National Exams December 2019

18-Geol-A6, Soil Mechanics

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is a CLOSED BOOK EXAM. Candidates may use one of two calculators, the Casio or Sharp-approved model. A compass and ruler are also required.

3. SIX (6) questions constitute a complete exam paper. YOU MUST ANSWER QUESTIONS 1 TO 5. For Question 6, candidates must choose three (3) more questions out of the eight (8) options. Where stated in the examination, please hand in any additional pages with your exam booklet.

4. The marks assigned to the subdivisions of each question are shown for information. The total number of marks for the exam is 100.

Question 1. Classification

10 Marks

1. Plot the grain-size curves and classify soils A and B according to the Unified Soil Classification System. Soil A has a liquid limit of 30% and plastic limit of 27%. Soil B has a liquid limit of 40% and a plastic limit of 30%.

Table Q1-1

Metric Sieve Size	US Sieve Size	Percent Finer Soil A	Percent Finer Soil B
75 mm	3 in	100	100
50 mm	2 in	100	100
25 mm	1 in	100	100
19 mm	0.75 in	95	100
9.5 mm	0.375 in	80	100
4.76 mm	No. 4	72	91
2.38 mm	No. 8	50	80
0.84 mm	No. 20	40	72
420 μm	No. 40	35	70
150 μm	No. 100	12	59
75 μm	No. 200	8	55

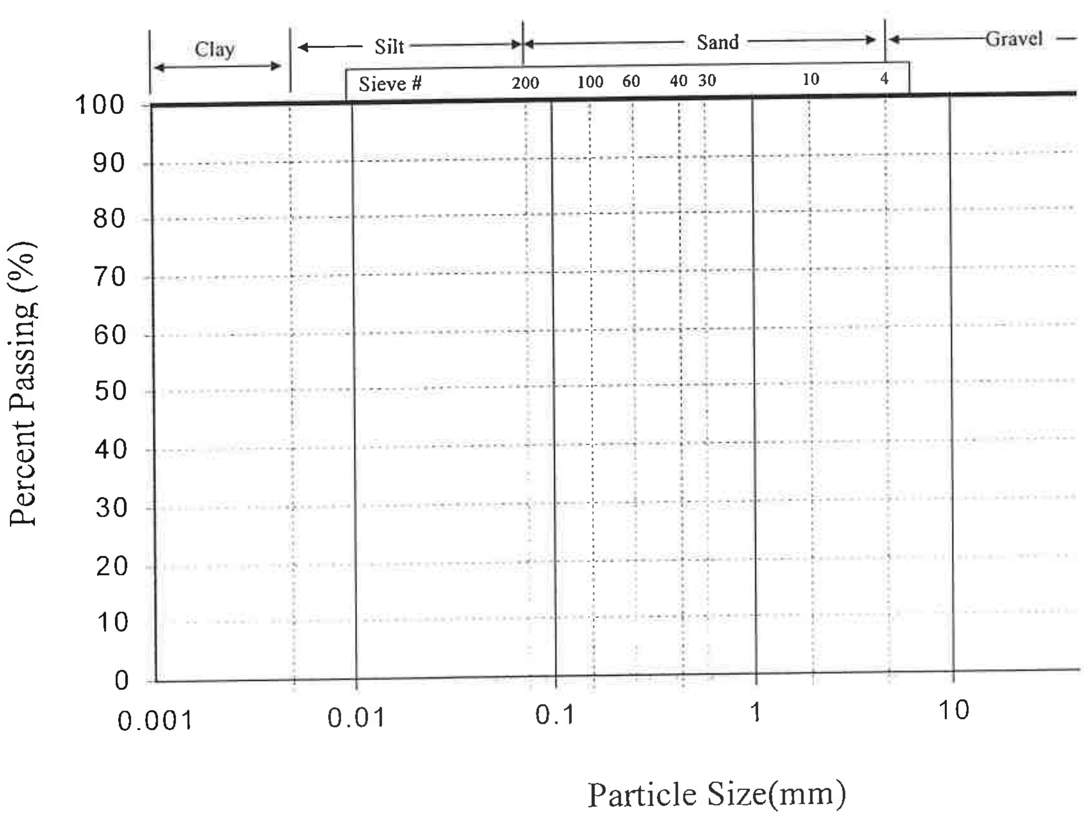


Figure Q1-1

Question 2. Soil Physical Properties

15 Marks

1. Standard and modified compaction curves for a soil is plotted below in **Figure Q2-1**.

   a) Label the axes and units on the graph.

   b) Using the graph interpret the:
      i) Standard Compaction curve
      ii) Modified Compaction curve
      iii) Optimum water content and maximum dry unit weight for the standard and modified proctor curves
      iv) Line of optimums

   c) For the test at 4% water content, determine:
      i) Void ratio
      ii) Degree of saturation
      iii) Total unit weight
      iv) Volumetric water content
      v) Porosity
      vi) Dry density

   d) An engineer is using the soil on a construction project. The specifications state the soil must be compacted to 102% Standard Proctor at optimum water content. +-1%. How many 10 Mg dump trucks of soil provided at optimum water content must the engineer order to fill a 50 m3 excavation?

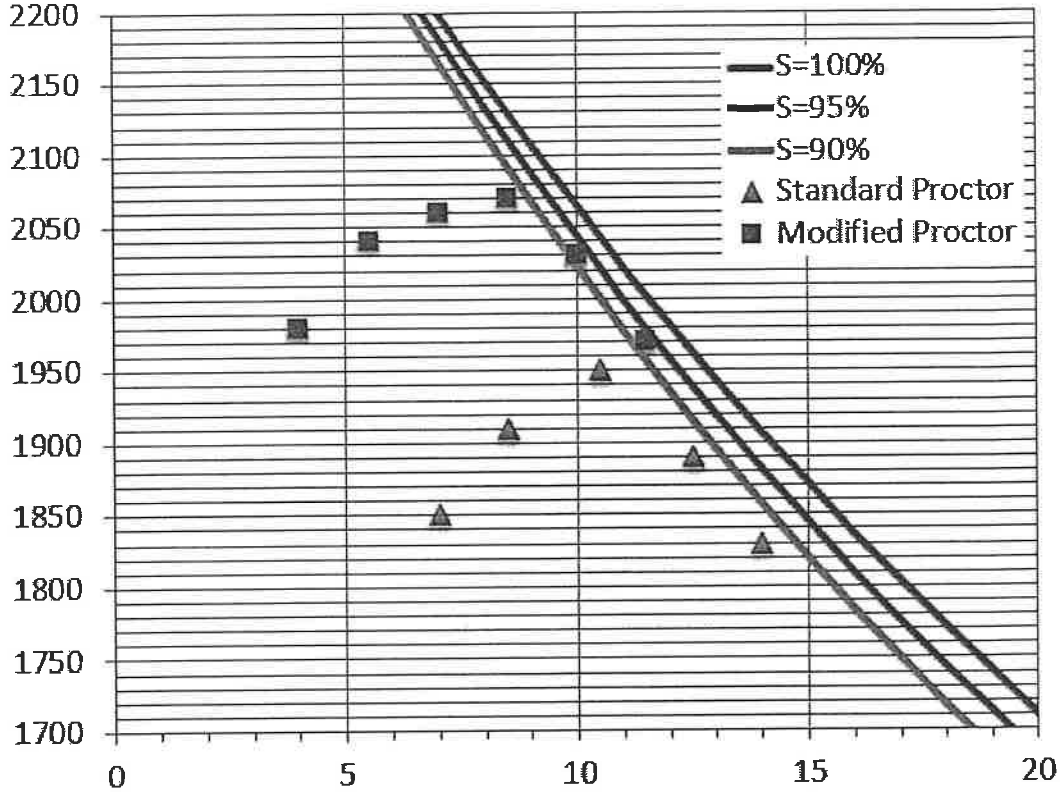

2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
0
5
10
15
20
S=100%
S=95%
S=90%
Standard Proctor
Modified Proctor

Figure Q2-1.

Question 3. Shear Strength

20 Marks

1. Test A is a conventional consolidated-drained (CD) triaxial. The cell pressure is 100 kPa, and the additional axial effective stress at failure is 125 kPa. No back pressure is applied during saturation or consolidation.

   You are asked to:

   a) Plot the Mohr circles for both the initial and failure stress conditions.

   b) Plot the Mohr-Coulomb failure envelope.

   c) Determine the strength parameters, c' and ϕ', for the sand.

   d) Determine the normal stress and shear stress on the failure plane at failure.

   e) Determine the angle of the failure plane in the specimen.

   f) Determine the maximum shear stress at failure and the angle of the plane on which it acts. Calculate the available shear strength on this plane

2. Test B is a direct shear test. The normal stress of 50 kPa is held constant during the test. The initial horizontal stress is 25 kPa. At failure, the normal stress is still 60 kPa and the shear stress is 45 kPa.

   You are asked to determine:

   a) Principal stresses at failure.

   b) Orientation of the failure plane.

   c) Orientation of the major principal plane at failure.

   d) Maximum shear stress at failure and the angle of the plane on which acts. Calculate the available shear strength on this plane and the factor of safety on this plane. Compare this values to your answer in 1.(f) above.

3. Of the two test results which ones do you trust the most. Describe the test steps in detail.

Question 4. Consolidation

20 Marks

1. A new building is to be constructed on the soil profile shown in **Figure Q4-1**, which is 2m of saturated sand above 8m of clay on fractured sandstone. A hydrostatic pore pressure regime was found with the water table at the surface. The new construction will provide an additional 100 kPa of stress at mid-height of the clay layer. You are asked to:

   a. Calculate and plot i) total stress, ii) porewater pressure, and iii) effective stress at depths of 0m, 2m, 4m, and 10m for: 1) before, 2) immediately after the 100 kPa is applied and 3) at time=infinity (assume that the load from construction is applied instantaneously).

   b. Calculate total settlement of the clay layer due to construction.

   c. How long with it take for 50% and 100% consolidation?

   d. Sketch a plot of settlement of time using the times you determined in question c.

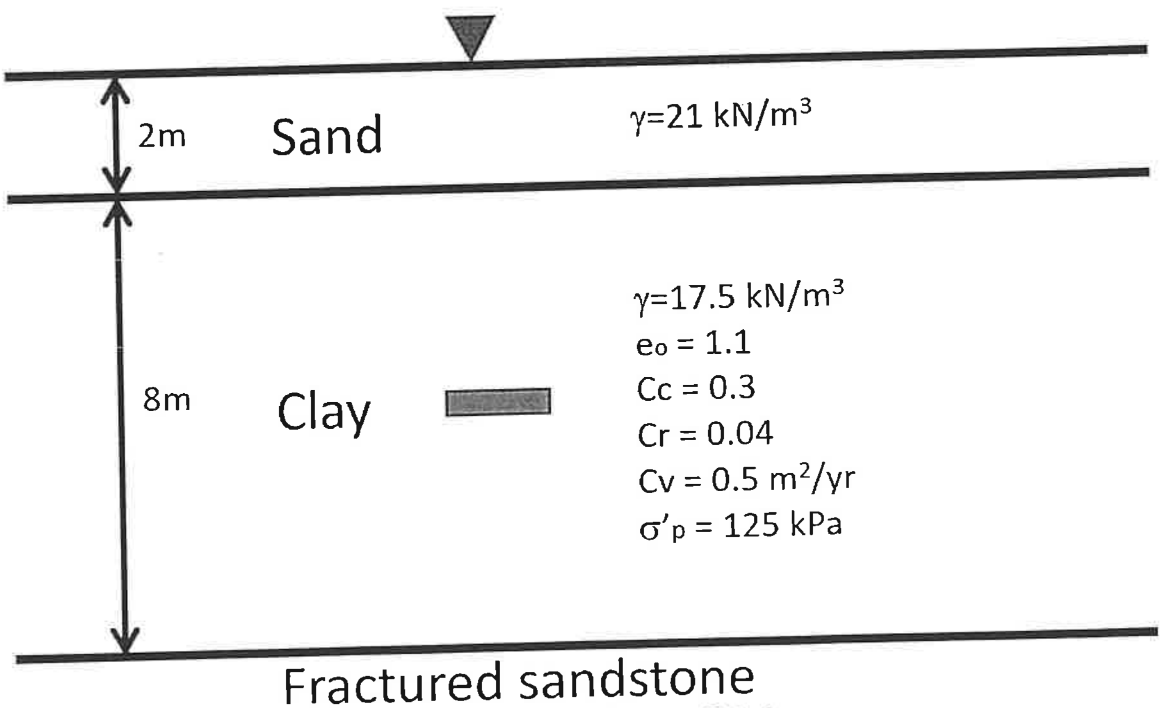


Figure Q4-1

2. For a different clay, an oedometer test was performed. The results are plotted in **Figure Q4-2**.

   You are asked to determine:

   a. Preconsolidation pressure

   b. Cc

   c. Cr

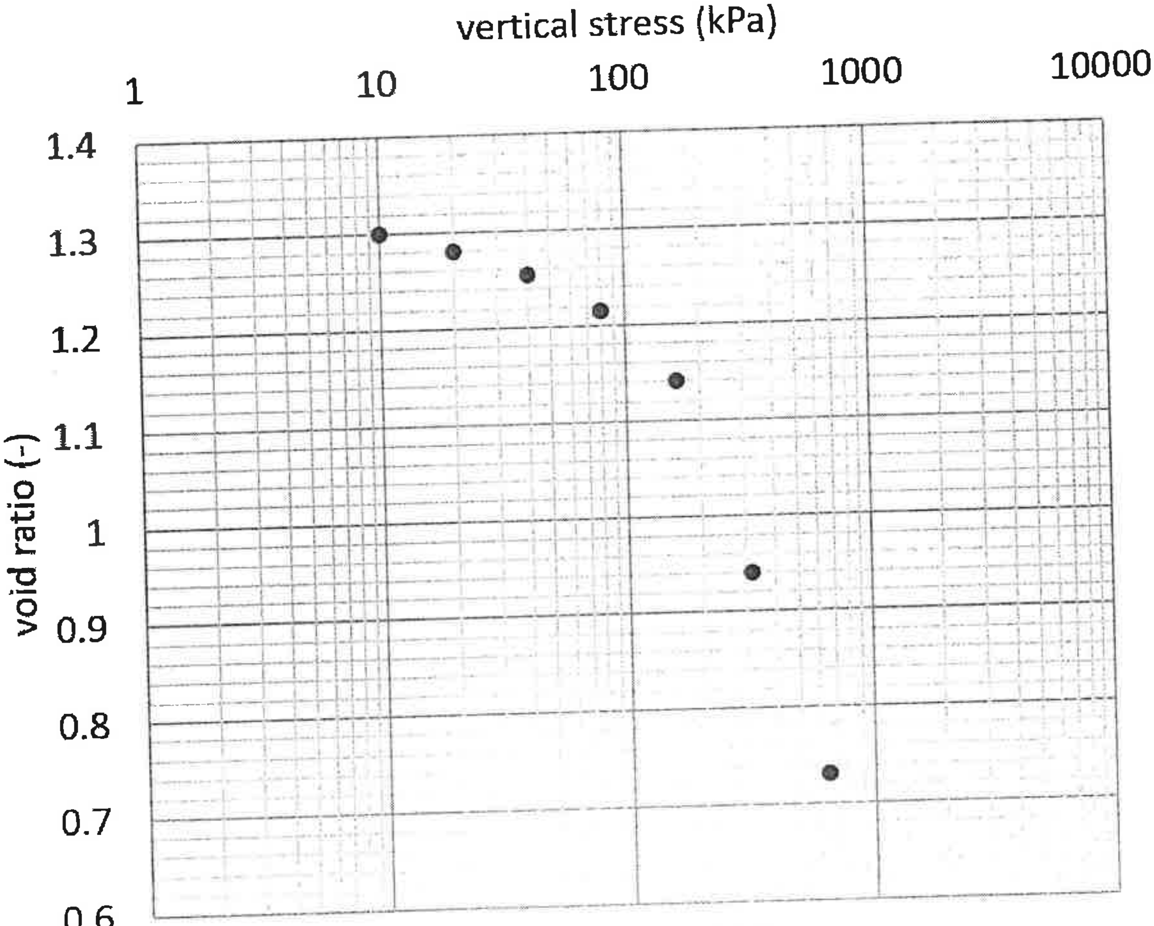


Figure Q4-2

3. What is the difference between an overconsolidated clay and a normally consolidated clay?

Question 5. Seepage

20 Marks

1. Two configurations are shown in **Figure Q5-1a** and **Figure Q5-1b** for a concrete dam constructed on a saturated homogeneous clay layer. The conductivity of the clay layer is 4x10-6 m/s.

   For BOTH **Figure Q5-1a** and **Figure Q5-1b** you are asked to:

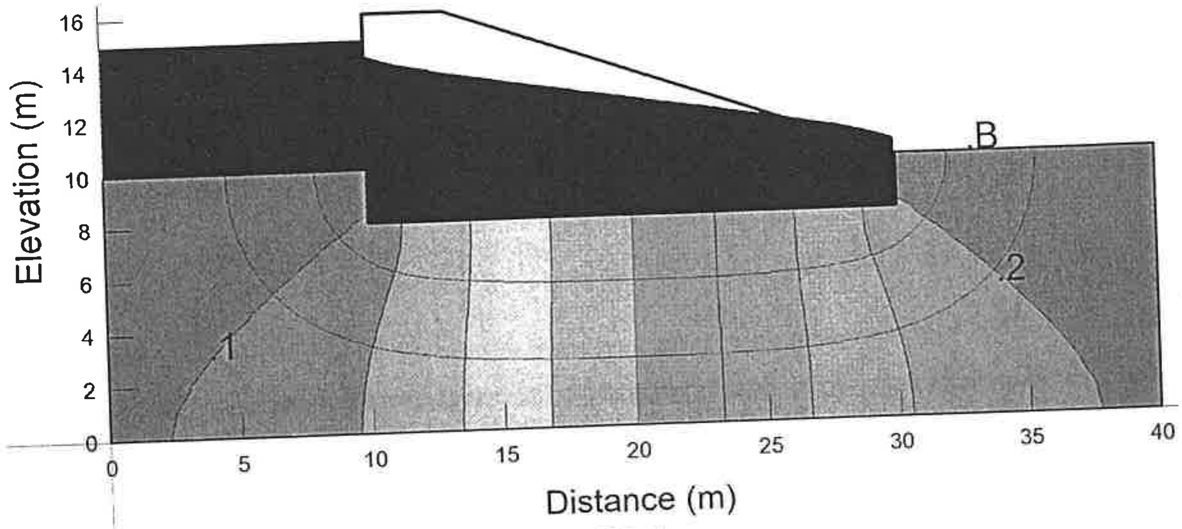
   a. Label the boundary conditions at A and B.

   b. Calculate total head, elevation head and pressure head for points 1 and 2.

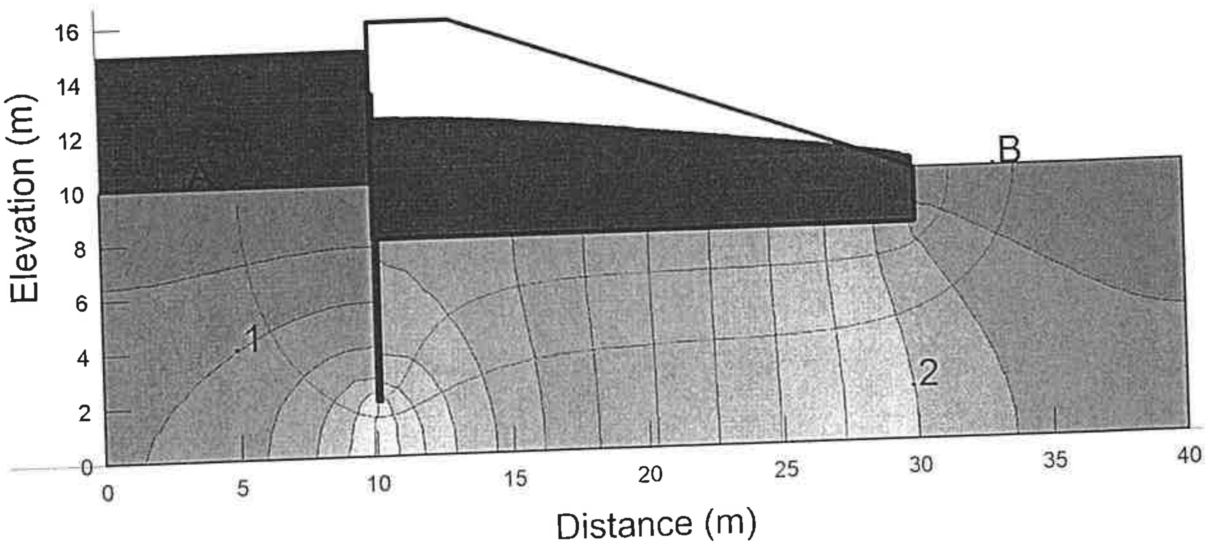
   c. Calculate the gradient between any two points. Show clearly where on the figures you are calculating the gradient.

   d. Plot the distribution of pore pressure head along the bottom of the dam.

   e. Without any calculation, which of the two dams is subject to the highest uplift forces? Why?



<u>**Figure Q5-1a**</u>.



<u>**Figure Q5-1b**</u>.

Optional Questions

Answer **three** of the **following five questions**. **Only** the **first three** answers will be marked.

5 Marks each

1) Write the equation for Darcy's Law and describe its components. Use a diagram to help explain your answer.

2) Draw the conceptual model for effective stress between two grains of sand and provide a brief derivation for the effective stress equation. Use a diagram to help explain your answer.

3) Describe capillary rise in a capillary tube and relate it to water retention curves for unsaturated soils. Use a diagram to help explain your answer.

4) You are an earthwork construction control inspector checking the field compaction of a layer of soil. When you conducted the sand cone test, the volume of soil excavated was 1165 cm^3. It weighed 2600 g wet and 1645 g dry.
   a) What is the field compacted dry density?
   b) What is the field water content?

5) Define the term groundwater table and plot the components of total head for the case of a 5 m thick sand layer with the groundwater table 1.5 m below the surface. Use a diagram to help explain your answer.

6) Soil behaviour is affected by water content. Describe the change in strength and stiffness of a clay soil based on its water content and relate it to consistency (Atterberg) limits.

7) A falling head test was performed on a soil. The soil specimen was 5 cm diameter and 10 cm tall. The head in the 5 mm diameter burette fell from 1.25 m to 1.15 m in 35 minutes.
   a) Calculate the conductivity of the soil in centimeters per second.
   b) What type of soil was being tested?

8) General questions on shear strength:
   a) Describe the difference between a consolidated-drained triaxial test and a consolidated-undrained triaxial test.
   b) What is the difference between undrained strength and drained strength?

USEFUL INFORMATION

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{(D_{30})^2}{D_{10}D_{60}}$$

$$N_{corrected} = 100\% \frac{N - N_{fines}}{100 - N_{fines}}$$

PI = 0.73(LL-20)

I_P = 0.73(w_L -20)

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$$I_L = \frac{w - w_P}{w_L - w_P}$$

$$Activity = \frac{w_L - w_P}{\%clay}$$

$$\rho_d = \frac{\rho_t}{(1+w)}$$

$\rho' = \rho_{sat} - \rho_w$

$$h_t = h_e + h_p = z + \frac{u}{\gamma_w}$$

$$i = \frac{\Delta h}{L}$$

$$v = ki$$

$$k = \frac{\gamma_w}{\eta}\overline{K}$$

$$v_s = \frac{v}{n}$$

$$q = vA = kiA$$

$$q = k\Delta h \frac{N_f}{N_d}$$

$$k = \frac{aL}{A\Delta t}\ln\frac{h_1}{h_2} = 2.3\frac{aL}{A(t_2 - t_1)}\log\frac{h_1}{h_2}$$

k =QL/hA

$$k_N = \frac{H}{\left(\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}\right)}$$

$$k_p = \frac{k_1H_1 + k_2H_2 + k_3H_3}{H}$$

$$p = \frac{\sigma_1 + \sigma_3}{2}$$

$$q = \frac{\sigma_1 - \sigma_3}{2}$$

Force → Newton (N) → 1 N = 1 kg m/s^2

Pressure → Pascal (Pa) → 1 Pa = 1N/m^2

→ 1 kPa = 1 kN/m^2

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$$

$$\tau_{rupt} = c' + \sigma' \tan\phi'$$

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

$\psi' = \arctan(\sin\phi')$ $\qquad a = c'\cos\phi'$

$T = \dfrac{c_v t}{H_{dr}^2}$ $\qquad c_v = \dfrac{k}{m_v \gamma_w}$

$$\Delta H = C_r\left(\frac{H_o}{1+e_o}\right)\log\frac{\sigma'_p}{\sigma'_{vo}} + C_c\left(\frac{H_o}{1+e_o}\right)\log\frac{\sigma'_{vf}}{\sigma'_p}$$

$T = \dfrac{\pi}{4}\left(\dfrac{U}{100}\right)^2$ $\qquad U < 60\%$

$T = 1.781 - 0.933\log(100 - U)$ $\qquad U > 60\%$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$\sigma_{ff} = (\sigma_{1f}+\sigma_{3f})/2-((\sigma_{1f}-\sigma_{3f})\sin\phi)/2$

$\tau_{ff} = \sigma_{ff}\tan\phi$

$\alpha_{ff} = 45° + \phi/2$

$N\phi = \sigma_{1f}/\sigma_{3f}$

$n = e/(1+e)$

$\psi' = \arctan(\sin\phi')$

$a = c'\cos\phi'$

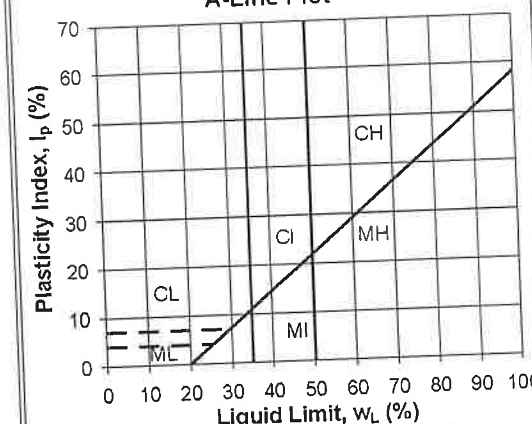
United Soil Classification System

Major division		Field identification procedures (Excluding particles larger than 75 mm and basing fractions on estimated mass)		Grp Sym	Typical names	Information required for describing soils	Laboratory classification criteria	
COARSE GRAINED SOILS (MORE THAN HALF OF MATERIAL IS LARGER THAN 75 µm)	GRAVELS (MORE THAN HALF OF COARSE FRACTION IS LARGER THAN 4.75 mm)	CLEAN GRAVELS (little or no fines)	Wide range in grain size & substantial amounts of all intermediate particle sizes	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GIVE TYPE; NAME, IF NECESSARY; INDICATE APPROX % OF SAND & GRAVEL; MAX. SIZE; ANGULARITY, SURFACE CONDITION & HARDNESS OF GRAINS; LOCAL OR GEOLOGIC NAME & OTHER PERTINENT DESCRIPTIVE INFORMATION; & SYMBOL IN PARENTHESES FOR UNDISTURBED SOILS ADD INFORMATION ON STRATIFICATION, DEGREE OF COMPACTNESS, CEMENTATION, MOISTURE CONDITIONS & DRAINAGE CHARACTERISTICS	DETERMINE PERDENTAGES OF GRAVEL & SAND FROM GRAIN SIZE CURVE. DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN 75 µm) COARSE GRAINED SOILS ARE CLASSIFIED AS FOLLOWS: $C_U = \frac{D_{60}}{D_{10}}$ $C_C = \frac{(D_{30})^2}{D_{10}D_{60}}$ LESS THAN 5%; GW, GP, SW, SP MORE THAN 12% GM, GC, SM, SC 5% TO 12% BORDERLINE CASES REQ. USE OF DUAL SYMBOLS (USE GRAIN SIZE CURVE IN IDENTIFYING THE FRACTIONS AS GIVEN UNDER FIELD IDENTIFICATION)	$C_U > 4; 1 < C_C < 3$
			Predominantly one size of a range of sizes with some intermediate sizes missing	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES			NOT MEETING ALL GRADATION REQUIREMENTS FOR GW
		GRAVEL WITH FINES (appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	GM	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES			ATTERBERG LIMITS BELOW A-LINE, OR $I_p<4$ — ABOVE A-LINE WITH I_p BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			Plastic fines (for identification procedures see CL below)	GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES			ATTERBERG LIMITS ABOVE A-LINE WITH $I_p>7$
	SANDS (MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN 4.75 mm)	CLEAN SANDS (little or no fines)	Wide range in grain size & substantial amounts of all intermediate particle sizes	SW	WELL GRADED SANDS, LITTLE OR NO FINES			$C_U > 6; 1 < C_C < 3$
			Predominantly one size of a range of sizes with some intermediate sizes missing	SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES			NOT MEETING ALL GRADATION REQUIREMENTS FOR SW
		SANDS WITH FINES (appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	SM	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES			ATTERBERG LIMITS BELOW A-LINE, OR $I_p<4$ — ABOVE A-LINE WITH I_p BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			Plastic fines (for identification procedures see CL below)	SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES			ATTERBERG LIMITS ABOVE A-LINE WITH $I_p>7$

IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN 425 µm

Major division			DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATENCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	Grp Sym	Typical names	Information required for describing soils
FINE GRAINED SOILS (MORE THAN HALF OF MATERIAL IS SMALLER THAN 75 µm)	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 35%	NONE	QUICK	NONE	ML	INORGANIC SILTS & SANDY SILTS OF SLIGHTLY PLASTICITY, ROCK FLOUR	GIVE TYPE; NAME, IF NECESSARY, INDICATE DEGREE & CHARACTER OF PLASTICITY, AMOUNT & MAXIMUM SIZE OF COARSE GRAINS, COLOUR IN WET CONDITION, ODOUR, IF ANY, LOCAL OR GEOLOGIC NAME & OTHER PERTINANT INFORMATION & SYMBOL IN PARENTHESES FOR UNDISTURBED SOILS AND INFORMATION ON STRUCTURE, STRATIFICATION, CONSISTENCY IN UNDISTURBED & REMOULDED STATES, MOISTURE & DRAINAGE CONDITIONS
			MEDIUIM TO HIGH	NONE TO VERY SLOW	MEDIUM	CL	SILTY CLAYS (INORGANIC), GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS	
			SLIGHT TO MEDIUM	SLOW	SLIGHT	OL	ORGANIC SILY OF LOW PLASTICITY, ORGANIC SANDY SILTS	
		LIQUID LIMIT BETWEEN 35% AND 50%	NONE TO SLIGHT	SLOW TO QUICK	SLIGHT	MI	INORGANIC COMPRESSIBLE FINE SANDY SILT WITH CLAY OF MEDIUM PLASTICITY, CLAYEY SILTS	
			HIGH	NONE	MEDIUM TO HIGH	CI	SILTY CLAYS (INORGANIC) OF MEDIUM PLASTICITY	
			SLIGHT TO MEDIUM	VERY SLOW	SLIGHT	OI	ORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	
		LIQUID LIMIT GREATER THAN 50%	SLIGHT TO MEDIUM	SLOW TO NONE	MEDIUM	MH	INORGANIC SILTS, HIGHLY COMPRESSIBLE MICACEOUS OR DIATOMACEOUS FINE SANDY SILTS, ELASTIC SILTS	
			HIGH TO VERY HIGH	NONE	HIGH	CH	CLAYS (INORGANIC) OF HIGH PLASTICITY, FAT CLAYS	
			MEDIUM TO HIGH	NONE TO VERY SLOW	SLIGHT TO MEDIUM	OH	ORGANIC CLAYS OF HIGH PLASTICITY	
HIGHLY ORGANIC SOILS			IDENTIFIED BY COLOUR, ODOUR, SPONGY FEEL & FREQUENTLY BY FIBROUS TEXTURE			PL	PEAT & OTHER HIGHLY ORGANIC SOILS	

A-Line Plot



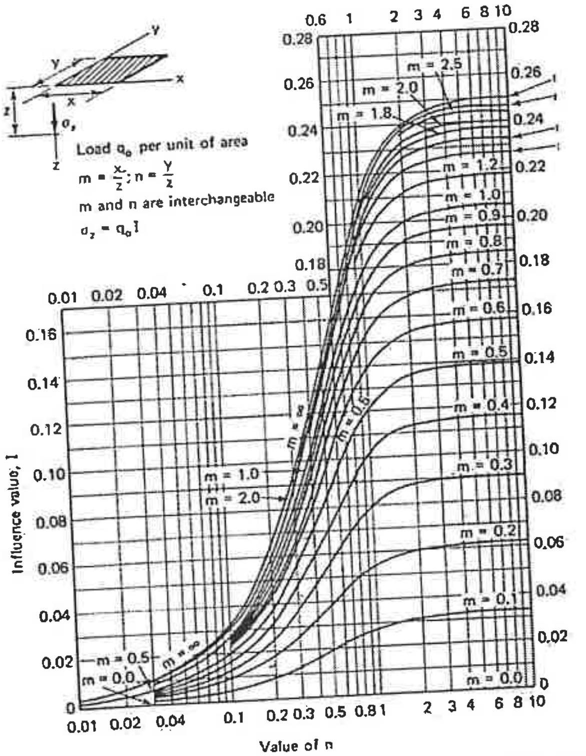


Fig. 8.21 Influence value for vertical stress under corner of a uniformly loaded rectangular area (after U.S. Navy, 1971).

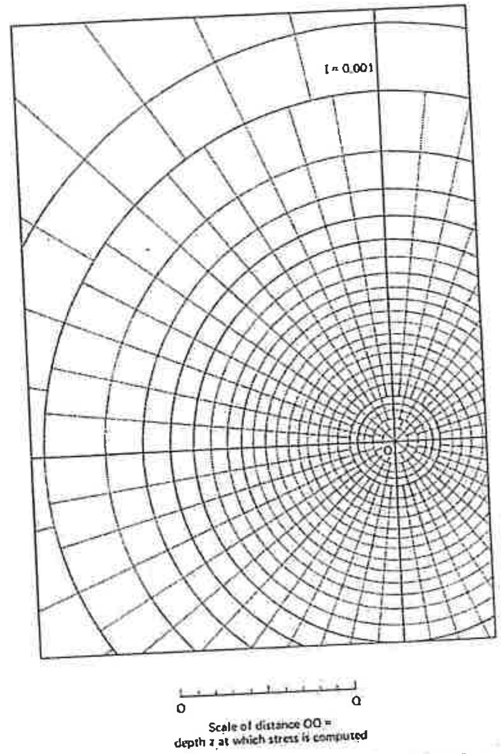


Fig. 8.25 Influence chart for vertical stress on horizontal planes (after Newmark, 1942).

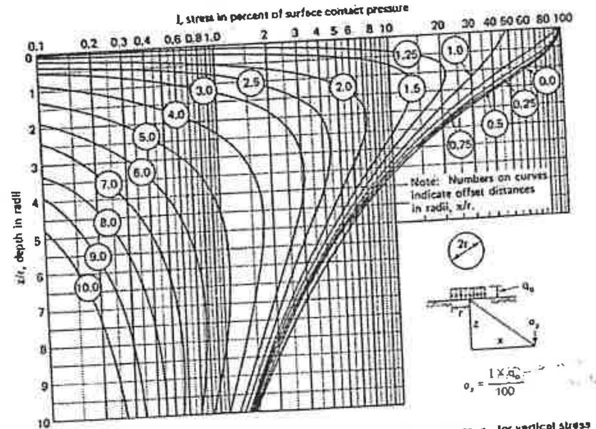
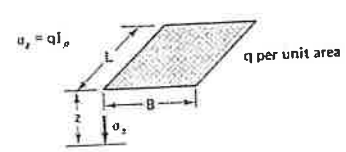


Fig. 8.22 Influence values, expressed in percentage of surface contact pressure, q_o, for vertical stress under uniformly loaded circular area (after Foster and Ahlvin, 1954, as cited by U.S. Navy, 1971).

TABLE 8-6 Influence Values for Vertical Stress Under Corner of a Uniformly Loaded Rectangular Area*



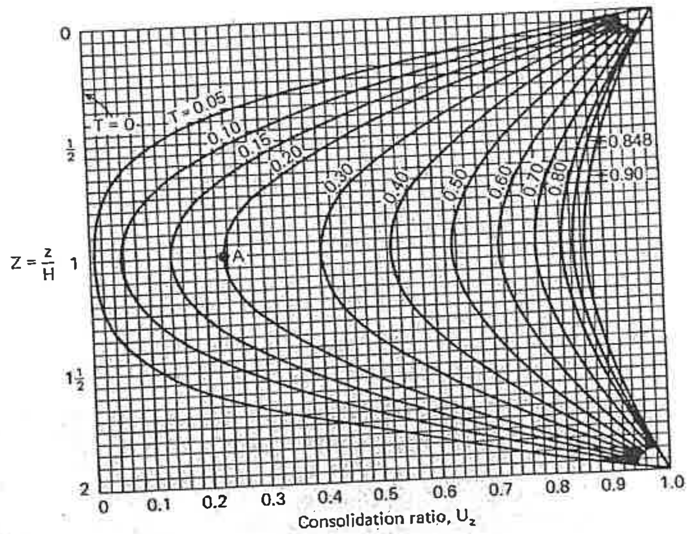
Boussinesq Case

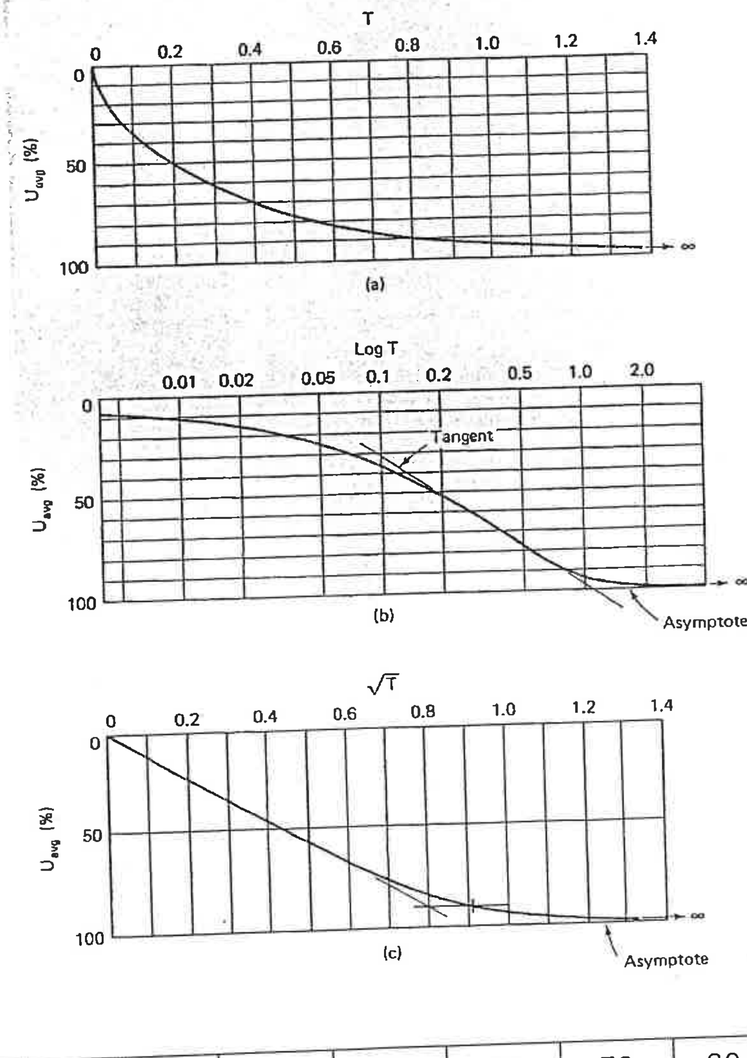
	L/z							
B/z	0.1	0.2	0.4	0.6	0.8	1.0	2.0	∞
0.1	0.005	0.009	0.017	0.022	0.026	0.028	0.031	0.032
0.2	0.009	0.018	0.033	0.043	0.050	0.055	0.061	0.062
0.4	0.017	0.033	0.060	0.080	0.093	0.101	0.113	0.115
0.6	0.022	0.043	0.080	0.107	0.125	0.136	0.153	0.156
0.8	0.026	0.050	0.093	0.125	0.146	0.160	0.181	0.185
1.0	0.028	0.055	0.101	0.136	0.160	0.175	0.200	0.205
2.0	0.031	0.061	0.113	0.153	0.181	0.200	0.232	0.240
∞	0.032	0.062	0.115	0.156	0.185	0.205	0.240	0.250

Westergaard Case

	L/z							
B/z	0.1	0.2	0.4	0.6	0.8	1.0	2.0	∞
0.1	0.003	0.006	0.011	0.014	0.017	0.018	0.021	0.022
0.2	0.006	0.012	0.021	0.028	0.033	0.036	0.041	0.044
0.4	0.011	0.021	0.039	0.052	0.060	0.066	0.077	0.082
0.6	0.014	0.028	0.052	0.069	0.081	0.089	0.104	0.112
0.8	0.017	0.033	0.060	0.081	0.095	0.105	0.125	0.135
1.0	0.018	0.036	0.066	0.089	0.105	0.116	0.140	0.152
2.0	0.021	0.041	0.077	0.104	0.125	0.140	0.174	0.196
∞	0.022	0.044	0.082	0.112	0.135	0.152	0.196	0.250

*After Duncan and Buchignani (1976).





U%	10	20	30	40	50	60	70	80	90	100
T	.008	.031	.071	.126	.197	.287	.403	.567	.848	1.125