Problems on Settlement

Problem # 01

A reinforced concrete foundation of dimensions 20m x 40m exerts a uniform pressure of 200 kN/m^2 on a semi infinite soil layer. Determine the value of immediate settlement under the foundation. Assume the values of E = 50 MN/m^2 , I = 1.0, μ = 0.5.

$\rho_i = q_n\ B\ (1-\mu)\ I/E$

q_n = 200 kN/m^2 , B = 20 m E = 50 MN/m^2

ρ_i = 200 x 20 x (1- 0.5) 1/50 x 1000 = **60 mm**.

Problem # 02

A soft, normally consolidated clay layer is **15m** thick with a natural moisture content of **45 %**.

The clay has a saturated unit weight of **172** kN/m^3 , a particle specific gravity of **2.68** and a liquid limit of **65%**. A foundation load will subject the centre of the layer to a vertical stress increase of **10** kN/m^2. Determine an approximate value for the settlement of the foundation, if ground water level is at the surface of the clay.

Solution:

Initial vertical effective stress at

Centre of layer = (17.2 – 9.81) x 15/2

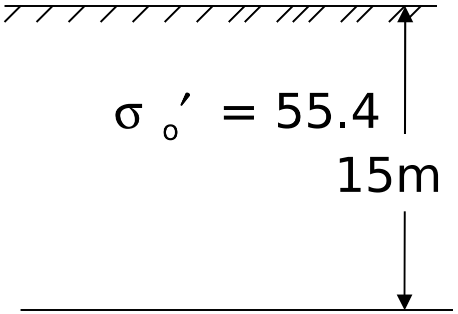
= 55.4 kN/m².

Final effective vertical stress=

55.4 + 10 = 65.4

Initial void ratio $e_1 = w \times G_s$ =0.45 x 2.68 = 1.21

C_c =0.009 ($L.L$ – 10) = 0.009 x (65 – 10) = 0.495



$$S_c = \frac{H}{1+e_1} c_c \log \frac{p_o' + \sigma_z}{p_o'}$$

$$S_c = \frac{15}{1+1.21} 0.49 \log\left(\frac{65.4}{55.4}\right)$$

$$= 0.024\,m \;=\; 240\,mm.$$

$$Total\ \ settlement = S_T = S_i + S_c'.$$

$$For\ \ normally\ \ consolidated\ \ clay \quad S_i = 0.1 of\ S_c'$$

$$\mu_g\ \ for\ \ normally\ consolidated\ clay\ \ 0.7-1.0$$

$$Let\ \ us\ \ assume\ \ \mu_g = 0.9.$$

$$\therefore\ \ S_T\ = S_i + S_c' = 0.1 + 0.9 = 1S_c$$

$$S_T = 240\,mm$$

Problem # 03

A layer of sand **9 m** thick is underlain by a **4m** thick deposit of normally consolidated clay resting on an impermeable shale. The ground water level is initially **one meter** below ground level. In order to facilitate the construction of engineering works on an adjoining site, the ground water level is to be lowered by **seven meter** over a wide area and is to be maintained at this new level for a period of **one year** until the construction is complete, when the ground water table will be allowed to rise back upto its original level.

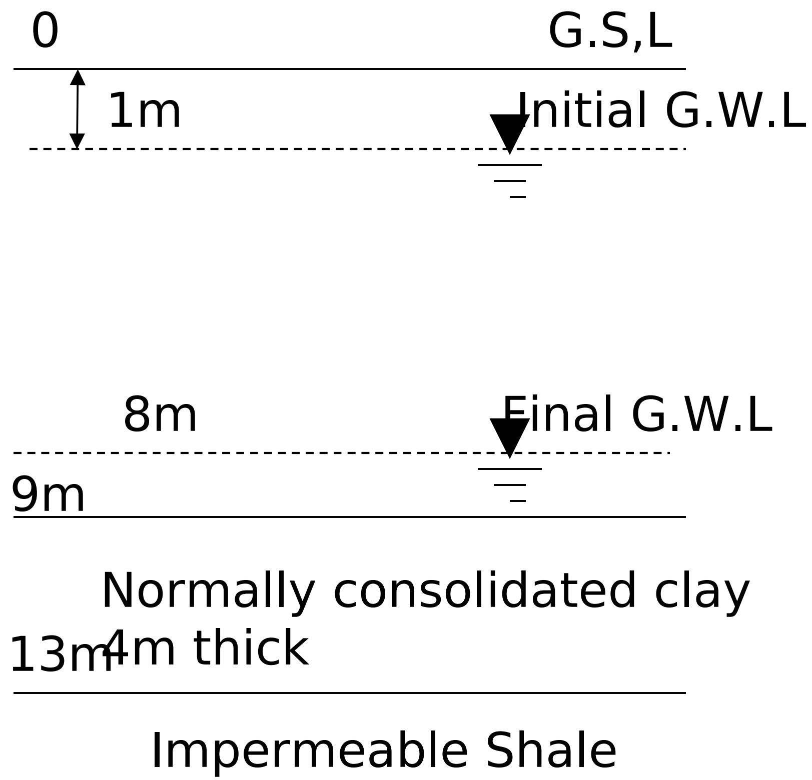
Calculate the consolidation settlement of the clay deposit after this period of time, given that the properties of the sand are :

γ_b = 1.90 Mg/m^3, γ_s = 2.0 Mg/m^3 and for normally consolidated clay γ_s = 1.96 Mg/m^3,e_o= 0.825, c_c = 0.60 , and c_v = 4 m^2/year.

Solution:

Now consolidation settlement

$$S_c = \frac{H}{1+e_1} c_c \log \frac{p_o' + \sigma_z}{p_o'}$$



Now H = 4m

e_1 = 0.825

c_c = 0.6

p_o' = ?

σ_z = ?

Find out p'_o before G.W.L is lowered

Overburden pressure at the centre of clay layer.

$p_o' = 1.9 \times 9.81 \times 1 + 2.0 \times 9.81 \times 8 + 1.96 \times 9.81 \times 2 – 1 \times 9.81 \times 10 = 115.96$ kN/m^2.

Now $p_o' + \sigma_z$ = Effective stress when water table is lowered down.

$p_o' + \sigma_z' = (1.9 \times 9.81 \times 8 + 2.0 \times 9.81 \times 1 + 1.96 \times 9.81 \times 2) - 1 \times 9.81 \times 3 = 177.76$ kN/m^2

$\sigma_z' = p_o' + \sigma_z - p_o' = 177.76 – 115.96 = 61.8$ kN/m^2

$\therefore$ S_c = 4x 0.6/1+0.825 log 177.76/115.96 = 0.244 m. This is total settlement.

What will be in one year.

T_v= c_v x t/H^2 = 4 x 1/$(4)^2$ = 0.25

Now from table for T_v=0.25 , U = 57%

$\therefore$ Settlement after one year = 0.244 x 0.57 = **0.139 m or 139 mm**

Problem # 04

A vertical concrete column is to carry a load of **520 kN**, inclusive of self weight above ground level. The column is to be supported by a square concrete footing **2m x 2m** founded at a depth of **1.5m** in a **14m** thick deposit of firm boulder clay. The clay is fully saturated and overlies a sand stone. Calculate the total settlement of the footing, given that the properties of the clay are: $\boldsymbol{E}$ **= 10500 kN/m²** , $\boldsymbol{\mu}$ **= 0.5** , $\boldsymbol{m_v}$= 0.00012 m²/kN, **I** = 0.98 , $\boldsymbol{\mu_g}$= 0.5.

Solution:

$S_T = S_i + S_c'$

$$Now \quad S_i = q_n \frac{B \times (1-\mu^2)}{E} I$$

$$E = 10500\, kN/m^2, \; \mu = 0.5 \quad I = 0.98, \quad B = 2$$

$$q_n = \frac{520}{2 \times 2} = 130 \; kN/m^2$$

$$\therefore \quad S_i = \frac{130 \times 2(1-0.5^2) \times 0.98}{10500} = 0.0182\, m \, or \; 18.2\, mm.$$

$$S_c' = \mu_g \, S_c$$

$$S_c = m_v \times \sigma_z \times H$$

$$or \quad = m_v \times 0.55 q_n \times H = \quad Where \; H = 1.5B \; approximate$$

$$= 0.00012 \times 0.55 \times 130 \times 3 = 0.2574\, m = 25.74\, mm.$$

$$S_c' = 0.5 \times 25.74 = 12.87\, mm.$$

$$\therefore \quad S_T = 18.2 + 12.87 = 31.07\, mm$$

$$or \; 10\% \, stress. \quad Trials \; say \, 6m \; down. \; > 10\%$$

$$\sigma_z \; at \, 2.5m = \frac{520}{(4.5)^2} = 25.7$$

$$S_c = 0.00012 \times 25.7 \times 5 = 0.01542\, m \, or \, 15.42\, mm$$

Problem # 05

Time taken for construction of a building above ground level was from ***March 1962 to August 1963.*** In ***August 1966*** average settlement was found to be **6 cm**. Estimate the settlement in ***December 1967***, if it was known that ultimate settlement will be **25cm**.

Solution:

Now loading period is from March 1962 to August 1963 i-e 18 months.

For calculating settlement time ***t*** is taken from the middle of the loading period.

∴ The settlement 6 cm occurred in 18/2 + 3 x 12 = 45 months.

Now required is to know the settlement after 18/2 +12 x 4 +4 = 61 months.

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Let us assume that the degree of consolidation U, after 61 months will be < 60%.

Under the condition $U = 12.73 \sqrt{T_v}$

$(T_v = \pi /4(U/100)^2)$

Let s_1 = settlement at time t_1

s_2 = settlement at time t_2

Contd...

$$\therefore \quad \frac{S_1}{S_2} = \frac{U_1}{U_2} = \frac{12.73\sqrt{T_{v1}}}{12.73\sqrt{T_{v2}}}$$

$$\frac{S_1}{S_2} = \frac{U_1}{U_2} = \frac{\sqrt{T_{v1}}}{\sqrt{T_{v2}}} = \frac{\sqrt{t_1}}{\sqrt{t_2}} \qquad \left(T_v = \frac{c_v t}{H^2} \right)$$

$$\frac{S_1}{S_2} = \frac{\sqrt{t_1}}{\sqrt{t_2}} \qquad Put\ values: \left\{ \begin{array}{l} S_1 = 6\ cm \\ t_1 = 45\,months \\ t_2 = 61\,months \\ S_2 = ? \end{array} \right\}$$

$$\frac{6}{S_2} = \frac{\sqrt{45}}{\sqrt{61}}$$

$$S_2 = 6.98\,cm$$

Check U%

U % = 6.98/25 x100 = 27.92%

It is less than 60% S OK

Contd...

Problem # 06

A foundation was constructed 5 m below the surface of sandy stratum. The profile of ground with soil properties is shown below. From consolidation test it was found that the clay was just consolidated under original overburden, and relationship between the effective pressure ***p*** in kg/cm^2 and the void ratio ***e*** of the clay was expressed by the formula: $e = 1.30 - 0.32 \log_{10} p$

Contd...

If gross pressure increase caused by the weight of structure be ***10 t/m²*** at the top and ***1 t/m²*** at the bottom of clay stratum and pressure release due to excavation is ***5 t/m²*** and ***0.75 t/m²*** at the top and bottom of the clay stratum respectively. Calculate the settlement expected due to compression of the clay stratum. Assume the pressure within the clay stratum to be linear, density of sand ***2.4 g/cc*** and density of clay ***2.1 g/cc***

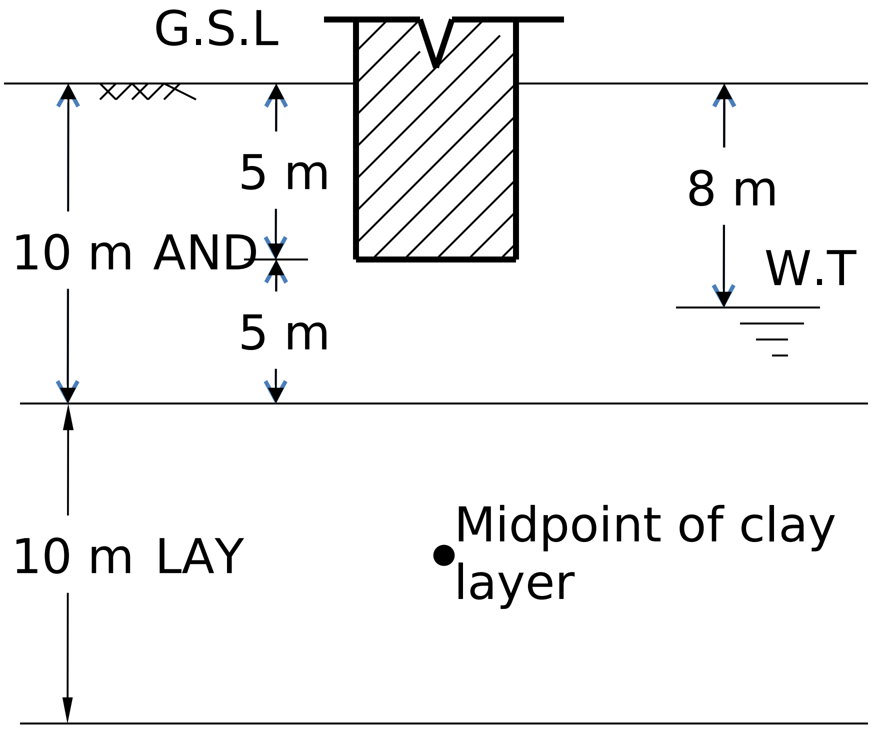
Contd…

Solution:

Effective pressure at mid depth of clay layer

$= (2.4 \times 8) + [(2.4-1) \times 2] + [(2.1-1) \times 5]$

$= 19.2 + 2.8 + 5.5 = 27.5\ t/m^2 \approx 2.75\ kg/cm^2$



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Pressure increase at the top of clay stratum $= 10 \text{ t/m}^2$

Pressure increase at the bottom of clay stratum $= 1 \text{ t/m}^2$

As the pressure increase is linear,

$\therefore$ pressure at centre point of clay layer $= 10 + 1/2 = 5.5 \text{ t/m}^2$

Pressure decrease at mid depth due to excavation $= 5+0.75/2 = 2.875 \text{ t/m}^2$

$\therefore$ Net average pressure increase $\sigma_z = 5.5 - 2.875 = 2.625 \text{ t/m}^2$.

Or $\sigma_z = 2.625 = 0.2625 \text{ kg/m}^2$

Contd...

Now settlement $S_c = m_v H \Delta p = m_v H \sigma_z$.

$$m_v = a/1+e_o = \Delta e/\Delta p \times 1/1+ e_o$$

$$S_c = \Delta e/\Delta p \times 1/1+ e_o \times H \Delta p$$

$$= \Delta e/1+ e_o \times H.$$

Let us find e_o and Δe.

$e = 1.3 – 0.32 \log_{10} p$ (Given)

To find out e_o put the values of p_o' (original overburden pressure)

$\therefore$ $e_o = 1.3 – 0.32 \log_{10} 2.75$

$e_o = 1.1596$

Now $\Delta e = ?$

We know $e_o – e = c_c \log_{10} p_o' + \sigma_z / p_o'$

Contd...

$e_o - e = \Delta e$ and $c_c = 0.32$

Put the values

$\therefore \quad \Delta e = 0.32 \log_{10} 2.75 + 0.2625/2.75$

$= 0.0119$

$S_c = \Delta e / 1 + e_o \times H = 0.0119/1 + 1.1596 \times 10 \times 100 =$ **5.52 cm**

For normally consolidated clay $S_c' = S_c$

Settlement = 5.52 cm

Or Total settlement = S_c' $(0.1 S_i + 0.9 S_c)$

Example # 07

A footing 3m square, carries a net pressure of ***220 kPa*** at a depth of ***0.5m*** in a deep deposit of sand of bulk unit weight ***19 kN/m³*** . The average cone resistance with depth is given in Table below. Estimate the settlement of the footing.

Depth below footing *(m)*	*0-1*	*1-2*	*2-4*	*4-6*
Average q_c, *MPa*	*2.0*	*3.0*	*3.5*	*6.0*

Contd…

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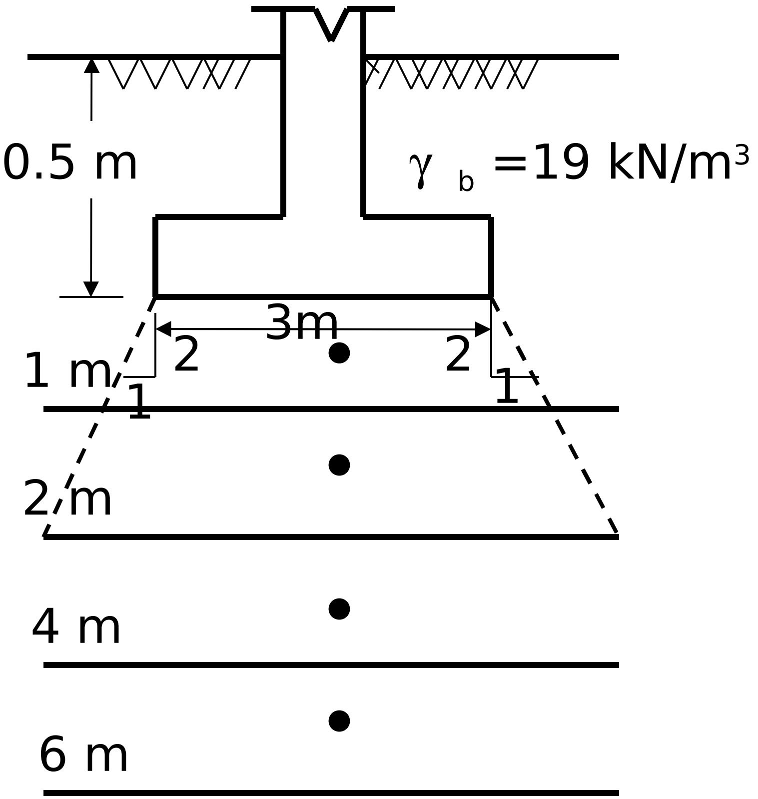
Settlement
$$S = \frac{H}{C} 2.3 \log_{10} \frac{p_o' + \sigma_z}{p_o'}$$

where
$$C = \frac{1.5\, q_c}{p_o'}$$

Strata are sandy but with different q_c *values.*

There are four different layers each having a different value of q_c.



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1. calculate overburden pressure p_o' at mid depth of each layer.
2. Total load on footing 220 x 3 x 3 = 1980 kN.
3. By assuming 2 vertical to 1 horizontal spread of pressure under the footing, calculate the pressure increase σ_z at mid depth of each layer.
4. Apply the above formula for calculating the settlement for each layer. Add them up to determine the settlement under the footing. Calculations are shown on a next slide.

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1	2	3	4	5	6	7	8
LAYER DEPTH BELOW FOOTING (m)	p_o' *kPa*	q_c *kPa*	$C = 1.5q_c/p_o'$	*Area at Mid Depth* (m^2)	σ_z *kPa*	$p_o' + \sigma_z$ *kPa*	*S Settle ment cm*
0-1	19	2000	157.89	12.25	161.6	180.60	1.42
1-2	38	3000	118.42	20.25	97.78	135.78	1.07
2-4	66.5	3500	78.94	36.0	55.0	121.50	1.52
4-6	104.5	6000	86.12	64.0	30.90	135.4	0.60
					Total		4.61

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Settlement = **4.61**

Calculations:

Column 2 = $\gamma' D$

3 = q_c = *MPa* = 1000 kPa.

4 = c = $1.5q_c/p_o'$

5 = (B+ Depth of centre of layer) = $(B + 0.5)^2$

6 = Total load /column 5 = 1980/(5).

7 = $p_o' + \sigma_z$

8 = Settlement = $H/C\ 2.3 \log_{10} p_o' + \sigma_z/p_o$ for each layer.

Problem # 08

Estimate the maximum settlement of ***4.5 m*** square footing placed at a depth of ***10m*** in saturated sand. The corrected SPT blows within the depth of ***4.5*** m below the footing are ***30***. The net pressure on the footing is ***200 kPa.***

Solution:

Given :

B = 4.5m , N = 30 corrected q_n = 200 kPa

$$Now\ \ Settlement\quad S = q_n \frac{\sqrt{B}}{N}(Meyerhof)$$

$$S = 200\frac{\sqrt{4.5}}{30} = 14\,mm.$$

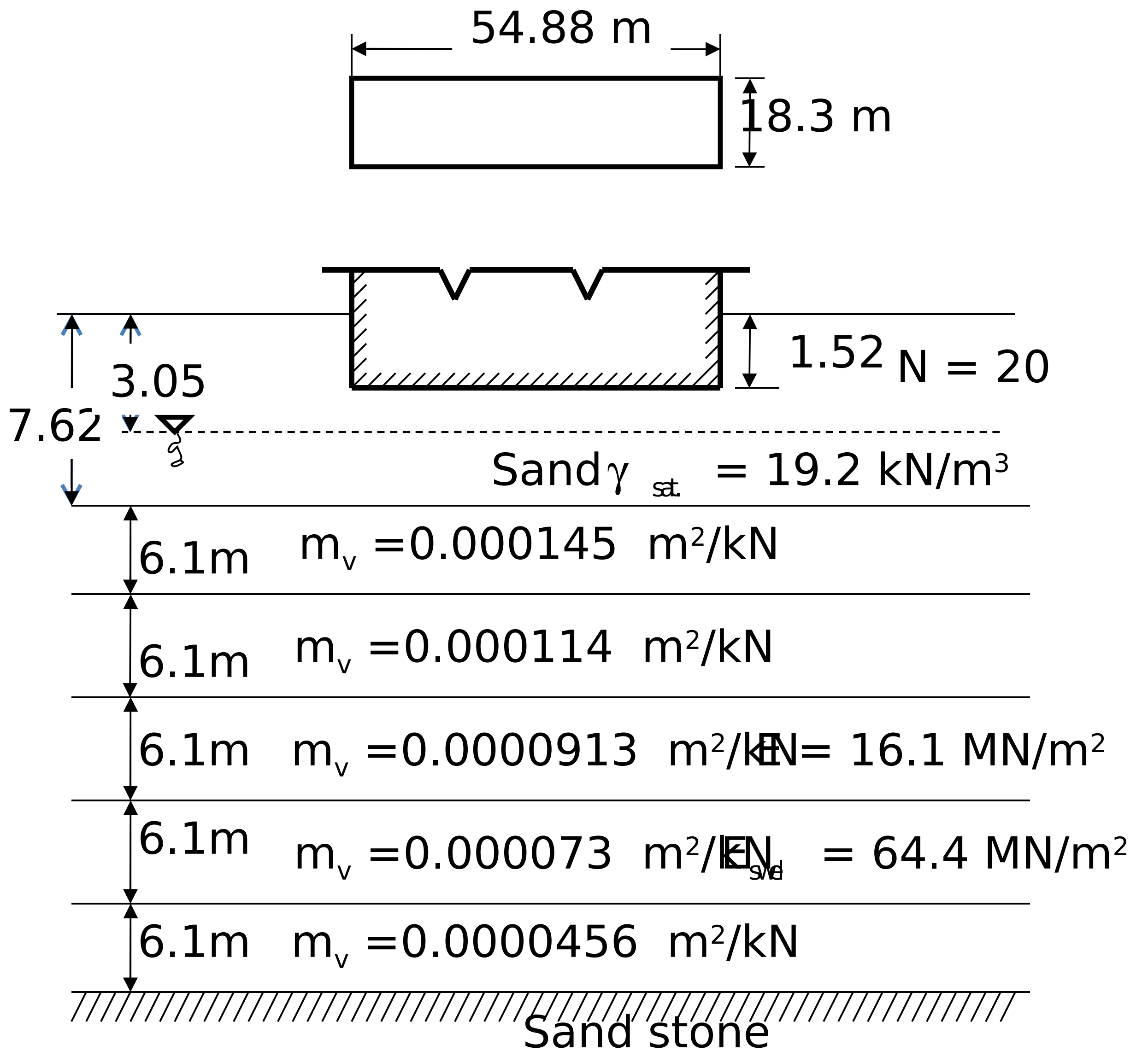
$$Peck\ \ formula\quad q_{net} = 0.41\,N\,S.$$

$$S = \frac{q}{0.41 \times N} = \frac{200}{0.41 \times 30} = 16.26\,mm.$$

Problem # 09

The plan of a proposed raft foundation is shown in Fig. The uniform bearing pressure from the foundation will be ***351 kN/m²*** and a site investigation has shown that the upper ***7.62 m*** of the subsoil is a saturated coarse sand of unit weight ***19.2 kN/m³*** with ground water level occurring at a depth of ***3.05m*** below the top of sand. The result from a standard penetration test taken at a depth of ***4.57m*** below the top of the sand gave ***N = 20.***

Below the sand there is a 30.5m thick layer of clay (A = 0.75 , E = 16.1 MN/m^2, E_{swel}= 64.4 MN/m^2, μ = 0.5, I = 0.5). The clay rests on the hard sandstone. Determine the total settlement under the foundation. (Assume 2 v to 1H spreading of pressure under the footing.



54.88 m
18.3 m
1.52
N = 20
3.05
7.62
Sand γ sat = 19.2 kN/m3
6.1m
mv =0.000145 m2/kN
6.1m
mv =0.000114 m2/kN
6.1m
mv =0.0000913 m2/kN
E = 16.1 MN/m2
6.1m
mv =0.000073 m2/kN
E sand = 64.4 MN/m2
6.1m
mv =0.0000456 m2/kN
Sand stone

Solution:

Vertical pressure increments = Gross pr. – Relief pr.

= 351-1.52 x 19.2

= 351-29.184 = 322 kN/m² Immediate settlement of clay layer

$$\rho_{ic} = q_n B \frac{1-\mu^2}{E_a} \times I \quad for\ clay$$

$$S_{is} = \frac{q_n \sqrt{B}}{N} = \frac{322 \times \sqrt{18.3}}{22} = 62.61\,mm$$

$$p_o' = 4.57 \times 19.2 - 1.52 \times 9.81 = 73\,kN/m^2$$

$$C_n = 1.1$$

$$(\quad N' = C_n \times N = 1.1 \times 20 = 22)$$

$$\rho_{ic} = \frac{322 \times 18.3\left(1 - 0.5^2\right) \times 0.5}{16100} = 0.150\, m = 150\, mm$$

$$Swelling = \frac{29 \times 18.3(1 - 0.5^2)}{64400} \times 0.5 = 0.0031\, m = 3.1\, mm$$

$$Net\ S_i\ in\ clay = 146.9\, mm$$

Layer below the footing	Depth of centre of layer below the base of footing	Area (L+Z)(B+Z)	σ_z	m_v	Settlement = m_v x $\Delta \sigma_z$ .H
1	9.15	1757.62	184	0.000145	0.163
2	15.25	2352.86	137.4	0.000114	0.096
3	21.36	3023.68	106.95	0.0000413	0,027
4	27.45	3766.6	85.86	0.000073	0.038
5	33.55	4585.1	70.53	0.0000456	0.020

μ_g for A of o.75 = 0.82

$S_c' = \mu_g \, x \, S$ = 0.82 x 344 = 288.08 mm

Total settlement = settlement of sand + Settlement of clay = $S_{is} + S_{iclay} + S_c'$ of clay

= 62.61 + 146.9 + 282.08 = **491.59 mm**

Total net load on Foundation = 322 x 54.88 x 18.3 = 323385.89 kN

Total load = $A \, x \, q_n$ = 54.88 x 18.3 x 322 = 323385.9