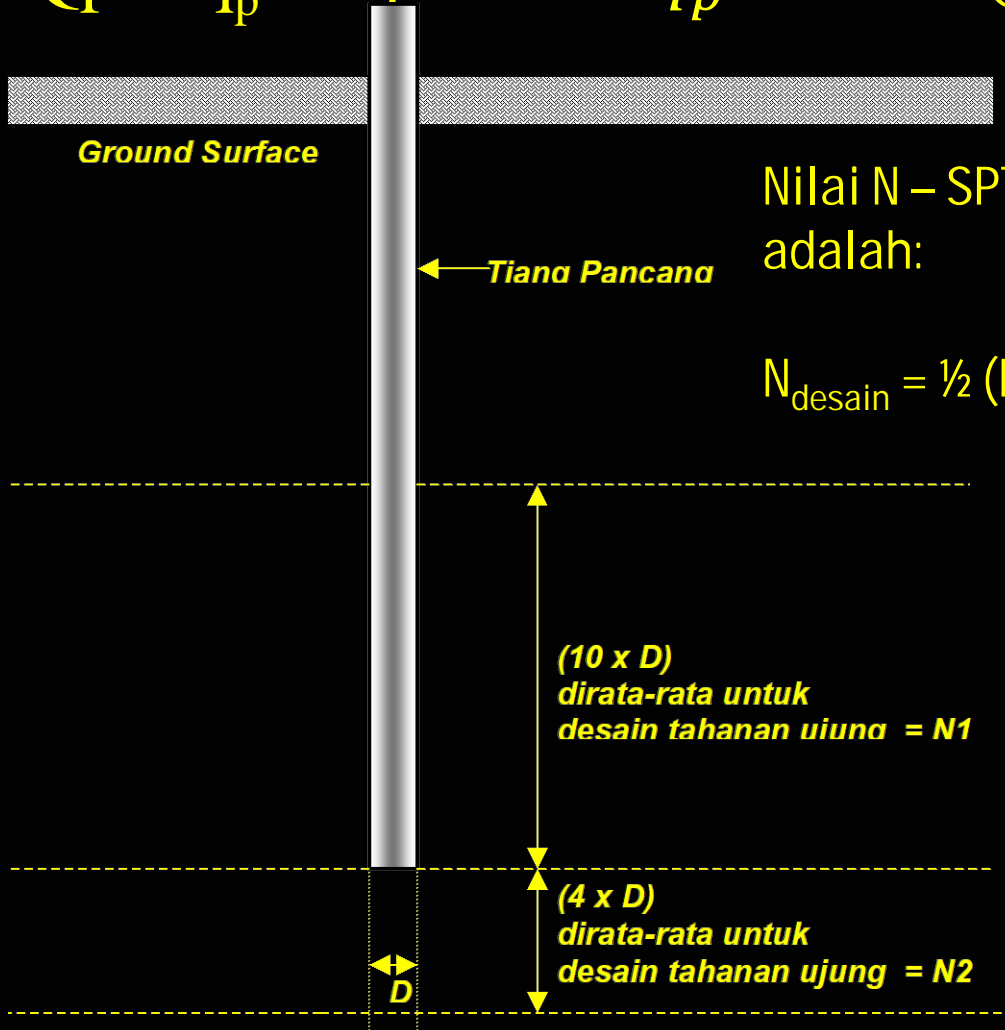
Daya Dukung Ujung untuk Tanah Pasiran ϕ



→Tiang Pancang :

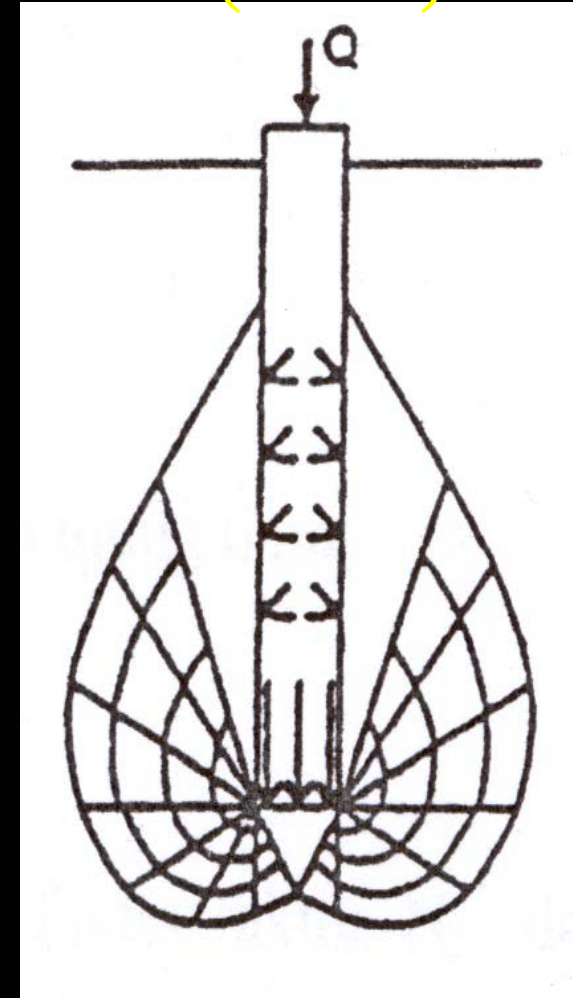
$$Q_p = q_p \times A_p$$

$$q_p = 40 N(t/m^2) < 1600 (t/m^2)$$



Nilai N – SPT Desain adalah:

$$N_{\text{desain}} = \frac{1}{2} (N1 + N2)$$



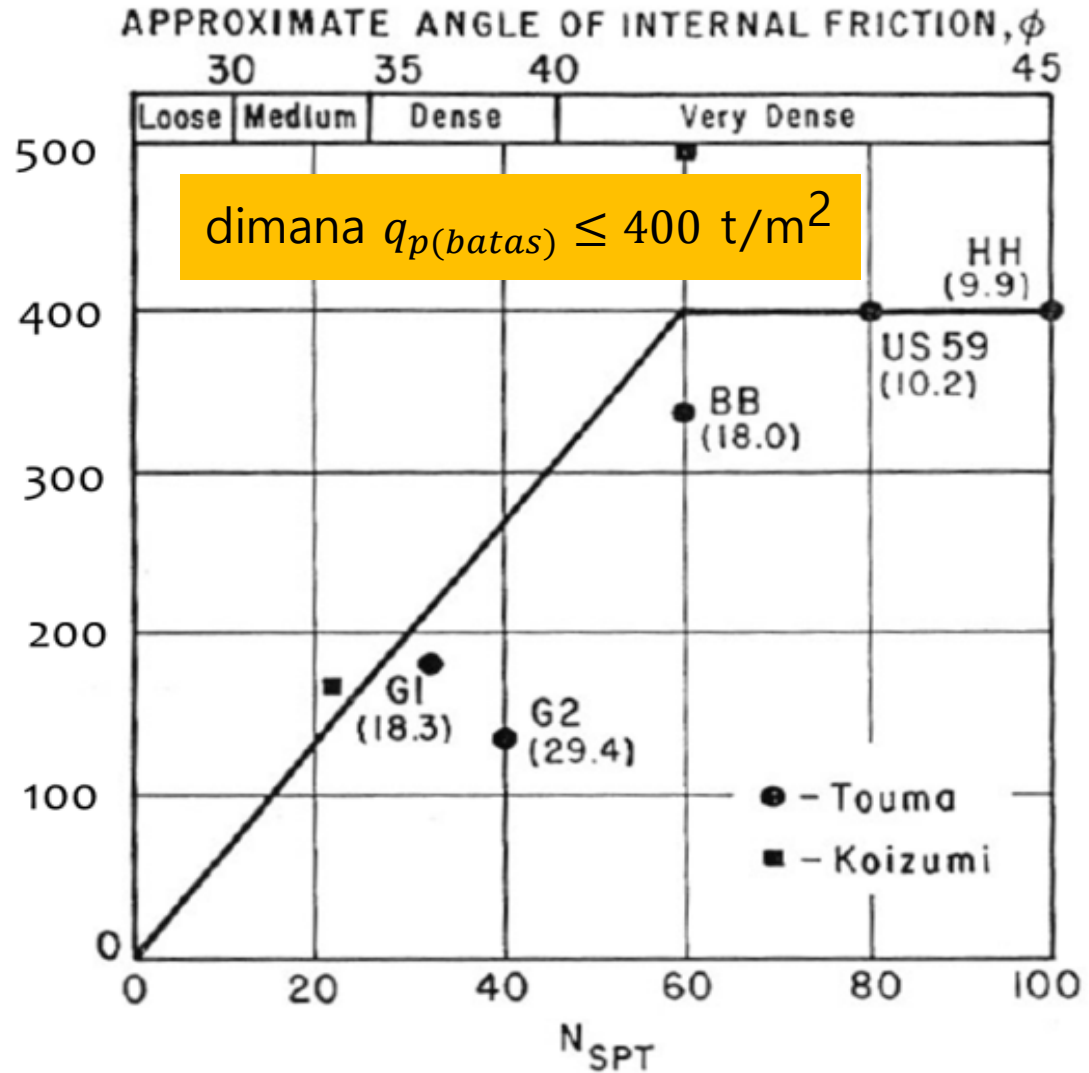
Daya Dukung Ujung untuk Tanah Pasiran



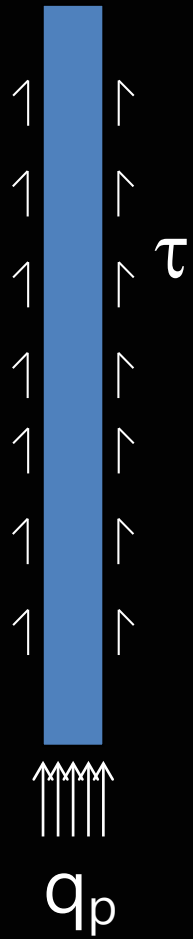
Tiang Bor

$$q_p = 7 N \text{ (t/m}^2\text{)}$$

Ultimate End Bearing Resistance (t/m²)



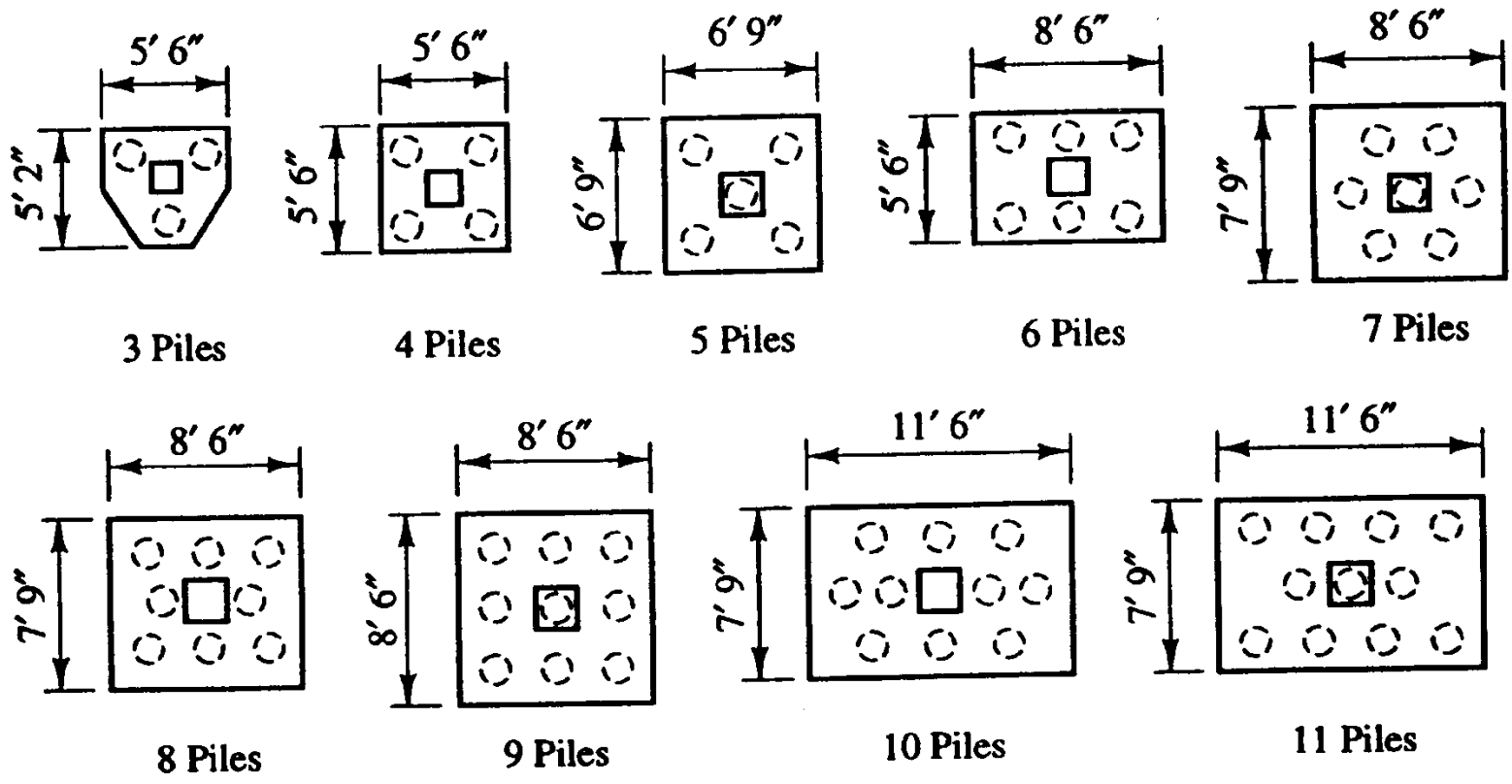
Summary



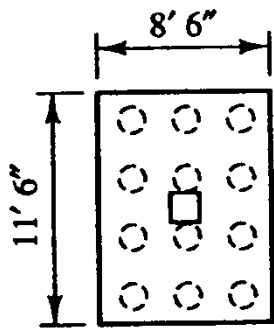
Clay		Sand	
Pancang	Tiang Bor	Pancang	Tiang Bor
αc ↑ Untuk pancang API, 2001	αc ↑ Untuk Tiang Bor Reese and O'Neill, 1988	0.2 N < 2 tsf	0.1 N < 1 tsf
$9 c$		$40 \underline{N}$ $< 1600 \text{ t/m}^2$ $\underline{N} = (N1 + N2) / 2$	$7 \text{ N (t/m}^2)$ $\leq 400 \text{ (t/m}^2)$

$$P_{ult} = 2\pi r \sum \Delta l \tau + \pi r^2 q_p$$

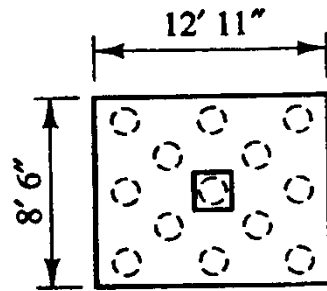
Pile Group



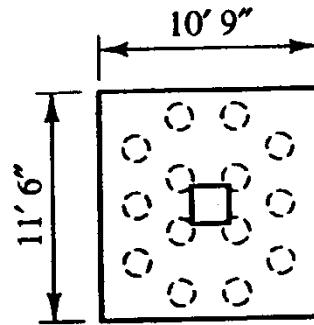
Pile Group



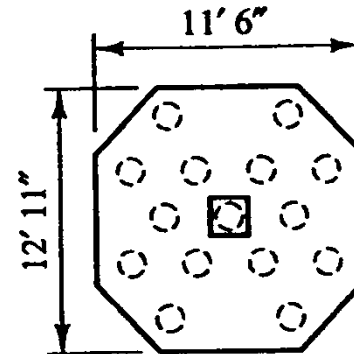
12 Piles



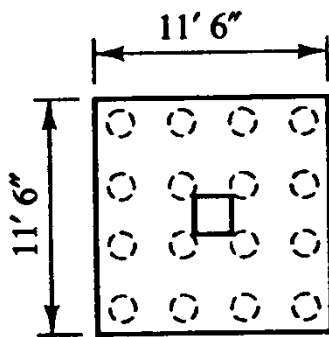
13 Piles



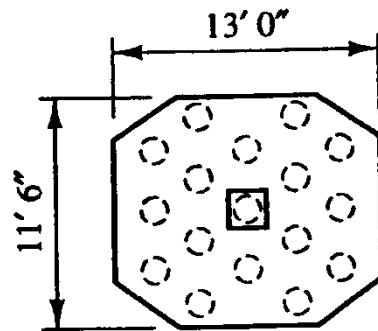
14 Piles



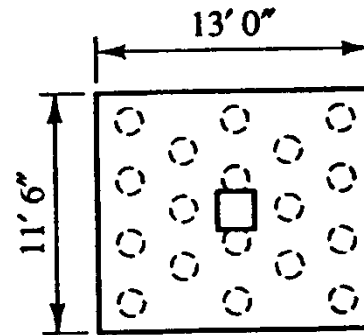
15 Piles



16 Piles



17 Piles



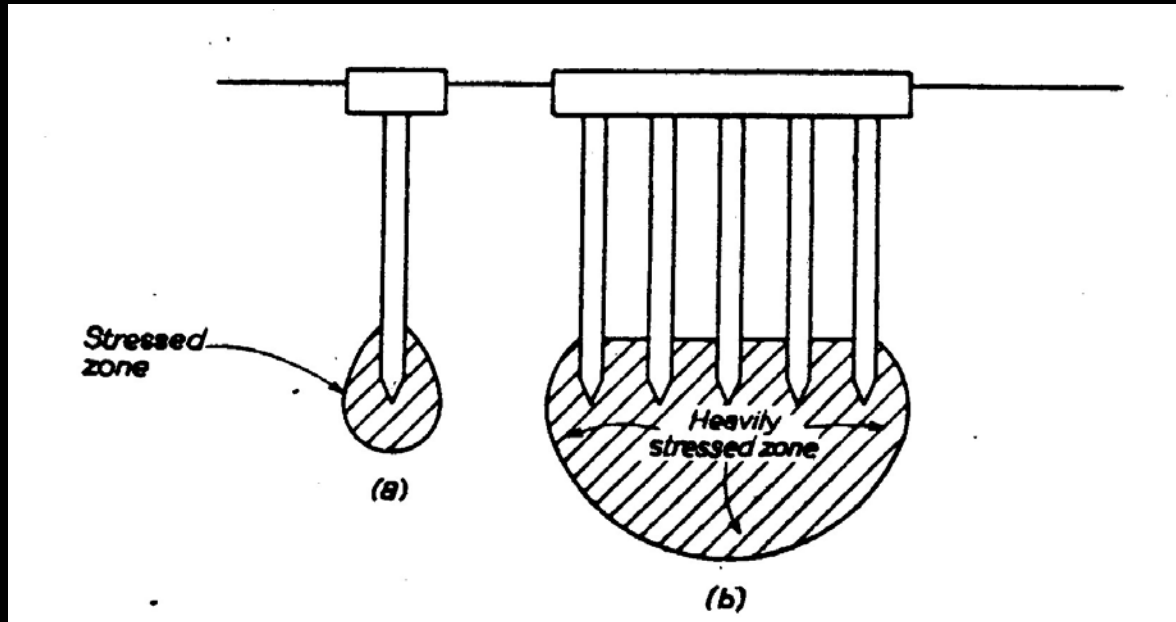
18 Piles

Keuntungan Kelompok tiang



- ❑ Tiang tunggal tidak memadai
- ❑ Deviasi pada instalasi tiang
- ❑ Timbulnya eksentrisitas menambah momen
- ❑ Satu tiang gagal, dibantu tiang lain (prinsip redundancy)
- ❑ Pemadatan ke arah lateral pada pemancangan (terutama sandy soil)

Zona Tegangan



Pengaruh Pada Kelompok Tiang

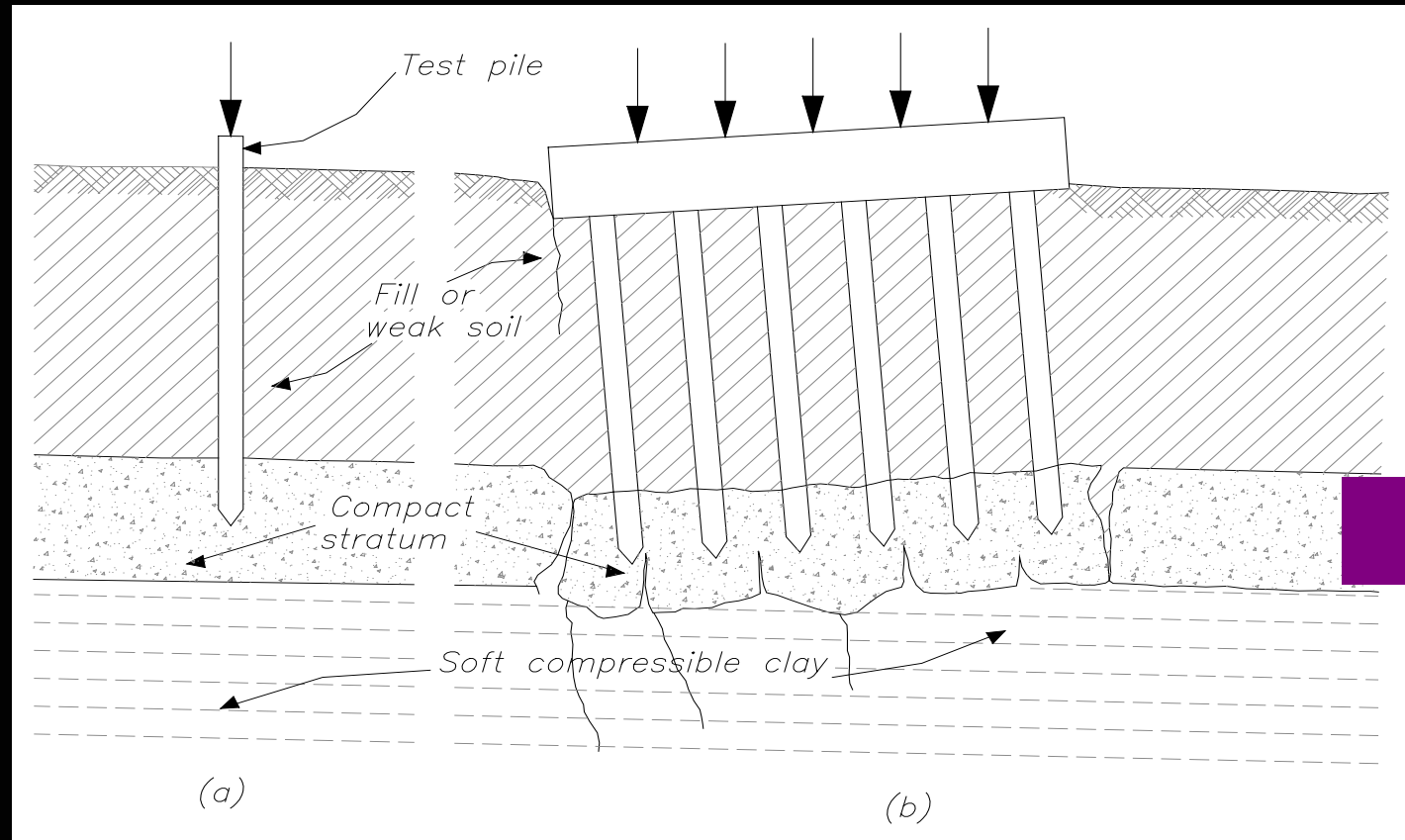
Bearing capacity

Pile Group $<$ Single Pile

Settlement

Pile Group $>$ Single Pile

Aksi Tiang Tunggal dan Kelompok



Lensa

Prilaku kelompok tiang sangat berbeda

(Tomlinson, 1977)

Efisiensi

Daya dukung batas
kelompok tiang

$$\eta = \frac{Q_{g(u)}}{\sum Q_u}$$

Daya dukung batas
tiang tunggal

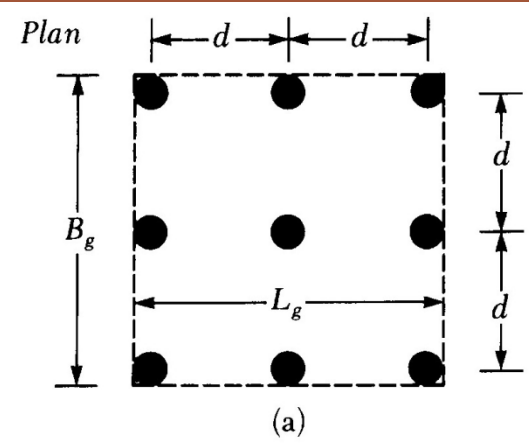
Efisiensi bergantung pada:



- Jumlah tiang, panjang, diameter, pengaturan tiang, dan jarak
- Modus transfer beban
- Prosedur instalasi (pancang atau bor)
- Urutan instalasi
- Jangka waktu setelah pemancangan
- Interaksi pile cap dan ground



Efisiensi Pile Group



Number of piles in group = $n_1 \times n_2$
 Note: $L_g \geq B_g$
 $L_g = (n_1 - 1)d + 2(D/2)$
 $B_g = (n_2 - 1)d + 2(D/2)$

$$Q_{g(u)} = \eta \Sigma Q_u$$

$$Q_{g(u)} = \Sigma Q_u$$

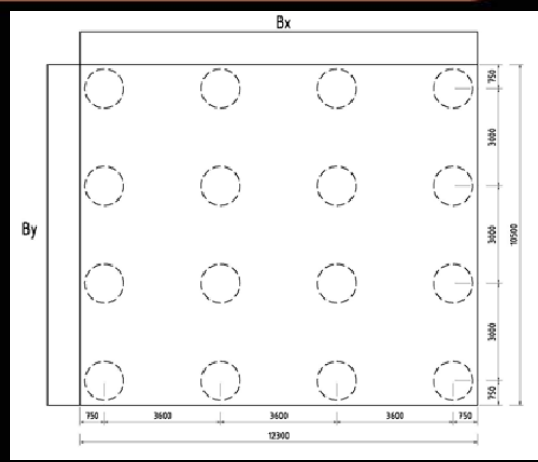
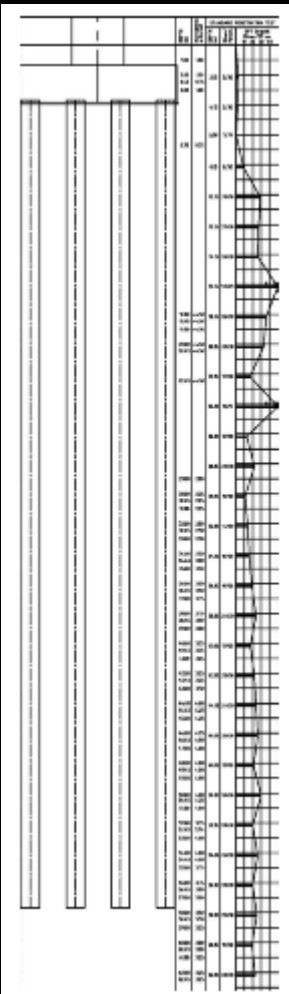
$$\eta = \frac{Q_{g(u)}}{\Sigma Q_u} = \frac{f_{av} [2(n_1 + n_2 - 2)d + 4D] L}{n_1 n_2 p L f_{av}}$$

$$= \frac{2(n_1 + n_2 - 2)d + 4D}{pn_1 n_2}$$

$$Q_{g(u)} = \left[\frac{2(n_1 + n_2 - 2)d + 4D}{pn_1 n_2} \right] \Sigma Q_u$$



Efisiensi Pile Group

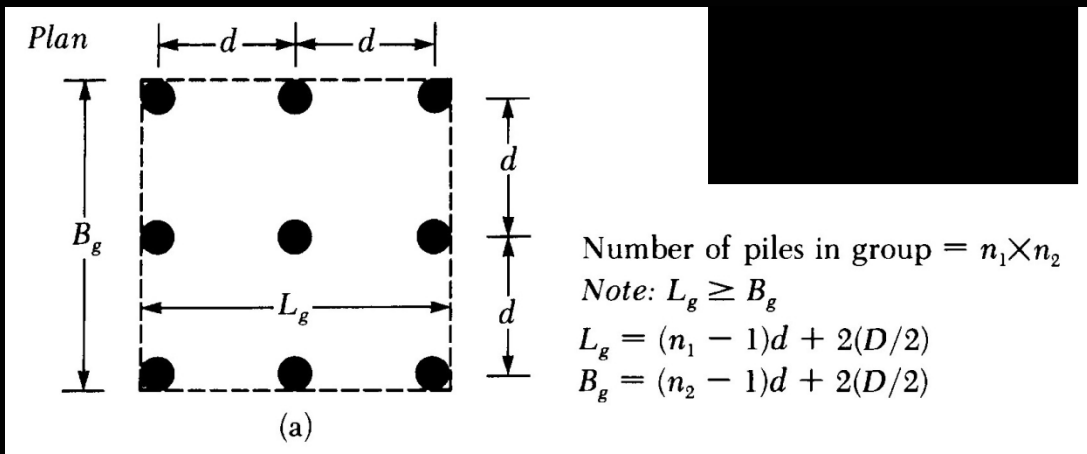


Number of Piles	16		Perimeter	44.4	m
Nx	4	columns	Qs block	164166	m
Sx (Column spacing)	3.6	m	Qb block	32322	kN
Ny	4	rows	Qu grup block	196488	kN
Sy (Row spacing)	3	m	n Qsingle	255346	kN
Bx	12	m	Efisiensi Grup Pile	0.77	
By	10.2	m			

Qs block = 164166 kN
 Qb block = 32322 kN
 Qu Block = Qs block + Qb block = 196488 kN
 N Qu single = 16 * 15959 = 255346 kN

$$\eta = \frac{Q_{u \text{ block}}}{n Q_{u \text{ single}}} = \frac{196488}{255346} = 0.77$$

Persamaan Converse-Labarre



$$\eta = 1 - \left[\frac{(n_1 - 1)n_2 + (n_2 - 1)n_1}{90n_1n_2} \right] \theta$$

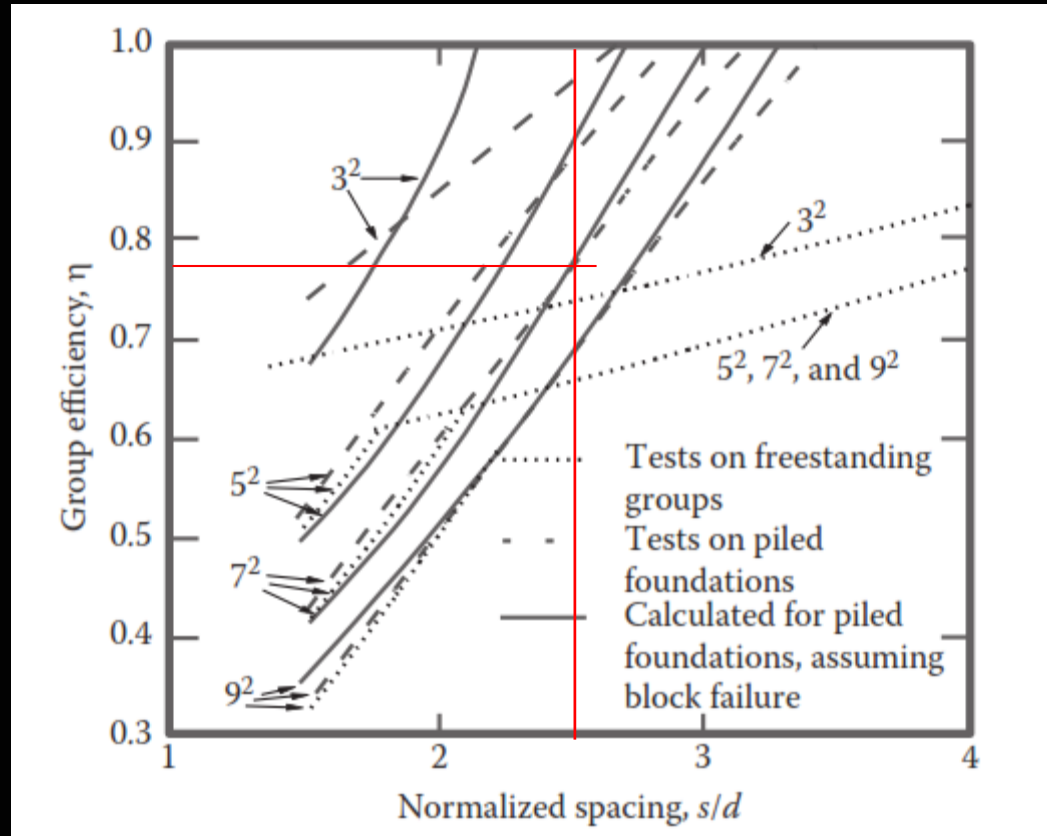
dimana θ (derajat) = $\tan^{-1}(D/d)$

Efisiensi Pile Group



Name	Equation
Converse–Labarre equation	$\eta = 1 - \left[\frac{(n_1 - 1)n_2 + (n_2 - 1)n_1}{90n_1n_2} \right] \theta$ <p>where $\theta(\text{deg}) = \tan^{-1}(D/d)$</p>
Los Angeles Group Action equation	$\eta = 1 - \frac{D}{\pi d n_1 n_2} [n_1(n_2 - 1) + n_2(n_1 - 1) + \sqrt{2}(n_1 - 1)(n_2 - 1)]$
Seiler–Keeney equation (Seiler and Keeney, 1944)	$\eta = \left\{ 1 - \left[\frac{11d}{7(d^2 - 1)} \right] \left[\frac{n_1 + n_2 - 2}{n_1 + n_2 - 1} \right] \right\} + \frac{0.3}{n_1 + n_2}$ <p>where d is in ft</p>

Daya Dukung Pile Group



Untuk perhitungan dengan efisiensi, kapasitas dukung pile group dihitung dengan cara sebagai berikut,

$$Q_g (\text{ijin}) = Q_s (\text{ijin}) \times \eta \times n$$

Daya Dukung Pile Group

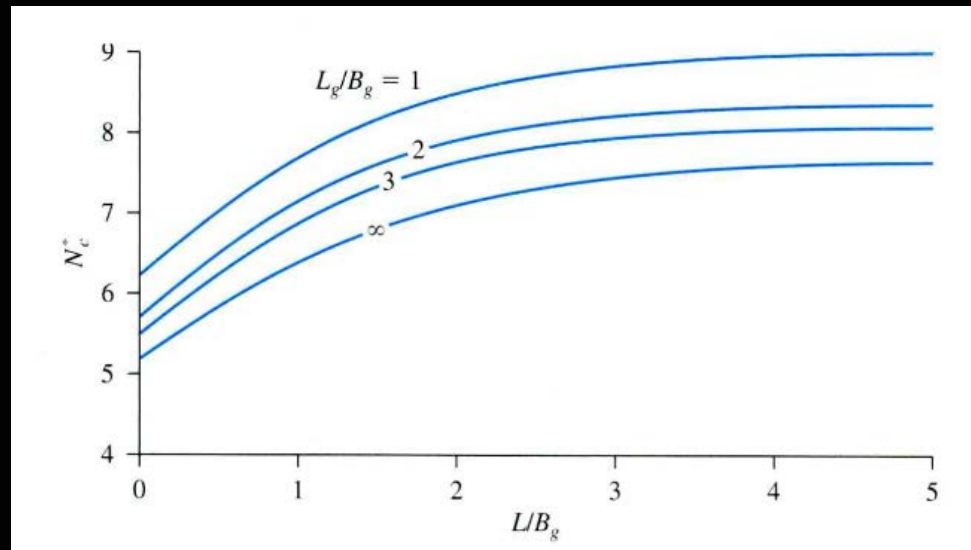


Untuk perhitungan block failure digunakan formula berikut,

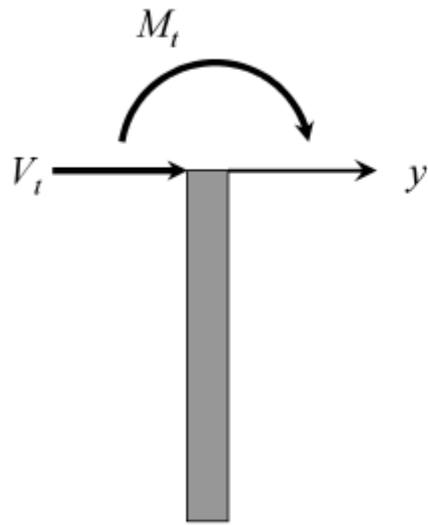
$$Q_g (block) = L_g \times B_g \times c_u \times N_c^* + \sum f_s \times p \times H$$

Untuk lapisan lempung f_s diganti dengan $\alpha \times c_u$

Nilai N_c^* diperoleh dari Gambar berikut.

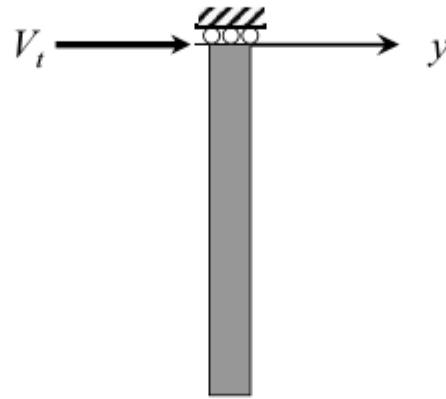


4.4 Daya Dukung Lateral Tiang



Free-head

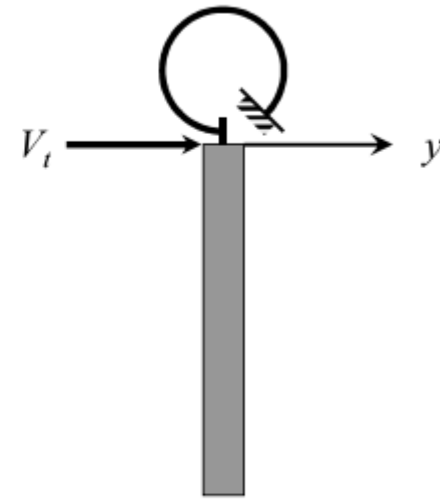
(a)



Fixed-Head

(b)

Spring (takes no shear, but restrains pile head rotation)



Partially Restrained

(c)

Daya Dukung Lateral Tiang

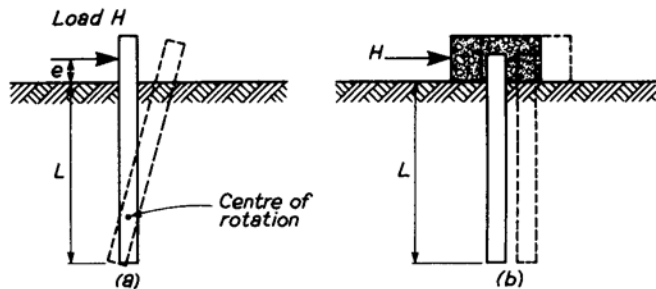


Fig. 6.18 Short vertical pile under horizontal load

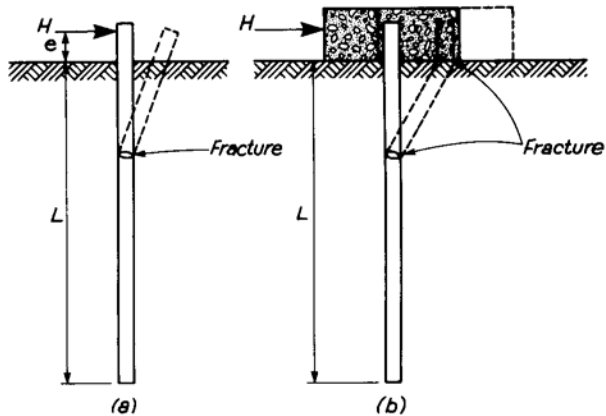


Fig. 6.19 Long vertical pile under horizontal load
(a) Free head (b) Fixed head

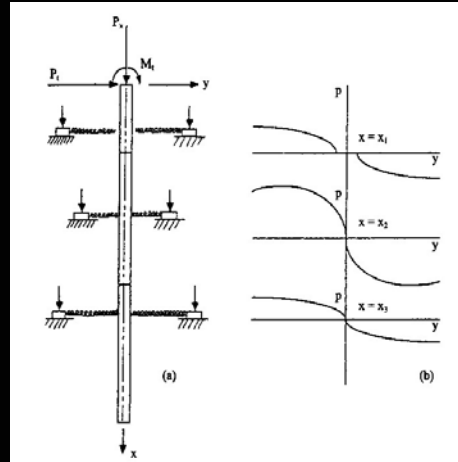
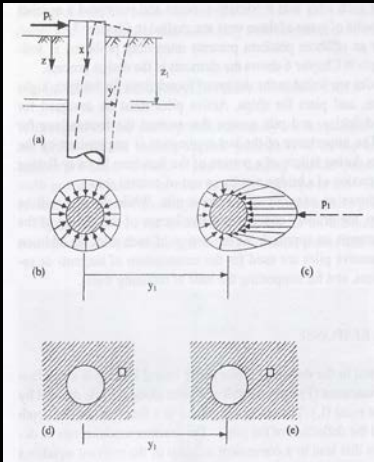
- ❑ Metode Brom
- ❑ Metode p-y curve

Metode Brom

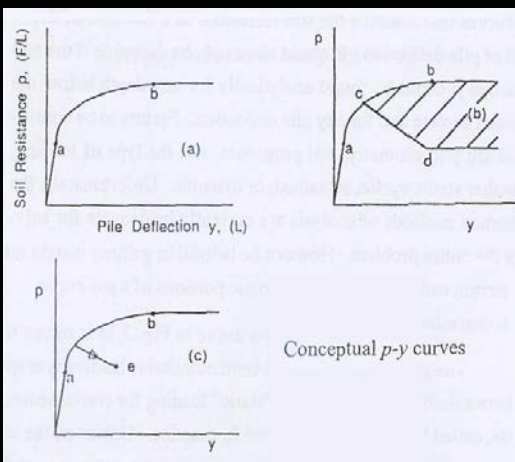
Daya Dukung Lateral Tiang



Metode p-y Curve



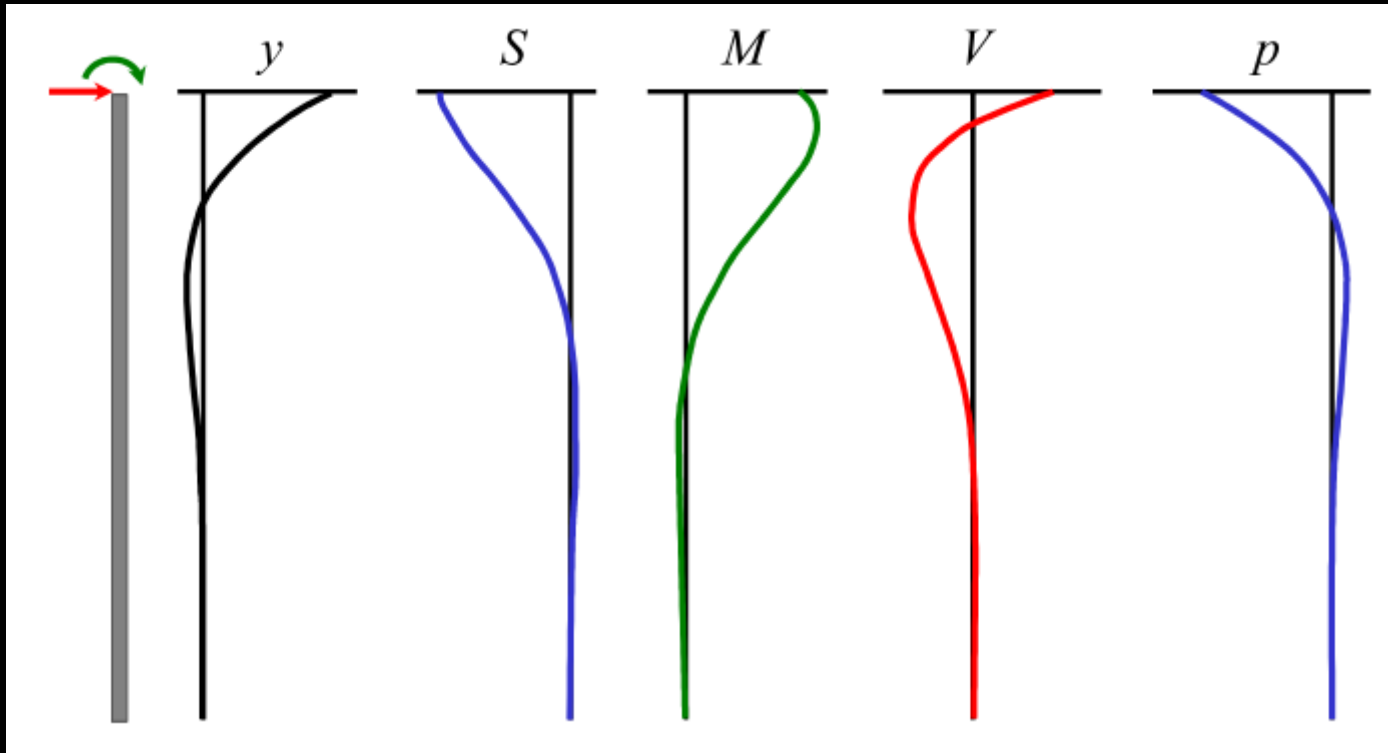
Lebih tepat menggunakan metoda p-y curves: memperhitungkan interaksi antara tanah dan tiang, dapat digunakan untuk lapisan tanah yang berbeda-beda, dll.



Computer Program :

1. COM 624
2. LPILE

Gaya lateral V pada defleksi kepala tiang y



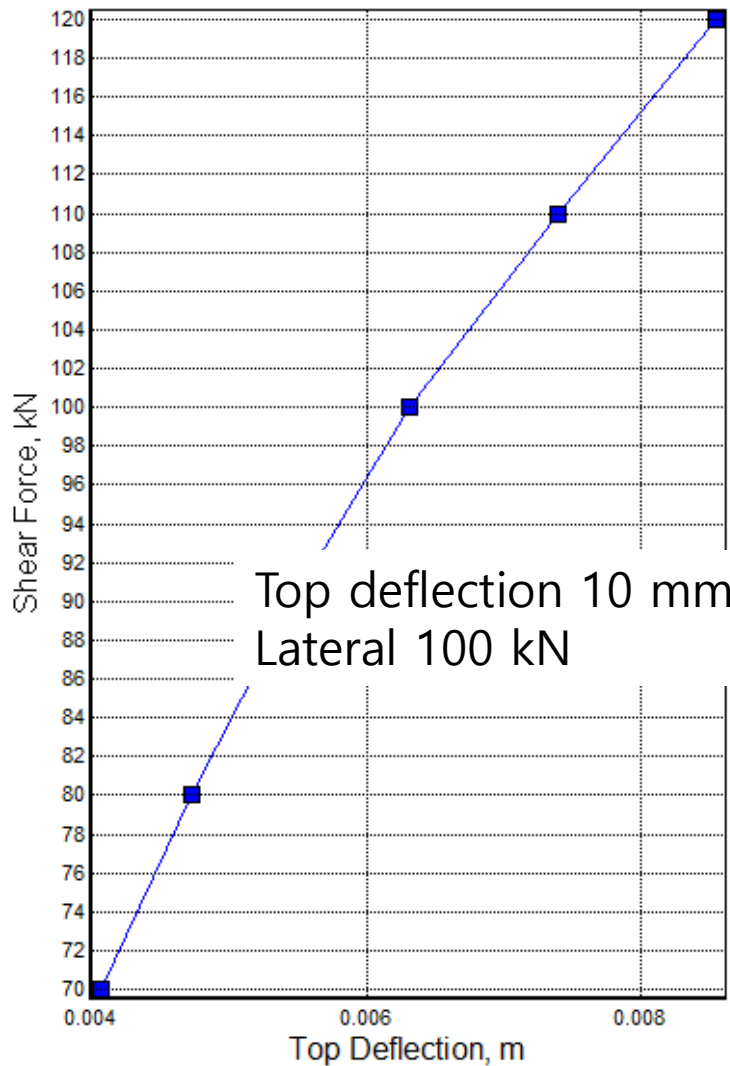
S = slope of curve
 M = bending moment
 p = soil reaction

Single Pile



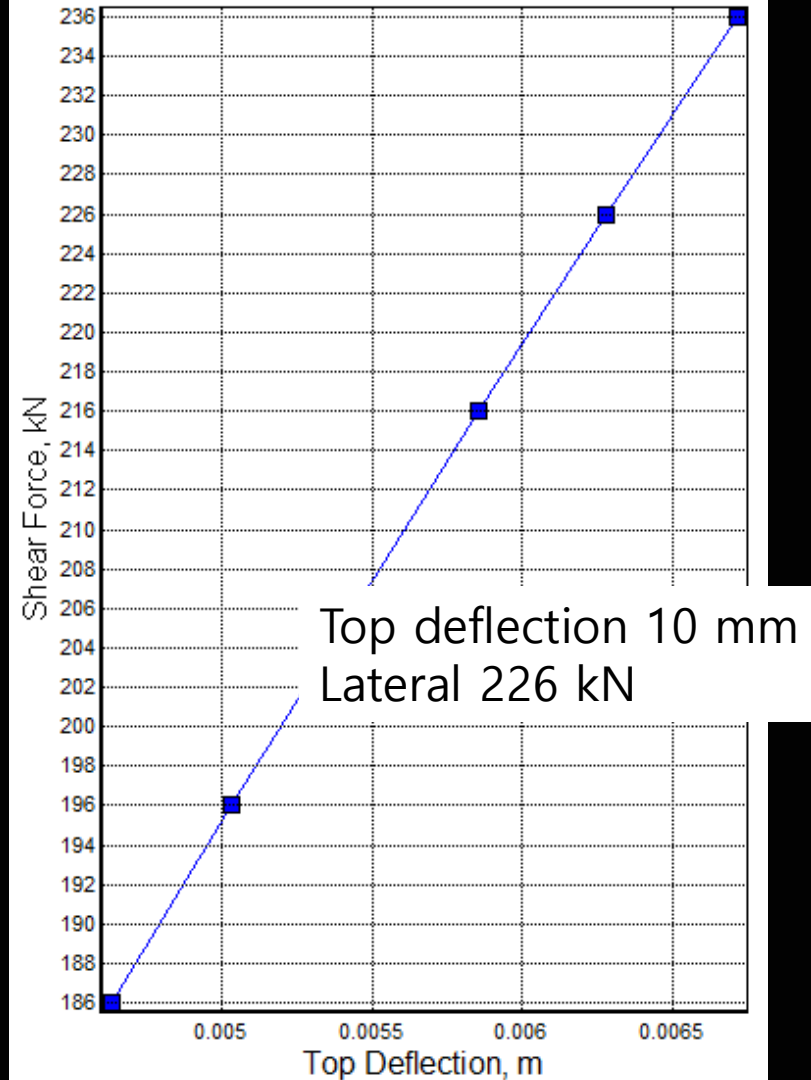
Free Head

Shear Force vs. Top Deflection

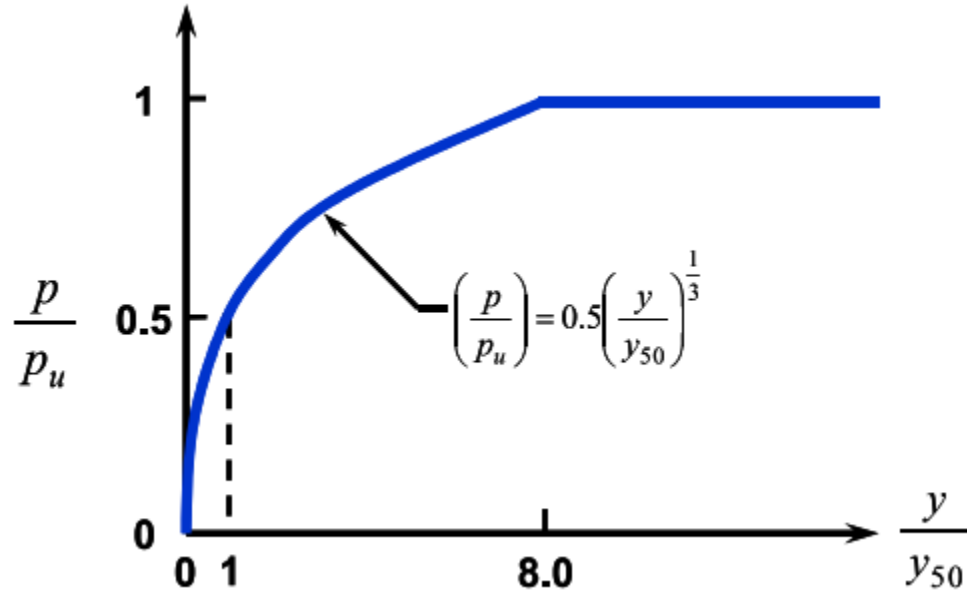


Fixed Head

Shear Force vs. Top Deflection

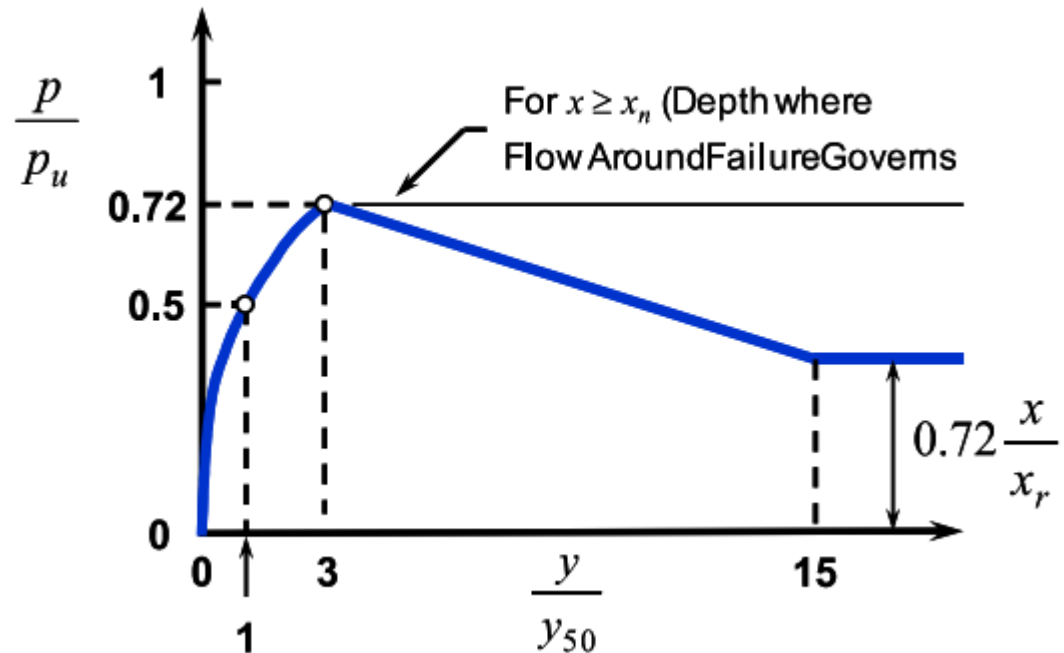


Single Pile



Static loading

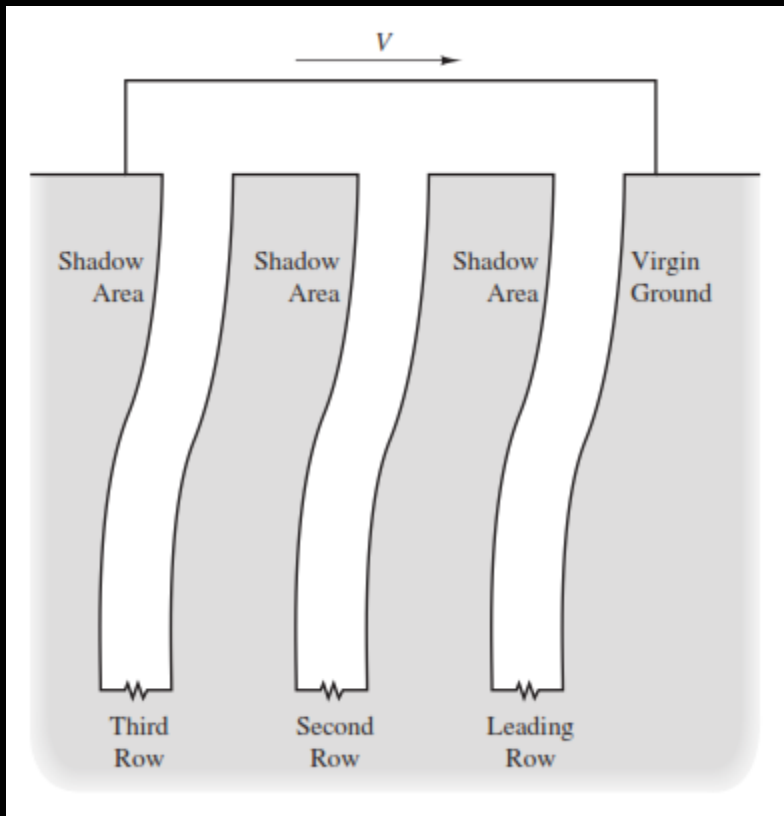
Cyclic loading



Pile Group



Efek pile group diperoleh dengan mereduksi p-y curve berdasarkan suatu p-multiplier



Center-to-center Spacing of Piles	P_m		
	Leading Row	2nd Row	3rd and Subsequent Rows
$3B$	0.70	0.50	0.35
$4B$	0.85	0.65	0.50
$5B$	1.00	0.85	0.70
$\geq 6B$	1.00	1.00	1.00

Coduto, Kitch, Yeung (2016)

Reduksi p-y curve

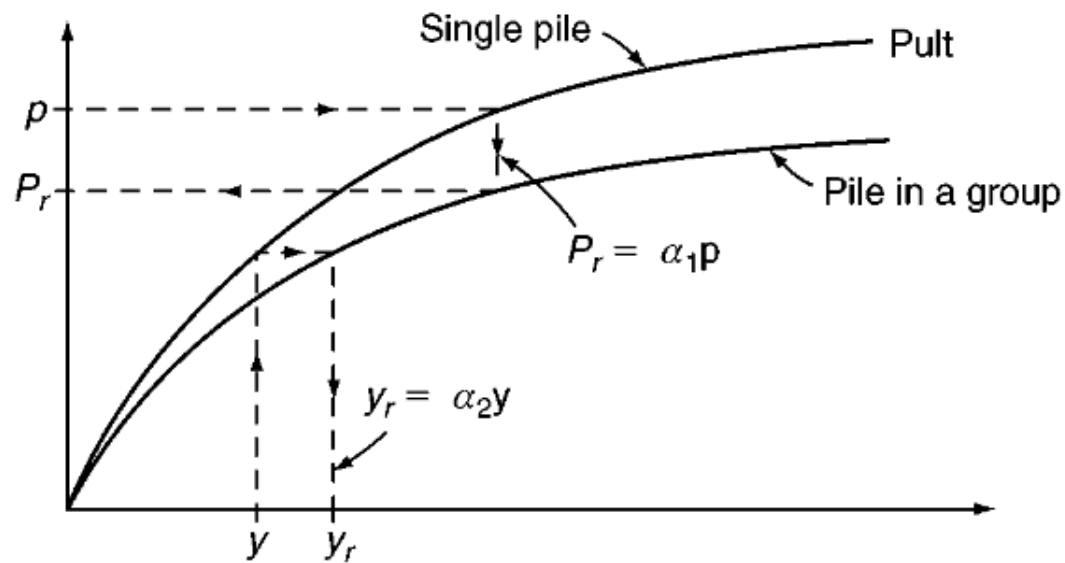


Figure 5.20 Modification of soil resistance for a p - y curve for a single pile to for interaction of piles in a group.

Reese and van Impe (2011)

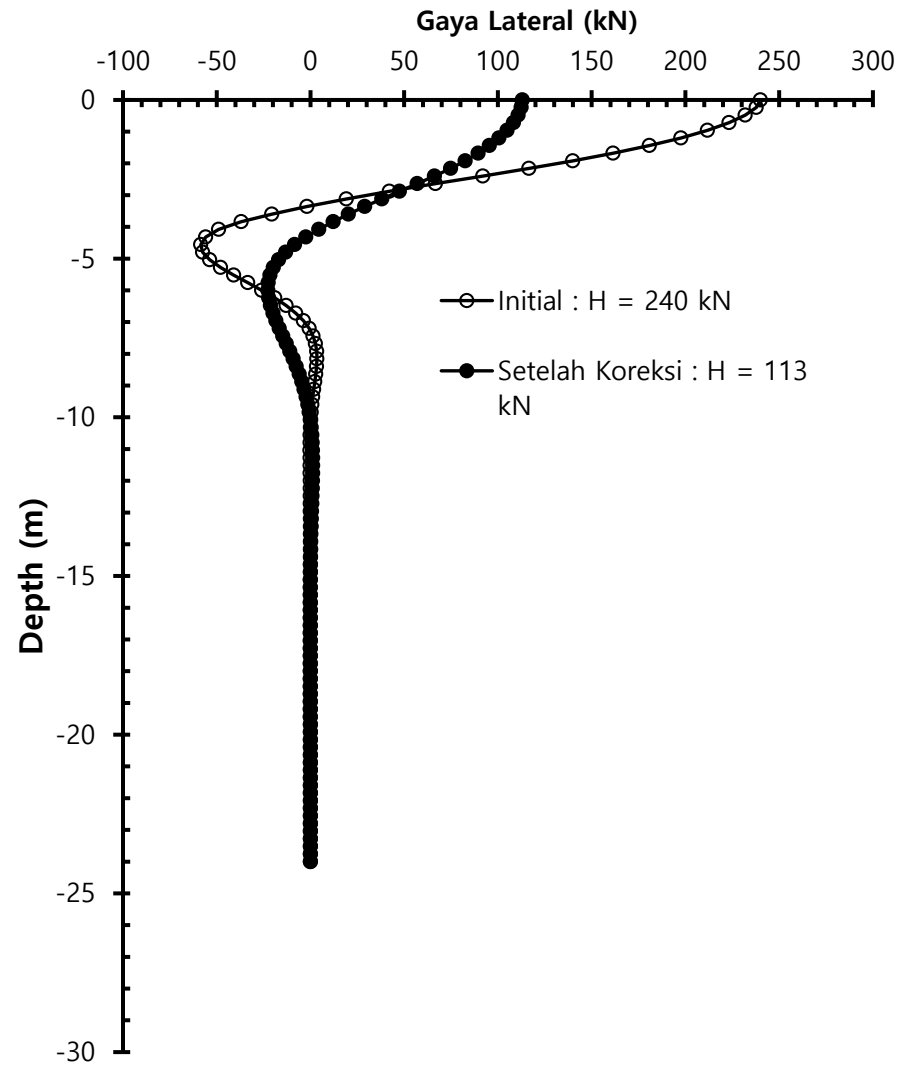
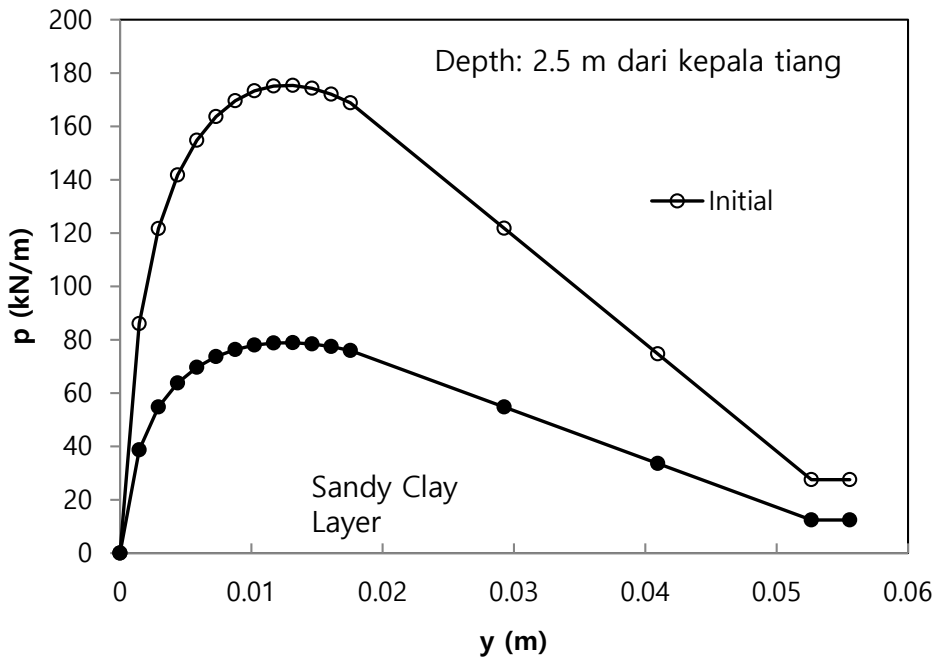
Reduksi p-y Curve Untuk Lateral Grup Pile

S/B^b	G_e
3	0.50
4	0.60
5	0.68
6	0.70

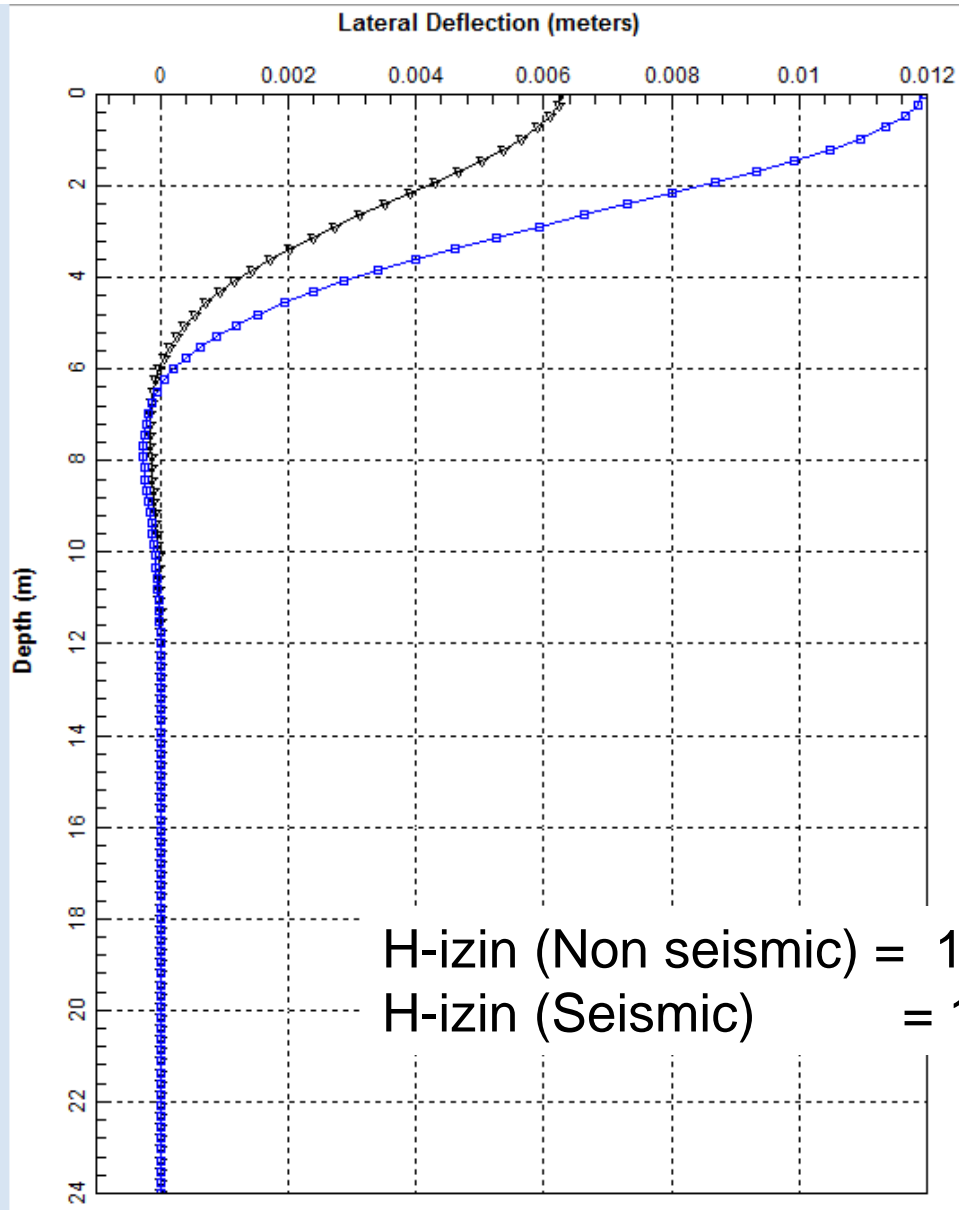
*These are interpolated values from graphs provided by Oteo (1972).

^bS = center-to-center pile spacing.
 B = pile diameter or width.

Faktor koreksi : 0.45

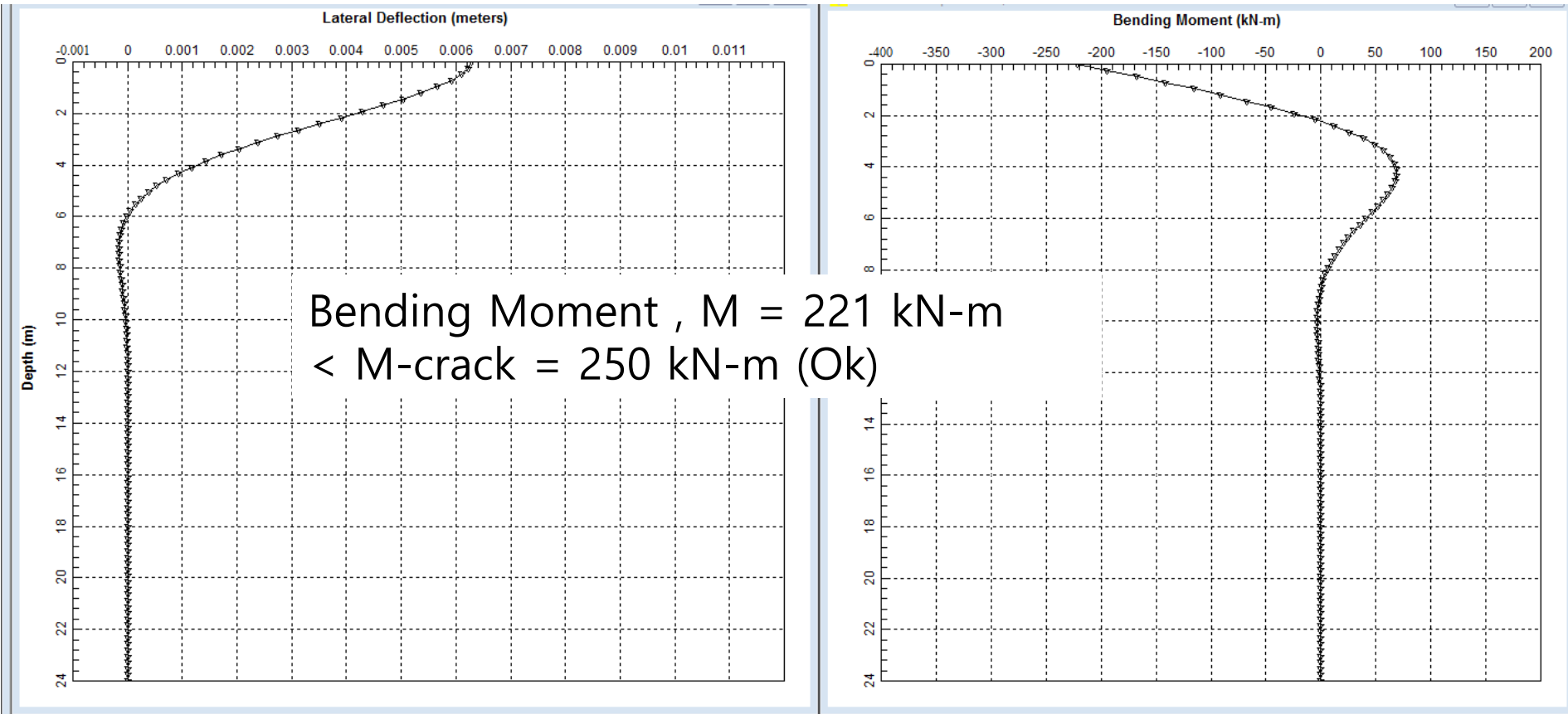


Contoh Daya Dukung Izin Lateral Tiang Tunggal Dalam Grup

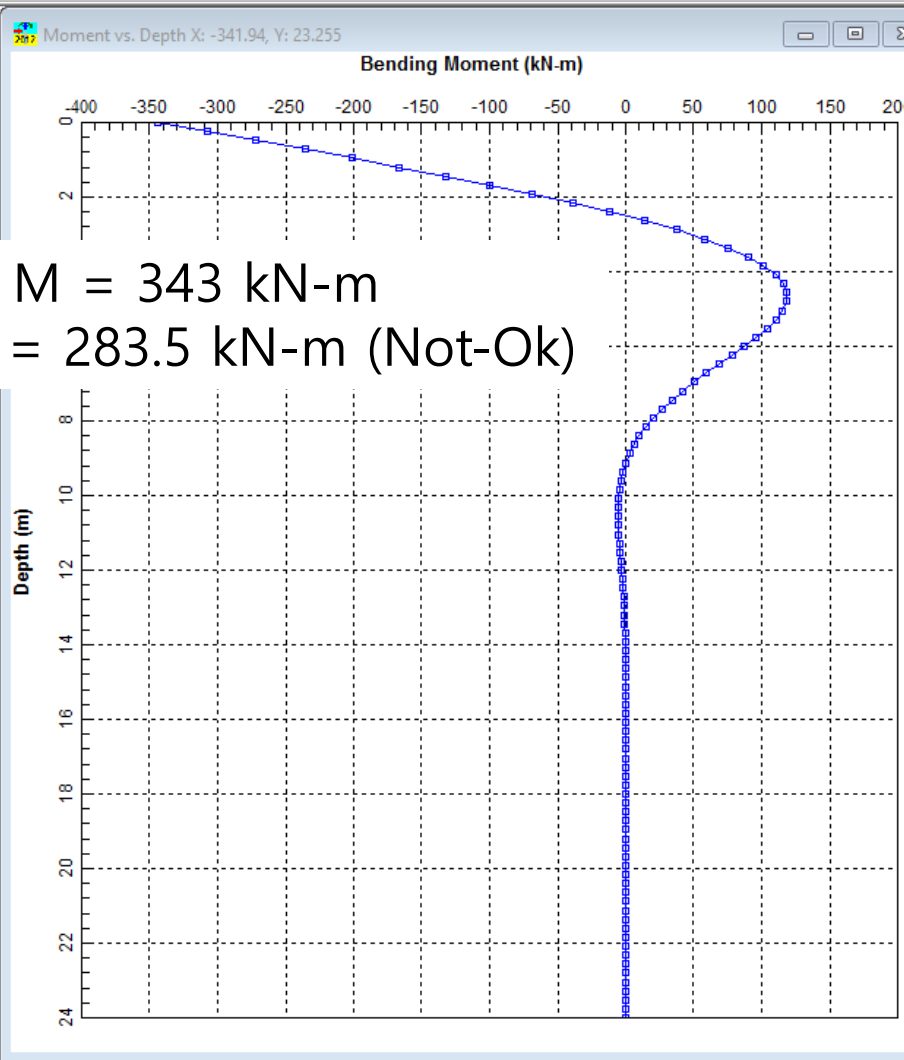
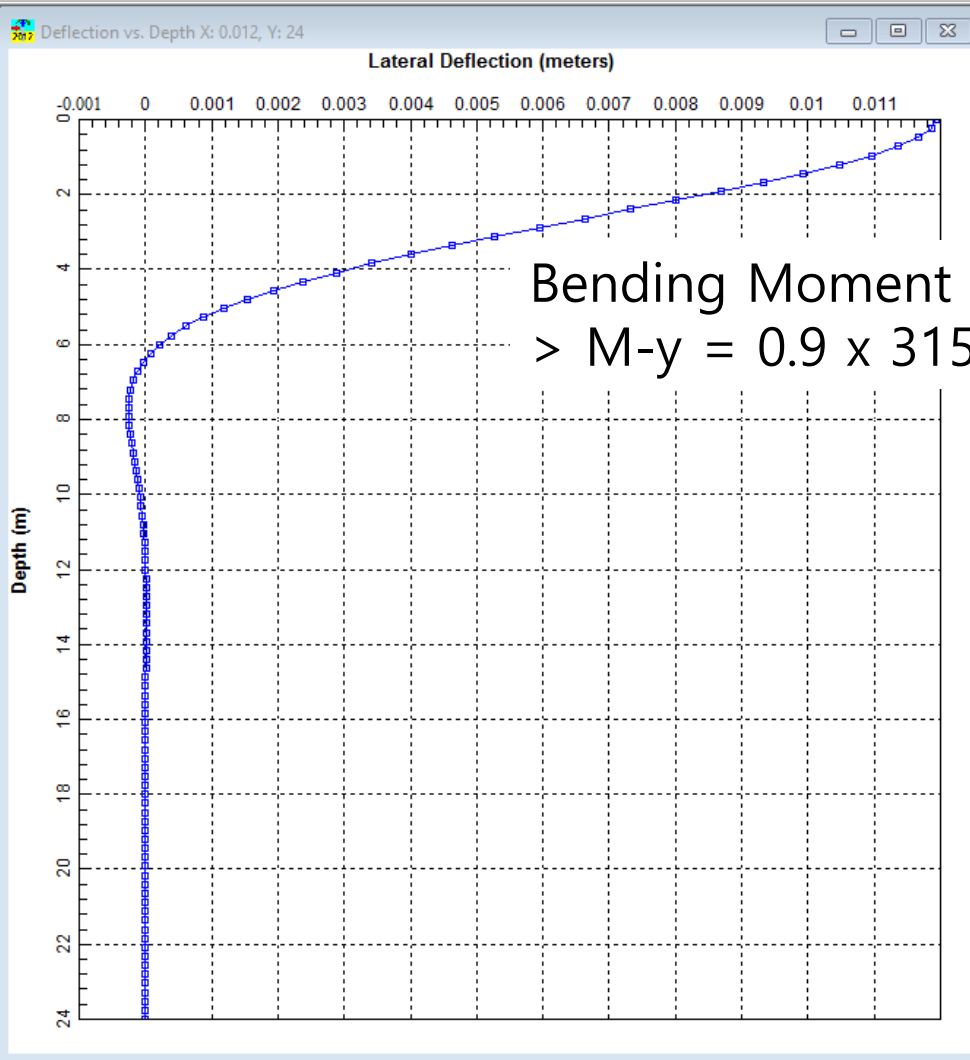


H-izin (Non seismic) = 113 kN ; Top Deflec. : 6.30 mm
H-izin (Seismic) = 151 kN ; Top Deflec. : 12.0 mm

Bending Moment

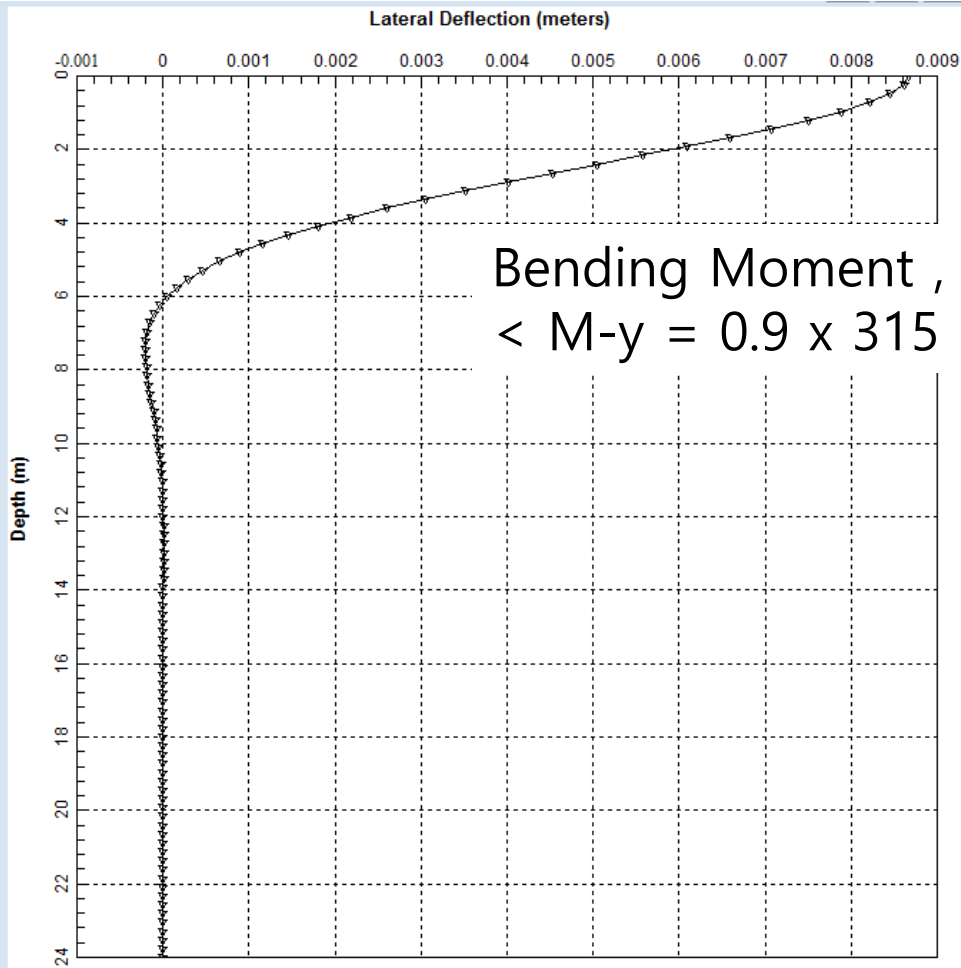


H-izin (Non seismic) = 113 kN

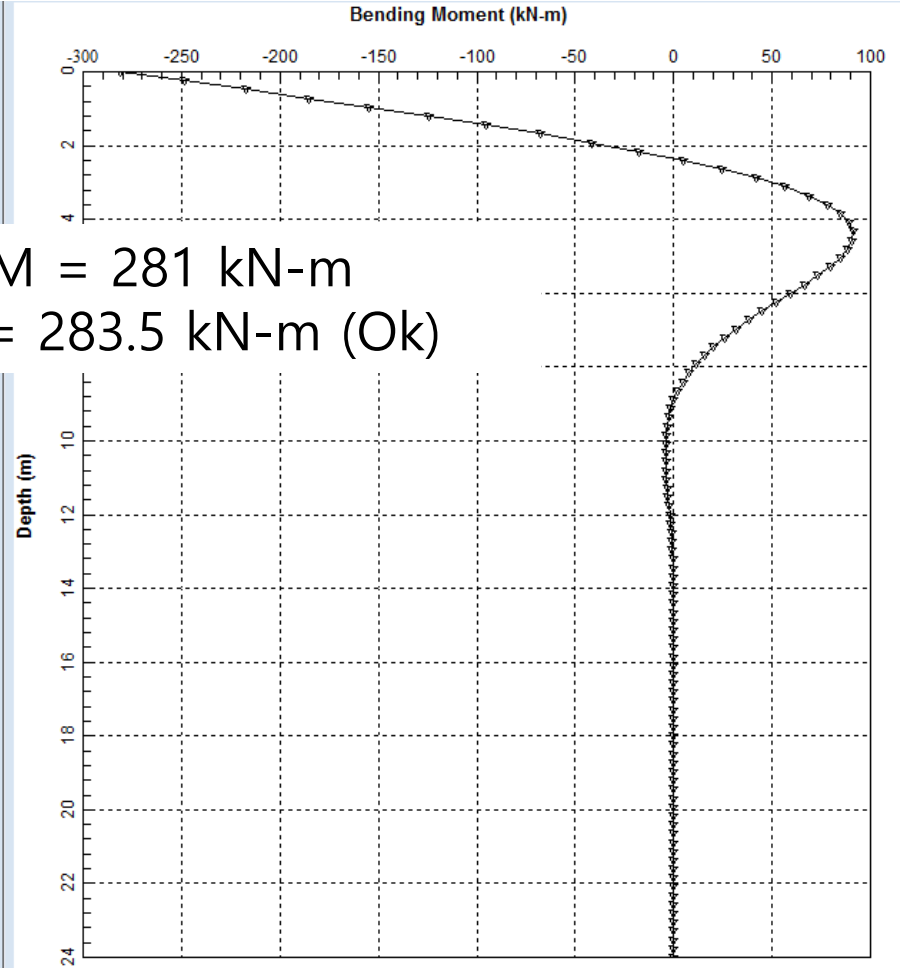


Bending Moment , $M = 343 \text{ kN-m}$
 $> M-y = 0.9 \times 315 = 283.5 \text{ kN-m (Not-Ok)}$

H-izin (Seismic) = 151 kN



Bending Moment , $M = 281 \text{ kN-m}$
 $< M-y = 0.9 \times 315 = 283.5 \text{ kN-m (Ok)}$



H-izin (Seismic) = 134 kN

4.5 Settlement



- Immediate Settlement
- Consolidation Settlement
- Total Settlement
- Differential Settlement

4.5 Settlement



- Immediate Settlement

$$s_{g(e)} = \sqrt{\frac{B_g}{D}} s_e \quad (12.139)$$

where

$s_{g(e)}$ = elastic settlement of group piles

B_g = width of group pile section

D = width or diameter of each pile in the group

s_e = elastic settlement of each pile at comparable working load (see Section 12.18)

(Das and Sivakugan, 2019)

4.5 Settlement



- Consolidation Settlement

$$S_{c(p)} = \frac{C_c H_c}{1 + e_o} \log \frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o} \quad \text{(for normally consolidated clays)}$$

$$S_{c(p)} = \frac{C_s H_c}{1 + e_o} \log \frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o} \quad \text{for overconsolidated clays with } \sigma'_o + \Delta\sigma'_{av} < \sigma'_c$$

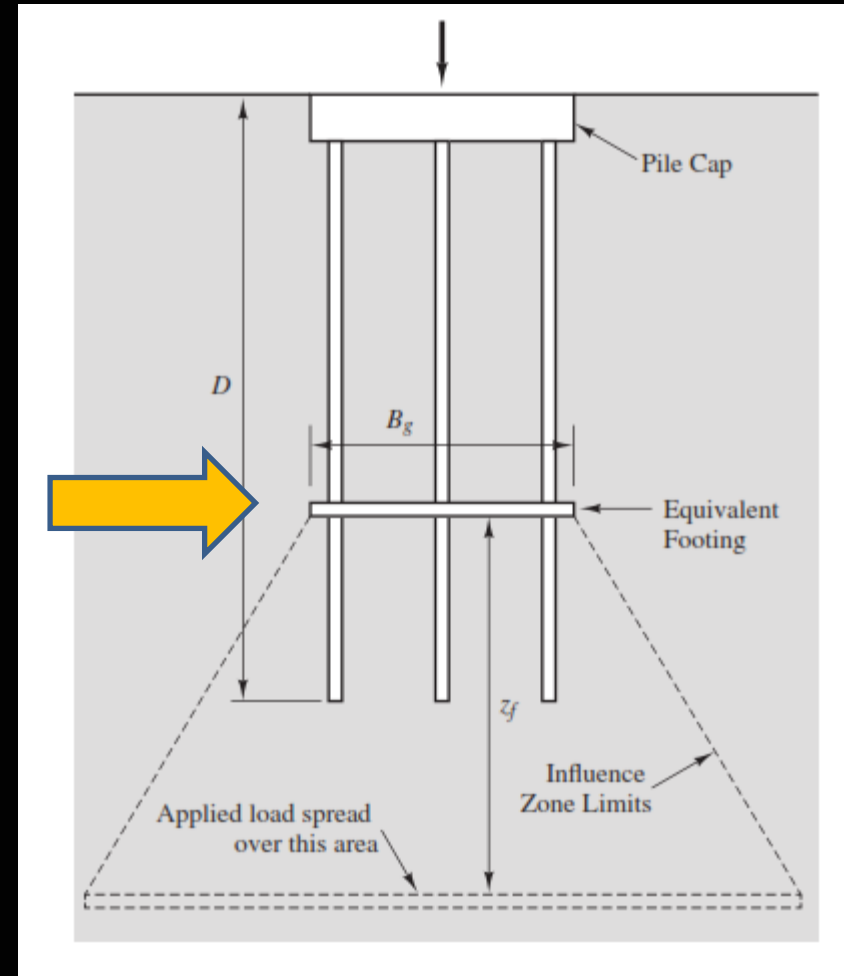
$$S_{c(p)} = \frac{C_s H_c}{1 + e_o} \log \frac{\sigma'_c}{\sigma'_o} + \frac{C_c H_c}{1 + e_o} \log \frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_c} \quad \text{for overconsolidated clays with } \sigma'_o < \sigma'_c < \sigma'_o + \Delta\sigma'_{av}$$

(Das and Sivakugan, 2019)

4.5 Settlement



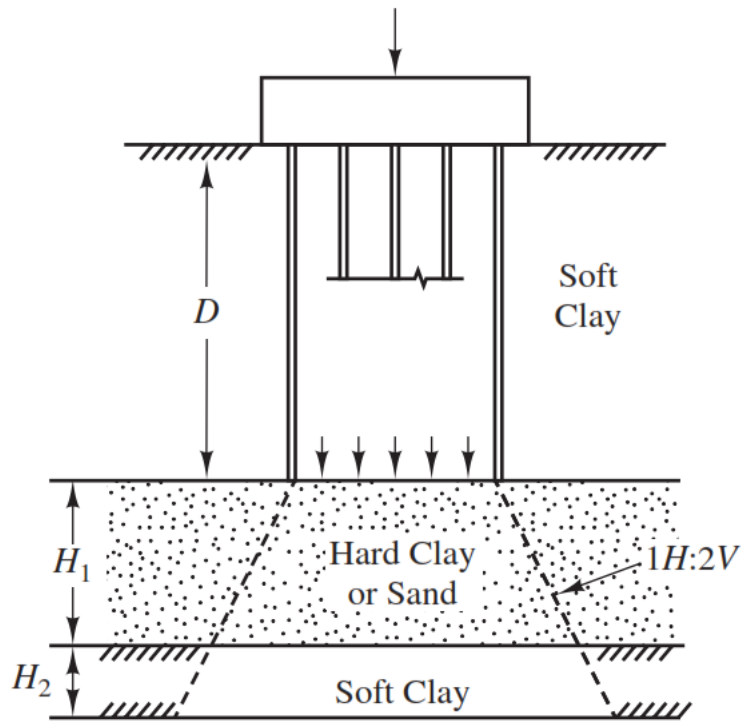
Posisi Equivalent Footing



4.5 Settlement



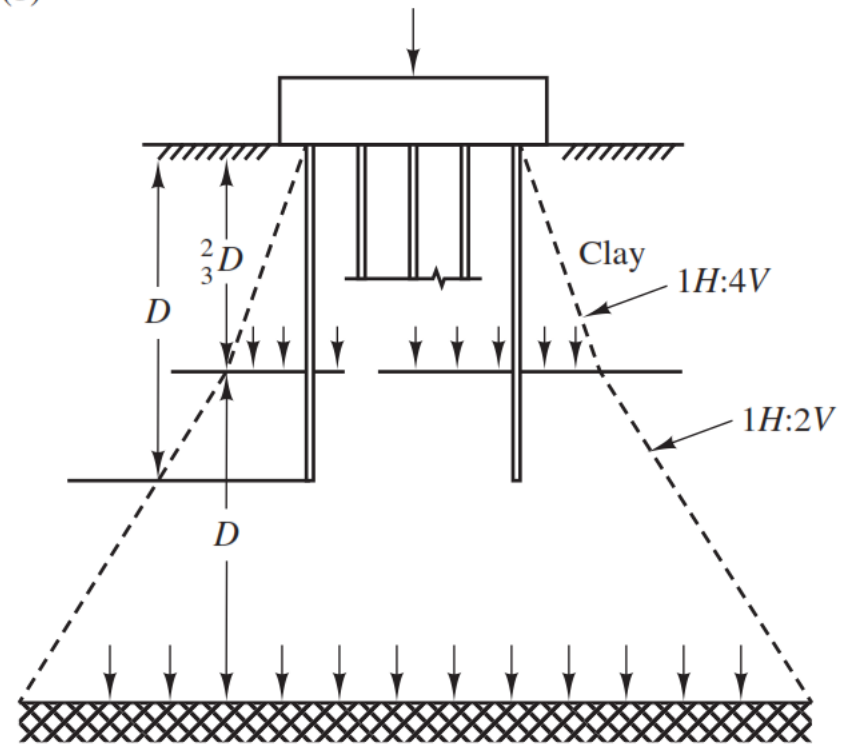
(a)



Equivalent Footing at Depth D

Settlement of Pile Group = Compression of Layers H_1 and H_2 Under Pressure Distribution Shown.

(b)



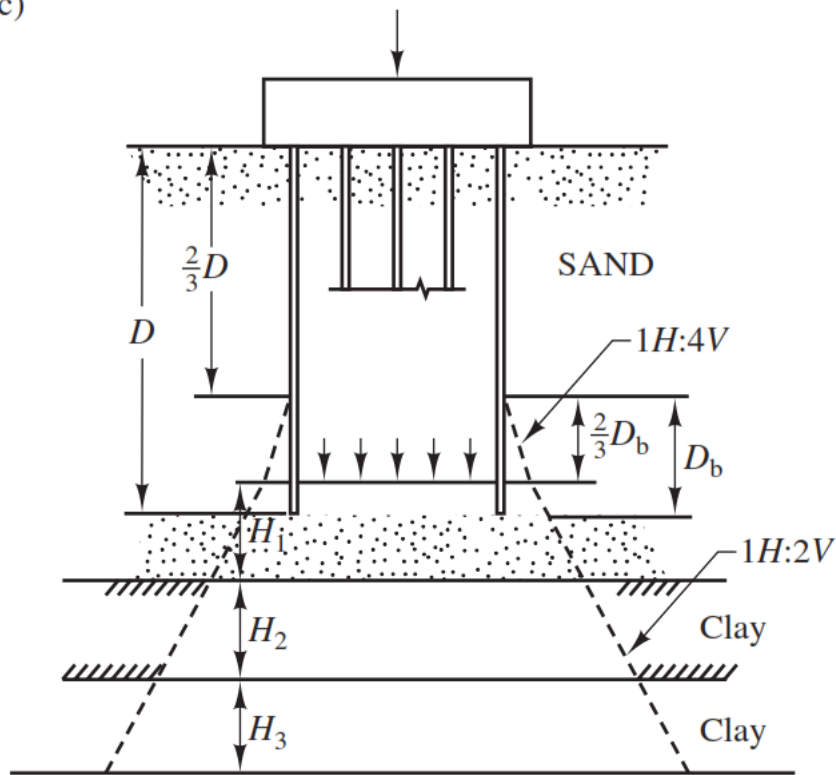
Equivalent Footing at Depth $2/3 D$

Settlement of Pile Group = Compression of Layer H Under Pressure Distribution Shown.

4.5 Settlement



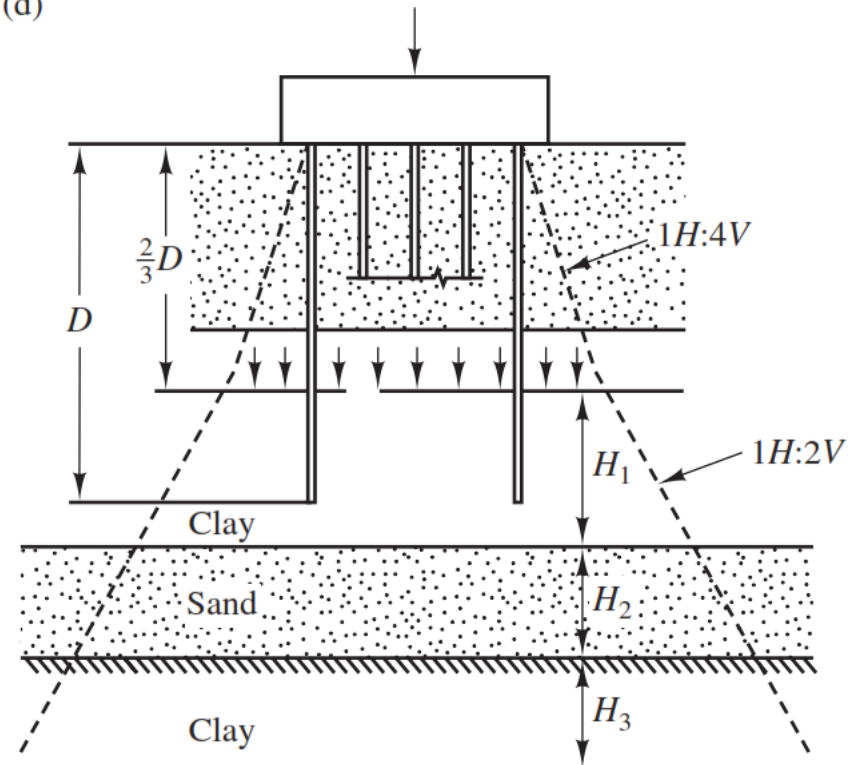
(c)



Equivalent Footing at Depth $8/9D$

Settlement of Pile Group = Compression of Layers H_1 , H_2 , and H_3 Under Pressure Distribution Shown.

(d)



Equivalent Footing at Depth $2/3D$

Settlement of Pile Group = Compression of Layers H_1 , H_2 , and H_3 Under Pressure Distribution Shown.



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