Ground Improvement Technology

Why Ground improvement?

1. Increases shear strength
2. Reduces permeability, and
3. Reduces compressibility

Understanding Ground Improvement

- Ground improvement includes two parts.

1. First Understand the ground
2. Then find out the most engineered[1] solution for improvement

[1]. Engineered means most economical , safe and ease of simplicity to adopt

Methods for Soil Improvement?

Ground Reinforcement

- Stone Columns
- Soil Nails
- Deep Soil Nailing
- Micro piles (Mini-piles)
- Jet Grouting
- Ground Anchors
- Geosynthetics
- Fiber Reinforcement

Ground Improvement

- Deep Dynamic Compaction
- Drainage/Surcharge
- Compaction grouting
- Surface Compaction

Ground Treatment

- Soil Cement
- Lime Admixtures
- Fly ash
- Dewatering

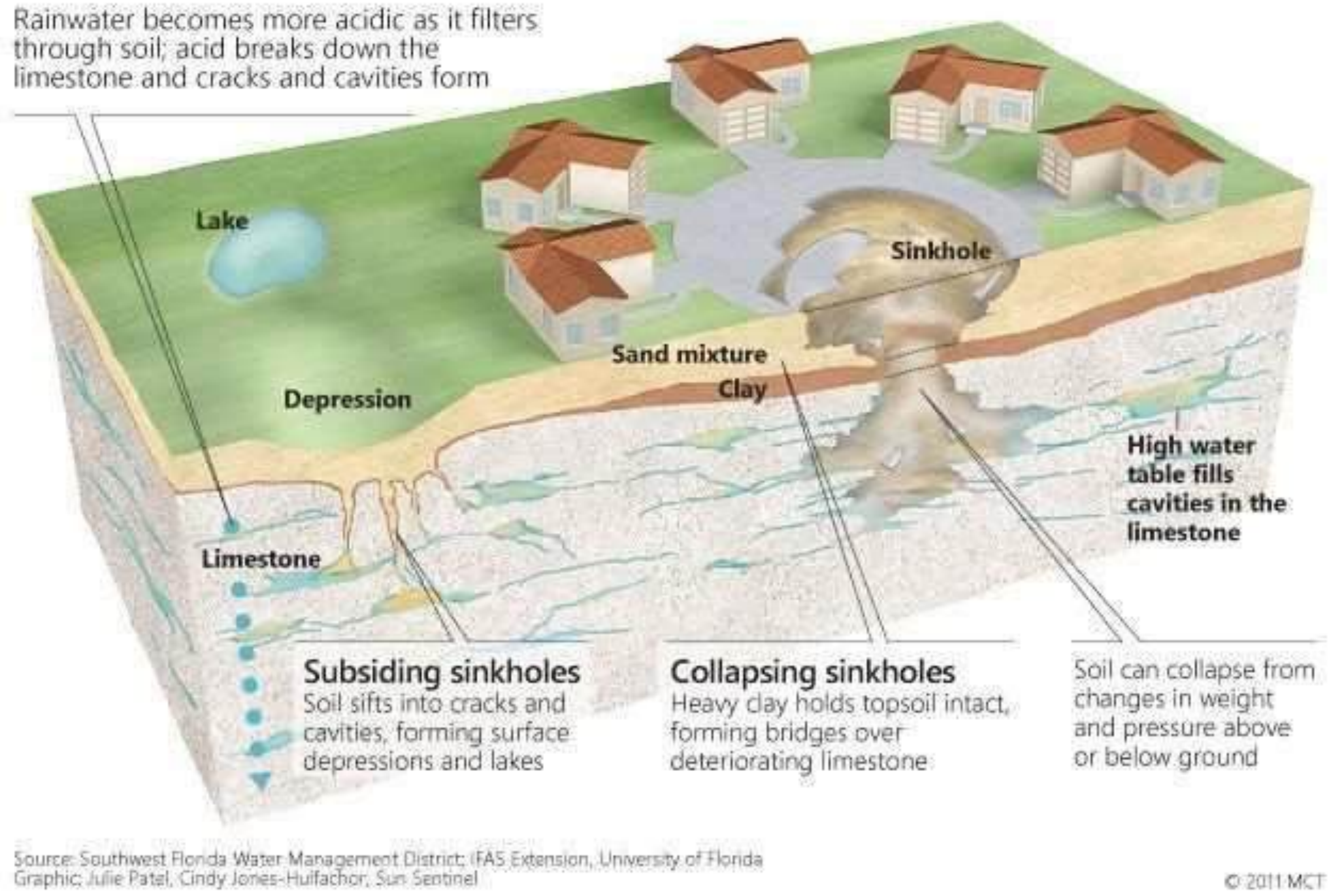
Tilting of structure : Overturning

Leaning temple dome, Huma, Orissa, India

A building at the Lotus Riverside complex in Shanghai’s Minhang district collapsed

Sink Holes

Formation of Sink Holes



Rain Water

↓

Acidic Water

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Lime stones

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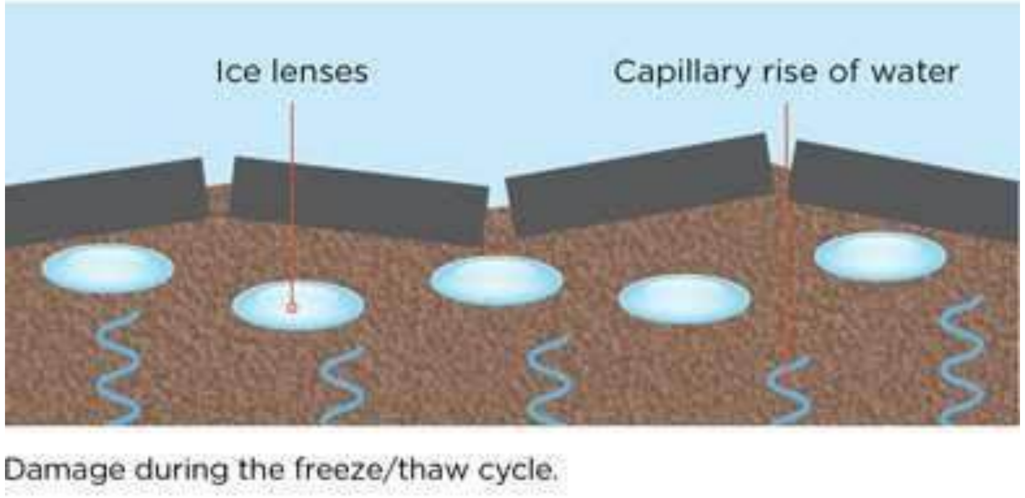
Formation of Sink Holes

Frost heave

Thawed Soil
Coalesced Ice-Rich Soil
15 cm
Needle Ice



Ice lenses
Capillary rise of water
Damage during the freeze/thaw cycle.

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Overturned apartment complex, Niigata 1964

Why we study geotechnical Structure Failure?

- Because we want engineered design of geotechnical structures.
- Engineered means

✓ Economical

✓ Safe

✓ Durable

✓ Strong

List of ground improvement techniques

Ground Improvement

- Deep Dynamic Compaction
- Drainage/Surcharge
- Electro-osmosis
- Compaction grouting
- Blasting
- Surface Compaction
- Ground Freezing

Basic Operations:
Increasing soil Density
Removing Air Voids, Pore water
Changing soil water properties

List of ground improvement techniques

Ground Treatment

- Soil Cement
- Lime Admixtures
- Fly ash
- Soil Mixing
- Deep Soil Mixing

Basic Operations:
Changing soil Properties by Adding Soil, fly ash, slag, cement Chemicals (admixtures) etc.

It means that the modified property represents the property of mixture and not soil as an Independent element

List of ground improvement techniques

Ground Reinforcement

- Stone Columns
- Soil Nails
- Deep Soil Nailing
- Micro piles (Mini-piles)
- Jet Grouting
- Geosynthetics
- Fiber Reinforcement
- Lime Columns
- Vibro-Concrete Column
- Mechanically Stabilized Earth

Basic Operations:

Soil and Reinforcing material act as a structure in which reinforcing elements takes majority of load

Ground Improvement

Field Compaction

Equipment

Smooth-wheel roller (drum)

- 100% coverage under the wheel
- Can be used on all soil types except for rocky soils.
- The most common use of large smooth wheel rollers is for proof-rolling subgrades and compacting asphalt pavement.

- Now a days Vertical vibrator is also attached to smooth wheel rollers.

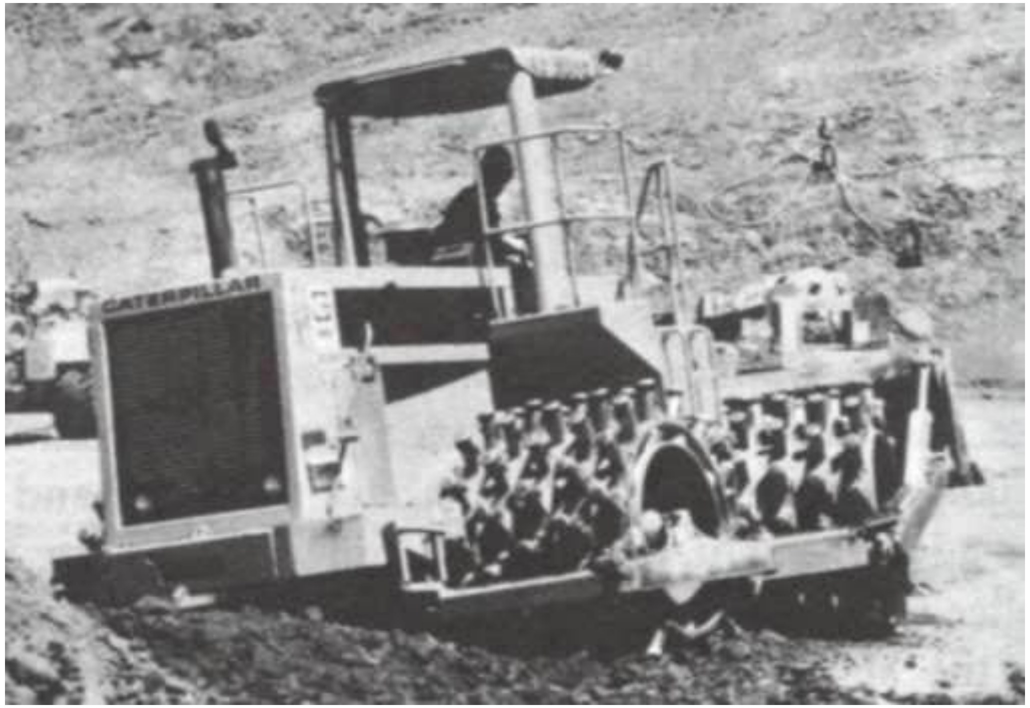
Equipment (Cont.)

Pneumatic (or rubber-tired) roller

- 80% coverage under the wheel
- Can be used for both granular and fine-grained soils.
- Can be used for highway fills or earth dam construction.

Equipment (Cont.)

Sheepsfoot rollers



- Has many round or rectangular shaped protrusions or “feet” attached to a steel drum
- 8% ~ 12 % coverage
- It is best suited for clayed soils.

Equipment (Cont.)

Tamping foot roller

- About 40% coverage
- It is best for compacting fine-grained soils (silt and clay).

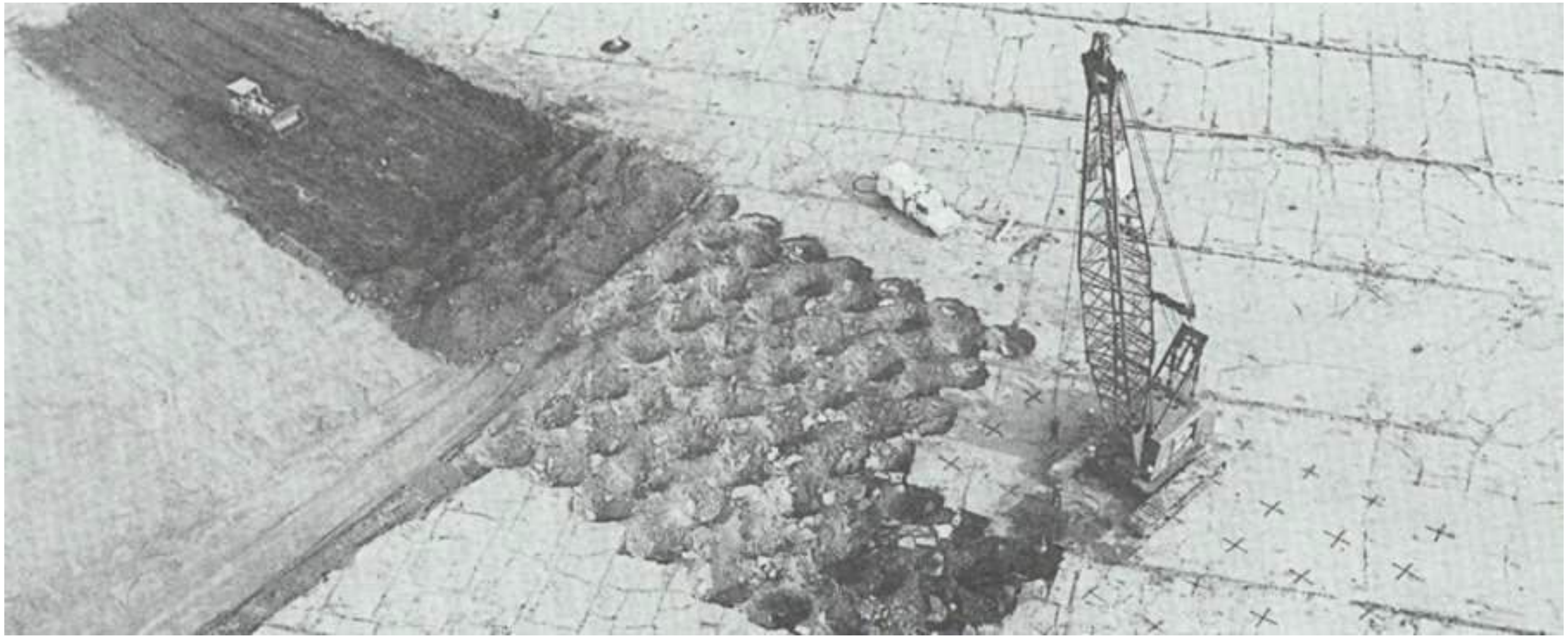
Dynamic Compaction

- When
  - Existing surface or near-surface soil is poor with regard to foundation support
- For which soil?
  - Both cohesive and cohesionless soils
- How
  - Drop a very heavy (2~20 tons) weight onto the soil from a relatively great height (20 ~ 100 ft)
  - Dropping weight randomly? → a closely spaced grid pattern is selected.

Dynamic Compaction

Dynamic compaction was first used in Germany in the mid-1930’s.

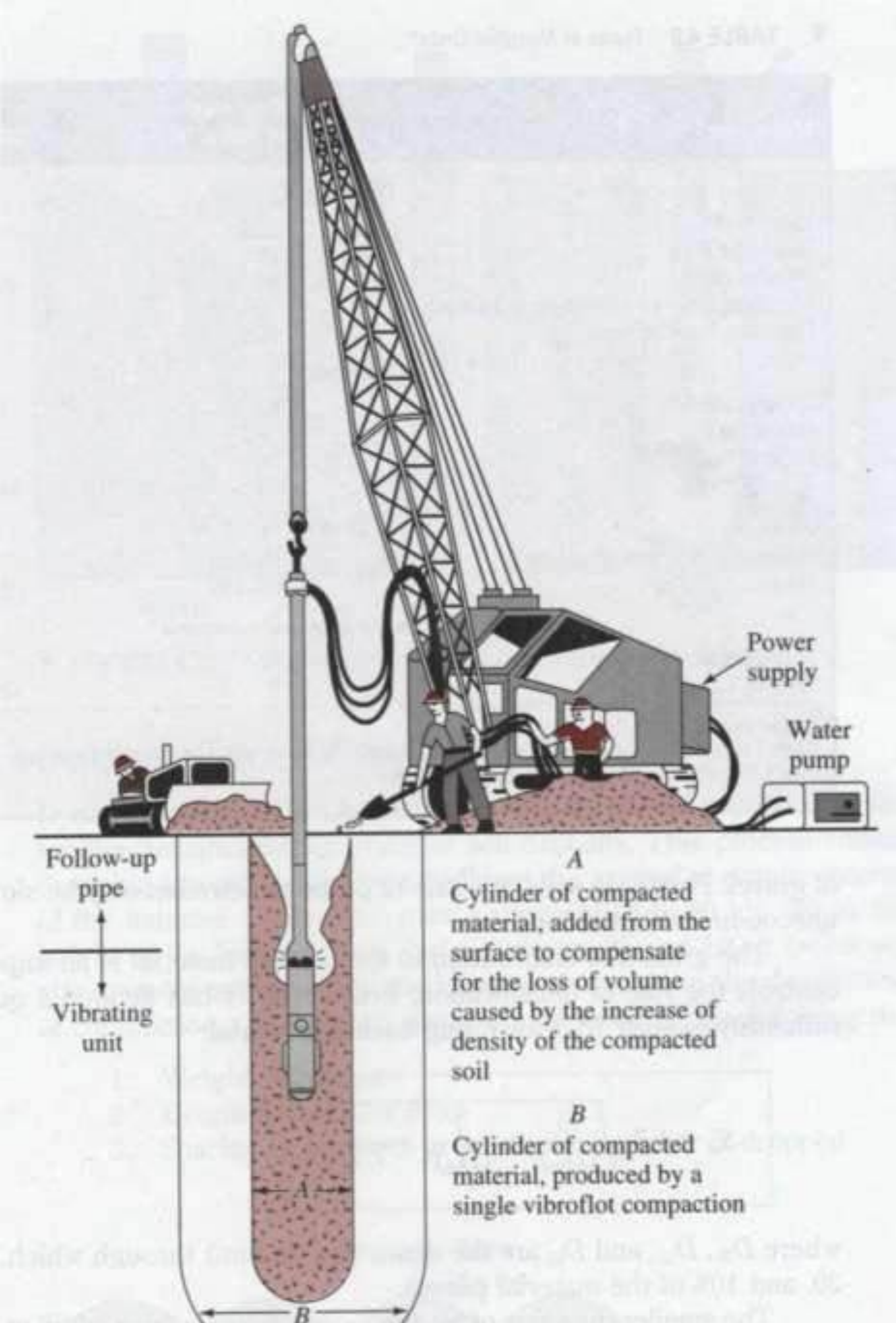
Dynamic Compaction



Vibro-Compaction

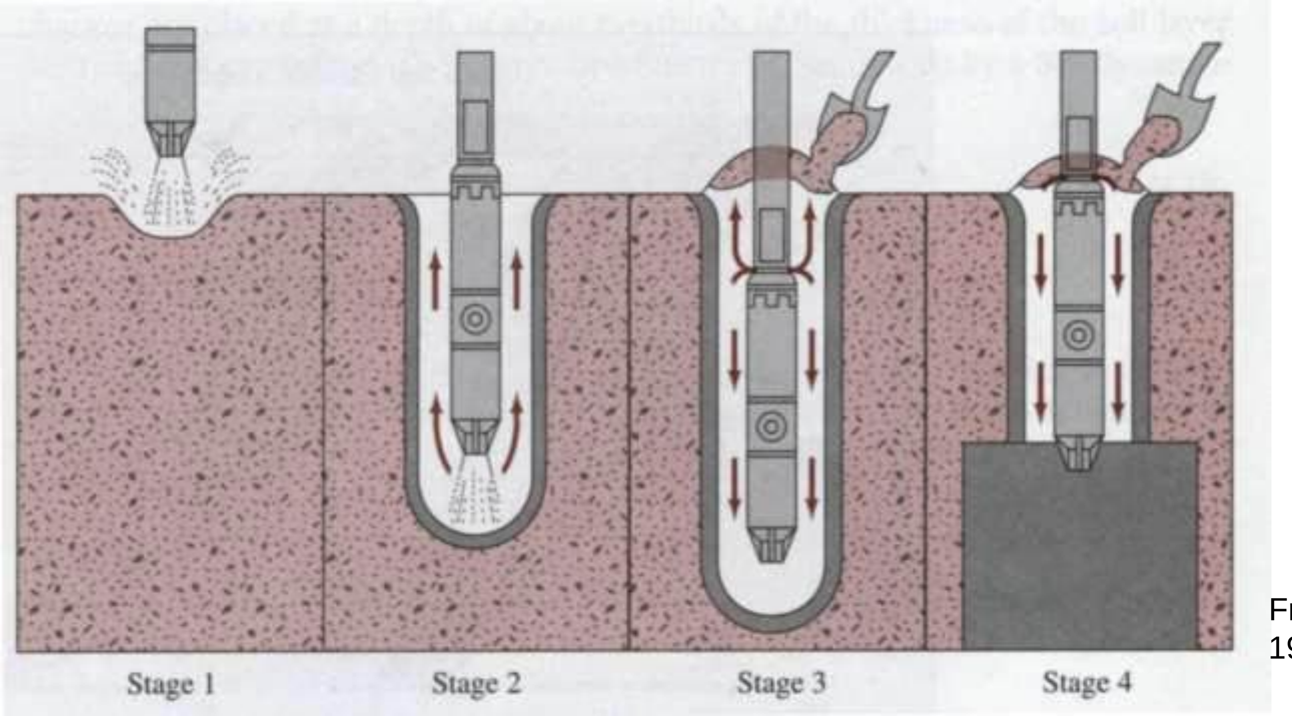
Vibroflotation

Vibroflotation is a technique for in situ densification of thick layers of loose granular soil deposits.
It was developed in Germany in the 1930s.



From Das, 1998

Vibroflotation-Procedures



From Das, 1998

Stage1: The jet at the bottom of the Vibroflot is turned on and lowered into the ground

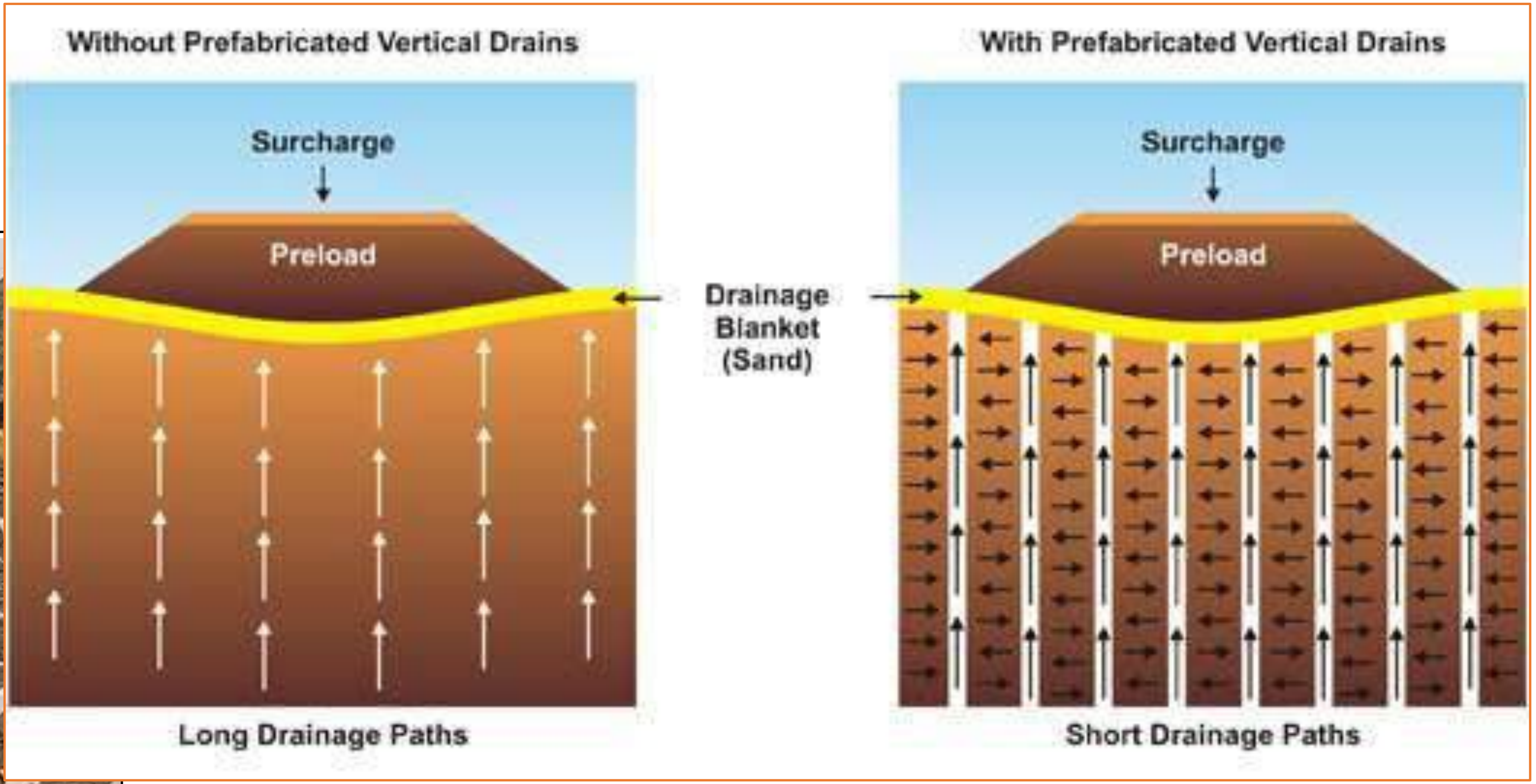
Stage2: The water jet creates a quick condition in the soil. It allows the vibrating unit to sink into the ground

Stage 3: Granular material is poured from the top of the hole. The water from the lower jet is transferred to the jet at the top of the vibrating unit. This water carries the granular material down the hole

Stage 4: The vibrating unit is gradually raised in about 0.3-m lifts and held vibrating for about 30 seconds at each lift. This process compacts the soil to the desired unit weight.

Pre-loading: Vertical Drains

Prefabricated Vertical Drains (PVDs) are composed of a plastic core encased by a geotextile for the purpose of ***expediting consolidation of slow draining soils.***


Without Prefabricated Vertical Drains
With Prefabricated Vertical Drains
Surcharge
Preload
Drainage
Blanket
(Sand)
Surcharge
Preload
Long Drainage Paths
Short Drainage Paths

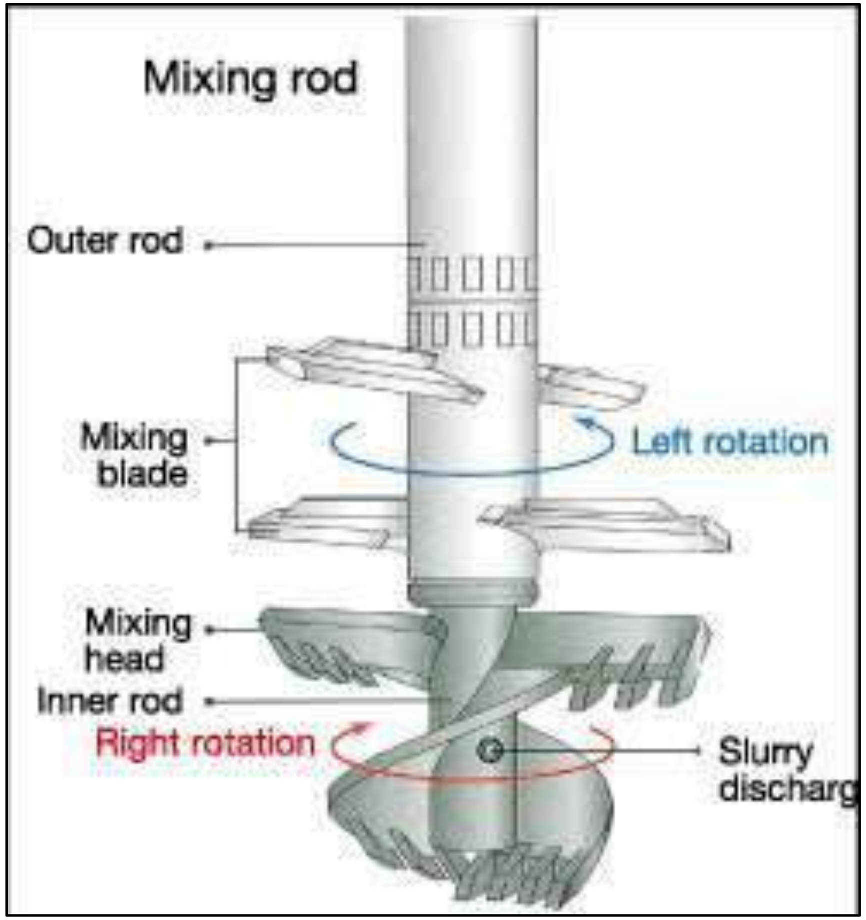
Ground Treatment

Soil-Cement stabilization

Stabilization using cement and other admixtures such as fly ash, blast furnace slag has been adopted in many geotechnical and highway engineering projects.

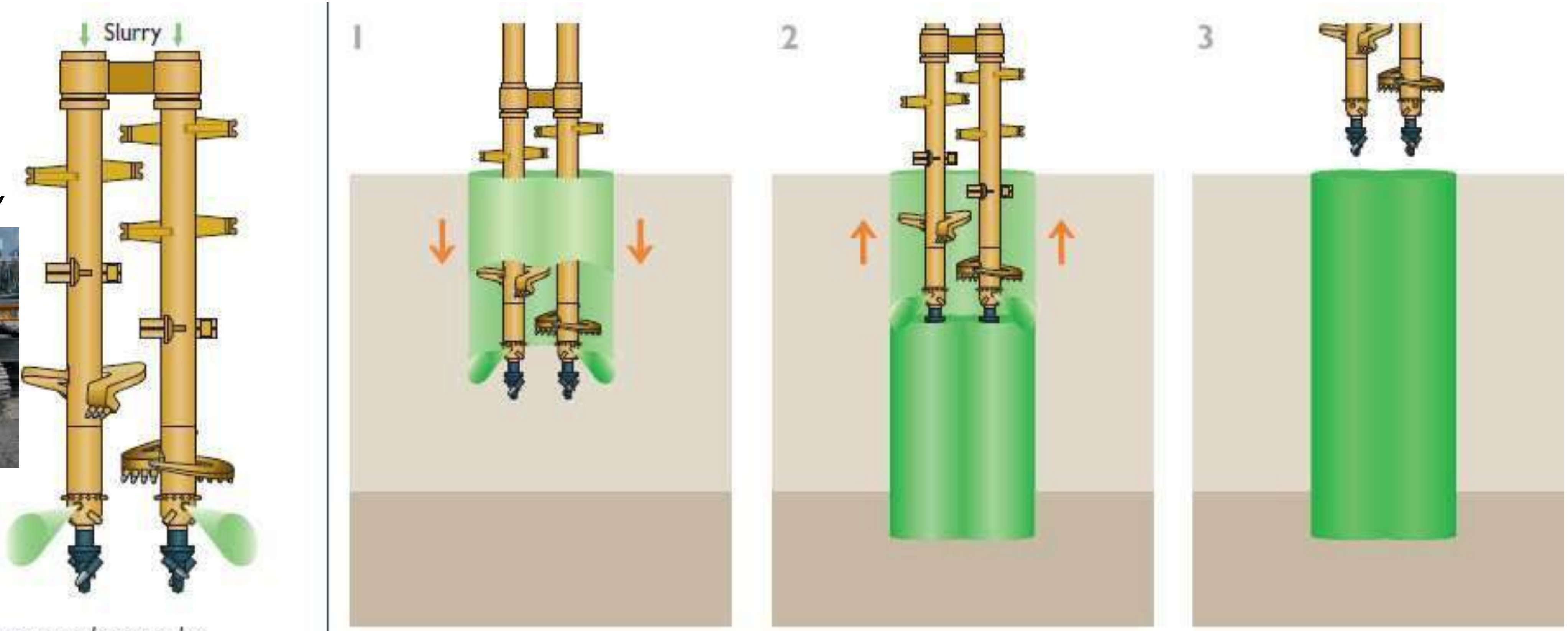
Soil Mixing & Deep Soil Mixing

Mixing tools used for different soils



Process of deep soil Mixing

Ejection of slurry

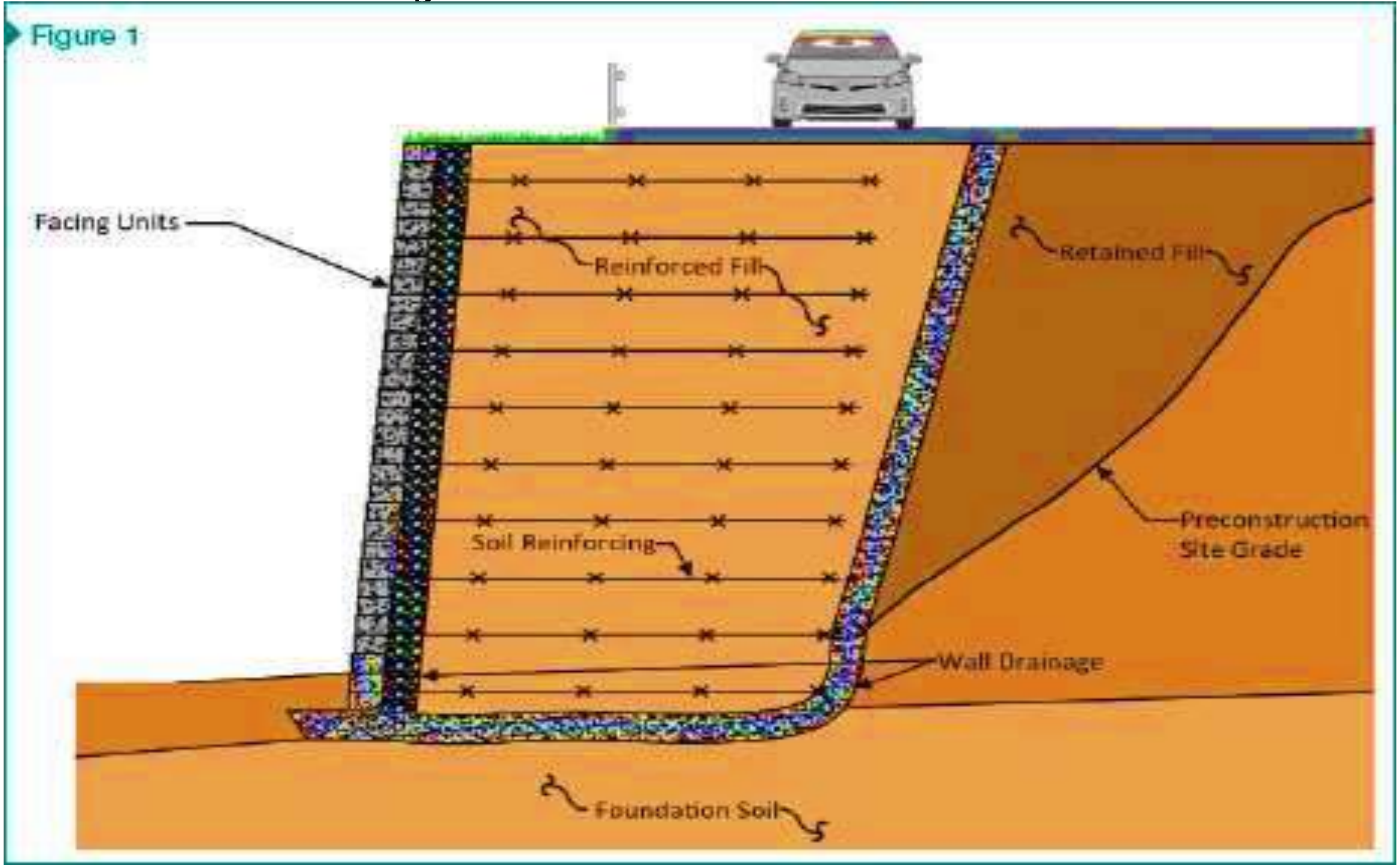


Slurry nozzles can be located at the main rod or along mixing blades

Slurry can be injected during the penetration and withdrawal phases, with an intensity depending on soil conditions

Ground Reinforcement

Mechanically Stabilized Soil

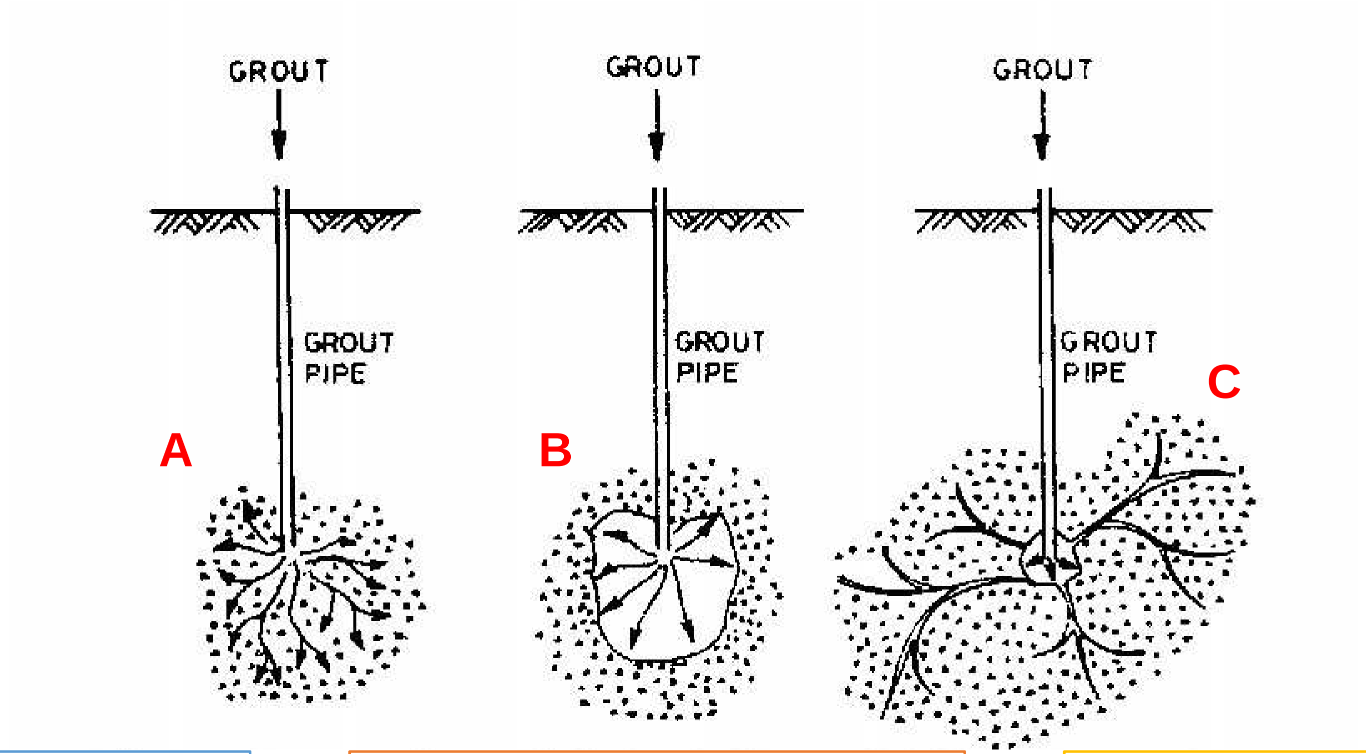


Elevated Highway,

Grouting

- Injection of a slurry or a liquid solution into a soil or rock formation
- The grout subsequently hardens - increases the strength and decreases compressibility and permeability.

MODES OF GROUTING



A. *Penetration-* Grout flows into soil voids freely with minimal effect

B. *Compaction or Controlled displacement-* Grout remains more or less intact as a mass

C. *Hydraulic Fracturing or Uncontrolled displacement-* Grout rapidly penetrates into a fractured zone created when the grout pressure is greater

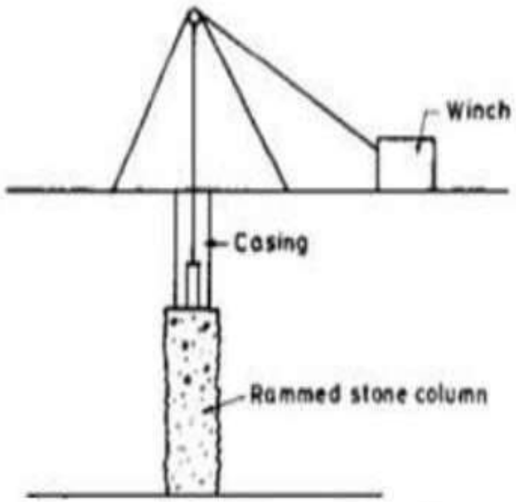
Stone Column

❖A ground improvement technique to improve the load bearing capacity and reduce the settlement of the soil

❖Stone column consists of crushed coarse aggregates of various sizes

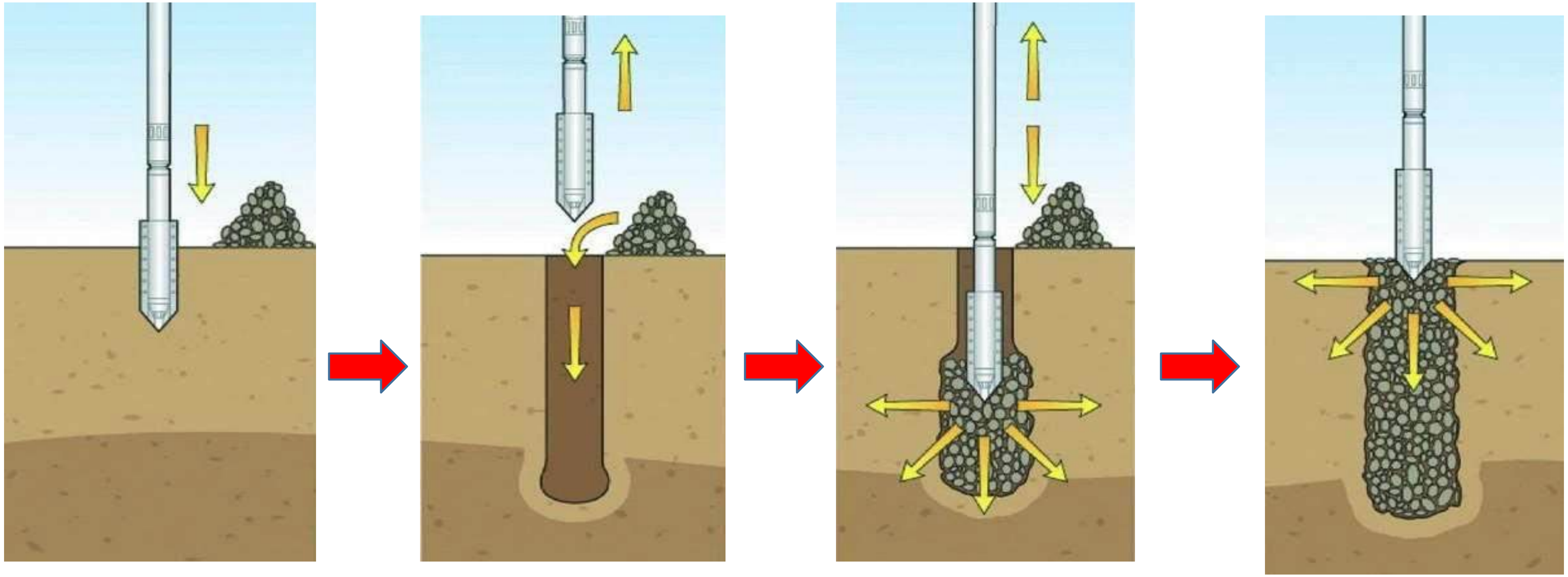
INSTALLATION TECHNIQUES

- **BORED RAMMED SYSTEM**



- **VIBRO REPLACEMENT METHOD**

Procedure



Penetration

Stone Feeding

Compaction

Finishing


STAY
CLEAR

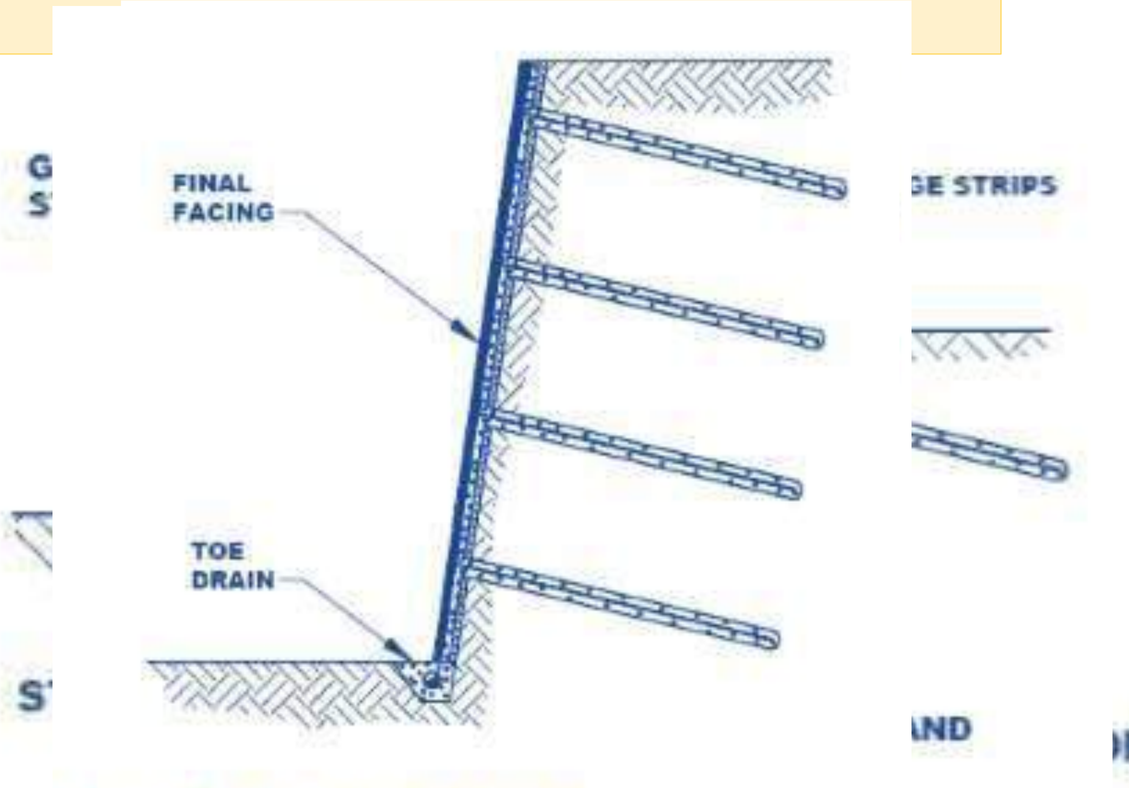
Soil nailing

INTRODUCTION

- Soil nailing is the method of reinforcing the soil with steel bars or other material.

CONSTRUCTION SEQUENCE

- *Excavation of Slope*
- *Drilling Nail Holes*
- *Nail Installation and Grouting*
- *Construction of Temporary Shotcrete Facing*
- *Construction of Subsequent Level*
- *Construction of a Final, Permanent Facing*



STEP 6. PLACE FINAL FACING ON PERMANENT WALLS (INCLUDES BUILDING OF TOE DRAIN)

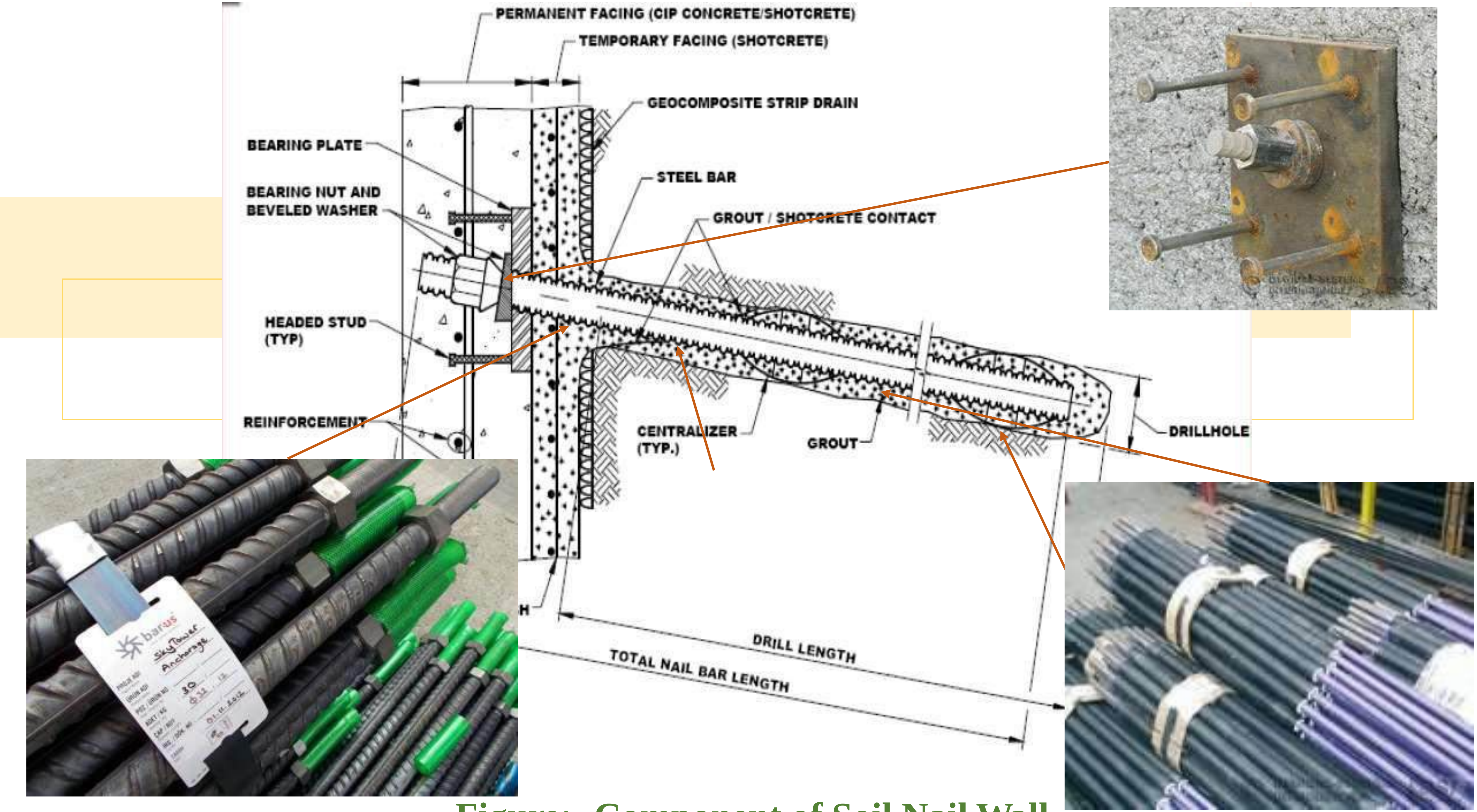


Figure:- Component of Soil Nail Wall

Gabions

What are Gabions?

- The term gabion refers to a modular containment system that enables rock, stone or other inert materials to be used as a construction material.

Micro piles

- A micropile is a small-diameter (typically less than 300 mm), drilled and grouted replacement pile that is typically **(up to 20% As/Ac)** reinforced.
- A micropile is constructed by drilling a borehole, placing reinforcement, and grouting the hole.
- Micropiles can withstand axial and/or lateral loads.

Geosynthetics

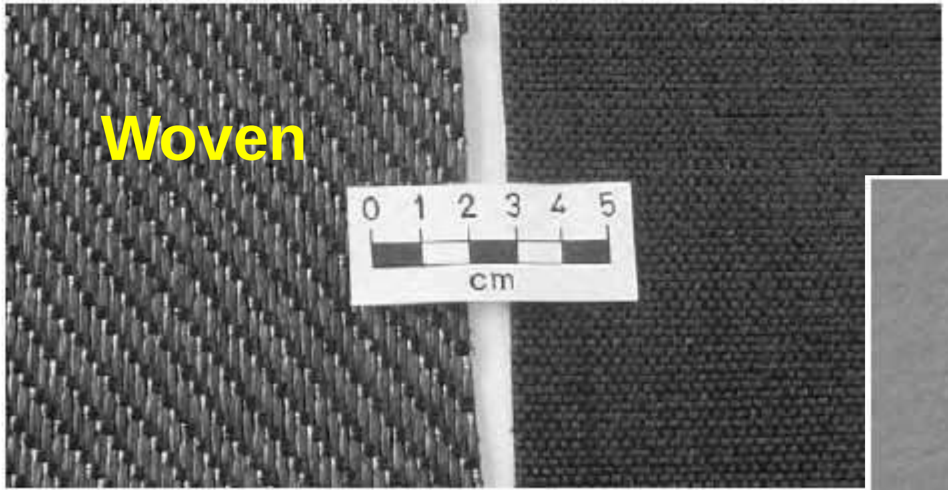
What is a Geosynthetic ?

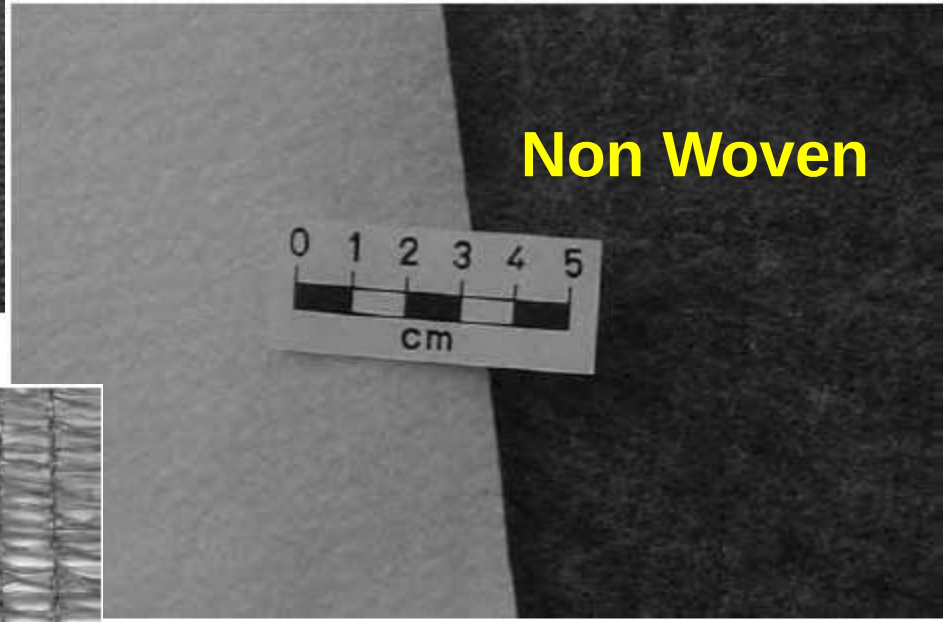
- Natural or artificial product that is used along with soil in geotechnical constructions.
- **Natural:** coir , jute, hemp, etc.
- **Artificial:** polymeric or metallic

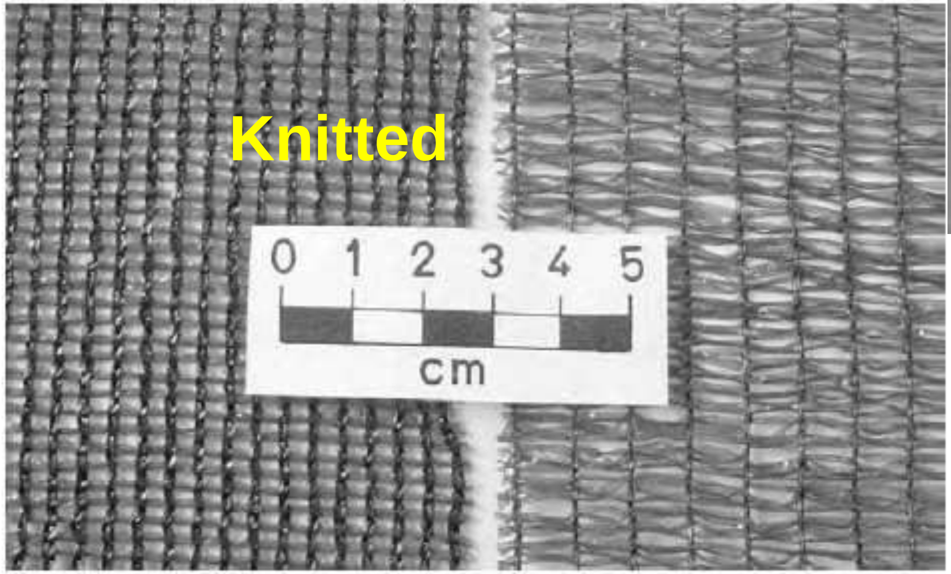
Types of Geo-Materials (Geosynthetics family)

1. Geotextile.
2. Geogrid.
3. Geonet.
4. Geo Membrane
5. GeoComposites
6. Geofoam
7. Geocell
8. Geomat
9. Geomesh
10. Geopipe
11. Geospacer

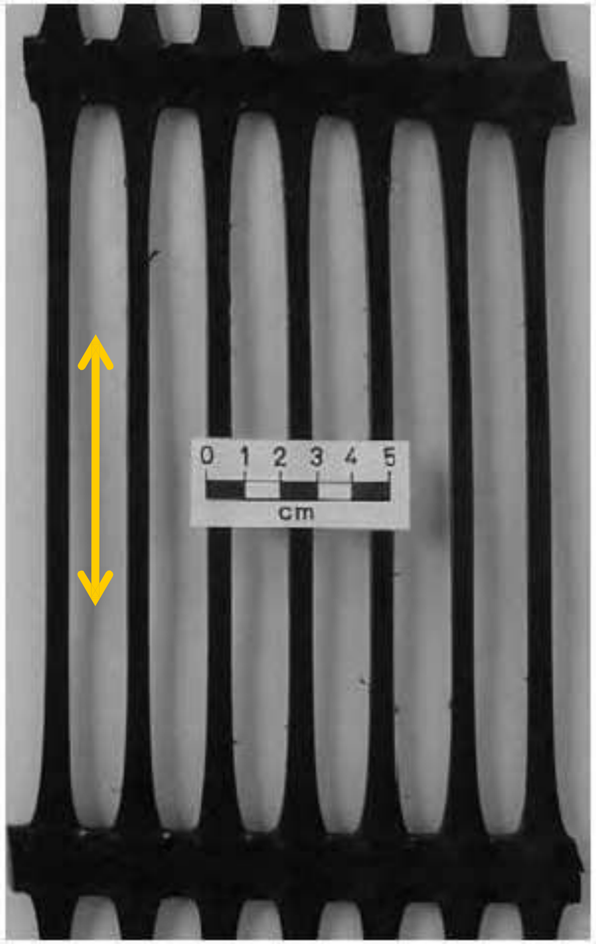
1. Geotextile



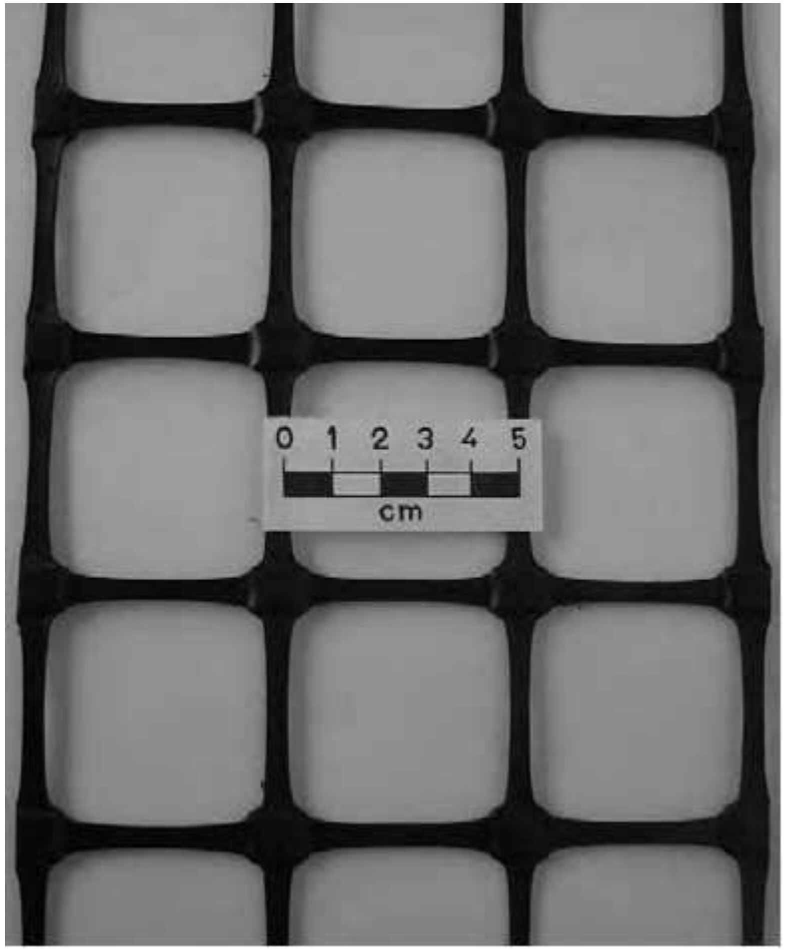




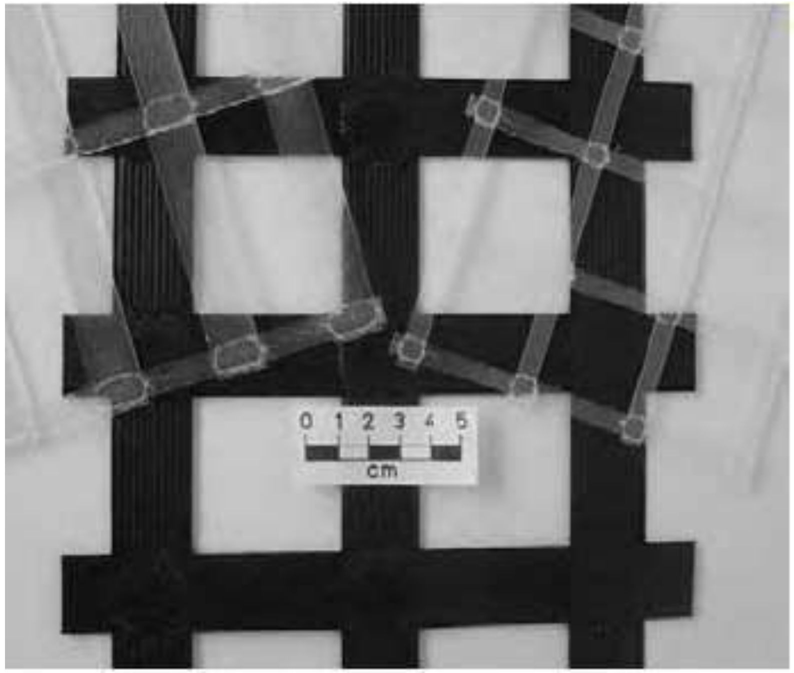
2.Geo Grid



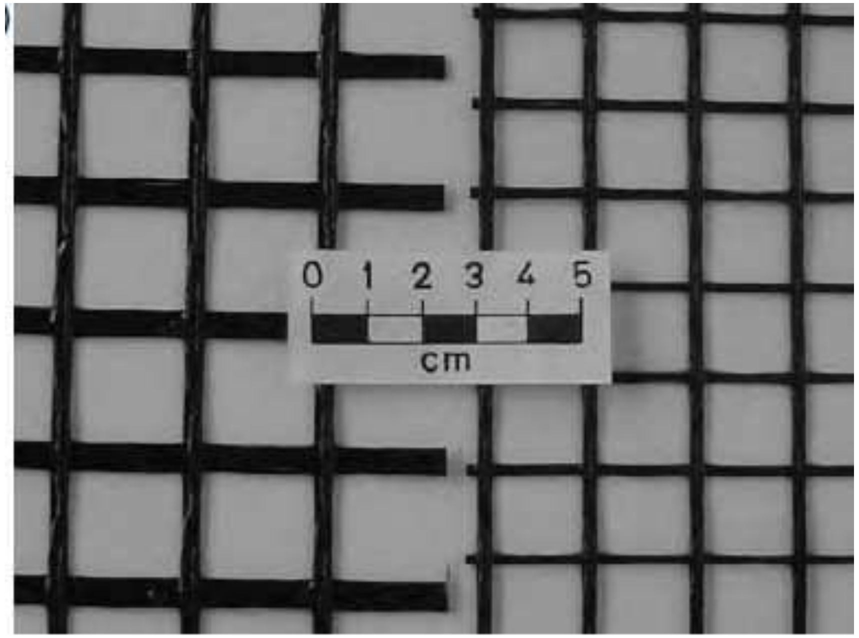
(i) Uniaxial



(ii) Biaxial

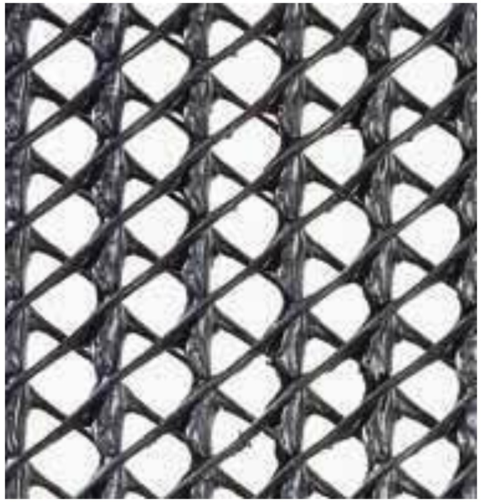


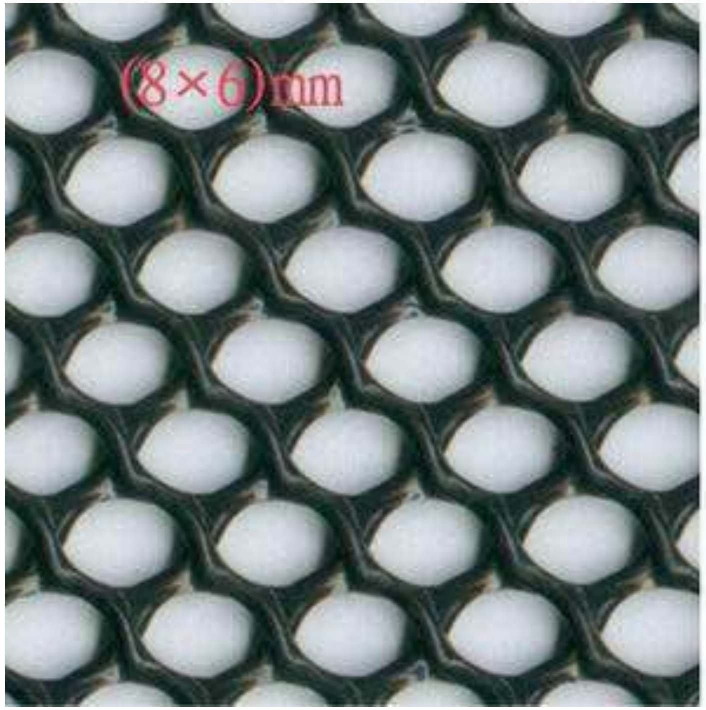
(iii) Bonded



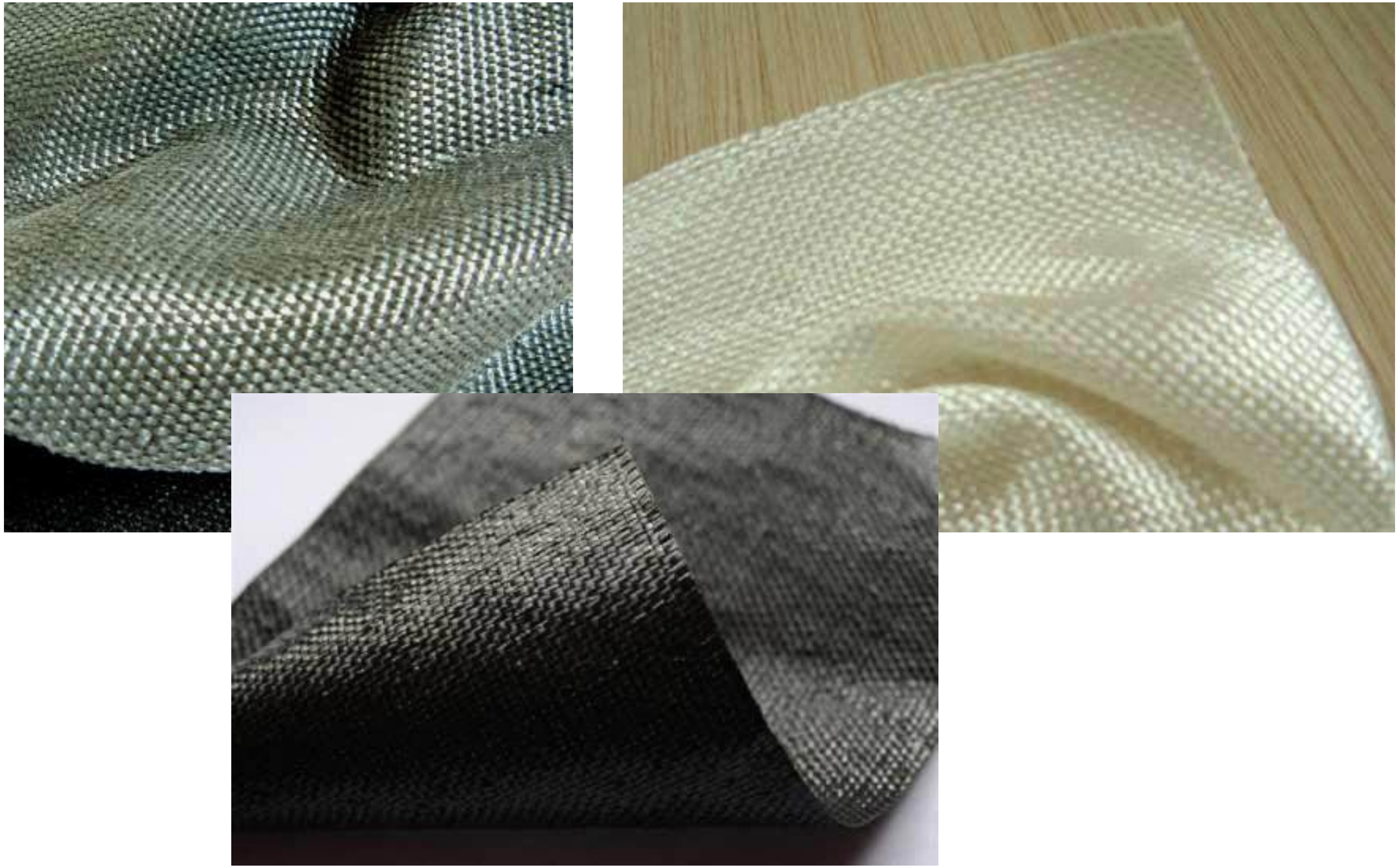
(iv) Woven

3. Geonet.





4. Geo Membrane



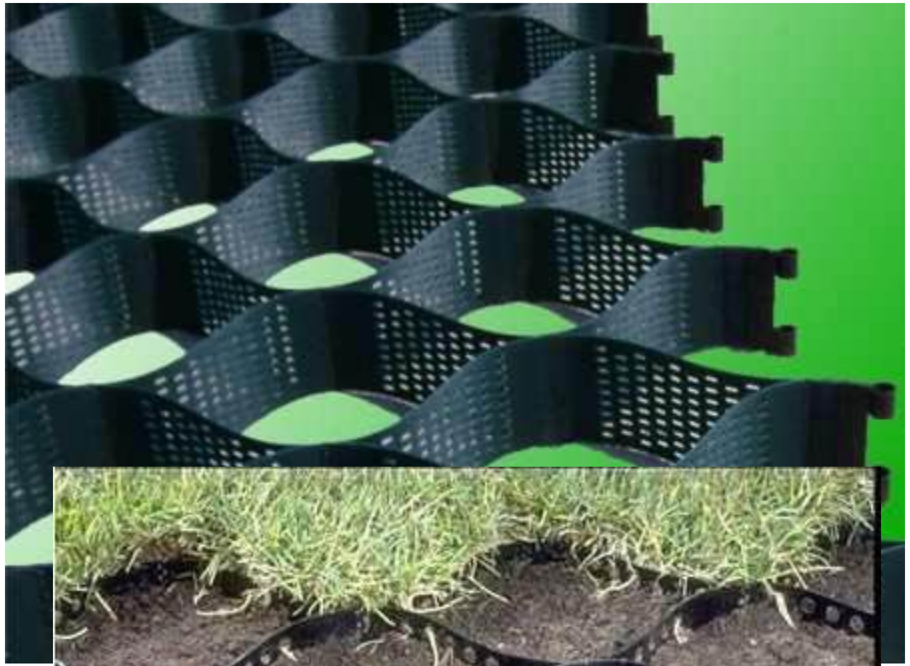
5. Geo-composites

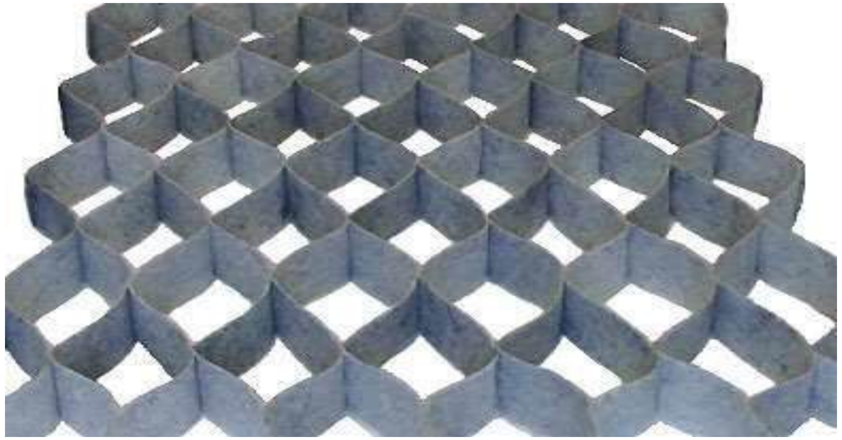
- Combination of one or more type of geosynthetics for modified function.

6. Geofoam

- Foam like material, provided for functions mentioned below:
- Moisture retention.
- Erosion protection.
- Generally gives temporary solution of the problem.

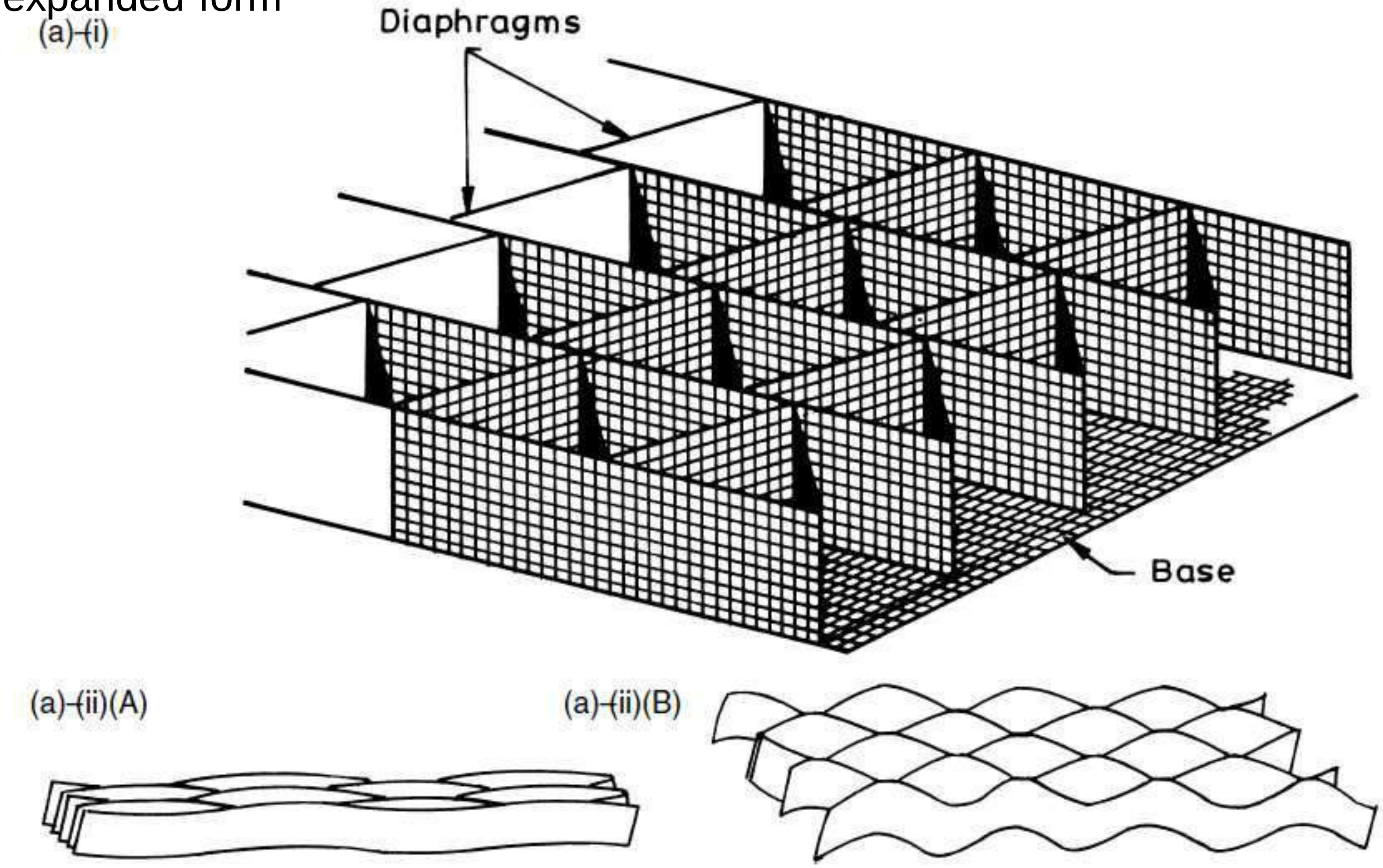
7.Geocell





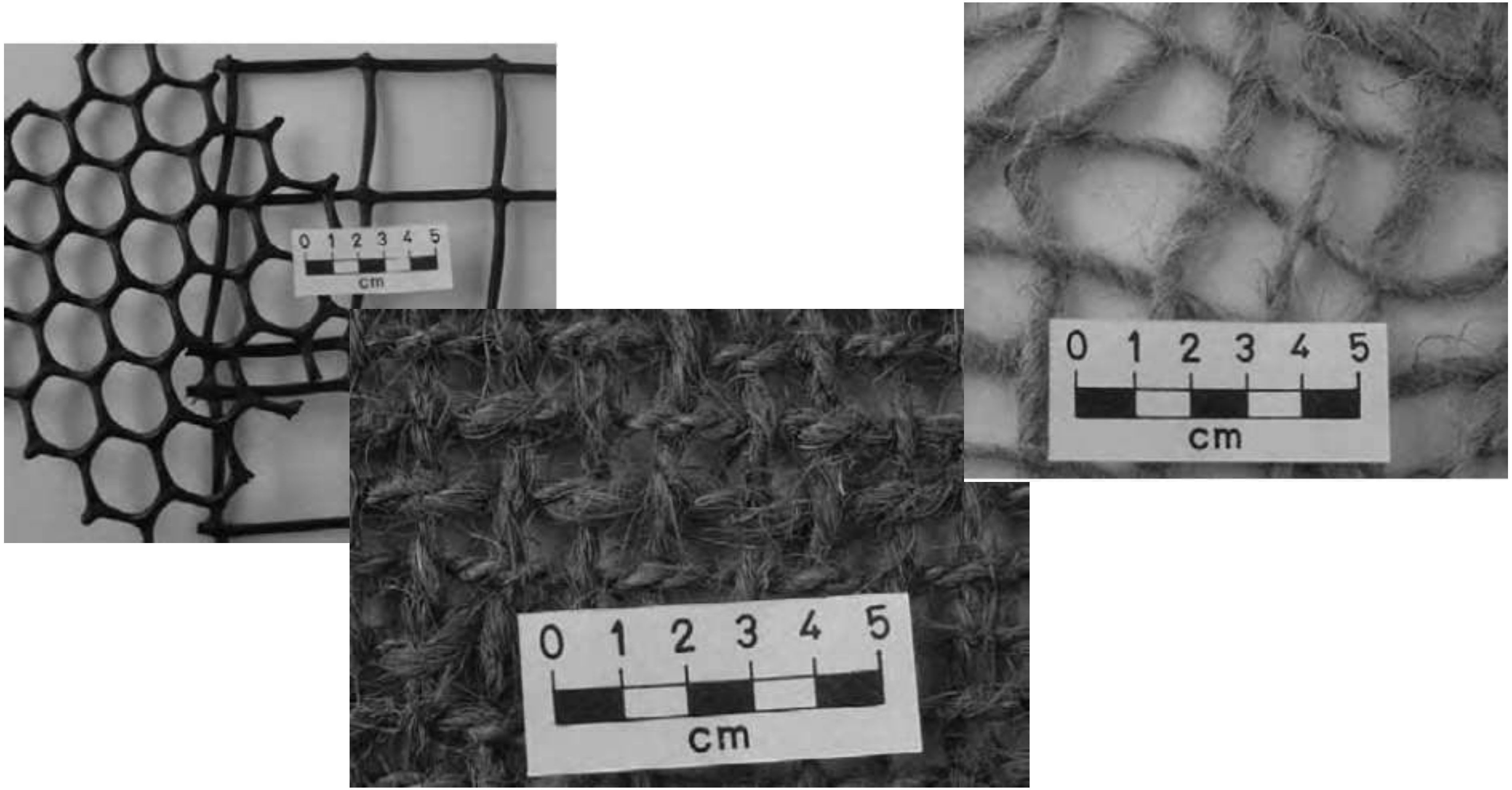
Geo Cell

(a) Geocell – (i) site assembled, (ii) factory produced (A) collapsed form, (B) expanded form



8.Geomat

9.Geomesh



10.Geopipe

Summary of ground improvement Methods

Method	Soil Type	Typical Spacing	Attainable Improvement	Advantages	Limitations	Costs
1) Compaction	All soils	—	Std. density 95+%	Low cost, simple	Equipment – soil compatability, field control	Low
2) Deep Dynamic Compaction (DDC)	Saturated sands and silty sands; partly saturated sands	Square pattern, 2 to 6 m spacing	D_r = 80% $(N_1)_{60}$ = 25 q_{c1} = 10-15 MPa	Low cost, simple	Limited effective depth (10 m), clearance required, vibrations	Low ≈ \$5/m^3
3) Vibrocompaction	Sands, silty sands, gravelly sands < 20% fines	Square or triangular pattern, 1.5 to 3 m spacing	D_r = 80+% $(N_1)_{60}$ = 25 q_{c1} = 10-15 MPa	Proven effectiveness, uniformity with depth Depths ≈ 20 m	Special equipment, unsuitable in cobbles and boulders, ineffective above 3 m	Low to moderate \$1-\$4 / m^3
4) Surcharging and use of prefabricated vertical (PV) Drains (Wick Drains)	Moderately to highly compressible soils; clayey sands, silts, clays and their mixtures	Square or triangular pattern, spacing 1.5 to 6 m	Depends on final consolidation pressure	Proven effectiveness, low cost, simple, computer software	Unsuitable if obstructions exist above compressible layer, time	Drains only \$2-\$4 / lin m.
5) Penetration Grouting	Sands and coarser materials	Triangular pattern, 1 to 2.5 m spacing	Void filling and solidification	No excess pore pressure or liquefaction, can localize treatment area, unlimited depths	High cost, fines prevent use in many soils	Moderate – High \$3-\$30 / m^3
6) Compaction grouting	Any rapidly consolidating, compressible soil including loose sands	Square or triangular pattern, 1 to 4.5 m spacing, with 1.5 to 2 m typical	Up to D_r = 80+% $(N_1)_{60}$ = 25 q_{c1} = 10-15 MPa (Soil type dependent)	Controllable treatment zone, useful in soils with fines	High cost, post-treatment loss of prestress	Moderate – High \$5-\$50/m^3
7) Jet grouting	Any soil; more difficult in highly plastic clays	Depends on application	Solidification of the ground – depends on size, strength and configuration of jetted elements	Controllable treatment zone, useful in soils with fines, slant drilling beneath structures	High cost	High \$200 - \$650 /m

Reference: US corps of army engineers, 1999

Summary of ground improvement Methods

Method	Soil Type	Typical Spacing	Attainable Improvement	Advantages	Limitations	Costs
8) Replacement	All soils	N/A	High density fills to cemented materials	Can design to desired improvement level	Expensive, might require temporary support of existing structures, Depths ≈ 2-3 m	----
9) Admixture Stabilization	Cement – sands and silty sands Lime – clays and clayey sands	N/A	High density fills to cemented materials	Can design to desired improvement level	Results depend on degree of mixing & compaction achieved in field, Depth ≈ 2 m	Low – Moderate ≈\$2-\$4 / m^3
10) MSE Walls	Clean cohesionless backfill	Continuous horizontal geogrids, Metal strips 2-3 m spacings	N/A	Excellent walls, well known computer software	Wall heights 3-15 m, ROW behind wall	\$225 / m^2 wall face
11) Reinforced Slopes	Clean cohesionless backfill	Continuous horizontal geogrids	Slopes up to 2V:1H	Well known computer software	ROW constructing slope erosion protection of face	Moderate – High ≈\$45 / m^3
12) Soil Nailing	Any drillable soil, except very soft clays	1 grouted nail per 1 to 5 m^2, 1 driven nail per 0.25 m^2	Stabilize cut slopes and excavations	Flexible system, can tolerate large movements, highly resistant to dynamic loading, can install with small, mobile equipment, reinforcement is redundant, so weak nail will not cause catastrophic failure, computer software	Excavation or cut slope must remain stable until nails are installed, difficult to construct reliable drainage systems, may require underground easement on adjacent property	Moderate – High \$165-\$ 775/m^2 face

Summary of ground improvement Methods

Method	Soil Type	Typical Spacing	Attainable Improvement	Advantages	Limitations	Costs
13) Stone columns (Vibro-replacement)	Soft, silty or clayey sands, silts, clayey silts	Square or triangular pattern, 1.5 to 3 m center to center column spacing	$(N_1)_{60} = 20$ $q_{c1} = 10\text{-}12$ MPa	Proven effectiveness, drainage, reinforcement, uniformity with depth, bottom feed dry process puts fill where needed	Special equipment, can not use in soil with cobbles and boulders, Depth ≈ 20 m	Moderate $45-$60/m
14) Geogrids	Base course	1 to 2 grids	Reduction of base thickness by ½	Simple, cost effective	Granular base course	Moderate $20 /m^2
15) Light-weight fills	Soft compressible soils	N/A	Elimination of undesirable settlements	Simple	Tire shreds compressible special construction	Moderate - High
16) Deep soil mixing	All soils	Select treatment pattern depending upon application	Depends upon size, strength and configuration of DSM elements	Positive ground reinforcement, high strength	Requires special equipment, Depth ≈ 20 m	High – V. High

Thank You