UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: July 2017

Module Number: CE7305 **Module Name: Geotechnical Engineering Design**

[Three Hours]

[Answer **all questions**, each question carries **FIFTEEN** marks]

Q1. a) Briefly explain two situations where negative skin friction would develop on piles.

[1.0 Marks]

b) Sub surface soil profile at an interchange in the Southern Expressway project is shown in Figure Q1.1. A series of laboratory tests were conducted for the soil samples obtained from each layer during the site investigations and results are illustrated in Table Q1.1. The water table was found to be at the existing ground surface. The unit weight of water can be taken as 9.81 kN/m³.

Due to the presence of very soft clay, it is not possible to adopt shallow foundations to carry the structural loads of the Facility Building and it was decided adopt pile foundations at each column location to carry the superstructure load. Hence, Geotechnical Engineer has decided to drive the 0.4 m diameter precast concrete solid piles up to the dense sand layer (15.0 m from the existing ground surface).

Based on the structural analysis, maximum working load on a footing was found to be 1500 kN.

Following equations with general notations may be useful in the calculations.

$$\eta = 1 - \frac{\theta}{90}\left[\frac{(n-1)m + (m-1)n}{mn}\right]$$

$$\theta = tan^{-1}(d/s)$$

$$Q_p = A_p q' N_q^* \leq A_p q_1$$

$$q_1 = 50 N_q^* tan\varphi$$

$$s_1 = \frac{(Q_{wp} + \theta Q_{ws})L}{A_p E_p}$$

$$\theta = 0.6$$

$$s_2 = \frac{q_{wp} D (1-\mu_s^2) I_{wp}}{E_s}$$

$$I_{wp} = 0.85$$

$$s_3 = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1-\mu_s^2) I_{ws}$$

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}}$$

Figure Q1.2, Figure Q1.3 and Figure Q1.4 may also be useful in the calculations.

i) If a 1.0 m height soil fill is placed over the existing ground surface to support the pile driving machine, what would be the expected negative skin frictional force on a single pile? Assume that the negative skin friction will develop only upto a depth of 9.0 m from the existing ground surface. Unit weigh of the fill material can be taken as 18.0 kN/m³.

[2.0 Marks]

ii) As a junior Geotechnical Engineer in the project, show that the proposed driven depth of the pile is not sufficient to carry the superstructure load at each column location.

Hint: Deduct negative skin frictional force from the summation of frictional force and end bearing force to compute the ultimate bearing capacity

[6.0 Marks]

iii) Since the capacity of a single pile is not sufficient to carry the superstructure load of a column, it is proposed to drive 2 x 2 precast concrete piles with the same diameter at 1.0 m spacing up to the same depth as a pile group to carry the superstructure load. What would be the expected pile group capacity?

[2.0 Marks]

iv) What would be the expected elastic settlement of a single pile? The average weighted young's modulus of soil upto the dense sand layer is 13,000 kPa where as the young's modulus of dense sand is 50,000 kPa. The Young's modulus of concrete is 20.67x10⁶ kPa. The average weighted poisson's ratio of soil upto the dense sand layer is 0.5 where as the poisson's ratio of dense sand is 0.25.

[4.0 Marks]

Q2. A 3.0 m x 3.0 m box culvert is proposed to be constructed across a highway embankment in order to provide a proper drainage as shown in Figure Q2.1. According to the hydrological study, it was decided to place box culvert at an elevation of 42.000 m MSL. The finished embankment level is at an elevation of 53.200 m MSL. The expected pavement load and traffic load of the highway is 25.0 kN/m². In order to control the consolidation settlement, soft peaty clay below the foundation level is removed upto the completely weathered rock layer and is replaced with boulders and crushed aggregates as shown in Figure Q2.1. The ground water table is at an elevation of 42.000 m MSL.

The geotechnical properties of the sub surface soil profile are shown in Table Q2.1. The unit weight of water can be taken as 9.81 kN/m³.

As width of the embankment is large, length of the box culvert is much larger than the width. Hence, for the analysis, foundation of the box culvert can be considered as a strip footing.

Following equations with general notations may be useful in the calculations.

$$q_u = cN_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

$$F_{cs} = 1 + \frac{B}{L}\frac{N_q}{N_c}\ ,\ F_{qs} = 1 + \frac{B}{L}\tan\phi \quad \text{and} \quad F_{\gamma s} = 1 - 0.4\frac{B}{L}$$

$$\text{when } \frac{D_f}{B} \le 1 \quad F_{cd} = 1 + 0.4\frac{D_f}{B},\ F_{qd} = 1 + 2\tan\phi(1-\sin\phi)^2\frac{D_f}{B} \text{ and } F_{\gamma d} = 1$$

$$\text{when } \frac{D_f}{B} > 1 \quad F_{cd} = 1 + 0.4\tan^{-1}\left(\frac{D_f}{B}\right),\ F_{qd} = 1 + 2\tan\phi(1-\sin\phi)^2\tan^{-1}\left(\frac{D_f}{B}\right) \text{ and}$$

$$F_{\gamma d} = 1$$

$$F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2 \text{ and } F_{\gamma i} = \left(1 - \frac{\beta}{\phi}\right)^2$$

when $0 \le d \le B$ $\quad \bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma')$ where $\gamma' = \gamma_{sat} - \gamma_w$

Elastic settlement of foundation $S_e = q_0(\alpha B')\frac{(1-\mu_s^2)}{E_s} I_s I_f$

$B' = B/2$ for center of foundation

$B' = B$ for corner of foundation

$\alpha = 4$ at the center of the foundation

$\alpha = 1$ at the corner of the foundation

Center of foundation $m' = \frac{L}{B}$, $n' = \frac{H}{B/2}$

Corner of foundation $m' = \frac{L}{B}$, $n' = \frac{H}{B}$

$$I_s = F_1 + \frac{(1 - 2\mu_s)}{(1 - \mu_s)} F_2$$

Table Q2.2, Table Q2.3, Table Q2.4 and Figure Q2.2 may also useful in the calculations.

a) Embankment fill is placed once the box culvert is constructed. Hence, what would be the allowable bearing capacity at the foundation level (Elevation of 42.000 m MSL) before the embankment construction, assuming that the factor of safety is 3.0?

[4.5 Marks]

b) What would be the allowable bearing capacity at the foundation level (Elevation of 42.000 m MSL) after the highway construction is over assuming that the factor of safety is 3.0.

[1.5 Marks]

c) In order to control the shrinkage cracks of the box culvert, the Structural Engineer has advised to construct the box culvert as 6.0 m length segments, as such foundation of the box culvert can be considered as an individual pad footing. Hence, what would be the expected allowable bearing capacity at the foundation level (Elevation of 42.000 m MSL) under the new arrangement after the highway construction is over assuming that the factor of safety is 3.0.

[4.0 Marks]

d) What would be the expected elastic settlement at the corner and the center of the foundation once the highway construction is over? The estimated working stress on the foundation level is 250.0 kN/m².

[5.0 Marks]

Q3. Figure Q3.1 depicts an abutment in a proposed earth dam constructed for a local reservoir in a rural area. Stability of the abutment is to be evaluated for different stages in its life. A trial failure surface with radius of 25.0 m is selected and the failure mass is divided into seven slices as shown in the Figure Q3.1. Using the steady state flow net, pore water pressure (u) at the mid points of the bottom of the slices are obtained and tabulated in Table Q3.1 together with other information such as, weight of the slice (W), width of the slice (Δx) and slice angle (θ). The effective shear strength parameters of the soil, cohesion is 20 kN/m² and internal friction angle is 36°. The average unit weight of the soil can be taken as 19.0 kN/m³.

The average water level in the reservoir is marked as AWL in the Figure Q3.1. It is assumed that soil above the AWL is also fully saturated due to capillary action.

Following Simplified Bishop's expression with general notations may be useful in the calculations.

$$F = \frac{\sum_{i=1}^{n}\left[c'\Delta x_i + (W_i - u_i\Delta x_i)\tan\phi'\right]\left[1/M_i(\theta)\right]}{\sum_{i=1}^{n} W_i Sin\theta_i}$$

where $M_i(\theta) = Cos\theta_i + \frac{Sin\theta_i \tan\phi'}{F}$

a) Briefly describe the variation of safety factor with time for the soil beneath a fill (under an embankment) with the aid of sketches.

[2.0 Marks]

b) It was decided to evaluate the stability of the abutment immediately after water level drops to the Low Water Level (LWL) using the Simplified Bishop's method of slices.

Note:- Calculation of the factor of safety can be done in Table Q3.1 and should be attached to the answer book.

i) What would be the trial factor of safety for the first iteration?

[4.5 Marks]

ii) What would be the trial factor of safety for the second iteration?

[4.0 Marks]

iii) What would be the average factor of safety after second iteration?

[3.5 Marks]

iv) State 2 methods to enhance the stability of the above slope?

[1.0 Marks]

Q4. Due to limited Right of Way (ROW), a segment of a highway embankment is to be supported by a cantilevered retaining wall as shown in Figure Q4.1. Retaining wall is to be constructed of reinforced concrete and backfilled with compacted lateritic soil. Backfill material has effective shear strength parameters of cohesion (c') = 5 kPa and internal friction angle (ϕ') =32°. Dry unit weight and saturated unit weight of backfill are 16.5 kN/m^3 and 18.0 kN/m^3, respectively.

Trial wall section of the retaining wall is shown in Figure Q4.1. Dense sand exists beneath the proposed foundation level and a bearing pressure of 275 kPa can be allowed. Dense sand has a friction angle of 38°. Water table was well below the ground surface. The unit weights of water and concrete can be taken as 9.81 kN/m^3 and 24.0 kN/m^3, respectively. The variation of K_A with φ'_{design} is illustrated in Figure Q4.2.

a) What would be the expected active earth force on virtual back of retaining wall (AB) according to BS8002?

[4.5 Marks]

b) Evaluate the stability of the retaining wall against sliding according to BS8002.

[4.0 Marks]

c) Evaluate the stability of the retaining wall against overturning according to BS8002.

[2.0 Marks]

d) Evaluate the stability of the retaining wall against bearing failure.

[2.5 Marks]

e) Abutment of an underpass is decided be constructed using reinforced earth mechanism. What are the advantages of reinforced earth mechanism over conventional retaining walls? List 4 factors.

[2.0 Marks]

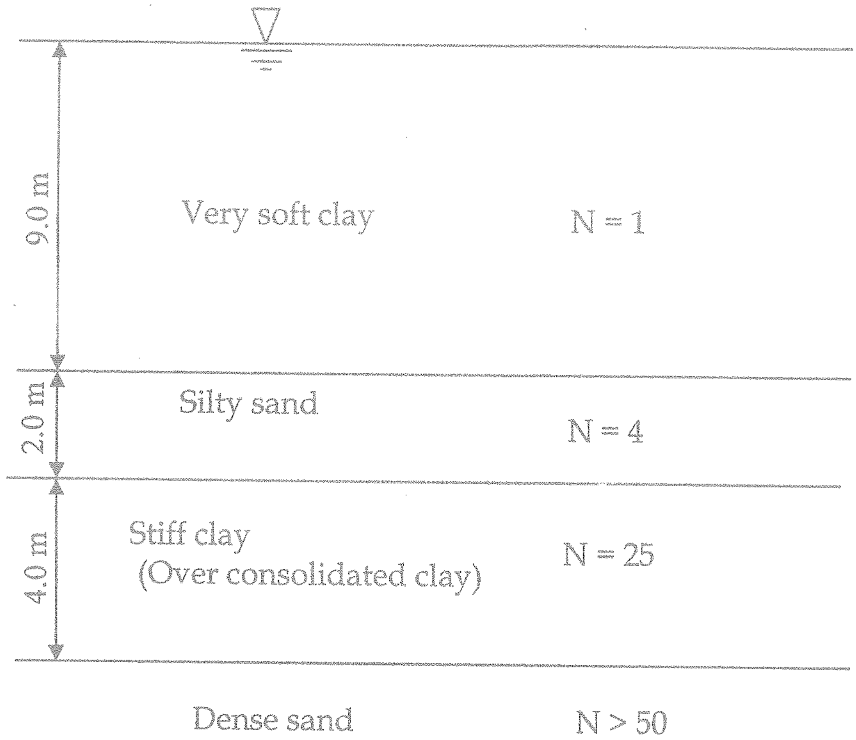

Figure Q1.1 Sub-surface soil profile at the proposed Facility Building

Table Q1.1 – Engineering properties of subsurface soil

	Very soft clay	Silty sand	Stiff clay (OC clay)	Dense sand
Drained cohesion (kN/m^2)	0	2.0	8.0	0
Undrained cohesion (kN/m^2)	5.0	10.0	80.0	0
Internal friction angle (^{0})	18	20	30	35
Bulk unit weight (kN/m^3)	14.0	16.0	18.0	20.0

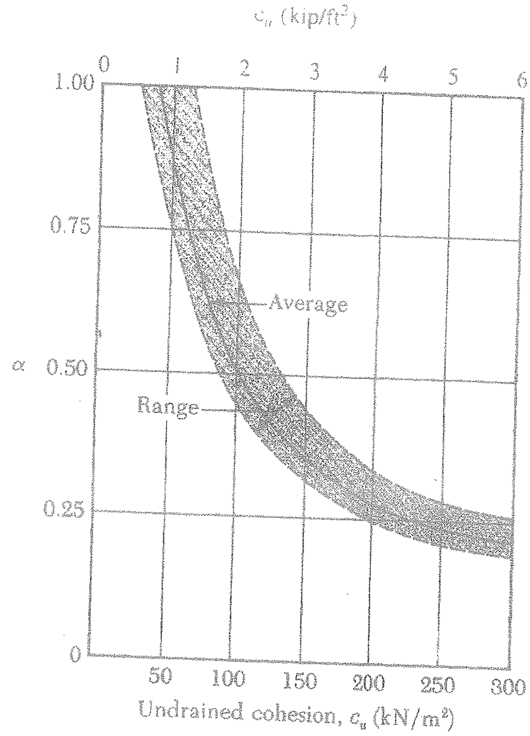

Figure Q1.2 - Variation of α with undrained cohesion of clay

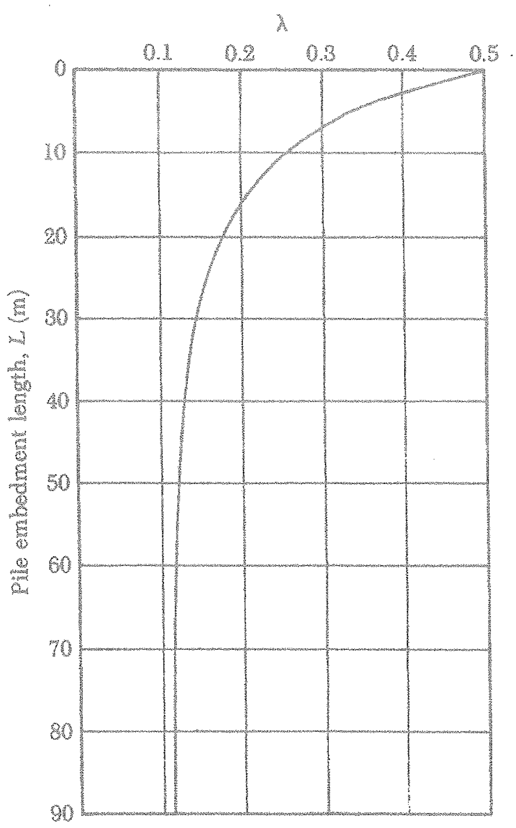

Figure Q1.3 - Variation of λ with pile embedded length

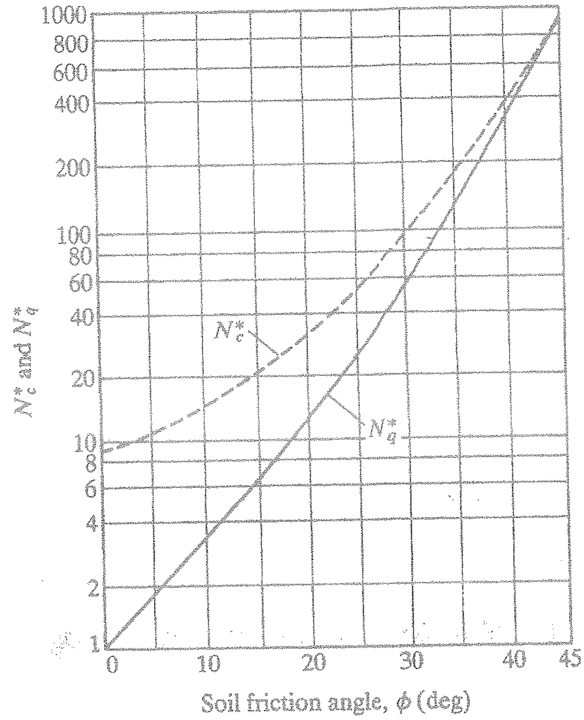

Figure Q1.4 - Variation of N_c^* and N_q^* with soil friction angle

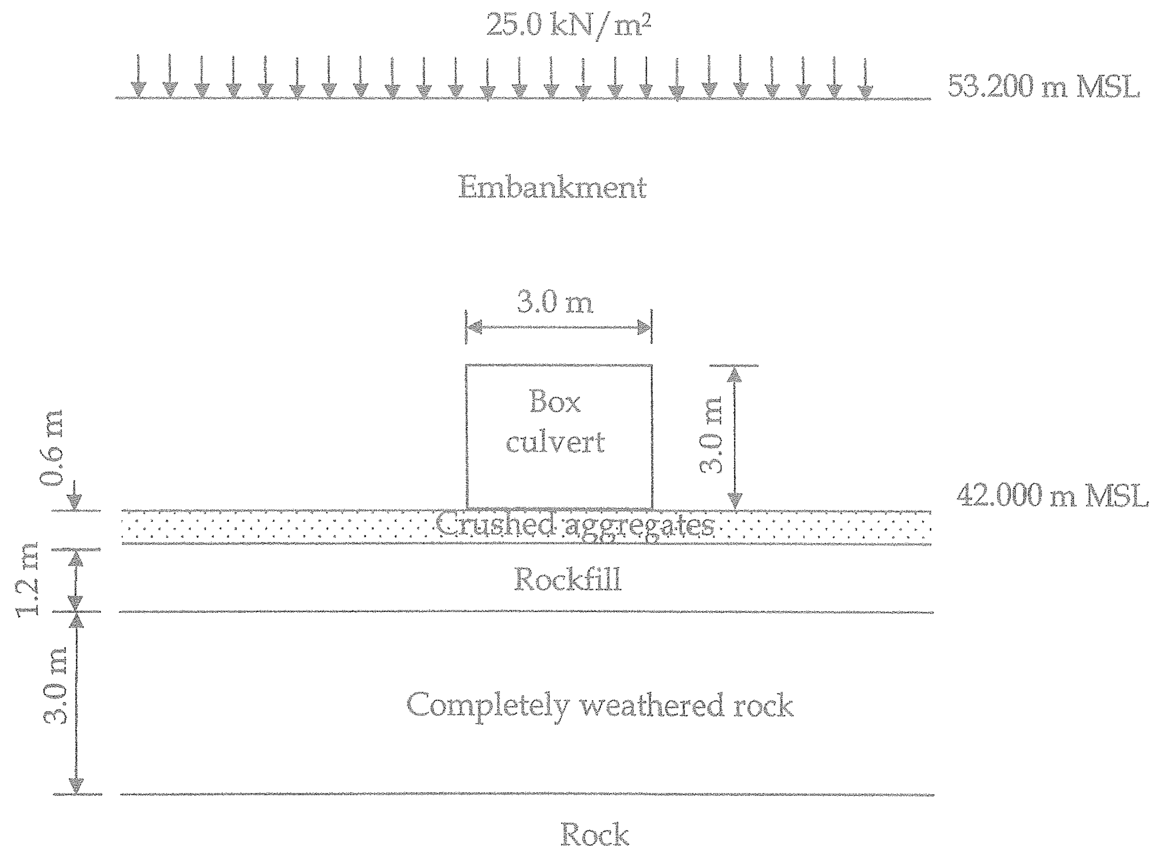

Figure Q2.1 – Cross section of embankment

Table Q2.1 – Engineering properties of sub surface soil

	Embankment	Crushed aggregates	Rockfill	Completely weathered rock
Drained cohesion (kN/m^2)	5.0	10.0	0	8.0
Internal friction angle (^{0})	30	35	32	30
Bulk unit weight (kN/m^3)	16.5	22.0	20.0	18.0
Poisson's ratio	0.33	0.25	0.28	0.30
Young's Modulus (kN/m^2)	25,000	35,000	30,000	25,000

Table Q2.2- Bearing capacity factors

ϕ	N_c	N_q	N_γ	N_q/N_c	$\tan\phi$	ϕ	N_c	N_q	N_γ	N_q/N_c	$\tan\phi$
0	5.14	1.00	0.00	0.20	0.00	26	22.25	11.85	12.54	0.53	0.49
1	5.38	1.09	0.07	0.20	0.02	27	23.94	13.20	14.47	0.55	0.51
2	5.63	1.20	0.15	0.21	0.03	28	25.80	14.72	16.72	0.57	0.53
3	5.90	1.31	0.24	0.22	0.05	29	27.86	16.44	19.34	0.59	0.55
4	6.19	1.43	0.34	0.23	0.07	30	30.14	18.40	22.40	0.61	0.58
5	6.49	1.57	0.45	0.24	0.09	31	32.67	20.63	25.99	0.63	0.60
6	6.81	1.72	0.57	0.25	0.11	32	35.49	23.18	30.22	0.65	0.62
7	7.16	1.88	0.71	0.26	0.12	33	38.64	26.09	35.19	0.68	0.65
8	7.53	2.06	0.86	0.27	0.14	34	42.16	29.44	41.06	0.70	0.67
9	7.92	2.25	1.03	0.28	0.16	35	46.12	33.30	48.03	0.72	0.70
10	8.35	2.47	1.22	0.30	0.18	36	50.59	37.75	56.31	0.75	0.73
11	8.80	2.71	1.44	0.31	0.19	37	55.63	42.92	66.19	0.77	0.75
12	9.28	2.97	1.69	0.32	0.21	38	61.35	48.93	78.03	0.80	0.78
13	9.81	3.26	1.97	0.33	0.23	39	67.87	55.96	92.25	0.82	0.81
14	10.37	3.59	2.29	0.35	0.25	40	75.31	64.20	109.41	0.85	0.84
15	10.98	3.94	2.65	0.36	0.27	41	83.86	73.90	130.22	0.88	0.87
16	11.63	4.34	3.06	0.37	0.29	42	93.71	85.38	155.55	0.91	0.90
17	12.34	4.77	3.53	0.39	0.31	43	105.11	99.02	186.54	0.94	0.93
18	13.10	5.26	4.07	0.40	0.32	44	118.37	115.31	224.64	0.97	0.97
19	13.93	5.80	4.68	0.42	0.34	45	133.88	134.88	271.76	1.01	1.00
20	14.83	6.40	5.39	0.43	0.36	46	152.10	158.51	330.35	1.04	1.04
21	15.82	7.07	6.20	0.45	0.38	47	173.64	187.21	403.67	1.08	1.07
22	16.88	7.82	7.13	0.46	0.40	48	199.26	222.31	496.01	1.12	1.11
23	18.05	8.66	8.20	0.48	0.42	49	229.93	265.51	613.16	1.15	1.15
24	19.32	9.60	9.44	0.50	0.45	50	266.89	319.07	762.89	1.20	1.19
25	20.72	10.66	10.88	0.51	0.47						

* After Vesic (1973)

Table Q2.3 - Variation of F_1 with m′ and n′

n′	m′																			
	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	25.0	50.0	100.0
0.25	0.014	0.013	0.012	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
0.50	0.049	0.046	0.044	0.042	0.041	0.040	0.038	0.038	0.037	0.037	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
0.75	0.095	0.090	0.087	0.084	0.082	0.080	0.077	0.076	0.074	0.074	0.073	0.073	0.072	0.072	0.072	0.072	0.071	0.071	0.071	0.071
1.00	0.142	0.138	0.134	0.130	0.127	0.125	0.121	0.118	0.116	0.115	0.114	0.113	0.112	0.112	0.112	0.111	0.111	0.110	0.110	0.110
1.25	0.186	0.183	0.179	0.176	0.173	0.170	0.165	0.161	0.158	0.157	0.155	0.154	0.153	0.152	0.152	0.151	0.151	0.150	0.150	0.150
1.50	0.224	0.224	0.222	0.219	0.216	0.213	0.207	0.203	0.199	0.197	0.195	0.194	0.192	0.191	0.190	0.190	0.189	0.188	0.188	0.188
1.75	0.257	0.259	0.259	0.258	0.255	0.253	0.247	0.242	0.238	0.235	0.233	0.232	0.229	0.228	0.227	0.226	0.225	0.223	0.223	0.223
2.00	0.285	0.290	0.292	0.292	0.291	0.289	0.284	0.279	0.275	0.271	0.269	0.267	0.264	0.262	0.261	0.260	0.259	0.257	0.256	0.256
2.25	0.309	0.317	0.321	0.323	0.323	0.322	0.317	0.313	0.308	0.305	0.302	0.300	0.296	0.294	0.293	0.291	0.291	0.287	0.287	0.287
2.50	0.330	0.341	0.347	0.350	0.351	0.351	0.348	0.344	0.340	0.336	0.333	0.331	0.327	0.324	0.322	0.321	0.320	0.316	0.315	0.315
2.75	0.348	0.361	0.369	0.374	0.377	0.378	0.377	0.373	0.369	0.365	0.362	0.359	0.355	0.352	0.350	0.348	0.347	0.343	0.342	0.342
3.00	0.363	0.379	0.389	0.396	0.400	0.402	0.402	0.400	0.396	0.392	0.389	0.386	0.382	0.378	0.376	0.374	0.373	0.368	0.367	0.367
3.25	0.376	0.394	0.406	0.415	0.420	0.423	0.426	0.424	0.421	0.418	0.415	0.412	0.407	0.403	0.401	0.399	0.397	0.391	0.390	0.390
3.50	0.388	0.408	0.422	0.431	0.438	0.442	0.447	0.447	0.444	0.441	0.438	0.435	0.430	0.427	0.424	0.421	0.420	0.413	0.412	0.411
3.75	0.399	0.420	0.436	0.447	0.454	0.460	0.467	0.458	0.466	0.464	0.461	0.458	0.453	0.449	0.446	0.443	0.441	0.433	0.432	0.432
4.00	0.408	0.431	0.448	0.460	0.469	0.476	0.484	0.487	0.486	0.484	0.482	0.479	0.474	0.470	0.466	0.464	0.462	0.453	0.451	0.451
4.25	0.417	0.440	0.458	0.472	0.481	0.484	0.495	0.514	0.515	0.515	0.516	0.496	0.484	0.473	0.471	0.471	0.470	0.468	0.462	0.460
4.50	0.424	0.450	0.469	0.484	0.495	0.503	0.516	0.521	0.522	0.522	0.520	0.517	0.513	0.508	0.505	0.502	0.499	0.489	0.487	0.487
4.75	0.431	0.458	0.478	0.494	0.506	0.515	0.530	0.536	0.539	0.539	0.537	0.535	0.530	0.526	0.523	0.519	0.517	-0.506	0.504	0.503
5.00	0.437	0.465	0.487	0.503	0.516	0.526	0.543	0.551	0.554	0.554	0.554	0.552	0.548	0.543	0.540	0.536	0.534	0.522	0.519	0.519
5.25	0.443	0.472	0.494	0.512	0.526	0.537	0.555	0.564	0.568	0.569	0.569	0.568	0.564	0.560	0.556	0.553	0.550	0.537	0.534	0.534
5.50	0.448	0.478	0.501	0.520	0.534	0.546	0.566	0.576	0.581	0.584	0.584	0.583	0.579	0.575	0.571	0.568	0.585	0.551	0.549	0.548
5.75	0.453	0.483	0.508	0.527	0.542	0.555	0.576	0.588	0.594	0.597	0.597	0.597	0.594	0.590	0.586	0.583	0.580	0.565	0.583	0.562
6.00	0.457	0.489	0.514	0.534	0.550	0.563	0.585	0.598	0.606	0.609	0.611	0.610	0.608	0.604	0.601	0.598	0.595	0.579	0.576	0.575
6.25	0.461	0.493	0.519	0.540	0.557	0.570	0.594	0.609	0.617	0.621	0.623	0.623	0.621	0.618	0.615	0.611	0.608	0.592	0.589	0.588
6.50	0.465	0.498	0.524	0.546	0.563	0.577	0.603	0.618	0.627	0.632	0.635	0.635	0.634	0.631	0.628	0.625	0.622	0.605	0.601	0.600
6.75	0.468	0.502	0.529	0.551	0.569	0.584	0.610	0.627	0.637	0.643	0.646	0.647	0.646	0.644	0.641	0.637	0.634	0.617	0.613	0.612
7.00	0.471	0.506	0.533	0.556	0.575	0.590	0.618	0.635	0.646	0.653	0.656	0.658	0.658	0.656	0.653	0.650	0.647	0.628	0.624	0.623
7.25	0.474	0.509	0.538	0.561	0.580	0.596	0.625	0.643	0.655	0.662	0.666	0.669	0.669	0.668	0.665	0.662	0.659	0.640	0.635	0.634
7.50	0.477	0.513	0.541	0.565	0.585	0.601	0.631	0.650	0.663	0.671	0.676	0.679	0.680	0.679	0.676	0.673	0.670	0.651	0.646	0.645
7.75	0.480	0.516	0.545	0.569	0.589	0.606	0.637	0.658	0.671	0.680	0.685	0.688	0.690	0.689	0.687	0.684	0.681	0.661	0.656	0.655
8.00	0.482	0.519	0.549	0.573	0.594	0.611	0.643	0.664	0.678	0.688	0.694	0.697	0.700	0.700	0.698	0.695	0.692	0.672	0.666	0.665
8.25	0.485	0.522	0.552	0.577	0.598	0.615	0.648	0.670	0.685	0.695	0.702	0.706	0.710	0.710	0.708	0.705	0.703	0.682	0.676	0.675
8.50	0.487	0.524	0.555	0.580	0.601	0.619	0.653	0.676	0.692	0.703	0.710	0.714	0.719	0.719	0.718	0.715	0.713	0.692	0.686	0.684
8.75	0.489	0.527	0.558	0.583	0.605	0.623	0.658	0.682	0.698	0.710	0.717	0.722	0.727	0.728	0.727	0.725	0.723	0.701	0.695	0.693
9.00	0.491	0.529	0.560	0.587	0.609	0.627	0.663	0.687	0.705	0.716	0.725	0.730	0.736	0.737	0.736	0.735	0.732	0.710	0.704	0.702
9.25	0.493	0.531	0.563	0.589	0.612	0.631	0.667	0.693	0.710	0.723	0.731	0.737	0.744	0.746	0.745	0.744	0.742	0.719	0.713	0.711
9.50	0.495	0.533	0.565	0.592	0.615	0.634	0.671	0.697	0.716	0.719	0.738	0.744	0.752	0.754	0.754	0.753	0.751	0.728	0.721	0.719
9.75	0.496	0.536	0.568	0.595	0.618	0.638	0.675	0.702	0.721	0.735	0.744	0.751	0.759	0.762	0.762	0.761	0.759	0.737	0.729	0.727
10.00	0.498	0.537	0.570	0.597	0.621	0.641	0.679	0.707	0.726	0.740	0.750	0.758	0.766	0.770	0.770	0.770	0.768	0.745	0.738	0.735
20.00	0.529	0.575	0.614	0.647	0.677	0.702	0.756	0.797	0.830	0.858	0.878	0.896	0.925	0.945	0.959	0.969	0.977	0.982	0.965	0.957
50.00	0.548	0.598	0.640	0.678	0.711	0.740	0.803	0.853	0.895	0.931	0.962	0.989	1.034	1.070	1.100	1.125	1.146	1.265	1.279	1.261
100.00	0.555	0.605	0.649	0.688	0.722	0.753	0.819	0.872	0.918	0.956	0.990	1.020	1.072	1.114	1.150	1.182	1.209	1.408	1.489	1.499

Table Q2.4 - Variation of F_2 with m′ and n′

n′ \ m′	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	25.0	50.0	100.0
0.25	0.049	0.050	0.051	0.051	0.051	0.052	0.052	0.052	0.052	0.052	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
0.50	0.074	0.077	0.080	0.081	0.083	0.084	0.086	0.086	0.0878	0.087	0.087	0.087	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
0.75	0.083	0.089	0.093	0.097	0.099	0.101	0.104	0.106	0.107	0.108	0.109	0.109	0.109	0.110	0.110	0.110	0.110	0.111	0.111	0.111
1.00	0.083	0.091	0.098	0.102	0.106	0.109	0.114	0.117	0.119	0.120	0.121	0.122	0.123	0.123	0.124	0.124	0.124	0.125	0.125	0.125
1.25	0.080	0.089	0.096	0.102	0.107	0.111	0.118	0.122	0.125	0.127	0.128	0.130	0.131	0.132	0.132	0.133	0.133	0.134	0.134	0.134
1.50	0.075	0.084	0.093	0.099	0.105	0.110	0.118	0.124	0.128	0.130	0.132	0.134	0.136	0.137	0.138	0.138	0.139	0.140	0.140	0.140
1.75	0.069	0.079	0.088	0.095	0.101	0.107	0.117	0.123	0.128	0.131	0.134	0.136	0.138	0.140	0.141	0.142	0.142	0.144	0.144	0.145
2.00	0.064	0.074	0.083	0.090	0.097	0.102	0.114	0.121	0.127	0.131	0.134	0.136	0.139	0.141	0.143	0.144	0.145	0.147	0.147	0.148
2.25	0.059	0.069	0.077	0.085	0.092	0.098	0.110	0.119	0.125	0.130	0.133	0.136	0.140	0.142	0.144	0.145	0.146	0.149	0.150	0.150
2.50	0.055	0.064	0.073	0.080	0.087	0.093	0.106	0.115	0.122	0.127	0.132	0.135	0.139	0.142	0.144	0.146	0.147	0.151	0.151	0.151
2.75	0.051	0.060	0.068	0.076	0.082	0.089	0.102	0.111	0.119	0.125	0.130	0.133	0.138	0.142	0.144	0.146	0.147	0.152	0.152	0.153
3.00	0.048	0.056	0.064	0.071	0.078	0.084	0.097	0.108	0.116	0.122	0.127	0.131	0.137	0.141	0.144	0.145	0.147	0.152	0.153	0.154
3.25	0.045	0.053	0.060	0.067	0.074	0.080	0.093	0.104	0.112	0.119	0.125	0.129	0.135	0.140	0.143	0.145	0.147	0.153	0.154	0.154
3.50	0.042	0.050	0.057	0.064	0.070	0.076	0.089	0.100	0.109	0.116	0.122	0.126	0.133	0.138	0.142	0.144	0.146	0.153	0.155	0.155
3.75	0.040	0.047	0.054	0.060	0.067	0.073	0.086	0.096	0.105	0.113	0.119	0.124	0.131	0.137	0.141	0.143	0.145	0.154	0.155	0.155
4.00	0.037	0.044	0.051	0.057	0.063	0.069	0.082	0.093	0.102	0.110	0.116	0.121	0.129	0.135	0.139	0.142	0.145	0.154	0.155	0.156
4.25	0.036	0.042	0.049	0.055	0.061	0.066	0.079	0.090	0.099	0.107	0.113	0.119	0.127	0.133	0.138	0.141	0.144	0.154	0.156	0.156
4.50	0.034	0.040	0.046	0.052	0.058	0.063	0.076	0.086	0.096	0.104	0.110	0.116	0.125	0.131	0.136	0.140	0.143	0.154	0.156	0.156
4.75	0.032	0.038	0.044	0.050	0.055	0.061	0.073	0.083	0.093	0.101	0.107	0.113	0.123	0.130	0.135	0.139	0.142	0.154	0.156	0.157
5.00	0.031	0.036	0.042	0.048	0.053	0.058	0.070	0.080	0.090	0.098	0.105	0.111	0.120	0.128	0.133	0.137	0.140	0.154	0.156	0.157
5.25	0.029	0.035	0.040	0.046	0.051	0.056	0.067	0.078	0.087	0.095	0.102	0.108	0.118	0.126	0.131	0.136	0.139	0.154	0.156	0.157
5.50	0.028	0.033	0.039	0.044	0.049	0.054	0.065	0.075	0.084	0.092	0.099	0.106	0.116	0.124	0.130	0.134	0.138	0.154	0.156	0.157
5.75	0.027	0.032	0.037	0.042	0.047	0.052	0.063	0.073	0.082	0.090	0.097	0.103	0.113	0.122	0.128	0.133	0.136	0.154	0.157	0.157
6.00	0.026	0.031	0.036	0.040	0.045	0.050	0.060	0.070	0.079	0.087	0.094	0.101	0.111	0.120	0.126	0.131	0.135	0.153	0.157	0.157
6.25	0.025	0.030	0.034	0.039	0.044	0.048	0.058	0.068	0.077	0.085	0.092	0.098	0.109	0.118	0.124	0.129	0.134	0.153	0.157	0.158
6.50	0.024	0.029	0.033	0.038	0.042	0.046	0.056	0.066	0.075	0.083	0.090	0.096	0.107	0.116	0.122	0.128	0.132	0.153	0.157	0.158
6.75	0.023	0.028	0.032	0.036	0.041	0.045	0.055	0.064	0.073	0.080	0.087	0.094	0.105	0.114	0.121	0.126	0.131	0.153	0.157	0.158
7.00	0.022	0.027	0.031	0.035	0.039	0.043	0.053	0.062	0.071	0.078	0.085	0.092	0.103	0.112	0.119	0.125	0.129	0.152	0.157	0.158
7.25	0.022	0.026	0.030	0.034	0.038	0.042	0.051	0.060	0.069	0.076	0.083	0.090	0.101	0.110	0.117	0.123	0.128	0.152	0.157	0.158
7.50	0.021	0.025	0.029	0.033	0.037	0.041	0.050	0.059	0.067	0.074	0.081	0.088	0.099	0.108	0.115	0.121	0.126	0.152	0.156	0.158
7.75	0.020	0.024	0.028	0.032	0.036	0.039	0.048	0.057	0.065	0.072	0.079	0.086	0.097	0.106	0.114	0.120	0.125	0.151	0.156	0.158
8.00	0.020	0.023	0.027	0.031	0.035	0.038	0.047	0.055	0.063	0.071	0.077	0.084	0.095	0.104	0.112	0.118	0.124	0.151	0.156	0.158
8.25	0.019	0.023	0.026	0.030	0.034	0.037	0.046	0.054	0.062	0.069	0.076	0.082	0.093	0.102	0.110	0.117	0.122	0.150	0.156	0.158
8.50	0.018	0.022	0.026	0.029	0.033	0.036	0.045	0.053	0.060	0.067	0.074	0.080	0.091	0.101	0.108	0.115	0.121	0.150	0.156	0.158
8.75	0.018	0.021	0.025	0.028	0.032	0.035	0.043	0.051	0.059	0.066	0.072	0.078	0.089	0.099	0.107	0.114	0.119	0.150	0.156	0.158
9.00	0.017	0.021	0.024	0.028	0.031	0.034	0.042	0.050	0.057	0.064	0.071	0.077	0.088	0.097	0.105	0.112	0.118	0.149	0.156	0.158
9.25	0.017	0.020	0.024	0.027	0.030	0.033	0.041	0.049	0.056	0.063	0.069	0.075	0.086	0.096	0.104	0.110	0.116	0.149	0.156	0.158
9.50	0.017	0.020	0.023	0.026	0.029	0.033	0.040	0.048	0.055	0.061	0.068	0.074	0.085	0.094	0.102	0.109	0.115	0.148	0.156	0.158
9.75	0.016	0.019	0.023	0.026	0.029	0.032	0.039	0.047	0.054	0.060	0.066	0.072	0.083	0.092	0.100	0.107	0.113	0.148	0.156	0.158
10.00	0.016	0.019	0.022	0.025	0.028	0.031	0.038	0.046	0.052	0.059	0.065	0.071	0.082	0.091	0.099	0.106	0.112	0.147	0.156	0.158
20.00	0.008	0.010	0.011	0.013	0.014	0.016	0.020	0.024	0.027	0.031	0.035	0.039	0.046	0.053	0.059	0.065	0.071	0.124	0.148	0.156
50.00	0.003	0.004	0.004	0.005	0.006	0.006	0.008	0.010	0.011	0.013	0.014	0.016	0.019	0.022	0.025	0.028	0.031	0.071	0.113	0.142
100.00	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.005	0.006	0.006	0.007	0.008	0.010	0.011	0.013	0.014	0.016	0.039	0.071	0.113

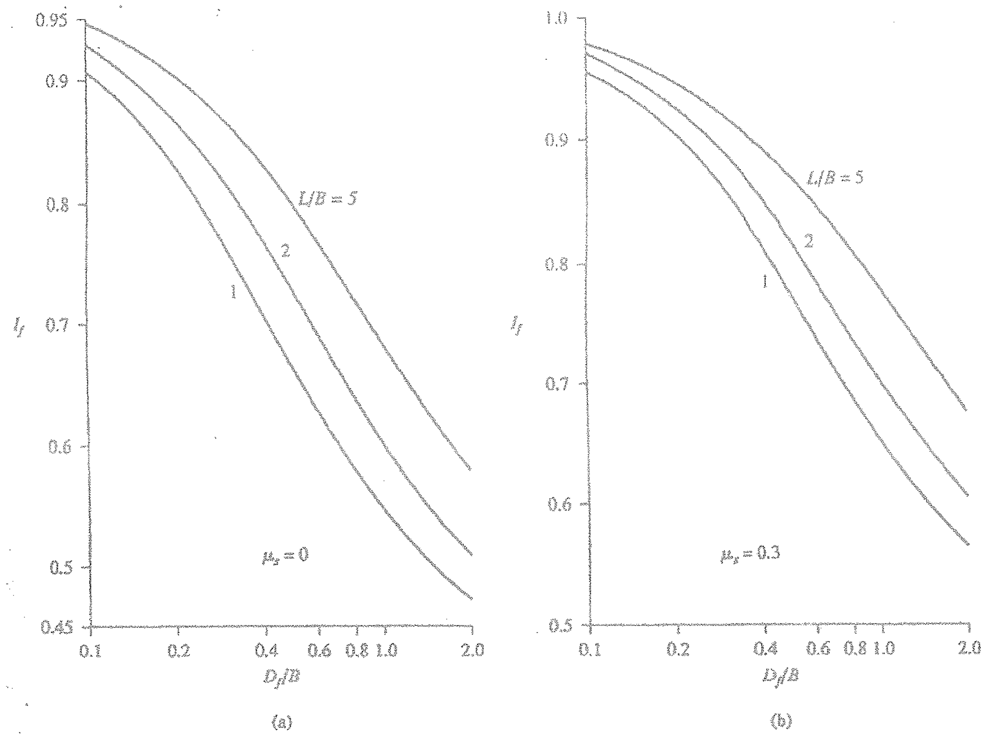

Figure Q2.2 - Variation of I_f with D_f/B, L/B and μ_s

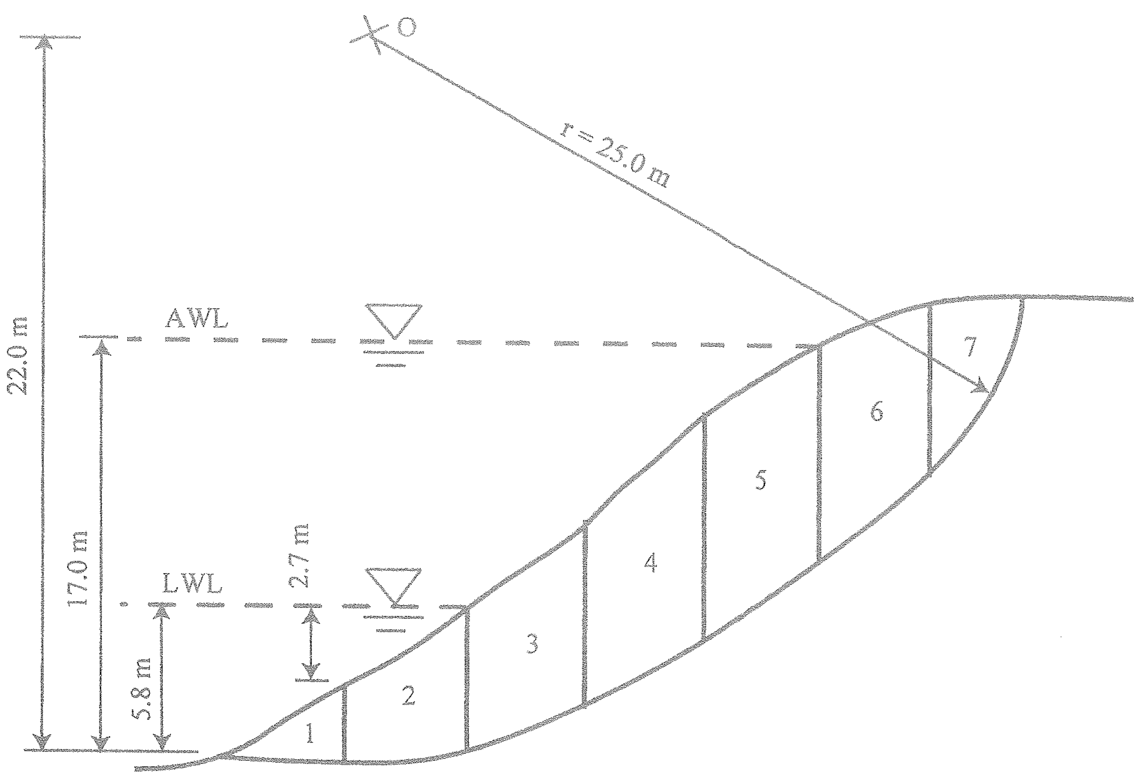

Figure Q3.1 - Circular slope failure

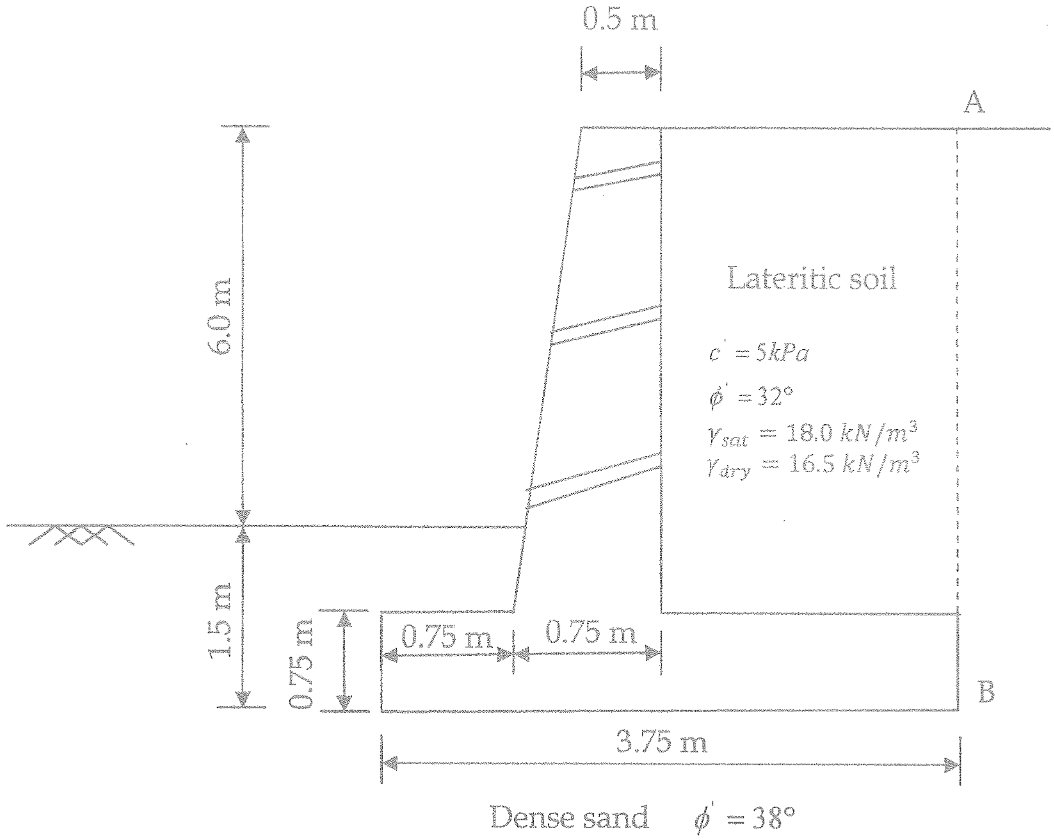

Figure Q4.1 Cross section of retaining wall

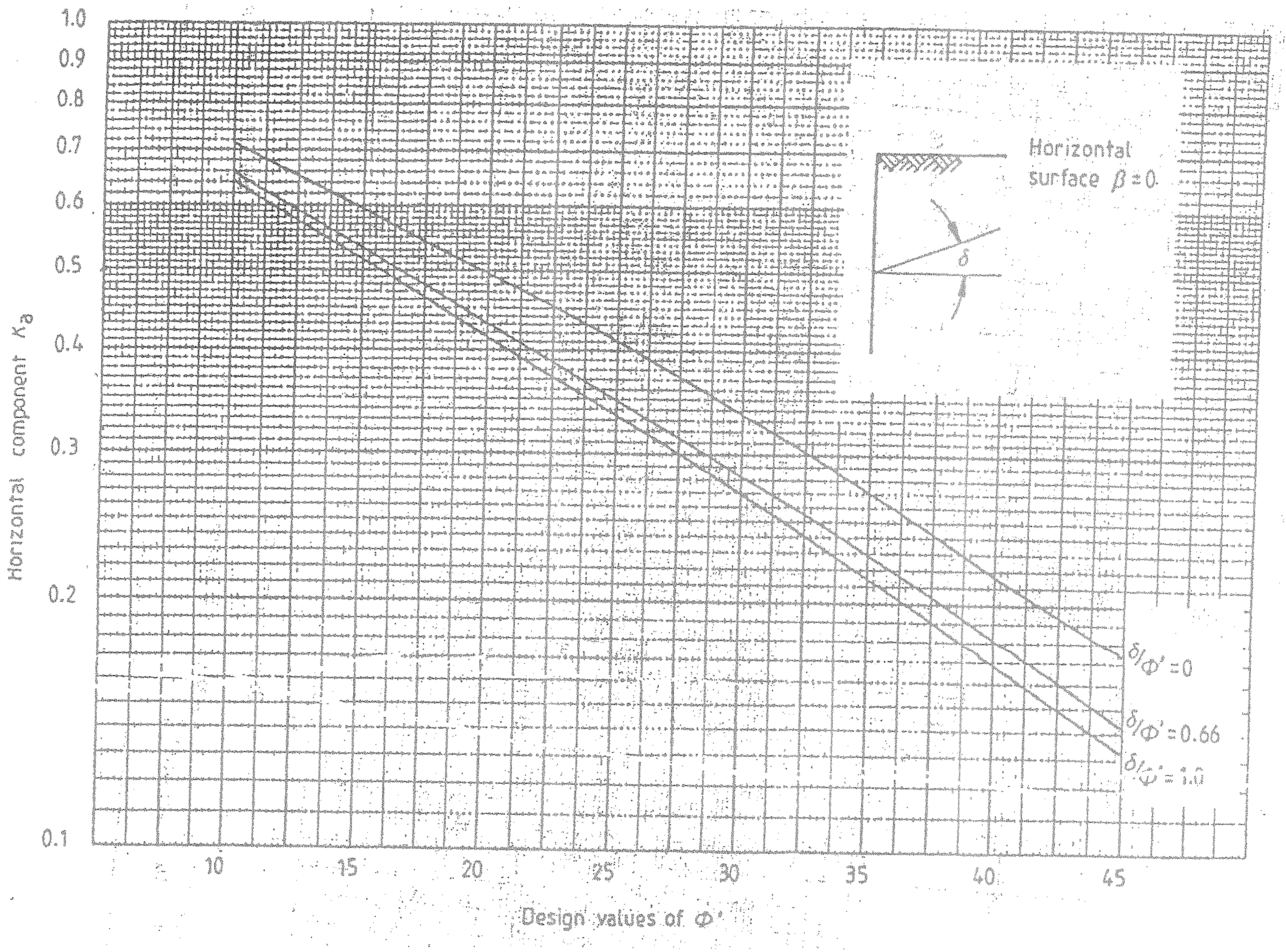

Figure Q4.2 Variation of K_A with φ'_{design}

Table Q3.1 - Data for estimation of FOS of the circular slope

Slice	w_i (kN)	θ°	u_i (kN/m²)	Δx (m)						
1	66.58	-8.0	93.4	4.0						
2	268.8	0	88.5	4.0						
3	390.4	12.0	78.3	4.0						
4	435.2	24.0	68.5	4.0						
5	435.2	38.0	55.3	4.0						
6	294.4	54.0	33.6	4.0						
7	22.4	70.0	2.9	4.0						