UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: August 2015

Module Number: CE7324 **Module Name: Geotechnical Engineering Design**

[Three Hours]

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

Q1. a) Briefly describe the situations in which pile foundations are required. Briefly explain 4 numbers of situations.

[2.0 Marks]

b) Sub-surface soil profile at a bridge abutment in a highway is shown in Figure Q1.1 together with soil parameters obtained from the soil investigations. Based on this information, design engineer has decided to install 0.4 m square type precast concrete piles up to the bed rock level.

However, during construction, the contractor had great difficulty in driving the pile through the dense sand layer, and requested approval to terminate the pile at top of the dense sand layer.

Water table was found to be at the existing ground surface. The unit weight of water can be taken as 9.81 kN/m³.

i) If the piles are rest on the bed rock, calculate the expected ultimate bearing capacity of a single pile. You may assume that entire load transfer to the ground at the pile tip.

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

$q_p = q_u(N_\phi + 1)$

where $N_\phi = \tan^2(45 + \phi/2)$

[2.0 Marks]

ii) If the piles terminate at top of the dense sand layer, calculate the ultimate bearing capacity of a single pile assuming the contributions by both skin friction and end bearing.

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

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

$q_1 = 50 N_q^* tan\varphi$

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

[5.0 Marks]

iii) It is proposed to drive 48 (12 x 4) precast concrete piles at 1.5 m spacing for the bridge abutment. If expected load of the bridge abutment is 1400 tons, would you give the approval for the contractor's request? You may use the factor of safety 3.0 against bearing failure.

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

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

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

[3.0 Marks]

Q2. a) Briefly describe the "Plate Load Test" procedure with suitable sketches.

[3.0 Marks]

b) List four numbers of common mistakes which occurred during the plate load test.

[2.0 Marks]

c) The subsurface soil profile at a building site is shown in Figure Q2.1. Due to presence of loose sand layer at the top, the consultant requested to carry out a plate load test in order to determine the bearing capacity of the shallow foundation.

Results of plate load test which was carried out at the proposed building site are shown in Figure Q2.2. The testing was done at the center of 2 m x 2 m pit excavated to the expected foundation depth of 1 m. It was revealed that water table is at a depth of 1.5 m below the ground surface and unit weight of loose sand above and below the water table are 15 kN/m³ and 16 kN/m³ respectively. The unit weight of coarse sand is found to be 17.5 kN/m³.

i) Estimate the ultimate bearing capacity of the proposed foundation assuming that trial footing size is 1 m x 1 m and diameter of the plate is 0.3 m.

[2.0 Marks]

ii) Determine the size of a square column foundation that should carry a load of 2500 kN with a maximum settlement of 20 mm.

Note:- The allowable bearing capacity of a foundation in sandy soil, based on settlement considerations and for a given intensity of load is given with general notations by,

$$S_F = S_P\left(\frac{2B_F}{B_F + B_P}\right)^2$$

[5.0 Marks]

Q3. A column supporting a structure is subjected to a vertical load of 250 kN at a distance 0.5 m from the center of the footing as shown in Figure Q3.1. It is proposed to use a 1.0 m x 2.0 m rectangular foundation placed at a depth of 1.0 m from the ground surface. The sub surface soil condition together with foundation arrangement is in Figure Q3.2. The ground water table was found to be at a depth of 1.0 m below the existing ground level. The properties of the silty sand and dense sand are depicted in Table Q3.1. The unit weight of water can be taken as 9.81 kN/m³.

Following equations with general notations, Table Q3.2, Table Q3.3, Table Q3.4 and Figure Q3.2 may useful in the calculations.

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

$$N_c = (N_q - 1)\cot\phi$$

$$N_q = \tan^2\left(45 + \phi/2\right)e^{\pi\tan\phi}$$

$$N_\gamma = 2(N_q + 1)\tan\phi$$

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

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

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

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

$$S_F = S_P \left(\frac{2B_F}{B_F + B_P}\right)^2$$

a) Estimate the ultimate carrying capacity of the trial footing.

[5.5 Marks]

b) Estimate the allowable bearing capacity of the foundation assuming that factor of safety is 3.0 against bearing failure.

[0.5 Marks]

c) Assuming that only the effective area of the foundation is loaded; estimate the immediate settlement at center and corner of the foundation. Hence, estimate the differential settlement of the foundation. You may assume that foundation is perfectly flexible.

[6.0 Marks]

Q4. a) Briefly describe the variation of safety factor with time for soil beneath a fill (under an embankment) with suitable sketches.

[2.0 Marks]

b) Briefly explain the differences between Ordinary method of slices (or Fellenious method or Swedish circle method) and Simplified Bishop's method in solving the circular slope failures.

[2.0 Marks]

c) Figure Q4.1 illustrates a cross section of an abutment in a proposed earth dam constructed for a local reservoir in a rural area. In order to find the stability of the embankment against sliding, a trial failure surface with radius 20 m has been selected and the failure mass is divided into several slices. The effective shear strength parameters of the fill material are cohesion of 25 kPa and internal friction angle of $28°$. The unit weigh of fill material can be taken as 18 kN/m^3.

During rainy season, water table increases up to 2 m above the existing ground level as shown in Figure Q4.1.

Using the Bishop's simplified method of slices, determine the factor of safety for the selected trial failure surface. Use a trial factor of safety as 1.65 and do only one iteration.

You may use the following Bishop's simplified expression with usual notations and the data given in Table Q4.1 to estimate the factor of safety.

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

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

Note:- Calculation of factor of safety can be done in Table Q4.1 and should be attached to the answer book.

[8.0 Marks]

Q5. There is a proposal to develop a recreational area for a new housing complex. Due to scarcity of land, the developer is planning to fill up an area to use as a recreational area. This area is to be supported by a gravity retaining wall made up of gabion units up to a height of 4.0 m as shown in Figure Q5.1. Backfill material has effective shear strength parameters, with usual notations, of $c' = 10$ kN/m² and $\varphi' = 28°$. The bulk unit weight of backfill material is 18 kN/m³. The water table is at the ground surface. The unit weights of water and gabion material can be taken as 9.81 kN/m³ and 16kN/m³, respectively.

a) Evaluate the long term stability of the retaining wall with respect to overturning. Variation of K_A with φ'_{design} is given in Figure Q5.2.

[7.0 Marks]

b) Check whether the given retaining wall section satisfies the stability criterion against sliding. Assume that founding material and backfill material are same.

[2.0 Marks]

d) If the allowable bearing capacity of the founding soil is 230 kN/m², evaluate the stability of the retaining wall against bearing failure.

[3.0 Marks]

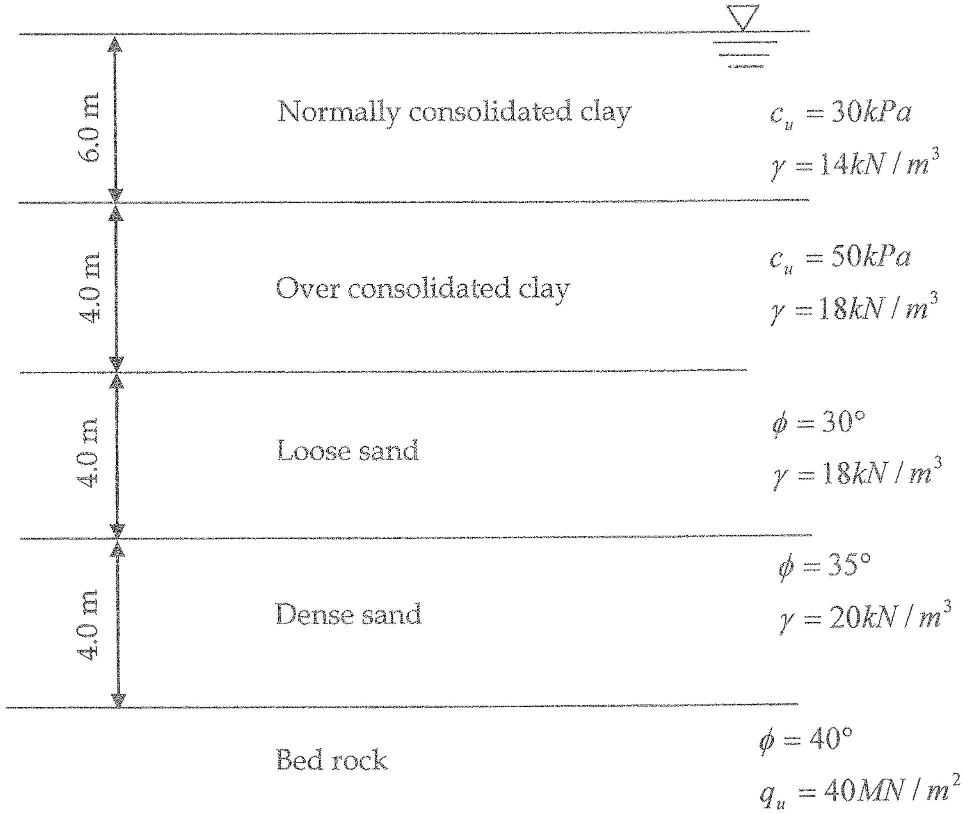

Figure Q1.1 Sub-surface soil profile at the proposed bridge abutment

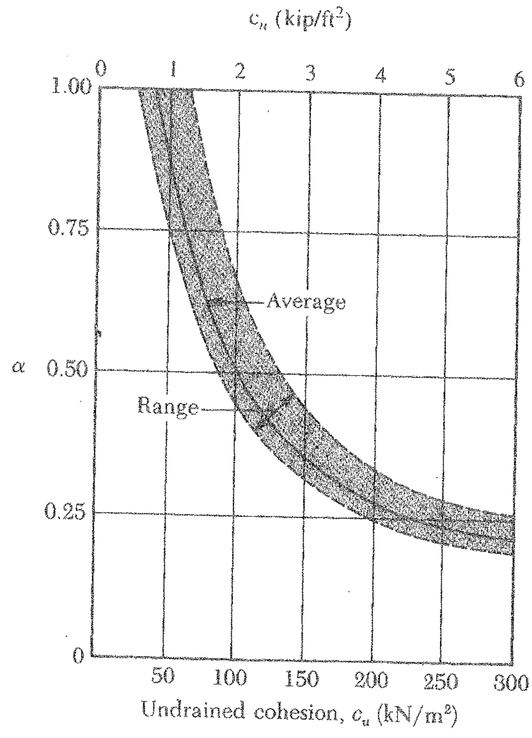

Figure Q1.2 - Variation of α with undrained cohesion of clay

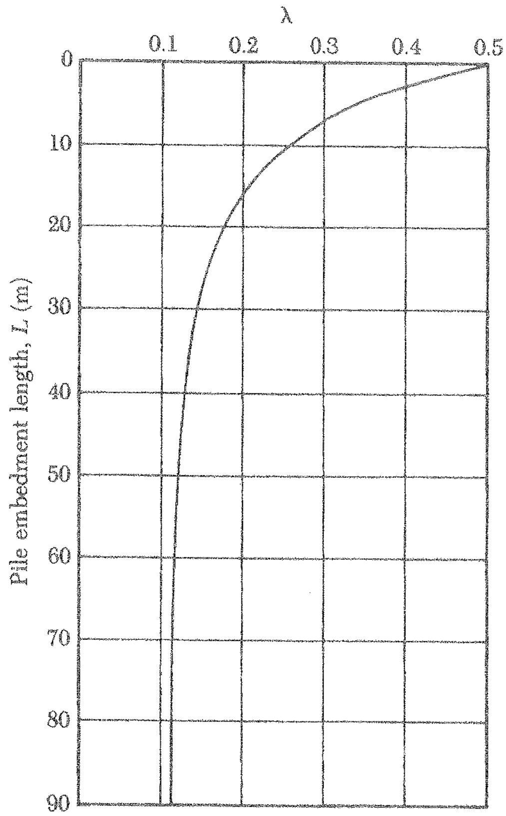

Figure Q1.3 - Variation of λ with pile embedded length

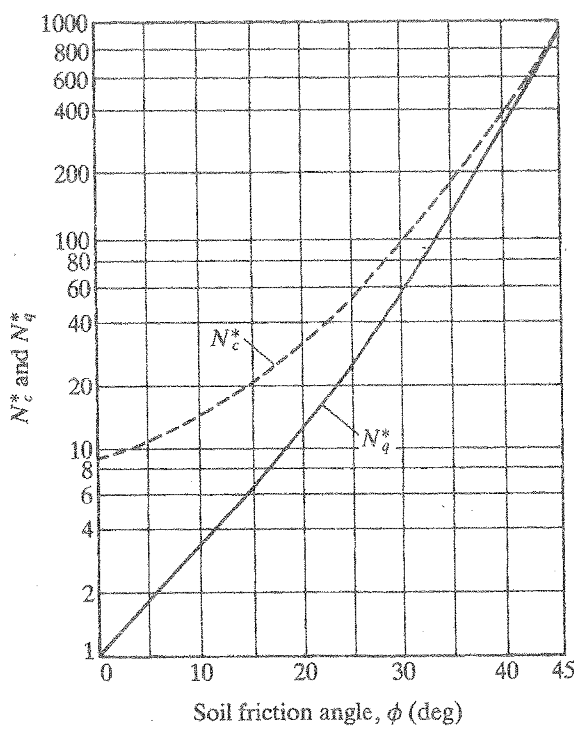

Figure Q1.4 - Variation of N_c^* and N_q^* with soil friction angle

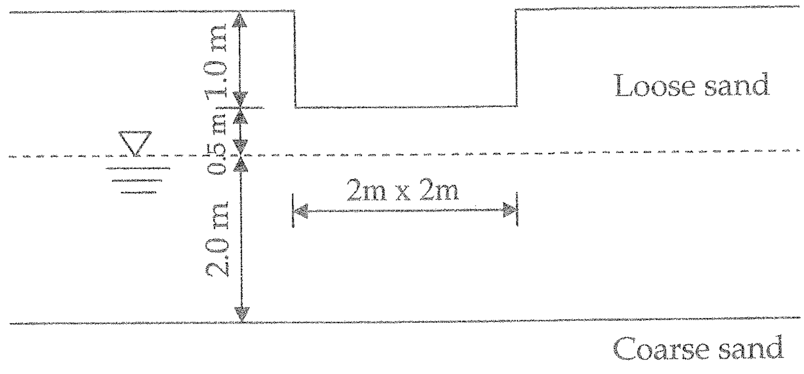

Figure Q2.1 Subsurface profile at the proposed building site

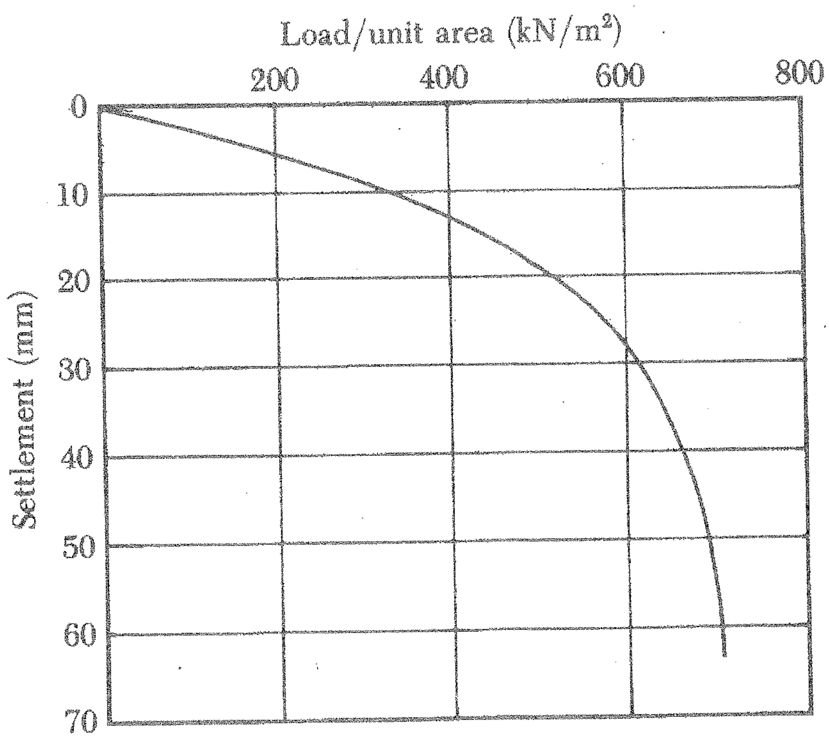

Figure Q2.2 Plate load test results

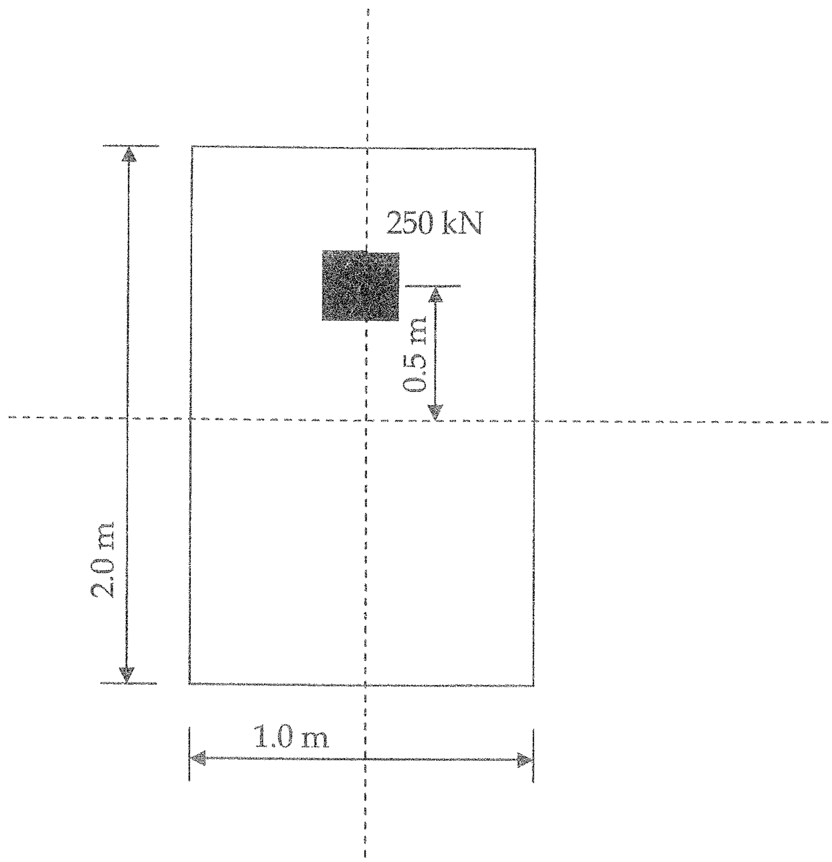

Figure Q3.1 - Shallow foundation arrangement

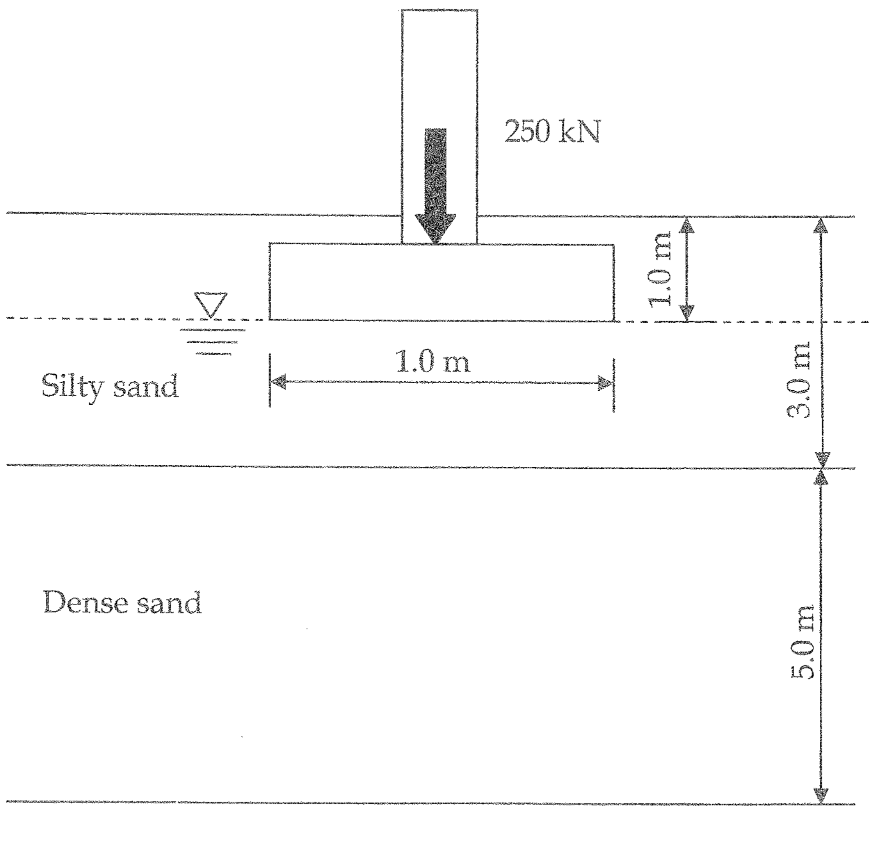

Figure Q3.2 - Sub surface soil profile

Table Q3.1- Properties of soil

	Silty Sand	Dense Sand
Dry unit weight (kN/m³)	16.0	17.5
Saturated unit weight (kN/m³)	17.0	19
Friction angle (°)	30	36
Young's modulus (MN/m²)	20	30
Poission's ratio	0.3	0.25

Table Q3.2- Bearing capacity factors

ϕ	N_c	N_q	N_γ	N_q/N_c	tan ϕ	ϕ	N_c	N_q	N_γ	N_q/N_c	tan ϕ
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						

[a] After Vesic (1973)

Table Q3.3 - 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
0.25	0.014	0.013	0.012	0.011	0.011	0.011	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
0.75	0.095	0.090	0.087	0.084	0.082	0.080	0.077	0.076	0.074	0.074
1.00	0.142	0.138	0.134	0.130	0.127	0.125	0.121	0.118	0.116	0.115
1.25	0.186	0.183	0.179	0.176	0.173	0.170	0.165	0.161	0.158	0.157
1.50	0.224	0.224	0.222	0.219	0.216	0.213	0.207	0.203	0.199	0.197
1.75	0.257	0.259	0.259	0.258	0.255	0.253	0.247	0.242	0.238	0.235
2.00	0.285	0.290	0.292	0.292	0.291	0.289	0.284	0.279	0.275	0.271
2.25	0.309	0.317	0.321	0.323	0.323	0.322	0.317	0.313	0.308	0.305
2.50	0.330	0.341	0.347	0.350	0.351	0.351	0.348	0.344	0.340	0.336
2.75	0.348	0.361	0.369	0.374	0.377	0.378	0.377	0.373	0.369	0.365
3.00	0.363	0.379	0.389	0.396	0.400	0.402	0.402	0.400	0.396	0.392
3.25	0.376	0.394	0.406	0.415	0.420	0.423	0.426	0.424	0.421	0.418
3.50	0.388	0.408	0.422	0.431	0.438	0.442	0.447	0.447	0.444	0.441
3.75	0.399	0.420	0.436	0.447	0.454	0.460	0.467	0.458	0.466	0.464
4.00	0.408	0.431	0.448	0.460	0.469	0.476	0.484	0.487	0.486	0.484
4.25	0.417	0.440	0.458	0.472	0.481	0.484	0.495	0.514	0.515	0.515
4.50	0.424	0.450	0.469	0.484	0.495	0.503	0.516	0.521	0.522	0.522
4.75	0.431	0.458	0.478	0.494	0.506	0.515	0.530	0.536	0.539	0.539
5.00	0.437	0.465	0.487	0.503	0.516	0.526	0.543	0.551	0.554	0.554
5.25	0.443	0.472	0.494	0.512	0.526	0.537	0.555	0.564	0.568	0.569
5.50	0.448	0.478	0.501	0.520	0.534	0.546	0.566	0.576	0.581	0.584
5.75	0.453	0.483	0.508	0.527	0.542	0.555	0.576	0.588	0.594	0.597
6.00	0.457	0.489	0.514	0.534	0.550	0.563	0.585	0.598	0.606	0.609
6.25	0.461	0.493	0.519	0.540	0.557	0.570	0.594	0.609	0.617	0.621
6.50	0.465	0.498	0.524	0.546	0.563	0.577	0.603	0.618	0.627	0.632
6.75	0.468	0.502	0.529	0.551	0.569	0.584	0.610	0.627	0.637	0.643
7.00	0.471	0.506	0.533	0.556	0.575	0.590	0.618	0.635	0.646	0.653
7.25	0.474	0.509	0.538	0.561	0.580	0.596	0.625	0.643	0.655	0.662
7.50	0.477	0.513	0.541	0.565	0.585	0.601	0.631	0.650	0.663	0.671
7.75	0.480	0.516	0.545	0.569	0.589	0.606	0.637	0.658	0.671	0.680
8.00	0.482	0.519	0.549	0.573	0.594	0.611	0.643	0.664	0.678	0.688
8.25	0.485	0.522	0.552	0.577	0.598	0.615	0.648	0.670	0.685	0.695
8.50	0.487	0.524	0.555	0.580	0.601	0.619	0.653	0.676	0.692	0.703
8.75	0.489	0.527	0.558	0.583	0.605	0.623	0.658	0.682	0.698	0.710
9.00	0.491	0.529	0.560	0.587	0.609	0.627	0.663	0.687	0.705	0.716
9.25	0.493	0.531	0.563	0.589	0.612	0.631	0.667	0.693	0.710	0.723
9.50	0.495	0.533	0.565	0.592	0.615	0.634	0.671	0.697	0.716	0.719
9.75	0.496	0.536	0.568	0.595	0.618	0.638	0.675	0.702	0.721	0.735
10.00	0.498	0.537	0.570	0.597	0.621	0.641	0.679	0.707	0.726	0.740
20.00	0.529	0.575	0.614	0.647	0.677	0.702	0.756	0.797	0.830	0.858
50.00	0.548	0.598	0.640	0.678	0.711	0.740	0.803	0.853	0.895	0.931
100.00	0.555	0.605	0.649	0.688	0.722	0.753	0.819	0.872	0.918	0.956

n'	m' = 4.5	5.0	6.0	7.0	8.0	9.0	10.0	25.0	50.0	100.0
0.25	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
0.50	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
0.75	0.073	0.073	0.072	0.072	0.072	0.072	0.071	0.071	0.071	0.071
1.00	0.114	0.113	0.112	0.112	0.112	0.111	0.111	0.110	0.110	0.110
1.25	0.155	0.154	0.153	0.152	0.152	0.151	0.151	0.150	0.150	0.150
1.50	0.195	0.194	0.192	0.191	0.190	0.190	0.189	0.188	0.188	0.188
1.75	0.233	0.232	0.229	0.228	0.227	0.226	0.225	0.223	0.223	0.223
2.00	0.269	0.267	0.264	0.262	0.261	0.260	0.259	0.257	0.256	0.256
2.25	0.302	0.300	0.296	0.294	0.293	0.291	0.291	0.287	0.287	0.287
2.50	0.333	0.331	0.327	0.324	0.322	0.321	0.320	0.316	0.315	0.315
2.75	0.362	0.359	0.355	0.352	0.350	0.348	0.347	0.343	0.342	0.342
3.00	0.389	0.386	0.382	0.378	0.376	0.374	0.373	0.368	0.367	0.367
3.25	0.415	0.412	0.407	0.403	0.401	0.399	0.397	0.391	0.390	0.390
3.50	0.438	0.435	0.430	0.427	0.424	0.421	0.420	0.413	0.412	0.411
3.75	0.461	0.458	0.453	0.449	0.446	0.443	0.441	0.433	0.432	0.432
4.00	0.482	0.479	0.474	0.470	0.466	0.464	0.462	0.453	0.451	0.451
4.25	0.516	0.496	0.484	0.473	0.471	0.471	0.470	0.468	0.462	0.460
4.50	0.520	0.517	0.513	0.508	0.505	0.502	0.499	0.489	0.487	0.487
4.75	0.537	0.535	0.530	0.526	0.523	0.519	0.517	0.506	0.504	0.503
5.00	0.554	0.552	0.548	0.543	0.540	0.536	0.534	0.522	0.519	0.519
5.25	0.569	0.568	0.564	0.560	0.556	0.553	0.550	0.537	0.534	0.534
5.50	0.584	0.583	0.579	0.575	0.571	0.568	0.585	0.551	0.549	0.548
5.75	0.597	0.597	0.594	0.590	0.586	0.583	0.580	0.565	0.583	0.562
6.00	0.611	0.610	0.608	0.604	0.601	0.598	0.595	0.579	0.576	0.575
6.25	0.623	0.623	0.621	0.618	0.615	0.611	0.608	0.592	0.589	0.588
6.50	0.635	0.635	0.634	0.631	0.628	0.625	0.622	0.605	0.601	0.600
6.75	0.646	0.647	0.646	0.644	0.641	0.637	0.634	0.617	0.613	0.612
7.00	0.656	0.658	0.658	0.656	0.653	0.650	0.647	0.628	0.624	0.623
7.25	0.666	0.669	0.669	0.668	0.665	0.662	0.659	0.640	0.635	0.634
7.50	0.676	0.679	0.680	0.679	0.676	0.673	0.670	0.651	0.646	0.645
7.75	0.685	0.688	0.690	0.689	0.687	0.684	0.681	0.661	0.656	0.655
8.00	0.694	0.697	0.700	0.700	0.698	0.695	0.692	0.672	0.666	0.665
8.25	0.702	0.706	0.710	0.710	0.708	0.705	0.703	0.682	0.676	0.675
8.50	0.710	0.714	0.719	0.719	0.718	0.715	0.713	0.692	0.686	0.684
8.75	0.717	0.722	0.727	0.728	0.727	0.725	0.723	0.701	0.695	0.693
9.00	0.725	0.730	0.736	0.737	0.736	0.735	0.732	0.710	0.704	0.702
9.25	0.731	0.737	0.744	0.746	0.745	0.744	0.742	0.719	0.713	0.711
9.50	0.738	0.744	0.752	0.754	0.754	0.753	0.751	0.728	0.721	0.719
9.75	0.744	0.751	0.759	0.762	0.762	0.761	0.759	0.737	0.729	0.727
10.00	0.750	0.758	0.766	0.770	0.770	0.770	0.768	0.745	0.738	0.735
20.00	0.878	0.896	0.925	0.945	0.959	0.969	0.977	0.982	0.965	0.957
50.00	0.962	0.989	1.034	1.070	1.100	1.125	1.146	1.265	1.279	1.261
100.00	0.990	1.020	1.072	1.114	1.150	1.182	1.209	1.408	1.489	1.499

Table Q3.4 - 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	0.158
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

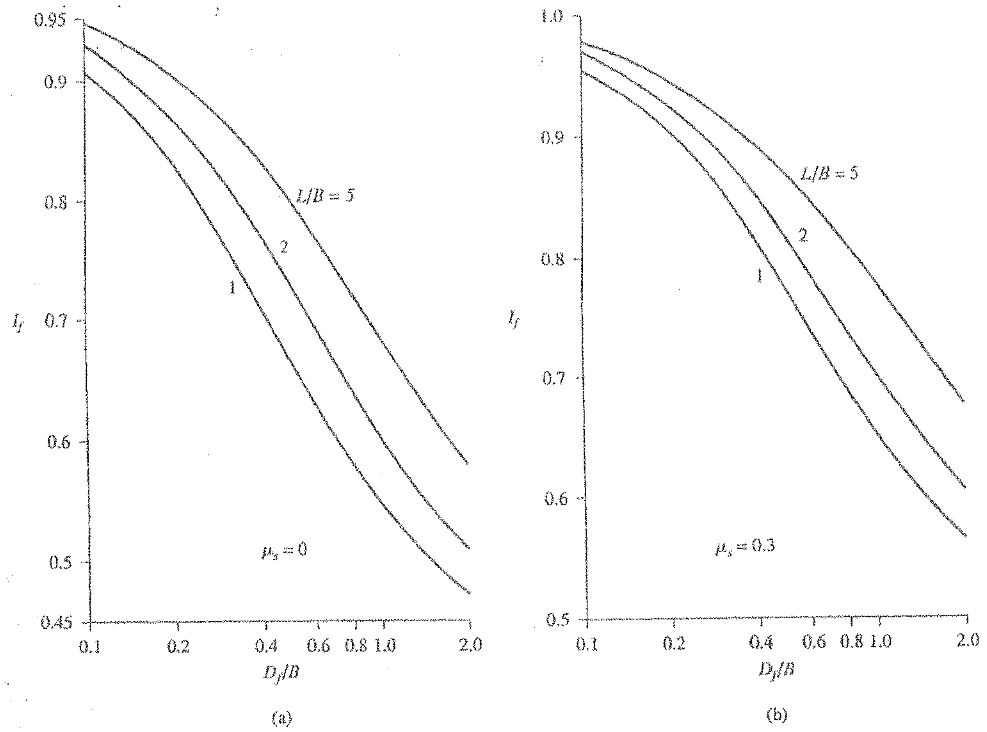

Figure Q3.5 - Variation of I_f with D_f/B, L/B and μ_s

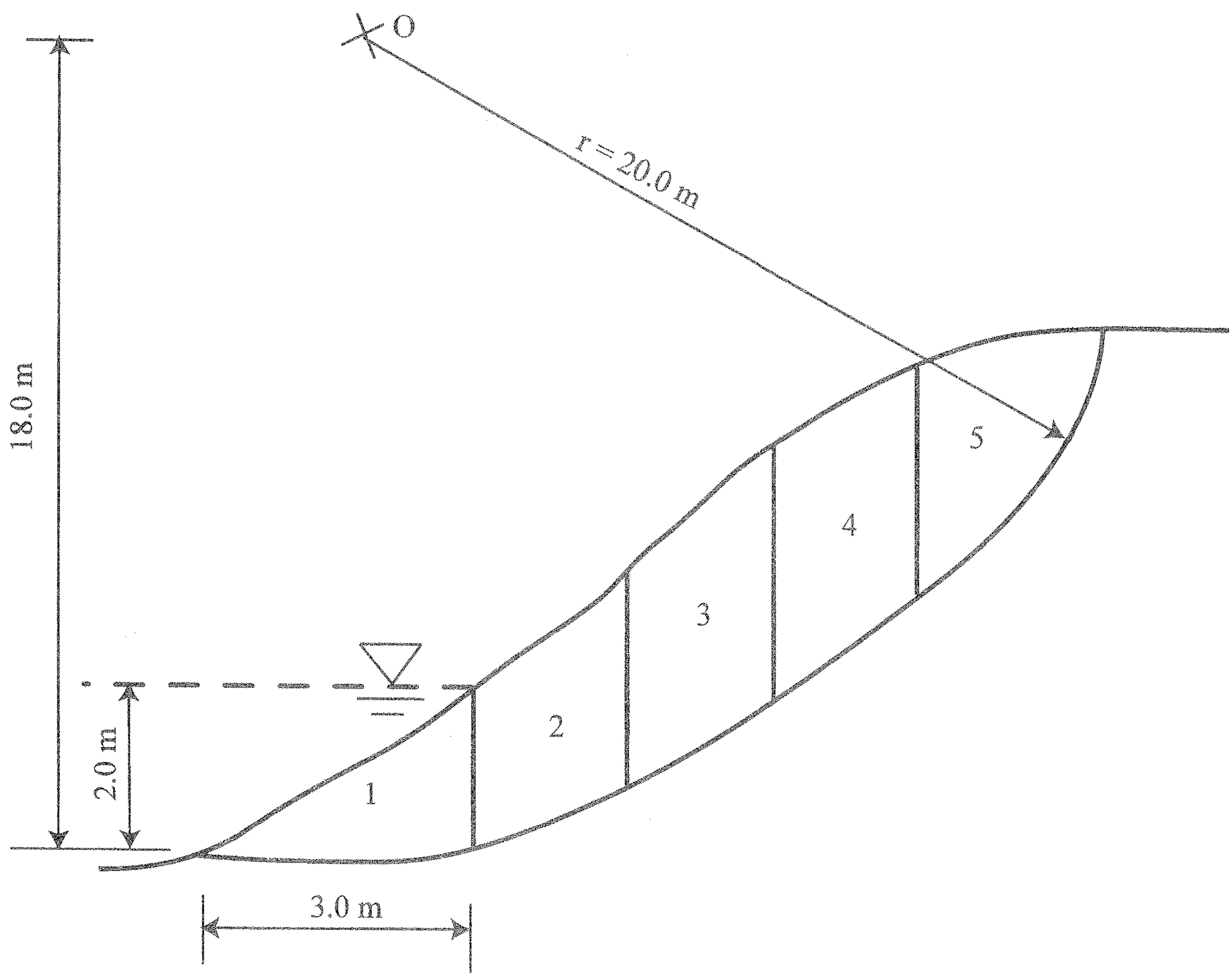

Figure Q4.1 - Circular slope failure

Table Q4.1 - Data for estimation of FOS of the circular slope

Slice	w_i (kN)	θ°	Δx_i (m)	u_i (kN/m^2)						
1	219.38	7.0	3.0	12.5						
2	438.75	17.0	3.0	19.6						
3	365.63	28.5	3.0	34.3						
4	234.00	43.5	3.0	22.1						
5	87.75	66.0	3.0	11.2						

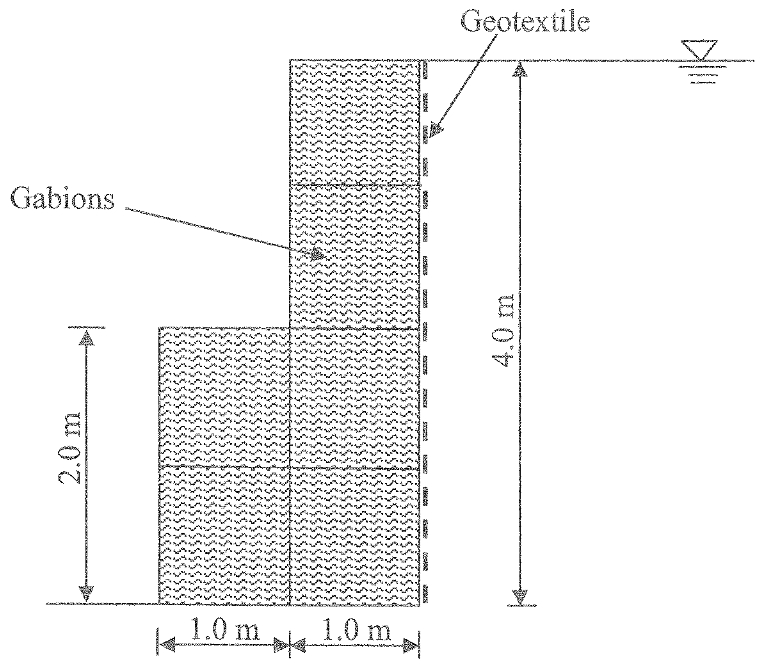

Figure Q5.1 Cross section of retaining wall

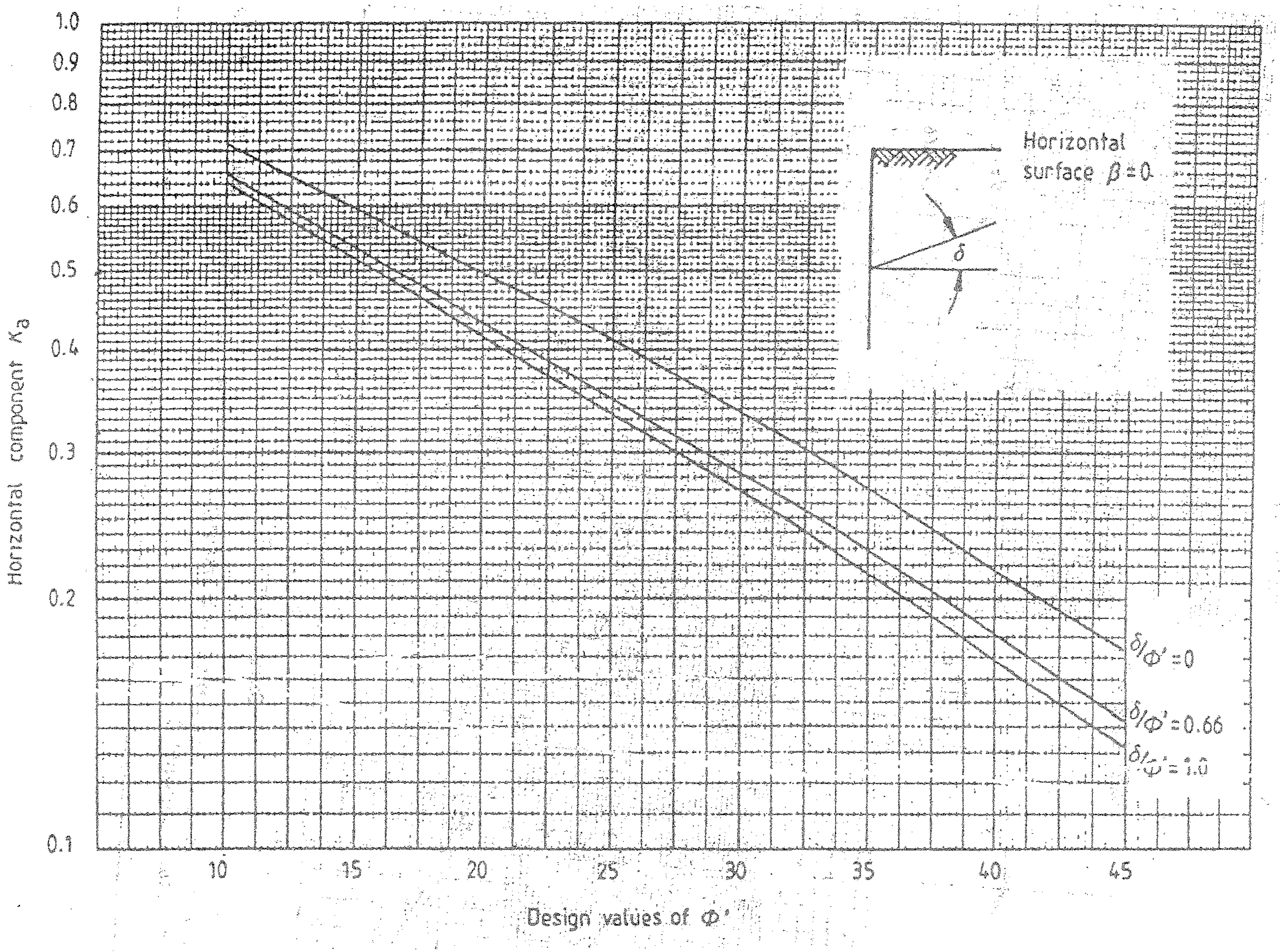

Figure Q5.2 Variation of K_A with φ'_{design}