Module 6: Consolidation (part 2)

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Spring 2022

March 28, 2022

COURSE CONTENTS AND SCHEDULE

Department of
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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 the process of consolidation of soils.
- We learned about the consolidation curve and the parameters that define it.
- We learned about the history-dependent behavior of soils and its effects on the consolidation path.
- We learned the concept of overconsolidaiton ratio and relation with the geological stress history of soils.
- We learned how to calculate primary consolidation settlements in normally and overconsolidated soils.
- Today we will discuss about the rate of consolidation.

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HOMEWORK ASSIGNMENT 5

- Due on 04/04/2022.
- 35 points total.
- Start ASAP.

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CIE-365 Spring 2022: Homework assignment 5

Due date: 04/04/2022 at 10:00 AM
Possible points: 35

Answer the following questions based on the contents of Module 5 parts 1 and 2.

1. [O3] (15 points) Given the void ratio versus pressure data shown below. The initial void ratio is 0.725, and the existing vertical effective overburden pressure is 130 kPa. Determine:
   (a) The overconsolidation ratio.
   (b) The compression and recompression index.
   (c) If this consolidation test is representative of a 12 m thick clay layer, compute the settlement of this layer if an additional stress of 220 kPa was added.

Table 1: Data for problem 1

Void ratio	Pressure (kPa)
0.708	25
0.691	50
0.67	100
0.632	200
0.635	100
0.65	25
0.642	50
0.623	200
0.574	400
0.51	800
0.445	1600
0.46	400
0.492	100
0.53	25

2. [O3] (15 points) A deposit of Swedish clay is 12 m thick, on the average, and apparently drained at the bottom. The coefficient of consolidation for the clay was estimated to be 1×10^{-4} cm^2/s from laboratory tests. A settlement analysis based on oedometer tests predicted ultimate consolidation settlement under the applied load in the field to be 1.2 m. Determine:
   (a) How long would it take for settlements of 40 and 70 cm to occur?
   (b) How much settlement would you expect to occur in 5 yr? 10 yr? 50 yr?
   (c) How long will it take for the ultimate settlement of 1.2 m to occur?.

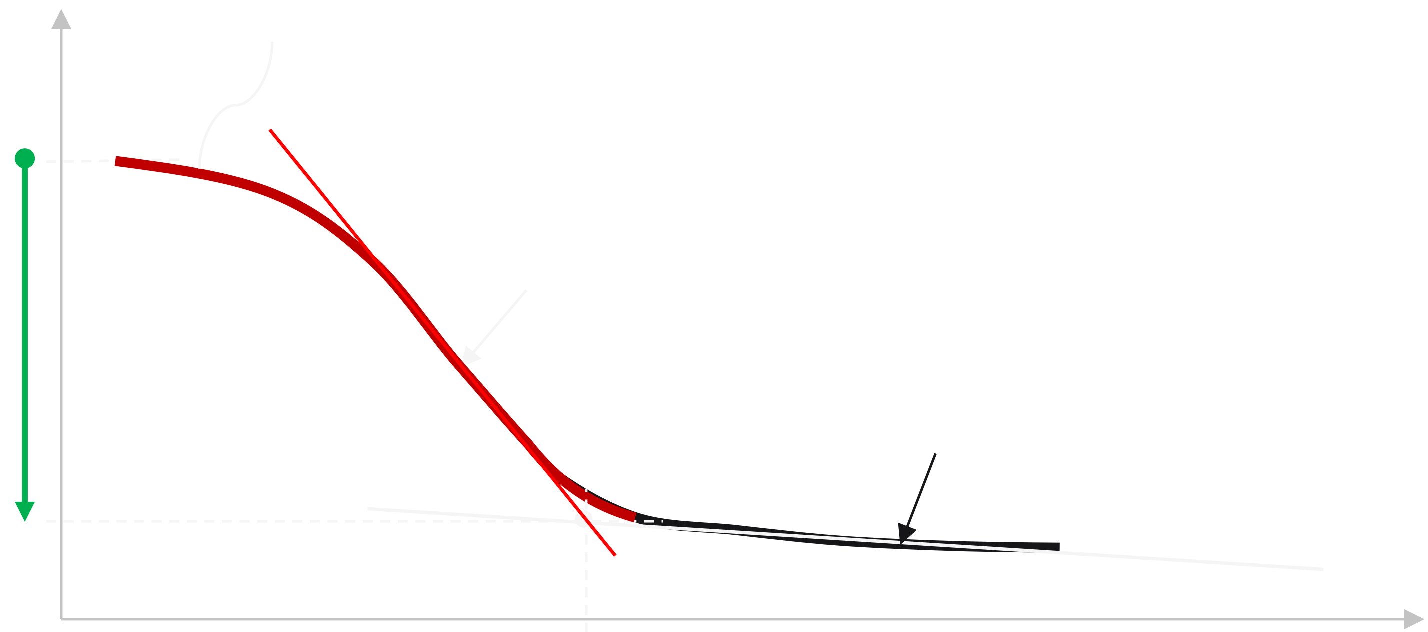
CONTENTS

- Terzaghi's one-dimensional consolidation theory.
- Effect of the drainage boundary conditions.
- Procedures for determining the coefficient of consolidation
- Degree of consolidaiton
- Secondary consolidation
- Preloading and vertical drains
- Case study

TIME RATE OF PRIMARY CONSOLIDATION

Final settlement in Primary Consolidation

S_{PC}



TERZAGHI'S CONSOLIDATION THEORY

$$\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2}$$

- $u =$ Excess pore water pressure
- $t =$ time
- $z =$ Drection of flow
- $C_v =$ Coefficient of consolidation

$$C_v = \frac{k}{\gamma_w m_v}$$

- $m_v =$ Coefficient of volume change

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TERZAGHI'S CONSOLIDATION THEORY

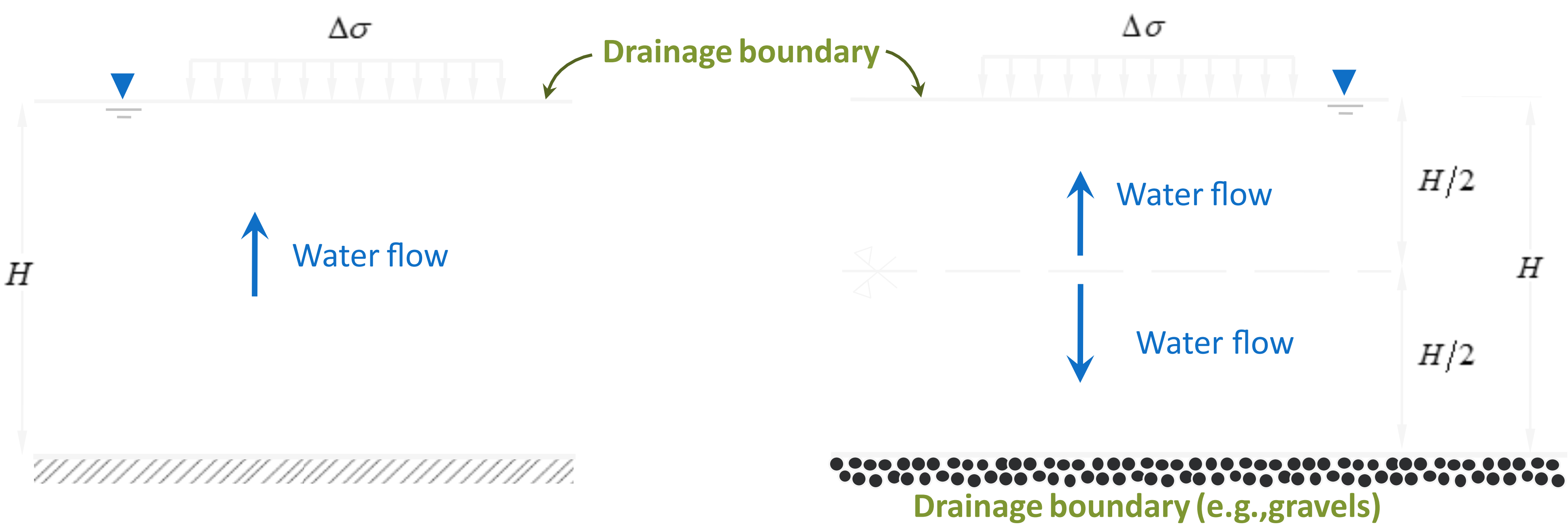
Analytical solution for Terzaghi's 1D consolidation theory

$$\Delta u(z,t) = \Delta\sigma \sum_{n=0}^{\infty} \frac{4}{(2n+1)\pi} \exp\left[-\frac{(2n+1)^2\pi^2}{4} T_v\right] \sin\left[\frac{(2n \cdots}{2 \cdots}\right.$$

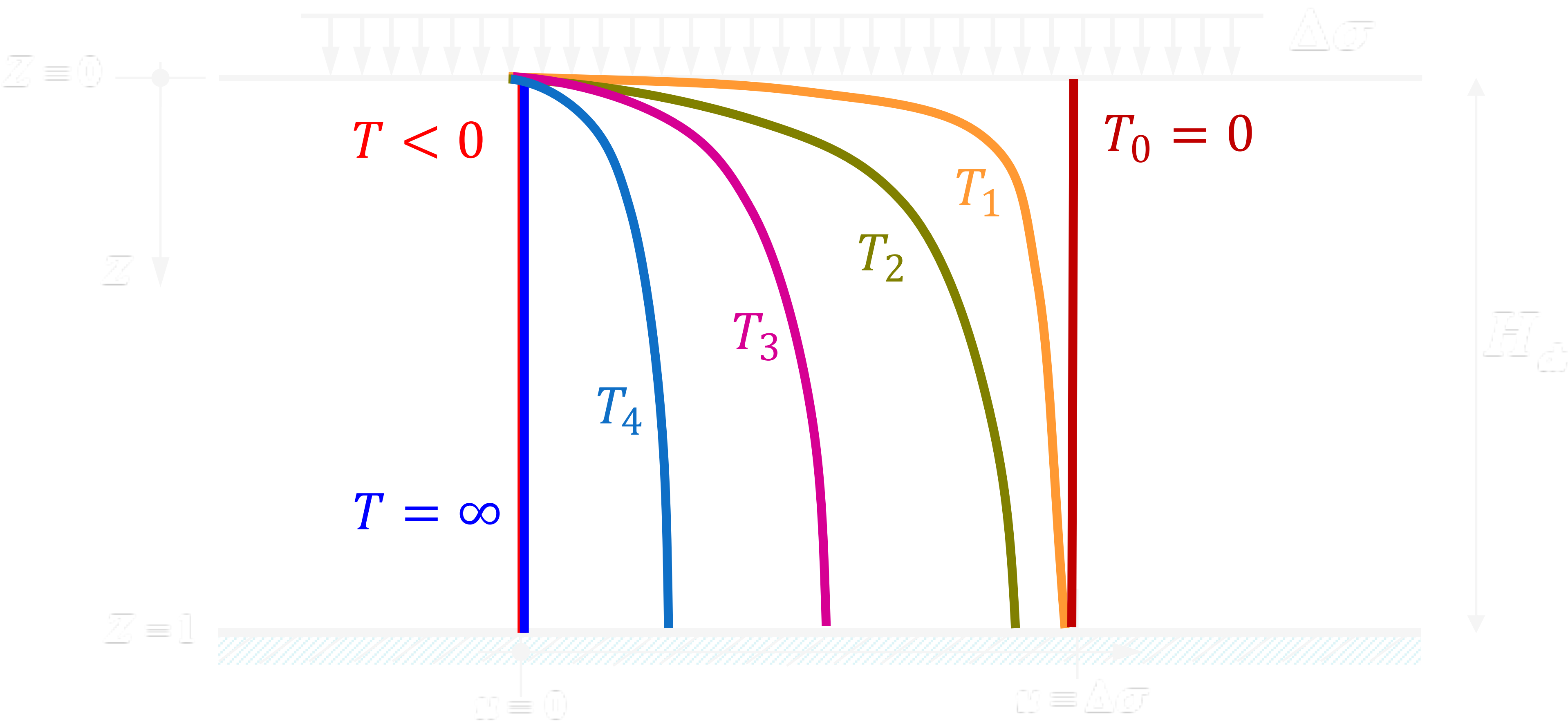
With $T_v = \dfrac{C_v t}{H_{dr}^2}$ and $Z = \dfrac{z}{H_{dr}}$

New concept: H_{dr}

DRAINAGE LENGTH H_{DR}



TERZAGHI'S CONSOLIDATION THEORY



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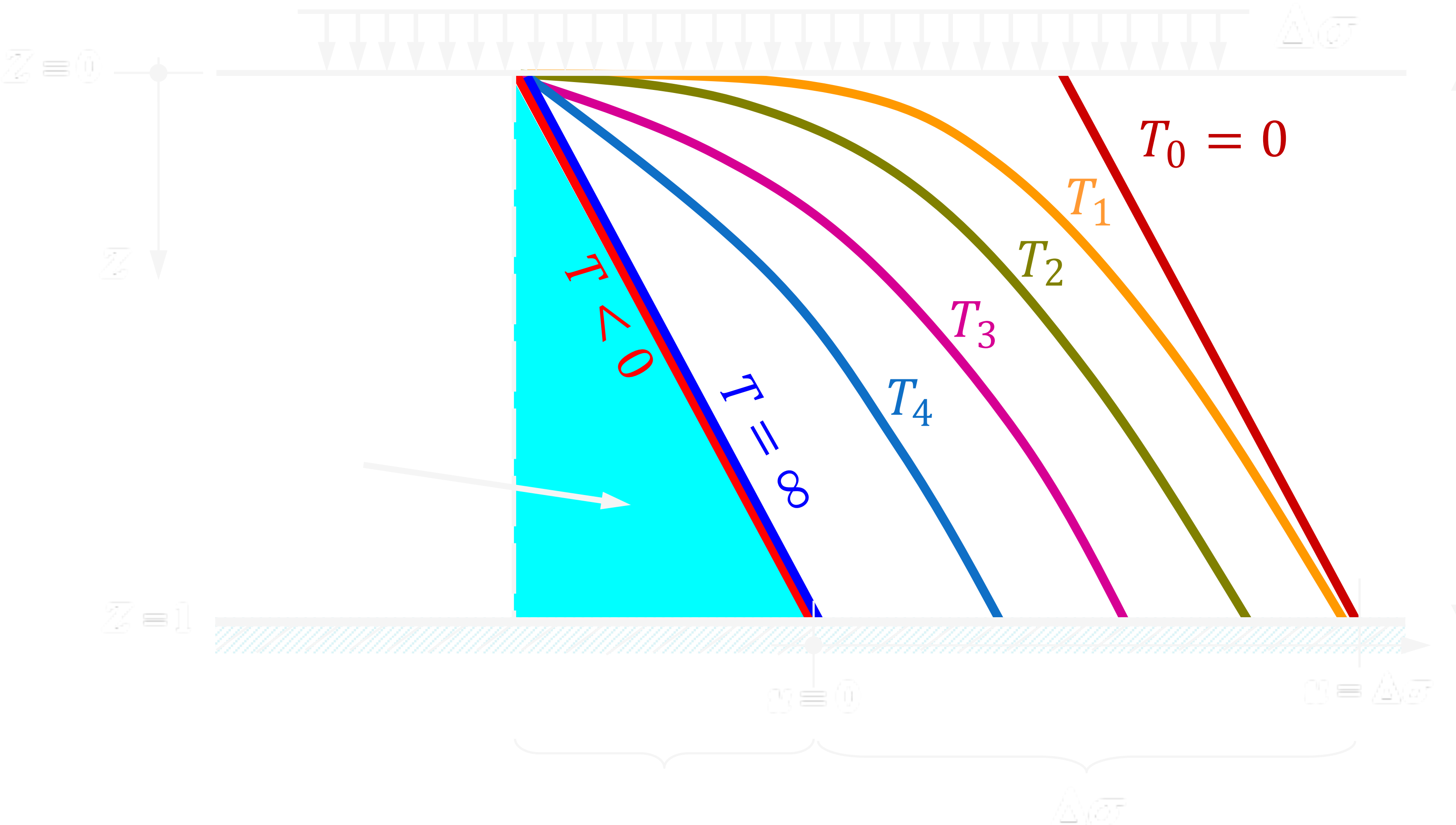
TERZAGHI'S CONSOLIDATION THEORY



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DEGREE OF CONSOLIDATION

We have a solution for $\Delta u(z,t)$ but we also need to decribe settlements vs time $S(t)$.

The degree of consolidation U is useful to compute $S(t)$

$$U = 1 - \Delta u(z,t)/\Delta u_0$$

- $\Delta u = \Delta u_0 \longrightarrow U = 0 \longrightarrow S = 0$
- $\Delta u = 0 \longrightarrow U = 1 \longrightarrow S = S_{pc}$

$$U = \frac{S(t)}{S_{pc}}$$

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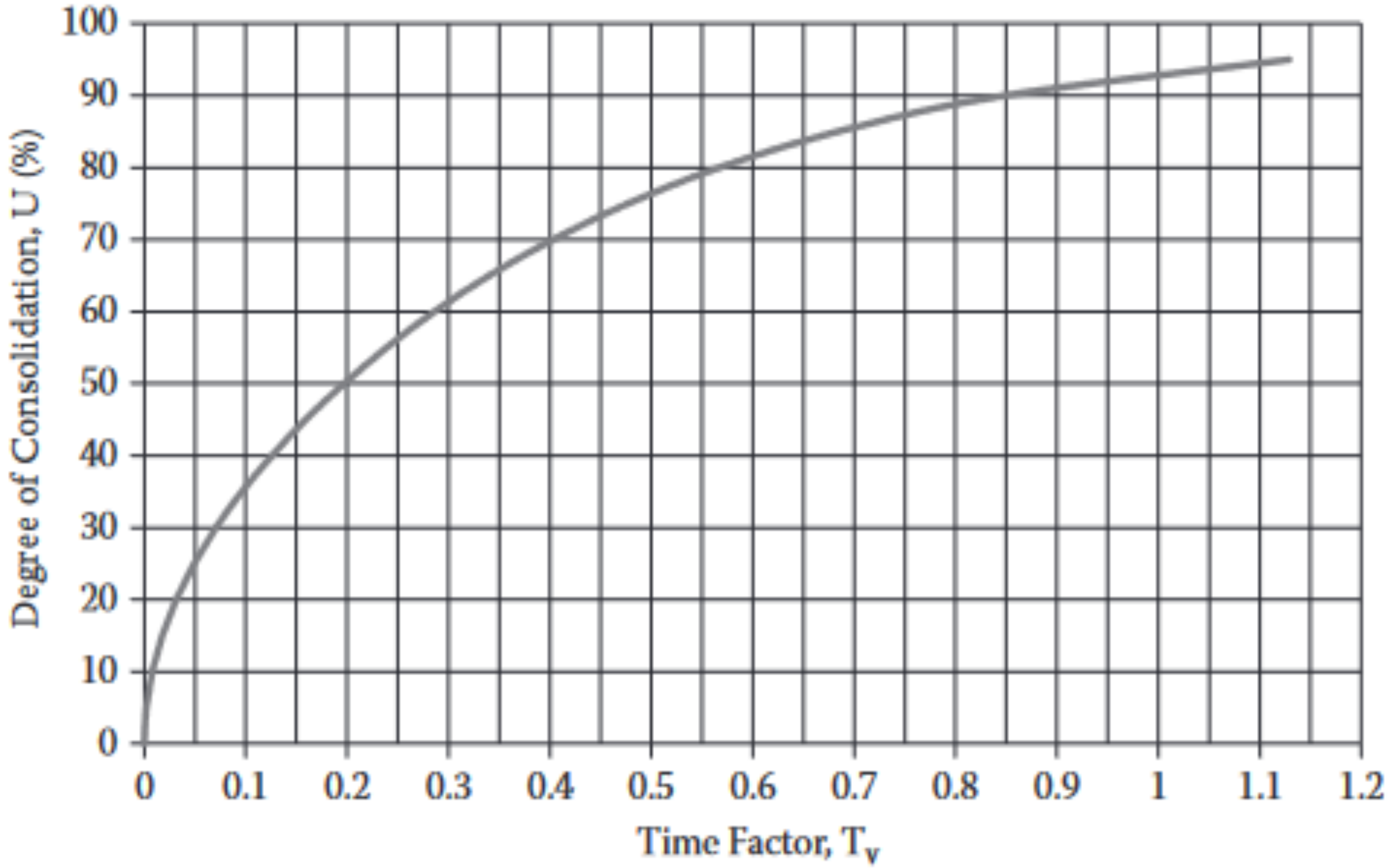
TERZAGHI'S CONSOLIDATION THEORY

Relationships between U and T_v

U (%)	T_v	U (%)	T_v
0	0	3.751	0.001
5	0.00196	5.665	0.0025
10	0.00785	7.980	0.005
15	0.0177	9.772	0.0075
20	0.0314	11.28	0.01
25	0.0491	17.84	0.025
30	0.0707	25.23	0.05
35	0.0962	30.90	0.075
40	0.126	35.68	0.1
45	0.159	56.22	0.25
50	**0.197**	76.40	0.5
55	0.239	87.26	0.75
60	0.286	93.13	1
65	0.340	99.83	2.5
70	0.403	100	5
75	0.477	100	7.5
80	0.567	100	9.5
85	0.684		
90	**0.848**		
95	1.129		
100	∞		



SOLUTION APPROXIMATION

Approximations exist for the analytical solution:

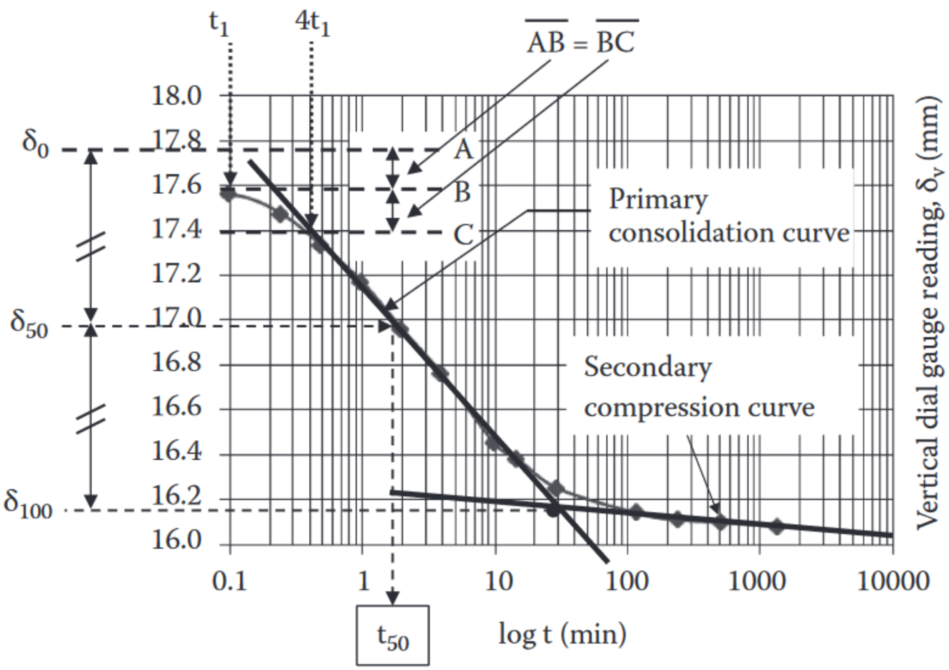
$$T_v = \frac{\pi}{4} U^2 \text{ for } U < 60\%$$

$$1.781 - 0.933 \log(1 - U) \text{ for } U \geq 60\%$$

- These approximations guided the development of methods to calculate C_v from laboratory curves

DETERMINING C_V

Log t method



1. Plot consolidation curve from experimental data
2. Determine settlement at end of primary (EOP) δ_{100} by intersecting tangents to primary and secondary compression lines.
3. Designate t_1 in "early" point of the curve, and identify its correspondent settlement as δ_1
4. Designate a second point at $4t_1$ and identify settlement δ_2
5. Determine initial settlement δ_0 by taking $\delta_1 - \delta_0 = \delta_2 - \delta_1$
6. Determine the mid-point settlement between δ_0 and δ_{100}, designated as δ_{50}
7. Determine the corresponding time t_{50}
8. Use Terzaghi's consolidation theory to compute C_v

EXAMPLE 5.6

Find the coefficient of consolidation for the test result shown in the figure below