HIMPUNAN AHLI TEKNIK TANAH INDONESIA
Indonesian Society for Geotechnical Engineering

SIMSG ISSMGE

HATTI MENGAJAR III - 2021
"Seepage, Stresses from Surface Load & Effective Stress"

Rabu,21 April 2021

13.00 - 15.00 Wib

ZOOM CONFERENCE

Registrasi : https://hatti.or.id/zoom
Info Lengkap : Sugino - 08118001250

Instructure

Dr. Ir. Idrus M. Alatas, MSc
Dosen Jurusan Teknik Sipil, ISTN - Jakarta
BPH HATTI Pusat

Free

No.	Tentatif Jadwal	Judul	Pengajar
1.	Rabu, 17 Februari	Introduction to Geotechnical Engineering, Origin of Soils, Particle Size & Grain Size Dist., Index Properties & Soil Classification.	Prof. Dr. Widjojo Prakoso (Ketua Hatti Pusat).
2.	Rabu, 17 Maret	Permeability, Seepage and Flow Nets.	Dr. Endra Susila/ Ir. Dandung Sri Harninto, MT.
3.	Rabu, 21 April	Effective Stress, Seepage Forces, Stresses Under Loaded Areas.	Dr. Idrus/Dr. Wiwik Rahayu.
4.	Rabu, 19 Mei	Consolidation Settlement and Time Rate of Consolidation	Dr. Bigman Hutapea/Ir. Agus Himawan, MT.
5.	Rabu, 16 Juni	Shear Strength of Soils: Undrained and Drained	Prof. Dr. Wayan Sengara.
6.	Rabu, 15 Juli	Foundation Design: Shallow and Deep Foundation Systems.	Dr. Pintor T. Simatupang./ Dr. Aksan Kawanda.
7.	Rabu, 18 Agustus	Lateral Earth Pressure and Retaining Wall.	Prof. Agus Setyo Muntohar/Dr. Ardy Arsyad
8.	Rabu, 15 Sept.	Slope Stability: Static and Earthquake.	Prof. Dr. Teuku Faisal Fathani/Dr. Aswin.
9.	Rabu, 15 Okt.	Introduction to Earthquake Engineering, Soil Liquefaction and Its Mitigation Methods.	Prof. Dr. Masyhur Irsyam/Dr. Asririfak
10.	Rabu, 17 Nov.	Soil Improvement: Soil Compaction, PVD Preloading, Vacuum, KGM, Stone Column.	Dr. Helmy Darjanto/Ir. Marcello, MT.
11.	Rabu, 15 Des.	Site Characterization: Soil Sampling and In-Situ Testing.	Dr. Erza Rismantojo.

OBJECT

- EFFECTIVE STRESS
- SEEPAGE FORCES
- STRESS UNDER LOADED AREA

By Idrus M Alatas

OBJECT

- EFFECTIVE STRESS √
- SEEPAGE FORCES
- STRESS UNDER LOADED AREA

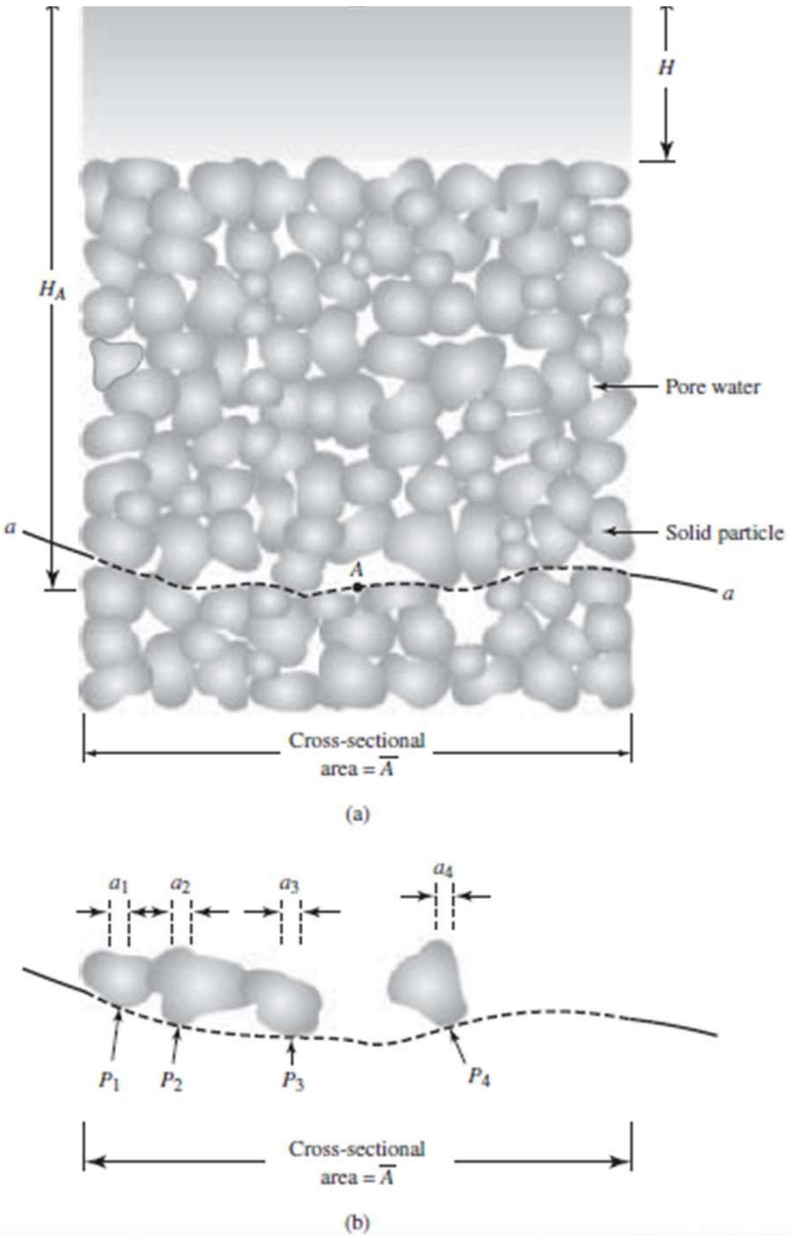
Pendahuluan

- Tanah dapat divisualisasikan sebagai kerangka partikel padat yang menutupi rongga kontinu yang mengandung air dan / atau udara. Untuk rentang tegangan yang biasanya ditemui dalam praktek, partikel padat dan air dapat dianggap tidak dapat dimampatkan; udara, di sisi lain, sangat mudah dimampatkan.
- Volume tanah secara keseluruhan dapat berubah karena penataan ulang partikel tanah ke posisi baru, terutama dengan akibat proses pemadatan tanah atau proses konsolidasi.
- Kompresibilitas sebenarnya dari kerangka tanah akan bergantung pada susunan struktural dari partikel padat. Pada tanah yang sepenuhnya jenuh, karena dianggap air tidak dapat dimampatkan, pengurangan volume hanya mungkin jika sebagian air dapat keluar dari rongga.
- Dalam tanah kering atau tanah jenuh sebagian, pengurangan volume selalu dimungkinkan karena kompresi udara di lubang-lubang, asalkan ada ruang untuk penataan ulang partikel.

Pendahuluan

The concept of effective stress can be illustrated by drawing a wavy line, *a-a*, through the point *A* that passes through only the points of contacts of the solid particles. Let $P_1, P_2, P_3, \ldots, P_n$ be the forces that act at the points of contact of the soil particles (Figure 6.1b). The sum of the vertical components of all such forces over the unit cross-sectional area is equal to the effective stress, σ', or

$$\sigma' = \frac{P_{1(v)} + P_{2(v)} + P_{3(v)} + \cdots + P_{n(v)}}{\overline{A}}$$



Prinsip Tegangan Effective

Tahun 1923 ketika Terzaghi mempresentasikan prinsip tegangan efektif, hubungan intuitif berdasarkan data eksperimen. **Prinsipnya hanya berlaku ke tanah yang sepenuhnya jenuh dan menghubungkan tiga tegangan berikut**

1. **Tegangan normal total (σ_t)** pada bidang dalam massa tanah, menjadi gaya per satuan luas yang ditransmisikan ke arah normal melintasi bidang tersebut, membayangkan tanah menjadi material padat (fase tunggal);
2. **Tekanan air pori (u)**, menjadi tekanan air yang mengisi ruang hampa antara partikel padat;
3. **Tegangan normal efektif (σ')** di bidang, yang mewakili tegangan yang ditransmisikan hanya melalui kerangka tanah.

Aplikasi Tegangan Effective

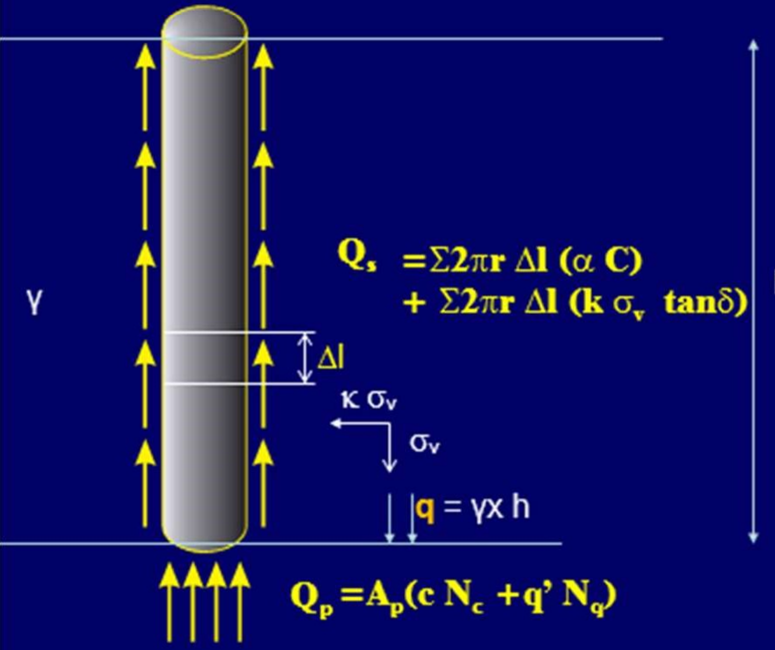
TEGANGAN EFFECTIVE SECARA UMUM DIGUNAKAN DALAM ANALISIS GEOTEKNIK DALAM , seperti

1. Bearing Capacity of Soil, Pile Capacity
2. Slope stability
3. Consolidation Settlement
4. Etc…etc etc

Aplikasi Tegangan Effective

$$q_u = c'\lambda_{cs}\lambda_{cd}N_c + q\lambda_{qs}\lambda_{qd}N_q + \tfrac{1}{2}\gamma'\lambda_{\gamma s}\lambda_{\gamma d}BN_\gamma$$

$\tau = c + \sigma v \tan\phi$ (Colomb)



$$Q_s = \Sigma 2\pi r\, \Delta l\, (\alpha\, C) + \Sigma 2\pi r\, \Delta l\, (k\, \sigma_v\, \tan\delta)$$

$$Q_p = A_p(c\, N_c + q'\, N_q)$$

$K = 1 - \sin\phi$, $\delta = 2/3\, \phi$

$$Q_u = Q_p + Q_s$$

$$Q_{all} = \frac{Q_u}{F.S.}$$

$$F_s = \frac{\sum_{n=1}^{n=p} (c'\Delta L_n + W_n \cos\alpha_n \tan\phi')}{\sum_{n=1}^{n=p} W_n \sin\alpha_n}$$

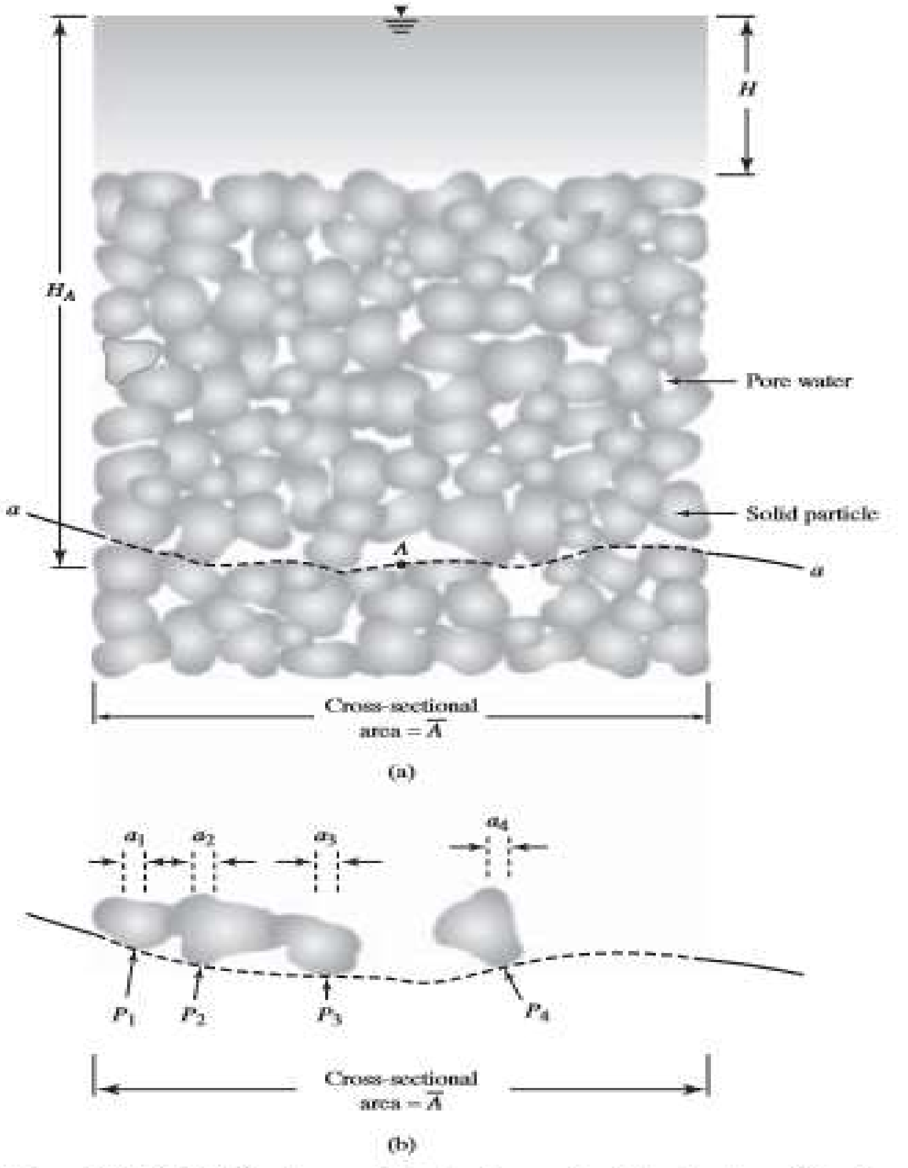


Figure 6.1 (a) Effective stress consideration for a saturated soil column without seepage; (b) forces acting at the points of contact of soil particles at the level of point *A*

Non Seepage (static)

$\sigma' = \sigma_{tot} - u$

dimana :

σ' = Tetangan Effektif

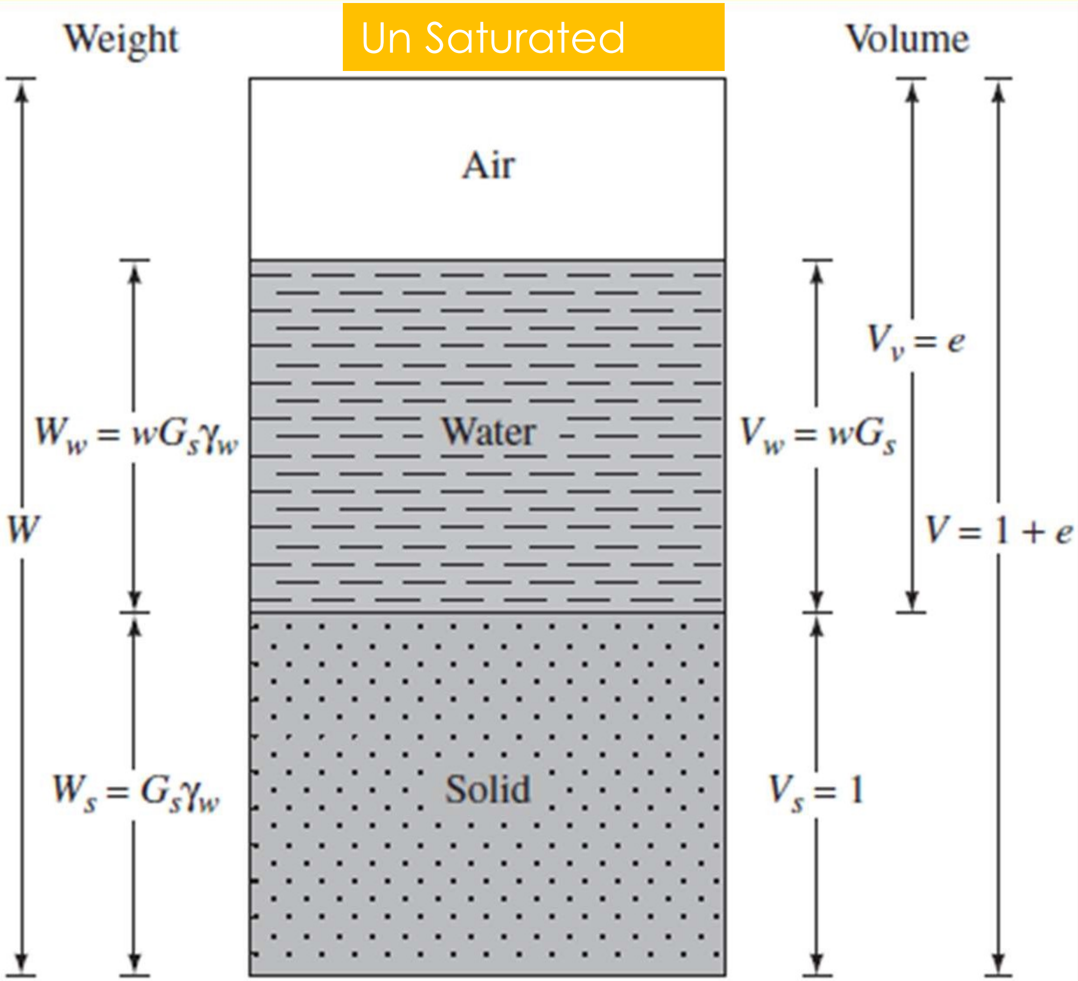
σ_{tot} = Tegangan Total

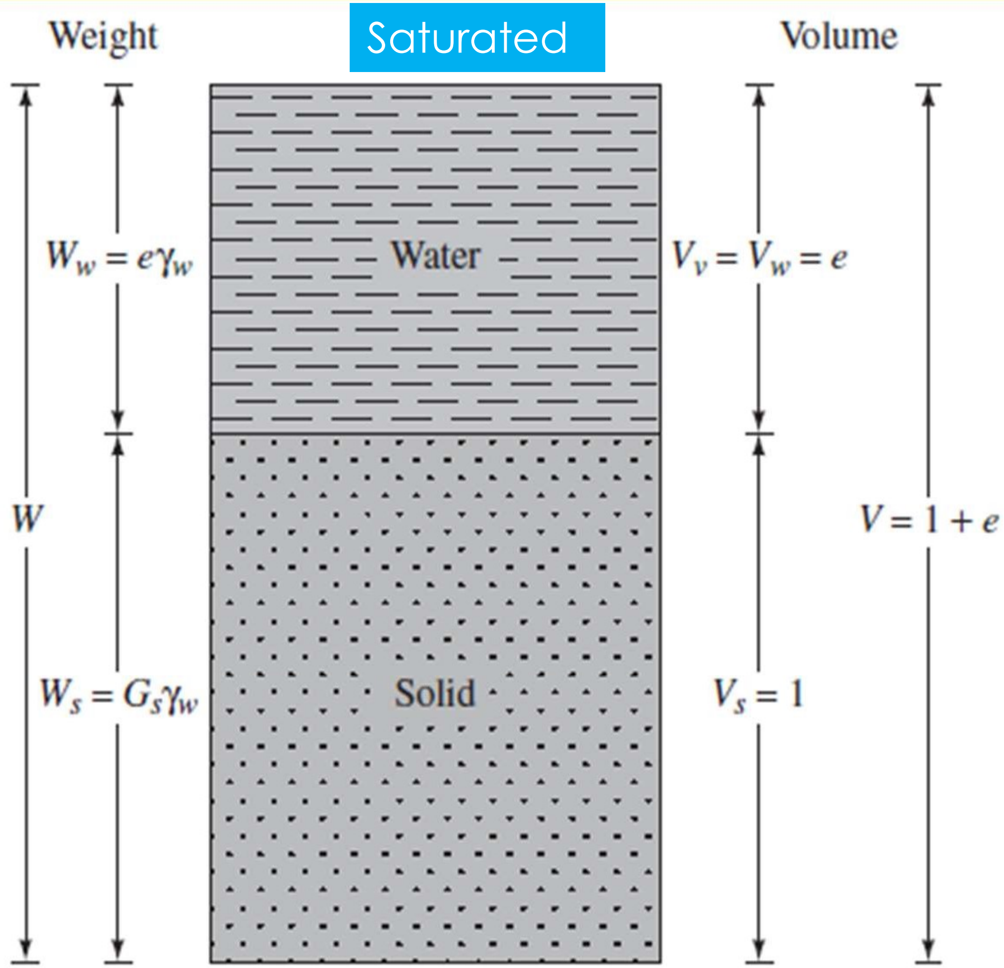
u = Tegangan air pori

Tegangan Total Tanpa Seepage (static)

- Tegangan Total (σ_{tot}), Tegangan yang diakibatkan oleh semua unsur di dalam tanah (butiran dan air)
- Pada Kedalaman tertentu (misalkan sedalam h)
- Pada Tanah tidak jenuh, maka Total (σ_{tot}) = γ x h (t/m^3 x m) = t/m^2
- Pada Tanah Jenuh, maka properties tanah yang diperlukan adalah γ_{sat}
- Jika tidak diketahui γ_{sat}nya dari hasil laporan Soil Investigation, maka harus di cari dengan parameter tanah lainnya, spt Gs (specific Gravity), w_n (kadar air), γ (berat isi tanah); e (angka pori) dsb.

Hubungan γsat dengan index properties





Hubungan γsat dengan index properties

$$\text{Density} = \rho = \frac{(1+w)G_s\rho_w}{1+e}$$

$$\text{Dry density} = \rho_d = \frac{G_s\rho_w}{1+e}$$

$$\text{Saturated density} = \rho_{sat} = \frac{(G_s+e)\rho_w}{1+e}$$

Hubungan antara parameter :

e.Sr = w. Gs

Bila Saturated, Sr= 1, (100%)
Maka :

e = w. Gs

$$\text{Shg } \gamma sat = \frac{(Gs + w.Gs).\ \gamma w}{(1 + w.Gs)} = \frac{Gs\ (1 + w).\ \gamma w}{(1 + w.\ Gs)}$$

Parameter Properties Tanah yang Utama dan diperoleh langsung dari Laboratorium adalah : γ , w and Gs, (γw)

Parameter lainnya seperti : γd ; γsat; e; n; Sr; diperoleh/didapat dari Hubungan antara parameter yang lainnya dengan parameter utama diatas

Tegangan air pori (static)

- Tegangan air pori (u) pada kondisi static, yaitu tegangan yang hanya dihitung akibat genangan air pada tanah di titik yang di tentukan.
- Air memiliki berat isi air sebesar γ_w = 1 ton/m^3, atau 9.8 ~ 10 kN/m^3, atau 1 kg/1 dm^3, atau 1 grm/cm^3
- Tekanan air pori (static) pada tanah adalah sebesar tekanan hidrostatiknya di tempat yang akan di hitung
- Contoh , pada tanah jenuh sedalam 8.00 meter, maka tekanan air porinya $U = \gamma_w \times 8$ m = 1.00 t/m^3 x 8 m = 8.00 t/m^2

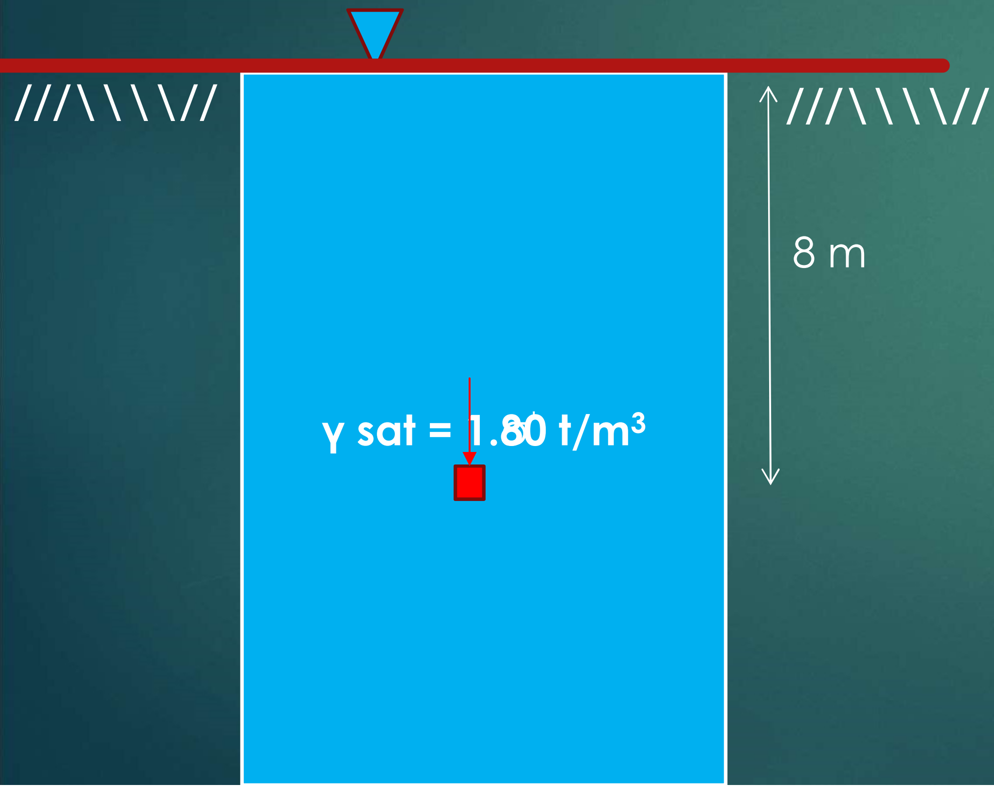
Tegangan Effektif

- Adalah suatu tegangan total akibat berat sendiri tanah dikurangi tekanan air porinya.

- Tegangan efektif $(\sigma') = \sigma_{tot} - u$

- $(\sigma')_A = \sigma_{tot\ A} - u_A$

Contoh 1:



$\sigma_{tot} = \gamma_{sat} \times h$

$= 1.8 \times 8 = 14.4 \text{ t/m}^2$

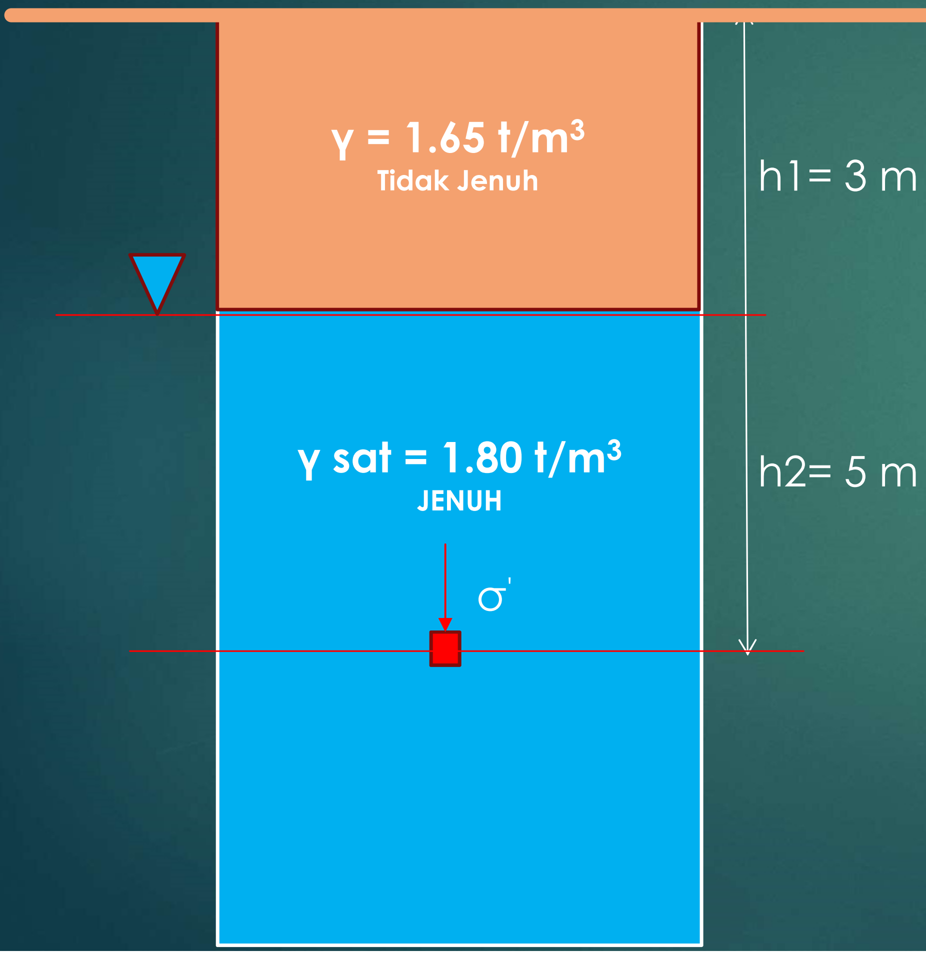
Tegangan air pori (u) =

$\gamma_w \times h = 1.00 \times 8 = 8 \text{ t/m}^2$

Tegangan efektif $(\sigma') = \sigma_{tot} - u$

$(\sigma') = (14.4 - 8) \text{ t/m}^2 = 6.4 \text{ t/m}^2$

Contoh 2:



$\sigma_{tot} = \gamma \times h1 + \gamma_{sat} \times h_2$

$= 1.65 \times 3 + 1.80 \times 5 = 13.95\ t/m^2$

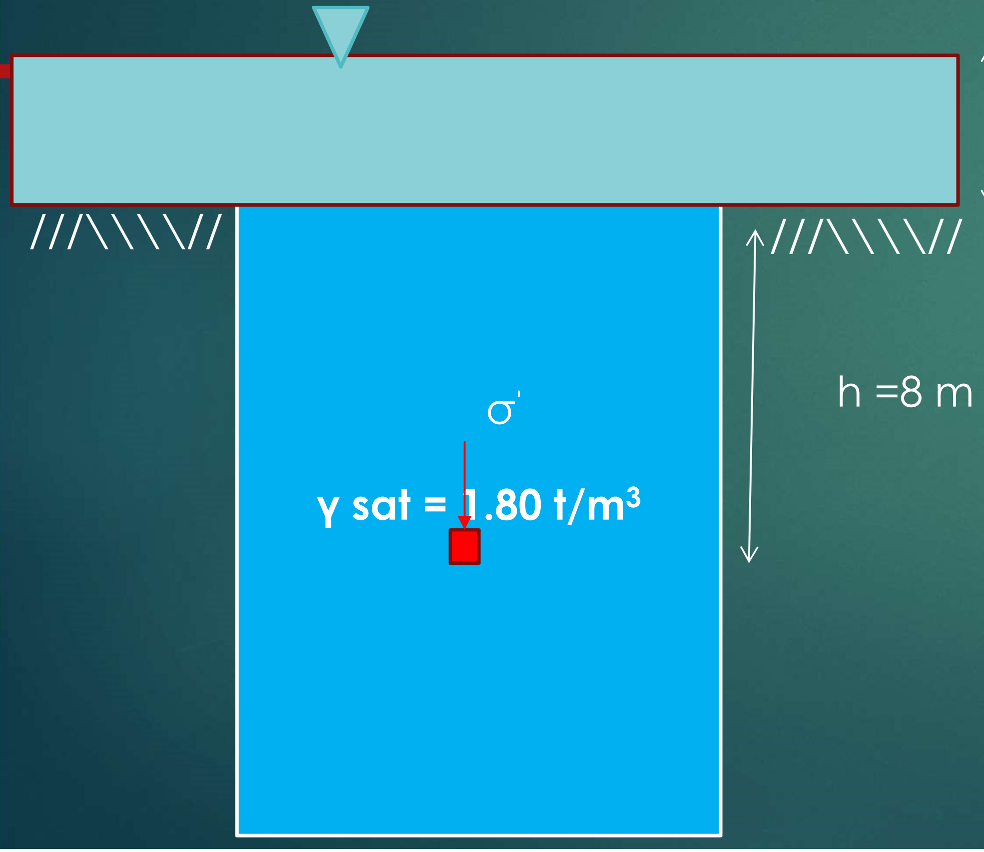
Tegangan air pori (u) =

$\gamma_w \times h = 1.00 \times 5 = 5\ t/m^2$

Tegangan efektif (σ') = $\sigma_{tot} - u$

(σ') = $(13.95 - 5)\ t/m^2 = 8.95\ t/m^2$

Contoh 3:



$\sigma_{tot} = \gamma_{sat} \times h + \gamma w \times (3)$

$= (1.8 \times 8) + 1 \times 3 = 17.4\ t/m^2$

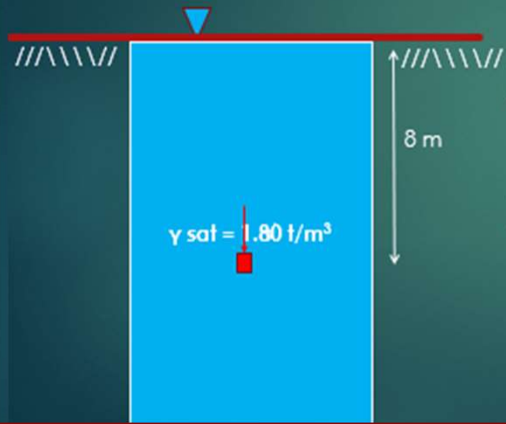
Tegangan air pori (u) =

$\gamma_w \times (h+3) = 1.00 \times 11 = 11\ t/m^2$

Tegangan efektif (σ') = $\sigma_{tot} - u$

$(\sigma') = (17.4 - 11)\ t/m^2 = 6.4\ t/m^2$

Contoh -1



$\sigma_{tot} = \gamma_{sat} \times h$

$= 1.8 \times 8 = 14.4\ t/m^2$

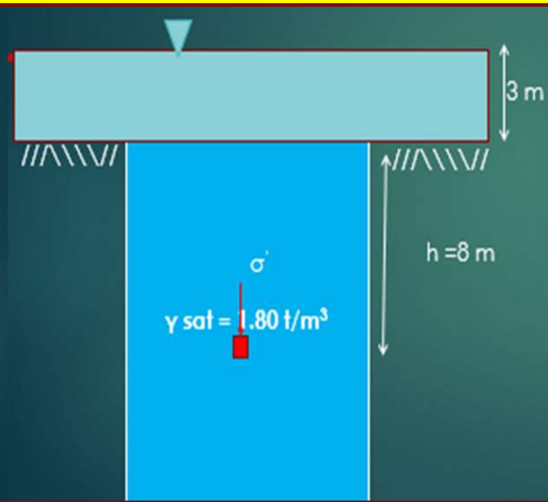
Tegangan air pori (u) =

$\gamma_w \times h = 1.00 \times 8 = 8\ t/m^2$

Tegangan efektif (σ') = $\sigma_{tot} - u$

$(\sigma') = (14.4 - 8)\ t/m^2 = 6.4\ t/m^2$

Contoh -3



$\sigma_{tot} = \gamma_{sat} \times h + \gamma w \times (3)$

$= (1.8 \times 8) + 1 \times 3 = 17.4\ t/m^2$

Tegangan air pori (u) =

$\gamma_w \times (h+3) = 1.00 \times 11 = 11\ t/m^2$

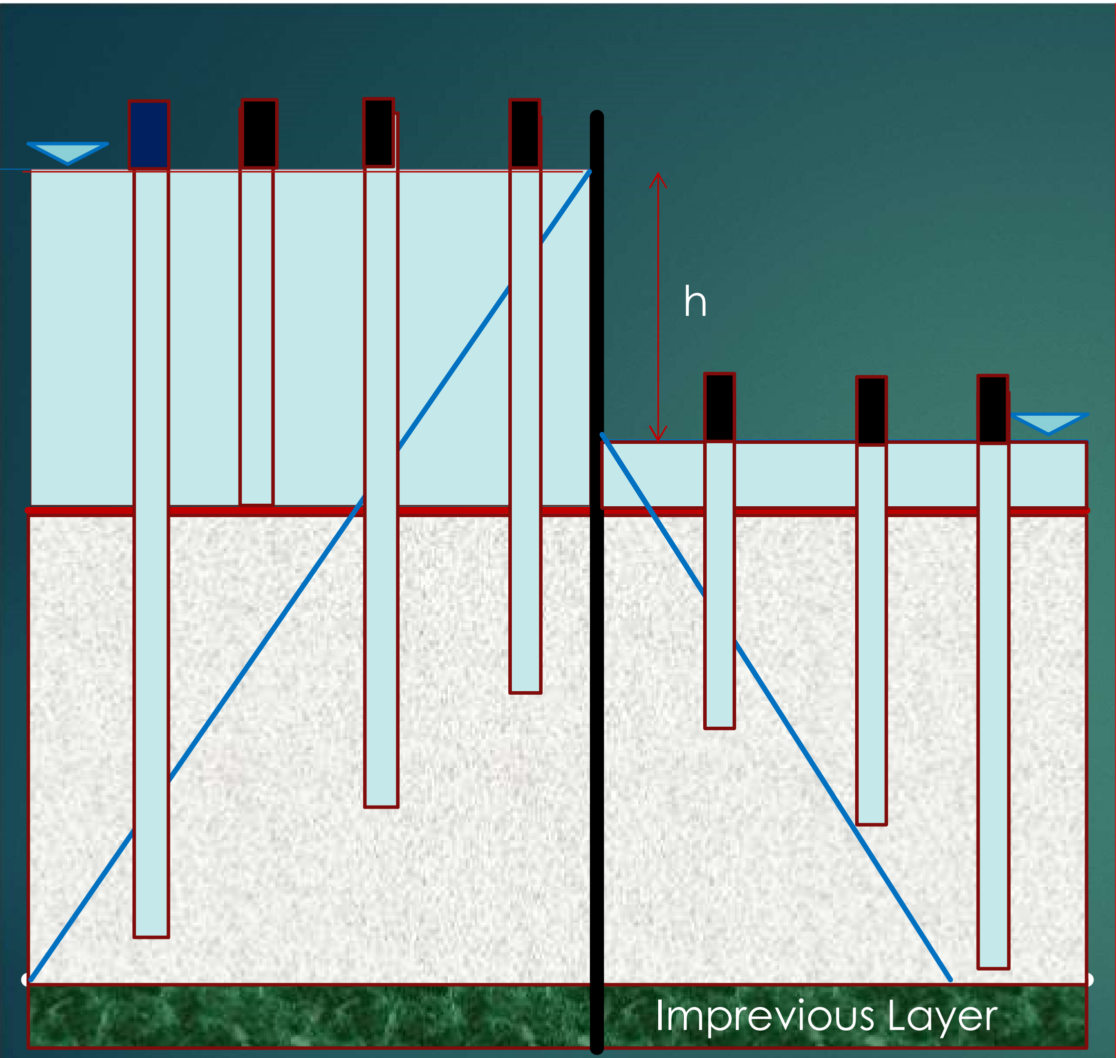
Tegangan efektif (σ') = $\sigma_{tot} - u$

$(\sigma') = (17.4 - 11)\ t/m^2 = 6.4\ t/m^2$

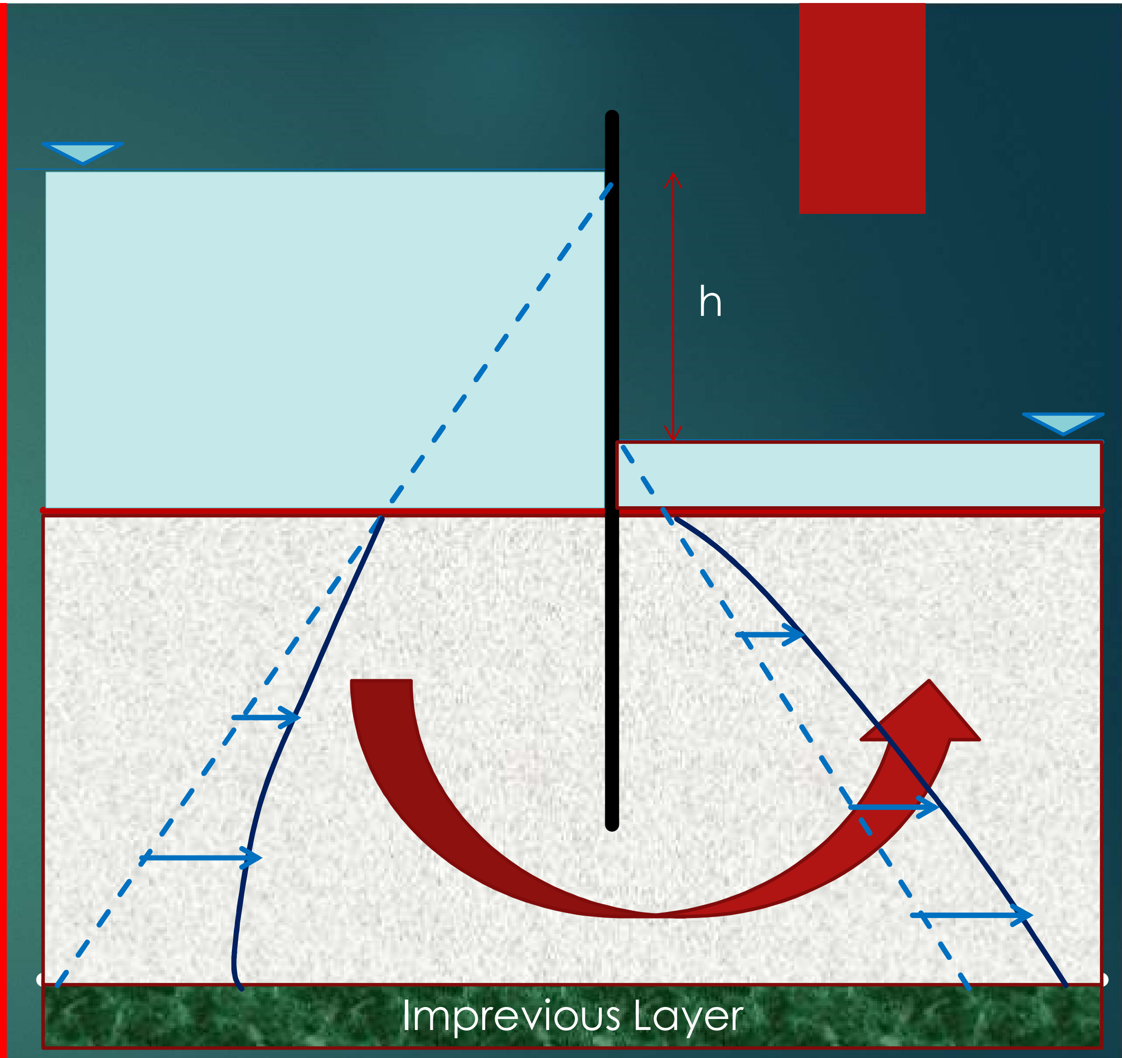
OBJECT

- EFFECTIVE STRESS
- SEEPAGE FORCES
- STRESS UNDER LOADED AREA

By Idrus M Alatas



STATIC PORE WATER PRESSURE
(HYDROSTATIC PRESSURE)



SEEPAGE PORE WATER PRESSURE
(SEEPAGE PRESSURE)

σ tot U σ eff

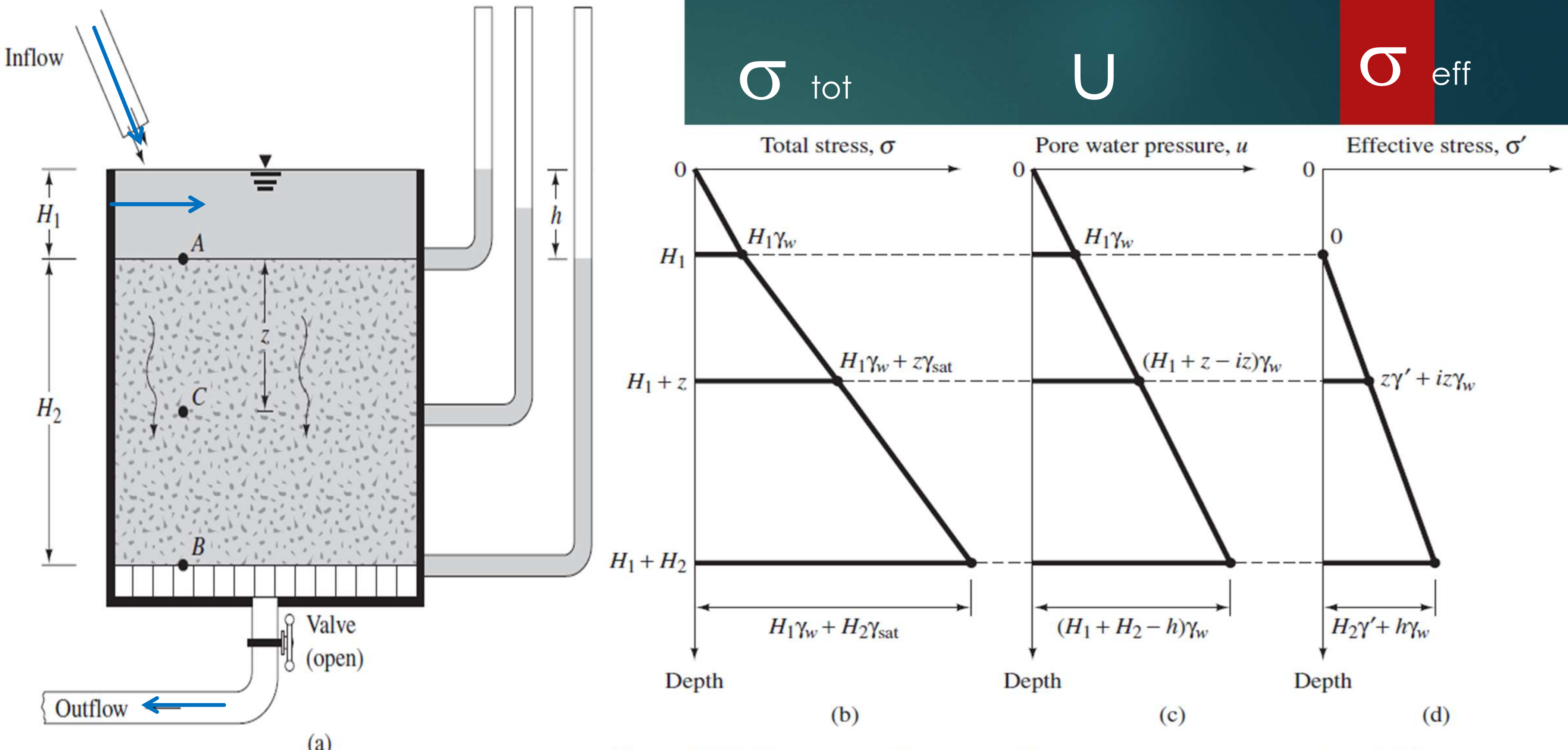


Figure 6.4 (a) Layer of soil in a tank with downward seepage; variation of (b) total stress; (c) pore water pressure; (d) effective stress with depth in a soil layer with downward seepage

σ tot U σ eff

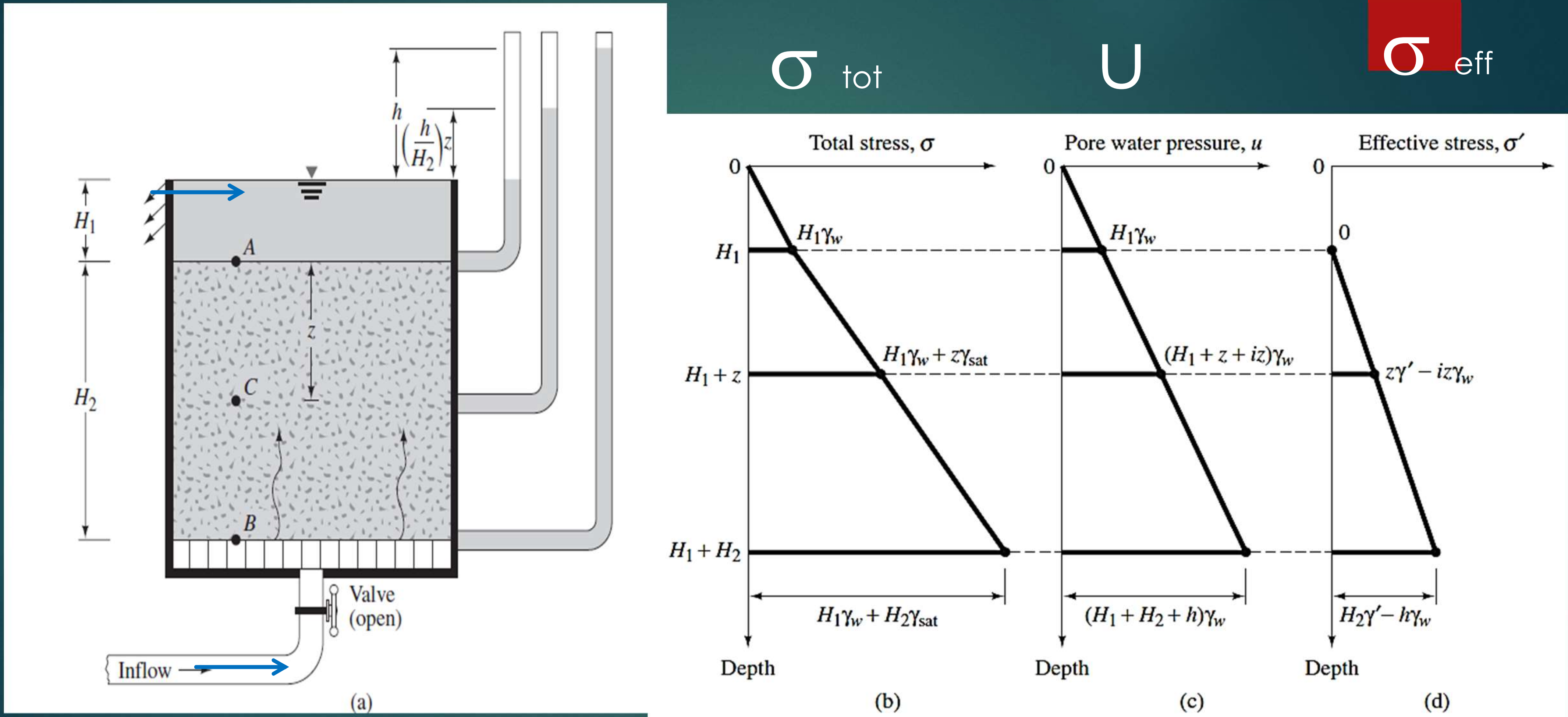


Figure 6.3 (a) Layer of soil in a tank with upward seepage; variation of (b) total stress; (c) pore water pressure; (d) effective stress with depth in a soil layer with upward seepage

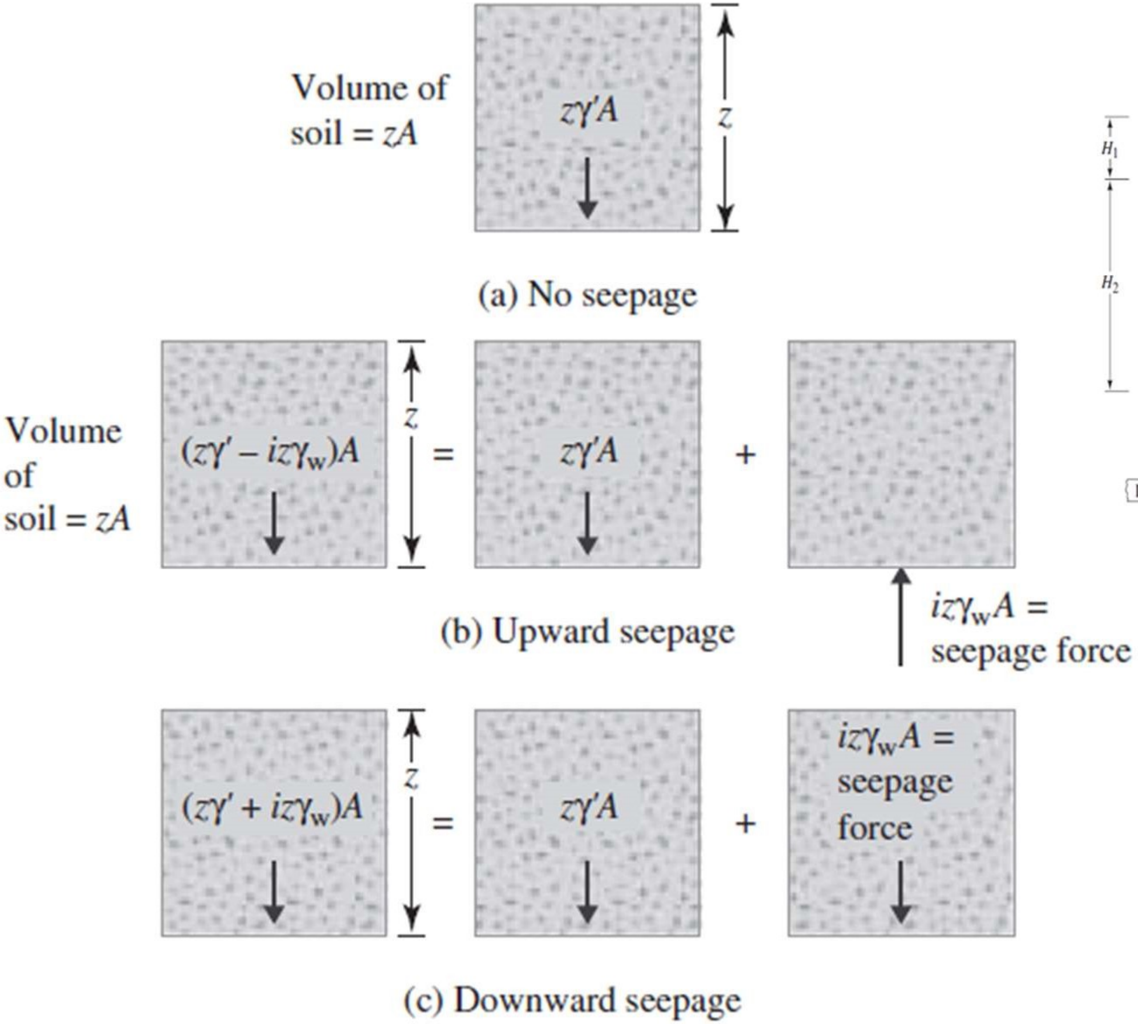


Figure 6.8 Force due to (a) no seepage; (b) upward seepage; (c) downw
on a volume of soil

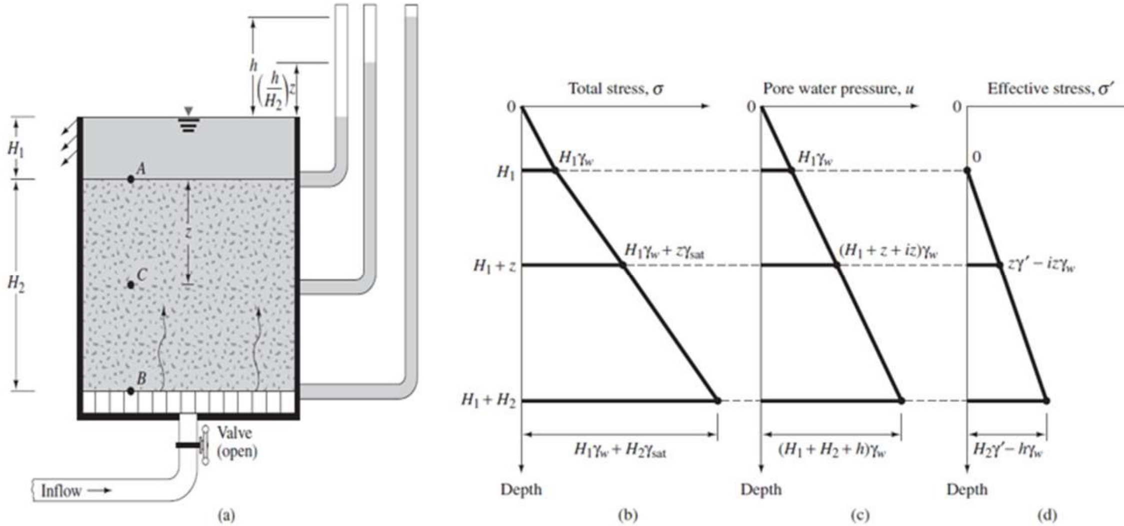
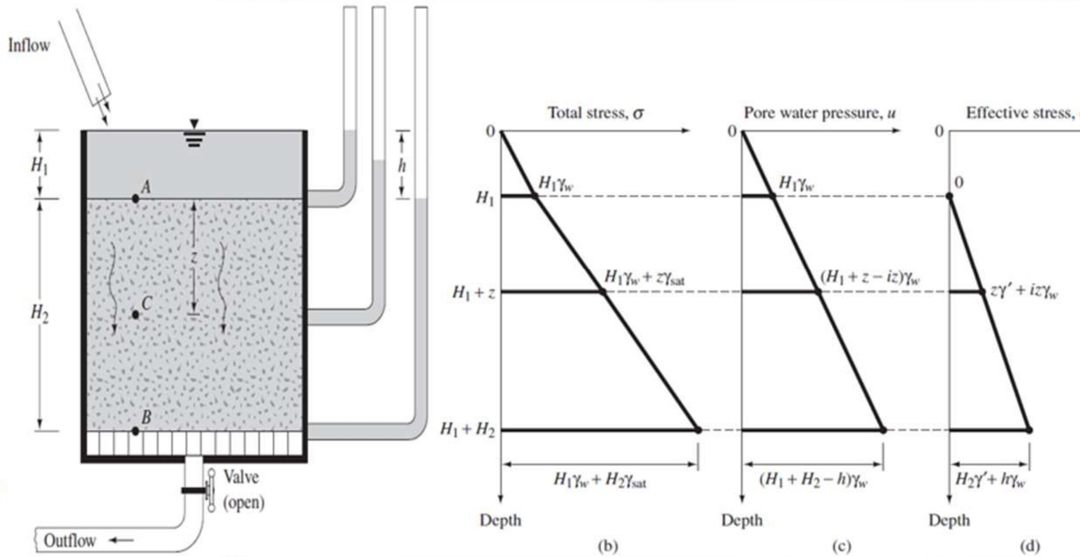
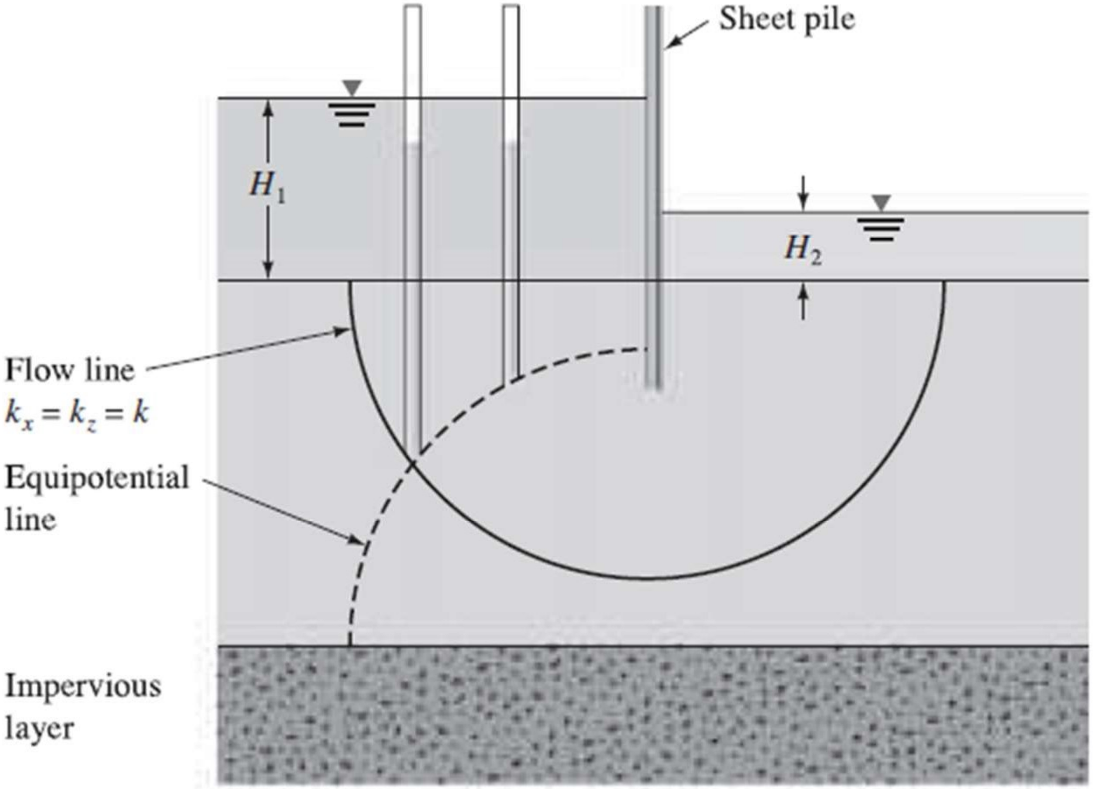


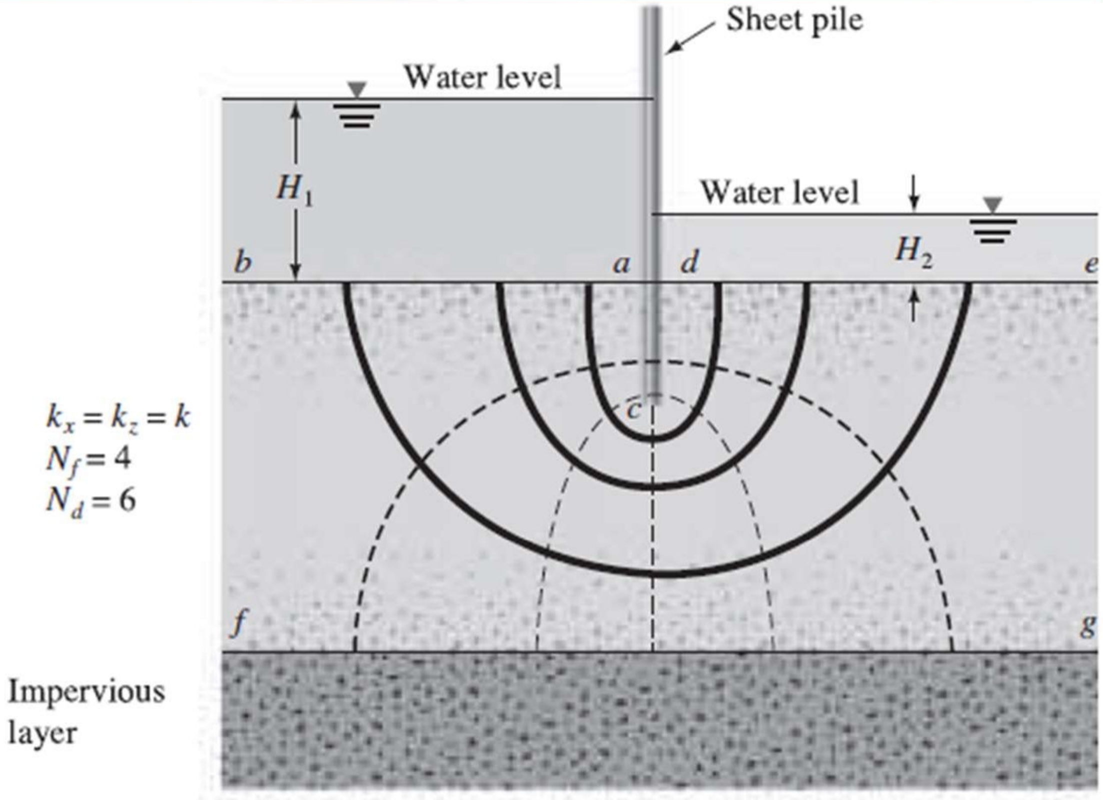
Figure 6.3 (a) Layer of soil in a tank with upward seepage; variation of (b) total stress; (c) pore water pressure; (d) effective stress with depth in a soil layer with upward seepage



Flow Net



Sheet pile
H_1
H_2
Flow line
$k_x = k_z = k$
Equipotential line
Impervious layer



Sheet pile
Water level
Water level
H_1
H_2
b
a
d
e
c
f
g
$k_x = k_z = k$
$N_f = 4$
$N_d = 6$
Impervious layer

Flow Net

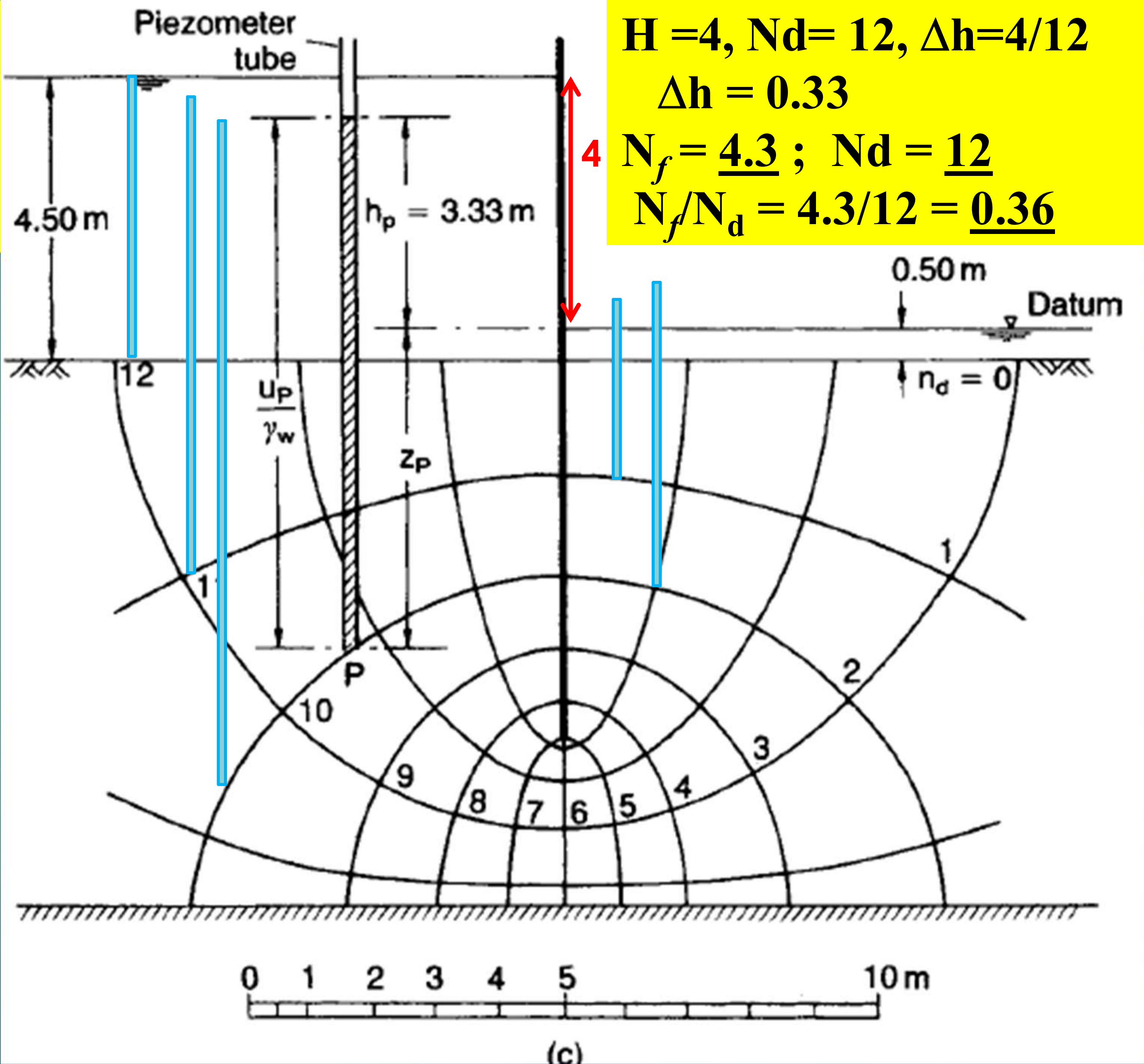
Darcy's empirical law:

$$q = Aki$$

or

$$v = \frac{q}{A} = ki$$

$$q = kh\frac{N_f}{N_d} = k \times 4.00 \times 0.36$$
$$= 1.44k \, m^3/s$$



H =4, Nd= 12, Δh=4/12

Δh = 0.33

N_f = <u>4.3</u> ; Nd = <u>12</u>

N_f/N_d = 4.3/12 = <u>0.36</u>

PENGARUH SEEPAGE TERHADAP EFFECTIVE TRESS

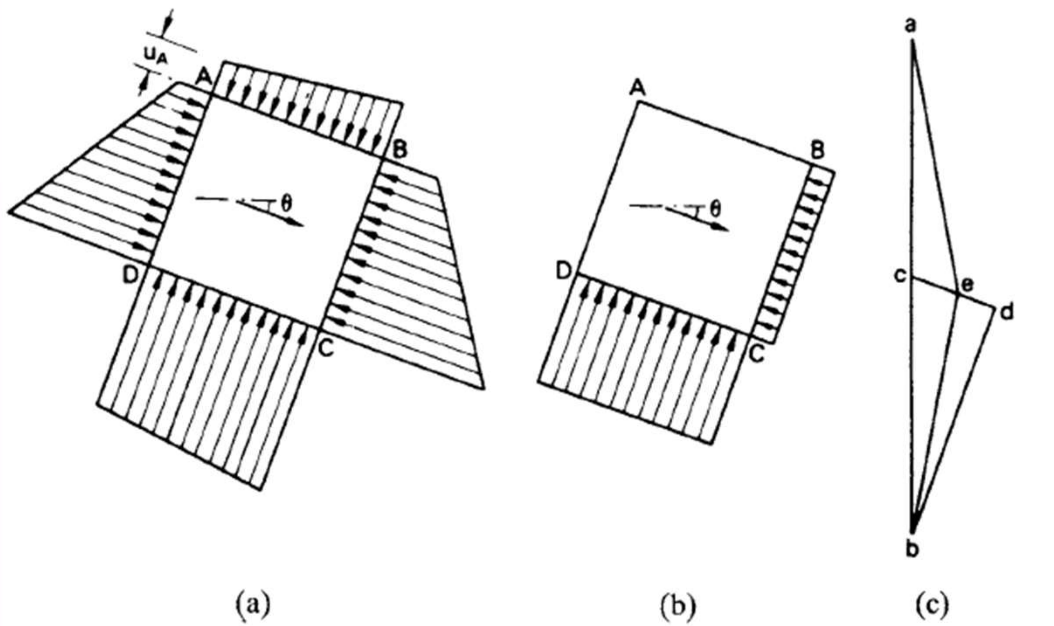


Figure 3.6 Forces under seepage conditions. (Reproduced from D.W. Taylor (1948) *Fundamentals of Soil Mechanics*, © John Wiley & Sons Inc. [2], by permission.)

CONTOH -1

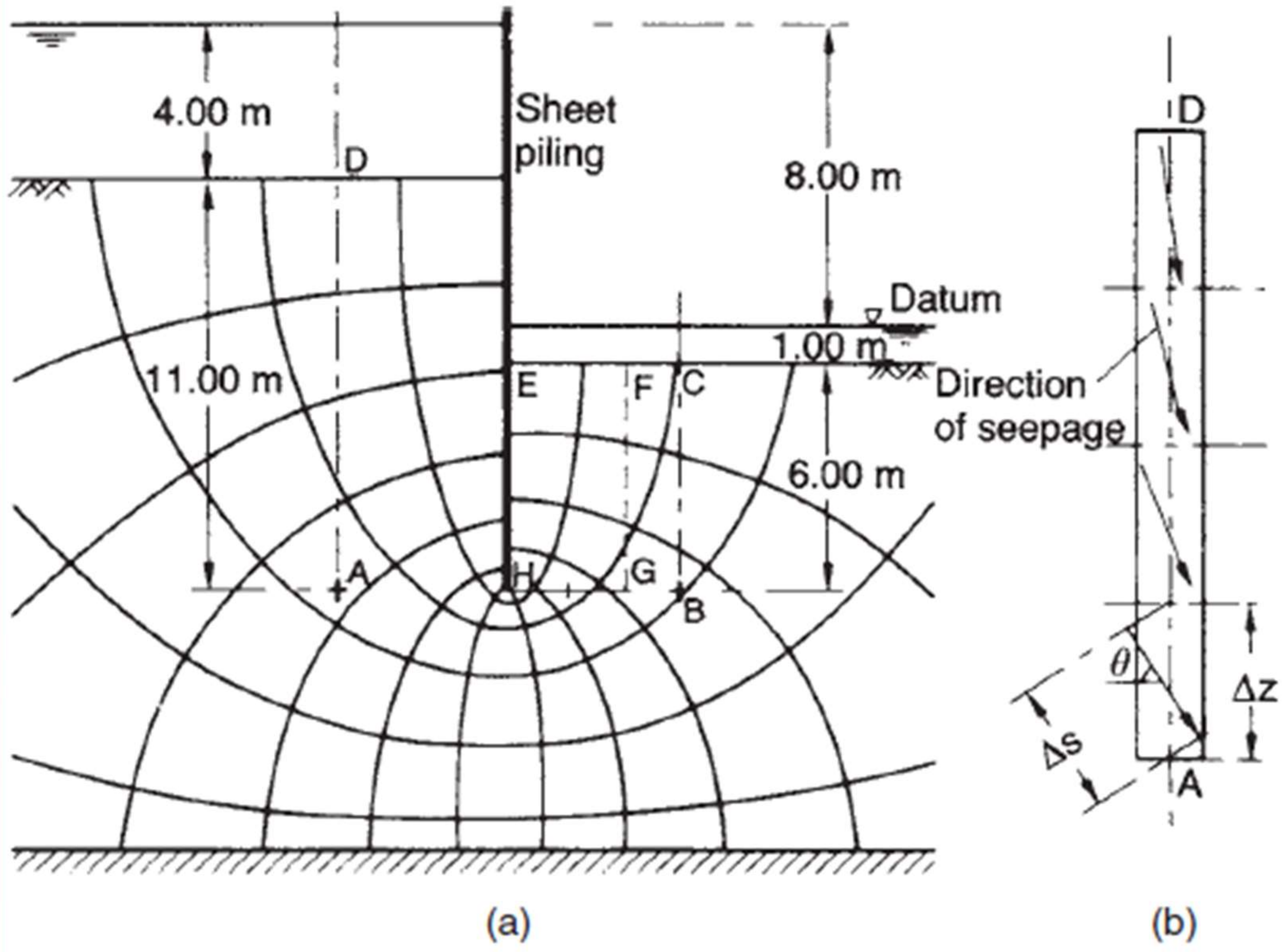


Figure 3.8 Examples 3.3 and 3.4.

The flow net for seepage under a sheet pile wall is shown in Figure 3.8(a), the saturated unit weight of the soil being 20 kN/m^3.(γsat) Determine the values of effective vertical stress at <u>A</u> and <u>B.</u>

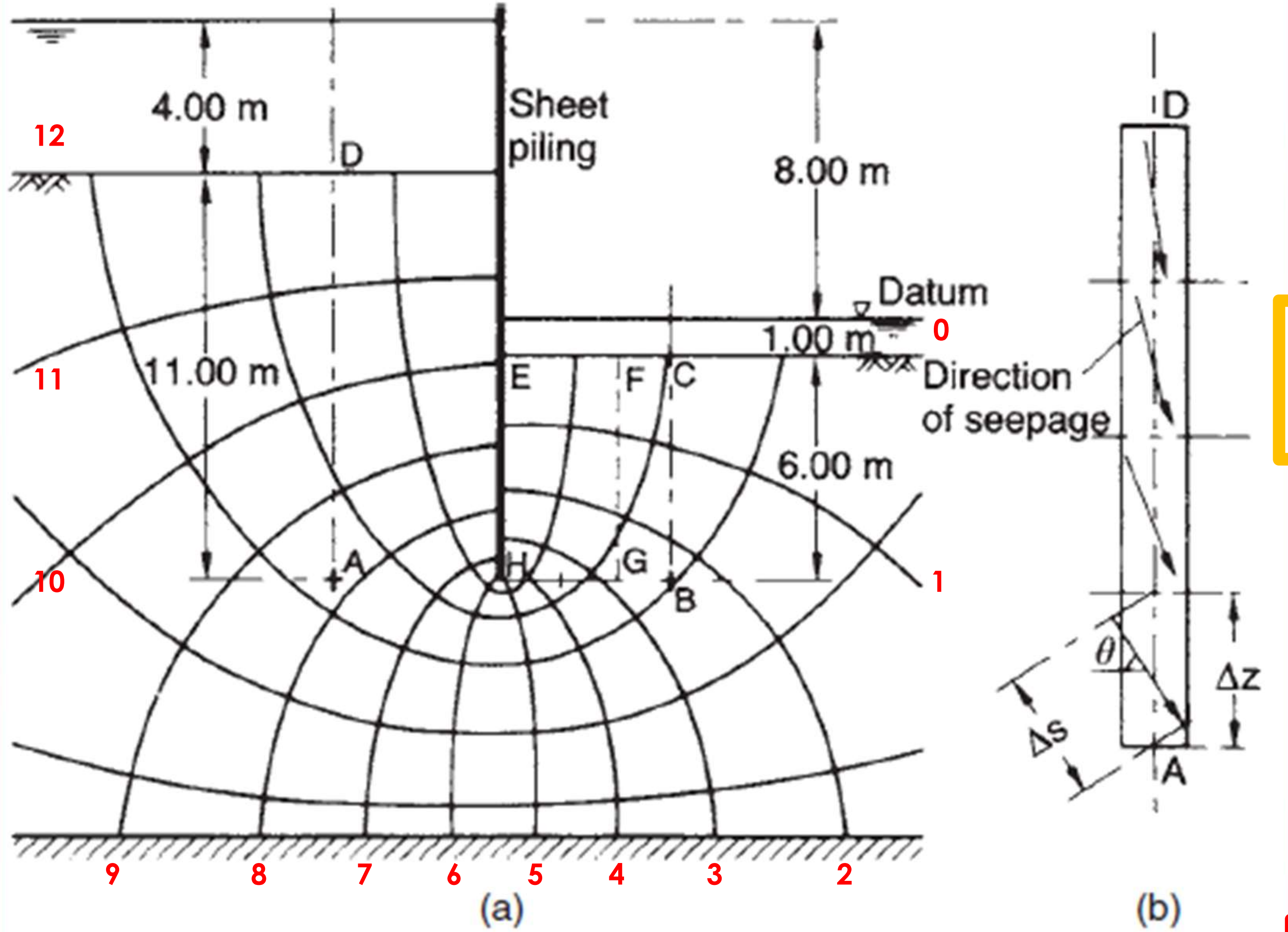


Figure 3.8 Examples 3.3 and 3.4.

CONTOH -1

Effective Verical Stress at A.

H = 8 .00 m

Δh = H/Nd = 8.00/12 = 0,67 m

Total Stress at A

4 (γw) + 11(γsat) = 4(9.8)+(220)

= 259.2 kN/m²

Pore Pressure (seepage) at A

(DOWN STREAM)

υ A = υ A (hs) – 3,8 (Δh)

{(15) – 3,8 (0,67)}x 9.8=

(15 -2.546)x9,8 = 122.05 kN/m²

(UP STREAM)

υ A = υ A (hs) + 8.2 (Δh)

{(7) + 8.2 (0,67)}x 9.8=

(7 +5.49)x9,8 = 122.4 kN/m²

σ Eff A = σ tot A – υ A

= 259.2 – 122.05 = 137.15 kN/m²

CONTOH -1

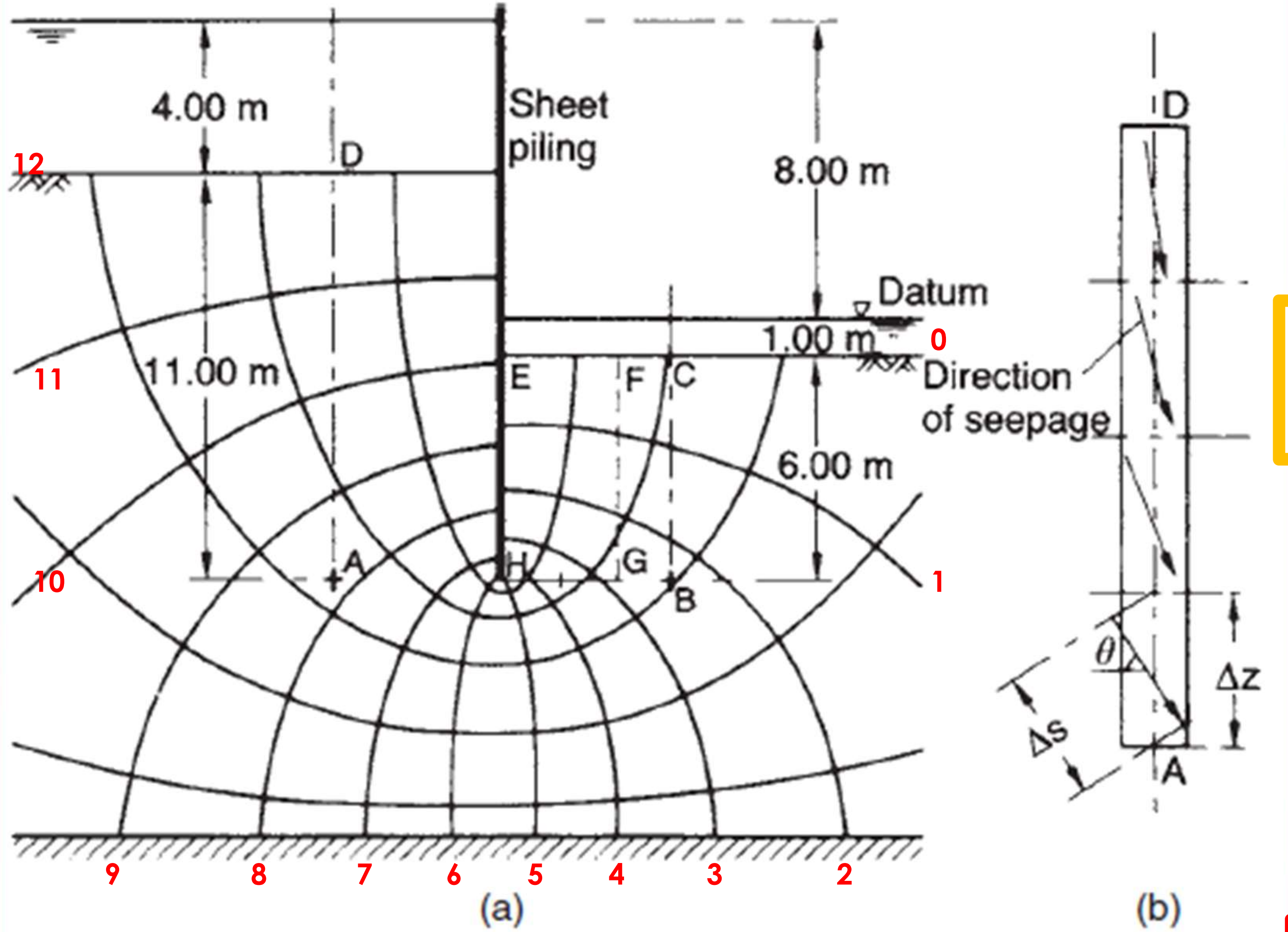


Figure 3.8 Examples 3.3 and 3.4.

Effective Verical Stress at B.

H = 8 .00 m

Δh = H/Nd = 8.00/12 = 0,67 m

Total Stress at B

1(γw) + 6(γsat) = 9.8+120

= 129.8 kN/m²

Pore Pressure (seepage) at A

(DOWN STREAM)

υ B = υ B (hs) – 9.6 (Δh)

{(15) – 9.6 (0,67)}x 9.8=

(15 -6.432)x9,8 = 83.97 kN/m²

(UP STREAM)

υ B = υ B (hs) + 2.4 (Δh)

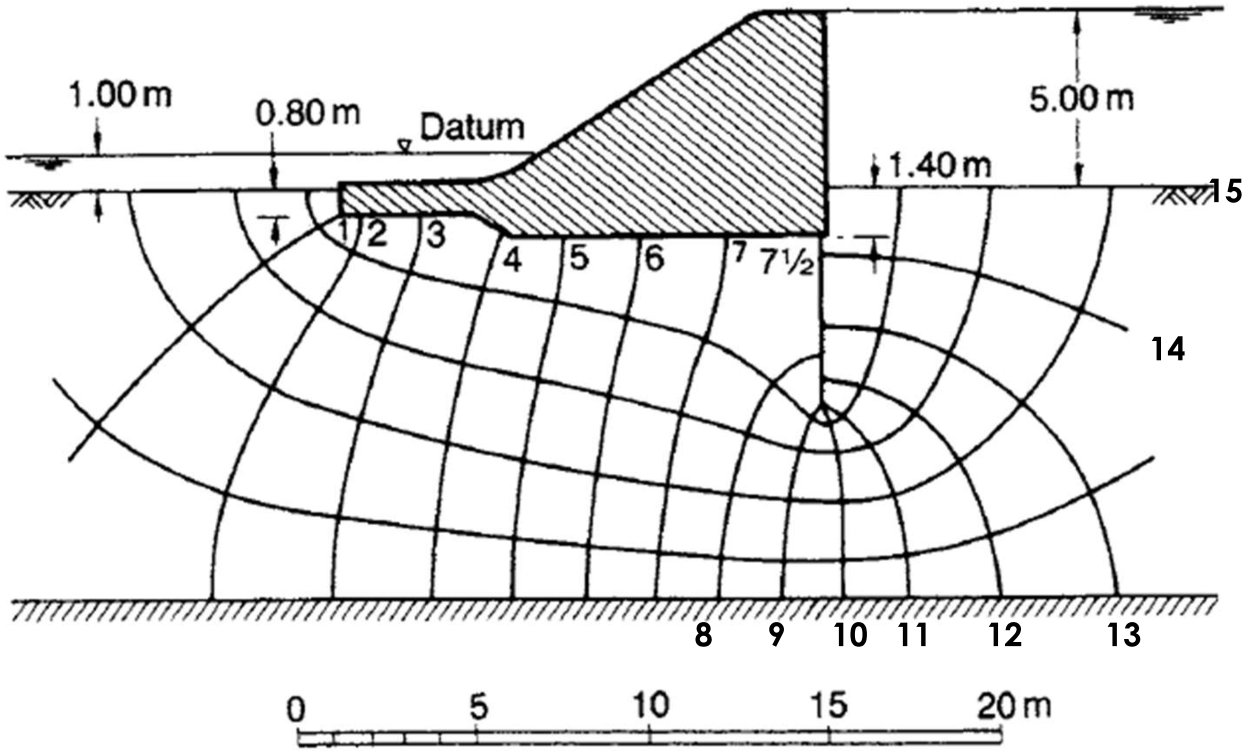
{(7) + 2.4 (0,67)}x 9.8=

(7 +1.58)x9,8 = 84.12 kN/m²

σ Eff B = σ tot B – υ B

= 129.8 – 84= 45.8 kN/m²

CONTOH -2



The section through a dam is shown in Figure beside. Determine the quantity of seepage under the dam and plot the distribution of uplift pressure on the base of the dam. The coefficient of permeability of the foundation soil is k = 2.5 10^{-5} m/s.

The flow net is shown in the figure. The downstream water level is selected as datum. Between the upstream and downstream equipotentials the total head loss is 4.00 m. In the flow net there are 4.7 flow channels and 15 equipotential drops. The seepage is given by

$$q = kh\frac{N_f}{N_d} = 2.5 \times 10^{-5} \times 4.00 \times \frac{4.7}{15}$$
$$= 3.1 \times 10^{-5}\,\mathrm{m^3/s} \quad \text{(per m)}$$

UPLIFT PRESSURE DIBAWAH BENDUNG ?

CONTOH -2

The pore water pressure is calculated at the points of intersection of the equipotentials with the base of the dam.

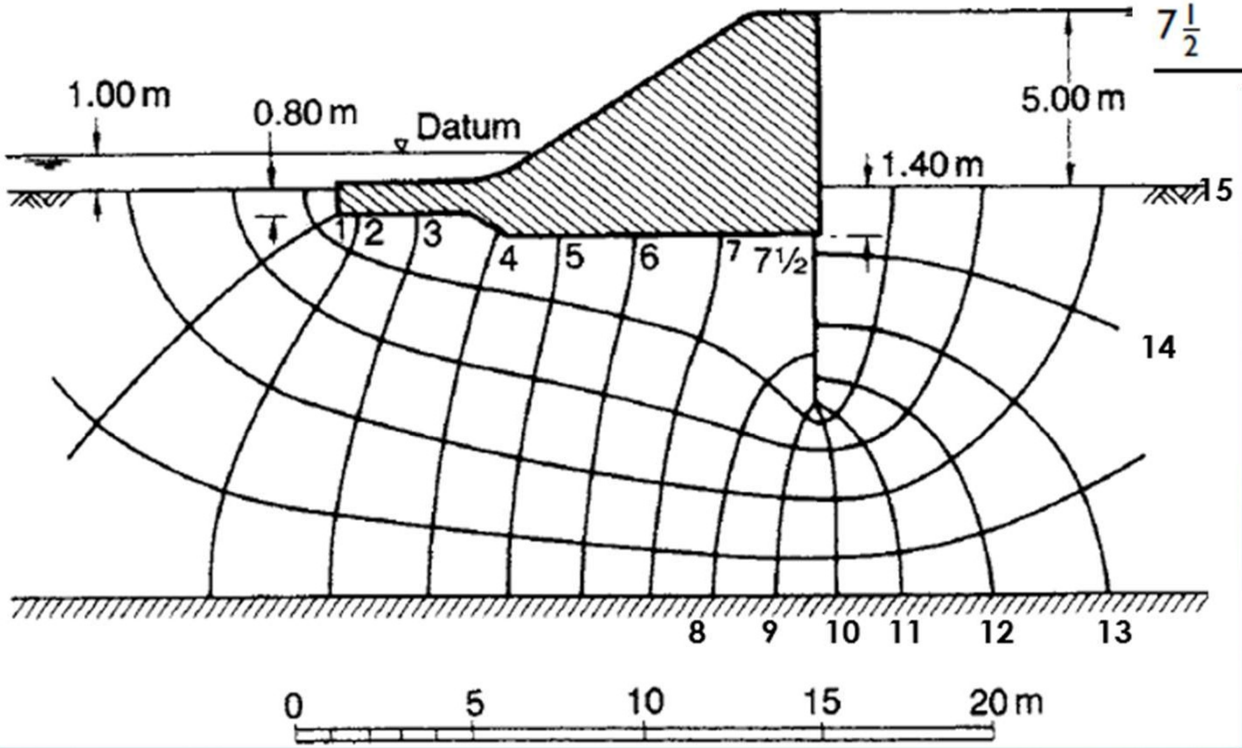
The total head at each point is obtained from the flownet and the elevation head from the section.

The calculations are shown in Table below :

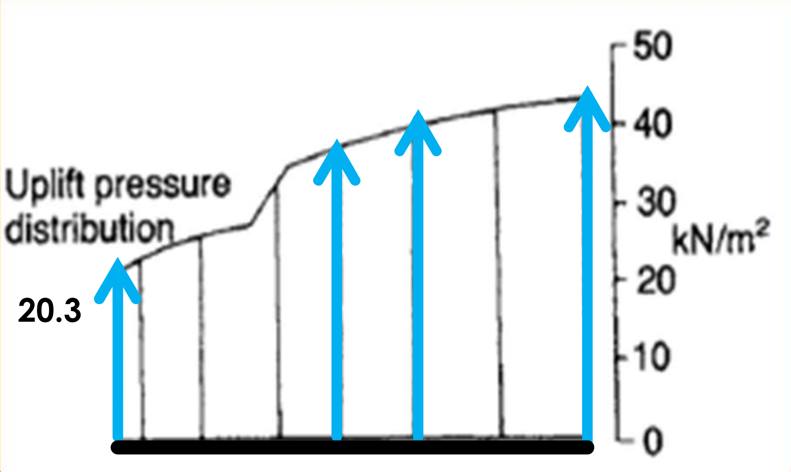
Point	h (m)	z (m)	$h - z$ (m)	$u = \gamma_w(h - z)$ (kN/m^2)
1	0.27	−1.80	2.07	20.3
2	0.53	−1.80	2.33	22.9
3	0.80	−1.80	2.60	25.5
4	1.07	−2.10	3.17	31.1
5	1.33	−2.40	3.73	36.6
6	1.60	−2.40	4.00	39.2
7	1.87	−2.40	4.27	41.9
$7\frac{1}{2}$	2.00	−2.40	4.40	43.1

CONTOH -2

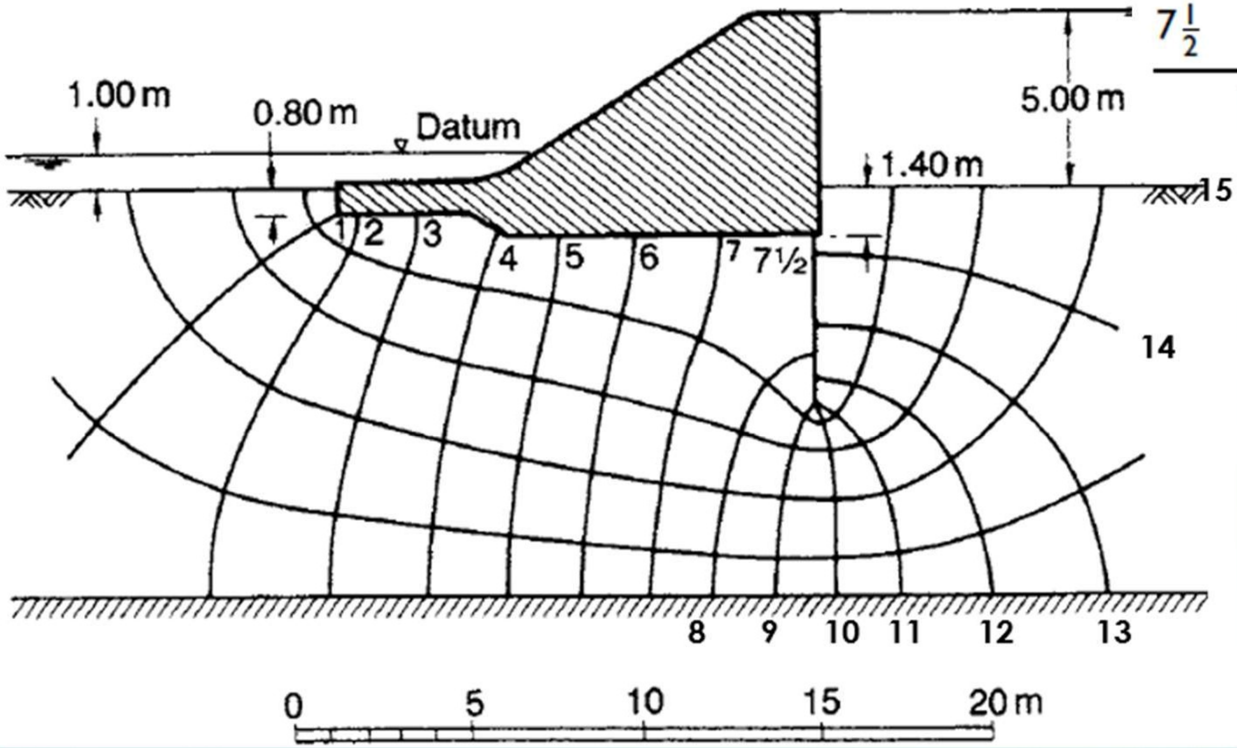
Point	h (m)	z (m)	h − z (m)	$u = \gamma_w(h - z)$ (kN/m²)
1	0.27	−1.80	2.07	20.3
2	0.53	−1.80	2.33	22.9
3	0.80	−1.80	2.60	25.5
4	1.07	−2.10	3.17	31.1
5	1.33	−2.40	3.73	36.6
6	1.60	−2.40	4.00	39.2
7	1.87	−2.40	4.27	41.9
$7\frac{1}{2}$	2.00	−2.40	4.40	43.1



$\Delta h = H / N_q = 4/15 = 0.26666 \sim 2.67$

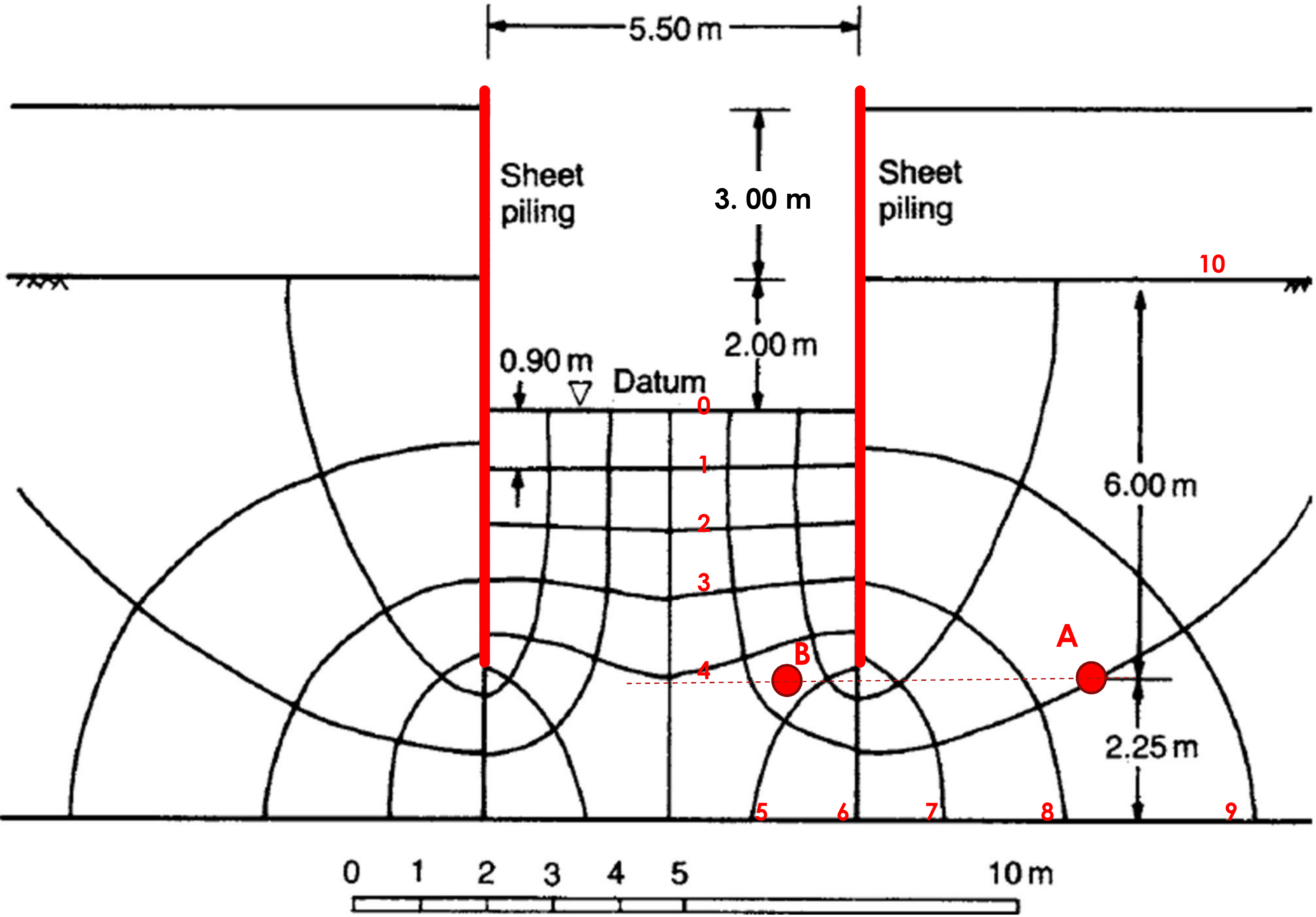


Point	h (m)	z (m)	$h - z$ (m)	$u = \gamma_w(h - z)$ (kN/m^2)
1	0.27	−1.80	2.07	20.3
2	0.53	−1.80	2.33	22.9
3	0.80	−1.80	2.60	25.5
4	1.07	−2.10	3.17	31.1
5	1.33	−2.40	3.73	36.6
6	1.60	−2.40	4.00	39.2
7	1.87	−2.40	4.27	41.9
$7\frac{1}{2}$	2.00	−2.40	4.40	43.1

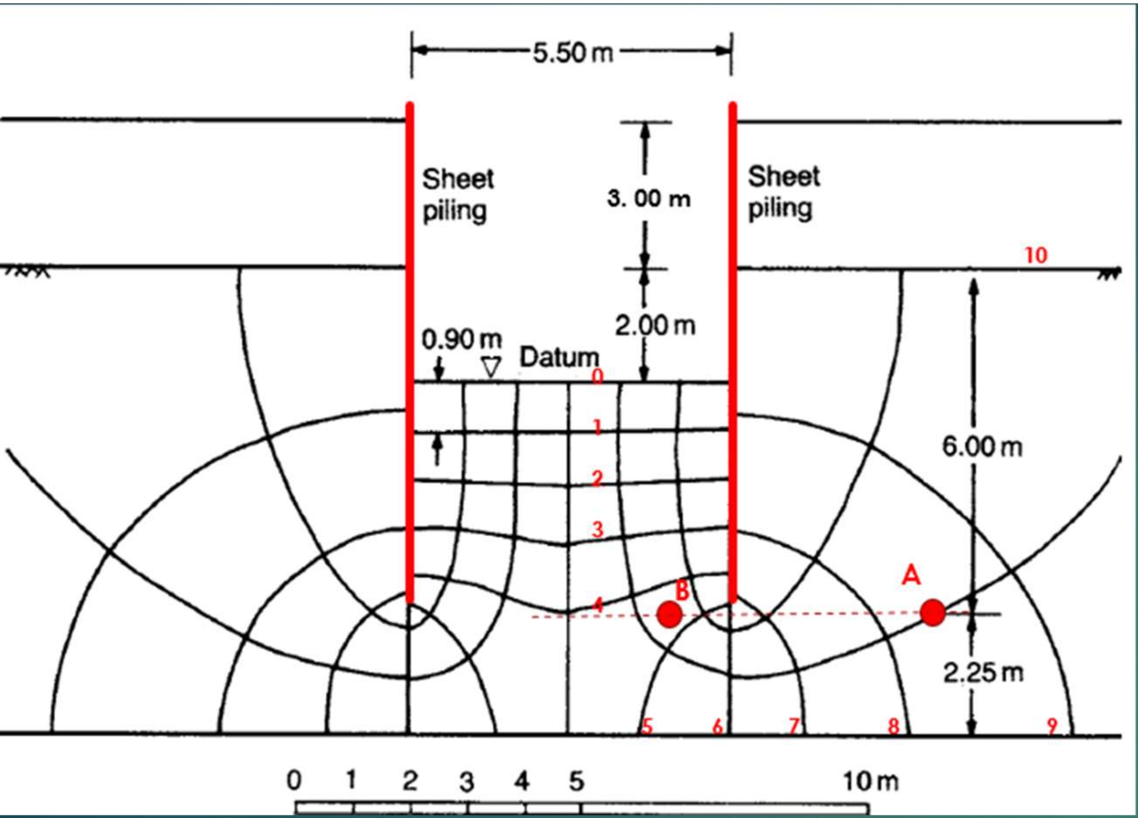


CONTOH -2

CONTOH -3



Thesaturated unit weight of the soil being 20 kN/m³ (γsat) .Determine the values of effective vertical stress at <u>A</u> and <u>B.</u>



CONTOH -3

Effective Verical Stress at A.

H = 5m

Δh = H/Nd = 5/10 = 0,50 m

Total Stress at A

3.0 (γw) + 6(γsat) = 3.0(9.8)+(120) = 149.4 kN/m^2

Pore Pressure (seepage) at A

(DOWN STREAM)

υ A = υ A (hs) – 1.6 (Δh) = {(9) – 1.6 (0,5)}x 9.8=

(9 -0.8)x9,8 = 80.36 kN/m^2

(UP STREAM)

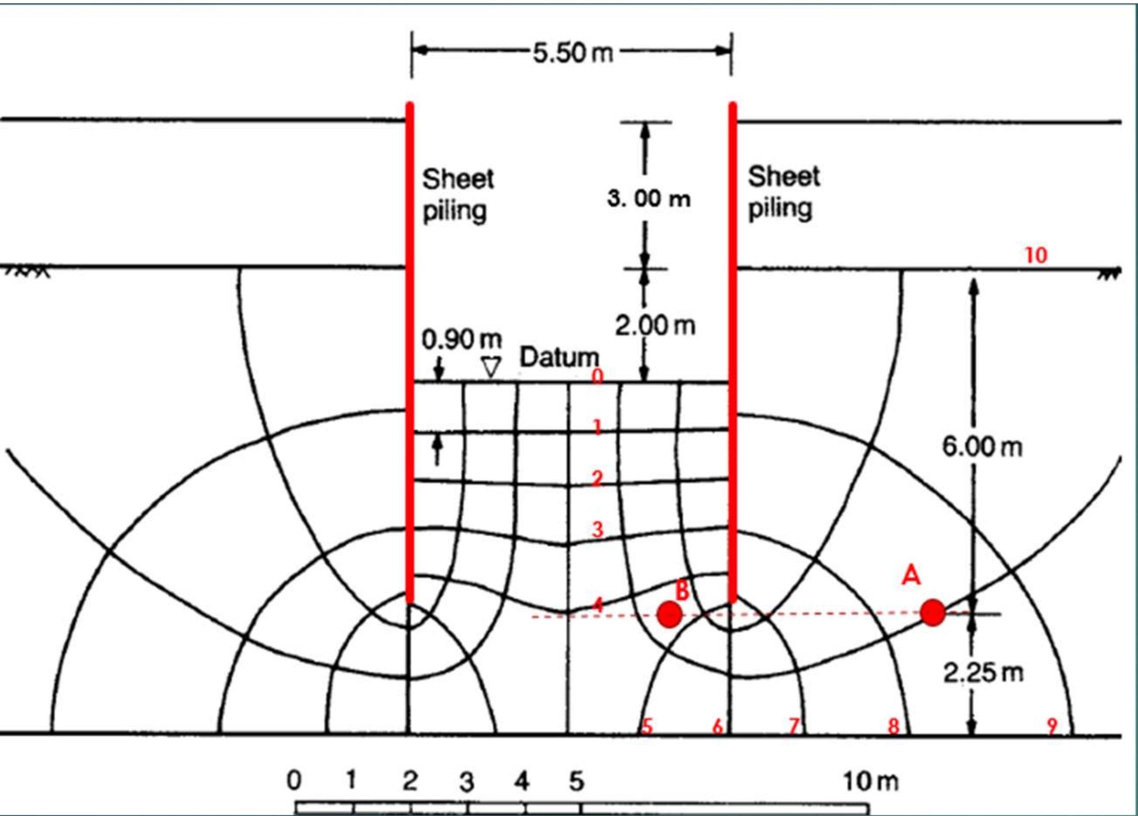
υ A = υ A (hs) + 8.4 (Δh)

{(4) + 8.4 (0,5)}x 9.8 = (4 +4.2)x9,8 = 80.36kN/m^2

σ Eff A = σ tot A – υ A

= 149.4 – 80.36 = 69.04 kN/m^2

CONTOH -3



Effective Verical Stress at B.

H = 5m

Δh = H/Nd = 5/10 = 0,50 m

Total Stress at B

4(γsat) = 80 kN/m^2

Pore Pressure (seepage) at B

(DOWN STREAM)

u B = u B (hs) – 5.4 (Δh) = {(9) – 5. 4(0,5)}x 9.8=

(9 -2.7)x9,8 = 61.74 kN/m^2

(UP STREAM)

u B = u B(hs) + 4.6 (Δh)

{(4) + 4.6 (0,5)}x 9.8 = (4 +2.3)x9,8 = 61.74 kN/m^2

σ Eff B = σ tot B – u B

= 80 – 61.74 = 18.26 kN/m^2

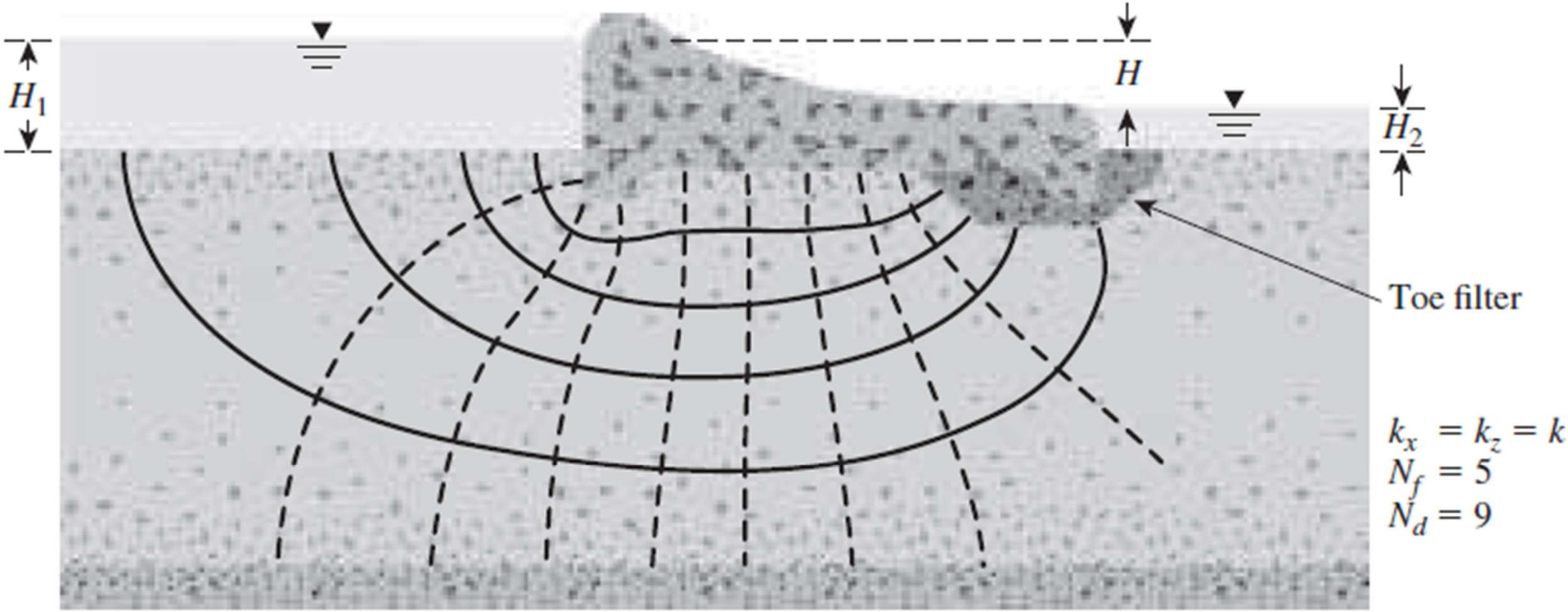


Figure 5.17 Flow net under a dam with toe filter

OBJECT

- EFFECTIVE STRESS
- SEEPAGE FORCES
- STRESS UNDER LOADED AREA

By Idrus M Alatas

STRESSES FROM ELASTIC THEORY

The stresses within ***a semi-infinite, homogeneous, isotropic mass,*** with a linear stress– strain relationship, due to a point load on the surface, were determined by Boussinesq in 1885. The vertical, radial, circumferential and shear stresses at a depth z and a horizontal distance r from the point of application of the load were given. The stresses due to surface loads distributed over a particular area can be obtained by integration from the point load solutions. The stresses at a point due to more than one surface load are obtained by superposition. In practice, loads are not usually applied directly on the surface but the results for surface loading can be applied conservatively in problems concerning loads at a shallow depth.

APLICATION

$$S_p = \frac{C_c H}{1 + e_0} \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right)$$

Normally consolidation … Using Cc

Over Consolidation, where σ'o + Δσ'< σ'c, Using Cs

$$S_p = \frac{C_s H}{1 + e_0} \log\left(\frac{\sigma'_c}{\sigma'_o}\right) + \frac{C_c H}{1 + e_0} \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_c}\right)$$

Over Consolidation, where σ'o + Δσ' > σ'c, Using Cs & Cc

LOADED TYPES

1. Point load
2. Line load
3. Strip area carrying uniform pressure
4. Strip area carrying linearly increasing pressure
5. Circular area carrying uniform pressure
6. Rectangular area carrying uniform pressure
7. Trapesium Load

POINT LOAD

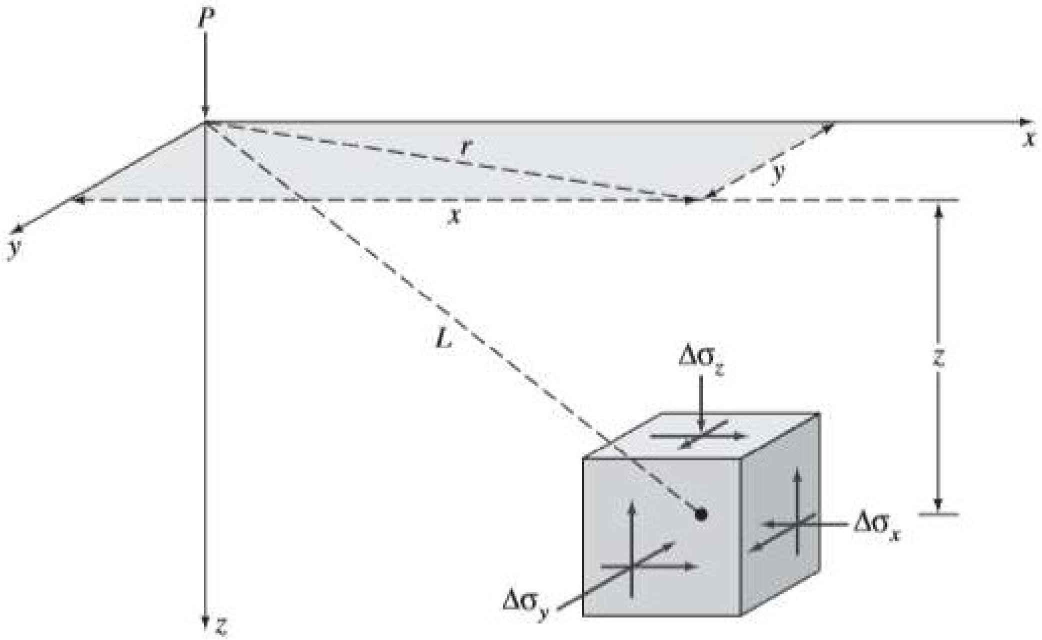


Figure 6.11 Stresses in an elastic medium caused by a point load

and

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

$$\Delta\sigma_x = \frac{P}{2\pi}\left\{\frac{3x^2z}{L^5} - (1-2\mu_s)\left[\frac{x^2-y^2}{Lr^2(L+z)} + \frac{y^2z}{L^3r^2}\right]\right\}$$

$$\Delta\sigma_y = \frac{P}{2\pi}\left\{\frac{3y^2z}{L^5} - (1-2\mu_s)\left[\frac{y^2-x^2}{Lr^2(L+z)} + \frac{x^2z}{L^3r^2}\right]\right\}$$

POINT LOAD

$$\Delta\sigma_z = \frac{P}{z^2}\left\{\frac{3}{2\pi}\frac{1}{[(r/z)^2+1]^{5/2}}\right\} = \frac{P}{z^2}I_1$$

where $I_1 = \dfrac{3}{2\pi}\dfrac{1}{[(r/z)^2+1]^{5/2}}$.

The variation of I_1 for various values of r/z is given in Table 6.1

Table 6.1 Variation of I_1 [Eq. (6.20)]

r/z	I_1	r/z	I_1
0	0.4775	0.9	0.1083
0.1	0.4657	1.0	0.0844
0.2	0.4329	1.5	0.0251
0.3	0.3849	1.75	0.0144
0.4	0.3295	2.0	0.0085
0.5	0.2733	2.5	0.0034
0.6	0.2214	3.0	0.0015
0.7	0.1762	4.0	0.0004
0.8	0.1386	5.0	0.00014

POINT LOAD with Westergaard Methods

$$\Delta\sigma_z = \frac{P\eta}{2\pi z^2}\left[\frac{1}{\eta^2 + (r/z)^2}\right]^{3/2}$$

where

$$\eta = \sqrt{\frac{1 - 2\mu_S}{2 - 2\mu_S}}$$

μ_S = Poisson's ratio of the solid between the rigid reinforcements

$$r = \sqrt{x^2 + y^2}$$

POINT LOAD with Westergaard Methods

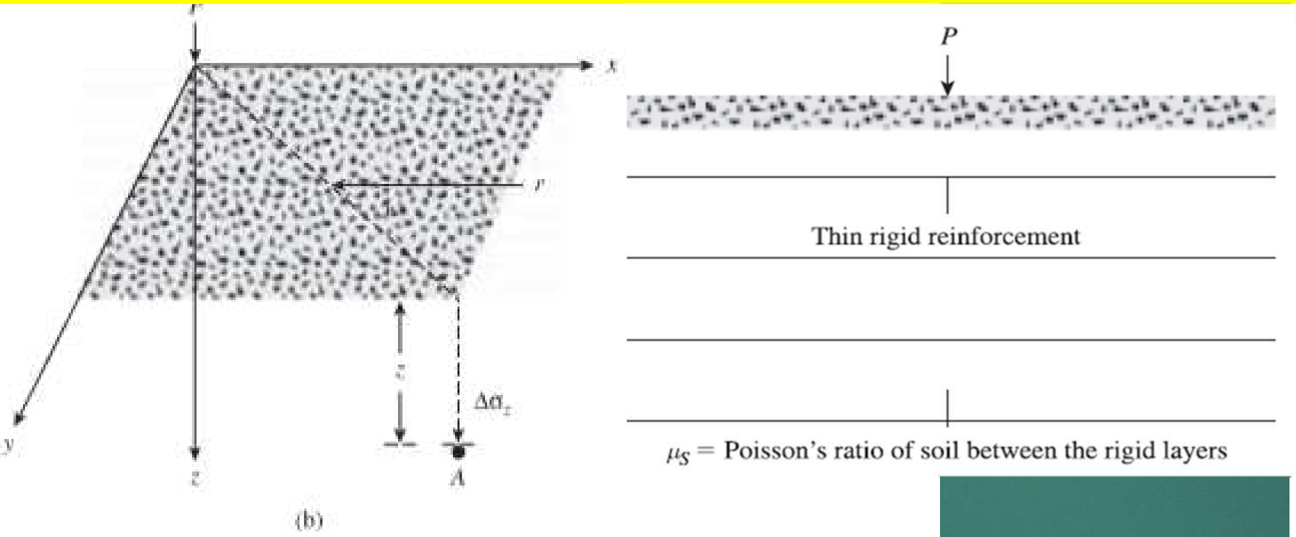


Figure 6.12 Westergaard's solution for vertical stress due to a point load

Equation (6.22) can be rewritten as

$$\Delta\sigma_z = \left(\frac{P}{z^2}\right) I_2$$

where

$$I_2 = \frac{1}{2\pi\eta^2}\left[\left(\frac{r}{\eta z}\right)^2 + 1\right]^{-3/2}$$

Table 6.3 Variation of I_2 [Eq. (6.25)].

	I_2		
r/z	$\mu_s = 0$	$\mu_s = 0.2$	$\mu_s = 0.4$
0	0.3183	0.4244	0.9550
0.1	0.3090	0.4080	0.8750
0.2	0.2836	0.3646	0.6916
0.3	0.2483	0.3074	0.4997
0.4	0.2099	0.2491	0.3480
0.5	0.1733	0.1973	0.2416
0.6	0.1411	0.1547	0.1700
0.7	0.1143	0.1212	0.1221
0.8	0.0925	0.0953	0.0897
0.9	0.0751	0.0756	0.0673
1.0	0.0613	0.0605	0.0516
1.5	0.0247	0.0229	0.0173
2.0	0.0118	0.0107	0.0076
2.5	0.0064	0.0057	0.0040
3.0	0.0038	0.0034	0.0023
4.0	0.0017	0.0015	0.0010
5.0	0.0009	0.0008	0.0005

SEMI FINITE LINE LOAD

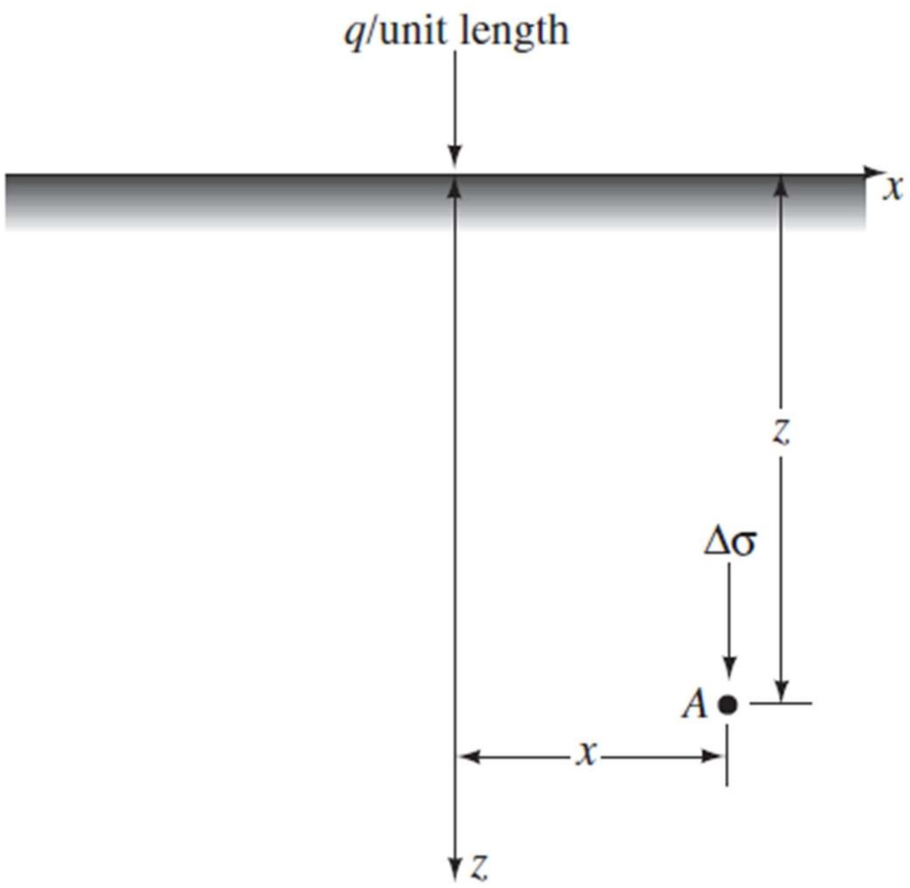


Figure 6.13 Line load over the surface of a semiinfinite soil mass

The vertical stress increase, inside the soil mass can be determined by using the principles of the theory of elasticity, or

$$\Delta\sigma = \frac{2qz^3}{\pi(x^2 + z^2)^2}$$

SEMI FINITE LINE LOAD

$$\Delta\sigma = \frac{2q}{\pi z[(x/z)^2 + 1]^2}$$

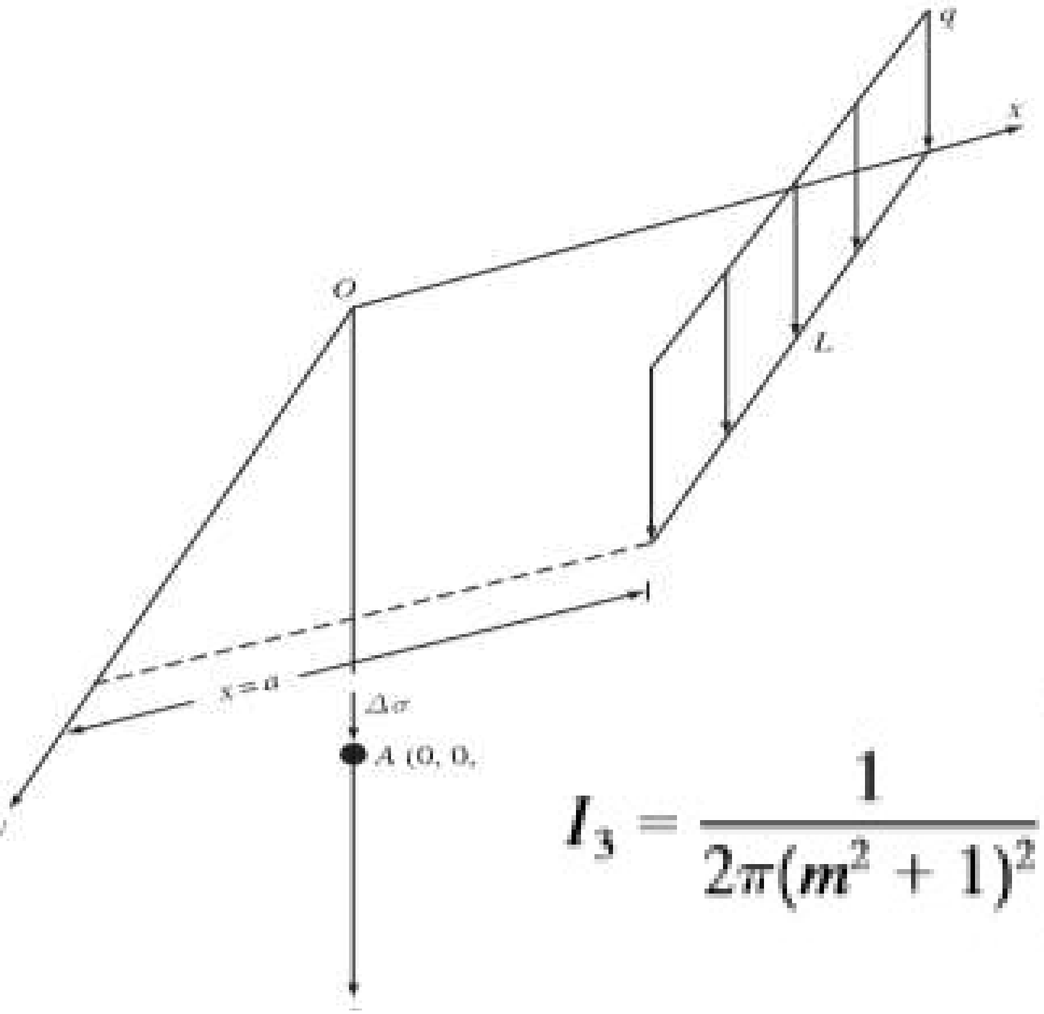
$$\frac{\Delta\sigma}{(q/z)} = \frac{2}{\pi\left[\left(\frac{x}{z}\right)^2 + 1\right]^2}$$

Table 6.4 Variation of $\Delta\sigma/(q/z)$ with x/z [Eq. (6.27)]

x/z	$\frac{\Delta\sigma}{q/z}$	x/z	$\frac{\Delta\sigma}{q/z}$
0	0.637	0.7	0.287
0.1	0.624	0.8	0.237
0.2	0.589	0.9	0.194
0.3	0.536	1.0	0.159
0.4	0.473	1.5	0.060
0.5	0.407	2.0	0.025
0.6	0.344	3.0	0.006

The value of does not include the overburden pressure of the soil above the point *A*.

INFINITE LINE LOAD



$$\Delta\sigma = \frac{q}{z} I_3$$

$$m = \frac{a}{z} \qquad n = \frac{L}{z}$$

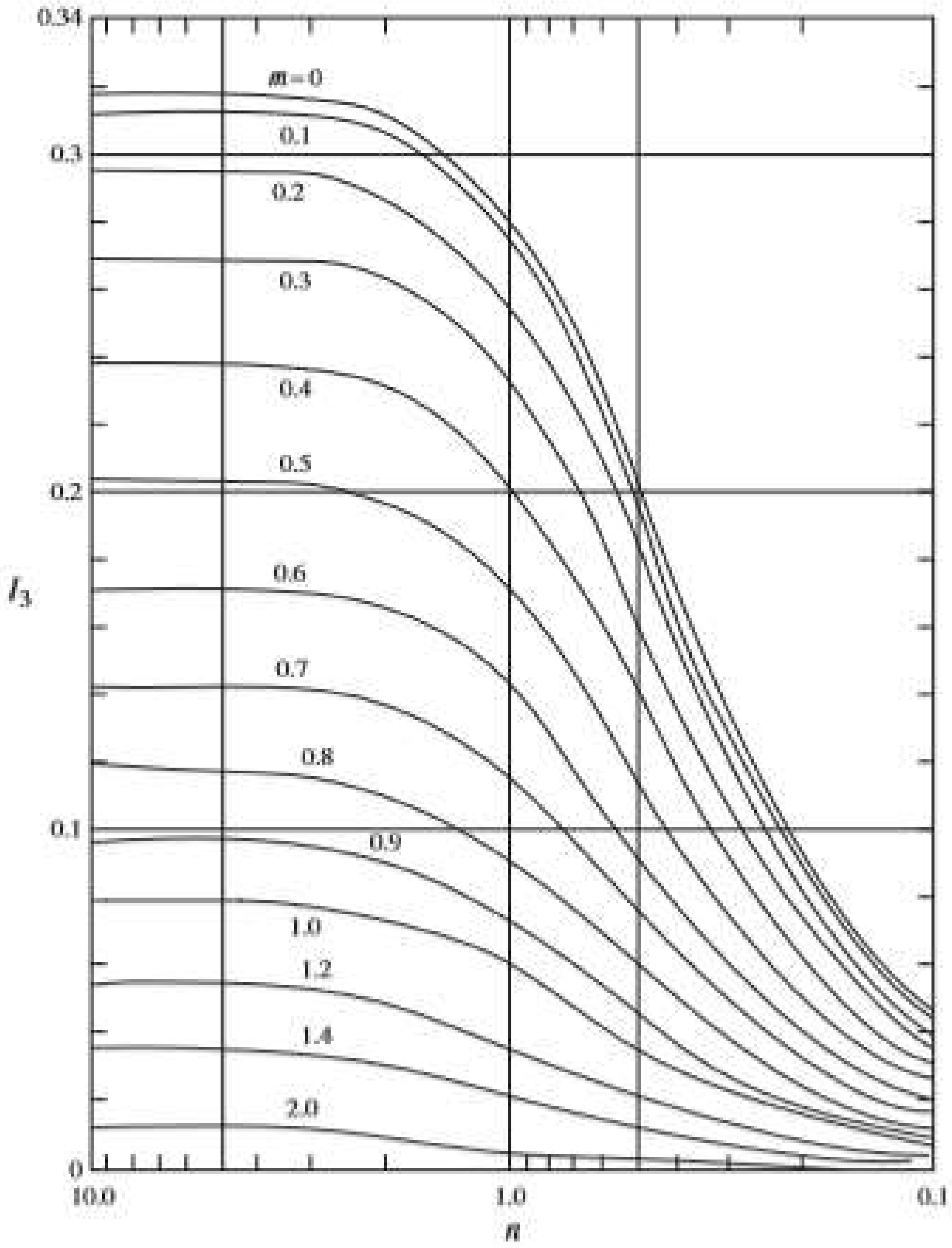
$$I_3 = \frac{1}{2\pi(m^2+1)^2}\left[\frac{3n}{\sqrt{m^2+n^2+1}} - \left(\frac{n}{\sqrt{(m^2+n^2+1)}}\right)^3\right]$$

INFINITE LINE LOAD

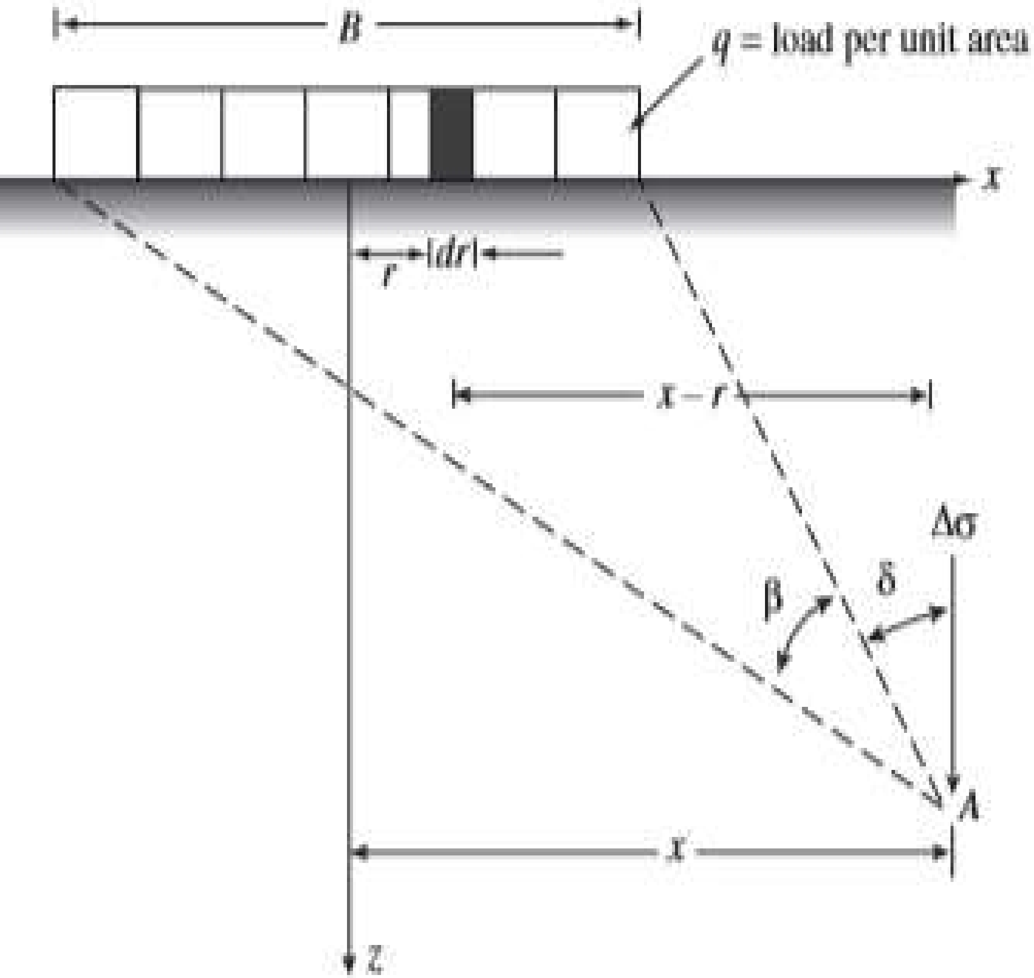
I_3 for Wetergaad Methods

$$m = \frac{a}{z}$$

$$n = \frac{L}{z}$$



Strip area carrying uniform pressure



$$\Delta\sigma = \int d\sigma = \int_{-B/2}^{+B/2} \left(\frac{2q}{\pi}\right) \left\{\frac{z^3}{[(x-r)^2 + z^2]^2}\right\} dr$$

$$= \frac{q}{\pi}\left\{\tan^{-1}\left[\frac{z}{x-(B/2)}\right] - \tan^{-1}\left[\frac{z}{x+(B/2)}\right] - \frac{Bz[x^2 - z^2 - (B^2/4)]}{[x^2 + z^2 - (B^2/4)]^2 + B^2z^2}\right\}$$

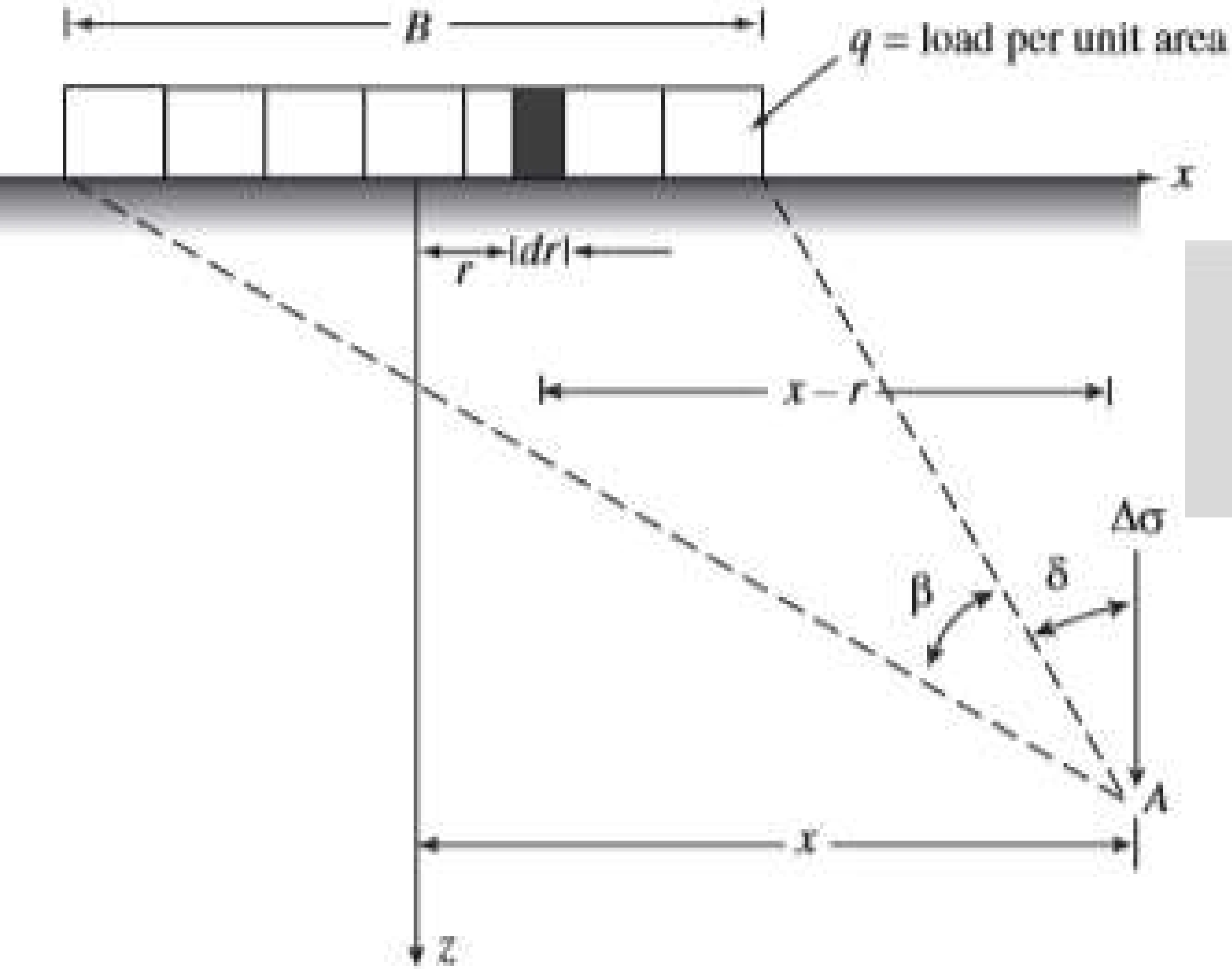
Equation (6.33) can be simplified to the form

$$\Delta\sigma = \frac{q}{\pi}[\beta + \sin\beta\cos(\beta + 2\delta)] \qquad (6.34)$$

The angles β and δ are defined in Figure 6.17.

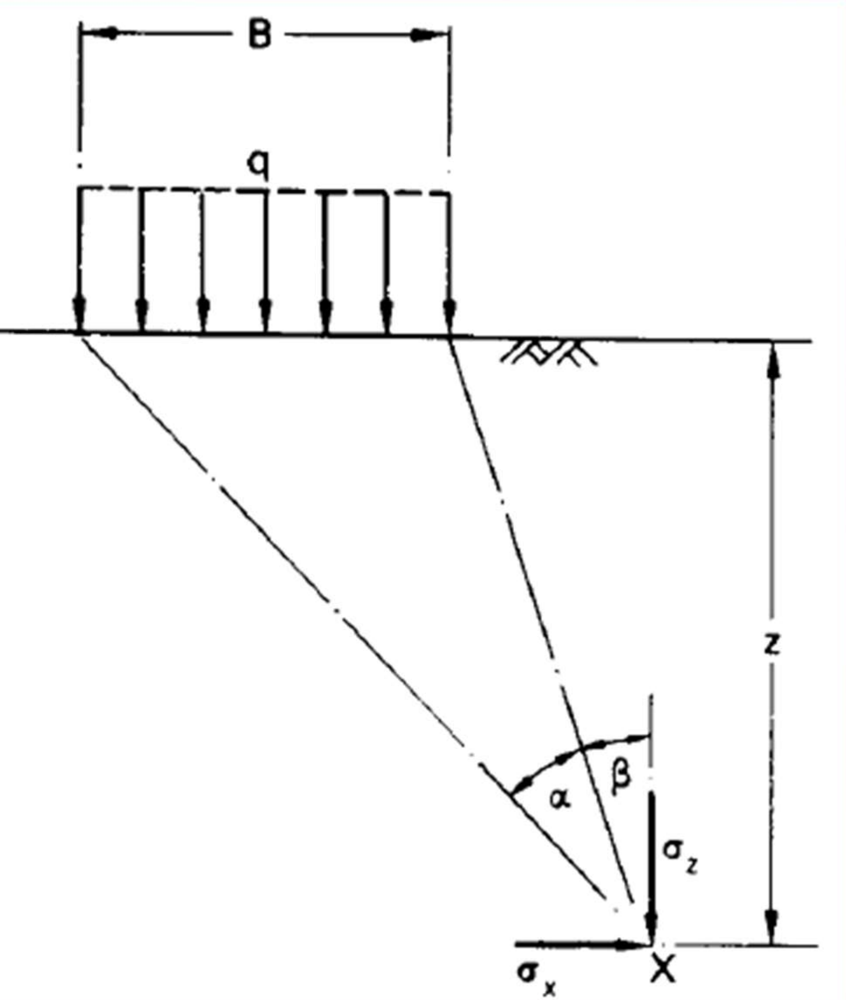
Table 6.5 shows the variation of $\Delta\sigma/q$ with $2z/B$ for $2x/B$ equal to 0, 0.5, 1.0, 1.5, and 2.0. This table can be conveniently used to calculate the vertical stress at a point caused by a flexible strip load.

Strip area carrying uniform pressure



$$\Delta\sigma = \frac{q}{\pi}[\beta + \sin\beta\cos(\beta + 2\delta)]$$

Strip area carrying uniform pressure

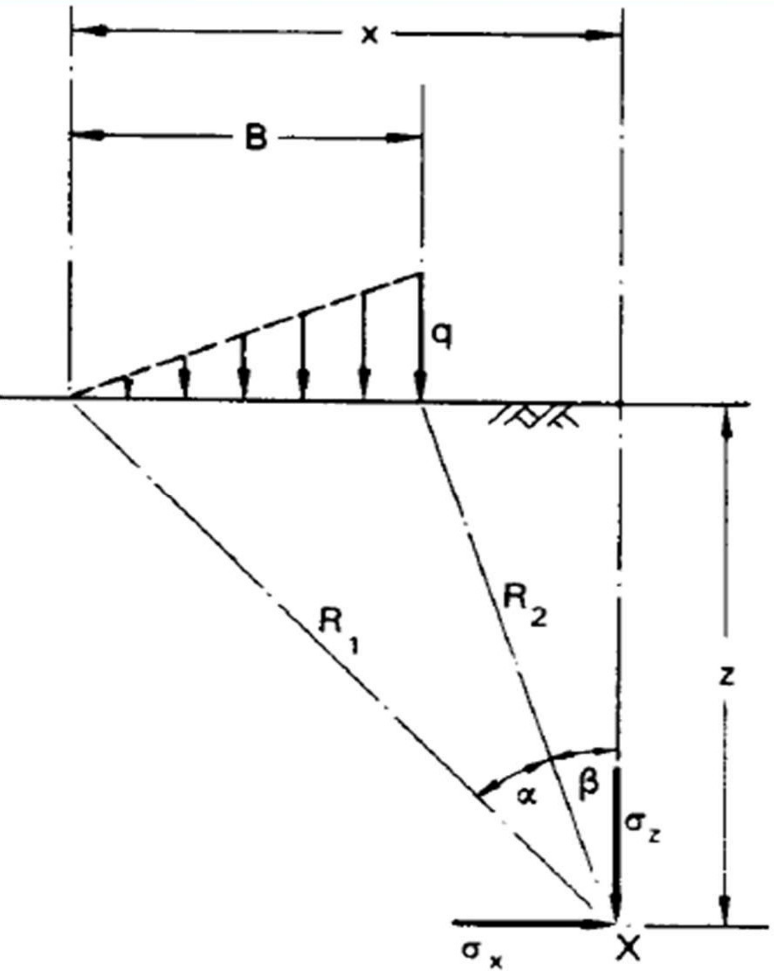


$$\sigma_z = \frac{q}{\pi}\{\alpha + \sin\alpha\cos(\alpha + 2\beta)\}$$

$$\sigma_x = \frac{q}{\pi}\{\alpha - \sin\alpha\cos(\alpha + 2\beta)\}$$

$$\tau_{xz} = \frac{q}{\pi}\{\sin\alpha\sin(\alpha + 2\beta)\}$$

Strip area carrying linearly increasing pressure

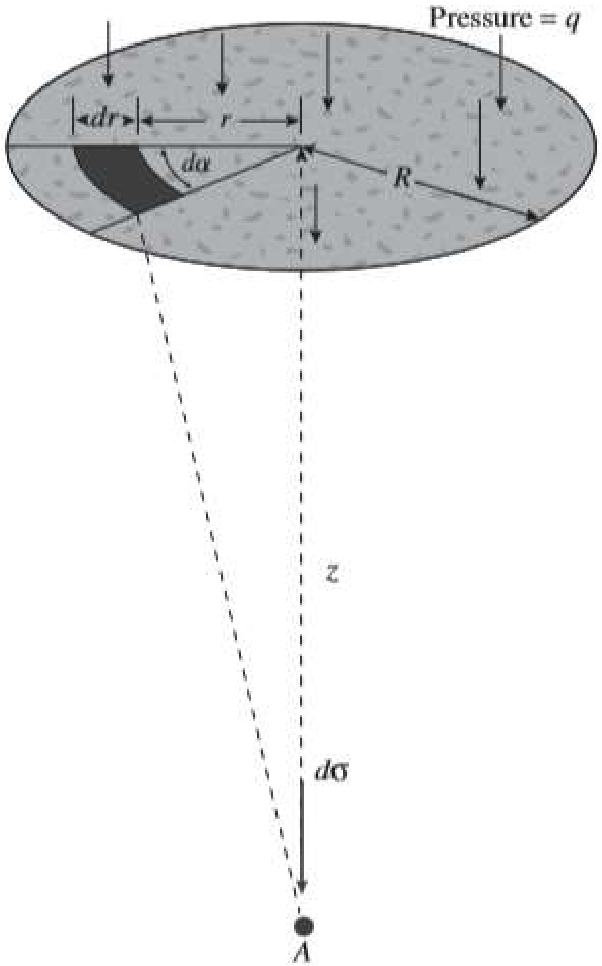


$$\sigma_z = \frac{q}{\pi}\left(\frac{x}{B}\alpha - \frac{1}{2}\sin 2\beta\right)$$

$$\sigma_x = \frac{q}{\pi}\left(\frac{x}{B}\alpha - \frac{z}{B}\ln\frac{R_1^2}{R_2^2} + \frac{1}{2}\sin 2\beta\right)$$

$$\tau_{xz} = \frac{q}{2\pi}\left(1 + \cos 2\beta - 2\frac{z}{B}\alpha\right)$$

Circular area carrying uniform pressure



$$\Delta\sigma = q\left\{1 - \frac{1}{[(R/z)^2 + 1]^{3/2}}\right\}$$

Table 6.6 Variation of $\Delta\sigma/q$ with z/R [Eq. (6.36)]

z/R	$\Delta\sigma/q$	z/R	$\Delta\sigma/q$
0	1	1.0	0.6465
0.02	0.9999	1.5	0.4240
0.05	0.9998	2.0	0.2845
0.10	0.9990	2.5	0.1996
0.2	0.9925	3.0	0.1436
0.4	0.9488	4.0	0.0869
0.5	0.9106	5.0	0.0571
0.8	0.7562		

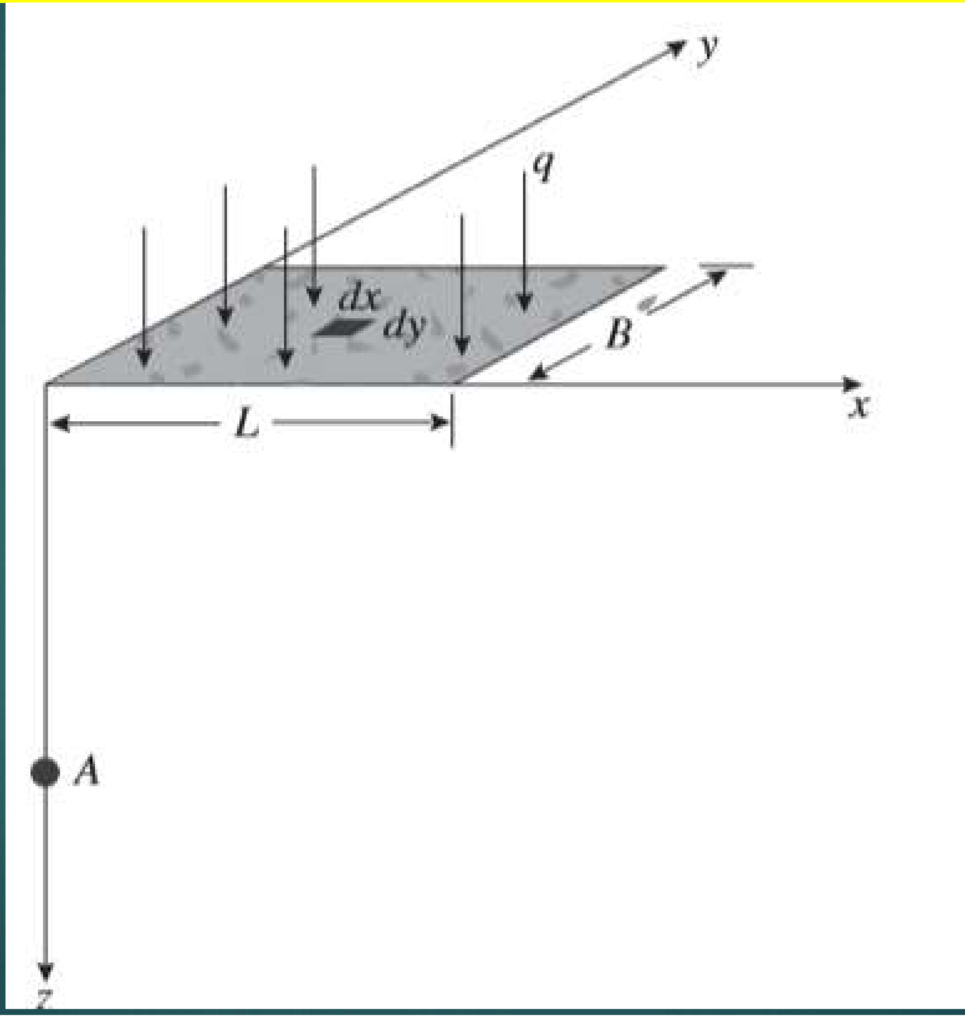
Circular area carrying uniform pressure

Table 6.7 Variation of I_4 [Eq. (6.37)]

	r/R					
z/R	**0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**
0	1.000	1.000	1.000	1.000	1.000	1.000
0.1	0.999	0.999	0.998	0.996	0.976	0.484
0.2	0.992	0.991	0.987	0.970	0.890	0.468
0.3	0.976	0.973	0.963	0.922	0.793	0.451
0.4	0.949	0.943	0.920	0.860	0.712	0.435
0.5	0.911	0.902	0.869	0.796	0.646	0.417
0.6	0.864	0.852	0.814	0.732	0.591	0.400
0.7	0.811	0.798	0.756	0.674	0.545	0.367
0.8	0.756	0.743	0.699	0.619	0.504	0.366
0.9	0.701	0.688	0.644	0.570	0.467	0.348
1.0	0.646	0.633	0.591	0.525	0.434	0.332
1.2	0.546	0.535	0.501	0.447	0.377	0.300
1.5	0.424	0.416	0.392	0.355	0.308	0.256
2.0	0.286	0.286	0.268	0.248	0.224	0.196
2.5	0.200	0.197	0.191	0.180	0.167	0.151
3.0	0.146	0.145	0.141	0.135	0.127	0.118
4.0	0.087	0.086	0.085	0.082	0.080	0.075

$$\frac{\Delta\sigma}{q} = I_4$$

RECTANGULAR LOAD



$m = L/Z$

$n = B/Z$

RECTANGULAR LOAD

$$\Delta\sigma = \int d\sigma = \int_{y=0}^{B}\int_{x=0}^{L} \frac{3qz^3(dx\,dy)}{2\pi(x^2 + y^2 + z^2)^{5/2}} = qI_5$$

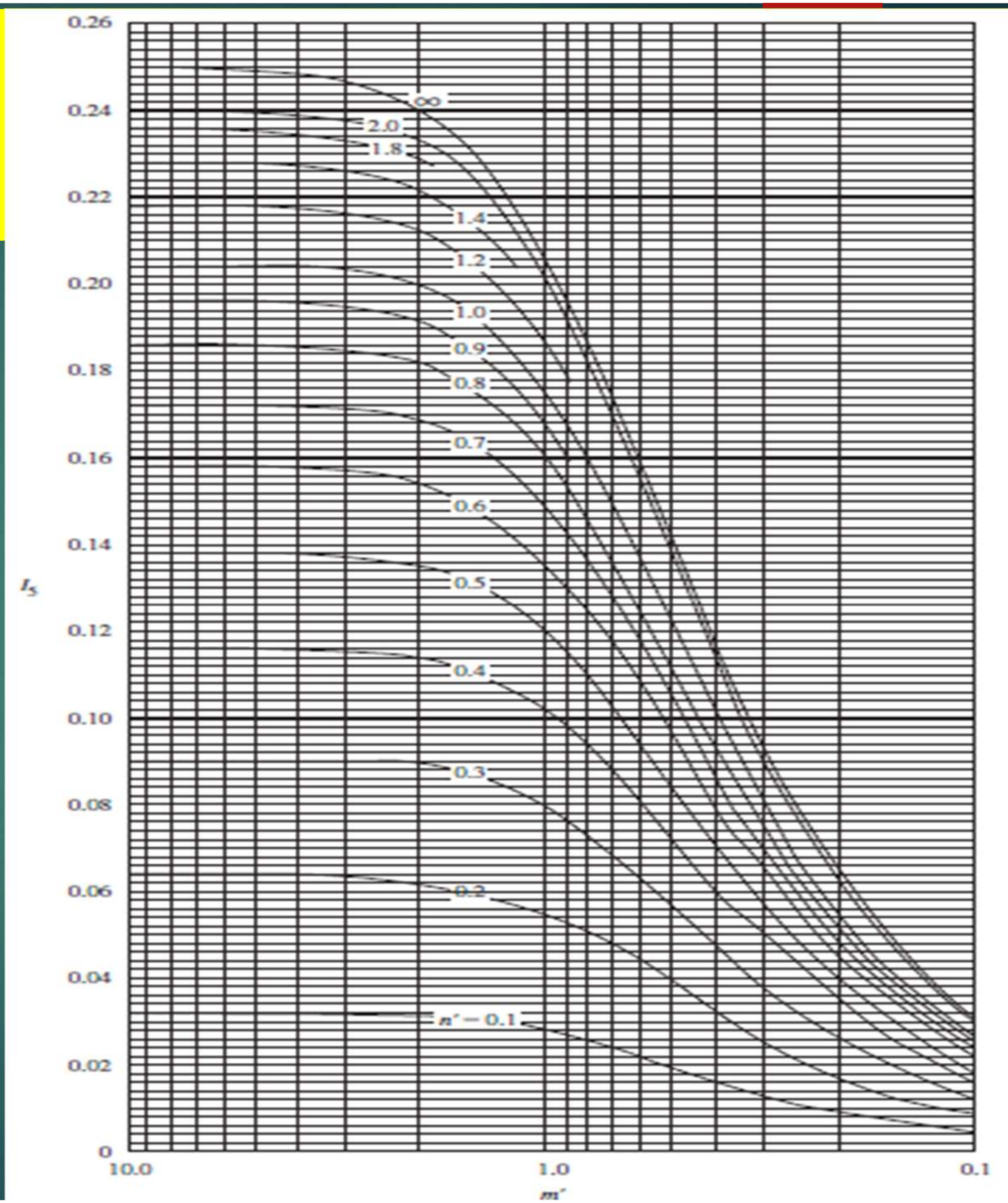
where

$$I_5 = \frac{1}{4\pi}\left[\frac{2m'n'\sqrt{m^{2\prime} + n^{2\prime} + 1}}{m^{2\prime} + n^{2\prime} + m^{2\prime}n^{2\prime} + 1}\left(\frac{m^{2\prime} + n^{2\prime} + 2}{m^{2\prime} + n^{2\prime} + 1}\right) + \tan^{-1}\left(\frac{2m'n'\sqrt{m^{2\prime} + n^{2\prime} + 1}}{m^{2\prime} + n^{2\prime} - m^{2\prime}n^{2\prime} + 1}\right)\right]$$

$$m' = \frac{B}{z}$$

$$n' = \frac{L}{z}$$

RECTANGULAR LOAD



RECTANGULAR LOAD

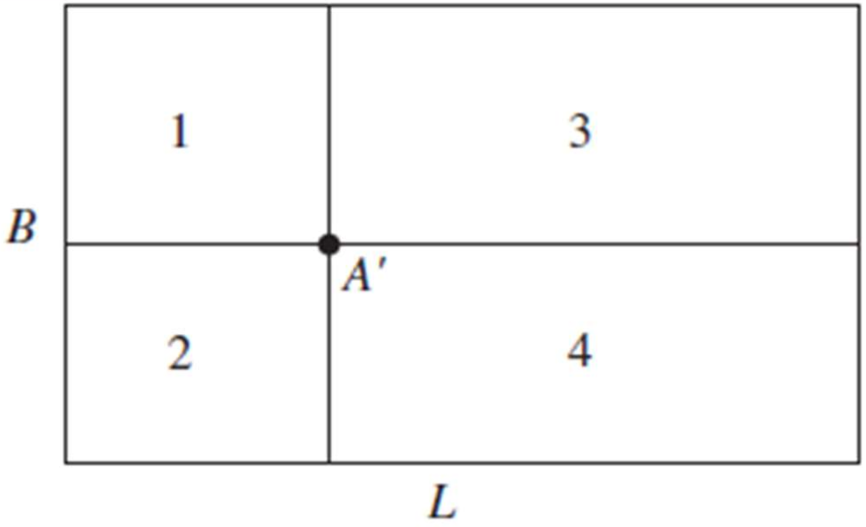


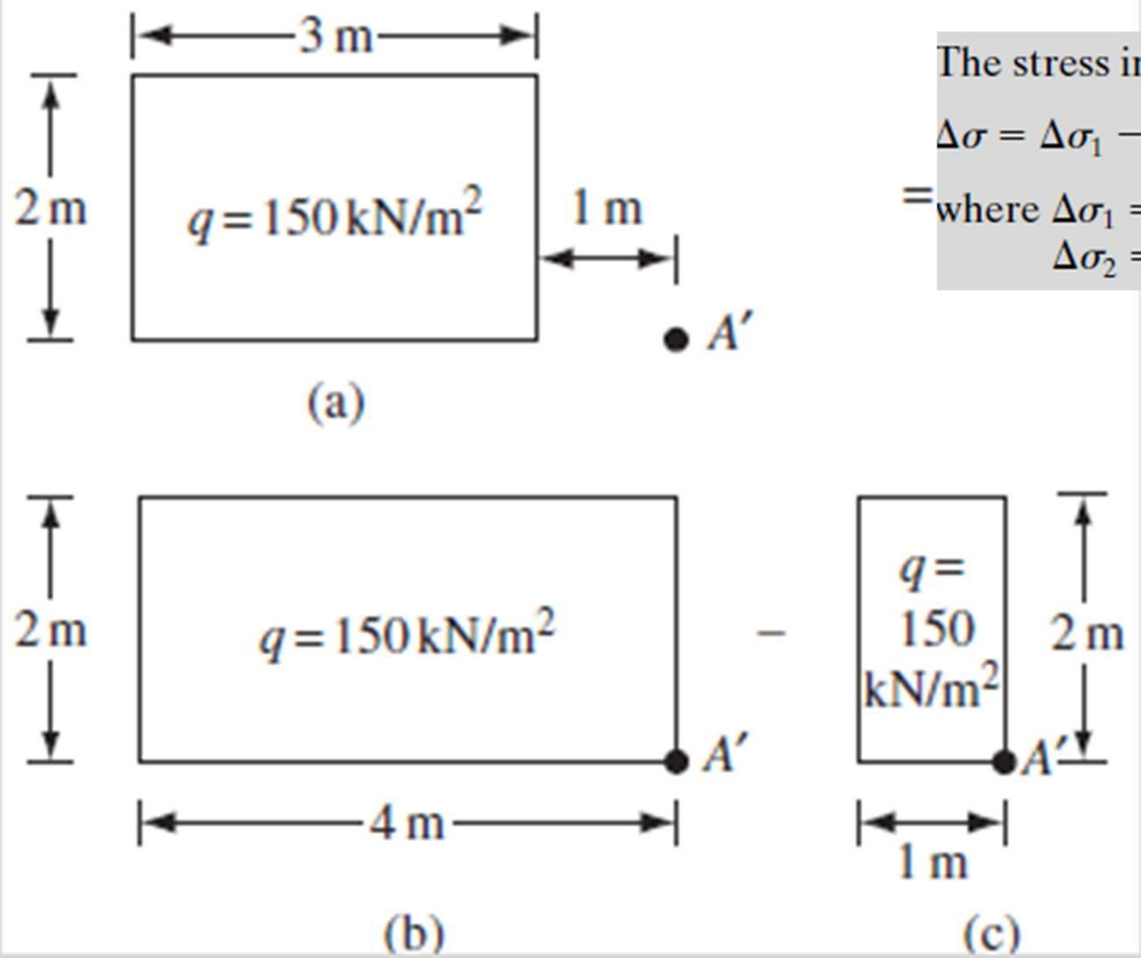
Figure 6.22 Increase of stress at any point below a rectangularly loaded flexible area

due to each rectangular area can now be calculated by using Eq. (6.40). The total stress increase caused by the entire loaded area can be given by

$$\Delta\sigma = q[I_{5(1)} + I_{5(2)} + I_{5(3)} + I_{5(4)}] \qquad (6.44)$$

RECTANGULAR LOAD

The plan of a uniformly loaded rectangular area is shown in this figure. Determine the vertical stress increase, below point *A* at a depth *z* 4 m.



=

The stress increase, $\Delta\sigma$ can be written as

$$\Delta\sigma = \Delta\sigma_1 - \Delta\sigma_2$$

where $\Delta\sigma_1$ = stress increase due to the loaded area shown in Figure 6.23b
$\Delta\sigma_2$ = stress increase due to the loaded area shown in Figure 6.23c

Figure 6.23b:

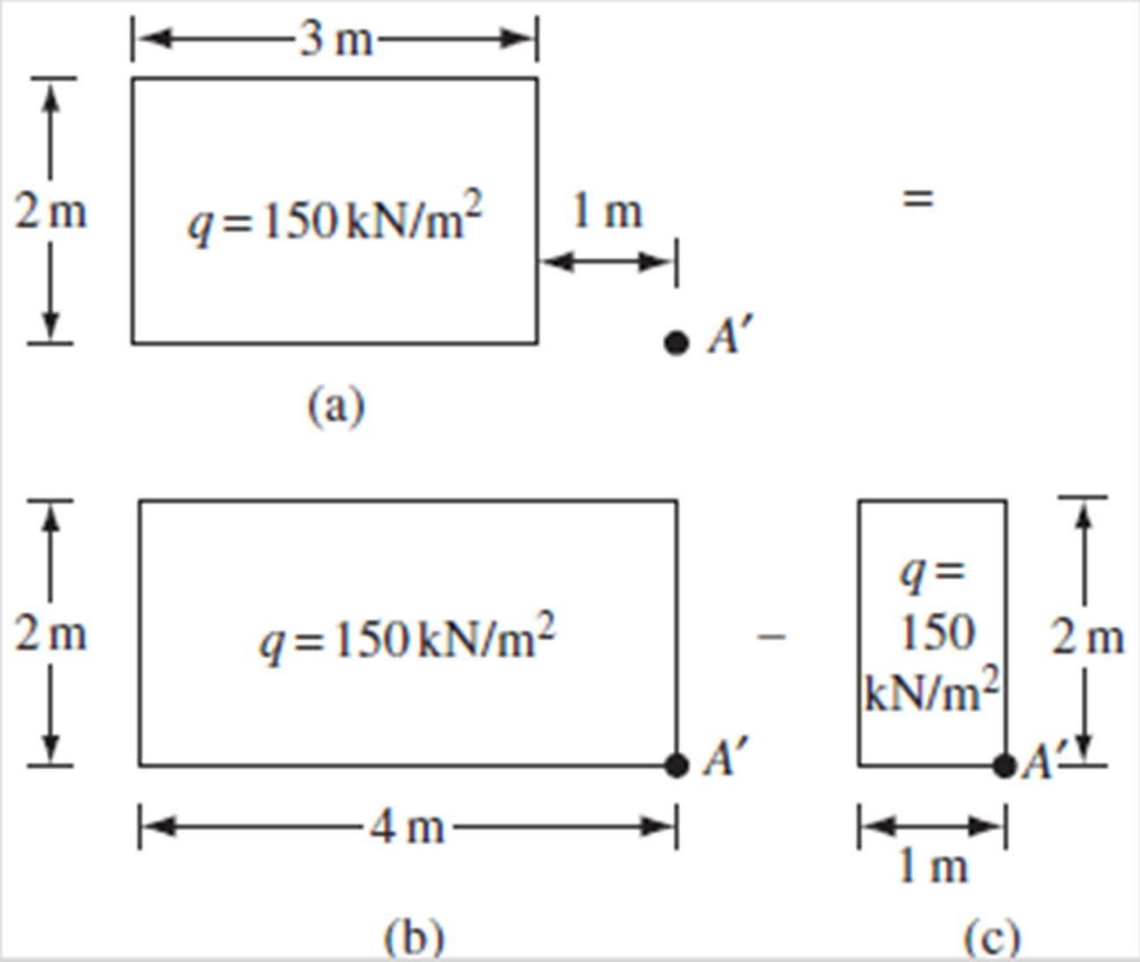
$$m' = \frac{B}{z} = \frac{2}{4} = 0.5$$

$$n' = \frac{L}{z} = \frac{4}{4} = 1$$

(b)

From Figure 6.21 for m 0.5 and n 1, the value of I_5 = 0.1225. So $\Delta\sigma_1 = \boldsymbol{qI_5} =$ **(150)(0.1225) =18.38 kN/m²**

RECTANGULAR LOAD



shown in Figure 6.23c:

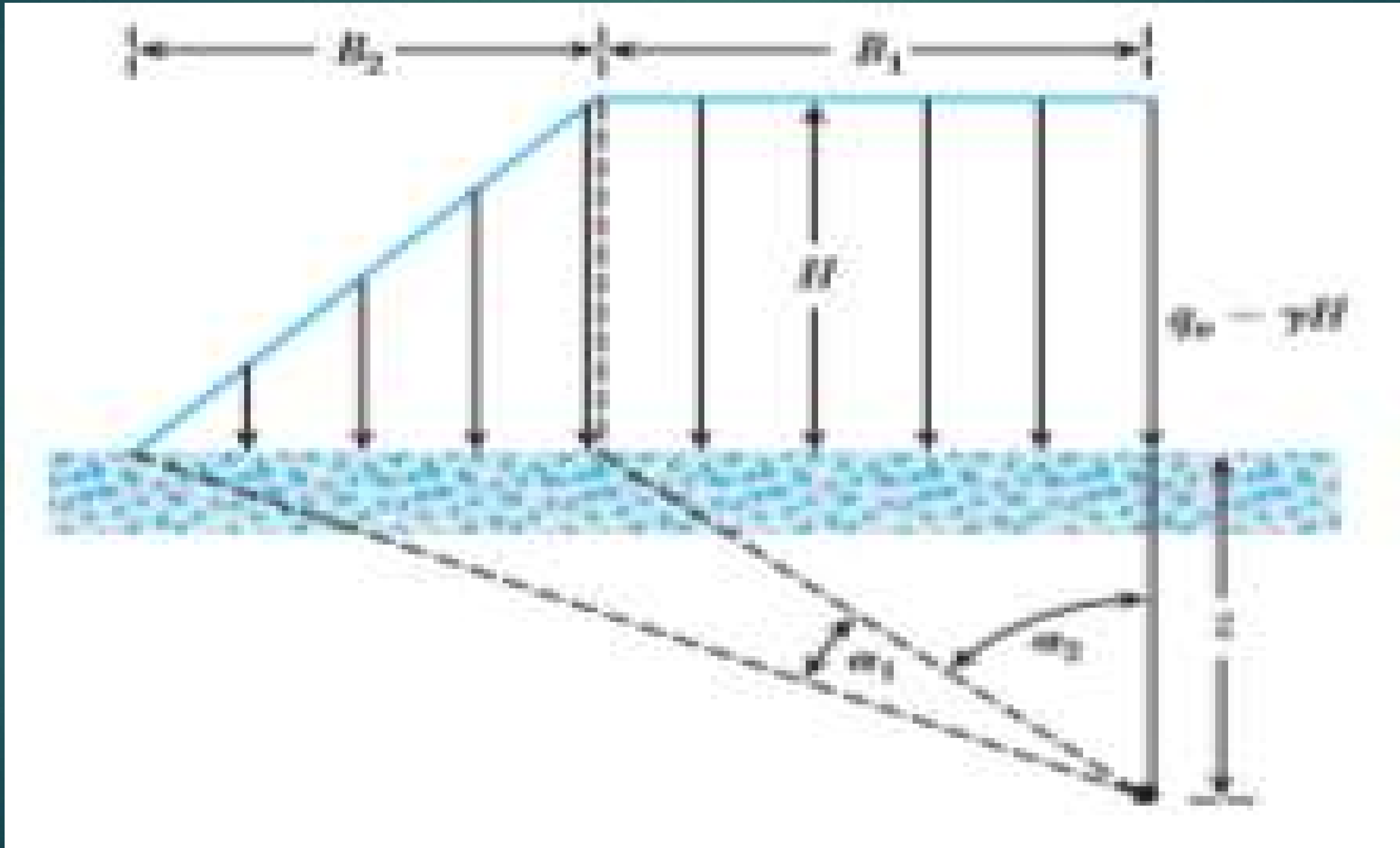
$$m' = \frac{B}{z} = \frac{1}{4} = 0.25$$

$$n' = \frac{L}{z} = \frac{2}{4} = 0.5$$

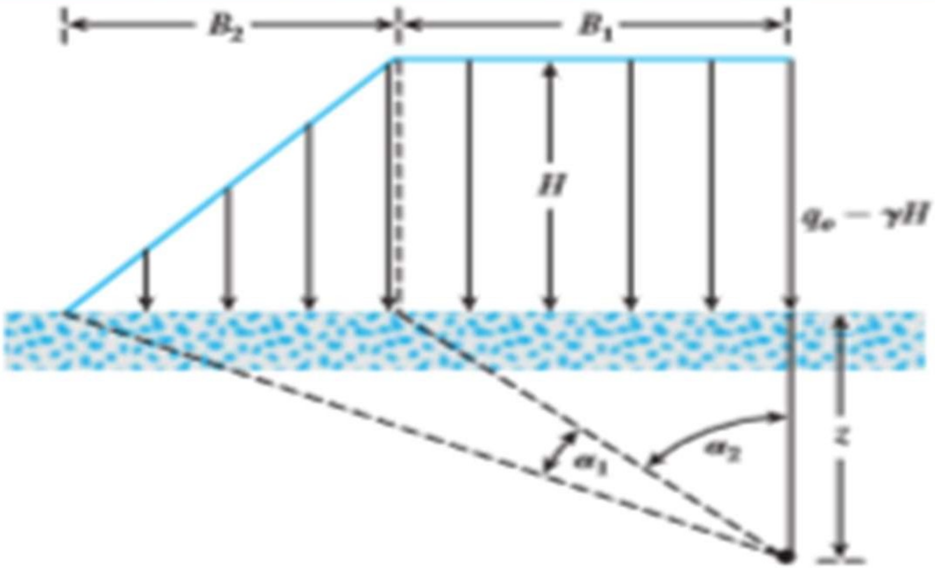
(c)

Thus, I_5 0.0473.
Hence $\Delta\sigma_2 =$ (150)(0.0473) = 7.1 kN/m ^{2}
So
$\Delta\sigma$ = (18.38 -7.1) = 11.28 kN/ m^2

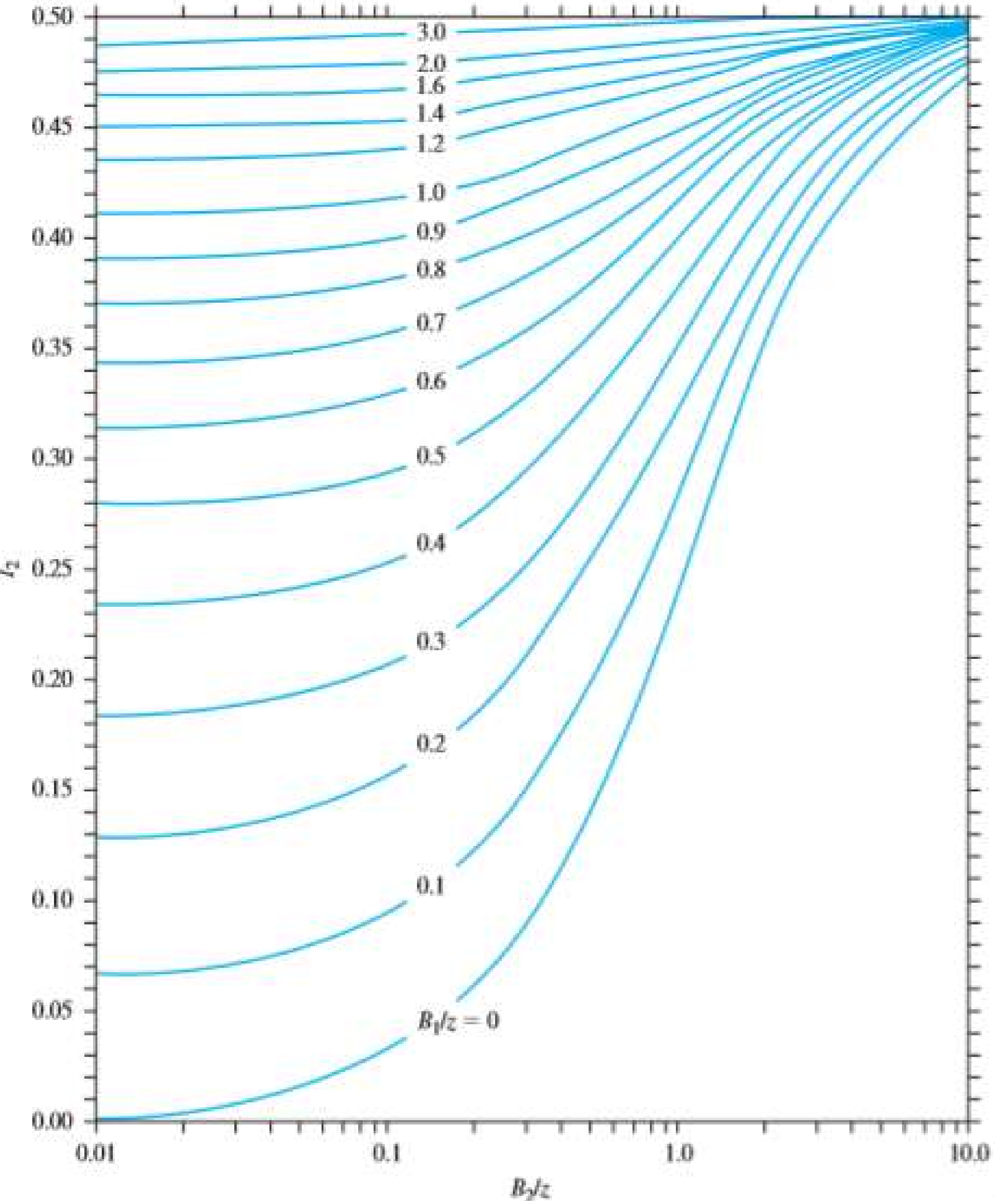
TRAPESIUM LOAD



TRAPESIUM LOAD



$$\Delta\sigma = q\,(I_2)$$



SEKIAN

&

TERIMA KASIH