2.6 Settlement:

Settlement is the vertical downward movement to the loaded base. As a result of settlement, the original depth of soil mass decrease due to soil grains coming closer together. Uneven settlement leads to cracks. The amount of settlement is different for different type of soil or rock

Types of foundation settlement

- Differential foundation settlement
- Uniform foundation settlement

Differential foundation settlement

- Settlement that occurs at differing rates between different portions of a building is termed differential settlement.
- Differential settlement occurs if there is difference in soils, loads, or structural systems between parts of a building. in this case, different parts of the building structure could settle by substantially different amounts.
- Consequently, the frame of the building may become distorted, floors may slope, walls and glass may crack, and doors and windows may not work properly.
- Uneven foundation settlement may force buildings to shift out of plumb which lead to crack initiation in foundation, structure, or finish.
- Majority of foundation failures are attributable to severe differential settlement.
- Lastly, for conventional buildings with isolated foundations, 20mm differential settlement is acceptable. And 50mm total settlement is tolerable for the same structures.

Uniform foundation settlement:

- when foundation settlement occurs at neraly the same rate throughout all portions of a building, it is called uniform settlement.
- If all parts of a building rest on the same kind of soil, then uniform settlement the most probable type to take place.
- Similarly, when loads on the building and the design of its structural system are uniform throughout, the anticipated settlement would be uniform type.
- Commonly, uniform settlement has small detrimental influence on the building safety.
- However, it influences utility of the building for example damaging sewer; water supply; and mains and jamming doors and windows.

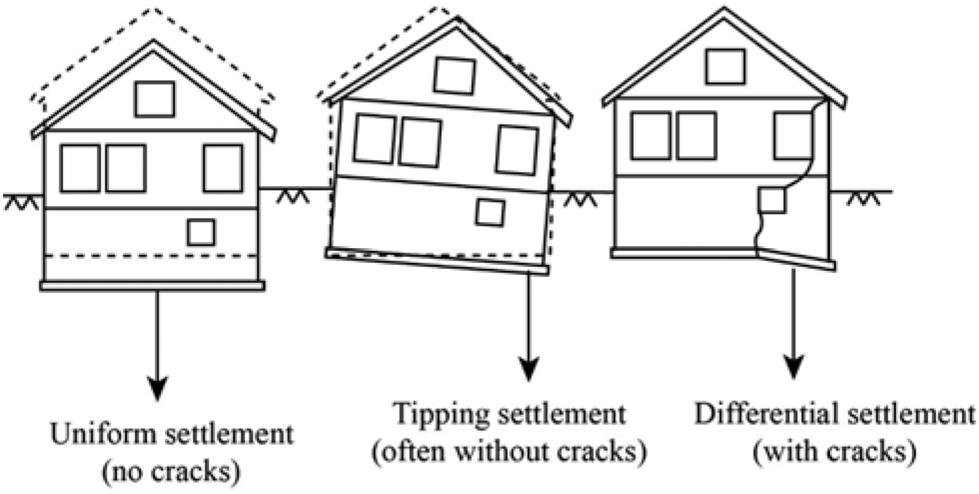


Fig.1: Difference between uniform and differential settlement

[Fig1https://www.chegg.com/homework-help/definitions/settlement-of-structure-8]

Foundation settlement causes

Direct causes

The direct cause of foundation settlement is the weight of building including dead load and live load.

Indirect causes

- Failure of collapsible soil underground infiltration
- Yielding of excavation done adjacent to foundation
- Failure of underground tunnels and mines
- Collapse of cavities of limestones
- Undermining of foundation while flood
- Earthquake induced settlement
- Finally, due to extraction of ground water and oil.

Components of total settlement of foundations

1.Immediate settlement:

- It is also called short term settlement.
- Immediate settlement take place mostly in coarse grained soils of high permeability and in unsaturated fine-grained soils of low permeability.
- Lastly, it occurs over short period of time which about 7 days. So, it ends during construction time.

Cohesive soil:

$$s_i = qB\left[\frac{1-\mu^2}{E_s}\right]I_f$$

Influence factor I_f:

I_f=0.82 for square footing

I_f=0.88 for circular footing

I_f=1.06 for rectangular footing$\frac{L}{B} = 1.5$

I_f=1.7 for square footing$\frac{L}{B} = 5$

Cohesionless Soil:

$$S_i = \frac{H}{C}\log_e\left(\frac{\overline{\sigma_o} + \Delta\bar{\sigma}}{\overline{\sigma_o}}\right)$$

C=compressibility

H= depth of stratum

2.Primary settlement

- It also termed as primary consolidation
- Take place over long period of time that ranges from 1 to 5 years or more
- Primary settlement frequently occurs in saturated inorganic fine grain soil.
- Expulsion of water from pores of saturated fine grain soil is the cause of primary settlement.

$$S_c = \frac{HC_c}{1+e_o}\log_{10}\left(\frac{\overline{\sigma_o} + \Delta\bar{\sigma}}{\overline{\sigma_o}}\right)$$

$$S_c = m_v\overline{\Delta\sigma}H$$

$$S_c = \frac{\Delta e}{1+e_o}H$$

i)compression index:

$$C_c = \frac{e_0 - e_1}{log_{10}\left(\left(\frac{\overline{\sigma_o}+\Delta\bar{\sigma}}{\overline{\sigma_o}}\right)\right)}$$

$$Or$$

$$C_c = 0.009(w_l - 10)$$

$$W_l = Liquid\ limit$$

$ii)Coefficient\ of\ volume\ change$:

$$m_v = \frac{\Delta e}{\Delta \bar{\sigma}} . \frac{1}{1 + e_0}$$

$$a_v = \frac{\Delta e}{\Delta \bar{\sigma}}$$

$$C_v = \frac{K}{m_v \gamma_w}$$

$$\overline{\sigma_o} = over\ burden\ pressure$$

$$\overline{\sigma_f} = final\ stress\ or\ pressure$$

K=permeability

$$\overline{\sigma_f} = \overline{\sigma_o} + \Delta\bar{\sigma}$$

$$\Delta e = e_0 - e_f$$

e_0= initial voids

e_f=final voids voids

3.Secondary settlement

Secondary settlement is the consolidation of soil under constant effective stress.

Frequently, it occurs in organic fine grain soil.

It continues over the life span of foundation structure similar to creep in concrete.

Total Settlement:

$$\mathbf{S = S_i + S_c + S_s}$$

$\mathbf{S_i = immediate\ or\ elastic\ settlement}$

$\mathbf{S_c = Primary\ or\ consolidation\ settlement}$

$\mathbf{S_s = secondary\ settlement}$

Causes of settlement are: -

- Uneven bearing capacity of soil at foundation level.
- Different loads on different parts of foundation.
- Varying ground water table height.
- Compressible foundation soil.
- Earthquakes and floods.
- Expansive soil such as black cotton soil.

Various remedial measures:

- Compaction of soil over the complete area at foundation level.

- Proper designs so that large load difference does not exist on different parts of the foundation.
- Dewatering of foundation if ground water table interference with construction of foundation.
- Stabilization of soil of foundation level if it is compressible.
- Special type of foundation for expansive soils such as black cotton soil.
- Consideration of earthquake loads and other earthquake resisting methods during design and construction of buildings.

Problems:

1.A normal consolidated clay layer is 6m thick with a natural water content of 30%of clay has a saturated unit weight of 17.4KN/m^3, specific gravity of 2.67 and liquid limit of 40%. The ground water level is at surface of the clay. Determine the settlement of the foundation. If foundation level will subject to center of a clay layer to a vertical stress increase of 8KN/m^3.

Given data:

W=30%
H=6m
$\gamma_{sat} = 17.4KN/m^3$
$G = 2.67$
W_l=40%
Increase or additional $\Delta\bar{\sigma} = 8KN/m^3$

$To\ find$:

$Settlement$=?

Solution:

$$S_c = \frac{HC_c}{1+e_o}\log_{10}\left(\frac{\overline{\sigma_o}+\Delta\bar{\sigma}}{\overline{\sigma_o}}\right)$$

$$C_c = 0.009(w_l - 10)$$

$$\overline{\sigma_o} = \gamma' Z$$

$$\gamma' or \gamma_{sub} = \gamma_{sat} - \gamma_w$$

$$= 17.4 - 9.81 = 7.59KN/m^3$$

$$Z = \frac{H}{2} = \frac{6}{2} = 3m$$

$$\overline{\sigma_o} = 7.59x3$$

$$= 22.7KN/m^3$$

$e = \frac{wG}{S_r}$[consider it as fully saturated S_r=1]

$$C_c = 0.009(40 - 10)$$

$$= 0.27$$

$$e = \frac{0.3x2.67}{1} = 0.801$$

$$S_c = \frac{6x0.27}{1 + 0.801} \log_{10}\left(\frac{22.7 + 8}{22.7}\right)$$

$$S_c = 0.117m = 117mm$$

2.A rectangular footing 2mx3m carries a column load of 600KN at a depth of 1m.The footing rest on a $C - \varphi\ soil$ strata 6m thick having Poisson's ratio of 0.25 and young's modulus E=20000KN/m^3.Calculate the immediate Settlement of footing.

Given Data:

B=2m

L=3m

Load=600KN

D=1m

H=6m

$\mu = 0.25$

E=20000KN/m^3

$$C - \varphi\ soil(cohesive\ soil)$$

To find:

immediate Settlement($S_{i)}$=?

Solution:

$$s_i = qB\left[\frac{1 - \mu^2}{E_s}\right] I_f$$

$$q = \frac{load}{area} = \frac{Load}{BxL}$$

$$\frac{L}{B} = \frac{3}{2} = 1.5m$$

I_f=1.06 for rectangular footing$\frac{L}{B} = 1.5$

3.A rectangular footing 1.2mx1.5m rest at a depth of 1m in a saturated clay layer 4m deep the clay is normally consolidated having an unconfined compression strength of 40KN/m^2. A soil has a liquid limit of 30% water content 23% Determine the load which the footing carrying safe with FOS=3 against shear. Also determine the settlement if the footing is loaded with safe load use Terzaghi analysis $\gamma = 17.8KN/m^2$

Given Data:

B=1.2m

L=1.5m

D=1m

H=4m

normally consolidated

Strength (q)=40KN/m^2

W_l=30%

W=23%

FOS=3

Here $\varphi = 0, N_c = 5.7, N_q = 1, N_\gamma = 0$

$$\gamma = 17.8KN/m^2$$

To find:

Load=?

Settlement=?

$$q_f = [1 - 0.3\frac{B}{L}]cN_c + \gamma DN_q + [1 + 0.3\frac{B}{L}]\gamma BN_\gamma]$$

$$q_{nf} = q_f - \bar{\sigma}$$

$$q_{nf} = q_f - \gamma D$$

$$q_s = \frac{q_{nf}}{F} + \bar{\sigma}$$

$$q_s = \frac{Load}{area}$$

$$S_c = \frac{HC_c}{1 + e_o}\log_{10}\left(\frac{\overline{\sigma_o} + \Delta\bar{\sigma}}{\overline{\sigma_o}}\right)$$

$$C_c = 0.009(w_l - 10)$$

$$\overline{\sigma_o} = \gamma Z$$

$e = \frac{wG}{S_r}$[consider it as fully saturated S_r=1]

$$\Delta\bar{\sigma} = \frac{maximum\ safe\ load}{area}$$

4.A 30cm square bearing plate settles by 10 mm in the plate load test conducted on sandy soil.The intensity of load applied on the plate causing the settlement is 200KN/m^2.Estimate the possible settlement of a square shaped shallow foundation of side 2m under the same intensity of loading.

Given data:

B_p=30cm=0.3m

S_p=10mm=0.01m

Intensity(q)= 200KN/m^2

B=2m

To find:

S_f=?

Solution:

For sandy or granular soil:

$$S_f = S_p\left[\frac{B(B_p + 0.3)}{B_p(B + 0.3)}\right]^2$$

$$S_f = 0.01\left[\frac{2(0.3 + 0.3)}{0.3(2 + 0.3)}\right]^2$$

S_f=0.030m

5.The following data were obtained from a plate load test carried out on a 60cm square test plate at a depth of 2m below ground surface on a **sandy** soil which extends upto a large depth. Determine the settlement of foundation 3x3m carrying a load of 1100KN .

Load intensity(KN/m^2)	50	100	150	200	250	300	350	400
Settlement mm	2.0350	4.0	7.5	11.0	16.3	23.5	34.0	45.0

Given data:

B_p=60cm=0.6m

D=2m

sandy soil

B=3m

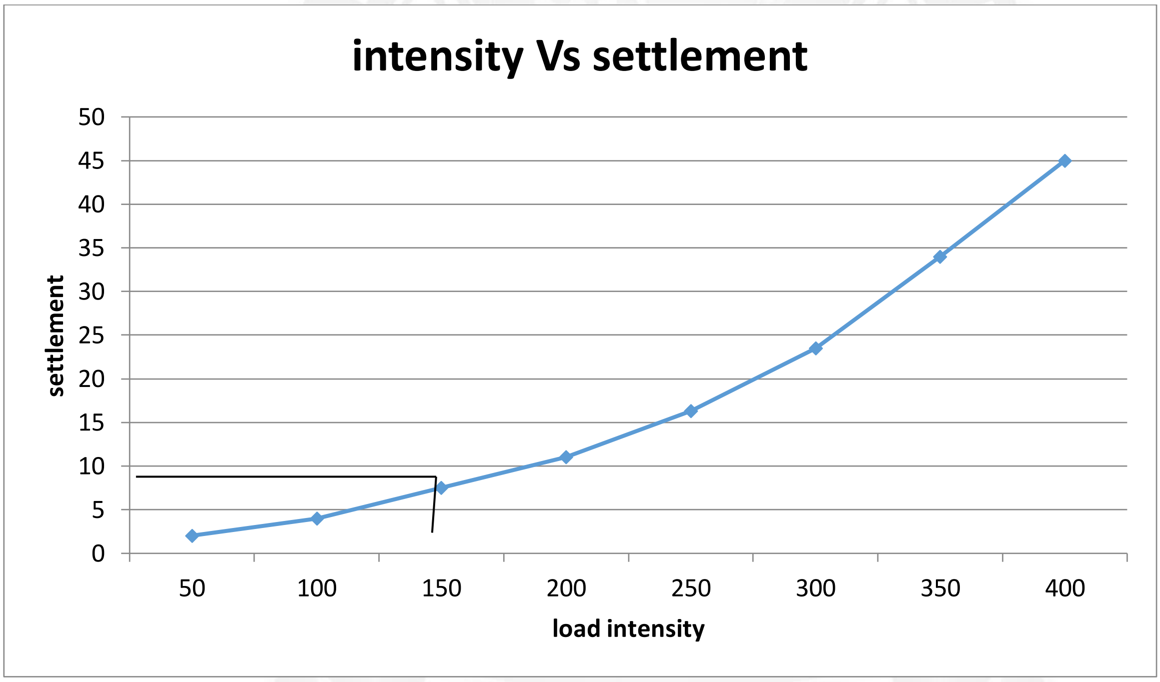
load = 1100KN

To find:

Settlement=?

Solution:

$$intensity = \frac{Load}{area} = \frac{1100}{3^2} = 122.22Kn/m^2$$



For load intensity 122.22 the settlement is 7mm

S_p=7mm

$$S_f = S_p \left[\frac{B\left(B_p + 0.3\right)}{B_p(B + 0.3)}\right]^2$$

$$S_f = 7 \left[\frac{3(0.6 + 0.3)}{0.6(3 + 0.3)}\right]^2$$

$$S_f = 13.01\text{mm}$$