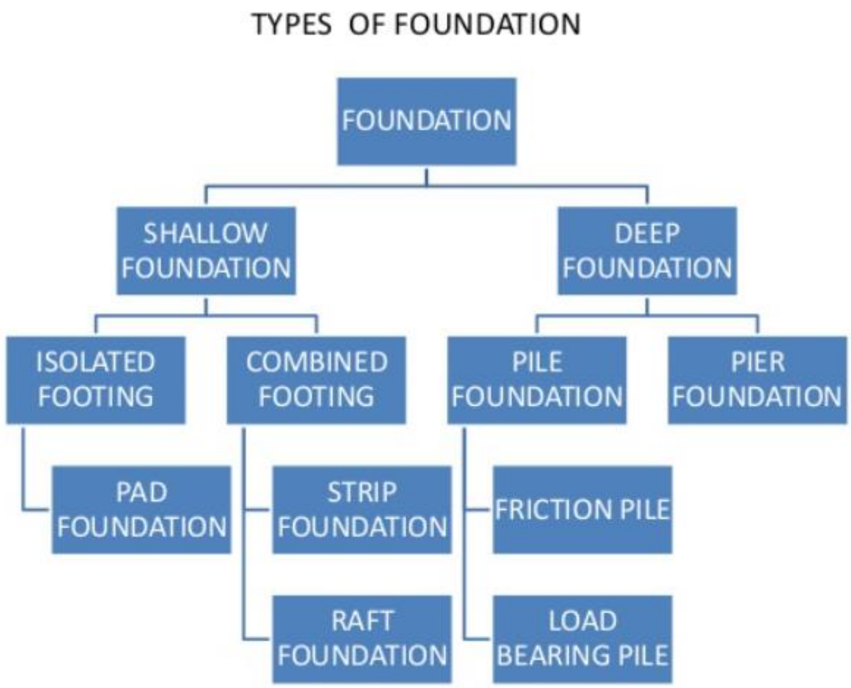
Shallow Foundation Settlement



Introduction

Foundation settlements must be estimated with great care for buildings, bridges, towers, power plants, and similar high-cost structures.
For structures such as fills, earth dams, levees, braced sheeting, and retaining walls a greater margin of error in the settlements can usually be tolerated.

Introduction

The settlement of a shallow foundation can be divided into two major categories: (a) elastic, or immediate, settlement and (b) consolidation settlement. Immediate, or elastic, settlement of a foundation takes place during or immediately after the construction of the structure.

Introduction

Consolidation settlement or those that are time-dependent and take months to years to develop. Pore water is extruded from the void spaces of saturated clayey soils submerged in water.
The total settlement of a foundation is the sum of the elastic settlement and the consolidation settlement.

Introduction

Consolidation settlement comprises two phases: primary and secondary.
Secondary consolidation settlement occurs after the completion of primary consolidation caused by slippage and reorientation of soil particles under a sustained load.

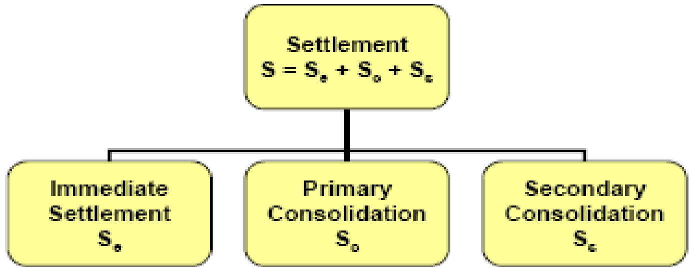
Introduction

Primary consolidation settlement is more significant than secondary settlement in inorganic clays and silty soils. However, in organic soils, secondary consolidation settlement is more significant.

Immediate settlement

Immediate settlement analyses are used for all fine-grained soils including silts and clays with a degree of saturation $S \leq 90$ percent and for all coarse-grained soils with a large coefficient of permeability.

Settlement



Immediate Settlement: Occurs immediately after the construction. This is computed using elasticity theory (Important for Granular soil)

Primary Consolidation: Due to gradual dissipation of pore pressure induced by external loading and consequently expulsion of water from the soil mass, hence volume change. (Important for Inorganic clays)

Secondary Consolidation: Occurs at constant effective stress with volume change due to rearrangement of particles. (Important for Organic soils)

For any of the above mentioned settlement calculations, we first need vertical stress increase in soil mass due to net load applied on the foundation

Foundation Settlement:

Total Foundation Settlement = Elastic Settlement + Consolidation Settlement

$$S_{total} = S_e + S_c$$

Elastic Settlement or Immediate Settlement depends on {
- Foundation Type (Rigid; Flexible)
- Settlement Location (Center or Corner)

Elastic Settlement {
- Theory of Elasticity
- Time Depended Elastic Settlement (Schmertman & Hartman Method (1978)

Elastic settlement occurs in sandy, silty, and clayey soils.

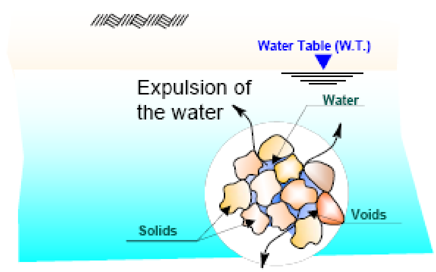
Consolidation Settlement (Time Dependent Settlement)

* Consolidation settlement occurs in cohesive soils due to the expulsion of the water from the voids.
* Because of the soil permeability the rate of settlement may varied from soil to another.
* Also the variation in the rate of consolidation settlement depends on the boundary conditions.

$$S_{Consolidation} = S_{primary} + S_{secondary}$$

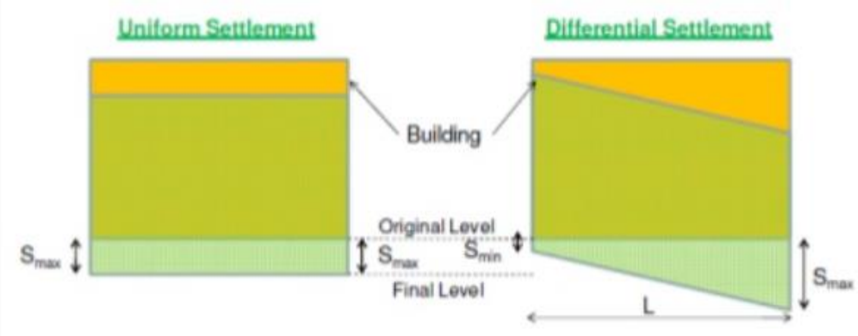
Primary Consolidation — Volume change is due to reduction in pore water pressure

Secondary Consolidation — Volume change is due to the rearrangement of the soil particles
(No pore water pressure change, $\Delta u = 0$, occurs after the primary consolidation)



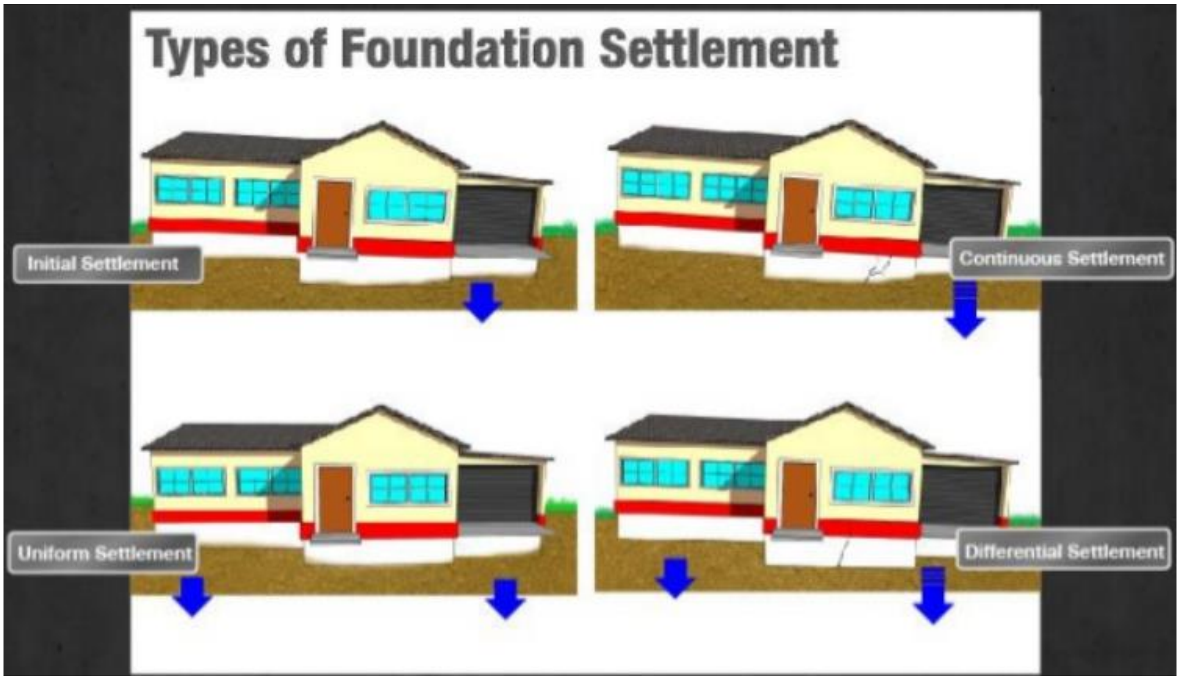
Definitions

✓ Settlement is the vertically downward movement of structure due to the compression of underlying soil because of increased load.



Concepts of uniform and differential settlement

• Maximum Settlement : It is the absolute maximum downward movement of any part of buildi ng element. • Maximum Settlement = Smax	• Differential Settlement : It is the maximum difference between two points in a building element. • Differential Settlement = Smax - S min


Types of Foundation Settlement
Initial Settlement
Continuous Settlement
Uniform Settlement
Differential Settlement

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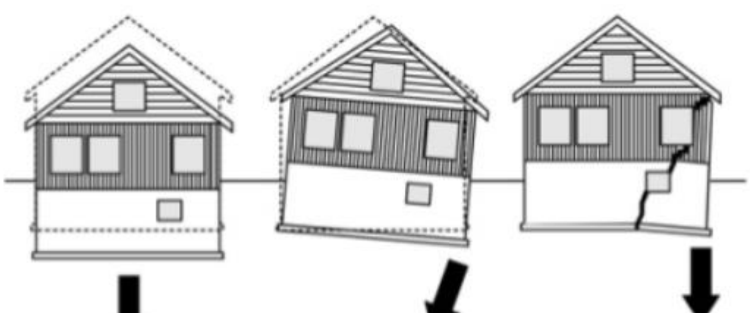
uniform settlement
(no cracks)
tipping settlement
(often without cracks)
differential settlement
(with cracks)

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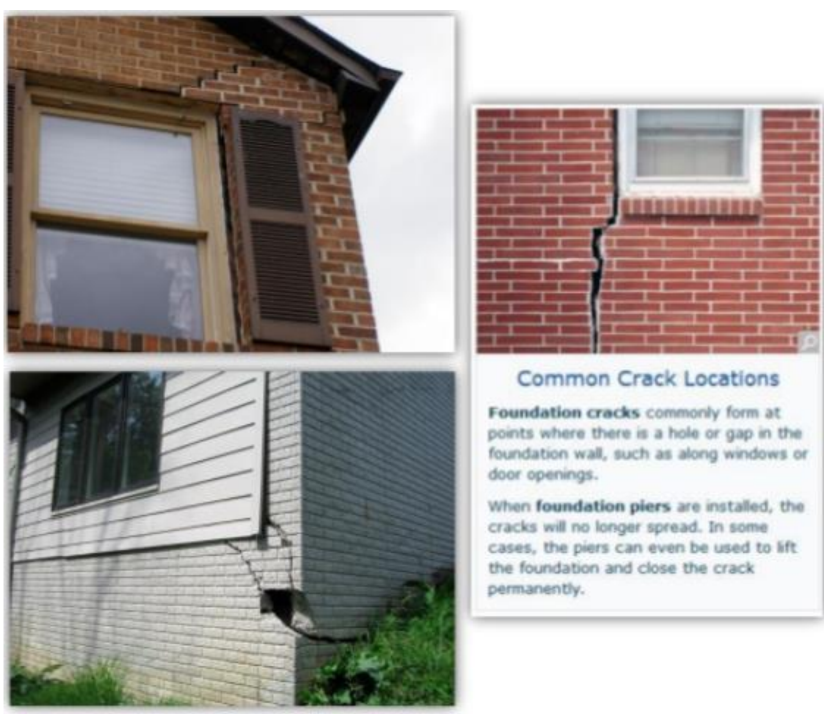
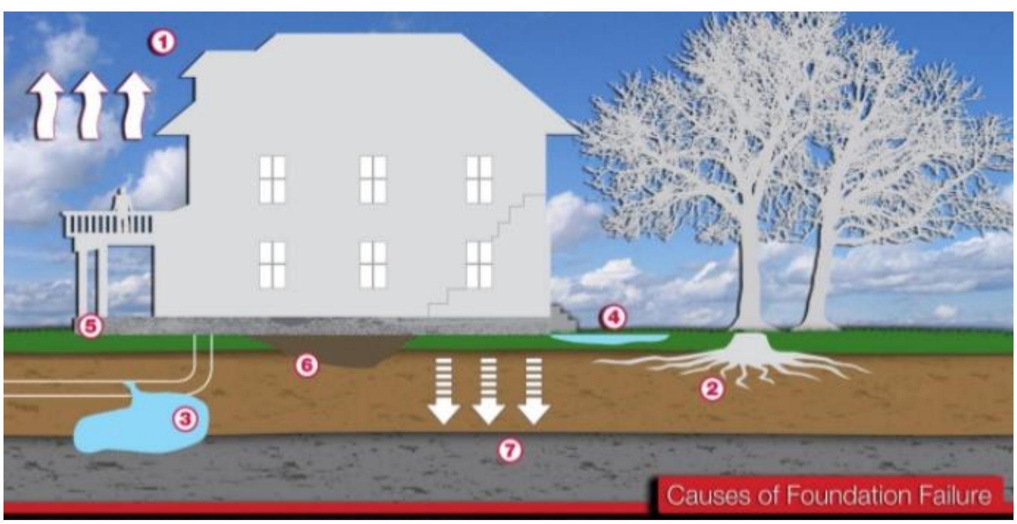

Common Crack Locations
Foundation cracks commonly form at points where there is a hole or gap in the foundation wall, such as along windows or door openings.
When **foundation piers** are installed, the cracks will no longer spread. In some cases, the piers can even be used to lift the foundation and close the crack permanently.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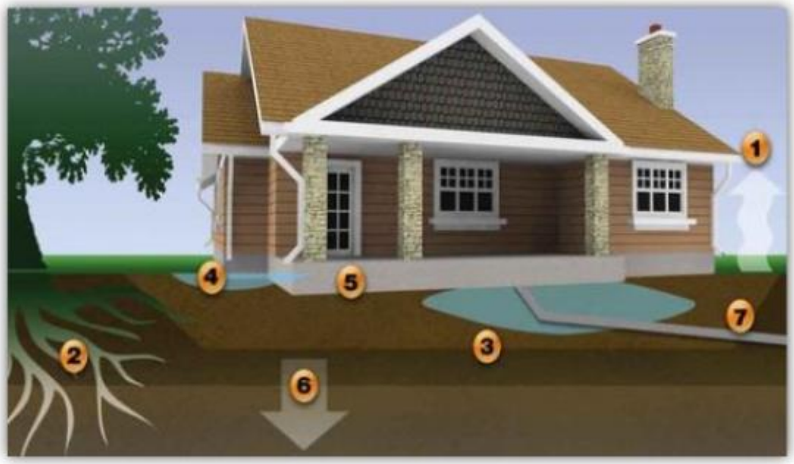
Causes of Foundation Failure

Several things cause a foundation to fail



1.Evaporation: Hot dry wind and intense heat will often cause the soil to shrink beneath the foundation. This settlement may cause cracks to appear throughout the structure.

2.Transpiration: Tree roots may desiccate the soil beneath a home causing the soil to shrink and the home to settle.

3.Plumbing Leaks: Water from plumbing leaks is often a cause to foundation problems.

4.Drainage: Improper drainage is one of the leading causes to foundation failure. Excess moisture will erode or consolidate soils and cause settlement.

5.Inferior Foundation Construction: Insufficient steel and inferior concrete will contribute to movement in the slab.

6.Inferior Ground Preparation: Soft, low density soils and/or improperly compacted soil beneath a home is the leading cause of foundation failure. Cut and fill methods are a leading cause of foundation settlement.

7.Poor Soil conditions: Poor soil and its expansion and/or contraction contribute to foundation failure.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Signs of foundation failure

INSIDE

Signs on the inside of the house that indicate foundation problems may include:

1. Misaligned doors and windows
2. Cracks in the sheetrock
3. Doors and windows that are sticking
4. Sloping of the floor
5. Cracks in the floor or tile

OUTSIDE

Signs on the outside of the house that indicate foundation problems may include:

1. Cracks in the brick
2. Gaps around the doors and windows
3. Cracks in the foundation
4. Fascia board pulling away

GARAGE

Signs in the garage that indicate foundation problems may include:

1. Separation from door
2. Wall rotating out
3. Cracked brick

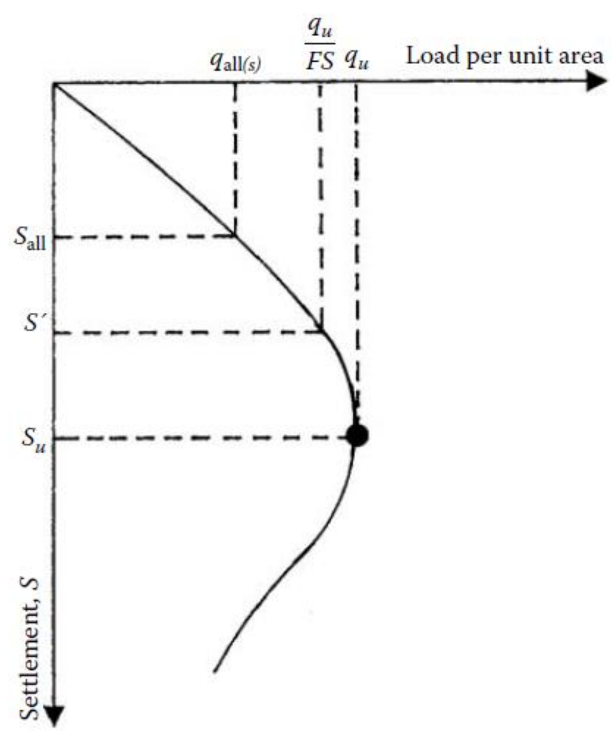
BASEMENT

Signs in the basement that indicate foundation problems may include:

1. Walls leaning in or out
2. Cracks in the wall
3. Water intrusion

✓ When all parts of a building rest on the same kind of soil, and the loads on the building and the design of its structural system are uniform throughout, differential settlement is normally not a concern. However where soils, loads, or structural systems differ between parts of a building, different parts of the building structure may settle by substantially different amounts, the frame of the building may become distorted, floors may slope, walls and glass may crack, and doors and windows may not work properly.

(a) Building before settlement occurs *(b) Uniform settlement* *(c) Differential settlement*



Load–settlement curve for shallow foundation.

COMPONENTS OF TOTAL SETTLEMENT

1. **Immediate settlement (**Si **)**
2. **Primary consolidation settlement (**Sc **)**
3. **Secondary consolidation settlement (**Ssc**)**

METHODS OF COMPUTING IMMEDIATE SETTLEMENT

Immediate Settlement Based on the Theory of Elasticity
Schmertmann's Method (1978): Use of Strain Influence Factor
Bjerrum's Method for Average Settlement of Layered Clay Soil

PRIMARY CONSOLIDATION SETTLEMENT
Secondary consolidation settlement

3-DIMENTIONAL CONSOLIDATION
DEGREE OR RATE OF SETTLEMENT

Immediate settlement

Settlement Based on the Theory of Elasticity

The elastic settlement of a shallow foundation can be estimated by using the theory of elasticity. From Hooke's law we obtain

$$S_e = \int_0^H \varepsilon_z \, d_z = \frac{1}{E_s} \int_0^H \left(\Delta\sigma_z - \mu_s \, \Delta\sigma_x - \mu_s \, \Delta\sigma_y \right) d\,z$$

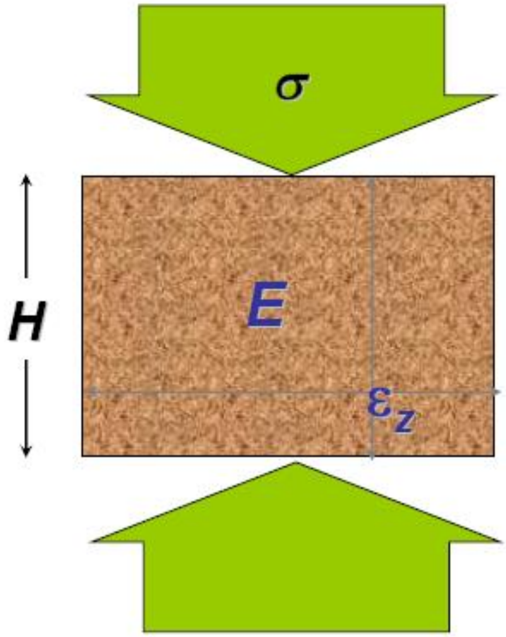
Where: $S_e = elastic\ settlement$ $\quad H = thickness\ of\ soil\ layer$

$E_s = modulus\ of\ elasticity\ of\ soil$

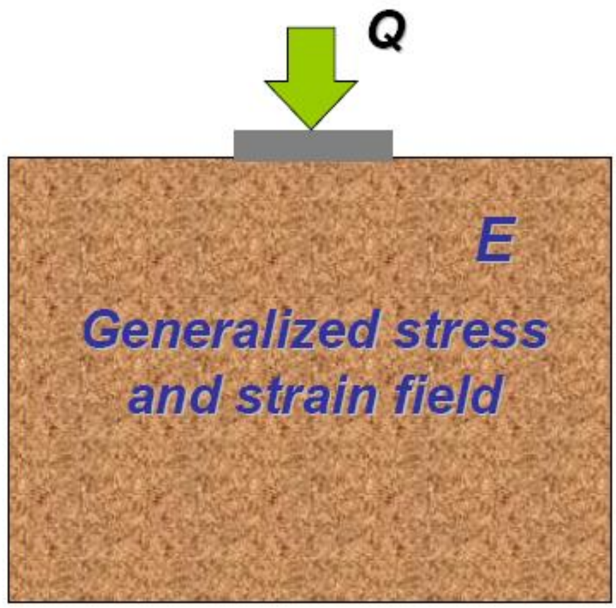
$\mu_s = Poisson's\ ratio\ of\ the\ soil$

$\Delta\sigma_z, \Delta\sigma_x, \Delta\sigma_y = stress\ increase\ due\ to$ *the net applied foundation load in the x, y, and z directions, respectively*

Elastic Settlement



$S_e = H\,\sigma/E = H.\varepsilon_z$



$S_e = \int_0^{\infty} \varepsilon_z\,.dz$

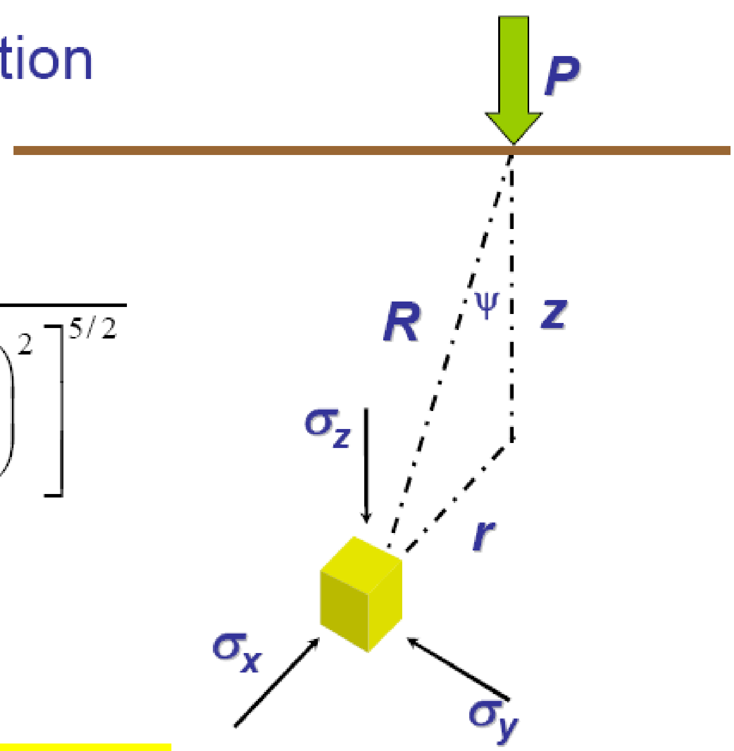
Stress Due to a Concentrated Load

- Boussinesq solution

$$\Delta\sigma = \frac{3P}{2\pi z^2\left[1+\left(\frac{r}{z}\right)^2\right]^{5/2}}$$

where

$$r = \sqrt{x^2 + y^2}$$



Section 3.16 of Das Eq. 3.93

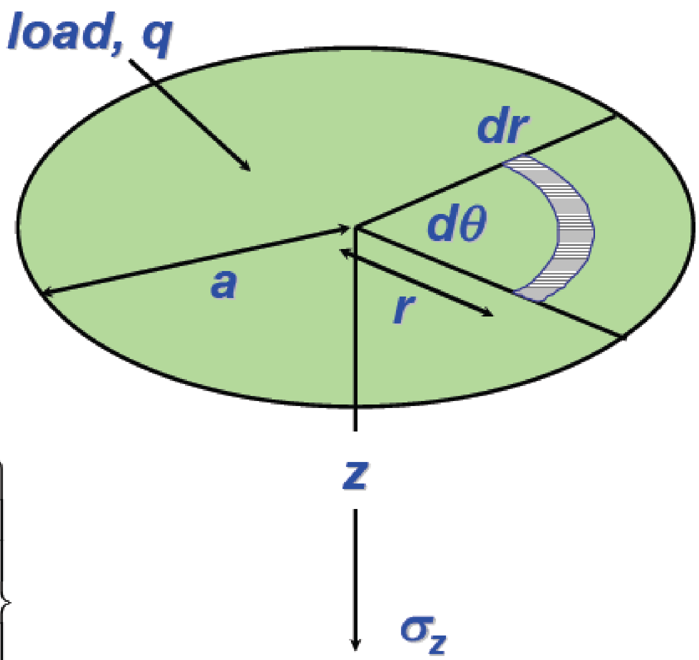
Stress due to a Circularly Loaded Area

For the incremental area shown settlement at the centre can be calculated as:

Load on incremental area

$$d\sigma = \frac{q_o r d\theta dr}{2\pi z^2 \left[1 + \left(\frac{r}{z}\right)^2\right]^{5/2}}$$

After the double integration



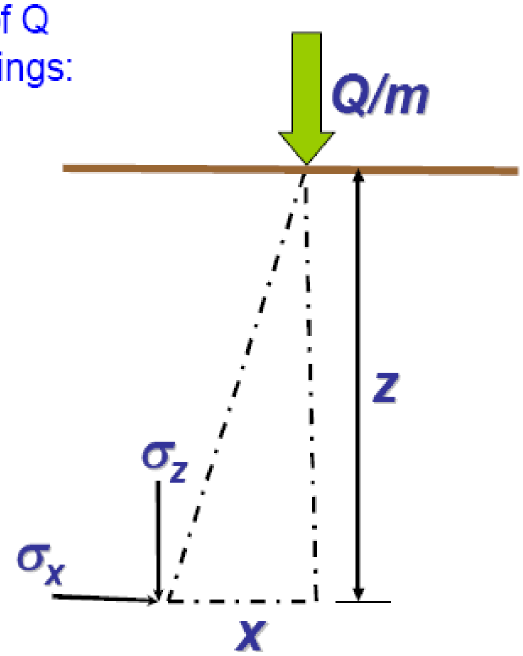
At Centre :

$$\Delta\sigma = q\left\{1 - \frac{1}{\left[1 + \left(\frac{B}{2z}\right)^2\right]^{3/2}}\right\}$$

Section 3.16 of Das Eq. 3.95

Distribution of Stress (from a vertical line load)

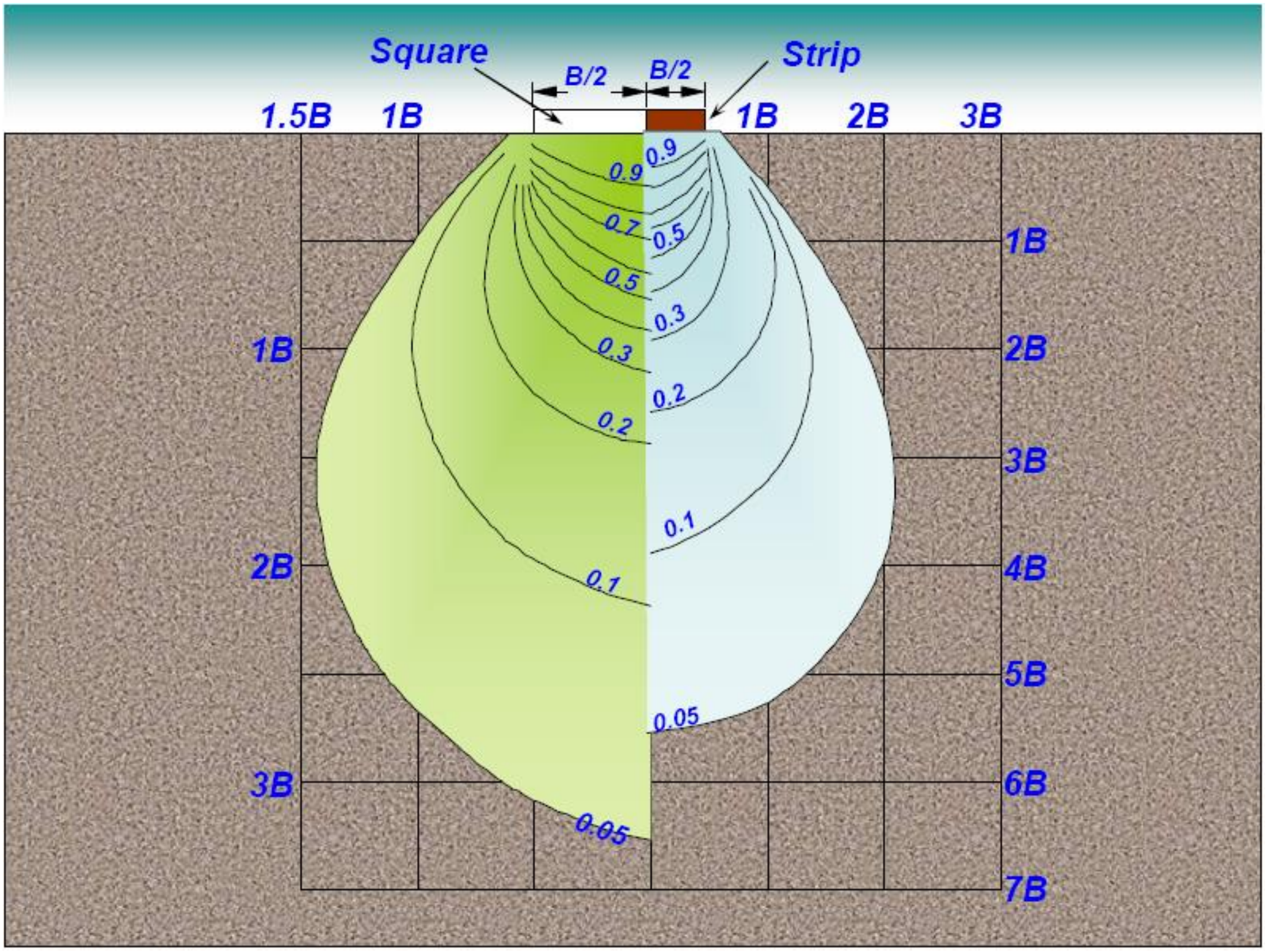
The stresses at point X due to a line load of Q per unit length on the surface are as followings:



$$\sigma_z = \frac{2Q}{\pi}\frac{Z^3}{(x^2 + Z^2)^2}$$

$$\sigma_x = \frac{2Q}{\pi}\frac{x^2 Z}{(x^2 + Z^2)^2}$$

$$\tau_{xy} = \frac{2Q}{\pi}\frac{xZ^2}{(x^2 + Z^2)^2}$$

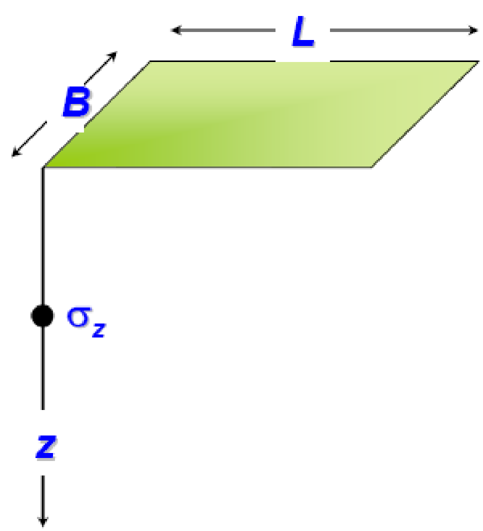


Stress below a Rectangular Area

- Solution after Newmark for stresses under the corner of a uniformly loaded flexible rectangular area:
- Define $m = B/z$ and $n = L/z$
- Solution by charts or numerically

$\Delta\sigma = q_o.I$

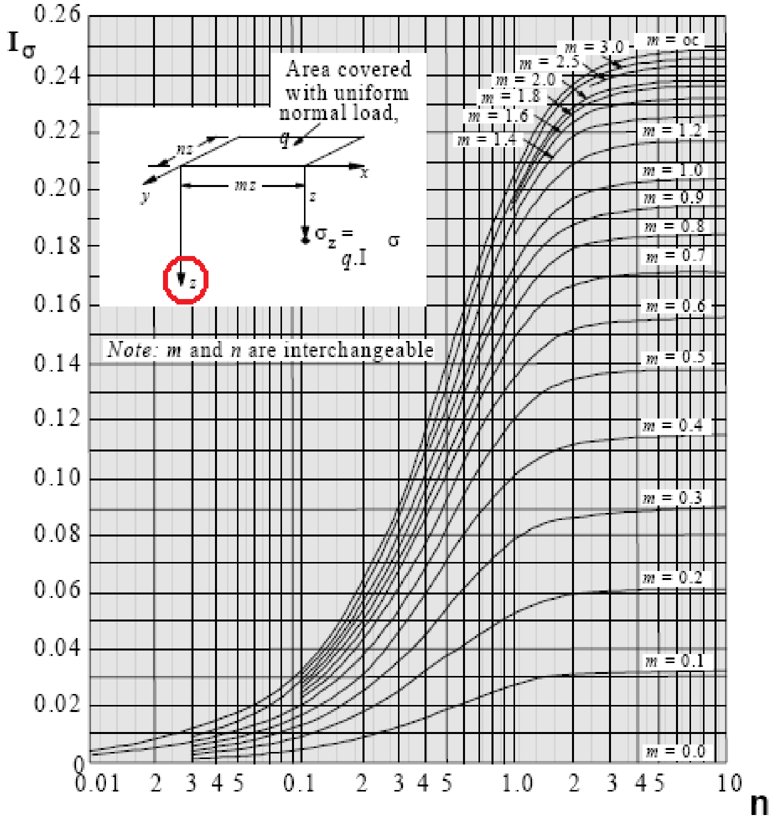
(It must be emphasised that the chart gives the stresses under the corner of uniformly load flexible rectangular area.)



Section 3.16 of Das Eq. 3.99

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

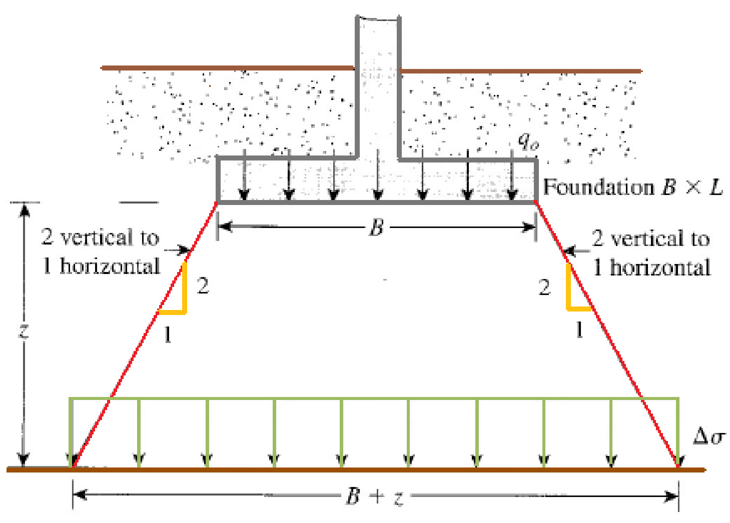
Stress Influence Chart



VERTICAL STRESS BELOW A CORNER OF A UNIFORMLY LOADED FLEXIBLE RECTANGULAR AREA.

Approximate methods

2:1 method



2:1 method of finding stress increase under a foundation

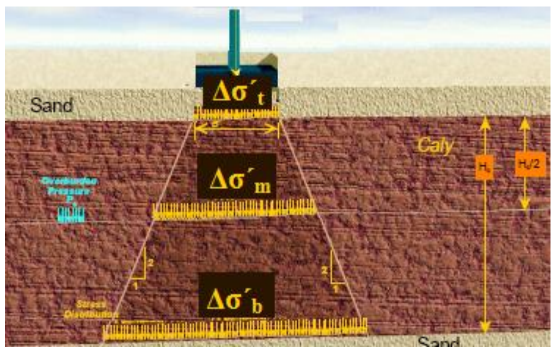
$$\Delta\sigma = \frac{q_o BL}{(B+z)(L+z)}$$

Section 3.16 of Das Eq. 3.103

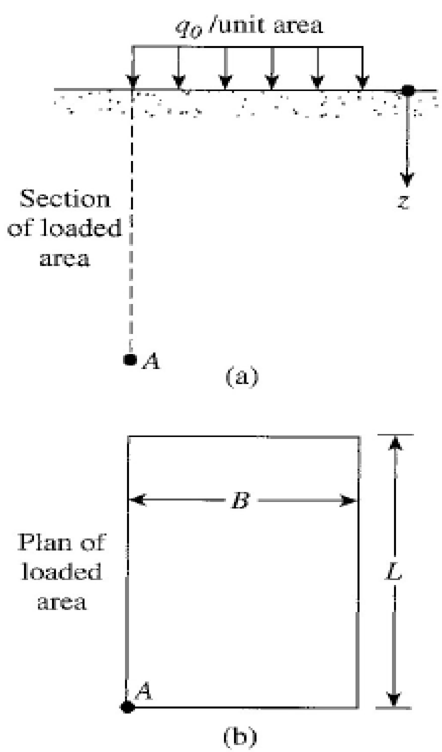
Approximate methods

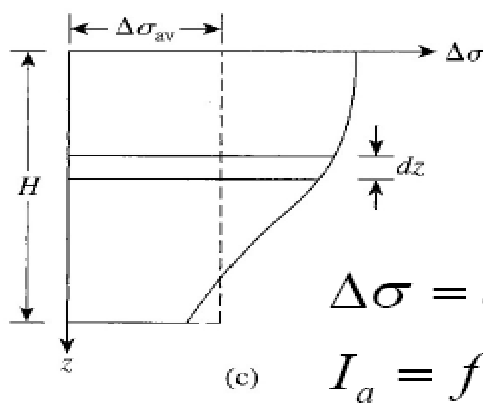
$$\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b)$$

where $\Delta\sigma'_t$, $\Delta\sigma'_m$, and $\Delta\sigma'_b$ are, respectively, the effective pressure increases at the *top, middle,* and *bottom* of the clay layer that are caused by the construction of the foundation.



Average Vertical Stress Increases Due to a Rectangularly Loaded Area





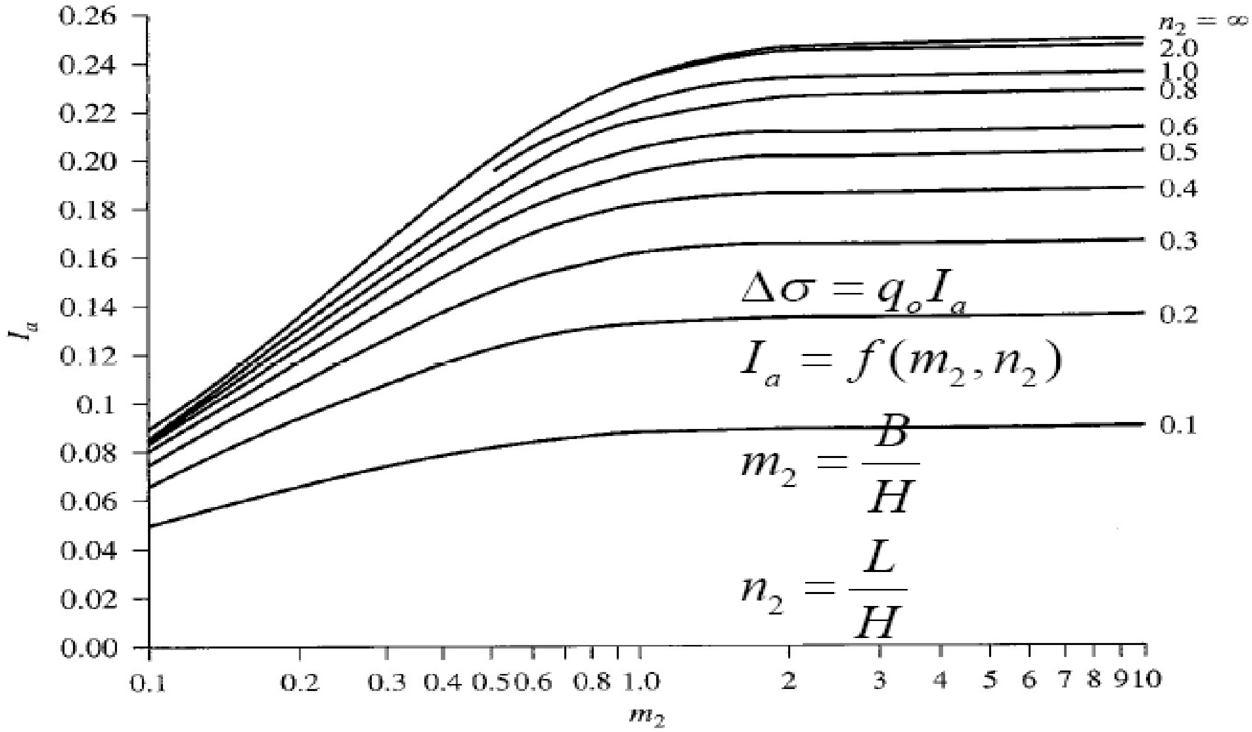
$$\Delta\sigma = q_o I_a$$

$$I_a = f(m_2, n_2)$$

$$m_2 = \frac{B}{H}$$

$$n_2 = \frac{L}{H}$$

Average Vertical Stress Increases Due to a Rectangularly Loaded Area



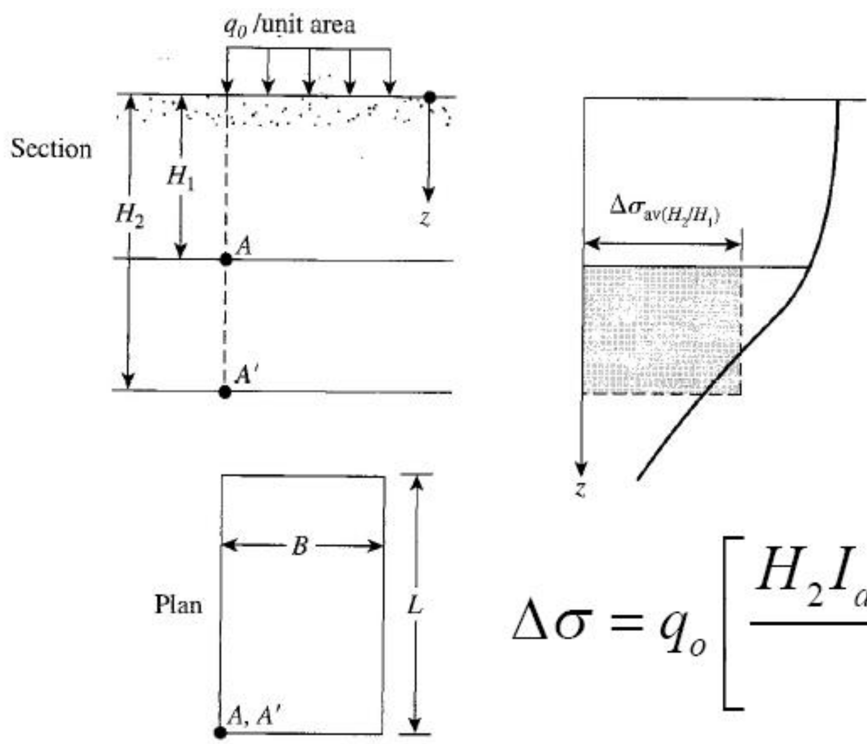
$$\Delta\sigma = q_o I_a$$

$$I_a = f(m_2, n_2)$$

$$m_2 = \frac{B}{H}$$

$$n_2 = \frac{L}{H}$$

Average Vertical Stress Increases in a given layer



$$\Delta\sigma = q_o \left[\frac{H_2 I_{a(H_2)} - H_1 I_{a(H_1)}}{H_2 - H_1} \right]$$