



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS:

Lecture 4: Shallow Foundations – Settlements

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Module - 2

Shallow Foundations



Module -2: Chapters

1. General Requirements
2. Bearing Capacity and Settlement
3. Combined Footings
4. Raft Foundations
5. Dynamic Bearing Capacity

Chapter 2

Bearing Capacity and Settlement



Chapter 2b: Settlement

- **Total Settlement of Shallow Foundations**
- **Settlement of Foundation on Granular Soil**
- **Modes or Types of Settlement**
- **Limiting Angular Displacement**

Total Settlement of Shallow Foundations

The total settlement (S_t) in a general case is

$$S_t = S_i + S_c + S_s$$

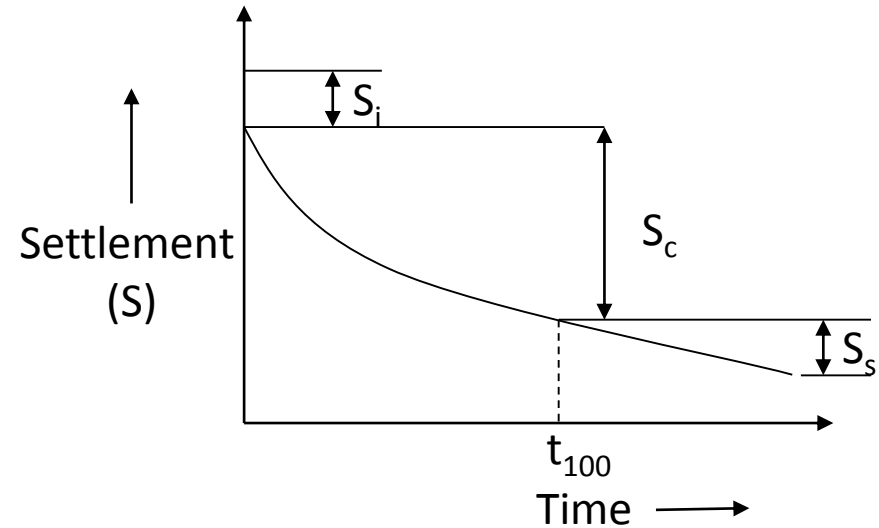
S_i = Immediate settlement or Elastic settlement, which takes place immediately or in a short time (less than about 7 days)

S_c = Primary consolidation settlement (gradual expulsion of pore water from the voids of soil resulting in dissipation of excess pore water pressure and increase in effective stress) **(Terzaghi Theory of consolidation)**

S_s = Secondary compression settlement occurs at constant effective stress

Settlement of Shallow Foundations

- Immediate settlement is not time dependent whereas primary consolidation and secondary compression are time dependent
- Secondary compression begins to start at the end of primary consolidation
- t_{100} = time required when excess pore water pressure is zero



Which of 3 Components is more Important ?

- In **granular soils**, **immediate settlement** accounts virtually for the entire settlement
- In **inorganic clays**, **primary consolidation** accounts virtually for most of the settlement
- In **organic soils**, **secondary compression** accounts virtually for most of the settlement

Immediate Settlement

The theory of elasticity can be used to determine displacement in soil caused by the load acting over the flexible and rigid footing.

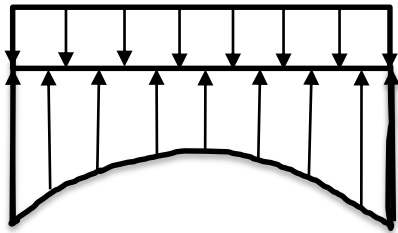
The vertical displacement, S_i of a foundation of width B on the surface of a semi-infinite, homogeneous isotropic material to which Hook's law is applicable given by

$$S_i = qB \left(\frac{1 - \mu^2}{E} \right) I_f$$

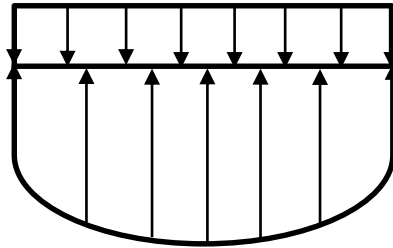
I_f is influence factor for settlement which depends on the shape and rigidity of the foundation.

Contact Pressure

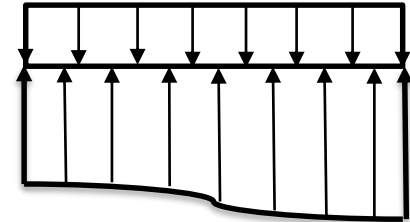
- In flexible footing, contact pressure at the interface of footing and soil is uniformly distributed, irrespective of the type of the subgrade on under soil material.
- In perfectly rigid footing, contact pressure depends on type of subgrade.



Isolated Clay



Cohesionless Sand



Intermediate Soil

Chapter 2b: Settlement

- **Total Settlement of Shallow Foundations**
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Settlement of Foundation on Granular Soil

- In cohesive soils, the **compressibility** and **consolidation** parameter are determined in the laboratory from the **oedometer test** and from these the magnitude of settlement and the rate of settlement can be estimated.
- However, for granular (cohesionless) soils, the undisturbed samples required for the laboratory tests are difficult to procure, therefore the settlement computations are based on in-situ tests. For granular soils, the **field tests** are more **reliable** than the lab tests.
- The most frequently used in-situ tests for granular soils are:
 1. Plate Load Test Method
 2. Penetration Tests (SPT and CPT)



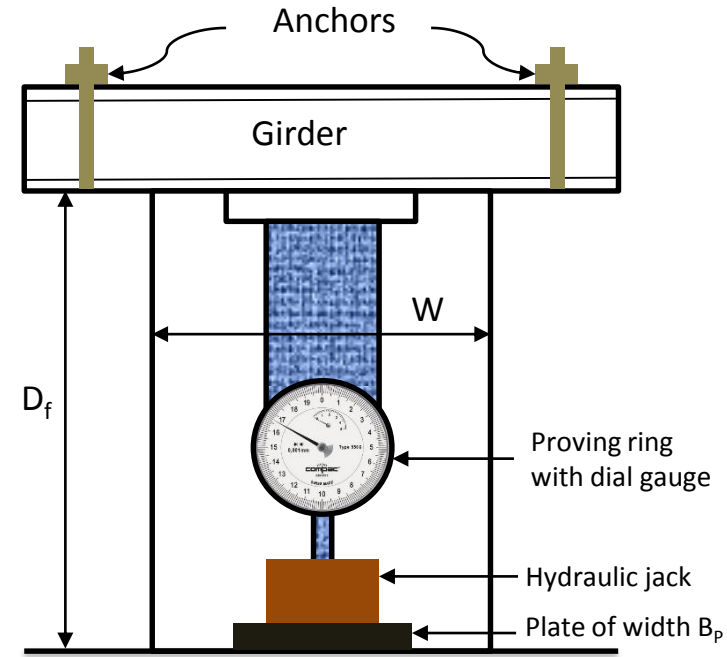
Plate Load Test Method

D_f = Depth of Foundation

W = Width of Pit = $5B_p$

Here B_p is the width of rough M.S. Square plate and could be 30, 45, 60, 75 cm.

Test Procedure is explained in IS:1888-1982
(Method of Load Tests on Soils)



Setup for vertical plate load test

Plate Load Test Method (Continued...)

- Rough M.S. square plate size = **30cm, 45cm, 60cm, 75cm** (small size for dense or stiff soil and large size for loose or soft soils). If the water table is above the level of pit, water is poured out to bring down the water table at the foundation level.
- Load on the test plate either of:
 - a) **Gravity Load**
 - b) **Reaction Load**
- A seating load of $70\text{g}/\text{cm}^2$ is applied and released after the same time. Further load is applied in the increment of $1/5$ of estimated load up to failure or at least a settlement of 25mm has occurred. Settlement is recorded at time interval of 1, 2.25, 4, 6.25, 9, 16, and 25 minutes and further at each 1 hour.
- The load settlement curve for the test plate can be plotted from the test data.

Plate Load Test Method (Continued...)

- Terzaghi and Peck (1948) recommended that the **settlement** of a footing on **cohesionless soil (granular soil)** is given by

$$\frac{S_f}{S_P} = \left[\frac{B_f(B_P + 30)}{B_P(B_f + 30)} \right]^2$$

S_f = settlement of foundation of width B_f (cm)

S_P = settlement of test plate of width B_P (cm) at the same load intensity as on foundation.

- For **cohesionless soil**, the **ultimate bearing capacity** of foundation

$$\frac{q_{uf}}{q_{uP}} = \frac{B_f}{B_P}$$

- For **cohesive soil**, the **Settlement** of foundation

$$\frac{S_f}{S_P} = \frac{B_f}{B_P}$$

- For **cohesive soil**, the **ultimate bearing capacity** of foundation

$$q_{uf} = q_{uP}$$

} Approximate Value

Plate Load Test Method (Continued...)

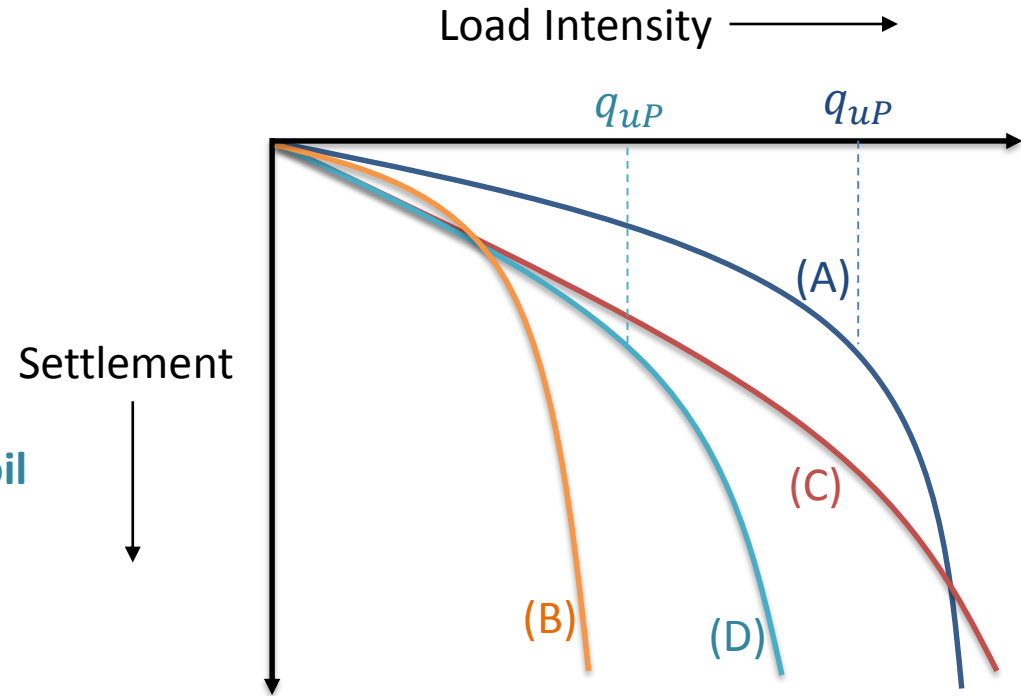
Load-Settlement Curves

A = Dense Cohesionless soil

B = Cohesive Soil

C = Partially Cohesive Soil

D = Loose to Medium Cohesionless Soil



Typical Load-Settlement Curve

Plate Load Test Method (Continued...)

Limitation of Plate Load Test

- In no case less than 30cm width of plate
- Valid for the medium and dense sands. In loose sand underestimate the settlement
- If soil is not homogeneous, effect of low bearing pressure shall be accounted. Actual settlement would be higher.
- A plate load test is of short duration, settlement measured is only the immediate settlement.

Standard Penetration Test (SPT)

The measured N values are corrected for

1. Over Burden Pressure

$$N' = C_N N$$

$$C_N = 0.77 \log_{10} \frac{2000}{\bar{\sigma}_{vo}}$$

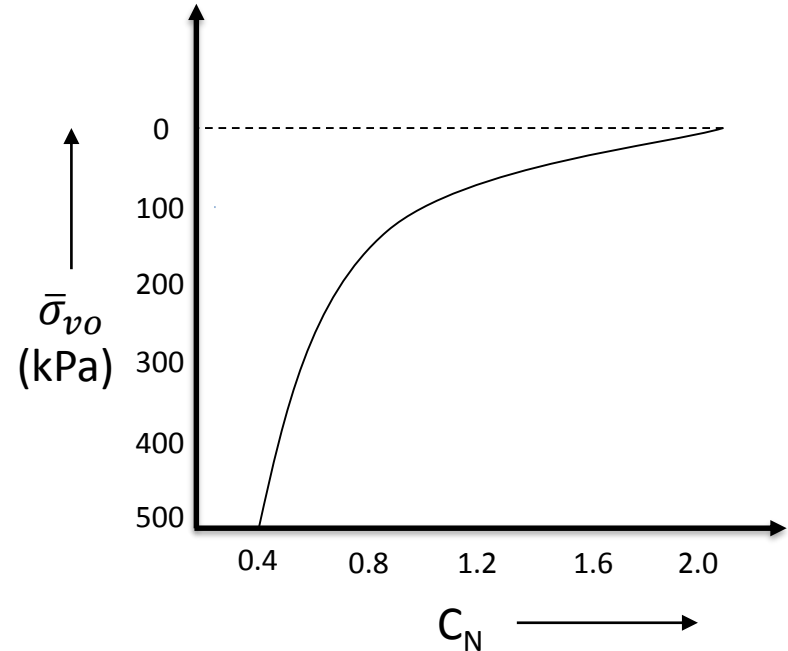
$\bar{\sigma}_{vo}$ = effective overburden pressure (kPa)

C_N = **0.4 to 2.0** (recommended value)

2. Correction for dilatancy (only for saturated fine sand and silt)

$$N'' = 15 + 0.5(N' - 15) \text{ if } N' > 15$$

$$N'' = N' \text{ if } N' \leq 15$$



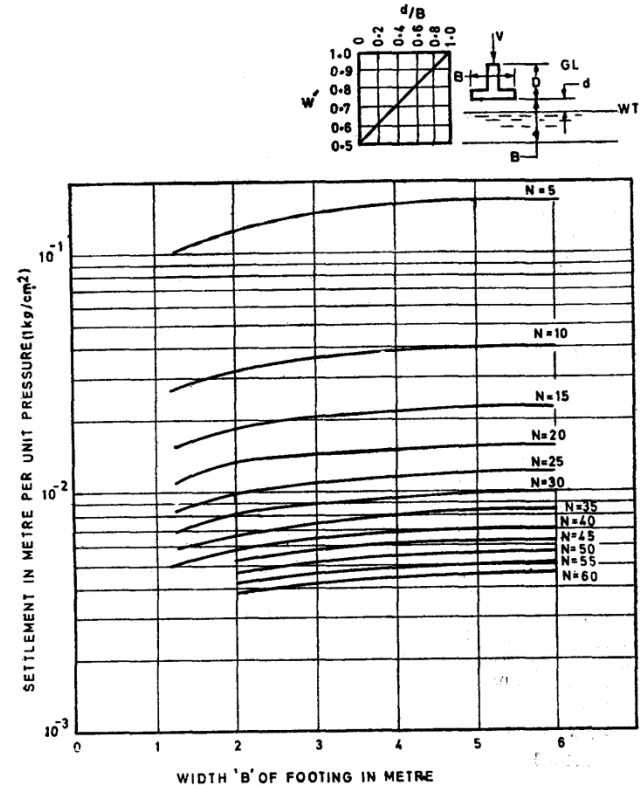
SPT (Continued...)

- IS 8009-Part 1-1976 gives chart as shown in Fig. for the calculation of settlement per unit pressure as a function of the width of footing and SPT N value.
- If the water table is close to the base of the foundation a Correction Factor (C.F.) is used as follows:

$$\text{C.F.} = 0.5 + 0.5 \frac{D'_W}{B} \leq 1$$

- No correction applied if $D'_W > B$

D'_W = depth of water table from the base of footing.



Settlement per unit pressure from standard penetration resistance

Cone Penetration Test (CPT)

- Settlement of each layer is given by

$$S = 2.3 \frac{H}{C} \log \frac{\bar{\sigma}_o + \Delta\sigma}{\bar{\sigma}_o}$$

H = Thickness of layer

$\Delta\sigma$ = Increase in vertical stress at the middle of layer

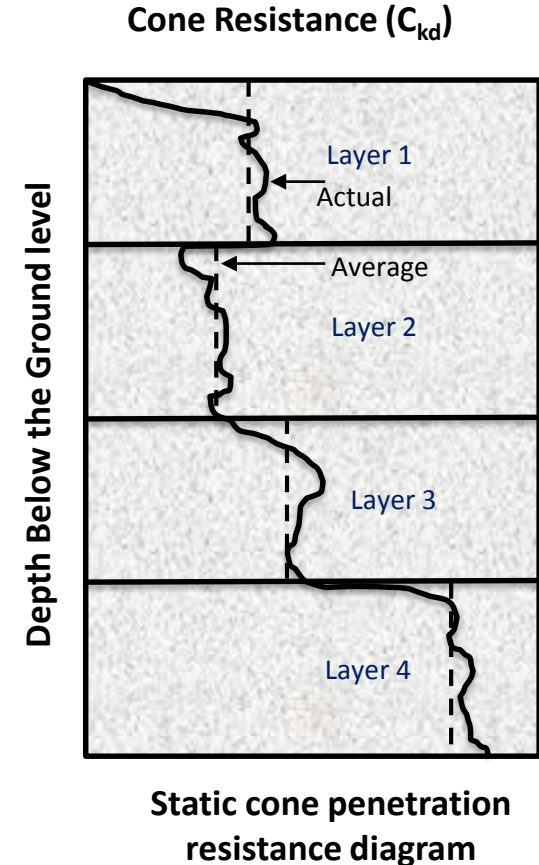
C = Compressibility coefficient

$$= 1.5 \times \frac{q_c}{\bar{\sigma}_o} \text{ by Dee Beer and Martens (1937)}$$

$$= 1.9 \times \frac{q_c}{\bar{\sigma}_o} \text{ by Meyrholf (1965)}$$

$\bar{\sigma}_o$ = effective vertical stress at the depth for which test is carried out

Note: Applicable to Normally consolidated sands

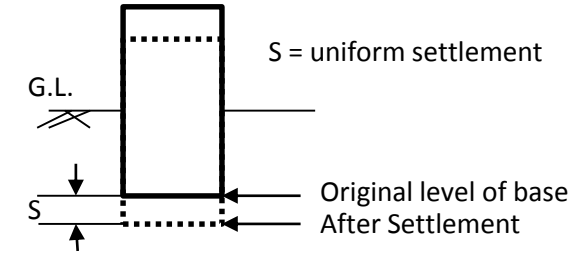


Chapter 2b: Settlement

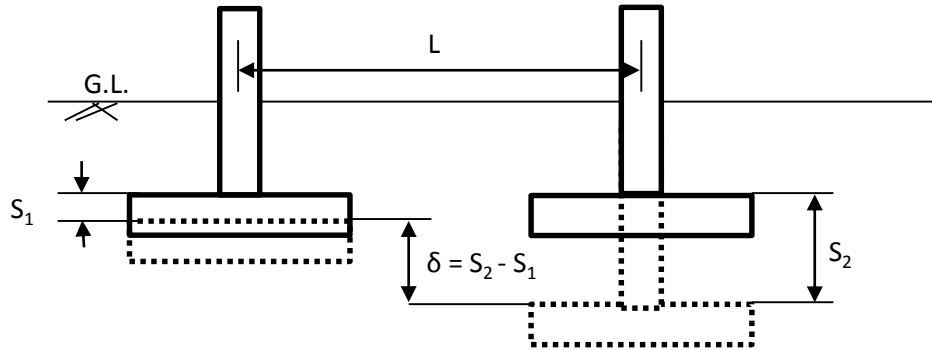
- **Total Settlement of Shallow Foundations**
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- **Modes or Types of Settlement**
- **Limiting Angular Displacement**

Modes or Types of Settlement

- a) Uniform Settlement
- b) Angular Distortion/Differential Settlement
- c) Tilt

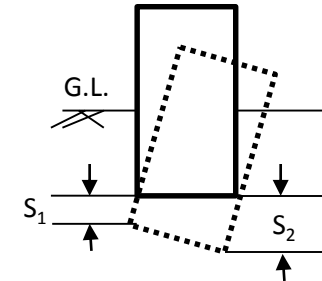


(a) Uniform Settlement



Angular distortion = $\frac{\delta}{L}$, $\delta = \text{differential settlement between two parts}$

(b) Angular Distortion/Differential Settlement

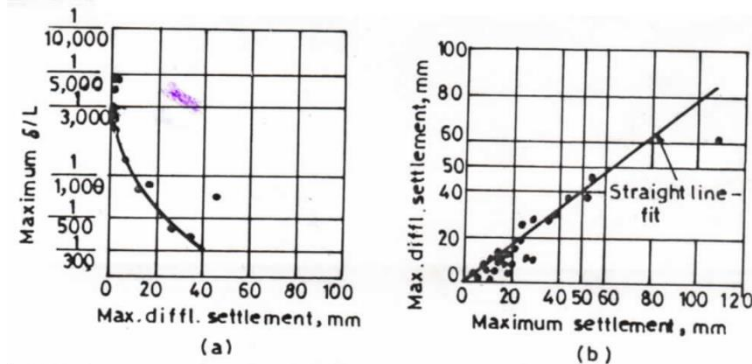


$$\text{Tilt} = \frac{\delta}{L} = \frac{S_2 - S_1}{L}$$

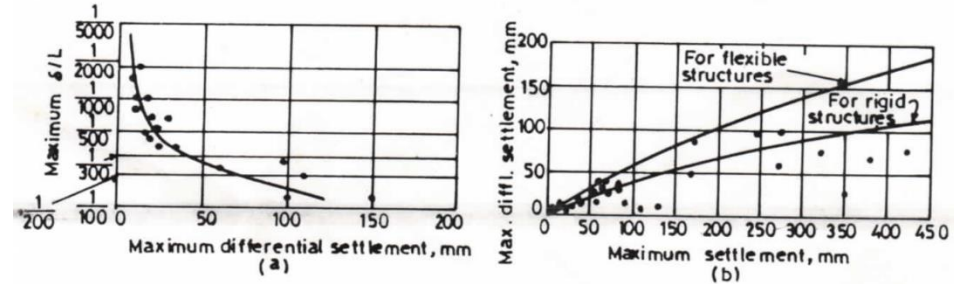
(c) Tilt

Relation between Total and differential Settlement

- In granular soil, the maximum differential settlement may be close to the maximum total settlement (**about 75% of total**)
- In clay soil, the differential settlement is much less than the total settlement (**does not exceed 50%**)
- Bejerrum's (1963a,1963b) observed settlement characteristics of structures on sand and clay as shown in below Fig.



Settlement characteristics of structures on sands
(After Bejerrum 1963a, 1963b)



Settlement characteristics of structures on clay
(After Bejerrum 1963a, 1963b)

Chapter 2b: Settlement

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Limiting Angular Displacement

Types of Structures Problem	Angular distortion (δ/l)
Difficulties with machinery sensitive to settlement	1/750
Dangers for frames with diagonals	1/600
Limit for buildings where cracking is not permissible	1/500
Limit where first cracking in panel wall is to be expected or where difficulties with overhead cranes are to be expected	1/300
Limit where tilting of high, rigid building may become noticeable	1/250
Considerable cracking in panel and brick walls. Safe limit for flexible brick wall $h/l < 1/4$. Limit where structural damage of general building may occur.	1/150

Maximum and differential settlement of Building

Sl. No.	Type of Structure	Isolated Foundations						Raft Foundations					
		Sand and Hard Clay			Plastic Clay			Sand and Hard Clay			Plastic Clay		
		Maximum Settlement mm	Differential Settlement mm	Angular Distortion mm	Maximum Settlement mm	Differential Settlement mm	Angular Distortion mm	Maximum Settlement mm	Differential Settlement mm	Angular Distortion mm	Maximum Settlement mm	Differential Settlement mm	Angular Distortion mm
1.	For steel structures	50	.0033 L	1/300	50	.0033 L	1/300	75	.0033 L	1/300	100	.0033 L	1/300
2.	For reinforced concrete structure	50	.0015 L	1/666	75	.0015 L	1/666	75	.002 L	1/500	100	.002 L	1/500
3.	For plain brick walls in multistoreyed buildings												
	(a) For $* L/H^{\dagger} \leq 3$	60	.00025 L	1/4000	80	.00025 L	1/4000	Not likely to be encountered					
	(b) For $L/H > 3$	60	.00033 L	1/3000	80	.00033 L	1/3000						
4.	For water towers and silos	50	.0015 L	1/666	75	.0015 L	1/666	100	.0025 L	1/400	125	.0025 L	1/400

Note: The values given in the table may be taken only as a guide and the permissible settlement and differential settlement in each case should be decided as per requirements of the designer.

* L denotes the length of deflected part of wall/raft or centre-to-centre-distance between columns.

+ H denotes the height of wall from foundation/footing.

Thank You

