Loughborough University

Soil Mechanics and Geology
24CVB102

Semester 2 2025 | In-Person Exam Paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **ALL EIGHT** questions from **Section A** and **TWO** questions from **Section B**. **Section A** is worth 40 marks and **Section B** is worth 60 marks.

A 6-page Formulae Sheet is provided.

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SECTION A
(Answer all EIGHT questions)
Students are advised to spend approximately 70 minutes on Section A

A1. A cube of fine-grained soil has an edge length of 50 mm, a wet mass of 242.5 g, and a dry mass of 208.5 g. The density of the soil particles (ρ_s) was found to be 2.7 Mg/m^3. For this soil block, determine the: bulk density; water content; void ratio; and degree of saturation.
[5 marks]

A2. A 4.5 m-thick layer of saturated CLAY (γ_{sat} = 21.5 kN/m^3) is underlain by SANDSTONE. The groundwater level is at ground level (i.e. at the top of the CLAY layer). A surcharge of 60 kPa is rapidly applied to the surface of the CLAY. Calculate the total stress, effective stress, and pore-water pressure immediately following application of the surcharge at a depth of 4.5 m (i.e. at the bottom of the CLAY layer).
[5 marks]

A3. Show what is meant by 'peak', 'critical state', and 'residual' shear strengths by sketching and annotating a shear stress versus shear strain graph for a stiff, overconsolidated CLAY.
[5 marks]

A4. A 50 mm diameter sample of coarse SAND was tested in a constant head permeameter. The distance between the manometer points was 100 mm, and the water level readings in the manometers had a difference of 325 mm. Water flowed through the sample for 9 seconds, and the discharge water during this time had a total volume of 5.11 x 10^{-4} m^3. Using Darcy's Law, determine the coefficient of permeability of the coarse SAND.
[5 marks]

A5. State the key factors and soil properties that control the compaction behaviour of a cohesive soil for use as an engineered fill material. Explain how these factors and soil properties influence compaction behaviour.
[5 marks]

A6. The following readings were taken from an oedometer test on a saturated CLAY. Using Casagrande's procedure, determine the preconsolidation pressure σ'_c.

Table QA6. Oedometer test data

Pressure (kPa)	50	100	200	400	800	1000
Void ratio (e)	0.840	0.826	0.774	0.696	0.612	0.528

[5 marks]

Section A continues/…

A7. Standard Penetration Test (SPT), Cone Penetration Test (CPT) and Vane Shear Test (VST) are *in situ* tests that can be carried out as part of a site investigation. List the parameters that are measured in each of these *in situ* tests.

[5 marks]

A8. Describe the role of benches to manage rockfall risk in quarries.

[5 marks]

SECTION B

(Answer TWO questions, each question is worth 30 marks)

Students are advised to spend approximately 110 minutes on Section B

B1. a) Consolidated-Undrained (CU) triaxial tests were performed on three specimens of the same saturated CLAY. The results at failure are given in **Table QB1.**

Table QB1. Triaxial test data

Cell pressure (kPa)	350	400	500
Deviator stress at failure (kPa)	141	209	317
Pore pressure at failure (kPa)	307	325	371

i) Using the data in **Table QB1**, construct a table that shows values of major and minor principal stresses at failure in both total stress and effective stress terms. Show in full how you have calculated all answers.

[6 marks]

ii) Determine the effective stress shear strength parameters for the CLAY by plotting three effective stress Mohr circles.

[8 marks]

Question B1 continues/…

b) **Figure QB1** shows an annotated cross-section of a CLAY slope. A client is proposing a development on the crest (top) of the slope, which would comprise a foundation (shown in Figure QB1) subject to a vertical load of 1890 kN (per metre length of the foundation). The CLAY has a bulk unit weight of 20 kN/m^3 and an undrained shear strength of 50 kPa.

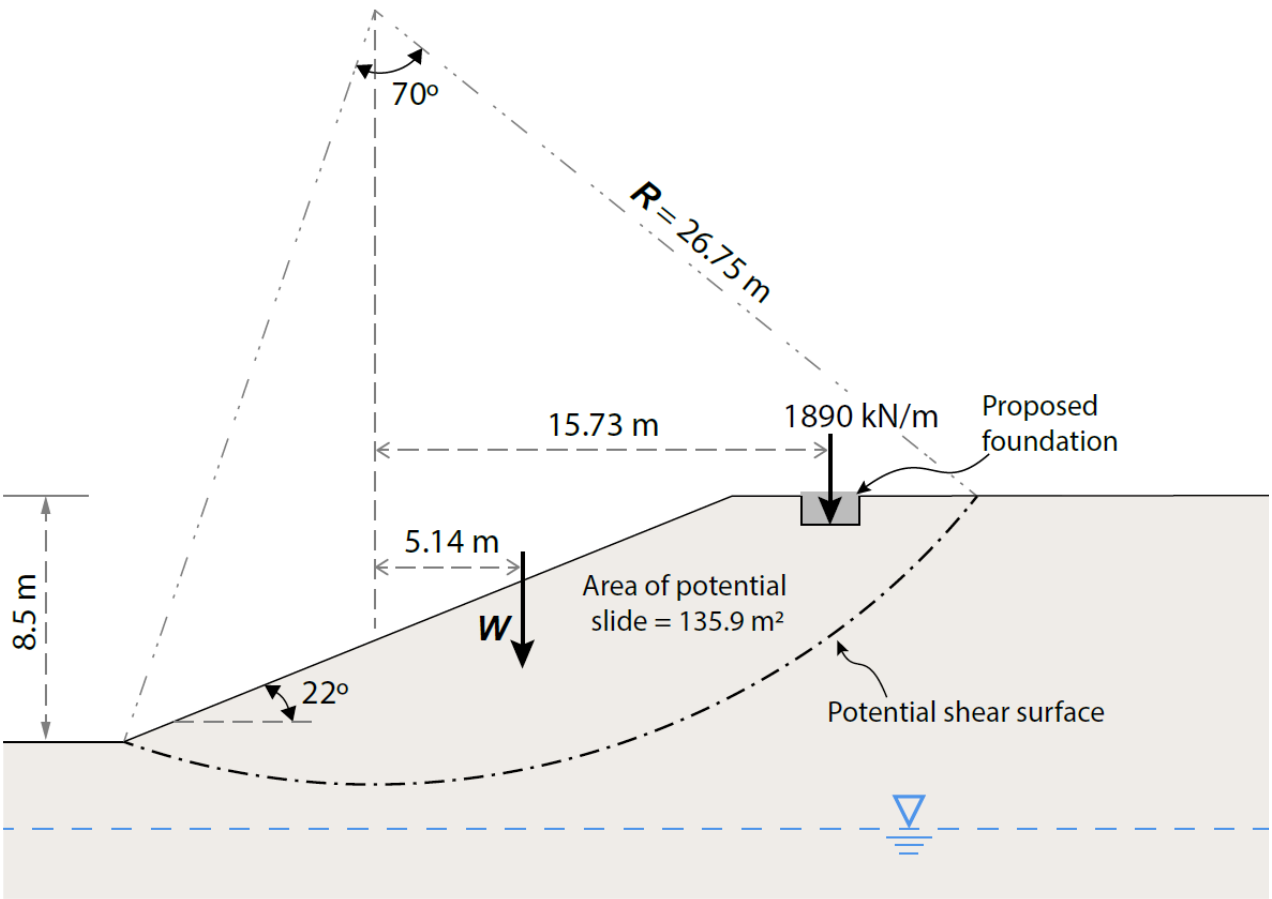

Figure QB1. Annotated slope cross-section

i) Determine the factor of safety against undrained shear failure for the potential circular shear surface shown in **Figure QB1** before the proposed development (i.e. without the foundation and its associated vertical load).

[7 marks]

ii) Determine the factor of safety against undrained shear failure following the development scenario by modifying your solution to QB1(b)(i) above to include the additional destabilising moment provided by the vertical foundation load (ignore the foundation self-weight).

[4 marks]

iii) Comment on the factor of safety values that you obtained in parts (i) and (ii). What advice would you give to the client?

[5 marks]

Section B continues/…

B2. A site underlain by SAND is to be developed as part of a construction project (**Figure QB2**). Development of the site includes a concrete dam to retain a body of water, as well as a retaining wall. Beneath the SAND is stiff CLAY. Properties of the SAND are:

$$c' = 0 \text{ kPa}, \quad \phi' = 33°, \quad \gamma_{dry} = 19 \text{ kN/m}^3, \quad \gamma_{sat} = 22 \text{ kN/m}^3, \quad k = 1.5\times10^{-4} \text{ m/s}$$

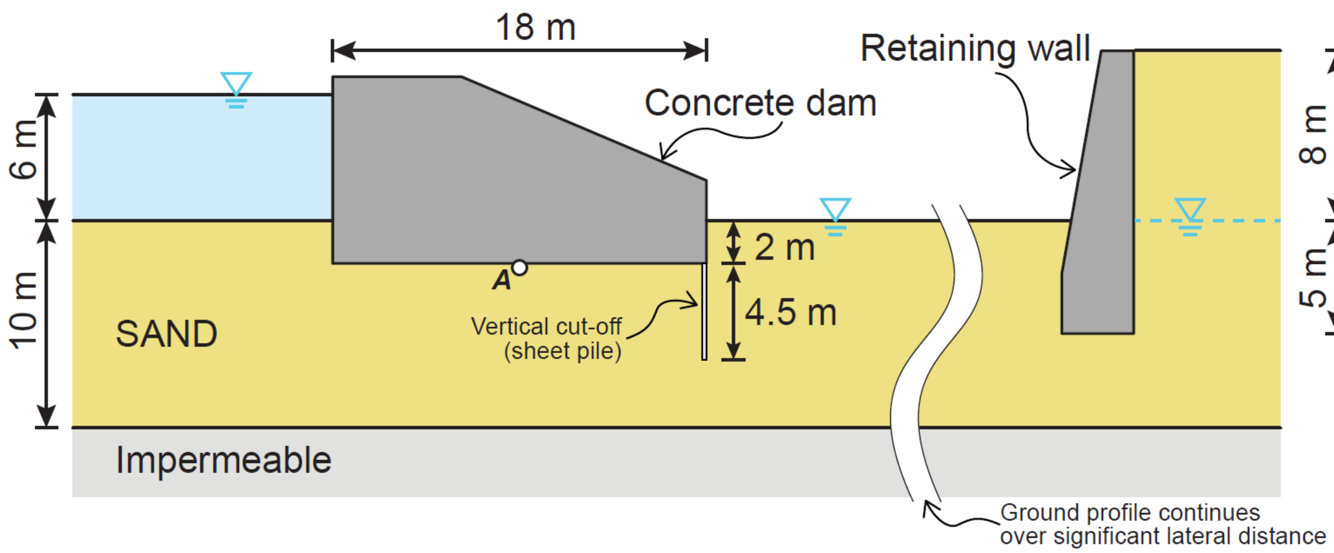

Figure QB2. Cross-section of the site comprising SAND

a) The 13 m high retaining wall shown in **Figure QB2** supports SAND with an effective friction angle of 33°. The groundwater level is 8 m below the top of the wall. Determine the total forces acting on the back of the wall (active thrust) per metre run. Assume hydrostatic pore-water pressures behind the wall.

[10 marks]

b) Draw a flow net for seepage under the concrete dam in **Figure QB2**. Flow through the underlying CLAY layer is negligible (i.e., treat it as impermeable for the purpose of drawing the flow net). *[Note: You must draw **Figure QB2** to scale to obtain a solution. Please use the graph paper provided. Ignore the adjacent retaining wall for the purpose of drawing the flow net.]*

[10 marks]

c) Using your flow net from part B2(b), calculate the pore-water pressure under the dam at point A, which is located half-way along the base of the dam.

[6 marks]

d) Using your flow net from part B2(b), calculate the flow of water per day (m^3/day) per metre run under the dam.

[4 marks]

Section B continues/…

B3. a) Boreholes have revealed that the ground profile succession at the site of a proposed building is as shown in **Table QB3**.

Table QB3. Ground profile information

Depth	**Type of soil**	**Properties**
0 → 2m	Dense sand	highly permeable, negligible compressibility
2 → 6m	Clay	m_v = 0.28 m^2/MN, c_v = 1.0 m^2/yr
6 → 8m	Loose gravel	highly permeable, negligible compressibility
8 → 11m	Clay	m_v = 0.25 m^2/MN, c_v = 1.3 m^2/yr
11 → 13m	Loose sand	highly permeable, negligible compressibility
13 → 14m	Clay	m_v = 0.30 m^2/MN, c_v = 1.1 m^2/yr
14 → ∞	Impervious rock	-

The building is founded on the upper dense sand layer, and will impose net effective stress increases, at the centers of the respective clay layers, starting from the top to the bottom clay layer, of 150 kPa, 80 kPa and 120 kPa, respectively.

i) Estimate the ultimate settlement of the building caused by consolidation of the clay layers.

[4 marks]

ii) Making the assumption that $T_v = (\pi/3)\, U_z^2$, which is valid for $U_z < 0.6$, estimate the time likely to elapse before half of the total consolidation settlement has occurred.

[9 marks]

b) i) Discuss, in point form, the various methods an engineer can use to reduce settlements.

[12 marks]

ii) State 2 methods that could be used to accelerate consolidation.

[2 marks]

iii) State 3 methods that could be integrated into the design of structures to reduce settlement.

[3 marks]

Section B continues/…

B4. In the northeast of England, coastal cliffs in Upper Cretaceous Chalk (95-65 Ma) reach some 10 to 15 m in height over a length of approximately 130 m. Rockfall from this cliff poses a serious hazard.

A survey of the rock slope resulted in the stereographic plot of **Figure QB4**. Partial results of the survey are shown in **Table QB4**. Uncertainties in dip and strike measurements are of the order of 5 degrees.

Table QB4 Summary of survey results.

Feature	Dip and strike	Typical spacing	Persistence
Cliff face		-	130 m
Joint set A		3 m	3-5 m
Joint set B		1 m	0.5-1 m
Bedding plane		0.5-1.0 m	-
Fault		10-25 m	-

Friction angle	

a) Using the stereographic plot (**Figure QB4**), complete the missing dip and strike and friction angle information in **Table QB4,** Include your answers in your answer book.
[6 marks]

b) i) Draw a sketch of a typical section through the cliff that shows the slope, discontinuities, bedding plane and friction angle.
[6 marks]

ii) Identify the mode(s) of rock slope failure that are apparent from the stereographic plot and the dip/strike of relevant plunge lines.
[8 marks]

iii) Provide an assessment of the likely dimensions of these potential rock slope failures.
[5 marks]

c) Considering the information provided, what range of rock slope failure mitigation interventions would be appropriate?
[5 marks]

Question B4 continues/…

…/Question B4 continued

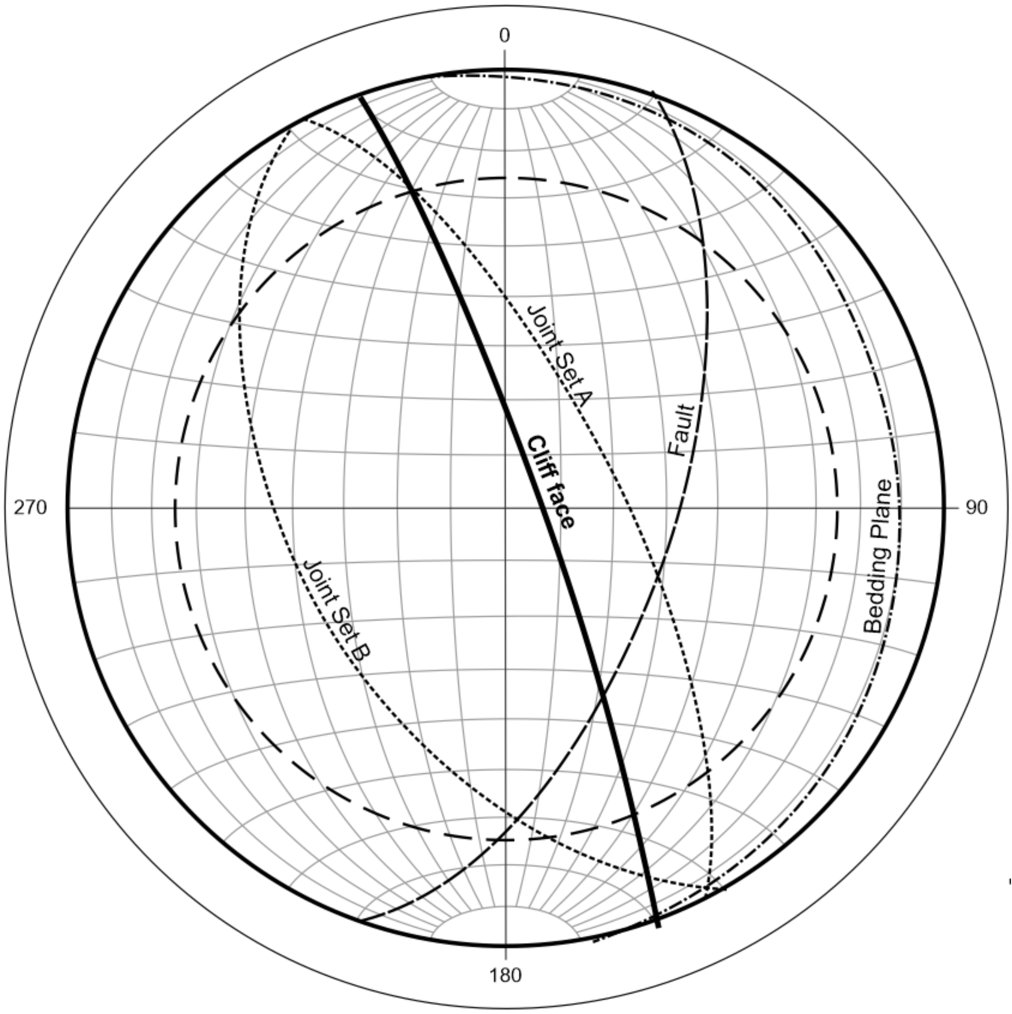

Figure QB4. A stereographic plot representing the coastal cliff face and its discontinuities.

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LOUGHBOROUGH UNIVERSITY
School of Architecture, Building and Civil Engineering
Soil Mechanics & Geology (CVB102) - FORMULAE SHEET and CHARTS

Classification & Phase relationships

Specific gravity	G_S	= density of solids/density of water = ρ_S/ρ_W = γ_S/γ_W
Bulk density	ρ	= overall mass of soil per unit volume = m/V
Bulk unit weight	γ	= overall weight of soil per unit volume = W/V
Unit weight of water	γ_W	= ρ_W g = 9.81 kN/m^3
Submerged (buoyant) density	ρ'	= $\rho - \rho_W$
Dry density (mass of solid particles per unit volume of soil)	ρ_d	= $\rho/(1 + w)$
Density of water	ρ_W	= 1000 kg/m^3 = 1.0 g/cm^3
Moisture content	w	= mass of water in soil/mass of solids = m_W/m_S
Total soil volume	V	= $V_s + V_v = V_W + V_S + V_a$
Air content	A_v	= volume of air/volume of soil = V_a/V
Degree of saturation	S_r	= V_W/V_V = volume of water/volume of voids
Void ratio	e	= V_V/V_S = volume of voids/volume of solids
Porosity	n	= $V_v/V = V_V/(V_S + V_V)$ = e/(1 + e)
Plasticity Index	PI	= LL - PL
Grading, Coefficient of Uniformity	C_u	= D_{60}/D_{10}
Grading, Coefficient of Curvature	C_c	= $\dfrac{(D_{30})^2}{D_{10}\,D_{60}}$

Moisture content	w	= $S_r \cdot e / G_S$	These are examples - you can derive any
Bulk density	ρ_b	= $\rho_W G_S(1 + w)/(1 + e)$	phase relationship required from the
Unit weight	γ	= $\gamma_W G_S(1 + w)/(1 + e)$	definitions above.

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Seepage

Darcy's Law $v = k.i$, $q = A.k.i$

Bernoulli's Theorem $H = z + u/\gamma_w = z + h_w$

Hazen's approximation $k \sim 0.01\, d_{10}^2$ (k in m/s, d in mm)

k from laboratory falling head tests $$k = \frac{2.3aL}{A(t_2 - t_1)} \log\left(\frac{h_1}{h_2}\right)$$

k from well pumping tests (unconfined flow) $$k = \frac{2.3q \log(r_2 / r_1)}{\pi(h_2^2 - h_1^2)}$$

k from well pumping tests (confined flow) $$k = \frac{2.3q \log(r_2 / r_1)}{2\pi H(h_2 - h_1)}$$

Stratified soils $k_h = \frac{\Sigma kH}{\Sigma H}$

$k_v = \frac{\Sigma H}{\Sigma(H/k)}$

Piping $i_c = \frac{\gamma'}{\gamma_w}$

Flow nets $q = k\left(\frac{Nf}{Nd}\right) H$

Anisotropic soil scale factor for x = $\sqrt{\frac{k_v}{k_h}}$ k' = $\sqrt{k_v k_h}$

Boundary condition $\frac{k_1}{k_2} = \frac{\tan\alpha_1}{\tan\alpha_2}$

Modification to position of exit phreatic surface in an embankment dam:

β	30°	60°	90°
Δa/a	0.36	0.3	0.26

Shear strength

Coulomb $\tau_f = c + \sigma \tan \phi$

$\tau_f = c' + \sigma' \tan \phi'$

Mohr's Circle $\sigma_1 - \sigma_3 = P/A$ (= deviator stress)

$\tau_{max} = (\sigma_1 - \sigma_3)/2$ (undrained)

$\theta = 45 + \varphi/2$

Pore Pressure parameters

$\Delta u = B\Delta\sigma_3 + A.B\, \Delta(\sigma_1 - \sigma_3)$

$A.B = \bar{A}$

$\bar{A}_f = u_f/(\sigma_1 - \sigma_3)_f$ (f refers to failure)

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Consolidation and Compression

Coefficient of volume compressibility $m_v = -\frac{\Delta\varepsilon_v}{\Delta\sigma'} = \frac{\Delta e}{(1+e_0)(\Delta\sigma')} = \frac{e_0 - e_1}{(1+e_0)(\sigma_1' - \sigma_0')} = \frac{a_v}{(1+e_0)}$

Coefficient of compressibility $a_v = \frac{e_0 - e_1}{\Delta\sigma'}$

Volumetric strain $\Delta\varepsilon_v = \frac{\Delta H}{H_0} = -\frac{\Delta e}{1+e_0}$; $\Delta e = e_0 - e_1$

Voids ratio e = water content * specific gravity = w. G_s (saturated)

Compression $\Delta H = s_{max} = H_0\, m_v\, \Delta\sigma'$

$$\frac{\Delta H}{H_0} = \frac{e_0 - e_1}{(1+e_0)} = \frac{c_c \log\left(\frac{\sigma_1'}{\sigma_0'}\right)}{(1+e_0)}$$

where e_0 = initial voids ratio, e_1=final voids ratio

σ_0' = initial effective stress, σ_1' = final effective stress

ΔH = primary consolidation settlement, H_0 = initial thickness

$\Delta\sigma'$= difference in effective stress

Compression Index $C_c = (e_0 - e_1) / \log(\sigma_1' / \sigma_0')$

Coefficient of Consolidation $c_v = \frac{k}{m_v \,.\, \gamma_w}$

Overconsolidation Ratio $R = \sigma'_{max} / \sigma'_{current}$

Degree of consolidation $U_z = \frac{e_0 - e}{e_0 - e_1} = \frac{\sigma' - \sigma_0'}{\sigma_1' - \sigma_0'} = 1 - \frac{u^e}{u^0} = \frac{s_t}{s_{max}}$

Time factor $T_v = \frac{c_v t}{d^2}$

$U_z = 0.9$ for $T_v = 0.848$; $U_z = 0.5$ for $T_v = 0.196$ Note: c_v in m^2/year

Finite difference calculation of excess pore pressure and settlement:

$$\bar{u}_{i,j+1} = \bar{u}_{i,j} + \frac{c_v \Delta t}{(\Delta z)^2}(\bar{u}_{i-1,j} + \bar{u}_{i+1,j} - 2\bar{u}_{i,j})$$

$$S_t = \sum_0^t m_v \,\Delta z\, \Delta\bar{u}$$

Correction for construction period:

For $0 \le t < t_c$: $s_t^{corrected} = s_{t/2}^{instant} \left(\Delta\sigma^t / \Delta\sigma^{net}\right) = s_{t/2}^{instant} (t/t_c)$

For $t = t_c$: $s_t^{corrected} = s_{tc/2}^{instant}$

For $t > t_c$: $s_t^{corrected} = s_{t-tc/2}^{instant}$

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Compaction of Earthworks

Dry Density $\rho_d = \rho_b / (1+w)$ $\rho_d = (G_S / (1+e)) . \rho_w$

ρ_b = Bulk Density

ρ_d = Dry density

$\rho_d = (1-A) / ((1/\rho_s)+ (w/ \rho_w))$

Note: w = moisture content

Lateral Earth Pressure and Retaining Walls

$K_0 = 1 - \sin\phi'$

$K_a = (1 - \sin\phi') / (1 + \sin\phi')$

$K_p = (1 + \sin\phi') / (1 - \sin\phi')$

$P_a = K_a.\sigma'_z - 2.c'\sqrt{K_a}$

$P_p = K_p.\sigma'_z + 2.c'\sqrt{K_p}$

Bearing Capacity

$Q_{ult} = c.N_c.S_c + p_0.N_q.S_q + ½.\gamma'.B.N_\gamma.S_\gamma$

Bearing capacity factors:

$$N_q = e^{(\pi \tan\phi')} \tan^2\left(45° + \frac{\phi'}{2}\right)$$

$$N_c = \frac{N_q - 1}{\tan\phi'}$$

$$N_\gamma = 2(N_q - 1)\tan\phi'$$

ϕ'	N_q	N_c	N_γ
0	1	5.14	0
5	1.6	6.9	0.1
10	2.5	8.5	0.5
15	3.9	10.8	1.6
20	6.4	14.8	3.9
25	10.7	20.8	9.0
30	18.4	30.1	20.1
35	33.3	46.1	45.2
40	64.2	75.3	106.1
45	134.9	133.9	267.8
50	319.1	266.9	758.2

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Shape factors:

Shape	**S_c**	**S_q**	**S_γ**
Strip	1.0	1.0	1.0
Rectangle	$1+\frac{B}{L}\frac{N_q}{N_c}$	$1+\frac{B}{L}\tan\phi$	$1-0.4\frac{B}{L}$
Square, circle	$1+\frac{N_q}{N_c}$	$1+\tan\phi$	0.6

<u>Slope Stability</u>

Translational slides:

$$\mathrm{FoS} = \frac{\tau_{max}}{\tau} = \frac{c' + (\gamma z - \gamma_w m z)\cos^2\beta\tan\varphi'}{\gamma z\sin\beta\cos\beta}$$

Circular slides:

$$\mathrm{FoS} = \frac{c_u r^2\theta}{Wd}$$

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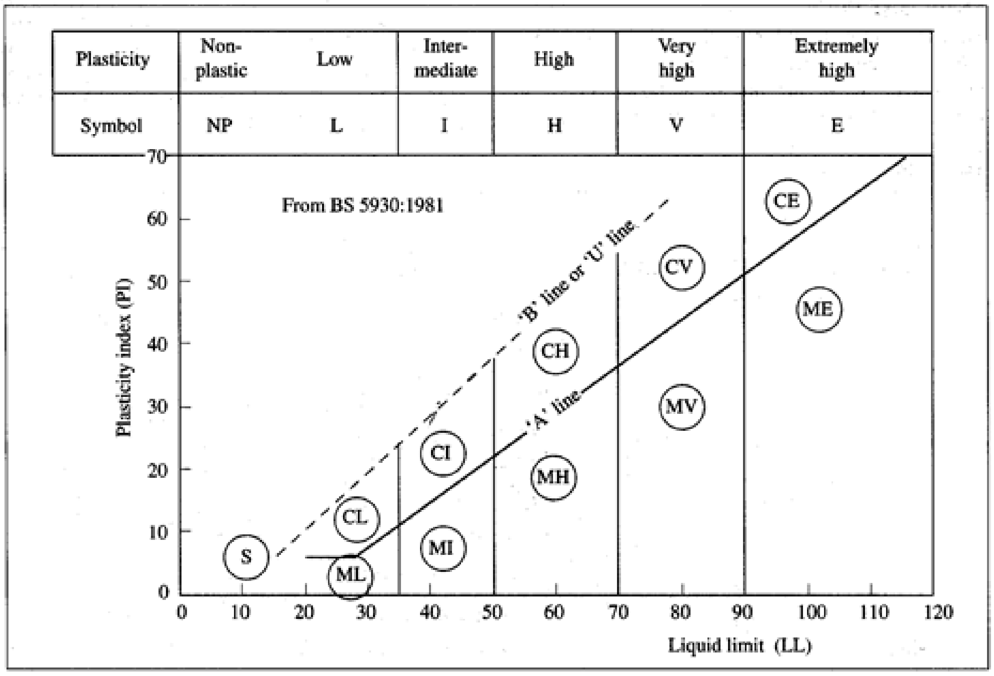
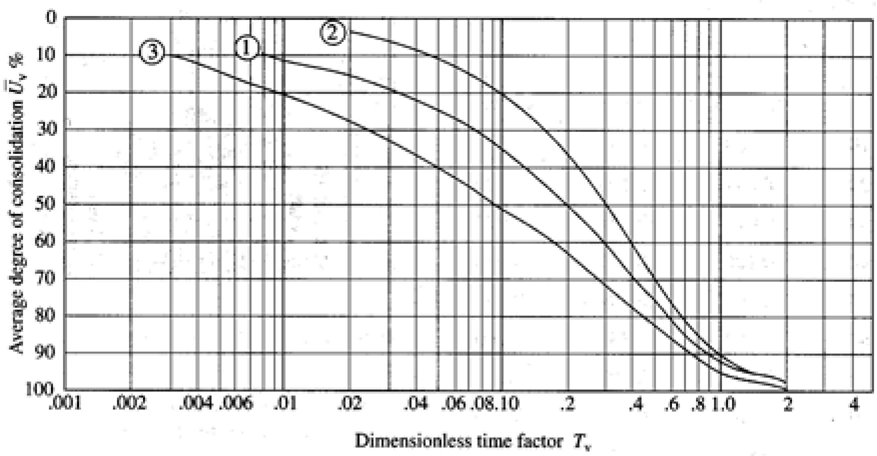
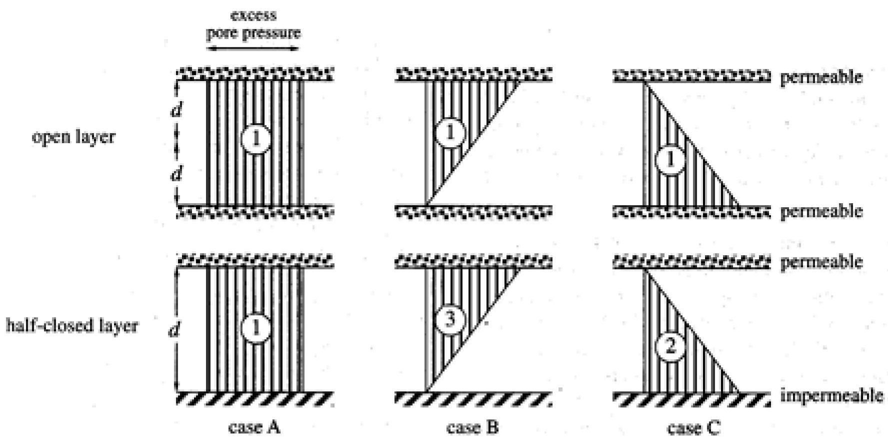




a) $\bar{U}_v$ - T_v relationships



b) Variations of initial excess pore water pressure