THIS EXAMINATION CONSISTS OF **8** PAGES (INCLUDING THIS PAGE).
PLEASE CHECK THAT IT IS COMPLETE.

THE UNIVERSITY OF BRITISH COLUMBIA

Department of Civil Engineering

FINAL EXAMINATION – DECEMBER 2007
SOIL MECHANICS II - CIVL 311
Instructor: Dr. D. Wijewickreme

Time: 3 hours

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1. **Closed Book** Examination; a calculator only is permitted.
2. Please ensure that you write your name and student number on the first page of all answer books.
3. Answer all 5 questions.
4. The formula sheet is attached.
5. Assume the unit weight of water to be 9.8 kN/m^3.
6. Make any reasonable assumptions (where appropriate and if required) to answer the questions.
7. Use sketches whenever possible.
8. Write clearly. Be neat and brief. Marks will be deducted for poor presentation.
9. Show all steps of your calculation to receive full marks.
10. Note the mark value distribution for each question.
11. POSSIBLE MAXIMUM MARKS = 150

Marks **Question 1**

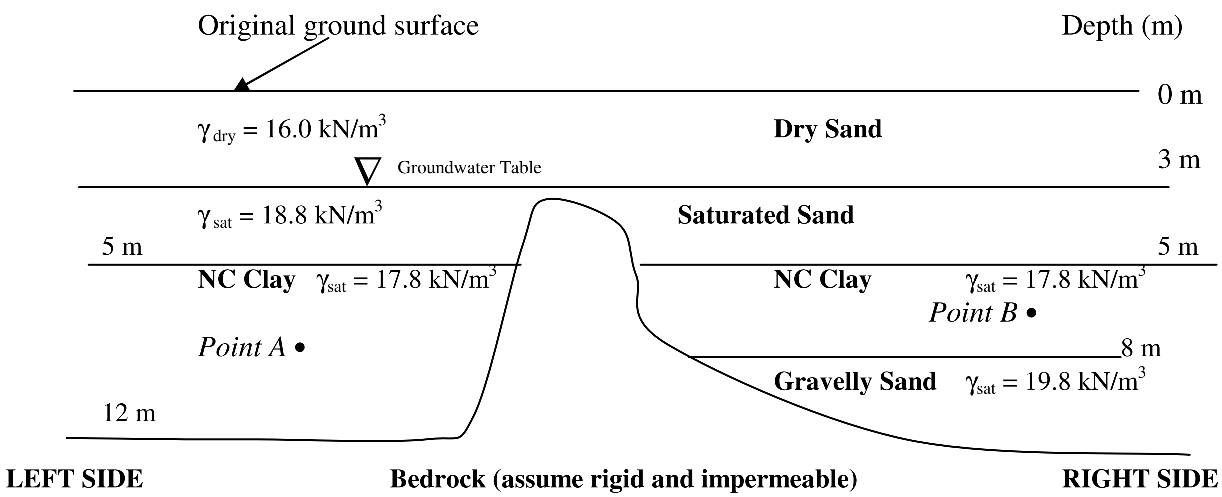
The inferred soil stratigraphy at a site, with soil parameters, is shown in the figure below (Note: Schematic diagram only. Not to scale). It has been given that the two clay zones shown in the figure, although separated due to the rising bedrock surface in the middle, are normally consolidated (NC) and have identical characteristics. During a geotechnical investigation, conducted prior to fill placement as per below, undisturbed soil samples were retrieved from the centre of the clay deposit on the left side (i.e., samples retrieved from the depth level of Point A). Some of the key results obtained from laboratory 1-D consolidation and unconsolidated undrained triaxial (UU) testing of these samples are summarized below: (i) Determined from Consolidation Testing: Initial void ratio (e_o) = 0.95; C_c = 0.37; avg. $C_v = 3.3 \times 10^{-3}$ cm^2/sec; (ii) Determined from UU Triaxial Testing: S_u = 25 kPa.

The site preparation requirements for a future development involves raising the site grade above the original ground surface level using a 3 m–thick permanent wide-area sand fill. It has been given that the permanent fill has a bulk unit weight of $\gamma_{sandfill}$ = 16.0 kN/m^3, and it would cover the full extent of the site shown in the figure. Assuming that the stress conditions at the mid-layer-depth Point A is representative of the clay layer on the "left side" of site, and mid-layer-depth Point B is representative of the clay layer on the "right side" of site:

(15) (a) compute the expected ultimate consolidation settlement within the clay layers on each of the two sides of the site due to the applied wide-area fill (ignore settlements within sand);

(5) (b) compute the expected consolidation settlement within the clay layers on each of the two sides of the site 30 days after application of the applied wide-area fill (ignore settlements within sand and assume that the fill is placed is relatively quickly);

(15) (c) estimate the time duration required to reach 90% of ultimate consolidation settlement within the clay layer on the right side after placement of the 3-m permanent fill. It is also desired to ensure that 90% of the ultimate consolidation settlement within the clay layer on the left side (due to the placement of the permanent 3-m fill) is also completed in the same time duration as that determined above for the U=90% condition on the right side; if this objective is to be accomplished by preloading the left side, compute the required thickness of additional preload fill. Assume bulk unit weight of preload = 16.0 kN/m^3. Is this preloading optional practical?



NOTE: Points A and B are mid-points of the clay layers. Depths in metres (m) shown are depths below original ground surface. Schematic figure only. Not to scale. Horizontal scale contracted in comparison to vertical.

(10) (d) estimate the expected S_u from an UU triaxial test conducted on an undisturbed soil sample obtained from Point B prior to any placement of fill.

Question 2

A series of triaxial tests carried out on undisturbed samples of saturated OC clay indicated that the shear strength and pore water pressure response of the soil could be characterized by the following parameters: c' = 20 kPa; ϕ' = 28 deg; and Skempton pore pressure parameter at failure = A_f = -0.1. The estimated pre-consolidation stress level for this clay is 480 kPa.

(10) (a) One of the undisturbed samples of the above clay was obtained from a depth where the overburden effective stress is 80 kPa. Assuming perfect sampling, calculate the expected shear strength at failure if the sample was sheared in an <u>unconsolidated undrained (UU)</u> loading mode. Estimate the change in pore water pressure during this shearing process.

(6) (b) What would be the deviator stress at failure in a <u>consolidated drained (CD)</u> triaxial compression test if a sample of this clay was consolidated to an effective all round stress of $\sigma'_{1c} = \sigma'_{3c} = 75$ kPa prior to shearing.

(10) (c) If another sample of this soil was consolidated to the same all round stress as above, estimate the deviator stress at failure if the sample was sheared in <u>consolidated undrained (CU)</u> triaxial compression.

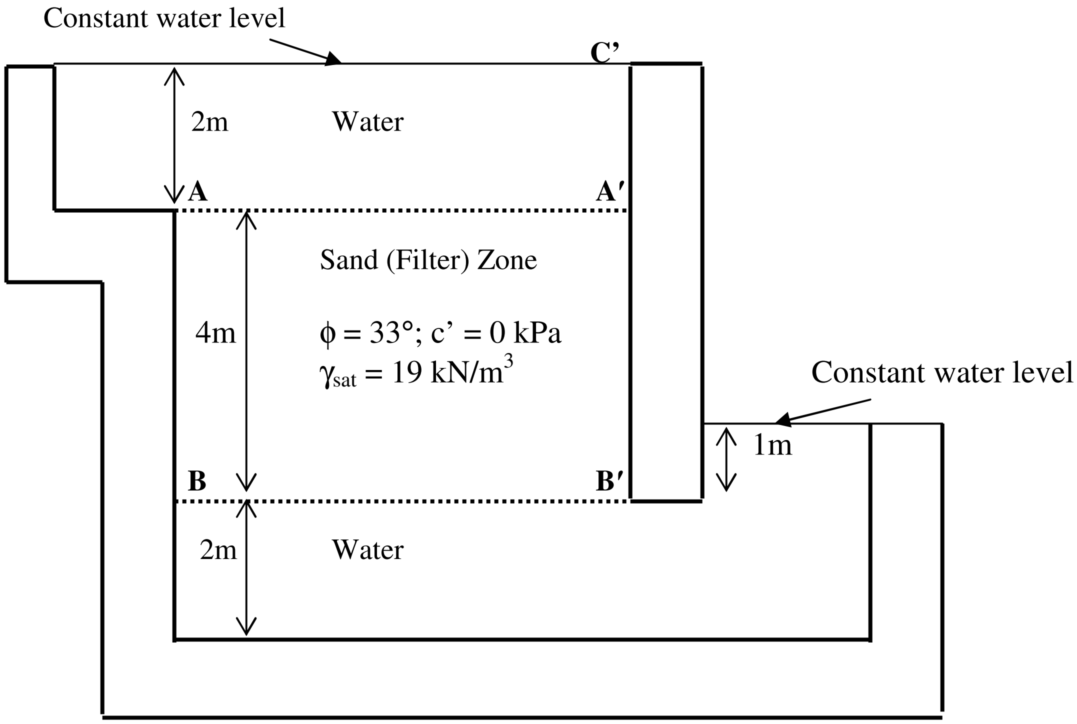
(4) (d) What would be the shear stress at failure in <u>drained direct shear</u> if the clay was initially consolidated under a vertical effective stress of 125 kPa.

Question 3

A schematic cross section of a filter system is illustrated below where a uniform homogeneous sand zone is constrained between two vertical walls (AB and A'B') and two horizontal thin metal plates with fine perforations (AA' and BB'). As shown, water from a reservoir (held at a constant water level) enters the top of sand filter at the boundary AA' and then exits from bottom boundary of the filter (BB') into another constant head reservoir.

(20) (a) Assuming that structural flexibility could lead to potential outward wall movements, determine the active lateral effective earth pressure and pore water pressure distributions on the wall-face C'A'B' (no need to compute pressures on the other side of the wall). Assume uniform, steady-state seepage flow conditions. In arriving at this solution, first, it is important to determine the distributions of total vertical stress, pore water pressure distributions, and effective vertical stress along C'A'B'. Calculate the <u>total</u> force (per metre length of wall) arising from the pressure distributions as appropriate (Use Rankine theory to compute lateral earth pressures).

(15) (b) During maintenance work, the water flow through the filter can be stopped by introducing a solid seal below the perforated plate at BB'. Assuming "at rest" conditions, illustrate with magnitudes, the anticipated effective lateral earth pressure distribution "at rest" and the pore water pressure distribution on the wall C'A'B' for this condition of no-flow during maintenance.



NOTE: Not to scale; assume dimension AA' is wide enough to develop active Rankine failure zones.

Question 4

Answer the following questions making liberal use of illustrations, or tables, wherever possible (Note: If the answer can be given exclusively using illustrations, or tables, you do not have to provide written text explaining your answer).

(3) (a) Using a plot of shear stress $(\sigma_1' - \sigma_3')/2$ vs. $(\sigma_1' + \sigma_3')/2$, schematically illustrate the typical effective stress paths during Consolidated Undrained (CU) triaxial tests for (i) NC clays; and (ii) heavily OC clays [use conventional symbols for stresses and pore water pressures as appropriate]. Note: Assume $A_f \sim 1$ for NC clays, and $A_f < 0$ for heavily OC clays.

(3) (b) Using a plot of void ratio (e) vs. log effective stress (σ'), sketch the typical consolidation characteristics of a clay. Identify the normally consolidated (NC) and overconsolidated (OC) regions of the e-log σ' response. Also provide the definition of the term overconsolidation ratio (OCR).

(4) (c) Using sketches, if desired, briefly explain the stress application stages in a conventional Consolidated Undrained (CD) test.

(4) (d) Provide the definition of Skempton B-parameter, and briefly discuss its importance in laboratory triaxial testing of soils.

(11) (e) A site is underlain by relatively "clean" (i.e., less than 5% fines content) medium to coarse sand. It is given that that the groundwater table is at the ground surface. The total unit weight of the

sand is 20 kN/m^3. The normalized Standard Penetration Test values $(N_1)_{60}$, representing the density, at two depth locations within the deposit are given below:

Depth (m)	$(N1)_{60}$
8	14
10	6

$$\left(\frac{\tau_{cyc}}{\sigma'_{z0}}\right)_{eqk} = 0.65\frac{a_{\max}}{g}\frac{\sigma_{zo}}{\sigma'_{zo}}r_d$$

where:

$\left(\frac{\tau_{cyc}}{\sigma'_{z0}}\right)_{eqk}$ = Cyclic stress ratio produced by an earthquake

$\frac{a_{\max}}{g}$ = Peak horizontal ground acceleration divided by acceleration of gravity

σ_{zo} = Initial vertical total stress

σ'_{zo} = Initial vertical effective stress

r_d = Stress reduction factor

The estimated peak horizontal ground acceleration at the ground surface (a_{max}) on site is 0.25g from a magnitude 7.5 design earthquake. Using the above equation and chart below calculate the variation of factor of safety against liquefaction at the four depth locations using the Seed's simplified method. For the stress reduction factor, r_d, you can use the following equations (use z value in metres):

$r_d = 1.0 – 0.00765z$ for $z < 9.15$ m, or
$r_d = 1.174 – 0.0267z$ for $z > 9.15$ m

Note: Liquefaction resistance chart [cyclic stress ratio vs. $(N_1)_{60}$] is given at the end of the formula sheet.

Question 5

(8) (a) Given the following information, compute the ultimate bearing capacity of a 2 m wide strip (continuous) footing founded on a uniform soil deposit.

(i) Shear strength parameters: ϕ' = 36 deg and c'= 5 kPa
(ii) Depth of footing below ground surface = D = 1.2 m;
(iii) Depth of groundwater table (from ground surface) = 2.5 m;
(iv) Total unit weight of soil above groundwater table = 17.0 kN/m^3.
(v) Total unit weight of soil below groundwater table = 19.8 kN/m^3.

(7) (b) A 1 m square footing for a column is founded in a clay with an undrained shear strength S_u = 50 kPa. The depth of footing embedment (D) is 0.6 m, and the soil has a total unit weight of 18 kN/m^3. Using a factor of safety (FOS) of 2.5, compute the allowable column load on the foundation. Assume that the bearing pressure from the weight of the footing is given by γ_{con}*D, where γ_{con} = Unit weight of concrete = 24.0 kN/m^3.

Note : for ϕ' = 36 deg $\Rightarrow$ Use $N_c = 51$; $N_q = 38$; $N_\gamma = 44$
for ϕ' = 0 deg $\Rightarrow$ Use $N_c = 5.14$; $N_q = 1.0$; $N_\gamma = 0$

EQUATION SHEET

$\sigma'_z = \Sigma \gamma_i h_i$; $\sigma' = \sigma - u$;
$\sigma'_z =$ Vertical effective stress; $\sigma' = \sigma - u$; u = Pore water pressure

Under static groundwater (no flow) conditions: $u = \gamma_w z$

With groundwater seepage (with flow) conditions:
$H_{total} = H_{elev} + H_{pwp}$; $H_{pwp} = u/\gamma_w$
H_{total} = Total Head; H_{elev} = Elevation head with respect to a pre-defined datum;
H_{pwp} = Pore water pressure head

Time Factor = $T_v = -0.933 \log(1-U) - 0.085$ - for Degree of Consolidation (U) > 0.53
$T_v = (\pi/4) * (U)^2$ - for Degree of Consolidation (U) < 0.53
$T_v = (c_v * t) / (H_{dr})^2$

$S_{ult} = \varepsilon_z \cdot H$ where $\varepsilon_z = [\Delta e / (1+e_o)]$ and $\Delta e = e_f - e_o = C_c \cdot \log_{10} [(\sigma'_{zo} + \Delta\sigma'_z)/ \sigma'_{zo}]$
H = thickness of consolidation layer considered for the calculation
e_o = initial void ratio; e_f = final void ratio; σ'_{zo} = initial stress; $\Delta\sigma'_z$ = increase in stress
C_c = compression index

Mohr Coulomb Failure Criterion $\Rightarrow$ Shear strength at failure = $s = c' + \sigma' \tan \phi'$

$\sigma_{df} = \sigma'_{1f} - \sigma'_{3f}$; $\sigma_{df} = \sigma'_{3f} (N_\phi - 1) + 2c' (N_\phi)^{0.5}$
$\sigma'_{3f} = (\sigma'_{3c} - \Delta u_f)$; $\Delta u_f = A_f \sigma_{df}$
$N_\phi = (1+\sin \phi')/(1- \sin \phi')$

$K_a = 1/N_\phi$; $K_p = N_\phi$; $K_o = (1- \sin \phi')$

Lateral earth pressure - Effective stress analysis (when $c'=0$):
σ_v' = Effective vertical stress at a given depth

$\sigma_h' = K \sigma_v'$ where K = one of K_a (active), K_o (at-rest), or K_p (passive) depending on the case analyzed.

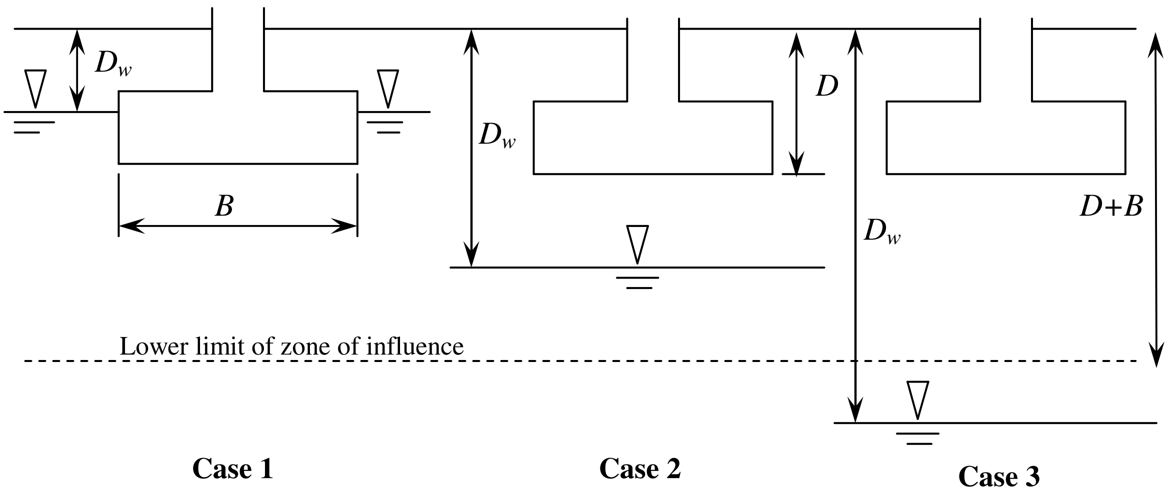
Lateral earth pressure - Effective stress analysis (with c' and ϕ'):
$(\sigma_h')_{active} = p_a = K_a \sigma_v' - 2c' (K_a)^{0.5}$ - Active
$(\sigma_h')_{passive} = p_p = K_p \sigma_v' + 2c' (K_p)^{0.5}$ - Passive

Lateral earth pressure - Total stress analysis:
$(\sigma_h)_{active} = p_a = \sigma_v - 2 S_u$;
$(\sigma_h')_{passive} = p_p = \sigma_v + 2 S_u$
σ_v = Total vertical stress at a given depth; Note: At tension crack depth level, Z_c, $p_a = 0$.

Strip footings : $q_{ult} = c'N_c + \sigma_D' N_q + 0.5 \gamma' B N_\gamma$
Square footings: $q_{ult} = 1.3 c'N_c + \sigma_D' N_q + 0.4 \gamma' B N_\gamma$
σ_D' = Effective stress of soil at footing underside level.
Correction to account for the depth of groundwater table for three cases:

- **Case 1:** $D_w \leq D$
- **Case 2:** $D < D_w < D + B$
- **Case 3:** $D + B \leq D_w$

All three cases are shown in the Figure below.



For Case 1 $(D_w \leq D)$:

$$\gamma' = \gamma_b = \gamma_{sat} - \gamma_w$$

γ_{sat} = Saturated unit weight of soil below GWT

For Case 2 $(D < D_w < D + B)$:

$$\gamma' = \gamma_{sat} - \gamma_w \left[1 - \left[\frac{D_w - D}{B} \right] \right]$$

γ_{sat} = Saturated unit weight of soil below GWT

For Case 3 $(D + B \leq D_w)$; no groundwater correction is necessary.

$$\gamma' = \gamma$$

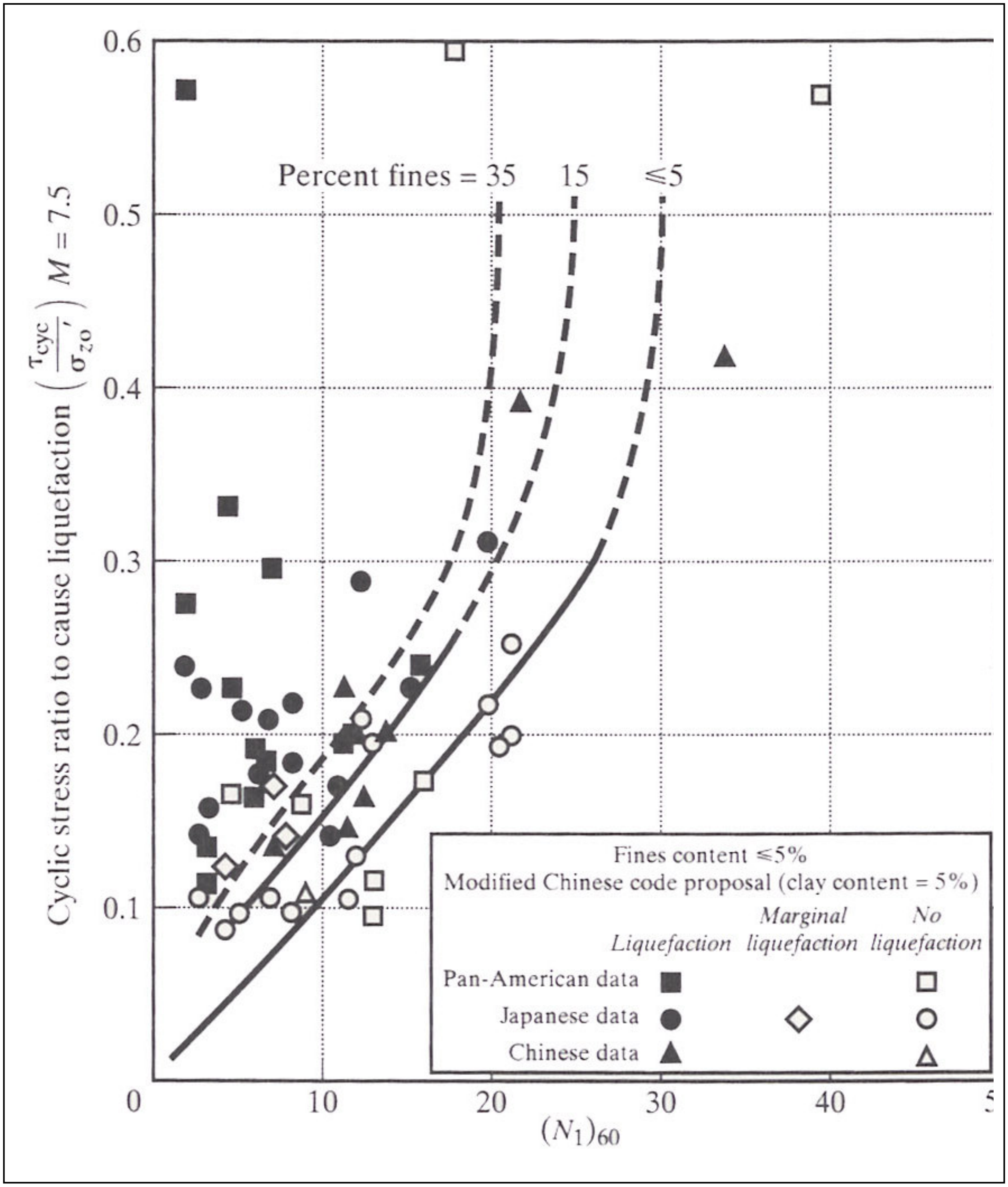


Chart for determining liquefaction Resistance (in terms of cyclic stress ratio) with respect to $(N_1)_{60}$ at a given depth (M=7.5 , Youd et al. 2001) is given at the end of the forumla sheet.