European Commission

Worked example – strip foundation

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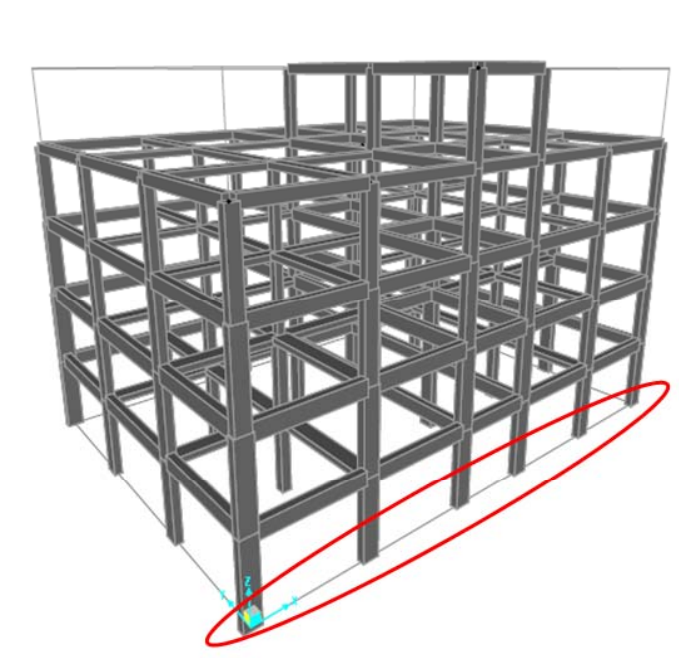
Spread foundations-

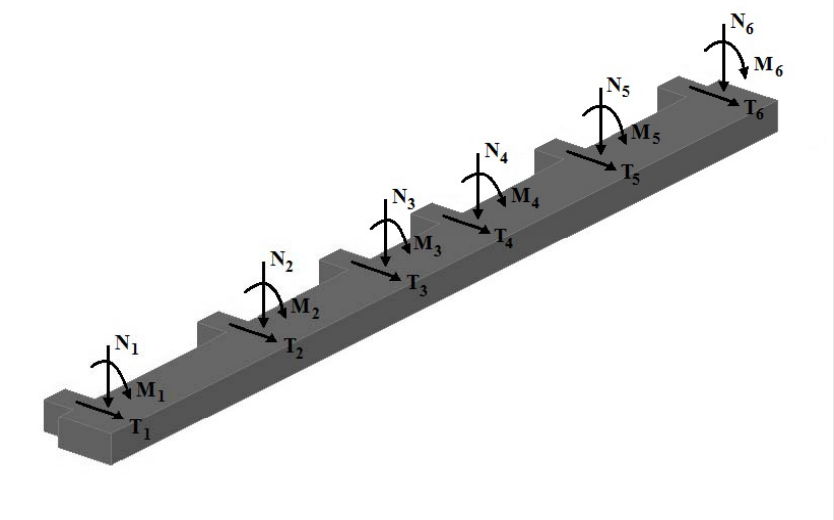
Design of a strip foundation

CASE STUDY

•Design situation:

Strip foundation for a concrete building whose destination is civil habitation. It is composed of four floors. The embedment depth of foundation is 1.5 m; the groundwater level is situated at 1.5 m from the ground surface. Allowable settlement is 5 cm.





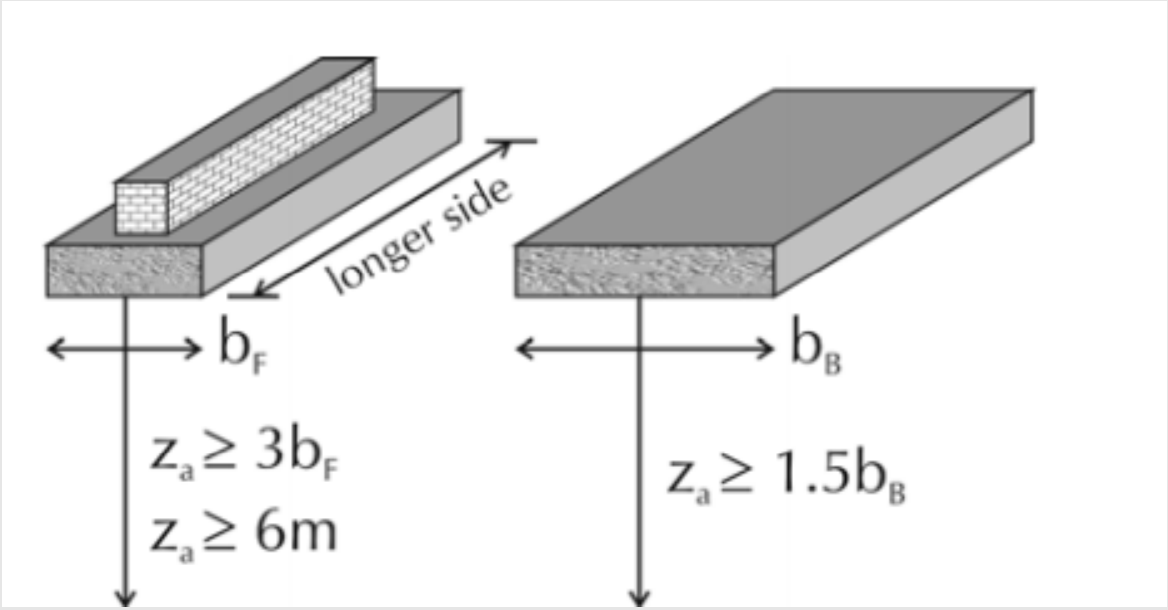
- **Characteristic values of actions:**
  - G_k=permanent vertical load;
  - Q_k=variable vertical load.

	Normal forces (kN)*	
C1	G_k	-460.147
	Q_k	-108.138
C2	G_k	-687.103
	Q_k	-222.355
C3	G_k	-627.8
	Q_k	-154.012
C4	G_k	-623.915
	Q_k	-152.261
C5	G_k	-685.011
	Q_k	-222.231
C6	G_k	-416.982
	Q_k	-108.103

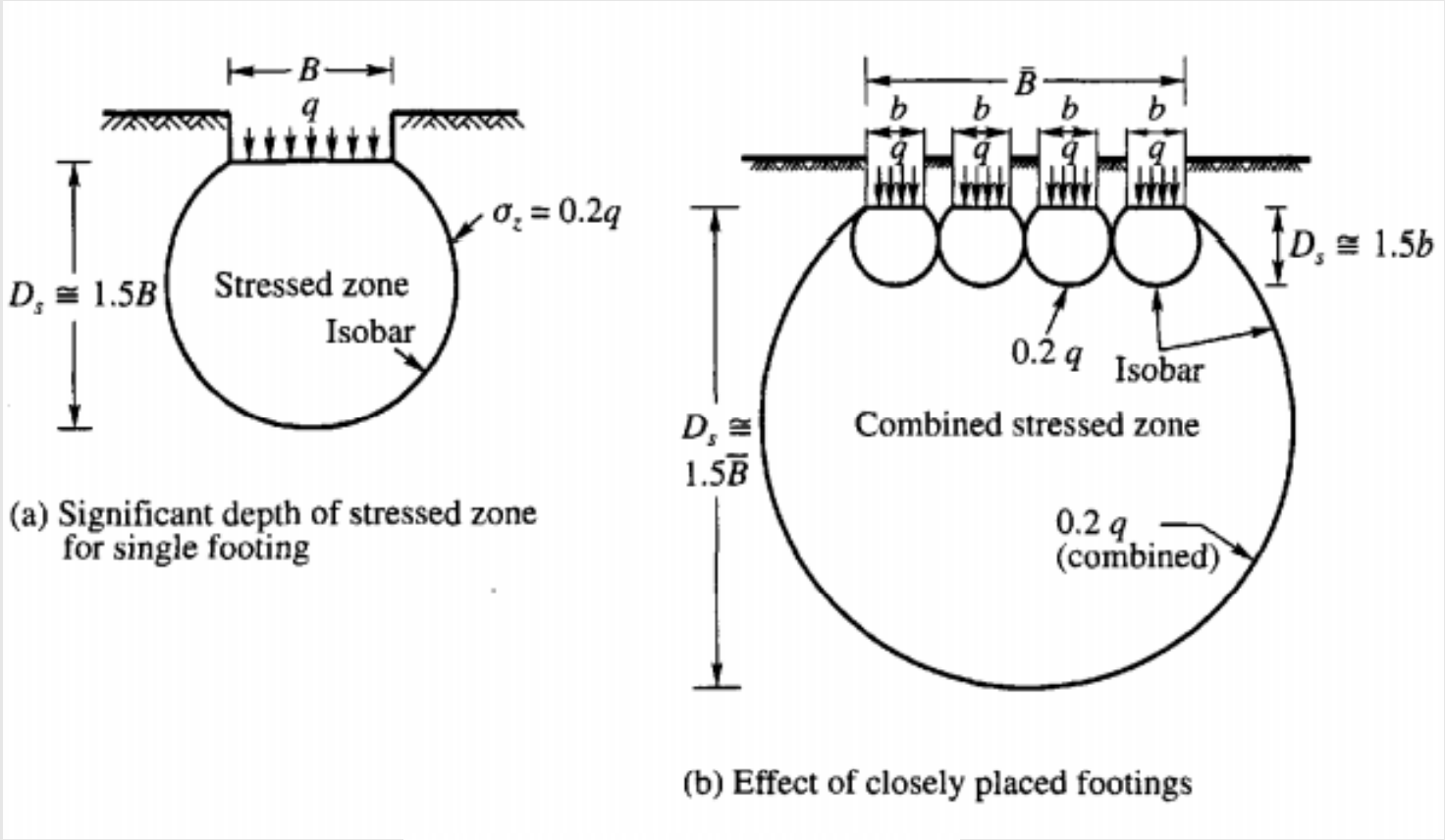
*(shear forces and bending moments are negligible for static conditions).

- **Require foundation width, B to satisfy both ULS and SLS.**

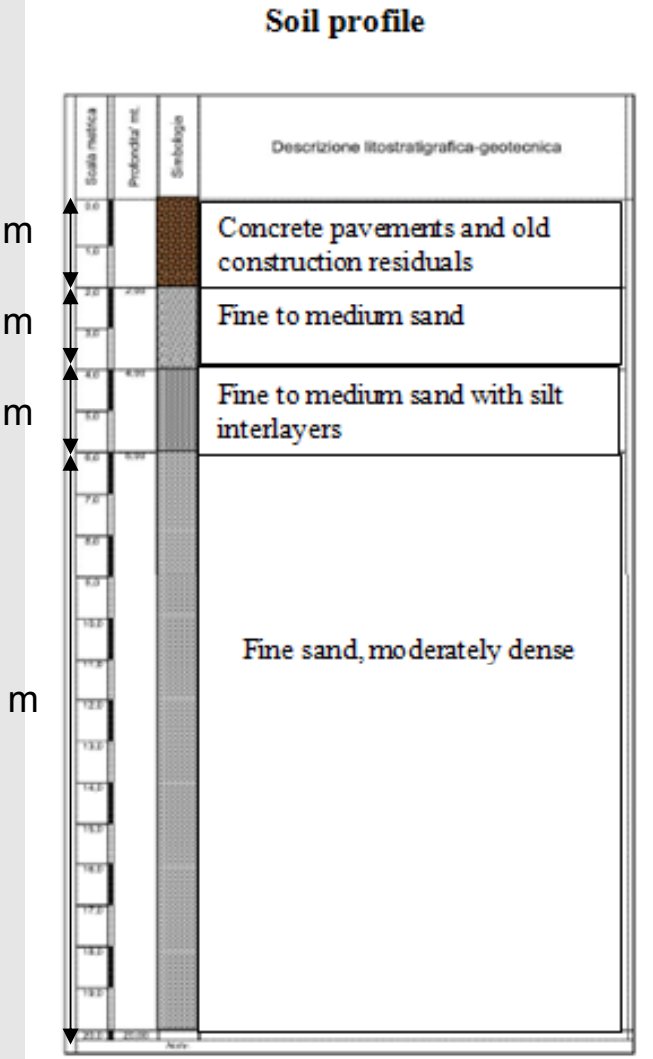
Annex B.3 of Eurocode 7 Part 2

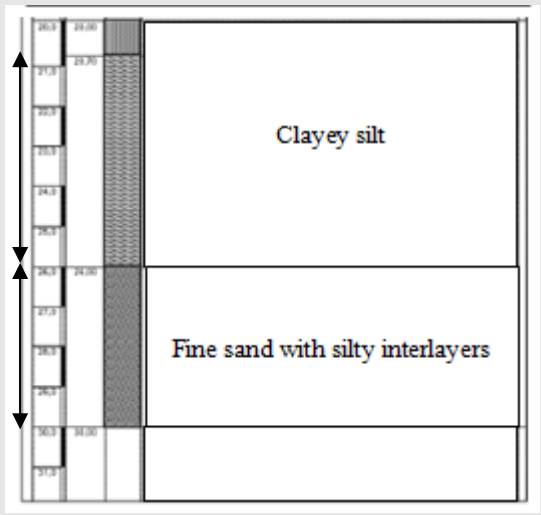


Recommended depth of investigation for spread foundations

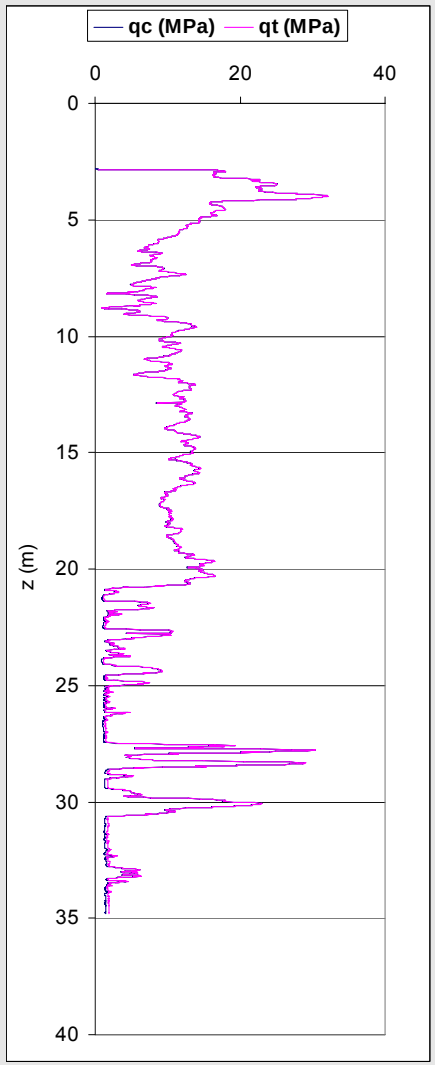


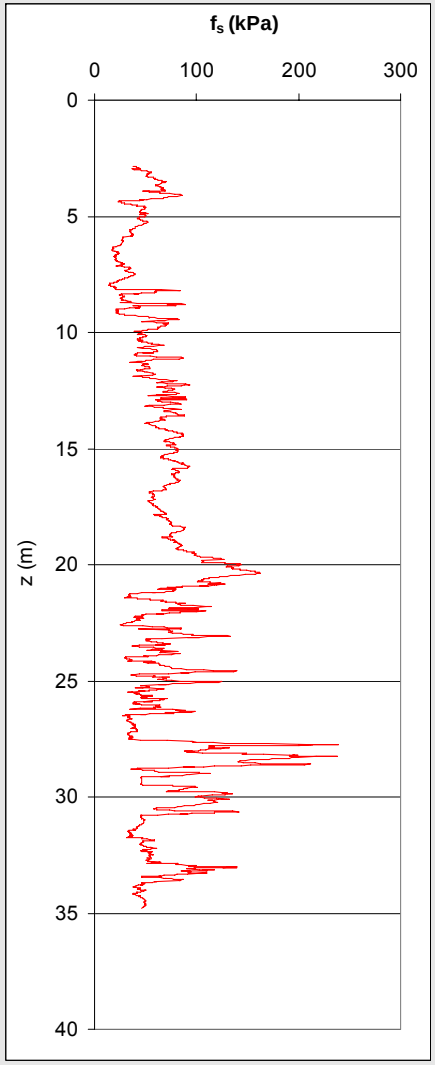
Significant depth of stressed zone

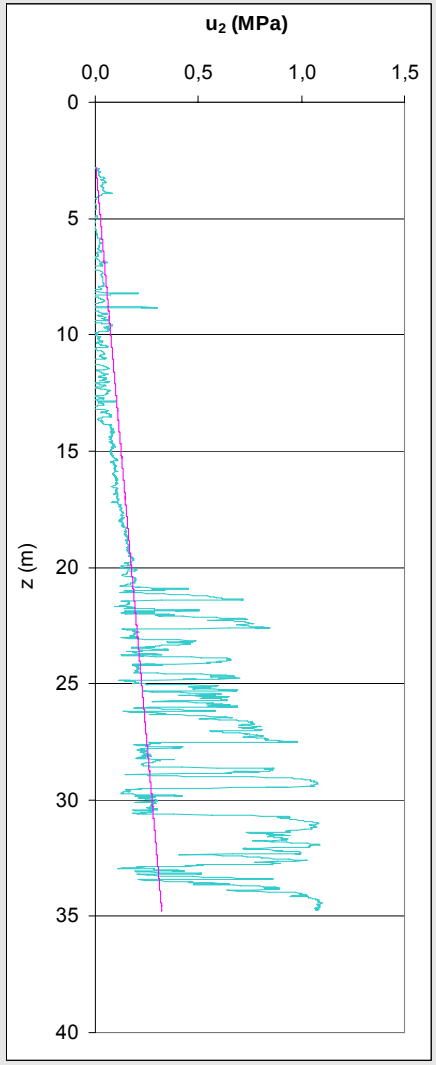


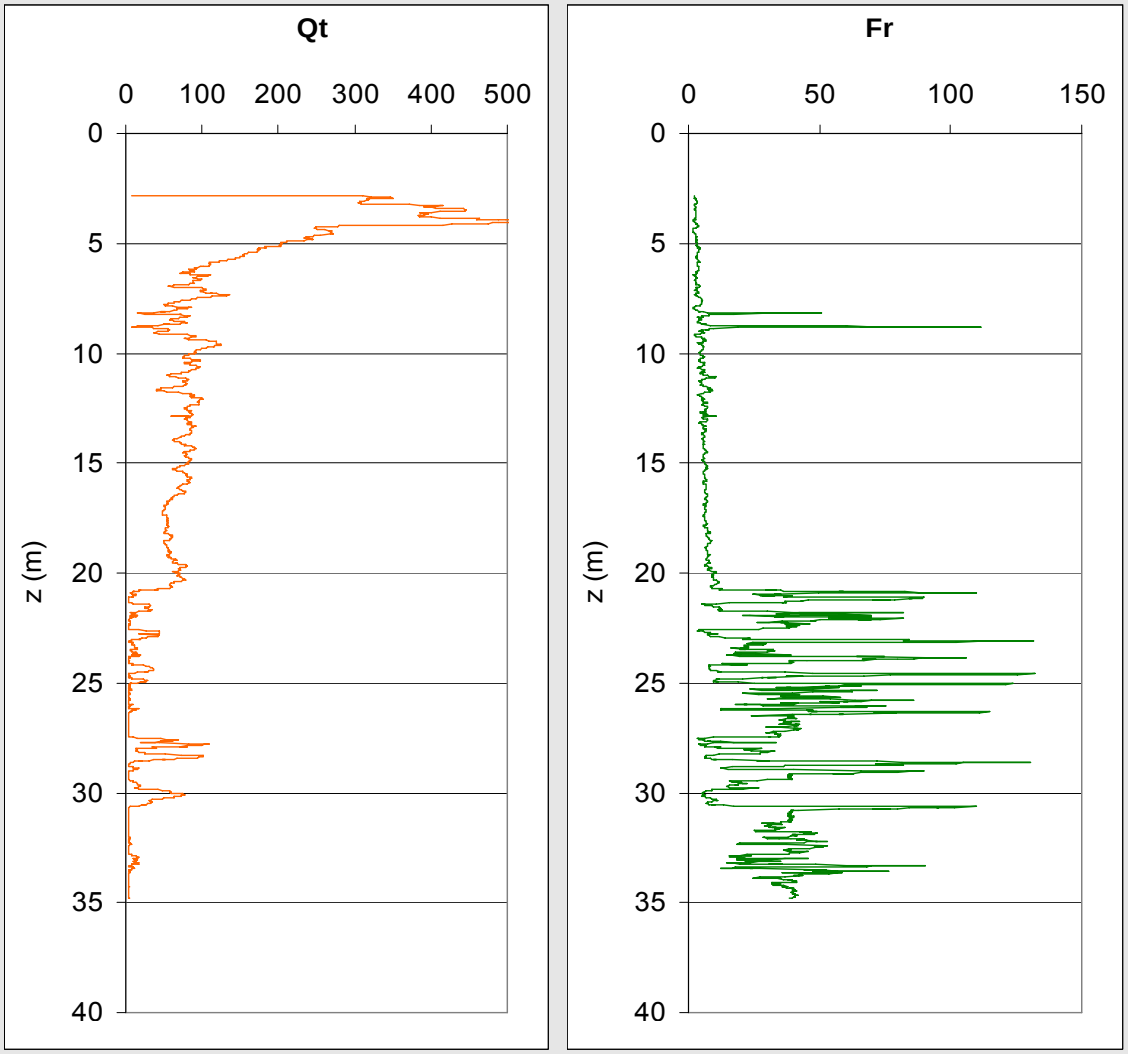


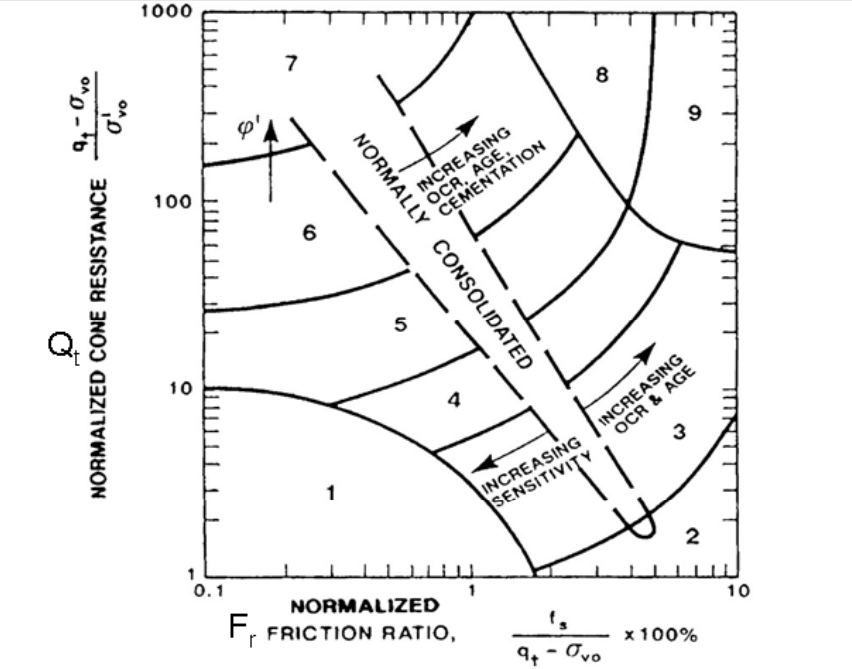
CPT results



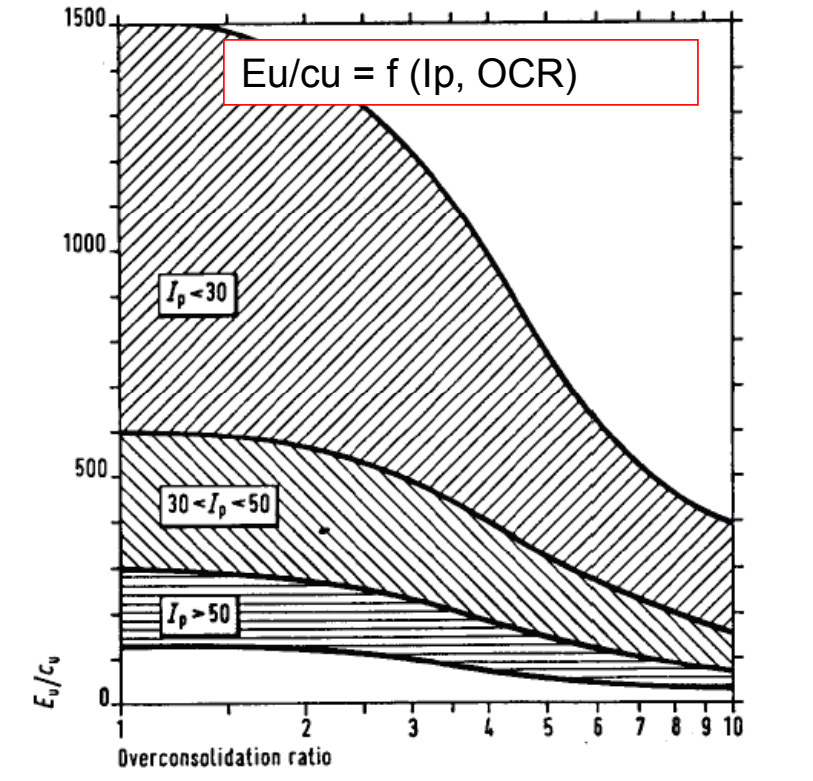








Normalized CPT soil behaviour type chart after Robertson (1990).



Duncan and Buchignani (1976).

$$c_u=(q_t-\sigma_{v0})/N_k$$

$$N_k=19$$

Undrained cohesion from CPT test, Lunne et al. (1977)

$$E_d \text{ (MPa)} = 4\ q_c$$

$$(\text{if } q_c > 10 \text{ MPa})$$

Oedometric modulus from CPT test (after Lunne-Christoffersen 1983 - Robertson and Powell 1997)

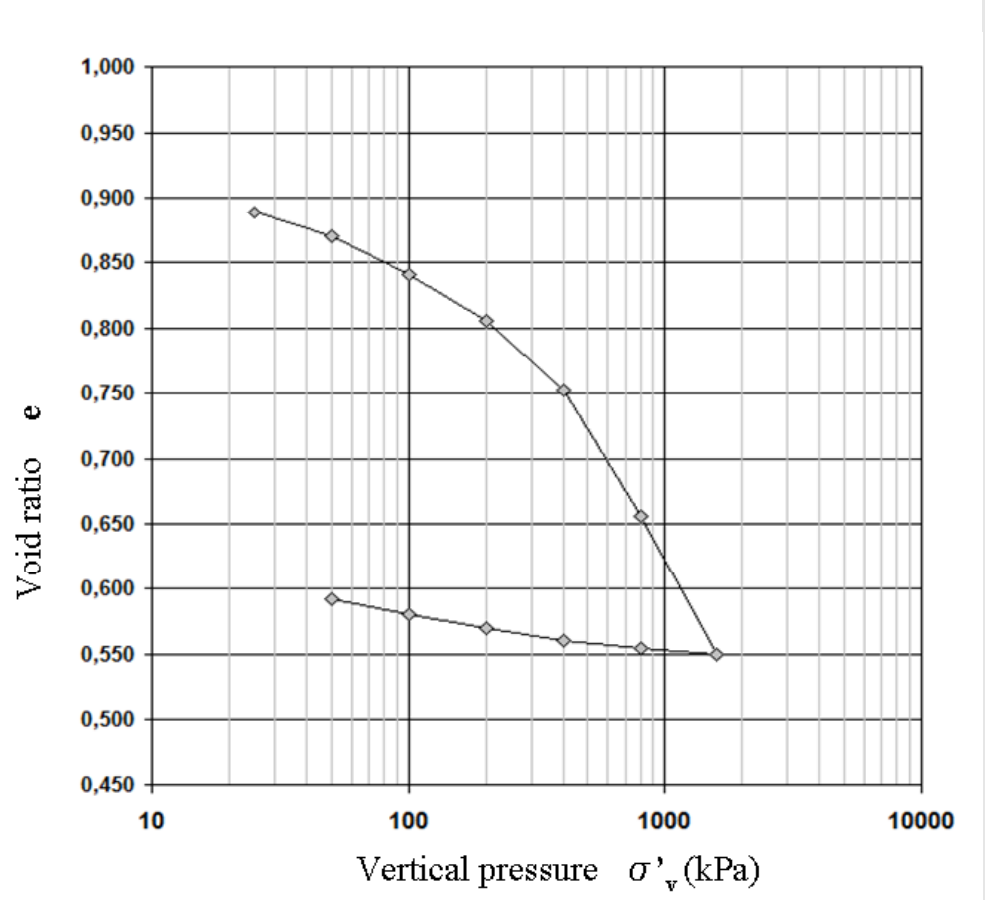
Oedometer test results

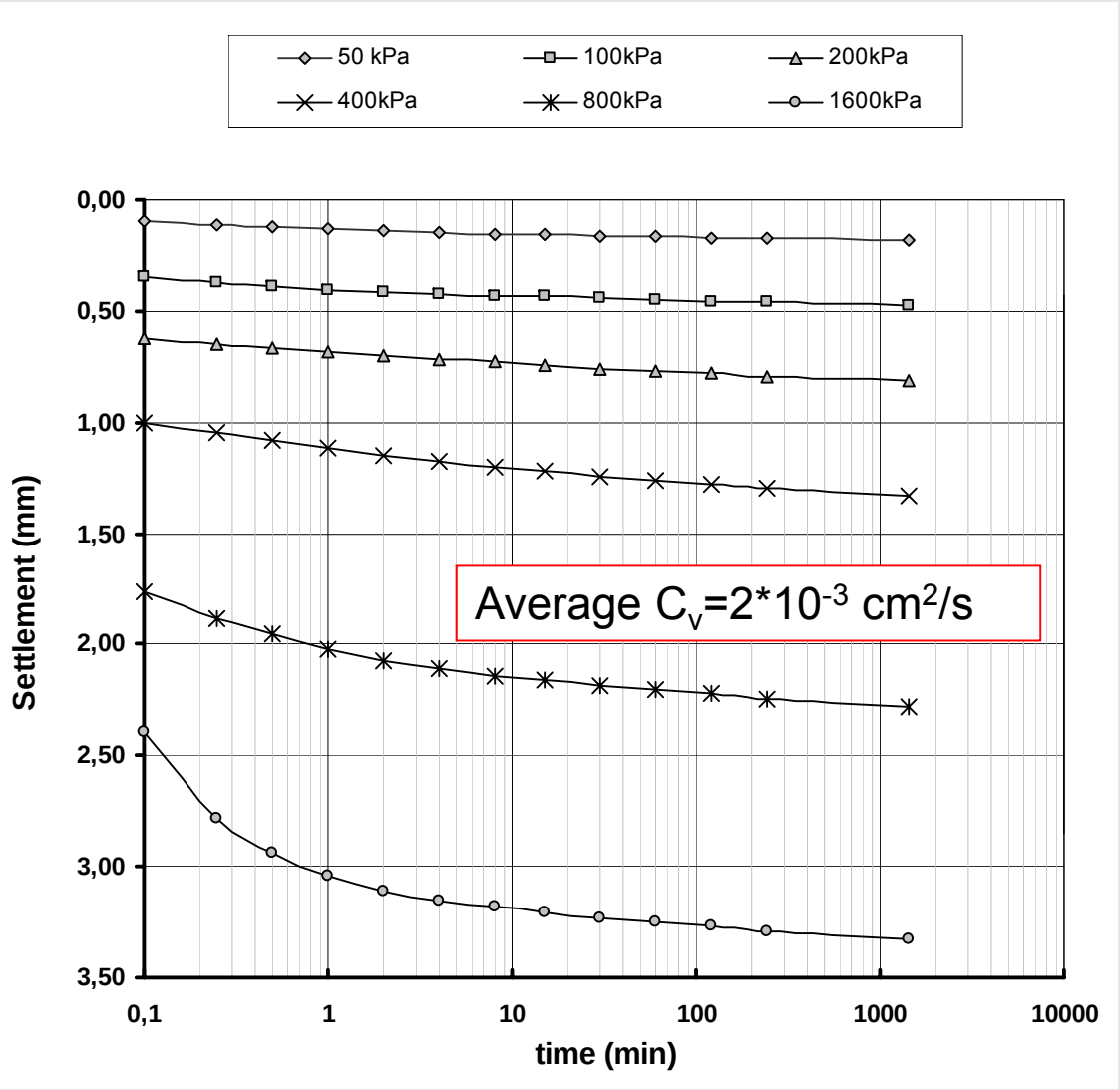
Sample depth (z) = 25 m

Natural water content (W) =32.74 %

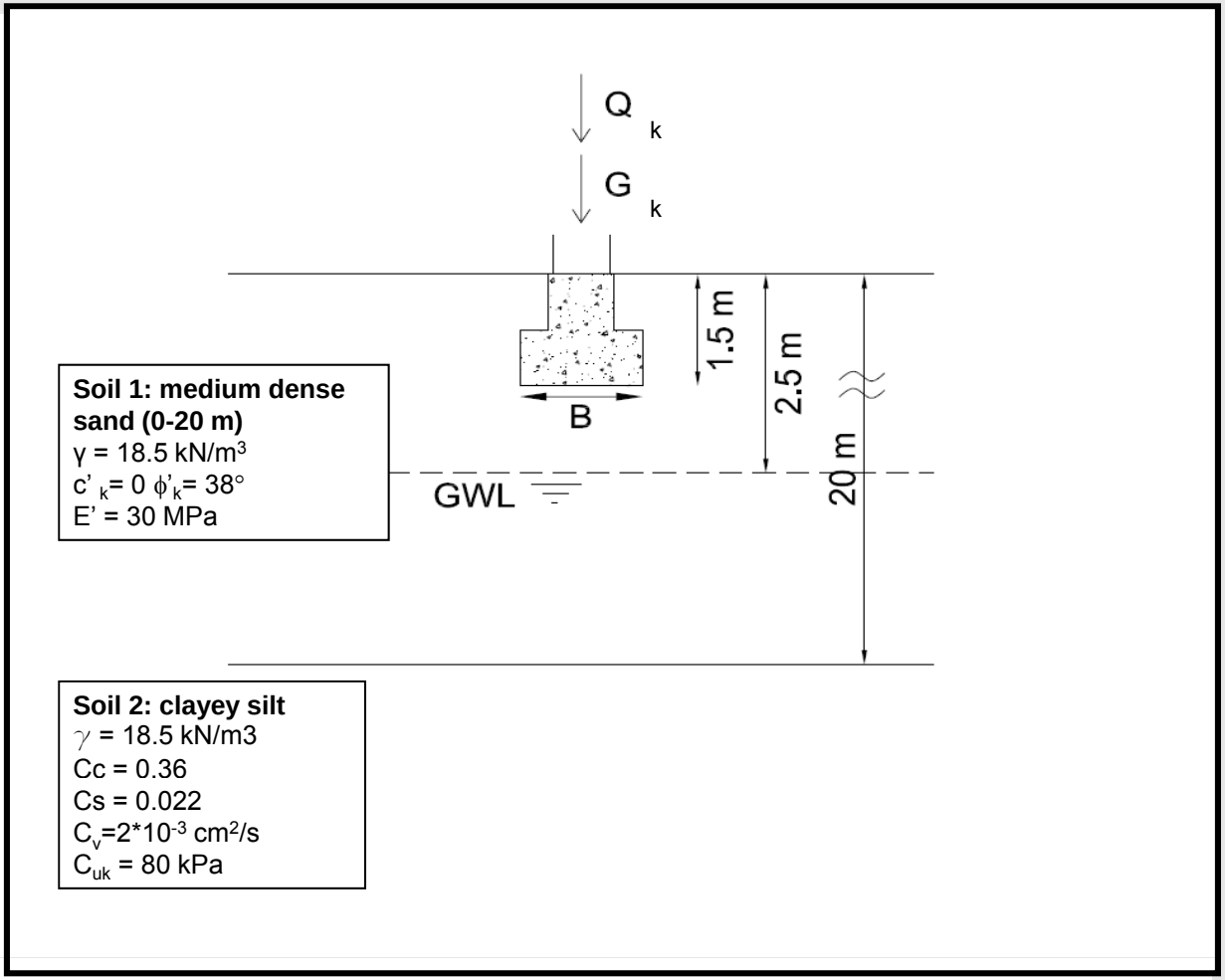
Unit weight (γ) =19 kN/m^3

Water depth ($z_{w)}$ = 2.5 m





Soil Conditions:



Spread foundations-

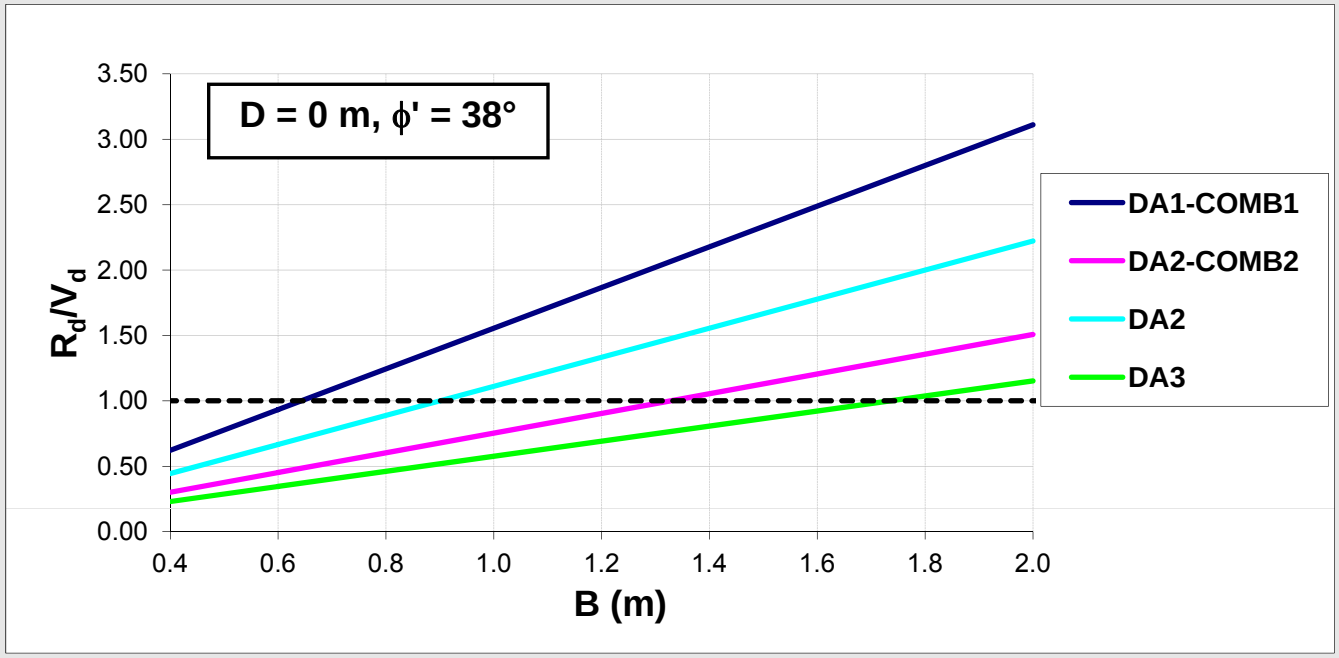
Design of a strip foundation

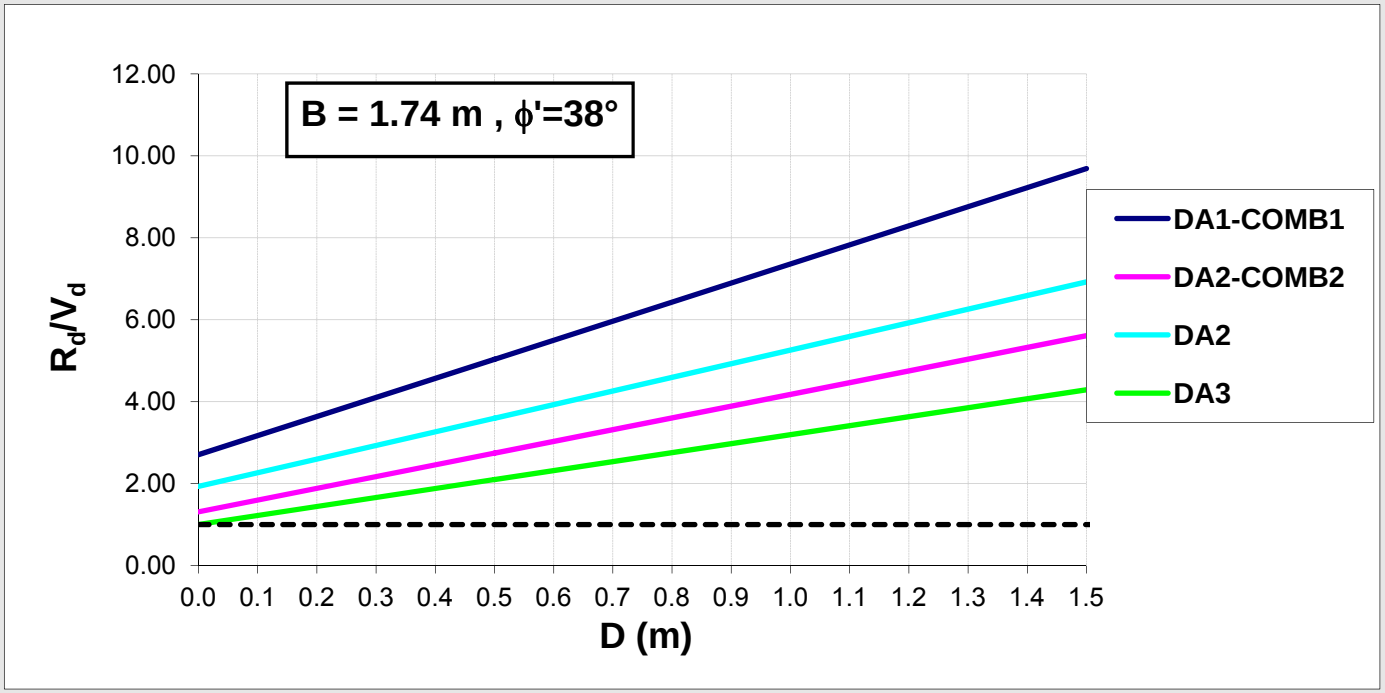
BEARING RESISTANCE

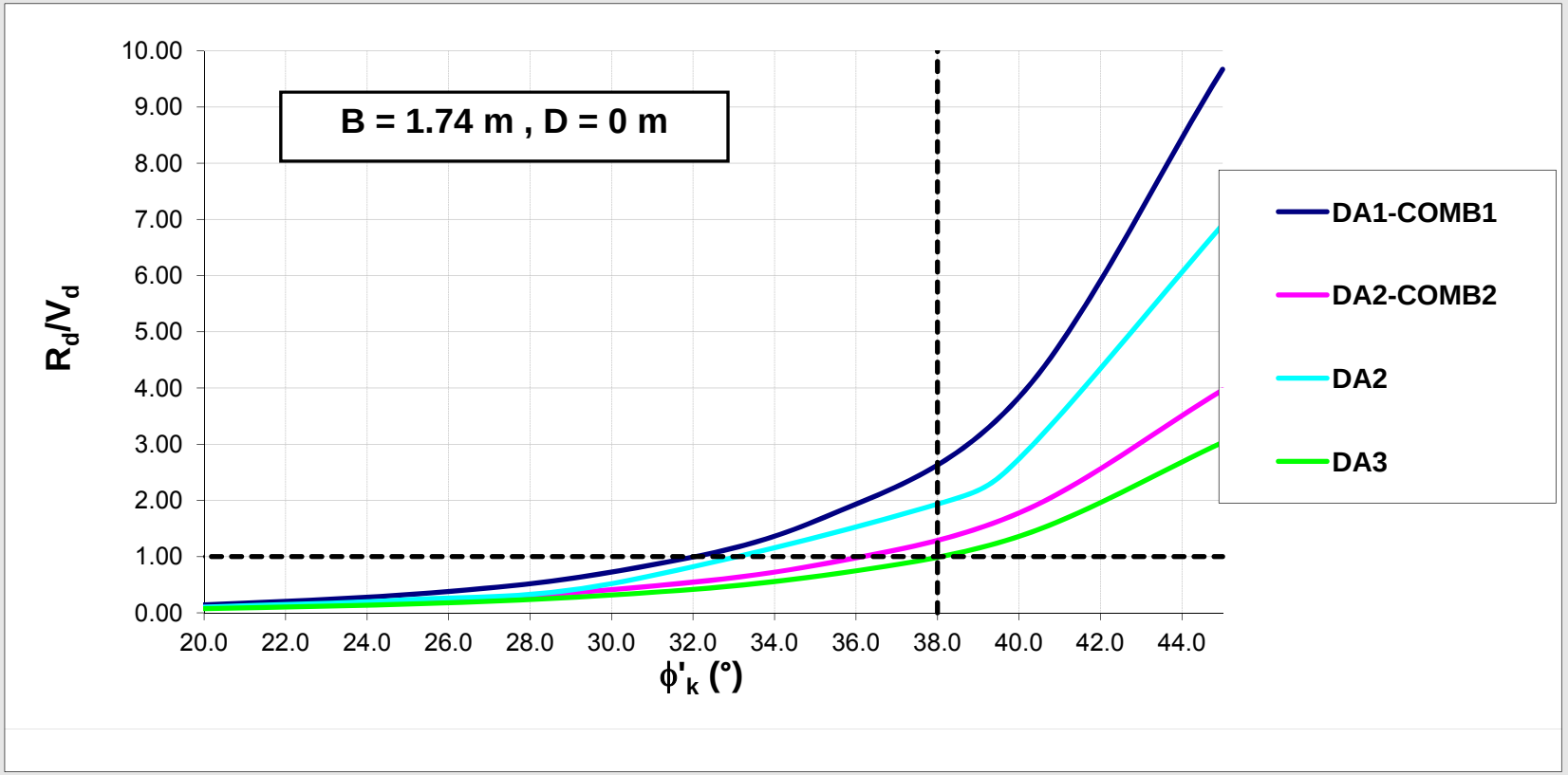
B=1.5	DA1-1	DA1-2
PARTIAL FACTORS	A1+M1+R1	A2+M2+R1
V_d (kN)	7395.74	5661.00
N_q	48.87	23.17
N_γ	74.80	27.72
s_q	1.04	1.04
s_γ	0.98	0.98
R_d (kN)	15320.80	5676.52
R_d/V_d	2.07	1.00

B=1.21	DA2
PARTIAL FACTORS	A1+M1+R2
V_d (kN)	7160.10
N_q	48.87
N_γ	74.80
s_q	1.03
s_γ	0.98
R_d (kN)	7150.58
R_d/V_d	1.00

B=1.74	DA3
PARTIAL FACTORS	A1/A2+M2+R3
V_d (kN)	7590.75
N_q	23.17
N_γ	27.72
s_q	1.04
s_γ	0.98
R_d (kN)	7612.07
R_d/V_d	1.00





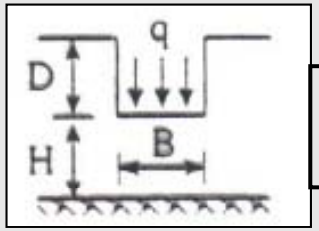


Spread foundations-

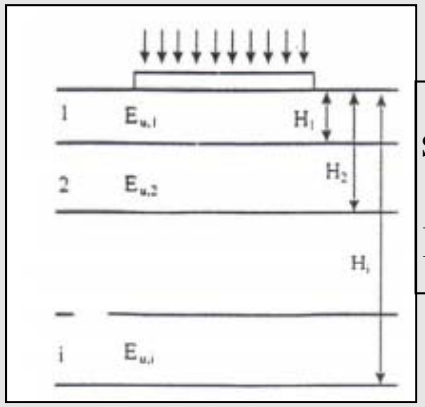
Design of a strip foundation

CHECK FOR SERVICEABILITY

Immediate settlement

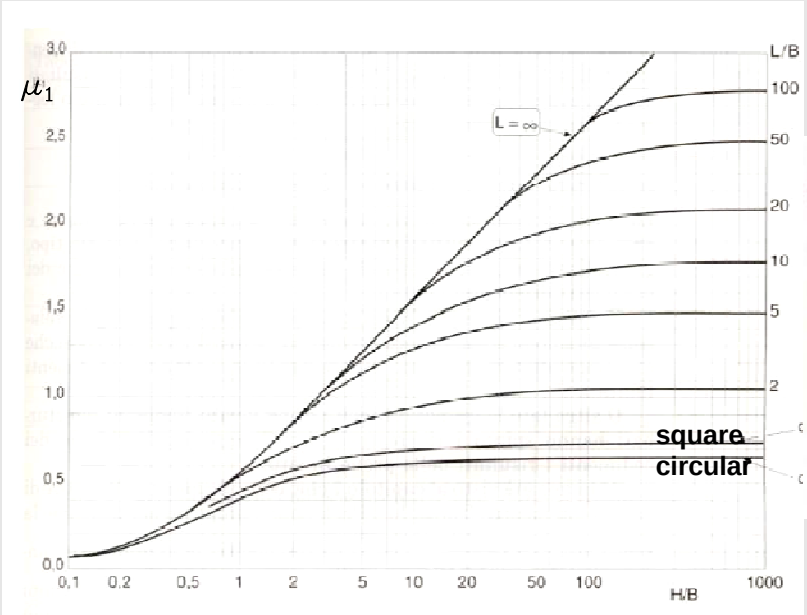


$$s_0 = \frac{qB}{E}\mu_0\mu_1(1-\nu^2)$$

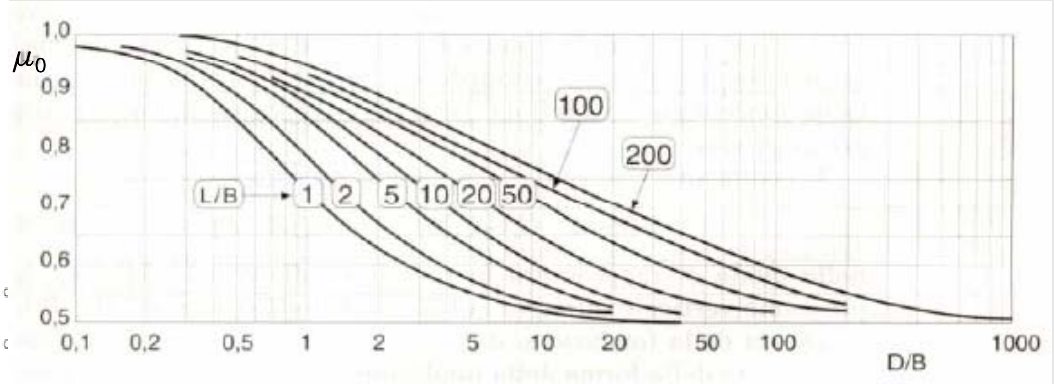


$$s_0 = qB\sum_{i=1}^{n}\frac{I(H_i) - I(H_{i-1})}{E_i}(1-\nu^2)$$

$$I = \mu_0\mu_1$$



Janbu et al. (1956)



....considering the single strip footing

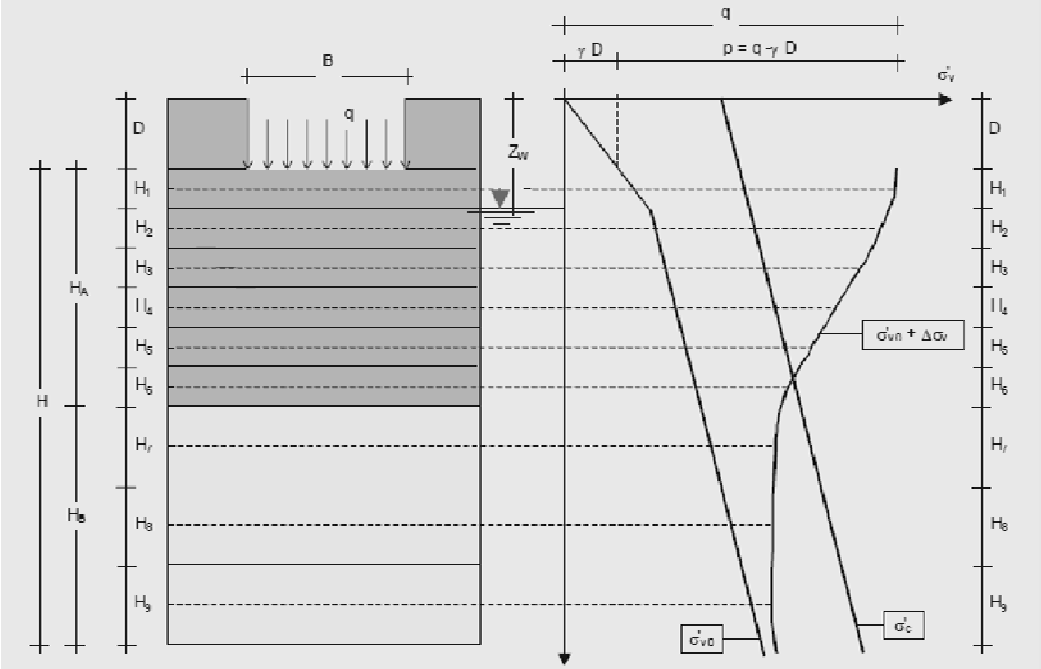
q (kPa)=	167.32
B (m) =	1.50
L (m) =	21.40
H (m) =	50
$\nu =$	0.3
E' (kPa) =	30000
H/B =	666.7
D/B =	1
L/B=	14.3
$\mu_0 =$	1
$\mu_1 =$	1.8
δ **(m)=**	**0.014**

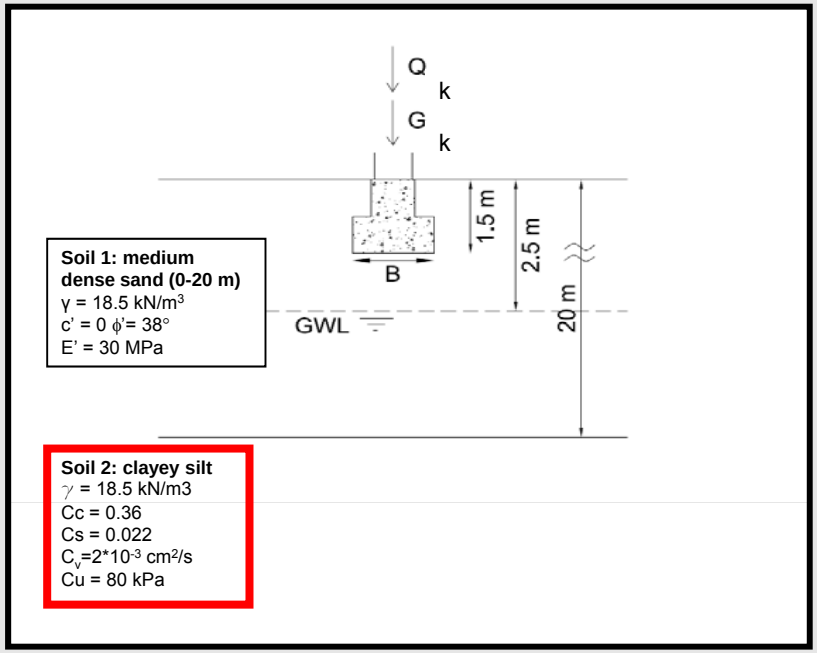
....considering an equivalent spread foundation spanning over the whole building base area

q (kPa) =	64.77
B (m) =	15.50
L (m) =	21.40
H1 =	20
H2 =	50
$\nu_1 =$	0.30
$\nu_2 =$	0.50
cu (kPa) =	80.00
Eu (kPa) =	32000
E' (kPa) =	30000
H1/B =	1.29
H2/B =	64.52
D/B =	0.00
L/B=	1.38
$\mu_{0\ (1)} =$	1.00
$\mu_{1\ (1)} =$	0.50
$\mu_{0\ (2)} =$	1.00
$\mu_{1\ (2)} =$	0.70
$\delta\ (\mathrm{m}) =$	**0.021**

Oedometric settlement

$$\Delta H_i = \frac{H_i}{(1+e_0)} \cdot \left[C_s \cdot \log\left(\frac{\sigma'_c}{\sigma'_{v0}} \right) + C_c \cdot \log\left(\frac{\sigma'_{v0} + \Delta\sigma_v}{\sigma'_c} \right) \right] \rightarrow S_{ed} = \Sigma \Delta H_i \rightarrow S_c = \mu \cdot S_{ed}$$





6.6.2 (5) The depth of the compressible soil layer to be considered when calculating settlement should depend on the size and shape of the foundation, the variation in soil stiffness with depth and the spacing of foundation elements.

Stress increment

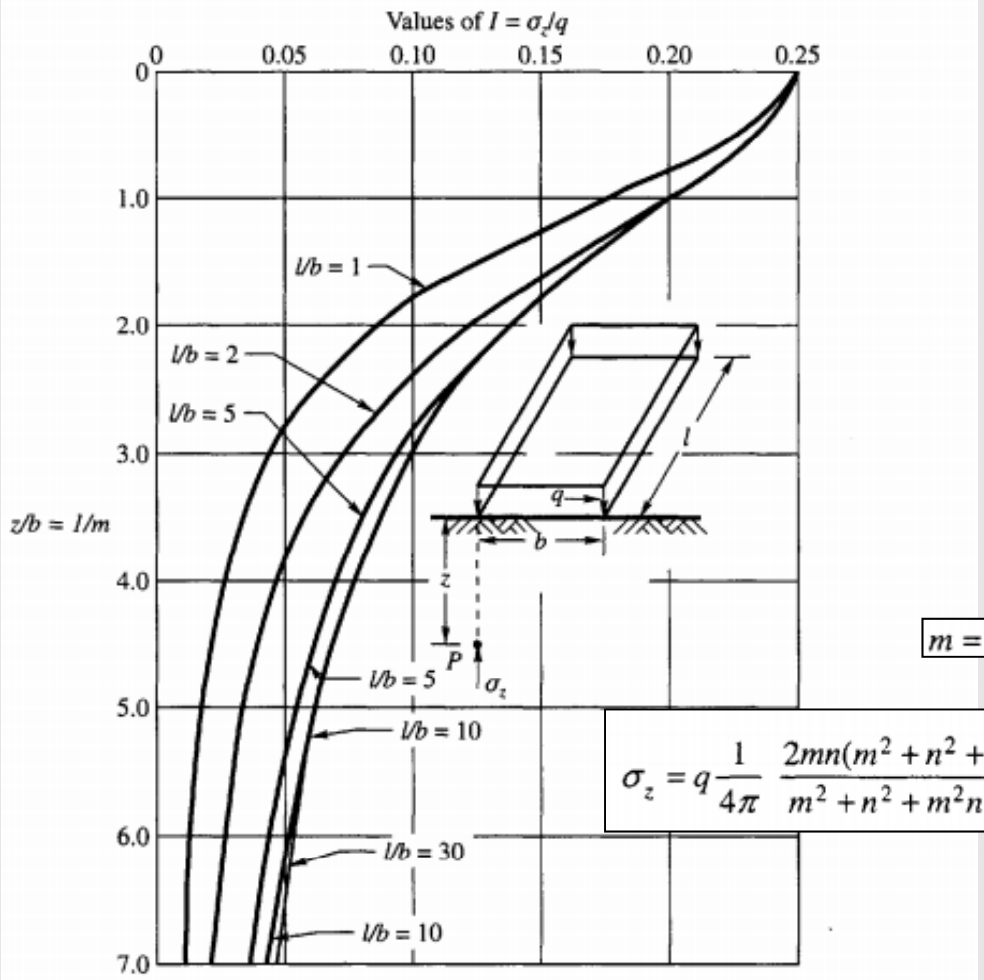


Chart for computing σ_z below the corner of a rectangular foundation (after Steinbrenner, 1934)

$$m = b/z,\ n = l/z$$

$$\sigma_z = q\frac{1}{4\pi}\left[\frac{2mn(m^2+n^2+1)^{1/2}}{m^2+n^2+m^2n^2+1}\cdot\frac{m^2+n^2+2}{m^2+n^2+1} + \tan^{-1}\frac{2mn(m^2+n^2+1)^{1/2}}{m^2+n^2-m^2n^2+1}\right]$$

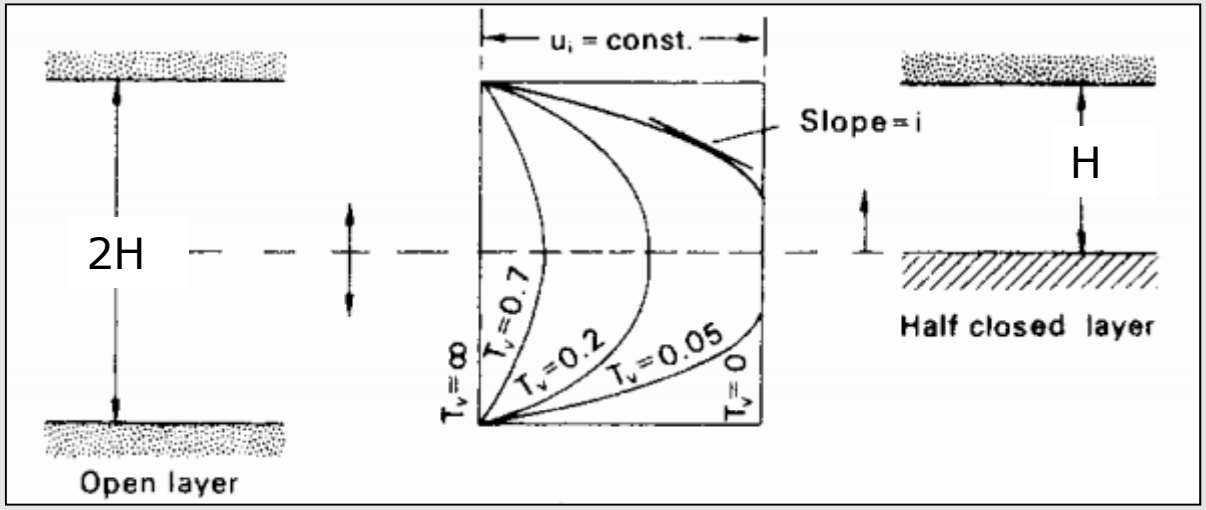
layers	Δz (m)	z (from g.s.) (m)	σ_z (kPa)	u (kPa)	σ'_z (kPa)	e_0	$\Delta\sigma_z$ (kPa)	$\Delta\sigma_z / \sigma'_z$	σ'_{z_fin} (kPa)	e_f	ε_z	S_{ed} (m)
1,00	0,50	20,25	374,63	174,13	200,50	0,91	21,67	0,11	222,17	0,86	0,023	0,012
2,00	0,50	20,75	383,88	179,03	204,84	0,90	20,87	0,10	225,71	0,86	0,022	0,011
3,00	0,50	21,25	393,13	183,94	209,19	0,90	20,10	0,10	229,29	0,86	0,021	0,010
4,00	0,50	21,75	402,38	188,84	213,53	0,90	19,37	0,09	232,90	0,86	0,020	0,010
5,00	0,50	22,25	411,63	193,75	217,88	0,89	18,68	0,09	236,55	0,86	0,019	0,009
6,00	0,50	22,75	420,88	198,65	222,22	0,89	18,01	0,08	240,24	0,86	0,018	0,009
7,00	0,50	23,25	430,13	203,56	226,57	0,89	17,38	0,08	243,95	0,86	0,017	0,009
8,00	0,50	23,75	439,38	208,46	230,91	0,88	16,78	0,07	247,69	0,85	0,016	0,008
9,00	0,50	24,25	448,63	213,37	235,26	0,88	16,20	0,07	251,46	0,85	0,015	0,008
10,00	0,50	24,75	457,88	218,27	239,60	0,88	15,66	0,07	255,26	0,85	0,015	0,007
11,00	0,50	25,25	467,13	223,18	243,95	0,88	15,13	0,06	259,08	0,85	0,014	0,007
12,00	0,50	25,75	476,38	228,08	248,29	0,87	14,63	0,06	262,93	0,85	0,013	0,007
13,00	0,50	26,25	485,63	232,99	252,64	0,87	14,16	0,06	266,79	0,85	0,013	0,006
											Stot=	**0,033**

layers	Δz (m)	z (from g.s.) (m)	σ_z (kPa)	u (kPa)	σ'_z (kPa)	$\Delta\sigma_z$ (kPa)	$\Delta\sigma_z / \sigma'_z$	σ'_{z_fin} (kPa)	e_f	ε_z	S_{ed} (m)
1,00	2,00	21,00	388,50	181,49	207,02	20,48	0,10	227,50	0,86	0,022	0,043
2,00	2,00	23,00	425,50	201,11	224,40	17,69	0,08	242,09	0,86	0,017	0,035
3,00	2,00	25,00	462,50	220,73	241,78	15,39	0,06	257,17	0,85	0,014	0,029
4,00	2,00	27,00	499,50	240,35	259,16	13,48	0,05	272,64	0,84	0,012	0,024
5,00	2,00	29,00	536,50	259,97	276,54	11,88	0,04	288,42	0,84	0,010	0,020
6,00	2,00	31,00	573,50	279,59	293,92	10,54	0,04	304,46	0,83	0,008	0,017
7,00	2,00	33,00	610,50	299,21	311,30	9,40	0,03	320,70	0,83	0,007	0,014
8,00	2,00	35,00	647,50	318,83	328,68	8,43	0,03	337,11	0,82	0,006	0,012
9,00	2,00	37,00	684,50	338,45	346,06	7,60	0,02	353,65	0,81	0,005	0,010
10,00	2,00	39,00	721,50	358,07	363,44	6,88	0,02	370,31	0,81	0,004	0,009
11,00	2,00	41,00	758,50	377,69	380,82	6,25	0,02	387,07	0,80	0,004	0,008
12,00	2,00	43,00	795,50	397,31	398,20	5,71	0,01	403,90	0,80	0,003	0,007
13,00	2,00	45,00	832,50	416,93	415,58	5,23	0,01	420,81	0,79	0,003	0,006
13,00	2,00	47,00	869,50	436,55	432,96	4,81	0,01	437,76	0,78	0,003	0,005
13,00	2,00	49,00	906,50	456,17	450,34	4,43	0,01	454,77	0,78	0,002	0,005
										Stot=	**0,243**

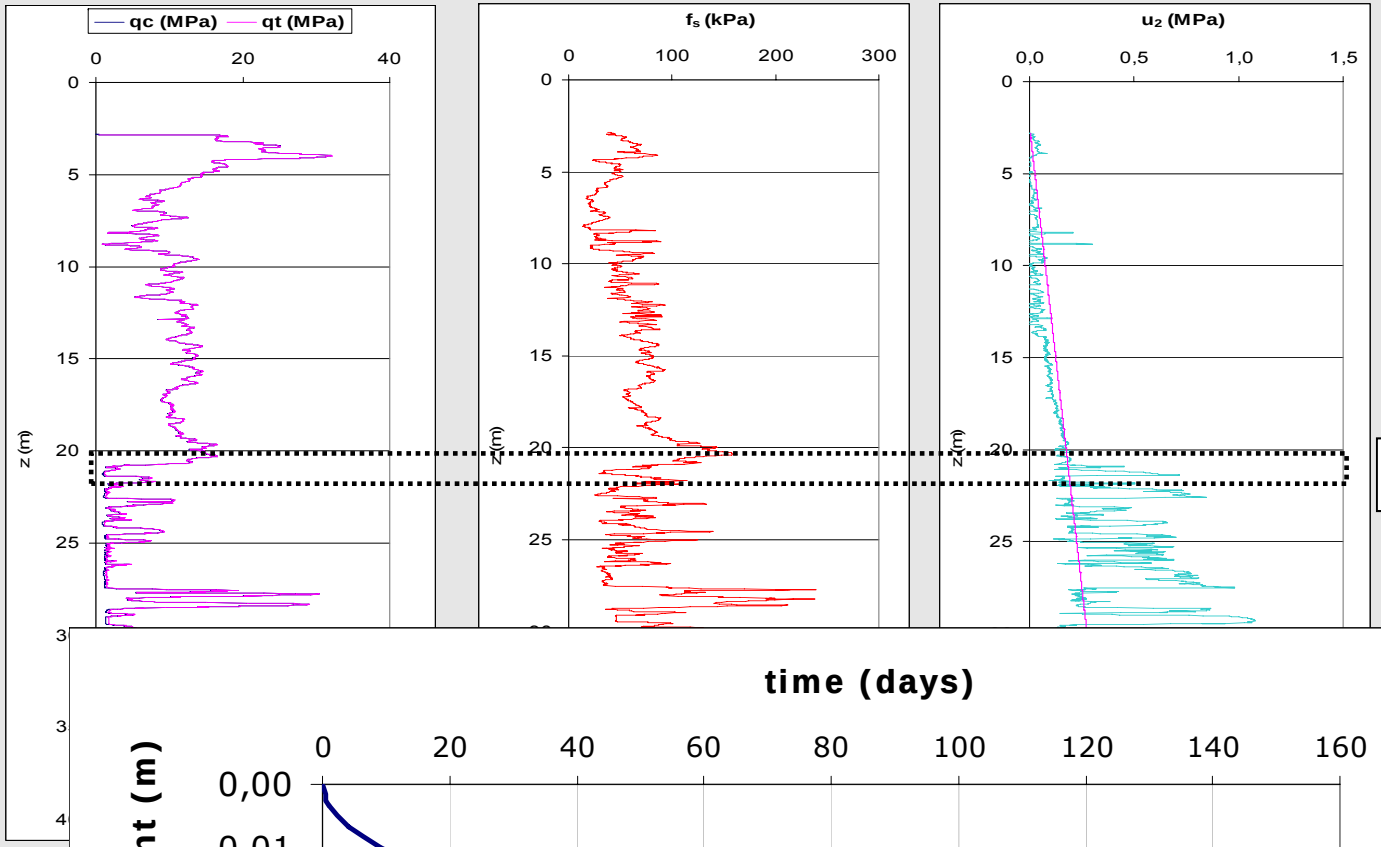
Settlement time development

$$U_m = 2 \cdot \sqrt{\frac{T_v}{\pi}}; \quad T_v = \frac{\pi}{4} \cdot U_m^{\,2} \qquad U_m \le 60\% \qquad \text{(Terzaghi)}$$

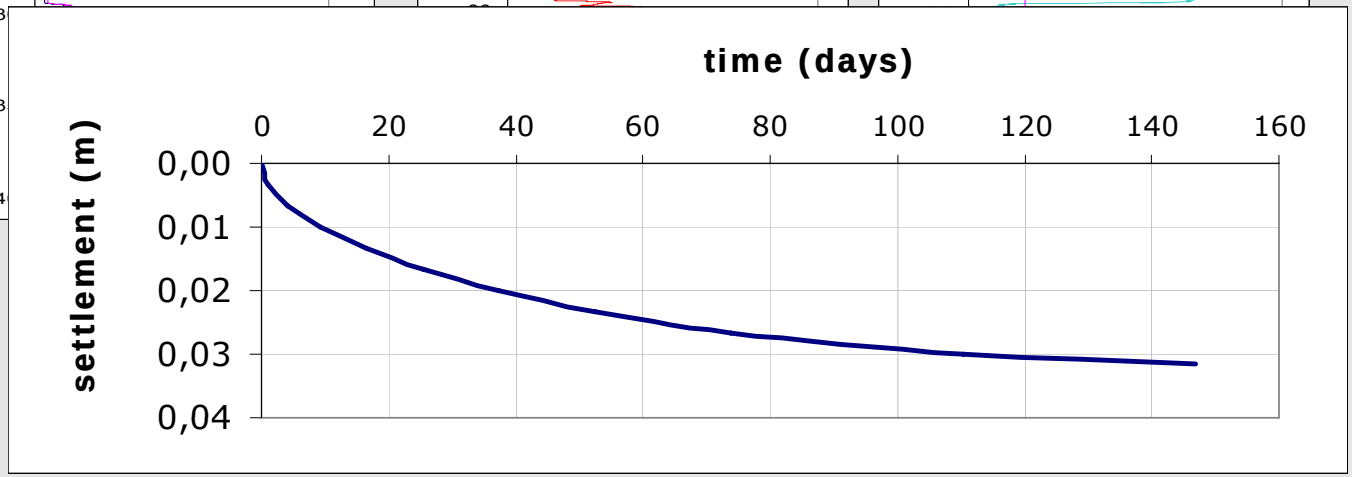
$$T_v = 1.781 - 0.933 \log(100 - U_m(\%)) \qquad U_m > 60\%$$

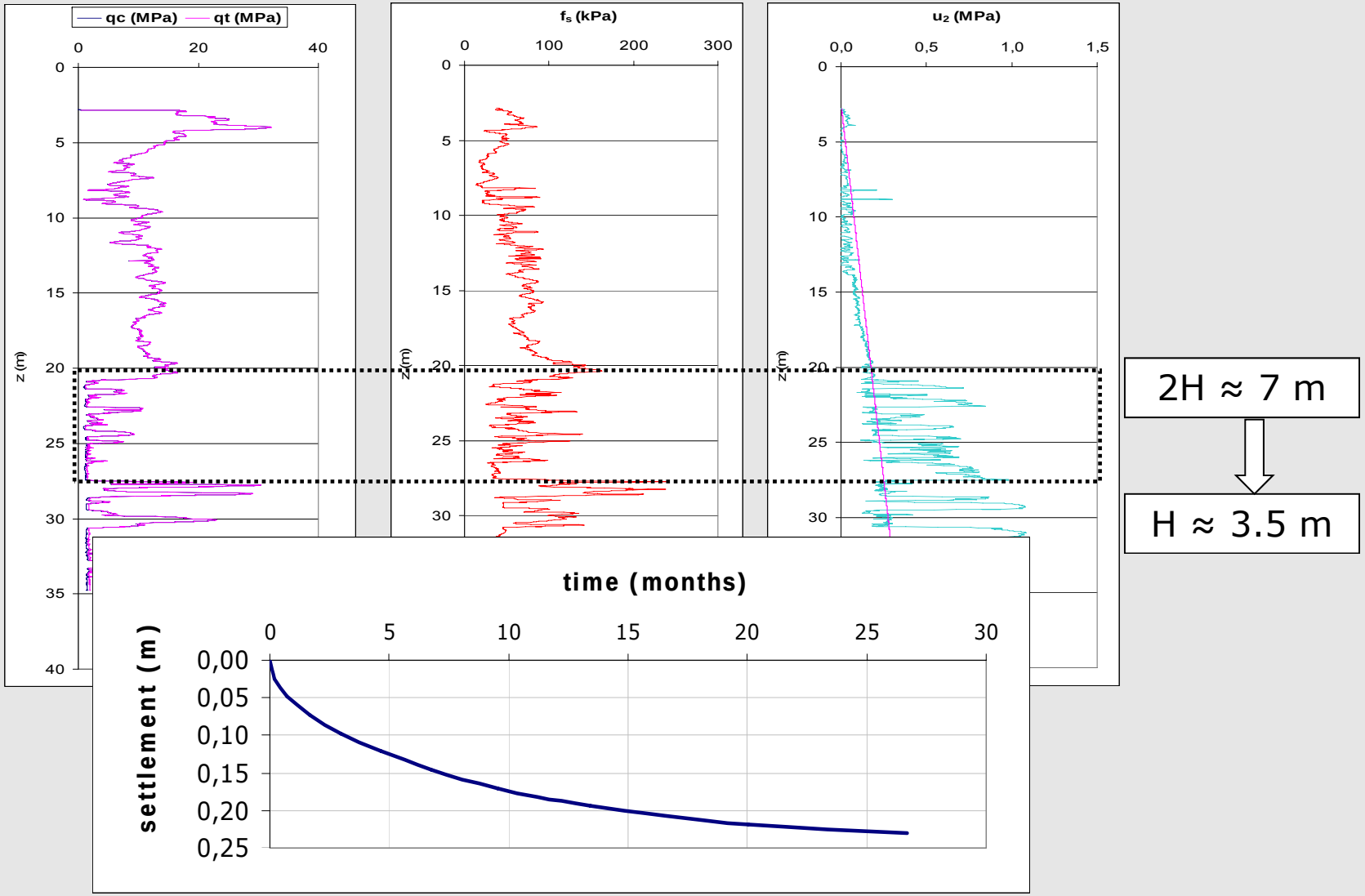


$$T_v = \frac{(c_v \cdot t)}{H^2}$$



H ≈ 1.5 m





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Geotechnical design with worked examples

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