NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND WATER ENGINEERING

GEOTECHNICAL ENGINEERING I

ECW 3210

Examination Paper

March 2025

This examination paper consists of 13 pages

Time Allowed: 3 hours

Total Marks: 100

Examiner's Name: Eng. K Z Mkwanazi

INSTRUCTIONS

1. Answer any four (4) questions.
2. Each question carries 25 marks.
3. Use graph paper where applicable
4. Use of calculators is permissible
5. This is a closed book examination.

MARK ALLOCATION

Total max marks achievable 100 marks

QUESTION 1

Retaining Walls

a) Define and explain the following terms with regards to retaining walls

    i)   Lateral earth pressure   (5 marks)
    ii)   Active earth pressure   (5 marks)
    iii)   Passive earth pressure   (5 marks)

b) A retaining wall is shown in Figure Q1b below. Determine Rankine's active force, Pa, per unit length of the wall.

Layer 1
$\gamma_1 = 16.5$ kN/m³
$\phi_1' = 30°$,
$c_1' = 0$

Below the water table
$\gamma_2 = 19.2$ kN/m³,
$\phi_2' = 35°$,
$c_2' = 0$ (10 marks)

(Total 25 marks)
Figure Qb1

Sand; $\gamma_1 = 16.5$ kN/m³; $\phi_1' = 30°$; $c_1' = 0$ 1.2m

Sand
γ_2 (Saturated unit weight) = 19.2 kN/m³,
$\phi_2' = 35°$,
$c_2' = 0$

Groundwater Table

Frictionless Wall

6m
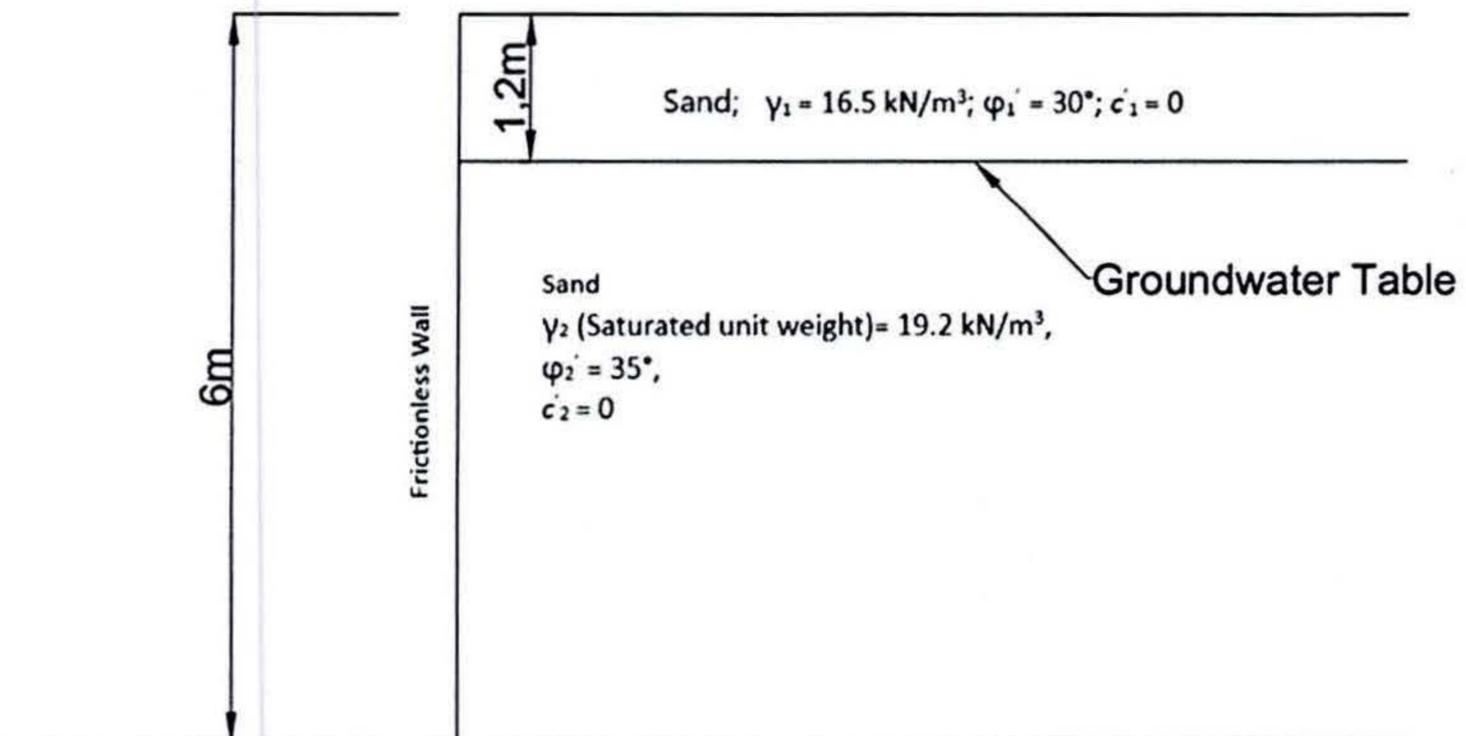
QUESTION 2

Allowable Bearing Capacity of Sands

a) Describe in detail the Standard Penetration Test (SPT) and explain what it is used for.

(10 marks)

b) Write notes on vibro-compaction methods. (5 marks)

c) Write notes on dynamic compaction methods. (5 marks)

d) Differentiate between wet top feed method and dry bottom feed method in stone columns (5 marks)

(Total 25 marks)

QUESTION 3

a) What are the soil engineering applications of Stone columns?   (6 marks)

b) 6m deep stone columns with a diameter of 0.75m were designed to support a building
load of 120kPa. The stones have an angle of internal friction of 40°. Given that the
columns were constructed in soil with a friction angle of 0°, unit weight of 16kN/m^3,
cohesion of 20kPa and $\mu_s = \dfrac{1}{3}$ for a 1.5m × 1.5m cell
Determine the following:

i) The basic improvement factor   (3 marks)
ii) The reduced improvement factor   (3 marks)
iii) The improvement factor with overburden constraint   (3 marks)

c) A slope composed of basalt is to be stabilised using rotary drilled soil nails to allow for
the construction of a structure whose load is 140kPa. Design a soil nail system given that
the unstable rock surface is 28m long and 8m high. The rock parameters are:
C = 5kPa
ϕ = 38
γ = 22
The factors of safety are:
F_{os} = 1.5
$F_{pullout}$ = 2
The angle of inclination of soil nails is 10 degrees and angle of slope failure is 45 degrees
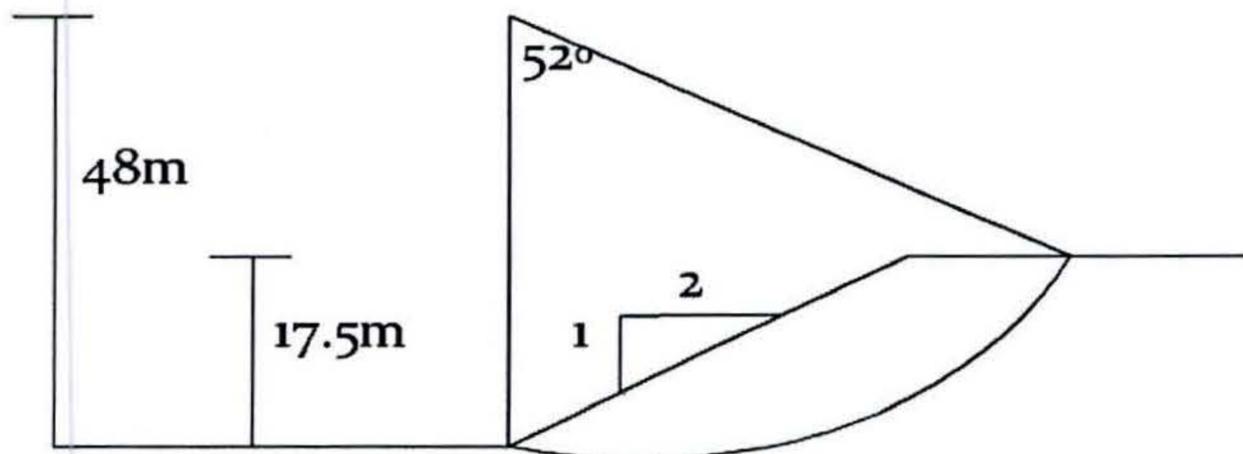   (10 marks)

(Total 25 marks)

QUESTION 4

Development of Limit Equilibrium Methods

Method of Slices

a) Describe the main difference between the different Methods of Slices   (5 marks)

b) Use the Bishop's Simplified method of slices to determine the factor of safety for the slope detailed in the figure Q4b below, The unit weight of the soil is 22 kN/m^3 c = 4kPa, Φ = 25 ^{0} (10 marks)

Fig Q4b

c) Geosynthetic Reinforced Slopes

   i.   What factors are considered when selecting a geosynthetic.   (5 marks)

   ii.   Briefly describe the procedure followed in the design of geosynthetics reinforced slopes.   (5 marks)

(Total 25 marks)

QUESTION 5

Deep Wells

a) Define and describe with the aid of a sketch deep wells systems   (10 marks)

b) Describe considerations made when constructing deep wells   (5 marks)

c) Describe in detail dewatering methods and how they work with emphasis on basement floors for high rise buildings.   (10 marks)

(Total marks 25)

END OF EXAMINATION

Formulas and Tables

$$k_a = \frac{1-\sin\varphi}{1+\sin\varphi} \qquad P_a = \sigma_z k_a - 2c\sqrt{k_a} \qquad P_a = 1/2 k_a \gamma H^2$$

$$k_p = \frac{1+\sin\varphi}{1-\sin\varphi} \qquad P_p = \sigma_z k_a + 2c\sqrt{k_a} \qquad P_p = 1/2 k_p \gamma D^2 + 2C\sqrt{k_p}\, D$$

$$F = k_a q H \qquad\qquad e = \frac{B}{2} - \frac{M_{resultant}}{\sum R_v} \qquad q = \frac{\sum R_v}{B}\left(1 \pm \frac{6e}{B}\right)$$

$$M_{des} = 1.4Fz \qquad k = \frac{M}{f_{cu}bd^2} \qquad z = d\left[0.5 + \sqrt{0.25 - \frac{k}{0.9}}\right]$$

$$A_s = \frac{M}{0.95 f_y z} \qquad A_{s\,min} = 0.13\% bH \qquad F = \frac{\sum[CL + (W\cos\alpha - U)\tan\varphi]}{\sum W\sin\alpha}$$

$$LTDS = \frac{T_{ult}}{RF_{ID}RF_{CR}RF_D FS} \qquad F.S_{sliding} = \frac{W_s \tan\sigma}{P} \qquad L_a = L - 2e$$

$$e = \frac{M_{ovrt}}{W + qxL} \qquad Pressure = (\gamma H + q)\frac{L}{L_a} \qquad \sigma_h = \gamma z k_{af} + q k_{af}$$

$$T_{reqd} = \frac{s_v \sigma_h}{c_{ds}} \qquad L_e = \frac{s_v \sigma_h FS_{pullout}}{2C_i C_{ds} \sigma_v \tan\varphi} \qquad L_R = (H - Z)\tan\left(45 - \frac{\varphi}{2}\right)$$

$$H' = H + \frac{q}{\gamma} \qquad S_{v\,max} = \frac{LTDS}{k\gamma z_{max}}$$

$$F.S_{sliding} = \frac{R_v \tan\sigma}{R_h}$$

$$L_{corrected} = C_{1L} \times C_{2L} \times C_{3L} \times L \text{ (from chart)} \qquad C_{3L} = 0.52Fos + 0.3 > 1$$

H   H

$$C_{1L} = 1.5 - 0.15D_{dh} + 0.0065\,D_{dh}^2 \qquad C_{2L} = -4\,C^* + 1.09 > 0.85 \qquad C^* = \underline{C}$$

g H

$$\text{Anchor force } T = \frac{(P + gH/2)\,HcosB\,(F - cotBtanF) - (CH/sinB)}{Sin\,(A+B)\,tanF + F\cos\,(A+B)}$$

$$\mu_{po} = \frac{q_u D_{DH}}{F_{po}\gamma S_h S_v}$$

Bar size (mm)	Spacing of bars								
	50	75	100	125	150	175	200	250	300
6	566	377	283	226	189	162	142	113	94.3
8	1010	671	503	402	335	287	252	201	168
10	1570	1050	785	628	523	449	393	314	262
12	2260	1510	1130	905	754	646	566	452	377
16	4020	2680	2010	1610	1340	1150	1010	804	670
20	6280	4190	3140	2510	2090	1800	1570	1260	1050
25	9820	6550	4910	3930	3270	2810	2450	1960	1640
32	16100	10700	8040	6430	5360	4600	4020	3220	2680
40	25100	16800	12600	10100	8380	7180	6280	5030	4190
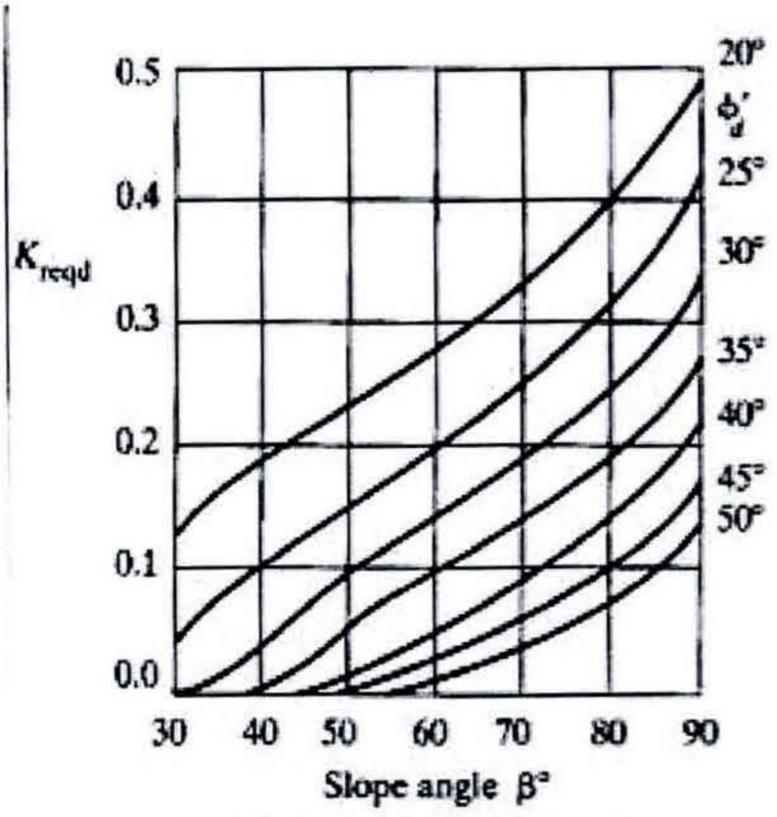
(a) Minimum required force K_{reqd}
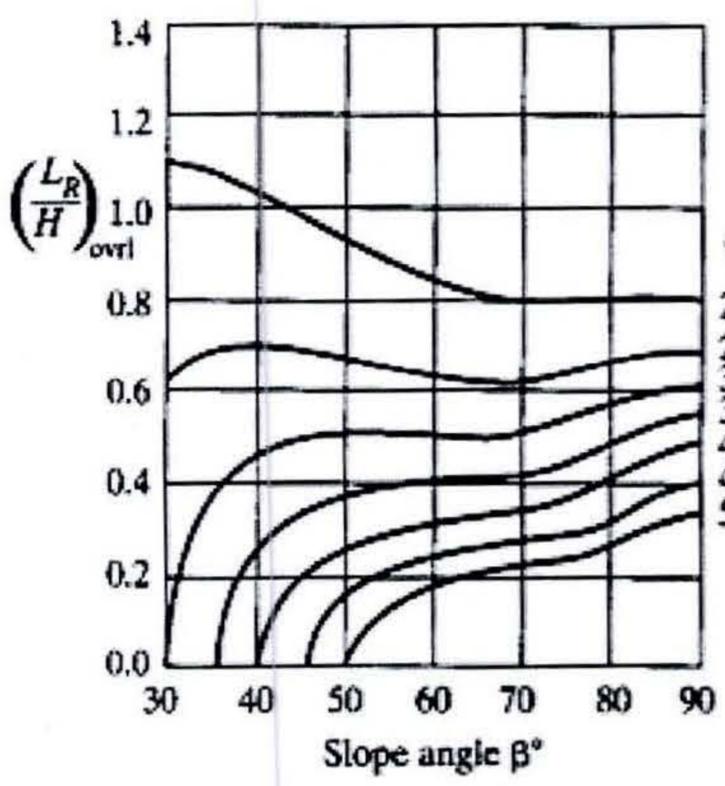
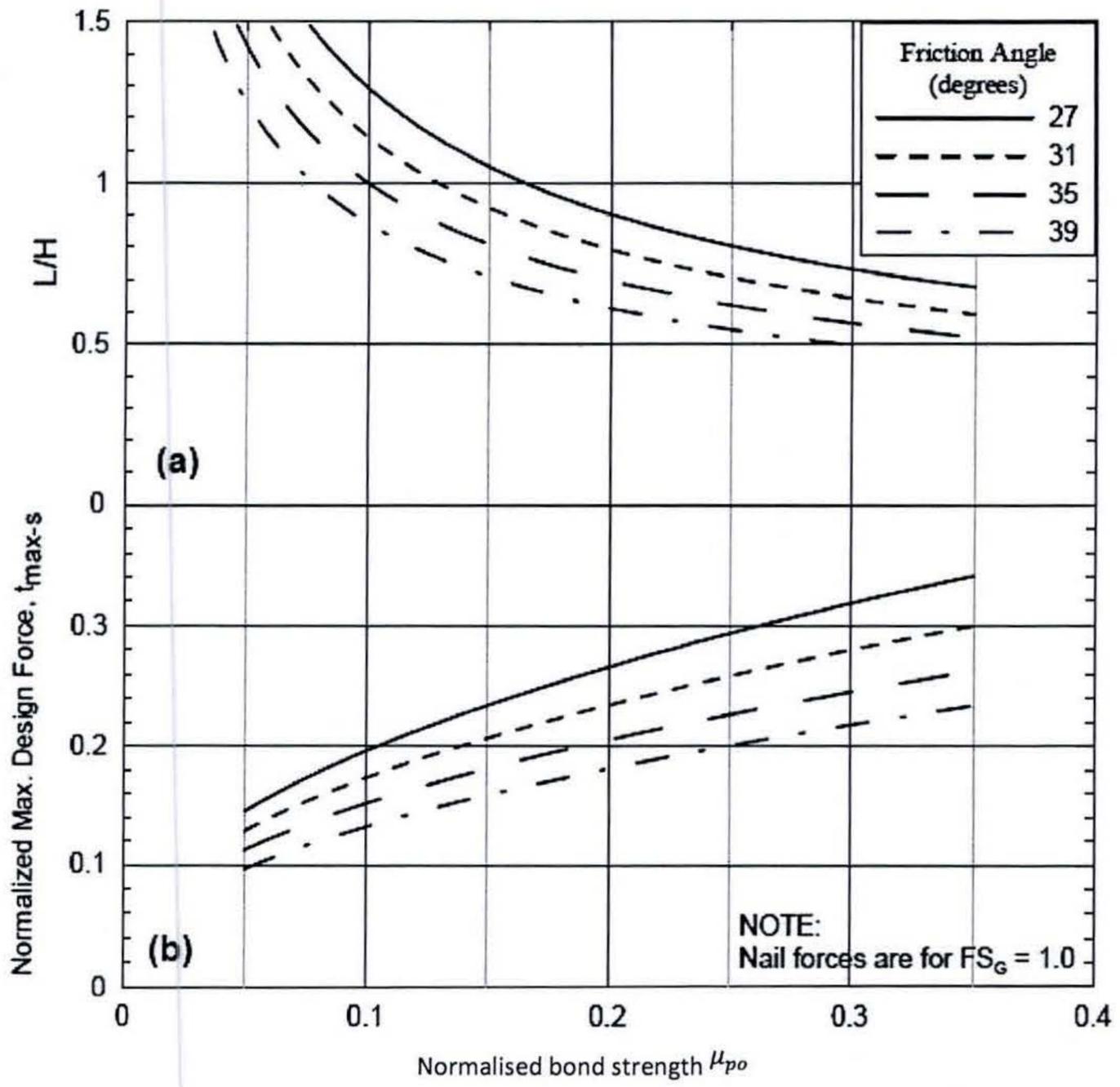(b) Minimum required length
overall stability $(L_R/H)_{ovrl}$
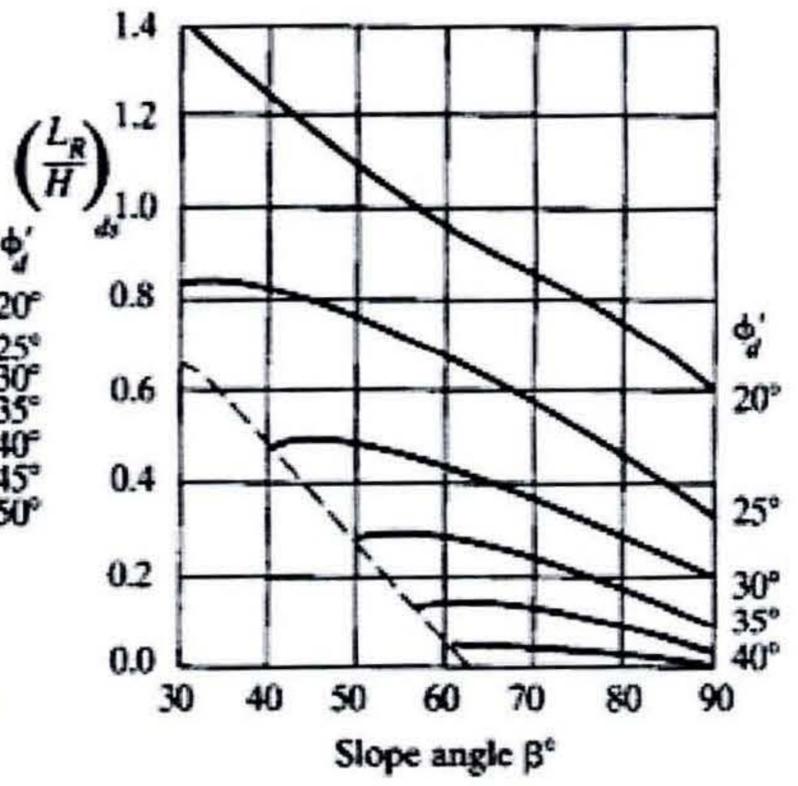
(c) Minimum required length
direct sliding $(L_R/H)_{ds}$

Material	Construction method	Soil / rock type	Ultimate bond strength q_s [kPa]
Rock	Rotary drilled	Marl / limestone	300 - 400
		Phyllite	100 - 300
		Chalk	500 - 600
		Soft dolomite	400 - 600
		Fissured dolomite	600 - 1000
		Weathered sandstone	200 - 300
		Weathered shale	100 - 150
		Weathered schist	100 - 175
		Basalt	500 - 600
		Slate / hard shale	300 - 400
Cohesionless soils	Rotary drilled	Sand / gravel	100 - 180
		Silty sand	100 - 150
		Silt	40 - 120
		Piedmont residual	40 - 120
		Fine colluvium	75 - 150
	Driven casing	Sand / gravel -low overburden	190 - 240
		-high overburden	280 - 430
		Dense moraine	380 - 480
		Colluvium	100 - 180
	Augered	Silty sand fill	20 - 40
		Silty fine sand	55 - 90
		Silty clayey sand	60 - 140
	Jet grouted	Sand	380
		Sand gravel	700

Threaded soil nail bar properties Grade 525MPa

Bar diameter (mm)	Cross sectional area (mm²)	Maximum Axial Load (KN)
19	284	147
22	387	206
25	510	264
29	645	334
32	819	424
36	1006	526
45	1452	751

Legend (Friction Angle (degrees)):
- ——— 27
- – – – 31
- — — 35
- —·— 39

(a) — L/H

(b) — Normalized Max. Design Force, t_{max-s}

NOTE:
Nail forces are for $FS_G = 1.0$

Normalised bond strength μ_{po}

Depth, d	Correction for rod length, C_R
$d < 3\,m$	0.75
$d = 3-4\,m$	0.8
$d = 4-6\,m$	0.85
$d = 6-10\,m$	0.95
$d = 10-30\,m$	1.0

LPI	Severity
0	None
0-5	Low
5-15	Medium
>15	High

Fines (%)	Q	R
5% silt	9.1	0.99
10% silt	9.3	0.98
2% clay	12.1	0.96
5% clay	11.7	0.95
10% clay	10.9	0.8

Approximate induced settlement as % of treatment depth

Soil type	% depth
Natural clays	1-3
Clay fills	3-5
Natural sands	3-10
Granular fills	5-15
Refuse and peat	7-20

Range of n values for various soil types

Soil type	Degree of saturation	Recommended n value
Pervious soil deposits - Granular soils	High low	0.5 0.5 - 0.6
Semipervious soil deposits - Primarily silts with plasticity index of < 8	High low	0.35 - 0.40 0.4 - 0.5
Impervious deposits - Primarily clayey soils with plasticity index of > 8	High Low	Not recommended 0.35 - 0.40 Soils should be at water content less than the plastic limit
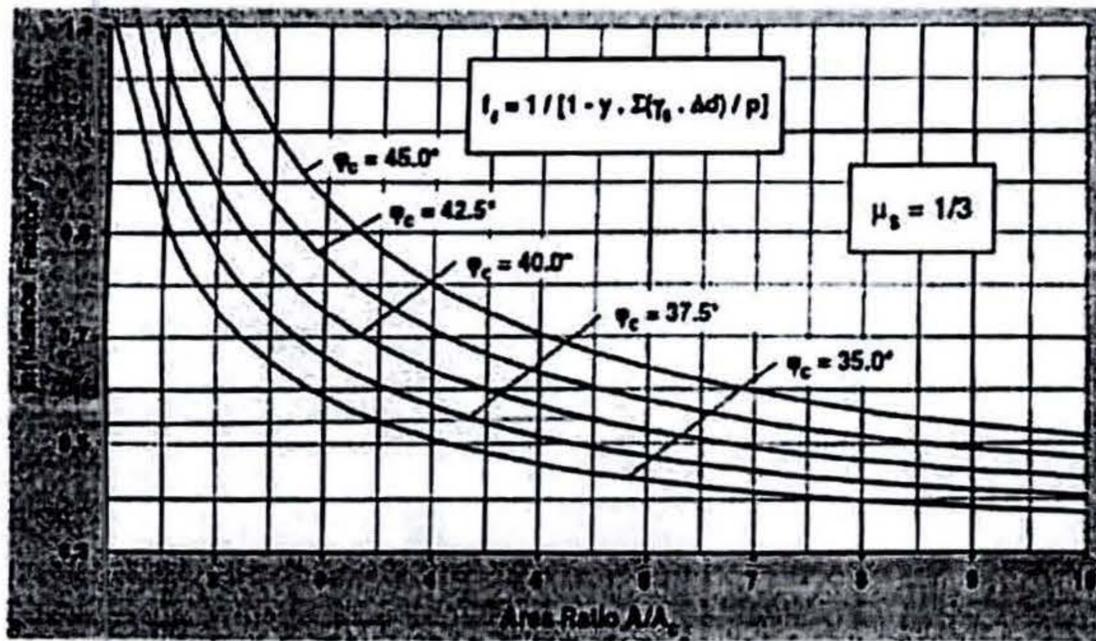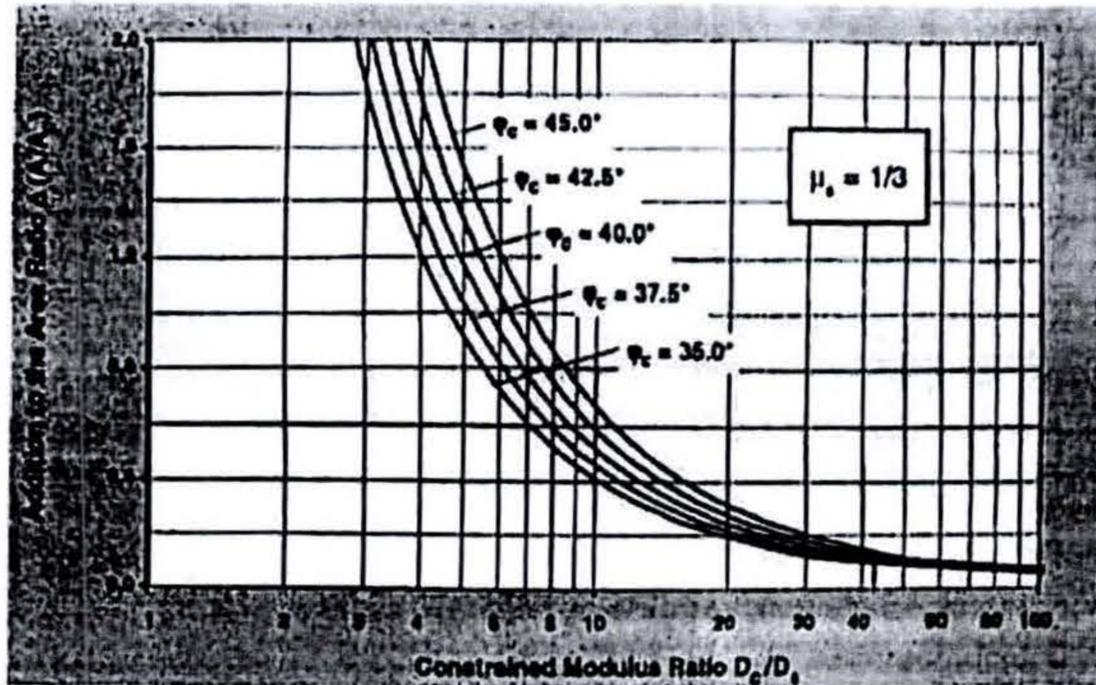
Chart 1: Vertical axis — Normalized Area Ratio A(A); Horizontal axis — Constrained Modulus Ratio D_c/D_s. Curves: $\varphi_c = 45.0°$, $\varphi_c = 42.5°$, $\varphi_c = 40.0°$, $\varphi_c = 37.5°$, $\varphi_c = 35.0°$. $\mu_s = 1/3$

Chart 2: Horizontal axis — Area Ratio A/A_c. $f_s = 1 / [1 - y \cdot \Sigma(\gamma_s \cdot \Delta d) / p]$. Curves: $\varphi_c = 45.0°$, $\varphi_c = 42.5°$, $\varphi_c = 40.0°$, $\varphi_c = 37.5°$, $\varphi_c = 35.0°$. $\mu_s = 1/3$

r

$$P = \frac{ES^2}{NMH} \qquad D = n\sqrt{mh} \qquad D = 0.4\sqrt{\frac{E_d h}{AC_u}}$$

$$Q_u = \left(\frac{1+\sin\varphi_c}{1-\sin\varphi_c}\right)\gamma H + 4C \qquad (N_1)_{60} = N_M C_N C_E C_B C_R C_S \qquad (N_1)_{60cs} = \alpha + \beta(N_1)_{60}$$

$$CRR = e^{\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{23.4}\right)^4 - 2.8\right)} \qquad FC \le 5\%: \alpha = 0, \beta = 1$$

$$5\% < FC < 35\%: \alpha = e^{\left(1.76 - \frac{190}{FC^2}\right)}, \beta = 0.99 + \frac{FC^{1.5}}{1000} \qquad FC \ge 35\%: \alpha = 5, \beta = 1.2$$

$$CSR = 0.65x\frac{a_{max}}{g}x\frac{\sigma}{\sigma'}x\,r_d \qquad z < 9.15m: r_d = 1 - 0.00765z$$

$$z > 9.15m: r_d = 1.174 - 0.0026z \qquad LPI = \sum_{i=1}^{N} w_i F_i H_i \qquad z < 20m: w = 10 - 0.5z$$

$$z > 20m: w = 0 \qquad FS < 1.0: F = 1 - FS \qquad FS > 1.0: F = 0$$

$$F = \frac{\sum[CL + (W\cos\alpha - U)\tan\varphi]}{\sum W \sin\alpha} \qquad \frac{L}{H}_{corrected} = C_{1L} \times C_{2L} \times C_{3L} \times \frac{L}{H} \text{(from chart)} \qquad C^* = \frac{C}{\gamma H}$$

$$C_{1L} = 1.5 - 0.15D_{dh} + 0.0065\,D_{dh}^2 \qquad C_{2L} = -4\,C^* + 1.09 > 0.85 \qquad C_{3L} = 0.52Fos + 0.3 > 1$$

Anchor force $T = \dfrac{(P + \gamma H/2)\,H\cos B\,(F - \cot B\tan\varphi) - (CH/\sin B)}{\sin(A+B)\tan\varphi + F\cos(A+B)}$ $\qquad \mu_{po} = \dfrac{q_u D_{DH}}{P_{po}\gamma S_h S_v}$

$$H' = H + \frac{q}{\gamma} \qquad S_{v\,max} = \frac{LTDS}{k\gamma z_{max}} \qquad \varphi_f = tan^{-1}\left(\frac{\tan\varphi}{FS}\right) \qquad P = \frac{1}{2}k\gamma H'^2$$

$$n = \frac{H}{S_v} \qquad k_a = \frac{1-\sin\varphi}{1+\sin\varphi} \qquad P_a = \sigma_z k_a - 2c\sqrt{k_a} \qquad P_a = 1/2k_a\gamma H^2$$

$$k_p = \frac{1+\sin\varphi}{1-\sin\varphi} \qquad P_p = \sigma_z k_a + 2c\sqrt{k_a} \qquad P_p = 1/2k_p\gamma D^2 + 2C\sqrt{k_p}\,D$$

$$k_a = \tan^2\left(45 - \frac{\varphi}{2}\right) \qquad n_o = 1 + \frac{A_c}{A}\left[\frac{\frac{1}{2} + f(\mu_s, {}^{A_c}/_A)}{k_{ac} \times f(\mu_s, {}^{A_c}/_A)} - 1\right]$$

$$f(\mu_s, {}^{A_c}/_A) = \frac{(1-\mu_s)(1 - {}^{A_c}/_A)}{1 - 2\mu_s + {}^{A_c}/_A} \qquad \frac{\overline{A_c}}{A} = \frac{1}{{}^{A}/_{A_c} + {}^{\Delta A}/_{A_c}} \qquad n_1 = 1 + \frac{\overline{A_c}}{A}x\left[\frac{\frac{1}{2} + f(\mu_s, \frac{\overline{A_c}}{A})}{k_{ac} \times f(\mu_s, \frac{A_c}{A})} - 1\right]$$

$$f(\mu_s, \overline{{}^{A_c}/_A}) = \frac{(1-\mu_s)(1 - \overline{{}^{A_c}/_A})}{1 - 2\mu_s + \overline{{}^{A_c}/_A}} \qquad n_2 = f_d x n_1 \qquad f_d = \frac{1}{1 - \frac{\gamma \sum \gamma_s \Delta d}{P}} \qquad m' = \frac{n-1}{n}$$

$$\tan\varphi = m'\tan\varphi_c + (1 - m')\tan\varphi_s \qquad Q_u = \left(\frac{1+\sin\varphi_c}{1-\sin\varphi_c}\right)\gamma H + 4C \qquad \text{/\textbackslash\,\textbackslash}$$