One- way Eccentricity (From Coduto, 2001)

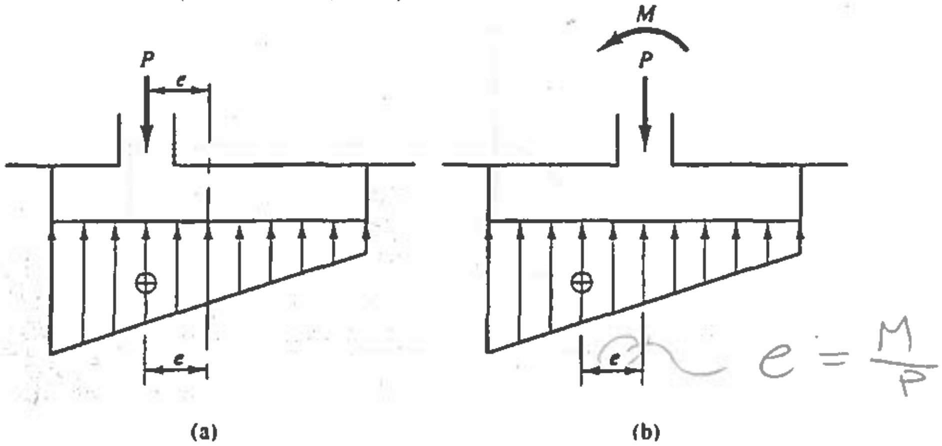
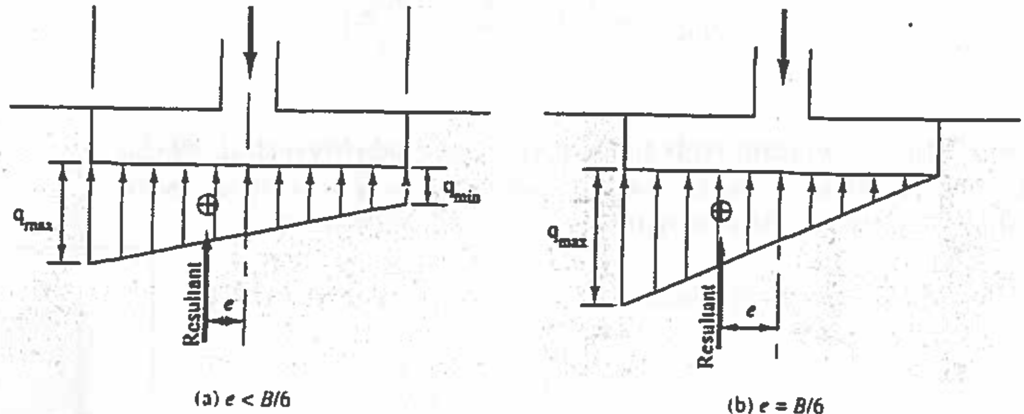
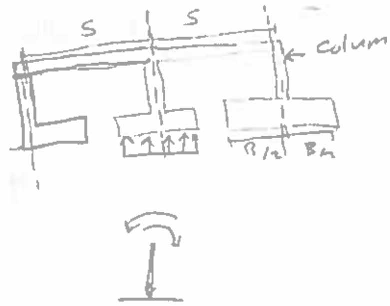
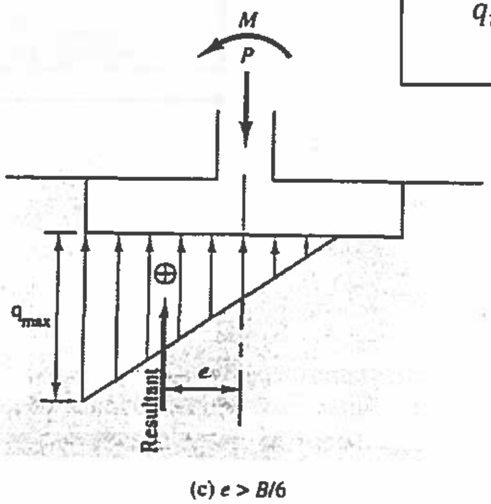


Figure 5.14 (a) Eccentric and (b) moment loads on shallow foundations.



$$q_{max} = \frac{P}{BL}\left(1 + \frac{6e}{B}\right)$$
$$q_{min} = \frac{P}{BL}\left(1 - \frac{6e}{B}\right)$$



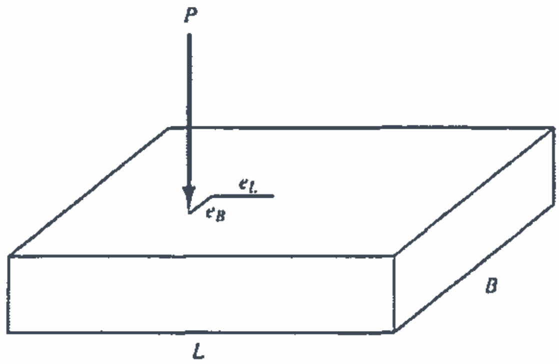


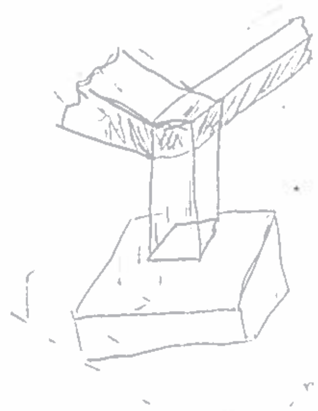
$$q_{max} = \frac{4P}{3L(B - 2e)}$$

e= M/P and

P is the gross load = Net structure load + q

Two-way Eccentricity





When:

$$\frac{6e_B}{B} + \frac{6e_L}{B} \leq 1.0$$

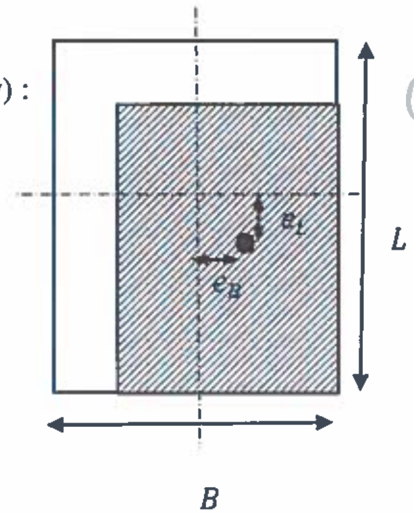
$$q_{max} = \frac{P}{BL}\left(1 \mp \frac{6e_B}{B} \mp \frac{6e_L}{L}\right)$$

F= q_u/q_{max}

Equivalent (Effective) uniformly loaded Area Method (Meyerhof, 1953):

Intermediate value between average and maximum bearing pressure

Will be used to calculate bearing capacity and settlement



1- Determine equivalent dimensions (one or two way eccentricity) :

$$B' = B - 2e_B$$
$$L' = L - 2e_L$$

2- Calculate q_u (ultimate bearing capacity):
   a. Use effective dimension to calculate shape factors
   b. Use original dimensions to calculate depth factors

3- $qa=q_{eq}= (P+W_f)/A'$
   - A'= from B' and L'

4- F= q_u/q_a

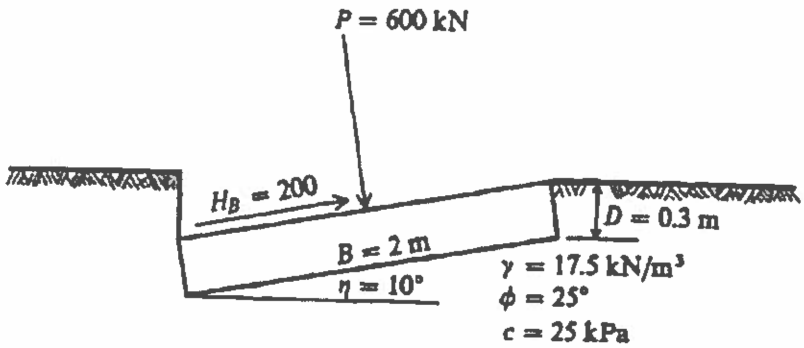
See Example 7.4 pp. 239

CVEG 4143 — **Bearing Capacity** — **Homework# 4**

1-

A 5-ft square, 2-ft deep spread footing is subjected to a concentric vertical load of 60 k and an overturning moment of 30 ft-k. The overturning moment acts parallel to one of the sides of the footing, the top of the footing is flush with the ground surface, and the groundwater table is at a depth of 20 ft below the ground surface. Determine whether the resultant force acts within the middle third of the footing, compute the minimum and maximum bearing pressures, and show the distribution of bearing pressure in a sketch.

2- A square footing 2 X 2 m has to be constructed as shown below. Are the footing dimensions adequate for the given loads if we use a safety factor F = 3?



3- (Bonus question): Based on what we have discussed in class about friction and adhesion between soils and construction materials such as concrete and steel, check sliding safety of the footing due to the effect of the force H_B. For now, neglect the footing weight and the lateral resistance of the soil (passive resistance).

Given
dime, P, F

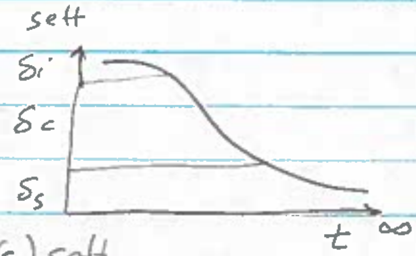
- either find F and check F given
- or find Pall and check with P given.

check

① - q_u
- $q_{all} = q = \frac{P + W_f}{A}$
- $F = \frac{q_u}{q_{all}}$ (check if F > 3)

② - q_u
- Find q_{all} from $q_{all} = \frac{q_u}{F \to \text{given}(3)}$
- Find P_{all} ($q_{all} = \frac{P_{all} + W_f}{A}$)
- check P_{all} with P

Settlement Analysis:



Sand → Initial (Elastic) sett

Clay → Consolidation Settlement + Elastic

usually to a depth where $\Delta\sigma \le 0.1q$

Settlement in Sand:

The analysis based on in-situ tests → CPT, → SPT, → plateload

why? Difficult to get und. samples from soil

*** ① See Next page (p. 6)

② Schmertmann's Method:

$$\delta = C_1 C_2 C_3 (q_{gross} - \sigma'_{zD}) \sum \frac{I_\varepsilon H}{E_s}$$

different — soil not perfectly elastic

C_1 = depth factor

C_2 = Creep factor

C_3 = Shape factor

I_ε = Strain influence factor

$\sigma'_{zD} = \gamma D$

E_s = Modulus of elasticity (see Page (5))

TABLE 2.1 TYPICAL ALLOWABLE TOTAL SETTLEMENTS FOR FOUNDATION DESIGN

Type of Structure	Typical Allowable Total Settlement, δ_a (in)	(mm)
Office buildings	0.5–2.0 (1.0 is the most common value)	12–50 (25 is the most common value)
Heavy industrial buildings	1.0–3.0	25–75
Bridges	2.0	50

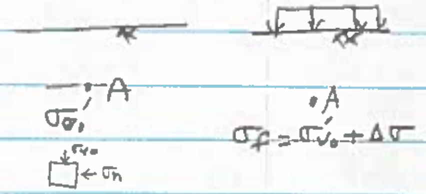
TABLE 2.2 ALLOWABLE ANGULAR DISTORTION, θ_a (COMPILED FROM WAHLS, 1994; AASHTO, 1996; AND OTHER SOURCES)

Type of Structure	θ_a
Steel tanks	1/25
Bridges with simply-supported spans	1/125
Bridges with continuous spans	1/250
Buildings that are very tolerant of differential settlements, such as industrial buildings with corrugated steel siding and no sensitive interior finishes.	1/250
Typical commercial and residential buildings.	1/500
Overhead traveling crane rails.	1/500
Buildings that are especially intolerant of differential settlement, such as those with sensitive wall or floor finishes.	1/1000
Machinery[a]	1/1500
Buildings with unreinforced masonry load-bearing walls	
Length/height ≤ 3	1/2500
Length/height ≥ 5	1/1250

[a] Large machines, such as turbines or large punch presses, often have their own foundation, separate from that of the building that houses them. It often is appropriate to discuss allowable differential settlement issues with the machine manufacturer.

②

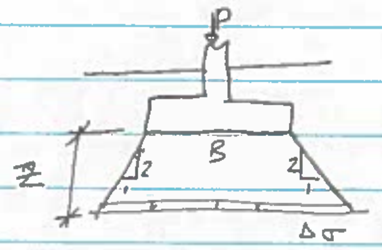
* Settlement is due to change in stress
  - → Add structures or fill
  - → Change in G.W.T
  - → lateral movement



How to calculate $(\Delta\sigma)$:

1- Approximate method:

$$\Delta\sigma = \frac{P}{(B+Z)(L+B)}$$



boo-see-nesk 2- Boussinesq Method:

* Square and cont.

$$\Delta\sigma_Z = I_\sigma \, q_s$$

③ Add the approximate equation

$$\Delta\sigma = \left[1 - \frac{1}{B} \; -- \right]$$

indosd

σ_Z = Induced Stress due to load

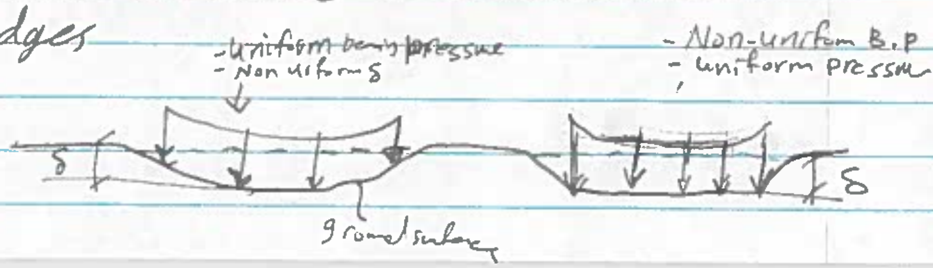
I_σ = stress influence factor Fig(7.2

→ q_s = Net bearing pressure = $\frac{P_{net}}{A_f}$

* Point, Rectangular, Circular footing → see FE Review Manual
  - ↳ $I_\sigma = I_Z$

* Foundation Stiffness:

Large foundations such as mat, need to calculate $\Delta\sigma$ and S @ the centre and the edges



3A

CVEG 4143 **Settlement** **Homework# 5**

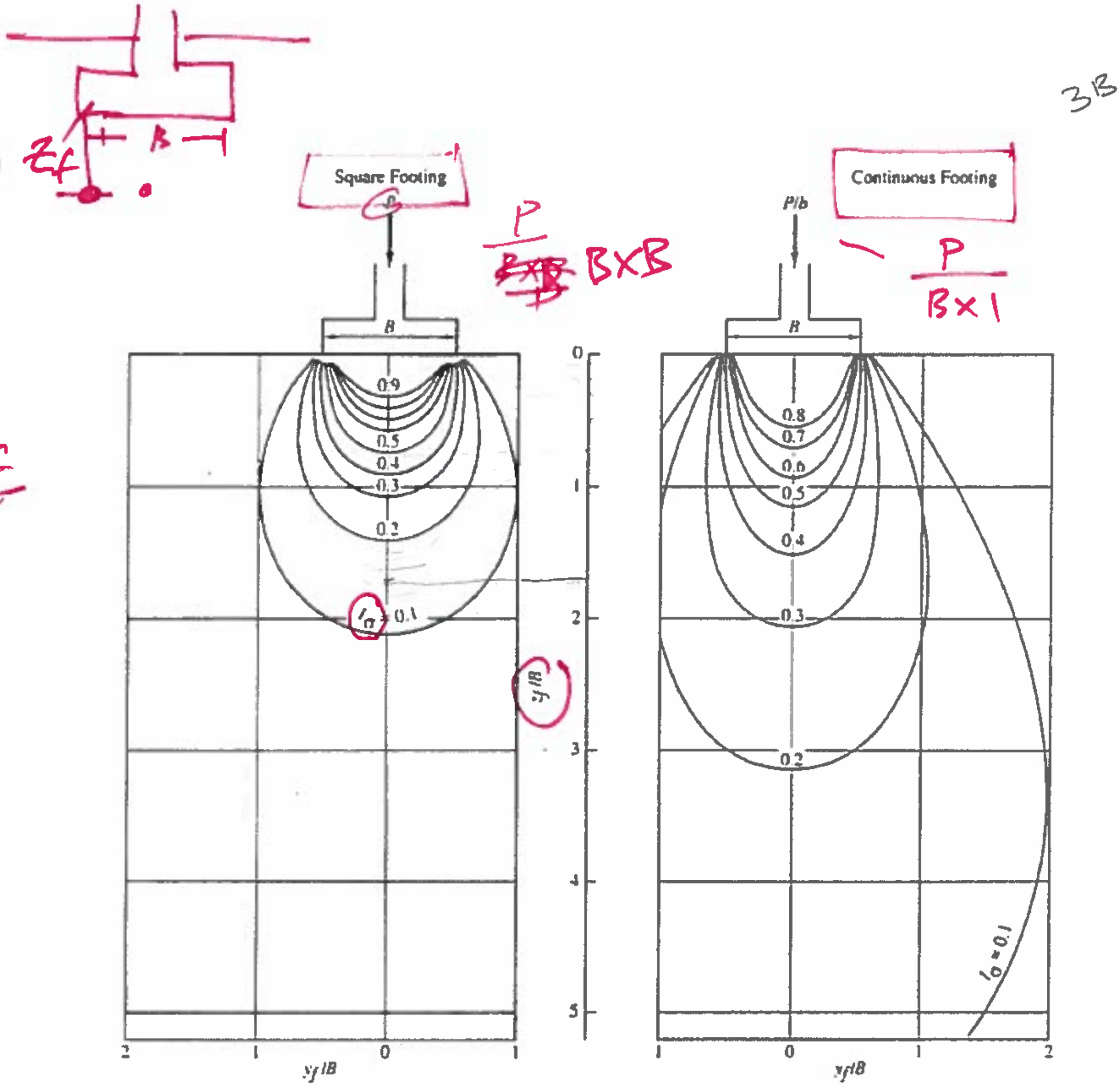
Solve 2.5, 2.6, and 2.7 [Coduto ,2001]

In Coduto (2014), these problems are 5.11, 5.12, and 5.13

2.5 A seven-story steel-frame office building will have columns spaced 7 m on center and will have typical interior and exterior finishes. Compute the allowable total and differential settlements for this building.

2.6 A two-story reinforced concrete art museum is to be built using an unusual architectural design. It will include many tile murals and other sensitive wall finishes. The column spacing will vary between 5 and 8 m. Compute the allowable total and differential settlements for this buiding.

2.7 A 40 ft × 60 ft one-story agricultural storage building will have corrugated steel siding and no interior finish or interior columns. However, it will have two roll-up doors. Compute the allowable total and differential settlement for this building.



y_f = horizontal distance from centerline of footing
z_f = depth below bottom of footing
B = footing width
I_σ = stress inflence factor

Figure 7.2 Stress bulbs based on Newmark's solution of Boussinesq's equation for square and continuous footings.

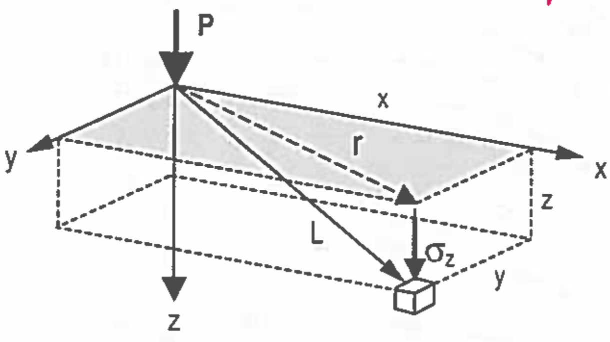
3c

Vertical Stress Caused by a Point Load

Boussinesq Equation:

$$\Delta\sigma_z = \frac{3P}{2\pi}\frac{z^3}{(r^2+z^2)^{5/2}} = C_r \bullet \frac{P}{z^2}$$

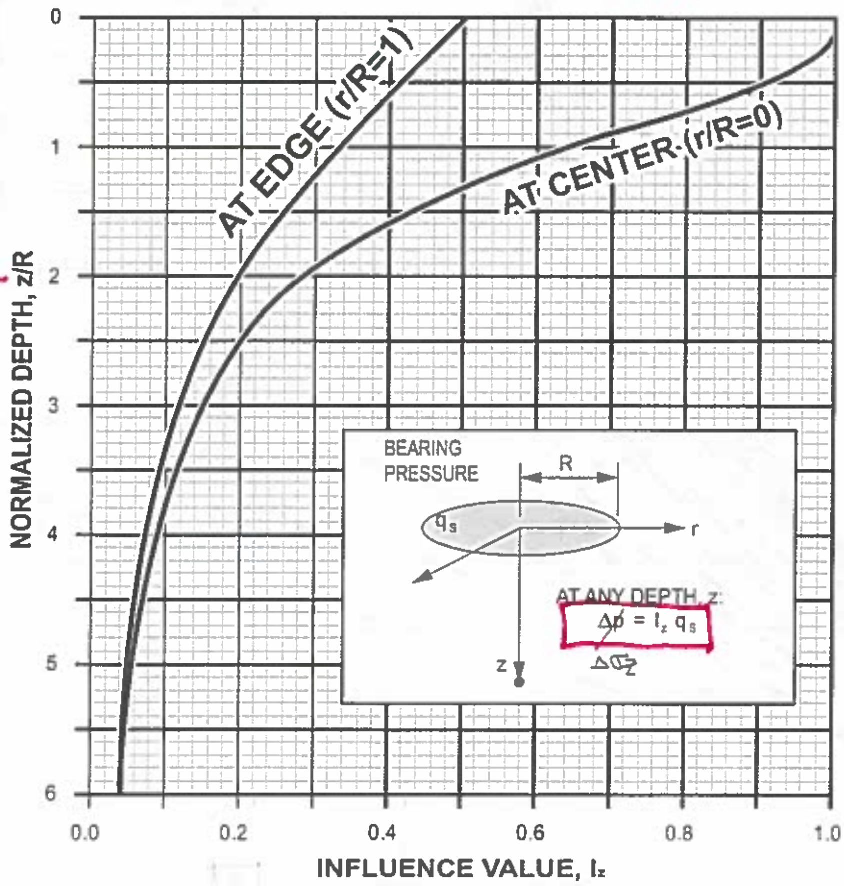
z_f



r/z	C_r	r/z	C_r	r/z	C_r
0.0	0.4775	0.32	0.3742	1.00	0.0844
0.02	0.4770	0.34	0.3632	1.20	0.0513
0.04	0.4765	0.36	0.3521	1.40	0.0317
0.06	0.4723	0.38	0.3408	1.60	0.0200
0.08	0.4699	0.40	0.3294	1.80	0.0129
0.10	0.4657	0.45	0.3011	2.00	0.0085
0.12	0.4607	0.50	0.2733	2.20	0.0058
0.14	0.4548	0.55	0.2466	2.40	0.0040
0.16	0.4482	0.60	0.2214	2.60	0.0029
0.18	0.4409	0.65	0.1978	2.80	0.0021
0.20	0.4329	0.70	0.1762	3.00	0.0015
0.22	0.4242	0.75	0.1565	3.20	0.0011
0.24	0.4151	0.80	0.1386	3.40	0.00085
0.26	0.4050	0.85	0.1226	3.60	0.00066
0.28	0.3954	0.90	0.1083	3.80	0.00051
0.30	0.3849	0.95	0.0956	4.00	0.00040

Vertical Stress Beneath a Uniformly Loaded Circular Area

z_f



$\Delta\sigma_z = I_z q_s$

- 2 -

After the first Pag

① Elastic solution For Settlement:

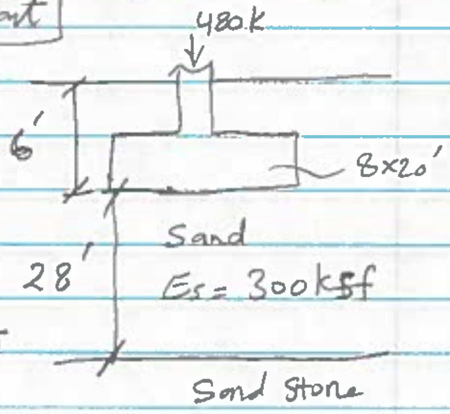
Using Elastic Theory

$$\delta = I_0 I_1 \frac{qB}{E_s}$$ Janbu et al. (1956)

q = Average bearing Stress
B = Footing width
E_s = Average modulus of compressible soil
I_0 = Influence factor accounting for footing depth
I_1 = Influence factor accounting for footing Shape. [Fig 8-2]

is applied only when Es constant

Example:



$\frac{D}{B} = \frac{6}{8} = 0.75$

from fig 8-2 → $I_0 = 0.96$

$\frac{L}{B} = \frac{20}{8} = 2.5$, $\frac{Z_f}{B} = \frac{28}{8} = 3.5$

from fig $I_1 = 0.8$

$$S = I_0 I_1 \frac{qB}{E_s} = (0.96)(3.5) \frac{\frac{480k}{(8 \times 20)\,ft} \times 8}{300\,k/ft^2}$$

$= 0.0608\,ft \simeq 0.73\,in$

6a

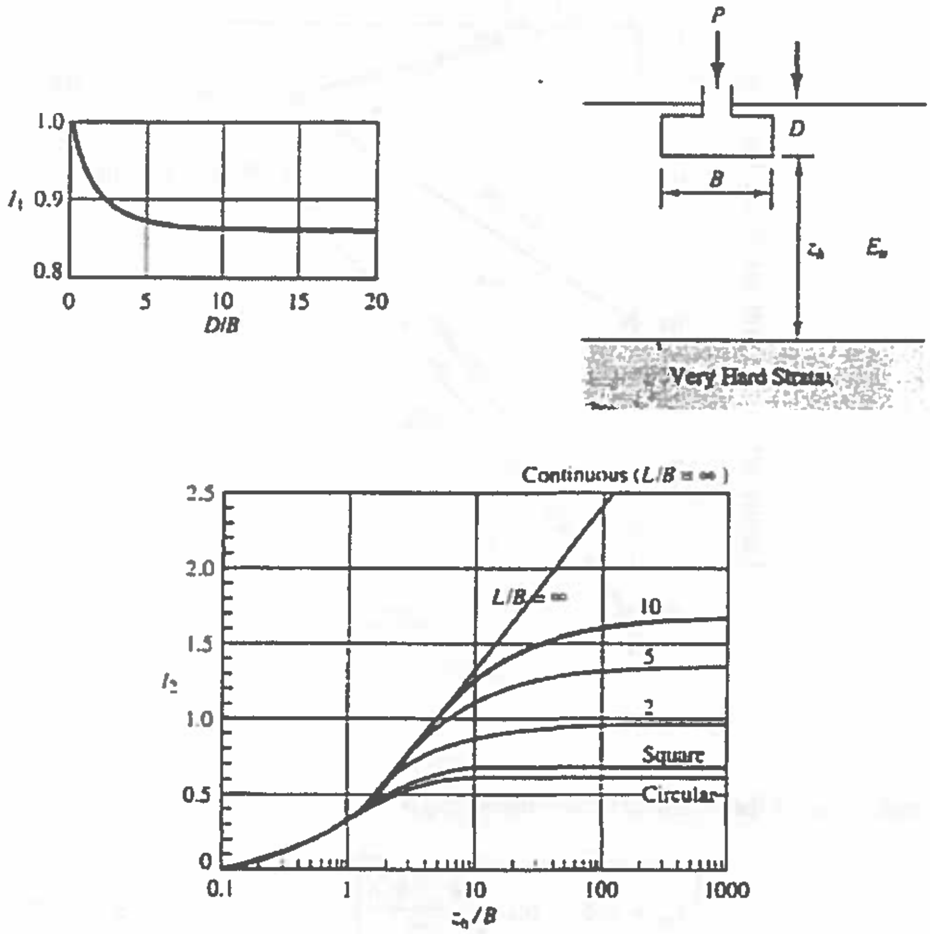
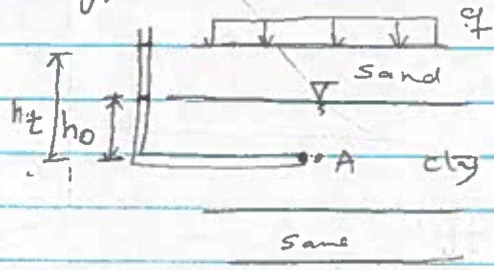


Figure (8.2) Influence factors for Janbu et al. Equation [Coduto, 2014].

Consolidation Settlement

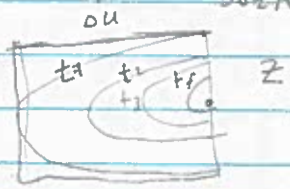
Cons. sett is time dependant (why)
clay

- initial cond. without loading
  $\sigma'_{v0} = \sum \gamma z$, $u = \gamma_w h_o$
  $\Delta u = 0$



- Loading
  Stress in soil $= \sigma'_{v0} + \Delta\sigma$
  $u = h_t \gamma_w$
  $\Delta u = (h_t - h_o)\gamma_w$
- @ the end of cons.
  $u = h_t \gamma_w$
  $\Delta u = 0$

	Load	$\Delta\sigma_z$	σ'_{vA}	Δu
initial	0	0	σ'_{v0}	[illegible]
Loading	q	$\Delta\sigma_{zA}$	$\sigma'_{v0} + \Delta\sigma_z$	$(h_t - h_o)\gamma_w$
End of cons	q	$\Delta\sigma_{zA}$	$\sigma'_{v0} + \Delta\sigma_z$	0

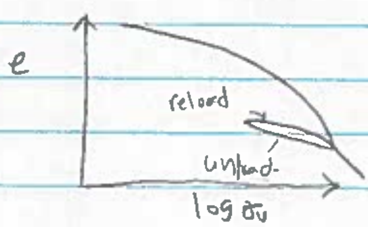


total cons. Sett.

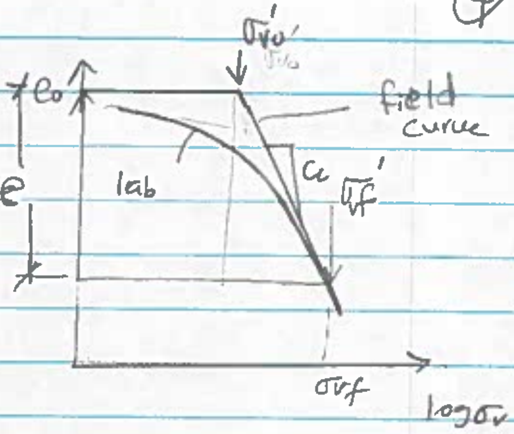
one-dim

$$\delta_c = \left(\frac{H_0}{1 + e_0}\right) \Delta e$$ (Ter Zaghi's Theory of consolidation)

H_0 = Initial layer thickness
e_0 = Initial Void ratio $(Se = G_s w) \Rightarrow e = \frac{G_s w}{S}$
Δe = Change in Void ratio
↳ e-log σv curve from consolidometer Test

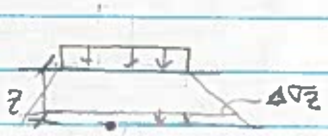


How to calculate Δe?



* NC clay $\sigma_{v0}' = \sigma_c'$

σ_{v0}' = vertical effective stress
σ_c' = Max. past effective stress (Pre-consolidation Stress)
C_c = Compression index
$\sigma_{vf}' = \sigma_{v0}' + \Delta\sigma_z$
$\sigma_c' = \sigma_{v0}' + \sigma_m'$
σ_m' = Overconsolidation margin



$$\Delta e = C_c (\log \sigma_{vf} - \log \sigma_{v0}') = C_c \log \frac{\sigma_{vf}'}{\sigma_{v0}'}$$

$$S_c = \frac{H\, C_c}{1+e_0} \log \frac{\sigma_{vf}'}{\sigma_{v0}}$$

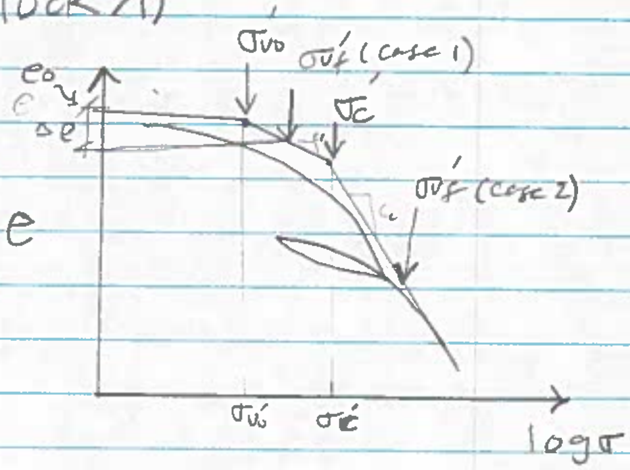
* OC clay $\sigma_c' > \sigma_{v0}'$ (OCR > 1)

Case (1) $\sigma_{vf}' < \sigma_c'$

$$S_c = \frac{H\, C_r}{1+e_0} \log \frac{\sigma_{vf}'}{\sigma_{v0}'}$$

C_r = Swelling index (recompression) or C_s

Case (2) $\sigma_{vf} > \sigma_{v0}' + \sigma_c$



$$S_c = \frac{H}{1+e_0}\left[C_r \log \frac{\sigma_c}{\sigma_{v0}'} + C_c \log \frac{\sigma_{vf}'}{\sigma_c'}\right]$$

imperical relationships for cons. paramuters

$$C_c = 0.009(LL - 10)$$

$$C_r = \frac{1}{5} C_c$$
$\sim \left(\frac{1}{5} - \frac{1}{10}\right)$

$$LI = \text{liquidity index} = \frac{w_n - PL}{PI}$$
$\searrow PI = LL - PL$

$LI \geq 0.9$		N.C
$LI < 0.75$		Lightly O.C
$LI < 0$		Heavily O.C

Procedure:

1) Break the consolidating layer into sub layers **
2) Calculate σ'_{v_o} and $\Delta\sigma_z$ @ mid-hight of each layer.

$\sigma'_{v_o} = \Sigma(\gamma \text{ or } \gamma')z$ ** w/o any additional stress

$\Delta\sigma_z$ = use Boussinesq

3) Get or estimate $N_c; o_c, C_c, C_s, \sigma'_c$
4) Calculate stettlement for each layer

$$S_{ct} = \sum_{i=1}^{n} S_{ci}$$

(5) Check $S_{ct} \leq S_a$

a - For computer analysis → use large number of sub layers

The last layer at a depth where $(\Delta\sigma_z < 0.1\, q)$

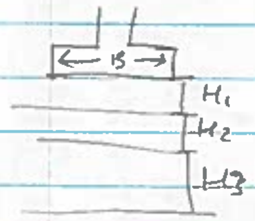
b - For manual calculations → use three layers of H_1, H_2, H_3

2nd ed

in 3rd ed. diff. division

see the back of the page

layer	Square and Circular	cont.
H_1	$B/2$	B
H_2	B	$2B$
H_3	$2B$	$4B$



From Coduto (2014)

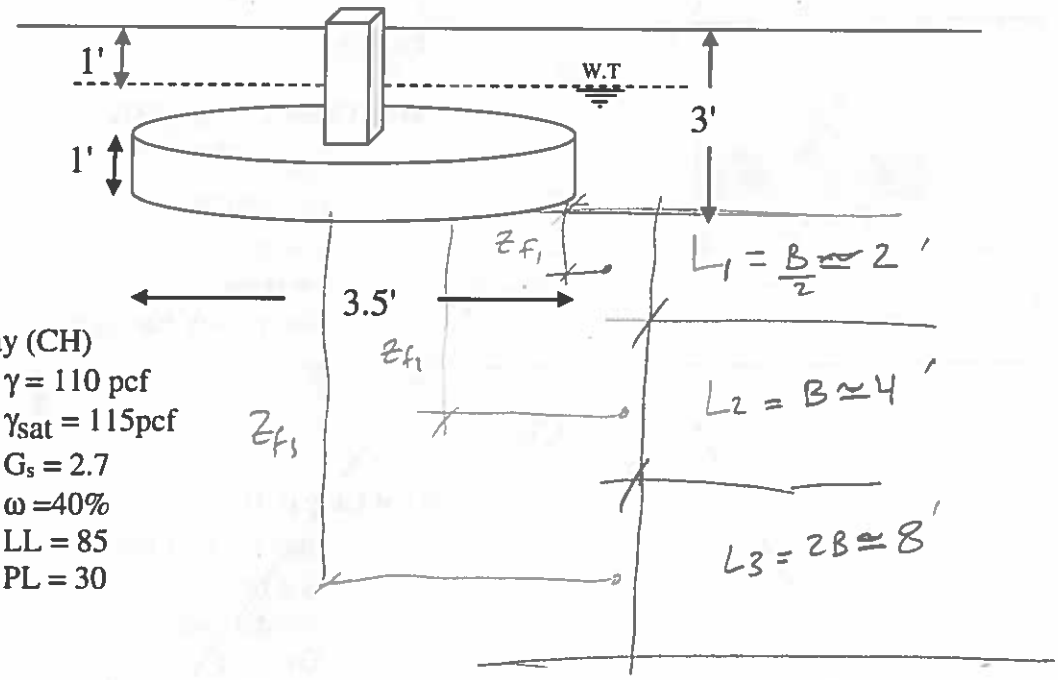
8.11 A proposed office building will include an 8 ft 6 in square, 3 ft deep spread footing that will support a vertical downward service load of 160 k. The soil below this footing is an overconsolidated clay with the following engineering properties: $C_c/(1 + e_0) = 0.10$, $C_r/(1 + e_0) = 0.022$, $\sigma'_m = 4{,}500\ \mathrm{lb/ft^2}$ and $\gamma = 113\ \mathrm{lb/ft^3}$. This soil strata extends to a great depth and the groundwater table is at a depth of 50 ft below the ground surface. Determine the total settlement of this footing.

8.12 A 1.0 m square, 0.5 m deep footing carries a downward service load of 200 kN. It is underlain by an overconsolidated clay with the following engineering properties: $C_c = 0.20$, $C_r = 0.05$, $e_0 = 0.7$, OCR = 8 and $\gamma = 15.0\ \mathrm{kN/m^3}$ above the groundwater table and $16.0\ \mathrm{kN/m^3}$ below. The groundwater table is at a depth of 1.0 m below the ground surface. Determine the total settlement of this footing.

0-01328

CVEG 4143	Foundation Settlement	Class Problem 2

You are required to predict the consolidation settlement of the water tank previously deemed dangerously close to a bearing capacity failure (See Bearing Capacity class problem # 3). As you may call the tank weighs approximately 80 tons when full and is supported on four legs. Each leg has a circular foundation as shown below. The soil is fat clay (CH) extends to a great depth. Assume Wf+Ws= 3550 lbs, and $\sigma'_c = 1000 + \sigma'_{vo}$. Is the calculated settlement acceptable?



Fat Clay (CH)

- $\gamma = 110$ pcf
- $\gamma_{sat} = 115$pcf
- $G_s = 2.7$
- $\omega = 40\%$
- LL = 85
- PL = 30