Module 4 : Design of Shallow Foundations

Lecture 19 : Settlement [Section19.1 : Introduction]

Objectives

In this section you will learn the following

- Introduction

Introduction

Settlement deals with the sinking of structure due to compression of soil.

As per IS code, the following types of settlements are reported:

1. Total settlement:- it is combination of initial and consolidation settlement

- Elastic settlement/ initial settlement:- initial/elastic settlement is the settlement caused due to elastic properties of the soil due to applied load.
- Consolidation settlement -
  - Primary consolidation: - is the consolidation occurs due to the expulsion of air from the voids.
  - Secondary/creep:- is the consolidation due to expulsion of water from the voids.

2. Differential settlement/ angular distortion:- it is the difference in settlement between two points below the footing.
3. Time dependent settlement

For sands, settlement is called **immediate settlement** as it is the major settlement, there being no or very less consolidation settlement. For clays, we talk about initial or elastic settlements and not immediate settlements.

Recap

In this section you have learnt the following

- Introduction

Objectives

In this section you will learn the following

- Obtain soil properties
- Stress distribution

Soil properties for settlement

1. **Obtain soil properties**

- E_s, μ.
- $e_o, c_c, c_v, m_v, w, \sigma', \Delta\sigma'$.
- c_α

2 **Stress distribution**

- 2H : 1V method
- Boussnesq theory
- Newmark chart
- Westergard theory

Initial/ elastic settlement

$s_i = qB\frac{1-\mu^2}{E_s}I_f$ where s_i is the initial or elastic settlement, q is the intensity of load , B is the width of the footing, E_s is the young's modulus of the soil, μ is the poisons ratio and If is the factor depends on shape of the footing ,size of the footing , type of the footing and point of calculation of settlement.

$s_i = \frac{Q}{2\pi\pi_i}\left[\frac{(1+\mu)z^2}{(r^2+z^2)^{\frac{3}{2}}}+\frac{2(1-\mu^2)}{(r^2+z^2)^{\frac{1}{2}}}\right]$ where Q is the concentrated load, r is the radial or diagonal distance from top centerline of the footing to the point under consideration, z is the depth of the point under consideration

Compression index, $c_c = -\frac{de}{d(\log\sigma)}$

Coefficient of compression, $a_v = \frac{\Delta e}{\Delta\sigma}$

Coefficient of volume compression, $m_v = \frac{\Delta V}{V}\frac{1}{\Delta\sigma}$ $m_v = \frac{\Delta e}{1+e_o}\frac{1}{\Delta\sigma} = \frac{a_v}{1+e_o}$

Coefficient of consolidation, $c_v = \frac{k}{m_v\,\gamma_w}$ $T_v = \frac{c_v t}{H^2}$

$$T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$ for U< 53%

$$T_v = 1.781 - 0.933(100 - U\%)$$ for U> 53%

where Δ_e is the change in void ration, Δ_σ is the increase in pressure, V is the volume of soil, e_0 is the initial void ratio, k is the permeability coefficient, γ_w unit weight of water, t is the time required to for settlement of soil layer of thickness H, and U is the percentage of consolidation occurred.

Consolidation settlement, $s_c = \frac{c_c}{1+e_o} H \log_{10}\left(\frac{p_0' + \Delta p_0'}{p_0'}\right)$

$$s_c = m_v H \Delta\sigma'$$

when $p_0 + \Delta_p > p_c$

$$s_c = \frac{c_r}{1+e_0} H \log_{10}\left(\frac{p_c}{p_0}\right) + \frac{c_c}{1+e_0} H \log_{10}\left(\frac{p_0 + \Delta p}{p_c}\right)$$

where c_c is the compression index, c_y is the recompression index, P_0 is the initial overburden pressure, Δ_p is the increase in over burden pressure, pc is the pre-consolidation pressure and H is the thickness of the layer.

Recap

In this section you have learnt the following.

- Obtain soil properties
- Stress distribution

Module 4 : Design of Shallow Foundations

Lecture 19 : Settlement [Section19.3 : Sources of settlement analysis]

Objectives

In this section you will learn the following

- Introduction

Settlement analysis

- Elastic compression of the foundation on the underlying soil
- Plastic compression of the soil
- Ground water table lowering
- Vibration due to pile driving, blasting and oscillatory machinery. this is more predominant in sand
- Seasonal swelling and shrinkage in expansive soils.
- Surface erosion creep or landslides in earth slopes.
- Miscellaneous sources such as collapse of soil mining subsidence, underground erosion, earthquake loading and adjacent excavation.
- Settlement of a rigid load resting on an elastic and isotropic material.

$$s = \mu_0 . \mu_1 q_{net} . \frac{B}{E}$$

q_{net} is the net applied pressure at the foundation

B=width of the foundation

μ_0 =coefficient due to the effect of embedment

μ_1 =coefficient due to the effect of the shape.

Corrections

$$s_{field} = \mu \times s_{oedometer}$$

μ=correction factor for lateral strain

Recap

In this section you have learnt the following

- Introduction

Objectives

In this section you will learn the following

- Problem 1
- Problem 2

Position 2 :

In this the footing B is at location 1 and footing A is at location 2. The calculations are done same as in position 1 case.

The calculations for the final settlement are given in table 4.16

Table 4.16 Final settlements for position 2

Layer	Depth z (m)		$\Delta\sigma'$ At center of each layer (t/m^2)		$S_{oedometer}(m) = m_v\,\Delta\sigma'\,\Delta z$	
	Footing B	Footing A	Footing B	Footing A	Footing B ($\Delta z = 1m$)	Footing A ($\Delta z = 0.4m$)
1	1.5	2.2	1.60	3.40	0.0032	0.0027
2	2.5	2.6	0.82	2.84	0.0016	0.0023
3	3.5	3	0.49	2.40	0.0010	0.0019
4	4.5	3.4	0.33	2.06	0.0007	0.0016
5	5.5	3.8	0.24	1.78	0.0005	0.0014
			Total settlement =		0.00695484	0.00998248

The calculations for time vs settlement graph is given in table 4.16

The graph of time (days) vs settlement (m) is plotted for both the footings which is given in fig. 4.71 and the graph of differential settlement is also plotted which is given in fig. 4.72. As seen from this graph the max differential settlement is 5.4mm (For second position).

Compression of settlements:

Position 1: Footing A at location 1, Footing B at location 2 $\Big\}$ $Maximum\,differential\,settlement = 22mm$

Position 2: Footing A at location 1, Footing B at location 2 $\Big\}$ $Maximum\,differential\,settlement = 5.4mm$

Therefore, footings should be placed as in posisiton 2.

Table 4.17 Values of time and settlement for each footing (for position 2)

Time(days)	Tv		U		Settelement(m)		Differential settlement(m)
	Footing A	Footing B	Footing A	Footing B	Footing A	Footing B	
0					0	0	0
50	0.135	0.54	0.41	0.79	0.0029	0.0078	0.0050
100	0.27	1.08	0.58	0.94	0.0041	0.0094	0.0054
150	0.405	1.62	0.70	0.99	0.0049	0.0098	0.0050
200	0.54	2.16	0.79	1.00	0.0055	0.0099	0.0045
250	0.675	2.7	0.85	1.00	0.0059	0.0100	0.0041
300	0.81	3.24	0.89	1.00	0.0062	0.0100	0.0038
350	0.945	3.78	0.92	1.00	0.0064	0.0100	0.0036
400	1.08	4.32	0.94	1.00	0.0066	0.0100	0.0034
450	1.215	4.86	0.96	1.00	0.0067	0.0100	0.0033
500	1.35	5.4	0.97	1.00	0.0068	0.0100	0.0032
550	1.485	5.94	0.98	1.00	0.0068	0.0100	0.0032
600	1.62	6.48	0.99	1.00	0.0069	0.0100	0.0031
650	1.755	7.02	0.99	1.00	0.0069	0.0100	0.0031
700	1.89	7.56	0.99	1.00	0.0069	0.0100	0.0031
750	2.025	8.1	0.99	1.00	0.0069	0.0100	0.0031
800	2.16	8.64	1.00	1.00	0.0069	0.0100	0.0031
850	2.295	9.18	1.00	1.00	0.0069	0.0100	0.0030
900	2.43	9.72	1.00	1.00	0.0069	0.0100	0.0030
950	2.565	10.26	1.00	1.00	0.0069	0.0100	0.0030

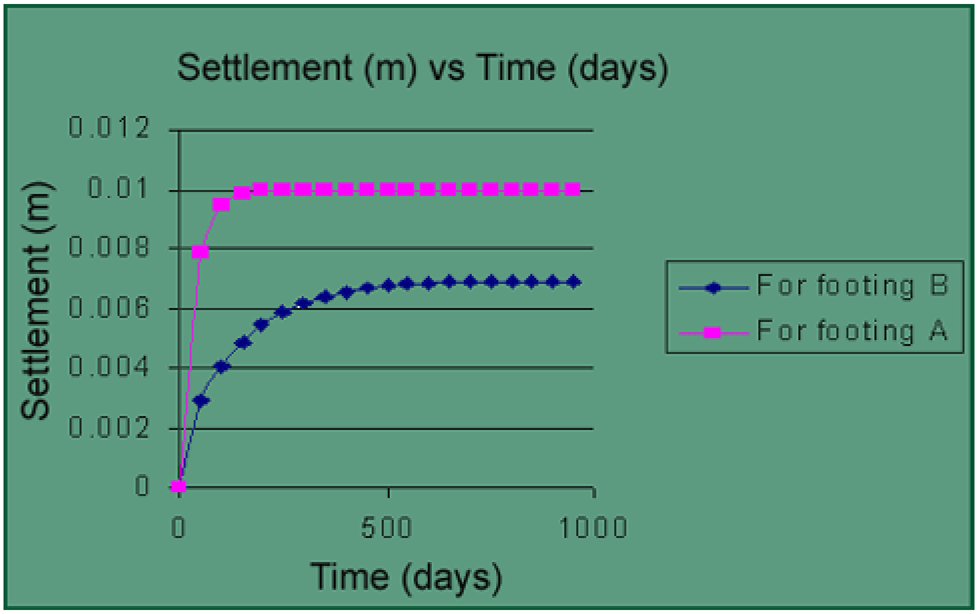

Fig. 4.71 Settlement vs time graph (For position 2)

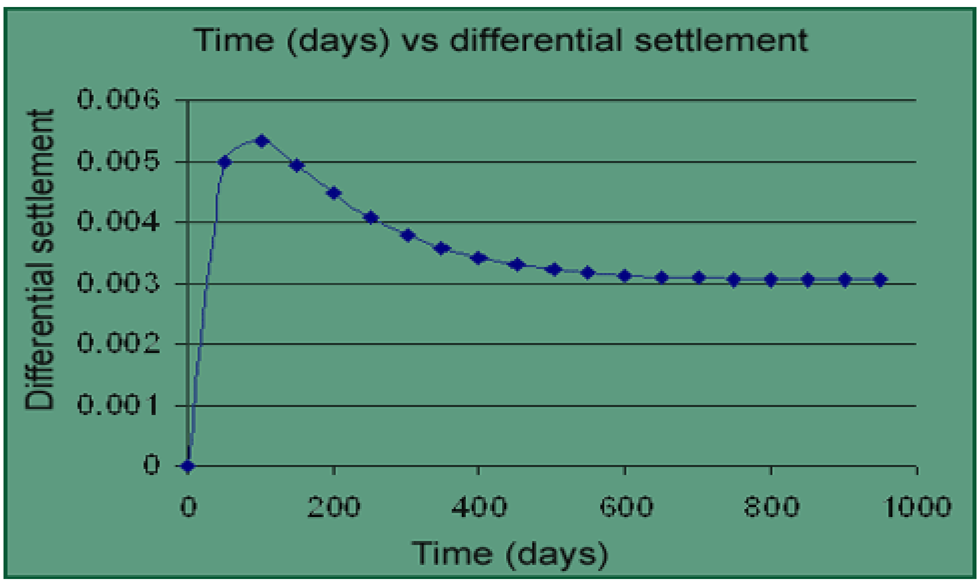

Fig. 4.72 Differential settlement vs time graph (For position 2)

Recap

In this section you have learnt the following.

- Problem 1
- Problem 2

Congratulations, you have finished Lecture 19. To view the next lecture select it from the left hand side menu of the page

Recap

In this section you will learn the following

- Problem 1
- Problem 2

Congratulations, you have finished Lecture 19. To view the next lecture select it from the left hand side menu of the page

Problem 1

Design of square footing to support column load 150 Klb, base of footing is at 3ft below the ground level. Soil is saturated clay with properties C_u = 1100 lb/ft^2, ϕ= 0^0, γ= 110 lb/ft^3, m_v = 0.01 ft^2/ton, c_v = 0.002 inch^2 /minute.

Determine safe bearing capacity and obtain the size of the footing for factor of safety. Clay 15ft below the base of the footing. Calculate Settlement of oedometer. Assuming the load is distributed 2:1, and m_v is constant over the strata. Consider five layers in calculations.

When Settlement is 75% completed, assume that initial pore pressure is uniform in stratum and clay is underlain by incompressible pervious layer.

By Skemptons

$$N_c = 5\left(1+0.2\tfrac{B}{L}\right)\left(1+0.2\tfrac{D}{B}\right)$$

Here D=3 ft, B/L = 1,(For square footing), then

$$N_c = 6\left(1+\tfrac{0.6}{B}\right)$$

$$q_{nu} = c.N_c$$

$$q_{nu} = 1100\times\left[6\times\left(1+\tfrac{0.6}{B}\right)\right]$$

$$q_{applied} = \tfrac{150\times10^3}{B^2}\times F.S.$$

$$3\times\tfrac{150\times10^3}{B^2} = 1100\times\left[6\times\left(1+\tfrac{0.6}{B}\right)\right]$$

$$409.091 = B^2(6+\tfrac{3.6}{B})$$

$$409.091 = 6B^2 + 3.6B$$

$$6B^2 + 3.6B - 409.091 = 0$$

$$B = 7.96ft$$

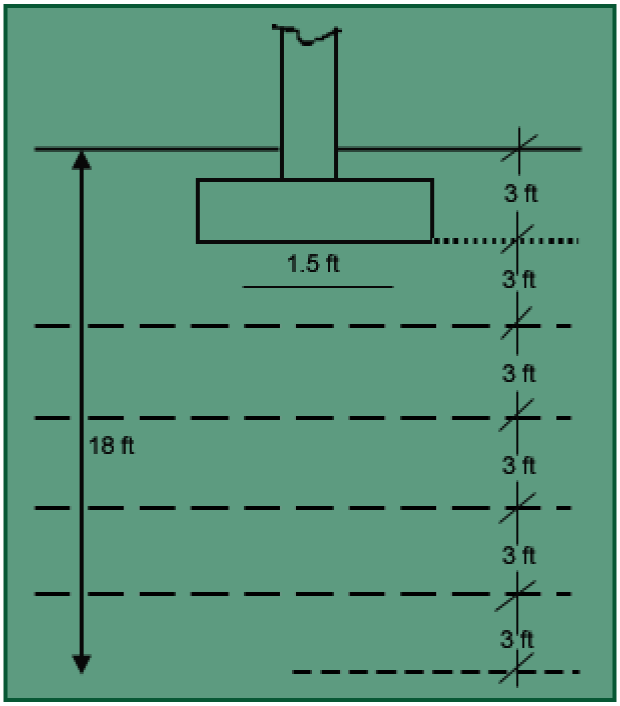

Fig 4.63 footing with different equal sub-layers

Table 4.13 calculation of increase in pressure and settlement.

Layer	$\Delta\sigma' = \frac{150\times10^3}{(8+Z)^2}\text{lb}/\text{ft}^2$ (by 2:1 distribution method)	St(odometer) = $m_v.\Delta\sigma'\Delta Z(\Delta Z = 3\text{ft})$
1	1662 (Z =1.5 ft)	0.023
2	960 (Z = 4.5 ft)	0.013
3	624.35 (Z = 7.5 ft)	0.009
4	438 (Z = 10.5 ft)	0.006
5	324 (Z = 13.5 ft)	0.004
-	**Total**	**0.055**

Degree of Consolidation = 75%

$0.75 = \frac{S}{S_{final}}$

S = 0.0413 ft

$T = 1.781 - 0.933\log_{10}(100 - U\%)$

$T = 1.781 - 0.933\log_{10}(100 - 75)$

$T = 0.48$

$t = \frac{TH^2}{C_v} = \frac{0.48 \times (15 \times 12)^2}{0.002} \text{minutes}$

t = 14 Years 290 days.

Problem 2

There are two locations 1 & 2 and two footings as shown in the fig. 4.64 and fig. 4.65 Find out the safest position of footings A and B.

m_v for clay layer is 2 x 10-5 m^2/t, and c_v is 3 x 10-5 m^2/min.

Ans.:

Position 1:

The settlement of the footing will be due to clay layers beneath the footings. To calculate the final settlement of the footings, the clay layers below the footings are divided into no. of layers, and total settlement will be the summation of the settlement at center of each layer. Refer fig. 4.63. The calculations are given in tabular form in table 4.14

Table 4.14 Final settlements for Position 1

Layer	**Depth z (m)**		$\Delta\sigma'$ **At center of each layer (t/m^2)**		$S_{oedometer}(m) = m_v\,\Delta\sigma'\,\Delta z$	
	Footing A	**Footing B**	**Footing A**	**Footing B**	**Footing A** ($\Delta z = 1m$)	**Footing B** ($\Delta z = 0.4m$)
1	1.5	2.2	4.90	0.98	0.0098	0.0008
2	2.5	2.6	2.96	0.77	0.0059	0.0006
3	3.5	3	1.98	0.63	0.0040	0.0005
4	4.5	3.4	1.42	0.52	0.0028	0.0004
5	5.5	3.8	1.07	0.43	0.0021	0.0003
			Total settlement(m)		**0.02466236**	**0.00265898**

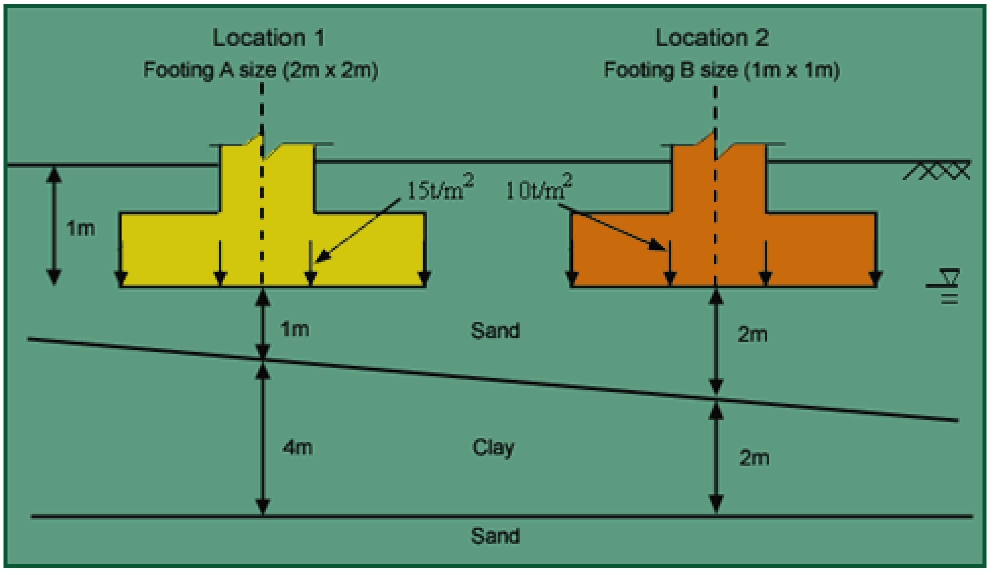

Fig. 4.64 Footings and locations (position 1)

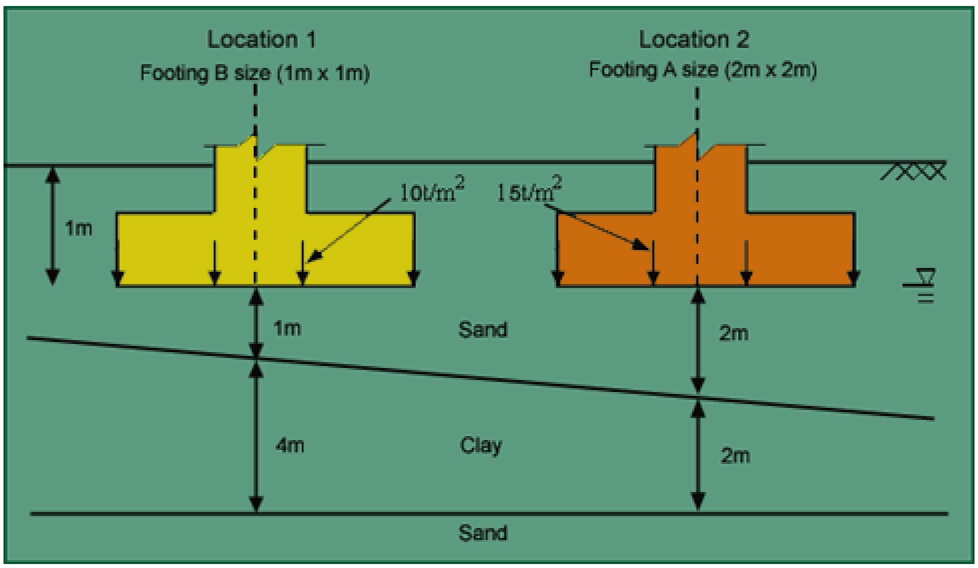

Fig. 4. 65 Footings and locations (position 2)

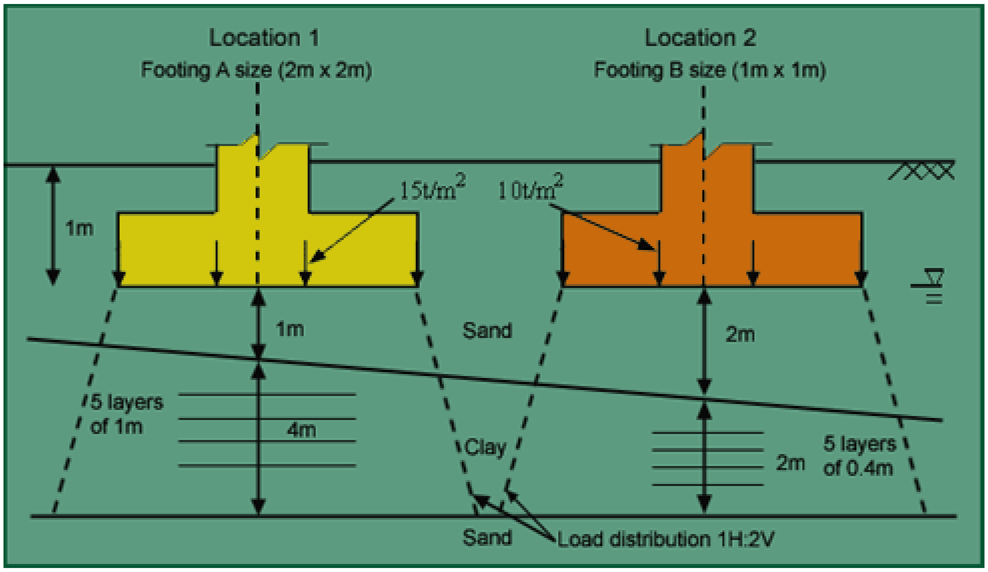

Fig. 4.66 Load dispersion (position 1)

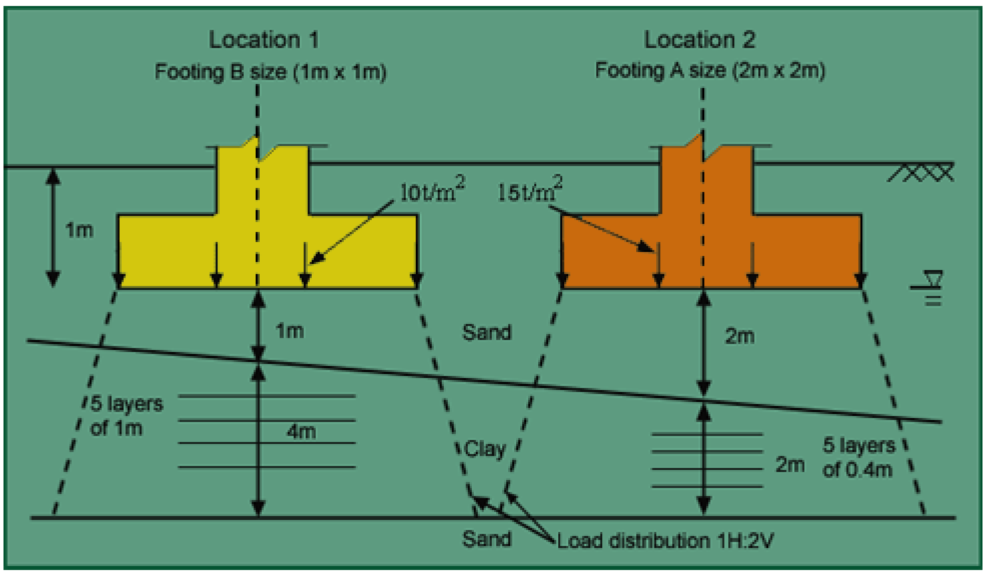

Fig. 4.67 Load dispertion (position 2)

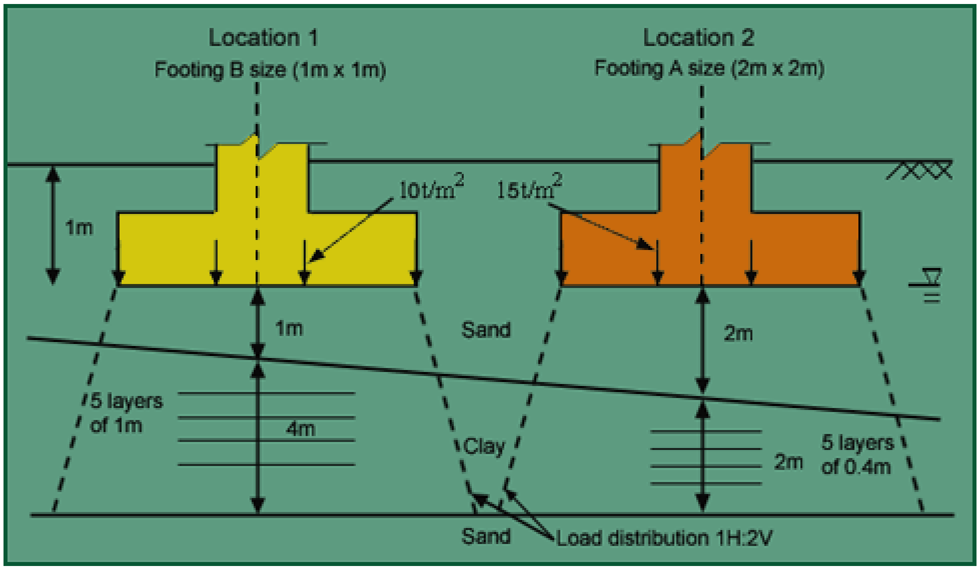

Fig. 4.68 Load dispersion (position 2)

For each footing, considering different time (t) for consolidation the settlement is calculated using following equations:

$T_v = \frac{c_v\, t}{H^2}$ where,

T_v is the time factor,

c_v is the coefficient of consolidation = 3 x 10^{-5} m^2/min,

t is time in days.

For different t values calculate T_v values. From T_v values calculate the U %(percentage of consolidation) using following equations:

$U = \sqrt{\frac{4T_v}{\pi}}$ for T_v < 0.2 and,

$U = 1 - \left(\frac{8}{\pi^2}\right)\exp\left(\frac{-\pi^2 T_v}{4}\right)$ for T_v > 0.2.

Get the settlement value as, S = S_{total} x (U%/100)

The calculations are given in the tabular form in table 4.15

The graph of time (days) vs settlement (m) is plotted for both the footings which is given in fig. 4.69 and the graph of differential settlement is also plotted which is given in fig. 4.70. As seen from this graph the max differential settlement is 22mm (For first position).

Table 4.15: Values of time and settlement for each footing (for position 2)

Time(days)	T_v		U		Settlement(m)		Differential settlement(m)
	Footing A	Footing B	Footing A	Footing B	Footing A	Footing B	
0					0	0	0
50	0.135	0.54	0.41	0.79	0.0102	0.0021	0.0081
100	0.27	1.08	0.58	0.94	0.0144	0.0025	0.0119
150	0.405	1.62	0.70	0.99	0.0173	0.0026	0.0147
200	0.54	2.16	0.79	1.00	0.0194	0.0026	0.0167
250	0.675	2.7	0.85	1.00	0.0209	0.0027	0.0182
300	0.81	3.24	0.89	1.00	0.0220	0.0027	0.0193
350	0.945	3.78	0.92	1.00	0.0227	0.0027	0.0201
400	1.08	4.32	0.94	1.00	0.0233	0.0027	0.0206
450	1.215	4.86	0.96	1.00	0.0237	0.0027	0.0210
500	1.35	5.4	0.97	1.00	0.0239	0.0027	0.0213
550	1.485	5.94	0.98	1.00	0.0242	0.0027	0.0215
600	1.62	6.48	0.99	1.00	0.0243	0.0027	0.0216
650	1.755	7.02	0.99	1.00	0.0244	0.0027	0.0217
700	1.89	7.56	0.99	1.00	0.0245	0.0027	0.0218
750	2.025	8.1	0.99	1.00	0.0245	0.0027	0.0219
800	2.16	8.64	1.00	1.00	0.0246	0.0027	0.0219
850	2.295	9.18	1.00	1.00	0.0246	0.0027	0.0219
900	2.43	9.72	1.00	1.00	0.0246	0.0027	0.0220
950	2.565	10.26	1.00	1.00	0.0246	0.0027	0.0220

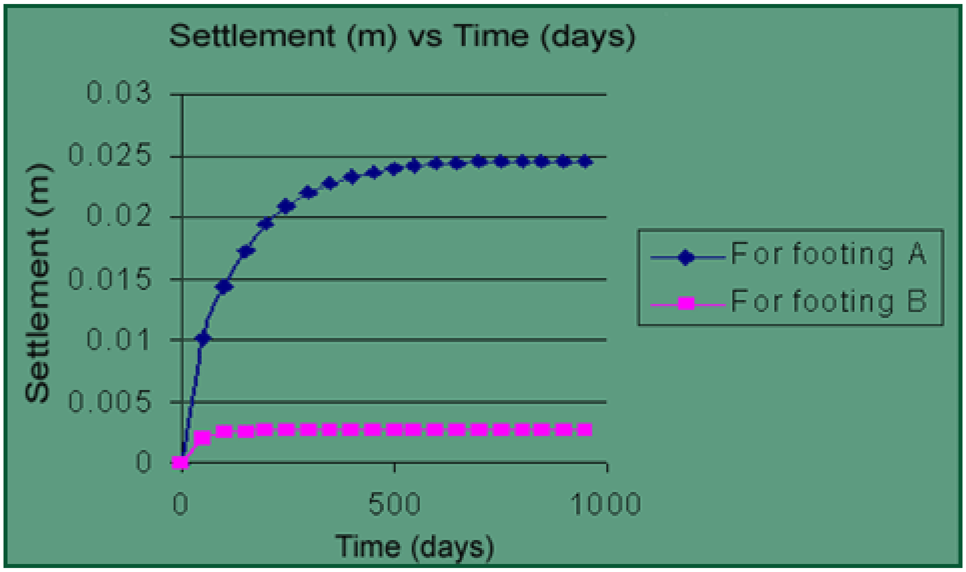

Fig. 4.69 Settlement vs time graph (For position 1)

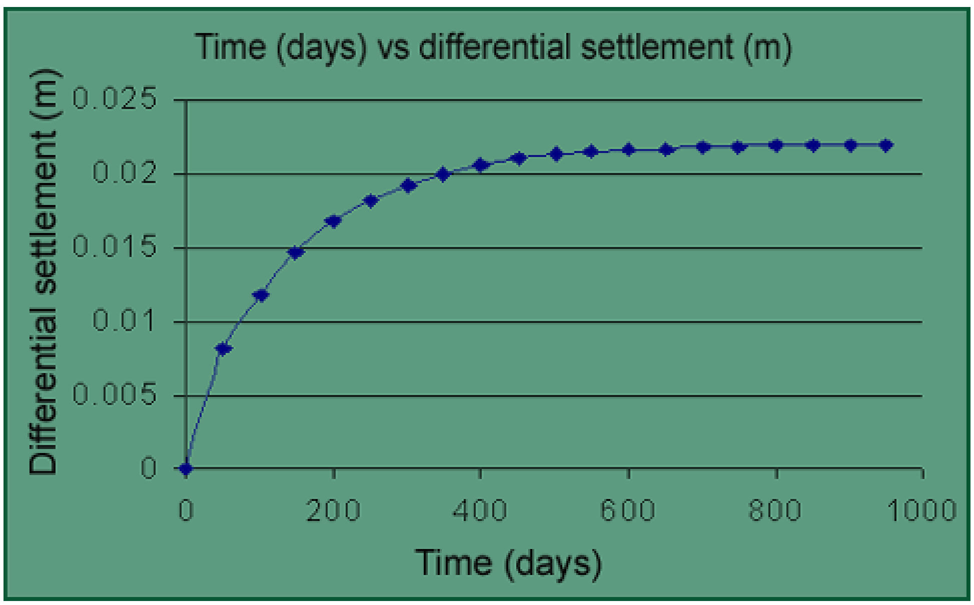

Fig. 4.70 Differential settlement vs time graph (For position 1)