1957 - 1958

HARVARD UNIVERSITY

Engineering 261a

Please read each question carefully before writing your answer ! !

1. (a) For a partially saturated soil are known its void ratio e, its water content w, and the specific gravity of the solids s_s. By means of an appropriate sketch, derive a formula for the degree of saturation G_w in terms of the known quantities.

   (b) Express the unit weight of this soil as a function of w, s_s and G_w.

2. In the attached table are listed names of soils. Fill in the blank spaces with representative data.

3. Explain why handling of moist sand causes it to assume a larger volume than the loosest volume in the dry or completely saturated state. By what name is this phenomenon commonly known? What happens if such sand later becomes fully saturated?

4. In a pipette test the following observations were made:

   Total volume of suspension = 1000 cubic cm
   Total dry weight in test = 50 grams
   Specific gravity of solid = 2.83
   Viscosity and density of water at test temperature of 17° C:

   $\eta = 1.10 \times 10^{-5}$ g. sec. cm^{-2}
   $\gamma_w = 0.999$ g. cm^{-3}

   After 9 minutes, 100 cubic cm of the suspension was siphoned off from a depth of 20 cm, and the dry weight contained therein determined by evaporation to be 1.2 grams.

   (a) Compute from these data the equivalent grain diameter and the percentage finer than this diameter.

   (b) Explain why it is or is not permissible to assume $\gamma_w = 1.0$ in Stokes' Law.

$$v = \frac{2}{9} \cdot \frac{\gamma_s - \gamma_w}{\eta} \cdot \left(\frac{D}{2}\right)^2$$

5. (a) State Darcy's law in words.

(b) A constant head permeability test on a sand yields the following data:

length of sample:	15 cm
diameter of sample:	4 cm
difference in head:	75 cm
discharge in 2 minutes:	100 cm^3
void ratio of sample:	0.65

Compute the coefficient of permeability from these data and then compute k for a void ratio of 0.75. State clearly the units in which k is expressed.

(c) Express the result in terms of ft/min.

6. (a) List the stages of consistency and their limits which Atterberg established.

(b) Explain in one brief sentence the reason why the liquid and plastic limits have a practical significance in soils engineering.

7. Starting from Darcy's equation, prove that when water is drawn by capillary forces horizontally through a dry soil sample, the rate of travel of the surface of wetting is inversely proportional to the distance already traveled.

8. (a) List the basic assumptions on which Terzaghi's theory of consolidation is based.

(b) By means of a clearly drawn sketch, show how in a laboratory consolidation test the stresses in the soil skeleton and in the pore water are distributed for 50% primary consolidation throughout the thickness of the test specimen.

(c) On this stress distribution curve, indicate two points corresponding to the entrance and exit surface of an element of thickness dz, and derive an equation which gives the amount of water that is squeezed from this element of thickness in the time element dt, assuming that the soil is 100% saturated and follows Darcy's law. State whether in your equation the volume decrease is a positive or negative quantity, and show that the sign in the right-hand side of the equation is the same.

(d) The expressions "a clay is not yet consolidated" and "a clay is fully consolidated" are often understood by engineers not trained in soil mechanics to mean that the "fully consolidated" clay is a much firmer or stiffer clay than the clay that "is not yet consolidated", or that a "consolidated clay" will cause less settlements than another clay that is "not yet consolidated." Your comments are invited.

9. (a) Define in one sentence the meaning of Mohr's stress circle.

   (b) Define in one sentence Mohr's rupture envelope. Explain the theory of failure on which this line is based.

   (c) Explain in one sentence the difference between stress circle and strength circle.

   (d) If an element in a mass is exposed to known principal stresses, to what extent are the stresses on different planes in this element dependent on the properties of the material?

10. A simple type of triaxial test on fine sand can be performed by utilizing capillary pressure. A saturated specimen is compacted inside a split mold and to the bottom is connected a U-shaped hose with the water level 100 cm below the test specimen. Then the jacket is removed and a compression test is performed. The specimen fails under an applied axial stress of 0.25 kg/cm^2. Using effective stresses, plot Mohr's circle for the failure condition, and compute the angle of internal friction.

Final, January 17, 1958

Engineering 261a | HOUR EXAMINATION | December 4, 1956

Question 3

Description of Soil	AC Group Symbols	Dry Strength	Reaction to Shaking Test	Consistency Near Plastic Limit	One Representative Set of Values		
					Liquid Limit	Plastic Limit	Shrinkage Limit
Typical Rock Flour							
Inorganic Clay of Low Plasticity							
Typical Kaolin Clay							
Highly Plastic Very Tough Clay							
Peat							

Soil Mechanics 4

HARVARD UNIVERSITY

Engineering 261a

March 31, 1965

1. Derive the formulas for the dry unit weight (weight of solids per unit of volume) and the degree of saturation of a compacted clay specimen in terms of the following measured quantities:

   Wet weight of specimen
   Water content of specimen
   Volume of specimen
   Specific gravity of solids.

2. A 20 ft thick gravel stratum overlies a 20 ft thick, normally consolidated clay stratum, which in turn is underlain by sand. The normal ground water level in the gravel stratum is at a depth of 5 ft below the ground surface; and it is then permanently lowered by 10 ft, i.e. to a depth of 15 ft below ground surface. The gravel has a porosity of 35%, a specific gravity of 2.66, and it may be assumed that only a negligible amount of water is held in the voids of the drained zone of the gravel.

   (a) Compute the effective stresses at the top and at the bottom of the clay stratum before the drawdown, and the loading of the clay stratum which results from the drawdown of the groundwater table. Assume a unit weight of the clay of 100 lb/cu ft.

   (b) Illustrate by separate sketches the gradual changes in the effective stress and in the neutral stress as the clay stratum consolidates as a result of the groundwater lowering.

3. (a) List the stages of consistency and their limits which Atterberg established.

   (b) Explain in one brief sentence the reason why the liquid and plastic limits have a practical significance in soils engineering.

4. (a) With the aid of an appropriate sketch, derive a formula for the shrinkage limit in terms of the following measured quantities:

    (1) weight of oven-dried specimen,

    (2) volume of oven-dried specimen,

    (3) specific gravity of solids.

   (b) How does this method of computing the shrinkage limit differ from the shrinkage limit as defined by Atterberg?

   (c) State in one sentence why the shrinkage limit is of little value as a supplement to the liquid and plastic limits in classifying soils.

5. (a) By what names are the following equations known

$$q = C.i.a^2 \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$q = k.i.A \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

   and what is the meaning of each of the quantities appearing in these equations?

   (b) Explain the apparent discrepancy between these two equations, considering that "a" in (1) appears in the second power, whereas "A" in (2) appears in the first power.

6. Make a sketch of a plasticity chart with the scales and the A and U lines drawn with reasonable care. Then indicate on this chart a typical location for the following materials, using for abbreviations the numbers listed below. For each material also indicate the group symbol of the U.S. classification system.

   (1) An inorganic clay of low toughness and low to medium dry strength.

   (2) An inorganic clay having great toughness and high dry strength.

   (3) A white clay of low toughness and low dry strength.

(Question 6 continued on next page)

9. The following data were obtained from a laboratory consolidation test on a clay specimen:

$$p_1 = 1.0 \text{ kg/sq cm} \qquad e_1 = 1.45$$

$$p_2 = 2.0 \text{ kg/sq cm} \qquad e_2 = 1.16$$

From the time curve for this load increment the average coefficient of permeability was computed as $k = 12 \times 10^{-9}$ cm/sec.

(a) Assuming that on a semi-log plot this load increment lies on the straight-line portion of the virgin-compression curve, compute the equation expressing the e-p relationship for this clay specimen.

(b) How long will it take for a 20 ft layer of this clay, which is drained only on its top surface, to reach 50% consolidation?

(c) Without any additional information, compute the time required to reach 20% consolidation.

10. Make a comparison of the following two clay strata:

The surface of clay stratum A is at a depth of 10 ft and it is 20 ft thick. Its natural water content is approximately equal to the plastic limit. The liquid limit is 80 and the plastic limit 25.

The surface of clay stratum B is also at a depth of 10 ft, and its thickness is also 20 ft. It has a natural water content of 40%, a liquid limit of 40 and a plastic limit of 23.

(a) On the basis of this information, is it possible to state which of these two clay strata probably will cause greater settlements under equal loading? Explain.

(b) Is it possible that both strata are normally consolidated under the present overburden? Explain.

Soil Mechanics I

1954–55

HARVARD UNIVERSITY

ENGINEERING 261a

Please read each question carefully before writing your answer.

1. In the appended Fig. 1 is shown an excavation into pervious ground. To lower the water table in the excavation, it is proposed to drive a steel sheet-pile wall into a relatively impervious silty sand stratum, as shown in Fig. 1, thus enclosing by this cut-off a rectangular area 400 ft x 600 ft. Inside this enclosure the water level will be lowered three feet below the excavation level. Since the head of water in the pervious sand underlying the fine silty sand will remain the same as the normal ground water surface, there will be continuous seepage from the lower pervious sand through the silty sand into the excavation area, and the pumping system must be dimensioned accordingly.

   (a) Assuming a coefficient of permeability of the silty sand of 0.1×10^{-4} cm/sec, and neglecting the local deviations from one-dimensional seepage which would develop around the bottom of the cut-off wall, *compute* the required pumping capacity in order to maintain the lowered water level in the excavation area.

   (b) *Plot in Fig. 1 the distribution of effective and neutral stresses* below the bottom of the excavation. Assume a vertical line sufficiently far removed from the cut-off, to assure for practical purposes one-dimensional seepage. Give the *numerical values* for the effective and neutral stresses at the *top* and at the *bottom* of the fine silty sand stratum.

2. By means of a void ratio-pressure diagram and the curve of potential maximum capillary pressure as function of the void ratio, explain the physical significance of the shrinkage limit.

3. Explain why the grain size curve of a fine-grained soil is of little value for classification purposes.

4. (a) State the principal reasons why the observed time-settlement curve of a structure which is built on a compressible clay stratum will hardly ever permit differentiation between the primary and the secondary compression.

   (b) What means must we employ in order to observe the progress of primary consolidation within the clay stratum?

5. By means of appropriate sketches, *explain the meaning* of each of the following equations, including each member:

$$(1)\ c_v \cdot \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t}$$

$$(2)\ U_z = f\left(\frac{z}{H}, T\right)$$

$$(3)\ U = F(T)$$

$$(4)\ T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$

$$(5)\ e = e_c - C_c \log \frac{p}{p_0}$$

6. (a) *List the simplifying assumptions* on which Terzaghi's theory of consolidation is based.

   (b) *Which* of these assumptions may cause the *greatest deviations* from the theory?

   (c) Order the following materials according to *decreasing accuracy* with which the *coefficient of permeability* can be *computed* from time curves obtained in consolidation tests:

   (1) Rock flour

   (2) Organic Clay, undisturbed

   (3) Highly sensitive, inorganic clay, undisturbed

   (4) Remolded inorganic clay

   (5) Peat

   (d) If for any of the soils listed above the coefficient of permeability cannot be determined with reasonable accuracy by computation from the results of consolidation tests, state the reasons.

7. Explain by means of the definition for the Time Factor, how a change in each of the following variables affects the primary time lag of a clay stratum:

   (a) Distribution of drainage surfaces within the clay stratum

   (b) Coefficient of permeability

   (c) Coefficient of consolidation

   (d) Magnitude of applied load.

8. (a) A compacted, isotropic, granular material has a *curved strength envelope* which goes through the origin, i.e. $c = 0$. Show by means of a carefully drawn sketch how you would obtain the *compressive strength* of a cylindrical specimen which at the start of the test is subjected to a confining pressure σ_3.

   (b) *Show* in this sketch the *angle* α_f between the plane of the major principal stress and the failure planes.

   (c) *Derive* from this sketch an expression for the *friction angle* which is effective along the failure planes, *in terms of the angle* α_f.

6. (Continued)

(4) A dark-gray clayey soil for which it takes a long time to reach the plastic limit, with the threads at the plastic limit being very soft and friable, having low dry strength, and which shows a substantial drop in plasticity due to oven-drying.

(5) A reddish clayey soil from Hawaii (or Java, or some other volcanic area), having low toughness, low dry strength, and which shows a substantial drop in plasticity due to oven-drying.

(6) A slightly plastic, highly micaceous, sandy soil having soft and spongy threads at the plastic limit and very low dry strength.

(7) A very sandy clay with considerable toughness and high dry strength.

(8) Mica powder, ground in a ball mill to approximately one micron size.

(9) Dark gray, waxy, non-cemented clay-shale (e.g. Bearpaw shale).

7. (a) Define in one sentence the meaning of Mohr's stress circle.

(b) If an element in a mass is exposed to known principal stresses, to what extent are the stresses on different planes in this element dependent on the properties of the material?

8. (a) Explain why the observed time-settlement curve of a structure founded on clay will hardly ever permit differentiation between primary and secondary compression.

(b) If the settlement curve does not permit such differentiation, what other observations can we undertake to permit this differentiation?

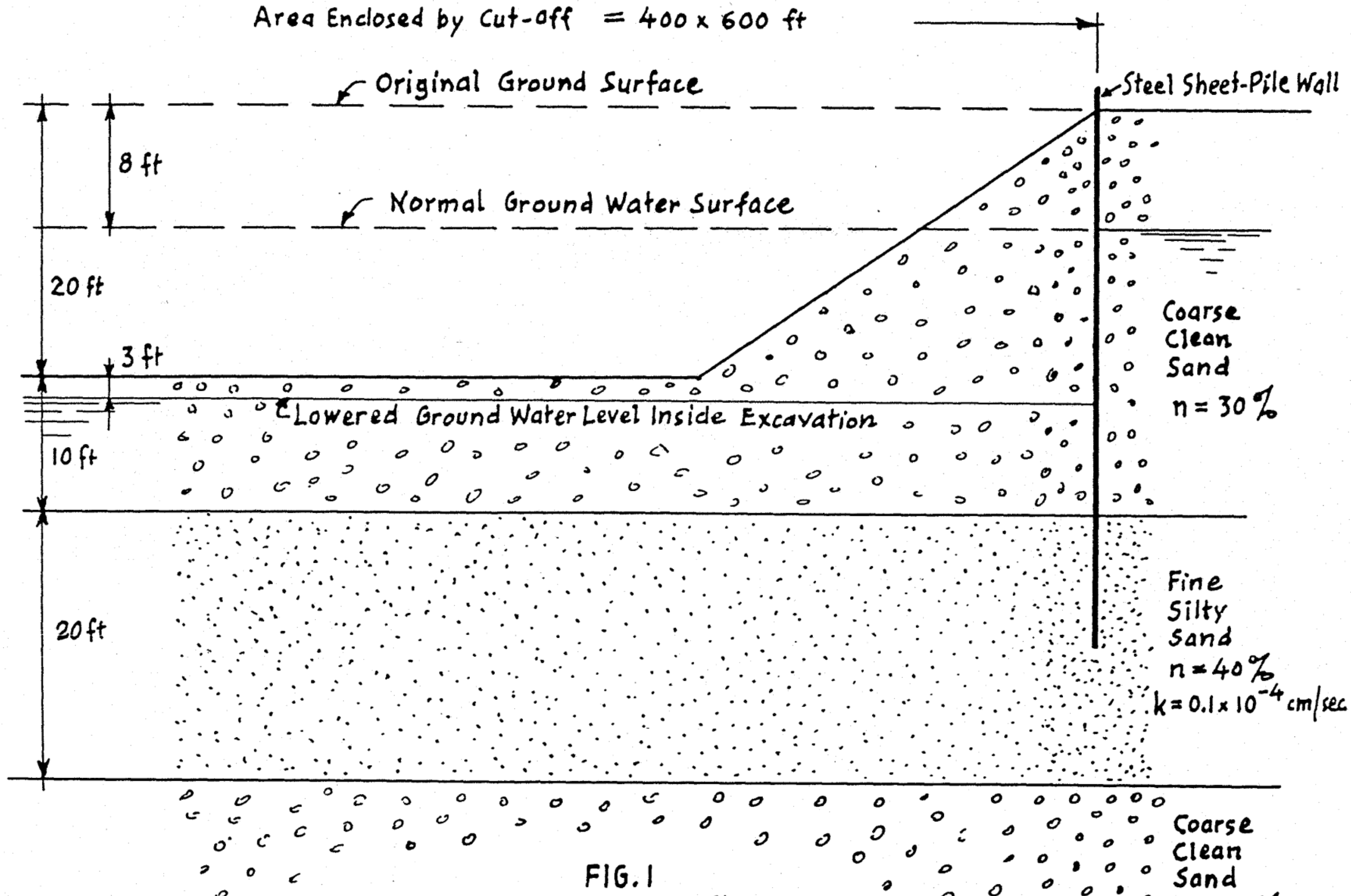


FIG. 1
Scale 1in. = 10 ft

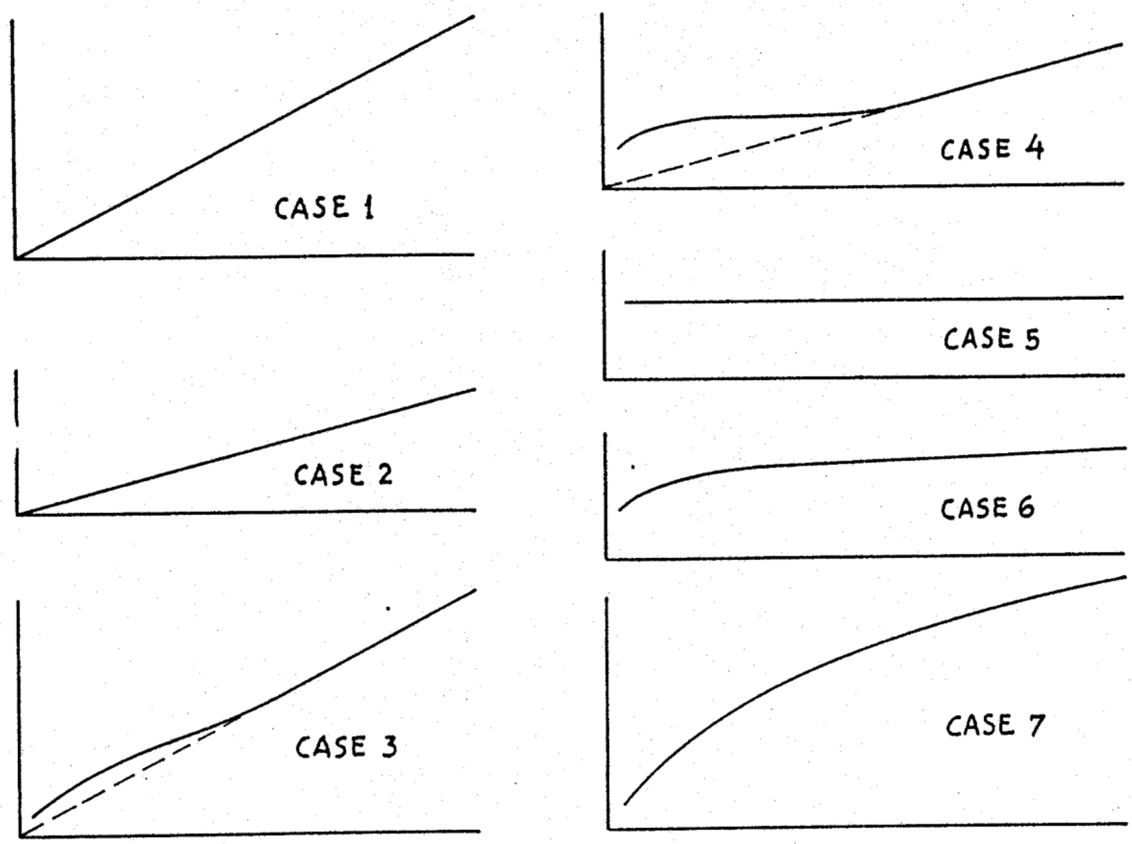


FIG. 2

9. In Fig. 2 are shown the strength envelopes obtained by means of triaxial compression tests on various clay materials.
State briefly for what type of clay material and for what type of test each strength curve is representative.

10. A series of triaxial compression tests on a given material yields a *straight-line envelope* which can be expressed by the equation

$$s = c + p.\tan \phi.$$

It is customary to assume that this line represents the relationship between normal stress and shear strength for this material. State the *two conditions* which the physical properties of this material *must fulfill* in order to *justify* the *above assumption.*

Final. January, 1955.

Soil Mechanics II

1968 - 1969

HARVARD UNIVERSITY

Engineering 261b

Final Examination May 24, 1969

1. (a) Certain soils that differ radically in their geologic origin and composition, have in common the property of "collapsible structure", i.e. they develop large settlements when they become saturated. Name and describe very briefly at least two types of soils that fall into this category.

   (b) Marl and Caliche are deposits which have in common

      (1) a certain easily identifiable ingredient, and

      (2) lack of clearly defined textural composition.

   Explain each point in one short sentence.

2. The relative position on the plasticity chart of "undried", "airdried" and "ovendried" specimens of highly overconsolidated organic clays (and clay-shales) is quite different from those of normally consolidated organic clays. Show these relative positions in an appropriate sketch and explain briefly the reason for the difference.

3. (a) By means of Mohr's circle, derive formulas for the active and passive earth pressure of a cohesionless soil against a vertical wall with horizontal fill surface, assuming a perfectly lubricated wall surface, i.e. a wall friction angle of zero.

   (b) According to the classical earth pressure theories (Coulomb and Rankine) the earth pressure always has a triangular distribution. Is it possible to obtain the same total earth pressures which you computed above with other than a triangular distribution of the earth pressure? By what name is the mechanism known which makes possible such variations? Illustrate this mechanism by means of a sketch. How did Terzaghi achieve such variations in his large earth pressure tests?

4. A gravity-type retaining wall with a vertical back and a height h = 20 ft, is backfilled with a fine silty sand. For the two cases described below, show the distribution of earth pressure and water pressure against the wall. Assume:

   (1) angle of internal friction of backfill ϕ = 32 degrees;

   (2) saturated unit weight of backfill material 125 lb/cu ft;

   (3) wall friction angle δ = zero.

Question 4 cont'd on page 2

(OVER)

4. (continued)

Case I - During a period of heavy rainfall the backfill is fully saturated, with a thin layer of water accumulated on top of the backfill (which eliminates capillary forces), and with the water draining downward into a clean sand stratum underlying the backfill. Assume the groundwater level is at the elevation of the surface of the clean sand stratum.

Case II - The same assumptions as for Case I, except that the backfill is underlain by a stratum of impervious soil. The excess rainwater drains away on the surface of the backfill.

5. (a) The classical earth pressure theories may lead to unsafe designs when applied to most types of modern structures. Explain briefly by means of a typical example.

   (b) Show by means of an appropriate sketch, but without any mathematical derivations, how Rendulic adapted the Engesser method for determining the horizontal forces which a granular embankment exerts upon a soft foundation.

6. For a mine development beneath a lake, clay is excavated hydraulically over the area where the rock is to be exposed. Then the lake is drained, so that the cut slopes in the clay are exposed to a "sudden drawdown condition". With the aid of force polygons for the conditions just before and immediately after drawdown, demonstrate that the mobilized shearing resistance after drawdown will be at least twice as great as before drawdown.

7. Discuss whether the Swedish method of stability analysis is applicable for:

   (a) a highly overconsolidated, very brittle clay containing joints,

   (b) a highly overconsolidated, intensely slickensided clay or clay-shale,

   (c) a normally consolidated, stratified clay containing layers of rock flour,

   (d) a normally consolidated clay of low sensitivity.

8. Assume that a 30 ft deep canal is excavated "in the dry" in a homogeneous clay stratum extending to great depth. The canal slopes are 1 on 2, and the bottom width of the canal is 150 ft. Show by means of appropriate sketches the shape and position of the critical sliding surface, and state the required shear strength for a factor of safety of unity, using

   (1) the solution by Fellenius

   (2) the Prandtl formula.

Question 8 cont'd on page 3

8. (continued)

To use the Prandtl formula, one neglects the shear strength along a certain portion of the potential sliding surface which explains in part the difference between the two solutions. Indicate in your sketches that portion of the sliding surface.

9. At different sites friction piles are driven into (I) a normally consolidated clay, and (II) into highly overconsolidated clay which is many times stronger than the normally consolidated clay. Several weeks after driving these piles, they are subjected to load tests, and it is observed that both piles develop approximately the same bearing capacity per unit of embedded area. Explain this apparent anomaly.

10. (a) Name the four principal methods for determining the bearing capacity of piles and state the limitations for each method.

(b) Derive the Engineering-News Formula.

(c) What modification of this formula was introduced in the revision of the Boston Building Code?

1967 - 1968

HARVARD UNIVERSITY

Engineering 261b

1. Describe briefly the three types of triaxial tests which are essential for a complete analysis of the strength characteristics of a clay.

2. Plot typical deviator stress vs axial strain and induced pore pressure vs axial strain curves obtained from triaxial $\bar{R}$ tests performed on 100% saturated specimens of

   a) a highly contractive soil

   b) a dilative soil.

   Plot the curves in such a manner that similarities or differences between these two soils will be clearly illustrated.

3. a) Derive by means of Mohr's stress circle a formula for the active earth pressure of a clean sand against a vertical retaining wall of height H, with horizontal backfill, and assuming zero friction between the back of the wall and the sand.

   b) If the active earth pressure in (a) is produced by yielding of the wall, what would be the actual inclination of the earth pressure? By means of the Engesser method, show whether the magnitude of this inclined earth pressure is greater or smaller than the horizontal earth pressure with zero wall friction.

4. Briefly describe how arching is influencing magnitude and distribution of earth pressure in dry sand, using for illustration:

   a) Trench excavation which is progressively sheeted and braced as the trench is deepened;

   b) Box-sheeted pit.

5. State simple formulas for computing the ultimate bearing capacity per unit of area for a strip footing resting on the surface of:

   a) An ideally cohesive-plastic material;

   b) A cohesionless sand.

   Explain why the width of the footing and the unit weight of the soil influence the bearing capacity of only one of these two types of soils.

6. An excavation is to be made into a 75 ft thick stratum of soft clay which has a shear strength of 0.15 tons per square foot. For each of the following cases compute or estimate the depth of the cut at which failure may occur, and illustrate in a sketch the probable shape of the sliding surface and the center of rotation:

   a) Vertical cut;

   b) A slope having a 50-degree angle with the horizontal;

   c) A slope having a 30-degree angle with the horizontal.

7. When analyzing slope stability by means of the friction circle procedure, one can express the result as follows:

$$\text{Factor of Safety} = \frac{F \cdot \bar{r} + C_{max} \cdot \bar{R}}{\text{overturning moment}}$$

   a) Show by means of a clearly drawn sketch how this expression is arrived at. You may explain the meaning of $\bar{R}$ and $\bar{r}$ in words, without mathematical derivation.

   b) State what assumptions are made concerning the maximum possible shearing resistance which can be mobilized along the sliding surface.

   c) How would the above expression change if one assumes a purely cohesive material and expresses the overturning moment as a function of the shear strength required for equilibrium?

8. a) Sketch the deflection of a perfectly flexible mat which is uniformly loaded and which rests on the surface of:

   1) Sand,

   2) Clay.

   b) Sketch the pressure distribution (soil reaction) acting against the bottom of a rigid footing resting on the surface of:

   1) Sand,

   2) Clay.

   c) As compared with the pressure distribution in (b), how will the pressure distribution differ for a bridge pier founded at substantial depth below the ground surface? How may the method of construction affect this distribution? What simple distribution is usually an acceptable assumption for design purposes?

9. a) Explain how one can use the unconfined compressive strength or triaxial Q strength of a clay for computing the ultimate bearing capacity of a friction pile driven into a clay stratum.

   b) Explain why this method leads to satisfactory results for normally consolidated clays, but to unsafe results for overconsolidated clays.

   c) Discuss the value of dynamic pile driving formulas for determining the bearing capacity of friction piles driven into clays.

10. Considering the complexities of soil conditions and properties and the serious limitations of theories which we use in applied soil mechanics, what guide rule should a practicing soils engineer adopt when designing a foundation or earthwork project.

Final Examination
May 22, 1968

1966 - 1967

HARVARD UNIVERSITY

Engineering 261ab

1. Two identical triaxial specimens of dense, fully saturated sand are subjected to S and $\bar{R}$ tests, respectively.

   a) In one diagram plot the following three curves and label them clearly:

      i) deviator stress vs axial strain for S test;
      ii) volume change vs axial strain for S test;
      iii) deviator stress vs axial strain for $\bar{R}$ test.

   b) Plot the total and effective stress circles and the vector curve for the $\bar{R}$ test.

   c) Estimate the true friction angles for the densest and loosest states for the following materials:

      i) Ottawa Standard sand;
      ii) typical concrete sand consisting of subangular grains;
      iii) well-graded crushed rock.

2. a) State the assumptions concerning (1) state of stress in backfill, (2) shape of failure surface, (3) distribution of earth pressure against retaining wall, and (4) direction of earth pressure, on which Coulomb's earth pressure theory is based.

   b) Can a state of active earth pressure exist without fulfillment of assumption (3)? Explain.

   c) How does Rankine's earth pressure theory differ from Coulomb's theory?

3. The classical earth pressure theories (i.e., those by Coulomb and Rankine) may lead to unsafe designs when applied to many types of modern structures. Explain by means of a typical example.

4. a) What basic assumption was made by Rendulic concerning the horizontal thrust that an embankment of granular soil will exert upon a soft foundation?

   b) With an appropriate sketch show how Rendulic has used the Engesser method for determining this thrust.

5. For short-term stability of a vertical cut, state or derive simple formulas for the critical height for each of the soils described below:

   a) Soft clay with low sensitivity.
   b) Hard, brittle clay with numerous vertical joints.

6. By means of a carefully drawn sketch, explain the friction circle procedure for analyzing the stability of a slope.

7. In his lecture, John Lowe recommended use of R tests with anisotropic consolidation (ACU test) for drawdown analysis of the upstream slope of earth dams.

   a) With the help of a Mohr diagram, explain why use of anisotropically consolidated R tests would more correctly reflect the stress conditions along a potential sliding surface in a clay slope subjected to rapid drawdown.

   b) Conventional factors of safety for drawdown analysis (as recommended for example in the Corps of Engineers' Manual) are based on the use of isotropically consolidated R tests. Would you consider it reasonable to apply the same factors of safety when using test results from R tests with anisotropic consolidation? If not, would you increase or decrease the required factor of safety, and why?

8. A shopping center, consisting of light one-storey buildings, is to be built on low-lying land with the ground water close to the ground surface. Borings, which were extended to a depth of 30 ft below original ground surface, disclosed only loose sand. To prepare a foundation that would be suitable for spread footings, and to increase the depth to ground-water, the area was covered with 5 ft of sand and gravel

fill which was well compacted.

Already during construction of the buildings substantial irregular settlements have developed, and they keep increasing in the course of years, forcing costly repairs to the buildings.

a) What is the probable cause of these settlements?

b) In what respect was the designer of the foundations negligent?

9. For a building foundation, wood piles were driven through 80 ft of soft, sensitive clay and about 10 ft into the underlying sand stratum. The driving resistance through the clay was small and in the sand it gradually increased to the specified final resistance of 20 blows for the last six inches, using a single-acting steam hammer delivering 15,000 ft lb per blow. A load test, carried out on a test pile two weeks after it was driven, showed a permanent settlement of only 0.2 in. under the maximum test load of 60 tons. Based on this test, a design load of 30 tons was proposed by the engineer and was approved by the Building Department.

In the course of years the building settled several inches, with irregular differential settlements, which caused substantial damage to the building.

a) Explain the cause of the settlements.
b) Did the pile load test correctly reflect the bearing capacity of the pile, considering that the designer intended to have the building load transferred by means of piles into the sand stratum?

10. An oil tank is 30 ft high and 100 ft in diameter. It has a thin steel bottom which is resting on a one foot thick sand levelling course. The subsoil is a 20 ft thick layer of clay, which has an unconfined compressive strength of one ton per sq ft. The clay is underlain by bedrock.

a) Check by means of an appropriate formula whether the shear stresses in the clay beneath the edge of the tank are amply safe against failure. State your reasons for selecting this particular formula.

b) What will be the relative magnitude of the settlements in the middle of the tank and along the edge? Explain.

1964 - 1965

HARVARD UNIVERSITY

Engineering 261b

1. (a) Make a careful plot of the Q, R and S envelopes for undisturbed, normally consolidated Boston Blue clay. Indicate the magnitude of the slope angles for the R and S envelopes above the effect of preconsolidation.

   (b) In the above sketch plot typical vector curves for R and S tests performed above the preconsolidation pressure.

2. (a) State briefly the basic assumptions of Coulomb's earth pressure theory.

   (b) Although this theory has been giving satisfactory results for the type of structures for which it was developed, it may lead to unsafe design when applied to many types of modern structures. Explain the reason.

   (c) Show by means of an appropriate sketch how Rendulic has adapted the Engesser method for the purpose of determining the horizontal force that an embankment consisting of granular soil exerts upon a soft foundation.

3. Beneath the center line of a uniformly loaded strip footing resting on the surface of a semi-infinite elastic mass, the maximum and minimum principal stresses can be expressed as follows:

$$\sigma_1 = \frac{p}{\pi} (\alpha + \sin\alpha)$$

$$\sigma_3 = \frac{p}{\pi} (\alpha - \sin\alpha)$$

where $\alpha = \frac{\alpha \text{ in degrees}}{180} \pi$

   (a) Using these equations, compute along the center line, in terms of p, the numerical values of σ_1, σ_3 and τ_{max} for

      (1) z = zero and

      (2) z = width of footing.

   (b) Using these values, show in a sketch the variation of σ_1, σ_3 and τ_{max} with depth.

   (c) Show the position of the planes on which τ_{max} acts.

Question 3 cont'd on page 2

3. (Continued)

   (d) Noting the ratio σ_1/σ_3 at depth z = width of footing, state whether such a stress distribution would be possible for a clean sand.

4. You are called upon to review the proposed foundation design for a 12-story office building covering an area of about 200 by 200 ft.

   Several borings showed a surface layer of soft organic silt-clay about 12 ft thick; then a compact sand layer about 25 ft thick which is underlain by a stratum of normally consolidated clay about 60 ft thick. The clay is resting directly on bedrock. The ground water level was found at a depth of about 8 ft below the ground surface.

   The building was designed with one basement, and with spread footings resting directly on the compact sand layer. Several load tests were conducted on the sand layer, and on the basis of these tests it was decided to design the footings for a bearing of 3 tons per sq ft.

   In his report the designer concludes from the results of the load tests that the settlements of the building will not exceed 1/4 inch.

   (a) Discuss the proposed design.

   (b) Describe briefly two different types of foundation design that in your judgment would deserve serious consideration for this project.

5. An excavation is to be made into a 100 ft thick stratum of soft clay which has a shear strength of 0.2 tons per square foot. For each of the following cases compute or estimate the depth of the cut at which failure may occur, and illustrate in a sketch the probable shape of the sliding surface and the center of rotation:

   (a) Vertical cut.

   (b) A slope having a 60-degree angle with the horizontal.

   (c) A slope having a 30-degree angle with the horizontal.

6. State briefly how you would determine a design value for the shear strength of clay for each of the following cases. (Note: A discussion of methods or procedures of stability analysis is <u>not</u> within the scope of this question.)

Question 6 cont'd on page 3

6. (Continued)

   (a) Stability of the slope of a compacted clay embankment immediately after construction.

   (b) Stability of a slope in an undisturbed clay stratum which was submerged for a long time and is then subjected to rapid drawdown of the water level.

   (c) Stability of a cut slope in intensely slickensided clay.

7. (a) By means of a sketch explain the friction-circle procedure for analyzing the stability of slopes.

   (b) In conjunction with this procedure, a factor of safety is sometimes defined as the ratio of the available "c" to the required "c". Explain why this definition is misleading and demonstrate whether it yields results which are on the safe or unsafe side.

8. You have the choice of two trucks for the purpose of transporting loads across dry sand. One truck is equipped with tires having an inflation pressure of 60 psi, the other with 25 psi, but both with the same wheel load. Assuming that both trucks have the same total capacity, which of these trucks would you choose, and why?

9. (a) Sketch the deflection of a perfectly flexible mat which is uniformly loaded and which rests on the surface of

   (1) sand,

   (2) clay.

   (b) Sketch the pressure distribution (soil reaction) acting against the bottom of a rigid footing resting on the surface of

   (1) sand,

   (2) clay.

   (c) As compared with the pressure distribution in (b) above how will the pressure distribution differ for a bridge pier founded at substantial depth below the ground surface? How may the method of construction affect this distribution? What simple distribution is usually an acceptable assumption for design purposes?

10. The following soil profile describes the subsoil conditions in a given area:

Depth ft	Description
0-30	Sand
10	Ground Water Level
30-50	Normally consolidated, fairly homogeneous inorganic clay
below 50	Sand with piezometric surface about 10 ft below ground surface

The clay has an average water content of 50%, an average liquid limit of 65, and an average plastic limit of 25. In the absence of consolidation tests on undisturbed samples, assume the following empirical relationship between the compression index and the liquid limit:

$$C_c = \frac{\text{Liquid Limit} - 10}{100}$$

Assuming that the ground water level in the upper sand stratum remains unchanged at a depth of 10 ft below ground surface, but that the piezometric surface in the sand below the clay is lowered by 20 ft (due to continuous withdrawal for water supply purposes), compute the settlement due to compression of the clay layer after 100% consolidation.

Final. June 1965

1965 - 1966

HARVARD UNIVERSITY

Engineering 261b

1. (a) Derive by means of Mohr's stress circle a formula for the active earth pressure of a clean sand against a vertical retaining wall of height H, with horizontal backfill, and assuming no friction between the back of the wall and the sand.

(b) If the active earth pressure in (a) is produced by yielding of the wall, what will be the actual inclination of the earth pressure? By means of the [redacted] Enges. method, show whether the magnitude of this inclined earth pressure is greater or smaller than the horizontal earth pressure without wall friction.

2. A simple gravity-type retaining wall is to be built in a humid climate, with ample provisions for drainage so that hydrostatic pressure cannot develop in a free-draining backfill material.

(a) Assuming that this wall is to last for many years, arrange the numerals of the following materials in the order of increasing magnitude of earth pressure when used as backfill for that wall:

I. Angular, light-weight slag.

II. Uniform, angular sand.

III. Well-graded mixture of rounded sand and rounded gravel.

IV. Very stiff clay which could stand temporarily for a height of that wall, even without the support of the wall.

V. Soft clay.

(b) State briefly the reasons for your selection of the two materials that in your opinion will cause the largest and the smallest earth pressures.

3. In spite of the extensive investigations which were carried out for the Great Salt Lake project, there remain great uncertainties concerning two vital quantities which enter into a stability analysis by the wedge method. Name these two quantities and explain briefly the reasons for the uncertainties.

4. State how you would determine a design value for the shear strength of clay when analyzing each of the following problems. Explain the reason for your choice in each case, and where you recommend tests, state clearly the type of tests. (Please note that this question does not ask you to explain how to perform the stability analysis.)

(a) Stability of the slopes of a cut in intensely slickensided clay.

(b) Stability of the slope of a compacted clay dam immediately after construction.

(c) Stability of the upstream slope of a compacted clay dam for sudden drawdown, assuming that prior to drawdown the reservoir had been full for a long time.

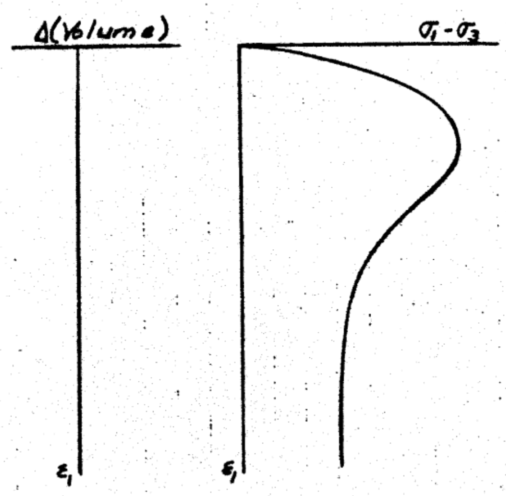
5. In their recent lectures in our Special Soil Mechanics Program, Professors Lambe and Seed, and Mr. Lowe, presented analyses in which they utilize results of laboratory tests that reproduce more closely conditions in a soil element in situ. State briefly, with the aid of sketches:

(1) the problem analyzed by each lecturer;

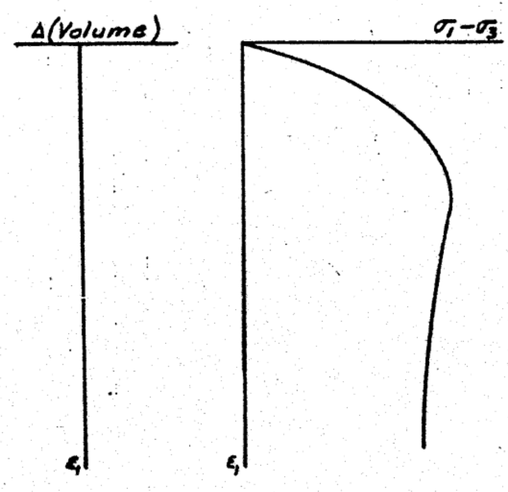
(2) how the proposed tests and analyses differ from conventional tests and analyses;

(3) whether the conventional analyses give results on the safe or unsafe side compared to the proposed analyses.

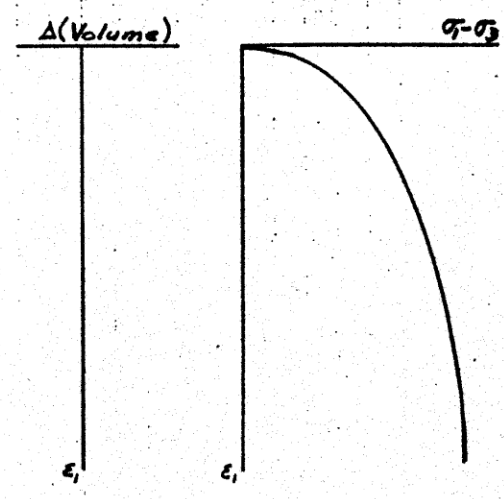
6. Building codes generally list allowable bearing values for the various types of soils encountered within the area of jurisdiction of the code, as e.g.:



S TEST (1)



S TEST (2)



S TEST (3)

QUESTION 10

Engineering 261 b, May 1966

Final Examination

Compact sand and gravel	-	5 ton/sq ft
Loose sand	-	1 ton/sq ft
Stiff clay	-	3 ton/sq ft
Soft clay	-	1 ton/sq ft

What is the meaning of these values (1) with respect to the design of building foundations, and (2) with respect to the settlements that a building will develop?

7. To determine the ultimate bearing capacity of clay for a uniformly distributed strip load applied at the ground surface, we may use the unconfined compressive strength, p_c, as determined on undisturbed samples, and one of the following formulas or analyses:

(1) an early, very simple formula by Terzaghi;

(2) an analysis by means of cylindrical sliding surfaces;

(3) Prandtl's formula;

(4) for the exaggerated requirement that the maximum shear stress as computed by means of the theory of elasticity not be exceeded.

Discuss the relative magnitude of the results obtained by these four methods, and their relative merits.

8.
$$R = \frac{2E}{s + 0.1}$$

(a) By what name is this equation known?

(b) Define the meaning and dimensions of each member.

(c) Derive this equation, but without attention to the numerical values of the constants.

(d) Discuss briefly the limitations of this equation:

(1) as to type of soil into which the pile load is transferred;

(2) for design loads much larger than 30 tons;

(3) when driving with a ram that weighs much less than the pile.

9. For a building foundation, wood piles were driven through 60 ft of soft, sensitive clay and about 10 ft into an underlying stratum of medium-dense sand. The driving resistance through the clay was small, and in the sand it gradually increased to the specified final resistance. A load test which was carried out on a test pile two weeks after it was driven, showed a permanent settlement of only 0.2 in. after the maximum test load of 60 tons was removed. Based on this load test, the engineer proposed a design load of 30 tons which was approved by the building department of that city.

In the course of years this building suffered substantial and irregular settlements.

(1) Explain the settlements.

(2) Why did the pile load test result in misleading information?

10. The observed curves of deviator stress versus axial strain for three triaxial S tests on a 100% saturated sand are shown in the attached figure.

(a) Sketch clearly on the attached sheet the corresponding volume change versus axial strain curves that you would expect to observe during each of these tests.

(b) The three tests were performed on the same sand yet the stress-strain curves have different shapes. Give two possible explanations for the observed differences. (Note: The three stress-strain curves are not plotted to the same scale.)

1965 - 1966

HARVARD UNIVERSITY

ENGINEERING 262

Try to save time by:

(1) not repeating the question;

(2) by using telegram style.

1. (a) Explain by means of a sketch the purpose of the following formula and compute the shape factor:

$$q = k \frac{(h_1^2 - h_2^2)}{2d}$$

(b) Derive this formula by introducing a crude simplification for an average hydraulic gradient and an average area.

(c) State in one brief sentence the simplifying assumptions which were made in the original derivation of this first formula.

(d) How would the rate of seepage change if you distorted the flow net of the above case by introducing an impervious diaphragm at the elevation of the tailwater level?

2. Explain and illustrate by means of a clearly drawn sketch, the method for constructing the line of seepage through a dam with an overhanging discharge slope which utilizes the basic parabola.

3. On the appended sheet is shown the cross-section of a proposed earth dam. Because of the variability of the silty sands in the borrow area for the upstream zone, a seepage

analysis is to be made with the conservative ratio $k_h/k_v = 16$.

(a) Plot the flow net in the transformed section assuming tailwater level to coincide with the impervious ground surface. (Divide the hydraulic head into four equal drops in head.)

(b) Why is the resulting seepage pattern objectionable from the standpoint of the safety of the dam?

(c) Assuming that you are limited to approximately the same volume of sand-gravel, how would you change the cross-section to achieve more satisfactory control of seepage? For this modification, plot the flow net in the transformed section and compute the shape factor.

4. (a) Derive the seepage pressure per unit of volume which acts upon soil in the direction of the flow lines.

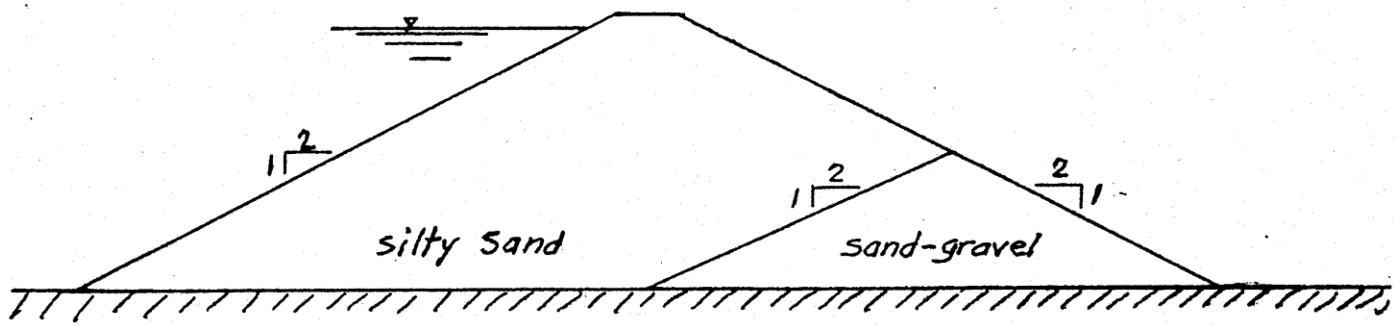
(b) Derive the critical hydraulic gradient for an average sand when exposed to vertical upward seepage.

5. A river dike consisting of sand is resting on an impervious foundation. Normal river levels are lower than the base of the dike. As a result of a prolonged flood stage, the dike is subjected to progressive saturation.

(a) Plot a flow net for the condition when the free surface along the base has advanced approximately to the center line of the dike. (Allow not more than seven minutes for this plot. Pay special attention to the accuracy of the boundary conditions and don't worry too much about the shape of the "squares".)

(b) By means of an enlargement of an element of the flow net, where the free surface and the impervious base meet, derive a relationship between the angle of this intersection and the rate at which the free surface is advancing along the impervious base.

6. State Terzaghi's criteria for the grain size distribution of a filter material.

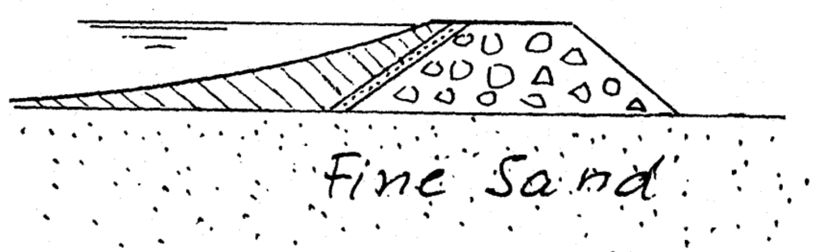


Your Name: ____________________

7. Where rockfill and glacial till are available, cofferdams have been built by (1) end-dumping a rockfill embankment, and (2) creating an impervious zone on the waterside by covering the slope first with a layer of sand-gravel, and dumping upon it glacial till which forms an average slope of about 1 on 8. Such cofferdams have been built with excellent results on a variety of foundations and with heights of up to 100 ft. However, the cofferdam sketched below has failed. Failure was preceded by development of longitudinal and transverse cracks in the crest combined with irregular subsidence of the crest.

(a) What was the probable cause of the failure?

(b) What modification in the design and construction of this cofferdam would have prevented a failure of the type you described?



8. A pumping test is made on a one-foot diameter well which fully penetrates the pervious sand stratum down to the horizontal impervious boundary. In the sketch, the groundwater surface before pumping is shown by the full-drawn line, and it discharges into a lake front which may be assumed to be a vertical plane. The test well is located b = 250 ft from the water front. The depth of water along the lake front is H_o = 20 ft, and the depth of groundwater at the location of the well before pumping was H_w = 30 ft.

Pumping from the well was carried out at the rate of 75 gallons per minute. When a steady state condition was obtained, the water level in the well was found to be

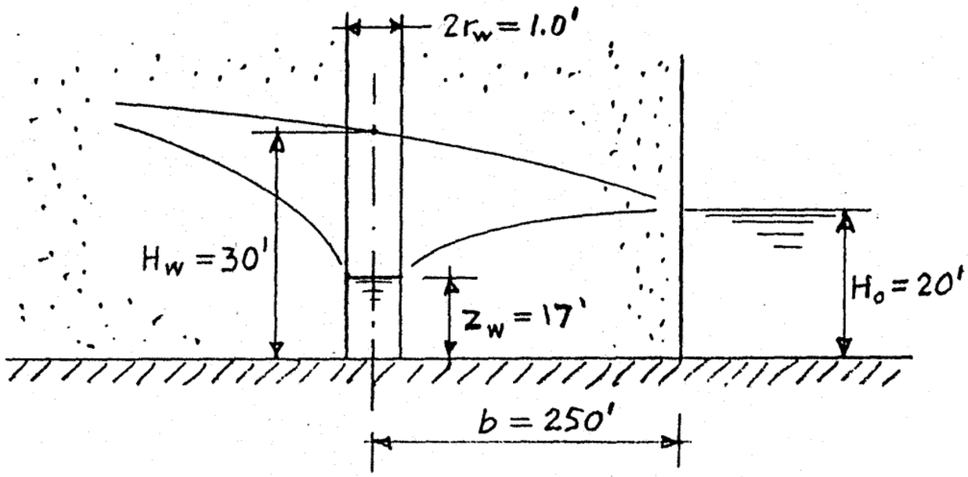
z_w = 17 ft above the impervious base.

(a) Assuming the pervious stratum to be homogeneous-isotropic, derive a formula for computing the coefficient of permeability of the pervious stratum.

(b) Although this derivation is not a rigorous one, would you consider the formula to be mathematically rigorous?

(c) Insert into this formula the given numerical values and compute the coefficient of permeability of the sand stratum. (Note: For convenience, you may wish to use feet and minutes as units, and the relation one cu ft = 7.5 U.S. gallons.)

(d) How would the above formula for k change if the original groundwater surface were level, and if $H_w = H_o$ = 30 ft, i.e. equal to the depth of groundwater at the well in the preceding example?



9. (a) Explain the purpose of the following equations, including the meaning of each term.

(1) $$z^2 = H^2 - \frac{q}{\pi k} . \ln \frac{R_t}{2r}$$

$$R_t = c\sqrt{\frac{Hkt}{n}}$$

(2) $$s = \frac{q}{4\pi kH} . (\ln \frac{1}{T} - 0.6)$$

(3) $$s = \frac{q}{4\pi kH} \int_T^{\infty} \frac{\epsilon^{-\tau}}{\tau} d\tau$$

(b) Discuss any relationships between these equations.

10. (a) State the three basic steps in applying the relaxation procedure.

(b) Define each term in the following equation and state the purpose for which the equation is used:

$$\Sigma b_i \ (h_i - H_o) = 0$$

Seepage

1964 - 1965

HARVARD UNIVERSITY

ENGINEERING 262

1. In the appended figure is shown the cross section of an earth dam constructed of silty sand, with internal drainage, and resting on an impervious foundation. The dam is 3000 ft long. Determine the entire line of seepage and the seepage loss in cubic feet per second, for the following sets of assumptions:

   (a) The material in the dam is isotropic, with a coefficient of permeability of 90×10^{-4} cm/sec.

   (b) The material in the dam is anisotropic, with $k_h = 90 \times 10^{-4}$ cm/sec and $k_v = 10 \times 10^{-4}$ cm/sec

   For each case state your reasons why you consider the selected method of analysis most appropriate.

   For the solution of (b) it will be more convenient to perform the transformation by enlarging the vertical dimensions, and the necessary space for such a transformed section is provided below the cross section of the dam. Transform only those lines of the cross section needed for the solution of your problem.

2. In one brief sentence each, define the following:

   (a) Equipotential line

   (b) Basic parabola

   (c) Free discharge surface

   (d) Dupuit's assumptions

   (e) Dupuit's formula.

3. (a) Show the boundary conditions for which each of the following formulas was derived:

   (1) $q = k \dfrac{h^2}{2d}$

   (2) $q = k \dfrac{h_1^2 - h_2^2}{2d}$

   (Note: Keep in mind that $h = h_1 - h_2$)

   (3) $q = k \dfrac{h^2}{d}$

   (4) $q = k \left(\sqrt{d^2 + h^2} - d\right)$

Question 3 cont'd on page 2

3. (Continued)

(b) Compute for each case the shape factor.

(c) Which of these formulas are rigorous solutions?

4. (a) Define Lane's weighted creep ratio.

(b) Why is this ratio an improvement over Bligh's original method for evaluating the degree of safety against piping?

(c) What is the principal objection against both methods?

(d) What factor is empirically reflected in these two methods which the flow net analysis fails to take into account? Explain.

5. (a) Explain the <u>meaning and purpose</u> of the following terms relating to drainage of base courses, and of each quantity that enters into these terms:

(1) Degree or percent drainage U

(2) Time factor $T = \frac{2tkH}{cn_e D^2}$

(3) Slope factor S

(b) Discuss the purpose of the following formula and how it is used:

$$t_{50} = \frac{n_e\ D^2}{2k\ (H + D \tan \alpha)}$$

6. State Terzaghi's criteria for the grain size distribution of a filter material.

7. (a) Derive the equation for the free water surface due to drawdown resulting from steady-state seepage toward a well.

(b) Will this equation give a satisfactory approximation for the water level in the well?

(c) Explain how you would apply this formula for the determination of the coefficient of permeability of the stratum in which the well is located.

8. (a) By means of an appropriate sketch, state the purpose of the following equation and state the meaning of each quantity:

$$z^2 = H_o^2 + \frac{2\bar{q}}{k} x - \frac{q}{\pi k} \ln \frac{b + x}{b - x}$$

(b) Explain briefly (without detailed derivation) how this equation is derived.

9. Explain the purpose of the following equations, including the meaning of each term. Discuss any relationships between these equations.

$$(1)\quad z^2 = H^2 - \frac{q}{\pi k} \cdot \ln \frac{R_t}{2r}$$

$$(2)\quad s = \frac{q}{4\pi k H} \cdot [\ln \frac{1}{T} - 0.6]$$

$$(3)\quad s = \frac{2}{4\pi k H} \int_T^\infty \frac{\varepsilon^{-\tau}}{\tau} d\tau$$

10. (a) State the three basic steps in applying the relaxation procedure.

(b) Define each term in the following equation and state the purpose for which the equation is used:

$$\Sigma b_i (h_i - H_o) = 0$$

Final. May 1965

1962 - 1963

HARVARD UNIVERSITY

Engineering 261b

Suggestions: (1) Be brief and to the point! Telegram or Kiplinger-style answers will be accepted.

(2) Where possible use clearly drawn sketches, to avoid lengthy description.

(3) Relax, and read each question slowly.

1. Make a sketch of a plasticity chart with the scales and the A-line drawn with reasonable care. Then indicate by points on this chart a typical location for the following materials, using for abbreviation the numbers listed below. For each material indicate the group symbol of the U. S. classification system.

(1) An inorganic clay of low toughness and low to medium dry strength.

(2) An inorganic clay having great toughness and high dry strength.

(3) A white clay of low toughness and low dry strength.

(4) A dark-gray clayey soil for which it takes a long time to reach the plastic limit, with the threads at the plastic limit being very soft and friable, having low dry strength, and which shows a substantial drop in plasticity due to oven-drying.

(5) A reddish clayey soil from Hawaii (or Java, or some other volcanic area), having low toughness, low dry strength, and which shows a substantial drop in plasticity due to oven-drying.

(6) A slightly plastic, highly micaceous, sandy soil having soft and spongy threads at the plastic limit and very low dry strength.

(7) A very sandy clay with considerable toughness and high dry strength.

(8) Mica powder, ground in a ball mill to approximately one micron size.

(9) Dark gray, waxy, non-cemented clay-shale (e.g. Bearpaw shale).

2. (a) Derive, by means of Mohr's circle of stress, a formula for the active earth pressure of a granular material against a vertical retaining wall with horizontal backfill, assuming that no friction is acting between the wall and the backfill.

   (b) In a humid climate, which of the following materials will cause the smallest earth pressure and which potentially the largest earth pressure, when placed as backfill behind a gravity-type retaining wall: Angular sand; well rounded sand; soft clay; stiff clay; dried clay chunks; a type of angular slag which is full of air bubbles so that its specific gravity is only slightly greater than water. State reasons for your answer.

3. (a) What is the basic weakness of the classical earth pressure theories when applied to many types of modern structures?

   (b) Give a typical example of a structure for which it would not be correct to use the classical formulas.

4. (a) Explain by means of a sketch the principle of the Engesser Method for determining the active earth pressure against a retaining wall.

   (b) How would one have to modify this method if one desired to obtain the passive earth pressure?

5. Discuss the limitations of the Swedish method of stability analysis for

   (a) highly overconsolidated, brittle clay containing joints,

   (b) highly overconsolidated, intensely slickensided clay or clay-shale,

   (c) normally consolidated, stratified clay containing layers of rock flour.

6. In high mountains, large deposits of coarse detritus which normally form stable slopes, sometimes liquefy and flow downhill. Such avalanches are known in the Alps as "Muren". Describe a mechanism which could explain such loss of stability.

7. For a large building, untreated wood piles are driven through 80 ft of soft, sensitive clay and about 10 ft into the underlying sand stratum. The driving resistance through the clay is small and in the sand it gradually increases to the specified final resistance of 20 blows for the last six inches, using a single-acting steam hammer delivering 15,000 ft lb per blow.

   (continued)

7. (continued)

A load test carried out some time after driving the test pile, showed a permanent settlement of only 0.2 in. under the maximum test load of 50 tons. Based on this test, a design load of 25 tons is proposed by the engineer and is approved by the Building Department.

Explain why in this case a load test is misleading, and why, in the course of years, the actual load on the piles may reach a much greater value than that applied by the building.

8. (A) A friction pile is driven into a deep stratum of normally consolidated clay. State what differences you would expect between bearing capacities determined as follows:

(a) computed from dynamic resistance during driving;

(b) computed from dynamic resistance during redriving several weeks after the pile was driven;

(c) by means of a load test conducted several weeks after the pile was driven.

(B) At another site a friction pile is driven into a deep stratum of highly overconsolidated, brittle clay, with a natural water content approximately at the liquid limit. A load test conducted several weeks after driving showed a "skin friction" over the embedded area considerably less than determined in (c) above, in the normally consolidated clay. Can you explain this apparent contradiction?

9. (a) A large oil tank, with a thin steel bottom plate, is resting on the surface of a soft clay layer having a thickness about one-fifth the diameter of the tank. State the relative magnitude of the settlement below the center and the edge of the tank, and explain the reason for this difference.

(b) What is approximately the magnitude of the maximum shear stress in the clay which is caused by this tank load, and approximately where are these maximum shear stresses located?

10. The four legs of a water tower will be founded on spread footings which are arranged in the corners of a square, 20 ft on centers. The total dead and water load is 300 tons, and the vertical component of the effect of extreme wind load is 40 tons on one leg.

The subsoil conditions are described below.

(continued)

10. (continued)

Depth in ft	Description
Surface to 25 ±	Compact sand and gravel with ground water surface about 10 ft below ground surface.
25 to 40 ±	Normally consolidated, inorganic clay; average water content = 50%; average liquid limit = 65; average plastic limit = 25.
40 ±	Surface of bedrock

(a) Select an appropriate design bearing value and a depth for the footings. Would you consider it necessary to perform load tests, or to verify in some other way your proposed bearing value and depth?

(b) Compute by the simplest possible means the maximum settlement due to consolidation of the clay. In the absence of consolidation tests on undisturbed samples, you may estimate the coefficient of compressibility for the clay by means of the formula given in the Terzaghi-Peck book: $C_c = 0.009\ (LL - 10)$.

(c) Considering the character of the granular stratum overlying the clay, have you an opinion whether your computed settlement will err on the high or on the low side, and why?

Final. May 1963