Module 4: Water in soils (part 1)

Luis Zambrano-Cruzatty, Ph.D.

Spring 2022

February 14, 2022

COURSE CONTENTS AND SCHEDULE

Department of
Civil and Environmental Engineering

THE UNIVERSITY OF MAINE

308 Boardman Hall
Orono, Maine 04469-5711
Tel: 207.581.1277
Fax: 207.581.3888
Email: luis.zambranocruzatty@maine.edu

Tentative schedule

Day	Date	Topic	Lab.
W	1/19/2022	Class introduction, syllabus, policies	Soil
F	1/21/2022	Invited speaker: Topic TBD	components
M	1/24/2022	Introduction: The geological cycle, soil origin	Grain size
W	1/26/2022	Introduction: Site investigation	dist.
F	1/28/2022	Index properties: Phase relationships	
M	1/31/2022	Index properties: Grain size distribution, Atterberg limits	Atterberg
W	2/2/2022	Index properties: Soil classification	limits
F	2/4/2022	Compaction	
M	2/7/2022	Quiz 1: Introduction, index properties, compaction, in-situ testing	Visual
W	2/9/2022	Water in soils: Groundawater table, pore pressure, total and effective stresses	classification
F	2/11/2022	Water in soils: Darcy's law	
M	2/14/2022	Water in soils: Permeability and hydraulic conductivity	Compaction
W	2/16/2022	Water in soils: One-dimensional seepage	
F	2/18/2022	Water in soils: 2D-3D seepage, flow nets, pore pressure, uplift force, seepage force	
M	2/21/2022	President's day: no class	In-situ
W	2/23/2022	Water in soils: piping	density
F	2/24/2022	Quiz 2: Water in soils	
M	2/28/2022	Induced stress: Approximations, Bousinesq's elastic solution	Permeability
W	3/2/2022	Induced stress: Bousinesq's elastic solution, superposition	
F	3/4/2022	Induced stress: Stress tensor, elastic deformations	
M	3/7/2022	Consolidation: Oedometer test, primary and secondary consolidation	Site
W	3/9/2022	Consolidation: Preconsolidation pressure, OCR	investigation
F	3/11/2022	Consolidation: Primary consolidation parameters	
M	3/14/2022	Spring break: no class	
W	3/16/2022	Spring break: no class	
F	3/18/2022	Spring break: no class	
M	3/21/2022	Consolidation: rate of consolidation	Bonus
W	3/23/2022	Consolidation: preloading, radial consolidation	
F	3/25/2022	Quiz 3: Induced stress and consolidaiton	
M	3/28/2022	State of stress: 2D stresses and Mohr's circle	Consolidation
W	3/30/2022	State of stress: principal stresses, stress invariants, rotations	
F	4/1/2022	State of stress:: Usage of Mohr's circle	
M	4/4/2022	State of stress: stress paths, simple shear, triaxial compression	Settlement
W	4/6/2022	Quiz 4: State of stress	estimates
F	4/8/2022	Shear strength: Mohr-Coulomb failure criteria	
M	4/11/2022	Shear strength: drained and undrained behavior	Unconfined
W	4/13/2022	Shear strength: Shear strength of clays	compression
F	4/15/2022	Shear strength: Shear strength of sands	test
M	4/18/2022	Quiz 5: Shear strength	Direct
W	4/20/2022	Lateral earth pressure: at-rest, passive, and active conditions [2]	shear
F	4/22/2022	Intro to slope stability [2]	
M	4/25/2022	Intro to bearing capacity [2]	Direct
W	4/27/2022	Maine's day: no class	shear
F	4/29/2022	Classes end: Q&A session	
M	5/2/2022	Final exam (1:30 PM- 3:30 PM) Williams Hall 110	

M: Monday - W: Wednesday - F: Friday

[2] This items may or may not be covered. It will be determined by how far the course has progressed.

RECAP

- We learned about compaction in granular and cohesive soils.
- We learned about Proctor test and the effect of compactive effort.
- We learned about the effect of water content on the fabric of soils in compaction.
- We learned about compaction specifications.
- We learned about compaction equipment and field control.
- Today we will learn about some effects of water and the principle of effective stress.

HOMEWORK ASSIGNMENT 3

- Due on 02/21/2022.
- 50 points total.
- Start ASAP.

Department of
Civil and Environmental Engineering

THE UNIVERSITY OF MAINE

308 Boardman Hall
Orono, Maine 04469-5711
Tel: 207.581.1277
Fax: 207.581.3888
Email: luis.zambranocruzatty@maine.edu

CIE-365 Spring 2022: Homework assignment 3

Due date: 02/21/2022 at 10:00 AM
Possible points: 50

Answer the following questions based on the contents of Module 4.

1. [O2] (8 points) Watch the this video and answer the following questions:
   (a) What is needed for frozen heave to occur?
   (b) Using a schematic figure, explain the mechanism of frost-heaving and thaw deformations in frost-susceptible soils.
   (c) What are the consequences of frost-susceptible soils in pavements.
   (d) List three mitigation techniques to prevent distress from frost-susceptible soils.
2. [O1] (6 points) During the shrinkage limit test on a silty clay, the volume of the dry soil pat was found to be 10.76 cm^3 and its dry mass was 22.68 g. If the shrinkage limit was 11.1 %, what is the density of the soil solids?
3. [O1] (6 points) Estimate the swelling potential of soils A-F with poperties in Tables 1 and 2 using Figure 1.

Table 1: Sieve and hydrometer analysis results for problem 7.

U.S. Standard Sieve No. or Particle Size	Percent Passing by Weight					
	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
75 mm (3 in)	100		100			
38 (1-1/2)	70		-			
19 (3/4)	49	100	91			
9.5 (3/8)	36	-	87			
No. 4	27	88	81		100	
No. 10	20	82	70	100	89	
No. 20	-	80	-	99	-	
No. 40	8	78	49	91	63	
No. 60	-	74	-	37	-	
No. 100	5	-	-	9	-	
No. 140	-	65	35	4	60	
No. 200	4	55	32	-	57	100
40 μm	3	31	27		41	99
20 μm	2	19	22		35	92
10 μm	1	13	18		20	82
5 μm	<1	10	14		8	71
2 μm	-	-	11		-	52
1 μm	-	2	10		-	39

4. [O2] (12 points) The soil profile shown in Figure 2 illustrates three cases:
   (a) The water table is at $h = 10$ m.
   (b) The water table is at the surface $h = 0$ m.
   (c) A case in which the water table is at $h = 36$ m.

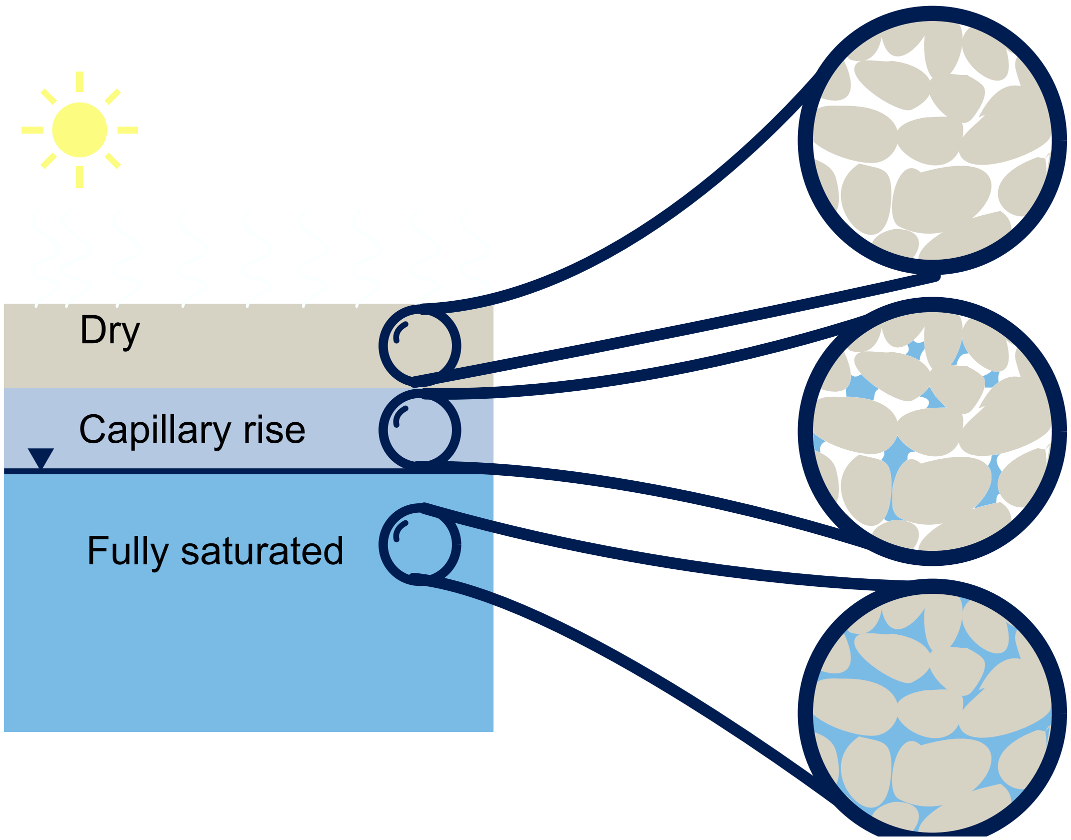
CONTENTS

- Suction and capillary action.
- Swelling/shrinkage in soils.
- Self-study: Frost action on soils.
- Total stress, pore pressure, and effective stress.

More in chapter X of Holtz et al. (2013)

≡

WATER IN HYDROSTATIC CONDITIONS



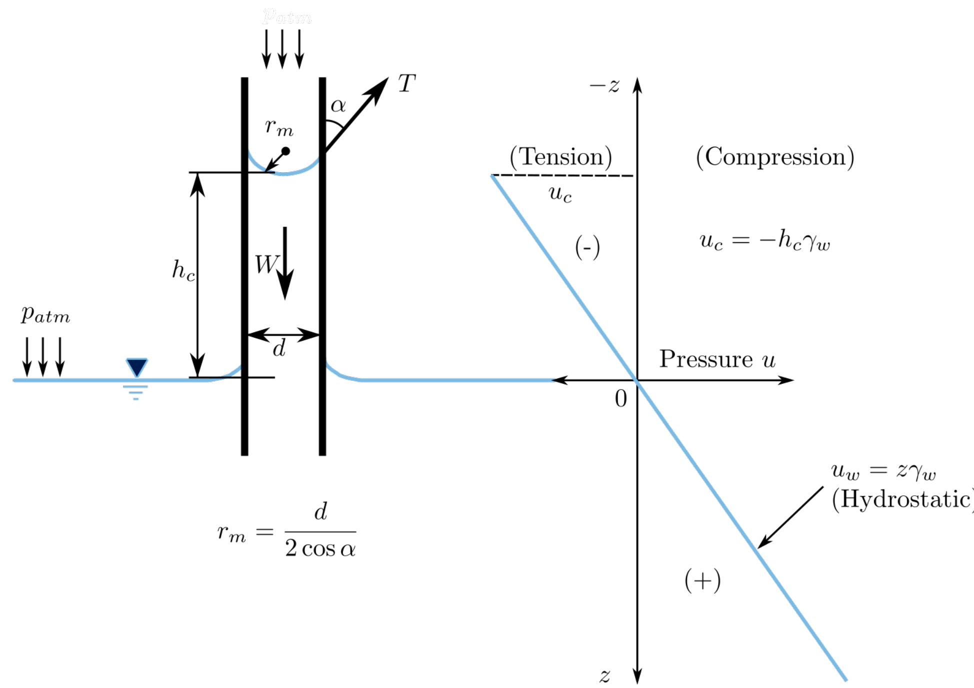
CAPILLARY RISE

- It arises from surface tension .
- In soils, it occurs between water and particles.

Capillary rise:

$$h_c = \frac{-4T}{\gamma_w d}$$

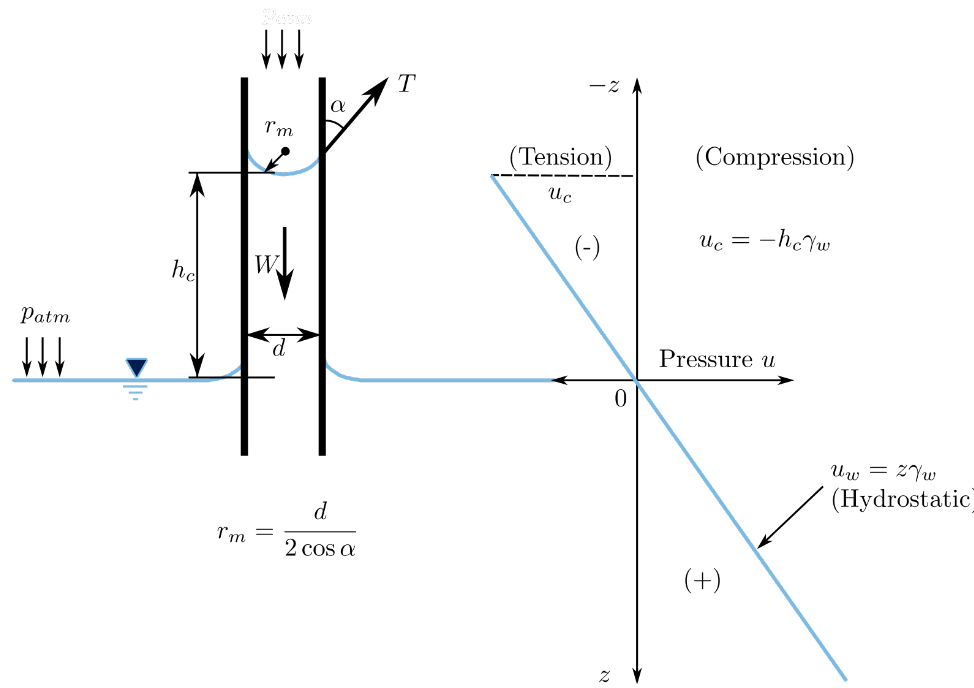
- $T =$ surface tension
- $d =$ tube diameter



SUCTION PRESSURE

Negative pore water pressure:

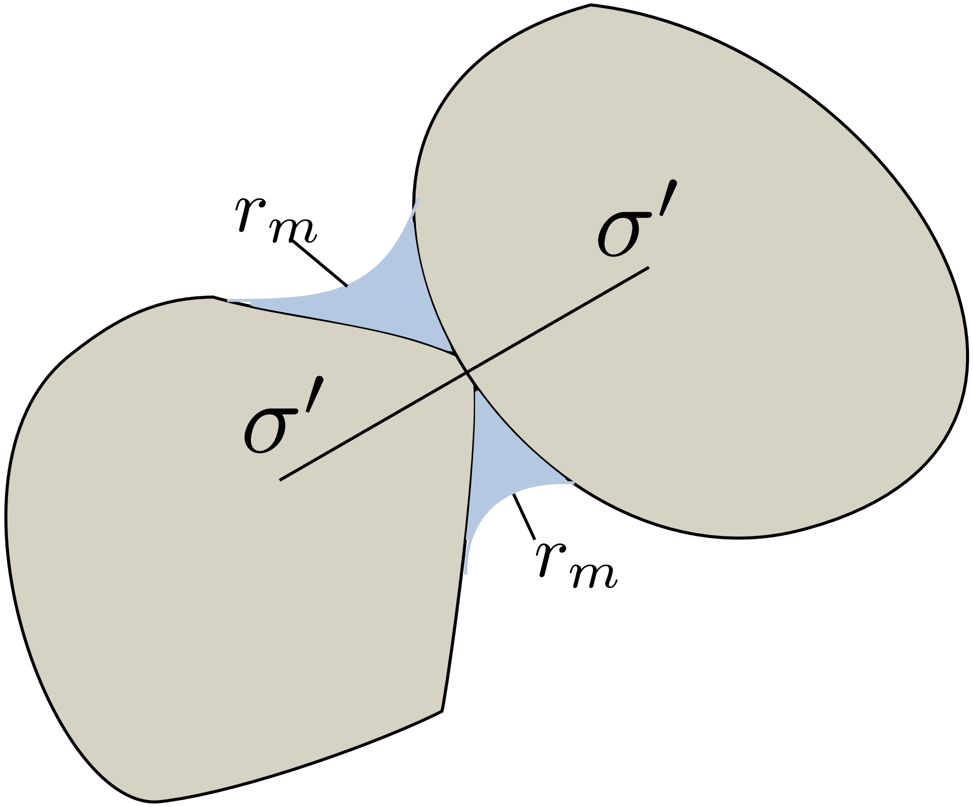
$$u_c = \frac{-2T}{r_m}$$



r_m = radius of water meniscus

- In coarse soils, suction is limited. Cavitation , or "boiling", occurs if $u_c < p_{atm}$.
- In fine soils, cavitaion is prevented. Thus, $h_c > 10$m.

CAPILLARY RISE

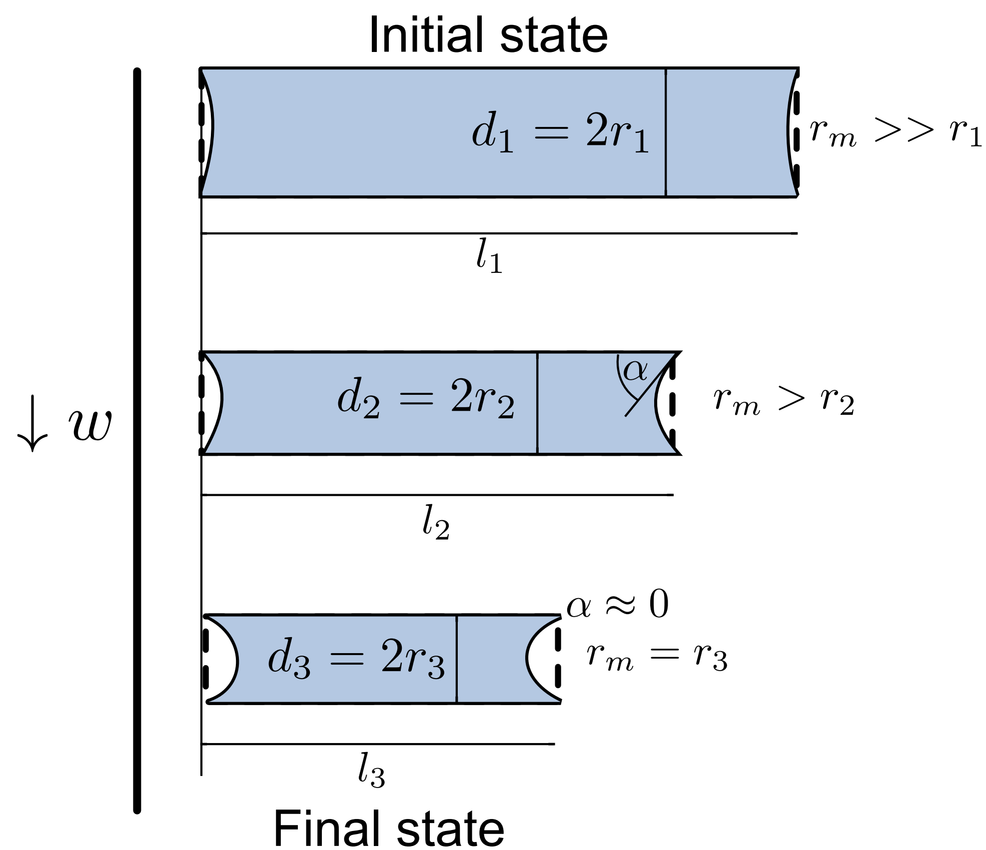


- Particles are connected by menisci.
- Interparicle effective stress increases.
- In soils, it is common to assume the effective size of pores is 20% of effective grain size D_{10}.

≡

SHRINKAGE IN SOILS

- Menisci radii and pores are not fully developed.
- The tube length and radius decrease with evaporation.
- Menisci tension and wall rigidity eventually balance.
- In water, the menisci are destroyed and the tube expands.



After Terzaghi (1972) and Holtz (2013)

≡

SHRINKAGE IN SOILS

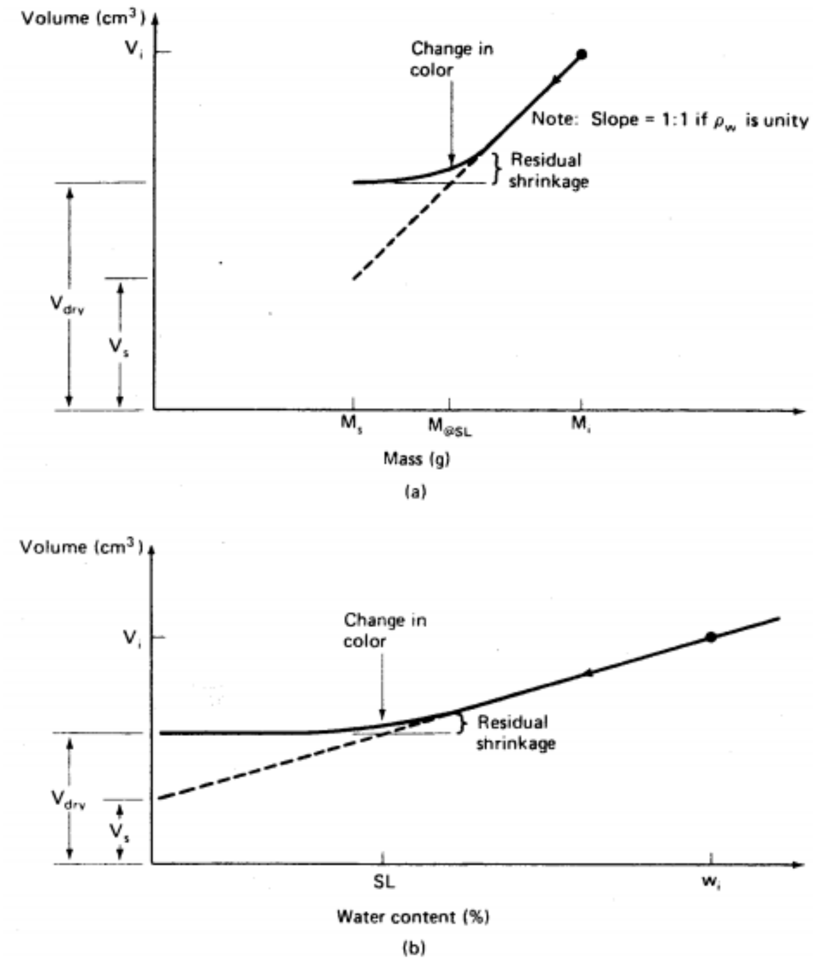
Can be computed using any of:

$$SL = \left(\frac{V_{dry}}{M_s} - \frac{1}{\rho_s}\right)\rho_w \times 100$$

$$SL = \left(\frac{V_{dry}\gamma_w}{W_s} - \frac{1}{G_s}\right) \times 100$$

$$SL = w_i - \left(\frac{(V_i - V_{dry})\gamma_w}{W_s}\right) \times 100$$

- V_i = initial volume
- w_i = initial water content
- V_{dry} dried volume



Reproduced from Holtz (2013)

EXAMPLE 4.1

During the determination of the shrinkage limit of a sandy clay, the following laboratory data was obtained:

- Wet wt. of soil + dish= 87.85 g
- Dry wt. + dish= 76.91 g
- Wt. dish = 52.7 g

Volumetric determination of soil pat:

- Wt. of dish + mercury= 430.8 g
- Wt. of dish = 244.62 g

calculate the SL assuming $G_s = 2.65$.

≡

SWELLING POTENTIAL

- Fine soils tend to swell when re-watered.
- Produces more damage than floods, hurricanes, tornadoes, and earthquakes combined.
- Swelling depends of clay mineralogy (e.g., Na montmorillonite expands more than Ca montmorillonite).
- Can tests for swelling potential or swelling pressure .
- Correlations with LL, γ_d, and activity A are useful.

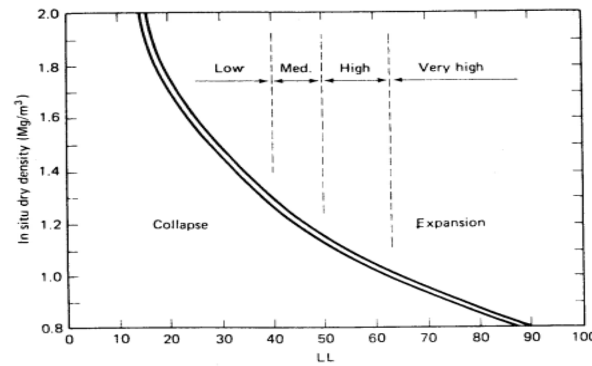


Fig. 6.14 Guide to collapsibility, compressibility, and expansion based on in situ dry densities and the liquid limit (adapted from Mitchell and Gardner, 1975, and Gibbs, 1969).

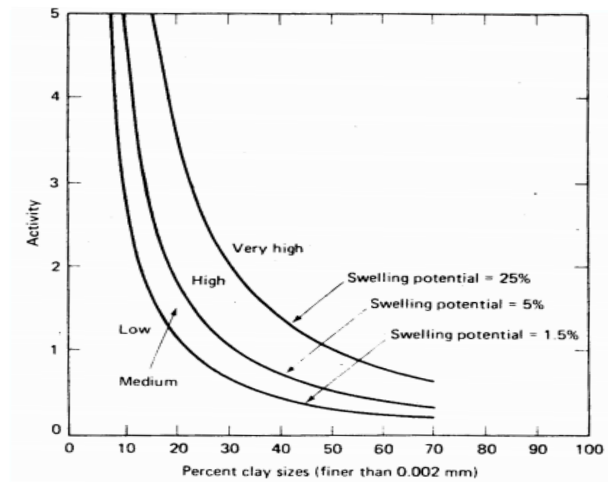


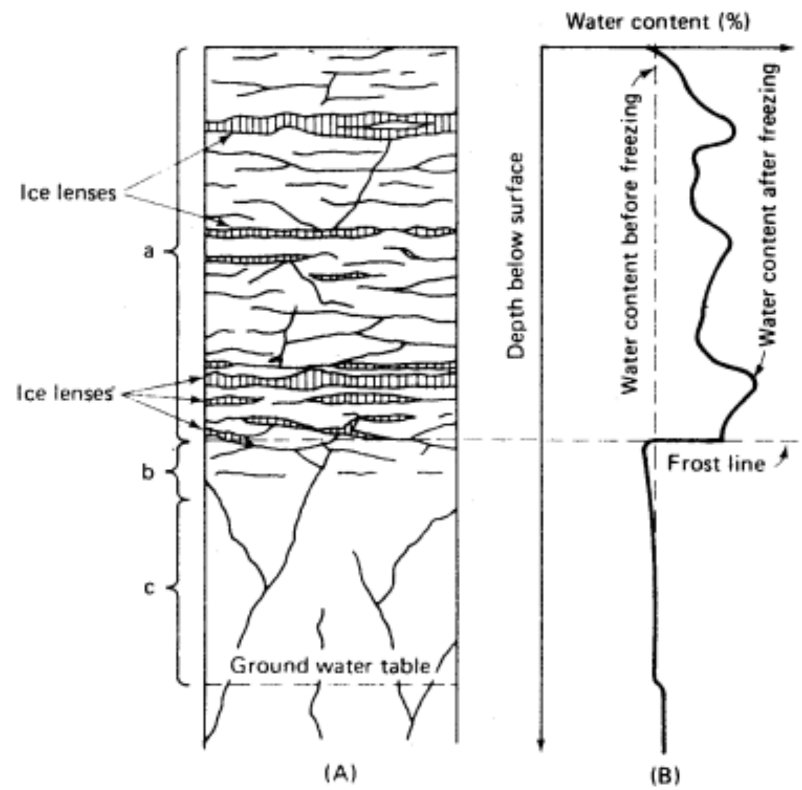
Fig. 6.15 Classification chart for swelling potential (after Seed, et al., 1962)

From Holtz et al. (2013)

≡

FROST ACTION

- Soil freezing cause a volume increase of about 10%.
- Frost action: three things are needed:
  1. Temperatures below freezing.
  2. High water table.
  3. Frost-susceptible soils.
- Ice lenses form where water rises from capillarity.
- The increase in water content weakens the soil structure, causing holes and deformations.



From Holtz et al. (2013)

≡

FROST ACTION

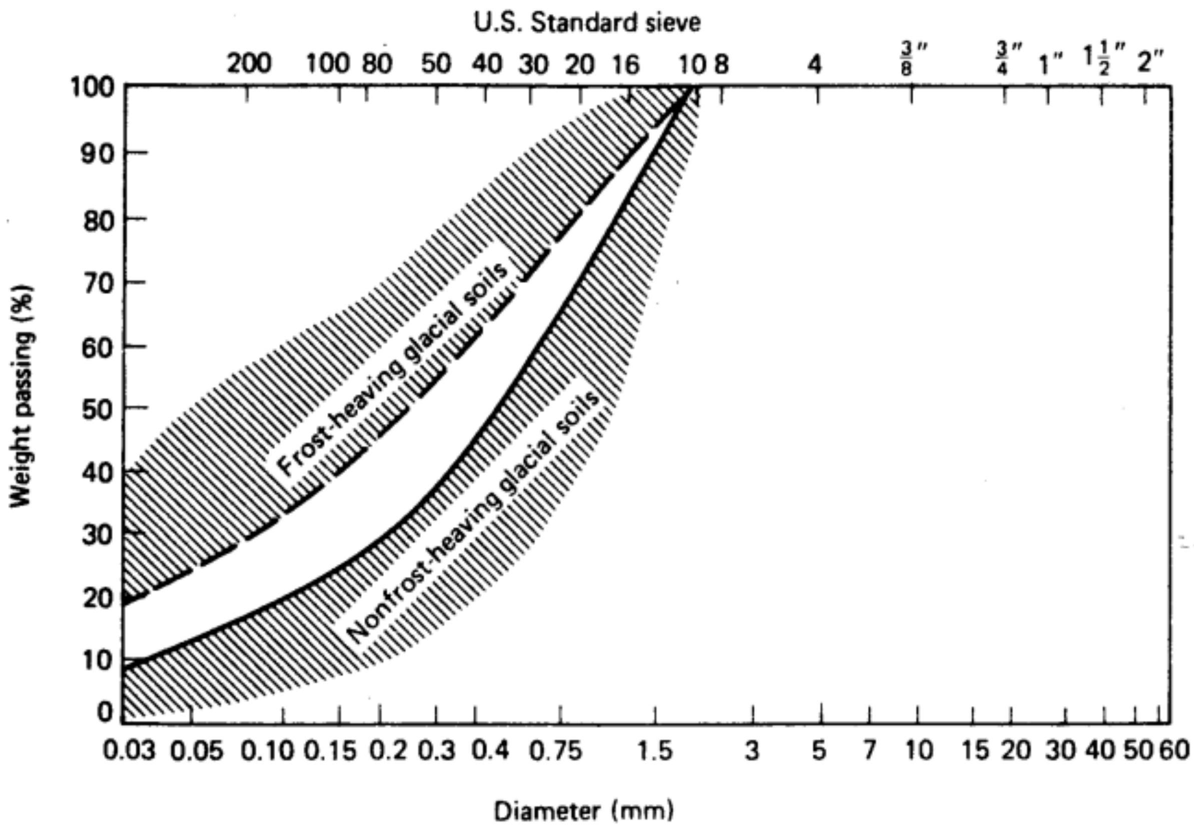


Fig. 6.17 Limits between frost susceptible and non-frost-susceptible mixtures of glacial tills or similar mixtures (after Beskow, 1935).

TABLE 6-3 Frost Susceptibility Soil Groups*

Group	Frost Susceptibility or Danger	Soils
I	None	Gravel, sand, gravelly tills
II	Moderate	Fine clay ($\geq$ 40% clay† content); sandy tills, clayey tills with 16% fines‡
III	Strong	Silt, coarse clay (clay† content 15–25%); silty tills

*After Hansbo (1975).
†Defined as $-2\ \mu$m.
‡Defined as -0.06 mm.

PRINCIPLE OF EFFECTIVE STRESS

- Terzaghi (1925) proposed a new concept for saturated and dry soils.
- The effective stress principle:
  Stress is carried by the solid particles trought contacts in the soil skeleton.

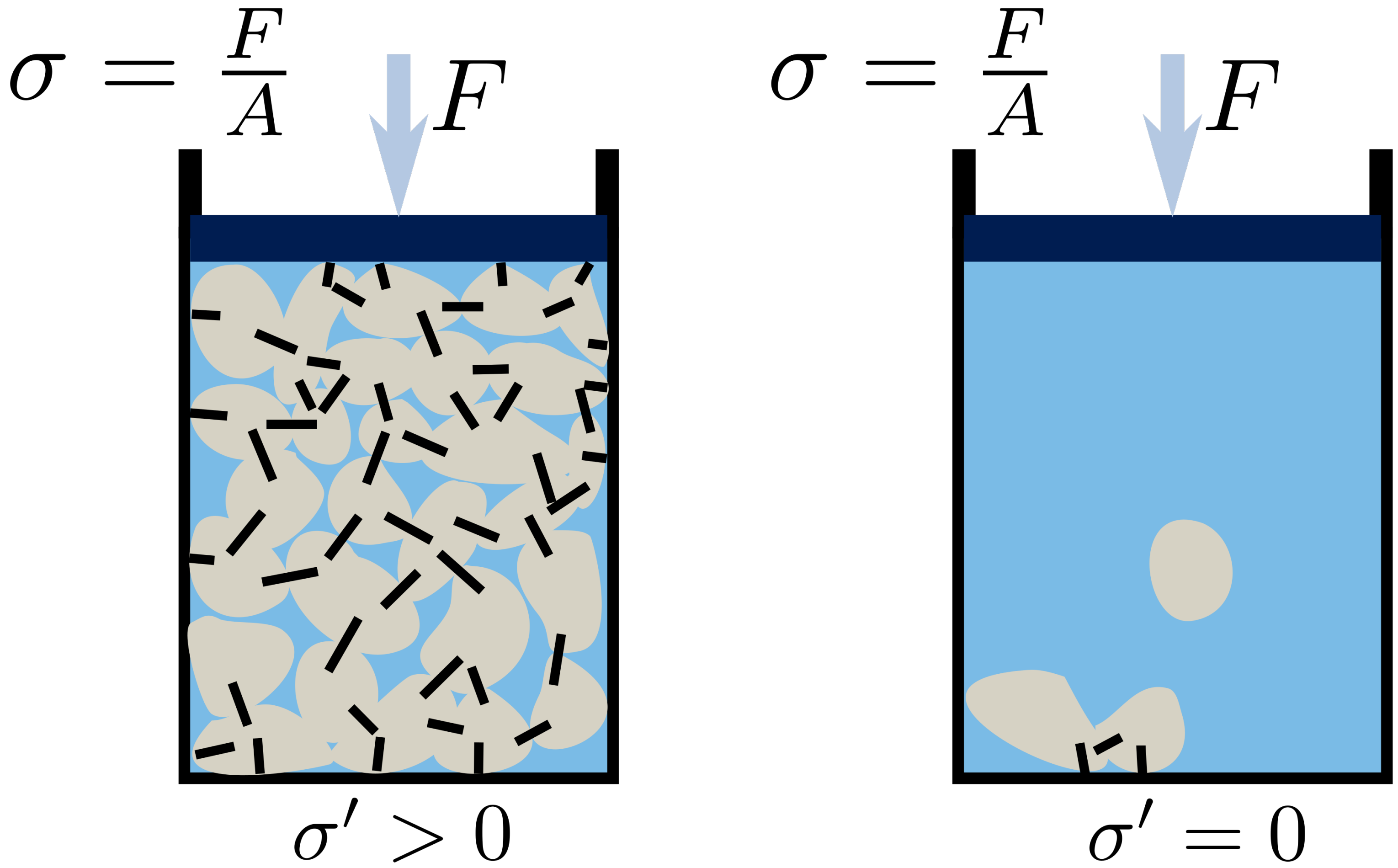
$$\sigma' = \sigma - u$$

  - $\sigma' =$ Effective stress.
  - $\sigma =$ Total stress.
  - $u =$ Pore water pressure.

Karl Terzaghi

≡

PRINCIPLE OF EFFECTIVE STRESS



IN-SITU VERTICAL STRESSES

The vertical total stress is the full weight of soil column:

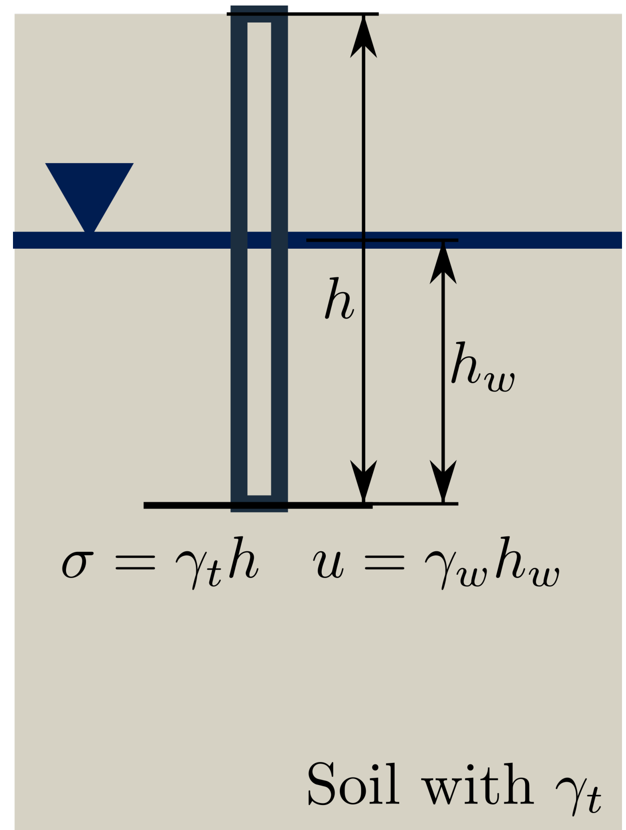
$$\sigma_v = \gamma_t h$$

The hydrostatic pore pressure can be calculated using:

$$u = \gamma_w h_w$$

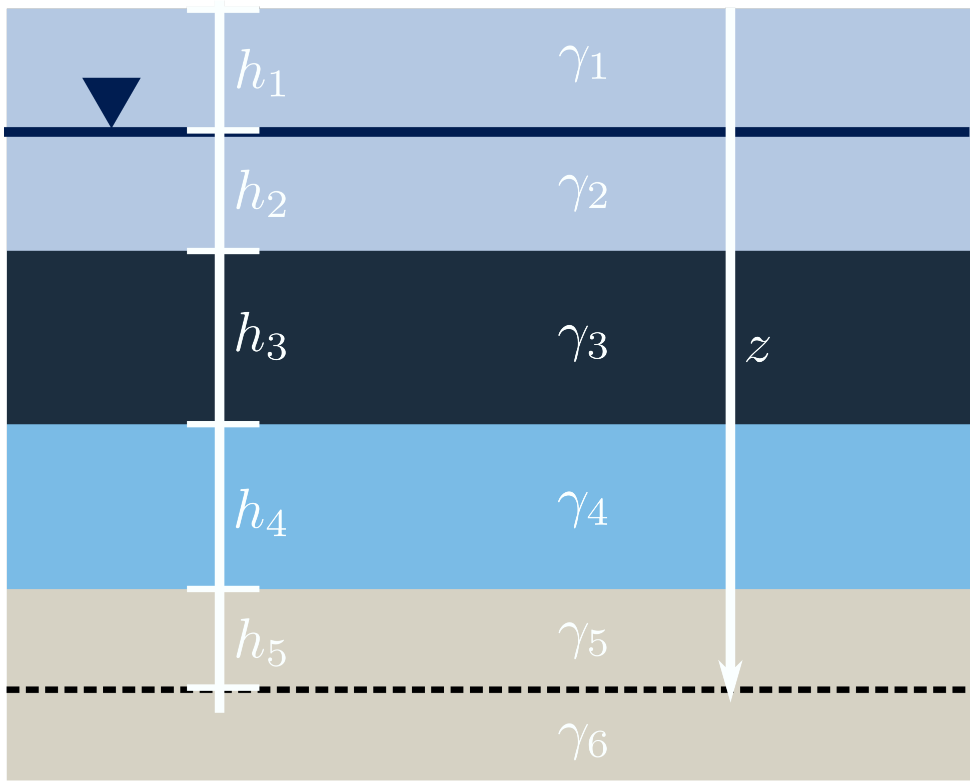
The vertical effective stress is:

$$\sigma'_v = \sigma_v - u$$



≡

MULTILAYER PROFILES



The total vertical stress at depth z is:

$$\sigma_v = \sum_{i=1}^{n} \gamma_i h_i$$

$n =$ number of interfaces below the ground surface including the water table.

≡

EXAMPLE 4.2

Compute the total and effective stress at point A. Plot the vertical total and effective stress with the pore pressure profile in the same graph.