# GEOTECHNIC FOR INFRASTRUCTURE

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# This presentation includes

1. Introduction to Geotechnics
2. Case Studies of a few typical failures
3. Basic Definitions
4. Classification of soil
5. Compaction
6. Relevance of Soil exploration
7. Important geotechnical structures
8. Foundations and types
9. Ground Improvement Techniques

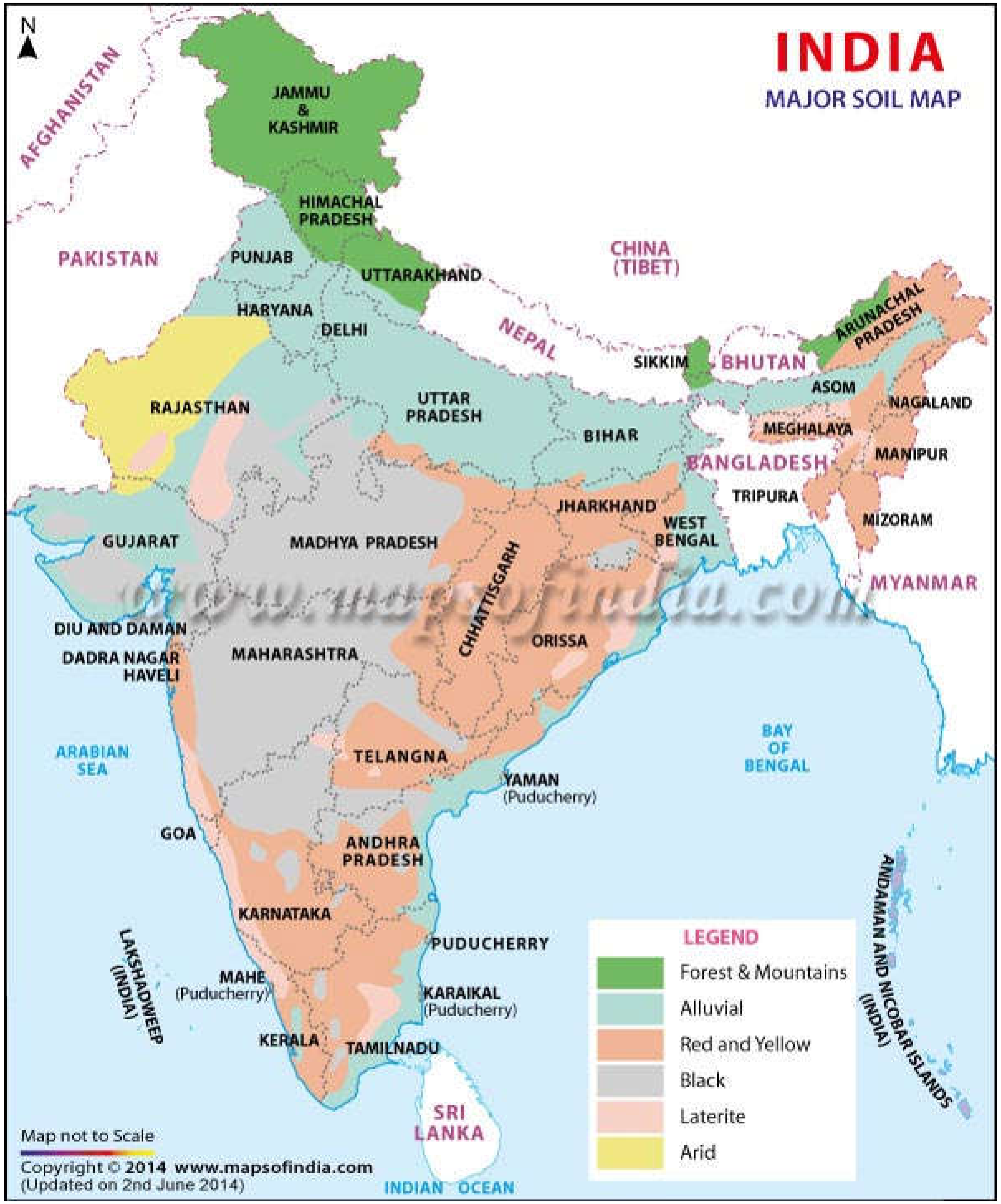
# Introduction to Geotechnics

**Soil is the most common, useful and least expensive construction material. Every structure should be built on it. Hence, it is most important for Civil Engineers.**

# Use of Soil in Civil Engineering Practice

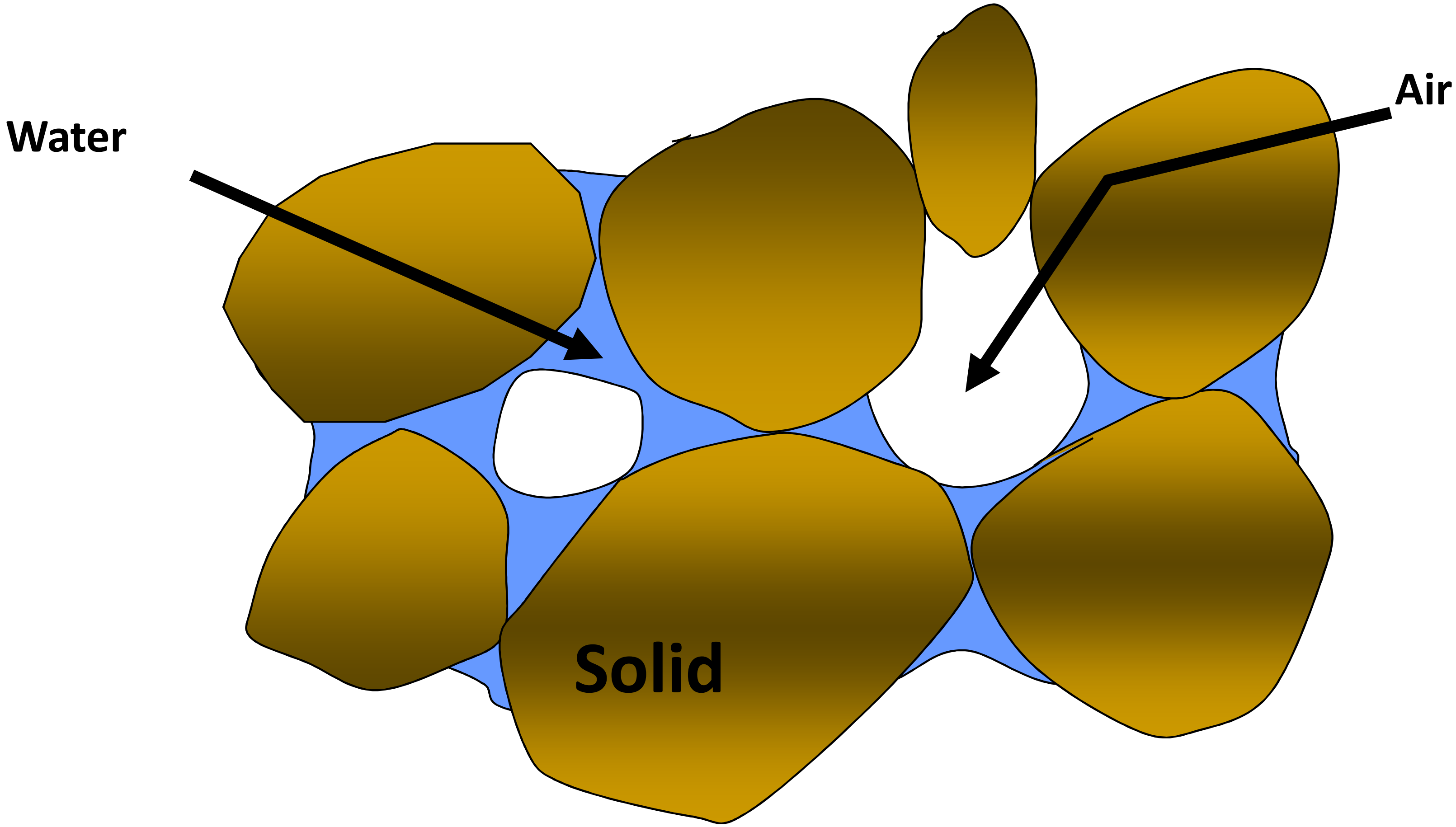
- Construction material (earth dam, embankments)
- Manufacture of bricks, tiles, earthenware
- Fill material behind retaining walls, abutments
- Foundation material
- Impermeable barrier

# Treacherous Soils in India




- Marine Clay
- Alluvial Soil
- Desert Sand
- Expansive soil
- Lateritic Soil
- Loose silt

# Typical Soil Mass as observed microscopically



# Why soil is complex ?

## Yet, Interesting

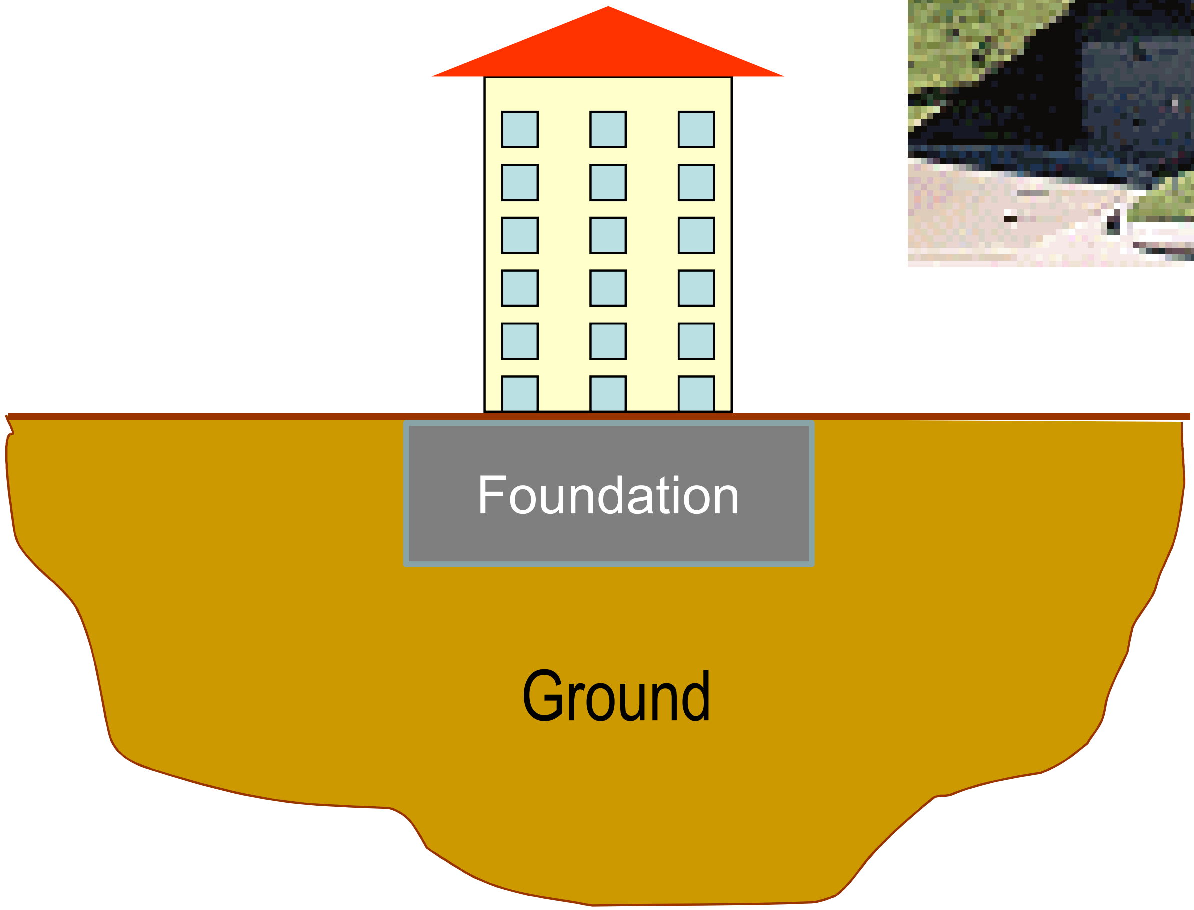
Colorful
Sensitive
Possesses Memory
Changes its properties with time

Porous
Polyphasic
Permeable
Particulate
Heterogeneous
Anisotropic
Non-Linear
Pressure Level Dependent
Strain Level Dependent
Strain Rate Dependent
Temperature Dependent
Undergoes volume change in shear

# Infrastructure & Civil Engineering

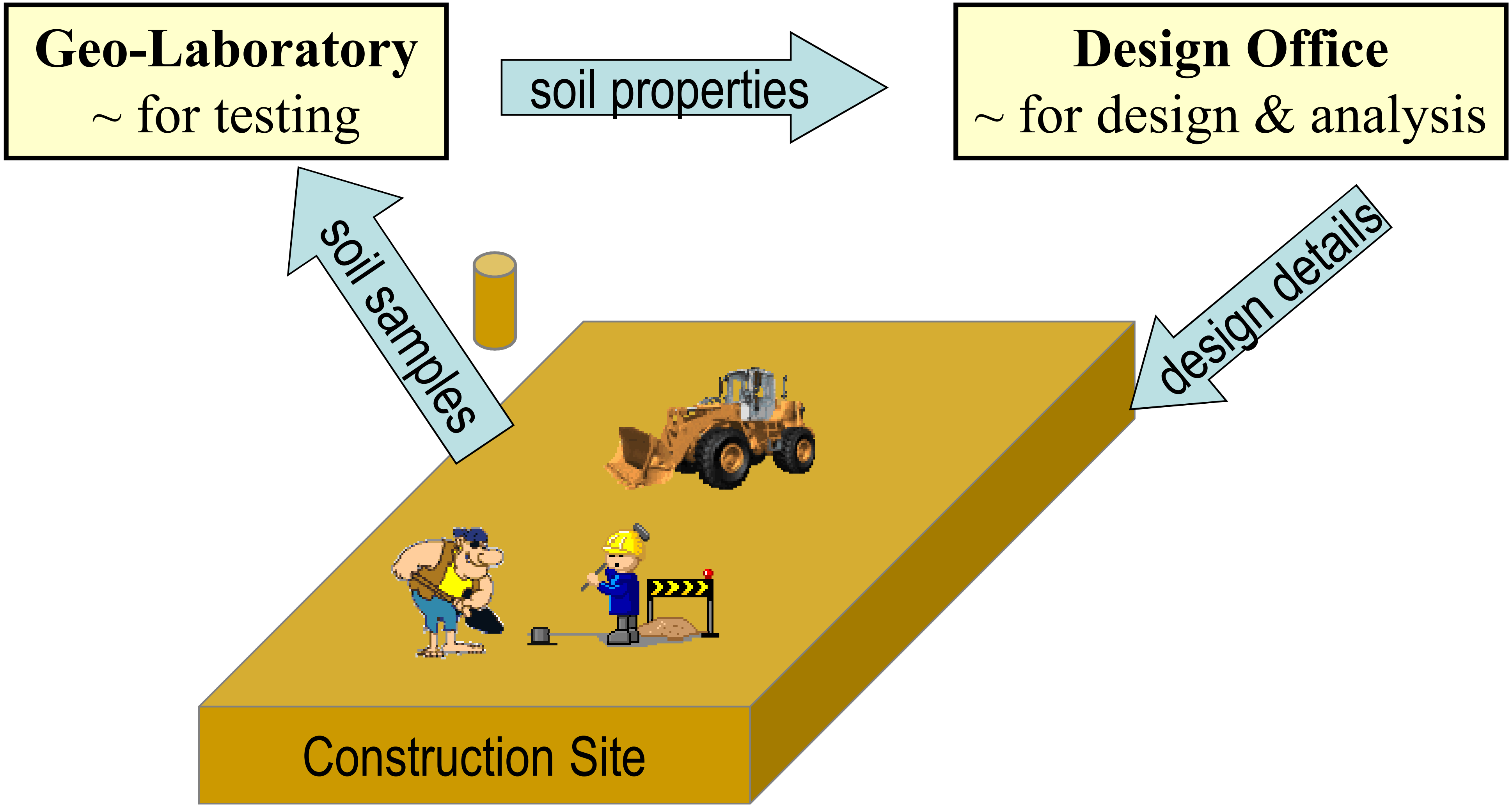
1. Name any facility, CIVIL ENGINEERS are the first to arrive.
2. No structure can be built in AIR (as of now).
3. Geotechnical Engineers are the most essential & construction begins with them.

# Geotechnic for Infrastructure

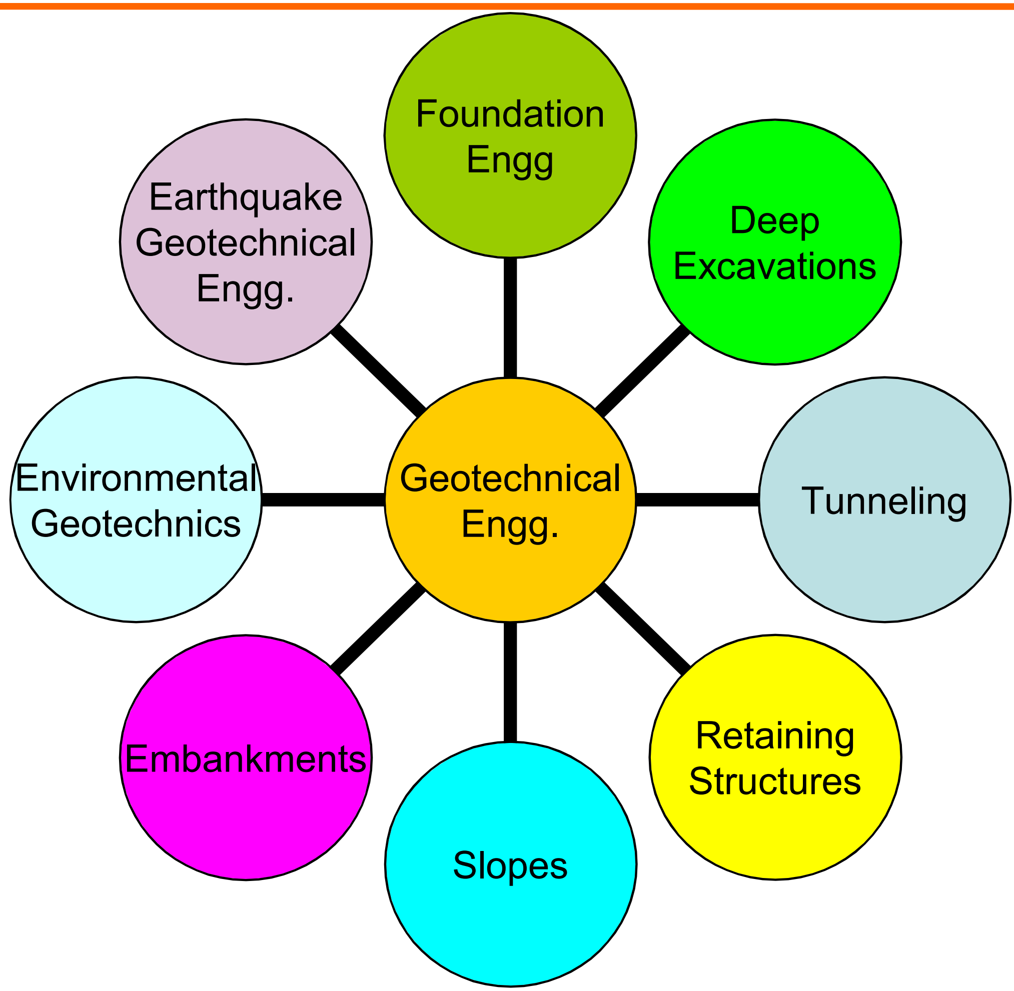



- Foundation
- Retaining Wall
- Earth / Rockfill Dam
- Embankment
- Canal
- Road
- Sloping ground
- Tunnel
- Landfill

# Typical Geotechnical Project



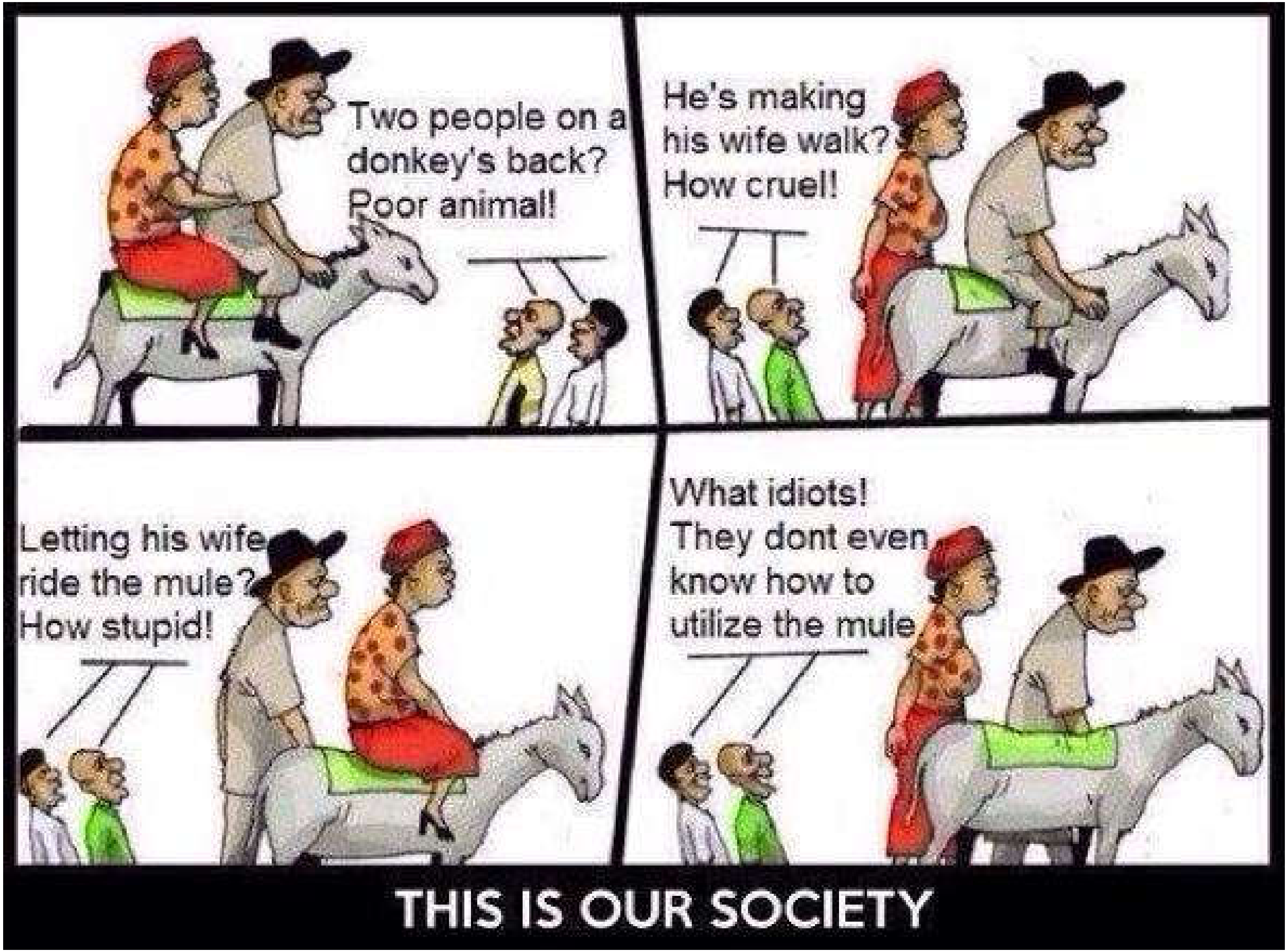
# Family of Geotechnical Engineering



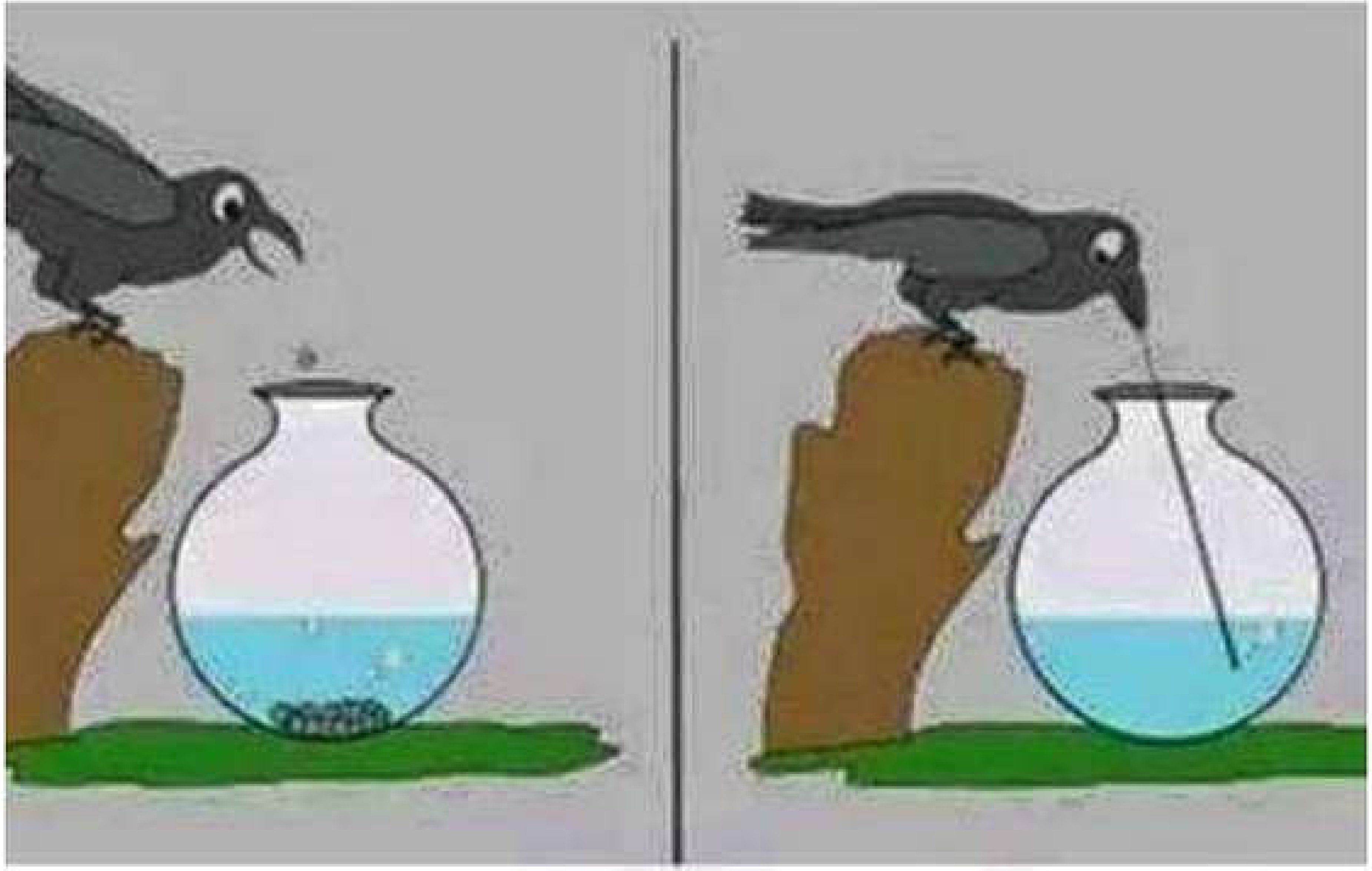

+

- Earth & Rockfill dams
- Ground Improvement Technique
- Reinforced Earth Structure & Geotextiles
- Soil Investigation / Exploration
- Many others

## You do anything, people do not recognize, they even criticize. Do those things which bring you pride



Old crow. Modern crow.



**Keep upgrading your skills.**

# CV650: Applied Geotechnical Engineering Syllabus

| Chapter | Title |
|---|---|
| 1 | STRESSES IN SOIL |
| 2 | FLOWNETS |
| 3 | LATERAL EARTH PRESSURE |
| 4 | STABILITY OF EARTH SLOPES |
| 5 | BEARING CAPACITY & SETTLEMENT |
| 6 | DEEP EXCAVATION |

# Self Learning component

1. Applications of GEOSTUDIO for solving geotechnical problems

2. Case studies of geotechnical failures

# Expected Course Outcomes

| CO | The student has the ability to |
|---|---|
| 1 | determine the stresses in soils using various approaches & to understand deep excavations |
| 2 | draw phreatic lines in earth dams and flownets |
| 3 | compute lateral earth pressure using different methods |
| 4 | analyse the stability of earth slopes |
| 5 | compute the bearing capacity of soils and determine foundation settlements |

# Continuous Internal Evaluation

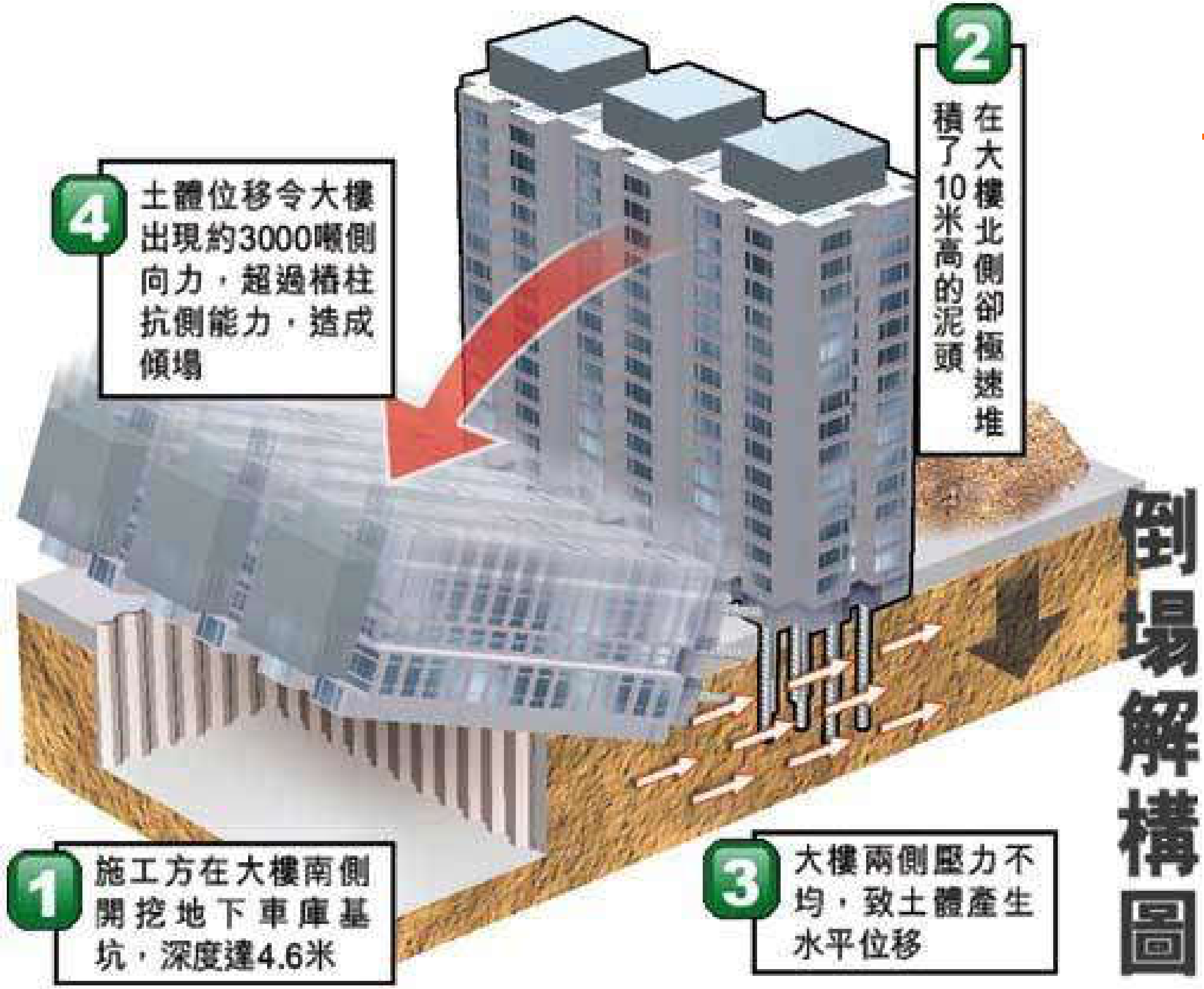
| EVENT | Description & Dates |
|---|---|
| 1 | CO5: Bearing Capacity & Settlement |
| 2 | CO3 : Lateral Earth Pressure |
| 3 | CO4: Stability of Slopes |
| 4 | General short answer question on all COs |
| 5 | CO1 & CO2 : Flownets & Stresses |

# Case Study 1
# Shangai Building Collapse

# Shangai Building Collapse

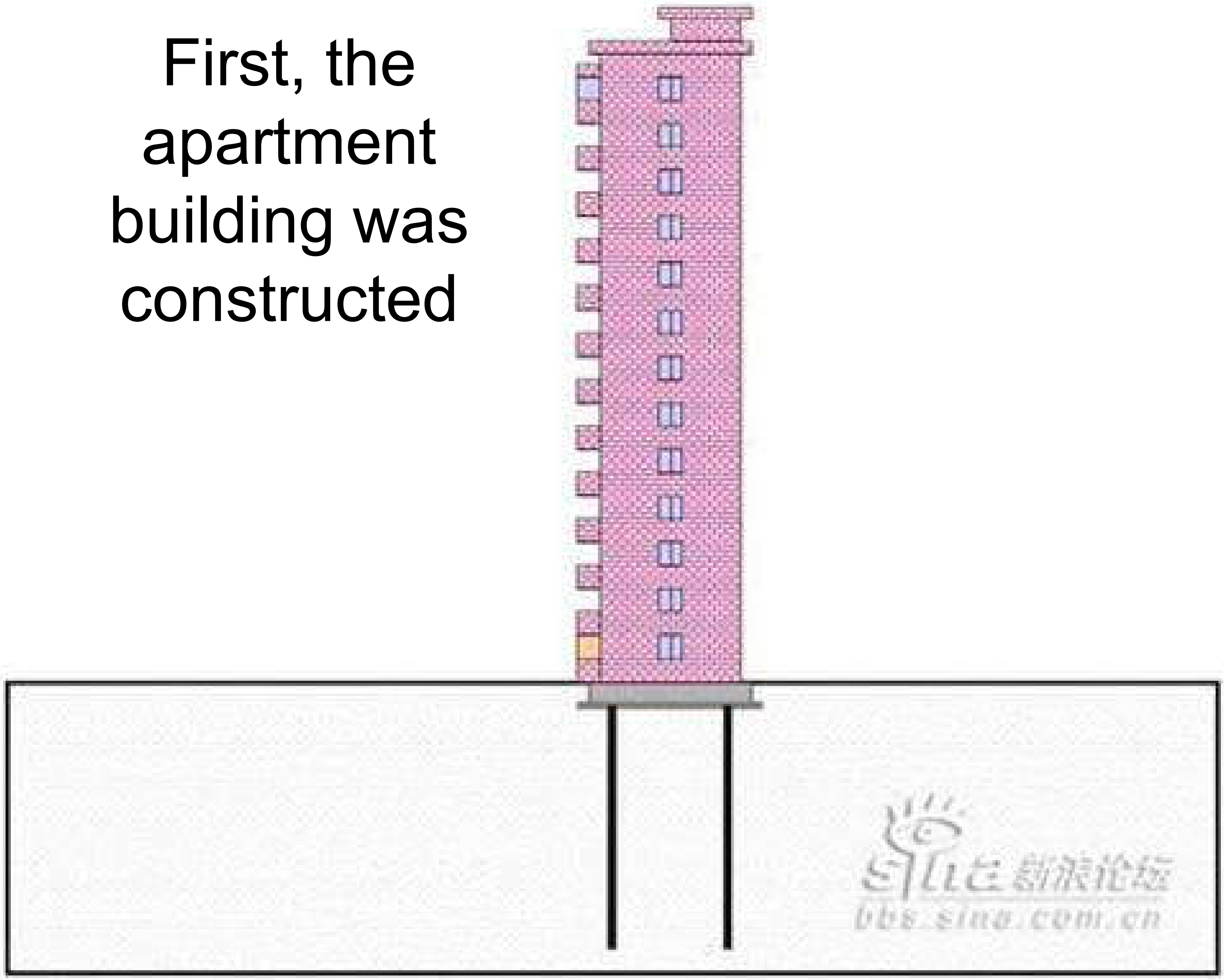
- At 5:30am 27th June 2009, an unoccupied building still under construction at Lianhuanan Road in Minhang district of Shanghai toppled.
- One worker was killed.
- A 70m section of flood prevention wall in nearby Dianpu River had suffered some cracks.
- Special geological condition in water bank area may have increased vulnerability.
- But, these factors are not the basic reasons for this accident.

Shangai Building Collapse

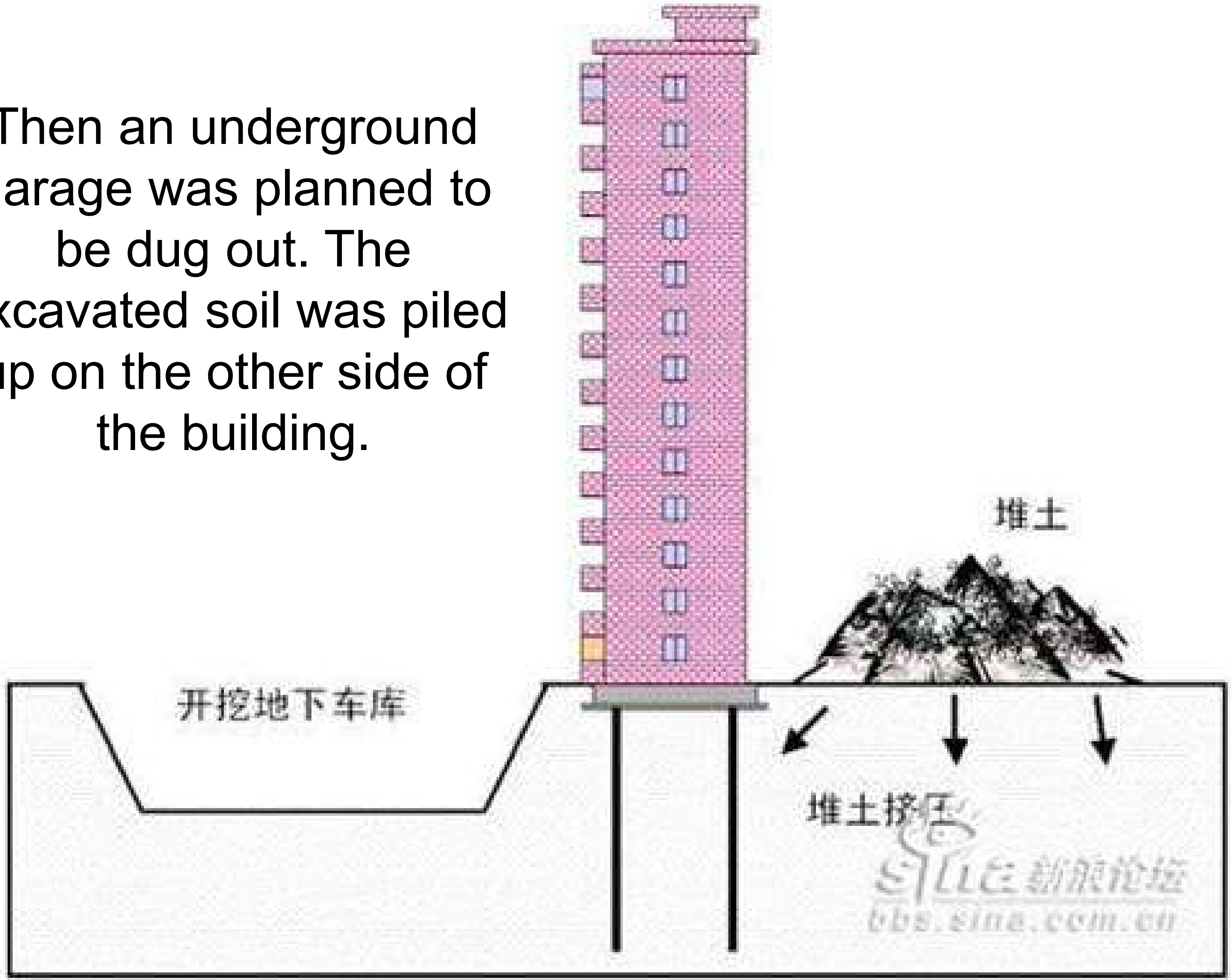



1. Underground garage was being dug on south side to a depth of 4.6 m
2. Excavated dirt was being piled up on north side to a height of 10 m
3. Building experienced uneven lateral pressure (30000 kN) from south and north greater than piles could tolerate.
4. Thus building toppled in south direction

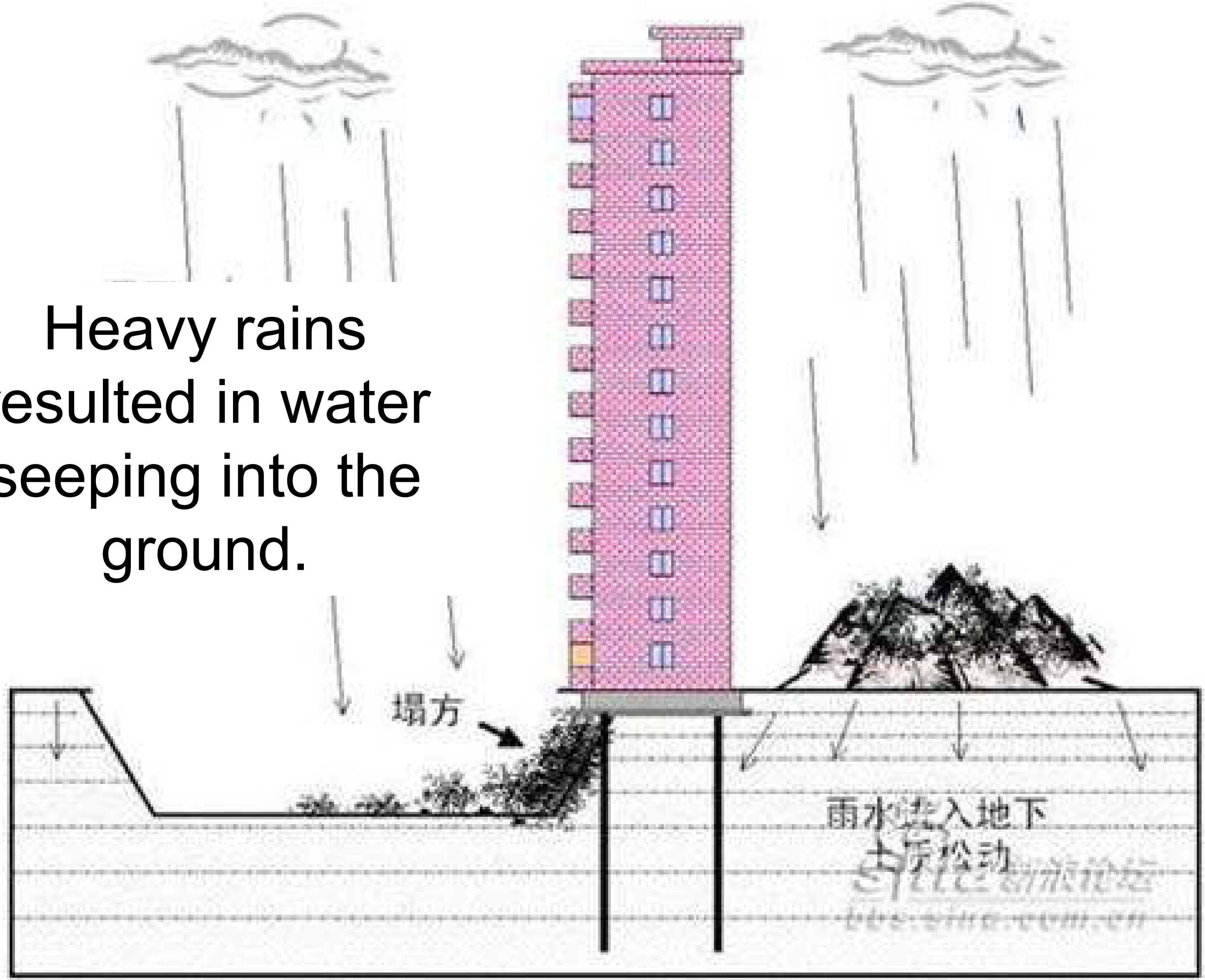
First, the apartment building was constructed



Then an underground garage was planned to be dug out. The excavated soil was piled up on the other side of the building.

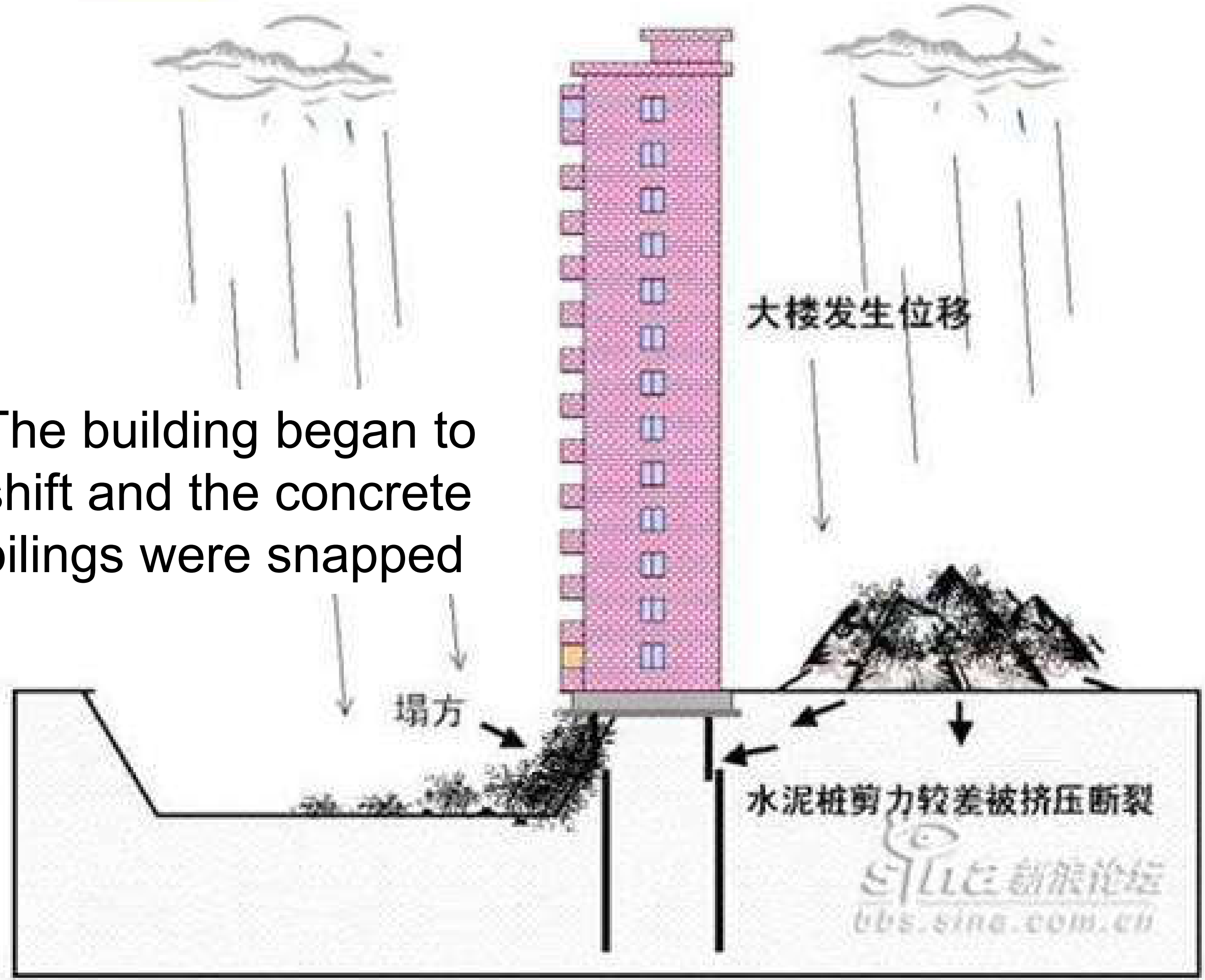


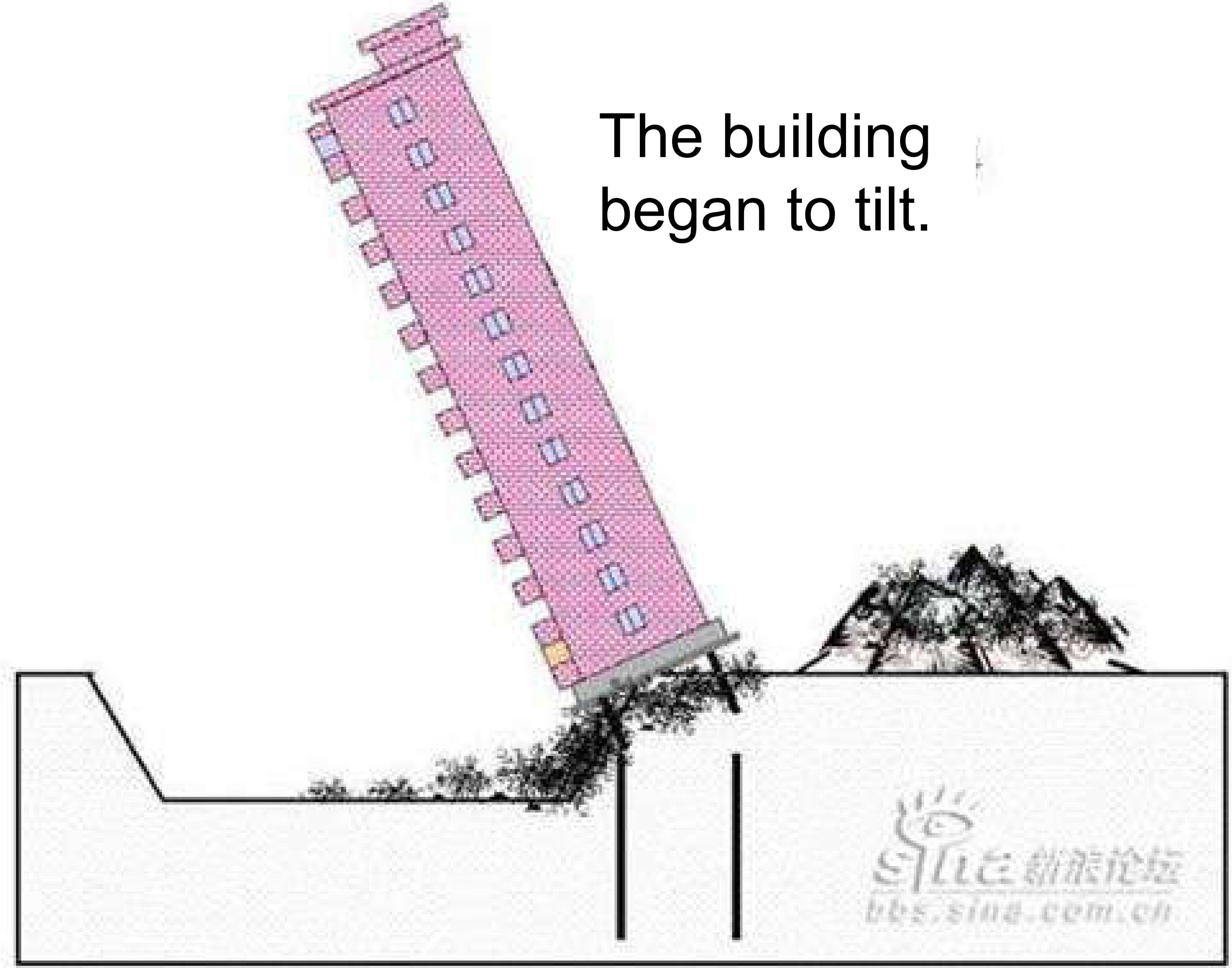
Heavy rains resulted in water seeping into the ground.



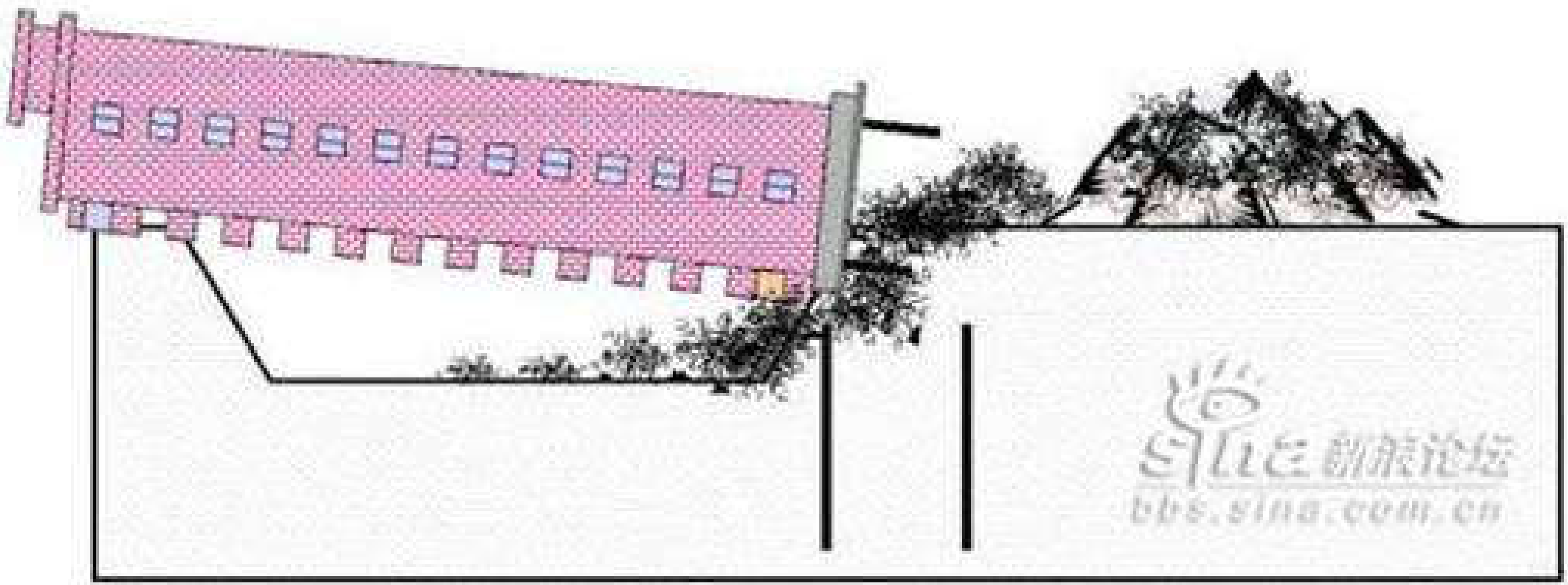
# Shangai Building Collapse

The building began to shift and the concrete pilings were snapped




The building
began to tilt.
bbs.sina.com.cn

And thus came the eighth
wonder of the world.




搜房
SouFun
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# Case Study 2
# Settlement of Buildings
## Mexico Clay and Leaning Tower of Pisa

# Is consideration of settlement important ?

Palace of Fine Arts, Mexico
Uniform settlement

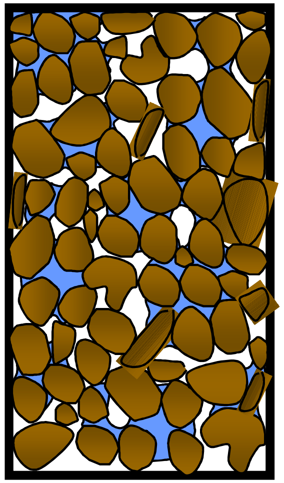
Leaning Tower of Pisa
Differential Settlement

# MEXICO CLAY

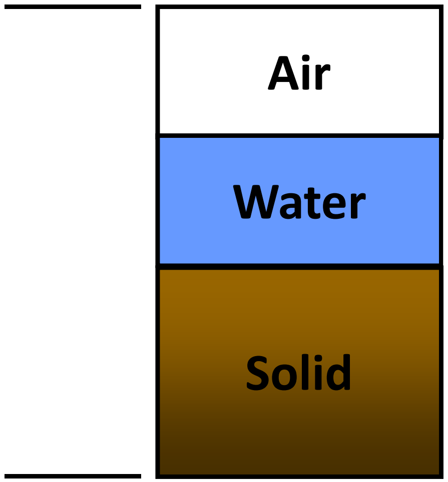
>50 m

Saturated
Fat Clay

Better Soil

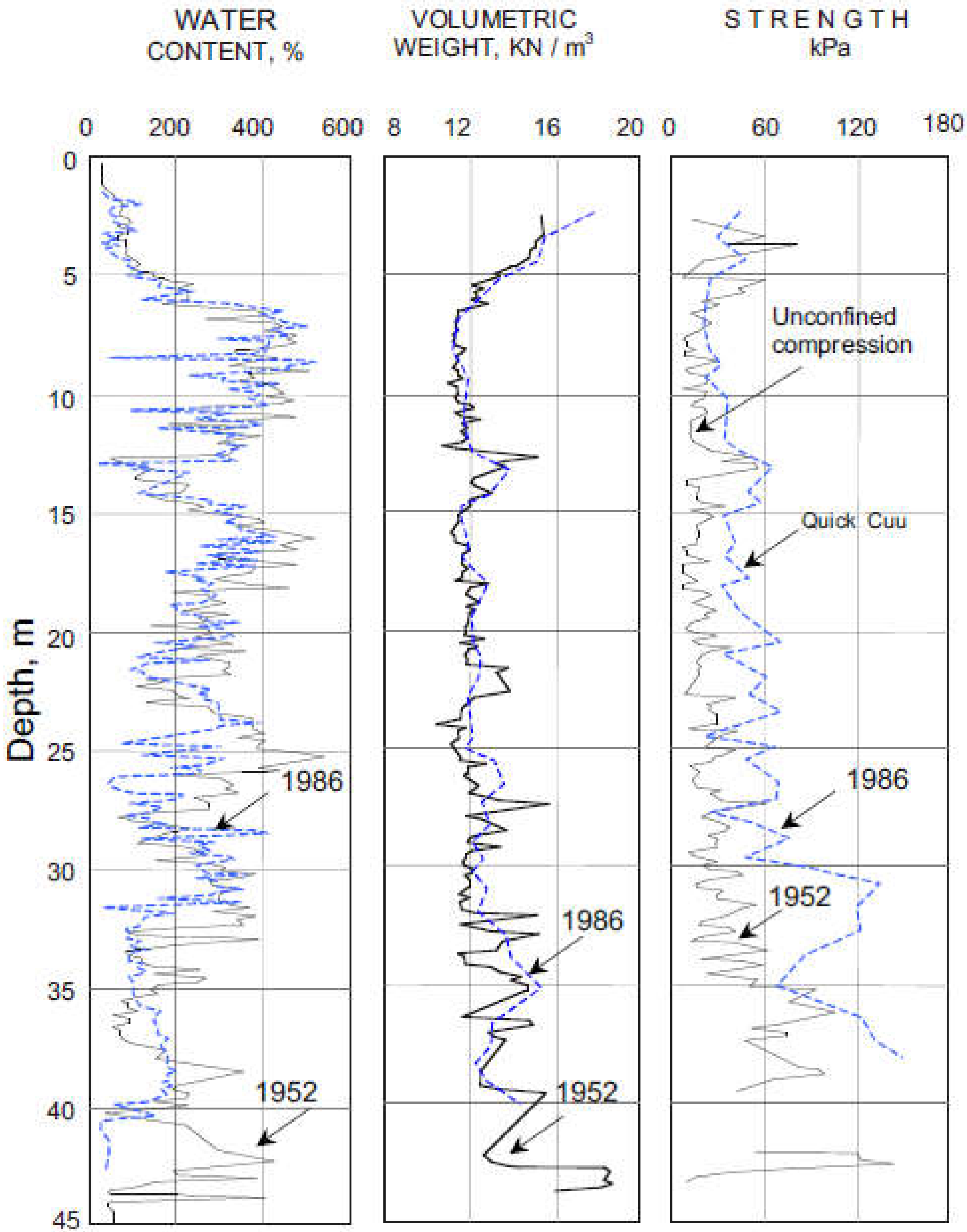


Mineral Skeleton

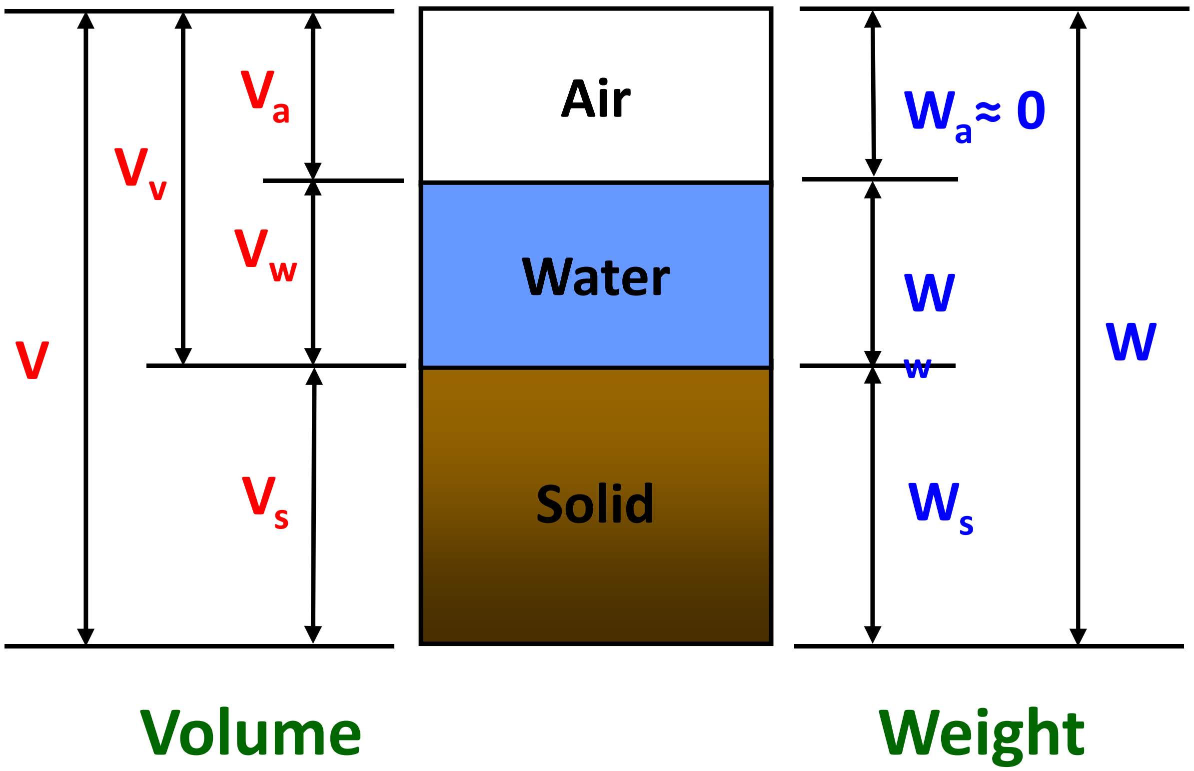



Idealization

**Three Phase Diagram**



# Three Phase system




$$\omega = \frac{W_W}{W_S}$$

$$e = \frac{V_v}{V_s}$$

$$\gamma_d = \frac{W_s}{V}$$

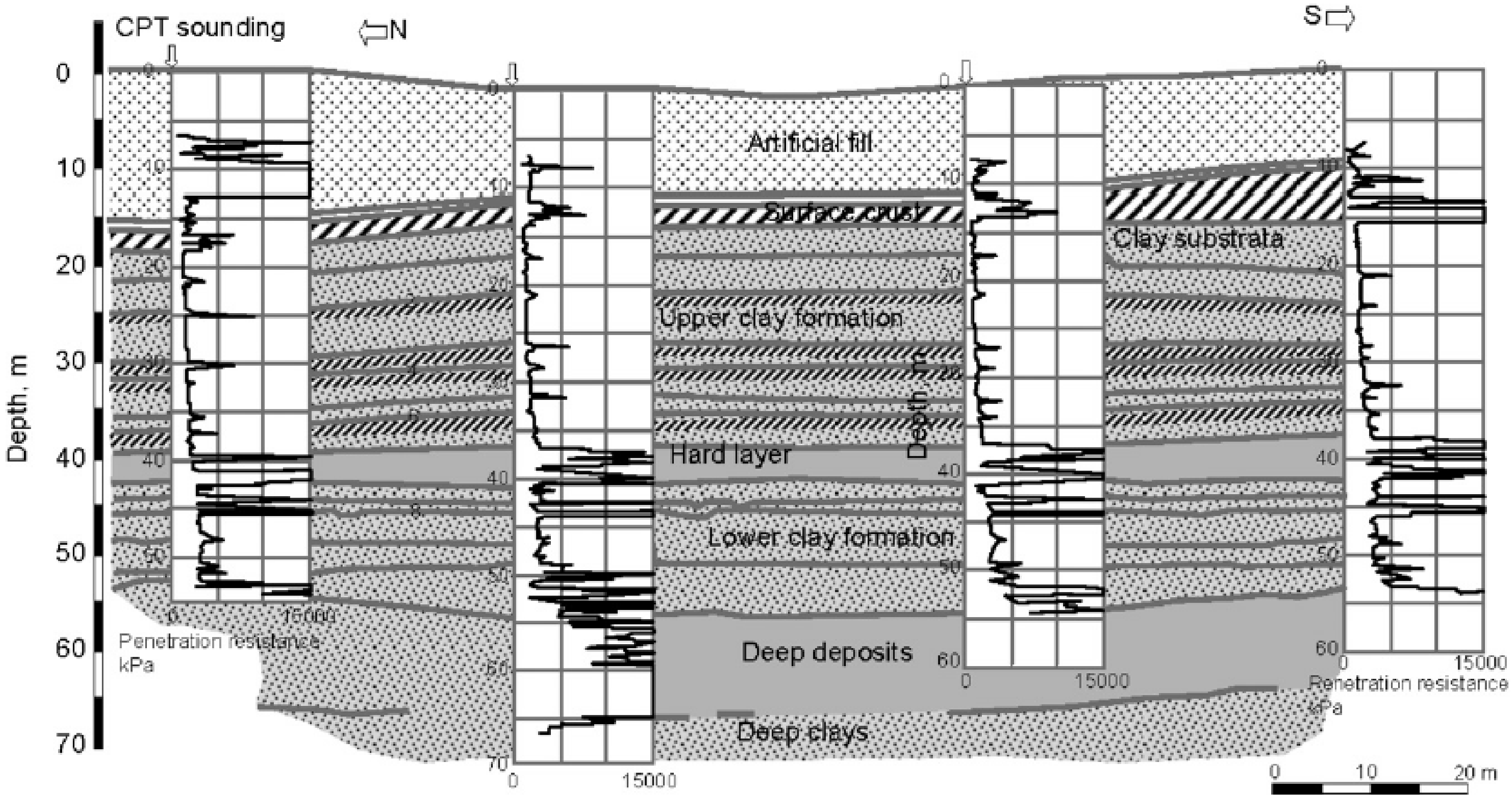
**Mexico Clay**

Water Content 300 to 400 %

Void Ratio 10 to 15

Dry density 10 kN/m$^3$

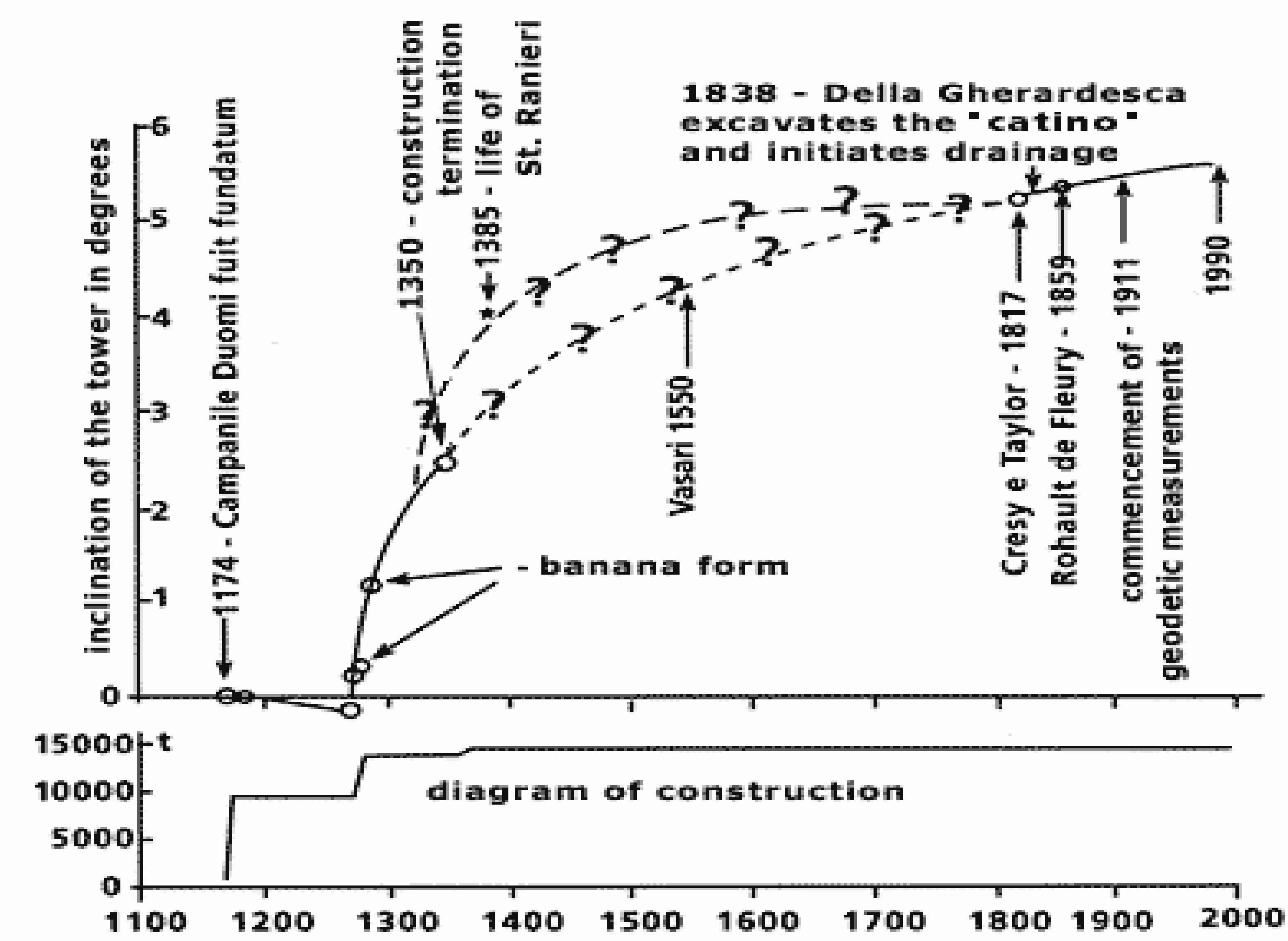
# Mexico Soil Profile



# Characteristics of Pisa Tower

- Weight = 14,700 metric tonnes.
- Ring shaped diameter = 19.6 m.
- Thickness of wall = 4.1m, & 2.7m for all other levels.
- Inclination = 5½$^{o}$ to the south.
- 32,240 blocks (ashlars) for facing the exterior and interior of the cylindrical wall structure.
- 15 half columns at the base.
- 180 columns for base.
- 12 columns for belfry.

# History of Inclination



# Leaning tower of Pisa

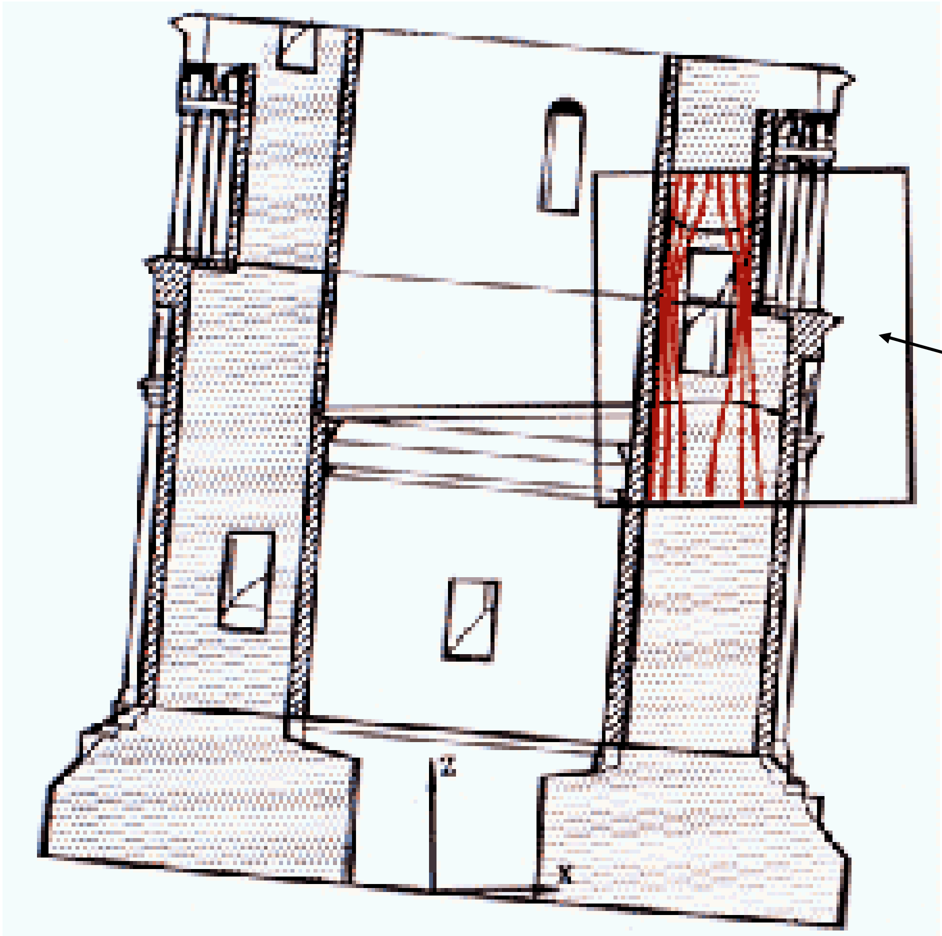
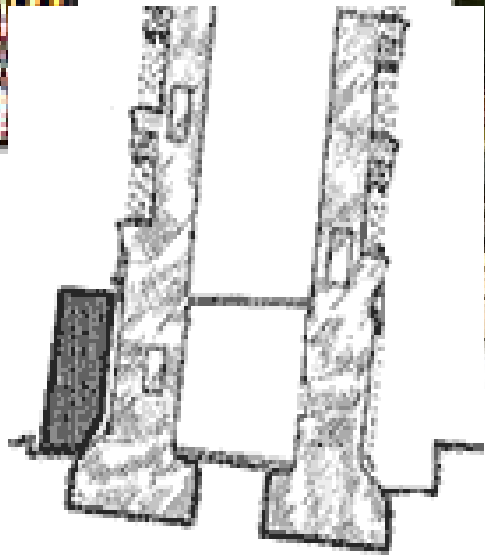


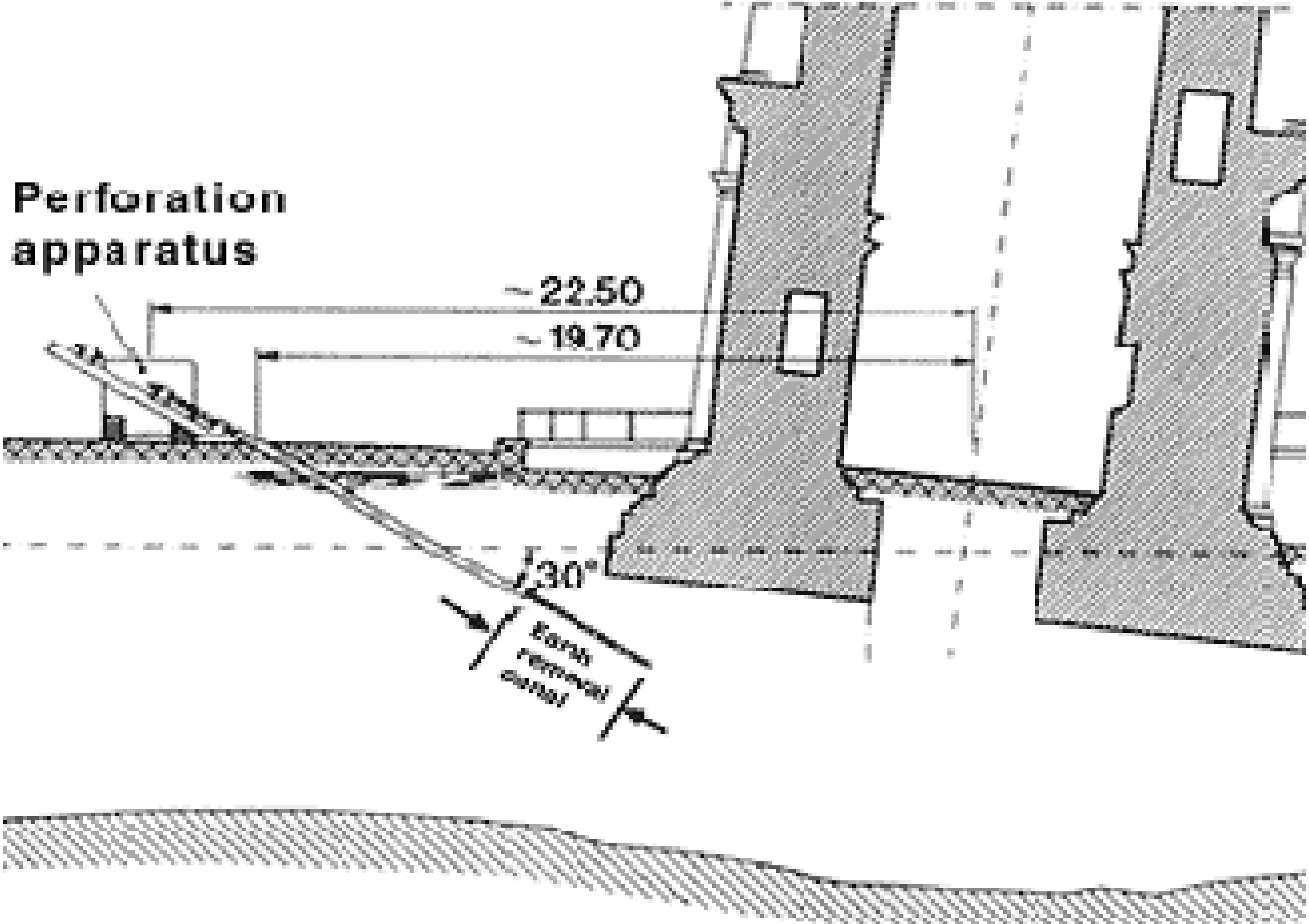

Figure 2. Lines around stairway represent large compressive forces [image courtesy of torre.duomo.pisa.it].

**Side of tower where the stress was causing the tower walls to collapse.**



750 tonnes of
lead ingot stacked
on north side

# Soil removal on North side



## Case Study 3
## Failure of buildings of B C Soil

# Vertical cracks in Masonry Wall

# Diagonal Cracks in Masonry Walls & Beams

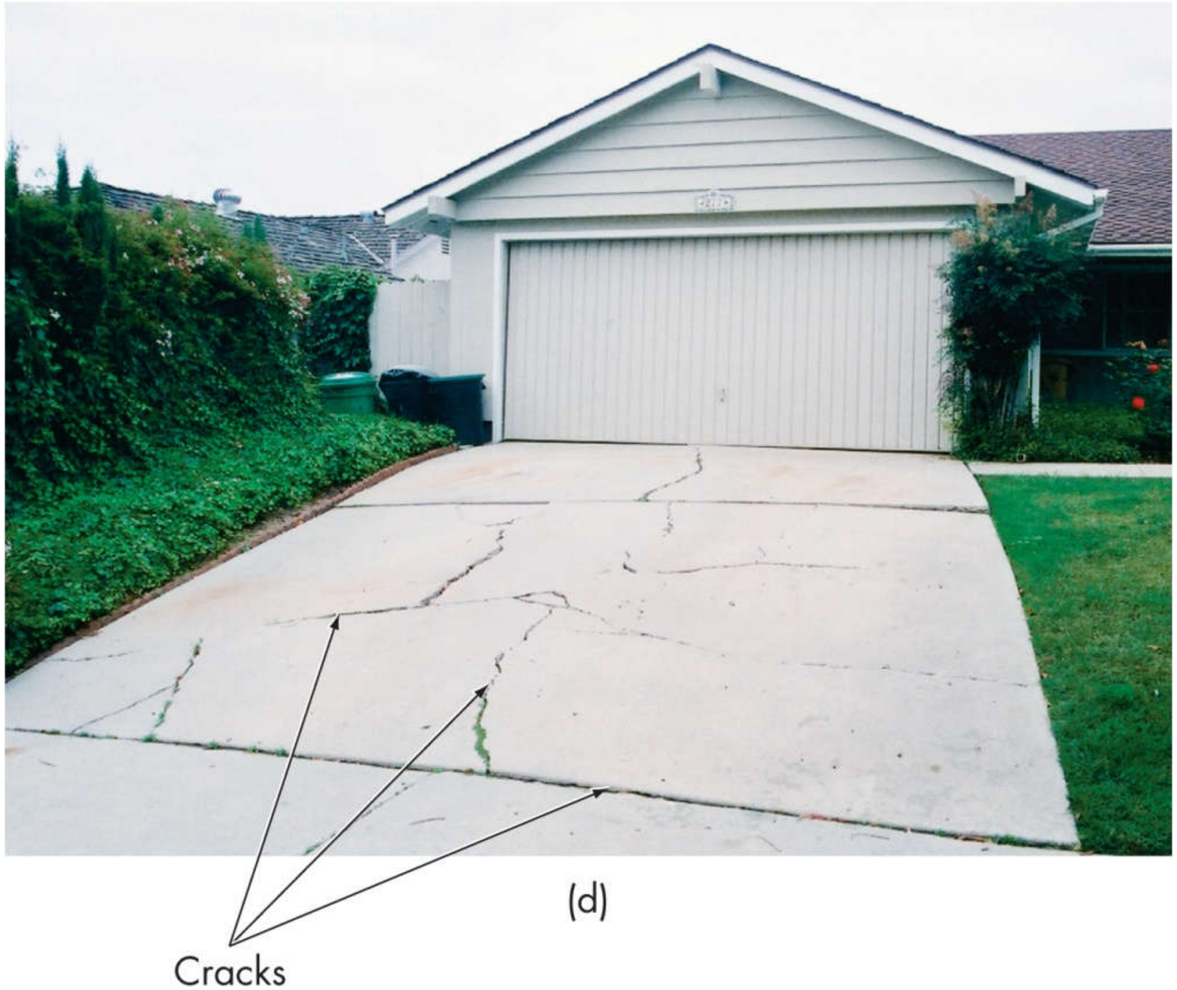
# Cracks in Masonry Walls at edges & plaster coming out

# Horizontal & Vertical Cracks in Masonry Walls

# Cracks in Masonry Walls. More damage in wet places

# Cracks in flooring and pavement

# Light floor & pavement lifted up unevenly



## Case Study 4

# SLOPE FAILURE SUFFERED BENEATH BAINDUR VIRAJPET HIGHWAY AT 29.10 km NEAR MADIKERI

# Slope failure at the edge of the highway

# 2 lane highway and slope failure at the road edge

# Temporary support with bamboo fencing was not sufficient to halt slope slide

# Excavated and leveled platforms at the bottom of the slope seen. Valley for the drain is visible.

# Another view of platform formed by a private party with valley

# Observations

1. Slope is sufficiently sleep, at approximately 70$^o$ to horizontal.
2. The depth of slide is about 10 m. Below this level, a small valley exists which perhaps is a drain for a small stream.
3. The road is a two lane highway with sufficient traffic.
4. The portion of terrain that suffered slide appears to be made up of fine silty soil, that can easily break if disturbed.
5. At the toe portion of slope, excavations are made and about 10 m wide platform is made.

# Observations

6. Near the failed slope portion, slope appears to be bald with no vegetation.
7. There appears to be no influence of ground water.
8. Drainage for run off water during rainy season appears to be improper.
9. The slide appears to be surface slide and planar.
10. Frequent rains of sever intensity occurs in the region with an annual rainfall of over 4000 mm.
11. Length of failure is about 40 m. Failure culminated at the rock face.
12. It is at an altitude of around 1650 m above mean sea level.

# Recommendations

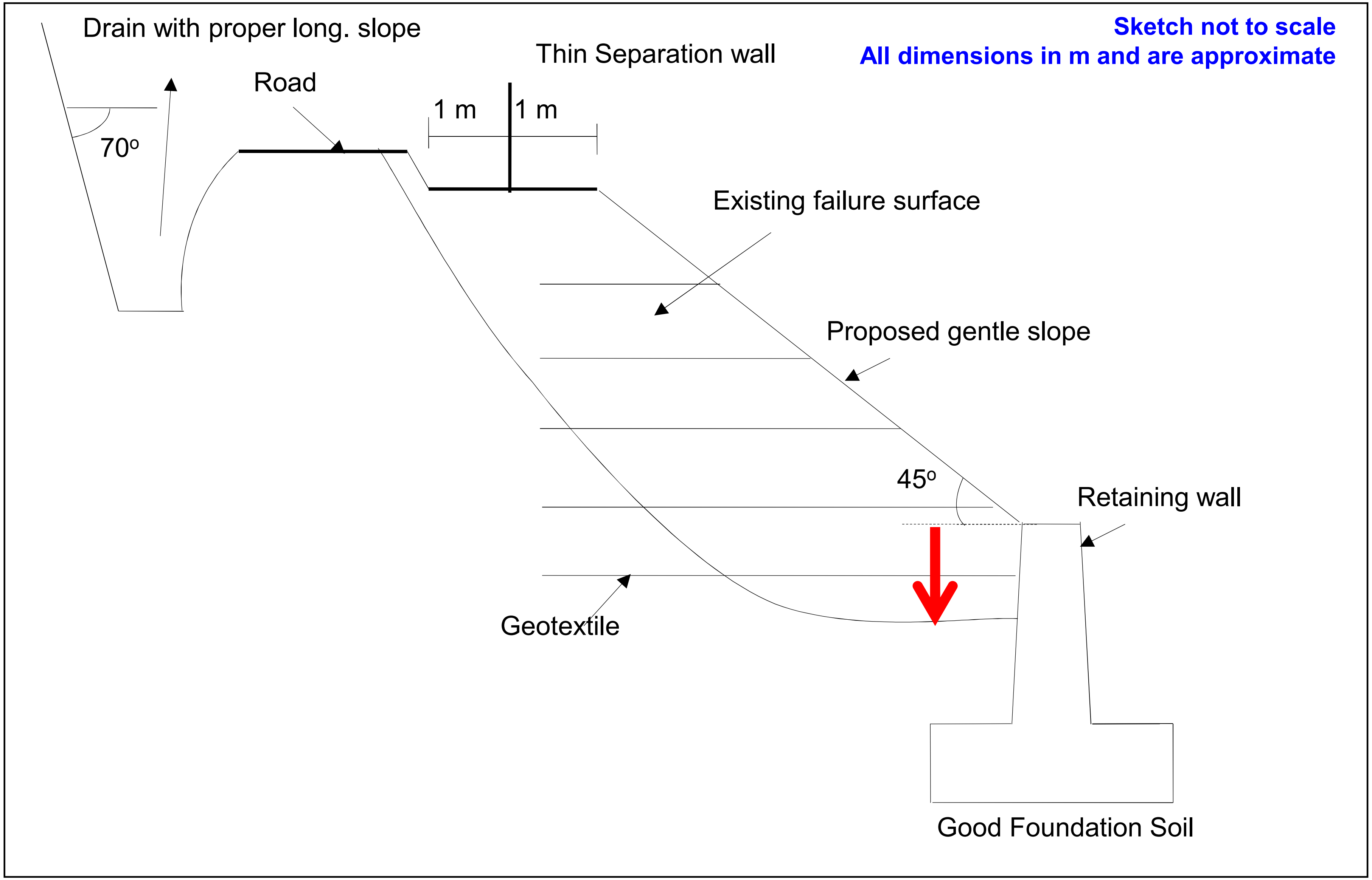
1. Steepness of the slope should be reduced. For this purpose at the toe end, a small retaining wall should be built after ascertaining that the foundation soil is adequately capable and a slope less than 45$^{o}$ should be made, if possible using geotextile.

2. The shoulder beyond the road at the distressed portion shall be at least 2 m and care should be taken to avoid vehicles going near the edge.

# Recommendations

3. Longitudinal drains on the cutting side should be repaired and improved.
4. For filling up the slope, murram type of soil with sufficient quantity of granular material should be used.
5. Toe portion needs to be stabilized.
6. Provision should be made to grow vegetation along the slope at a later time.

# Recommendations

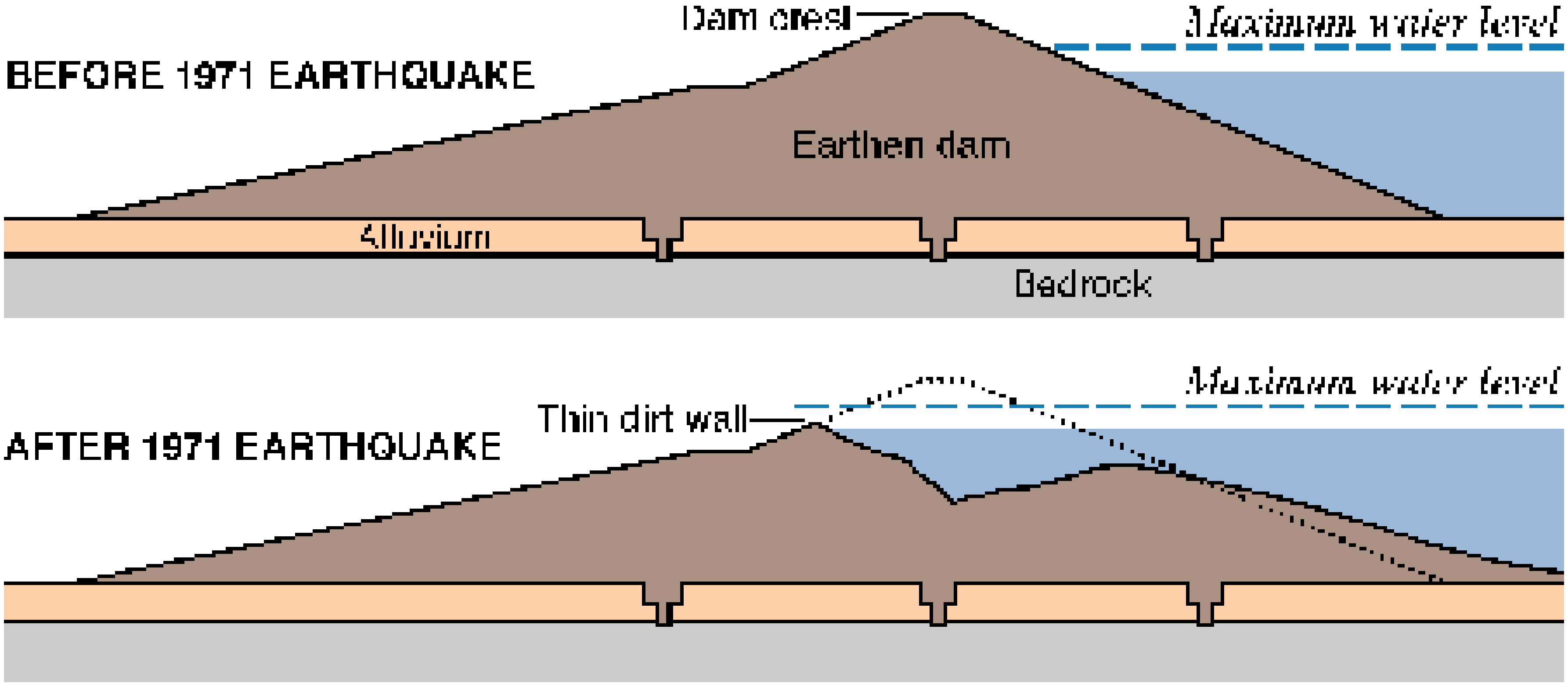


## Case Study 5

## Failure of Lower San Fernando Dam

# Lower San Fernando Dam failure (1971)
# Breach due to liquefaction of subsoil

# Lower San Fernando Dam failure (1971)



# Lower San Fernando Dam failure (1971)

# Road Embankment failure due to heavy rains

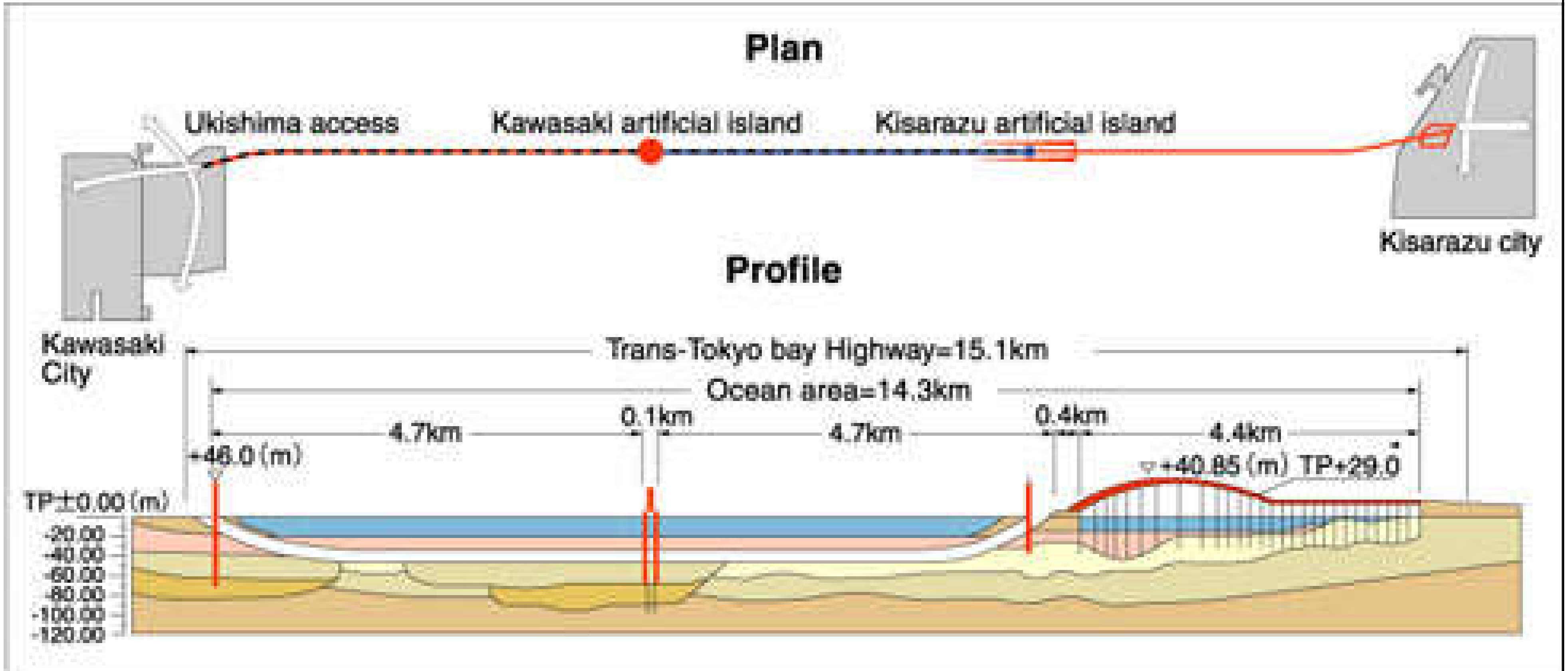
# Bhuj earthquake (2001) Earth Dam failure

# Hyogo Ken Nambu Earthquake, Japan January 17, 1995

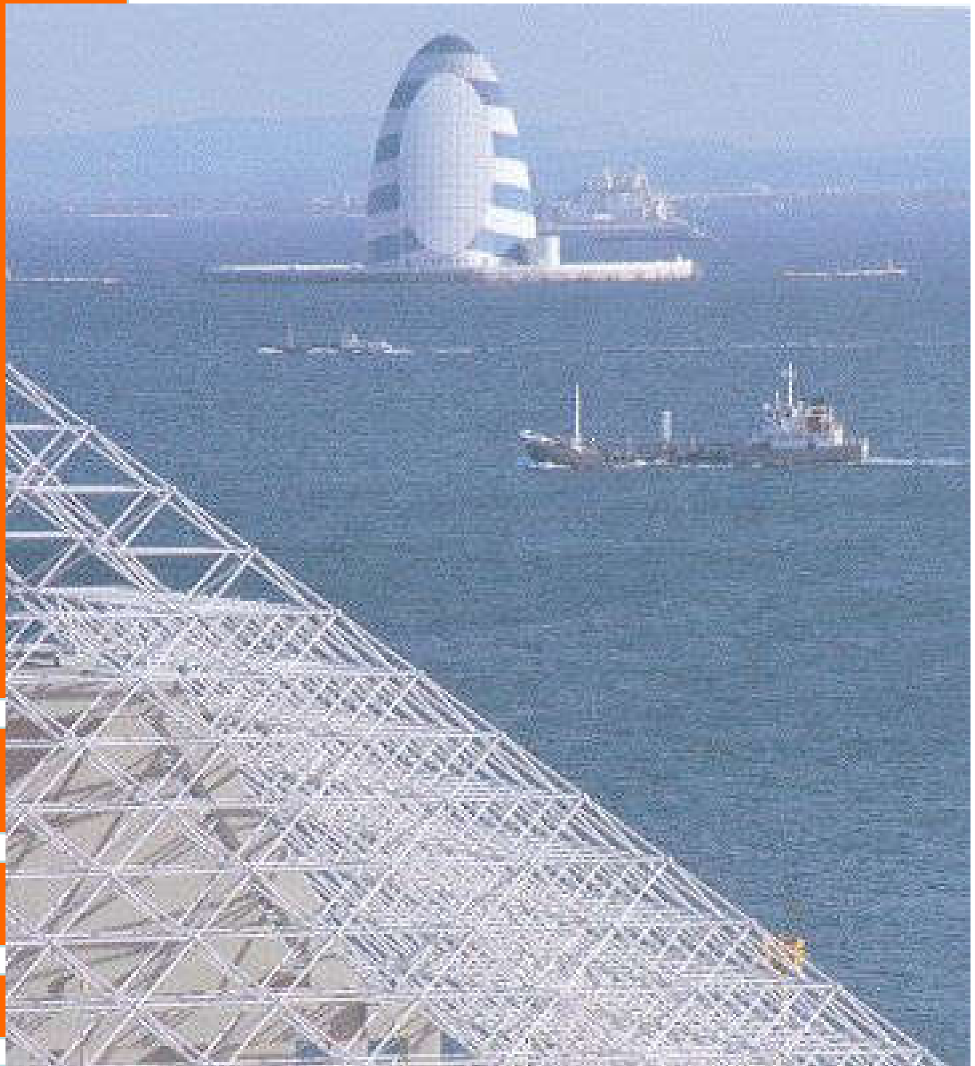
# Case Study 6

## TRANS TOKYO BAY HIGHWAY

# TRANS TOKYO BAY HIGHWAY



# Trans-Tokyo Bay Highway




15.1 km-long toll highway

# Brief history

**May 1971:**
Technical investigation started.

**May 1983:**
Japanese Government approved the construction.

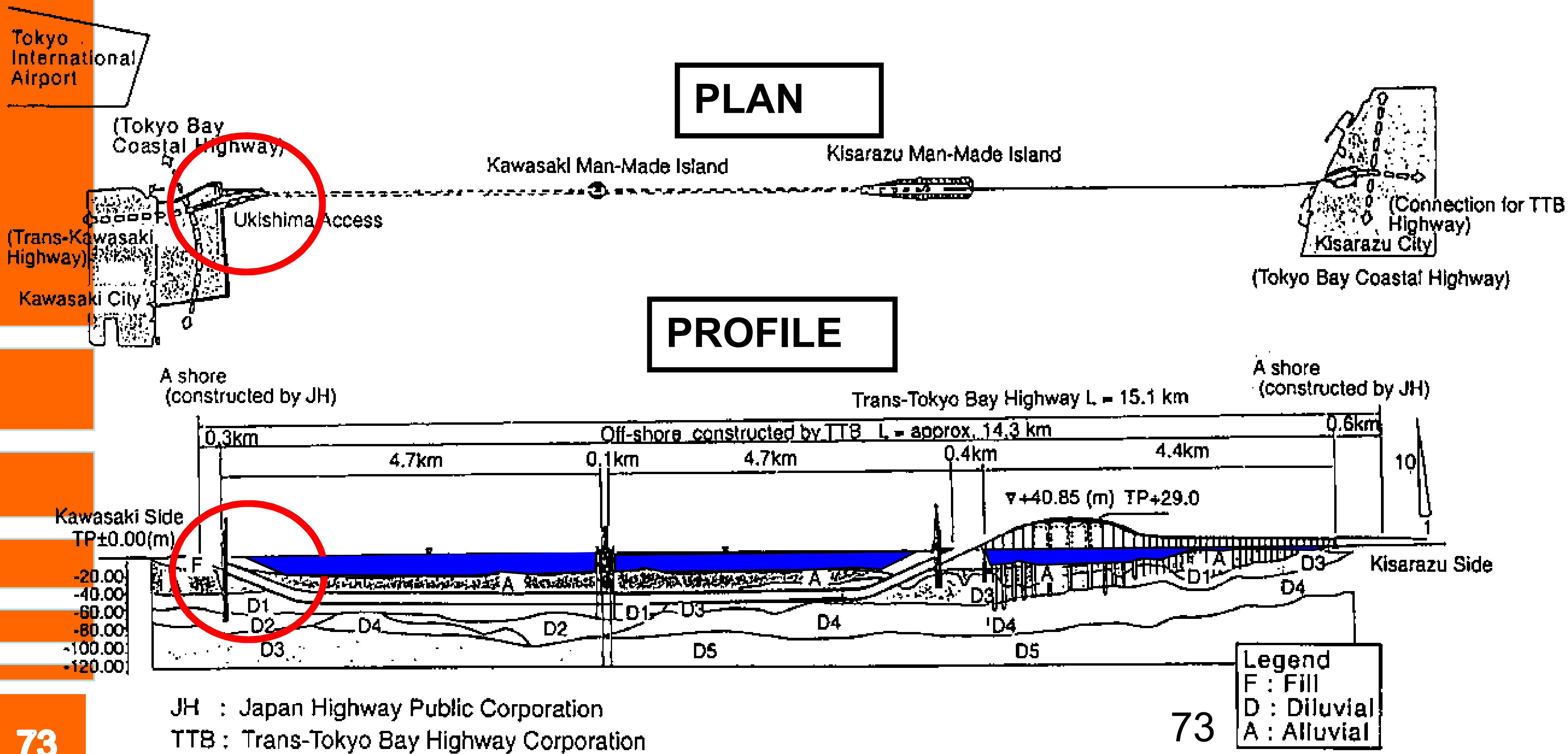
**October 1986:**
Trans-Tokyo Bay Highway Corporation was established.

**May 1989:**
Construction started.

**December 1997:**
Construction completed & highway was opened to public on 18th Dec.

# Structure of TTB Highway

- **Ukishima access;**
- Kawasaki man-made island;
- Bridge
- Two 9.5 km-long shield tunnels;
- Kisarazu man-made island;




JH : Japan Highway Public Corporation
TTB : Trans-Tokyo Bay Highway Corporation

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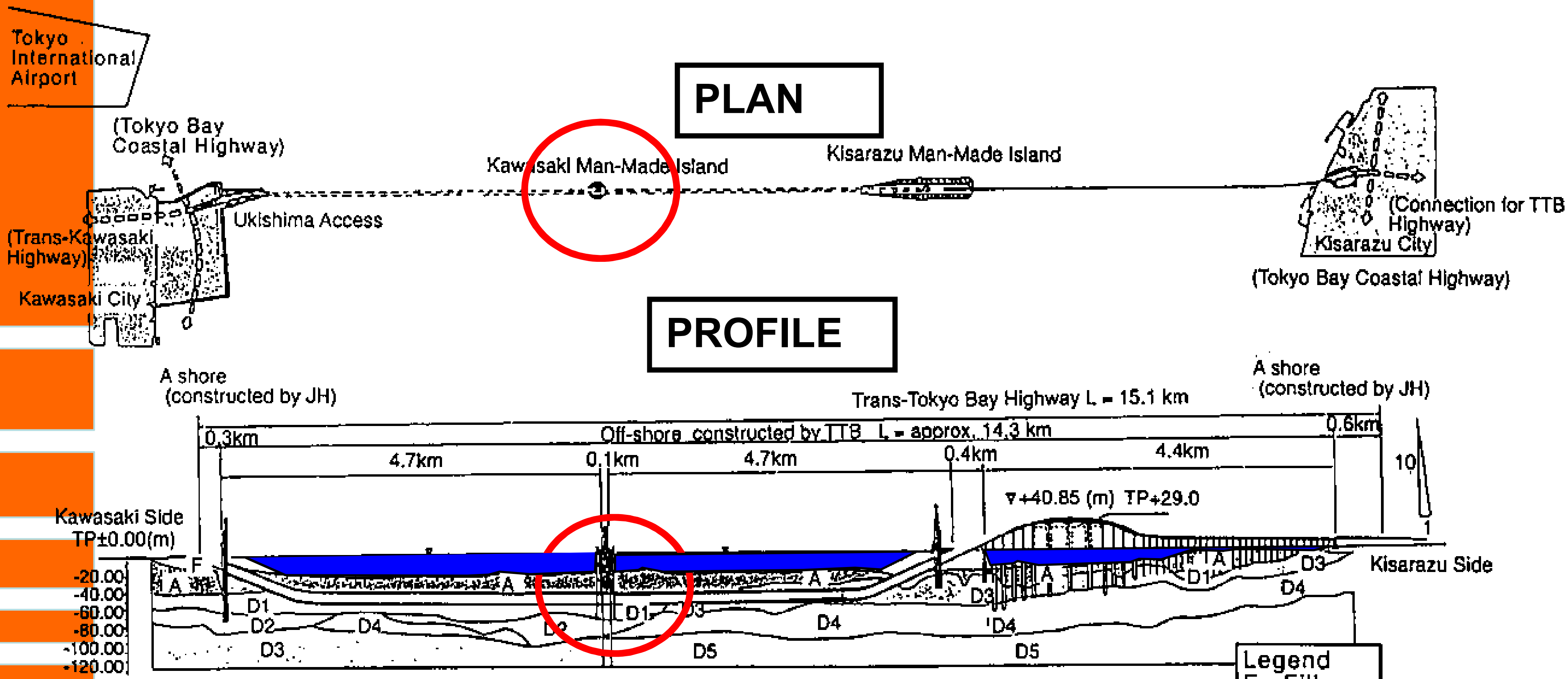


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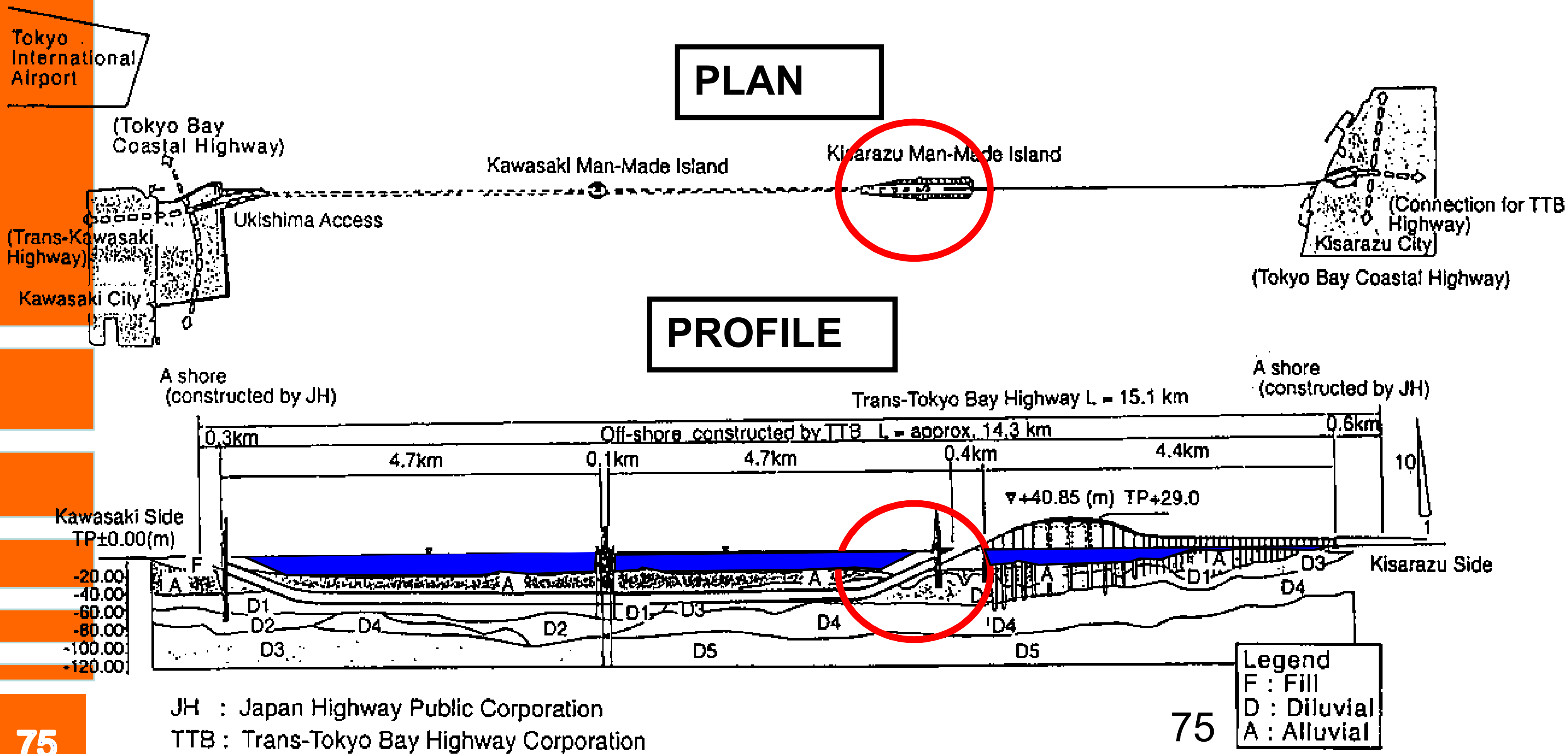


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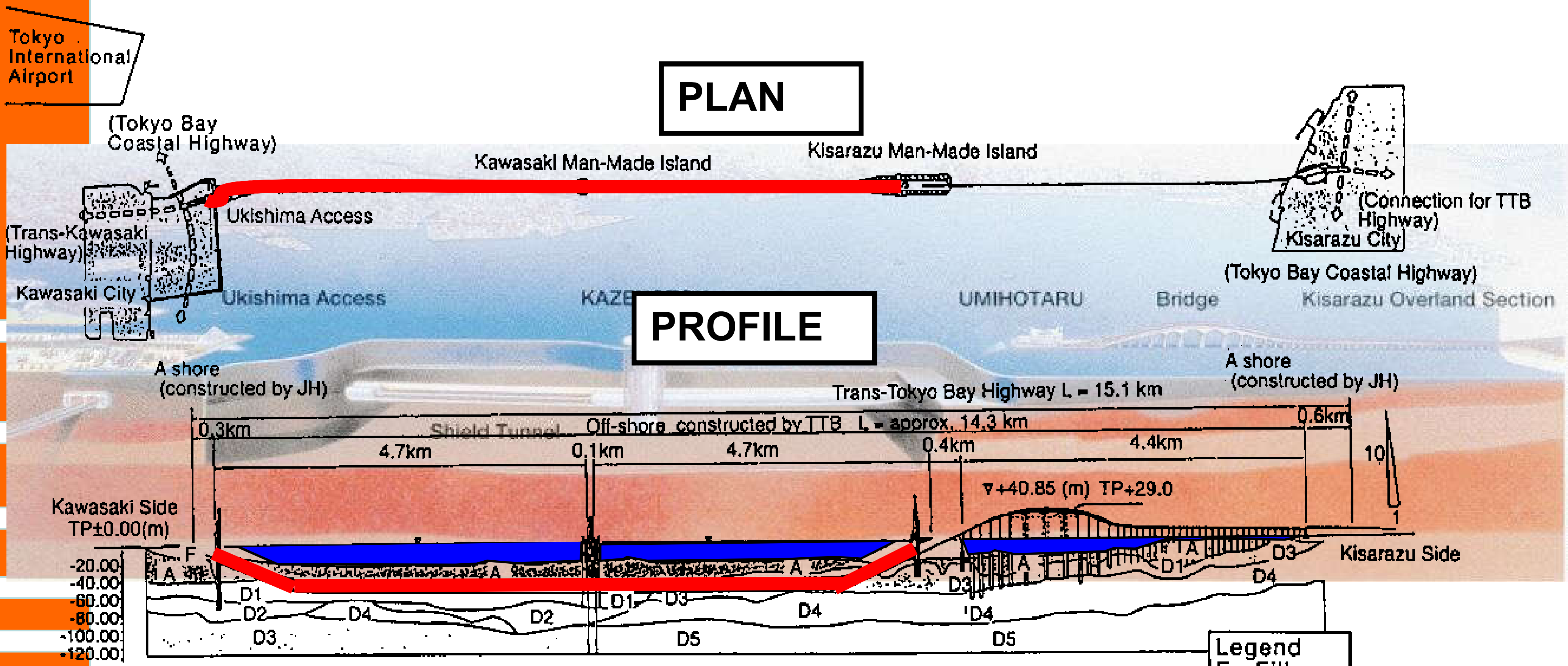


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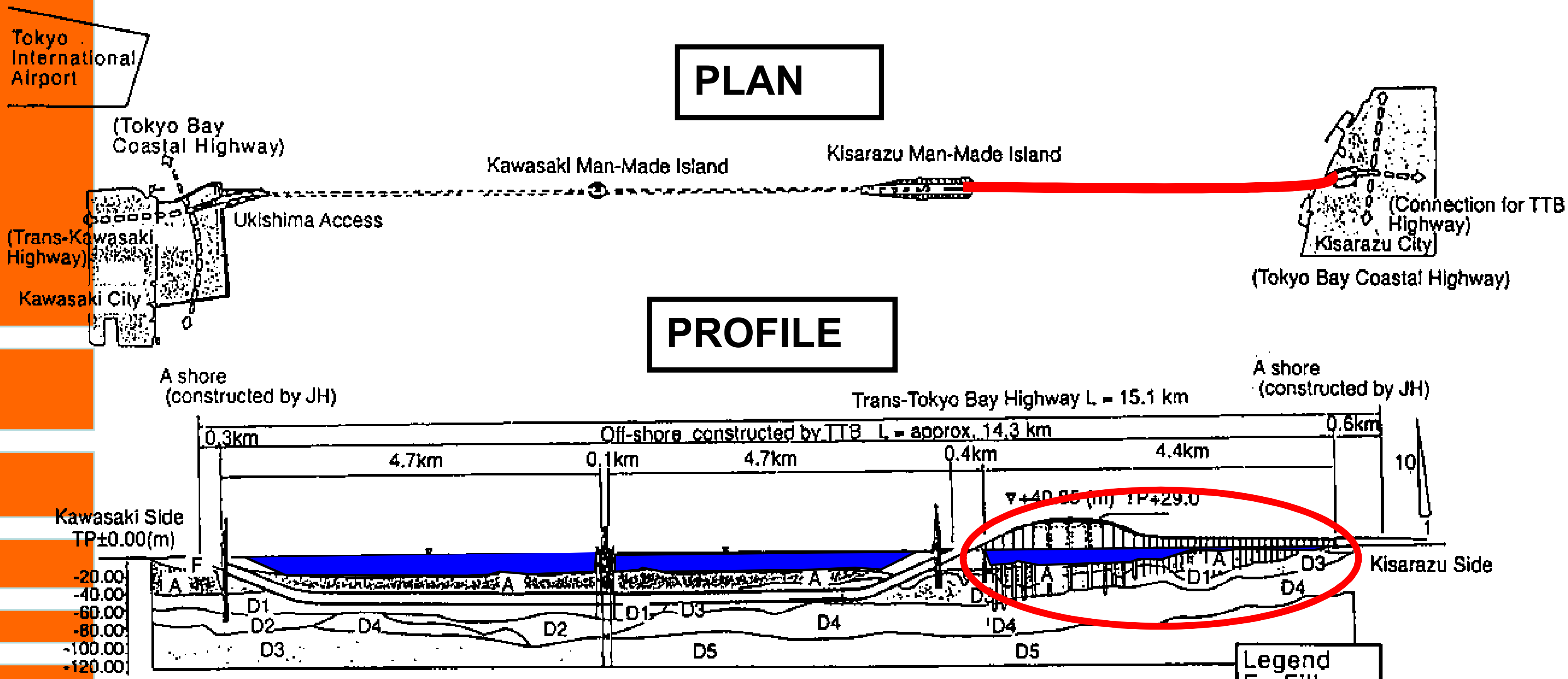


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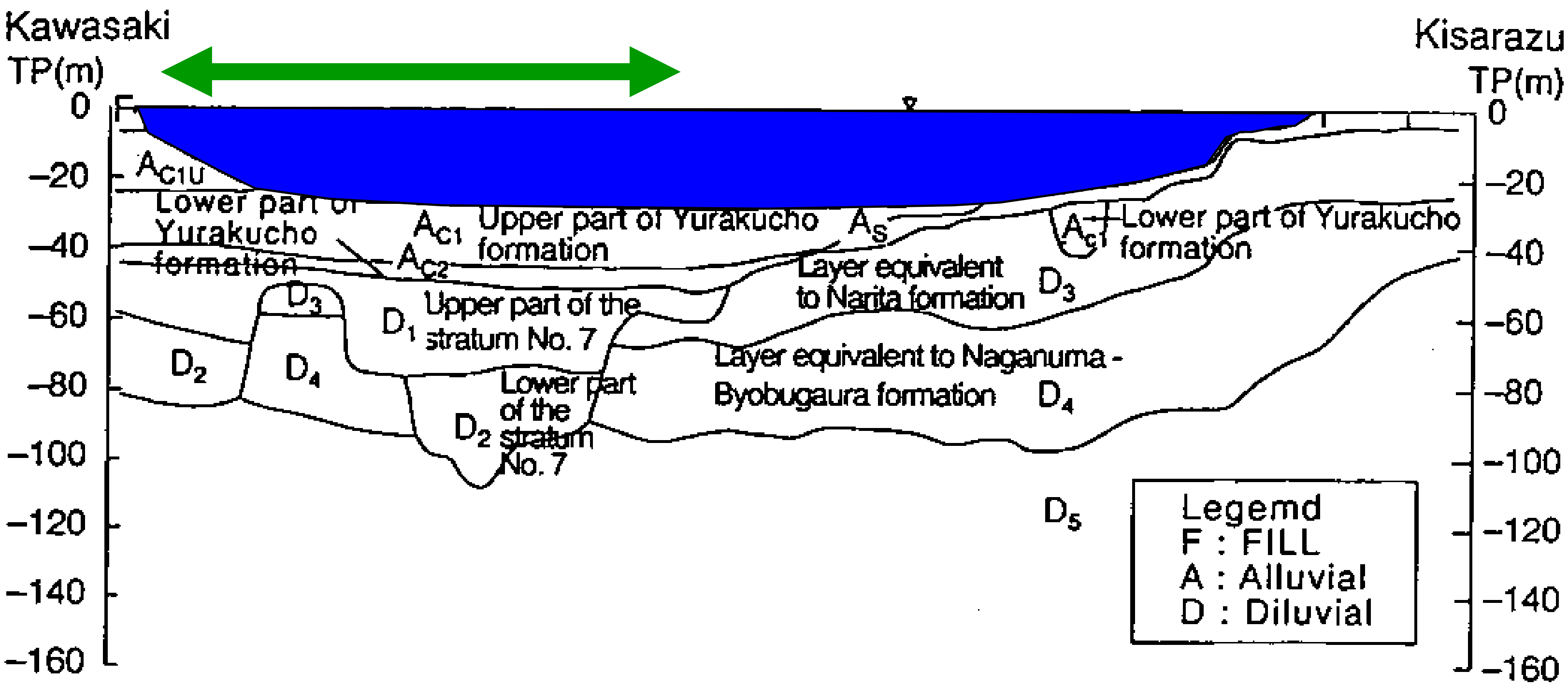
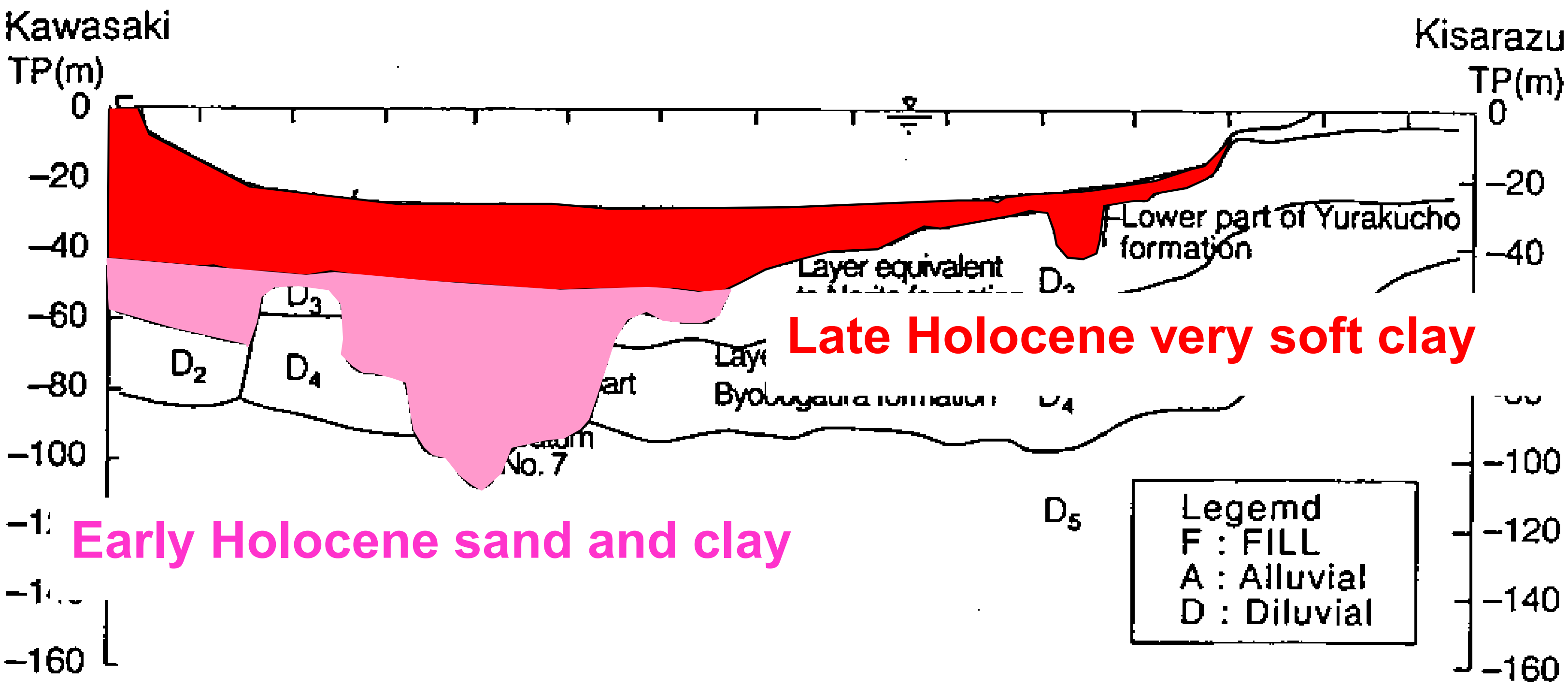
# Four difficult design conditions that controlled the structural form

- a relatively deep sea;
- heavy shipping routes;



# Four difficult design conditions that controlled the structural form


- a relatively deep sea;
- heavy crossing shipping routes;
- **poor ground conditions; and**
- **a high seismic activity.**



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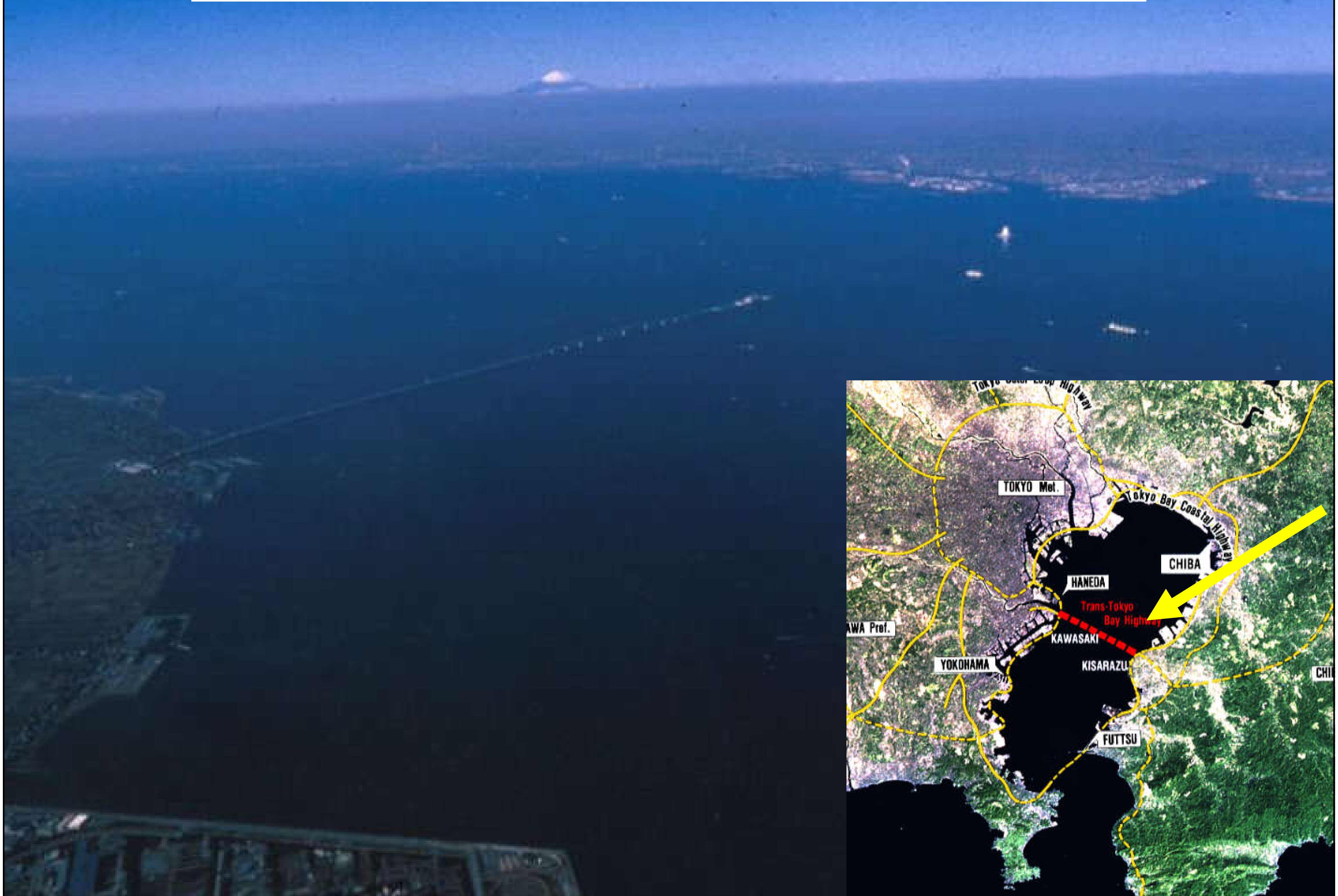
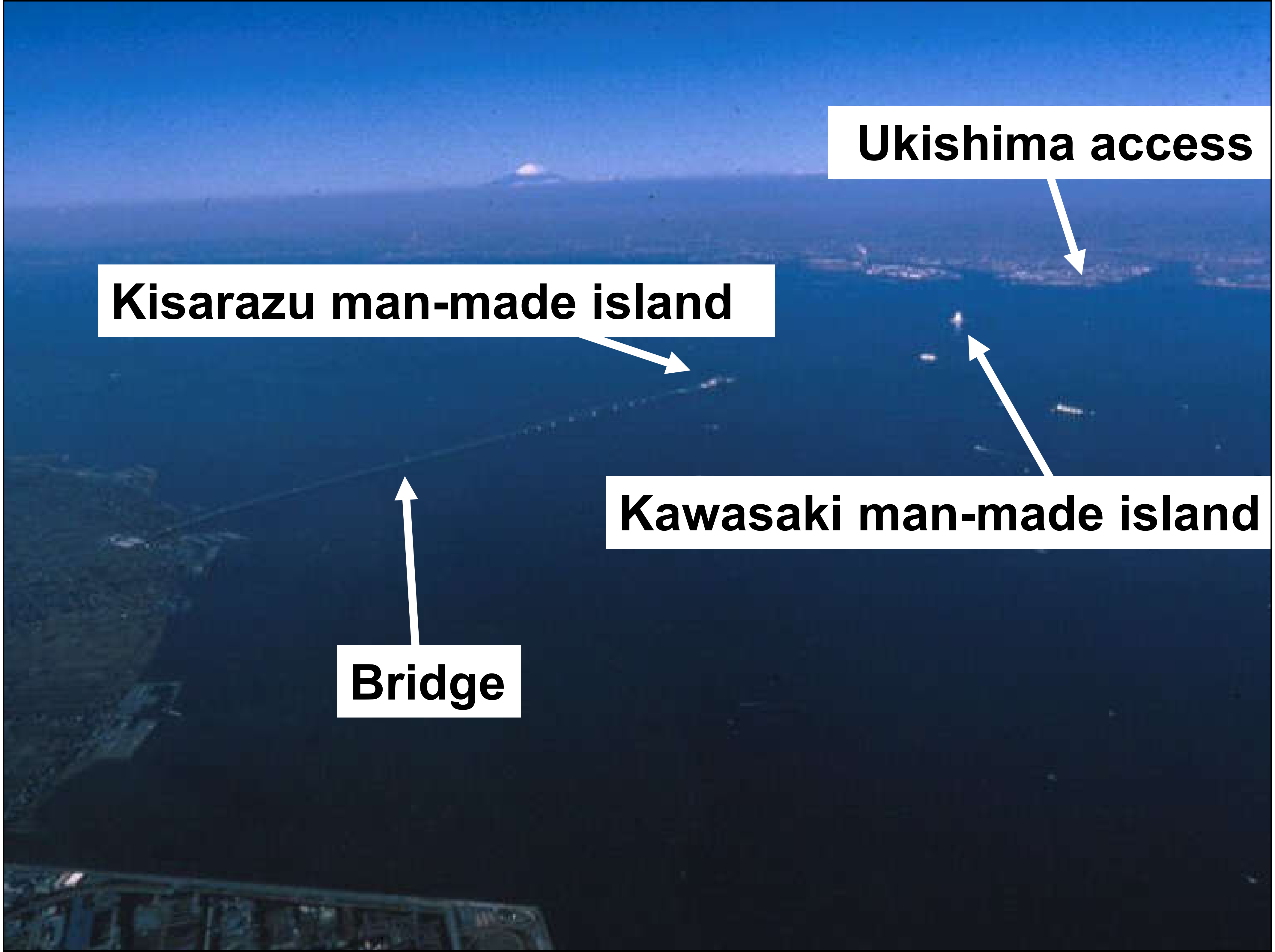
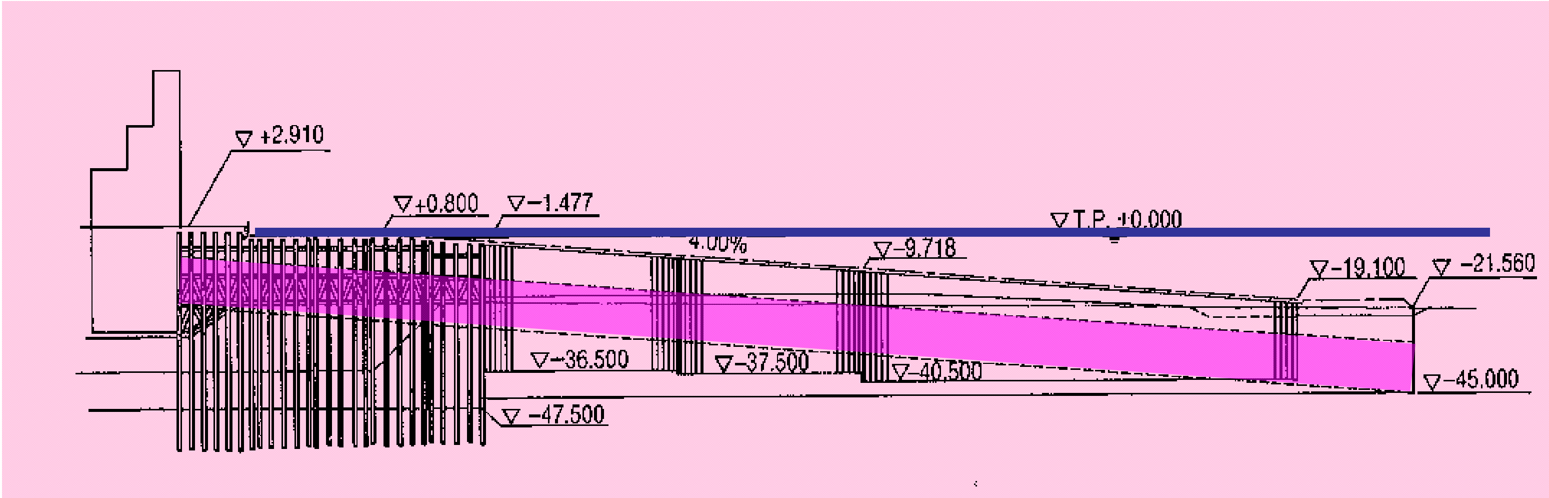
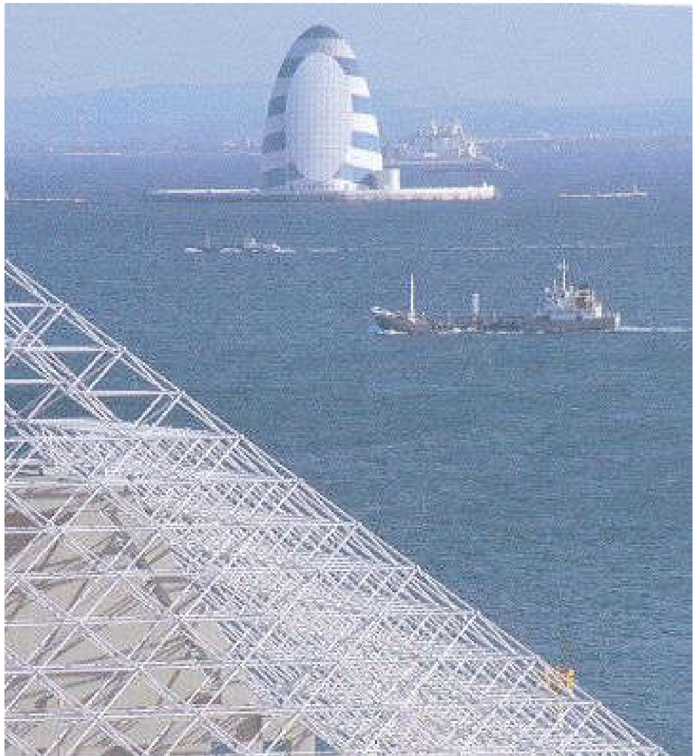
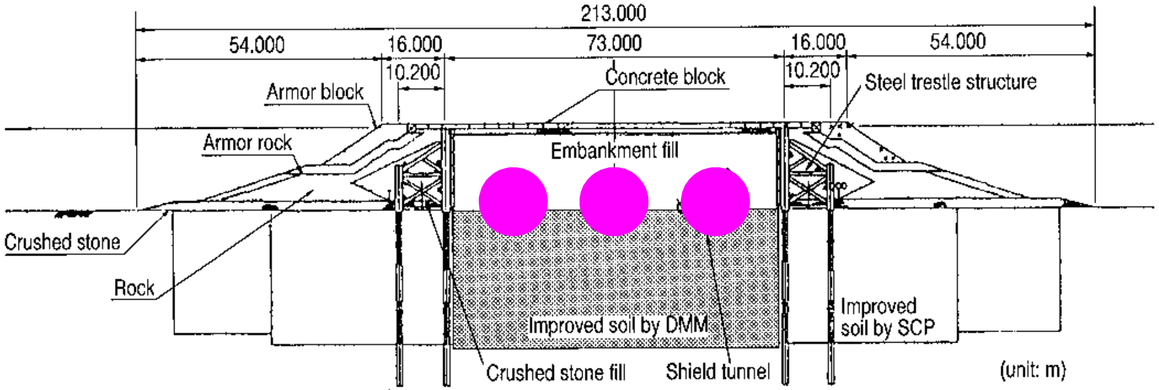



Ukishima access
Kisarazu man-made island
Kawasaki man-made island
Bridge

# Ukishima access



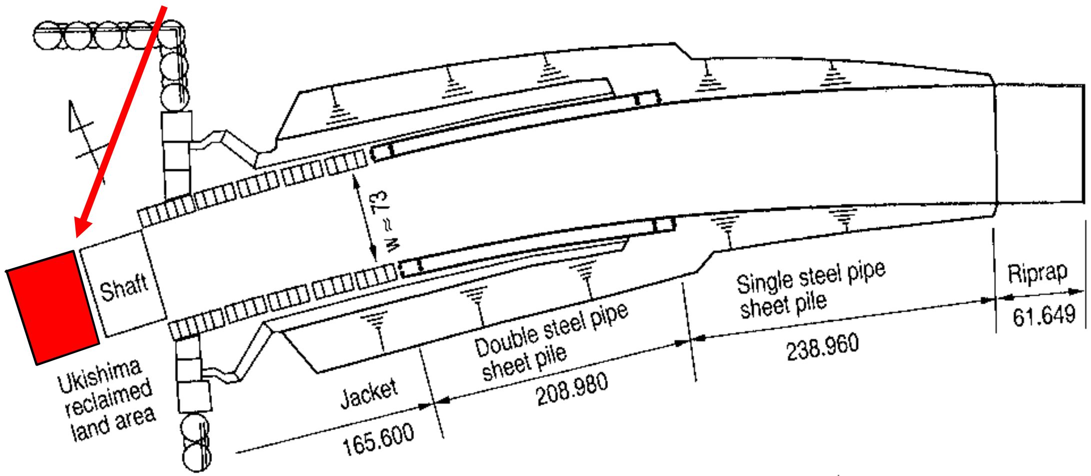



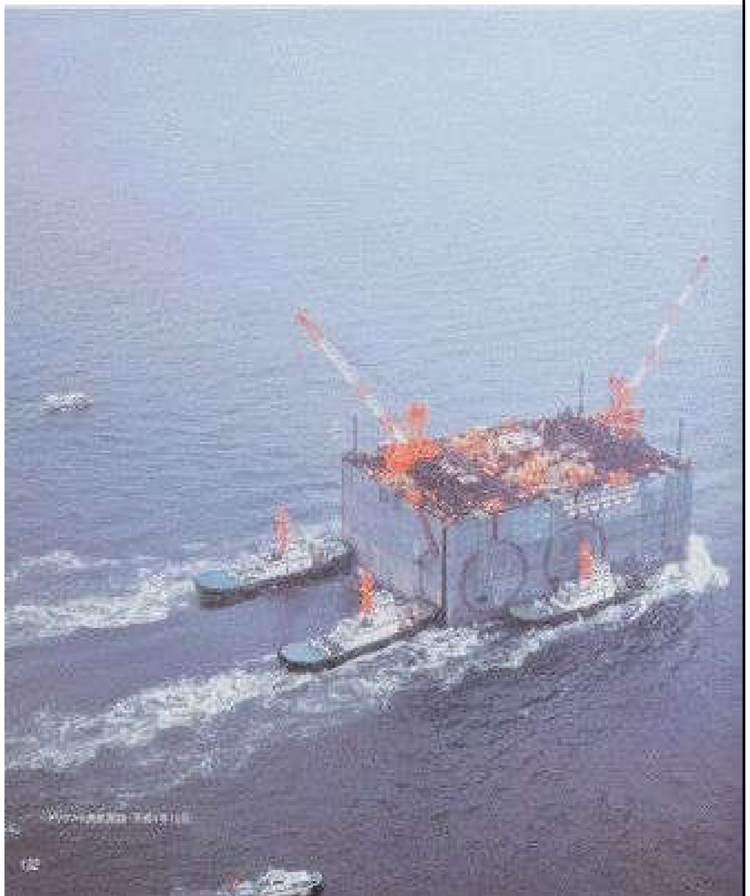



**The starting point**
**of the shield tunnels,**
**towards the center of the Tokyo Bay**

**Steel caisson:**

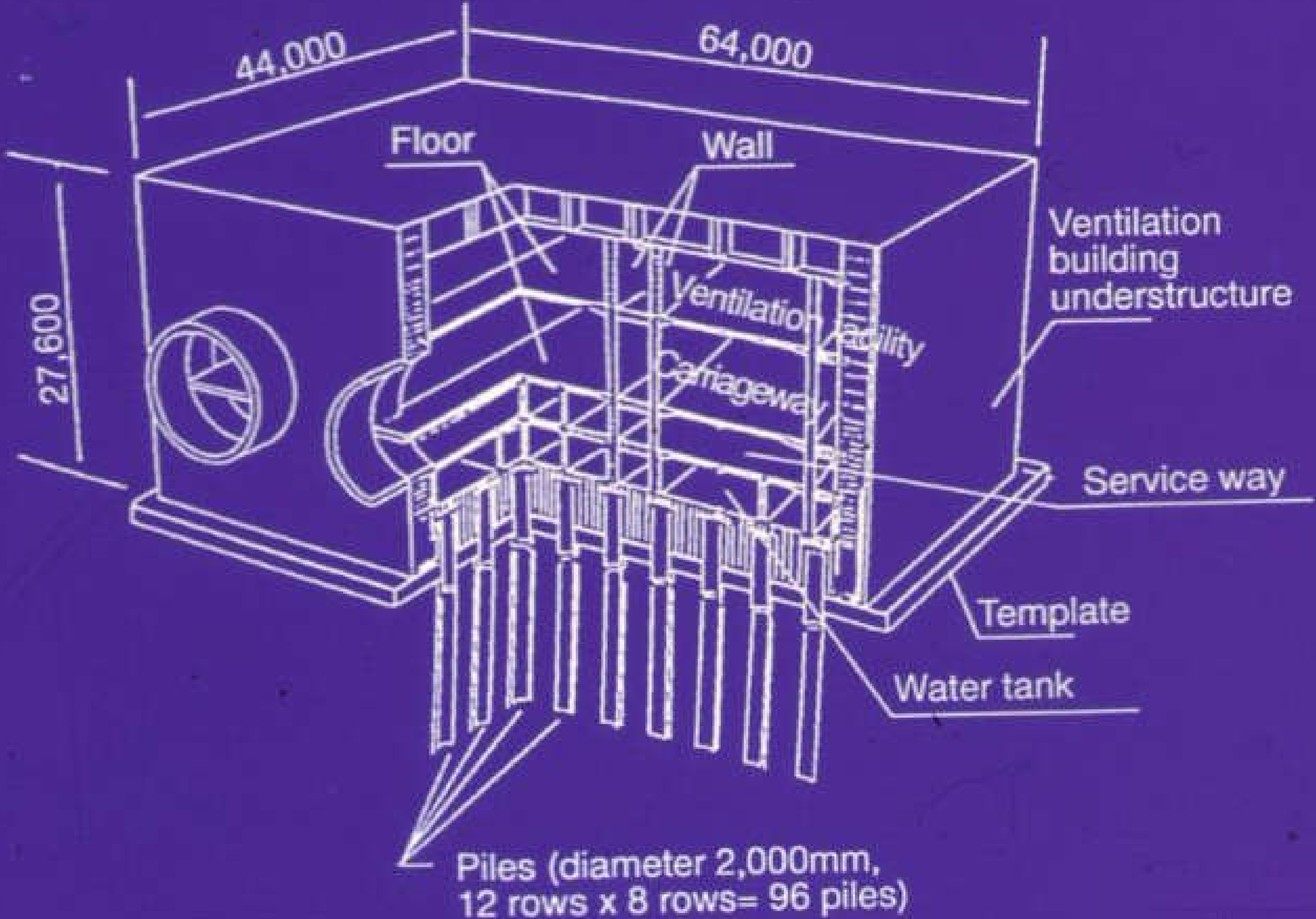
1) to start the shield tunnel construction;
2) the ventilation tower after completion.



## Ukishima Access - ventilation tower

- Also to start the shield tunneling work.
- A steel shell caisson was laid down on many piles, and then, the inside was filled with concrete.



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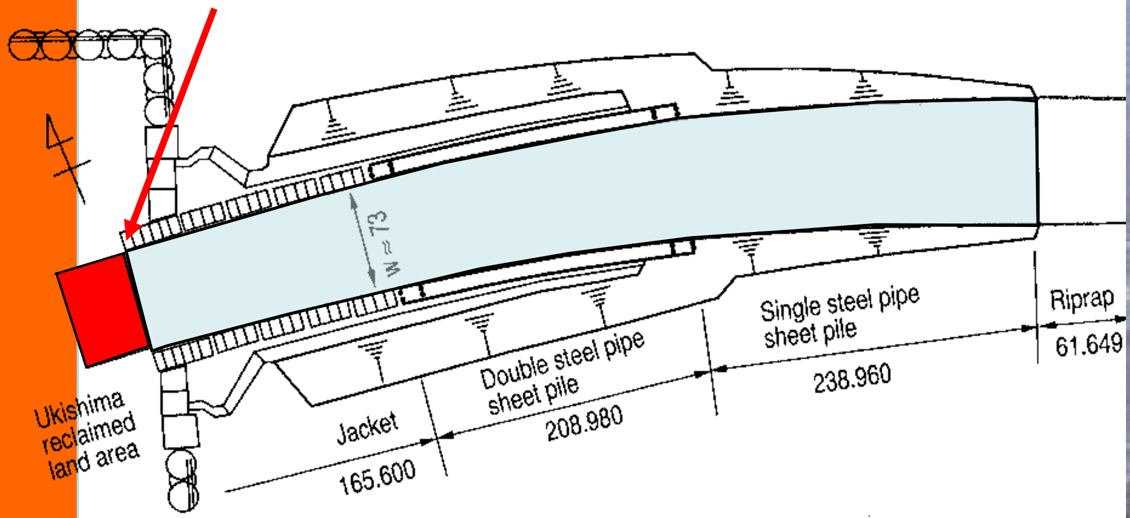
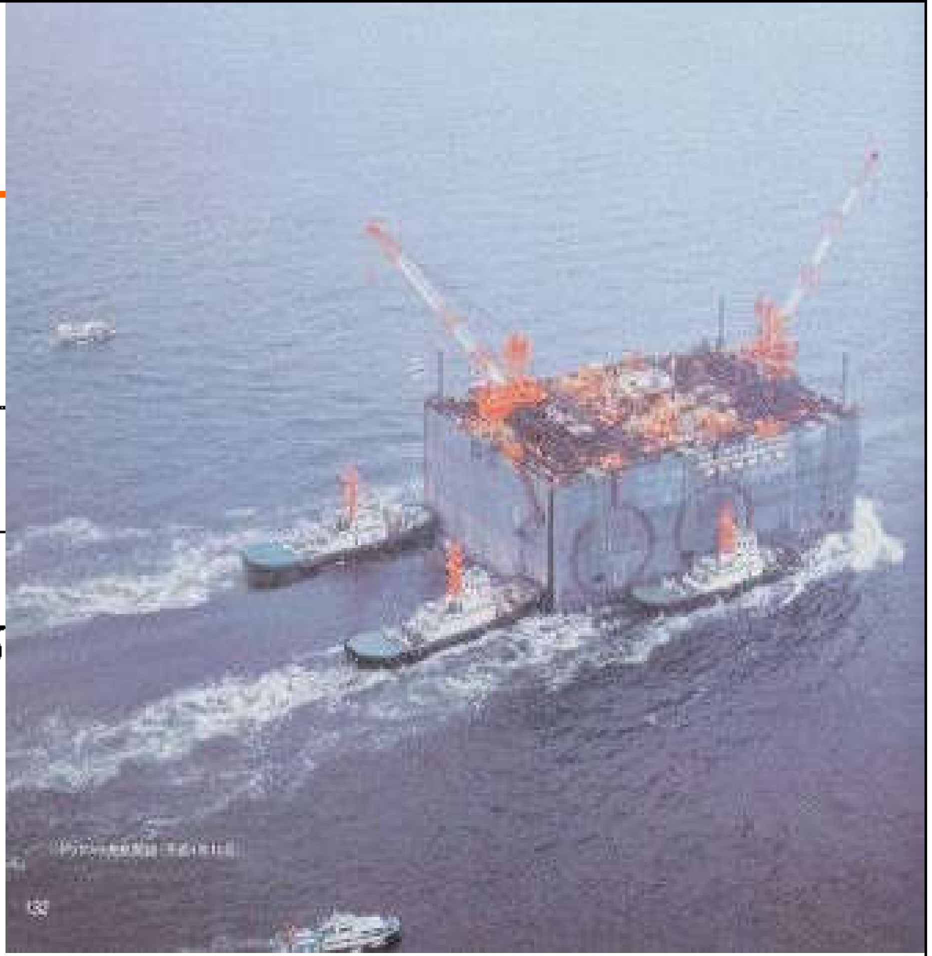
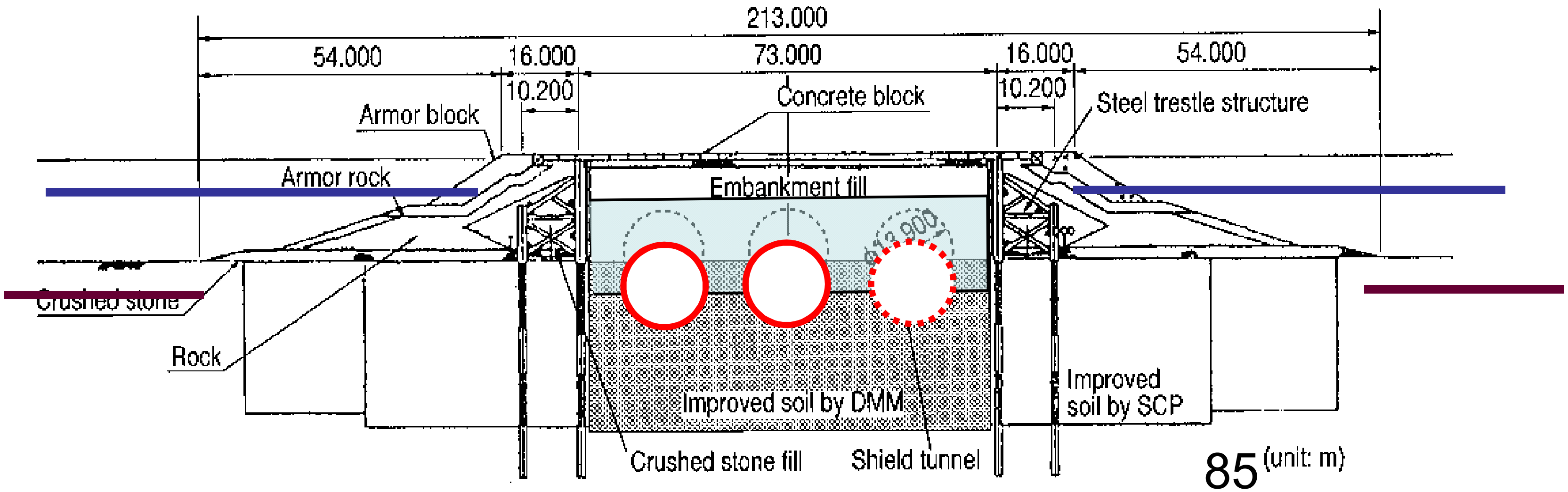


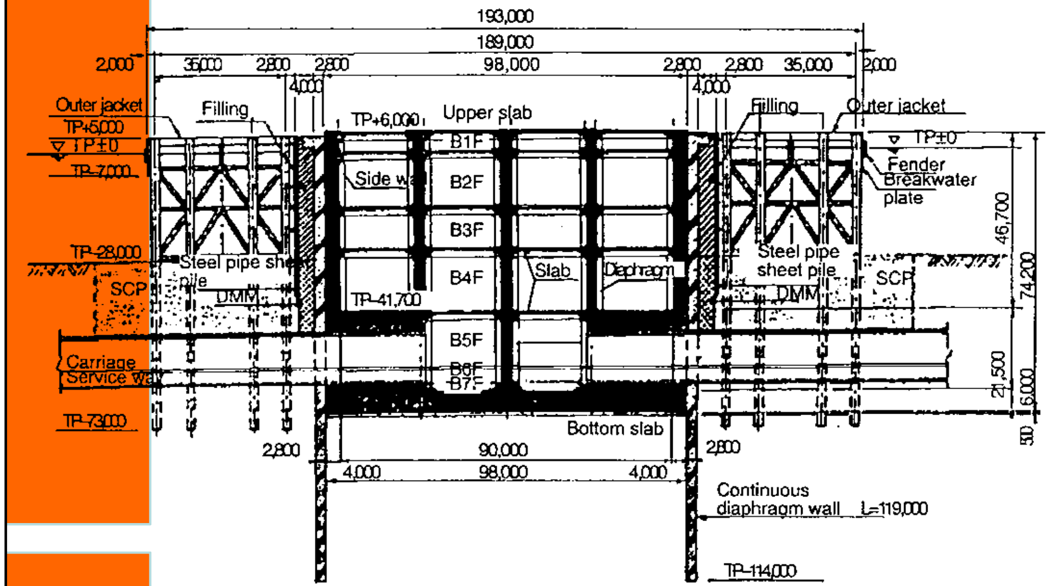



**Approach fill, retaining shield tunnels.**

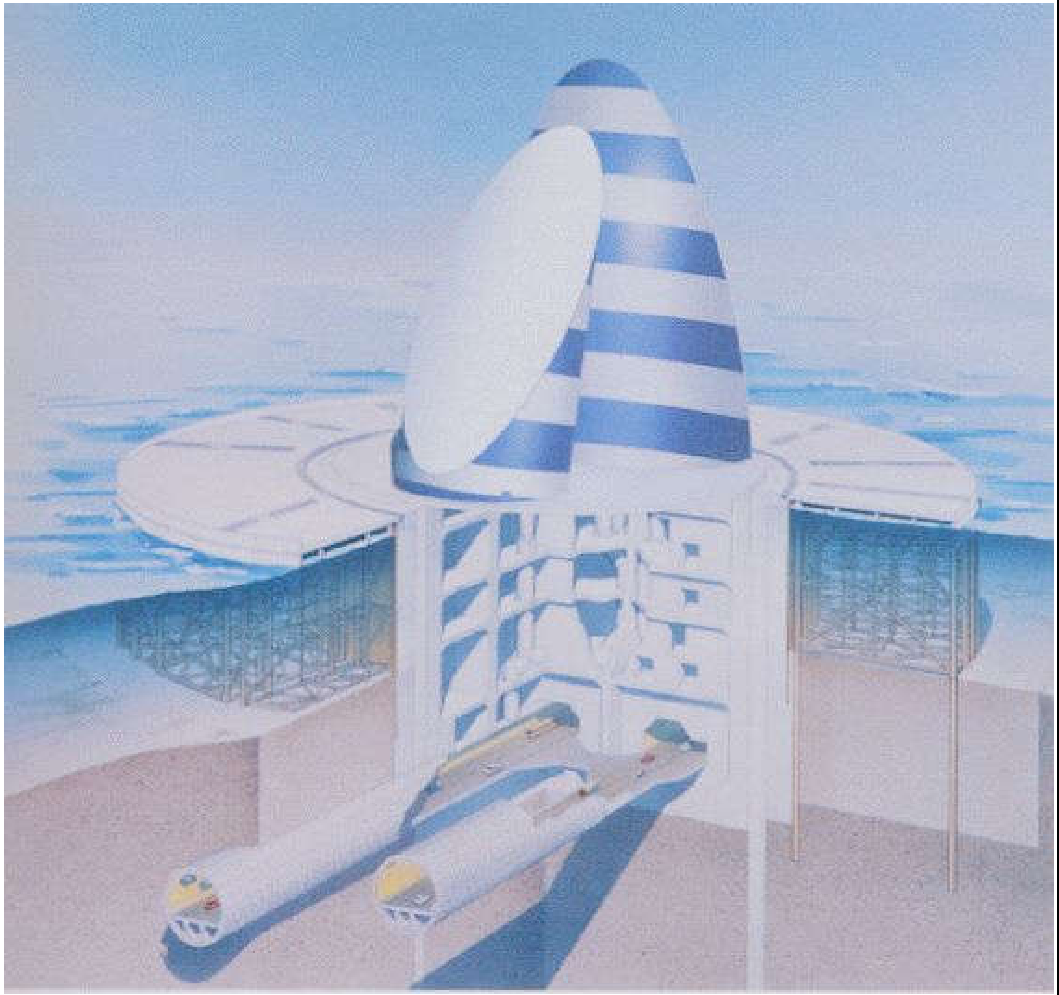


# Ukishima access

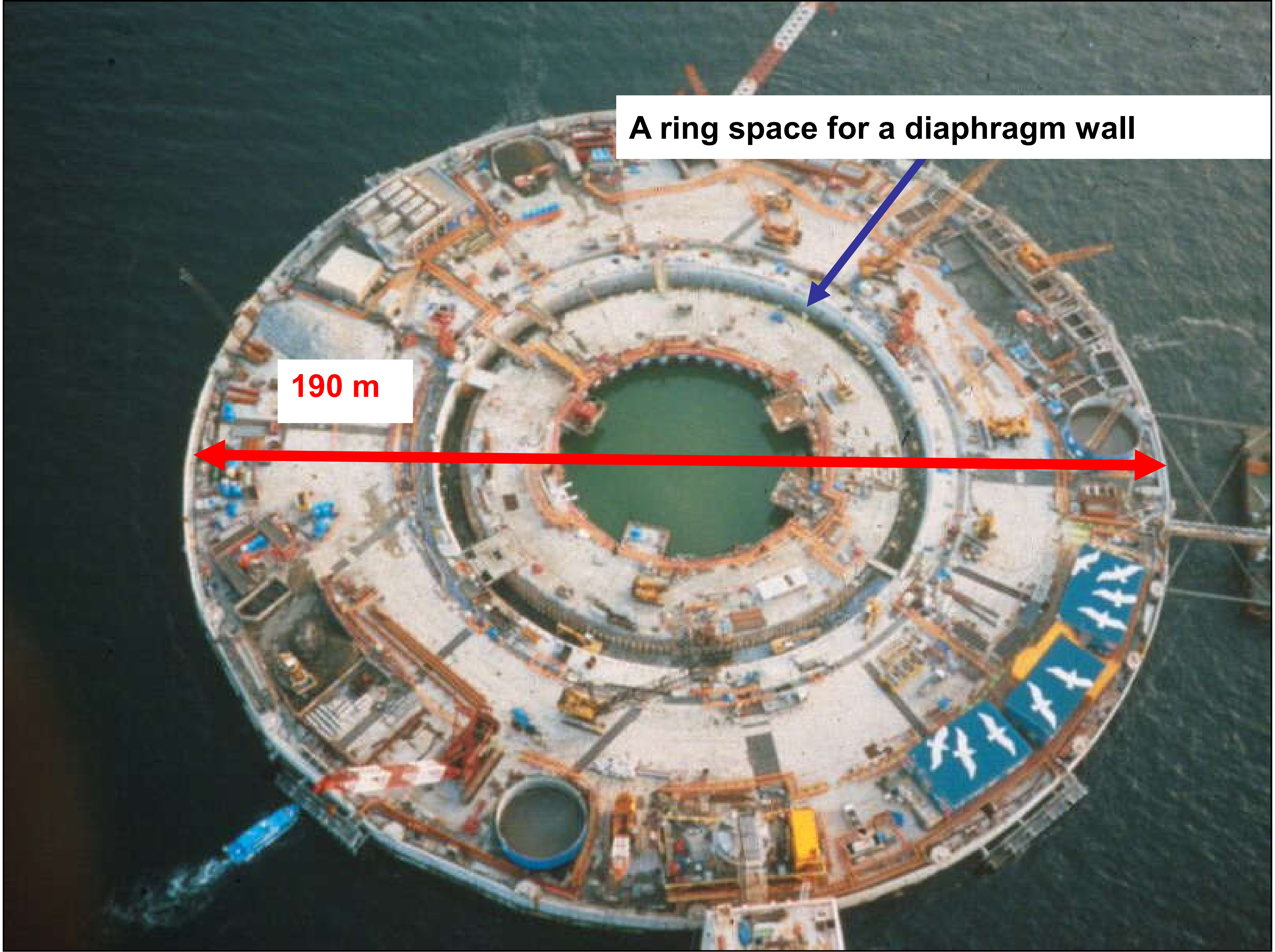
# Kawasaki man-made island



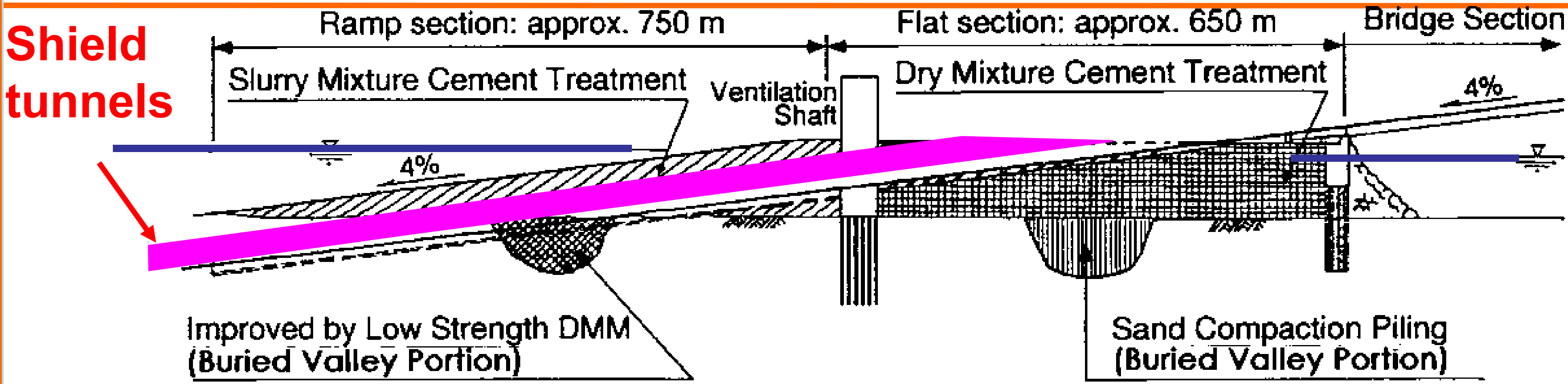

Cross-section

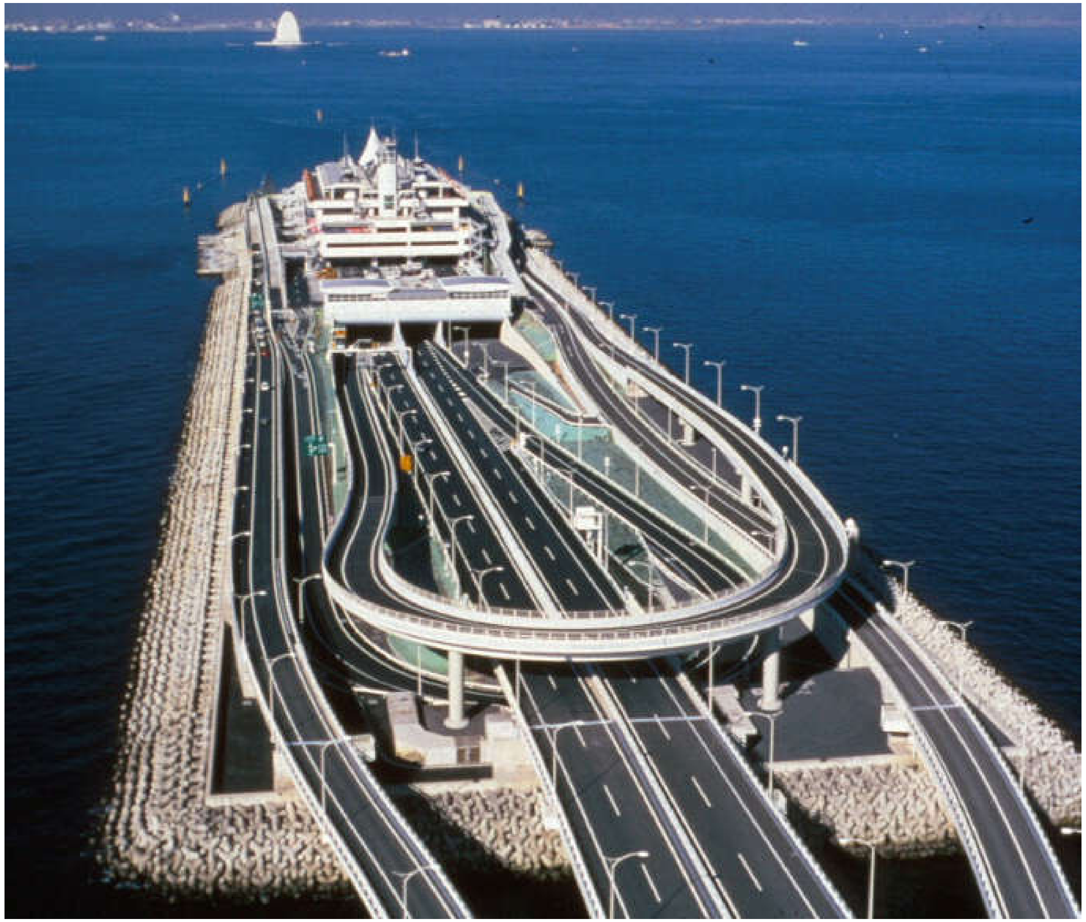


Artist’s view of the completed structure

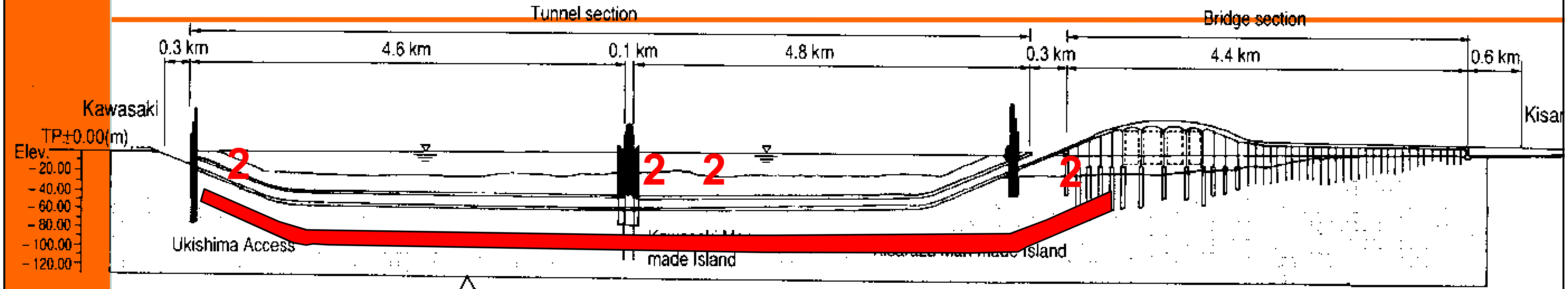

A ring space for a diaphragm wall
190 m

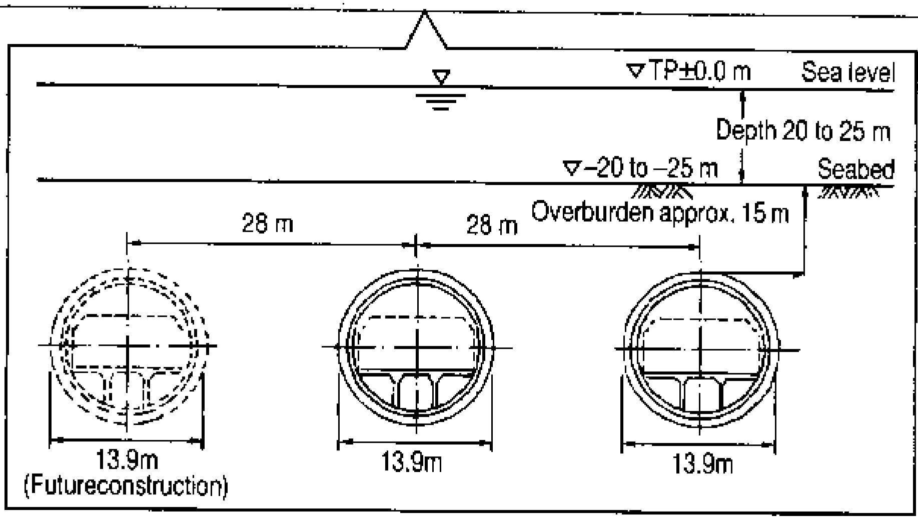
# Kisarazu man-made island



# Two 9.5 km-long shield tunnels

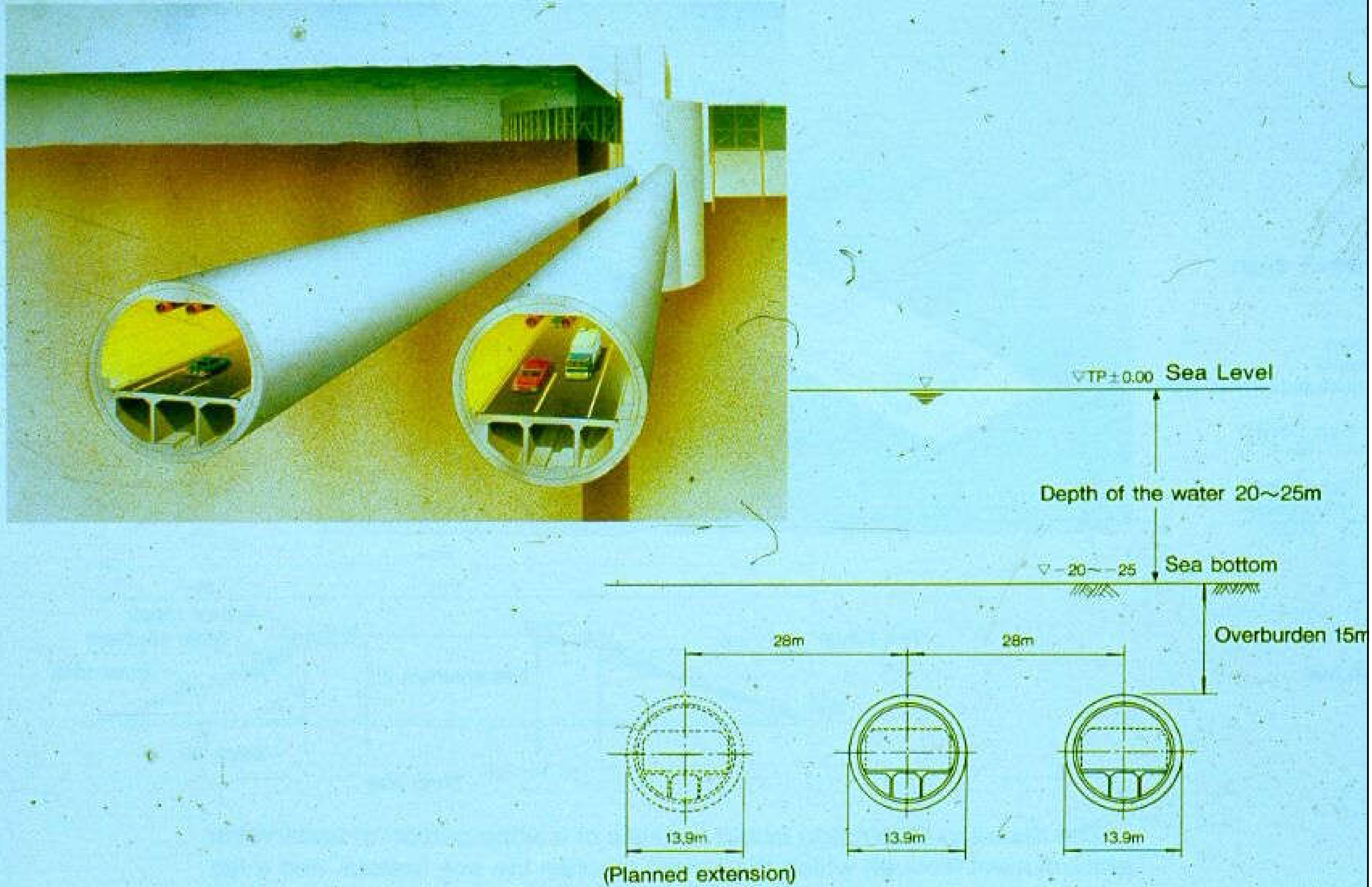


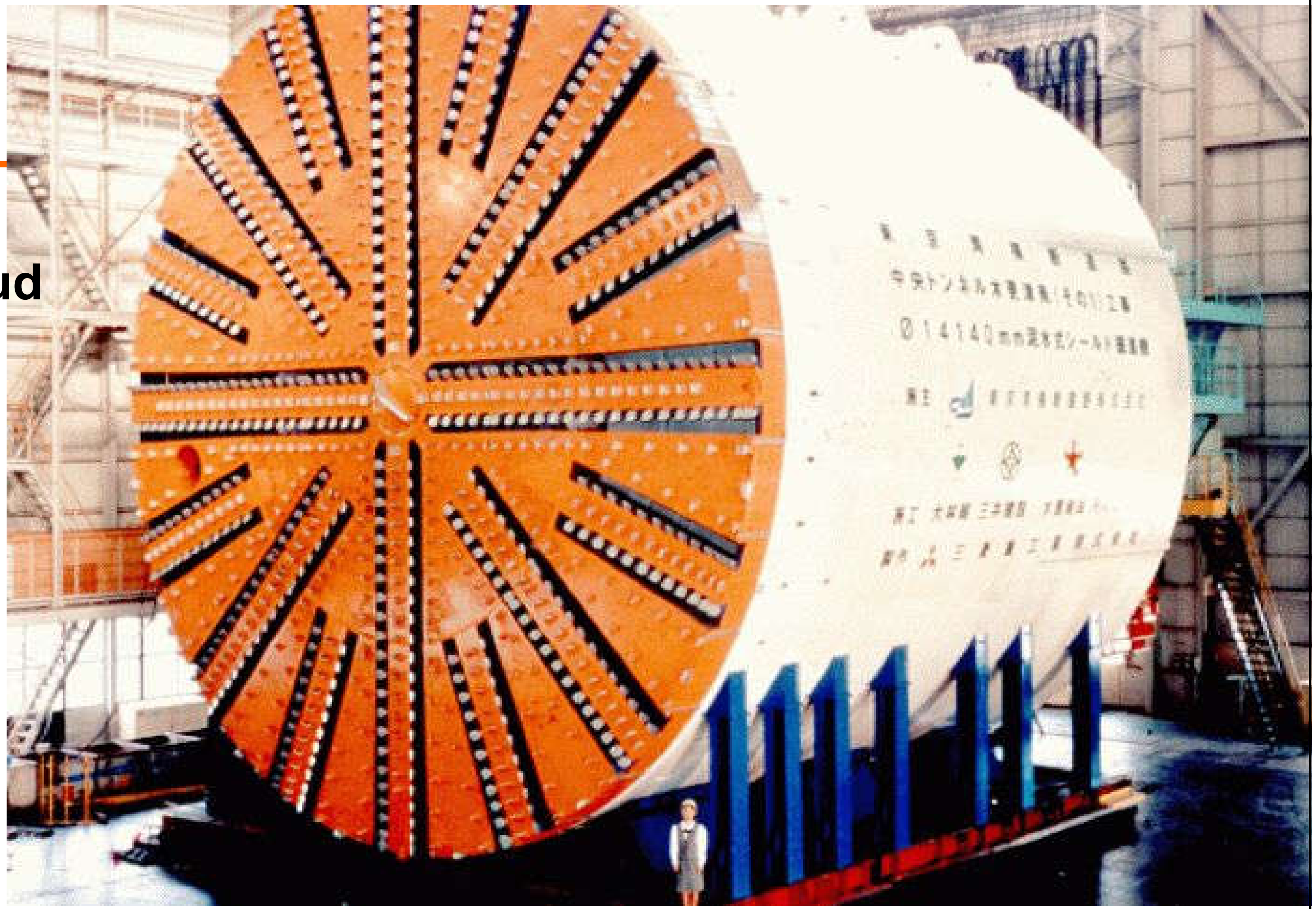

**Two tubes constructed**
**The third one for future**

**Eight shield tunnel machines worked simultaneously to reduce the total construction period.**

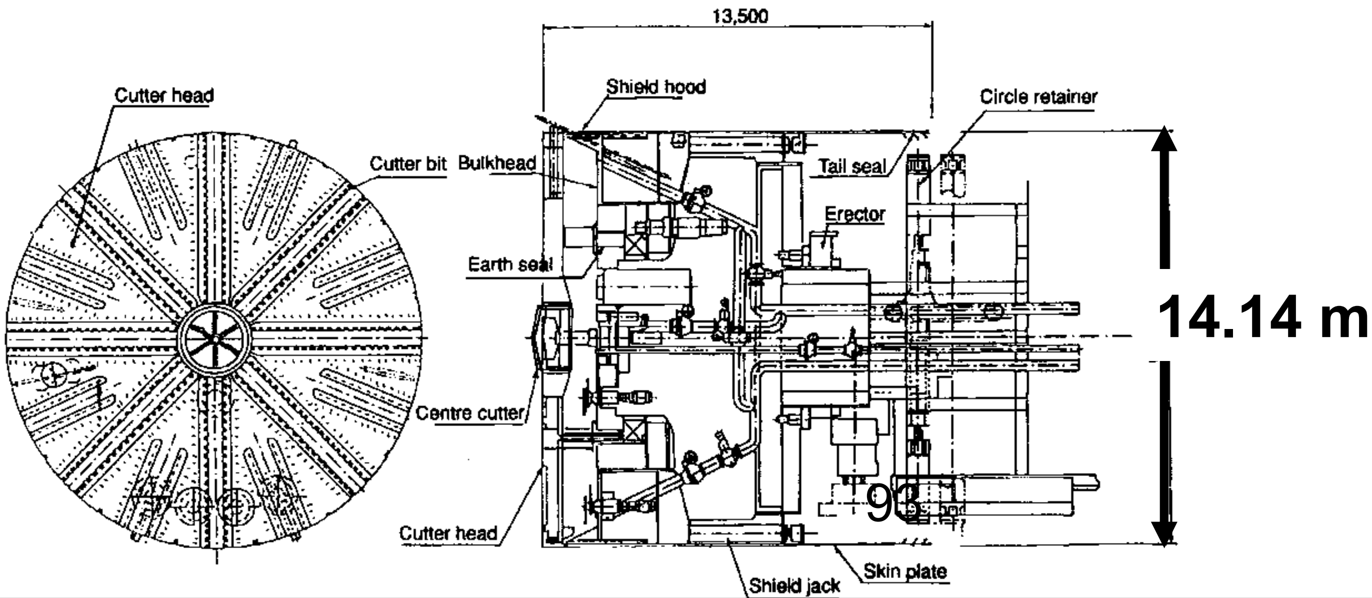
# Shield Tunnel

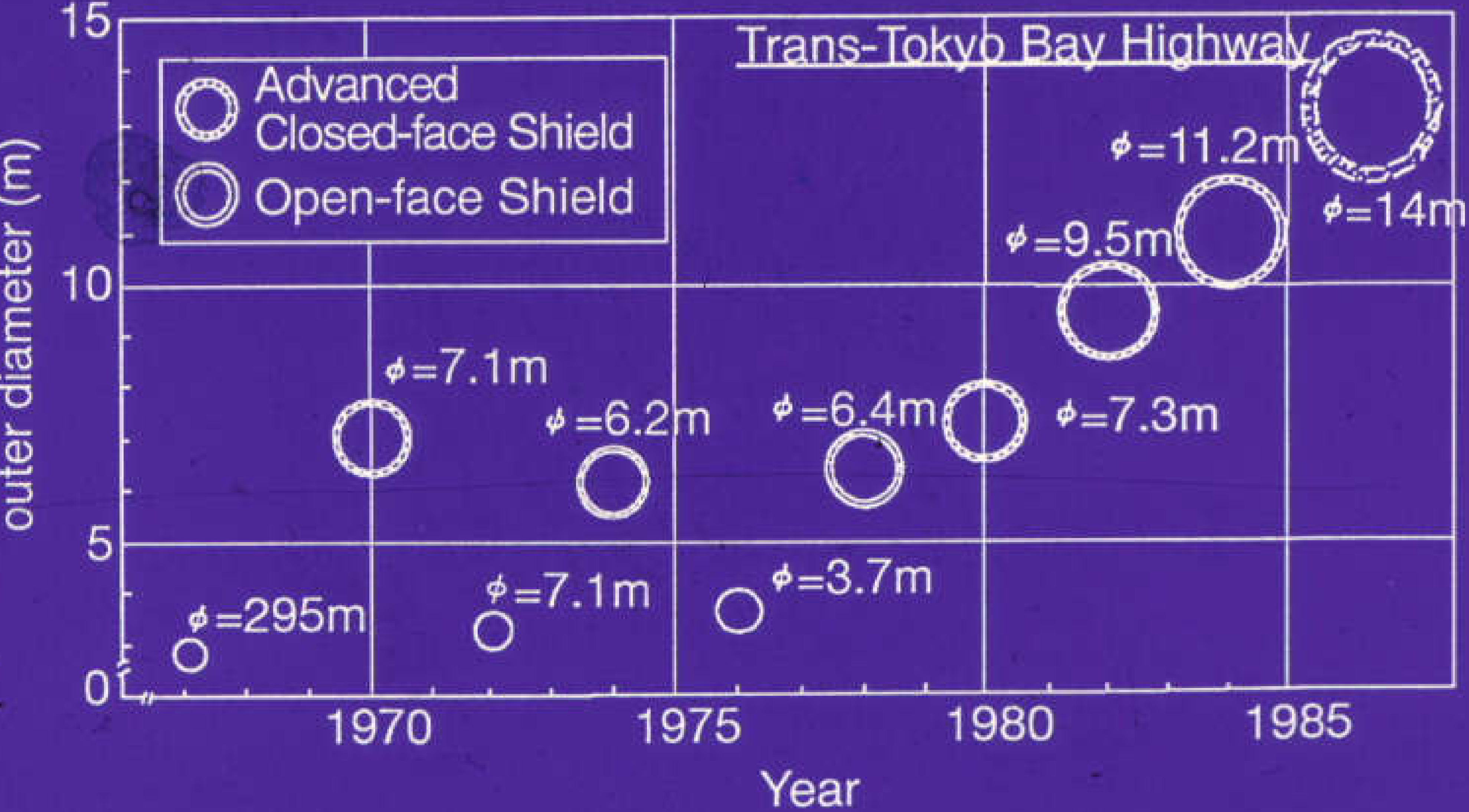


**Blind type**
**using pressurized mud slurry**



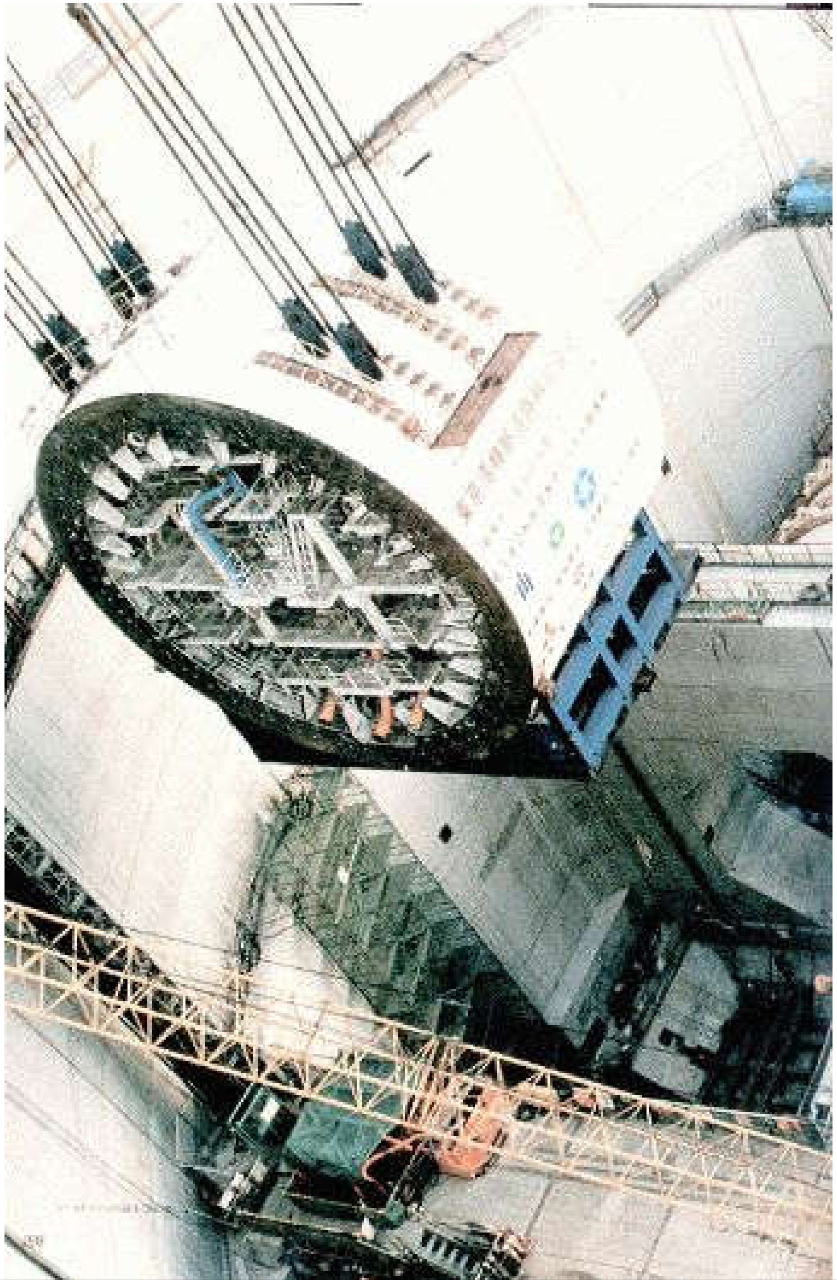
*The world's largest diameter at the time of construction*



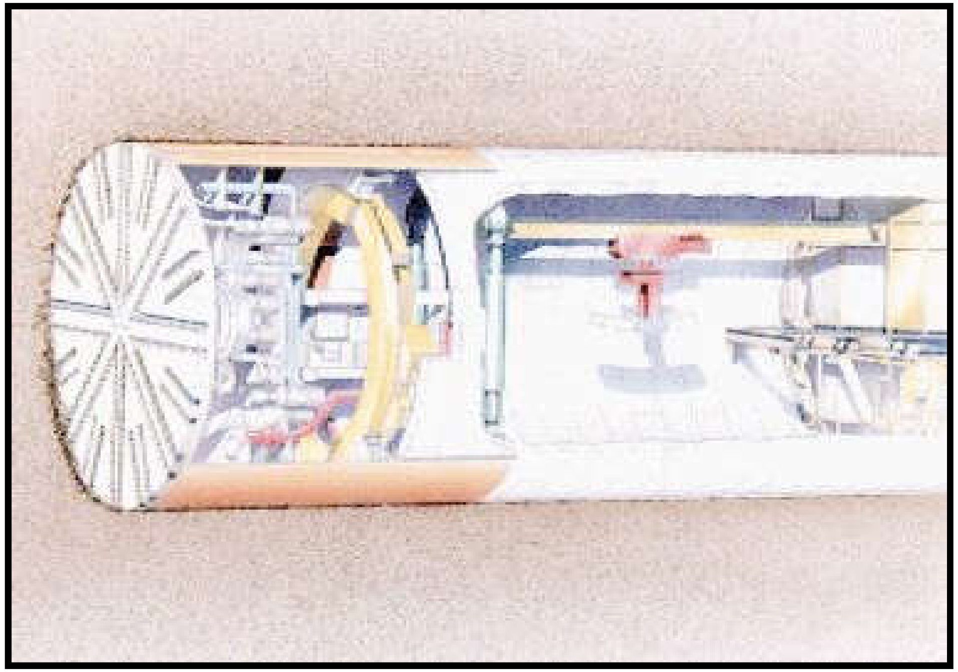


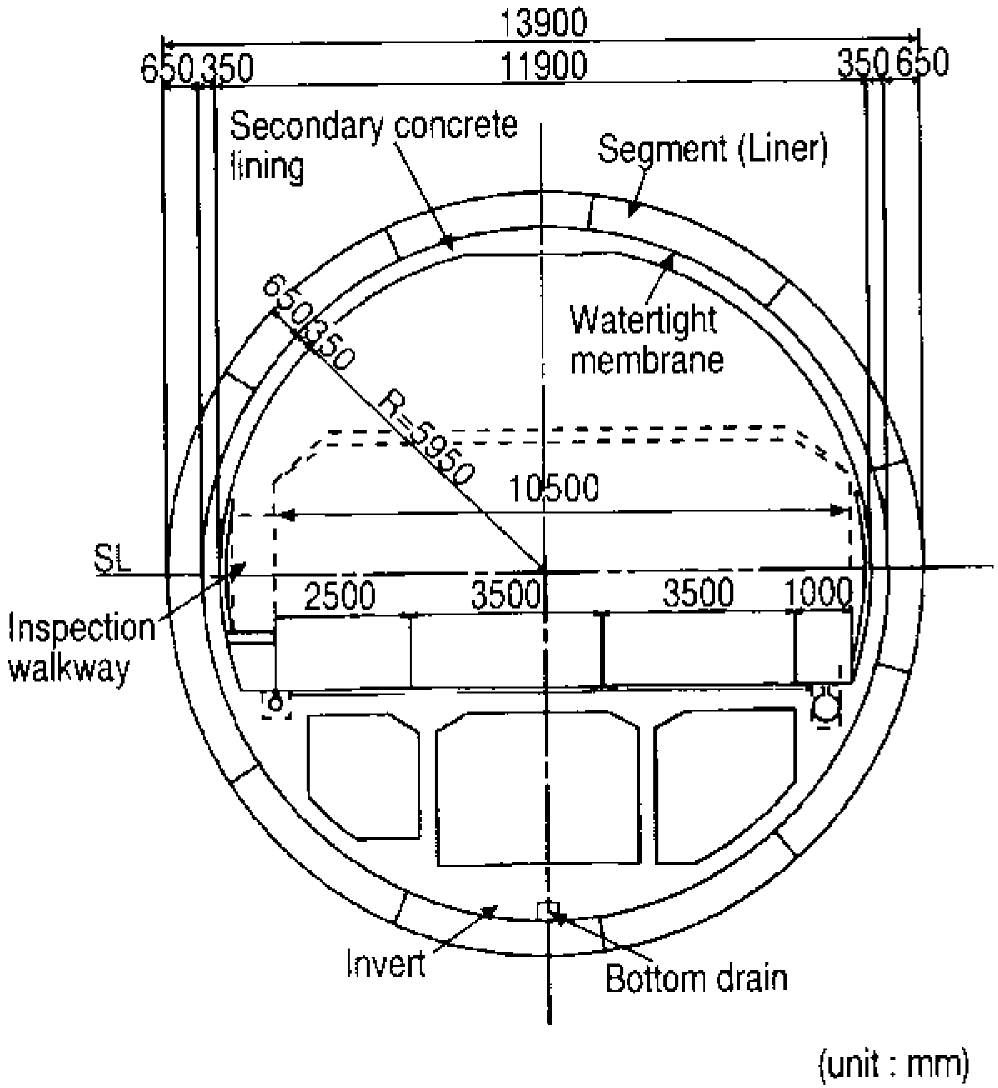

**Developments in shield tunnel diameter**

# Shield tunnel machine re-assembled to start from Kawasaki m-m island



# Two 9.5 km-long shield tunnels





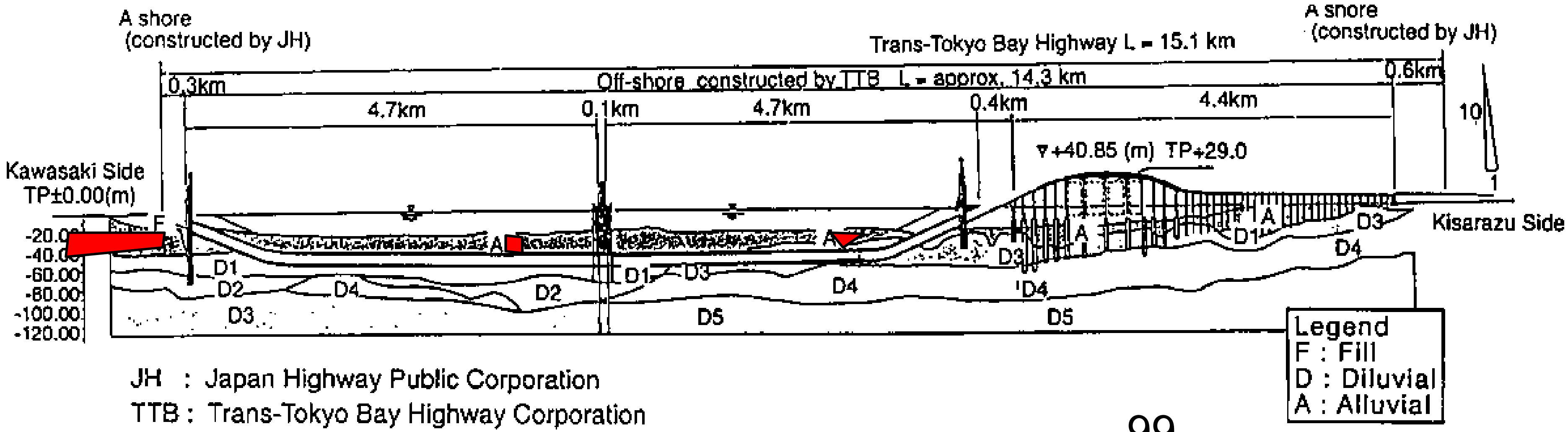
RC segments

## Secondary inner RC lining (inside the RC segments)

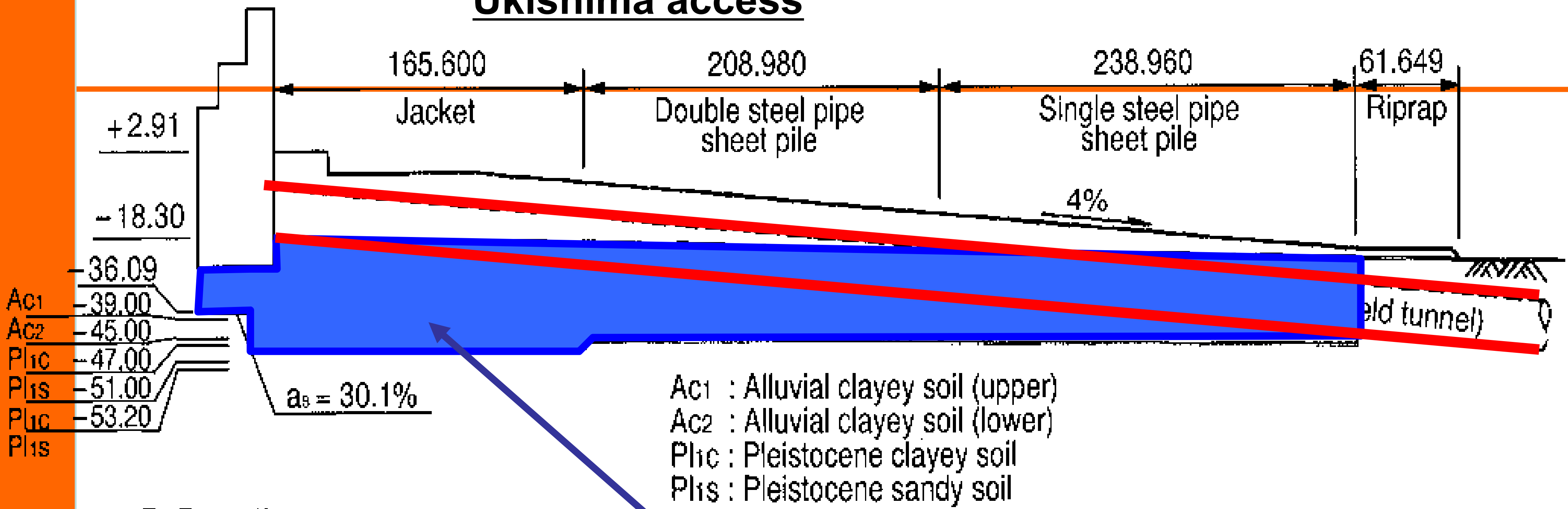
RC segments

## Significant design and construction issues related to geotechnical engineering:

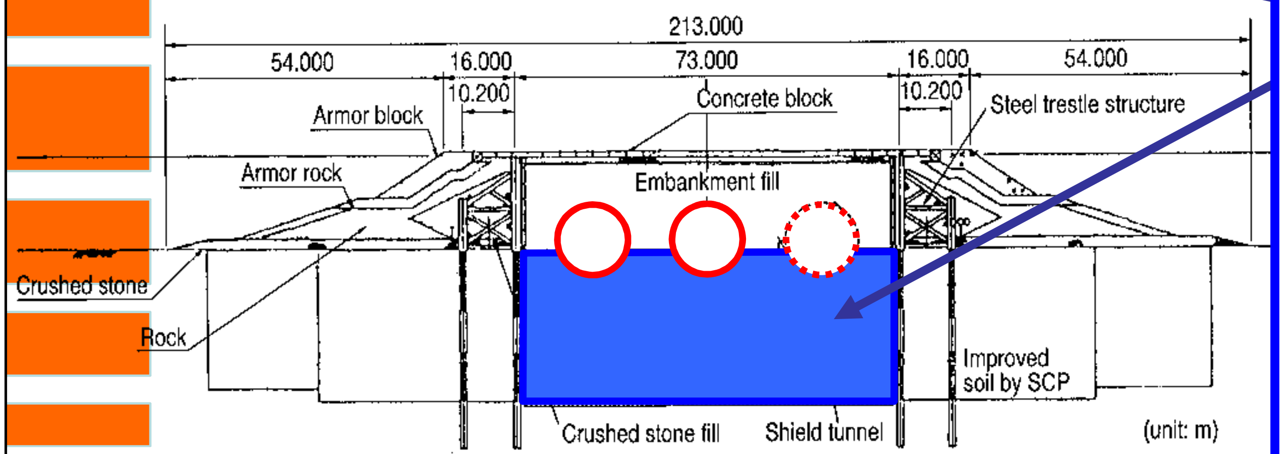
**Large-scale improvement of existing soft clay deposits by in-situ cement mixing,**
**- controlling the strength of cement-mixed soft clay; and**
**- in total 3.77 million $m^3$.**



# Ukishima access




B–B section

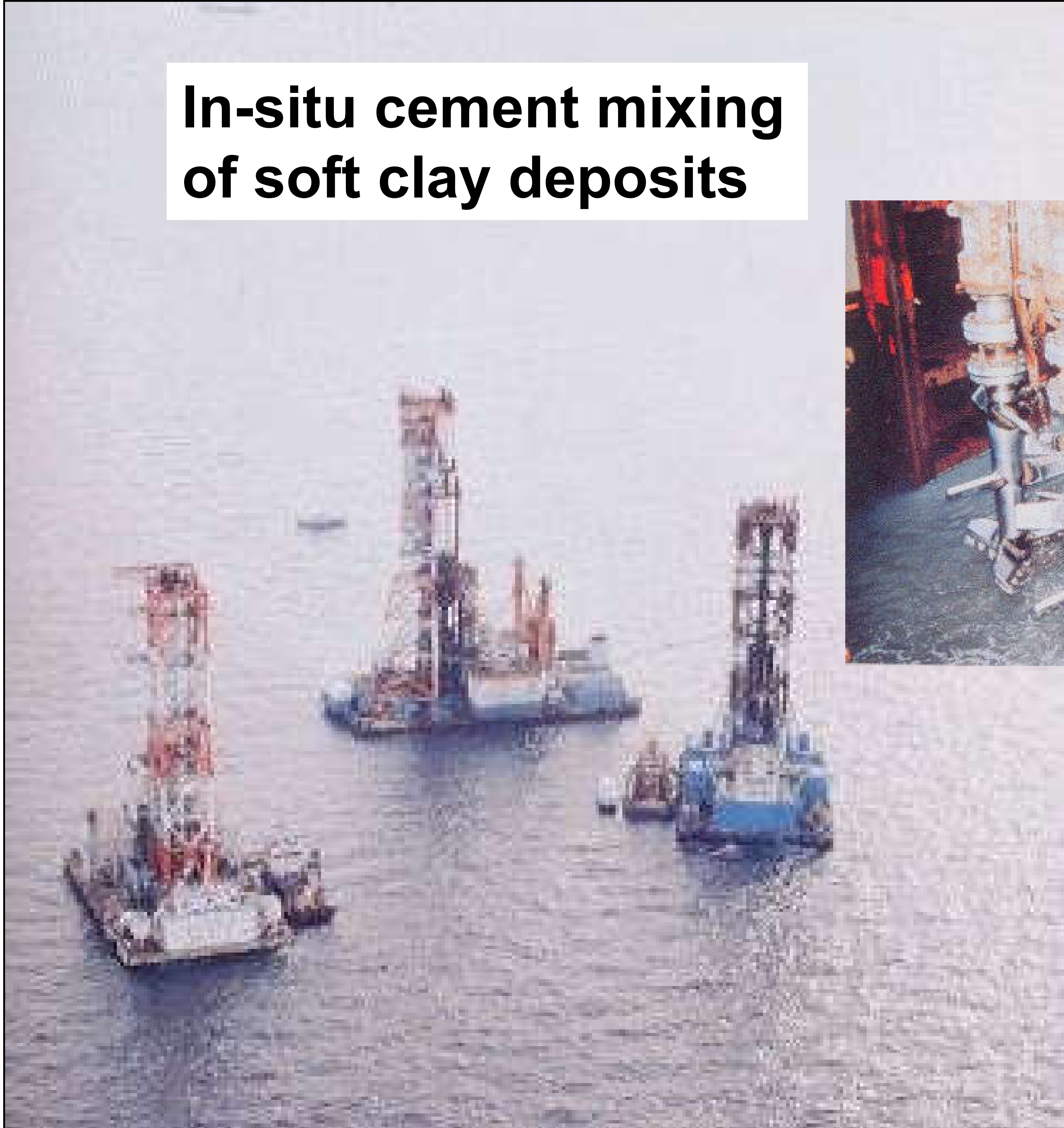



**Very soft clay improved by in-situ cement-mixing, achieving a controlled strength; i.e.,**

**a) strong enough for the stability of the structure; and**

**b) weak enough for smooth tunnelling.**

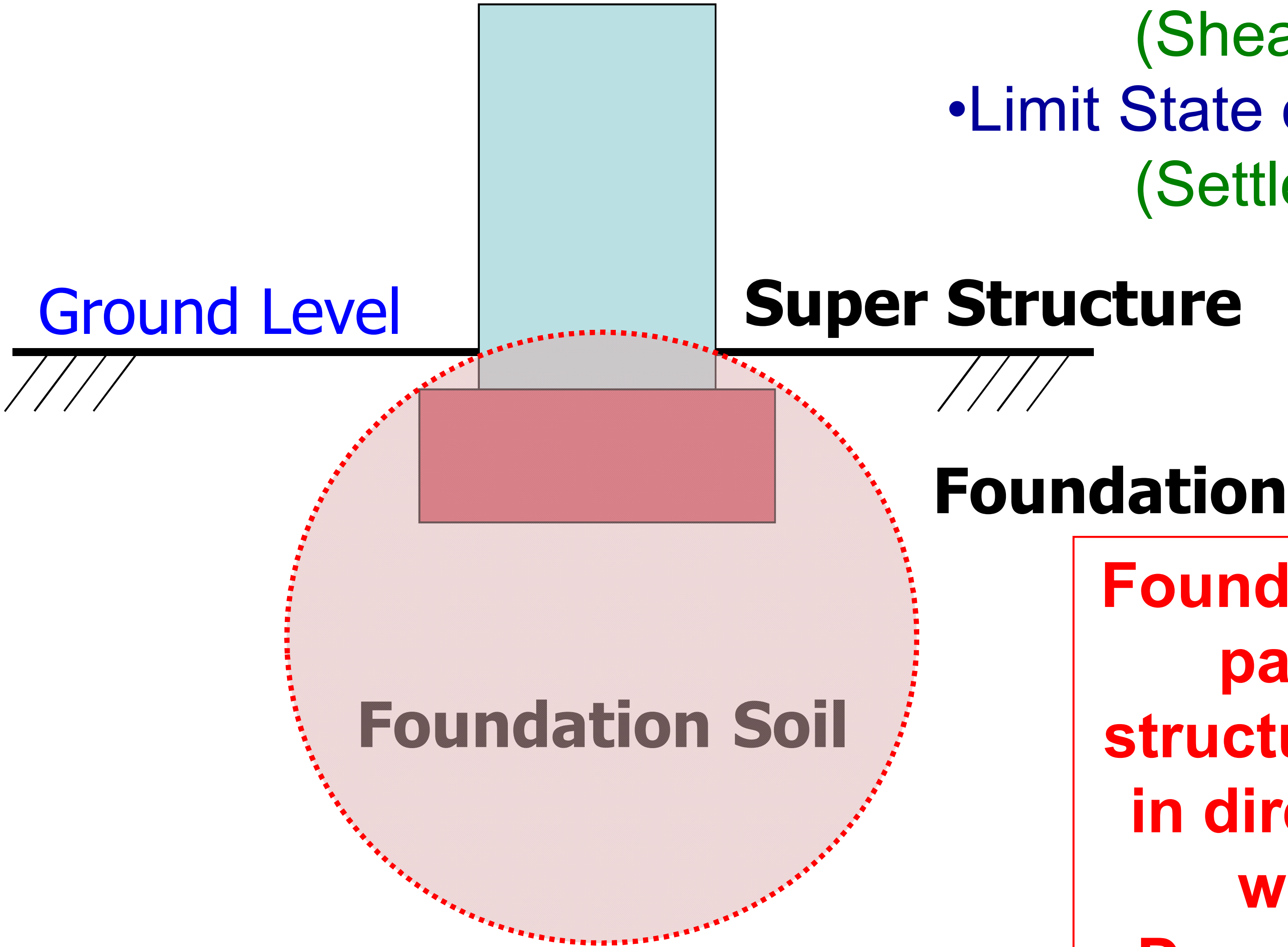
# In-situ cement mixing of soft clay deposits



# Important Geotechnical Structures

# For a geotechnical engineer,

- Limit State of Collapse
  (Shear Failure)
- Limit State of Serviceability
  (Settlement)




**Foundation is that part of the structure which is in direct contact with soil.**
**Do not abuse it.**

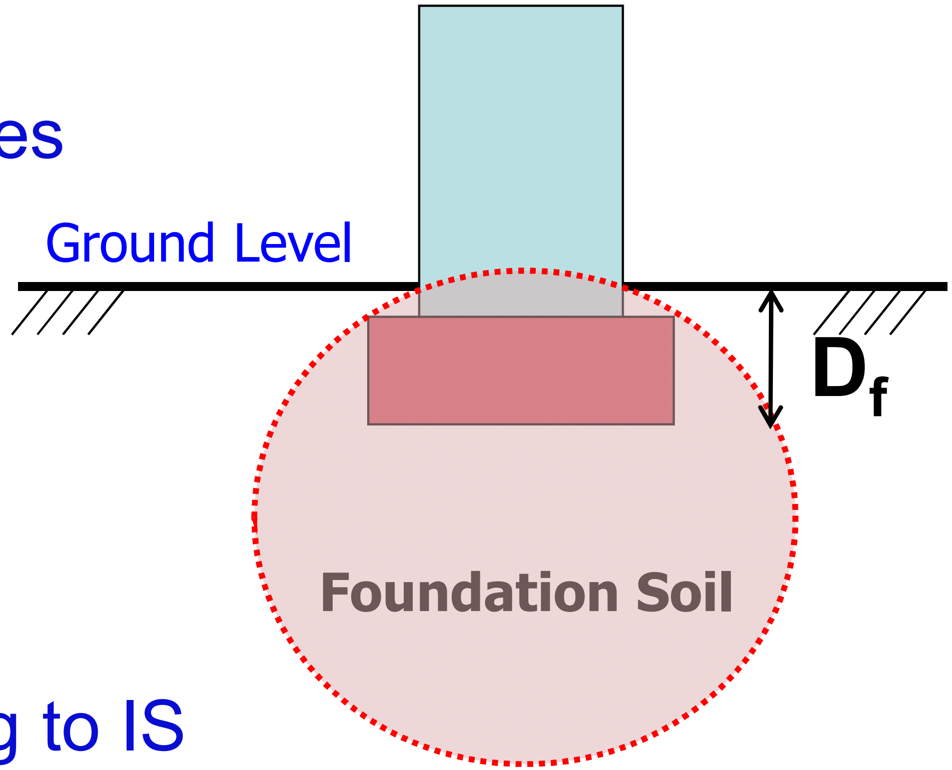
**Soil should resist forces without failure or excessive deformation**

# Purpose of Foundation

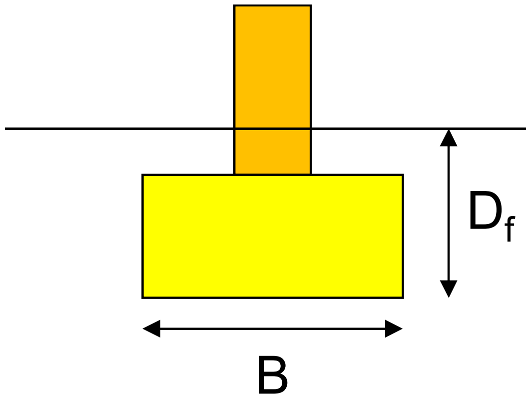
1. To transfer the forces from superstructure to firm soil below.
2. To distribute the stresses evenly on foundation soil such that foundation soil neither fails nor experiences excessive settlement.
3. To develop an anchor for stability against overturning.
4. To provide an even surface for smooth construction of superstructure.

# Factors influencing selection of Depth of Foundation

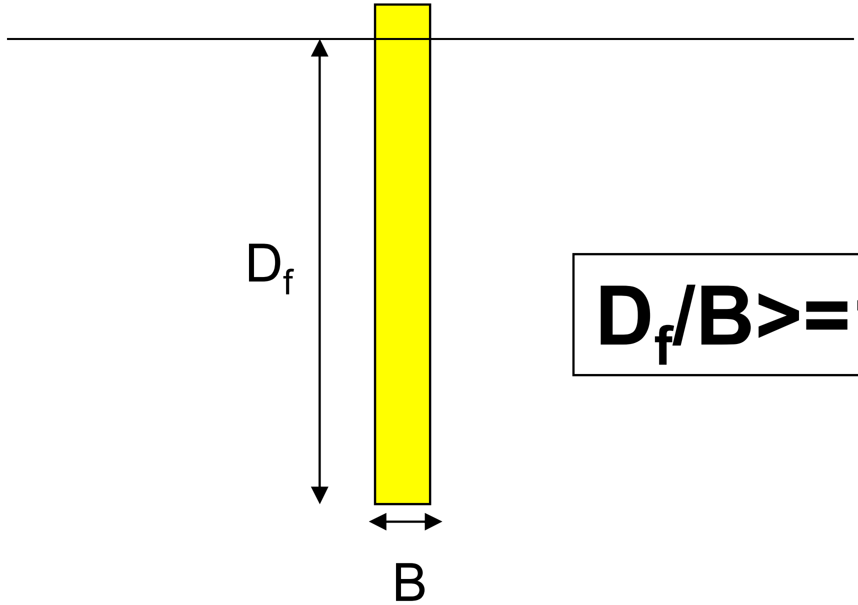
1. Bearing Capacity
2. Settlement Characteristics
3. Water Table
4. Seasonal Moisture changes
5. Freeze Thaw situation
6. Hydraulic considerations
7. Filled-up ground
8. Burrow animals
9. Neighbouring Structure
10. Sloping ground
11. Minimum depth according to IS
12. Height of Structure
13. Dynamic Load



# Types of Foundation




**$D_f/B < 1$**




**$D_f/B >= 1$**

## Shallow Foundation

- Wall footing
- Isolated Footing
- Combined footing
- Strap Footing
- Strip Footing
- Mat/Raft Foundation

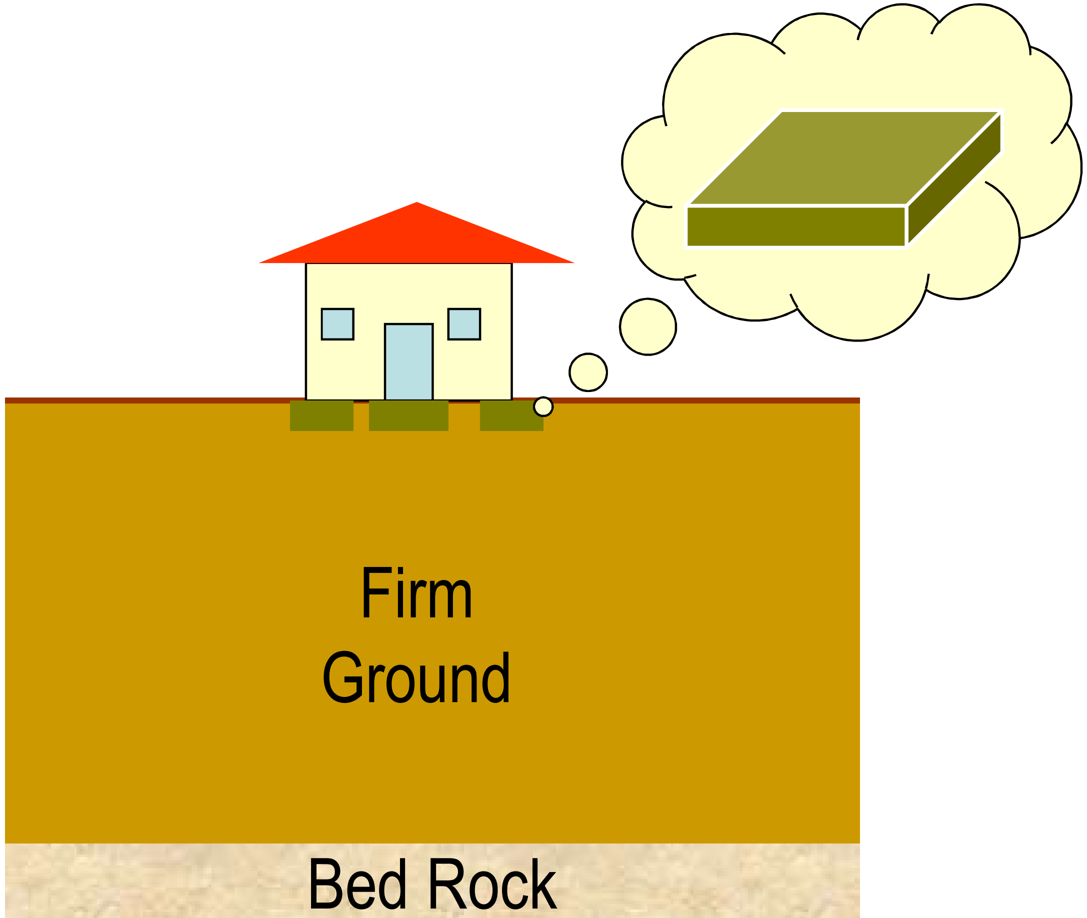
## Deep Foundation

- Pile Foundation
- Well Foundation

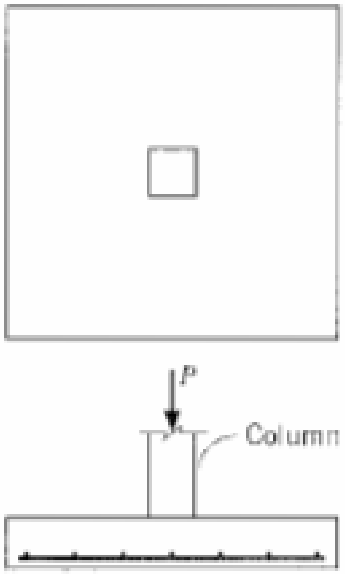
# Shallow Foundations

For transferring building loads to underlying ground

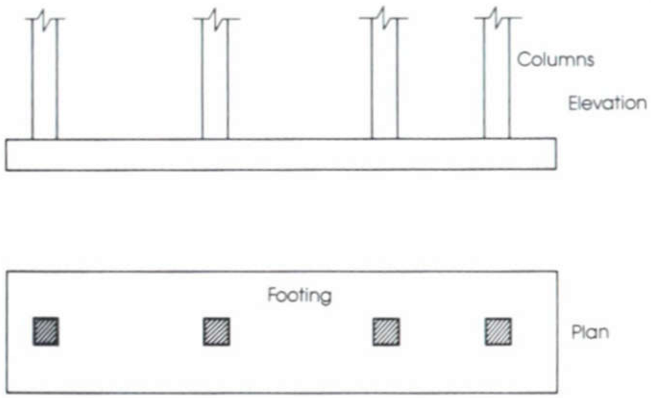
Mostly for firm soils or light loads



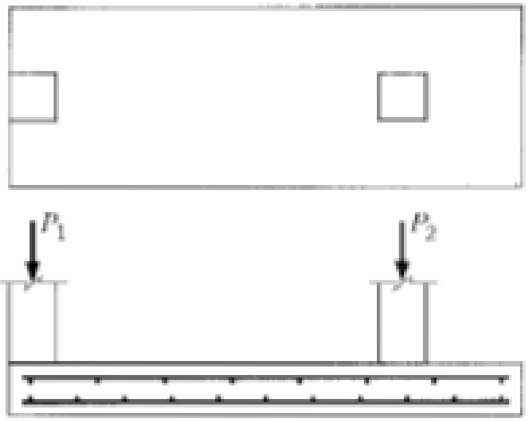
# Types of Shallow Foundation



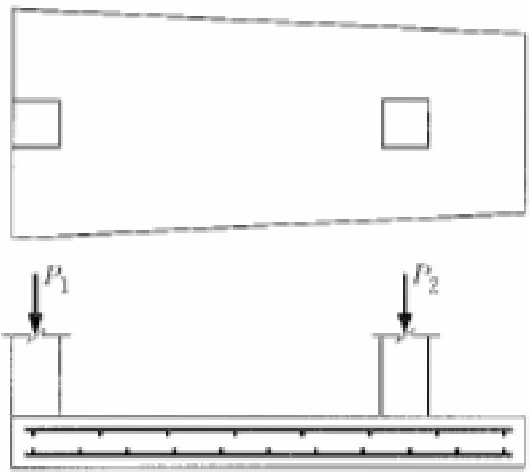

Isolated footing



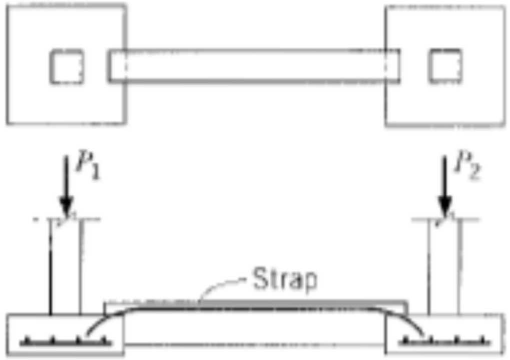

Strip Footing



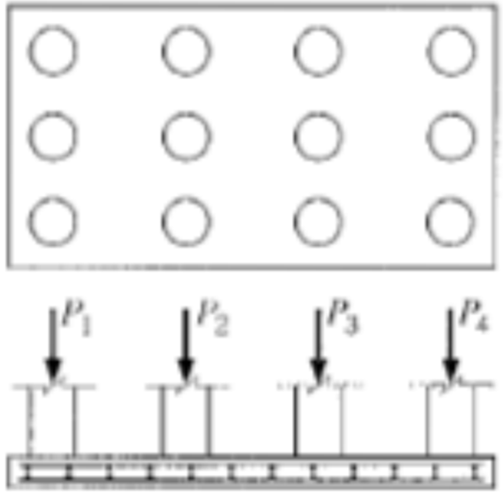

Combined footing




Trapezoidal footing




Cantilever or strap footing




Mat foundation

# Shallow Foundations

Examples of spread footings for residences and buildings.

# SHALLOW FOUNDATION


Combined Footing

Grade Beam


Mat Foundation

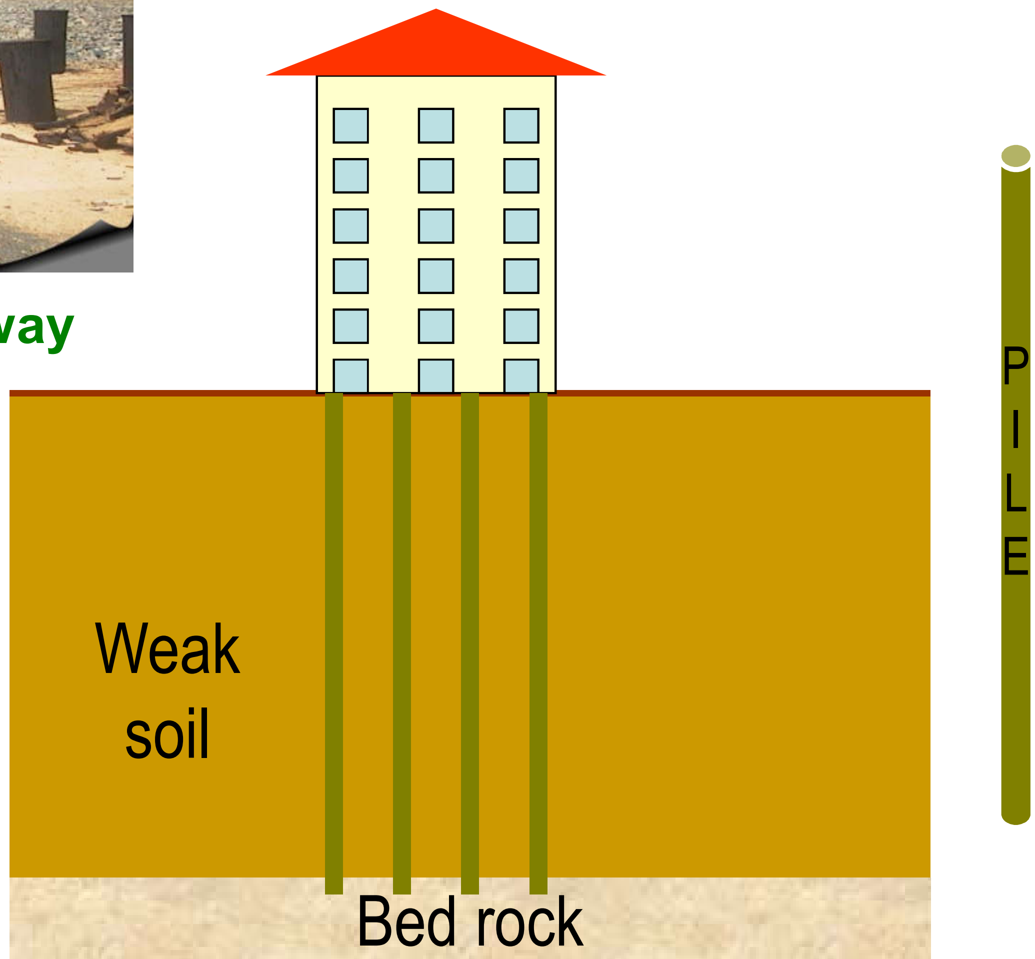
Strip Footing

# Deep Foundations

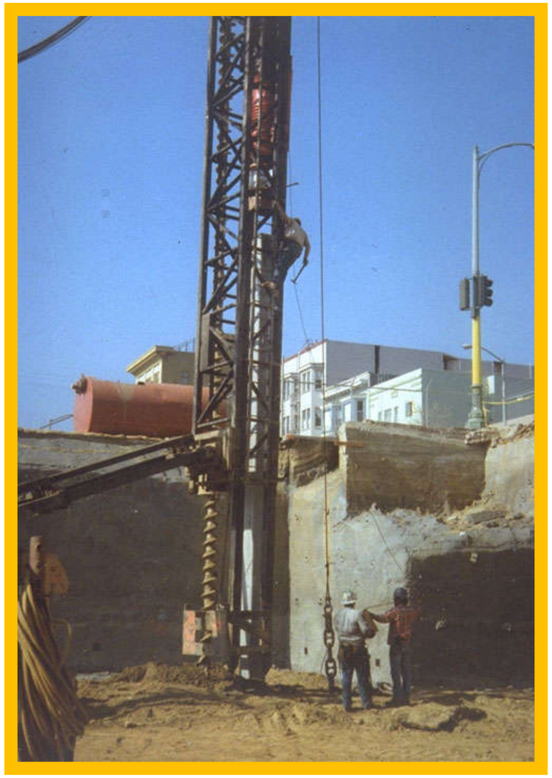
**Driven timber piles, Pacific Highway**

For transferring building loads to underlying ground

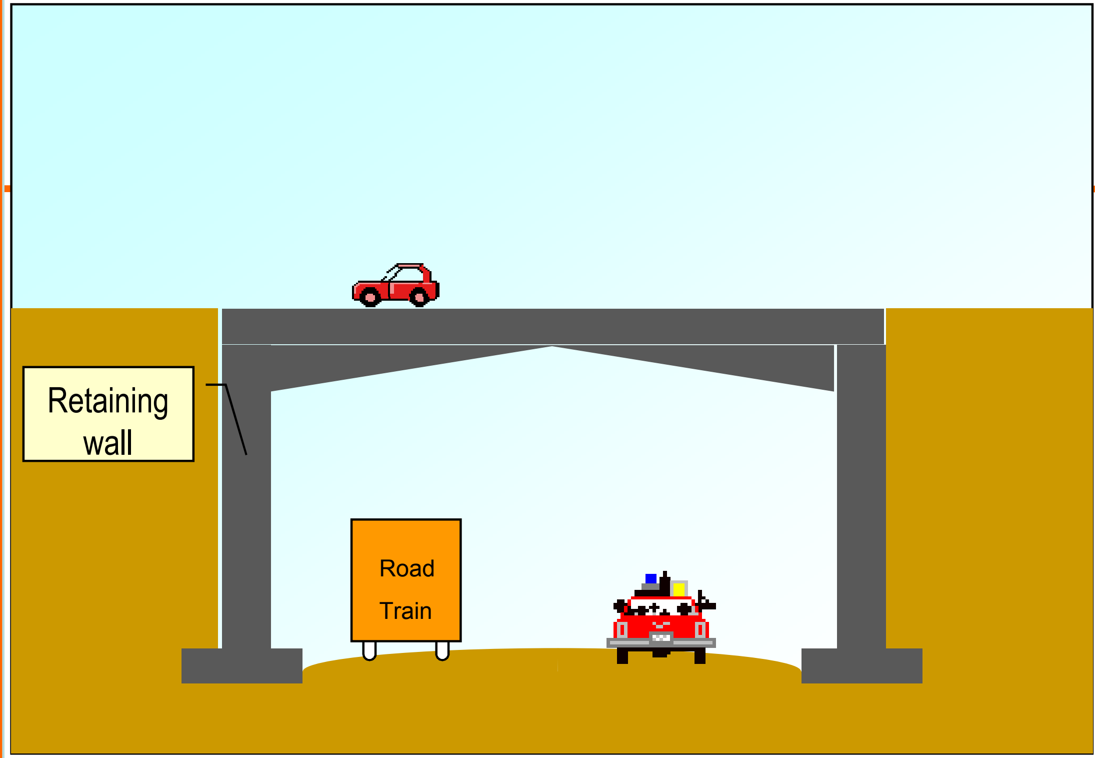
Mostly for weak soils or heavy loads

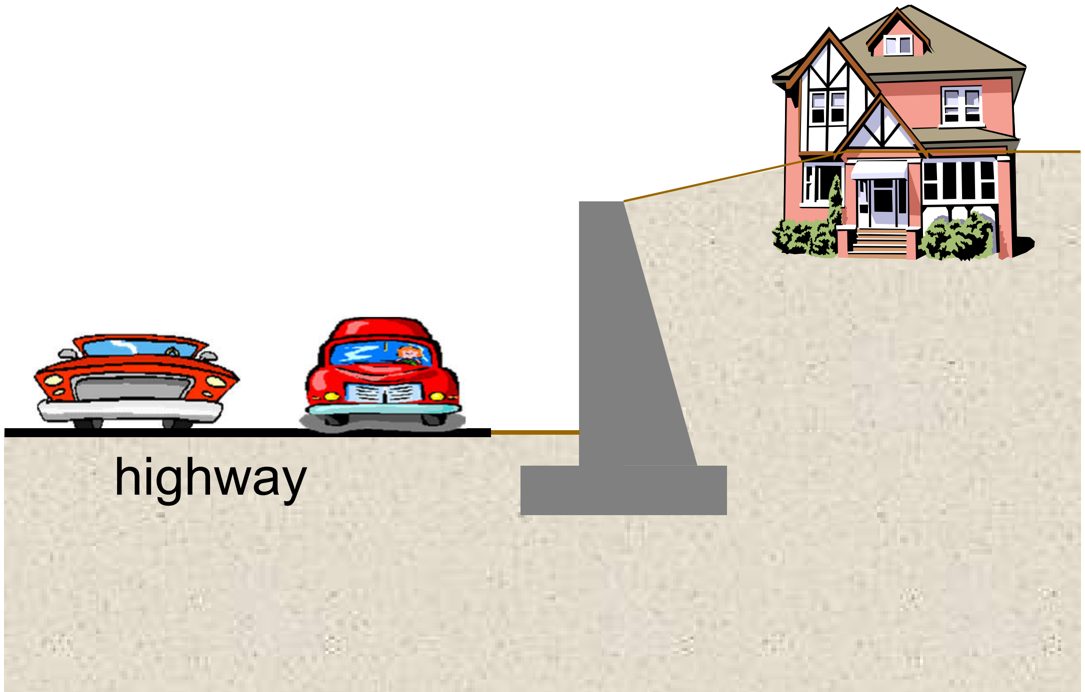


# Pile Foundation

# Retaining Walls

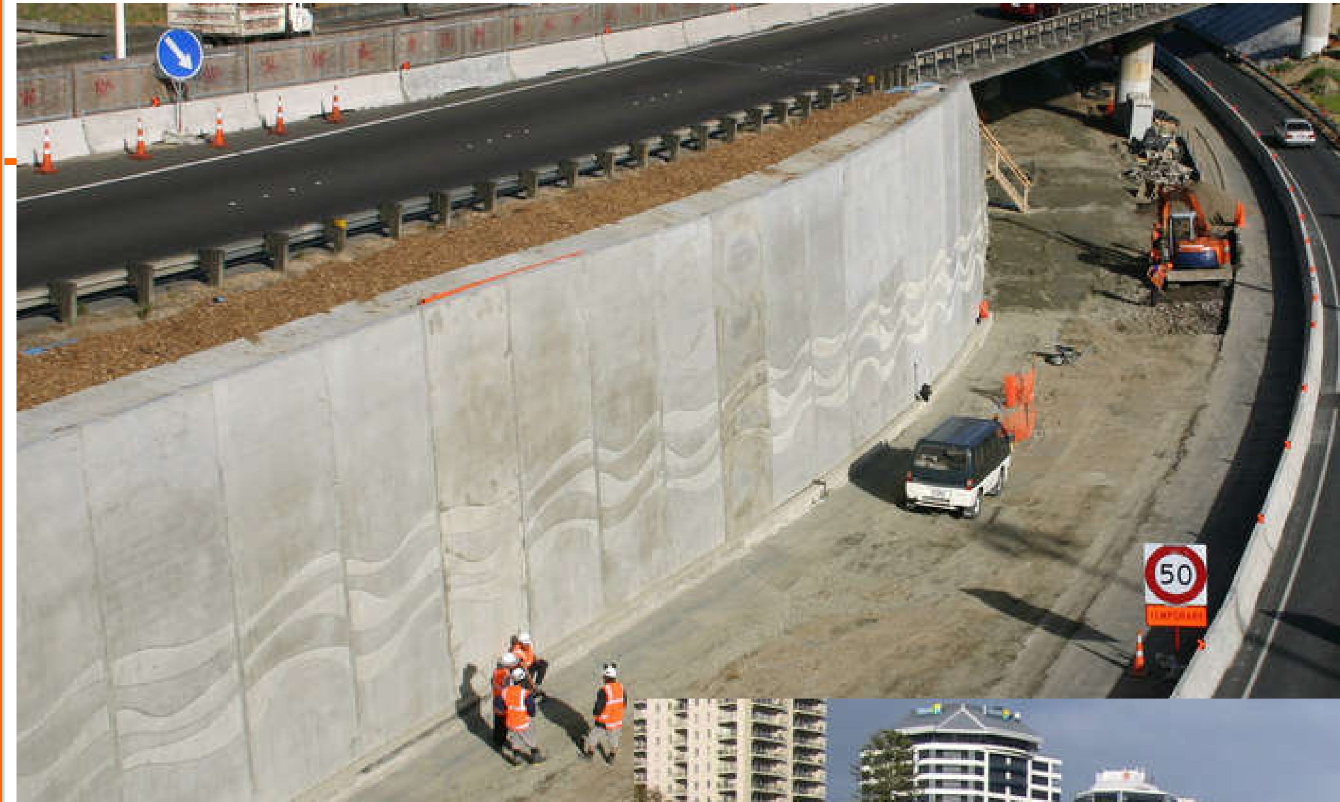


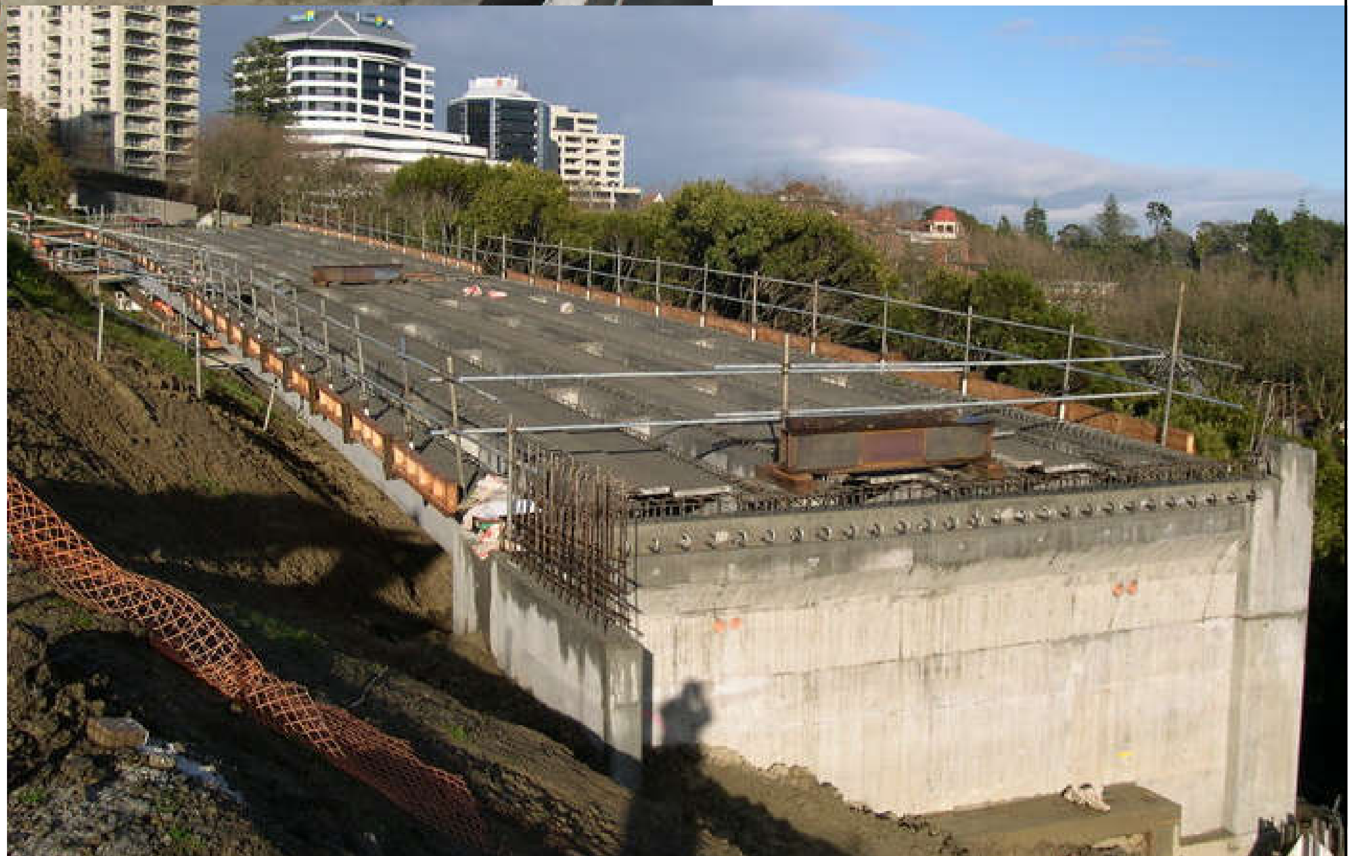




For retaining soils from spreading laterally

# Retaining Walls

# Retaining Walls



# Retaining Walls

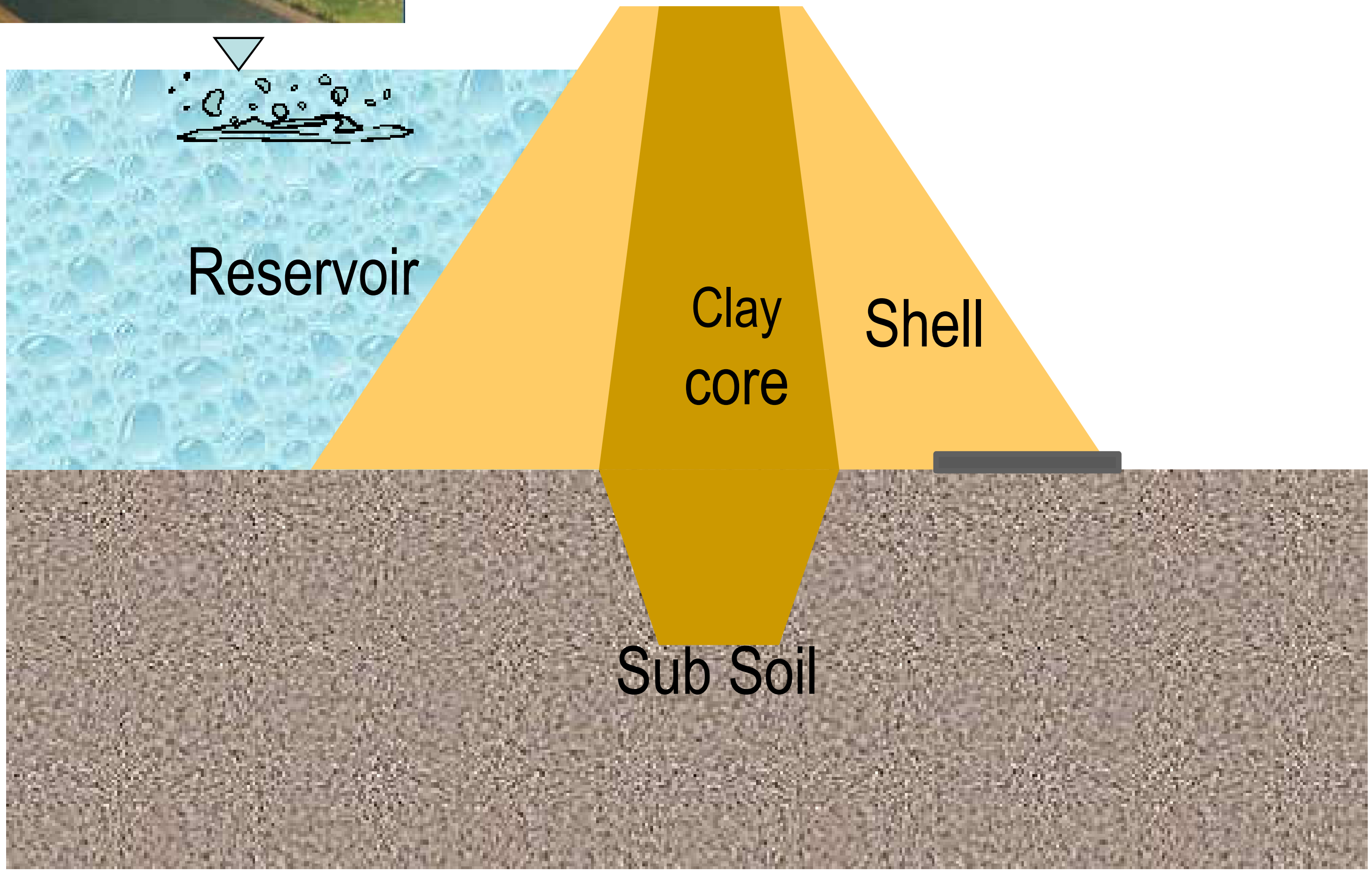
# Retaining Walls

# Retaining Walls



# Earth Dams

For impounding water



# Earth Dam

# Earth Embankments



# Earth Embankments

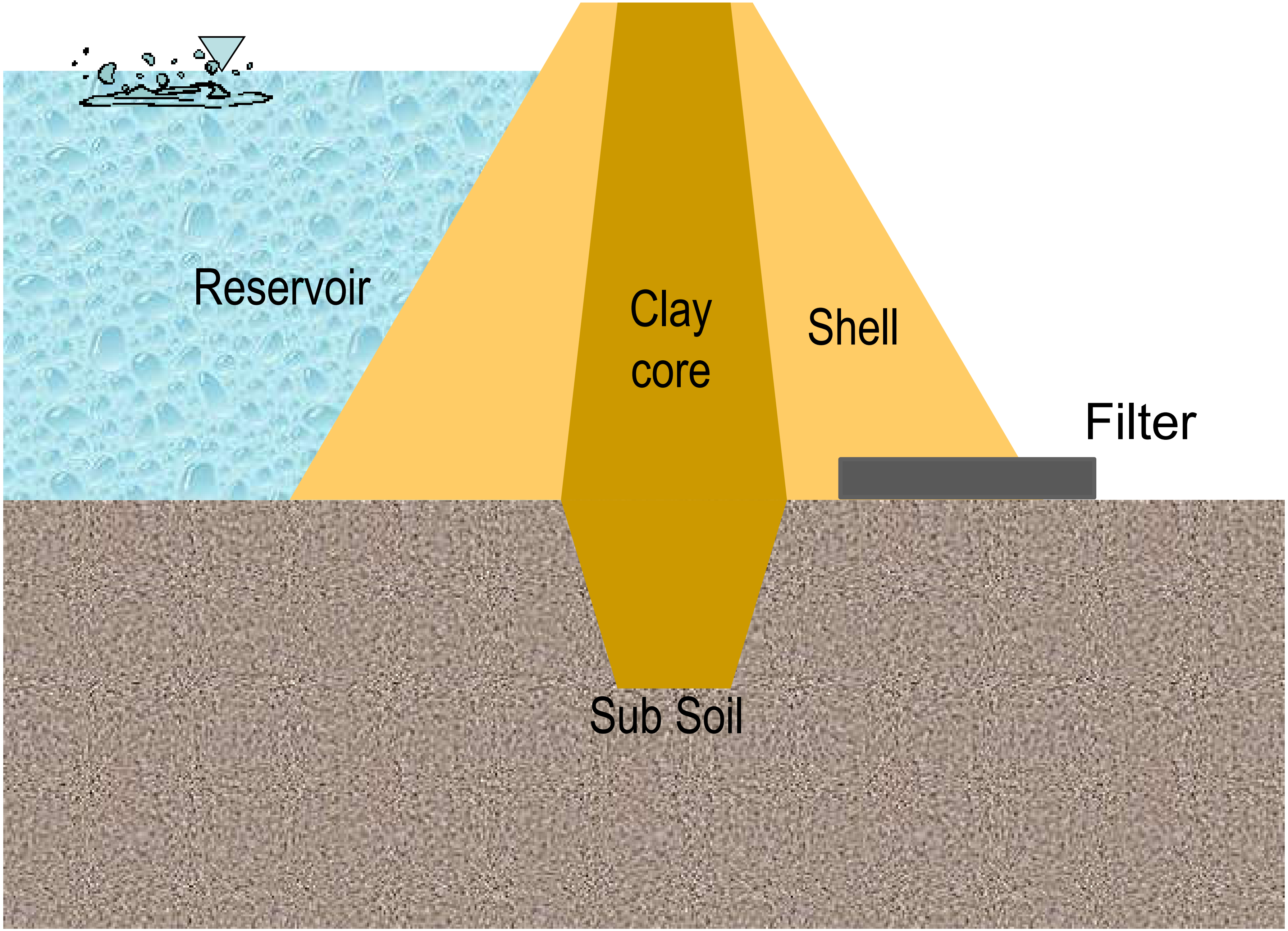

# Reasons for earth dam failure

- Deliberate acts of sabotage.
- Structural failure of materials of dam.
- Failure of dam foundation.
- Piping and internal erosion of soil.
- Inadequate maintenance and upkeep.
- Extreme inflow (Overtopping beyond capacity)
- Earthquake.

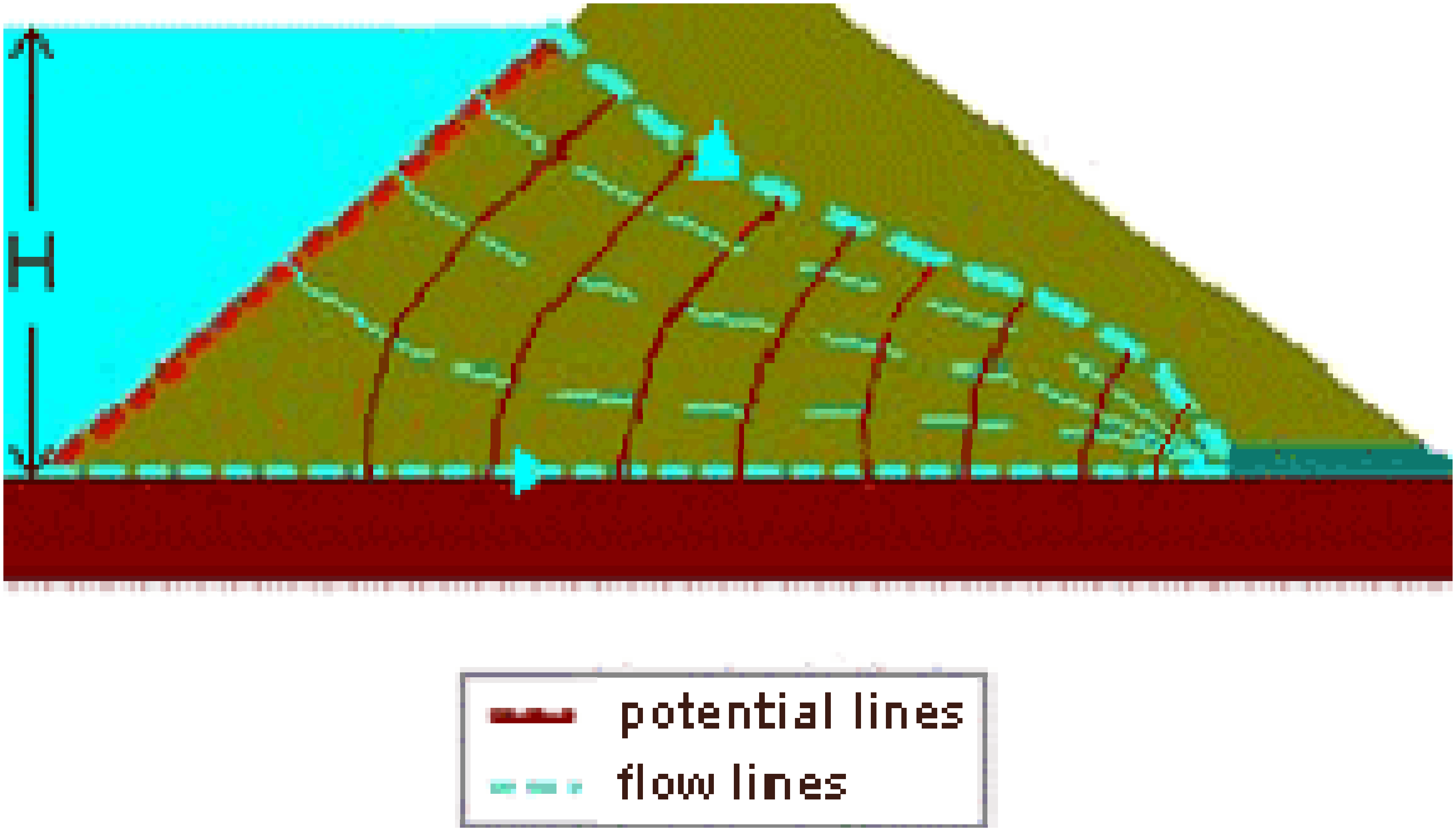
# Cause of failure of Dams

| Problem | Percentage Failure |
|---|---|
| Foundation problems | 40 % |
| Inadequate spillway | 23 % |
| Poor construction | 12 % |
| Uneven settlement | 10 % |
| High pore pressure | 5 % |
| Acts of war | 3 % |
| Embankment slips | 2 % |
| Defective materials | 2 % |
| Incorrect operations | 2 % |
| Earthquakes | 1 % |

# Earth Dam



# Phreatic Line in an Earth Dam



# Granular Filter Design

**Retention criteria:**

$D_{15,\ filter} < 5\ D_{85,\ soil}$

average filter pore size

**Permeability criteria:**

$D_{15,\ filter} > 4\ D_{15,\ soil}$

- after Terzaghi & Peck (1967)

$D_{15,\ filter} < 20\ D_{15,\ soil}$

$D_{50,\ filter} < 25\ D_{50,\ soil}$

- after US Navy (1971)

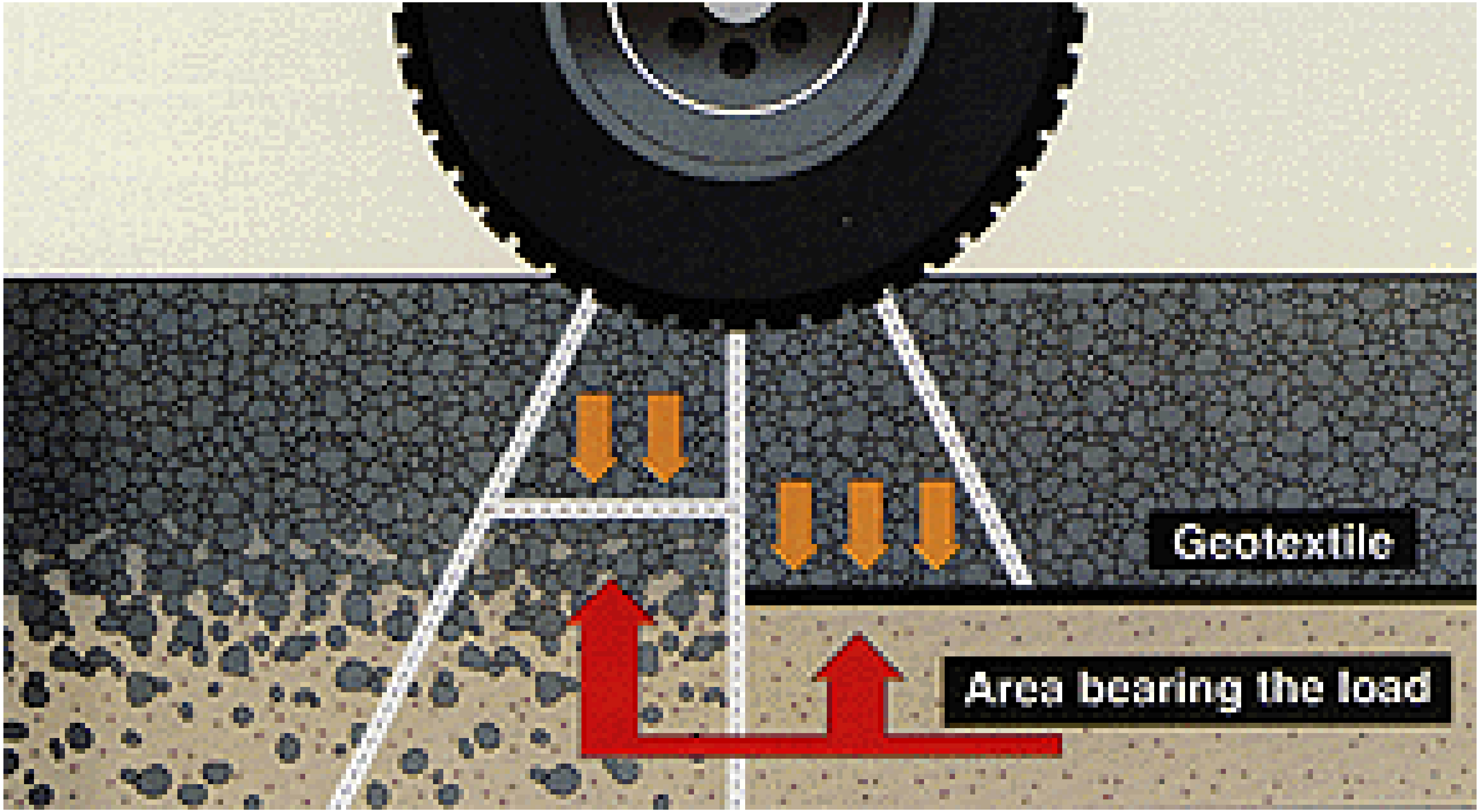
GSD Curves for the soil and filter must be parallel


Canal

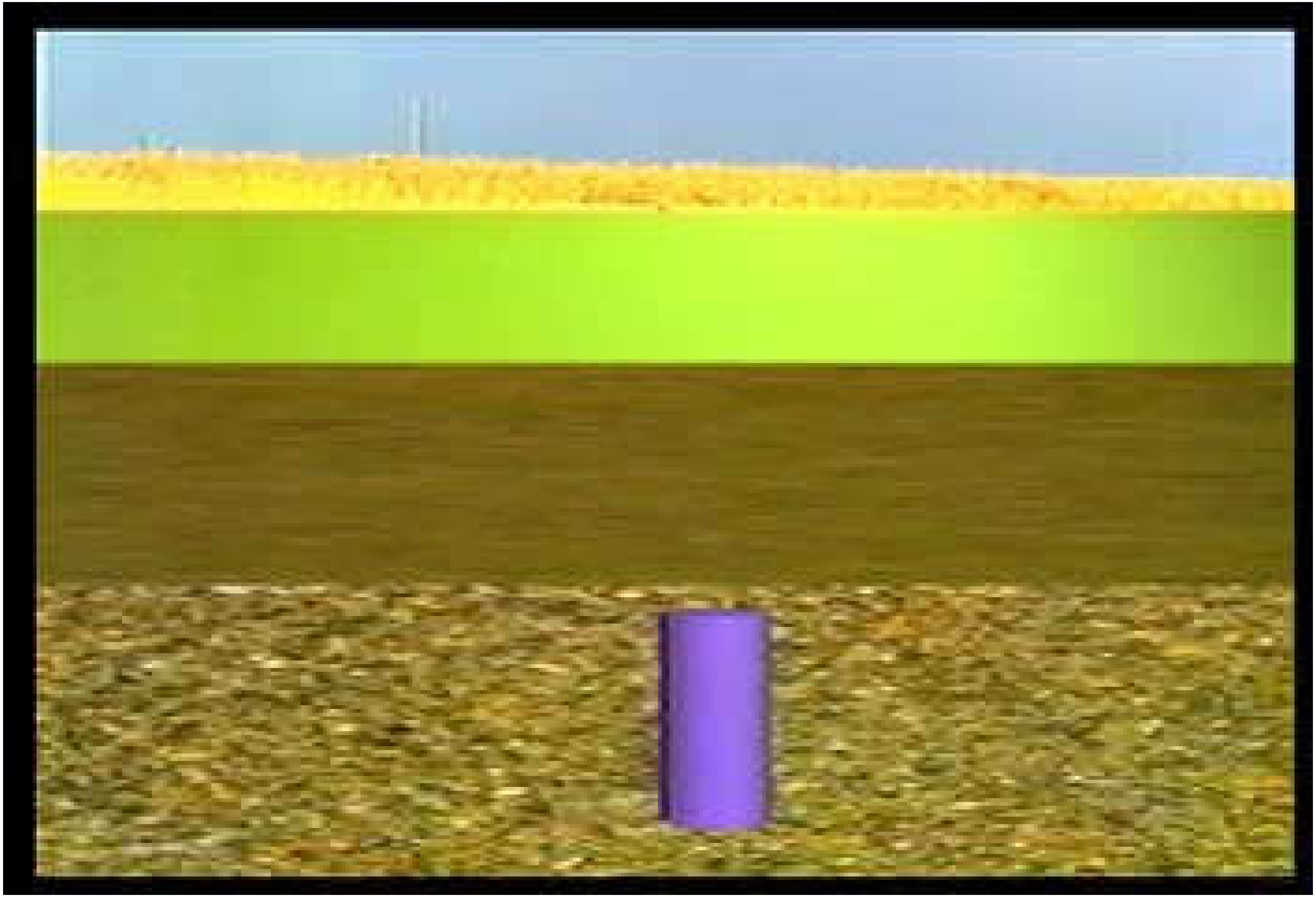
# ROADS

Most essential of Infrastructural growth

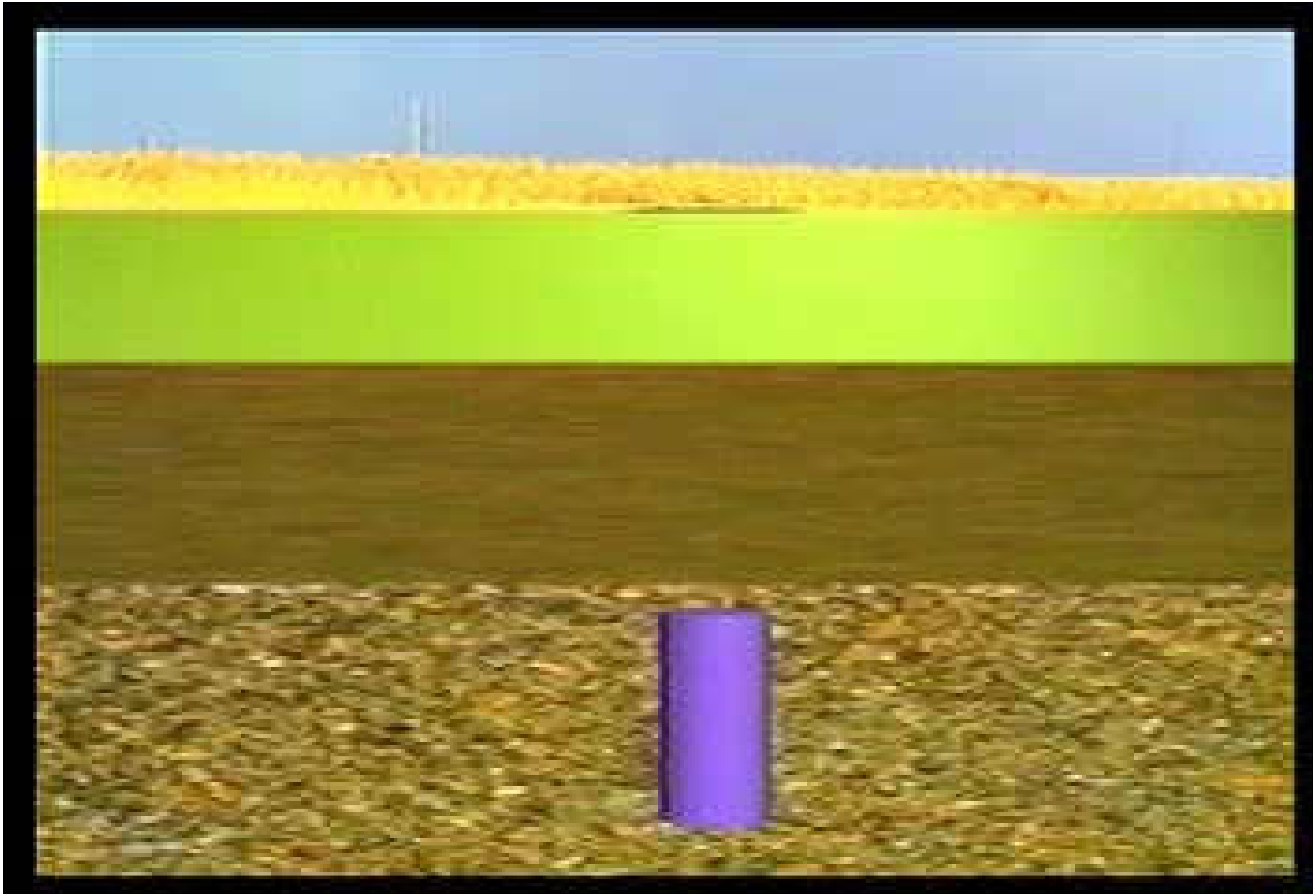
# Geotextile in Pavements



# Moving load causes changing stresses on subgrade, base & surface courses



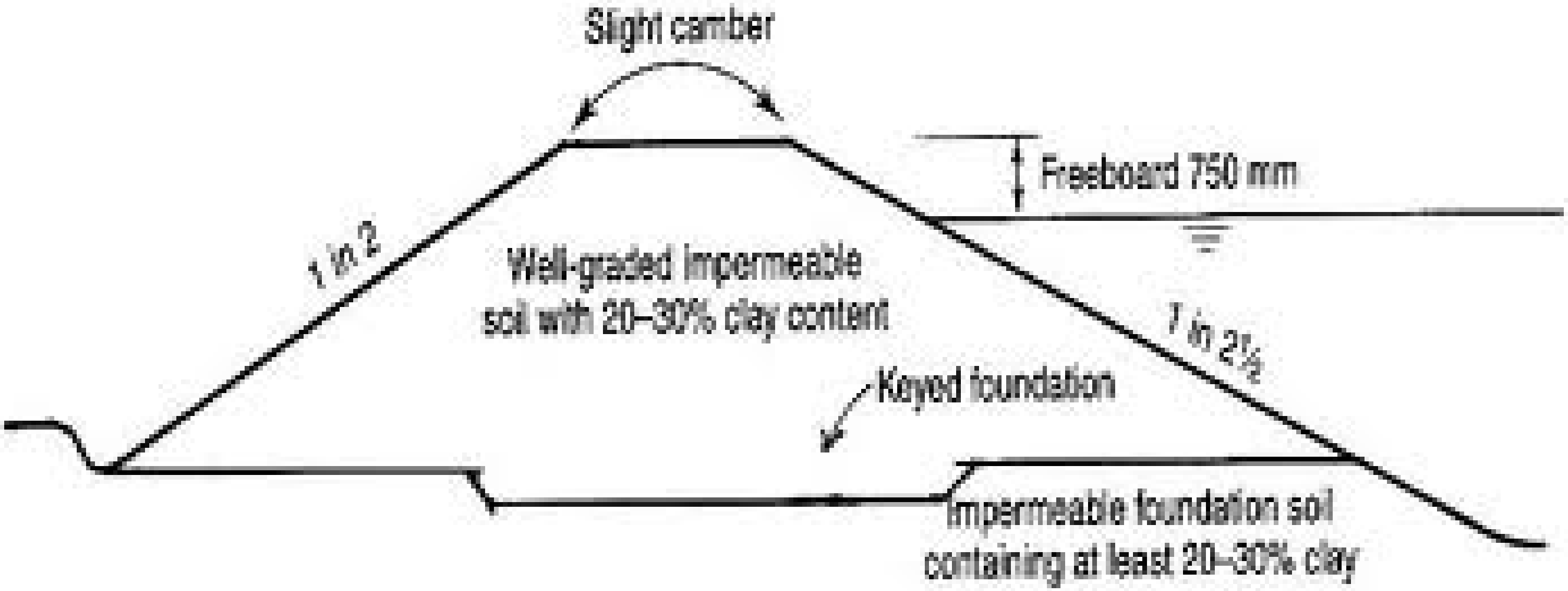
# Varying STRESSes result in changing STRAINs



# Twin Tunnel to ease Traffic congestion in Brisbane, Australia

# Water Intake structure in existing Vaal Dam, South Africa, including sinking shaft 25 m below water level for improved water supply

# Earth Embankments



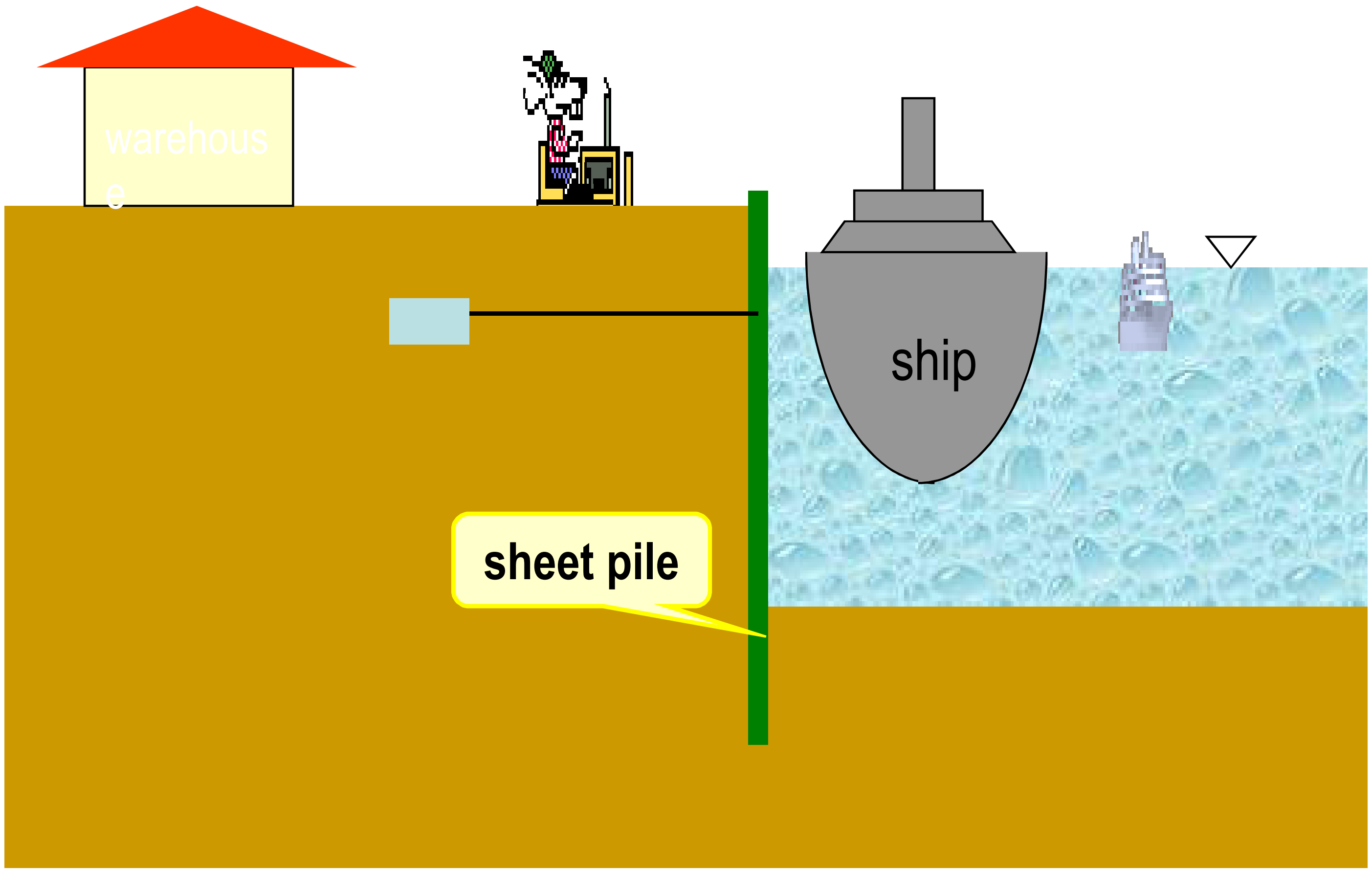
# Earth Embankments

# Canal

# Canal

# Sheet Piles

Sheets of interlocking steel or timber driven into the ground, forming a continuous sheet



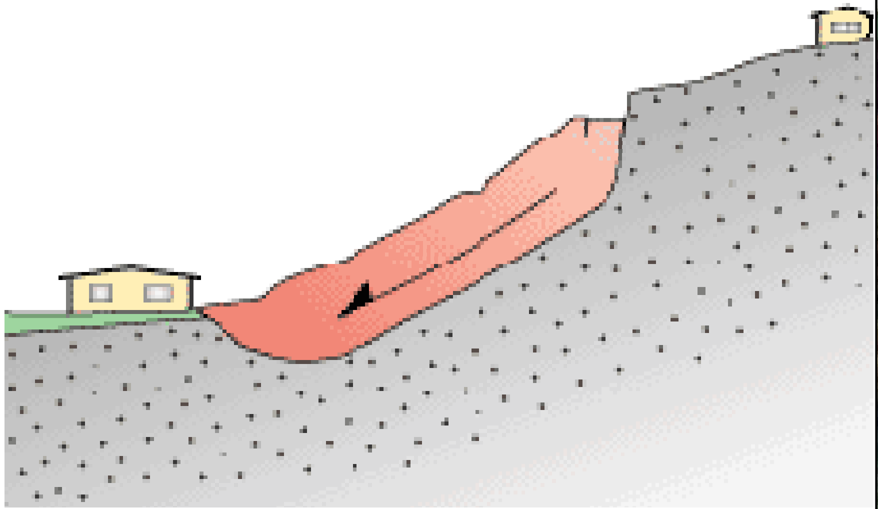
# Sheet Piles

- Resist lateral earth pressures
- Used in excavations, waterfront structures
- Used in temporary works
- Interlocking sections

# Cofferdam

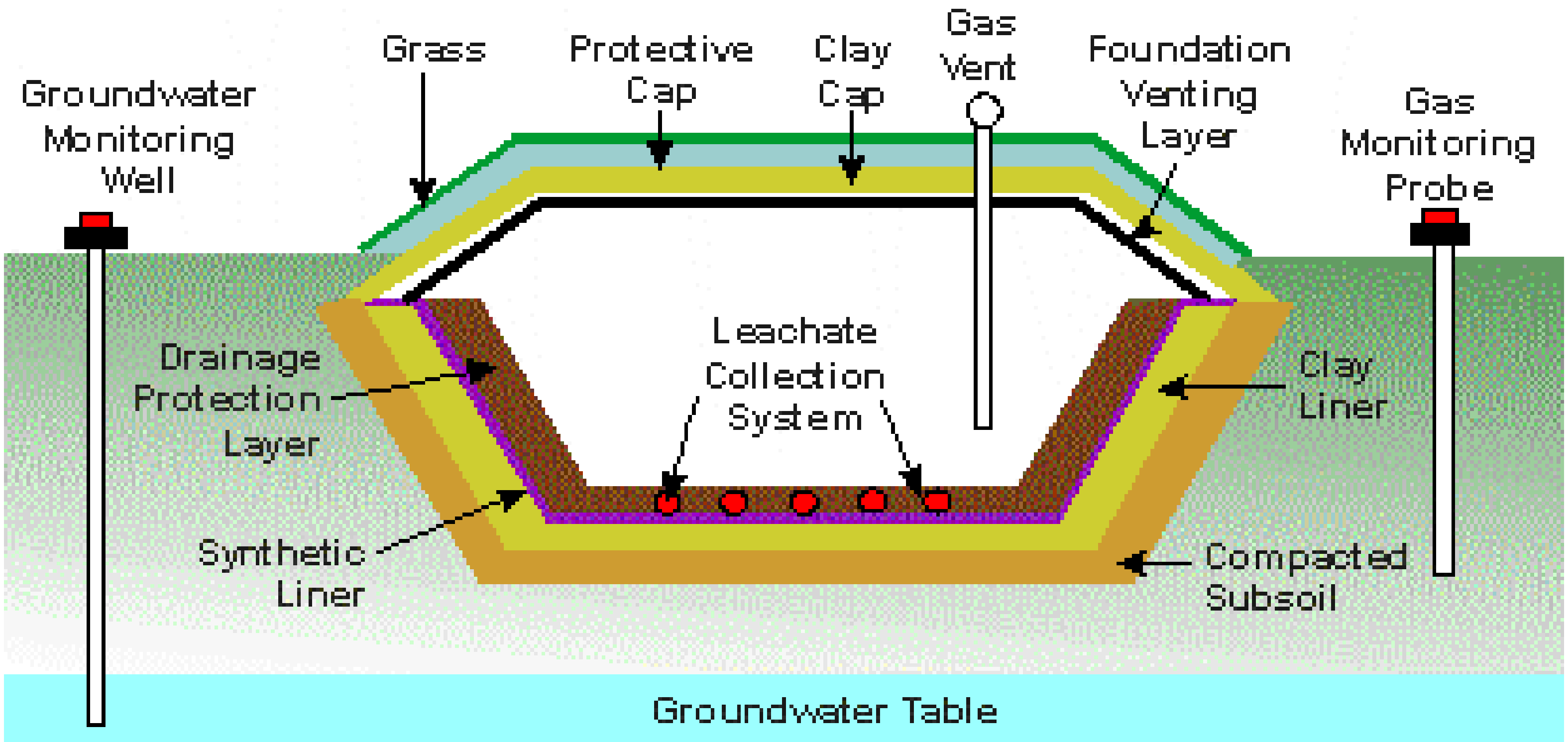
Sheet pile walls enclosing an area,
To prevent water seeping in
Specially during construction

# Landslides



# Tunneling

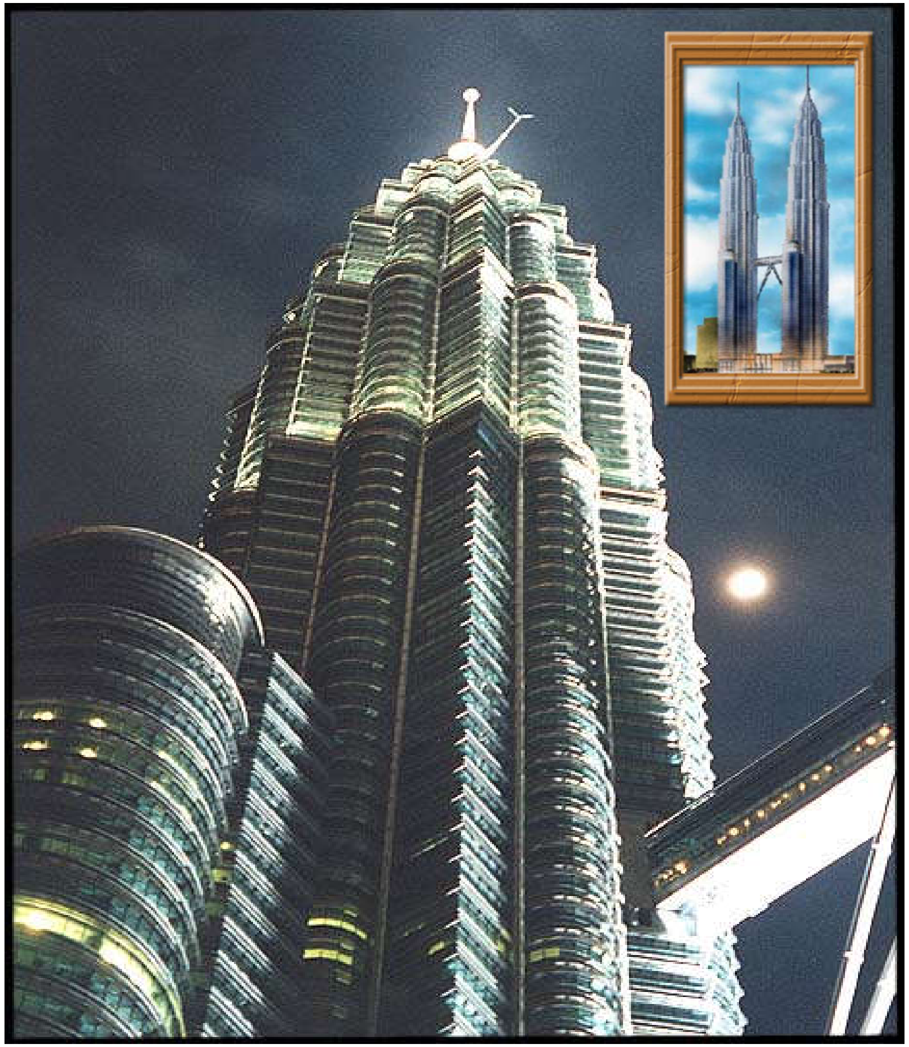
# Environmental Geomechanics




Waste Disposal in Landfills

# Petronas Tower, Malaysia	Leaning Tower of Pisa

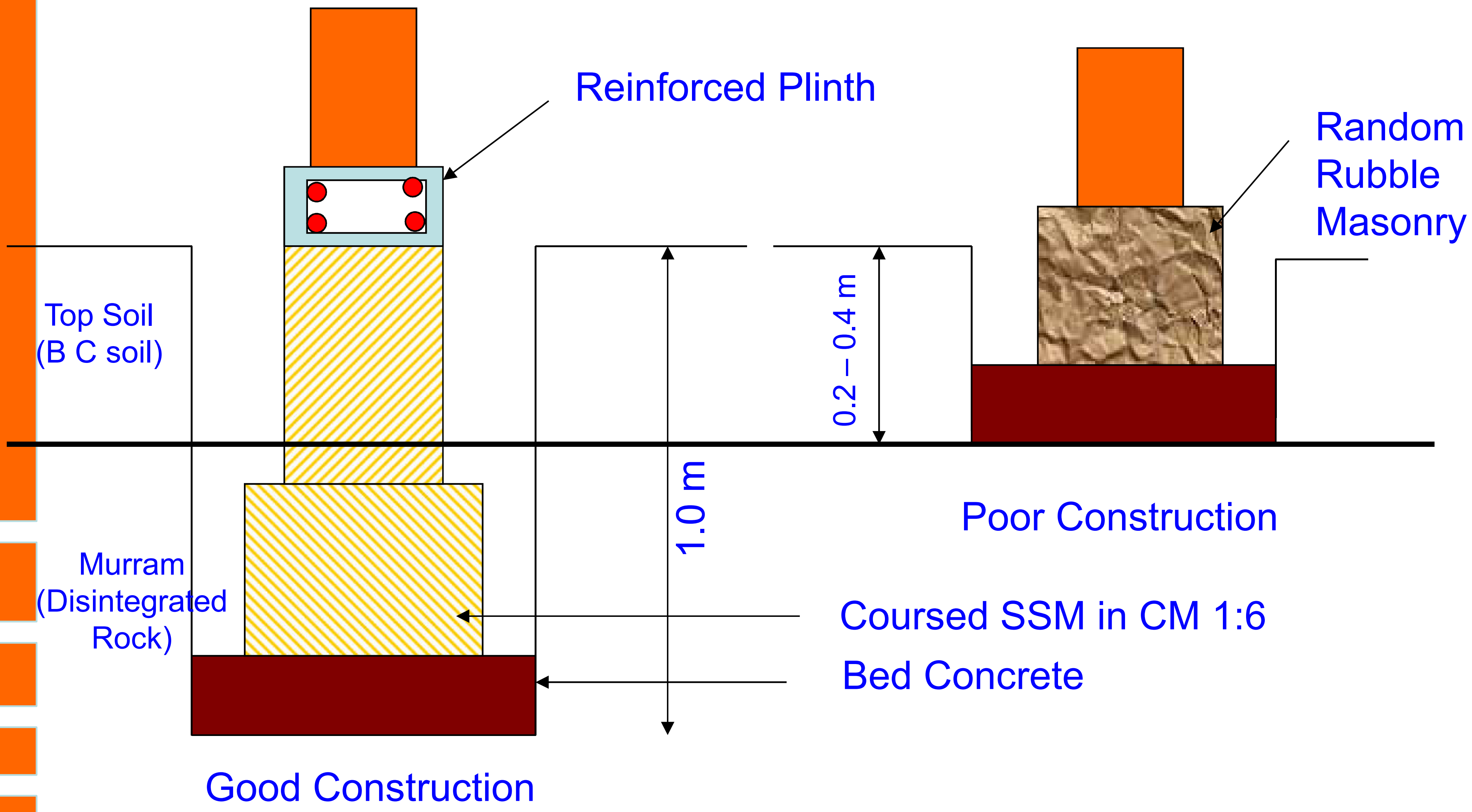
(Among the Tallest building in the world) (Our blunders become monuments!)



# Tall, Taller, Tallest !!!


**You can see the competition for height in Dubai Nakheel Towers**

# Typical Foundation details for Masonry Construction in Kutch Region

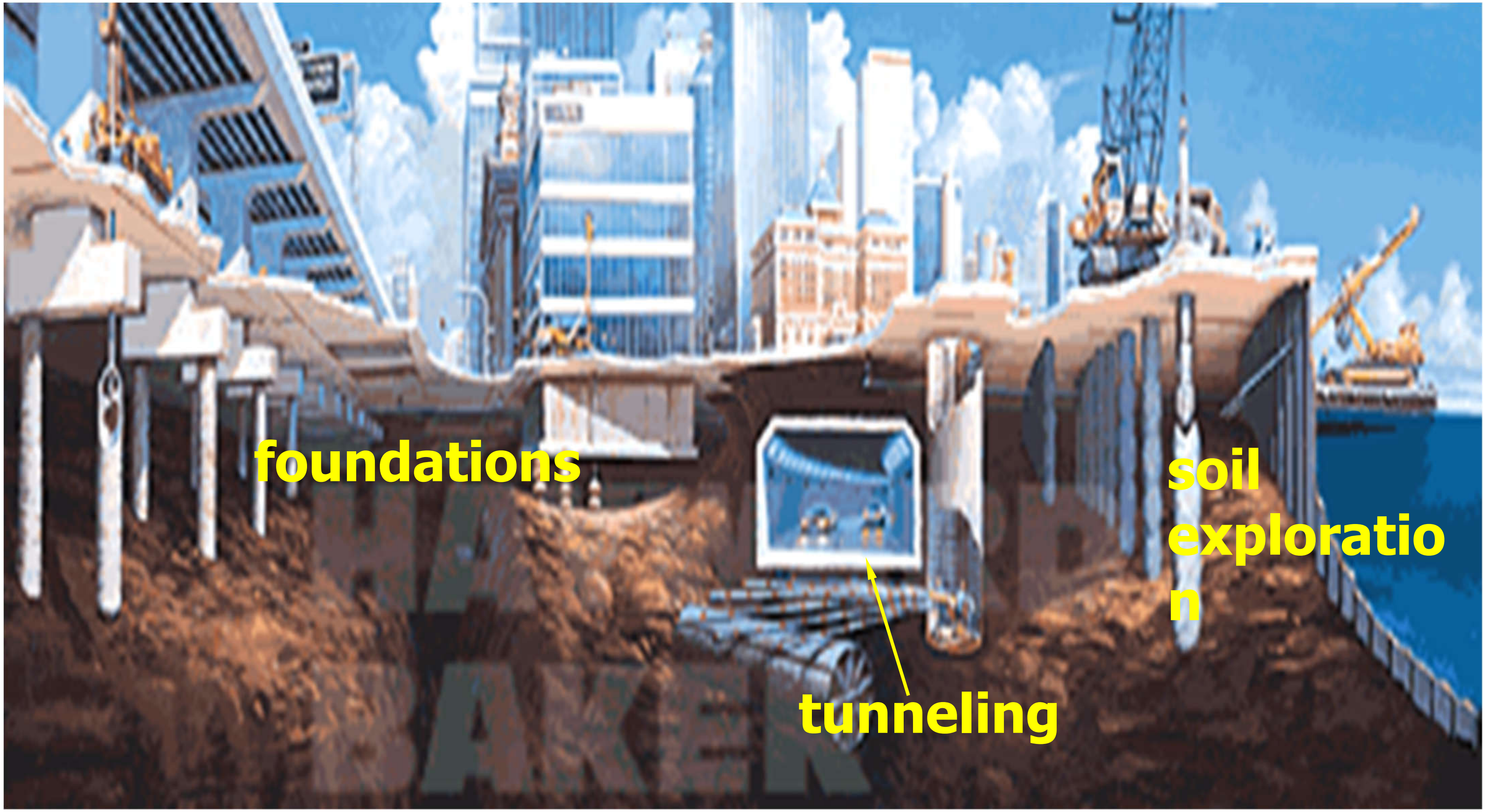



**Structures with better construction practice & STRONG FOUNDATION survive**

# Gas tank resting on Piers and surrounding soil liquefied

**Structures with better construction practice & STRONG FOUNDATION on stable base survive**

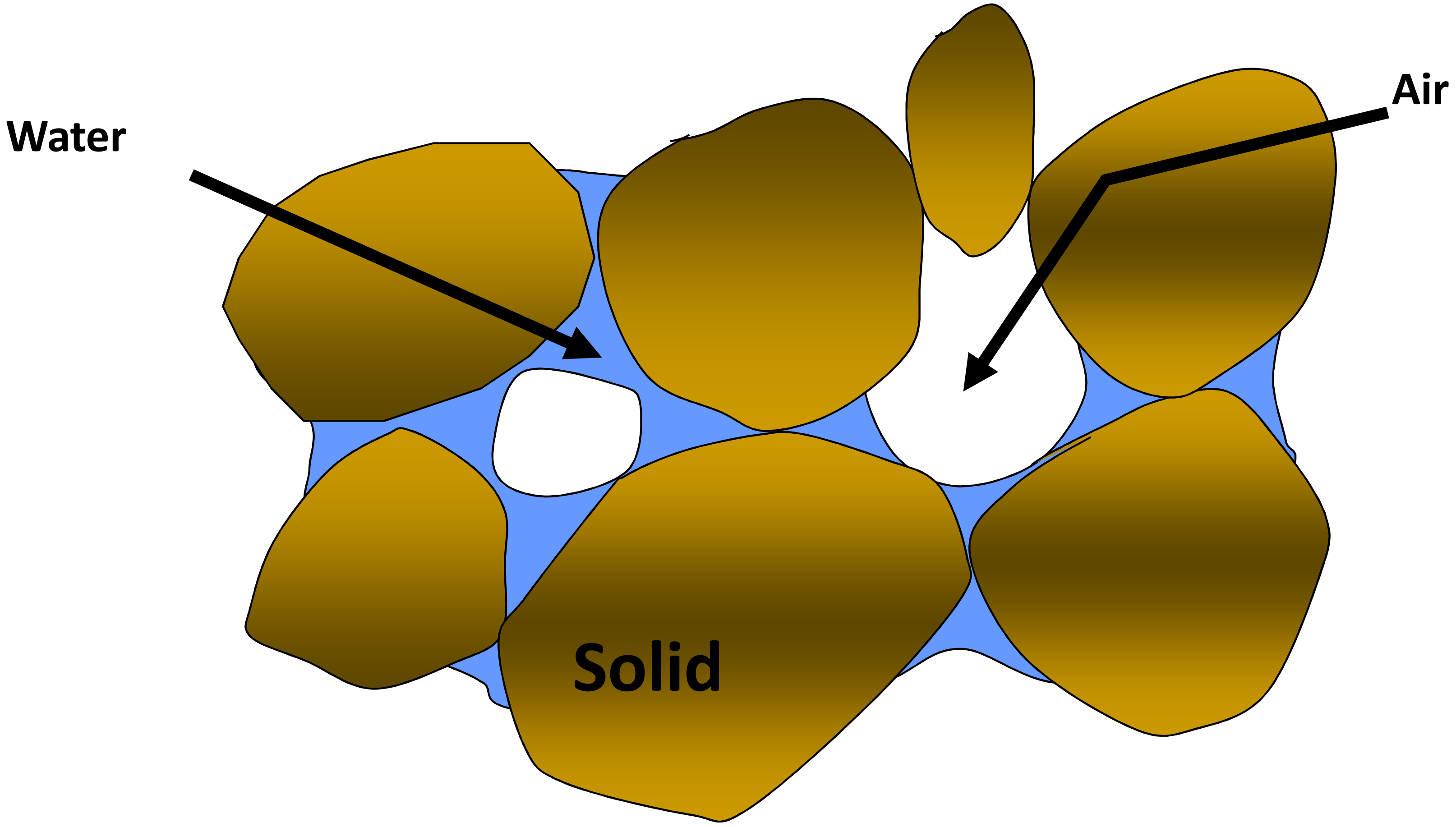
# Geotechnic for Infrastructure



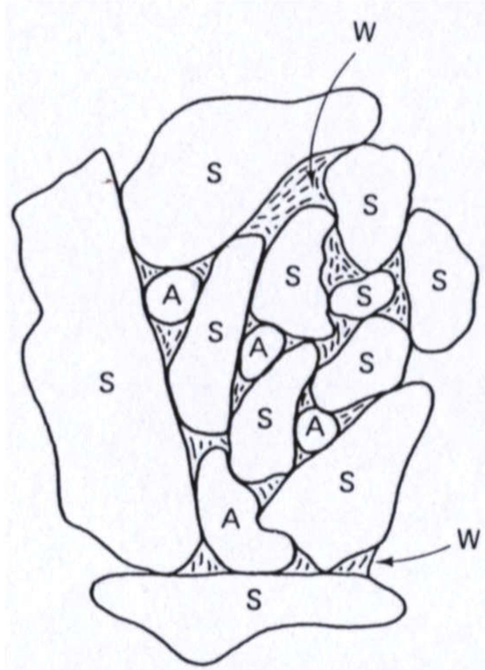

… buried right under your feet.

# Soil Mass as a THREE Phase System & Basic Definitions

# Typical Soil Mass as observed microscopically

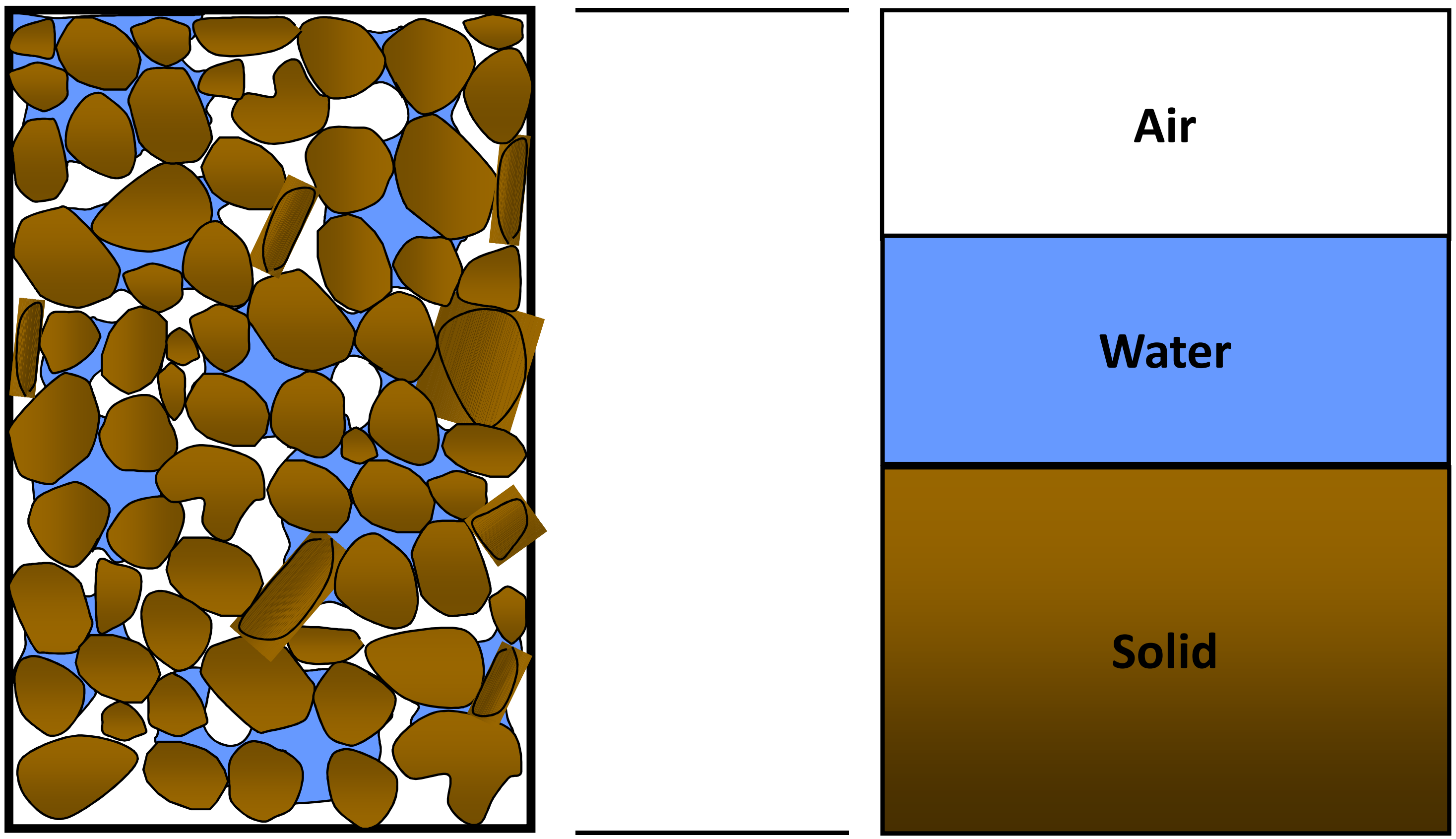


# Soil a 3-Phase Material


| | | |
|---|---|---|
| S | Solid | Soil particle |
| W | Liquid | Water (electrolytes) |
| A | Gas | Air |

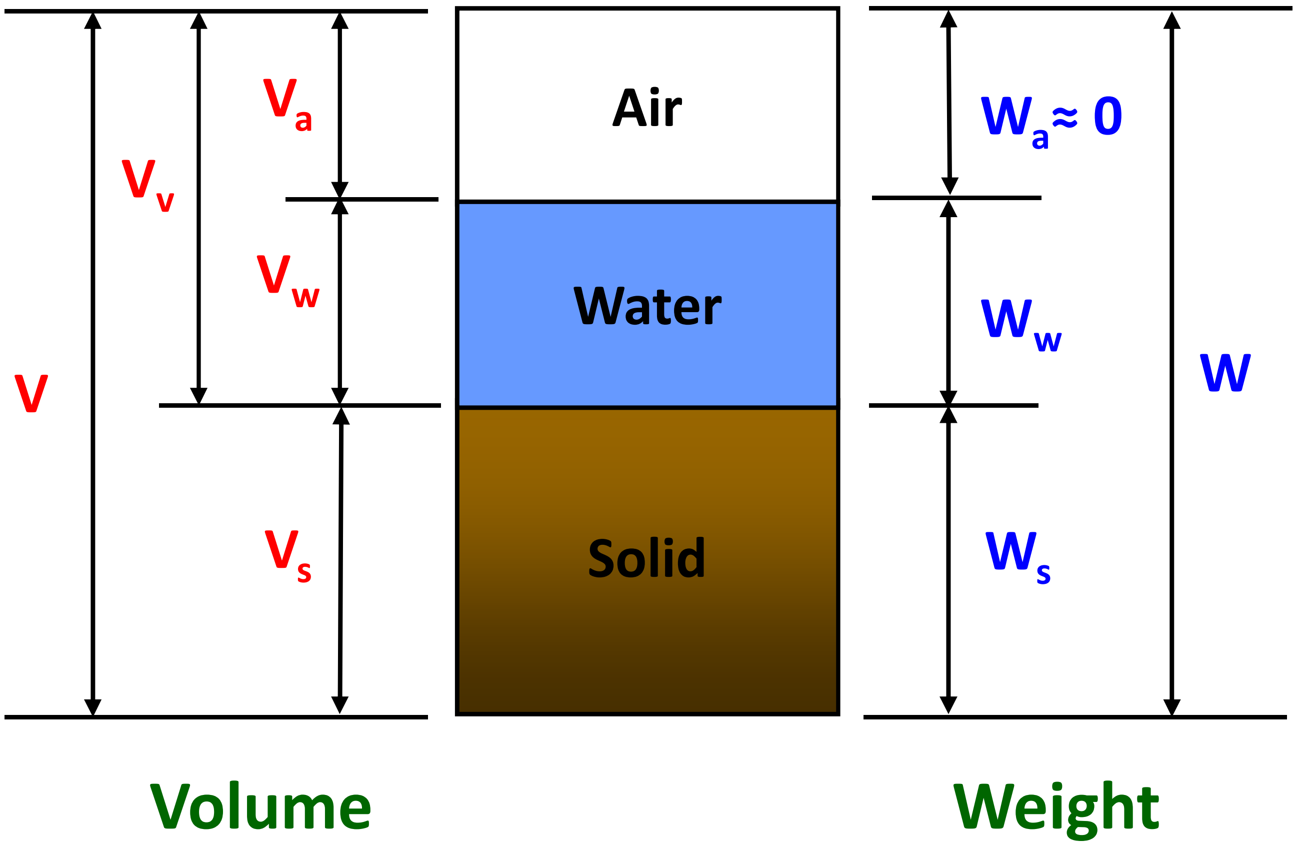
# Three Phase Diagram




Mineral Skeleton

Idealization

# Three Phase system

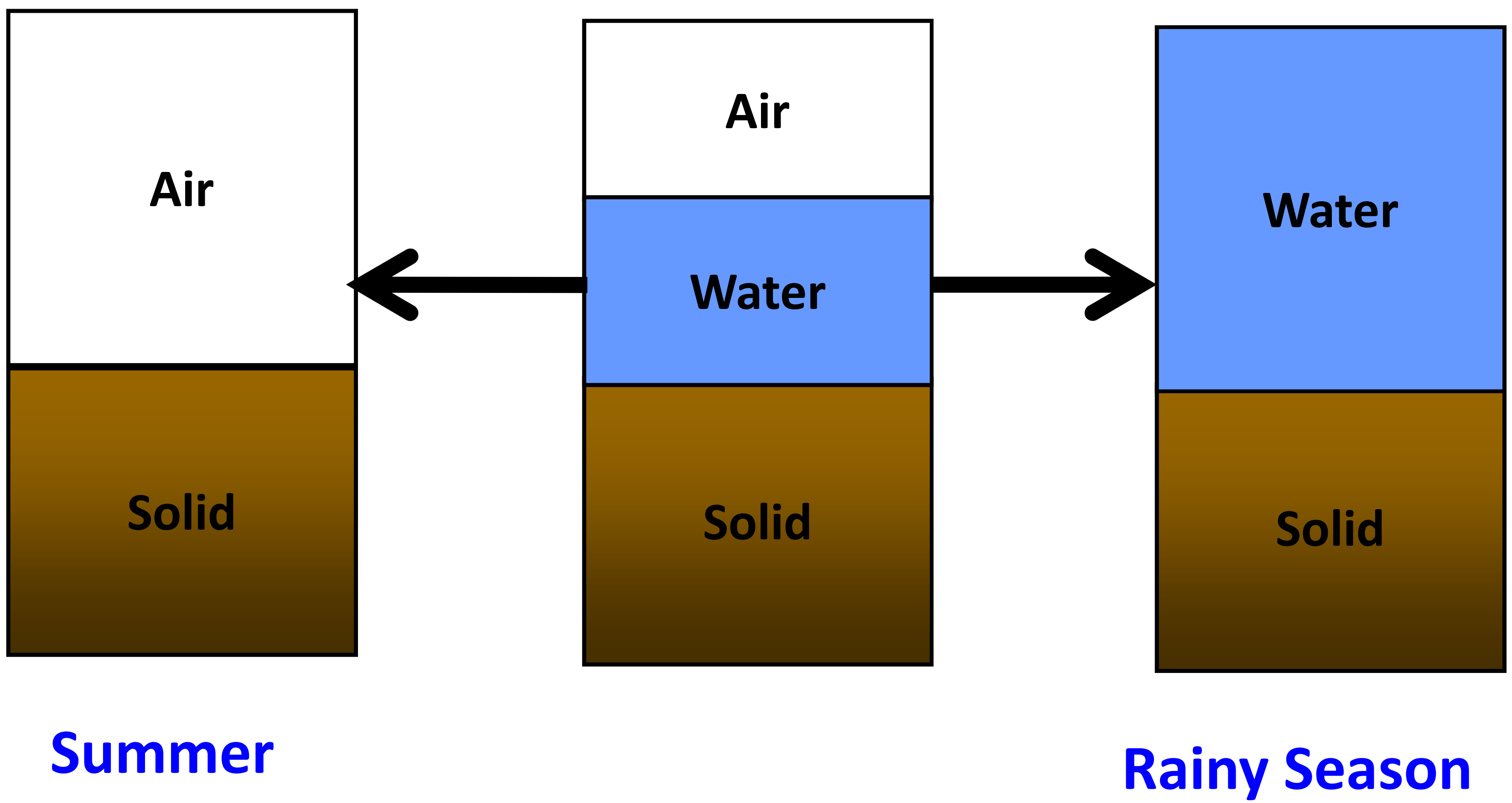



**Notation**

**W = Weight**
**V = Volume**

s = Soil grains
w = Water
a = Air
v = Voids

# 3 Phase system reduces to 2 Phase System



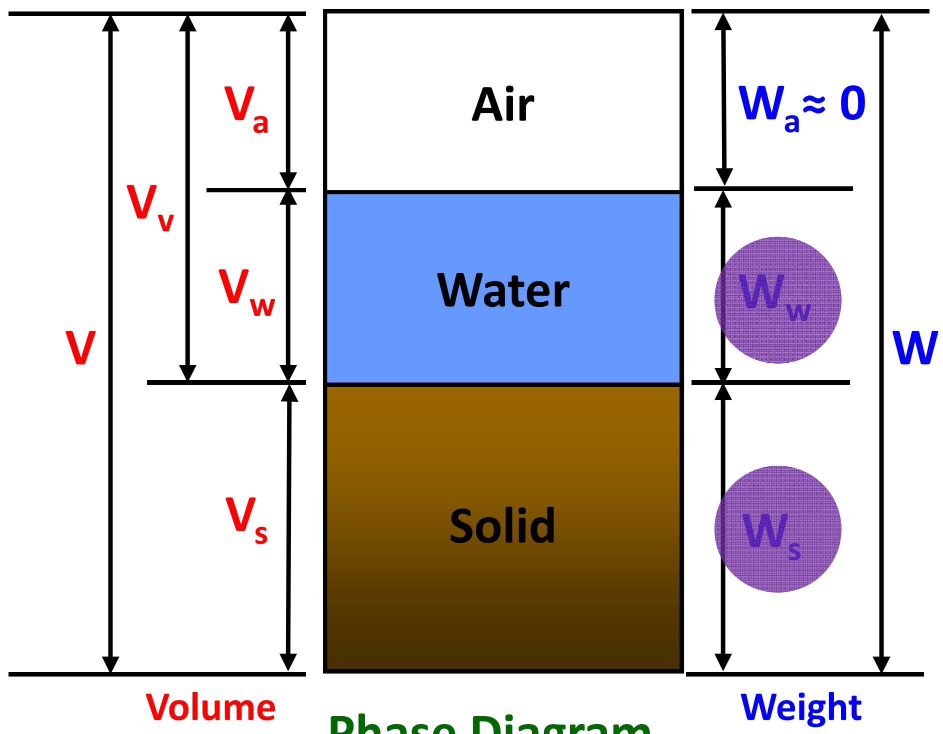
# Water content (ω)....

is a measure of the water present in the soil.

$$\omega = \frac{W_W}{W_S}$$

Expressed as percentage.

Range = 0 – 100+%.

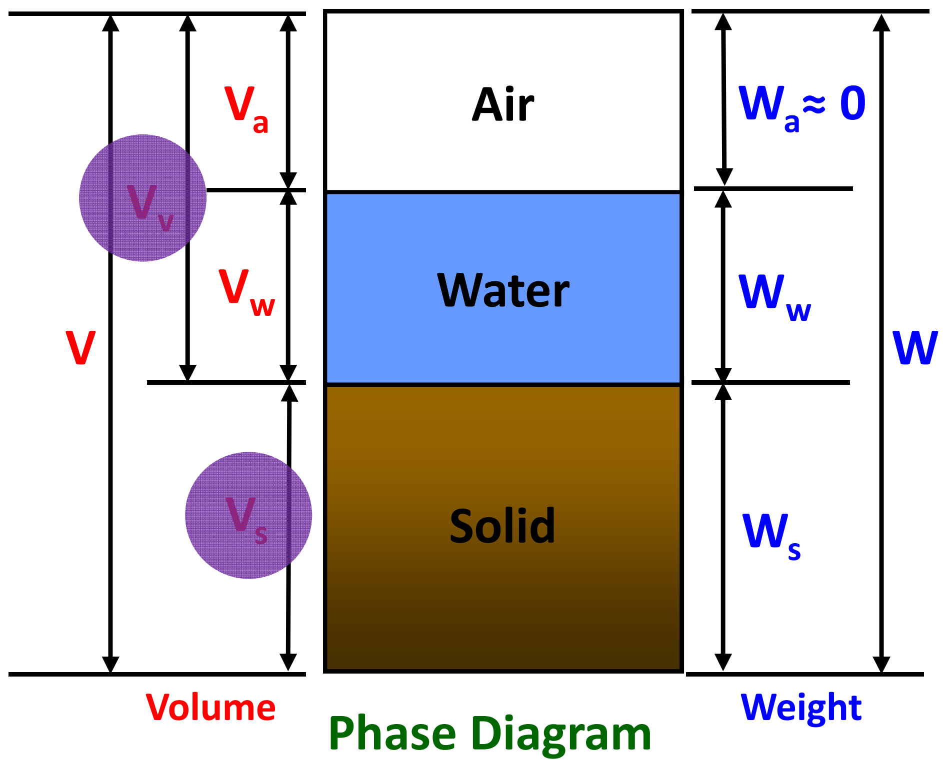


Phase Diagram

# Void ratio (e)

is a measure of the void volume

$$e = \frac{V_v}{V_s}$$

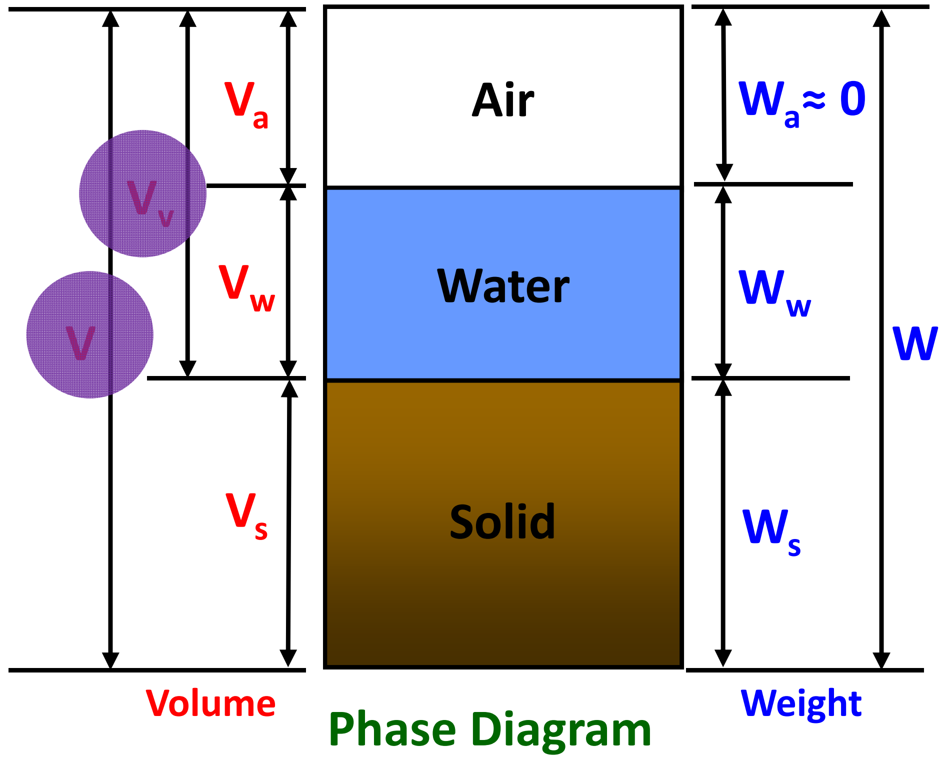


# Porosity (n)

is also a measure of the void volume, expressed as a percentage

$$n = \frac{V_v}{V}$$

Theoretical range: 0 – 100%



# Degree of saturation (S)

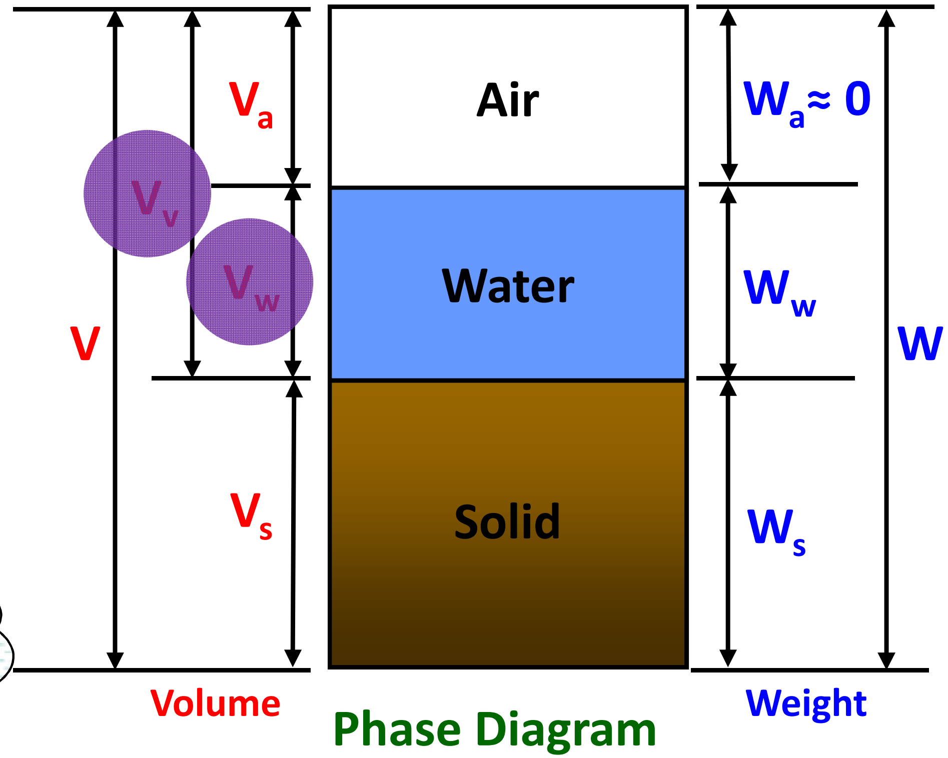
is the percentage of the void volume filled by water

$$S = \frac{V_w}{V_v}$$

Range: 0 – 100%

Dry

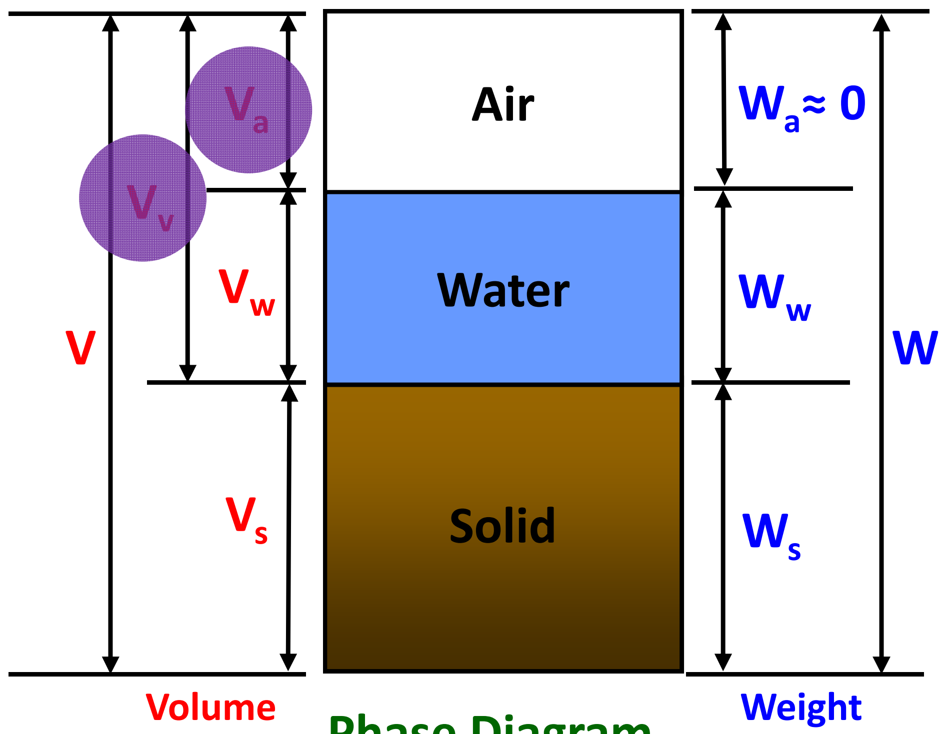
Saturated



# Air content ($A_c$)....

is the percentage of the void volume filled by air

$$A_c = \frac{V_a}{V_v}$$

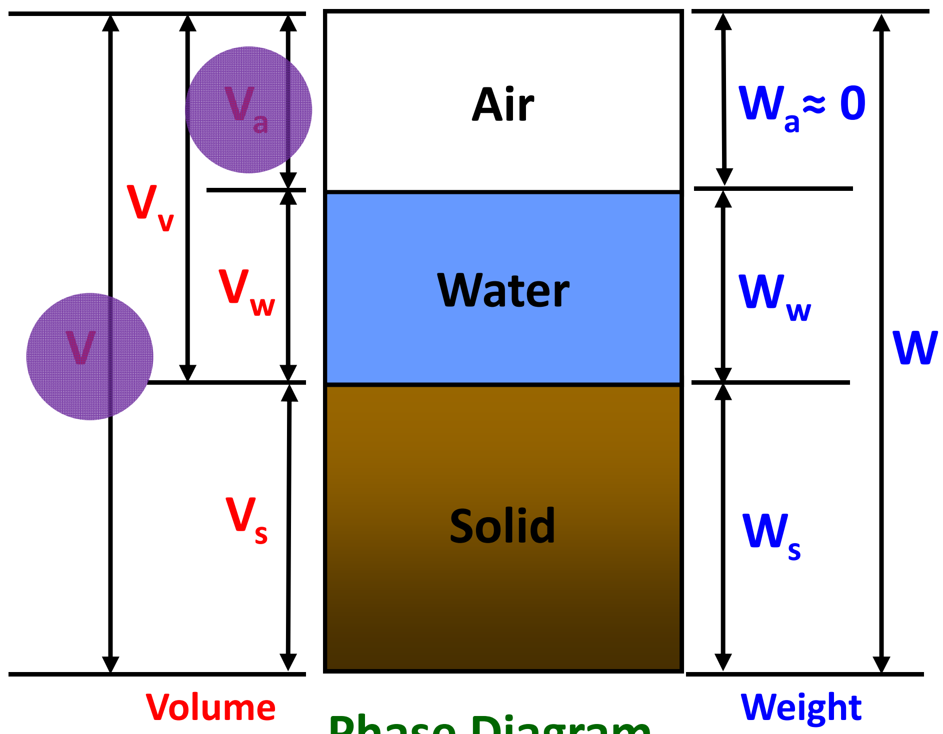


Phase Diagram

# Percentage Air voids ($n_a$)

is the percentage of total volume filled by air

$$n_a = \frac{V_a}{V}$$

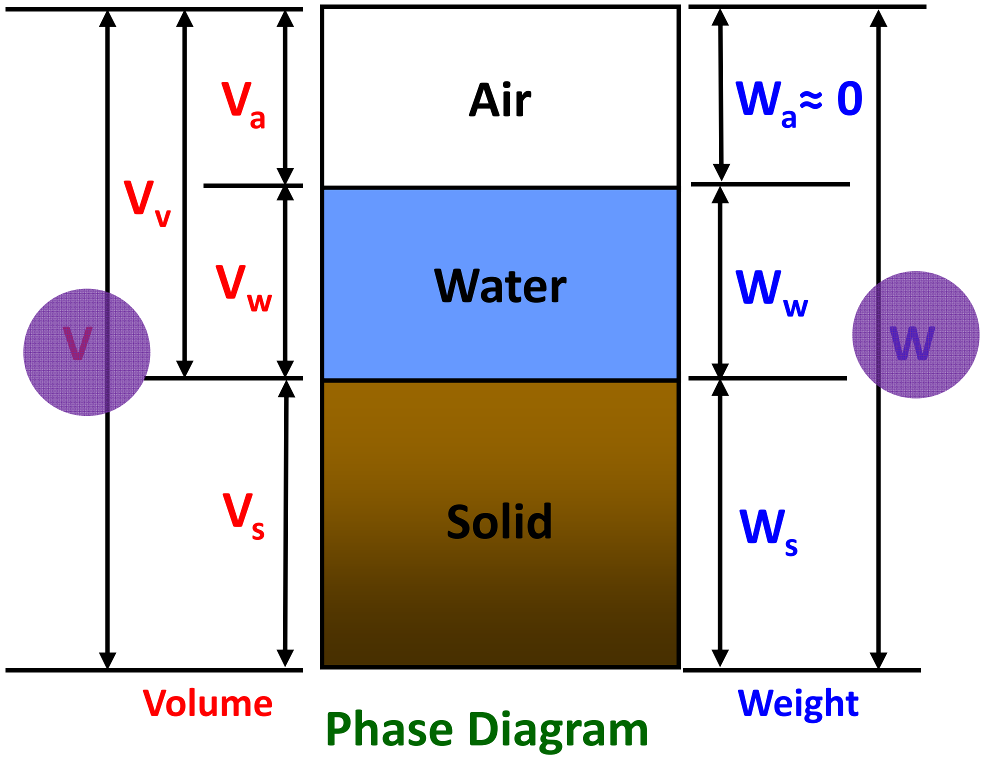


Phase Diagram

# Bulk unit weight ($\gamma_b$)....

is the weight of soil mass per unit volume

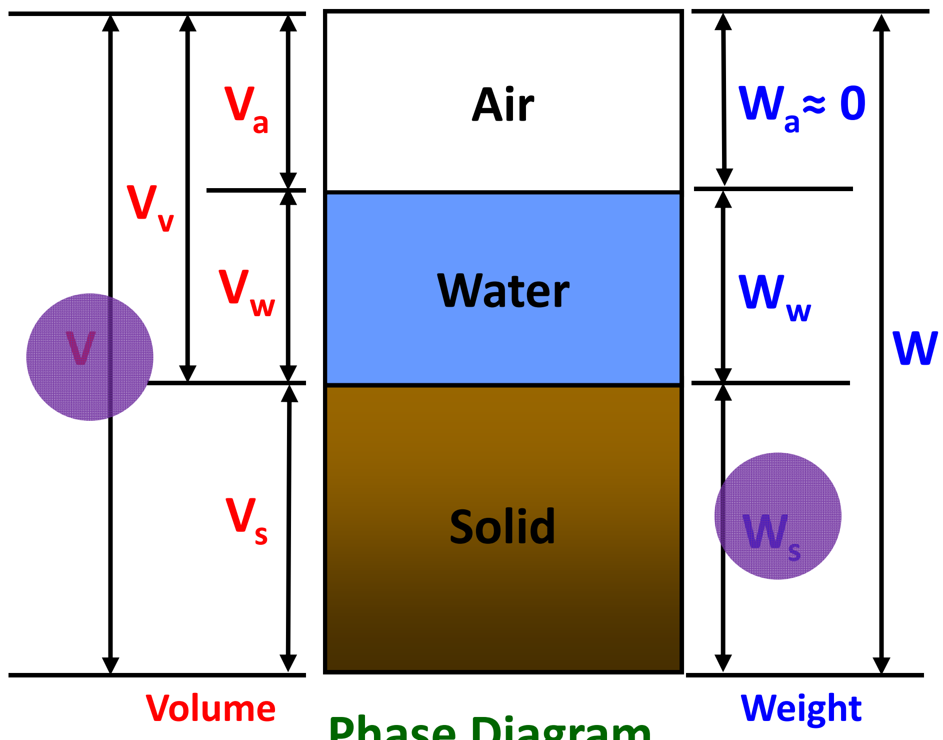
$$\gamma_b = \frac{W}{V}$$



# Dry unit weight ($\gamma_d$)....

is the weight of soil per unit volume, excluding water

$$\gamma_d = \frac{W_s}{V}$$



Phase Diagram

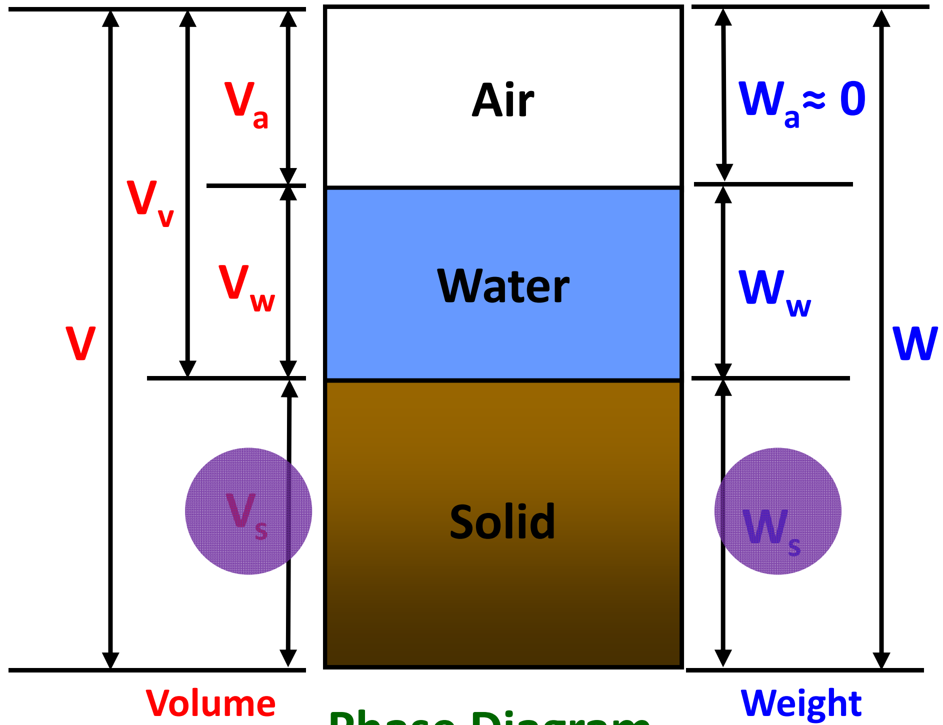
# Typical values of void ratios and dry densities for granular soil

| *Soil type* | *Void ratio, e* | | *Dry unit weight, $\gamma_d$* | |
| --- | --- | --- | --- | --- |
| | *Maximum* | *Minimum* | *Minimum* ($kN/m^3$) | *Maximum* ($kN/m^3$) |
| Gravel | 0.6 | 0.3 | 16 | 20 |
| Coarse sand | 0.75 | 0.35 | 15 | 19 |
| Fine sand | 0.85 | 0.4 | 14 | 19 |
| Standard Ottawa sand | 0.8 | 0.5 | 14 | 17 |
| Gravelly sand | 0.7 | 0.2 | 15 | 22 |
| Silty sand | 1 | 0.4 | 13 | 19 |
| Silty sand and gravel | 0.85 | 0.15 | 14 | 23 |

# Unit weight of solids ($\gamma_s$)

is the weight of soil solids per unit volume.

$$\gamma_s = \frac{W_s}{V_s}$$

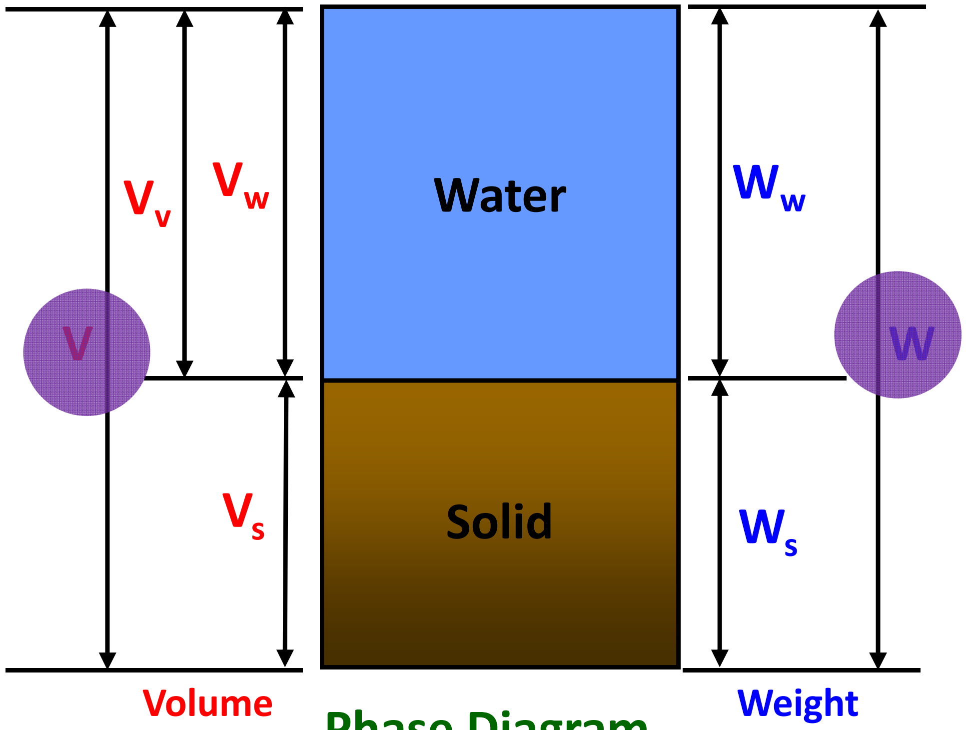


Phase Diagram

# Saturated unit weight ($\gamma_{sat}$)

is the weight of soil mass per unit volume when s = 1

$$\gamma_{sat} = \frac{W}{V}$$



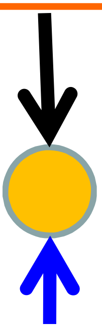
Phase Diagram

# Unit weight of water ($\gamma_\omega$)

1. It is defined as the ratio of weight of water to volume of water.
2. In SI units, it is expressed in $kN/m^3$ and can be taken as $9.8\ kN/m^3$.
3. It is used in computation of other quantities.

$$\gamma_\omega = \frac{W_\omega}{V_\omega}$$

# Submerged unit weight ($\gamma_{sub}$)



1. It is defined as the net weight per volume of soil mass in water.
2. In SI units, it is expressed as $kN/m^3$.
3. It is equal to saturated unit weight minus unit weight of water.

$$\gamma_{sub} = \gamma_{sat} - \gamma_{\omega}$$

# Specific gravity of soil solids (G)

$$G = \frac{\gamma_s}{\gamma_\omega}$$

1. It is defined as the weight of soil solids to weight of equal volume of water.
2. Hence, it is the ratio of unit weight of soil solids to unit weight of water.
3. It has no units and is expressed in decimals.

# Specific gravity of soil solids (G)

4. Normally, G of most soils varies from 2.6 to 2.8. Organic soils may have G up to 2.
5. G is determined in the laboratory and is used to compute other parameters such as void ratio.
6. Many a times, specific gravity means G.

$$G = \frac{\gamma_s}{\gamma_\omega}$$

# Apparent Specific gravity ($G_m$)

$$G_m = \frac{\gamma_b}{\gamma_\omega}$$

1. It is defined as the weight of soil mass to weight of equal volume of water.
2. It is also called Specific Gravity of soil mass.
3. It has no units and is expressed in decimals.
4. Its magnitude is always smaller than that of G.
5. It is less commonly used in calculations.

# Relative Density ($D_r$)

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

1. It is also called Density Index.
2. It has no unit. It is expressed in percentage.
3. $D_r$ ranges from 0 to 100 %.
4. It is applicable for coarse grained soil such as sand and gravel.
5. It indicates whether the in-situ density of soil is close to loosest or densest state.
6. When $D_r$ = 1, soil is in its densest state and when $D_r$ = 0, soil is in its loosest state

# Relative Density ($D_r$)

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

| Relative Density (%) | State |
|---|---|
| 0 to 20 | Very Loose |
| 20 to 40 | Loose |
| 40 to 60 | Medium dense |
| 60 to 80 | Dense |
| 80 to 100 | Very Dense |

# Soil Classification (as per IS 1498-1970)

If more than 50 % of weight of soil mass has size > 0.075 mm Coarse Grained Soil

# Coarse Grained Soil

| First Symbol | Second Symbol |
|---|---|
| G : Gravel | W : Well Graded Soil |
| S : Sand | P : Poorly Graded Soil |
| | C : Soil containing Clay |
| | M : Soil containing fines other than Clay |

# IS Soil Classification (IS: 1498-1970) Including Field Identification and Description

| Major Divisions | | | Group Symbol | Typical Names | Field Identification procedures | Information required for describing soils |
|---|---|---|---|---|---|---|
| COARSE-GRAINED SOILS More than half of material is larger 75 µm sieve size. The 75 µm sieve size is about the size particle visible to the naked eye | GRAVELS More than half of coarse fraction is smaller than 4.75 mm sieve size | Clean gravels (little or no fines) | GW | Well graded gravel, gravel-sand mixtures, little or no fines | Wide range in grain size and substantial amounts of all intermediate particle sizes | For undisturbed soils and information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. Give typical name; indicate approximate percentages of sand, gravel, maximum size, angularity, surface condition and hardness of the coarse grains, local or geologic names and other pertinent descriptive information and symbol in parenthesis. Example: Silty and gravelly, about 20 % hard angular gravels 10 mm maximum size, rounded and sub-circular sand grains about 15 %. Non-plastic fines with low dry strength, well compacted and moist in place alluvial sand, (SM) |
| | | | GP | Poorly graded gravels or gravel-sand mixtures, little or no fines | Predominantly one size or a range of sizes with some intermediate sizes missing | |
| | | Gravel with fines (Appreciable amount of fines) | GM | Silty gravels, poorly graded gravel-sand-silt mixtures | Non-plastic fines or fines with low plasticity (for identification procedures see ML and MI below) | |
| | | | GC | Clayey gravels, poorly graded gravel-sand-silt mixtures | Plastic fines (for identification procedures see CL and CI below) | |
| | SANDS More than half of coarse fraction is smaller than 4.75 mm sieve size | Clean sands (Little or no fines) | SW | Well graded sands, gravelly sands, little or no fines | Wide range in grain size and substantial amounts of all intermediate particle sizes | |
| | | | SP | Poorly graded sands or gravelly sands, little or no fines | Predominantly one size of a range of sizes with some intermediate sizes missing | |
| | | Sand with fines (Appreciable amount of fines) | SM | Silty sands, poorly graded sand silt mixtures | Non-plastic fines or fines with low plasticity (for identification procedures see ML and MI below) | |
| | | | SC | Clayey sands, poorly graded sand-clay mixtures | Plastic fines (for identification procedures see CL and CI below) | |

# IS Soil Classification for Coarse Grained soils (IS: 1498-1970)

<table>
<tr><th>Symbols</th><th colspan="3">Laboratory Classification Criteria</th></tr>
<tr><td>GW</td><td colspan="2">$C_u$ Greater than 4<br>$C_c$ Between 1 and 3</td><td rowspan="8">Determine percentage of gravel and sand from grain size curve depending on percentage of fines (fraction smaller than 75 µm sieve size); coarse-grained soils are classified as follows:<br>Less than 5 %: GW, GP, SW,SP<br>More than 12 %: GM, GC, SM,SC<br>5 % to 12 % : Border line cases requiring use of dual symbols<br>Uniformity coefficient,<br>Coefficient of Curvature,</td></tr>
<tr><td>GP</td><td colspan="2">Not meeting all gradation requirements for GW</td></tr>
<tr><td>GM</td><td>Atterberg limits below “A” line or $I_p$ less than 4</td><td rowspan="2">Limits plotting above “A” line with $I_p$ between 4 and 7 are border line cases requiring use of dual symbols</td></tr>
<tr><td>GC</td><td>Atterberg limits above “A” line with $I_p$ greater than 7</td></tr>
<tr><td>SW</td><td colspan="2">$C_u$ Greater than 6<br>$C_c$ Between 1 and 3</td></tr>
<tr><td>SP</td><td colspan="2">Not meeting all gradation requirements for SW</td></tr>
<tr><td>SM</td><td>Atterberg limits below “A” line or $I_p$ less than 4</td><td rowspan="2">Limits plotting above “A” line with $I_p$ between 4 and 7 are border line cases requiring use of dual symbols</td></tr>
<tr><td>SC</td><td>Atterberg limits above “A” line with $I_p$ greater than 7</td></tr>
</table>

# Classification from SM/GM to SC/GC

- Coarse-grained soils which contain more than 12 % fines (< 75 μm) are classified as GM or SM if fines are silty in character (meaning, the limits plot below the A-line on the plasticity chart).

- On the other hand they are classified as GC or SC if the fines are clayey in character (meaning the limits plot above the A-line on the plasticity chart).

If more than 50 % of weight of soil sample has size < 0.075 mm, it is Fine Grained Soil

# Fine Grained Soil

**First Symbol**

M : Silt
C : Clay
O : Organic Soil
Pt : Peat

**Second Symbol**

L : Soil with LOW plasticity
I : Soil with MEDIUM plasticity
H : Soil with HIGH plasticity

# Classification based on Plasticity

The fine-grained soils are further divided into three sub-divisions depending upon the values of the liquid limit:

Silts and clays of low compressibility – These soils have a liquid limit less than 35 % (represented by a symbol "**L**")

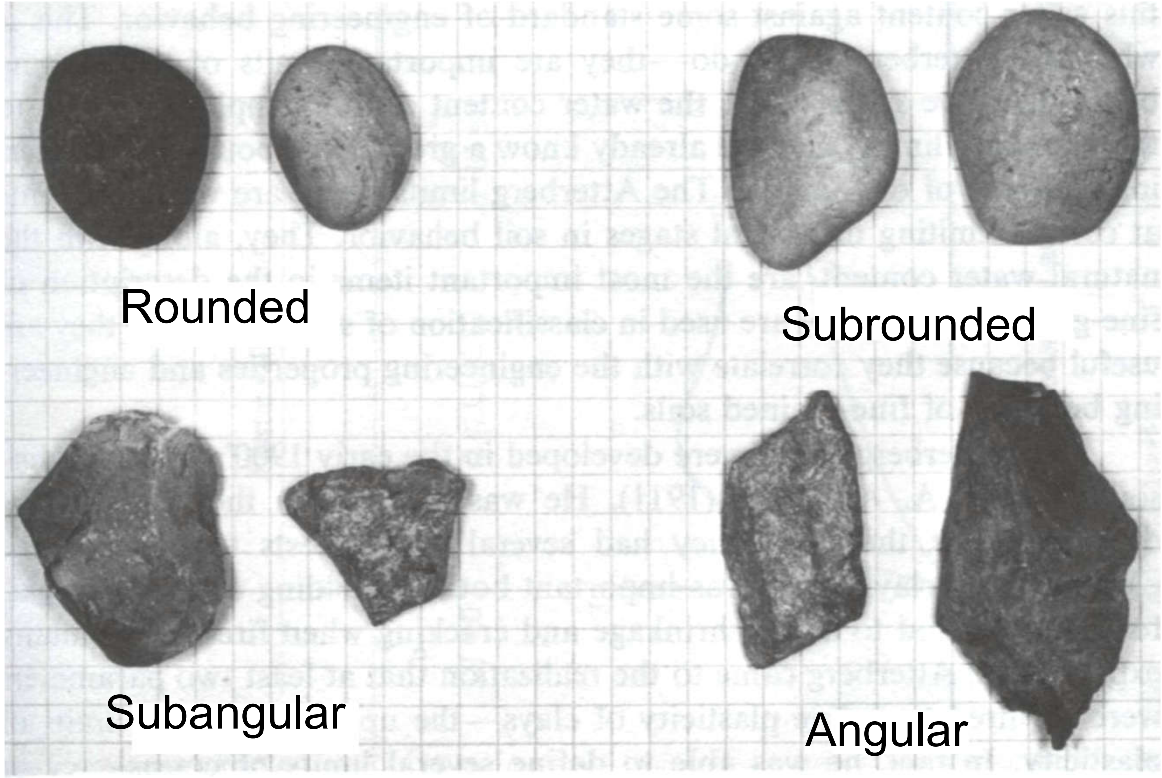
Silts and clays of medium compressibility – These soils have a liquid limit > 35 % but < 50 % (represented by a symbol "**I**")

Silts and clays of high compressibility – These soils have a liquid limit > 50 % (represented by a symbol "**H**")
Fine-grained soils are further sub-divided, as given in table in 9 groups.

# IS Soil Classification (IS: 1498-1970) Including Field Identification and Description

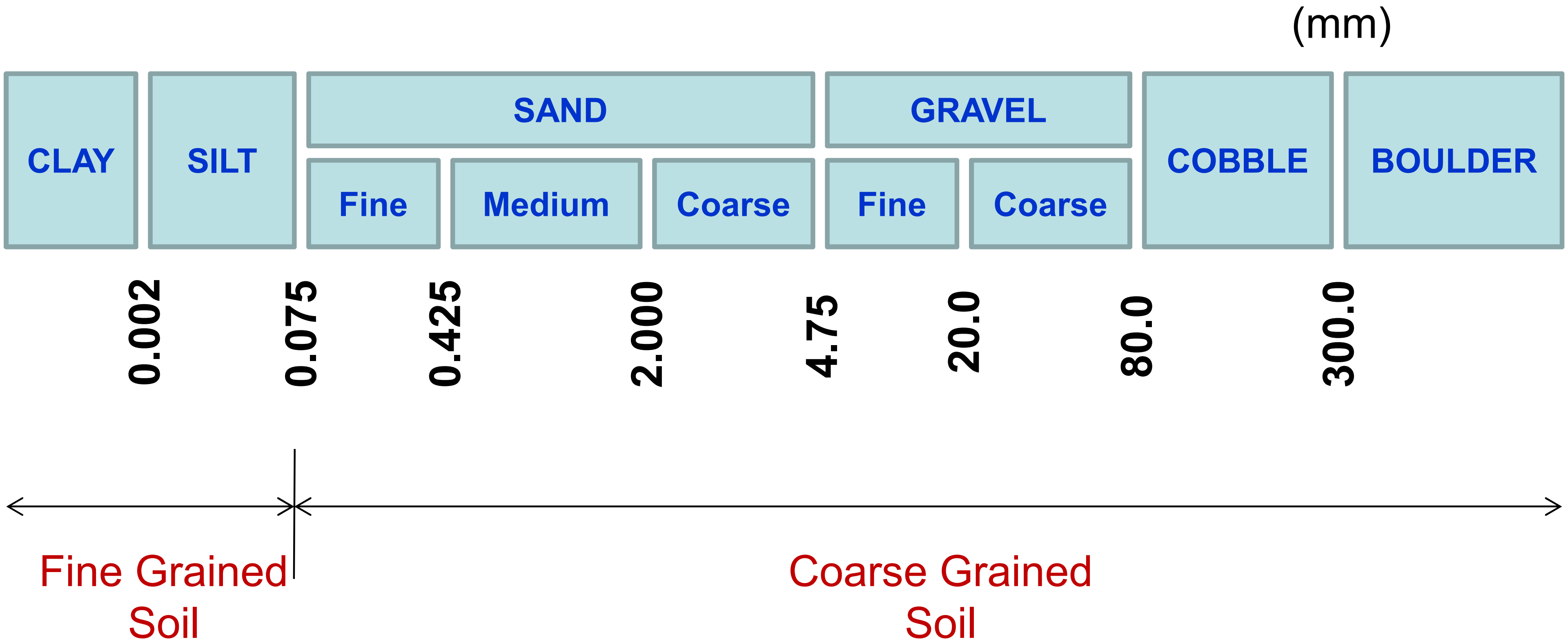
| Major Divisions | | Group Symbol | Typical Names | Identification procedures (on fraction smaller than 425 µm sieve size) | | | Information required for describing soils |
|---|---|---|---|---|---|---|---|
| | | | | Dry strength | Dilatancy | Toughness | |
| FINE-GRAINED SOILS<br>More than half of material is smaller than 75 µm sieve size.<br>The 75 µm sieve size is about the size particle visible to the naked eye | SILTS & CLAYS of low compressibility; liquid limit < 35 % | ML | Inorganic silts and very fine sands, rock flour, silty or clayey fine sand or clayey silts with none to low plasticity | None to low | Quick | None | For undisturbed soils, add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions<br><br>Give typical names, indicate degree and character of plasticity, amount and maximum size of coarse grains, colour in wet condition, odour, if any, local or geologic name and other pertinent descriptive information, and symbol in parenthesis.<br><br>Example:<br>Clayey silt, brown, slightly plastic, small percentage of fine-sand, numerous vertical root holes, firm and fry in place; losses, (ML) |
| | | CL | Inorganic clays, gravelly clays, sandy clays, lean clays of low plasticity | Medium | None to very slow | Medium | |
| | | OL | Organic silts of low plasticity | Low | Slow | Low | |
| | SILTS & CLAYS of medium compressibility: Liquid limit 35 and 50 % | MI | Inorganic silts, silty or clayey fine-sand or clayey silts of medium plasticity | Low | Quick to slow | None | |
| | | CI | Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of medium plasticity | Medium to high | None | Medium | |
| | | OI | Organic silts and organic silty clays of medium plasticity | Low to medium | Slow | Low | |
| | SILTS &CLAYS of high ompressibility Liquid limit > 50 % | MH | Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic silts | Low to medium | Slow to none | Low to medium | |
| | | CH | Inorganic clays of high plasticity, fat clays | High to very high | None | High | |
| | | OH | Organic clays of medium to high plasticity | Medium to high | Slow to very slow | Low to medium | |
| High organic soil | | Pt | Peat and other highly organic soils with very high compressibility | Readily identified by colour, odour, spongy feel and frequently by fibrous texture | | | |

# Particle Shape for Coarse-grained soils



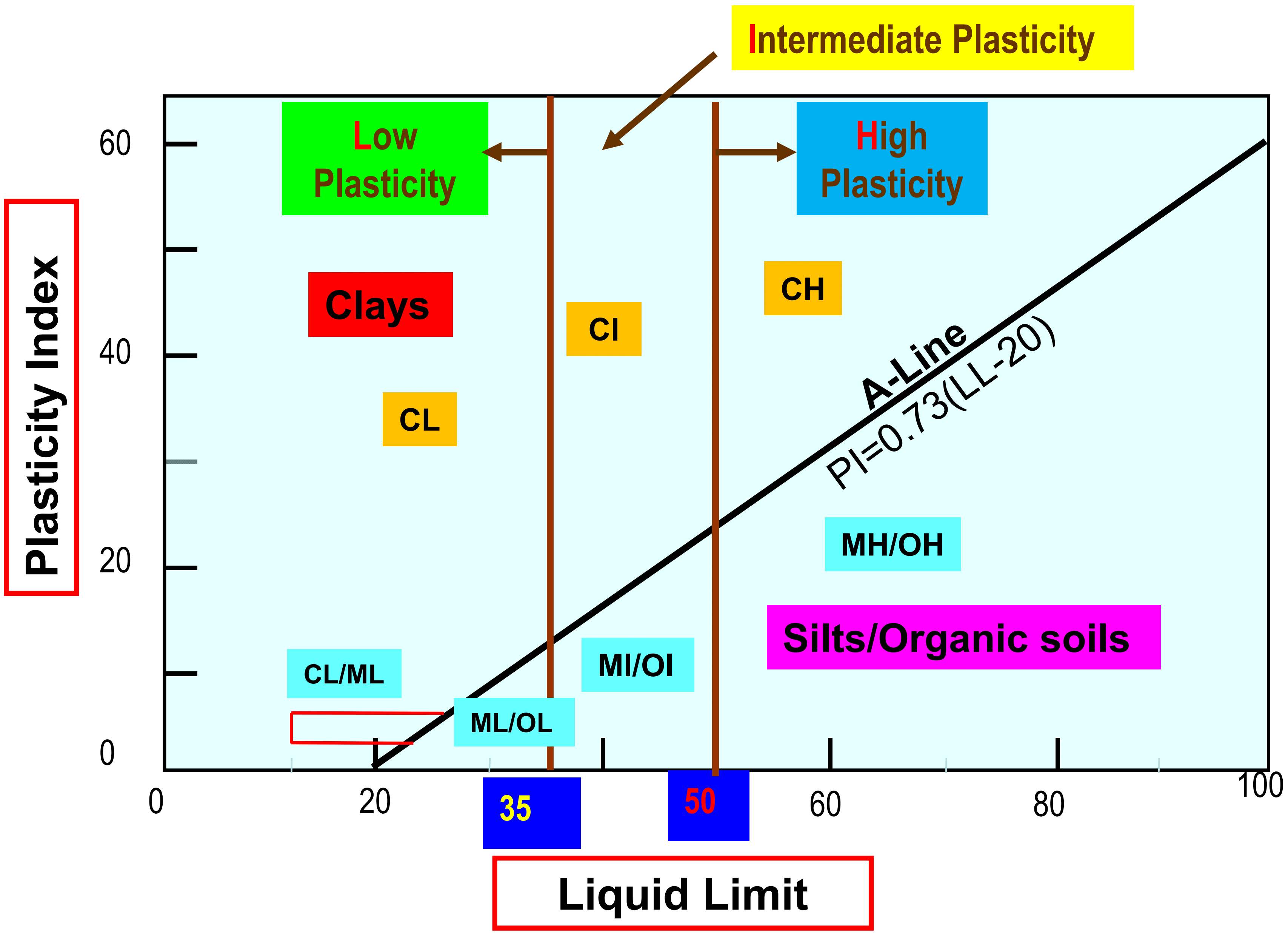

1. Important for granular soils.
2. Angular soil particle shows higher friction.
3. Round soil particle has lower friction.
4. Note that clay particles are sheet-like.

# I S Classification in accordance with size of soil particles

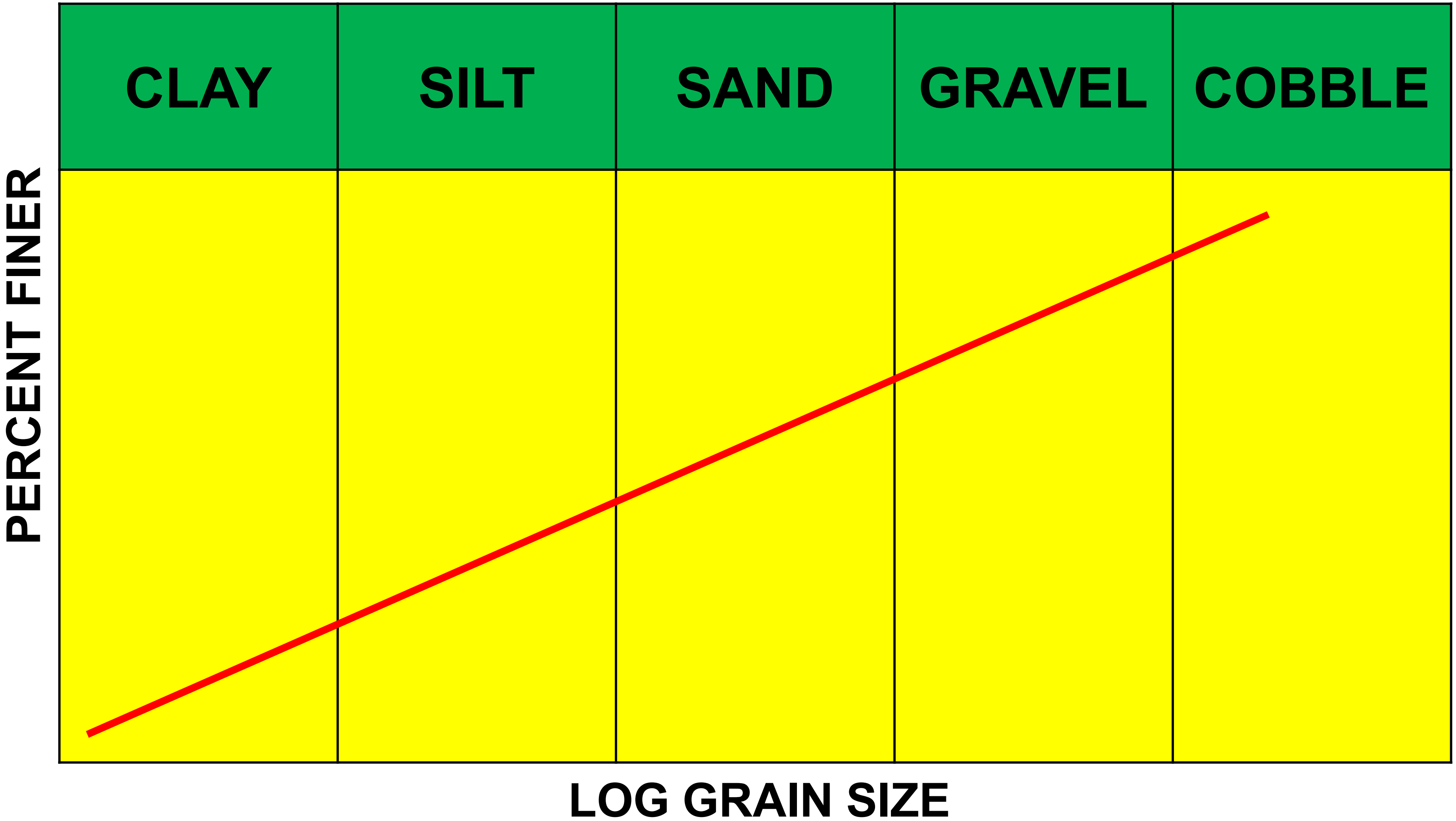


# Classifying Fines

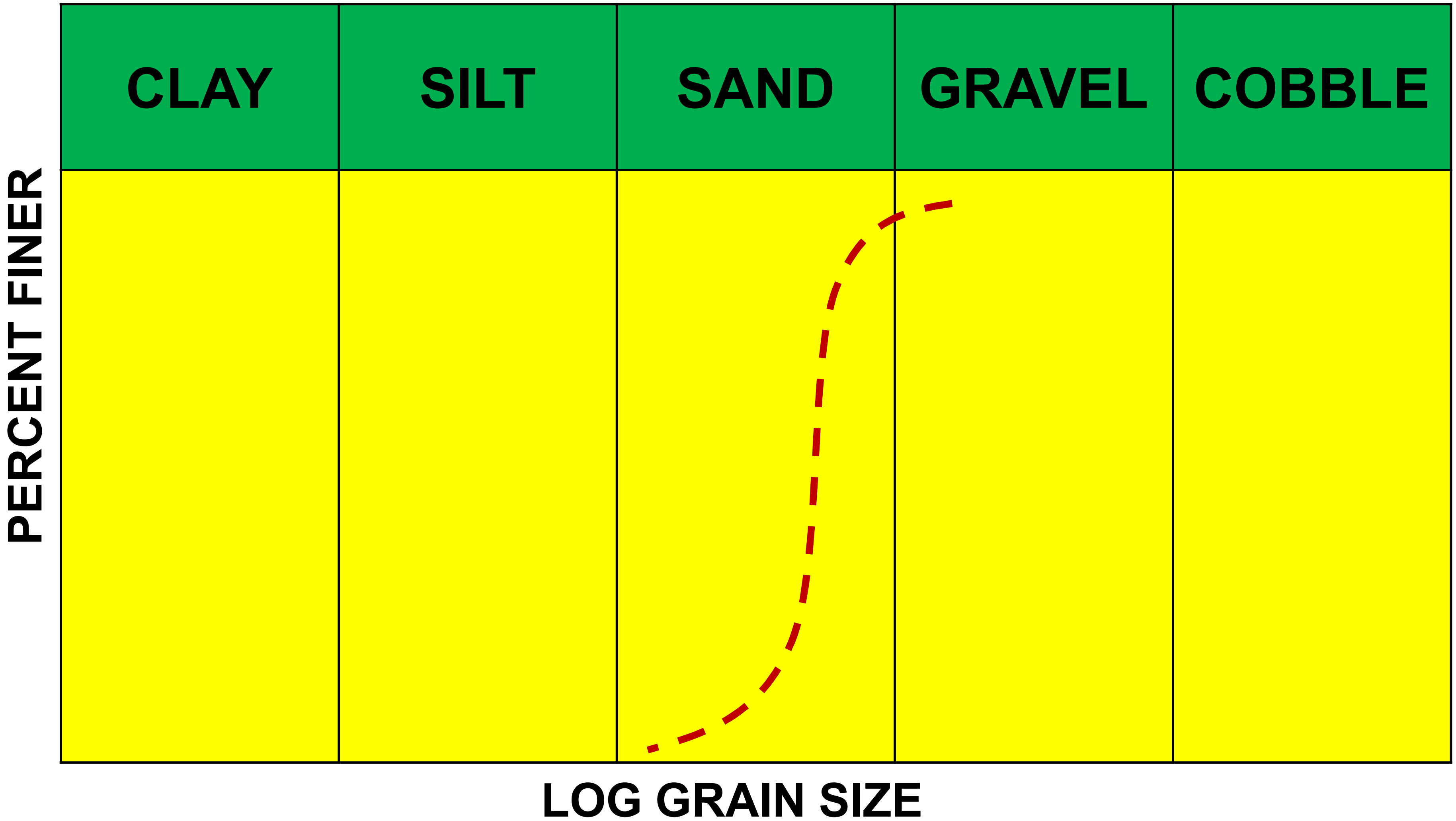
- Purely based on LL and PI



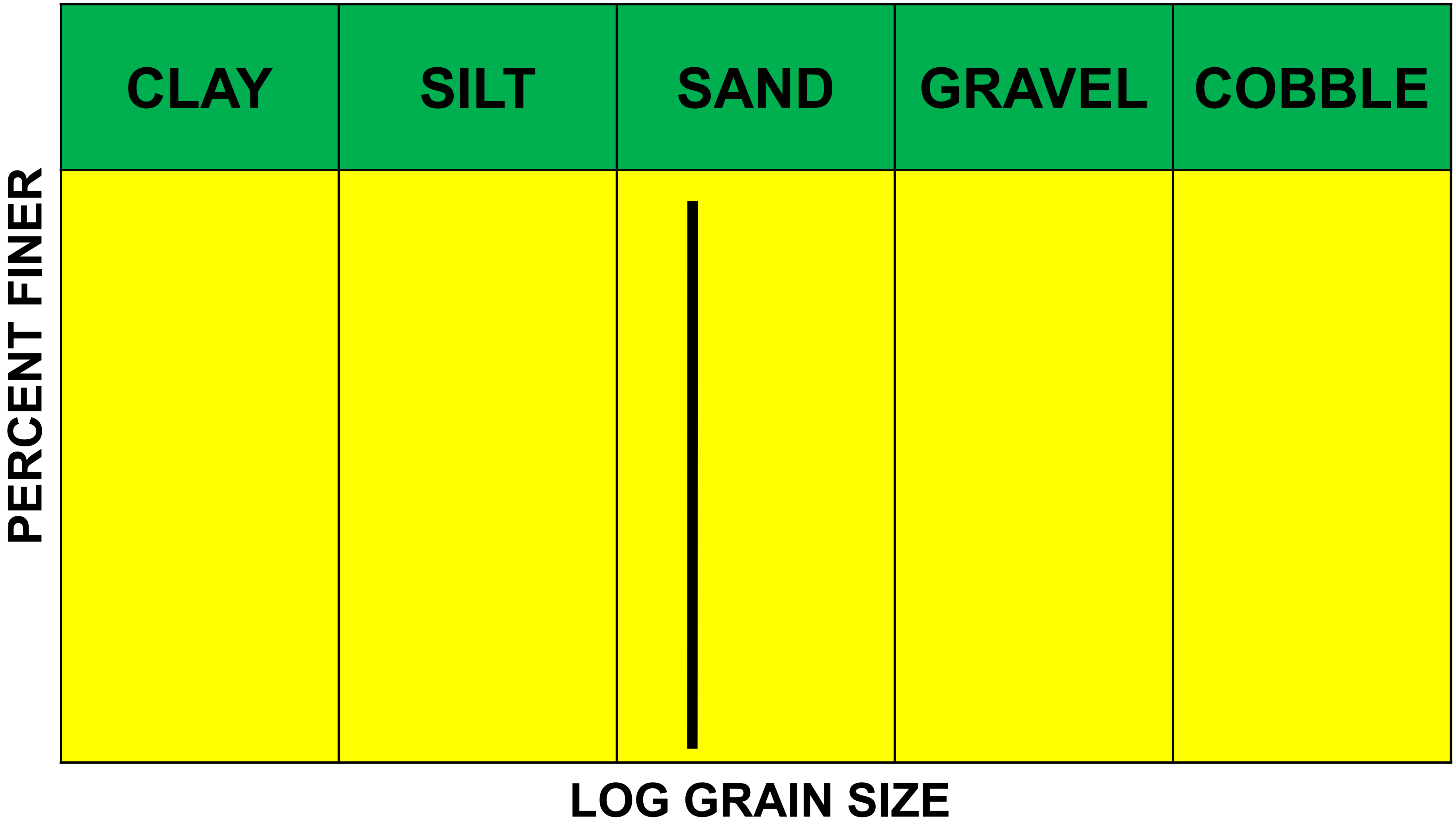
# Well Graded Soil



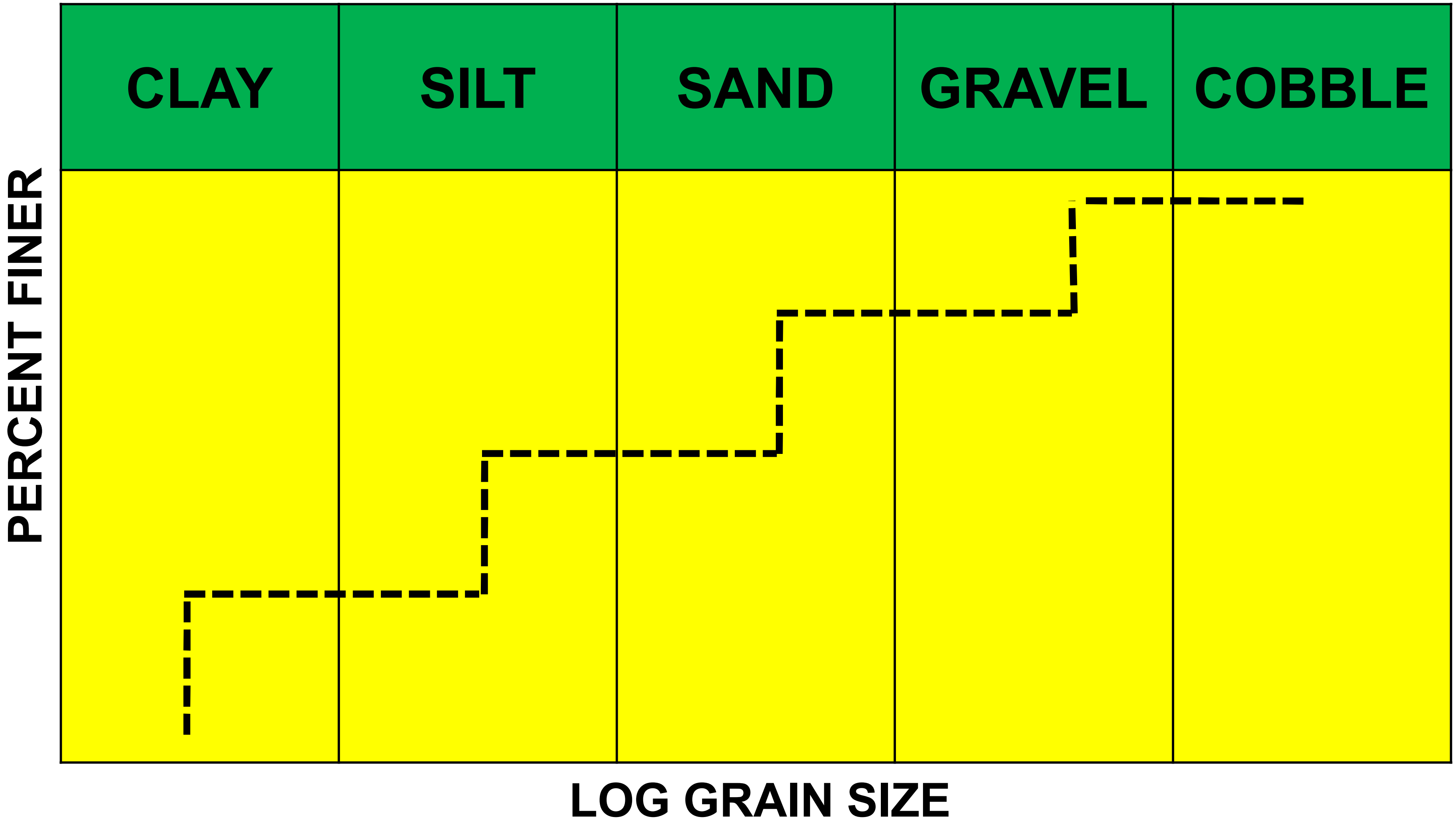
# Poorly Graded Soil



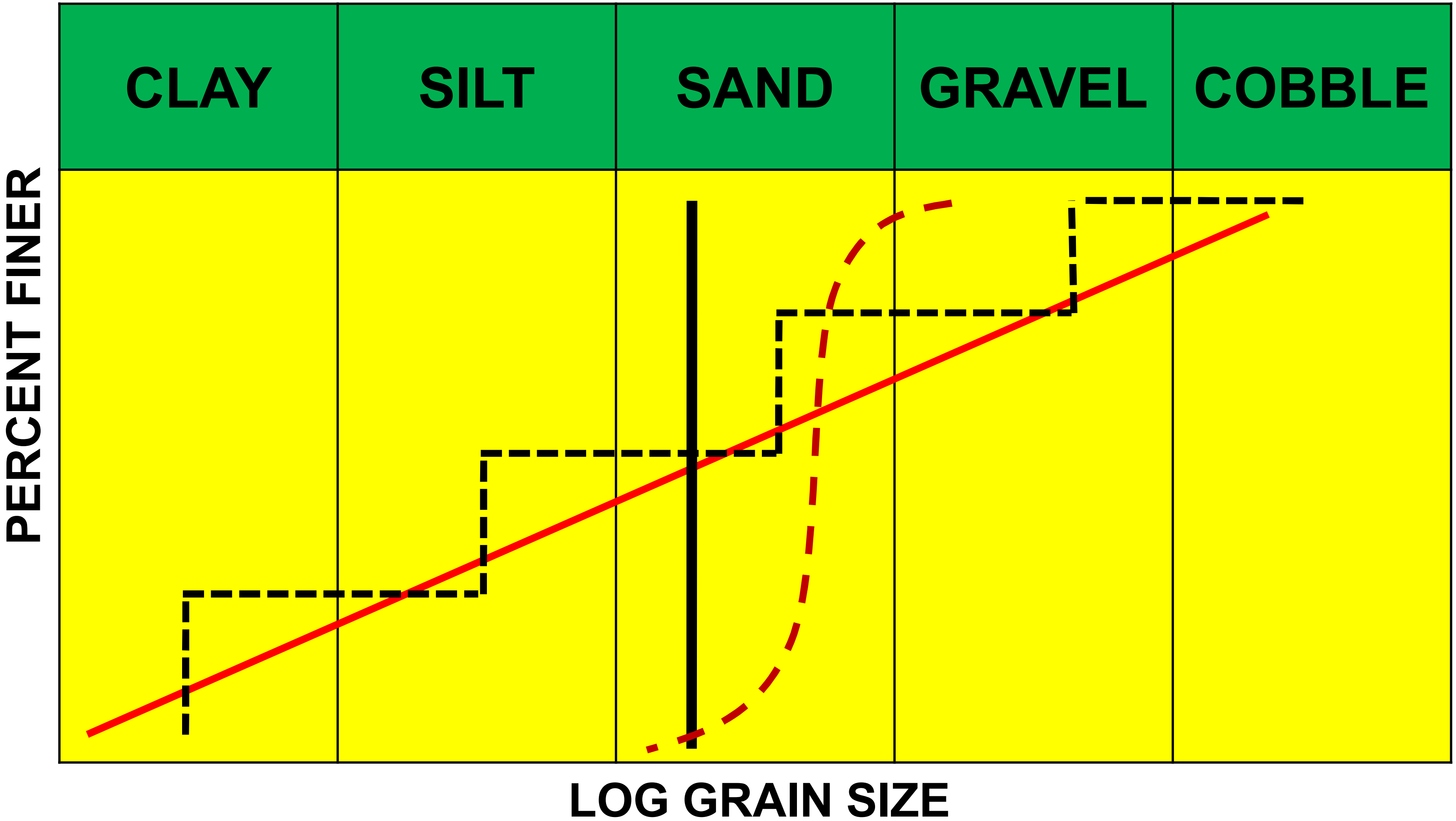
# Uniformly Graded Soil



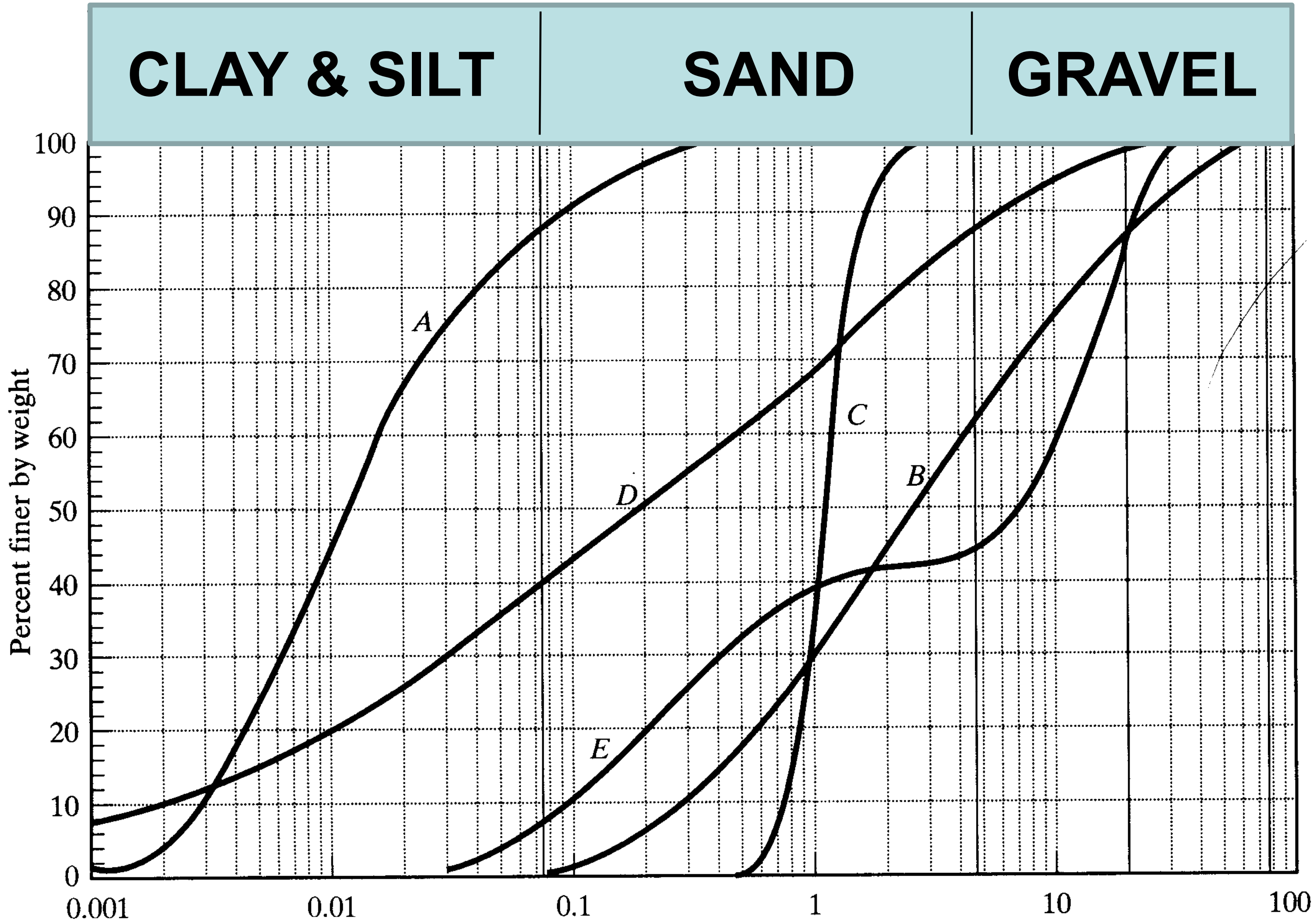
# Gap Graded Soil



# Different Gradations in Soil



# Grain Size Distribution Curves



# Boundary Classifications

Sometimes, it is not possible to classify a soil into any one of 18 groups discussed above.

A soil may possess characteristics of two groups, either in particle distribution or in plasticity.

For such cases, boundary classifications occur and **dual symbols** are used.

# COMPACTION OF SOILS

# What Is Compaction?

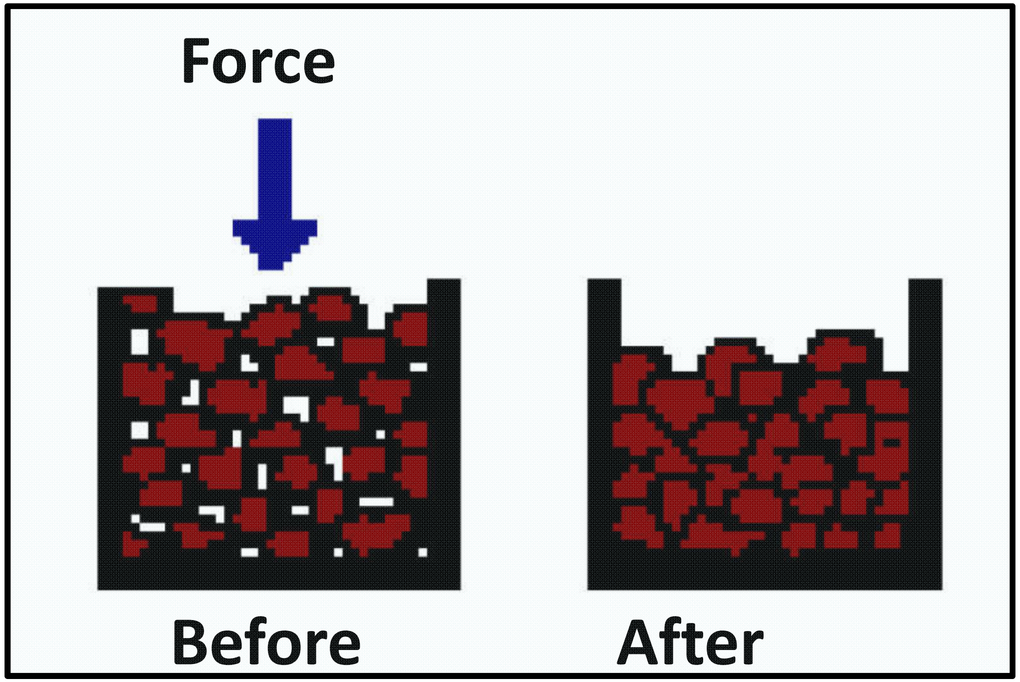
1. Compaction is the process of increasing the **Bulk Density** of a soil or aggregate by driving out air.
2. For any soil, at a given compactive effort, the density obtained depends on the moisture content.
3. For any soil, an "**Optimum Moisture Content**" exists at which it will achieve it's maximum density.

## Compaction is the method of mechanically increasing the density of soil.

1) **Increases load-bearing capacity (Strength)**
2) **Prevents soil settlement and frost damage**
3) **Provides stability**
4) **Reduces water seepage**
5) **Reduces Swelling & Shrinkage**

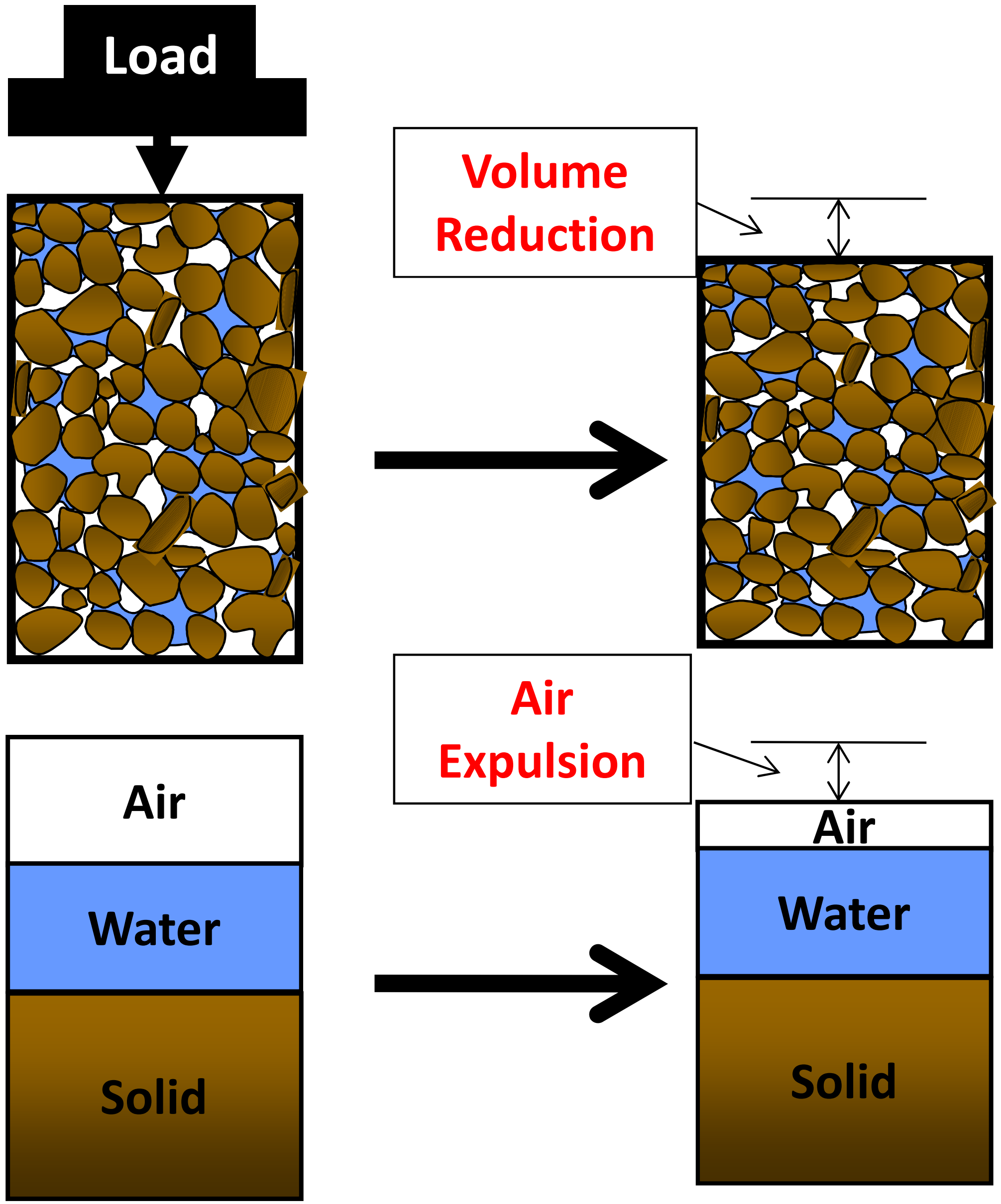
Compaction is the densification of soil by the application of mechanical energy to reduce air void space.

1. Air content reduces, but not water content
2. Not possible to compact saturated soil.

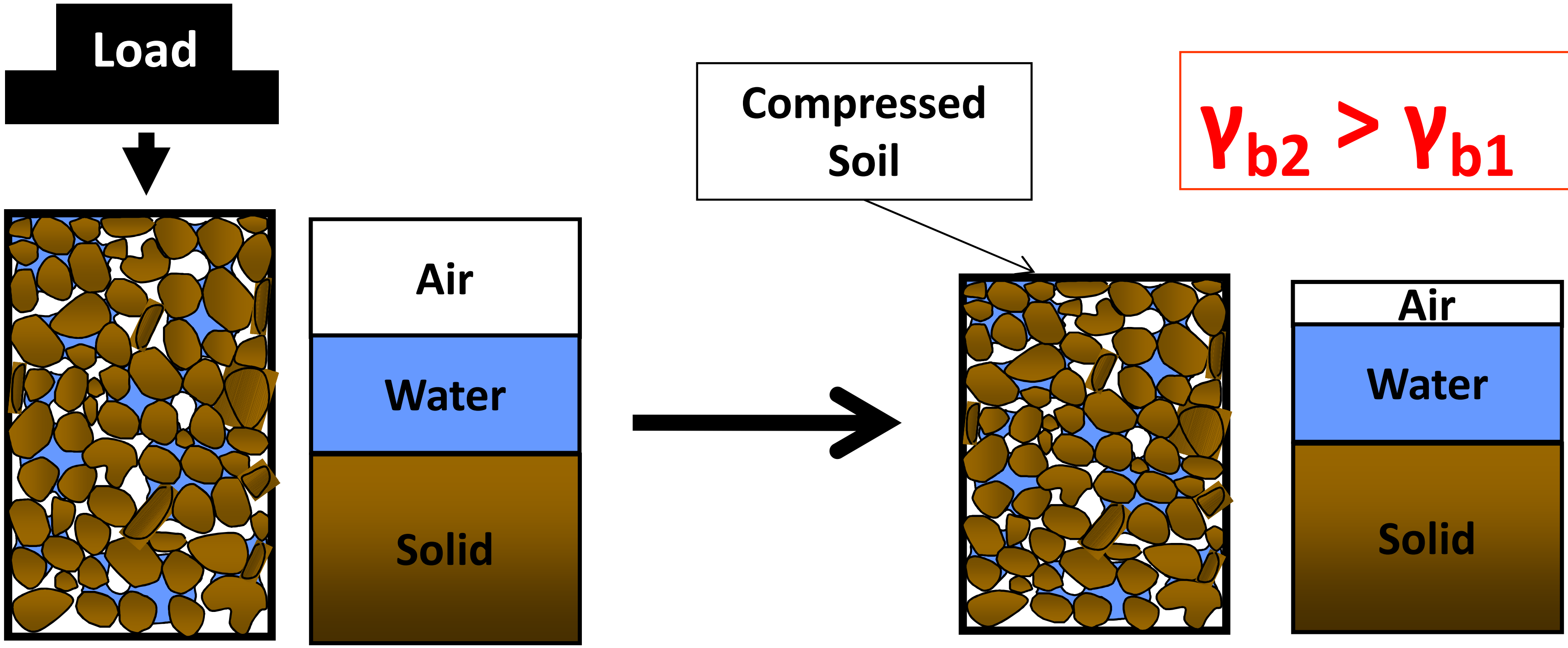


# EFFECT OF COMPACTION

**Reduction in volume due to expulsion of air**



# Principles of Compaction




$\gamma_{b2} > \gamma_{b1}$

Weight W
Volume $V_1$
Density $\gamma_{b1}=W/V_1$

Weight W
Volume $V_2$
Density $\gamma_{b2}=W/V_2$

**Higher the density,**

**Stronger, Stiffer, more Durable will be the soil mass.**

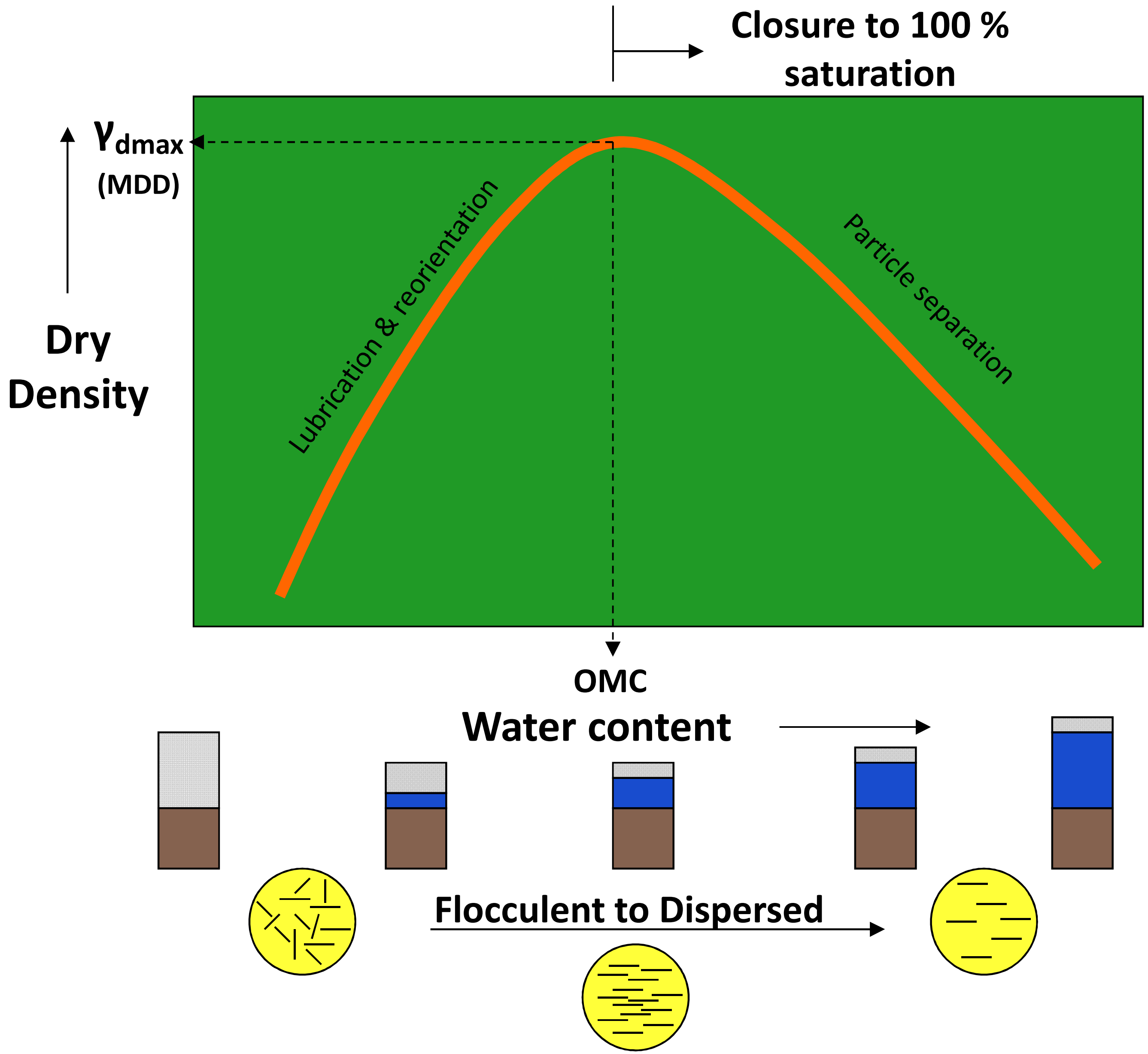
# How does Compaction influence ground ?

1. Increases density
2. Increases strength characteristics
3. Increases bearing capacity
4. Decreases undesirable settlement
5. Increases stability of slopes and embankments
6. Decreases permeability
7. Reduces frost damage
8. Reduces erosion damage

# Distinction between Compaction & Consolidation

| COMPACTION | CONSOLIDATION |
|---|---|
| 1. Man made | 1. Natural |
| 2. Expulsion of air | 2. Expulsion of pore water |
| 3. Fast process | 3. Gradual process |
| 4. Possible in dry or partially saturated soil | 4. Possible in saturated soil |
| 5. Air Content reduces | 5. Air Content = 0 always |
| 6. Water content constant | 6. Water content decreases |

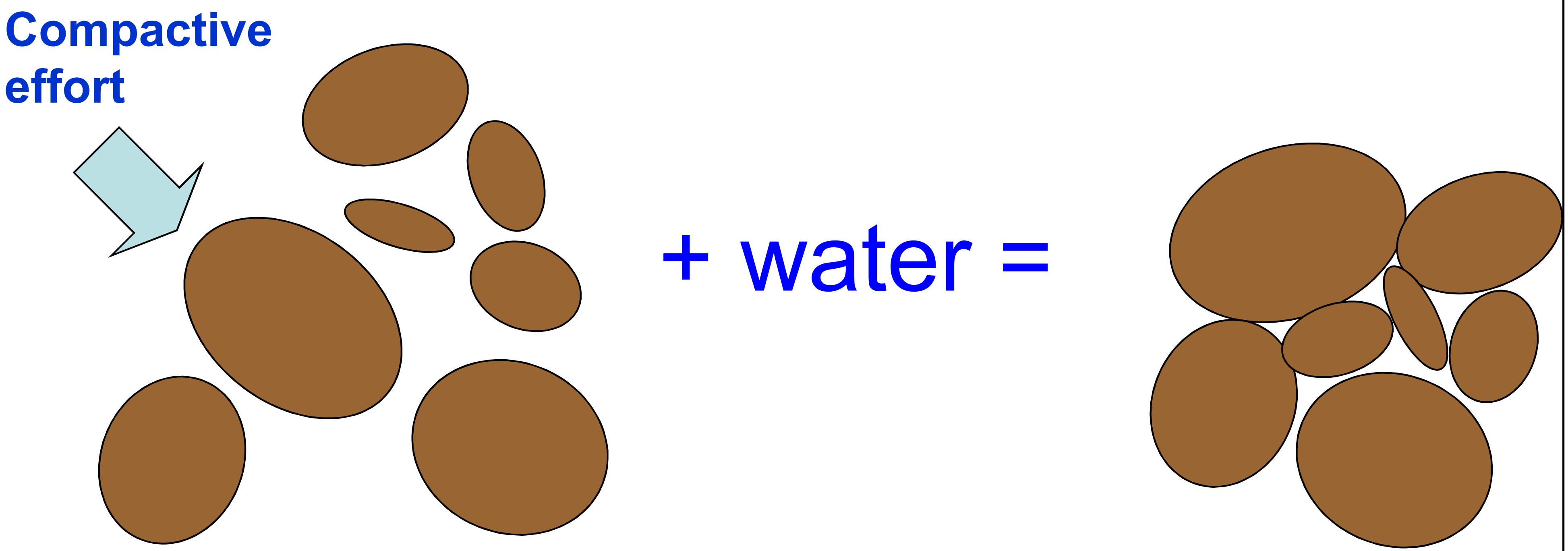
# Compaction of Fine grained Soil



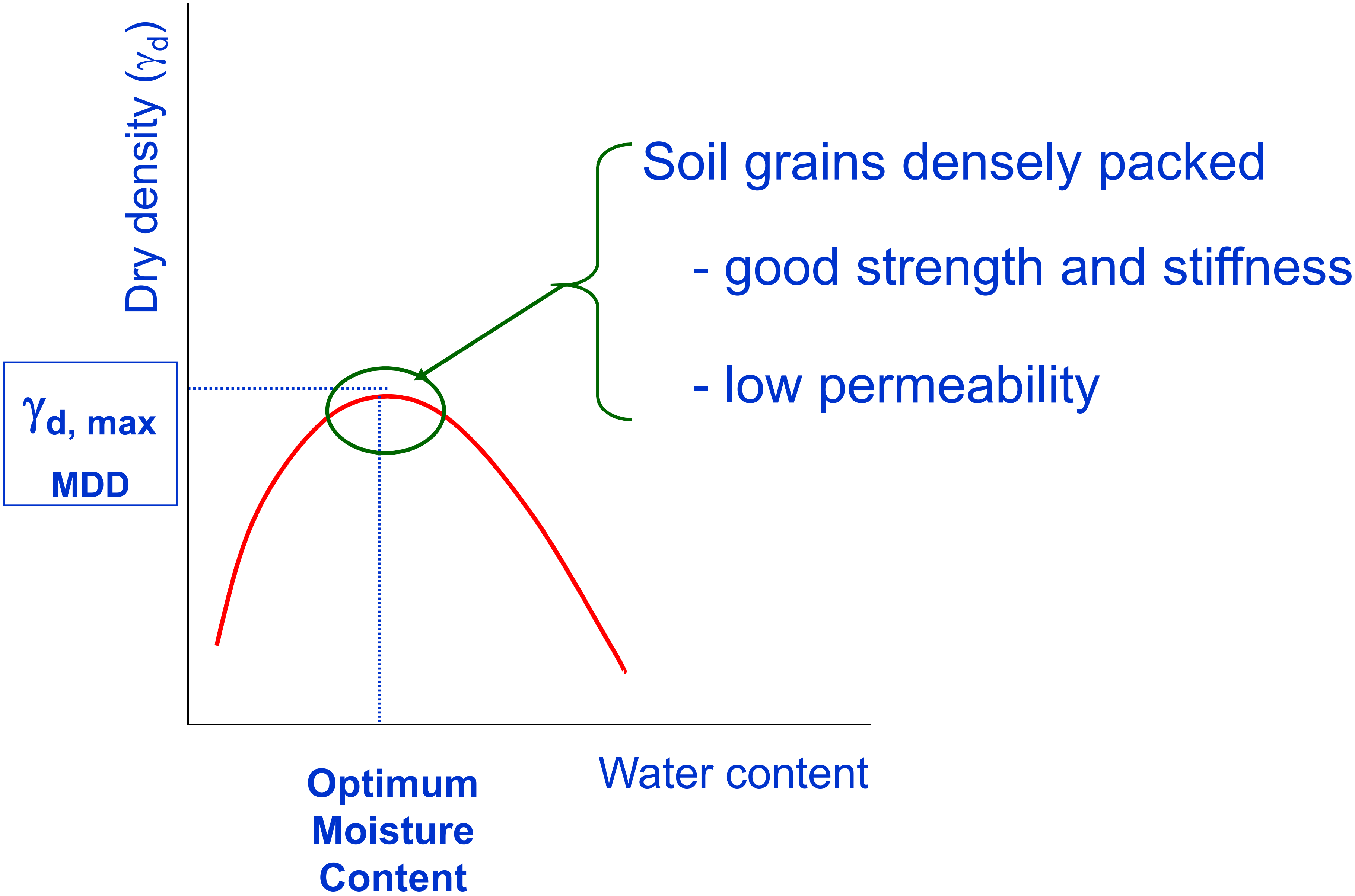
**Water is added to lubricate the contact surfaces of soil particles and improve the compressibility of the soil matrix**

# What is compaction?

A simple ground improvement technique, where the soil is densified through external compactive effort.



# Compaction Curve



# Compaction Control

-a systematic exercise where you check at regular intervals whether the compaction was done to specifications.

e.g., 1 test per 1000 $m^3$ of compacted soil

- Minimum dry density
- Range of water content

Field measurements (of $\gamma_d$) obtained using

- Sand cone / core cutter
- Nuclear density meter

# Laboratory Compaction Test

- to obtain the compaction curve and define the optimum water content and maximum dry density for a specific compactive effort.

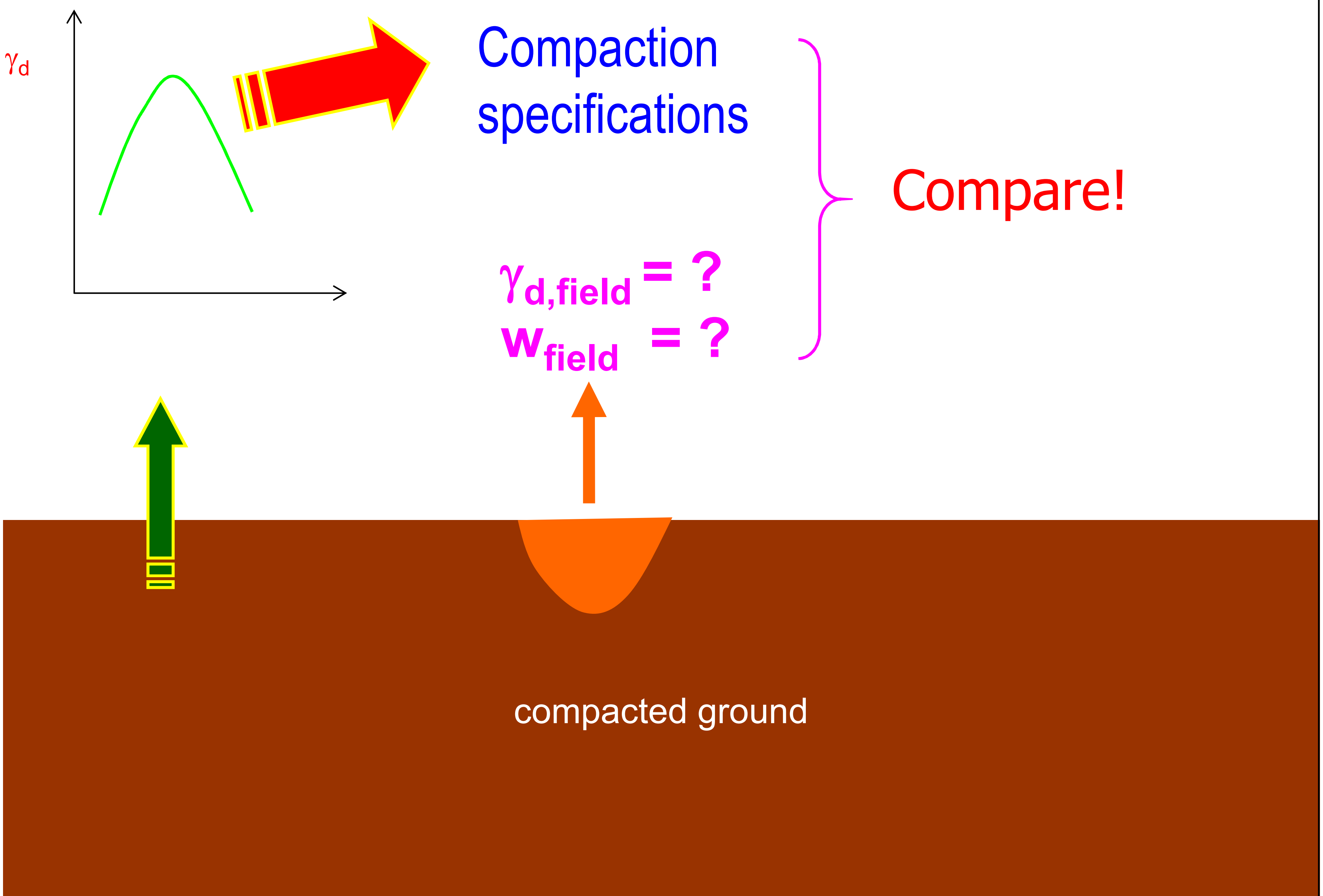
Standard Proctor:

- 3 layers
- 25 blows per layer
- 2.7 kg hammer
- 300 mm drop

Modified Proctor:

- 5 layers
- 25 blows per layer
- 4.9 kg hammer
- 450 mm drop

# Compaction Control Test



# Placement Water Content

**It is necessary to decide the**

1. Placement water content
2. Type of equipment for compaction
3. Number of passes

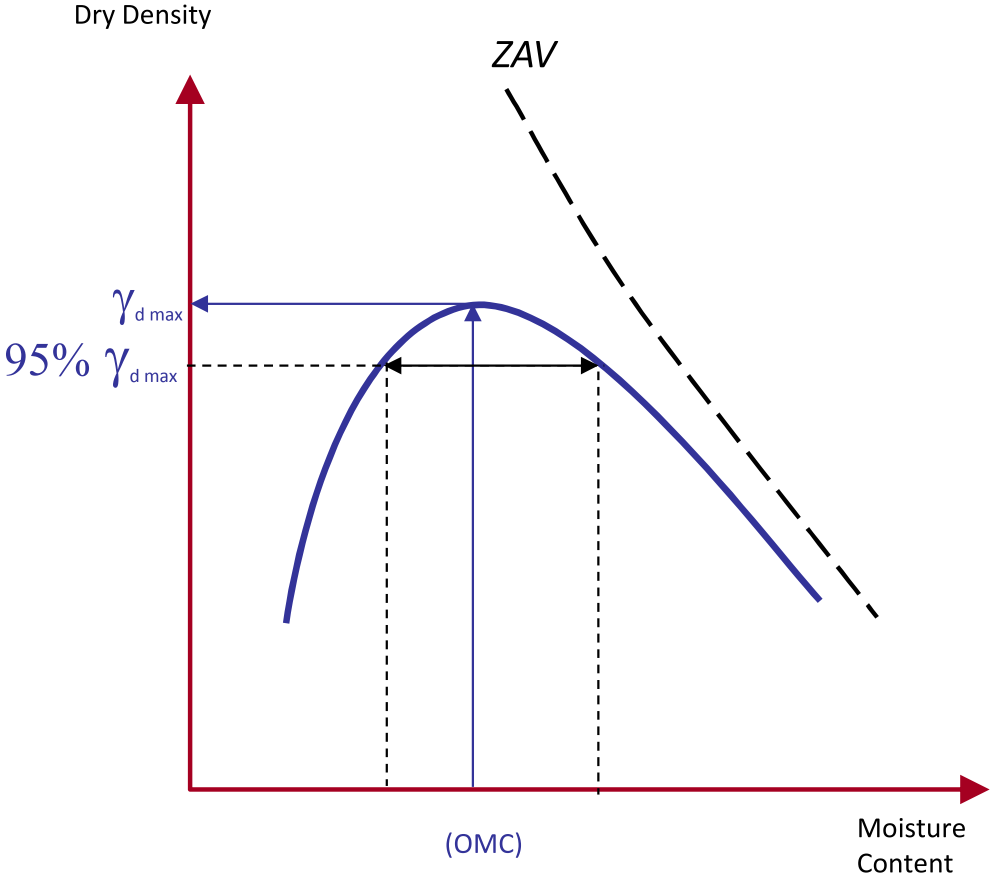
**Based on soil type & degree of compaction desired**

# Placement Water Content

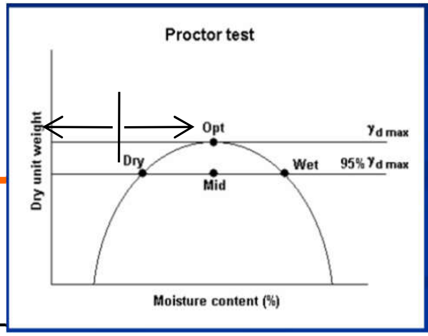
Water content at which the ground is compacted in the field

# Comparison between field & laboratory compaction methods



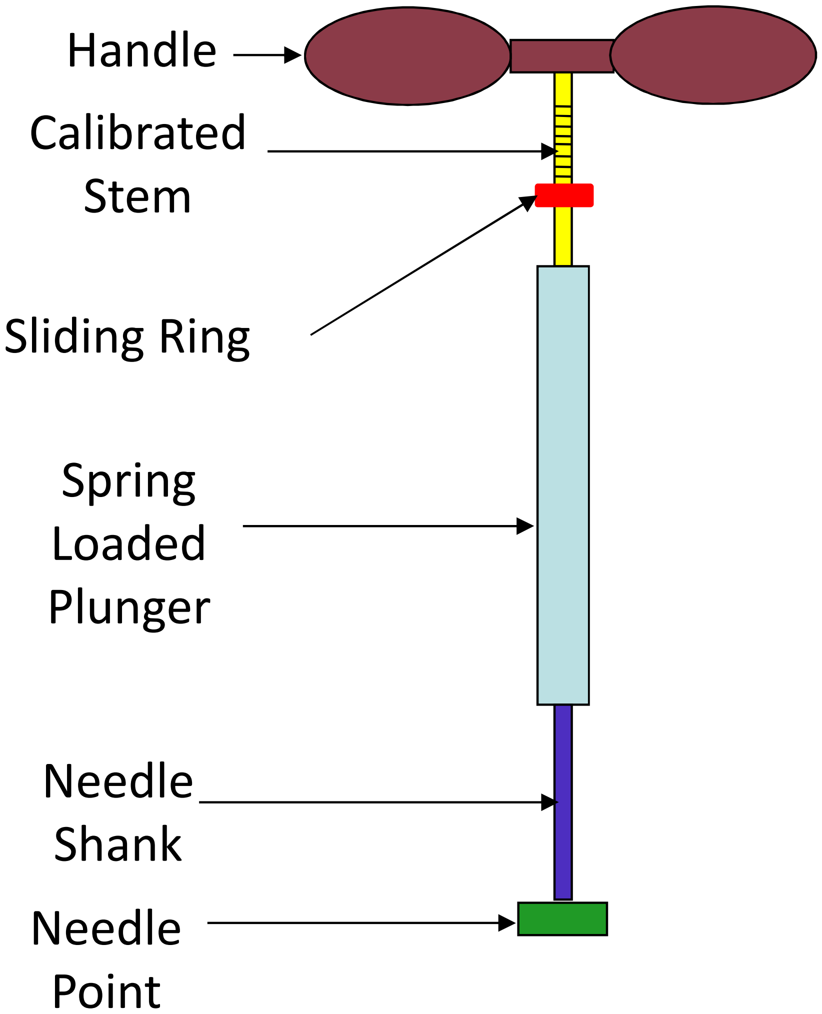


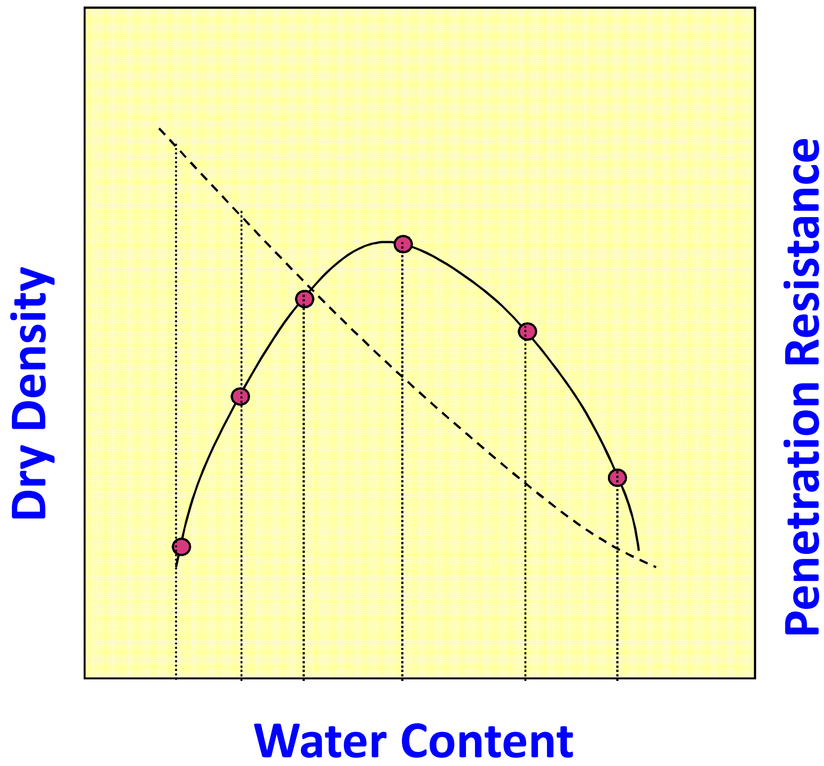
# Placement Water Content




| Dry side | Wet side |
|---|---|
| Highway embankment is compacted dry of optimum to achieve high strength, low volume compressibility and good resistance to deformation | Cohesive subgrade under pavements are compacted wet of optimum to eliminate swelling and swelling pressure upon submergence |
| High earth dams are compacted at 1 to 2.5 % less than OMC to reduce pore water pressure development | Impervious core of earth dam is compacted on wet side to achieve low permeability, greater safety against cracking due to differential settlement |

# Proctor's Needle



# Compaction control in field

There are many variables which control the vibratory compaction or densification of soils.

**Characteristics of the compactor:**

(1) Mass, size

(2) Operating frequency and frequency range

**Characteristics of the soil:**

(1) Initial density

(2) Grain size and shape

(3) Water content

# Compaction control in field

## Construction procedures:

(1) Number of passes of the roller

(2) Lift thickness

(3) Frequency of operation of vibrator

(4) Towing speed

# Degree of Compaction

**Relative compaction or degree of compaction**

$$R.C. = \frac{\gamma_{d-field}}{\gamma_{d\max-laboratory}} \times 100\%$$

Correlation between relative compaction & relative density

$$R.C. = 80 + 0.2D_r$$

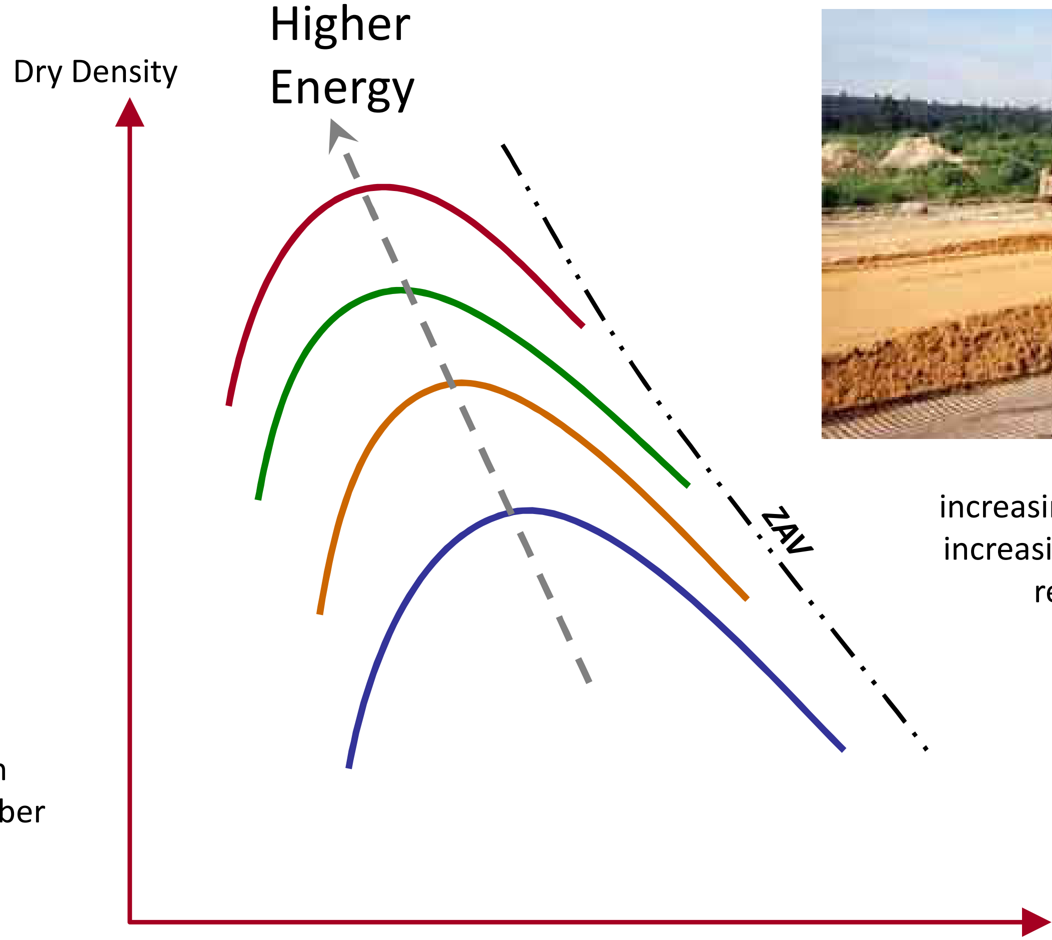
**It is a statistical result based on 47 soil samples.**

**As $D_r$ = 0, R.C. is 80, *Typical required R.C. >= 95%***

# Effect of Energy on Soil Compaction

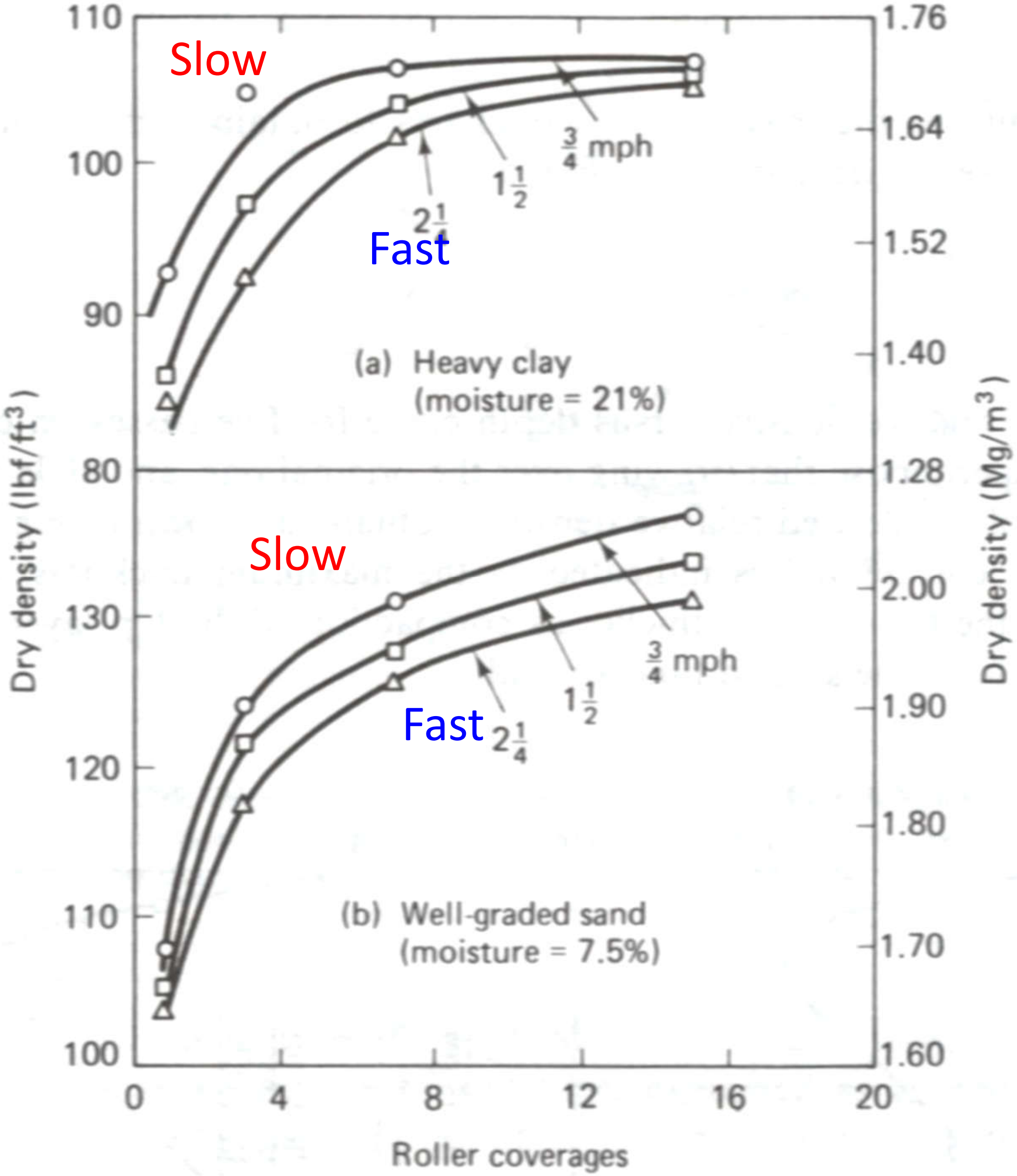
Increasing compaction energy → Lower OMC and higher dry density

In the lab
increasing compaction energy = increasing number of blows



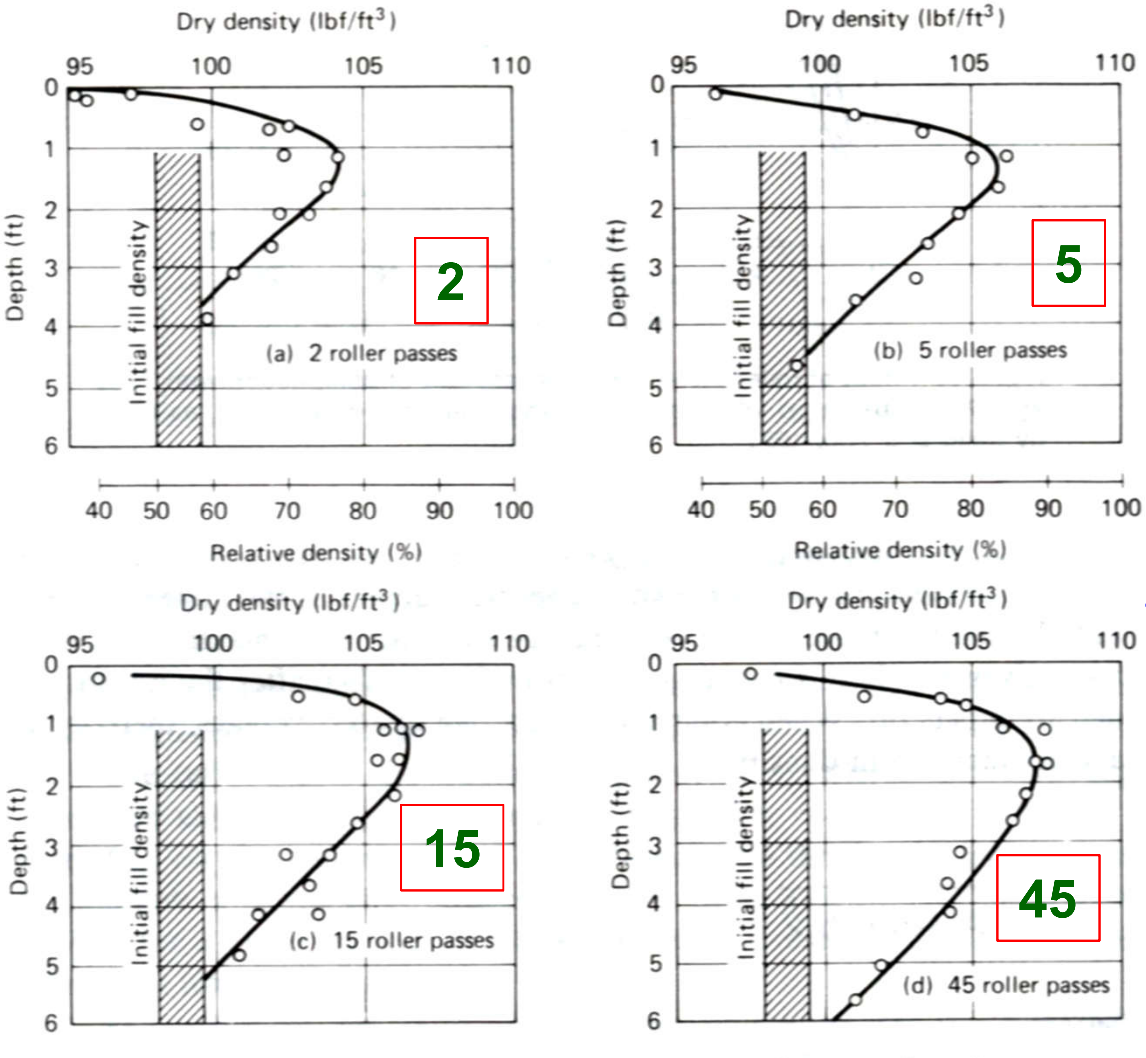

In the field
increasing compaction energy = increasing number of passes or reducing lift depth

# Roller Travel Speed




For a given number of passes, a higher density is obtained if the vibrator is towed more slowly.

# Roller Passes




1. More the number of passes, greater will be the density achieved.
2. Maximum density achieved will be at some depth below GL.
3. The effect of compaction will be felt up to some depth (say 2 m below GL) and it increases with number of passes.

# How Does a Contractor improve Compaction in the Field?

1. Adjust Water Content
2. More Passes
3. Thinner Lifts
4. Bigger Rollers
5. Right Compactor for the Soil Type

| Purpose | Relative Compaction | | Tolerance Range from OMC | Lift thickness (mm) | |
|---|---|---|---|---|---|
| | Granular Soil | Other Soil | | Granular Soil | Other Soil |
| Foundation for structure | 100 | 98 | -1 to +2 | 250 | 150 |
| Lining Canal / small reservoir | - | 95 | -1 to +2 | - | 150 |
| Earth dam > 15 m height | 98 | 98 | -1 to +2 | 300 | 150 |
| Earth dam < 15 m height | 95 | 95 | -1 to +2 | 300 | 150 |
| Foundation for highway / runway | 95 | 95 | -1 to +2 | 300 | 150 |
| Backfill | 98 | 95 | -1 to +2 | 250 | 150 |
| Drainage blanket / filter | 98 | - | Thoroughly wetted | 250 | - |
| Subgrade of excavation | 98 | 98 | -1 to +2 | - | - |
| Rockfill | - | - | Thoroughly wetted | > 600 | - |

# Minimum frequency of field density test for compaction control

| Nature of Earthwork | Minimum frequency | |
|---|---|---|
| | U S Bureau of Reclamation | U S Navy |
| Mass earthwork (embankment) | 1 in 1500 $m^3$ | 1 in 1500 $m^3$ |
| Relatively thin section (Canal / reservoir lining) | 1 in 750 $m^3$ | 1 in 750 $m^3$ |
| Backfill in trenches around structure | 1 in 150 $m^3$ | 1 in 150 to 375 $m^3$ |
| Minimum per shift on mass earthwork | 1 | 1 |
| Doubtful areas | 1 | 1 |
| Pervious materials | 1 in 750 to 7500 $m^3$ | - |

Ref : Winterkorn & Fang (1975) "Foundation Engineering Handbook"
Nayak N V (1982) "Foundation Design Manual"

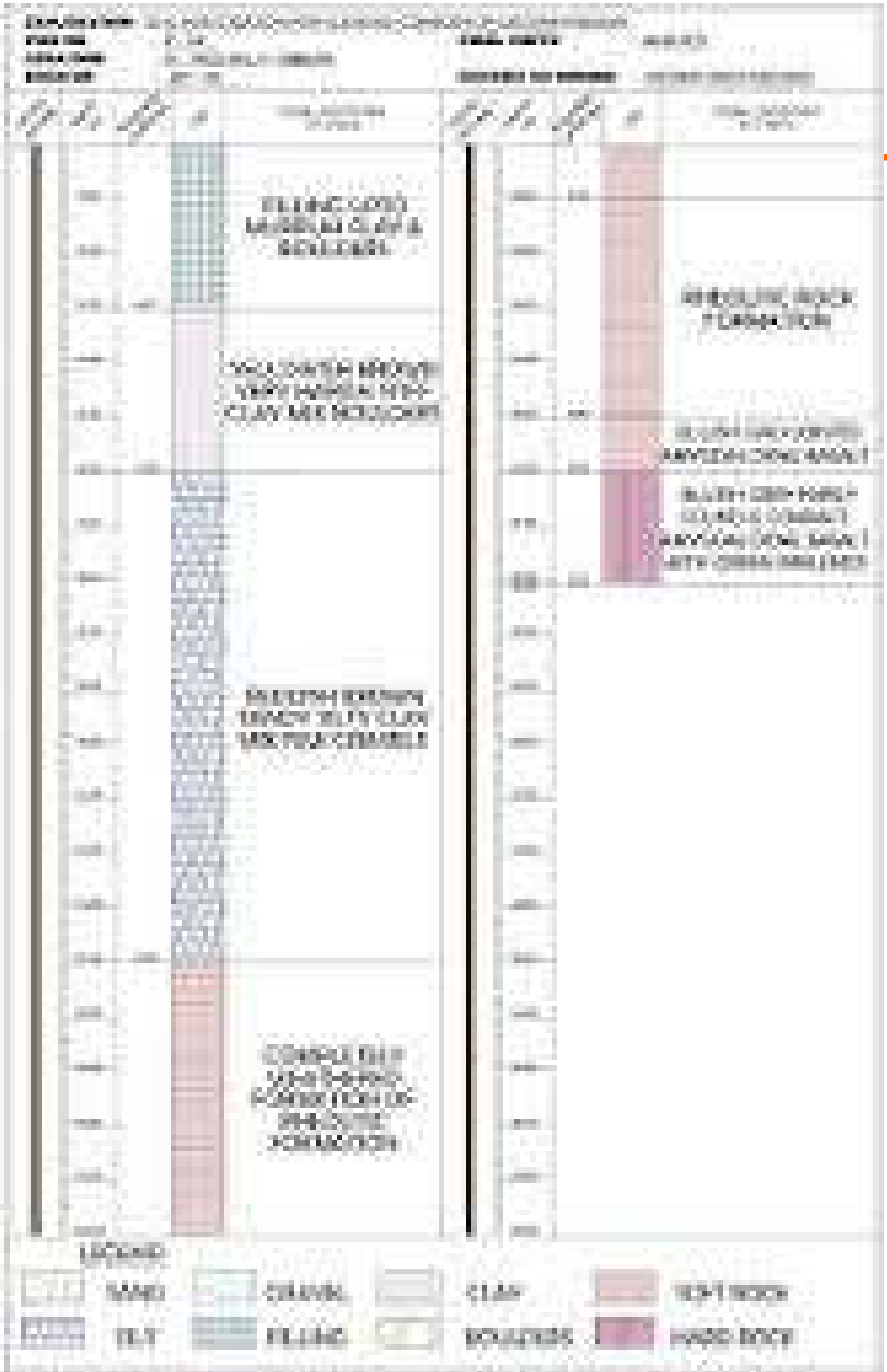
# Soil exploration

# Construction hazard

An unwelcome visitor at an earthwork site.


What does it have to do with Geo?#!

A dead Anaconda python



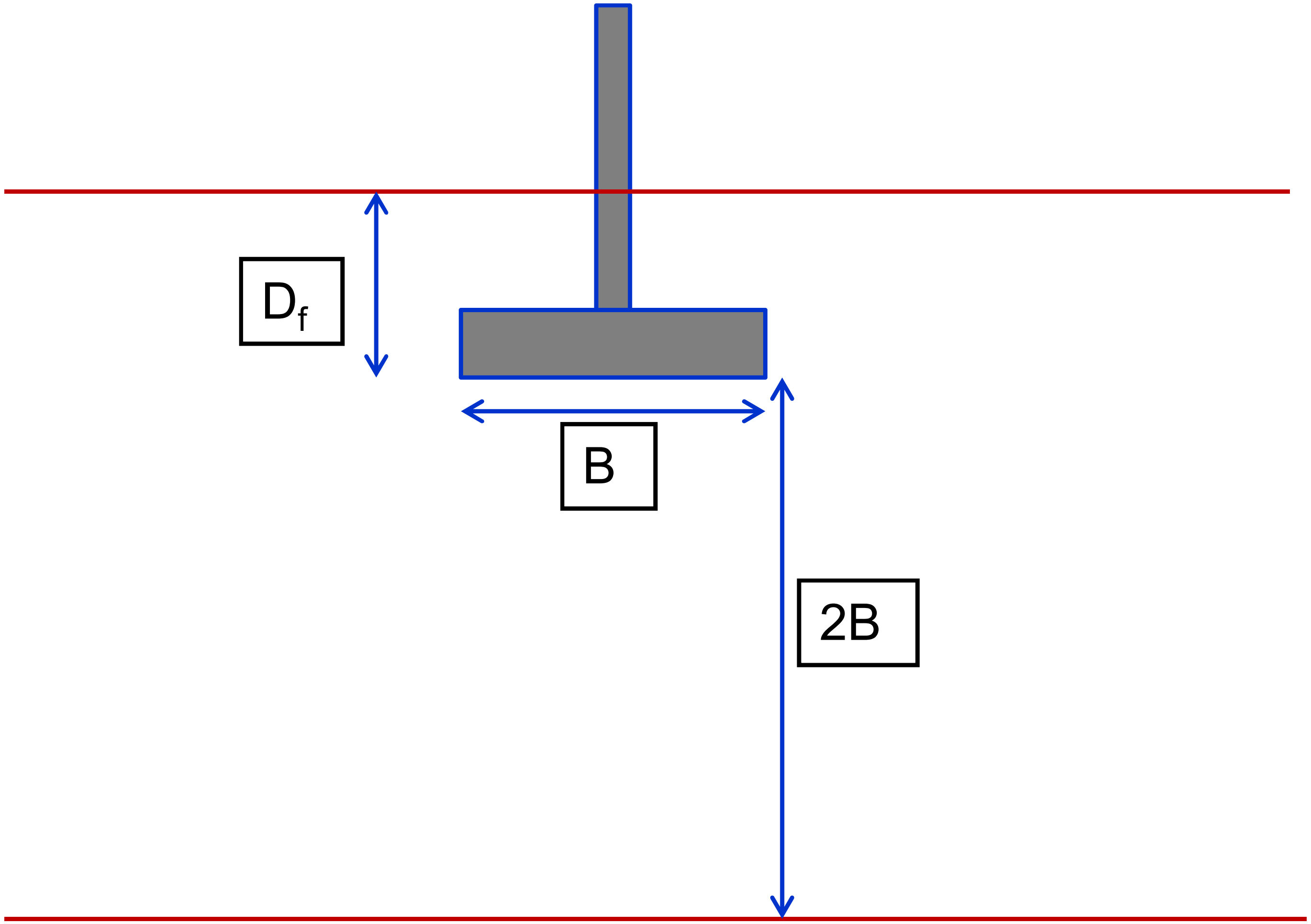
# Soil Investigation Report

- SPT ‘N’
- Shear Wave Velocity
- Water content
- Density
- Level of GWT
- Type of soil
- Strength parameters
- Settlement Characters

## Interpretation ???

- Depth of foundation
- Treatment & ground modification
- ABP
- Type of foundation

# *Depth of Geotechnical Investigation Required*



# TYPICAL BORELOG

| SOIL PROFILE | | | Project : Group Housing Complex at Sy Nos 174/4 and 175/2, Kotigenahalli, Yelahanka, Bangalore | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B.H. Location : | Water Table : Nil | | | | Term. Depth : 15.0m | | | | B.H. No.: 4 | | | |
| ■ N - Value | Depth (m) | Soil Description | Grain Size Analysis | | | | Atterberg Limits | | In-situ properties | | Triaxial Test | | | |
| | | | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Liquid (%) | Plastic (%) | Density $\gamma_b$(g/cm³) | Water Cont (%) | Type | c (kg/cm²) | φ (°) |
| | 0.00 | Existing ground level | | | | | | | | | | | |
| | 0.50 | Reddish brown clayey silty sand | | | | | | | | | | | |
| 25 | 1.50 | Yellowish brown with grey silty clayey sand with traces of gravel | 3 | 40 | 28 | 29 | - | - | | | | | |
| | 3.00 | Yellow with whitish grey clayey silty sand | | | | | | | 2.00 | 17.6 | CD | 0.25 | 24 |
| 54 | 4.50 | Pink with yellow and whitish grey clayey silty sand | | | | | | | | | | | |
| | 6.00 | Pink with yellow and whitish grey clayey silty sand | 0 | 44 | 35 | 21 | 43 | 21 | 2.04 | 19.9 | | | |
| 62 | 7.50 | Yellow with whitish grey and pink clayey silty sand | | | | | | | | | | | |

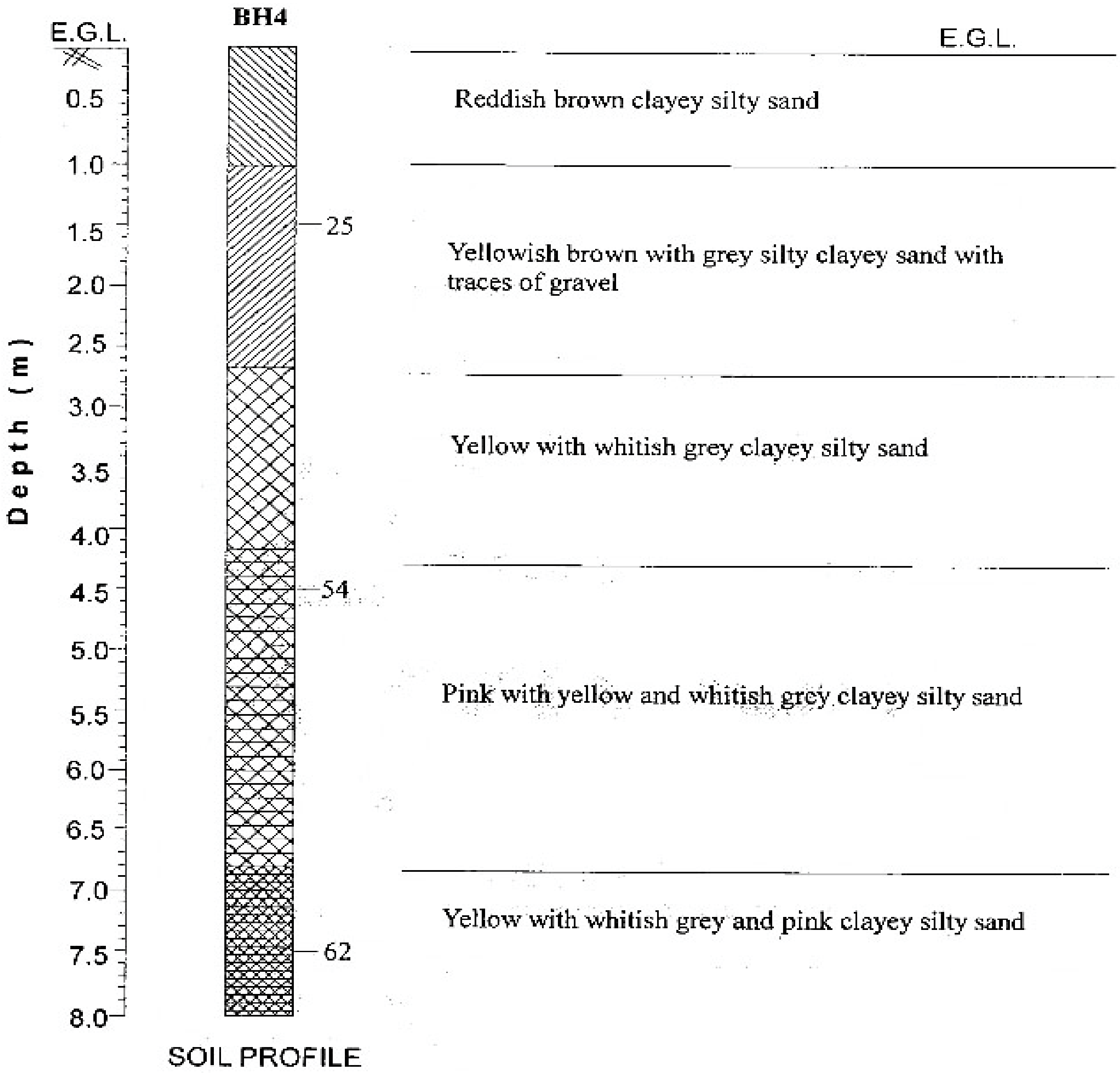
# TYPICAL BORELOG

| SOIL PROFILE | Project : Group Housing Complex at Sy Nos 174/4 and 175/2, Kotigenahalli, Yelahanka, Bangalore | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B.H. Location : | | Water Table : Nil | | | | Term. Depth : 15.0m | | | | B.H. No.: 4c | | | |
| ■ N - Value | Depth (m) | Soil Description | Grain Size Analysis | | | | Atterberg Limits | | In-situ properties | | Triaxial Test | | | |
| | | | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Liquid (%) | Plastic (%) | Density $\gamma_b$(g/cm³) | Water Cont (%) | Type | c (kg/cm²) | φ (°) | |
| | 9.00 | Yellow with whitish grey and pink clayey silty sand | | | | | | | 1.94 | 15.4 | CD | 0.30 | 24 | |
| 64 | 10.50 | Yellowish brown with pink clayey silty sand with gravel | 7 | 41 | 32 | 20 | - | - | | | | | | |
| | 12.00 | Yellowish brown with pink clayey silty sand with gravel | | | | | | | 1.90 | 15.6 | CD | 0.30 | 25 | |
| 78 | 13.50 | Dark yellow sandy silt with clay | 0 | 43 | 47 | 10 | 39 | 23 | | | | | | |
| | 15.00 | Dark yellow sandy silt with clay | | | | | | | 1.87 | 16.8 | CD | 0.10 | 29 | |

Note : 1) ■N-Value (Observed)

2) $\gamma_b$ : Bulk Density

# TYPICAL BORELOG



# Ground Improvement Technique

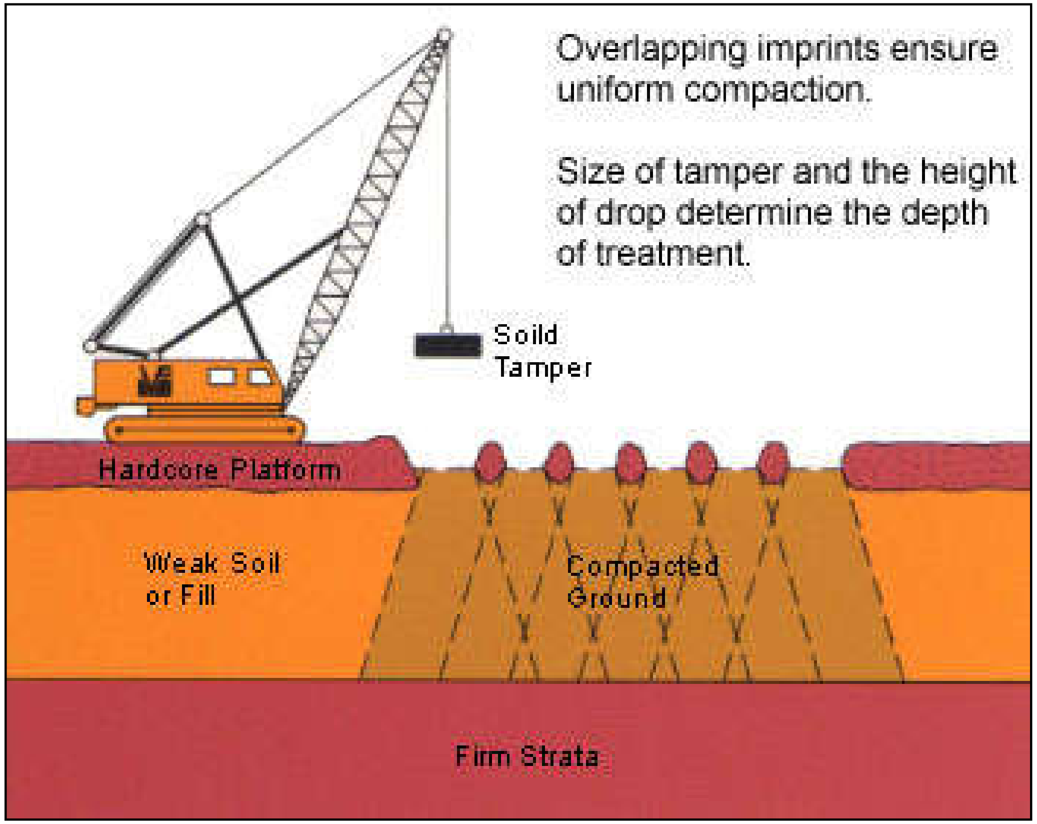
# Ground Improvement

Sheepsfoot Roller to Compact Clay Soils

Smooth-wheeled Roller

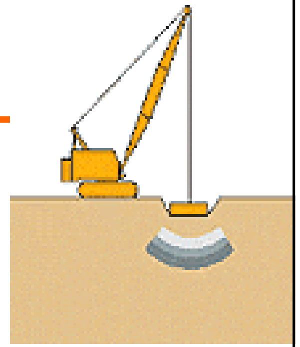
Impact Roller to Compact the Ground

# Dynamic Compaction



# Dynamic Compaction

- pounding the ground by a heavy weight



Suitable for granular soils, land fills and karst terrain with sink holes.

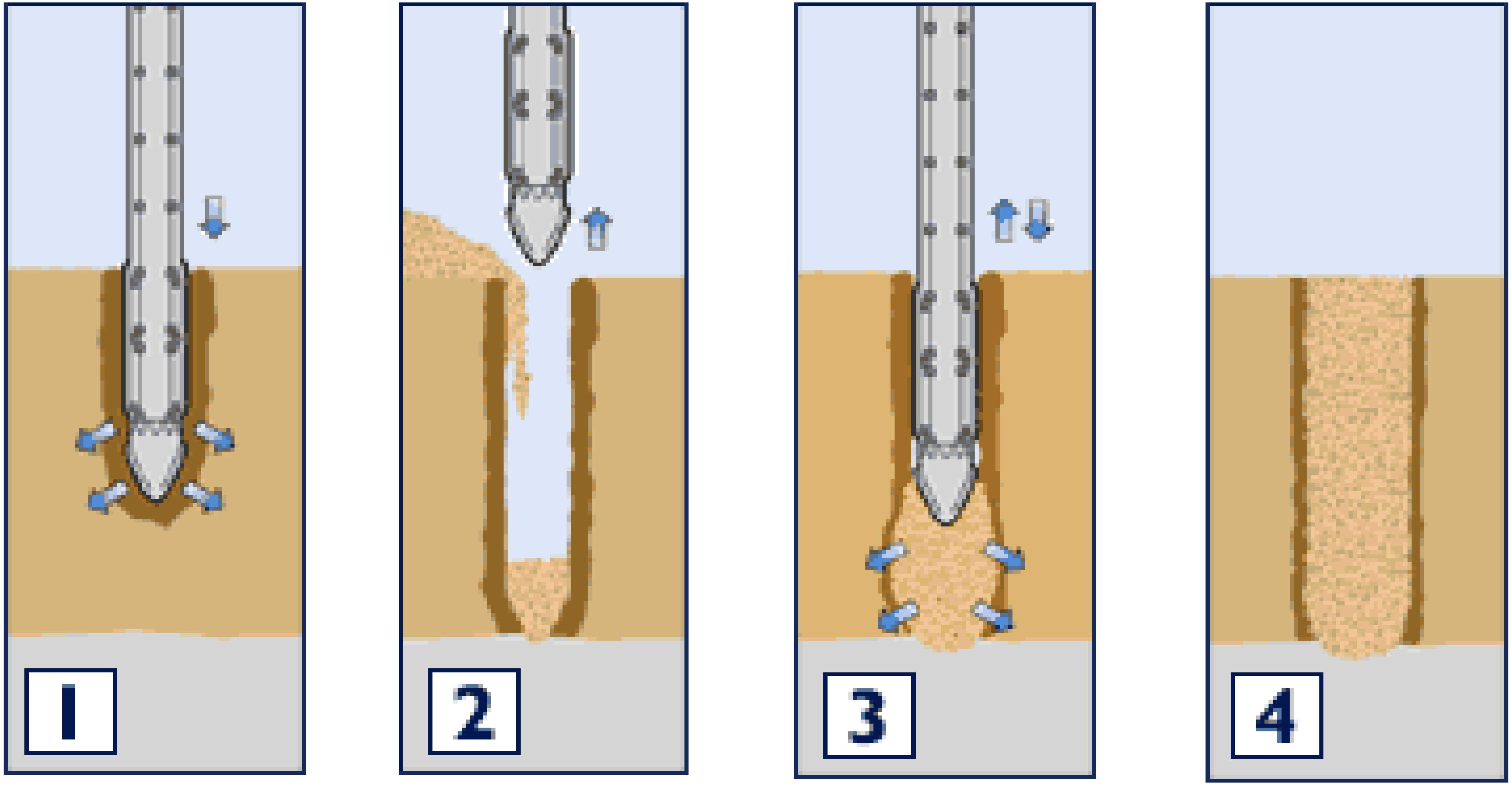
solution cavities in limestone

Pounder (Tamper)

Crater created by the impact

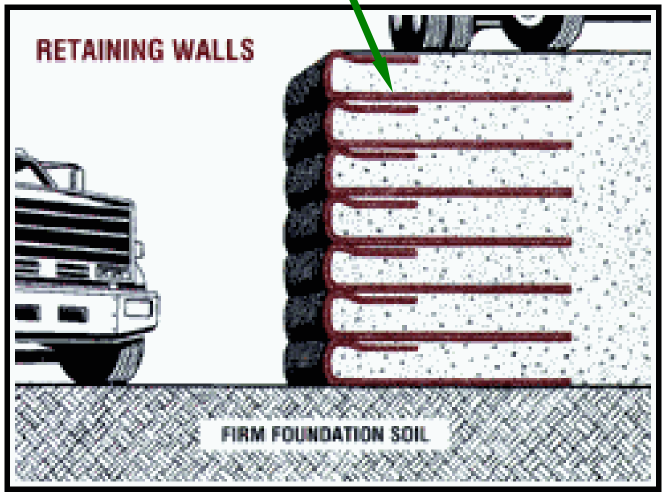
# Vibroflotation

# Vibrofloatation

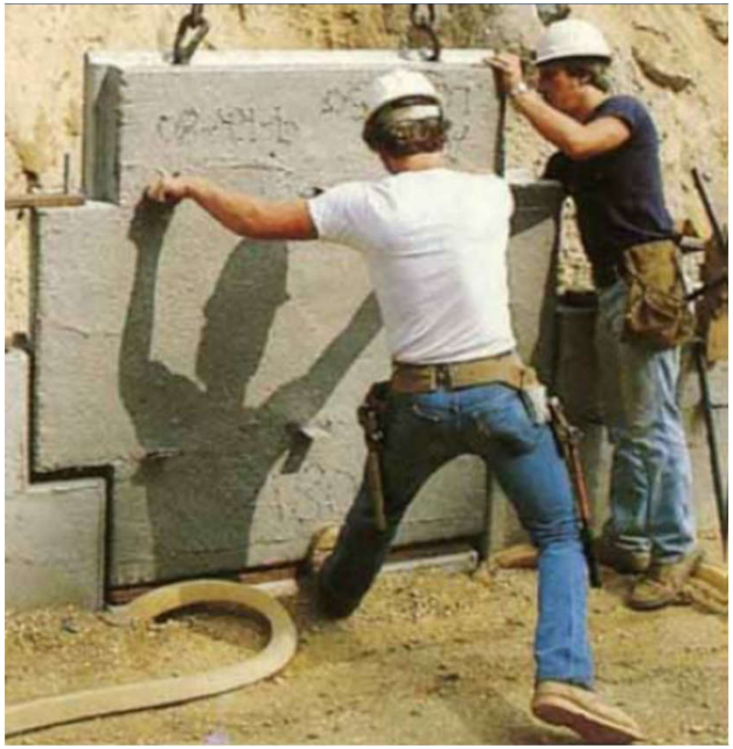


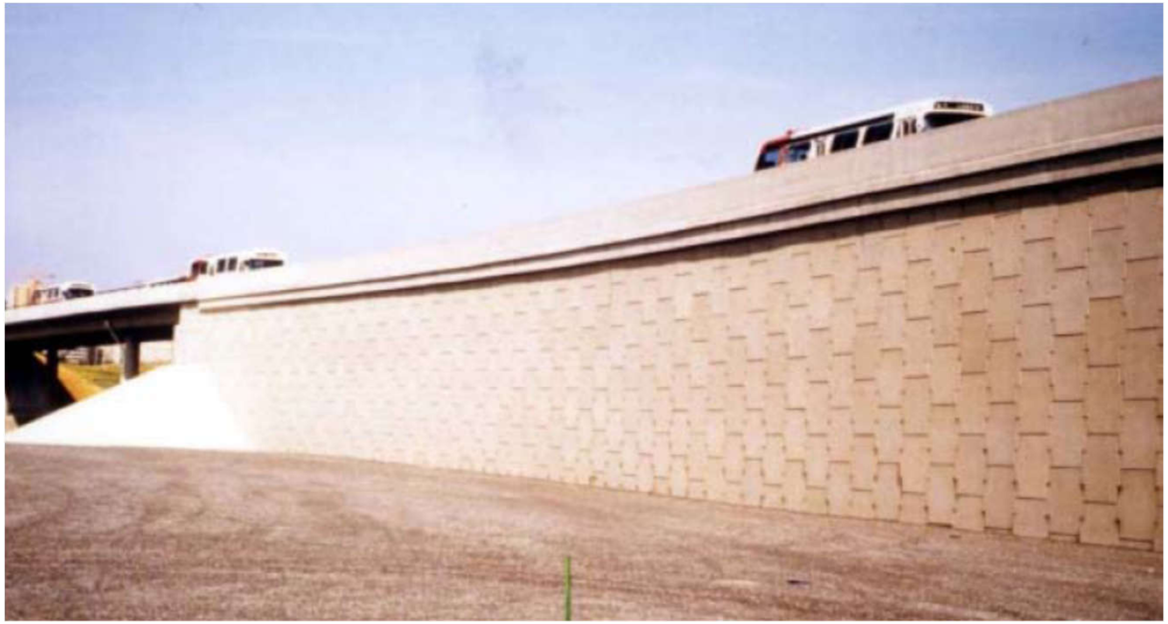
# Reinforced Earth Walls

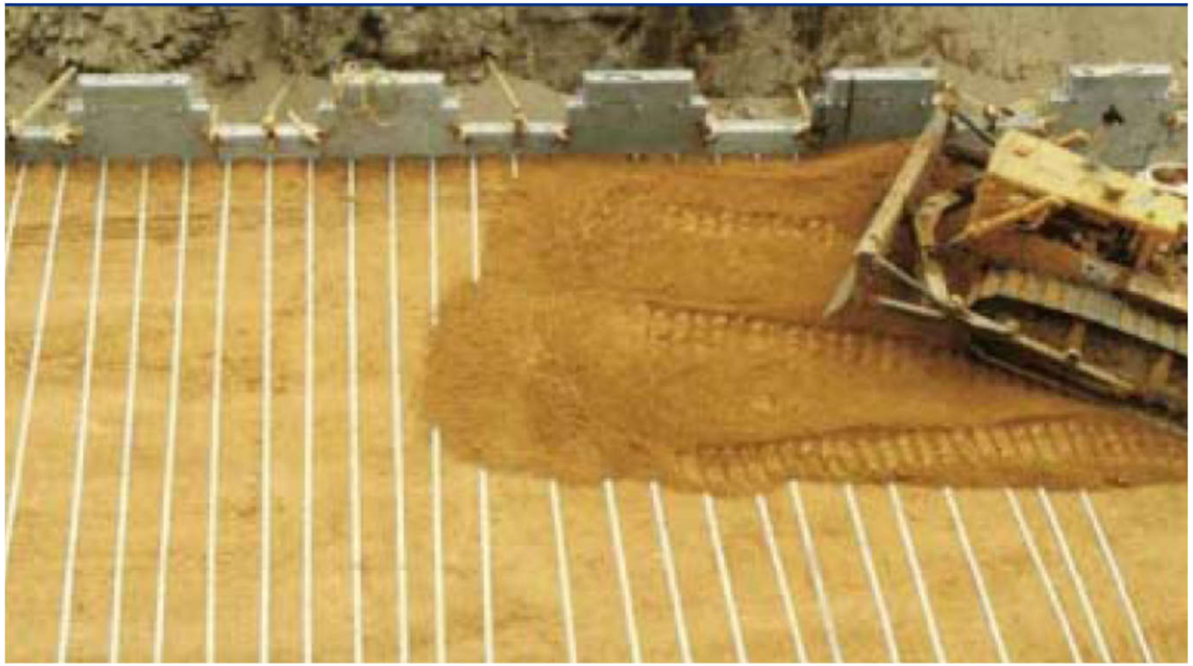
Using geofabrics to strengthen the soil




# MSE/Reinforced earth Wall







# Soil Nailing

Steel rods placed into holes drilled into the walls and grouted

# Geofabrics

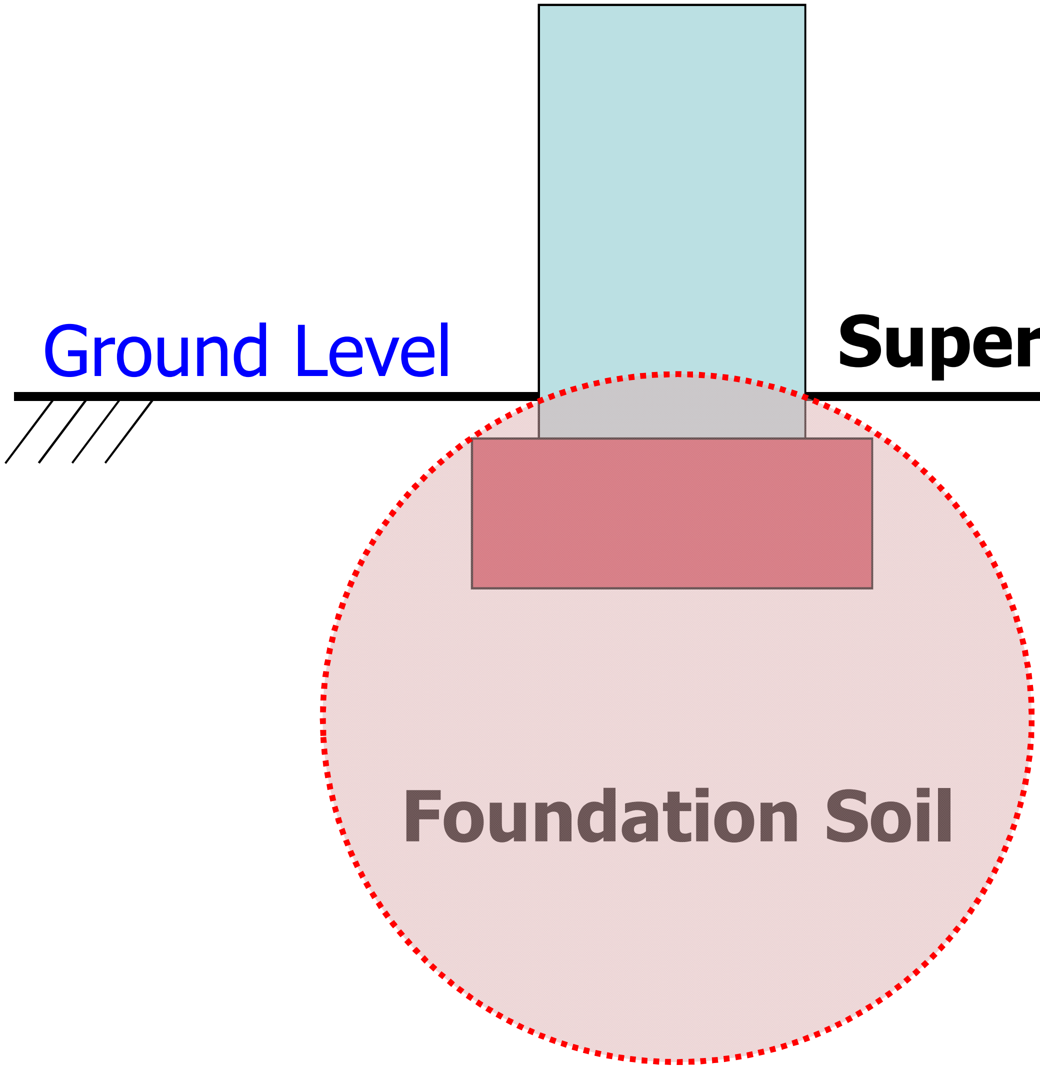
Used for reinforcement, separation, filter, drain and container in roads, retaining walls, embankments, earth dams, landfills…

- Sheets
- Strips
- Rods
- Net
- Foam
- Grid
- Pipes
- Composites

# Foundation Engineering

# For a geotechnical engineer,

- Limit State of Collapse
  (Shear Failure)
- Limit State of Serviceability
  (Settlement)

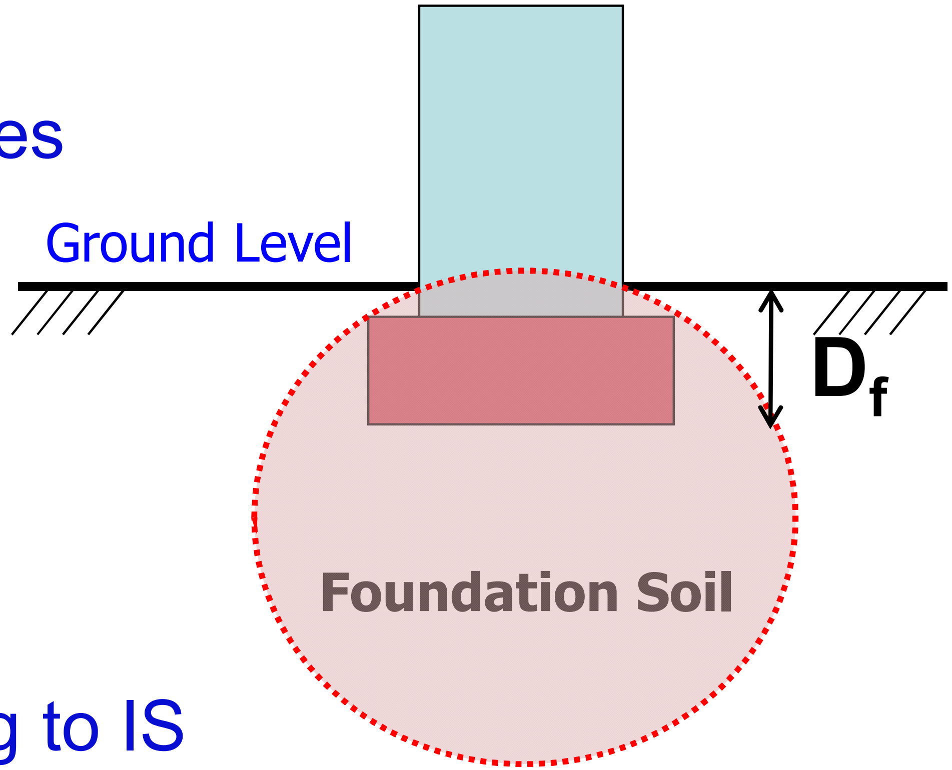



**Foundation is that part of the structure which is in direct contact with soil.**
**Do not abuse it.**

**Soil should resist forces without failure or excessive deformation**

# Factors influencing selection of Depth of Foundation

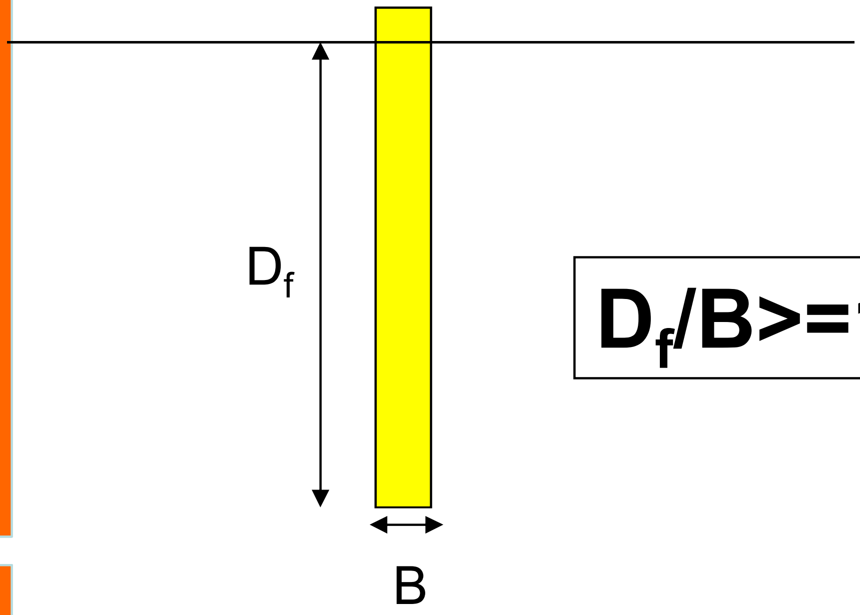
1. Bearing Capacity
2. Settlement Characteristics
3. Water Table
4. Seasonal Moisture changes
5. Freeze Thaw situation
6. Hydraulic considerations
7. Filled-up ground
8. Burrow animals
9. Neighbouring Structure
10. Sloping ground
11. Minimum depth according to IS
12. Height of Structure
13. Dynamic Load



# Purpose of Foundation

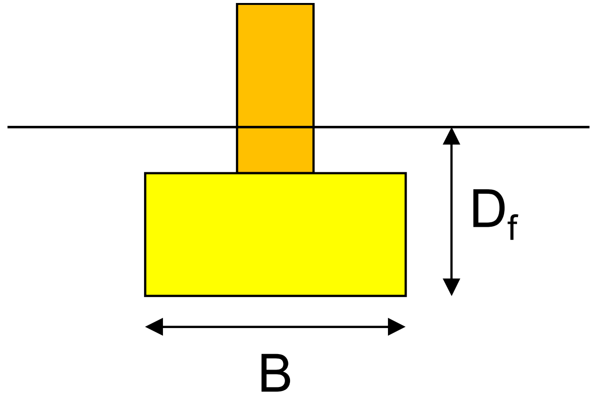
1. To transfer the forces from superstructure to firm soil below.
2. To distribute the stresses evenly on foundation soil such that foundation soil neither fails nor experiences excessive settlement.
3. To develop an anchor for stability against overturning.
4. To provide an even surface for smooth construction of superstructure.

# Types of Foundation




$D_f/B >= 1$

- Deep Foundation
  - Pile Foundation
  - Pier Foundation
  - Well Foundation



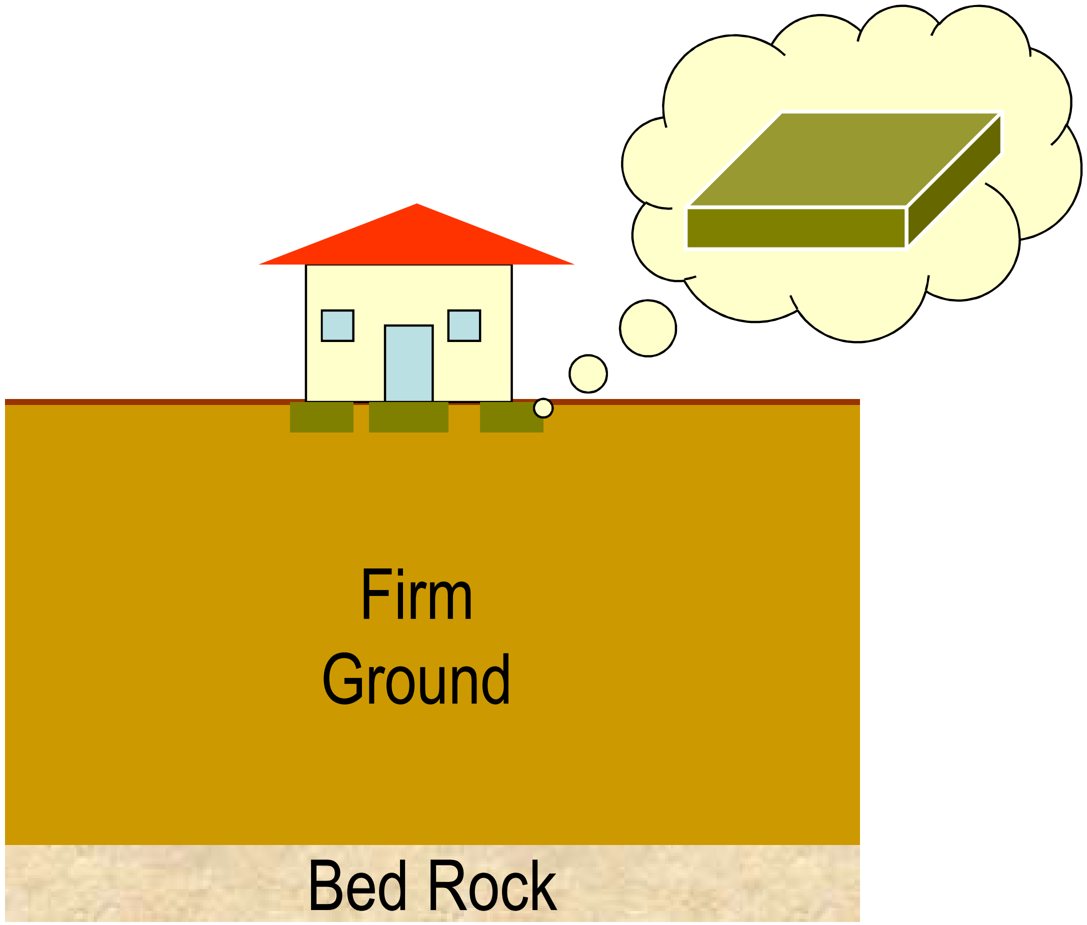

$D_f/B < 1$

- Shallow Foundation
  - Wall footing
  - Isolated Footing
  - Combined footing
  - Strap Footing
  - Strip Footing
  - Mat/Raft Foundation
  - Grillage Foundation

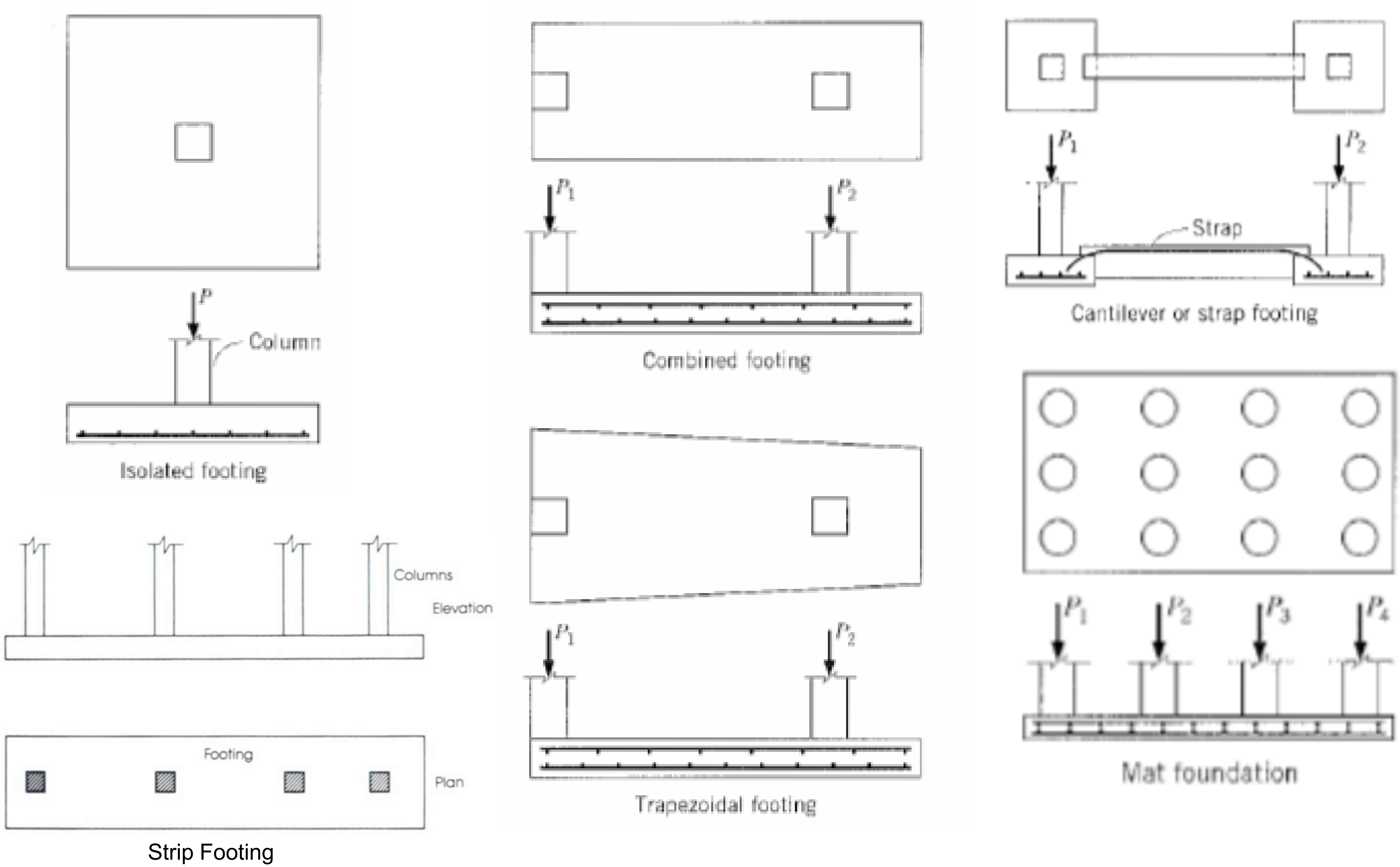
# Shallow Foundations

For transferring building loads to underlying ground

Mostly for firm soils or light loads



# Types of Shallow Foundation



# Shallow Foundations

Examples of spread footings for residences and buildings.

# SHALLOW FOUNDATION


**Combined Footing**

**Grade Beam**


**Mat Foundation**

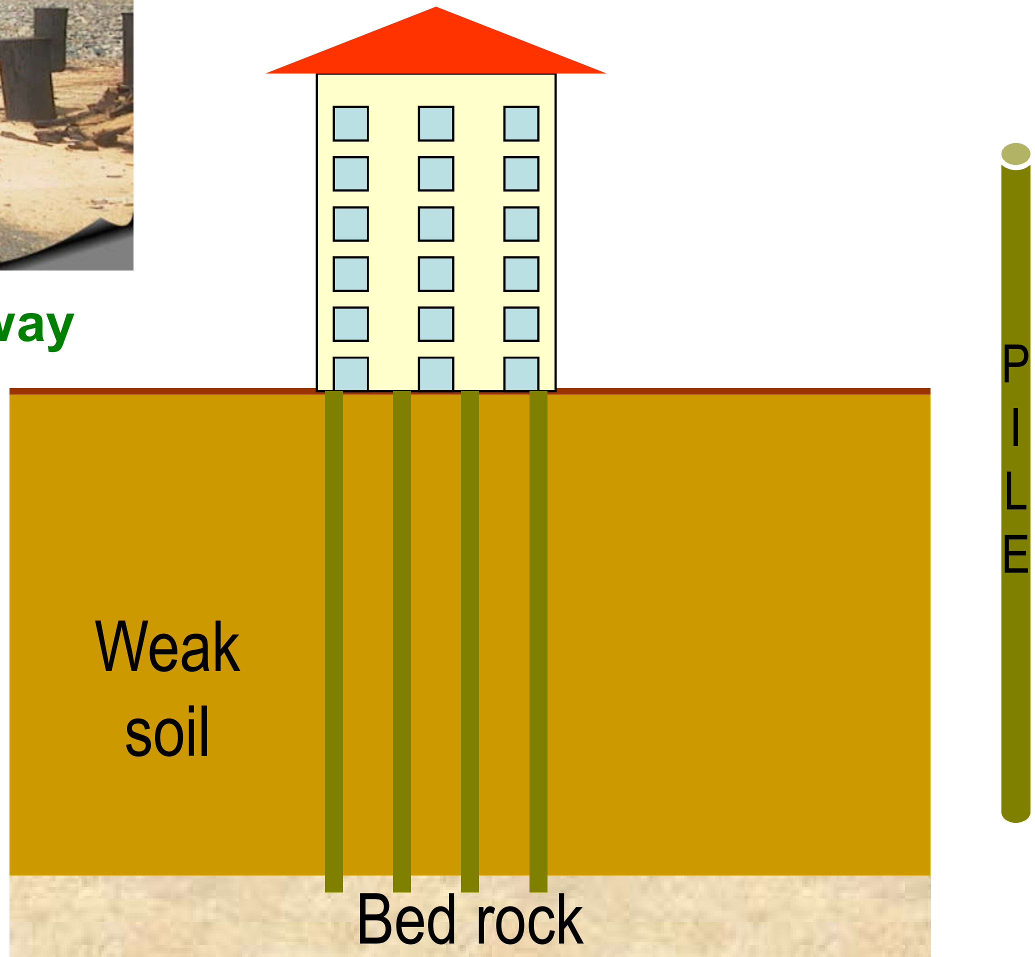
**Strip Footing**

# Deep Foundations

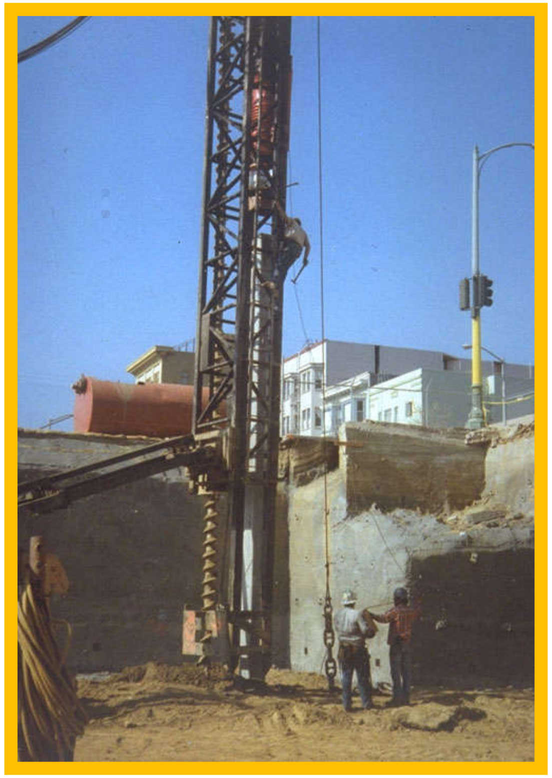
Driven timber piles, Pacific Highway

For transferring building loads to underlying ground

Mostly for weak soils or heavy loads



# Pile Foundation

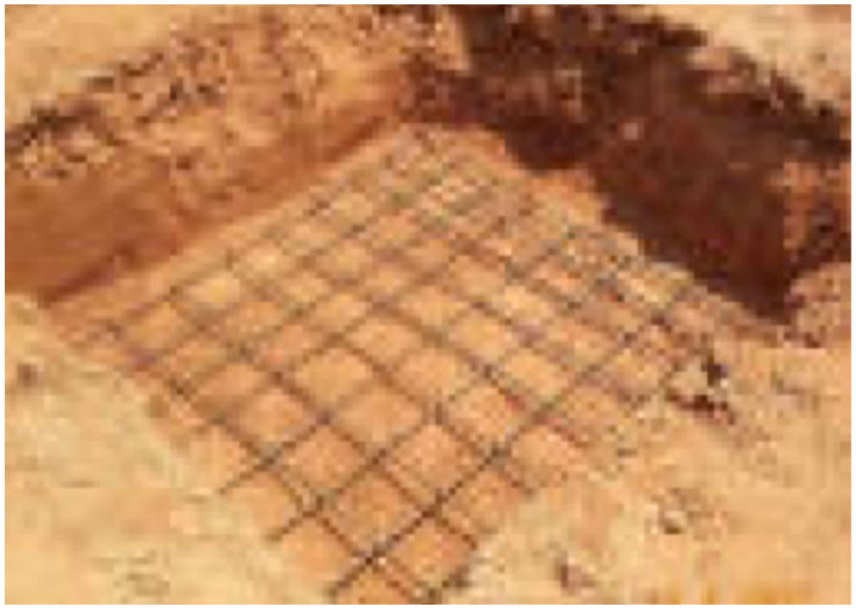
# Some Mantras in Foundation Engineering

1. Foundation is buried under earth. Hence, should one bother about its quality?
2. Is SBC is a unique value? Is SBC is the only parameter for Foundation design?
3. Building Foundation next to existing one at higher, lower or same elevation?
4. What precautions to take for Foundation on sloping ground?
5. Can one build Column at the edge of foundation?
6. Maintain foundation pressure as uniform as possible.
7. Is isolated footing OK, even if they are next to each other?
8. In BC soil, what kind of foundation treatment is preferred?

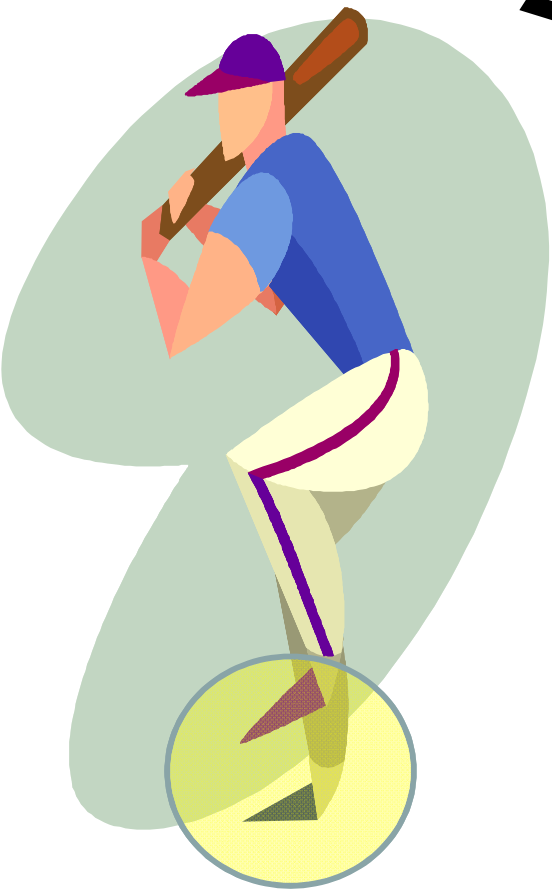
# Foundation is buried under earth.

## Should we bother about its quality?

- Most times quality of foundation is sacrificed as it is not exposed. Strong foundation can enhance the life of structure

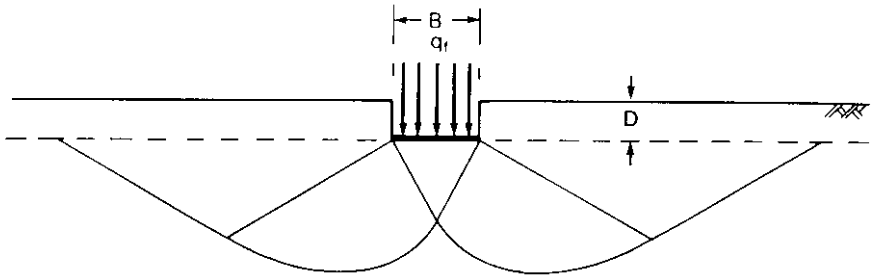


Where will all these loads go?
We do not see foundation.
Hence no need to worry about it



# Is SBC a unique value?

- Safe Bearing Capacity (SBC) is considered unique to a particular soil It is not so. It depends on
  - – Size of footing
  - – Shape of footing
  - – Inclination of footing
  - – Inclination of ground
  - – Type of load
  - – Depth of footing etc.



# Safe Bearing Capacity (SBC)

- SBC is the safe extra load soil can withstand without experiencing SHEAR FAILURE.

$$SBC = \frac{\text{Total Load}}{\text{Area of footing}}$$

# SBC is not the only parameter for Foundation design

Just like Limit states of COLLAPSE & SERVICEABILITY in concrete structures, there are two limit states in Geotechnical structures.

1. Shear failure criteria (SBC)
2. Settlement criteria

SBC alone is not sufficient for design

# Is consideration of settlement important ?

Palace of Fine Arts, Mexico
Uniform settlement

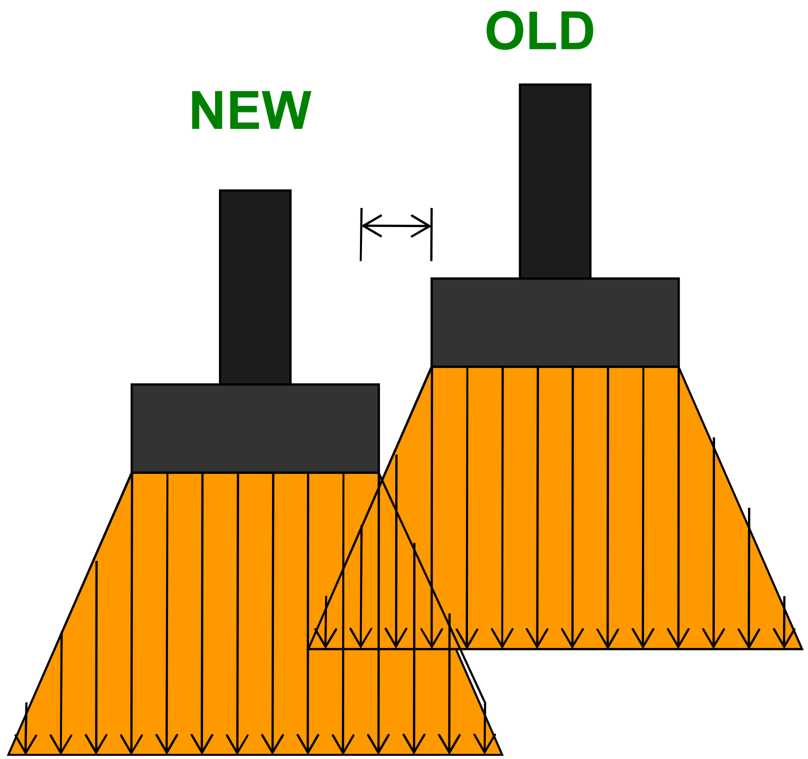
Leaning Tower of Pisa
Differential Settlement

# Settlement damage

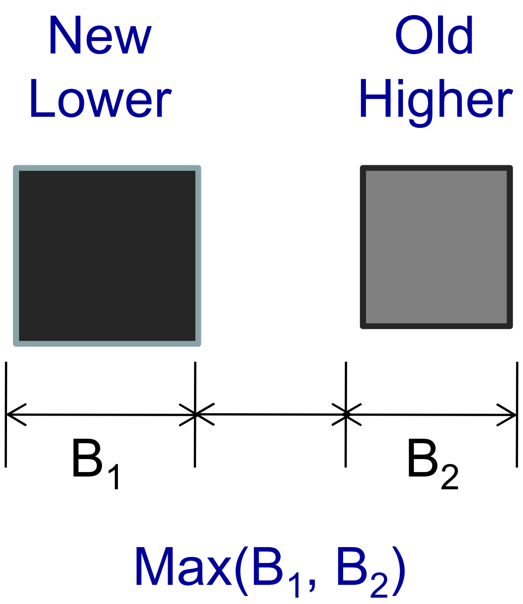


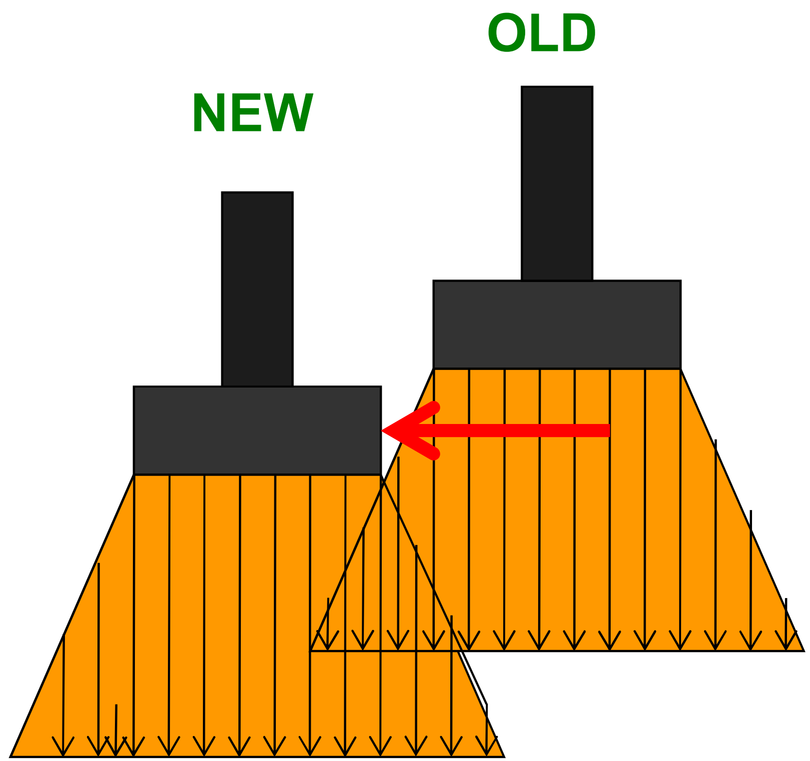
# Build Foundation next to existing one at lower elevation

1. Maintain distance between two footings.
2. Stresses in soil may overlap causing shear failure.
3. If necessary, it is preferred to put new footing below existing one.



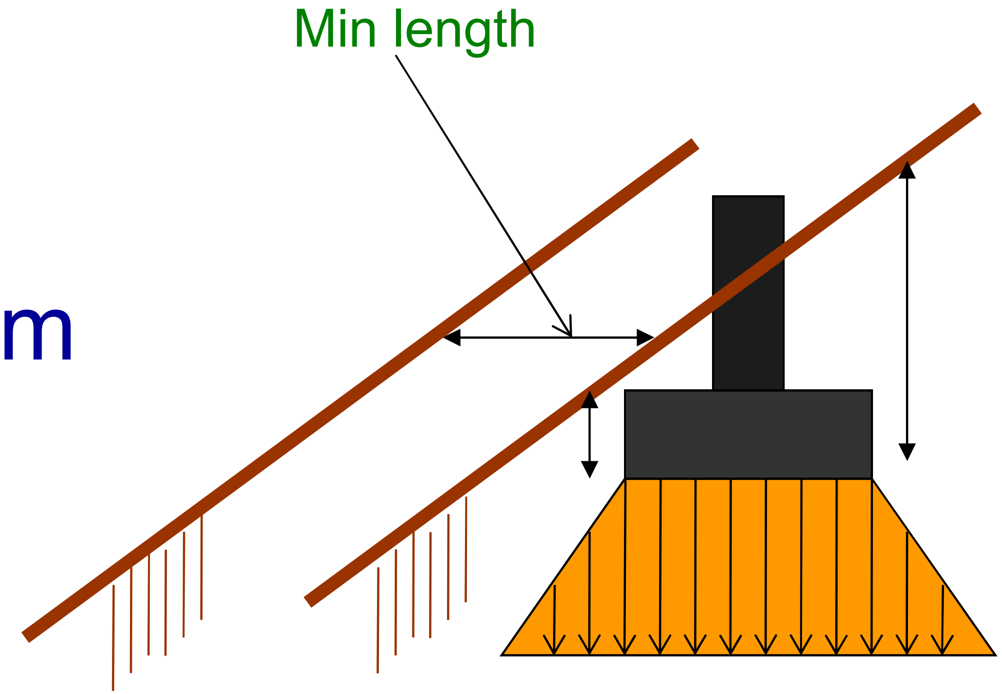
# Build Foundation next to existing one at lower elevation



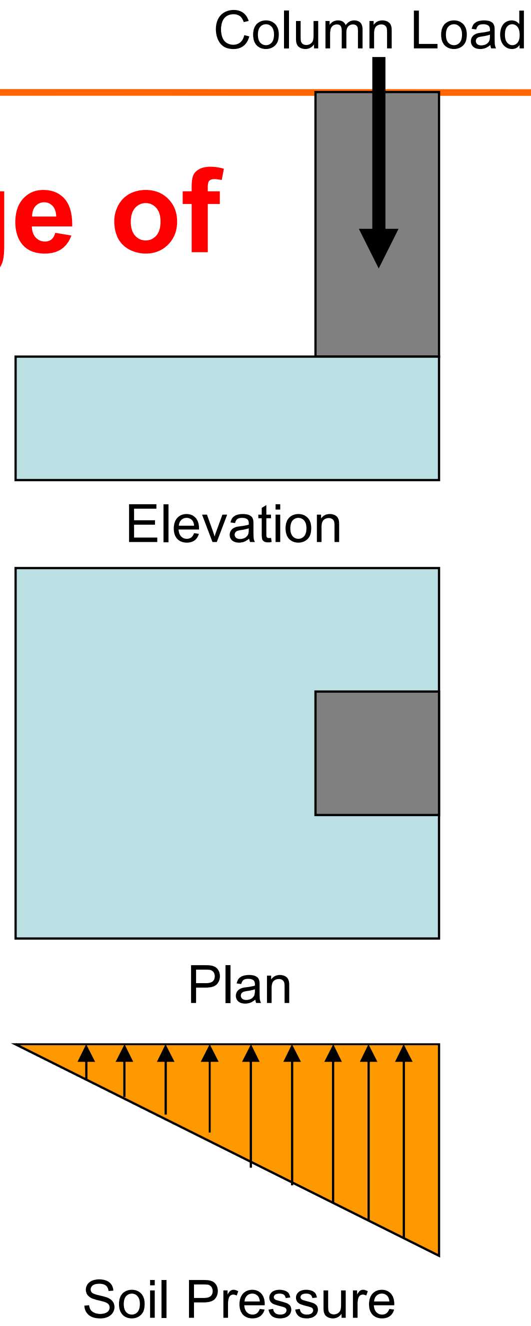



# Foundation on sloping ground close to the edge is not good

- Non-symmetry in overburden pressure
- Maintain minimum distance

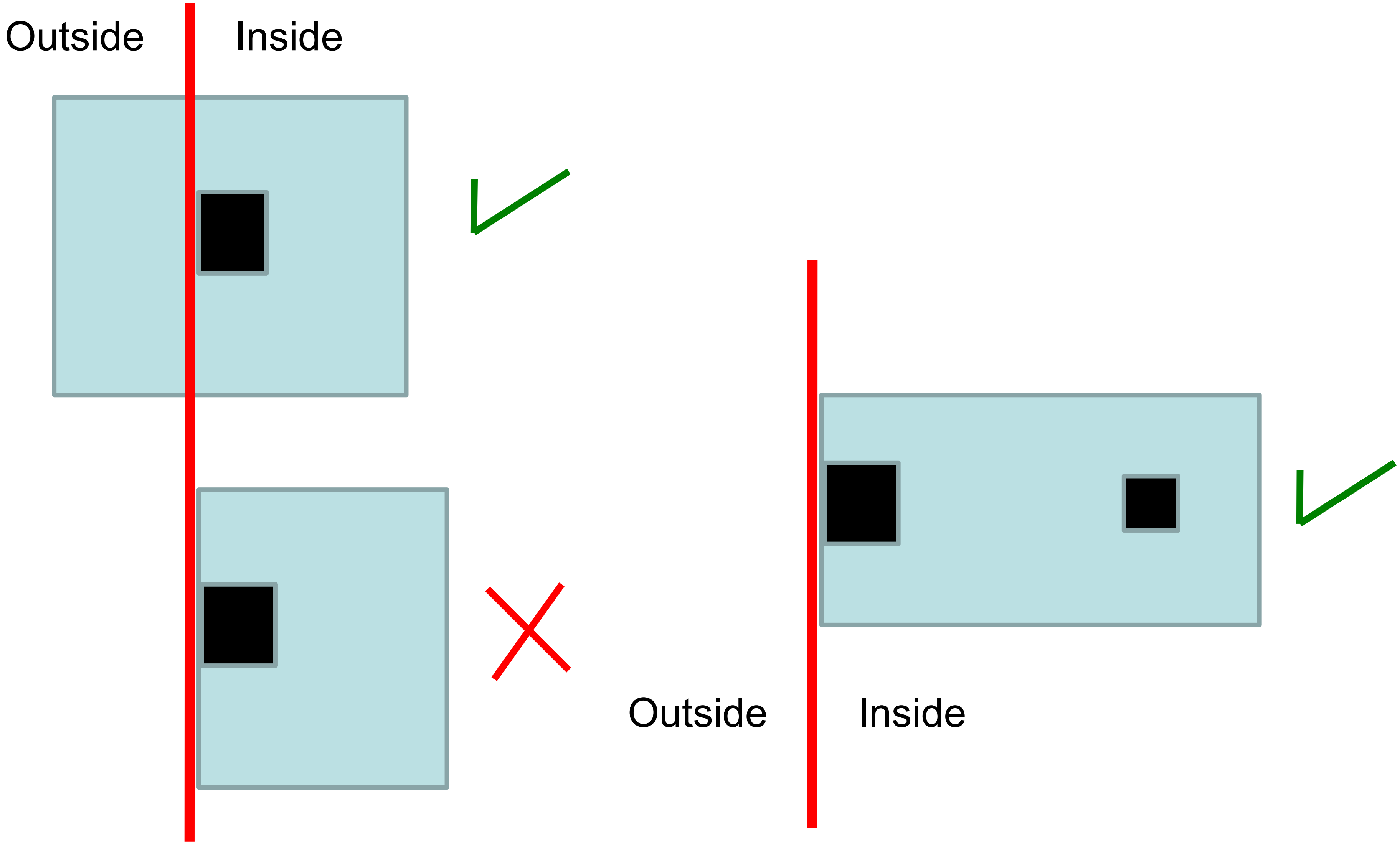


# Build Column at the edge of foundation



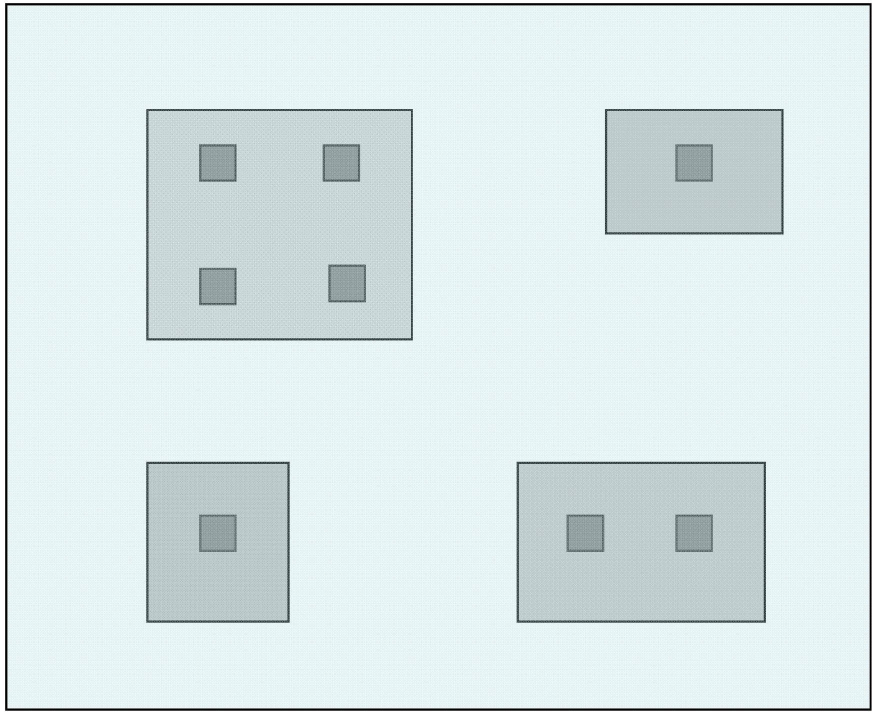

- Leads to eccentric loading
- Combined footing is preferred

# Column at the edge of property line

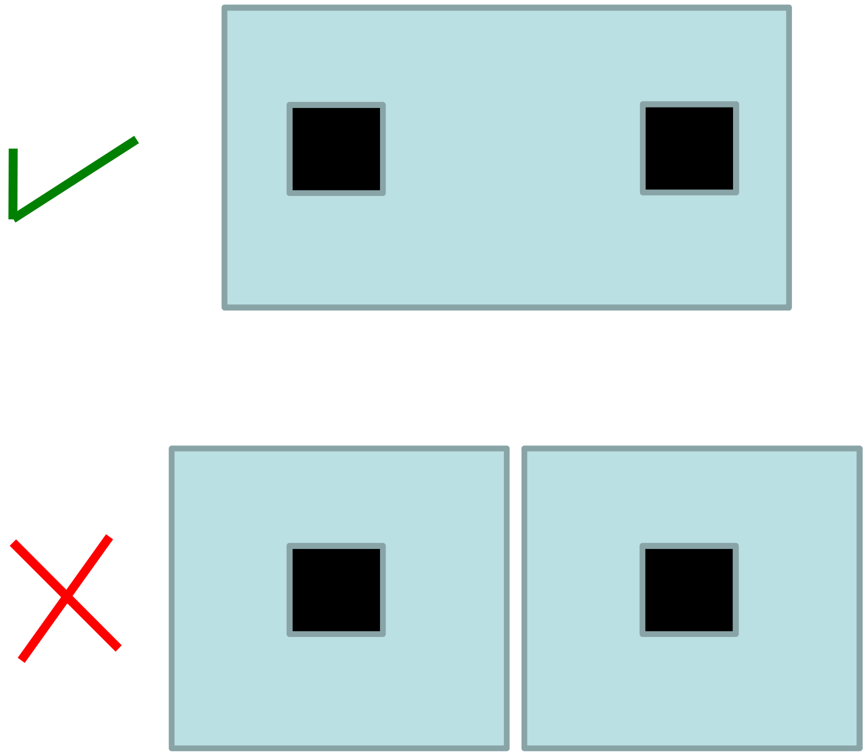


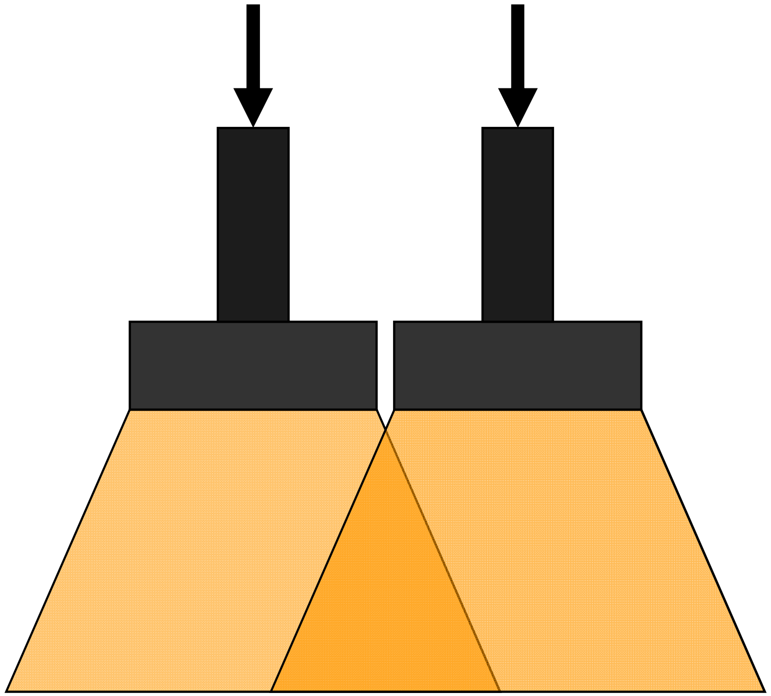
# Foundation pressure shall be uniform

- When different types of footings are provided for same building, maintain foundation pressure as uniform as possible



# Prefer combined footing if two isolated footings are next to each other





Overlap in stresses

- Provide combined footing to avoid overlap in stresses

# Foundation in B C Soil

# What is a B C Soil?

B C stands for Black Cotton. The soil is mostly Black in color. It is good for cotton growth. It is a nightmare to Civil Engineer.

It swells by drinking water and shrinks when water goes out.

Alternate swell – shrink is the major problem

# Expansive Soil

More than 20 % of country is covered

Tropical Soil

Nightmare to Civil Engineers

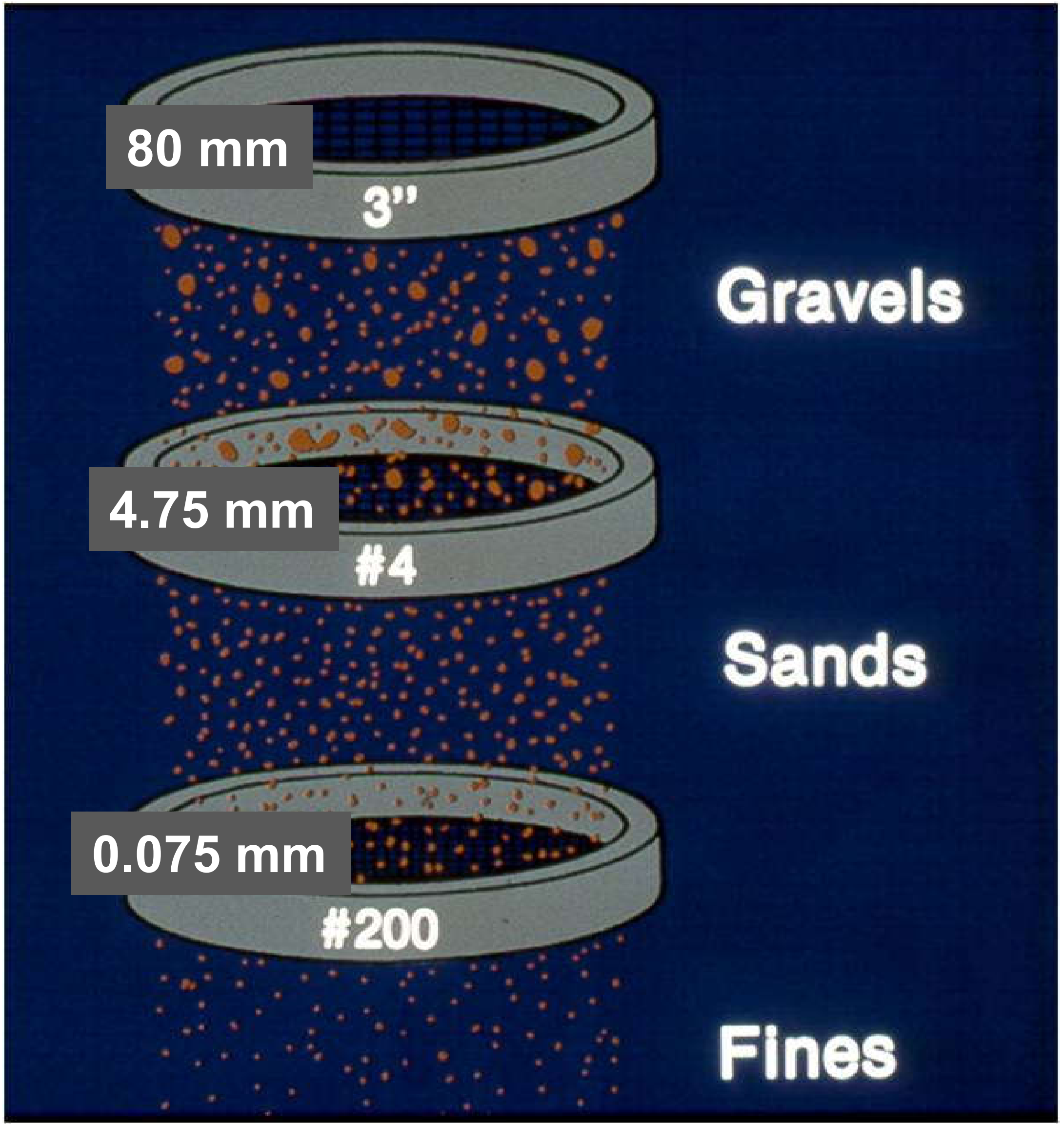
Swells when water is available shrinks when water is deficient

# In BC soil, what precautions are essential?

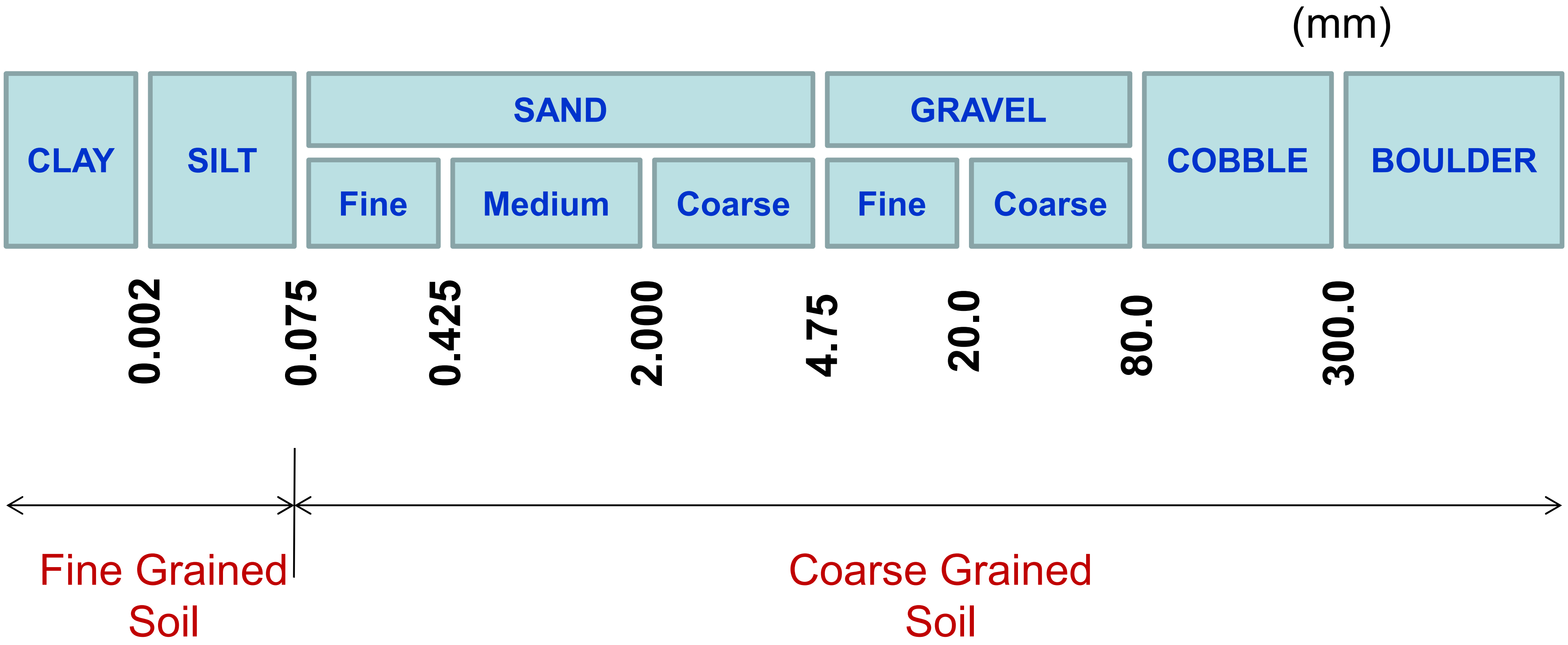
SBC is not the problem with BC soil. Most times lifting of light structure when the soil swells poses problem.

# Working in sticky soil

# Particle Size



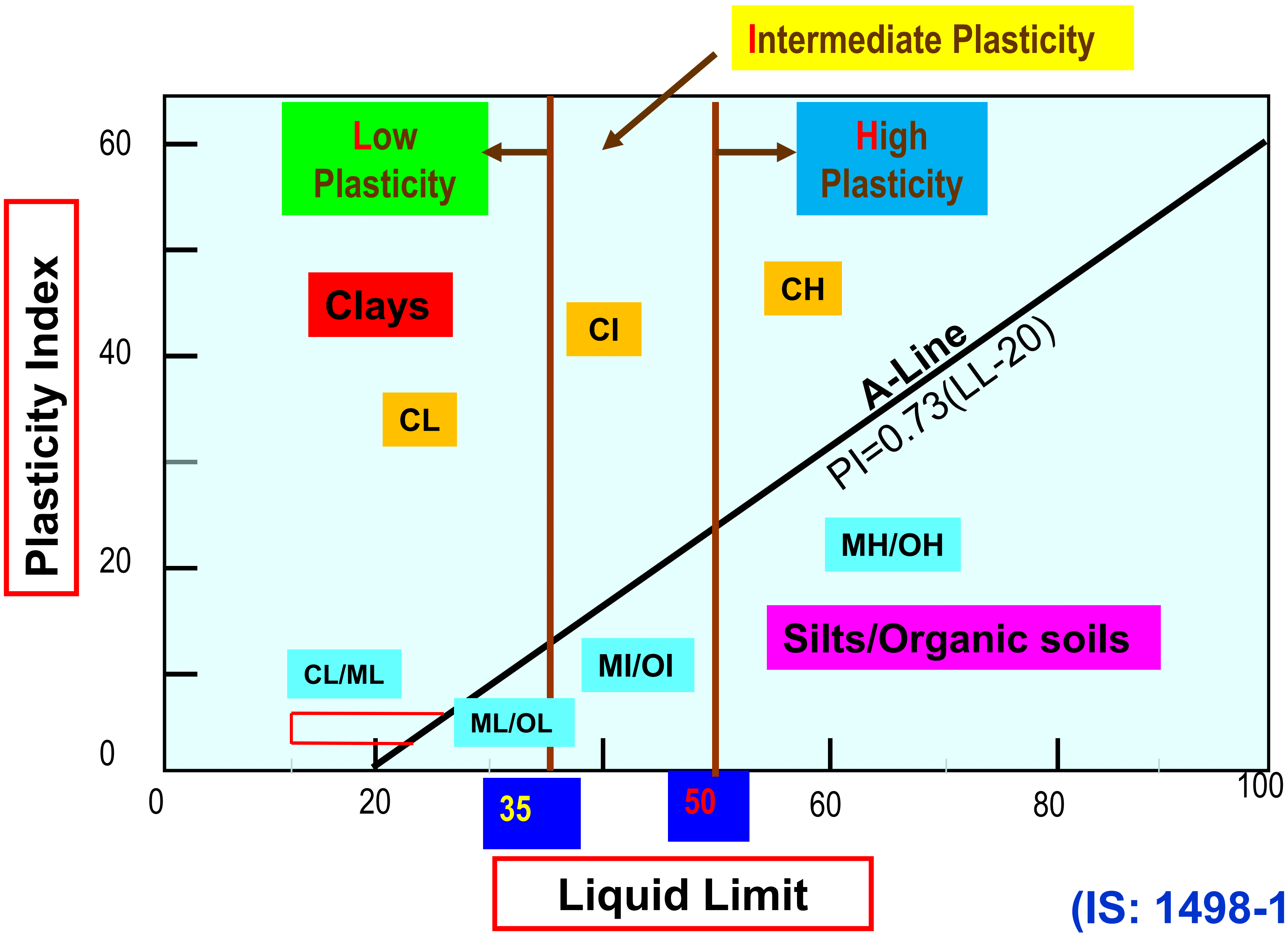

# I S Classification in accordance with size of soil particles




**(IS: 1498-1970)**

# Classifying Fines

➧ Purely based on LL and PI




(IS: 1498-1970)

# Checklist to ensure foundation soil is not troublesome

1. Is the soil nearby project area known to be expansive?
2. Is there evidence of crack in walls, curbs, side walks, pavements etc. of nearby construction?
3. Are there shrinkage cracks in soil during dry season?

# Checklist to ensure foundation soil is not troublesome

4. Is it hard to break a lump of dry soil using fingers?
5. If a lump of dry soil is dropped from a height of 1.5 m, does it stay without breaking?
6. If moist soil is moulded and rolled in to thread, does it stay with approximately 3 mm diameter?

# Checklist to ensure foundation soil is not troublesome

7. Is the soil sticky (adhering to shoe, tyre etc.) when wet?

8. If moist soil on palm is struck with short strokes from lower end, does it remain same without shiny surface?

# Checklist to ensure foundation soil is not troublesome

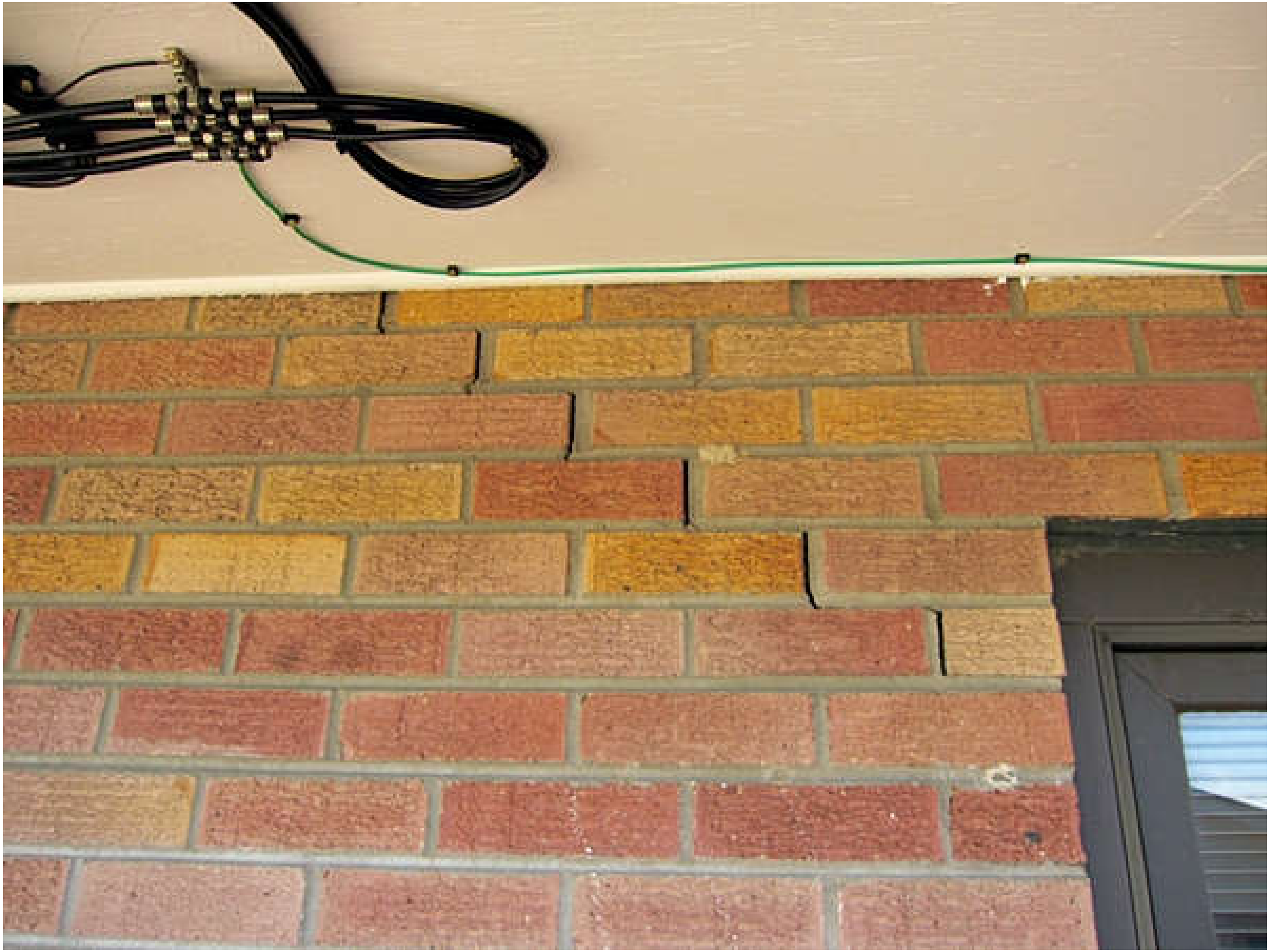
9. If a ball of wet soil is dropped on a glass plate from a height of 0.5 m, does it stick to glass, even if it is turned up side down?

   Even if one answer is YES, thorough investigation is necessary to make sure the soil at the site is not expansive.

- If expansive what is its degree of expansion is necessary.

# Cracks in building

# Cracks in building



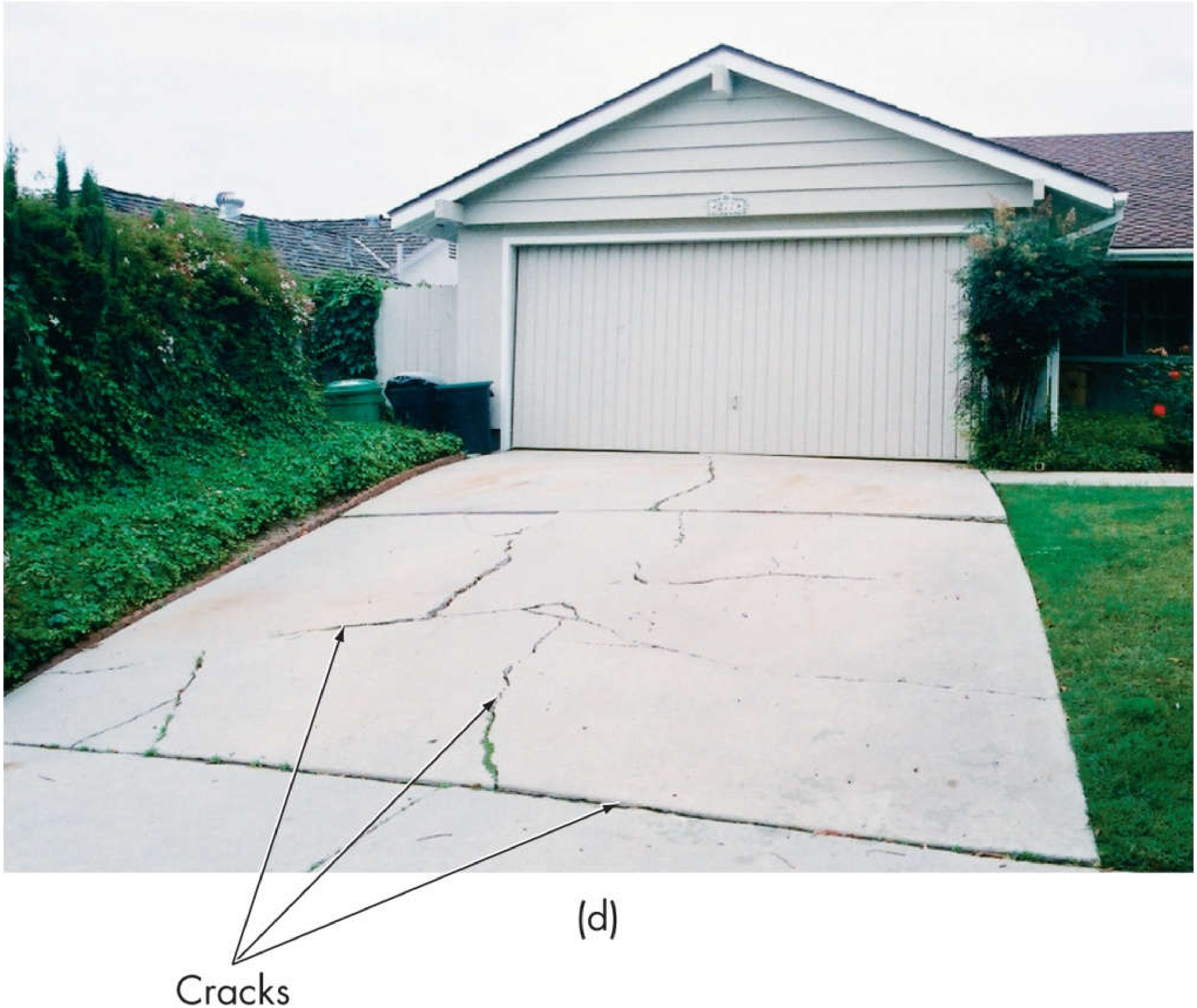
# Cracks in building

# Cracks in building

# Cracks in building

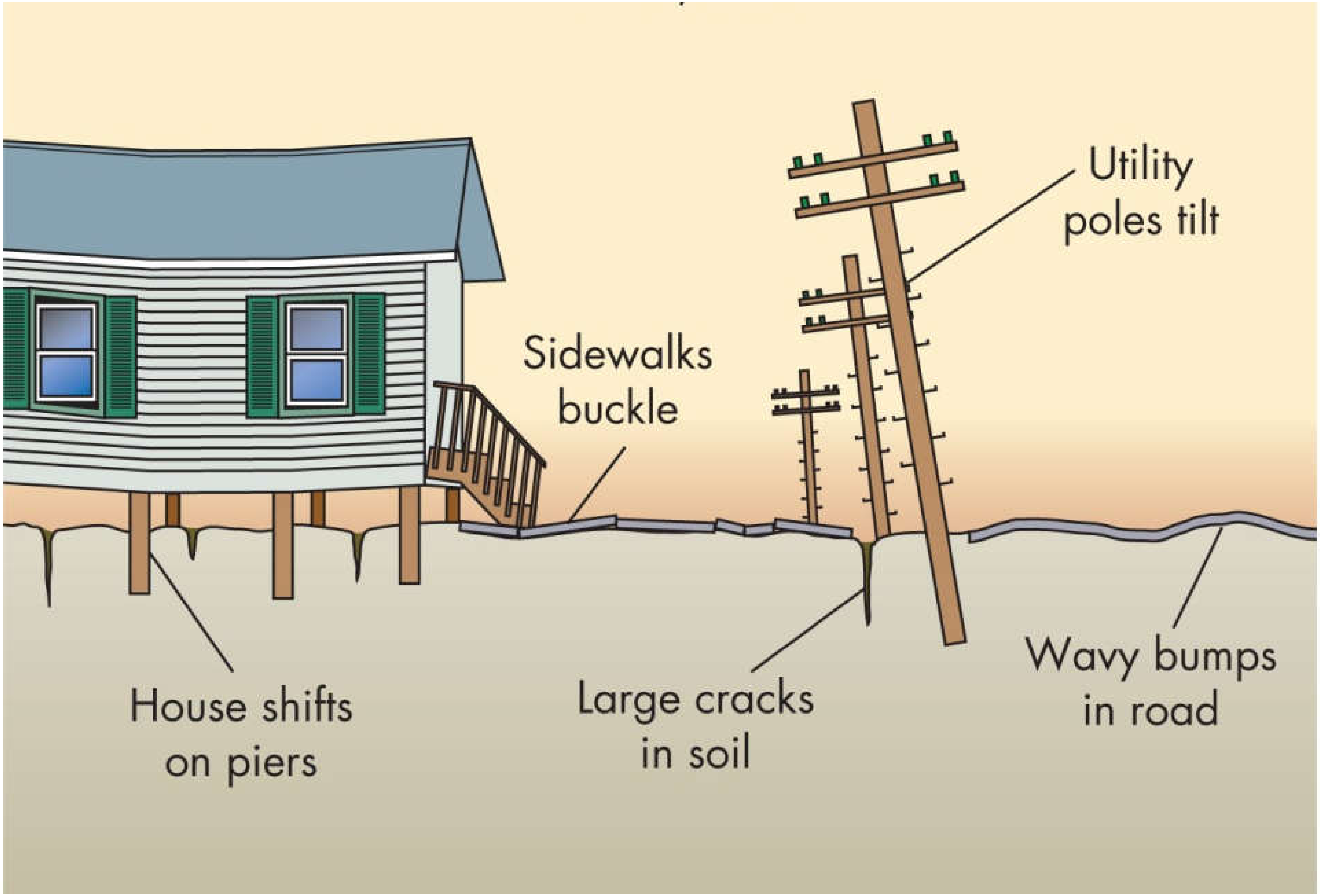
# Cracks in building

# Cracks in building

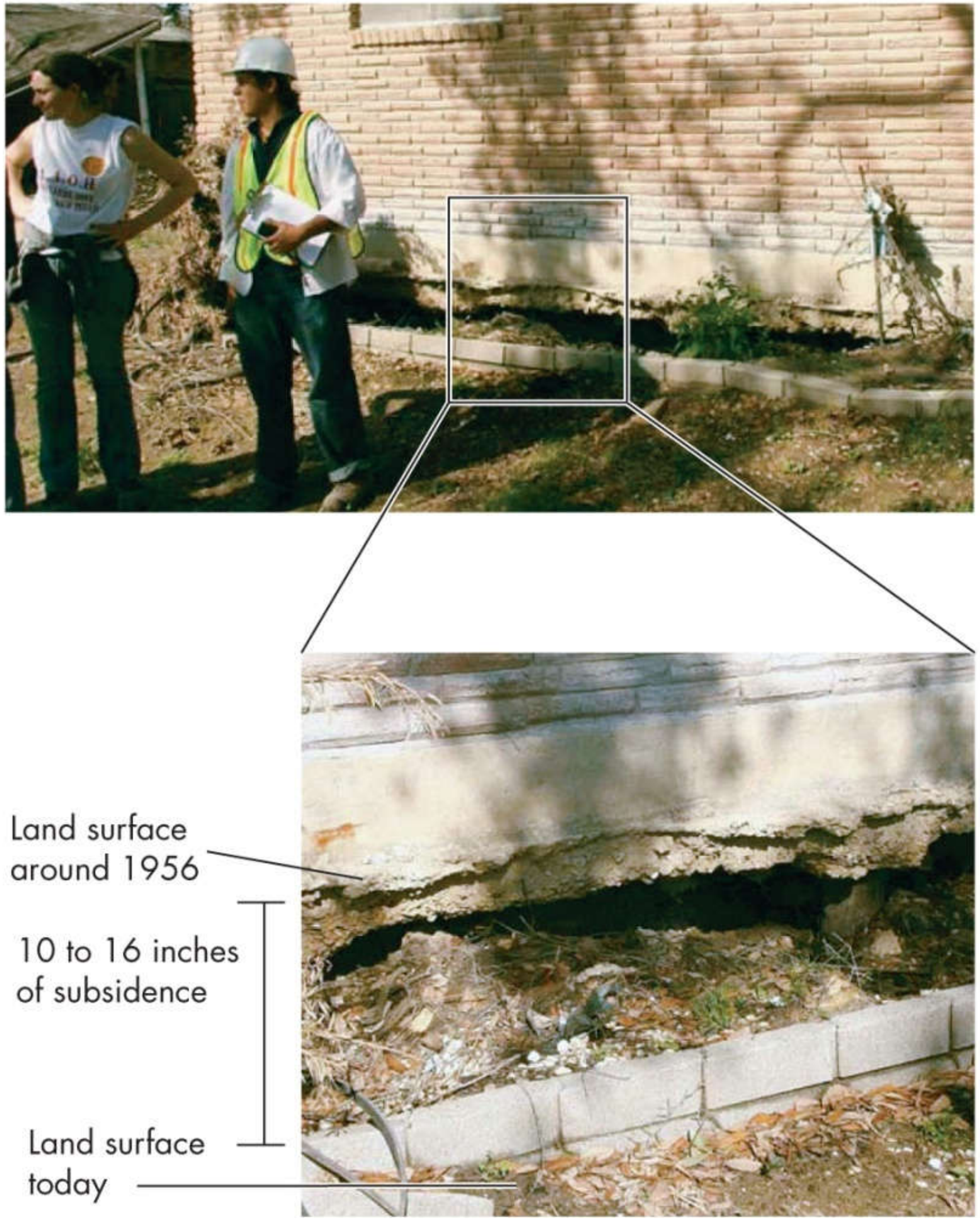



(d)

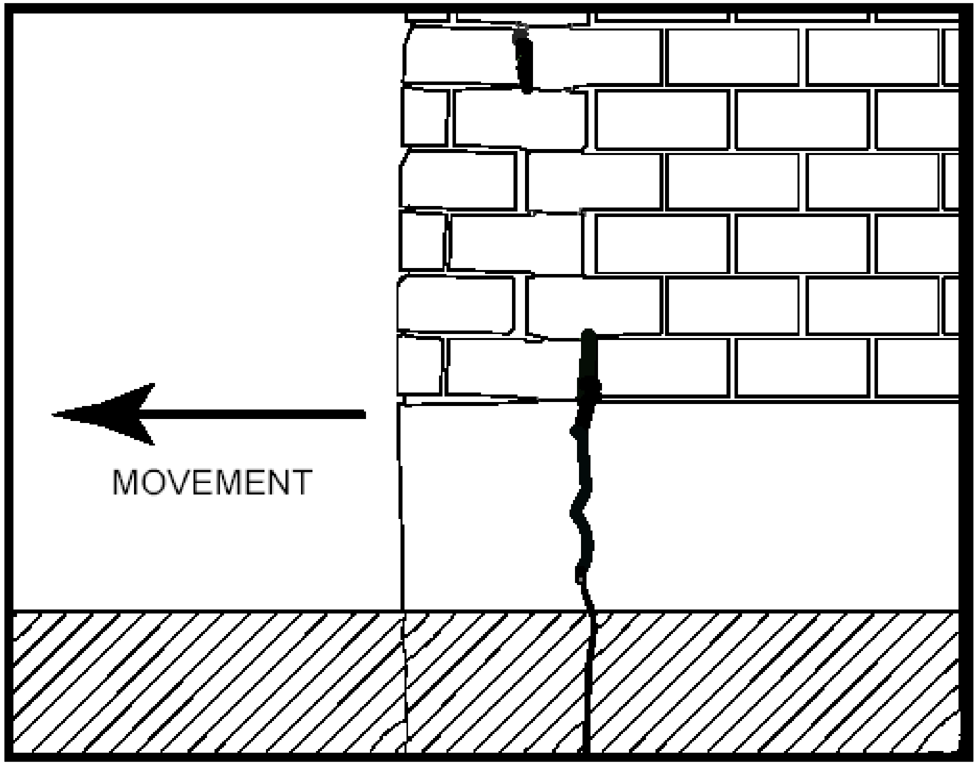
# Effects of alternate SHRINK & SWELL



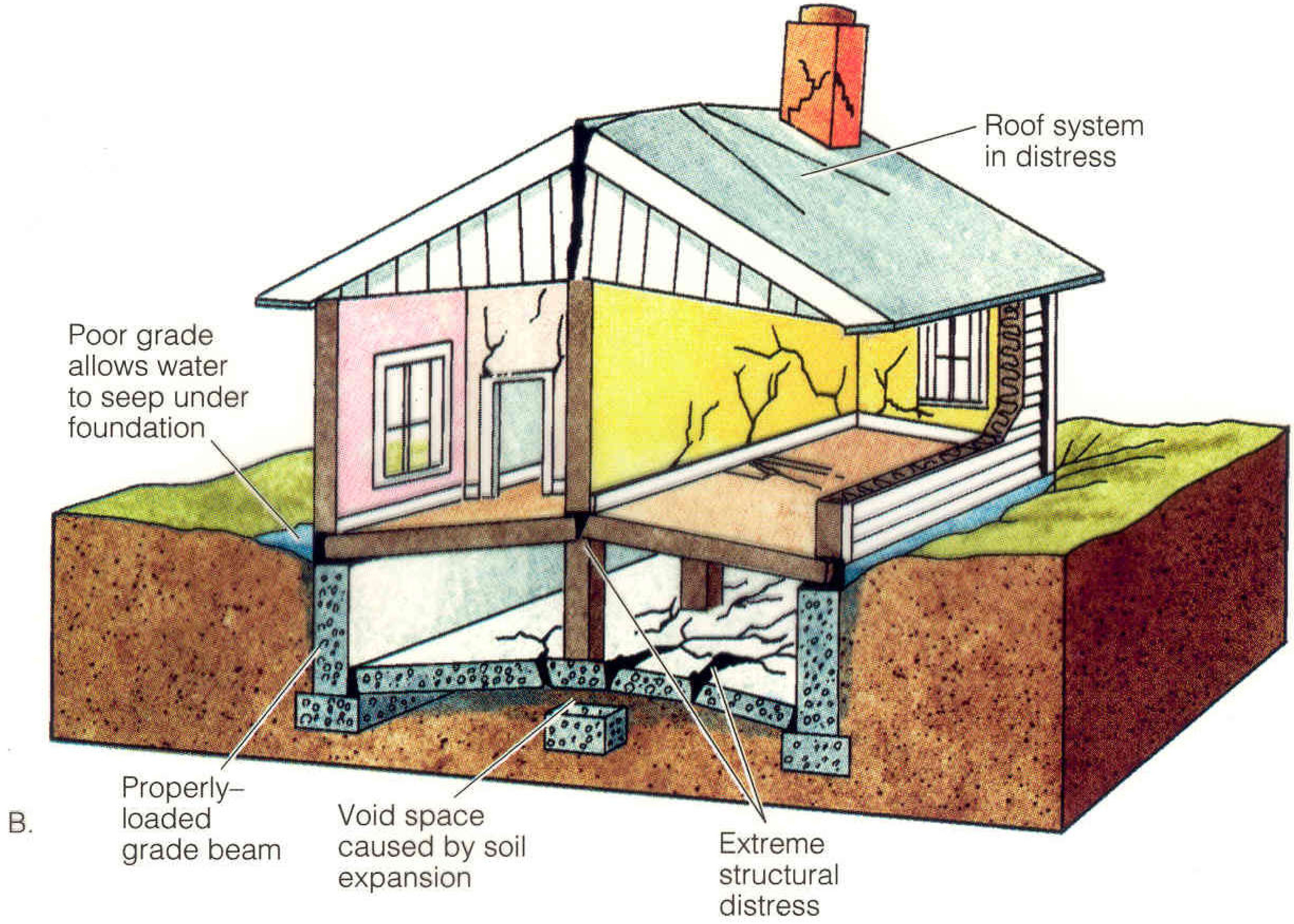
# Cracks in building



# Cracks in building



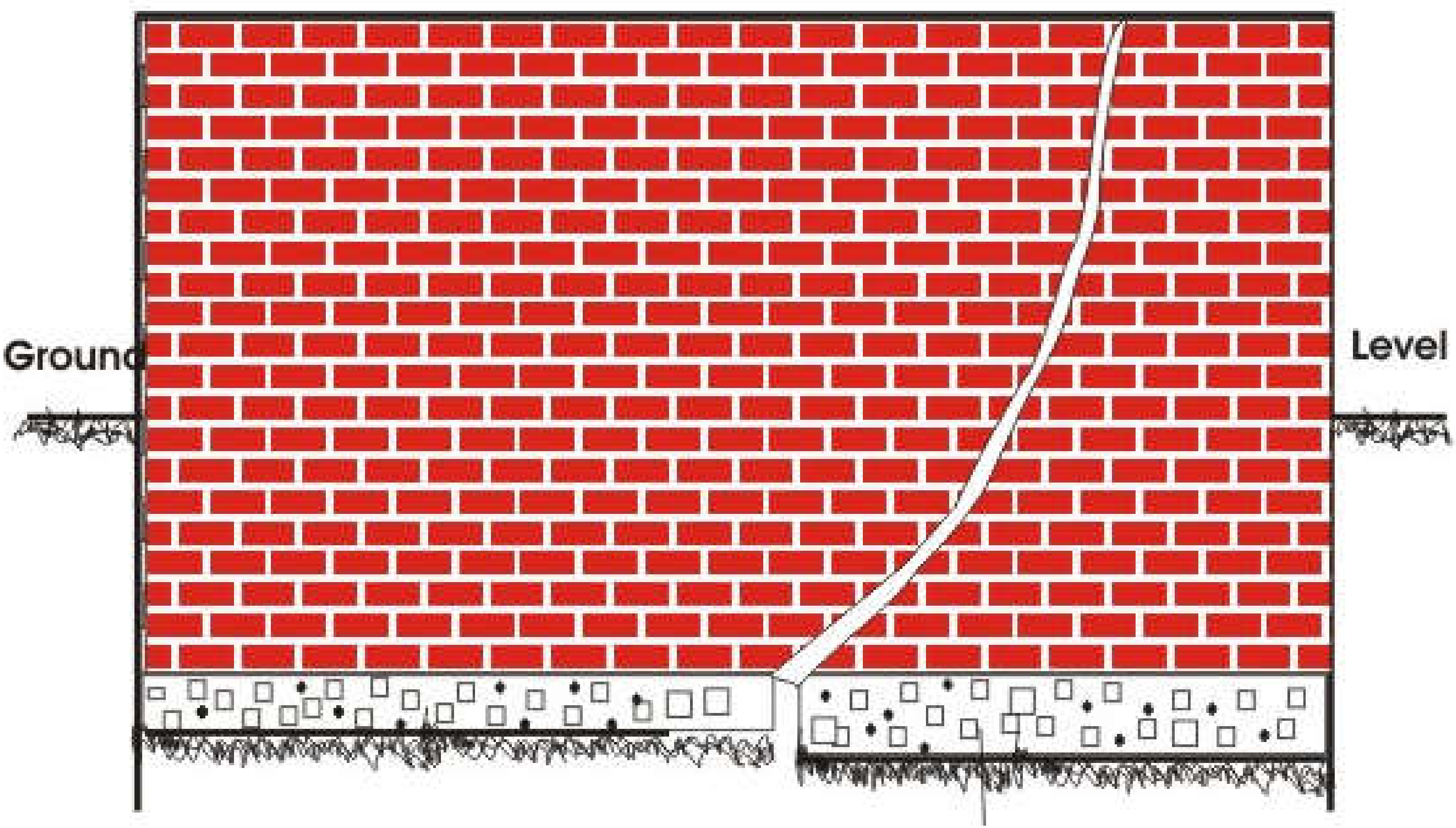
# Cracks in building



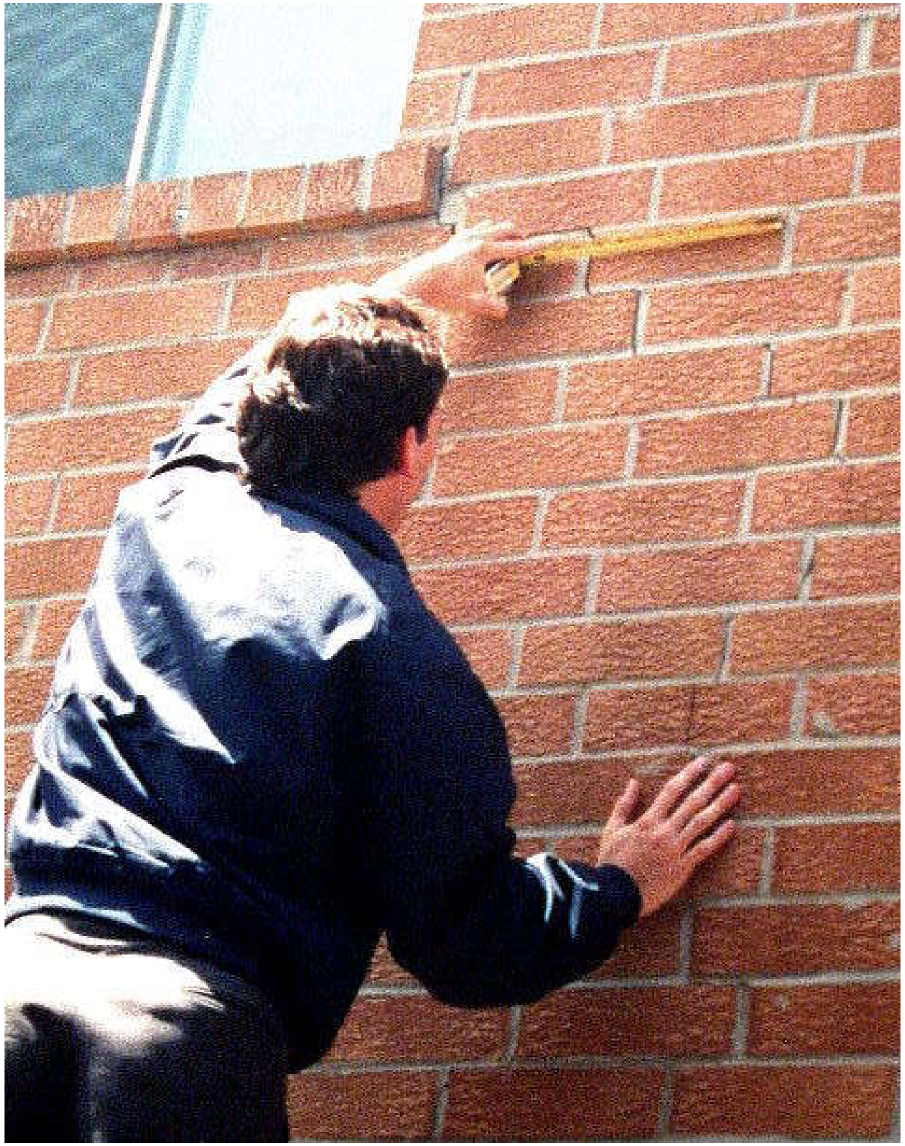
# Damage due to Differential Settlement



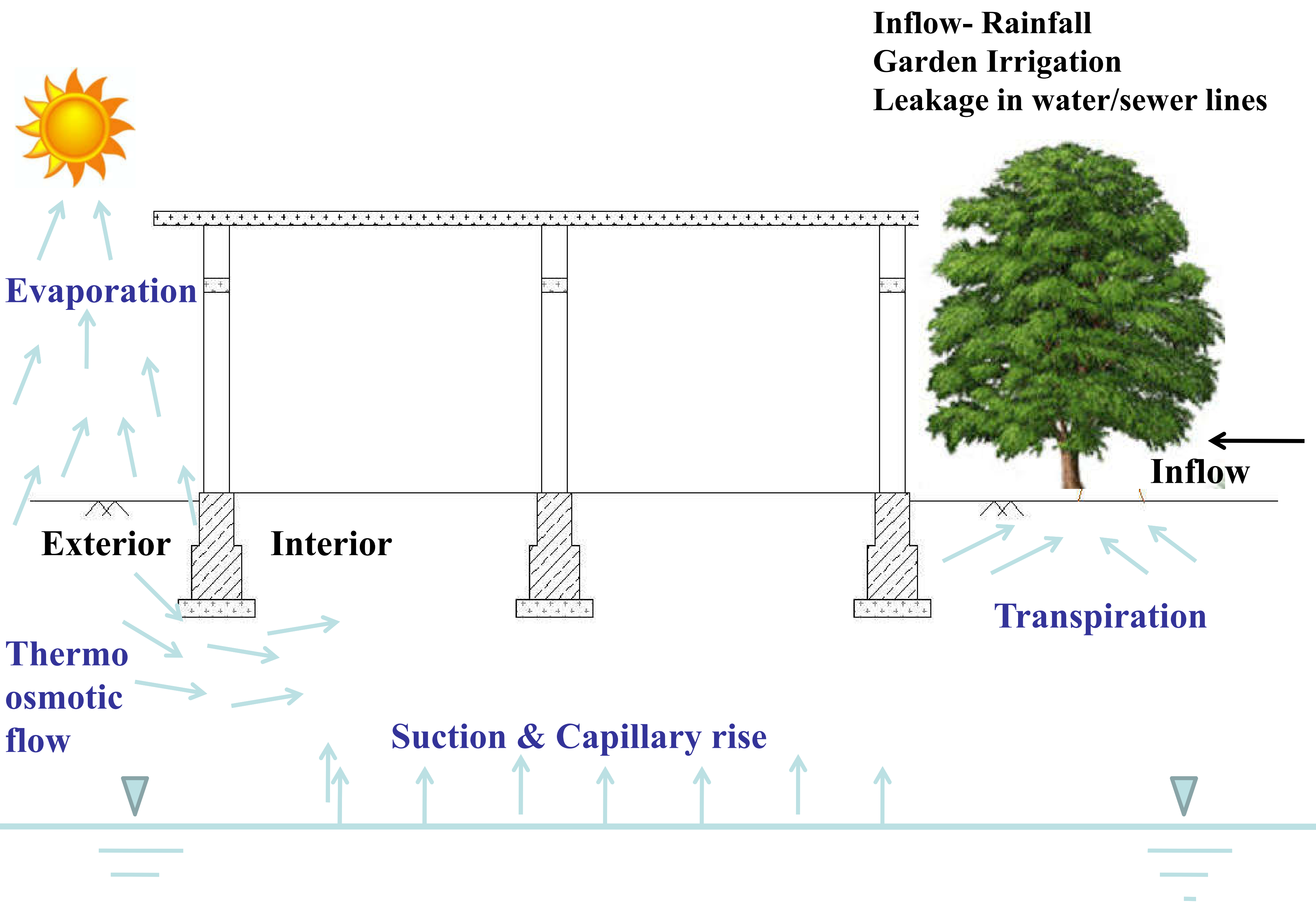
# Cracks in building



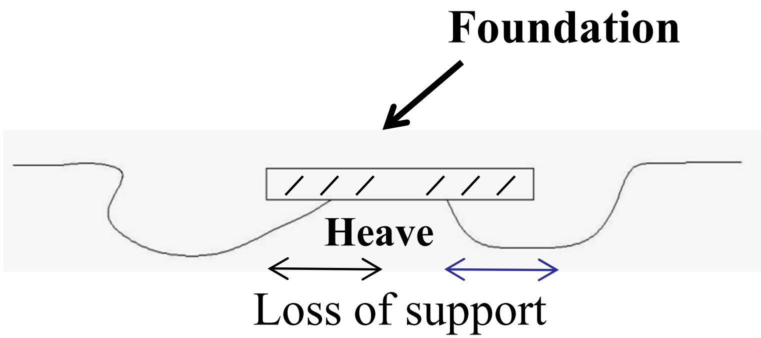
# Cracks in building



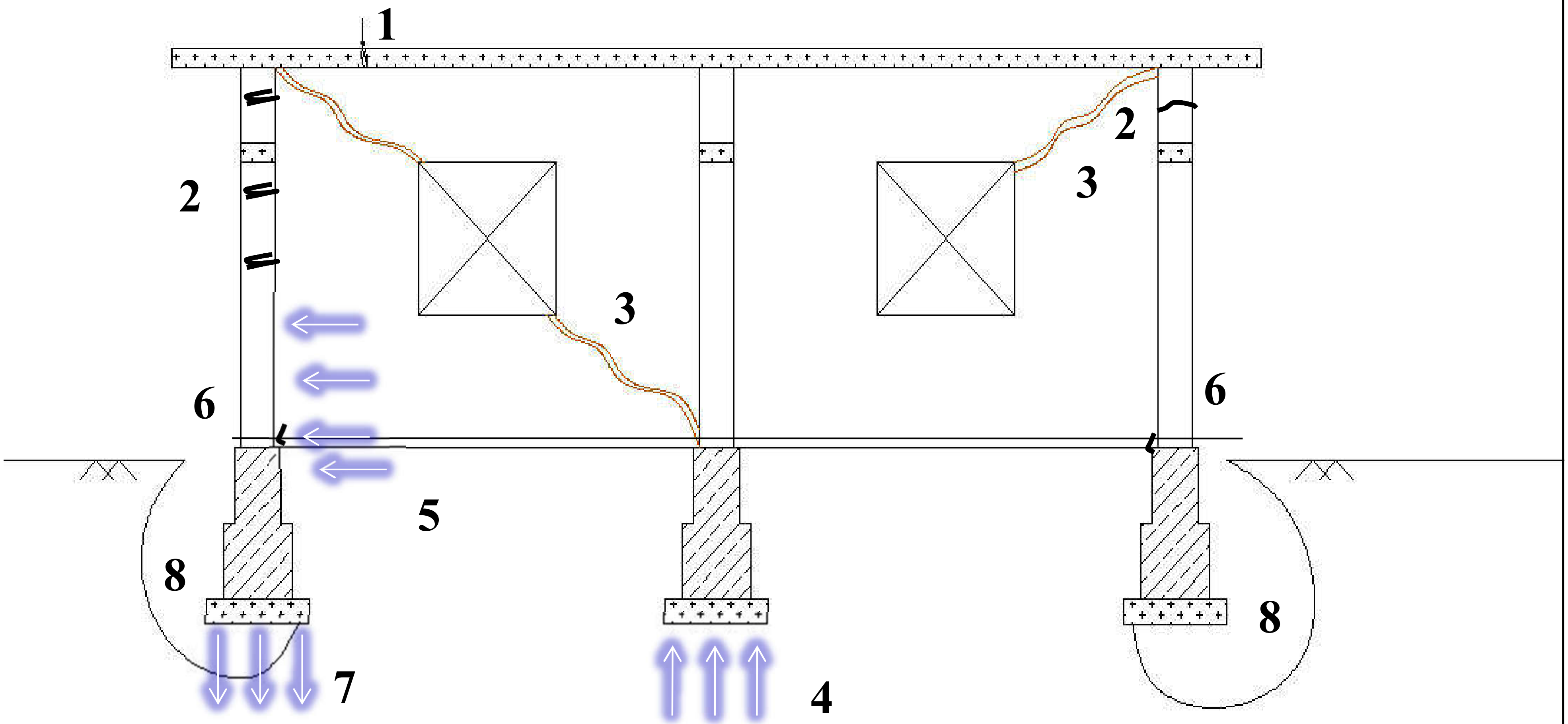
# MOISTURE MOVEMENT



# Common failures in light building on expansive soils




1. Crack in roof slab due to cantilever action.
2. Horizontal crack in exterior wall due to settlement
3. Diagonal crack in cross wall due to diff. settlement
4. Uplift of interior footing
5. Lateral pressure on exterior wall
6. Separation of floor from exterior wall
7. Shrinkage settlement of exterior footing
8. Loss of contact at external face

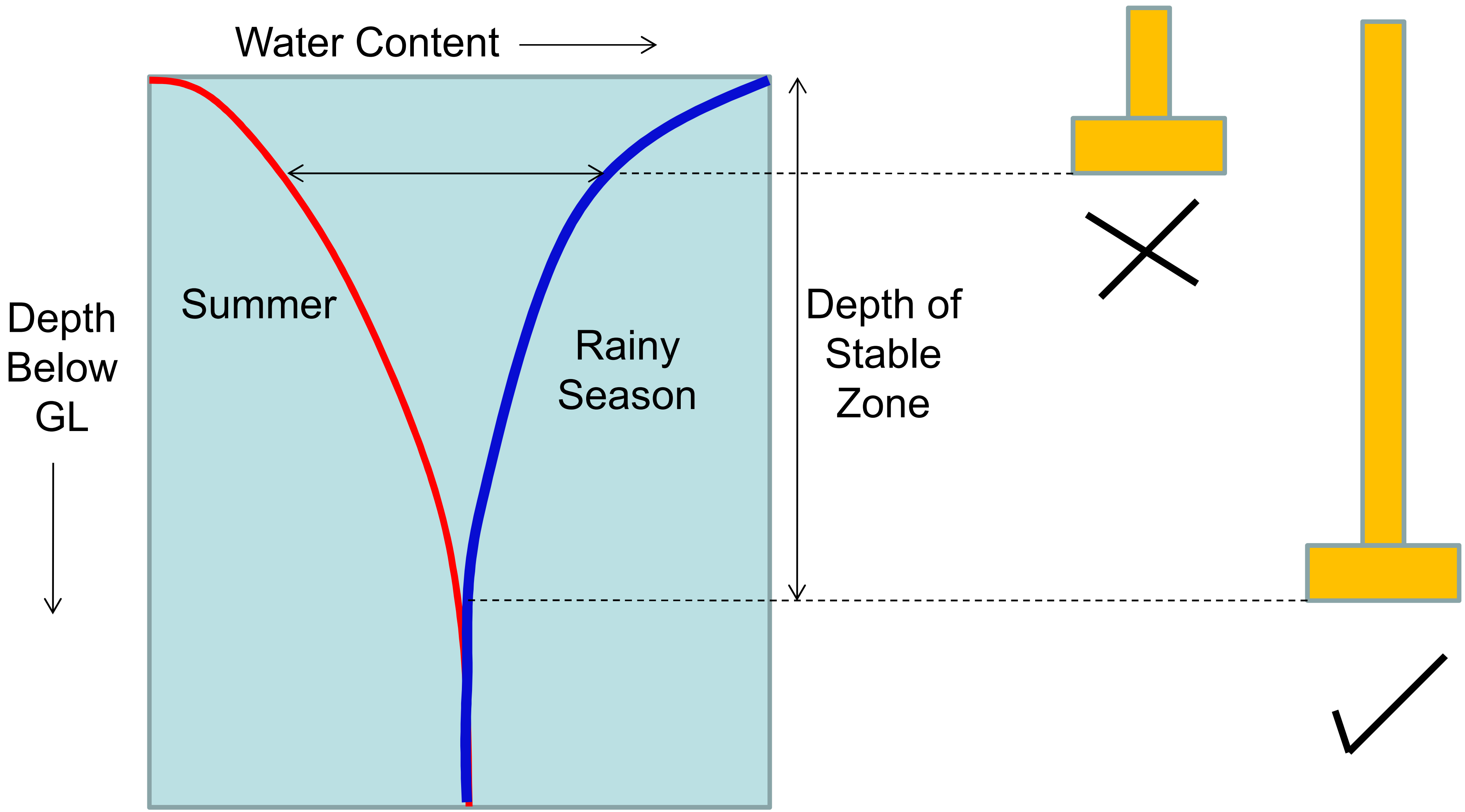


# Prevention is better than cure

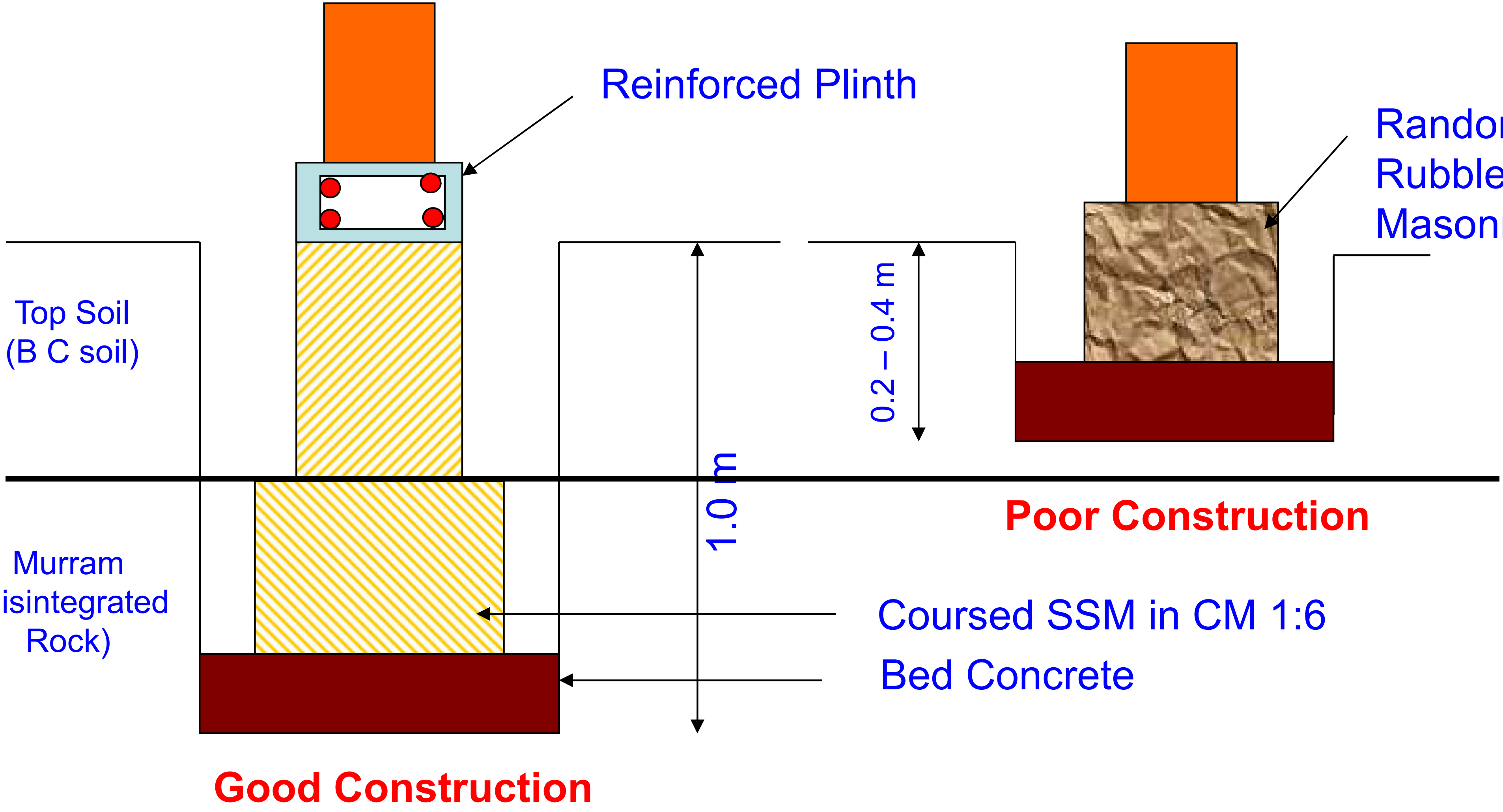
Not Good Soil. Change !!!!

# Increase depth of foundation

# Increase the depth of foundation

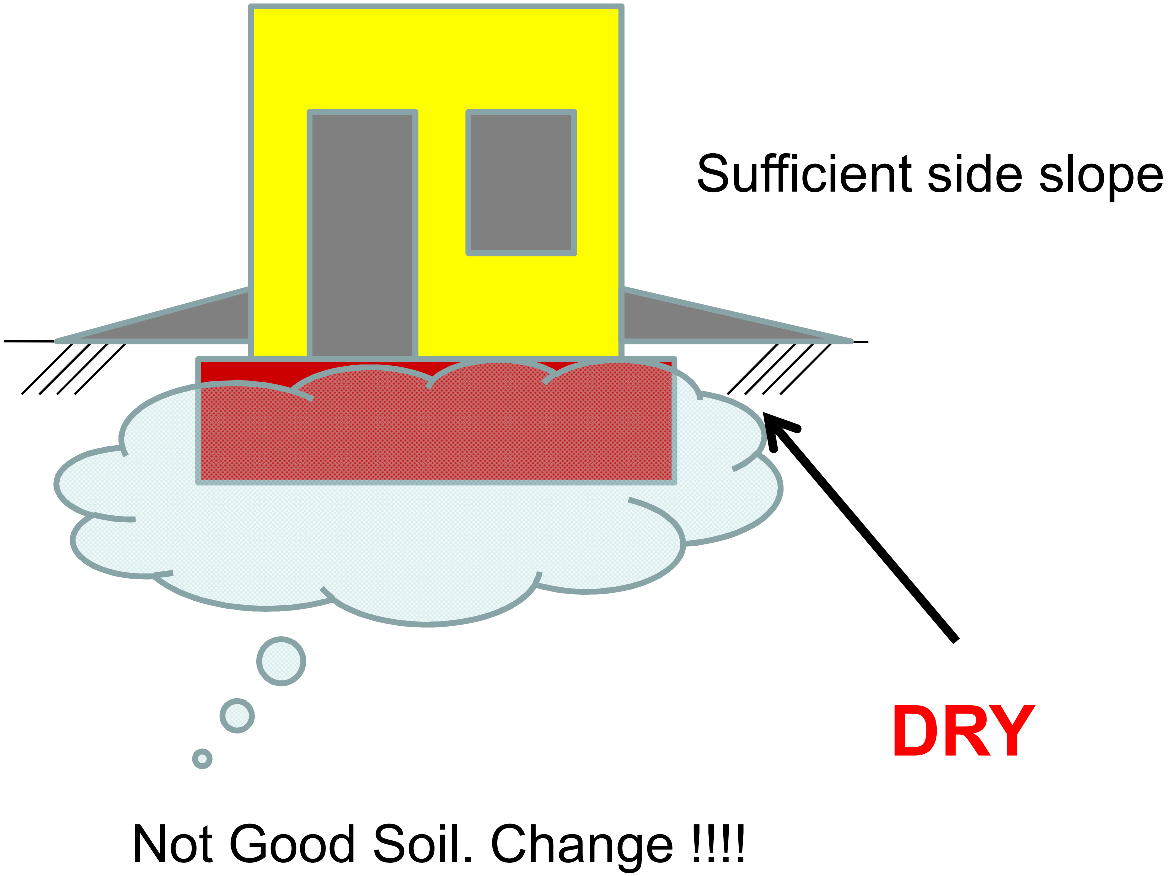


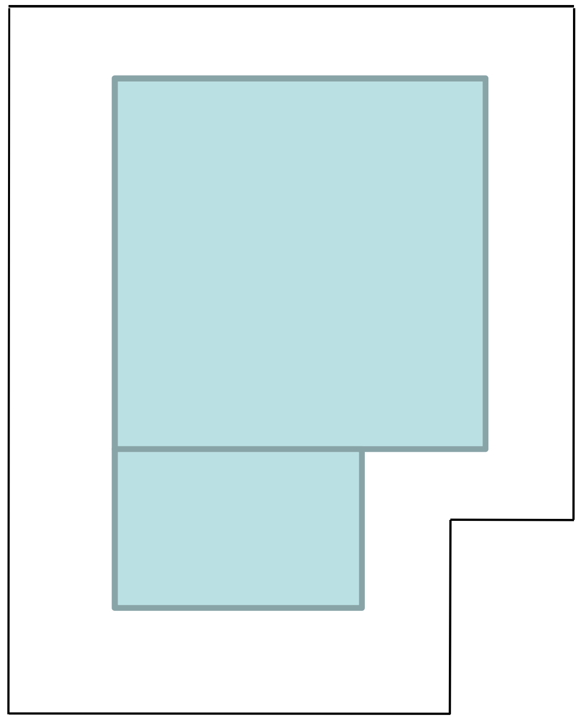
# Typical Foundation details for Masonry Construction



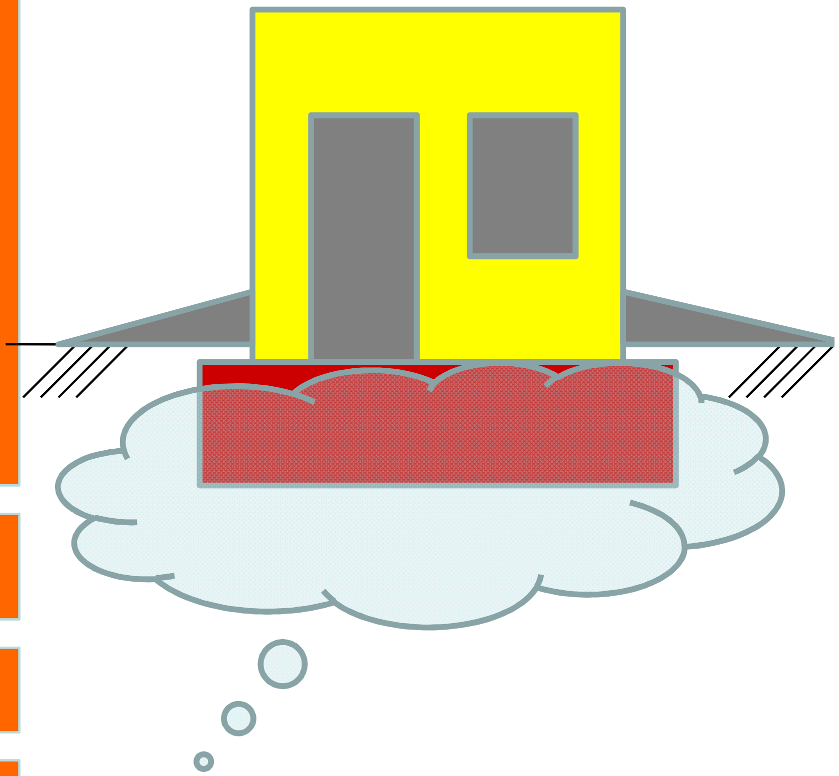

**Structures with better construction practice survive**

# Provide al-round Apron

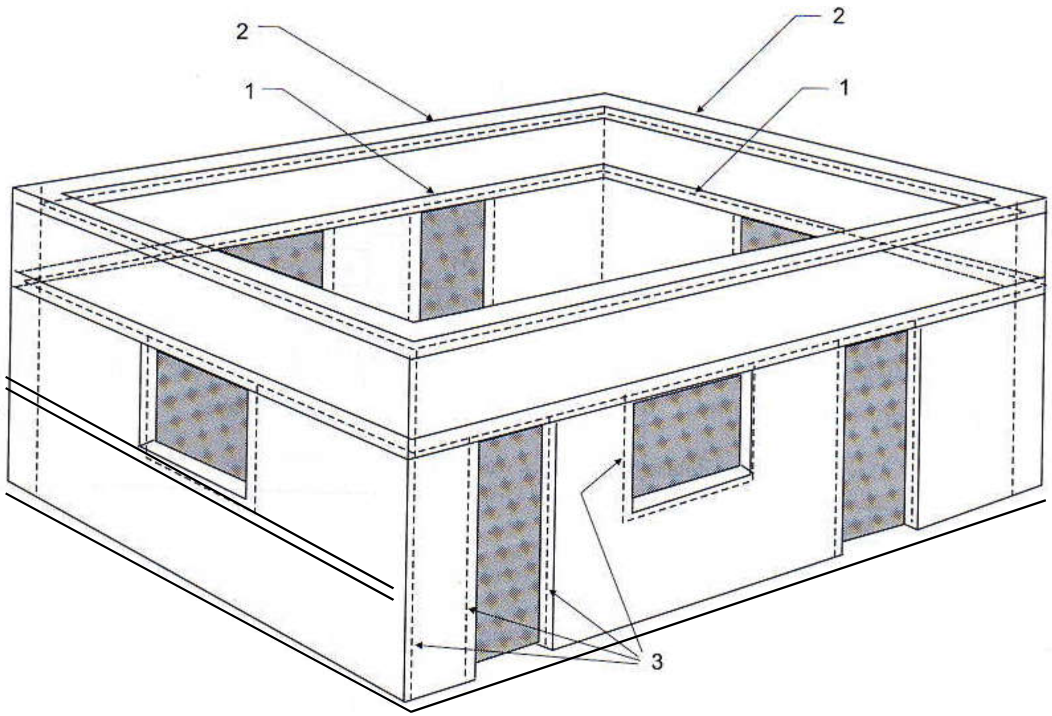


# Provide reinforcement at bed concrete, plinth, sill, lintel levels

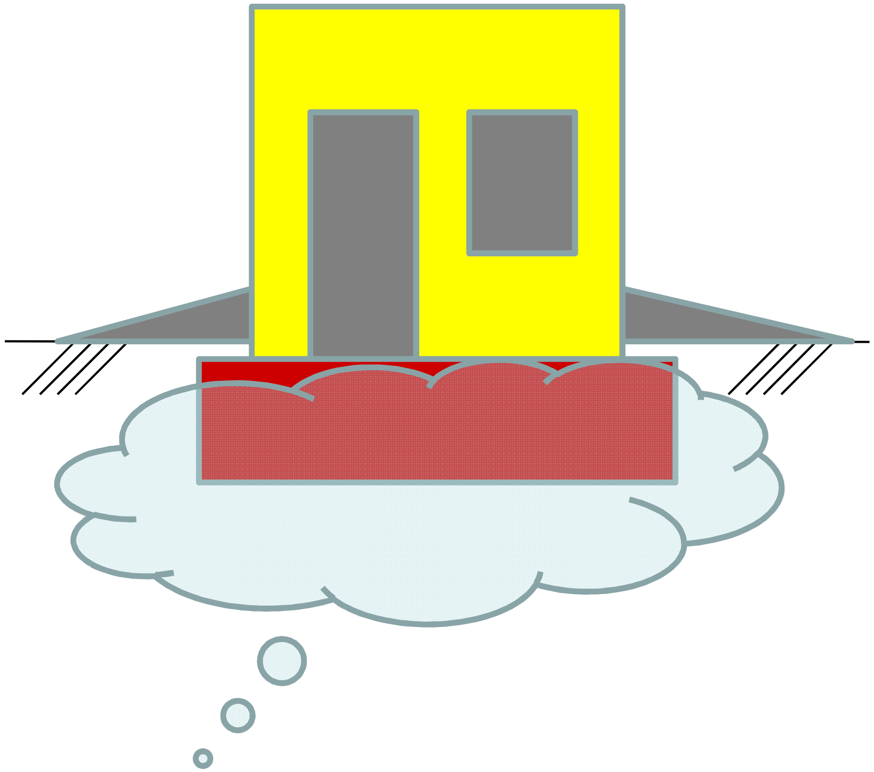


Not Good Soil. Change !!!!




**Roof Band**
**Lintel Band**
**Sill Band**
**Plinth Band**
**Bed Concrete Band**

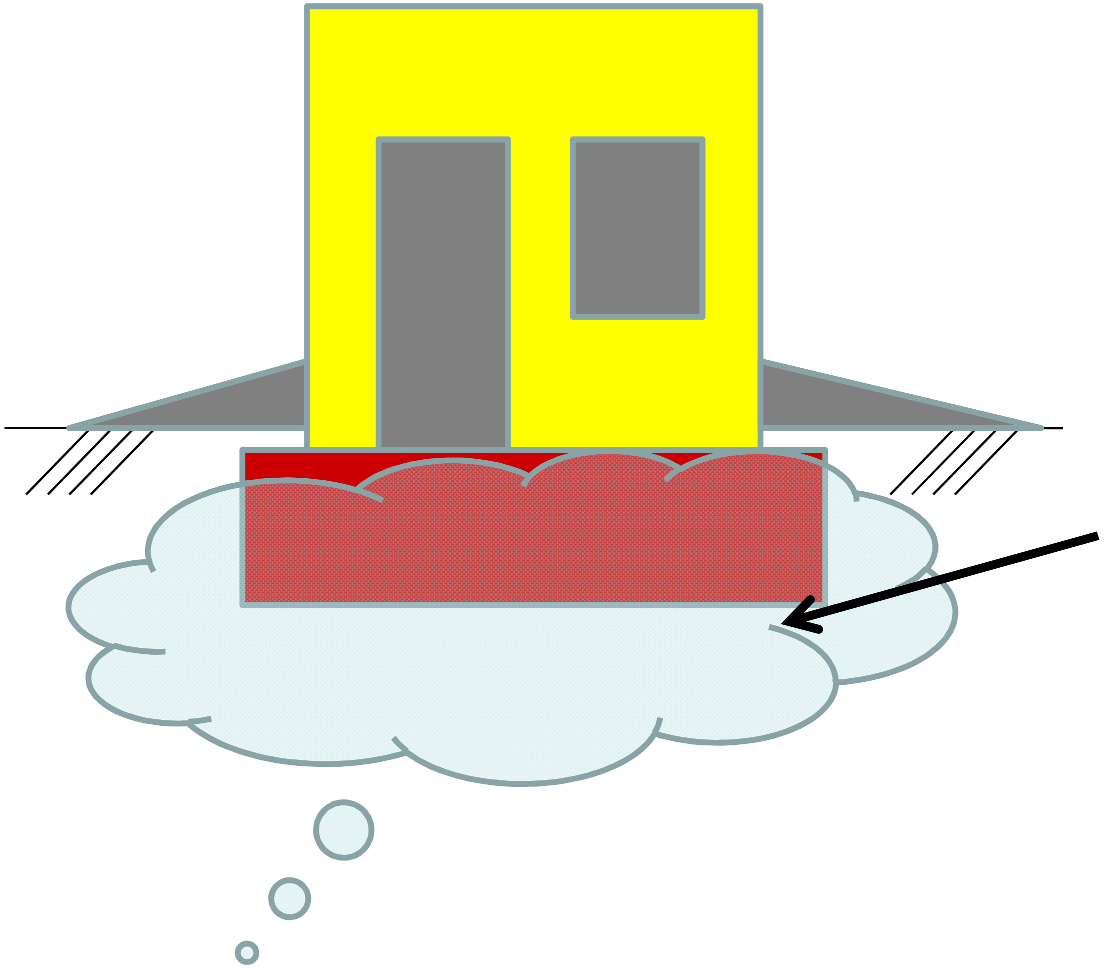
# Replace with better soil



Not Good Soil. Change !!!!

**Which is a better soil?**

# Stabilize the existing soil



Chemical Stabilization With LIME?

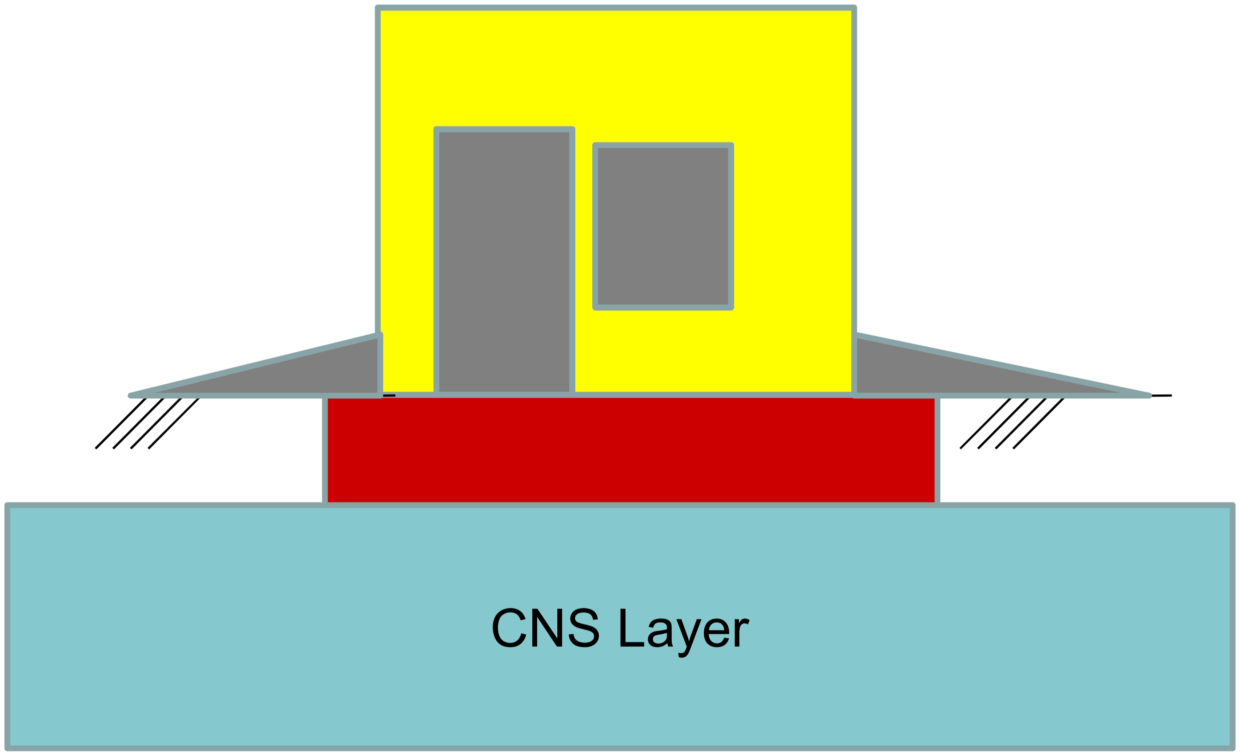
Not Good Soil. Change !!!!

# CNS Layer

- **Cohesive Non-Swell Layer**
- **Grain Size: 15 to 25 % Clay, 35 to 50 % Silt, 30 to 40 % Sand and < 10 % Gravel**
- **Consistency Limit: 30 – 50 %** $\omega_L$, 20 – 25 % $\omega_P$, > 15 % $\omega_S$ and 10 – 25 % $I_P$
- Swelling Pressure < 5 kPa when compacted at OMC of Standard Proctor Mould
- Clay Mineral: Kaolinite or Illite
- Shear Strength: 10 – 30 kPa Cohesion, 8 – 15$^o$ Friction Angle

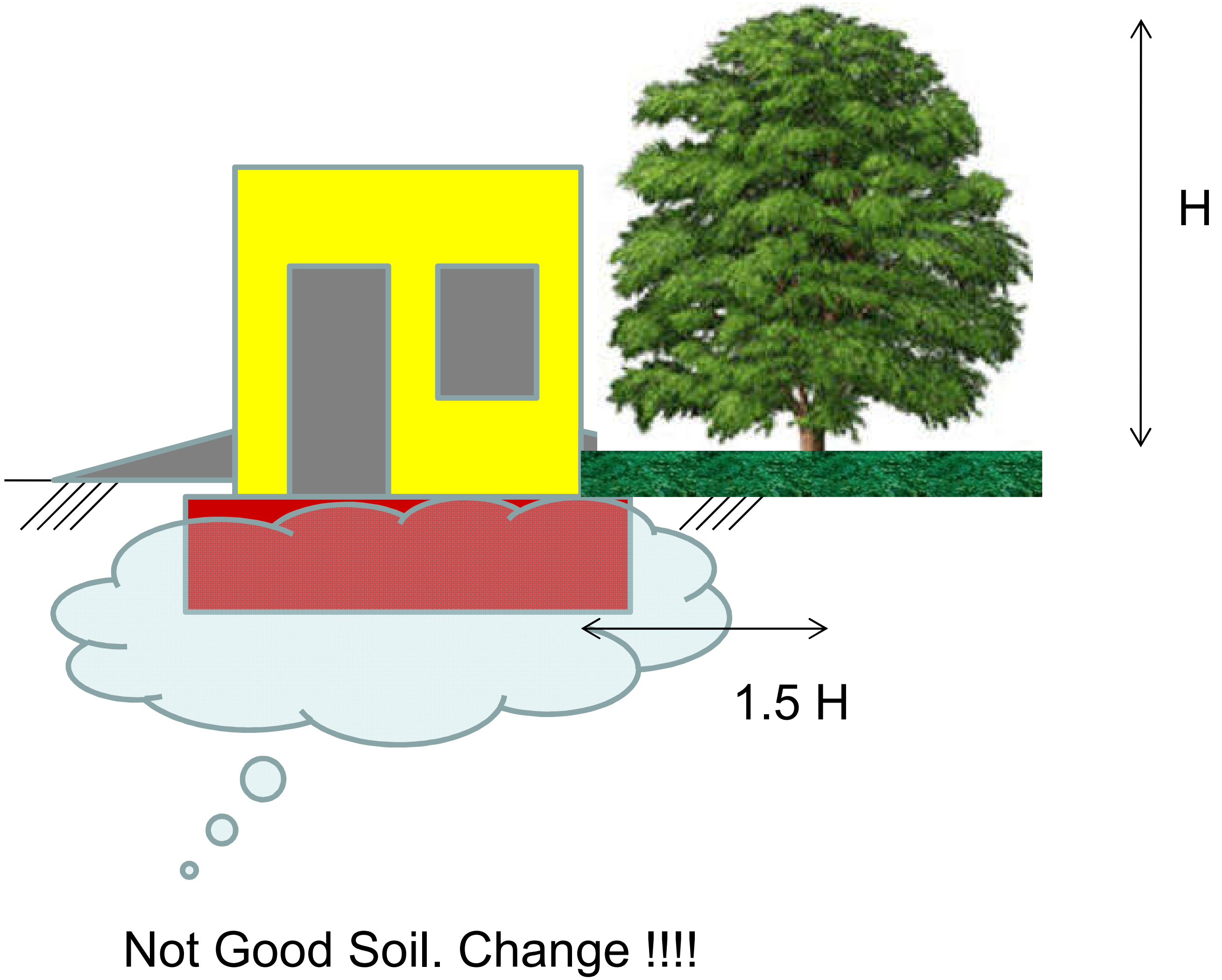
| Sl No | Swelling Pressure (kPa) | Thickness (m) |
|---|---|---|
| 1 | 100-150 | 0.75 – 0.85 |
| 2 | 200-300 | 0.90 – 1.00 |
| 3 | 350-500 | 1.05 – 1.15 |

# Stabilize the existing soil

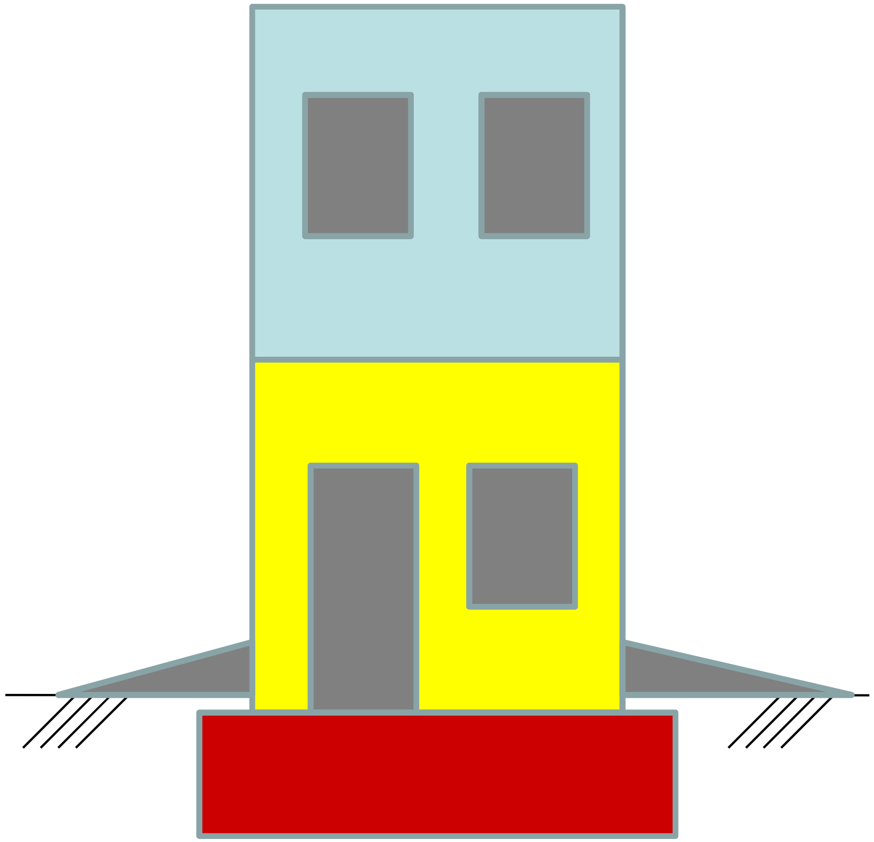


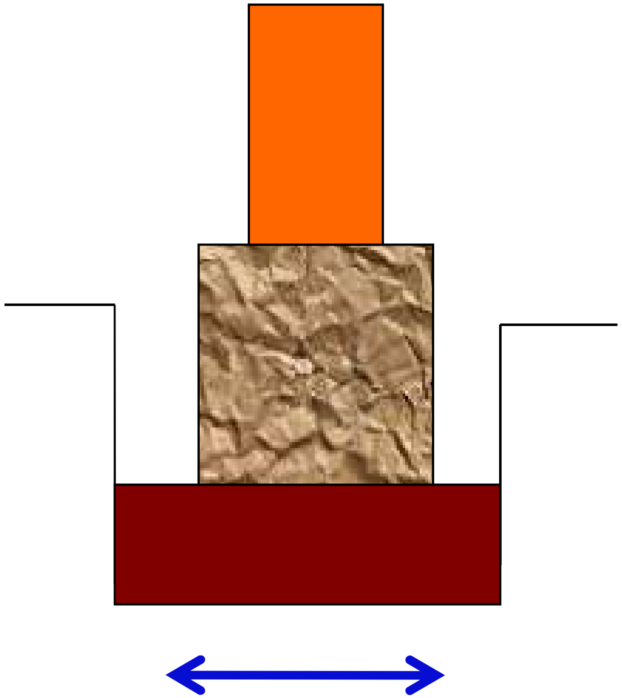

B C Soil

# Avoid Vegetation Around

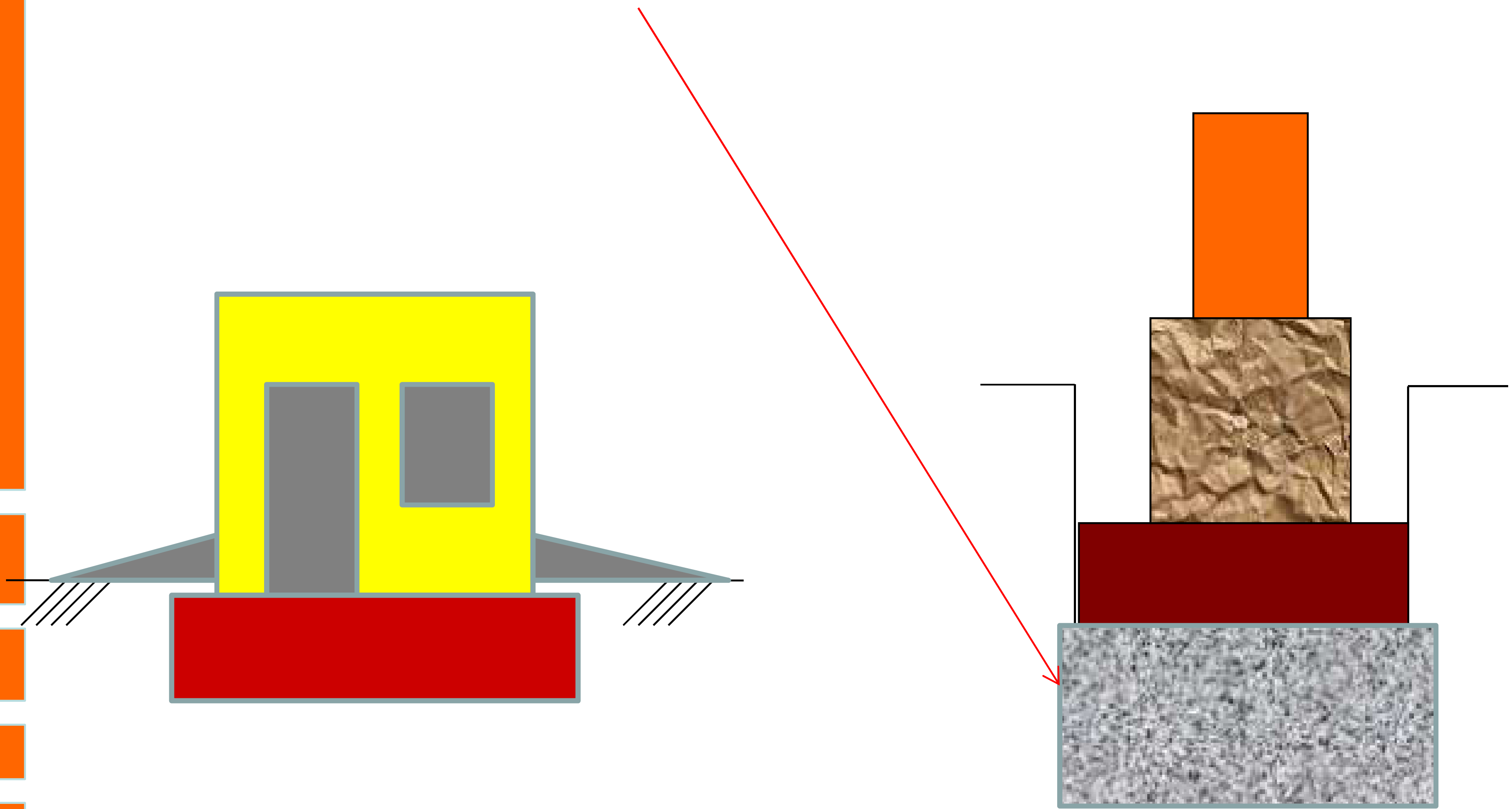


# Increase Bearing Pressure

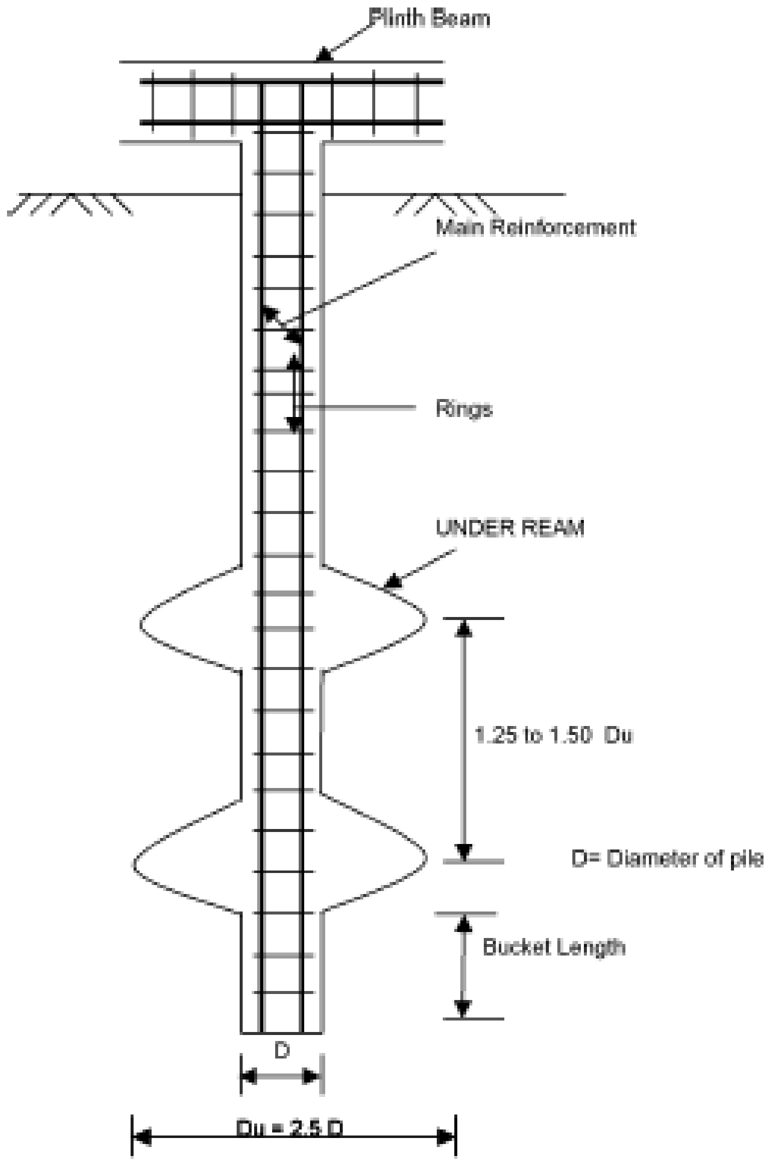




# Sand & Boulder Filling

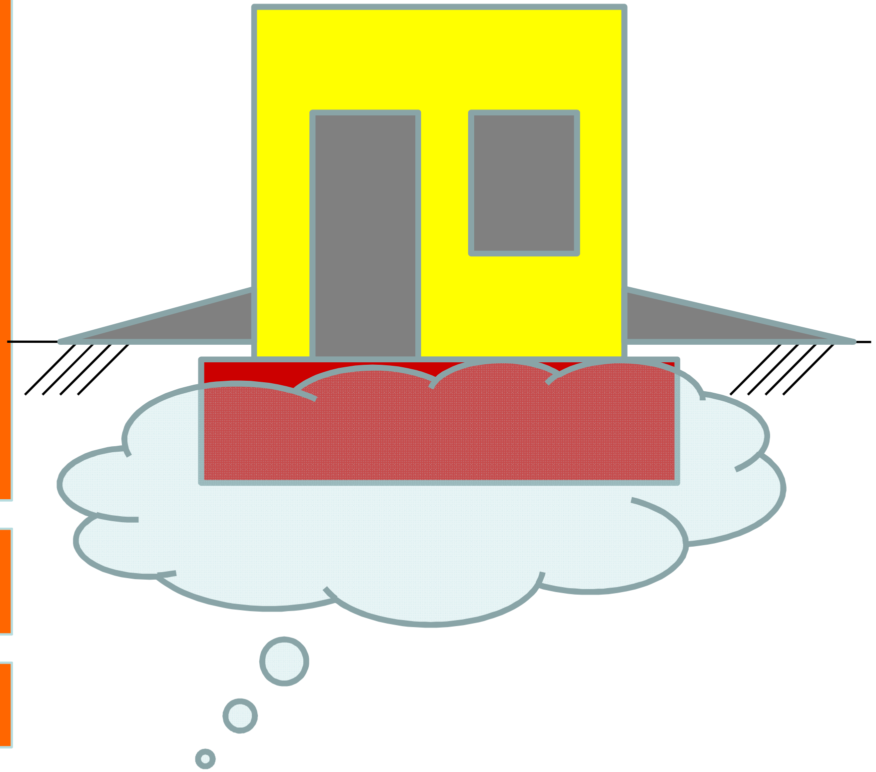


# Under Reamed Pile




**Under reamed pile with two under reams**

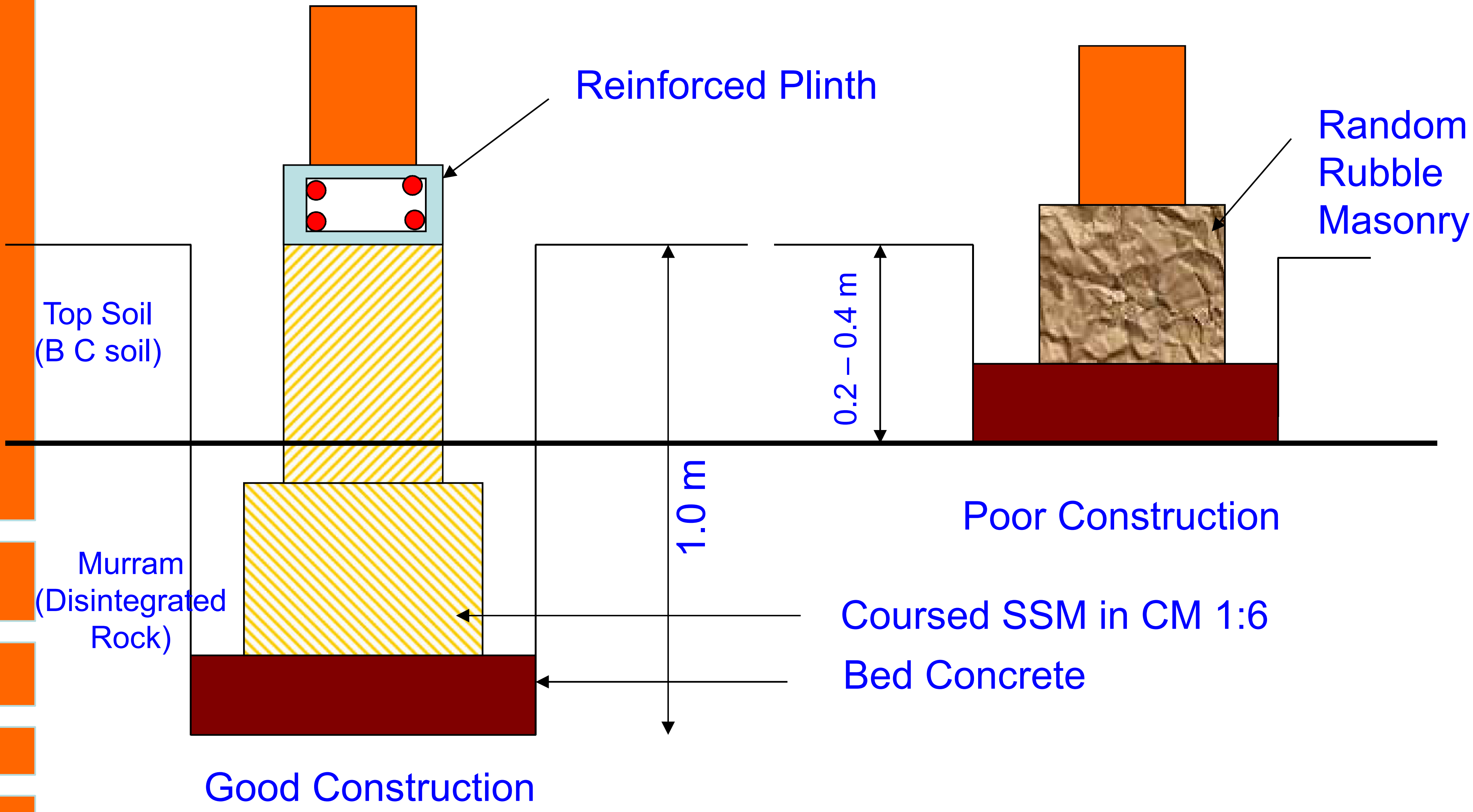
# Precautions for light structure on BC Soil



Not Good Soil. Change !!!!

1. Prevention is better than cure
2. Increase depth of foundation
3. Provide al-round apron with sufficient outside slope
4. Provide plinth, sill & lintel bands with RCC bed concrete.
5. Replace with better soil
6. Stabilize the existing soil
7. Provide CNS Layer
8. Provide sand & boulder filling
9. Avoid vegetation around
10. Allow good drainage
11. Increase bearing pressure

# Typical Foundation details for Masonry Construction in Kutch Region




**Structures with better construction practice & STRONG FOUNDATION survive**

# Gas tank resting on Piers and surrounding soil liquefied

**Structures with better construction practice & STRONG FOUNDATION on stable base survive**

# Ground Improvement Techniques

# DANGER!


DID YOU KNOW?
ONE OF EVERY FIVE
WORKPLACE FATALITIES IS
A CONSTRUCTION WORKER


DID YOU KNOW?
THE FATALITY RATE FOR
EXCAVATION WORK IS 112%
HIGHER THAN THE RATE FOR
GENERAL CONSTRUCTION.

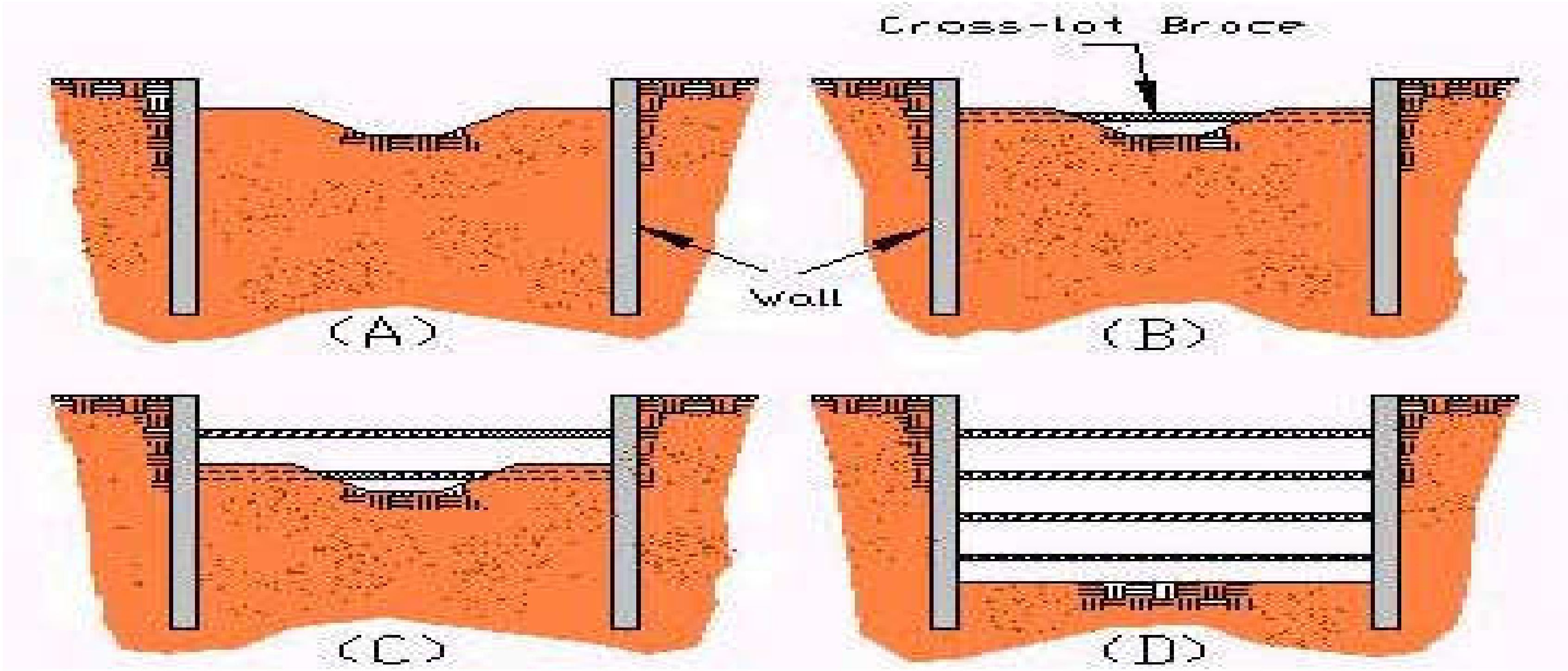
# Construction safety in deep excavation?

All open excavations made in the earth's surface including trenches.

# Deep Excavation

Propping and supporting the exposed walls to resist lateral earth pressures

# Deep Excavation – Proper Care




| Retaining System | Support System |
|---|---|
| Soldier Piles & Lagging Walls<br>Sheet Pile Walls<br>Secant Pile Walls<br>Soil Mix Walls<br>Diaphragm Walls | Tie back / Rock Anchors<br>Cross Lot & Internal Bracing<br>Top Down Construction<br>Soil Nailing |

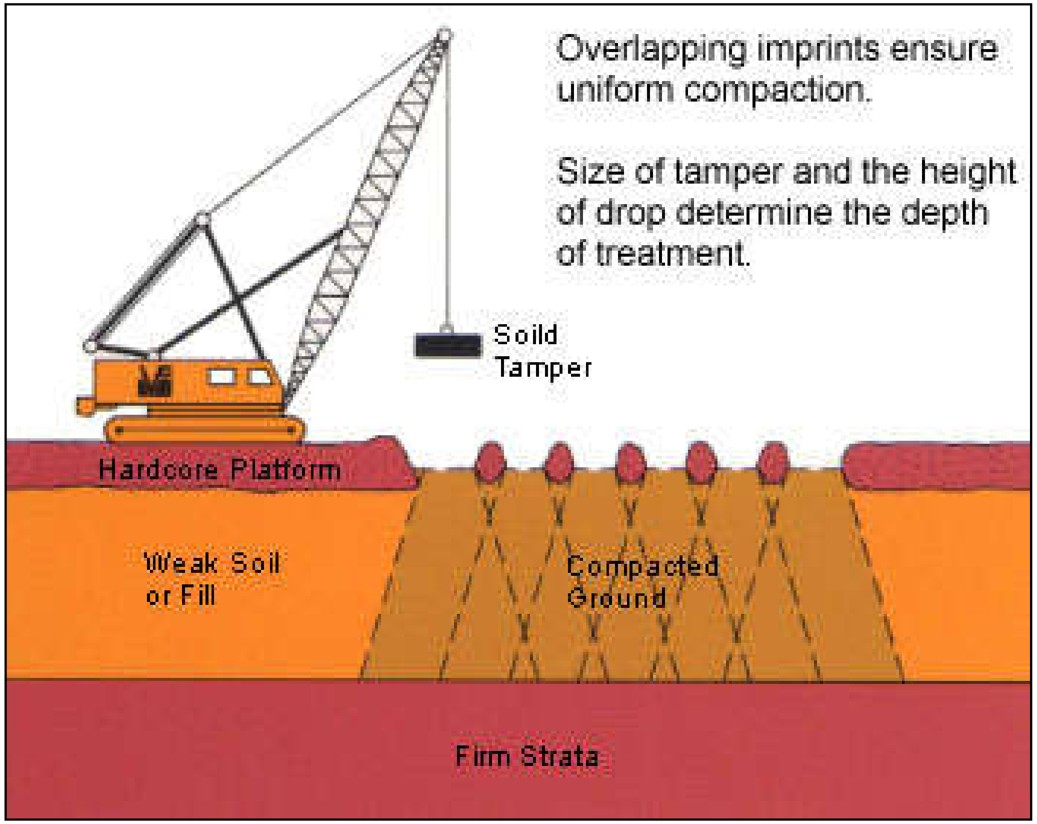
# Ground Improvement

Sheepsfoot Roller to Compact Clay Soils

Smooth-wheeled Roller

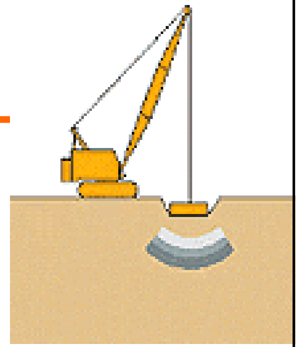
Impact Roller to Compact the Ground

# Dynamic Compaction



# Dynamic Compaction

- pounding the ground by  a heavy weight



Suitable for granular soils, land fills and karst terrain with sink holes.

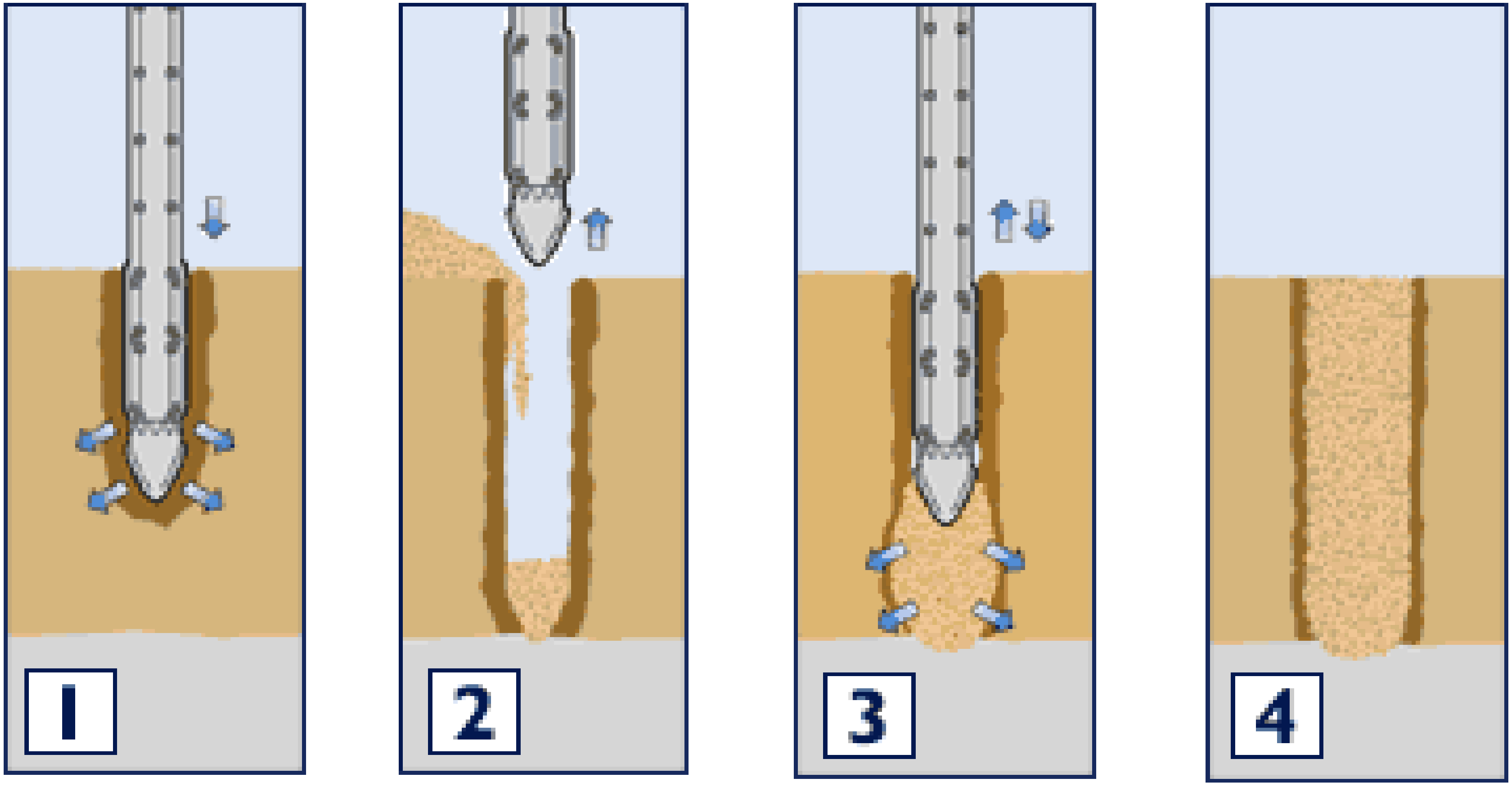
solution cavities in limestone

Pounder (Tamper)

Crater created by  the impact

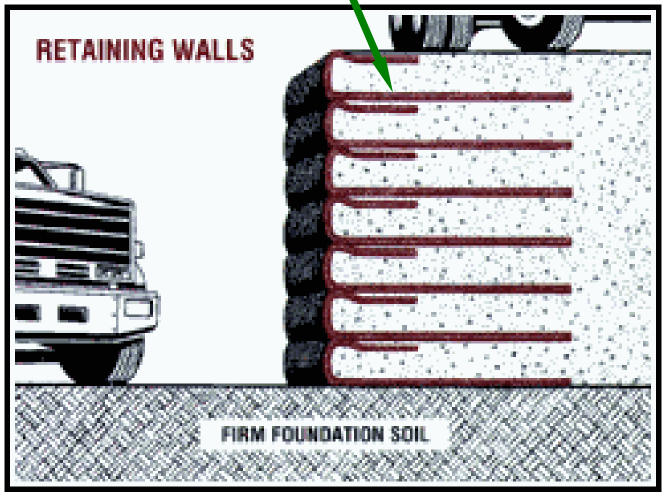
# Vibroflotation

# Vibrofloatation

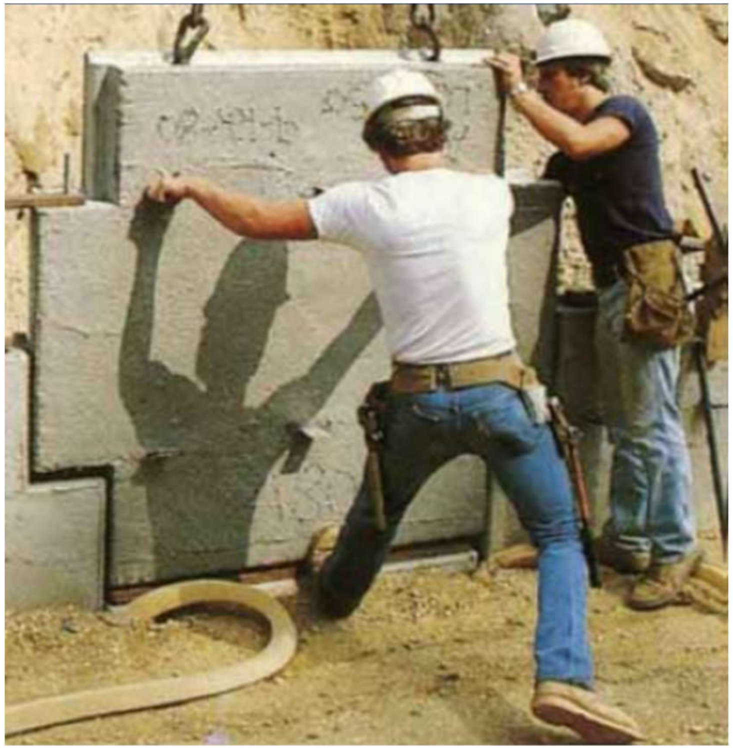


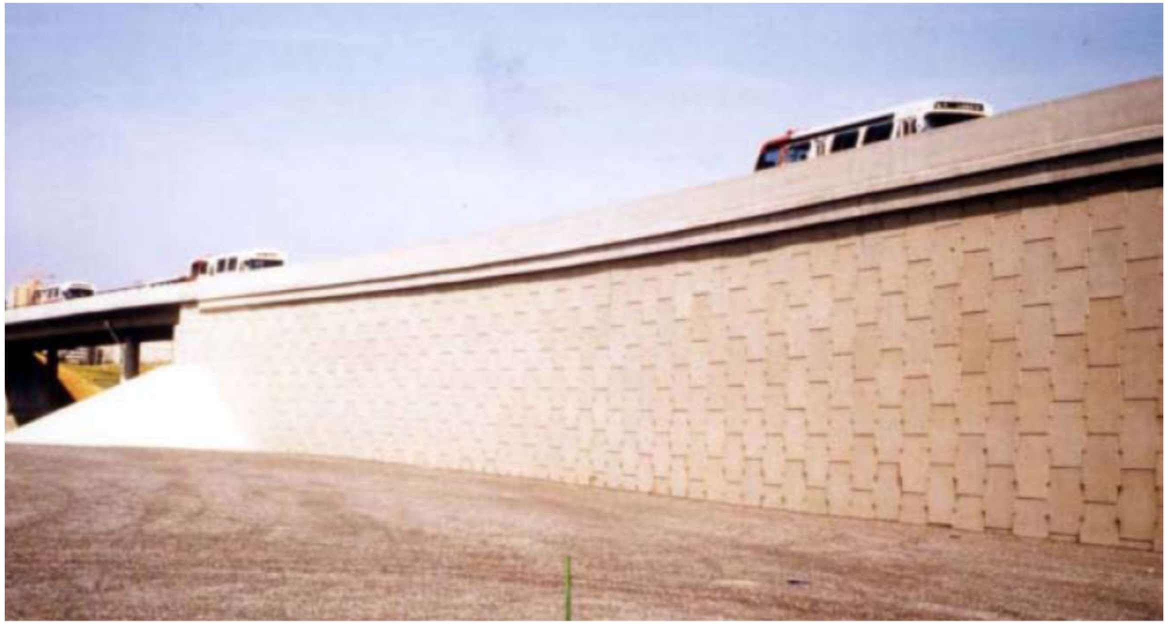
# Reinforced Earth Walls

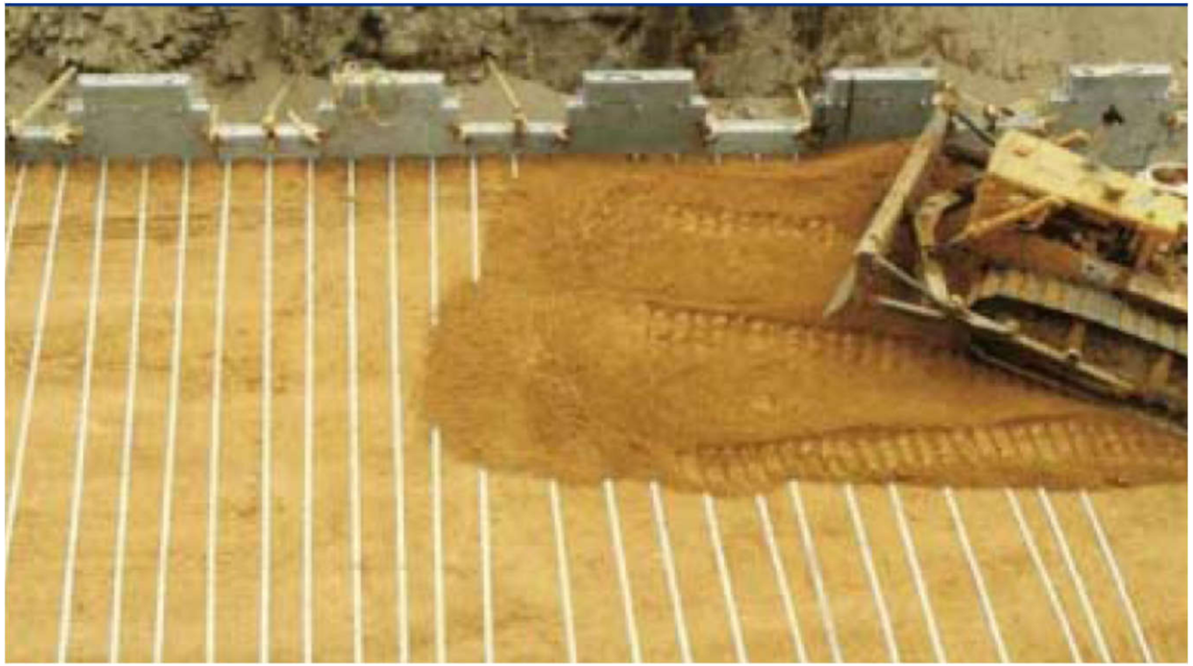
Using geofabrics to strengthen the soil




# MSE/Reinforced earth Wall







# Soil Nailing

Steel rods placed into holes drilled into the walls and grouted

# Geofabrics

Used for reinforcement, separation, filter, drain and container in roads, retaining walls, embankments, earth dams, landfills…

- Sheets
- Strips
- Rods
- Net
- Foam
- Grid
- Pipes
- Composites

# Reinforced Earth & Geosynthetics

- More recent technique of ground modification.
- Earth + Geotextile Composite.
- One solution for several problems.
- Used for strengthening, improving drainage, stabilizing slope, providing impermeable barrier, as a separator etc.
- Most effective and considered real innovation of $20^{th}$ C in Civil Engineering.

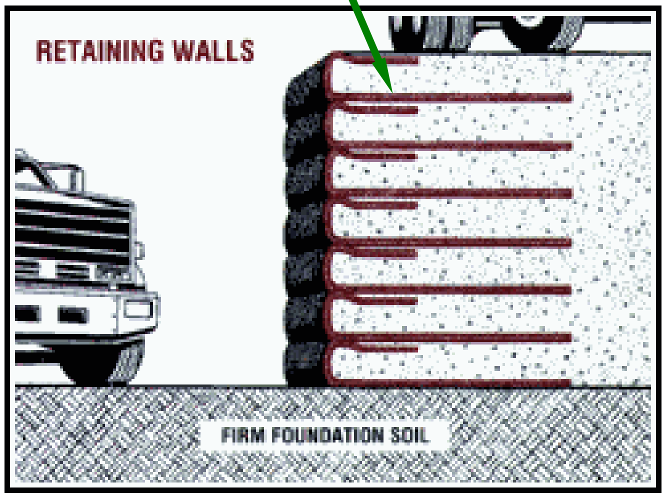
# Geofabrics

Used for reinforcement, separation, filtration and drainage in roads, retaining walls, embankments…

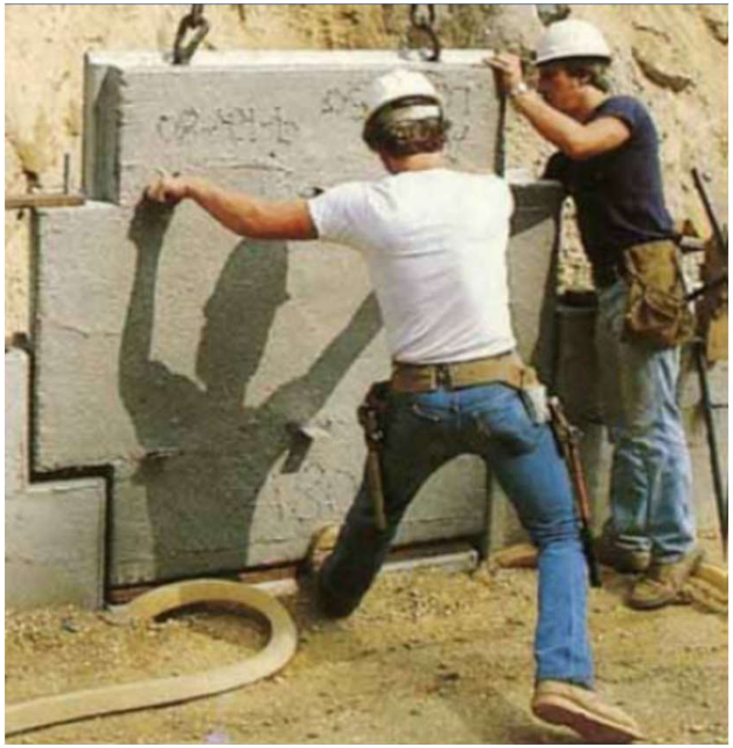
Geofabrics used on Pacific Highway

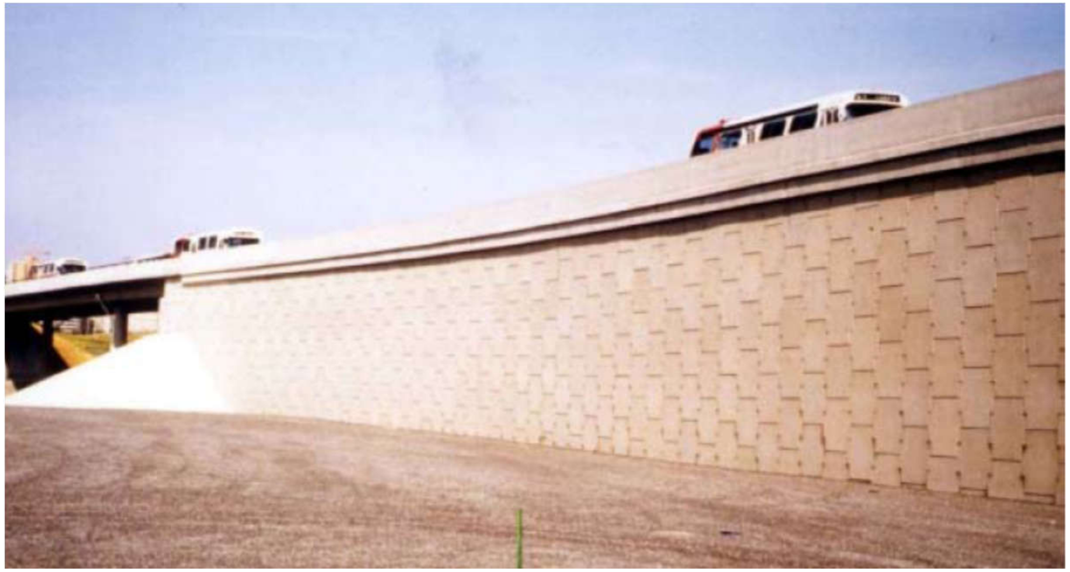
# Reinforced Earth Walls

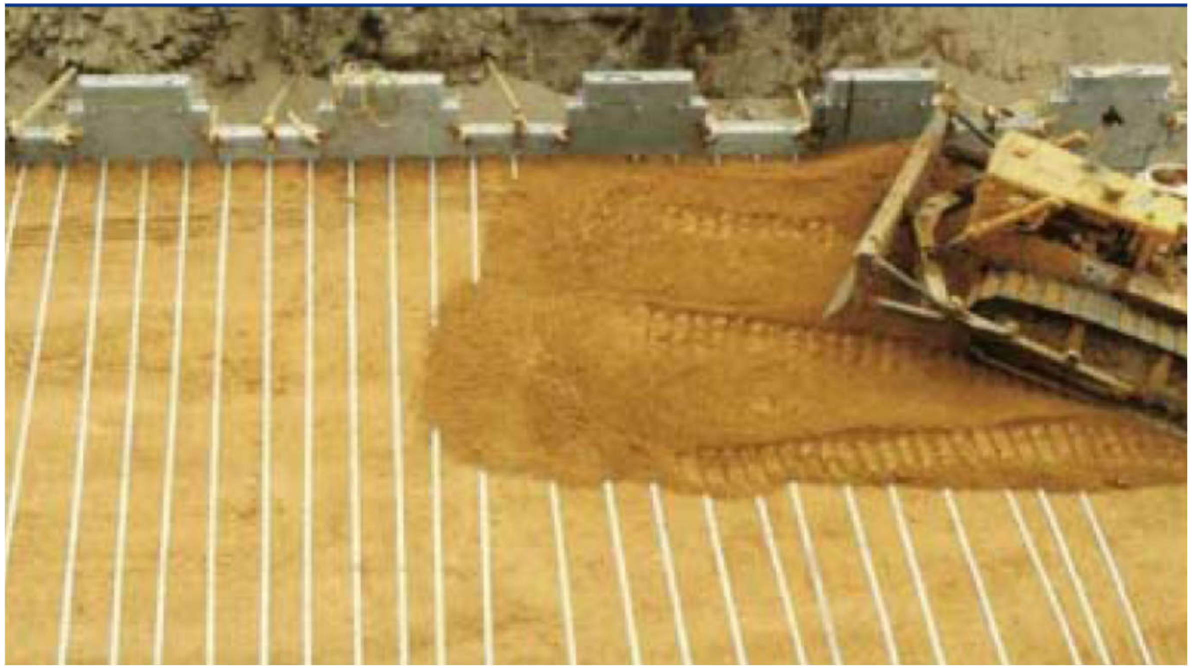
Using geofabrics to strengthen the soil




# MSE/Reinforced earth Wall







# Soil Nailing

Steel rods placed into holes drilled into the walls and grouted


 A technique for deep excavation maintaining stability

# Soil Nailing

# Soil Nailing

# Soil Nailing

# Soil Nailing

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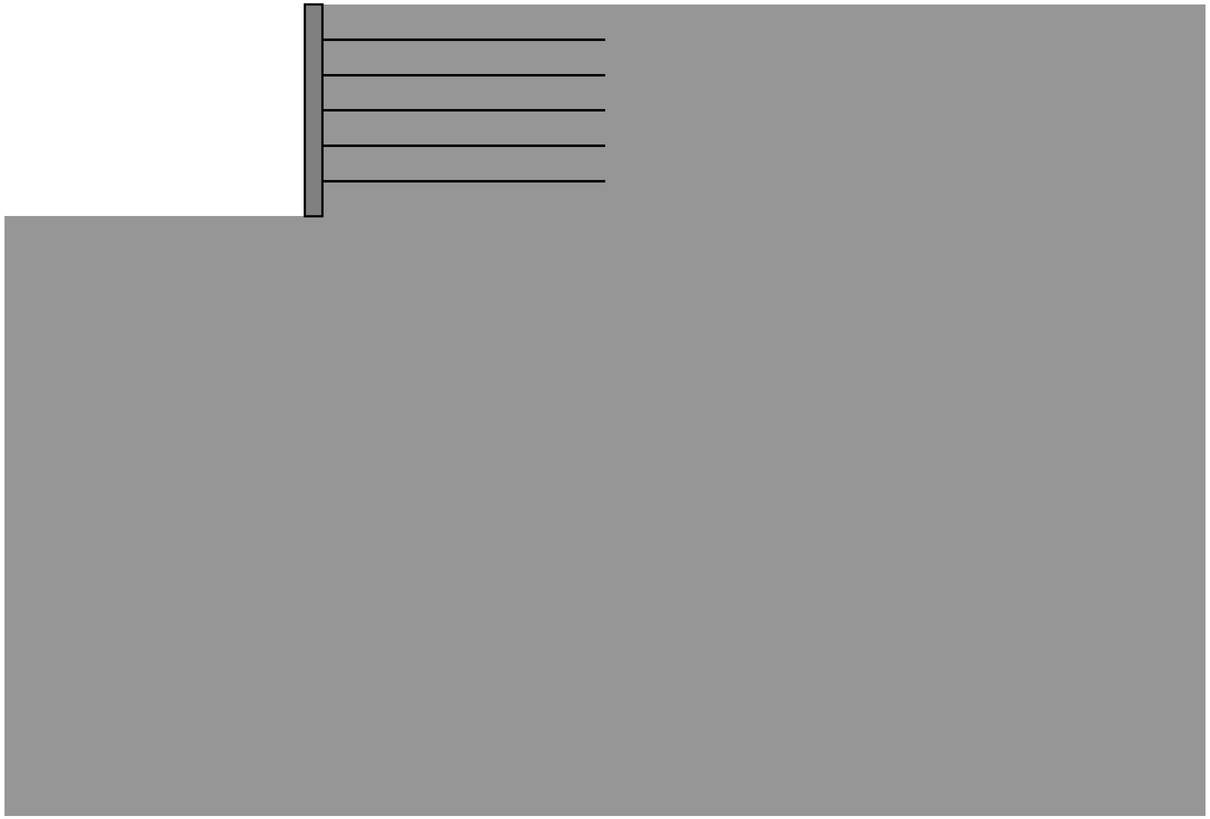
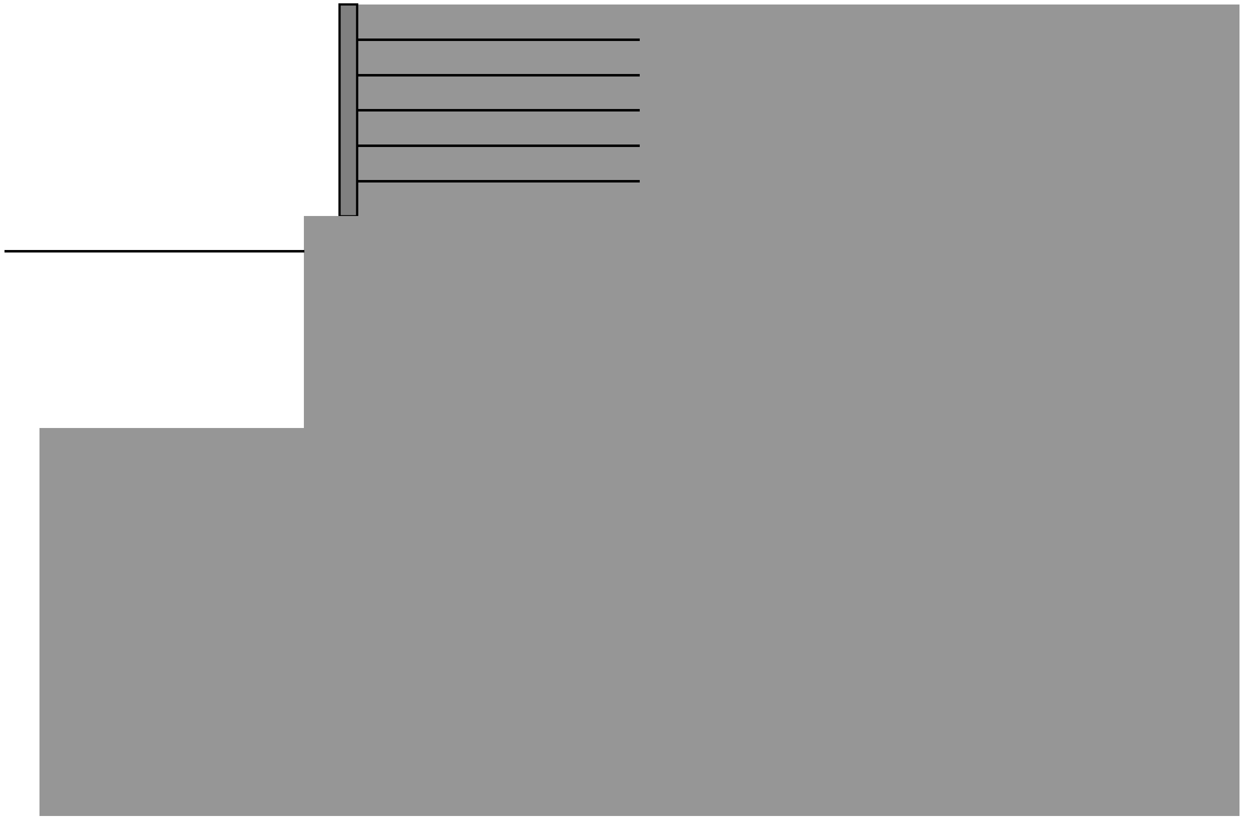
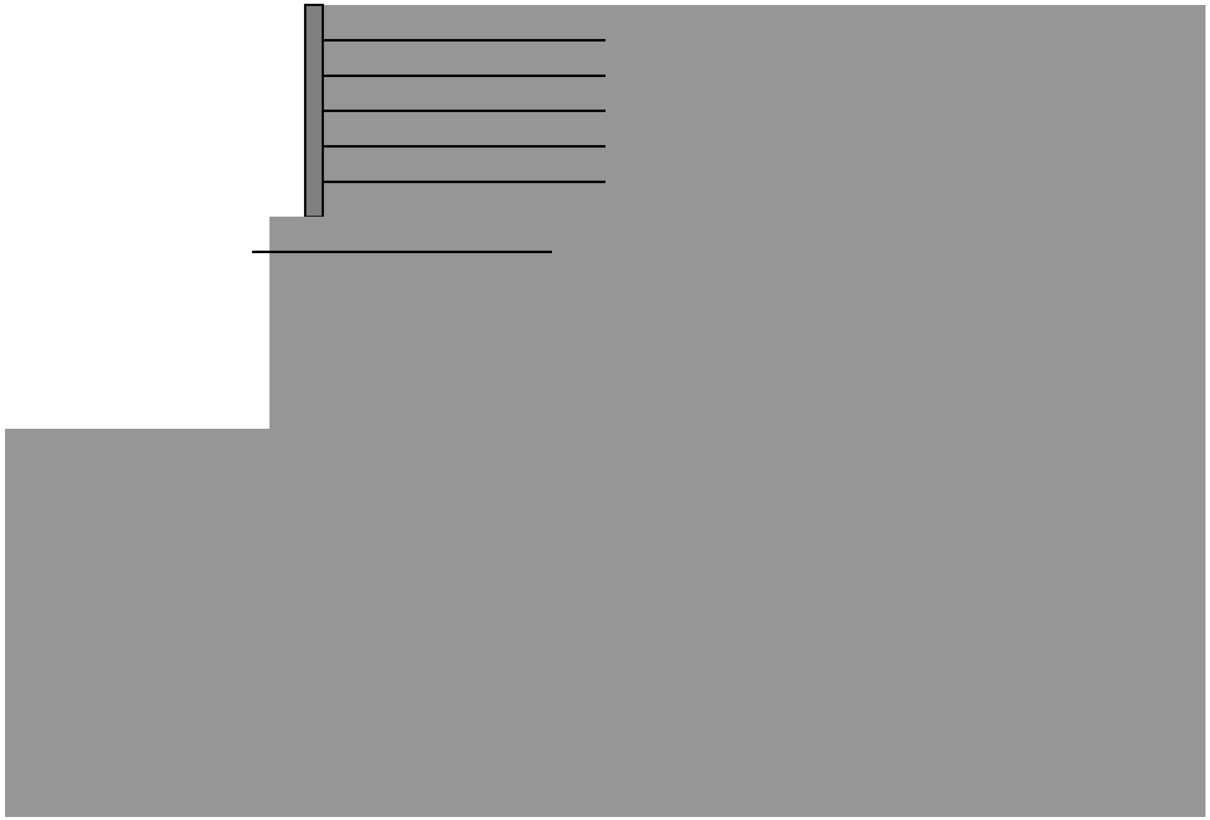


# Soil Nailing



# Soil Nailing



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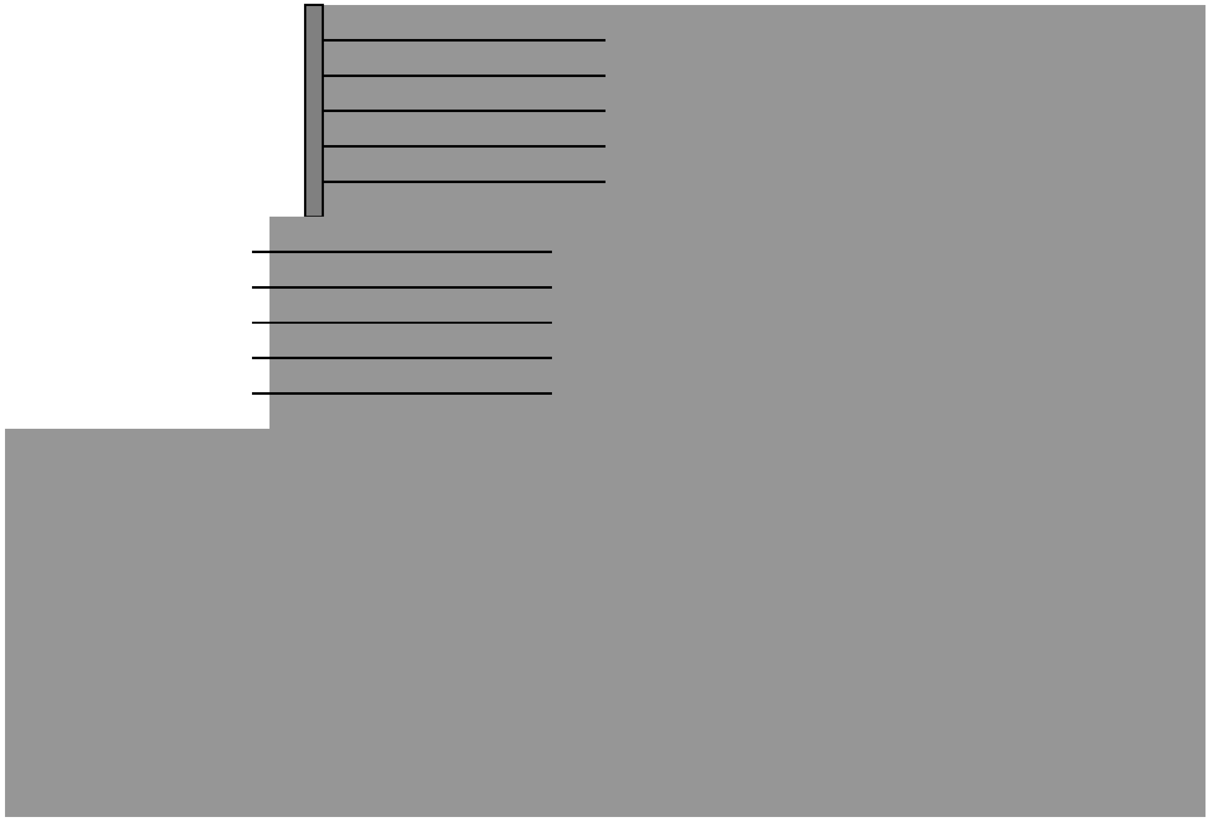

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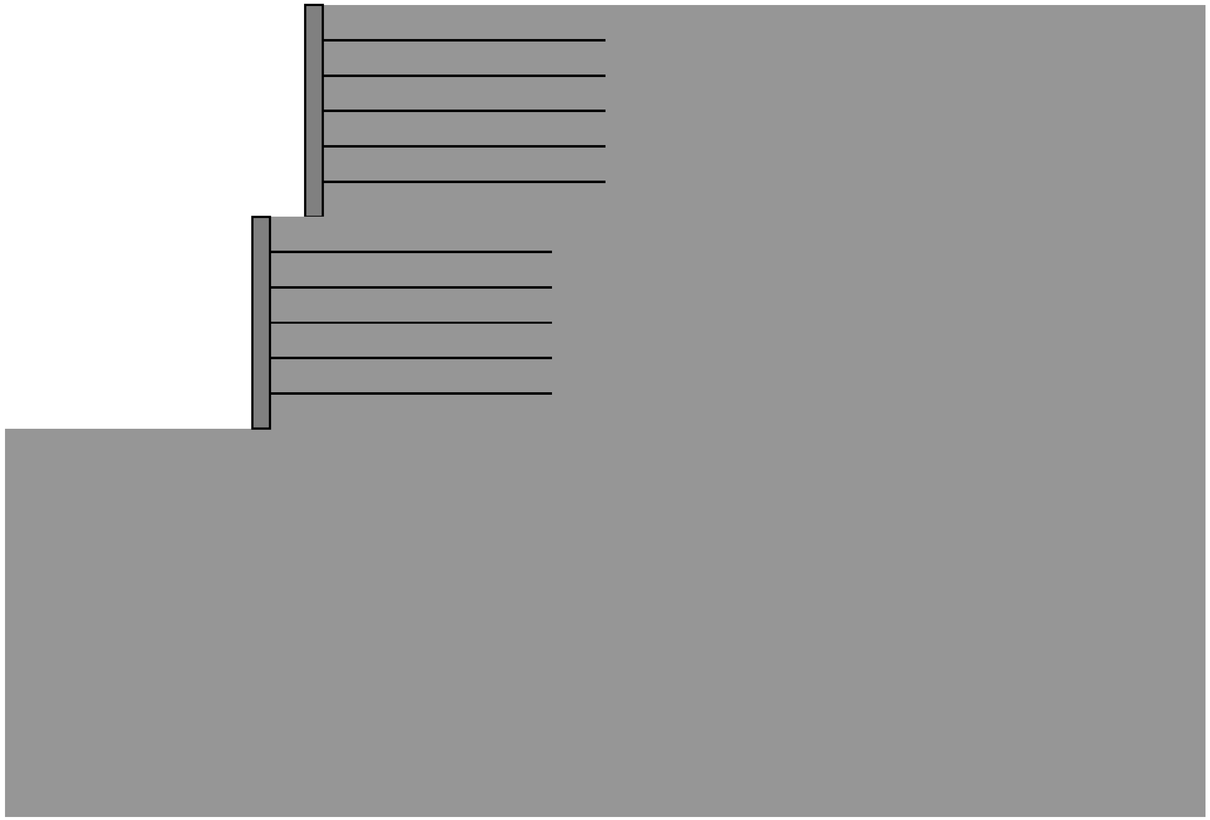

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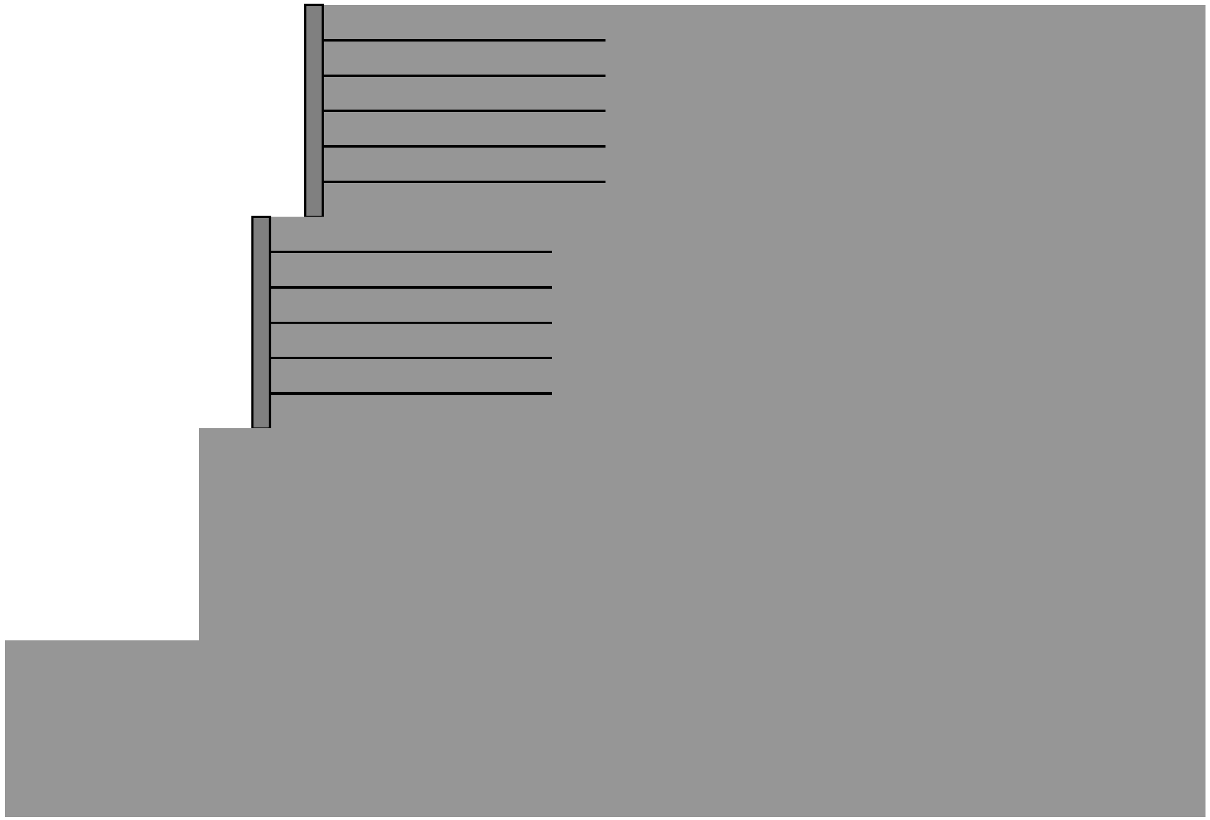

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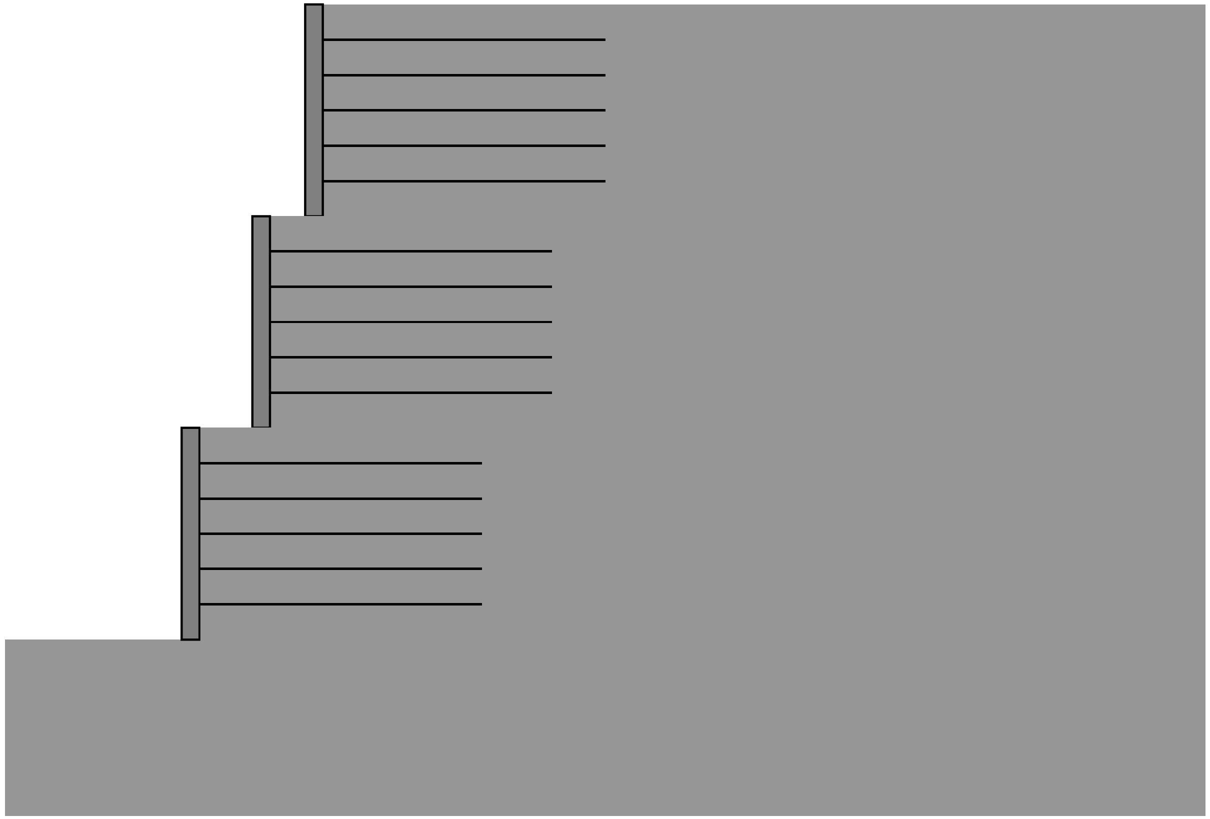

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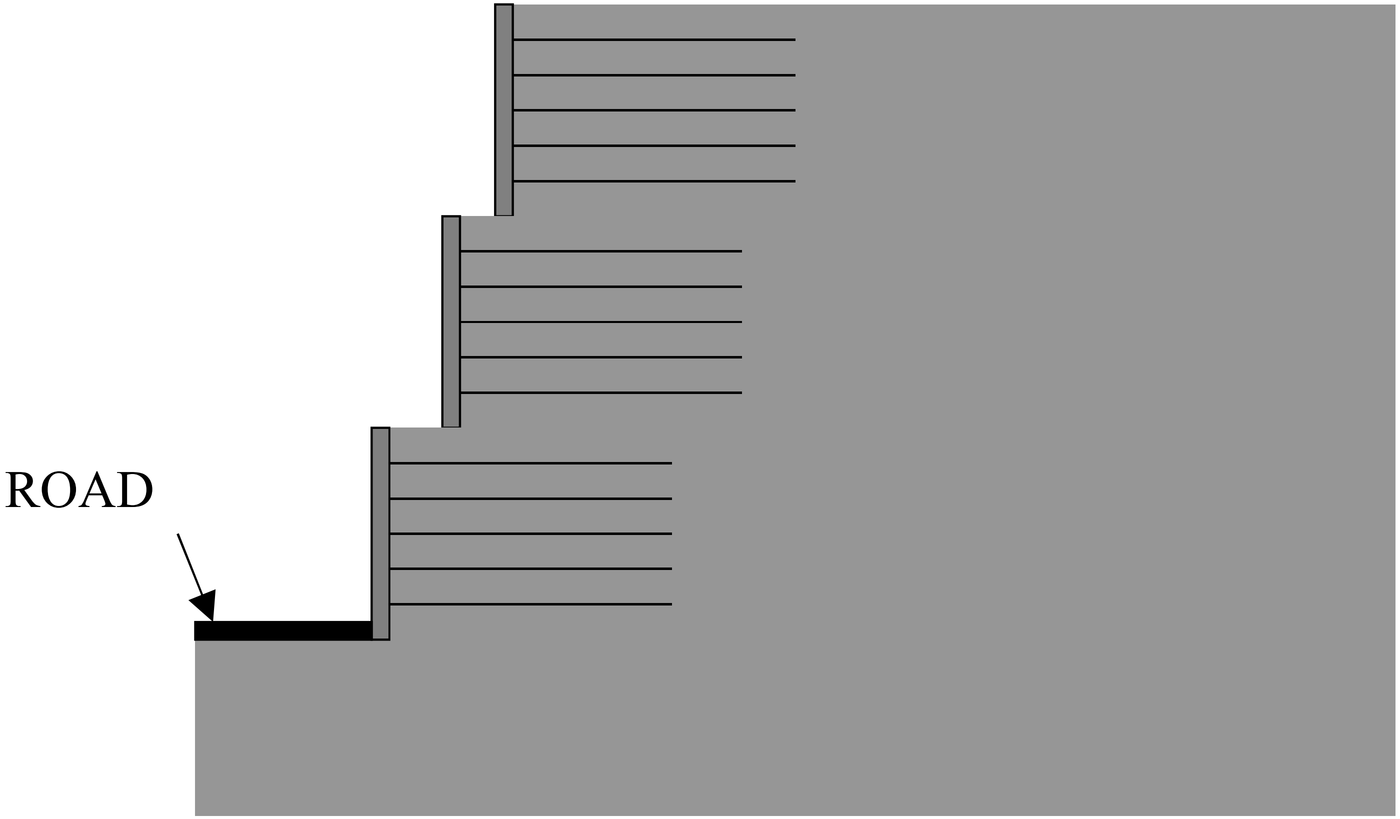
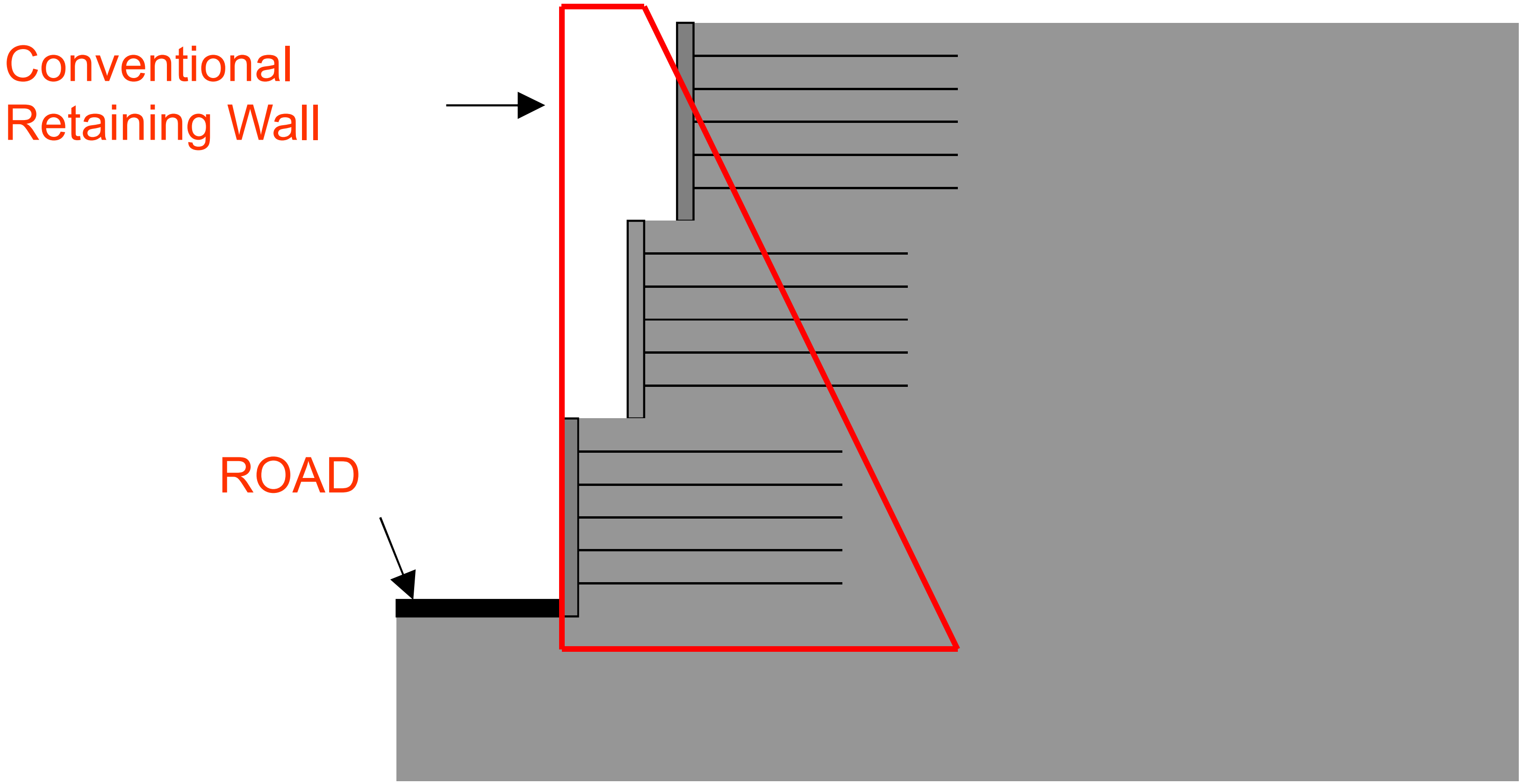


# Soil Nailing

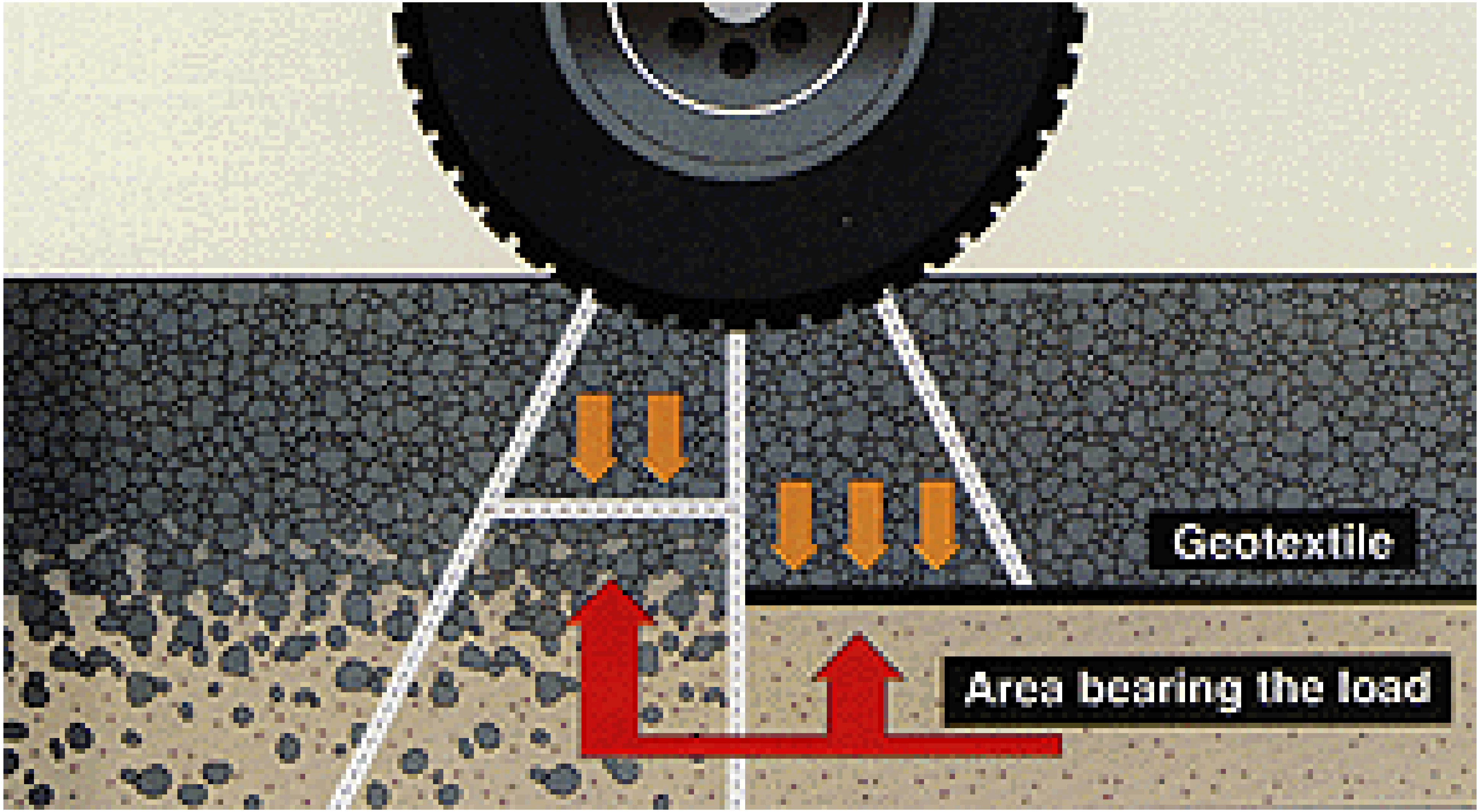


# Soil Nailing

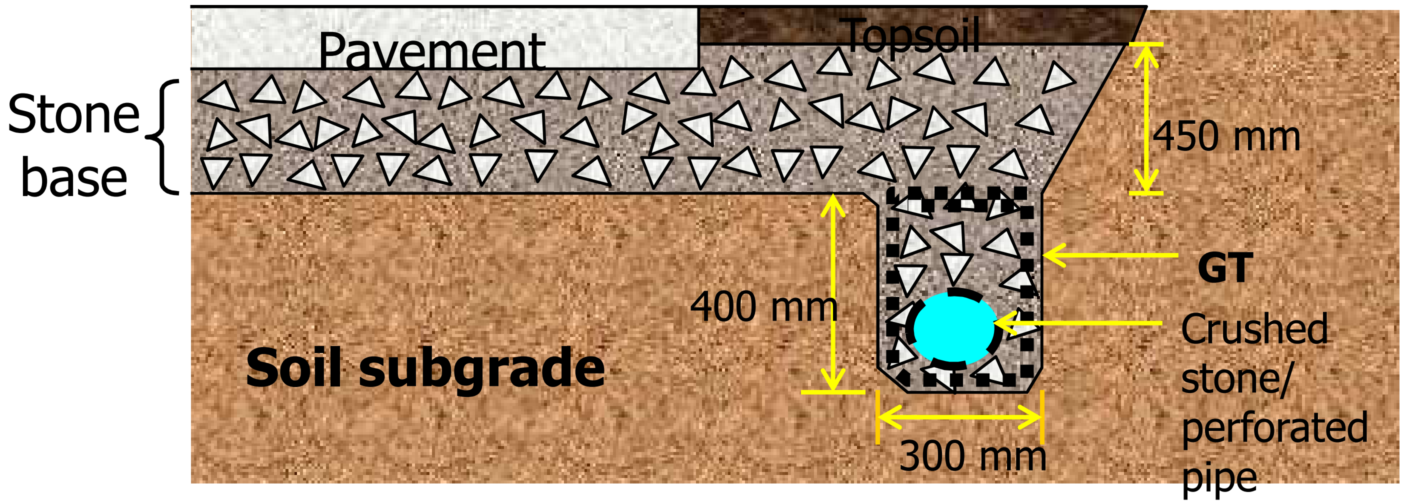
# Soil Nailing

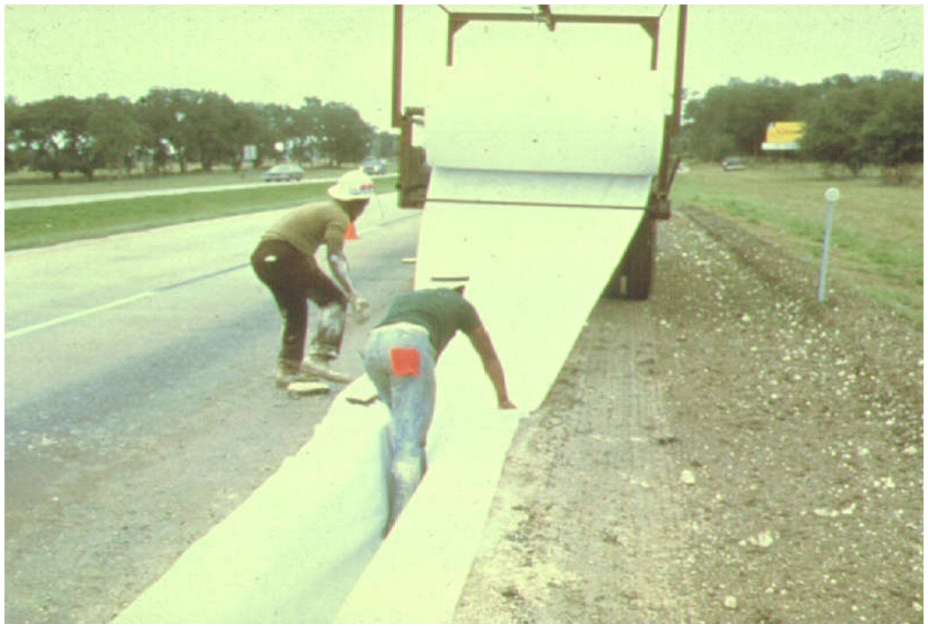
# Soil Nailing

# Geotextile in Pavements

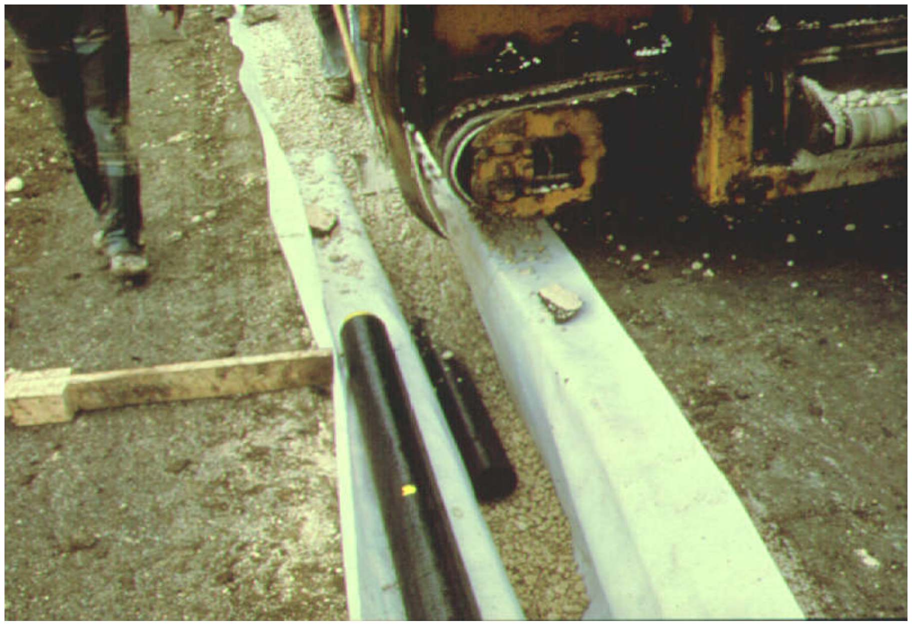


# Typical Applications of Geotextiles



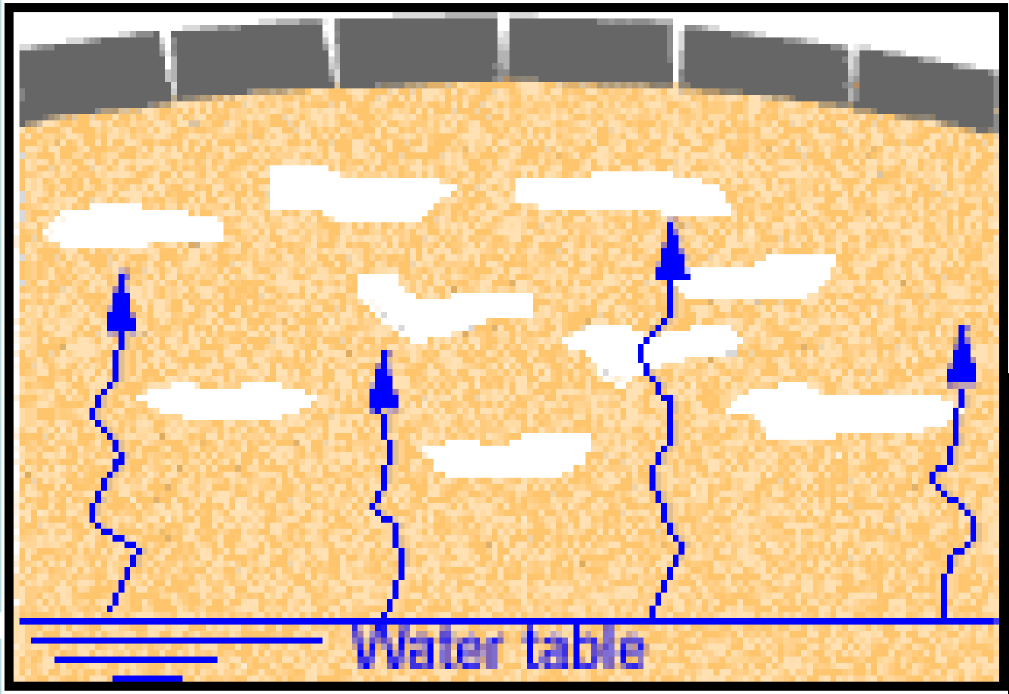



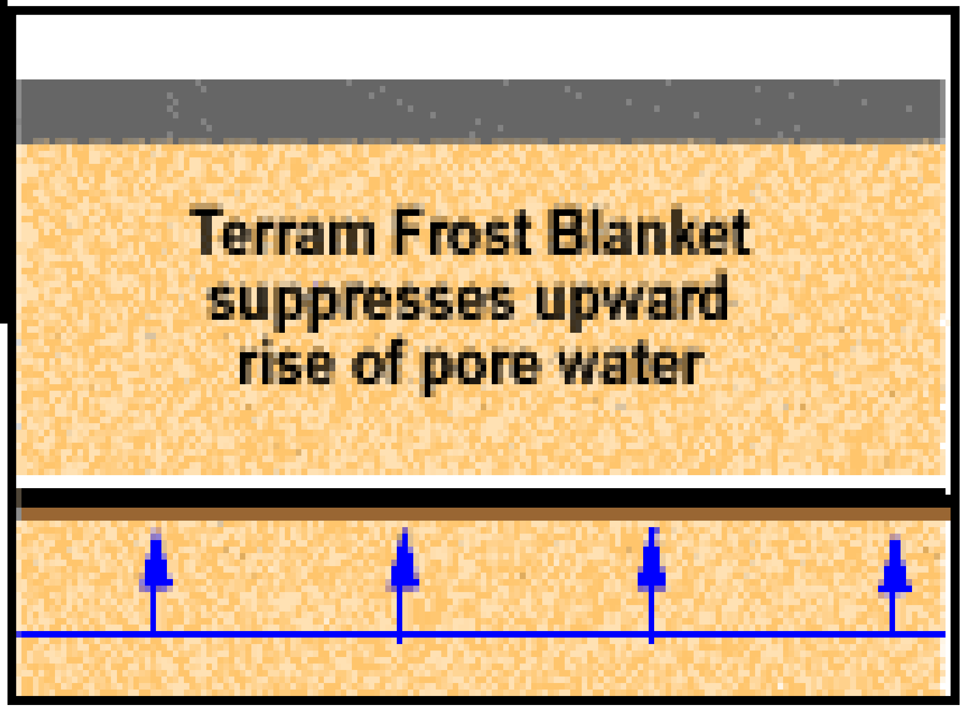
(GT Filter in Excavated Trench)



(Crushed Stone & Perforated Pipe)

# Typical Applications of Geotextiles

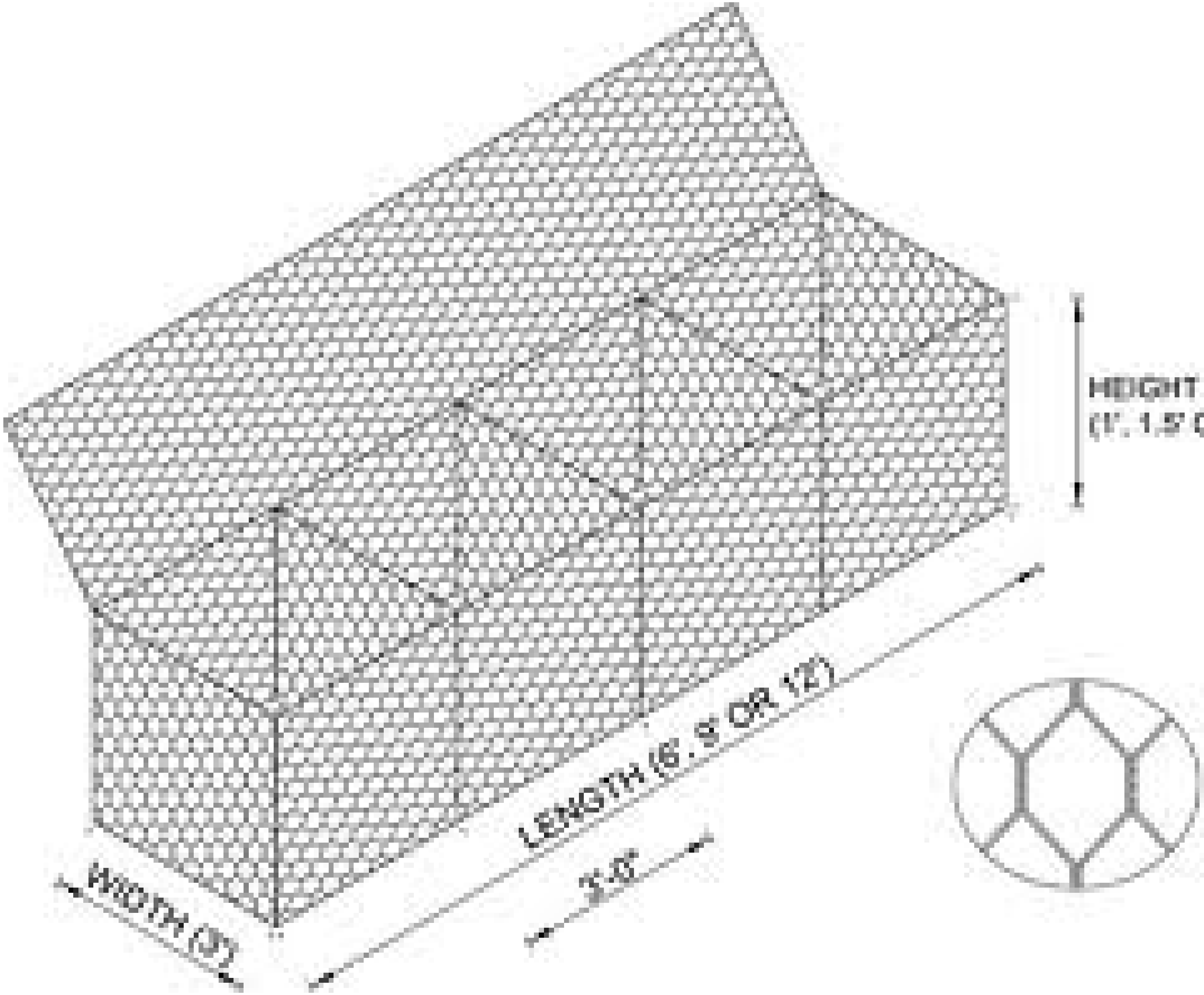


# Gabion Construction

# Gabion Construction

# Gabion Construction

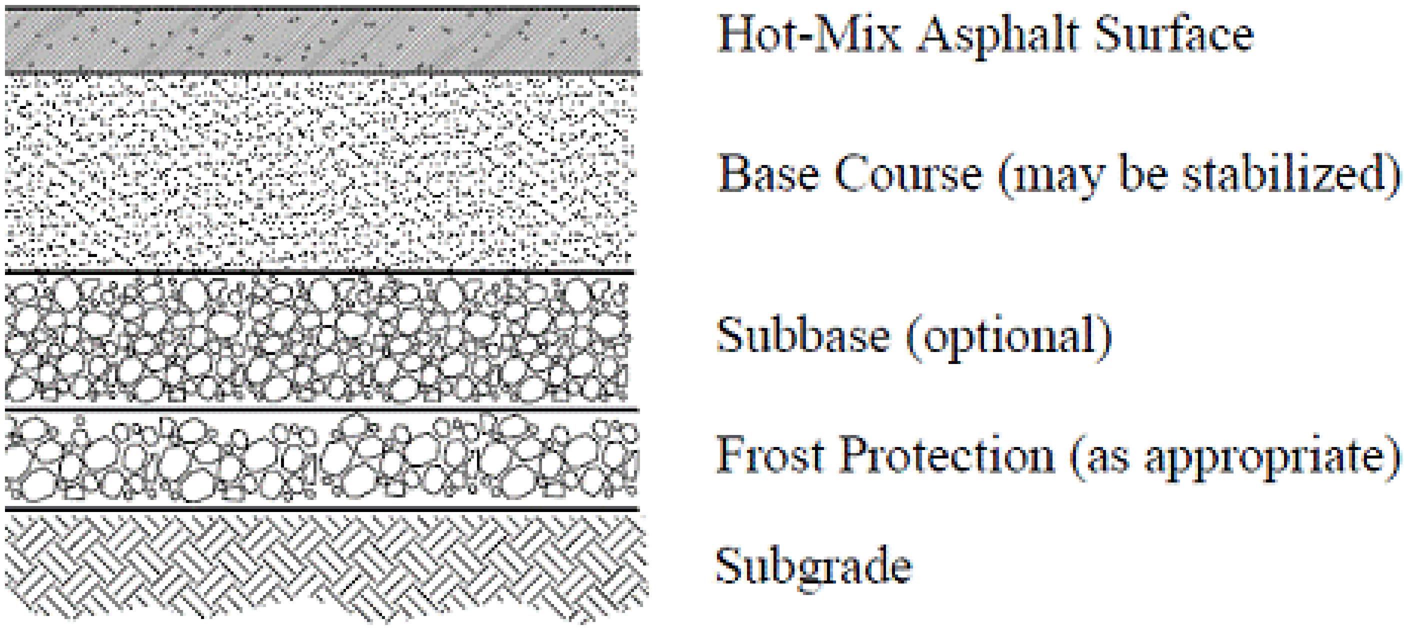


# Gabion Construction

# Gabion Construction

# Gabion Construction

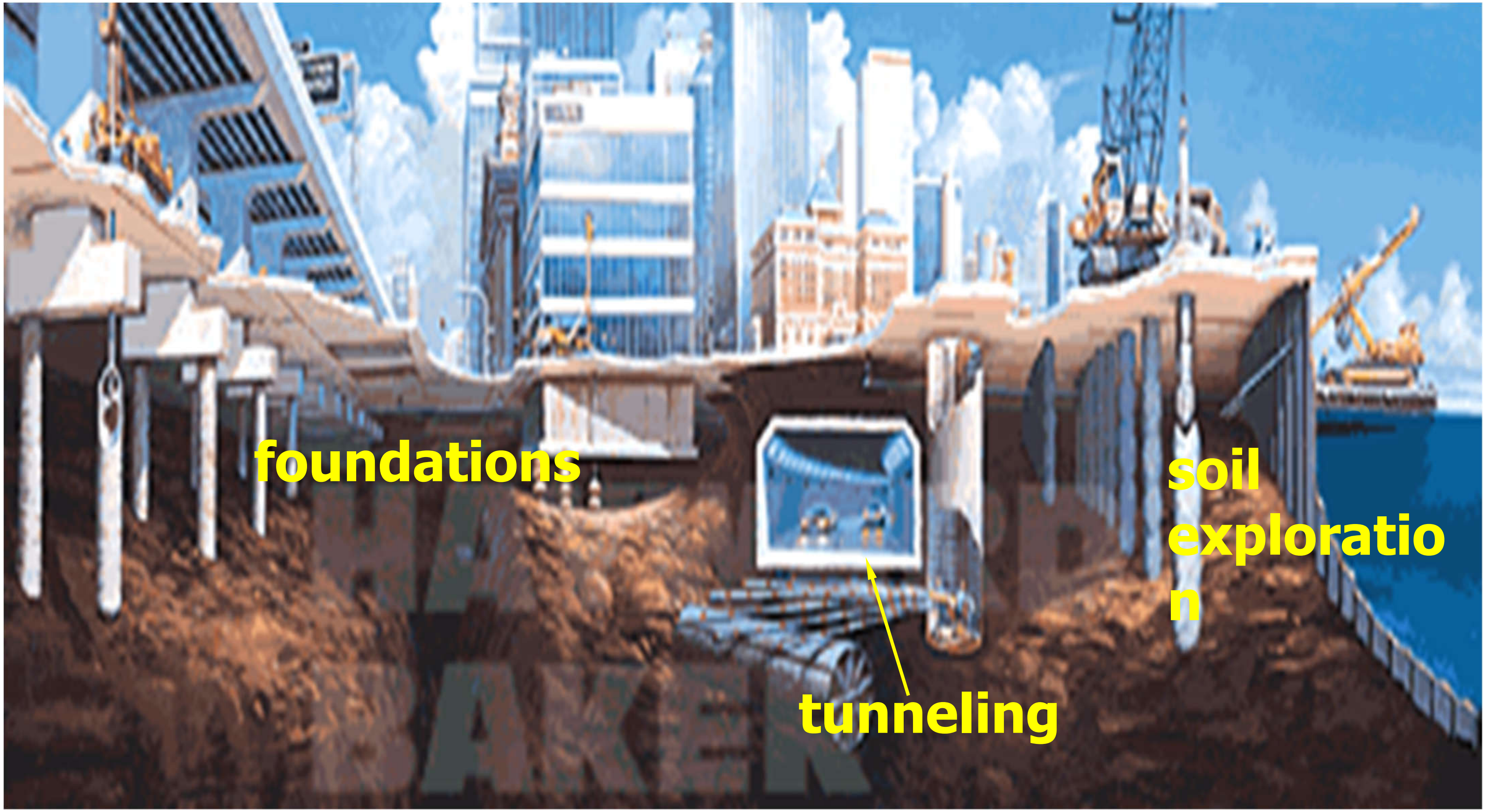
# ROADS


Hot-Mix Asphalt Surface
Base Course (may be stabilized)
Subbase (optional)
Frost Protection (as appropriate)
Subgrade

# BRIDGES


Tom Collins, U.S. Forest Service, Region 8

# Geotechnic for Infrastructure




… buried right under your feet.

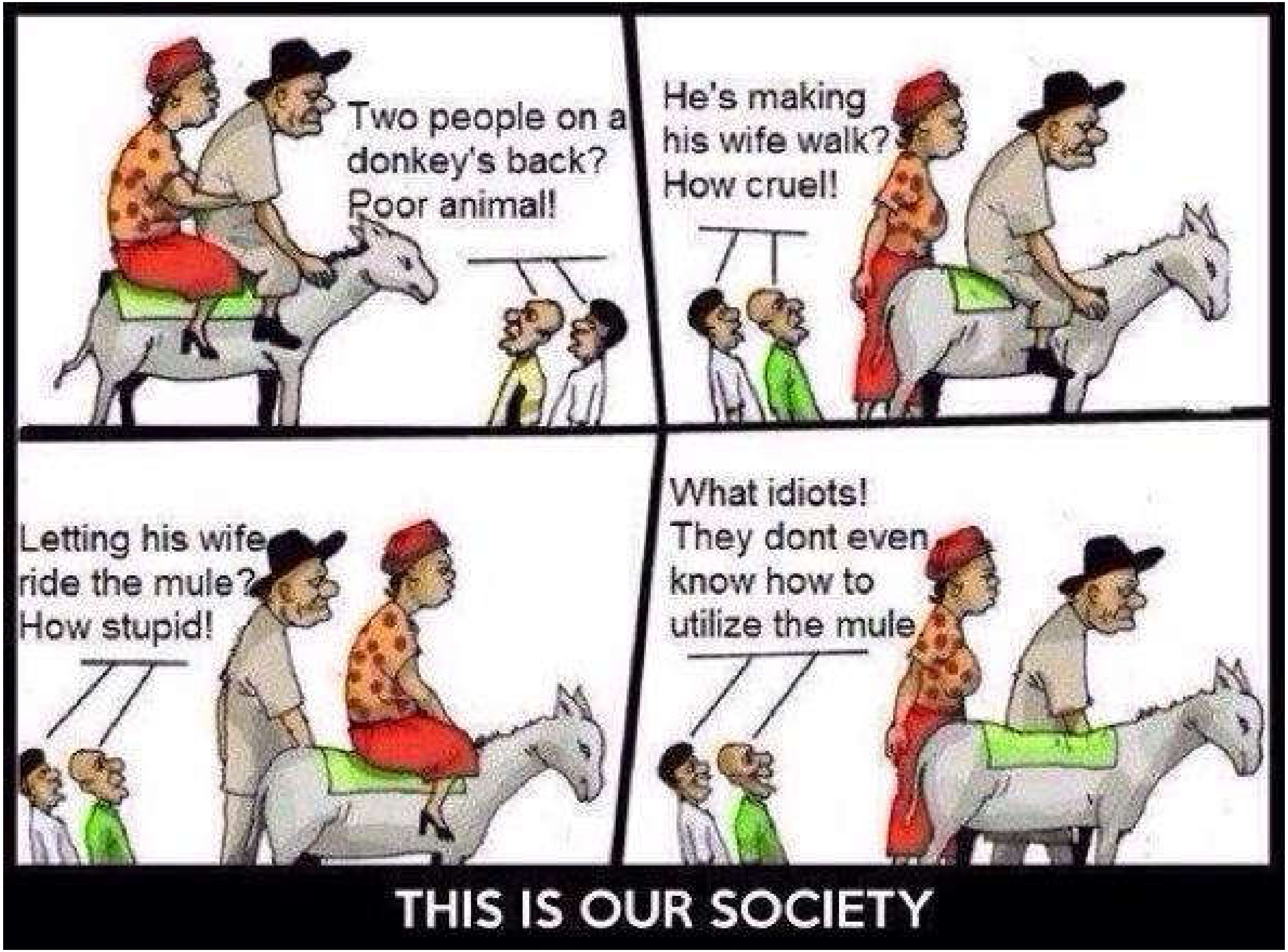
# Concluding Remarks

- Foundations are the most important components of structures, hence, should be handled with care
- Strong foundation on stable base is essential.
- Foundation and the supporting soil should neither fail nor suffer excessive settlement.
- Other geotechnical structures such as earthen dams, roads, canals, embankments, slopes, retaining walls require importance.

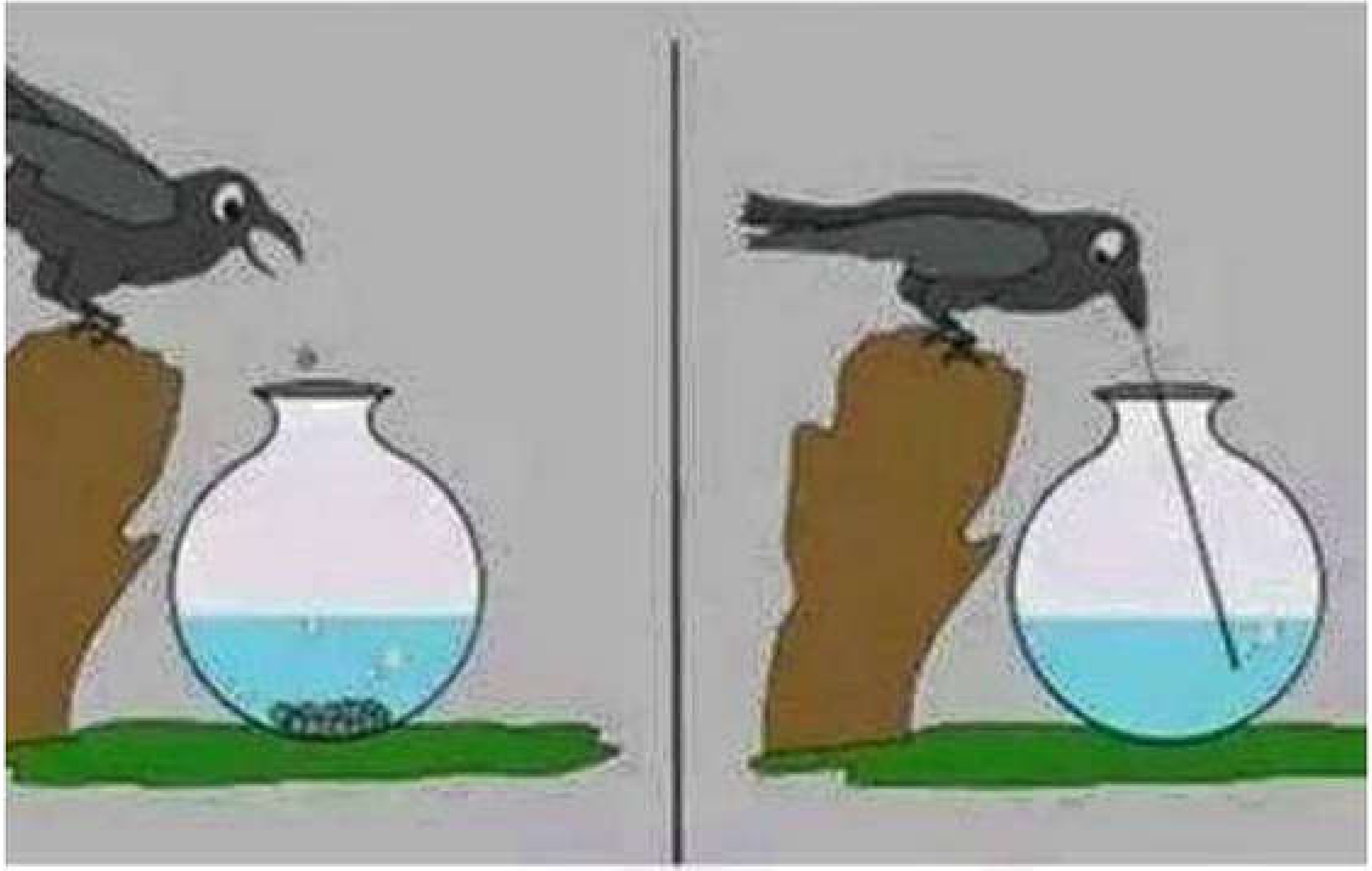
# Concluding Remarks

- Embankments and earth dams are most complete geotechnical structures involving problems of bearing capacity, settlement, slope stability, seepage etc.
- Strong foundation on stable base is essential. At the same time, suitable soil from borrow area should be used with proper compaction for fill material.
- Reasonable factor of safety of 1.5 is desirable against overturning, sliding and other factors.

# You do anything, people do not recognize, they even criticize. Do those things which bring you pride



Old crow. Modern crow.



**Keep upgrading your skills.**

# Thank You