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# Basics of Soil Mechanics


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# An Overview of Soil Mechanics

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Soil Problems
&
Solutions

A Preview of
Soil Behavior

Pioneers in
Soil Mechanics

## *WHERE ?*

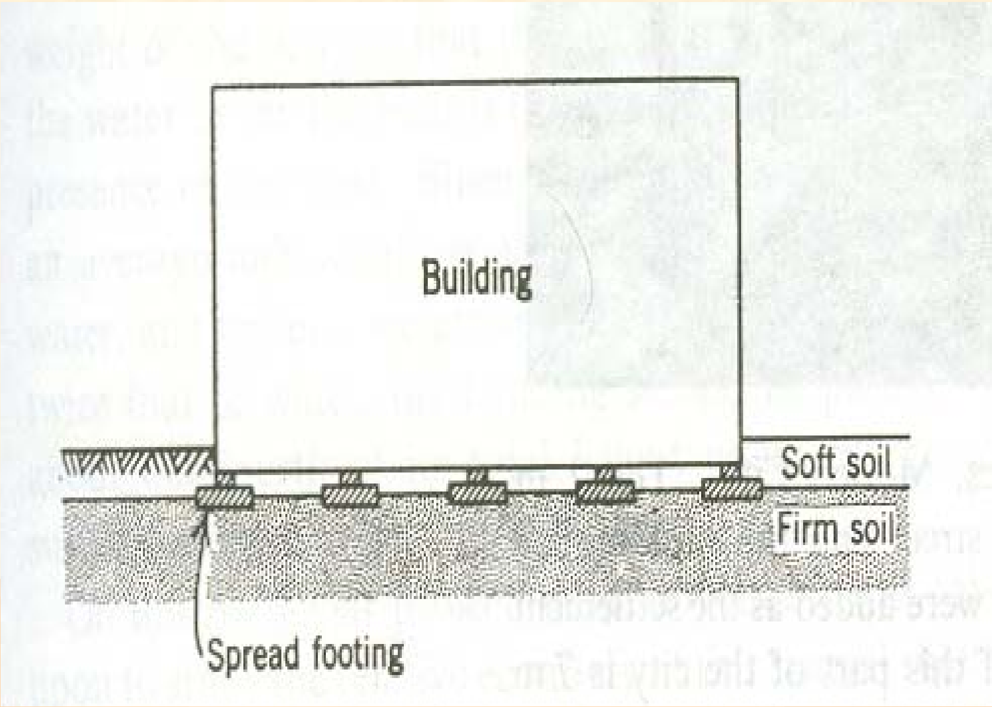
**CIVIL ENGINEER ⟷ ENCOUNTERS ⟷ SOIL**

- **SOIL AS A**
  - **FOUNDATION**
  - **CONSTRUCTION MATERIAL**
- **SOIL RETAINING**
- **SPECIAL PROBLEMS**

# FOUNDATIONS

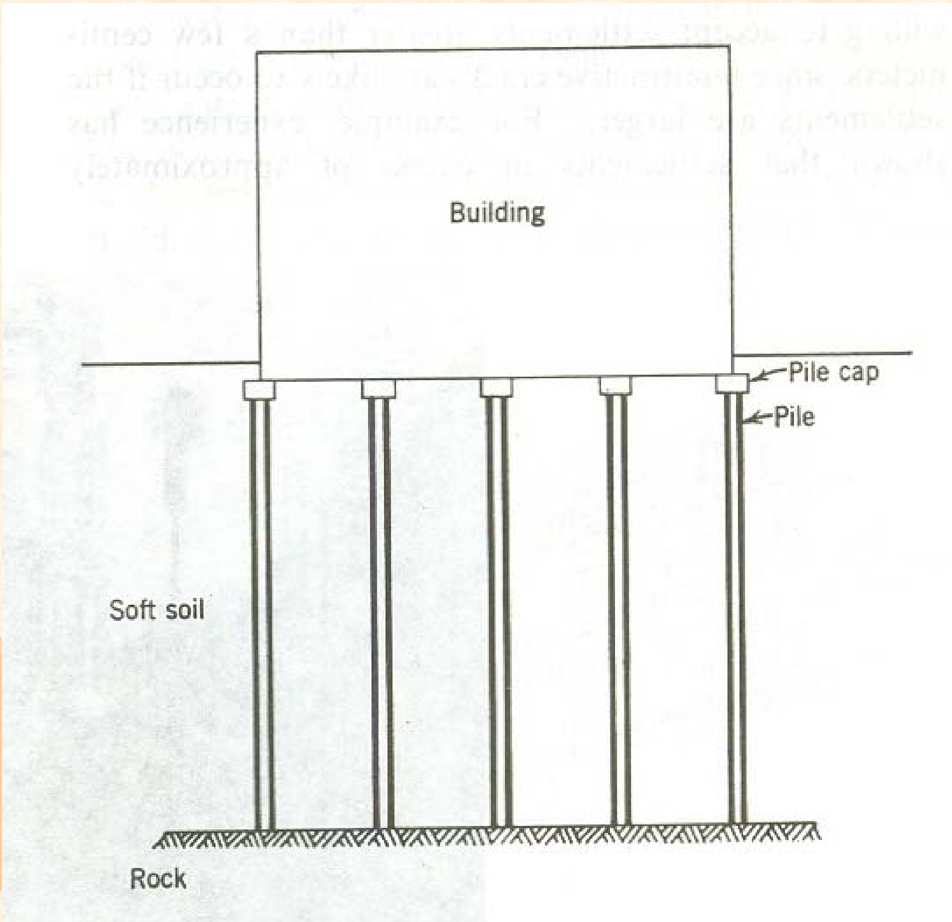
- WHAT ARE FOUNDATIONS?
- TYPES OF FOUNDATIONS
  - SHALLOW FOUNDATIONS
  - DEEP FOUNDATIONS
- MAIN PROBLEM IN THE DESIGN
  - TO PREVENT SETTLEMENT
    - TOTAL SETTLEMENT
    - DIFFERENTIAL SETTLEMENT

# SHALLOW FOUNDATIONS




- Structural loads are carried by the soil directly under the structure

# DEEP FOUNDATIONS




- Used to carry the loads to firm soil at some depth

# Classic case of bad foundation

- Fig. shows the Palacio de las Bellas Artes, Mexico City
- The 2 m differential settlement between the street and the building on the right necessitated the steps which were added as the settlement occurred
- The general subsidence of this part of the city is 7 m
- (Photograph compliments of Raul Marsal)

# Example of Shallow foundations

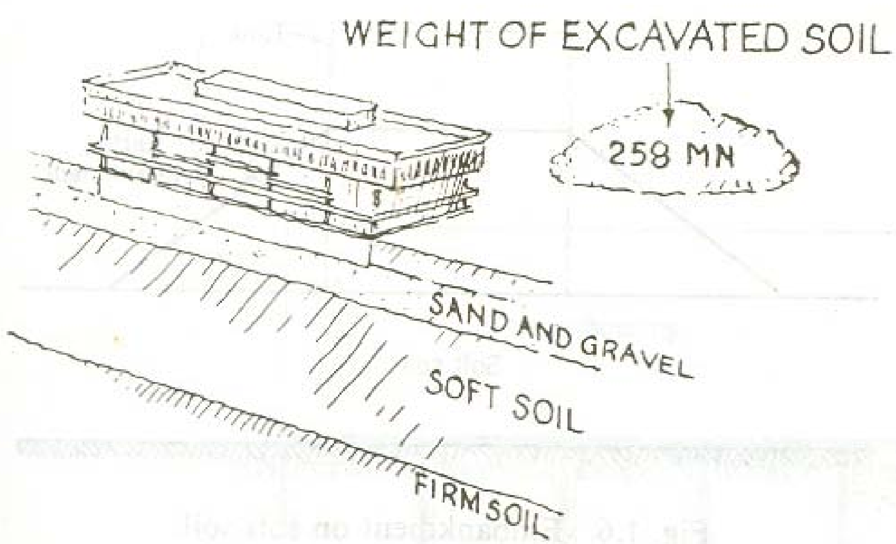



Fig. 1.4 Building on shallow mat foundation.

| | | |
|---|---|---|
| Weight of building | = | 285 MN |
| Weight of furniture, people, etc. (time average) | = | 45 MN |
| | | 330 MN |
| Weight of excavated soil | = | 258 MN |
| Net load to clay | = | 72 MN |

- Fig shows the MIT students centre
- Mat foundation
- Floatation technique

# Main Factors

1. Just how deep into the soil should the building be placed?
2. Would the excavation have to be enclosed by a wall during construction to prevent cave-ins of soil?
3. Would it be necessary to lower the water table in order to excavate and construct the foundation and, if so, what means should be used to accomplish this lowering of the ground water *(dewatering)?*
4. Was there a danger of damage to adjacent buildings?
5. How much would the completed building settle and would it settle uniformly?
6. For what stresses and what stress distribution should the mat of the building be designed?

# Example of Deep foundations

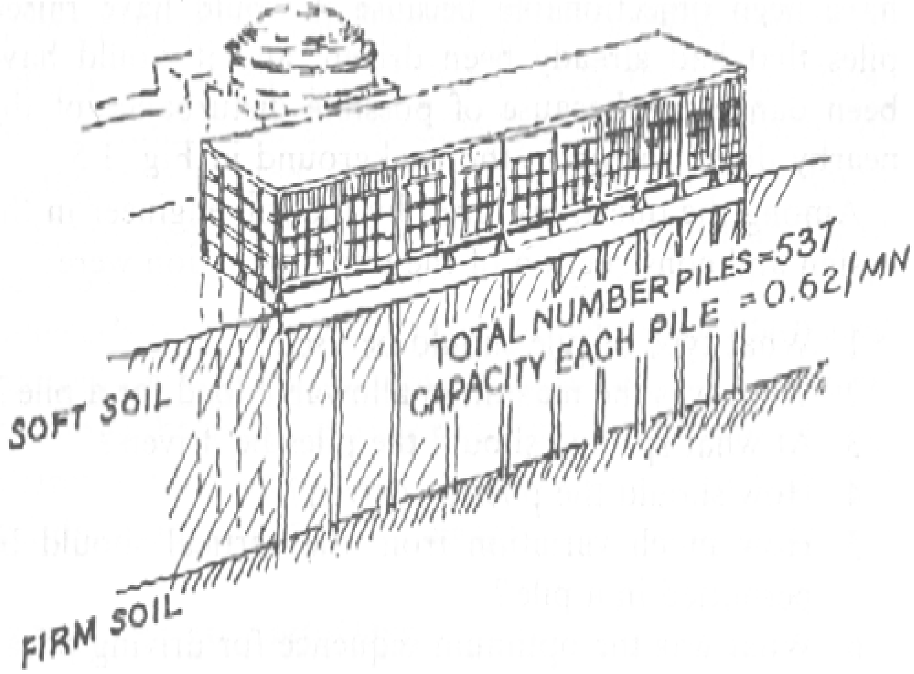



Fig. 1.5 Building on deep pile foundation.

Weight of building = 142 MN
Weight of equipment, books, people, etc. = 107 MN
Maximum total weight = 249 MN

- MIT material centre has deep pile foundation
- Reasons
  - Basement space not desirable
  - No sand and gravel at the site
  - Not to disturb underground utilities
- Point bearing pile
- Friction pile
- Augering

# Main Factors

I. What type of pile should be used?

2. What was the maximum allowable load for a pile?

3. At what spacing should the piles be driven?

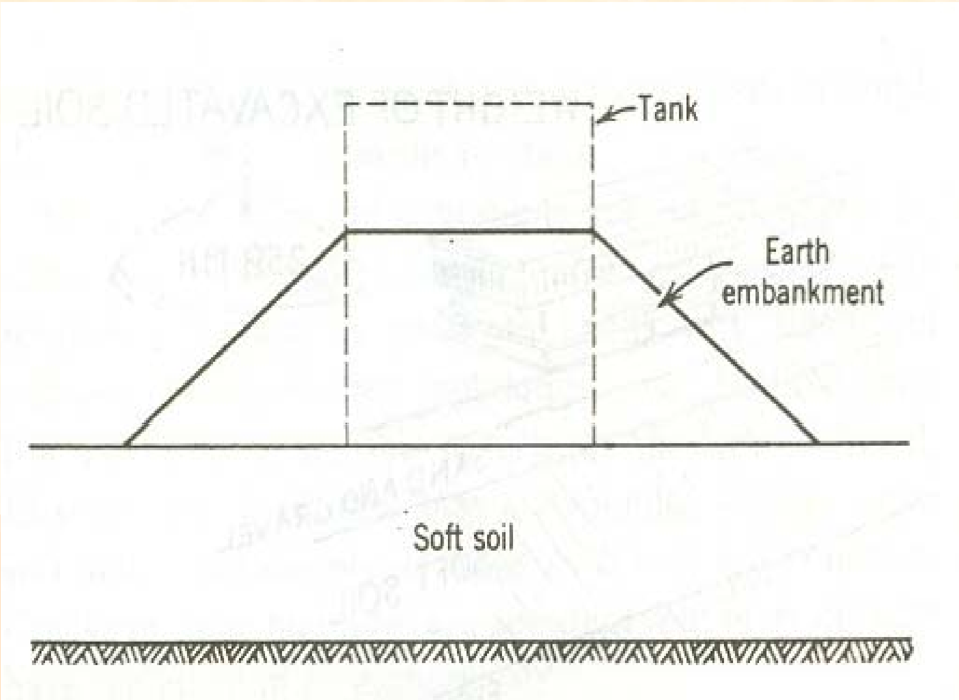
4. How should the piles be driven?

5. How much variation from the vertical should be permitted in a pile?

6. What was the optimum sequence for driving piles?

7. Would the driving of piles have an influence on adjacent structures?

# Example of Embankment on Soft Soil

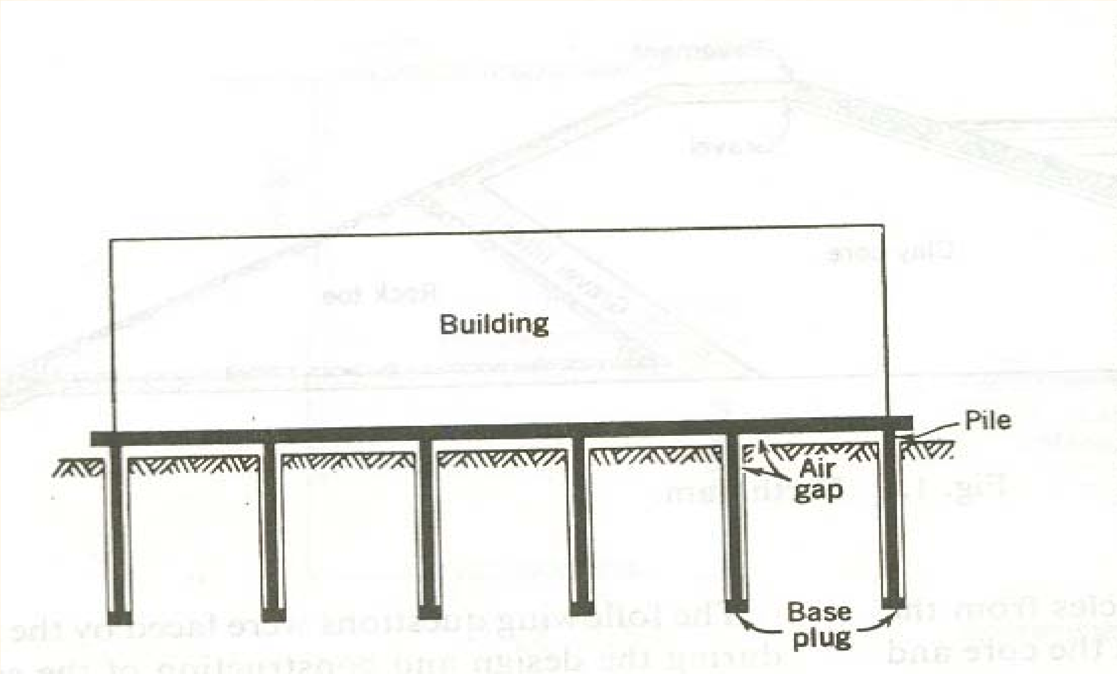



- 10.7 m embankment on a 9.8m layer of soft soil
- Preloading technique
- Shear rupture should not occur

# Main Factors

1. How high a fill could be placed?
2. How fast could the fill be placed?
3. What were the maximum slopes for the fill?
4. Could the fill be placed without employing special techniques to contain or drain the soft foundation soil?
5. How much would the fill settle?
6. How long should the fill be left in place in order that the foundation be compressed enough to permit construction and use of the tank?

# Example of Foundation Heave




- Occurs when foundation soil expands when the confining pressure is reduced and / or the water content of the soil is increased
- Arid regions
- Presence of montmorillonite

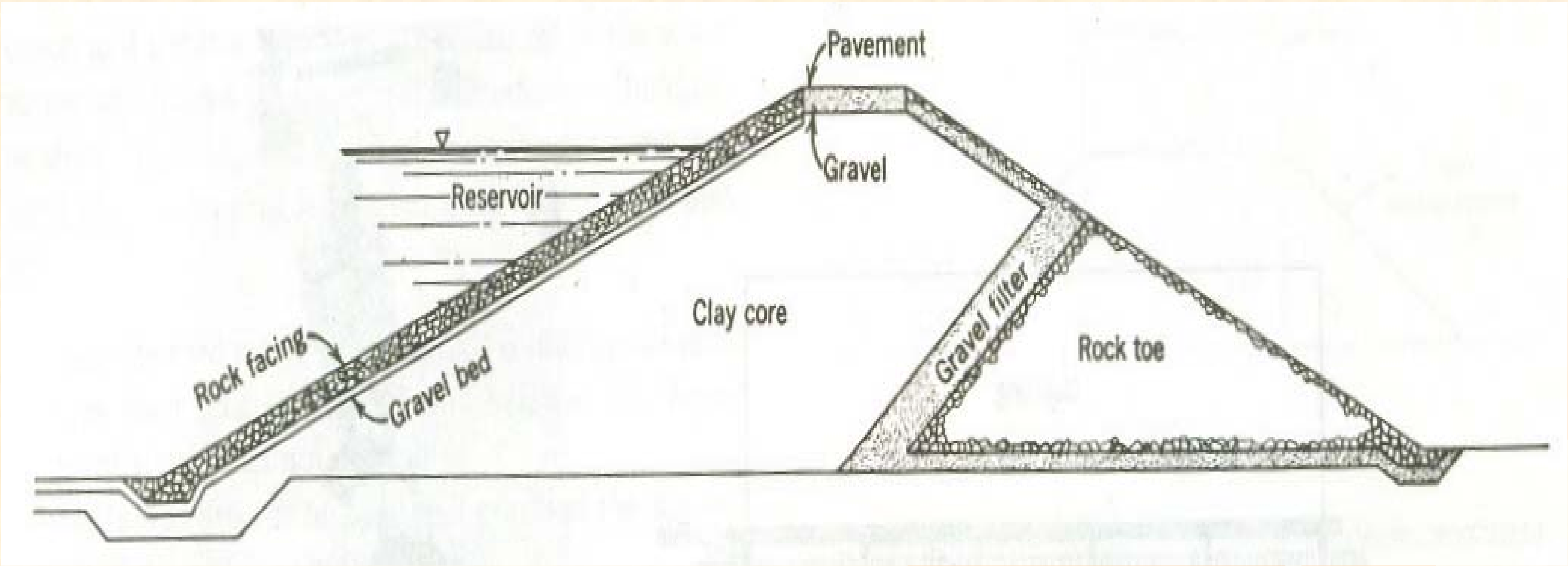
# Main Factors

- Proper size ,capacity, length and spacing of the piles
- The pile should be long enough to extend below the depth of the soil that would expand
- The depth selected in such a way that the confining pressure from the soil overburden plus minimum load is sufficient to prevent expansion

# CONSTRUCTION MATERIAL

- Select proper type of soil
- Method of placement
- Control of actual placement
- Filling

# Example of an Earth Dam




- Two main zones
  - Clay core
  - Rock toe
- Gravel filter
- Rock facing
- Zoned earth dam & homogeneous earth dam

# Main Factors

I. What should be the dimensions of the dam to give the most economical, safe structure?

2. What is the minimum safe thickness for the gravel layers?

3. How thick a layer of gravel and rock facing is necessary to keep any swelling of the clay core to a tolerable amount?

4. What moisture content and compaction technique should be employed to place the gravel and clay materials?

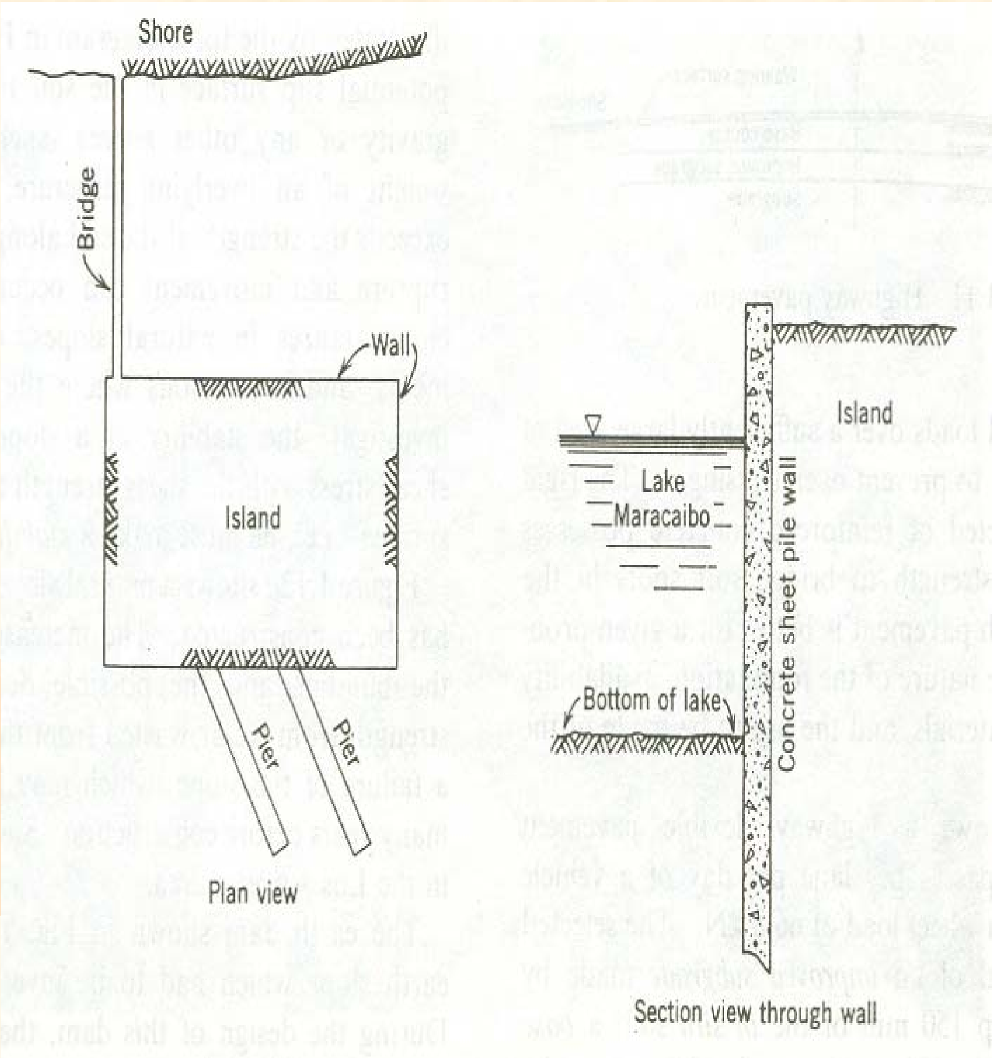
5. What are the strength and permeability characteristics of the constructed dam?

6. How would the strength and permeability of the darn vary with time and depth of water in the reservoir?

7. How much leakage would, occur under and through the dam?

8. What, if any, special restrictions on the operation of the reservoir are necessary?

# Example of a Reclamation Structure




- Non-availability of good building sites
- Harbor and terminal facilities
- Hydraulic filling

# Main Factors

I. How deep should the sheet pile wall penetrate the foundation soil?

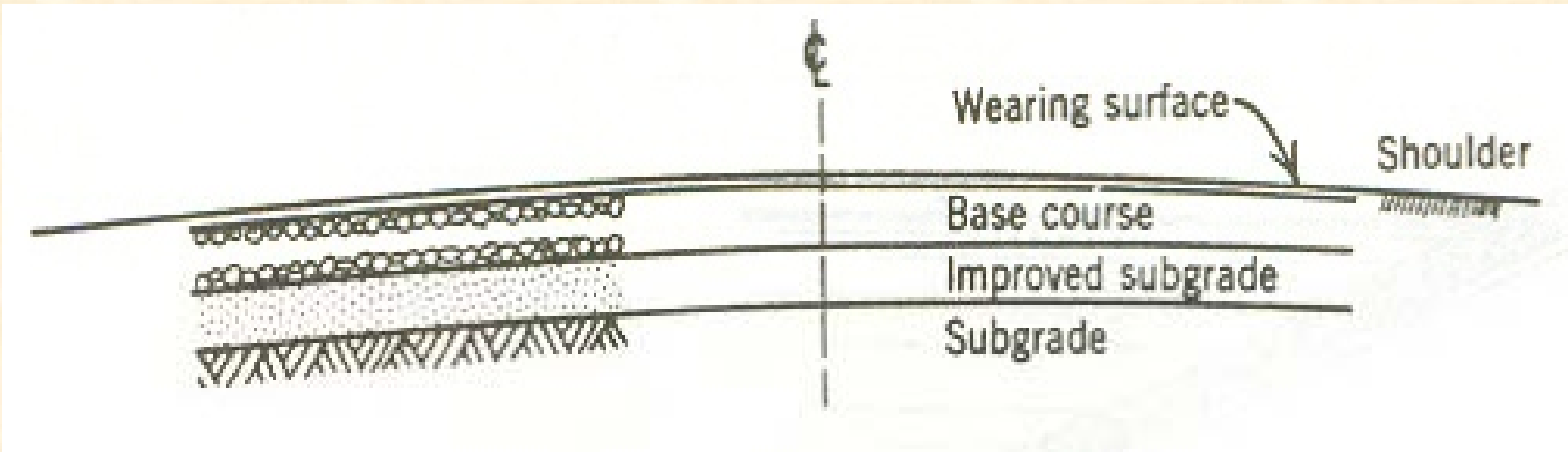
2. How should these piles be braced laterally?

3. What is the most desirable pattern of fill placement i.e., how should the exit of the dredge pipe be located in order to get the firmer part of the fill at the locations where the maximum foundation loads would be placed?

4. What design strength and compressibility of the hydraulic fill should be used for selecting foundations for the tanks, buildings, and pumping facilities to be placed on the island?

5. Where did the soil fines in the dirty effluent which went out of the island over the spillway ultimately settle?

# Example of Highway Pavement

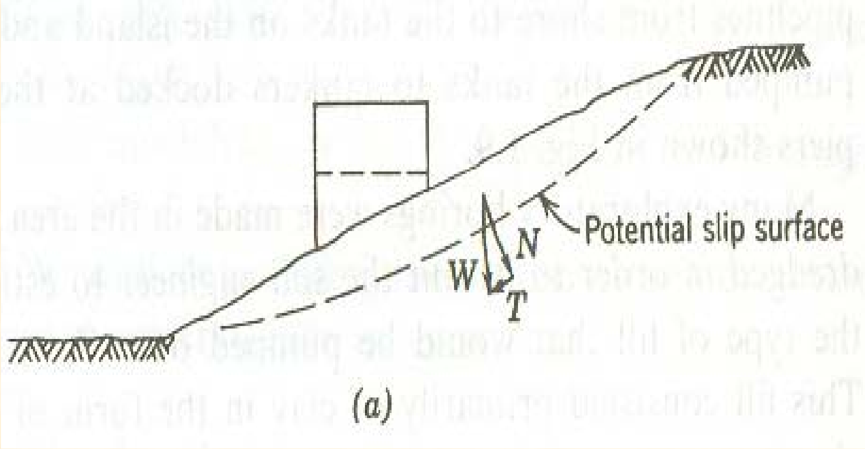



- Most common use of soil as construction material
- Pavements
  - Rigid
  - Flexible

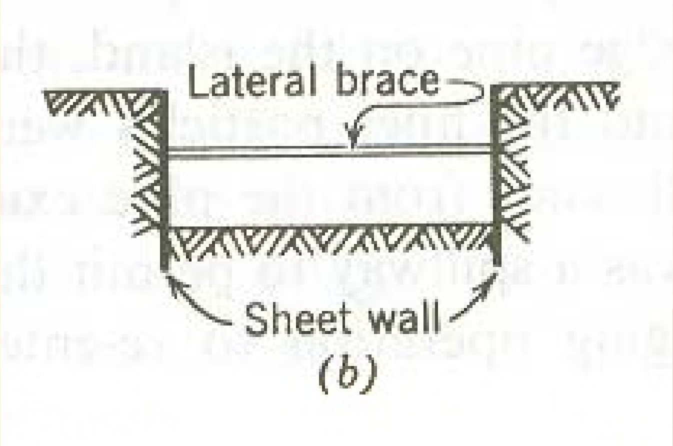
# Main Factors

1. How thick should the various components of the pavement be to carry the expected loads?
2. What is the optimum mixture of additives for stabilizing the desert sand?
3. Is the desert sand acceptable for the construction of the wearing surface?
4. What grade and weight of available asphalt make the most economical, satisfactory wearing surface?
5. What type and how much compaction should be used?

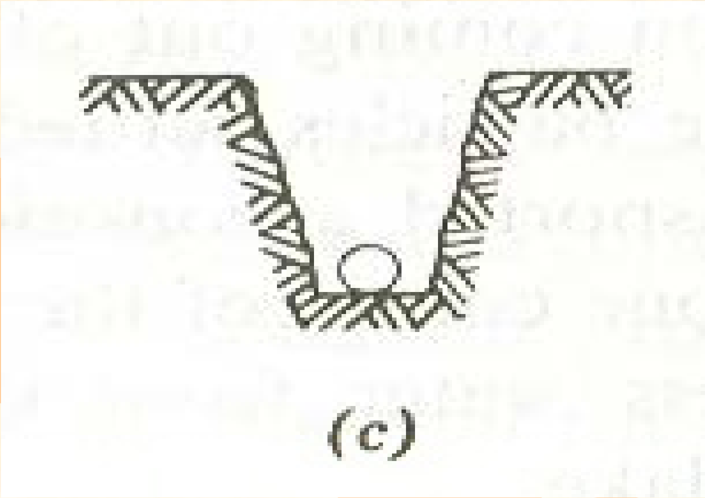
# SLOPES AND EXCAVATIONS



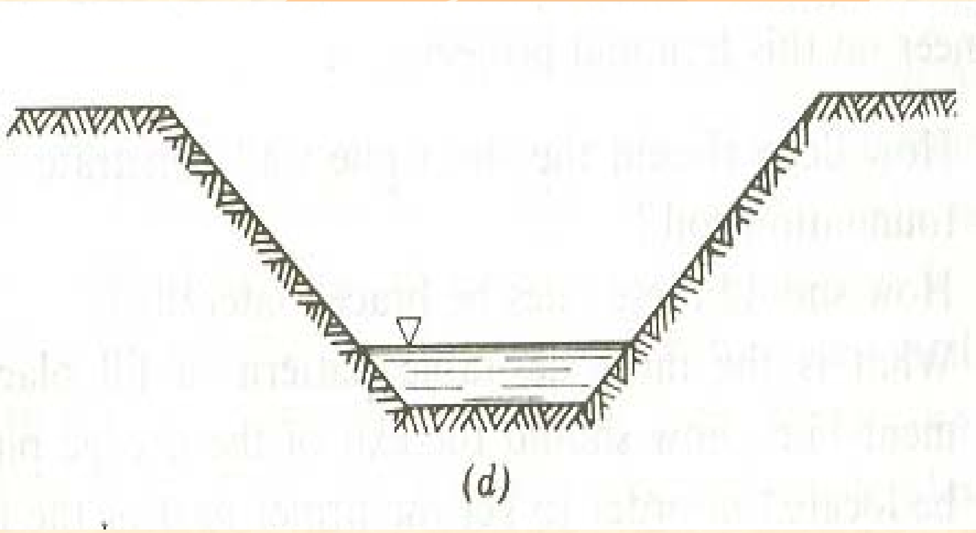

**(a) Natural Slope**




**(b) Excavation for Building**




**(c) Excavation for Pipe**

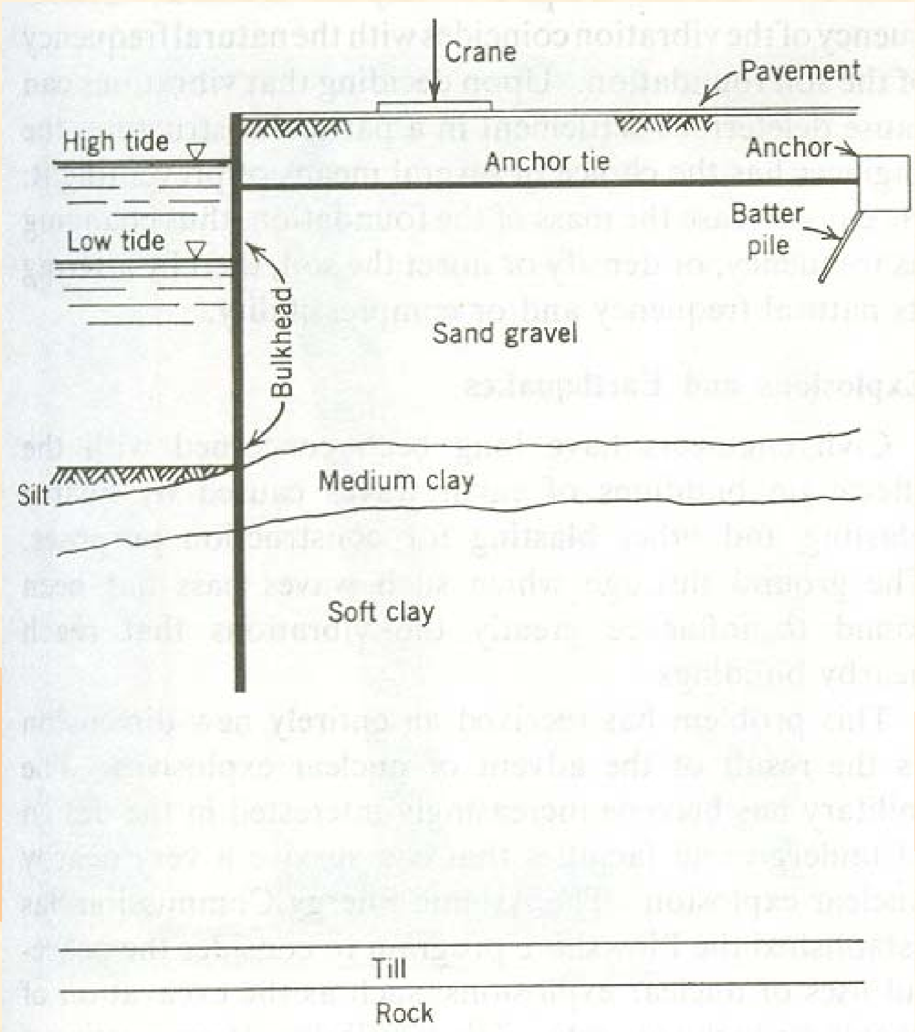



**(d) Canal**

# UNDERGROUND AND EARTH RETAINING STRUCTURES

- Soil-structure interaction
- Examples
  - Pipe shells
  - Basement walls of the building
  - Sheet pile wall
  - Tunnels
  - Drainage structures

# Example of Earth retaining structure

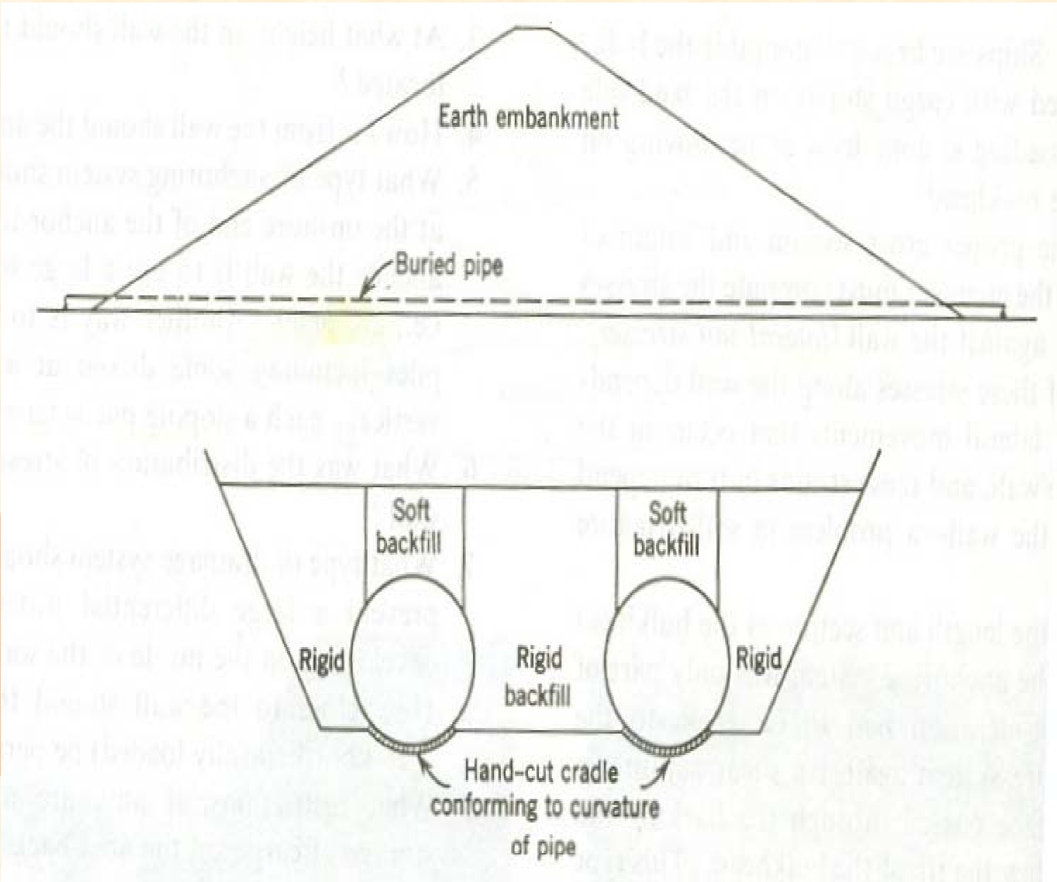



- Anchored bulkhead
- Take care of lateral stresses
- Stability against shear rupture

# Main Factors

1. What type of wall (material and cross section) should be used?
2. How deep must the wall penetrate the foundation soil in order to prevent the wall from kicking out to the left at its base?
3. At what height on the wall should the anchor tie be located?
4. How far from the wall should the anchor tie extend?
5. What type of anchoring system should be employed at the onshore end of the anchor tie? (One way to anchor the wall is to use a large mass of concrete, i.e., *dead man*. Another way is to use a system of piles ;including some driven at a slope with the vertical; such a sloping pile is termed a *batter pile)*
6. What was the distribution of stresses acting on the wall?
7. What type of (drainage system should be installed to prevent a large differential water pressure from developing on the inside of the wall?
8. How close to the wall should the loaded crane (578 kN when fully loaded) be permitted?
9. What restrictions, if any, are necessary on the storage of cargo on the area back of the wall?

# Example of Buried Pipeline




- Flexible and Rigid Pipes
- Failures
  - Faulty construction
  - Excess construction load
  - Sagging of pipe
- Select
  - Proper thickness of the pipe wall
  - Workout and supervise the installation

# SPECIAL PROBLEMS

- Vibrations
- Explosions and earthquakes
- Storage of industrial fluids in earth reservoirs
- Frost
- Regional subsidence

# Oil storage

# Frost Heave

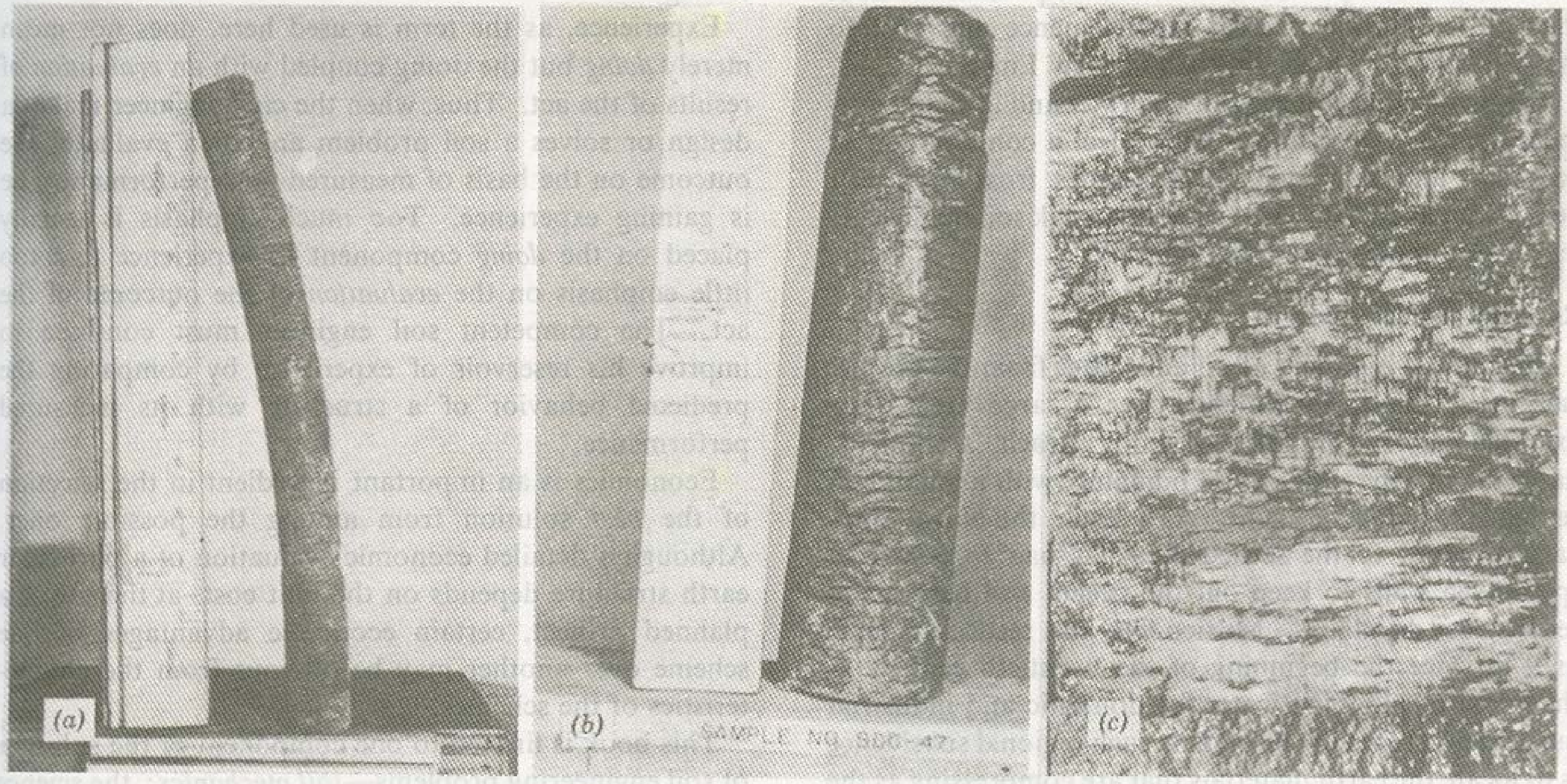



Fig. 1.18 Frost heave. (*a*) Soil sample which heaved from 79 to 320 mm on freezing. (*b*) Soil sample which heaved from 150 to 300 mm on freezing. (*c*) A close view of frozen soil. (Photographs compliments of C. W. Kaplar of U.S. Army CRREL.)

# SOLUTIONS

***SOIL MECHANICS***
***Stress-strain properties Theoretical analyses for soil masses***

***GEOLOGY, EXPLORATION***
***Composition of actual soil masses***

***EXPERIENCE***

***ECONOMICS***

***ENGINEERING JUDGEMENT***

# Why Soil problems are UNIQUE?

1. Soil does not possess a linear or unique stress-strain relationship
2. Soil behavior depends on pressure, time, and environment
3. The soil at essentially every location is different
4. In nearly all cases the mass of soil involved is underground and cannot be seen in its entirety but must be evaluated on the basis of small samples obtained from isolated locations
5. Most soils are very sensitive to disturbance from sampling, and thus the behavior measured by a laboratory test may be unlike that of the *in situ* soil

# *An Overview*

- ***Particulate Nature of Soil***
- ***Nature of Soil Deformation***
- ***Role of Pore Phase***
  - ***Chemical Interaction***
  - ***Physical Interaction***
  - ***Sharing the Load***
- ***A brief look at Consolidation***

# *Particulate Nature of Soil*

- Soil is composed of microscopic or macroscopic discrete particles, which are not strongly bonded together as crystals

- Soil particles are relatively free to move with respect to another, less fluent than the movement of fluid particles

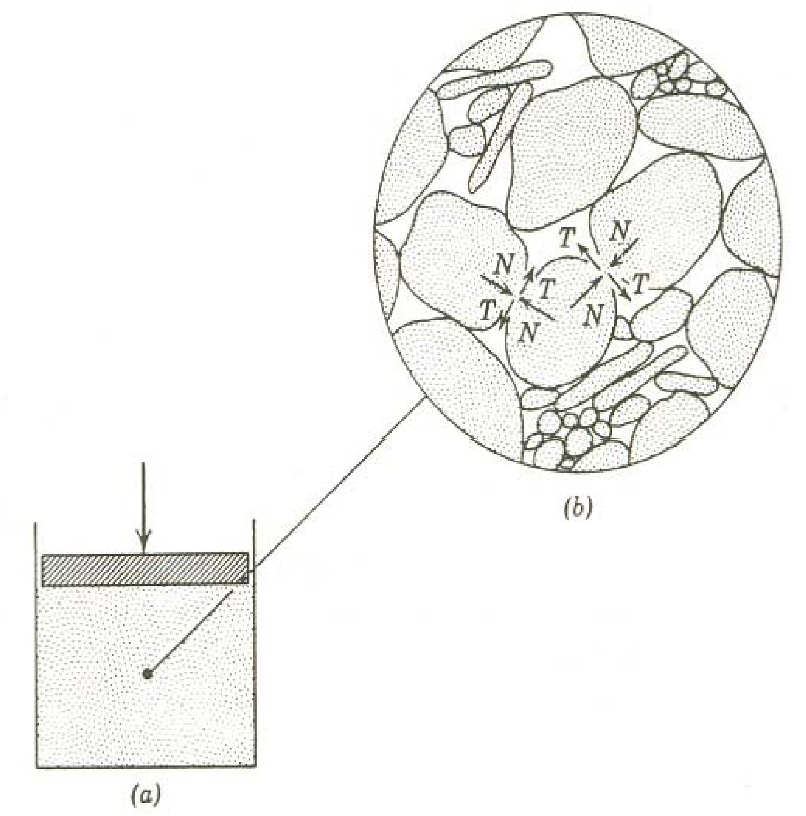
- Particulate system pertains to a system of particles, and the science dealing with the stress-strain behavior of soils is referred as ***Particulate Mechanics***

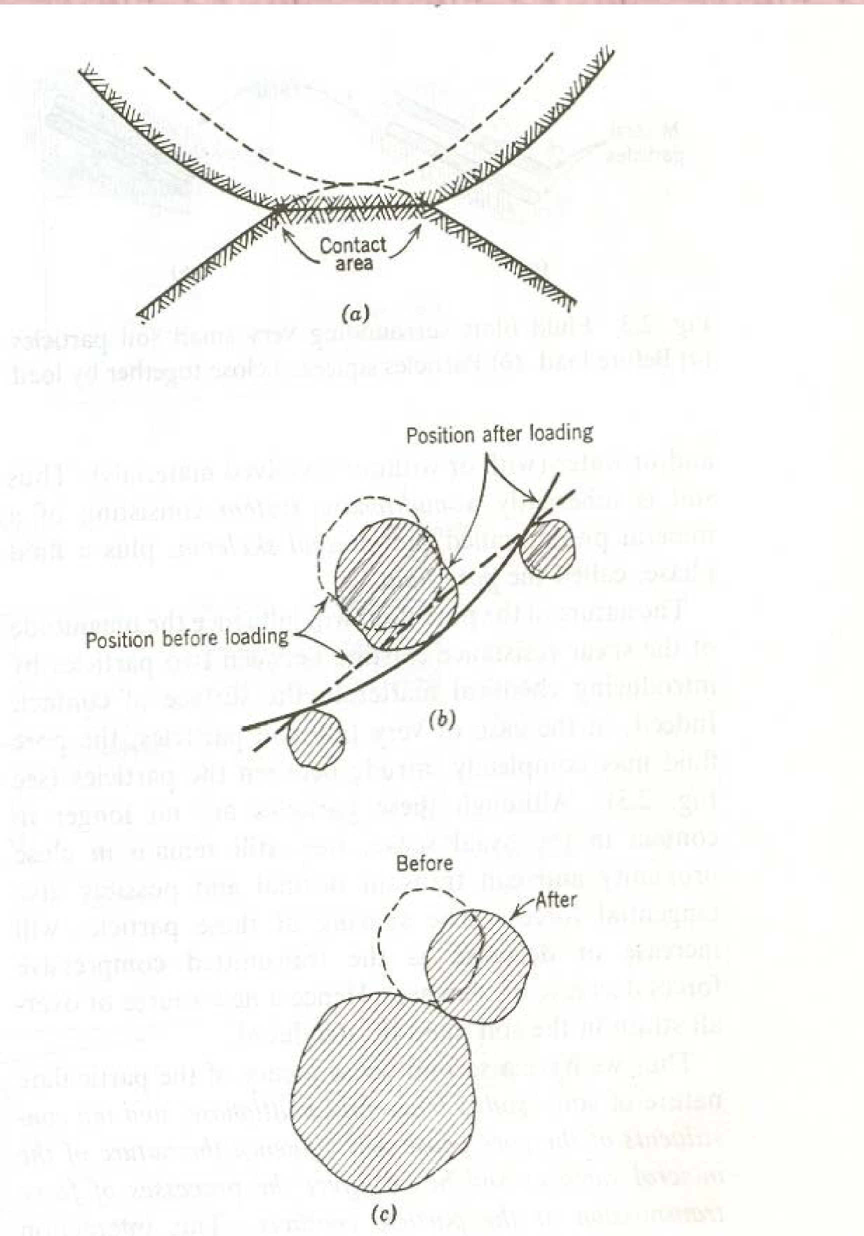
# *Nature of Soil Deformation*

- Contact forces develop due to applied forces

- Contact forces are resolved into normal ***N*** and tangential ***T*** forces

- The usual types of deformation in the vicinity of contact forces
  - ***Elastic strain***
  - ***Plastic strain***
  - ***Particle crushing under high stress***






- Contact area enlarges due to the deformations, and thus the center of the particles come closer ***(Fig. a)***

- Plate like particles bend to allow relative movement between adjacent particles ***(Fig. b)***

- Interparticle sliding occurs when the shear force at the contact surface exceeds the shear resistance of soil particle ***(Fig. c)***

- ***Overall strain of a soil mass*** is the combined effect of particle deformation and interparticle sliding.

- ***Relative sliding of soil particles*** result in rearrangement of soil particles , which is a nonlinear and irreversible phenomena, thus resulting in a non-linear and irreversible stress-strain behavior of soils.

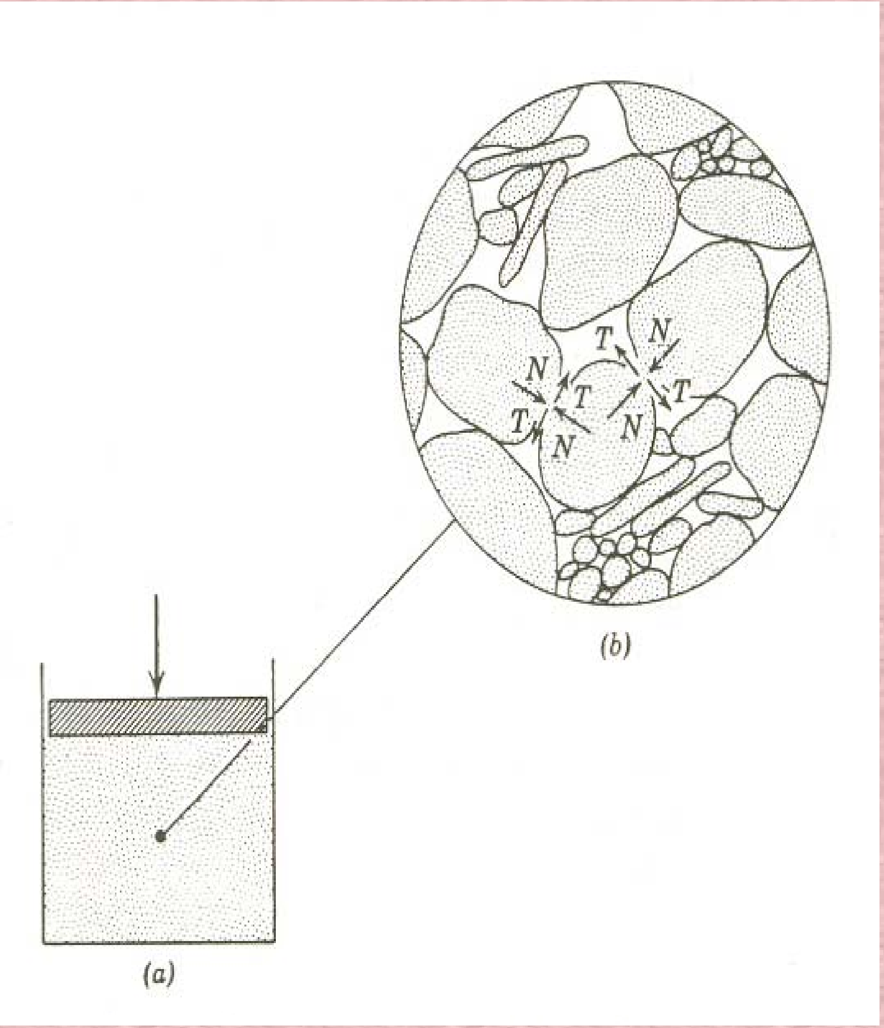
- ***Frictional and adhesion forces*** are also effective in producing particle deformation

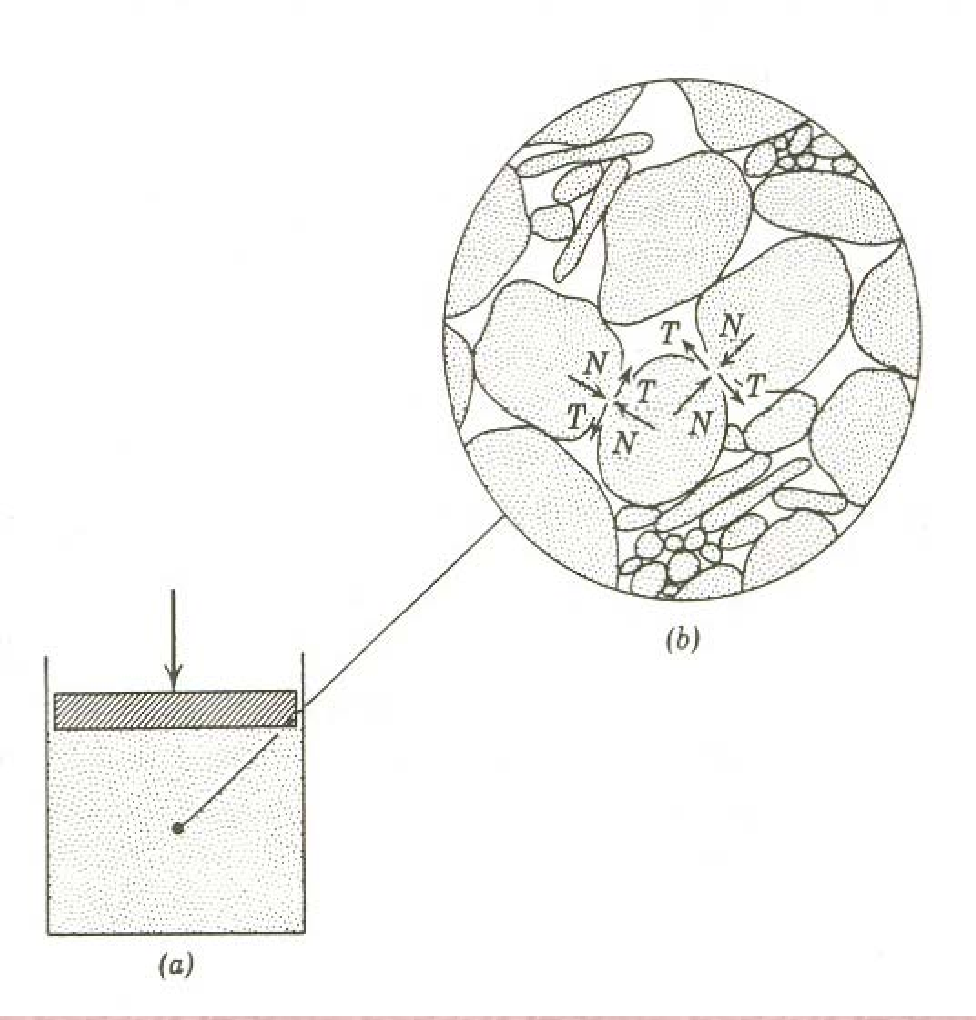
- There are ***5 million contacts within 1 $cm^3$ of sand mass***. Hence, defining stress-strain relation of soil at each of the contacts is impossible, and thus one has to rely on experimental results

- If the box has rigid walls, and the vertical load is increased, the soil particles will nestle closer and closer. This is called ***Volumetric Compression***

- Sliding failure will occur at individual contacts, but the soil mass will not undergo an overall shear failure

- Removal of the load will result in ***Expansion*** or ***Swell*** of soil mass through a reverse process due to rearrangement of particles






• If the box has flexible walls, the entire soil mass will undergo an overall shear failure

• The load at which failure occurs is called the ***Shear Strength of Soil***

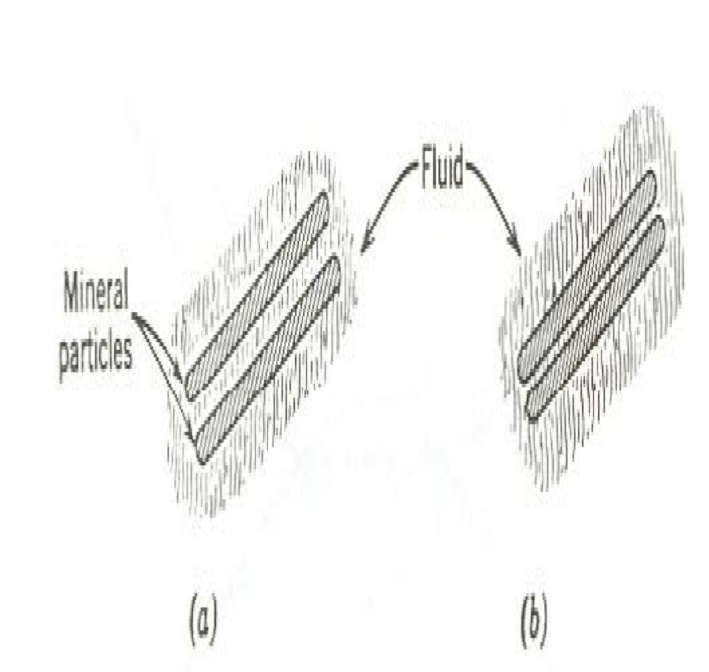
• Shear strength is determined by the resistance to sliding between particles moving laterally to each other

# Role of Pore Phase : Chemical Interaction

- The spaces among the soil particles are called ***Pore Spaces***

- The spaces are usually filled with air and/or water (with or without dissolved matter)

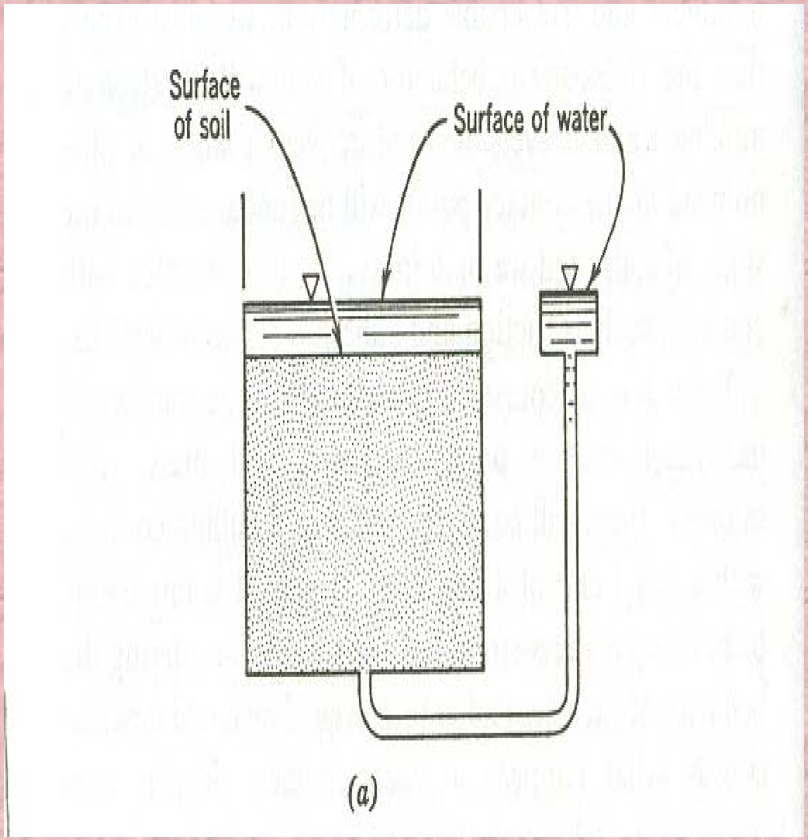
- Soil is a ***Multiphase system***
  - Mineral Phase ***(Mineral Skeleton)***
  - Fluid Phase ***(Pore Fluid)***




- Pore fluid influences the magnitude of the shear resistance existing between two particles by introducing chemical matter to the surface of contact

- Pore fluid intrudes particle spaces and acts in transmission of normal and tangential forces

# Role of Pore Phase : Physical Interaction

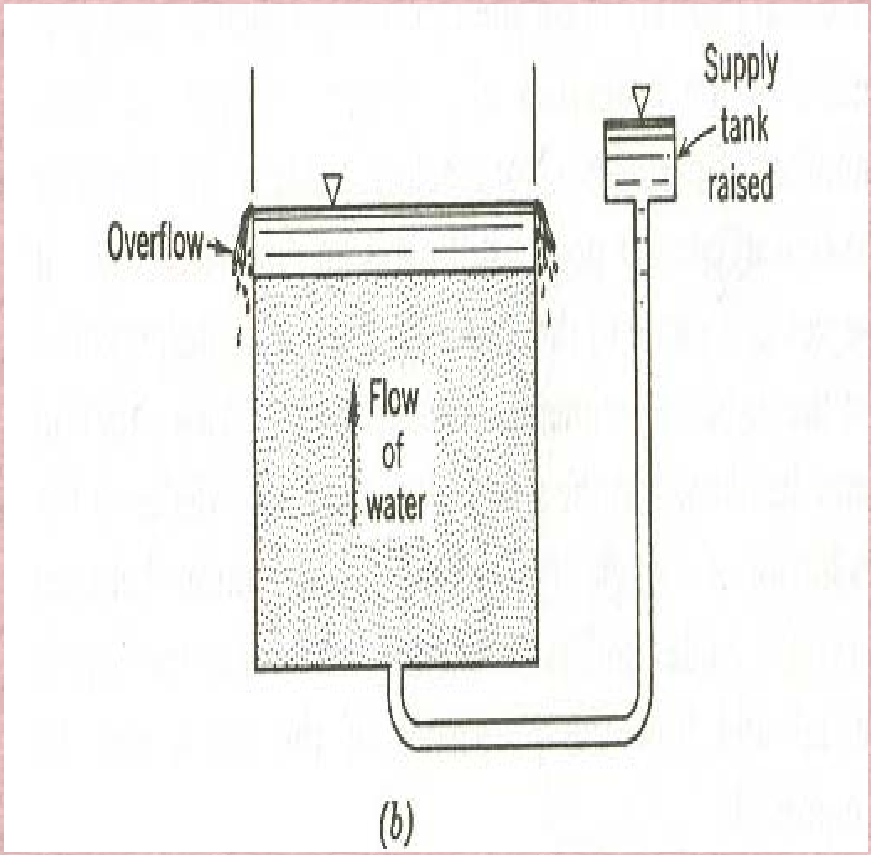


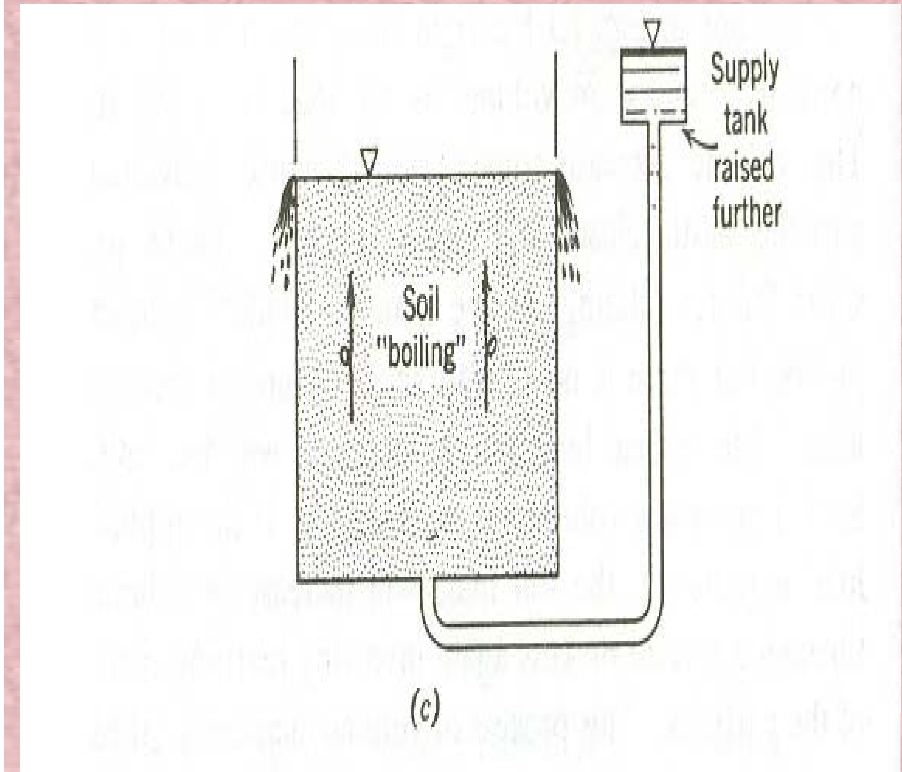

- Hydrostatic condition of water pressure
- The pressure in the pore water at any point is equal to the unit weight of water times the depth of the point below the water surface
- In this case, there is no flow of water

- Water pressure at the base of box is increased, while overflows hold the water surface constant

- Upward flow of water takes place, the amount of which is controlled by excess pressure at base and ***Permeability*** of the soil mass

- The more the permeable a soil, the more water will flow for a given excess pore pressure






- If the excess water pressure at the base is increased, a pressure will be reached where the sand will start to flow upwards along with the upward flowing water

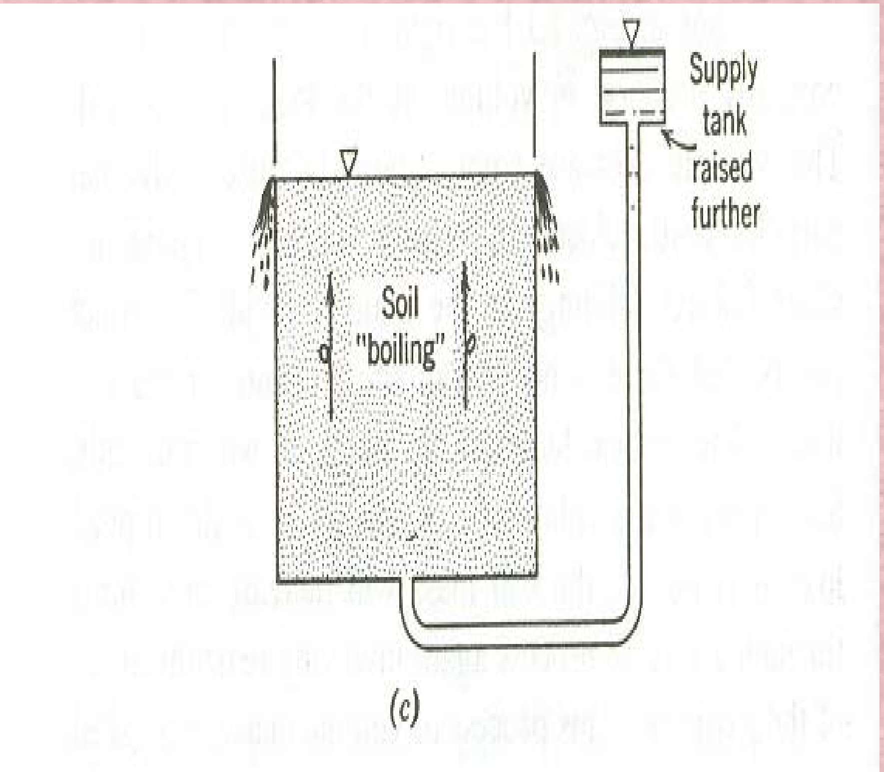
- It is called ***Quicksand condition*** or ***Sand Boiling***

- The soil will occupy greater volume than initial state, and has less shear strength than normal condition

- Changes in volume and shear strength come about due to the changes in contact pressure between the particles

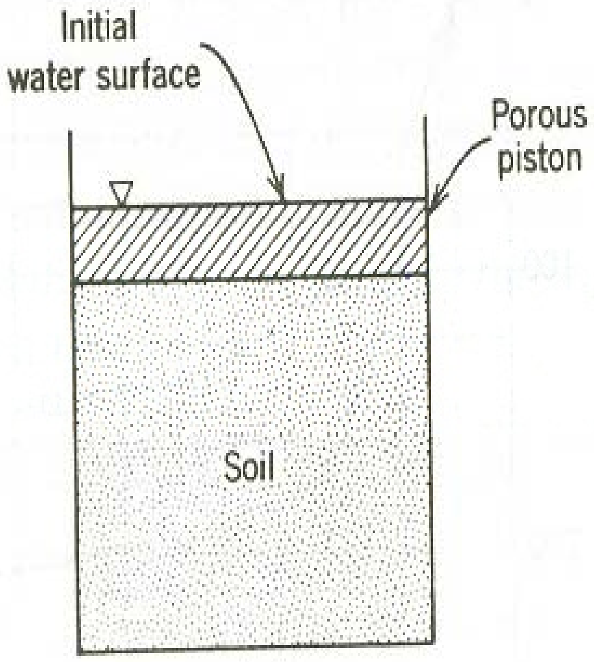
- Contact forces are related to the difference between the stress pressing downward ***(Total Stress) and*** the ***Pore Pressure***

- This difference is defined as the ***Effective Stress***



# *Role of Pore Phase : Sharing the Load*

- As soil is a multiphase system, the load applied to a soil mass would be carried in a part by the ***mineral skeleton*** and partly by the ***pore fluid***
- The sharing of the load is analogous to the partial pressure in gases, and is well simulated by the ***Hydromechanical Model*** for load sharing and consolidation.



(a)

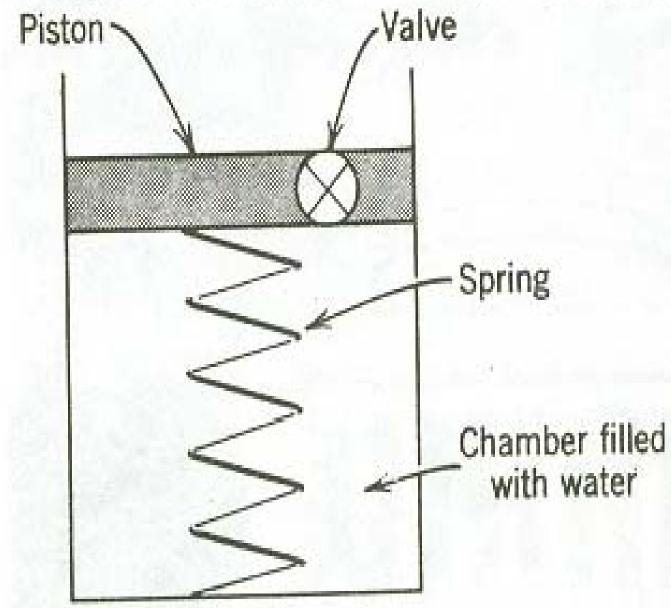
- ***Fig (a)*** shows a cylinder of saturated soil

- The porous piston permits load to be applied to saturated soil and yet permits escape of the fluid from the pores of the soil

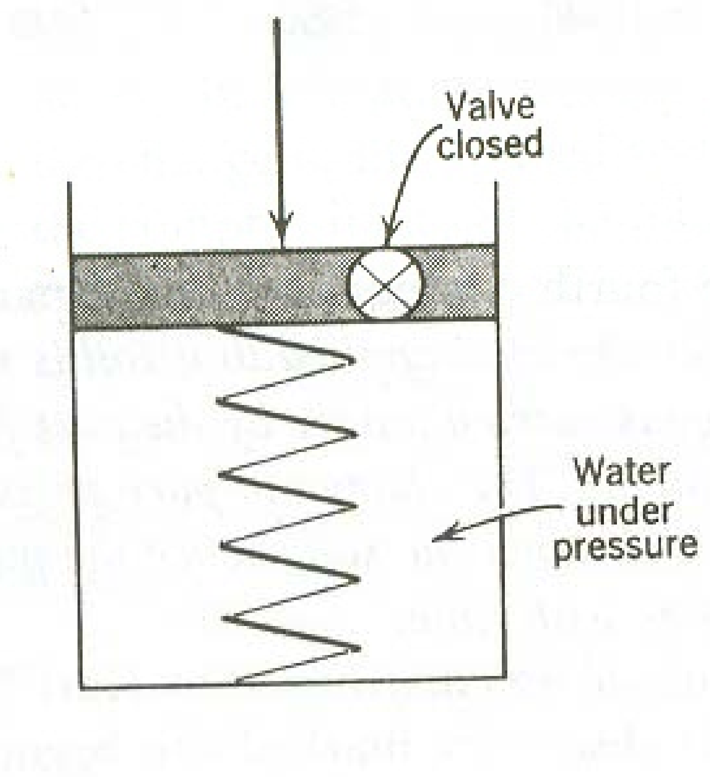
- ***Fig (b)*** shows a hydromechanical analog in which the properties has been lumped

- The resistance of the mineral skeleton to compression is represented by a spring

- The resistance to the flow of water through the soil is represented by a a valve in an otherwise impermeable piston




(b)



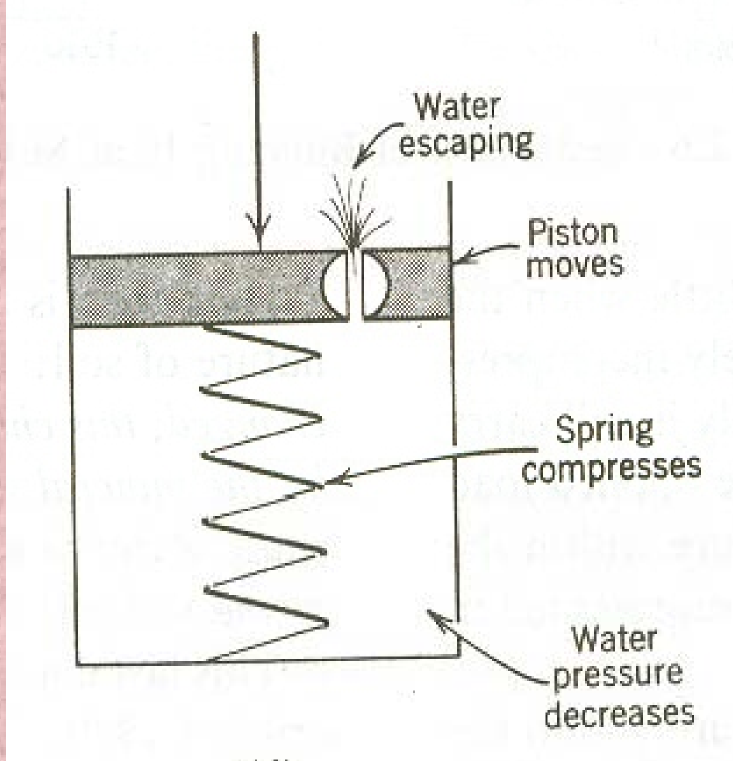
(c)

- ***Fig (c)*** represents a load applied to the piston of the hydromechanical analog but the valve is kept closed
- The piston load is apportioned by the water and the spring
- The piston will be moved very little as the water is nearly incompressble. The spring shortens very slightly as it carries a very little load
- Essentially all of the applied load is resisted by an increase in the fluid pressure within the chamber

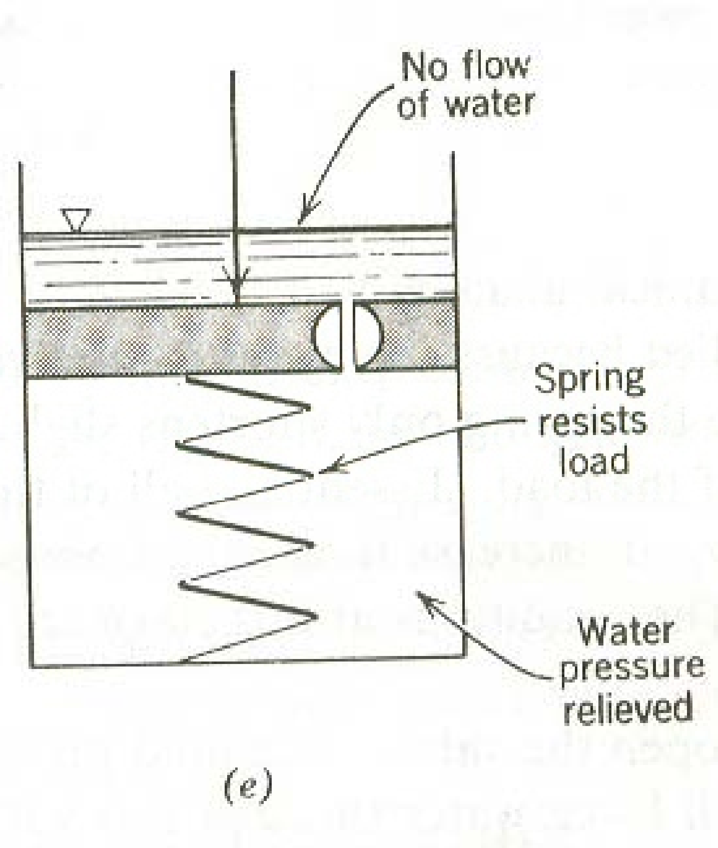
- ***Fig (d)*** shows the valve to be opened

- As water escapes, the spring shortens and begins to carry a significant fraction of the load applied

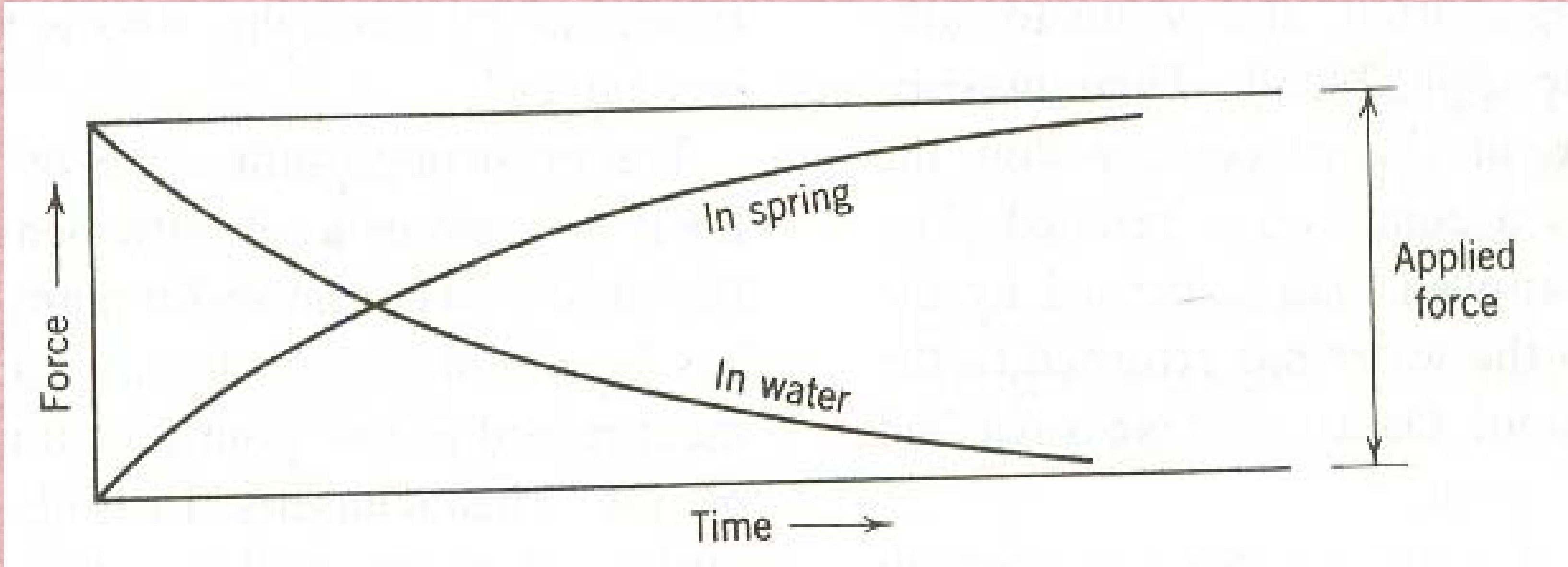
- There is a corresponding decrease in pressure in the chamber fluid



(d)




- ***Fig (e)*** shows a condition in which all the applied load is carried by the spring
- The pressure in the water has returned to the original hydrostatic condition
- Now, there is no further flow of water



(f)

- A limited amount of water can flow out through the valve at any interval of time

- The process of transferring load from water to the spring is a gradual process, which is shown in ***Fig (f)***

- This process of gradual squeezing out of water from the pore spaces of soil mass is call ***Consolidation***

- The time interval involved in the above mentioned phenomena is called ***Hydrodynamic Time Lag***

- The amount of compression that has occurred at any time is related to the applied load and also to the amount of stress transmitted at the particle contacts i.e. to the difference between the applied stress and the pore pressure. This difference gives the concept of ***Effective Stress***

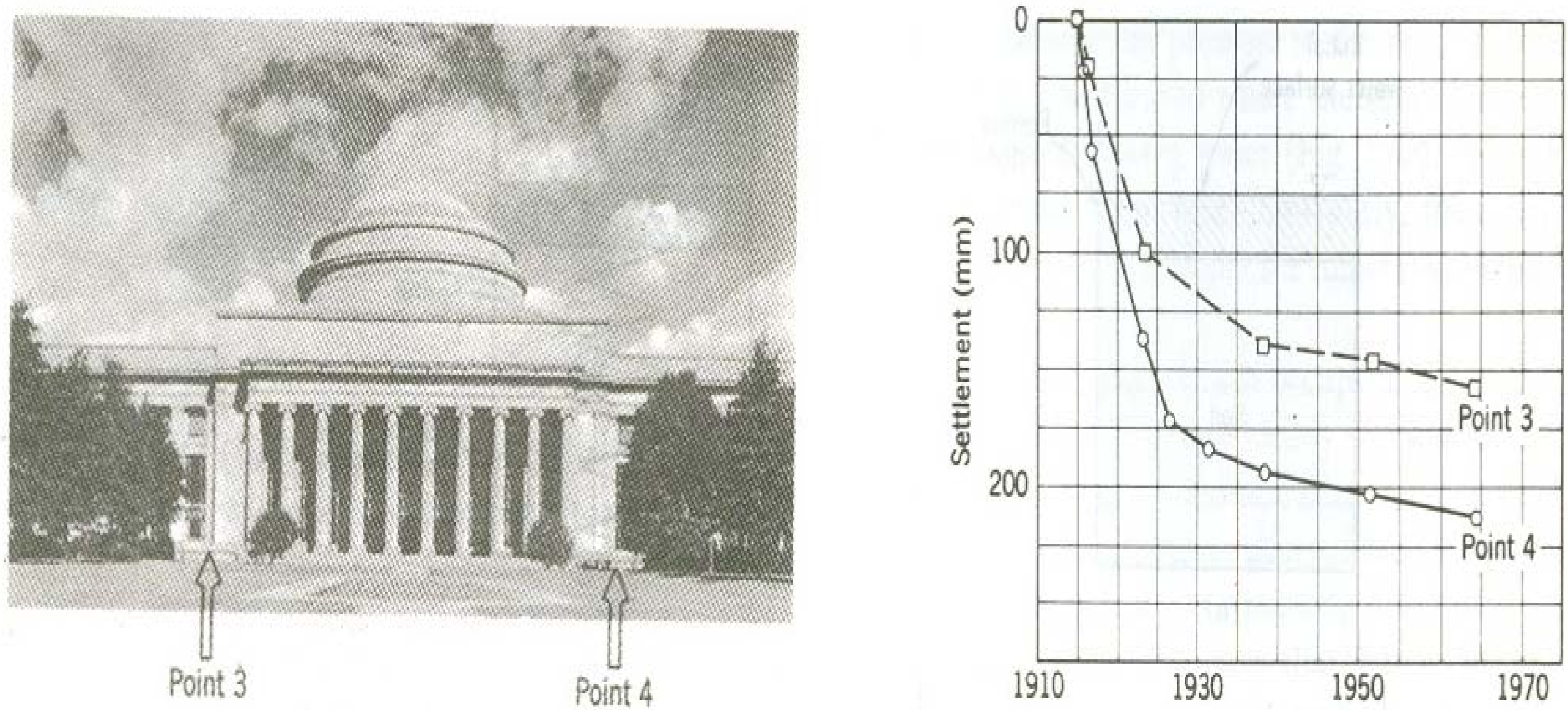



Fig. 2.6 Settlement of Building 10 at M.I.T.

- The most important effect of Hydrodynamic Time Lag is the delayed settlement of structures

# ***Consolidation***

- The time required for consolidation process is related to ::

  - The time should be directly proportional to the volume of water squeezed out of the soil. The volume of water is related to the product of stress change, the compressibility of the mineral skeleton, and the volume of the soil

  - The time should be inversely proportional to how fast the water can flow through the soil. The velocity of flow is related to the product of the permeability and the hydraulic gradient. The gradient is proportional to the fluid pressure lost within the soil divided by the distance of the flow path of the fluid.

$$t \propto \frac{(\Delta\sigma)(m)(H)}{(k)(\Delta\sigma / H)}$$

where,

- ***t* =** The time required to complete some percentage of consolidation process
- **Δσ** = The change in the applied stress
- ***m* =** The compressibility of the mineral skeleton
- ***H*** = The thickness of the soil mass (per drainage surface)
- ***k*** = The permeability of the soil

The time required to reach a specified stage in the consolidation process is given by ::

$$t \propto \frac{mH^2}{k}$$

The above relation suggests that the consolidation time :

- ❖ Increases with increasing compressibility
- ❖ Decreases with increasing permeability
- ❖ Increases rapidly with increasing size of soil mass
- ❖ Is independent of the magnitude of the stress change

- ➢ Soils with significant clay content requires long time for consolidation – from one year to many hundreds of years
- ➢ Coarse granular soils consolidates very quickly, in a matter of minutes

# *Consequences of Particulate Nature of Soils*

# 1st Consequence

The deformation of a mass of soil is controlled by interactions between individual particles, especially by sliding between particles

# *$2^{nd}$ Consequence*

Soil is inherently multiphase, and the constituents of the pore phase will influence the nature of the mineral surfaces and hence affect the processes of force transmission at the particle contacts

# 3rd Consequence

Water can flow through the soil and thus interact with the mineral skeleton, altering the magnitude of the forces at the contacts between particles and influencing the compression and shear resistance of the soil

# $4^{th}$ Consequence

When the load applied to a soil is suddenly changed, the change is carried by jointly by the pore fluid and by the mineral skeleton. The change in pore pressure will cause water to move through the soil, hence the properties of the soil will change with time

- *Consolidation Theory*
- *Foundation Design and Construction*
- *Cofferdam analysis*
- *Landslide Mechanisms*

*Famous Book*

**From Theory to Practice in Soil Mechanics**

# KARL VON TERZAGHI

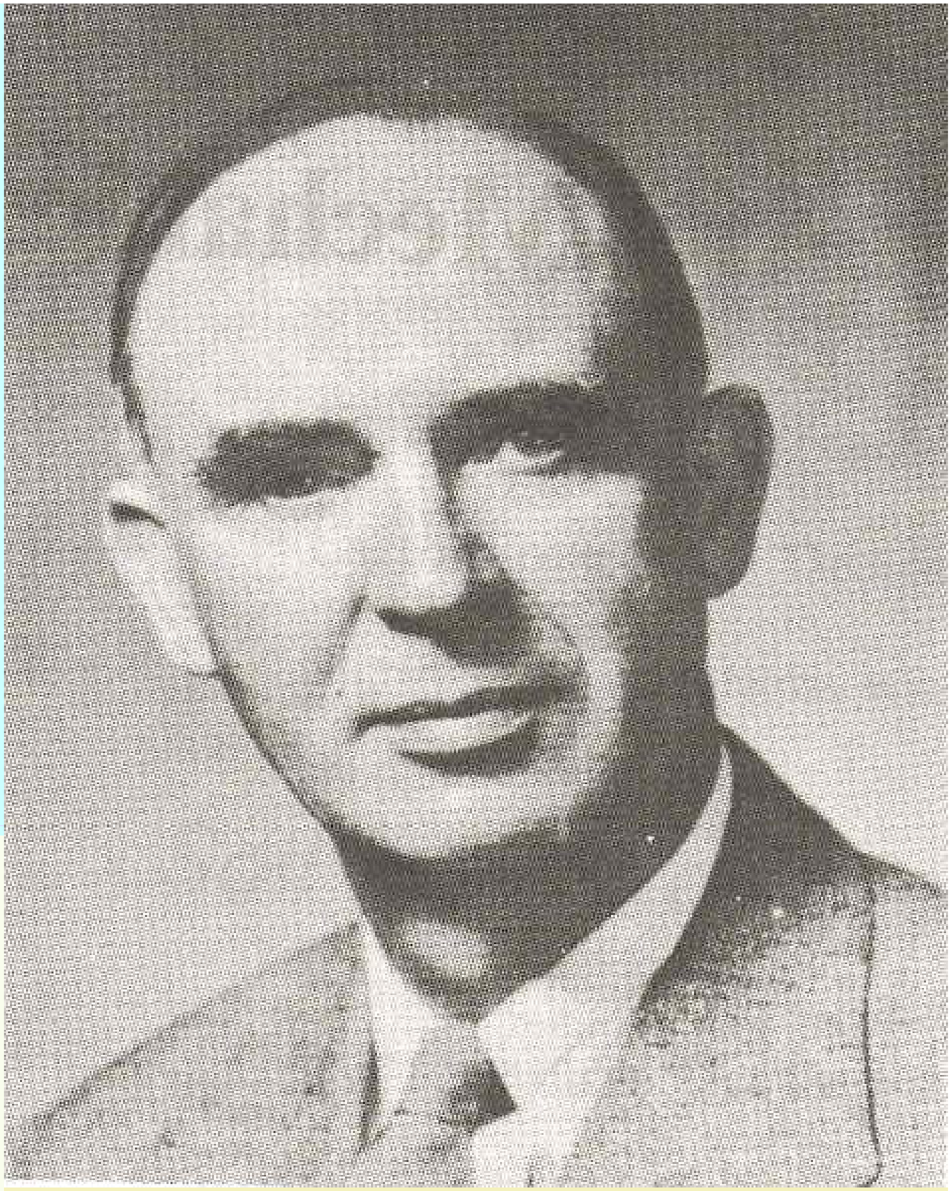
**(1883 - 1963)**

Father of Soil Mechanics

- *Fundamentals of soil mechanics.*
- *Consolidation*
- *Shear strength of cohesive soils*
- *Stability of earth slopes*

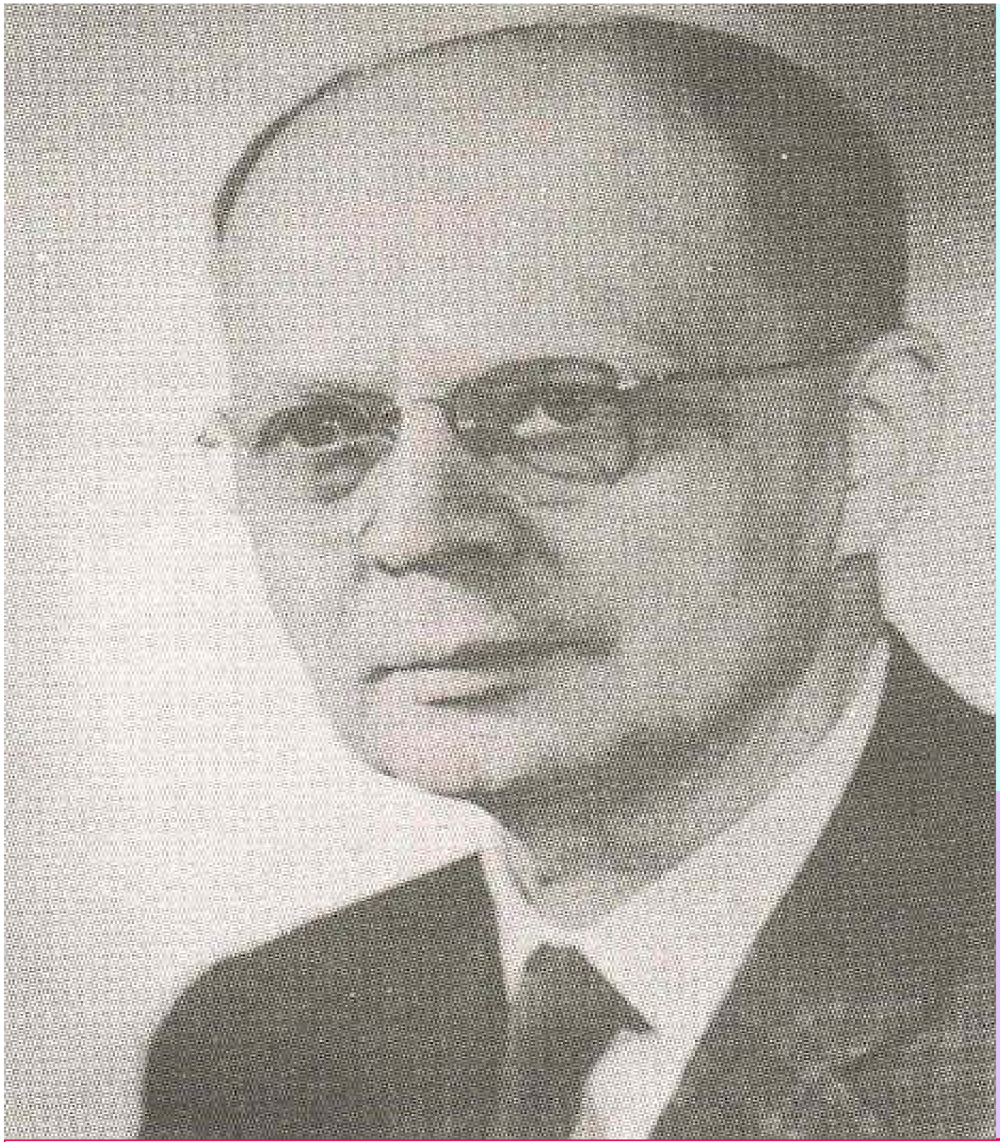
*Famous Book*

**Fundamentals of Soil Mechanics**



DONALD WOOD TAYLOR

**(1900 - 1955)**



- *Soil Classification*
- *Seepage through earth structures*
- *Shear Strength*

**Best Teacher in The Harvard University**

ARTHUR CASAGRANDE

**(1902 - 1981)**

- *Application of soil mechanics to design and construction*
- *Evaluation and presentation of the results of research in form suitable for ready use by the practicing engineer*

<u>*Famous Book*</u>

**Soil Mechanics in Engineering Practice**

RALPH BRAZELTON PECK **(1912 - )**

- *Fundamentals of effective stress*
- *Pore pressures in clays*
- *Bearing capacity*
- *Slope stability*

**Best Teacher in The Imperial College in The University of London**

ALEC WESTLEY SKEMPTON

**(1914 – 2001)**

- *Fundamentals of shear strength*
- *Sensitivity of clays*
- *Stability of natural slopes*

**Best Teacher and the First Director in The Norwegian Geotechnical Institute**

# LAURITS BJERRUM

**(1918 – 1973)**

- *Concepts of Active and Passive Earth Pressure*
- *Concept of Friction*
- *Coined the term "Cohesion"*

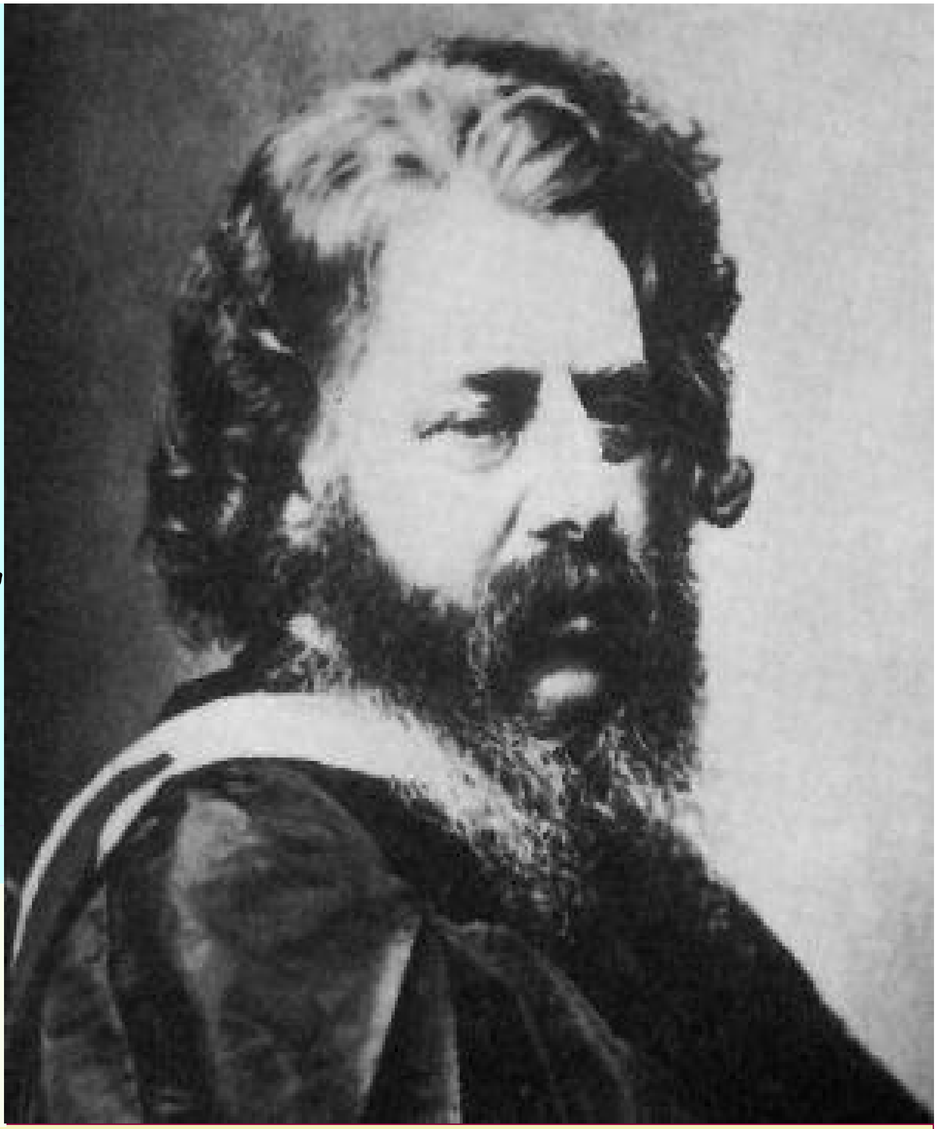
**Addressed the Academy of Science (Paris, 1773) presenting a modest "essay on the application of the rules of maxima and minima to certain statics problems relevant to architecture**

# CHARLES AUGUSTIN DE COULOMB

**(1736 - 1806)**

Grandfather of Soil Mechanics

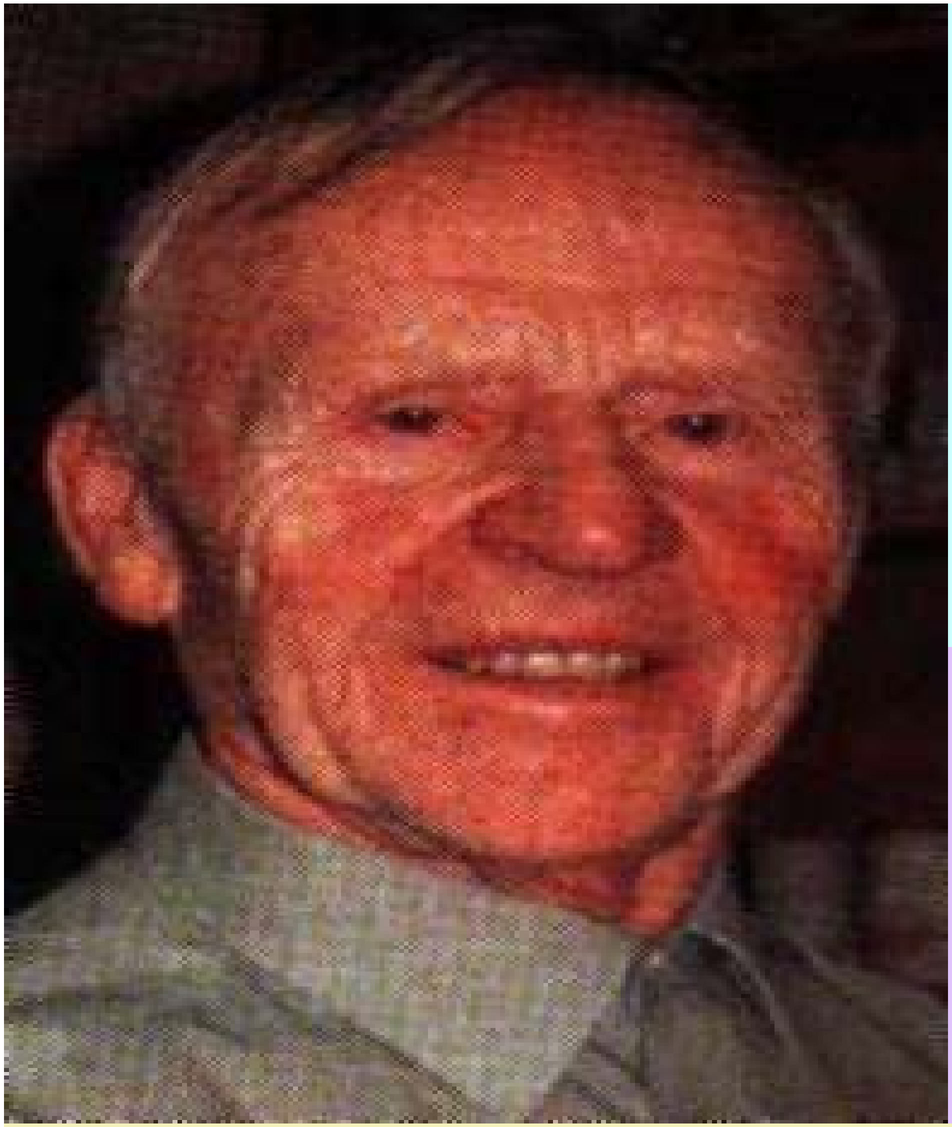
- *Active and Passive Earth Pressure theories*



**Pioneer with a determination**

WILLIAM JOHN MAQUORN RANKINE

**(1820 - 1872)**



- *Concepts in Slope Stability Analysis*

**Geotechnical professor emeritus at the Norwegian Technical University, Trondheim, Norway**

NILMAR JANBU

**(1920 - )**

*PIONEERING CONTRIBUTIONS on*

- *Strength and compressibility of compacted clay soils*
- *Strength and consolidation of natural deposits of soft clay*
- *Cracking of earth dams*
- *Frost action*
- *Flexible and rigid pavement design*
- *Analysis of buried conduits*
- *Pile foundations, stability of slopes and embankments on soft clays*
- *Stress-deformation and liquefaction of sand, and methodologies for investigating failures*

# GERALD A. LEONARDS

**(1921 – 1997)**

1. *Engineer of the Year (Georgia Society of Professional Engineers), 1973*
2. *The Herschel Prize (The Boston Society of Civil Engineers), 1976*
3. *The ASCE Middlebrooks Award, 1977*
4. *The Terzaghi Lecture, 1979*
5. *The ASCE Martin Kapp Lecture in New York, 1985*
6. *The Brooks Award, 1990*
7. *Elected to The National Academy of Engineering, 1994*
8. *The ASCE Middlebrooks Award, 1994*
9. *ASCE Forensic Engineer of the Year Award, 1994*
10. *The ASCE Terzaghi Award, 1995*

**Heck of an Engineer &**

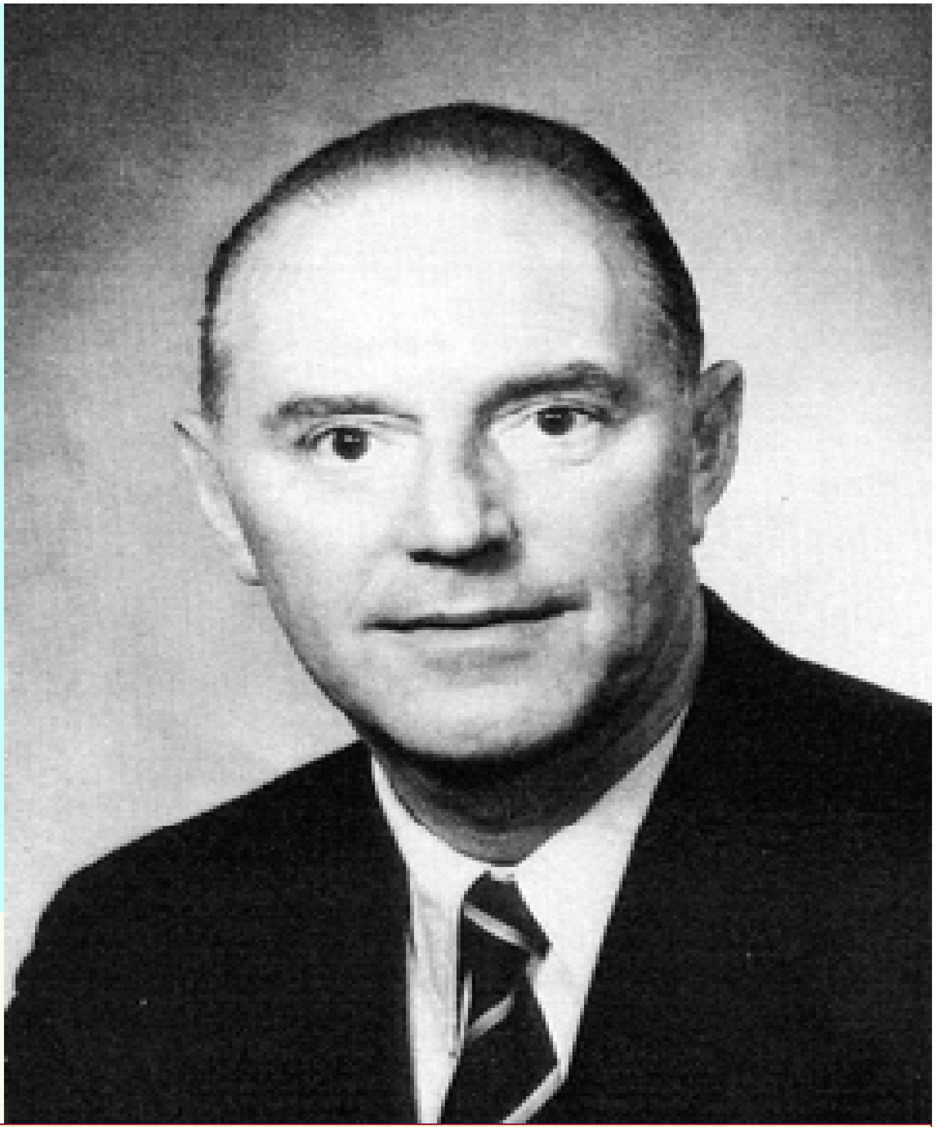
**A Master of Anecdotes**

# GEORGE F. SOWERS

**(1921 - 1996)**

- *Mechanics of Pile Foundations and Soil-Pile Interaction Analysis*
- *Soil Compaction*
- *Analytical Methods in Pavement Design*
- *Analytical and experimental techniques of earthquake engineering*

**Father of Geotechnical Earthquake Engineering**



HARRY BOLTON SEED

***August 19, 1922 — April 23, 1989***

- *Appropriate methods of calculation for Seismic Design of Foundations*
- *free Torsion Vibrating Pendulum to determine the dynamical properties of soil*
- *Resonance period of the subsoil*
- *Coastal Engineering and Dewatering System*
- *Highly compressible soils*

***Famous Book***

**Foundation Engineering for Difficult Subsoil Conditions**

LEONARDO ZEEVAERT WIECHERS

# Thank You