UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: July 2016

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

[Three Hours]

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

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

[2.0 Marks]

b) Briefly explain two numbers of situations where negative skin friction would develop on piles.

[1.0 Marks]

c) There is a proposal to construct a 7 storied 5-Star Hotel in Mirissa. Sub-surface soil profile at the site is shown in Figure Q1.1 together with SPT-N values, and Core Recovery (CR) and Rock Quality Designation (RQD) of bed rock obtained from the site investigation. A series of laboratory tests were conducted to find the engineering properties of soil 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/m^3.

Based on the structural analysis, critical ultimate column load was found to be 3200 kN. As soil profile consists of sandy soil up to a depth of 7.0 m from the ground surface, the client has requested to adopt 2.0 m x 2.0 m individual footing at a depth of 2.0 m from the ground surface at each column location.

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

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

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

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

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

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

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

Figure Q1.2, Figure 1.3, Figure Q1.4 and Table Q2.2 may also useful in the calculations.

i) As a junior geotechnical engineer in the project, show that proposed foundation is not sufficient to carry the structural load of the proposed building with suitable calculations.

[2.0 Marks]

ii) The geotechnical engineer in the project has decided to install 0.4 m x 0.4 m precast concrete piles upto a depth of 12.0 m from ground surface at each column location to carry the structural load. What would be the expected carrying capacity of a single pile?

\[6.5 Marks]

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

[1.5 Marks]

iv) If piles are driven upto the bed rock level, how many piles are required at a particular column location to carry the intended structural load?

[2.0 Marks]

Q2. The foundation supporting a structure is subjected to a vertical load as shown in Figure Q2.1. The size of the foundation is 2.0 m x 1.0 m rectangular type and which is placed at a depth of 1.5 m from the ground surface. The sub soil profile together with foundation arrangement is presented in Figure Q2.2. The geotechnical properties of the sub surface soil profile are shown in Table Q2.1. The water table is at a depth of 2.0 m from the ground surface. The unit weight of water can be taken as 9.81 kN/m³. Following equations with general notations may be useful in the calculations.

$$q_u = cN_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

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

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

$F_{\gamma d} = 1$

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

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

when $\frac{e_L}{L} \ge \frac{1}{6}$ and $\frac{e_B}{L} \ge \frac{1}{6}$ $\quad A' = \frac{1}{2}B_1L_1,\ B_1 = B(1.5 - \frac{3e_B}{B}),\ L_1 = L(1.5 - \frac{e_L}{L})$

when $\frac{e_L}{L} < 0.5$ and $0 < \frac{e_B}{L} \ge \frac{1}{6}$ $\quad A' = \frac{1}{2}(L_1 + L_2)$, L_1 and L_2 can be obtained from Figure Q2.3

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

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

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

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

a) Estimate the net allowable load of the trial footing assuming that factor of safety is 3.0.

[7.0 Marks]

b) Assuming that only the effective area of the foundation is loaded, estimate the immediate settlement at center of the foundation. You may assume that foundation is perfectly flexible.

[4.0 Marks]

c) In order to determine the actual bearing capacity of the foundation, a plate load test was conducted using a 0.3 m diameter plate at the proposed foundation depth and results are presented in Figure 2.5. Determine the size of a square column foundation that should carry a load of 1000 kN with a maximum settlement of 20 mm.

[4.0 Marks]

Q3. During the construction of a highway in a flood plain, it was decided to raise the finished road level by 7.0 m from the existing ground level. For the stability, side slopes of the embankment are constructed as 2:1 (2 vertical: 1 horizontal). In order to find the stability of the embankment against sliding, method of slices is adopted and a trial failure surface with radius 25.0 m has been selected. The failure mass is divided into 5.0 m wide seven slices as shown in Figure Q3.1. The data related to the trial failure mass is presented in Table Q3.1. The effective shear strength parameters of the fill material of the embankment are cohesion of 15 kPa and internal friction angle of 30°. The unit weight of fill material can be taken as 20 kN/m³. It was decided to use Simplified Bishop's method of slices for the slope stability calculations.
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 soil beneath a fill (under an embankment) with the aid of sketches.

[2.0 Marks]

b) Since embankment is in the flood plain, there is a possibility to raise the water level by 2.0 m during the rainy season for the trial failure surface as shown in Figure Q3.1. Hence, what would be the factor of safety against slope instability? Use two iterations only.
<u>Note:-</u> *Calculation of factor of safety can be done in Table Q3.1 and should be attached to the answer book.*

[10.0 Marks]

c) If slope stability of the embankment (fill) is not sufficient, as a junior geotechnical engineer in the project, state two methods to improve the stability.

[2.0 Marks]

d) During the embankment construction, surface cracks in longitudinal and transverse directions may occur. What would be the reasons for above observations?

[1.0 Marks]

Q4. Segment of a highway affected by an earth slip has to be reconstructed. One proposal is to construct a 4.0 m height gravity retaining wall. Retaining wall is to be constructed of random rubble masonry and backfilled with lateritic soil. Backfill material has effective shear strength parameters of cohesion (c') = 10 kPa and internal friction angle (ϕ') =30°. 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 found to be at the ground surface. The unit weights of water and rubble can be taken as 9.81 kN/m^3 and 22.0 kN/m^3, respectively. The variation of K_A with φ'_{design} is illustrated in Figure Q4.2.

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

[6.0 Marks]

b) Check whether the given retaining wall section satisfies the stability criterion against sliding.

[2.0 Marks]

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

[2.0 Marks]

d) Consultant has requested to improve the drainage behind the retaining wall for the stability. As a junior geotechnical engineer in the project suggest a suitable method to improve the drainage behind the retaining wall with the aid of a sketch.

[1.0 Marks]

e) Abutment of an underpass is decided construct using reinforced earth mechanism. Briefly describe the mechanism and construction sequence of reinforced earth retaining walls with the aid of sketches.

[2.0 Marks]

f) Another section of the highway is going through a cut slope area and soil nailing technique is selected to improve the stability of the slope. Briefly describe the advantage and limitations of the soil nailing technique.

[2.0 Marks]

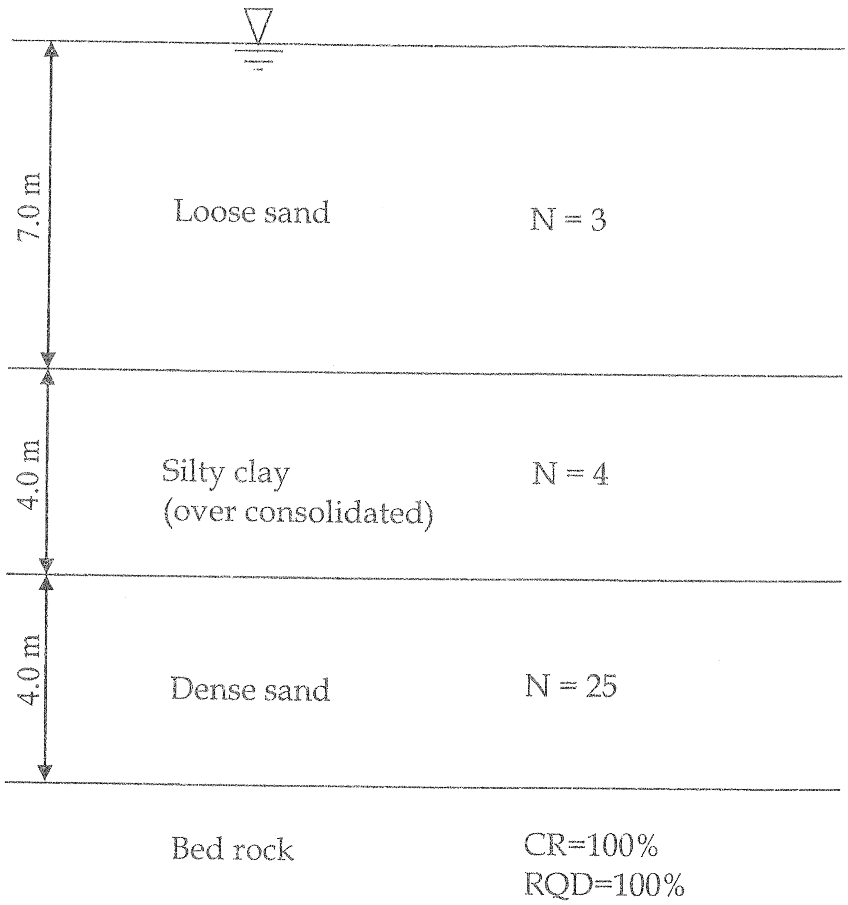

Figure Q1.1 Sub-surface soil profile at the proposed hotel site

Table Q1.1 – Engineering properties of subsurface soil

	Loose sand	Silty clay	Dense sand
Drained cohesion (kN/m²)	0	5	0
Undrained cohesion (kN/m²)	0	30	0
Internal friction angle (°)	20	18	35
Bulk unit weight (kN/m³)	17.0	16.0	18.0
Poisson's ratio	0.25	0.40	0.50
Young's Modulus (kN/m²)	30,000	20,000	50,000
Unconfined Compressive strength of bed rock = 50 MPa Drained friction angle of bed rock = 40°			

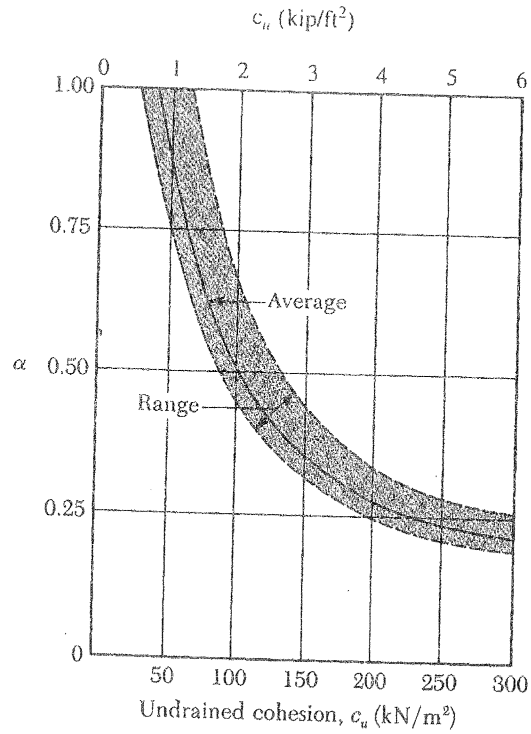

Figure Q1.2 - Variation of α with undrained cohesion of clay

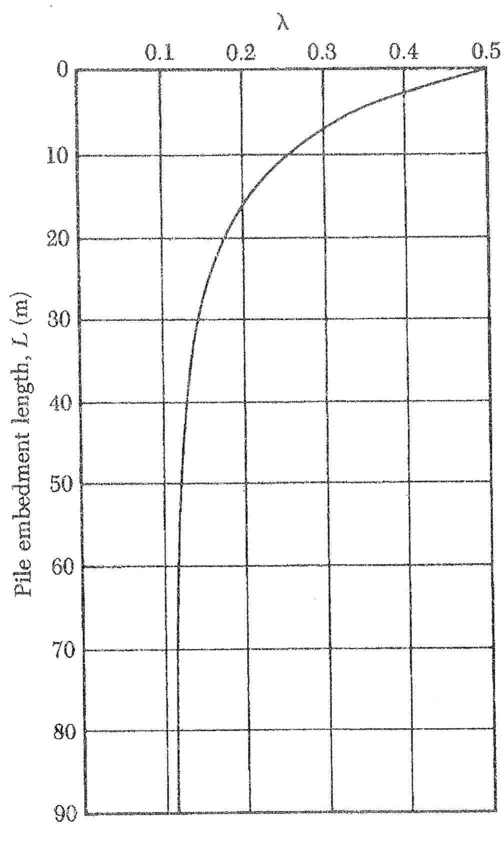

Figure Q1.3 - Variation of λ with pile embedded length

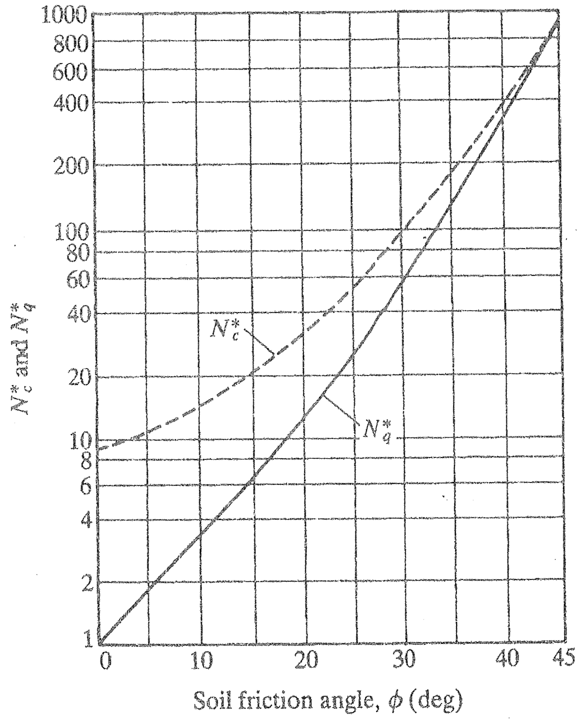

Figure Q1.4 - Variation of N_c^* and N_q^* with soil friction angle

Table Q2.1 – Engineering properties of sub surface soil

	Loose sand	Stiff clay	Dense sand
Drained cohesion (kN/m²)	0	10	0
Undrained cohesion (kN/m²)	0	50	0
Internal friction angle (°)	28	20	35
Saturated unit weight (kN/m³)	17.0	18.0	20.0
Dry unit weight (kN/m³)	16.5	17.0	18.0
Poisson's ratio	0.30	0.30	0.50
Young's Modulus (kN/m²)	30,000	20,000	50,000

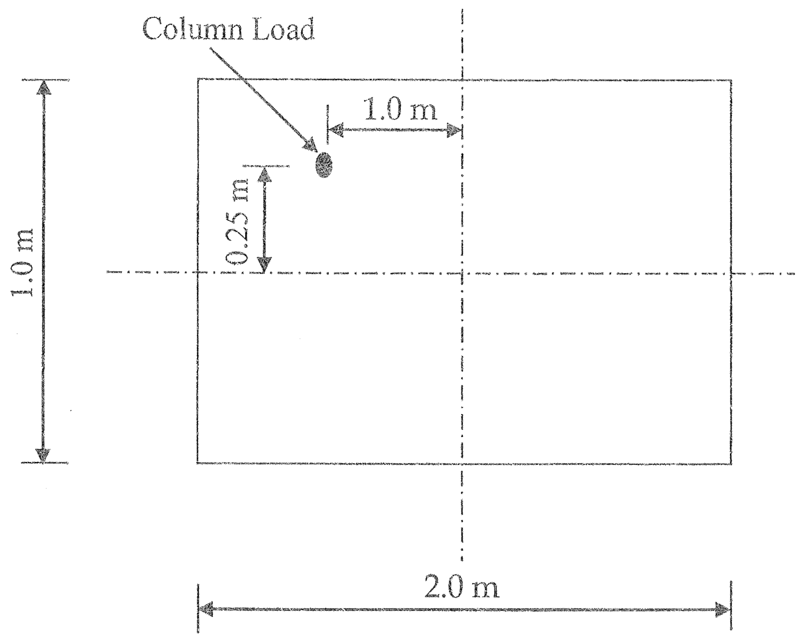

Figure Q2.1 Location of the column load with respect to footing

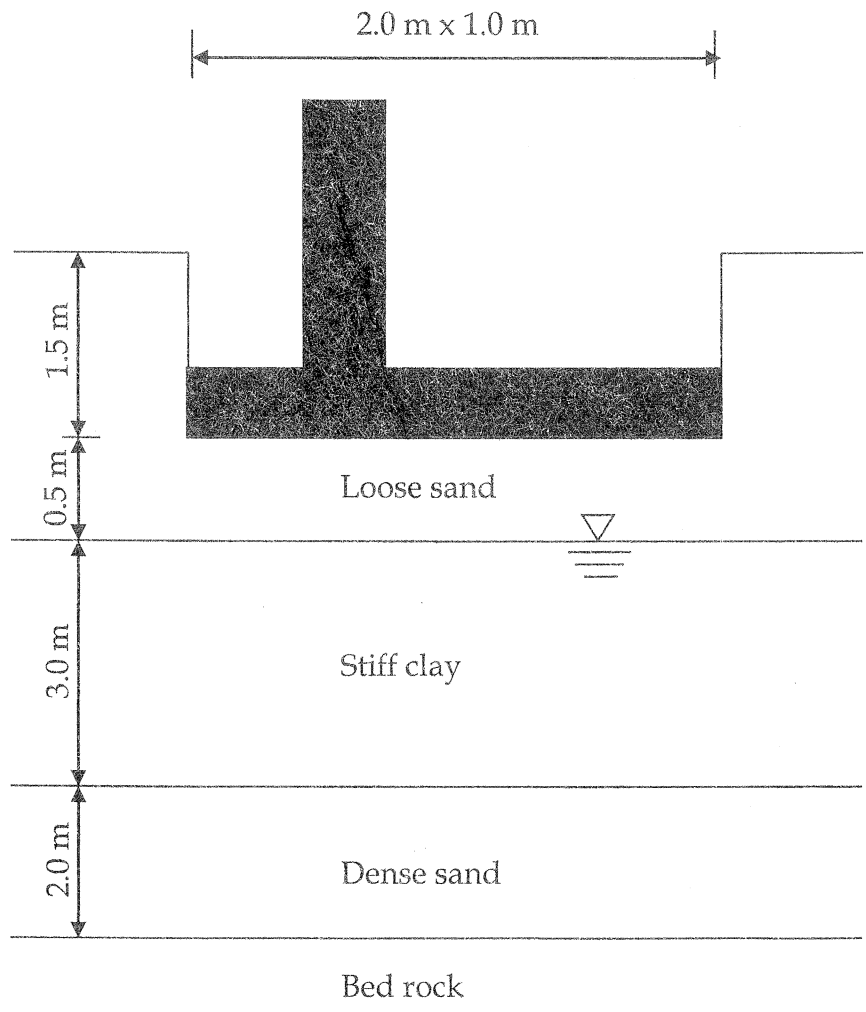

Figure Q2.2 Subsurface profile at the proposed building site

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						

[a] After Vesic (1973)

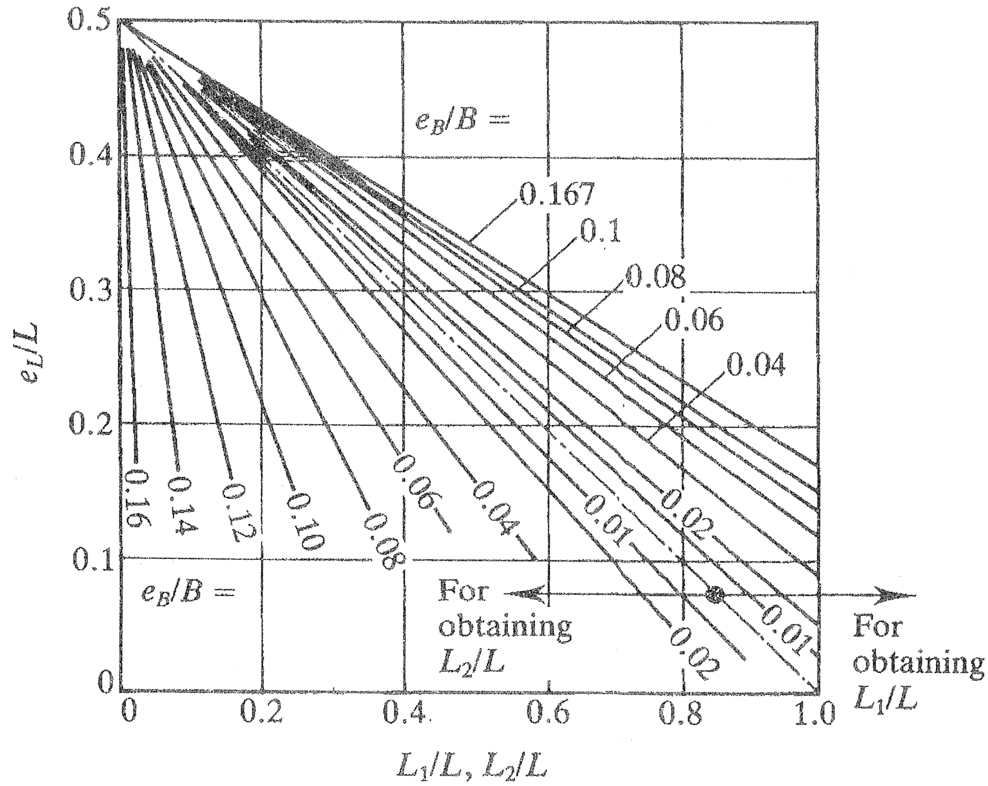

Figure Q2.3 Variation of L_1 and L_2 with e_L and e_B

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

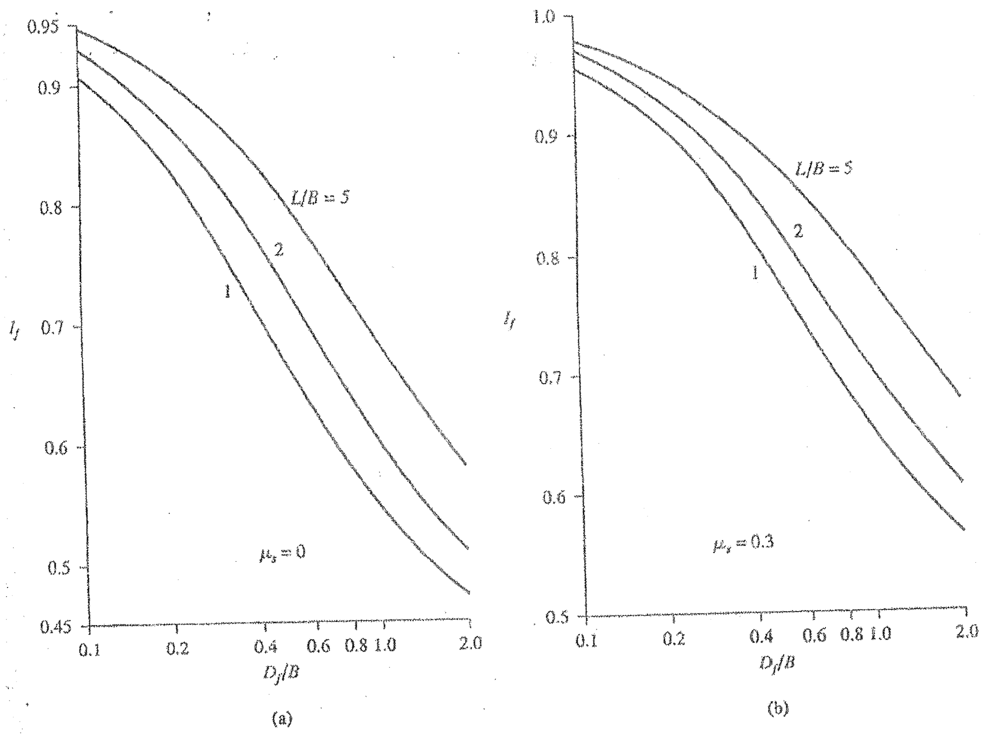

Figure Q2.4 - Variation of I_f with D_f/B, L/B and μ_s

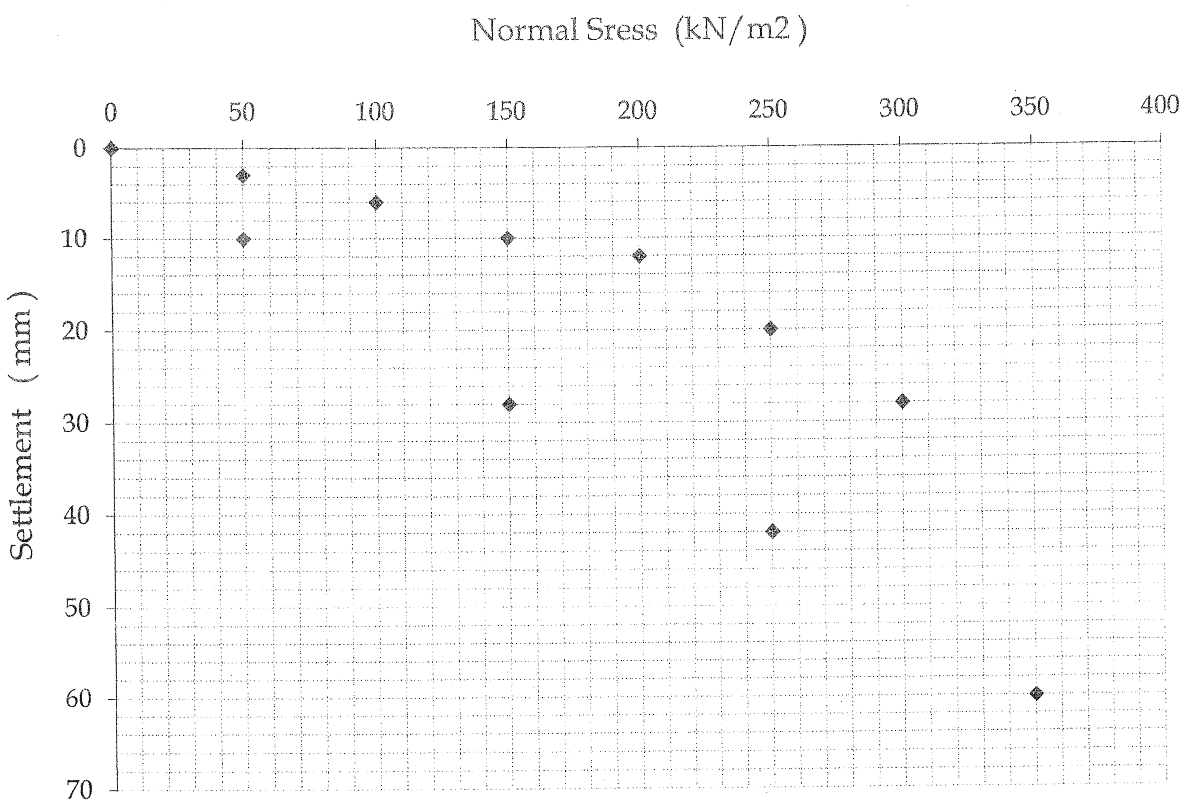

Figure Q2.5 – Plate load test results

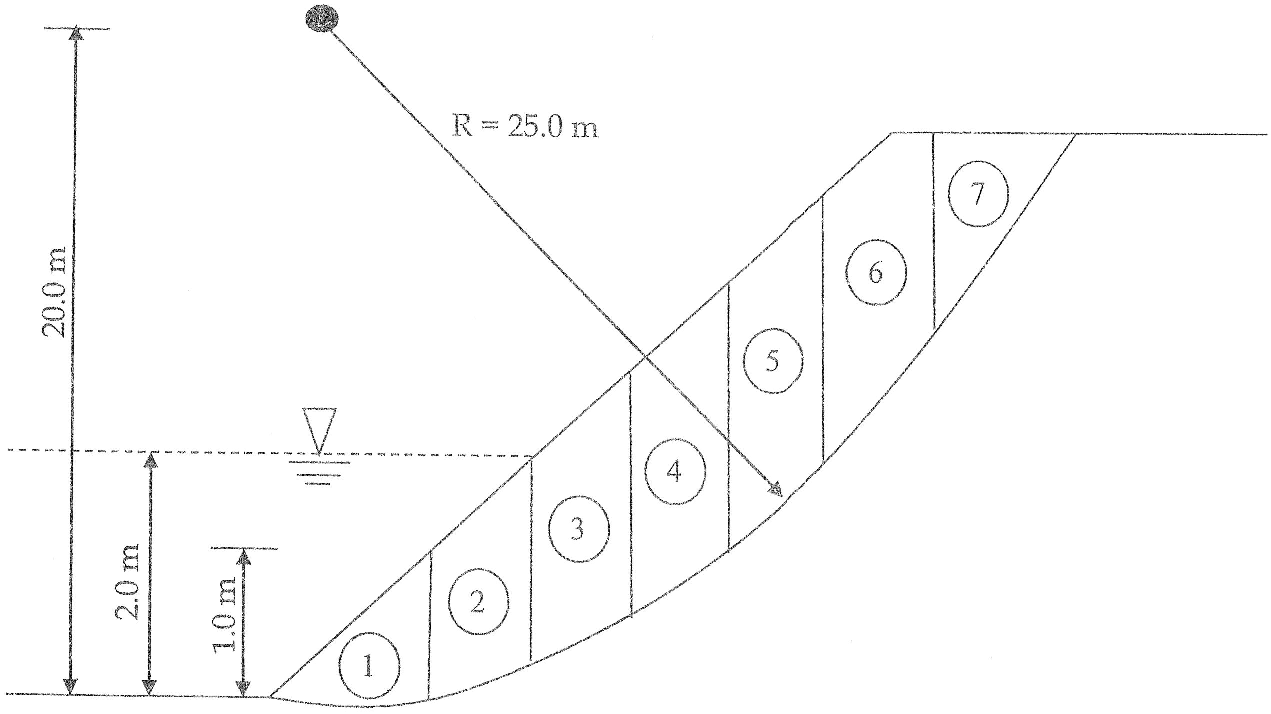

Figure Q3.1 - Circular slope failure

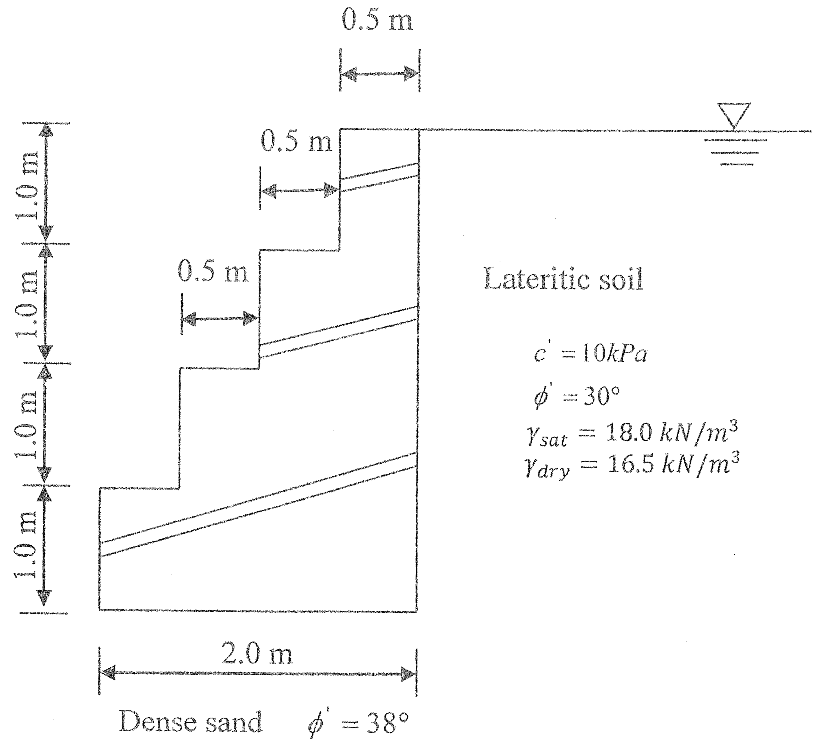

Figure Q4.1 Cross section of retaining wall

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

Slice	w_i (kN)	θ°	u_i (kN/m²)						
1	220	-3.0	25.0						
2	450	5.0	30.0						
3	320	15.5	35.0						
4	234	30.0	24.0						
5	265	56.0	15.0						
6	145	64.0	10.5						
7	54	76.0	0						

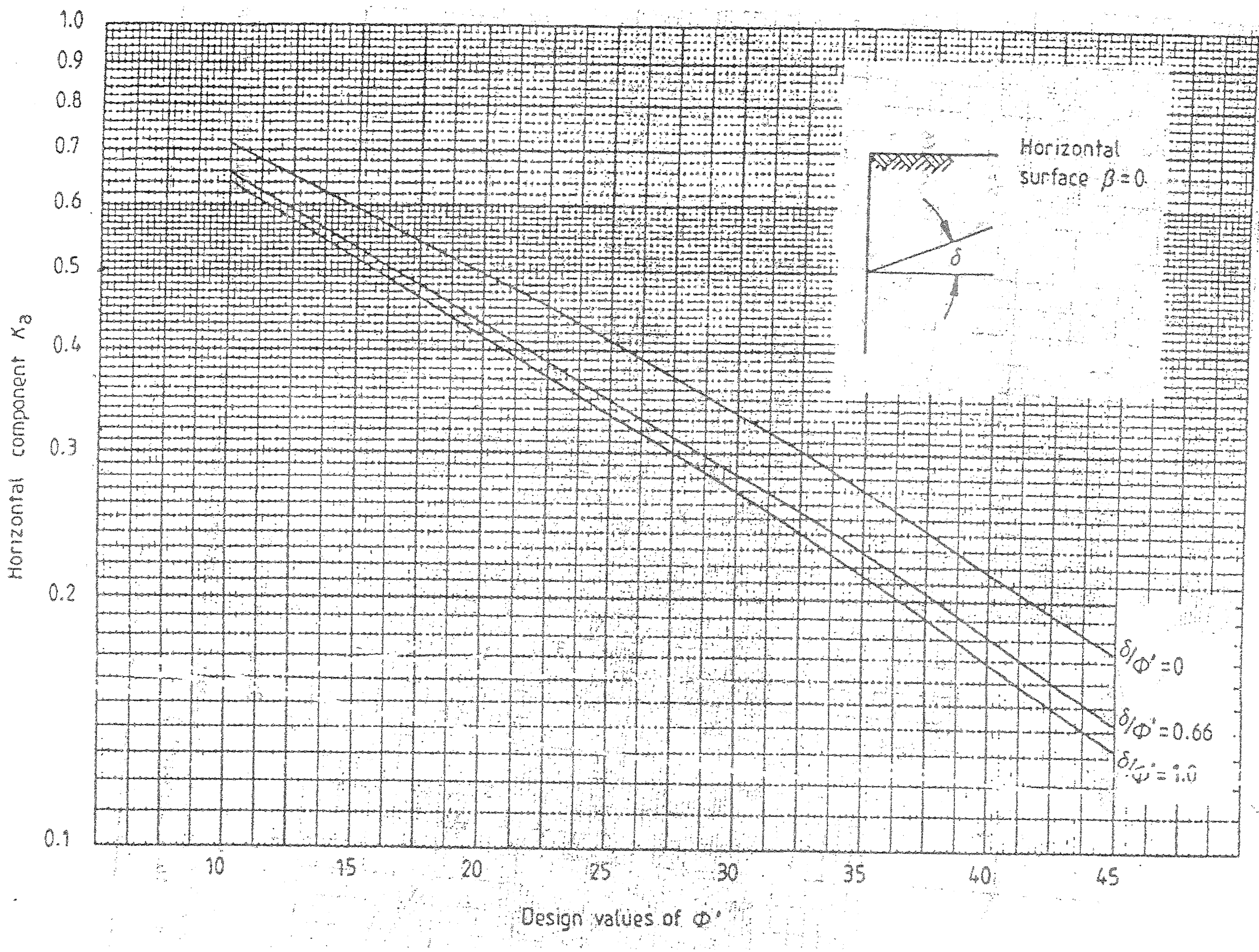

Figure Q4.2 Variation of K_A with φ'_{design}