

III-1 DRY SOIL: STRESSES

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13762 500 SHEETS, FILLER 5 SQUARE
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 42-382 100 SHEETS, FILLER 5 SQUARE
 42-383 50 SHEETS, FILLER 5 SQUARE
 42-384 25 SHEETS, FILLER 5 SQUARE
 42-385 10 SHEETS, FILLER 5 SQUARE
 42-386 5 SHEETS, FILLER 5 SQUARE
 42-387 2 SHEETS, FILLER 5 SQUARE
 42-388 1 SHEET, FILLER 5 SQUARE
 42-389 100% RECYCLED WHITE 5 SQUARE
 42-390 200% RECYCLED WHITE 5 SQUARE
 Made in U.S.A.



PART III DRY SOIL: No. 1 STRESSES (p1/b)

1. INTRODUCTION

1.1 Soil Stresses = force/unit area on plane thru soil: σ = normal stress

1.2. Part III deals w/ strength-deformation behavior of dry soil (sand), but principles wrt $\sigma' = \sigma - u$ apply to soils with H₂O τ = shear stress

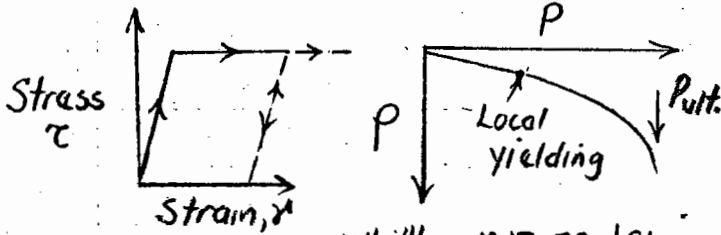
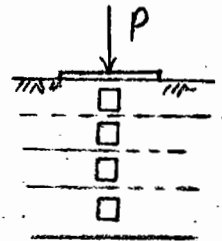
1.3 Approaches to predict load-settlement for footing on soil:

(a) Constitutive eqn. for soil + F.E. code
(Elasto-Plastic) (Soil Model)

(b) Lambe's "Stress Path" method

(1) Lab tests on soil samples from each layer

- Initial stresses
- Δ stresses
- Measure strains



Whittle: MIT-EB f SI

(2) $P = \sum (H_i \cdot E_i)$

Remarks: A lot research on soil modeling with increasing use in practice for major projects (nuclear, offshore...)

Remarks: Problems w/ sample disturbance (esp. sands) + sometimes difficult estimate stresses

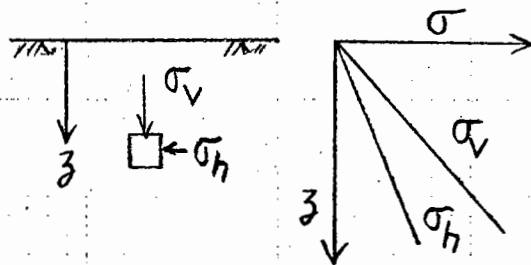
(c) Empirical prediction using results from in situ penetration tests, e.g. SPT N values for settlement of sands (clays use a or b usually)

- 1.4 Coverage:
- Initial stresses; Δ stresses due to construction; stress paths
 - Stress-strain-strength behavior of granular soils
 - Applications to lateral earth pressures, stability & settlement

2. GEOSTATIC STRESSES

2.1 Definition = stresses acting within horizontal soil deposit due to self weight of soil. Only for vertical 1-D load & unload, $\tau_v = \tau_h = 0$

2.2 Estimation ($\sigma \equiv \sigma'$ for dry soil)



$\sigma_v = \int_0^z \gamma \cdot dz$; γ = soil unit weight

$\sigma_h = K_0 \sigma_v$

K_0 = coef. of earth pressure at rest
= σ'_h / σ'_v for no lateral strain

Note: $K_0 \approx 1/2$ for NC soil & incr. w/ incr. OCR

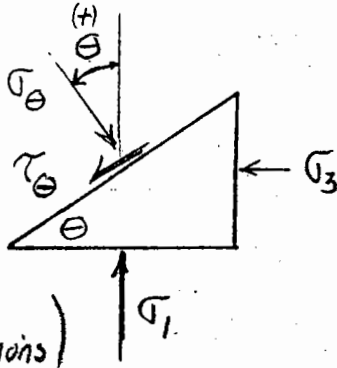
$K = \sigma'_h / \sigma'_v$ = lateral stress ratio

PART III-1 STRESSES (p 2/6)

3. PRINCIPAL STRESSES & MOHR CIRCLE

3.1 Principal Stresses: For any state of stress at a point have 3 \perp planes with $\tau=0$ called principal planes with $\sigma_1 \geq \sigma_2 \geq \sigma_3$

3.2 From Force Equilibrium (Plane \perp to σ_2 direction)



(See p 2a for derivations)

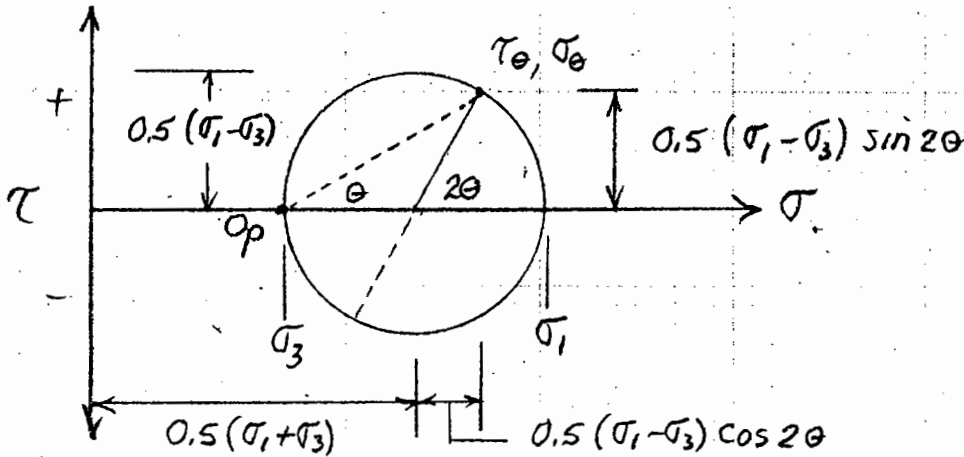
$\theta = \angle$ between planes of σ_1 & σ_θ (\swarrow)

$\tau_\theta =$ positive when counter clockwise

$$\begin{aligned} \sigma_\theta &= \sigma_1 \cos^2 \theta + \sigma_3 \sin^2 \theta \\ &= 0.5(\sigma_1 + \sigma_3) + 0.5(\sigma_1 - \sigma_3) \cos 2\theta \end{aligned}$$

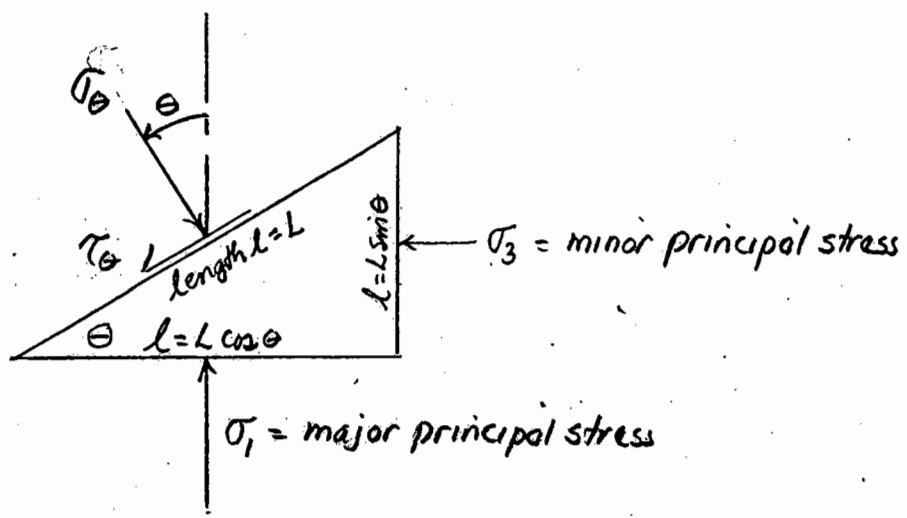
$$\tau_\theta = (\sigma_1 - \sigma_3) \sin \theta \cos \theta = 0.5(\sigma_1 - \sigma_3) \sin 2\theta$$

3.3 Mohr Circle (By plotting σ_θ & τ_θ at varying θ ; stresses \perp to σ_2)



- NOTES:
- Max. $\tau = 0.5(\sigma_1 - \sigma_3)$
 - $\sum \sigma$ on 2 \perp planes = constant = $(\sigma_1 + \sigma_3)$
 - τ on 2 \perp planes of same magnitude but opposite sign
 - Usually only deal with stresses \perp to σ_2 direction
 - Minimum information needed to define state of stress =
 - 1) σ_θ & τ_θ on one plane of known orientation, θ
 - 2) PLUS....

Supplement for Section 3.2: Derivation of Eqn. for Mohr Circle



$\Sigma V = 0 \quad \sigma_1 \cdot L \cos \theta = \sigma_\theta \cdot L \cdot \cos \theta + \tau_\theta \cdot L \cdot \sin \theta$

Eq. a $\sigma_1 \cos^2 \theta = \sigma_\theta \cos^2 \theta + \tau_\theta \cos \theta \sin \theta \quad \times \cos \theta / L$

$\Sigma H = 0 \quad \sigma_3 \cdot L \sin \theta = \sigma_\theta \cdot L \cdot \sin \theta - \tau_\theta \cdot L \cdot \cos \theta$

Eq. b $\sigma_3 \sin^2 \theta = \sigma_\theta \sin^2 \theta - \tau_\theta \cos \theta \sin \theta \quad \times \sin \theta / L$

Add Eq. a & b $\sigma_1 \cos^2 \theta + \sigma_3 \sin^2 \theta - \sigma_\theta (\cos^2 \theta + \sin^2 \theta) = \tau_\theta \quad QED$

Subtract Eq. a & b $\sigma_1 \cos^2 \theta - \sigma_3 \sin^2 \theta = \sigma_\theta (\cos^2 \theta - \sin^2 \theta) + \tau_\theta 2 \cos \theta \sin \theta$

Term (3) $\sigma_1 \cos^2 \theta (\cos^2 \theta - \sin^2 \theta) + \sigma_3 \sin^2 \theta (\cos^2 \theta - \sin^2 \theta)$ Substitute for σ_θ

Term (1)+(3) $\sigma_1 \cos^2 \theta (1 + \sin^2 \theta - \cos^2 \theta) - \sigma_3 \sin^2 \theta (1 + \cos^2 \theta - \sin^2 \theta)$

Term (1)+(4) $2 \sigma_1 \cos^2 \theta \sin^2 \theta - 2 \sigma_3 \sin^2 \theta \cos^2 \theta = 2 \tau_\theta \cos \theta \sin \theta$

$\sigma_1 - \sigma_3 = \tau_\theta \frac{\cos \theta \sin \theta}{\cos^2 \theta \sin^2 \theta} \quad \times \frac{1}{2 \cos^2 \theta \sin^2 \theta}$

$\therefore \tau_\theta = (\sigma_1 - \sigma_3) \cos \theta \sin \theta = 0.5 (\sigma_1 - \sigma_3) \sin 2\theta \quad QED$

$\cos^2 \theta + \sin^2 \theta = 1 ; \quad \cos \theta \sin \theta = 0.5 \sin 2\theta$

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42-632 100 SHEETS PER CASE 85070591730234615865843651857942052864 SQUARE
42-633 200 SHEETS PER CASE 85070591730234615865843651857942052864 SQUARE
42-634 100 SHEETS PER CASE 170141183460469231731687303715884105728 SQUARE
42-635 200 SHEETS PER CASE 170141183460469231731687303715884105728 SQUARE
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42-637 200 SHEETS PER CASE 340282366920938463463374607431768211456 SQUARE
42-638 100 SHEETS PER CASE 680564733841876926926749214863536422912 SQUARE
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42-642 100 SHEETS PER CASE 2722258935367507707706996859454145711648 SQUARE
42-643 200 SHEETS PER CASE 2722258935367507707706996859454145711648 SQUARE
42-644 100 SHEETS PER CASE 5444517870735015415413993718908291423296 SQUARE
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42-648 100 SHEETS PER CASE 21778071482940061661655974875633165693184 SQUARE
42-649 200 SHEETS PER CASE 21778071482940061661655974875633165693184 SQUARE
42-650 100 SHEETS PER CASE 43556142965880123323311949751266331387776 SQUARE
42-651 200 SHEETS PER CASE 43556142965880123323311949751266331387776 SQUARE
42-652 100 SHEETS PER CASE 87112285931760246646623899502532662775552 SQUARE
42-653 200 SHEETS PER CASE 87112285931760246646623899502532662775552 SQUARE
42-654 100 SHEETS PER CASE 174224571863520493293247799005065325551104 SQUARE
42-655 200 SHEETS PER CASE 174224571863520493293247799005065325551104 SQUARE
42-656 100 SHEETS PER CASE 348449143727040986586495598010130651102208 SQUARE
42-657 200 SHEETS PER CASE 3484491437270409865

PART III - 1 STRESSES (p3/6)

3.4 Origin of Planes = O_p

Point on Mohr circle such that any line drawn thru O_p parallel to plane of interest will intersect circle at the stresses on that plane. (Better than using 2θ)

4. STRESS PATHS (Essential to "survival" in MIT soil mechanics subjects)

4.1 Important Restriction . Should only use for states of stress wherein principal stresses act in vertical and horizontal directions

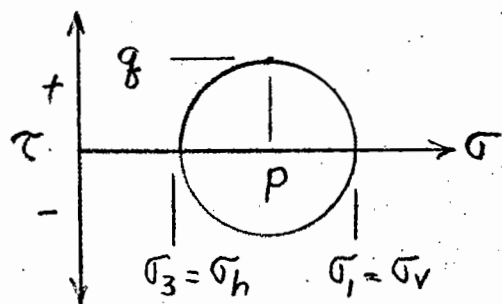
4.2 Purpose & Definition

To simplify presentation of states of stress by using peak points (q & p) rather than Mohr circles: + O_p

$$q = 0.5(\sigma_v - \sigma_h) \quad \& \quad p = 0.5(\sigma_v + \sigma_h)$$

q = positive for $\sigma_v > \sigma_h$ ($K < 1$)
 = negative for $\sigma_v < \sigma_h$ ($K > 1$)

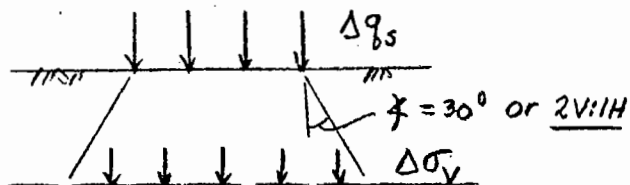
$$\sigma_v = p + q \quad \text{and} \quad \sigma_h = p - q$$



4.3 Examples (See p3a)

5 STRESS DISTRIBUTION: TYPICAL APPROACHES (Surface loads)

5.1 Vertical Stress from Codes



5.2 Finite Element with Layered Non-Linear σ - ϵ Model

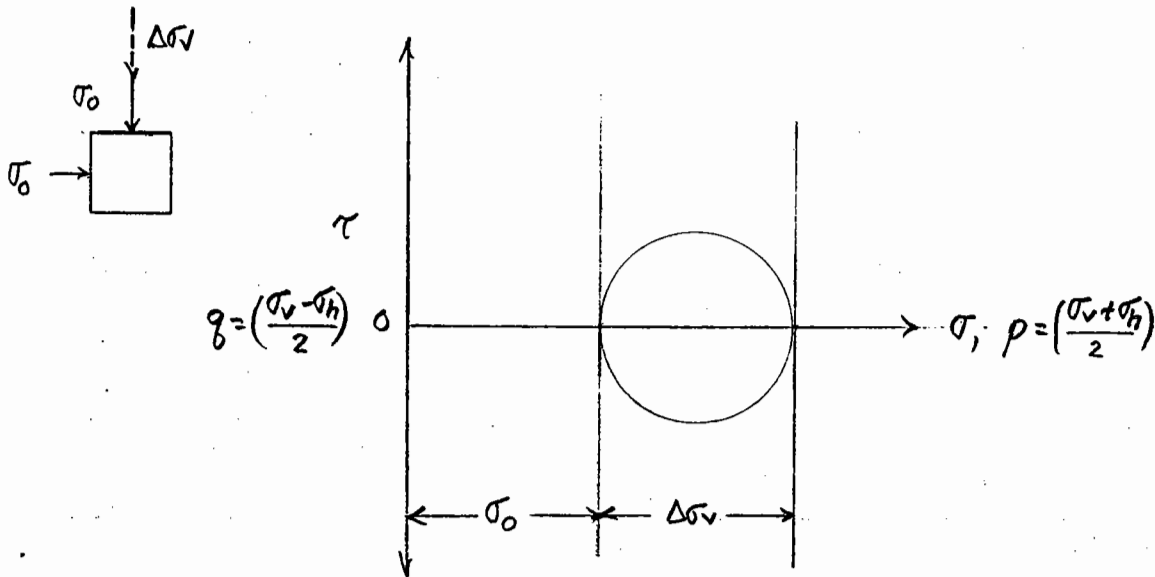
e.g. Hyperbolic

5.3 Theory of Elasticity - Most Common

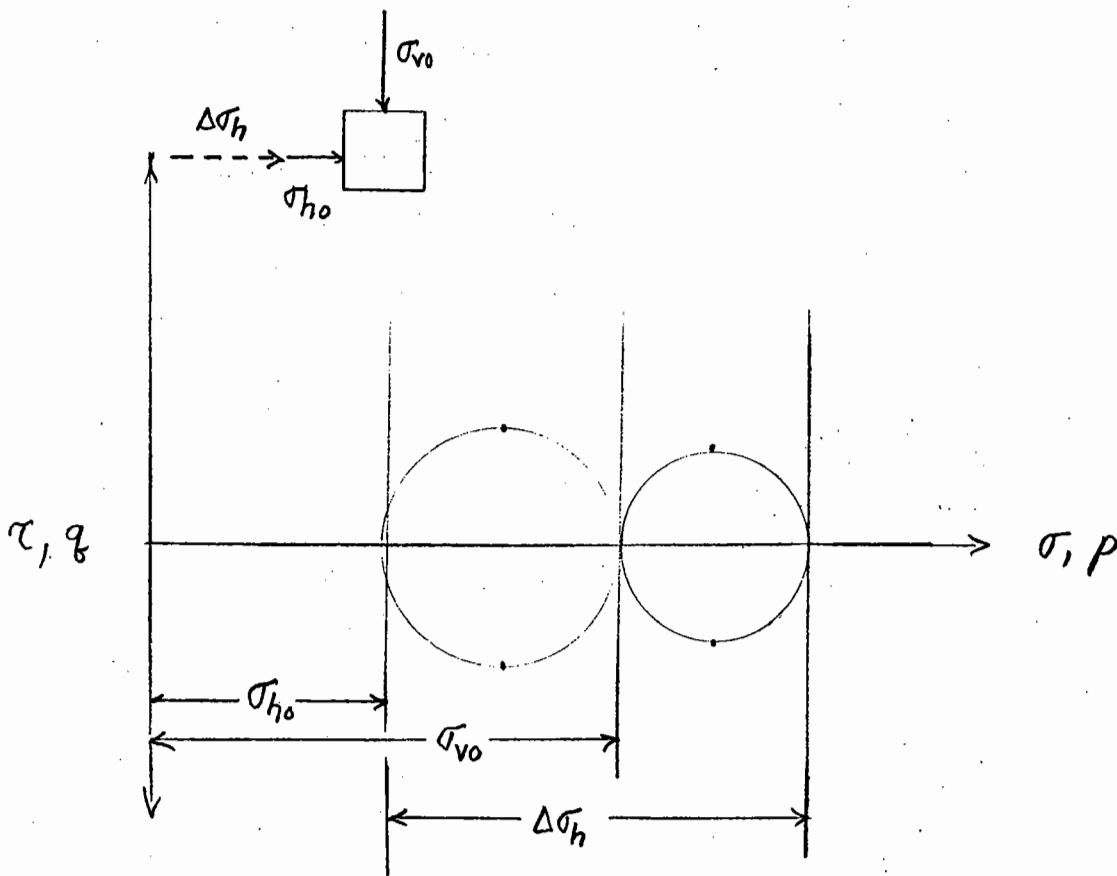
$$\sigma = \frac{\epsilon}{a + b\epsilon}$$

4.3 Examples of Stress Paths

1) Isotropic (hydrostatic) compression to σ_0 ; then increase σ_v



2) 1-D (K_0) compression of NC sand to σ_{v0} ; then increase σ_h



13-782 500 SHEETS, FILLER, 5 SQUARE
 47-181 40 SHEETS, 14" x 14" LAR, 5 SQUARE
 42-382 100 SHEETS, 14" x 14" LAR, 5 SQUARE
 42-382 200 SHEETS, 14" x 14" LAR, 5 SQUARE
 42-382 100 RECYCLED WHITE, 5 SQUARE
 42-382 200 RECYCLED WHITE, 5 SQUARE
 Made in U.S.A.



PART III-1 STRESSES (p4/6)

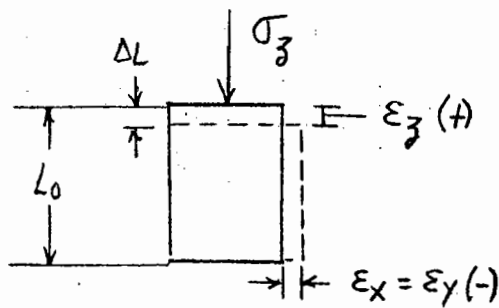
6. THEORY OF ELASTICITY

6.1 Conventional Assumptions

Theory	Soil
5) Homogeneous (same properties everywhere)	Often highly variable
4) Isotropic (properties independ. direction)	Cross anisotropic
1) Elastic (all strains recoverable)	Usually only true for very small strains
2) Linear (Hooke's Law: $\sigma \propto \epsilon$)	Ditto
3) Small strains (Enger strain $\epsilon = \frac{\Delta L}{L_0}$; Natural strain = $\frac{\Delta L}{L}$)	Usually o.k

6.2 Evaluation of Elastic Constants (Linear & Isotropic)

- Constitutive relationship defined by two constant properties
- If run unconfined compression test (compressive ϵ is positive)



Young's modulus $E = \sigma_3 / \epsilon_3$

Poisson's ratio $\mu = -\epsilon_x / \epsilon_3$

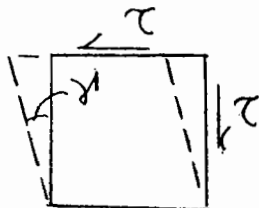
Notes: If $\epsilon_{vol.} = \epsilon_3 + \epsilon_x + \epsilon_y = \epsilon_3(1 - 2\mu) = 0 \rightarrow \mu = 0.5$

If $\epsilon_x = \epsilon_y = 0 \rightarrow \mu = 0$

If $\frac{1}{3}(\Delta\sigma_3 + \Delta\sigma_x + \Delta\sigma_y) = \Delta\sigma_{oct} = 0$, then theory predicts that $\epsilon_{vol.} = 0$

6.3 Real Soil Behavior

- E & μ vary with stress level & stress path
- μ' can be > 0.5 or < 0 ($\mu = 0.5$ saturated undrained shears; $\mu' \approx 1/3$ for drained shear clays)
- Results pure shear where $+\Delta\sigma_1 = -\Delta\sigma_3$ & $\Delta\sigma_2 = 0$



Shear modulus $G = \frac{\tau}{\gamma} = \frac{E}{2(1+\mu)}$

Altho. $\Delta\sigma_{oct} = 0$, $\epsilon_{vol.} \neq 0$

- Cross-Anisotropic ($1-D = K_0$ loading history) \rightarrow 5 constants $E_v, E_h, G_{hv}, \mu_{hv}$ & μ_{hh}

PART III-1 STRESSES (p 5/6)


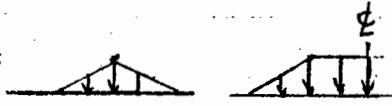
7. ELASTIC STRESS DISTRIBUTION

7.1 Best Reference

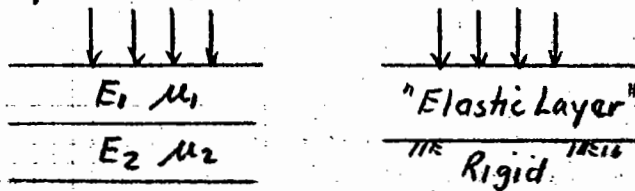
- Poulos & Davis (1974) "Elastic Solutions for Soil & Rock Mechanics", J. Wiley & Sons, 411p Also NAVFAC DM 7.1 (1982)

7.2 Typical Variables

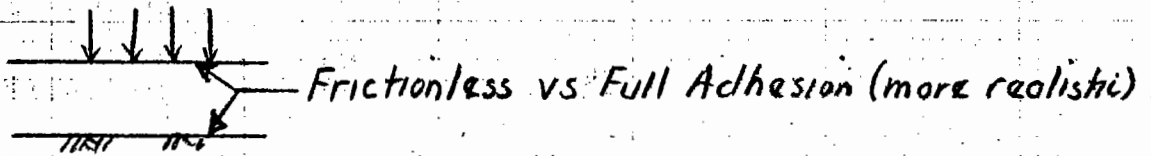
(1) Boussinesq = Elastic Half Space

- Point vs distributed 
- Shape of area: circle, square, rectangle, strip, ...
- Uniform stress vs uniform displacement 

(2) Layered System (Burmister)



(3) Boundaries



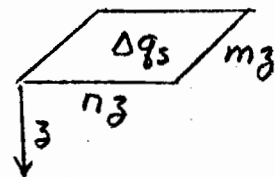
7.3 Boussinesq Charts for $\Delta\sigma_v$ (Westergaard less realistic since $\epsilon_h=0$)

(1) $\Delta\sigma_v = \Delta q_s \cdot f(m,n)$ is independent of μ

(2) Section 8.3 (know well, esp. p104)

(3) Values of $f(m,n)$

- When $m \neq n < 0.3 \rightarrow$ approx. Point Load
- When m or $n > 5 \rightarrow$ approx ∞ Load (in that direction)



Form $m, n > 5$ {

- Under corner, $f =$
- Under edge, $f =$

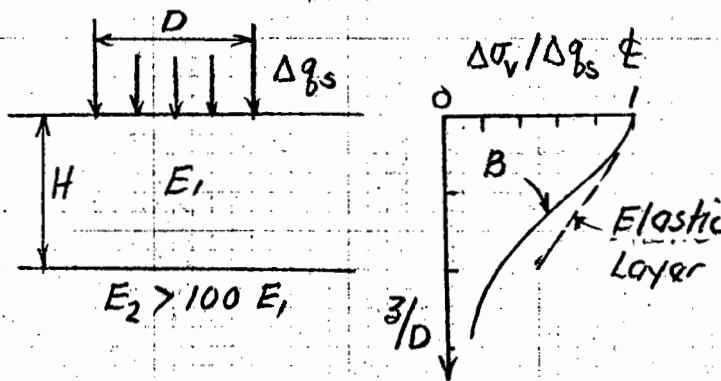
PART III-1 STRESSES (p 6/6)

7.4 Pressure Bulb (Refers to $\Delta\sigma_v / \Delta q_s$)

- Zone under loaded area where stress increase is significant, say $\Delta\sigma_v > 10-15\% \Delta q_s$ See Figs. 8.4 & 8.5
- Extends down to $z = 2B$ for circle/square ; $z = 4B$ for strip

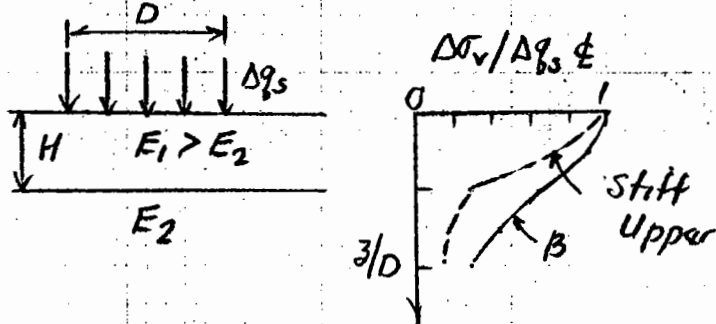
7.5 Effects of Layered System

(1) "Rigid base" \rightarrow "Elastic layer" (Soft over stiff)



- $B = \text{Boussinesq}$
- Rigid base increases $\Delta\sigma_v$ within overlying soil which is less effective in distributing the load

(2) stiff layer over soft layer \rightarrow Decreased $\Delta\sigma_v$ in both layers

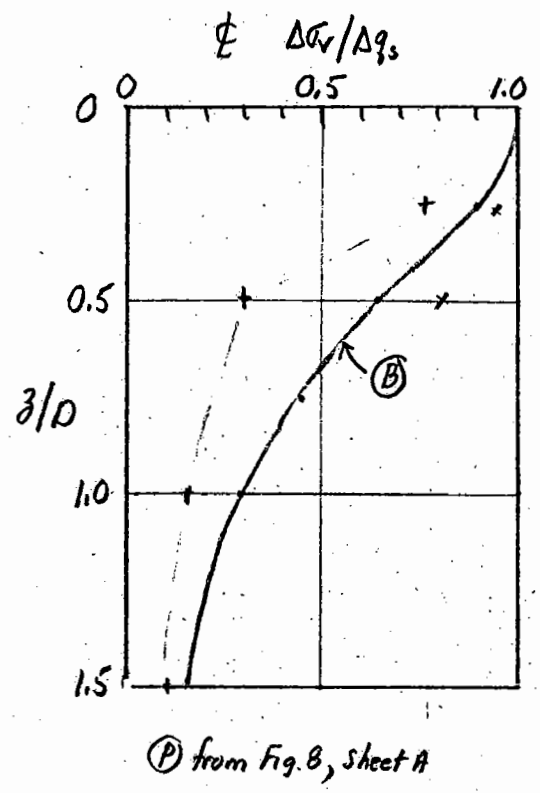
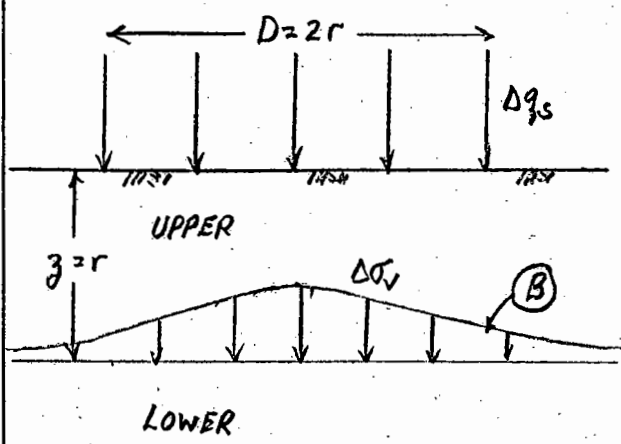


- For $D/H = 2$, at $z = H$:
 $E_1/E_2 = 10 \rightarrow \times 0.45$
 $= 100 \rightarrow \times 0.1$
- Rigid pavement design
- See Fig. 8, Sheet A

7.6 Effect of Poisson's Ratio

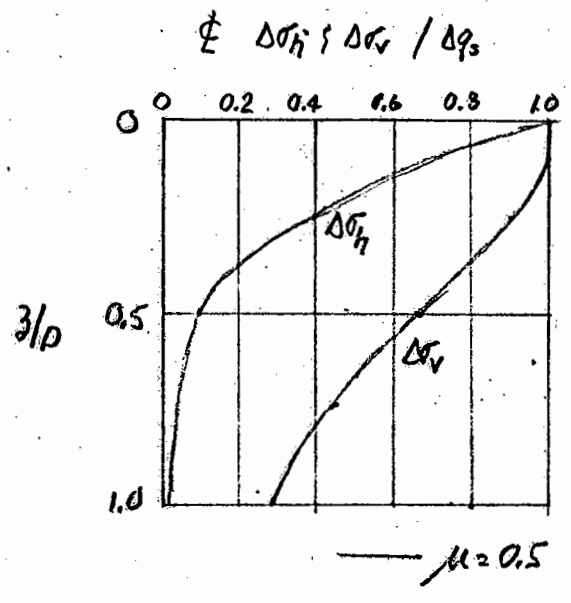
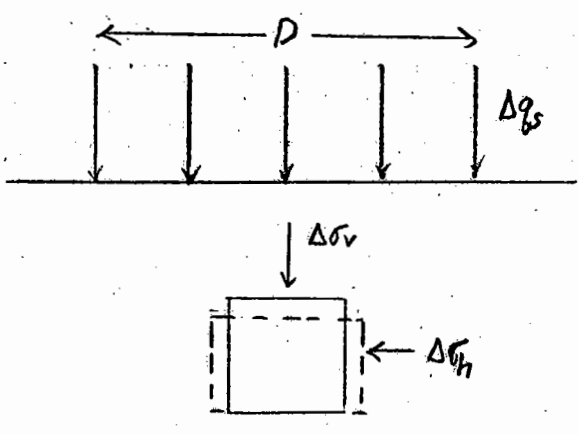
- (1) None on $\Delta\sigma_v$ (Except see Fig. 9, Sheet A)
- (2) Vary significant on $\Delta\sigma_h$ for non-strip loadings (Class discussion)

(a) LAYERING



- (B) Boussinesq = homogeneous elastic half space
- (P) Stiff upper layer (Pavement)
- (R) Soft upper layer (Clay over Rock)

(b) POISSON'S RATIO



- Undrained loading, $\mu = 0.5$
- Drained loading, $\mu' = 1/3$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

