CHAPTER I : Scope of Engineering Geology

1.1 Definition and Content

Engineering geology forms the bridge between geology and engineering. It is mainly concerned with the application of geology to civil and mining engineering practice. The purpose is to ensure that geological factors affecting the planning, design, construction and maintenance of engineering works, and the development of groundwater resources are recognized, adequately interpreted and presented for use in engineering practice.

تعريف:

الجيولوجيا الهندسية هي الرابط بين المواد الجيولوجية (الصخور والتربة) والاعمال الهندسية والاخذ في الاعتبار العوامل الجيولوجية المؤثرة على (1) التخطيط و (2) التصميم و (3)البناء و (4) الصيانة .

In engineering geology basic knowledge is required of the following **(Figure 1.1)**:

- **Soil mechanics**
- **Hydrology**
- **Foundation engineering**
- **Concrete and roadstone technology**
- **Mining technology**
- **Seismology**

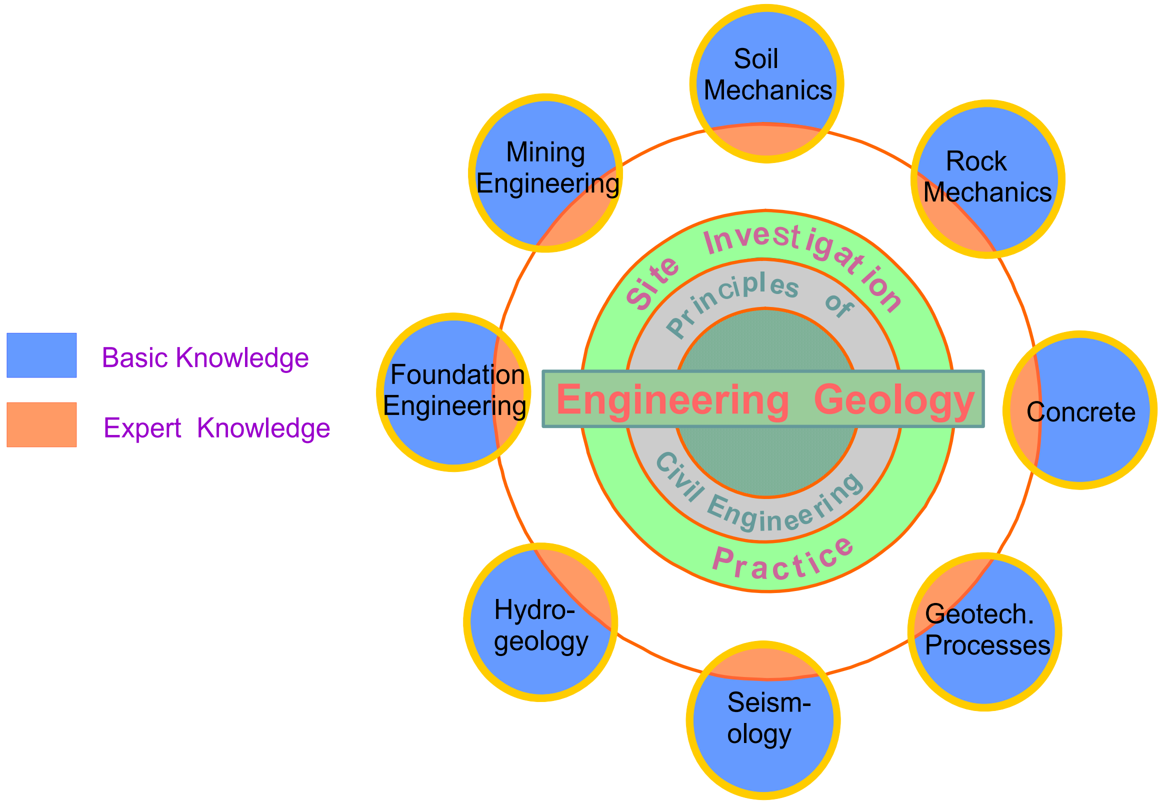

Figure 1.1 : The scope of Engineering Geology

A much greater knowledge is required of site investigation practice such as:

- boring
- engineering geophysics
- sampling
- photogeology
- lab in situ testing
- engineering geological mapping

This knowledge is printed on background of geology with emphasis on structural geology, geomorphology and sedimentology.

1.2 Functions of Engineering Geologist

The engineering geologist can contribute on the followings;

- Interpretation of the ground conditions
- Exploration and assessment
- Identification of hazards

More details are shown in **Figure 1.**2 .

1.3 Geotechnical Approached to a Typical Problem

The role of engineering geologist at different stages of work involve ;

- Boundary conditions ,
- Material,
- Prediction of behavior and
- Assessment of behavior.

His level of understanding of each stage as compared to the engineer is shown in Figure 1.3

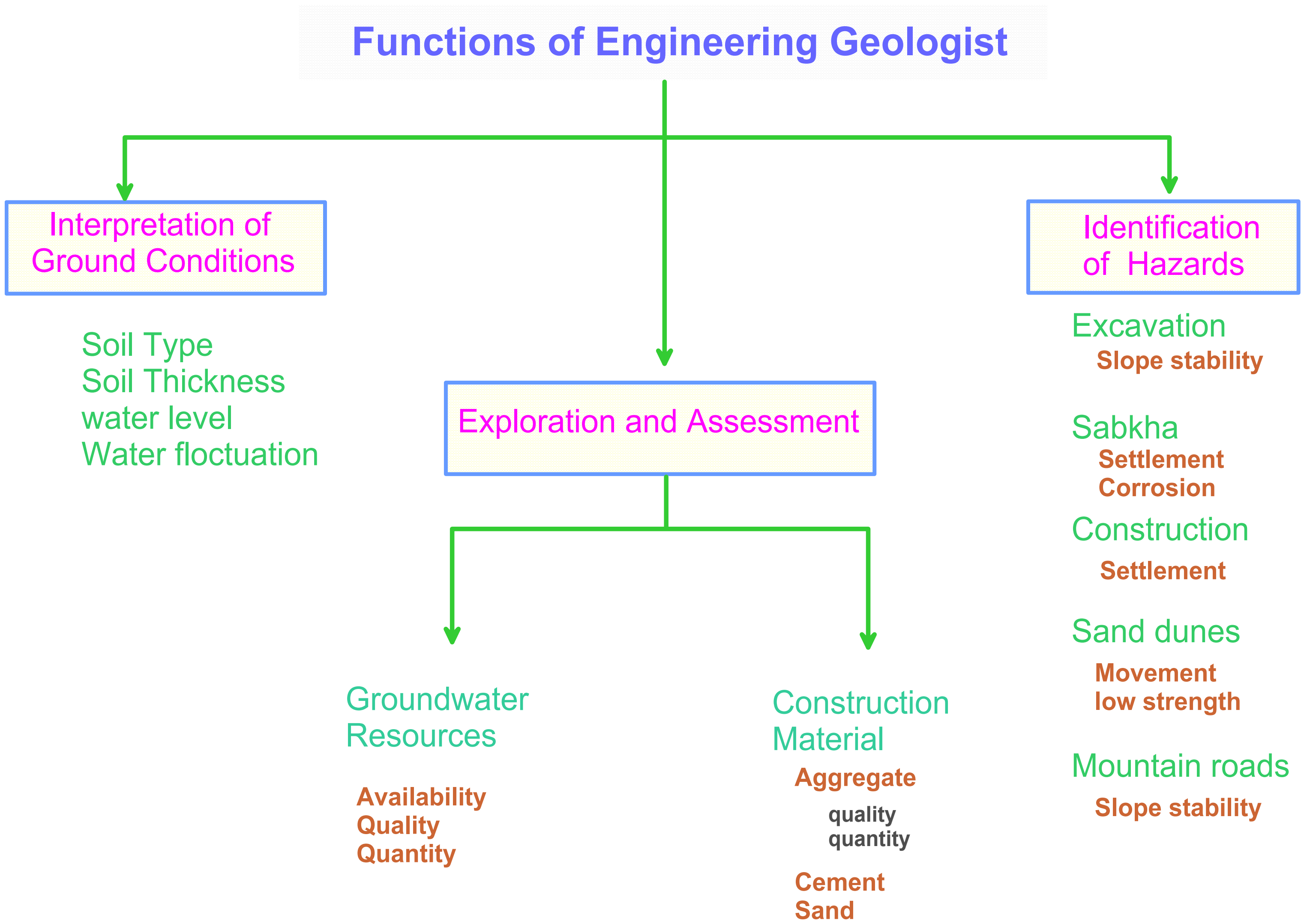
Functions of Engineering Geologist
Interpretation of Ground Conditions
Soil Type
Soil Thickness
water level
Water floctuation
Exploration and Assessment
Groundwater Resources
Availability
Quality
Quantity
Construction Material
Aggregate
quality
quantity
Cement
Sand
Identification of Hazards
Excavation
Slope stability
Sabkha
Settlement
Corrosion
Construction
Settlement
Sand dunes
Movement
low strength
Mountain roads
Slope stability

Figure 1.2

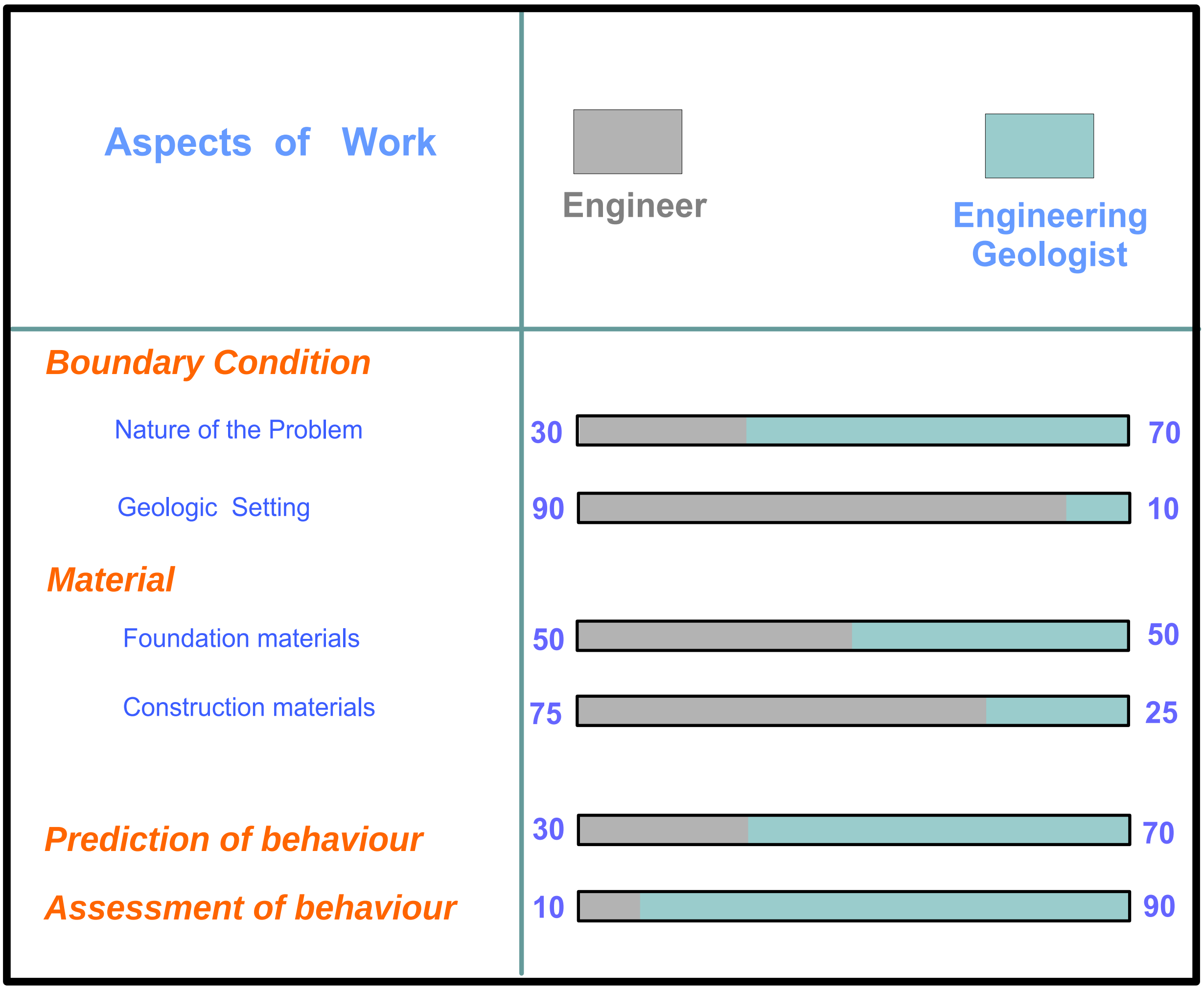

Figure 1.2 : Relative Level of Understanding

2.2.1 Boundary conditions:

a) Nature of problem

- The size and position of the loaded area,
- The magnitude and direction of loading **(Figure 1.4)**,
  - Normal loading
  - Lateral loading
  - Circular loading

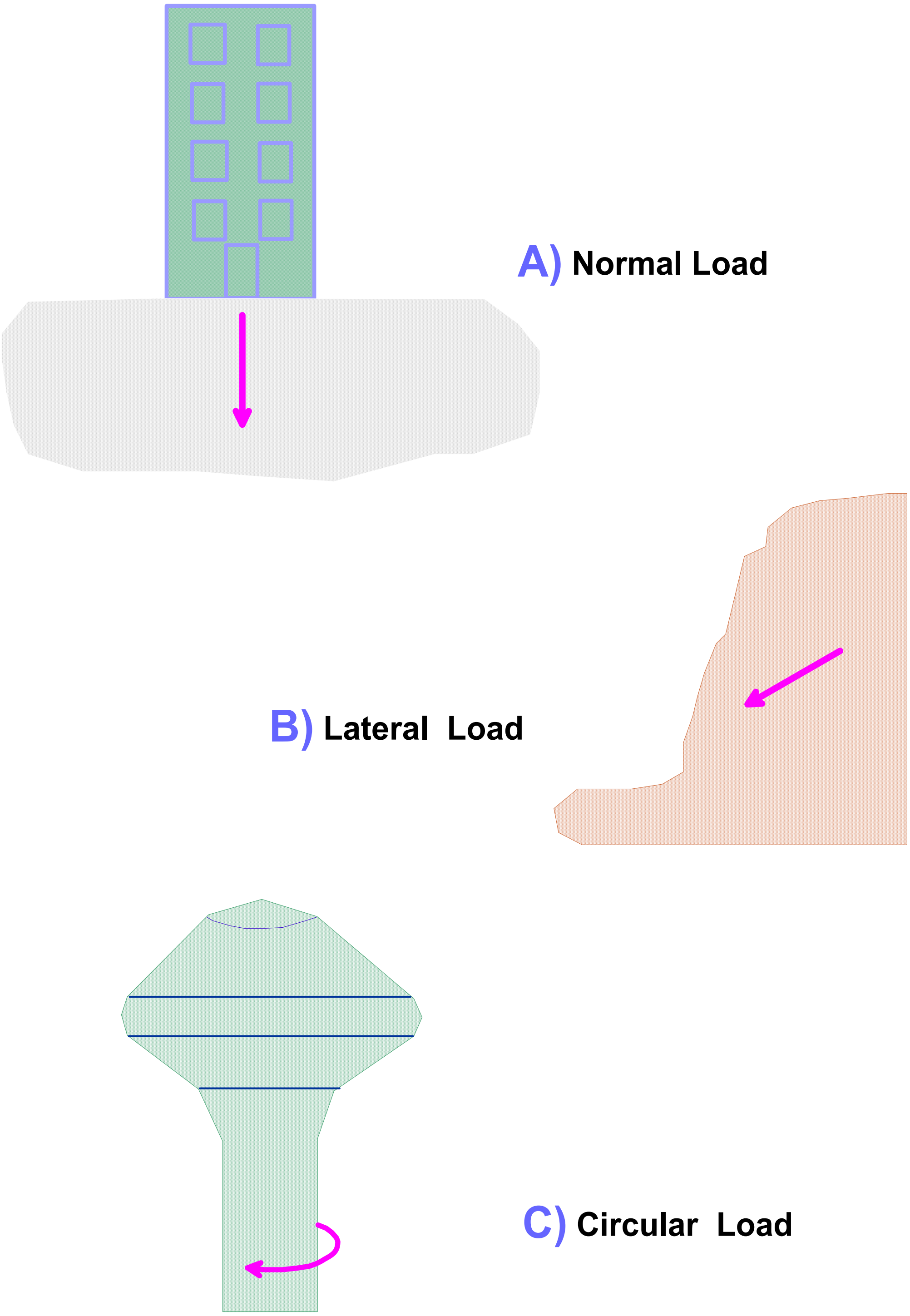

Figure 1.4 : Size, magnitude and direction of loads

b) Geotechnical setting

- Thickness and extent of the various lithological units affecting the structure **(Figure 1.5)**,

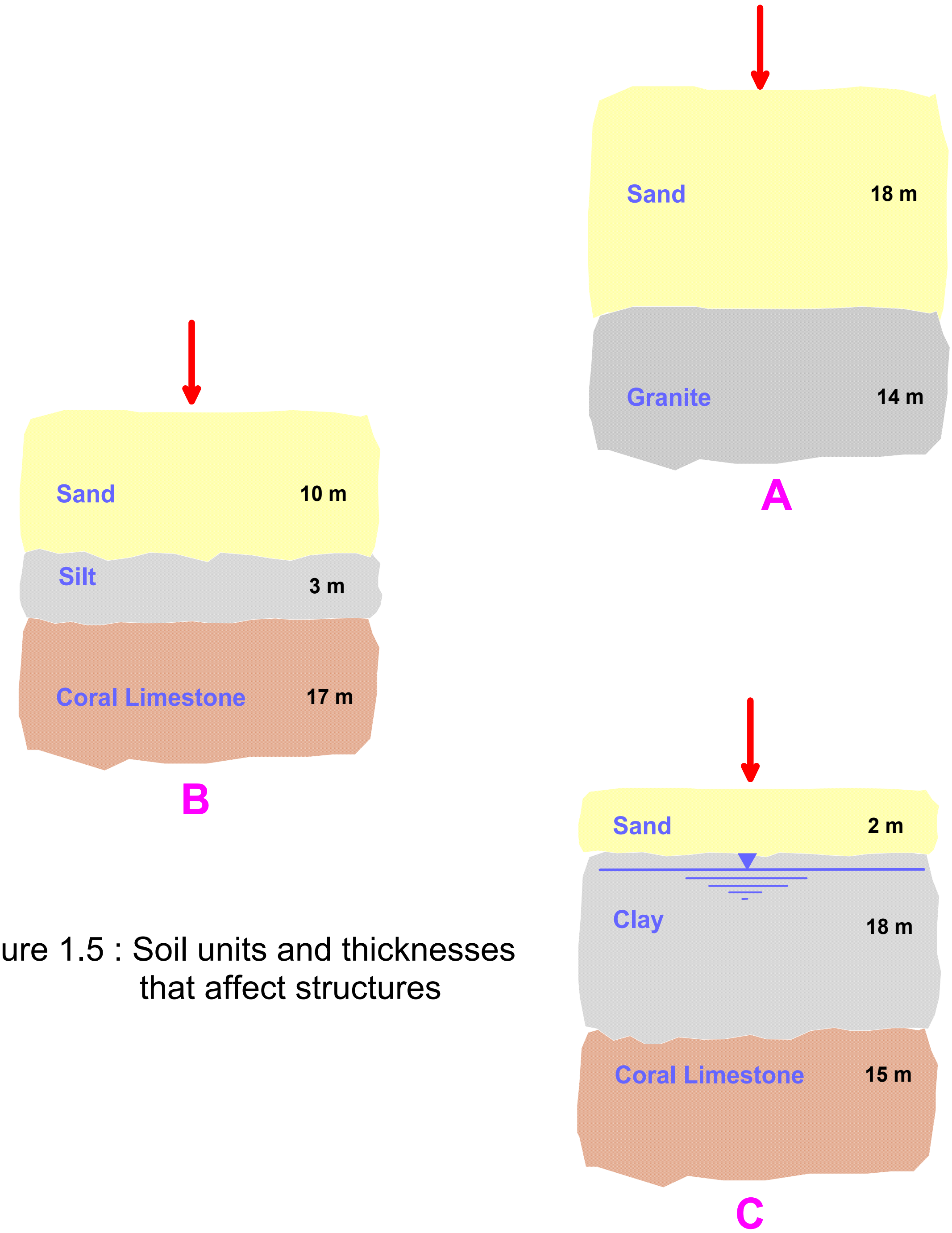

Figure 1.5 : Soil units and thicknesses that affect structures

- Nature and orientation of structure discontinuities affecting execution of works or safety of structure **(Figure 1.6 a & b)**,

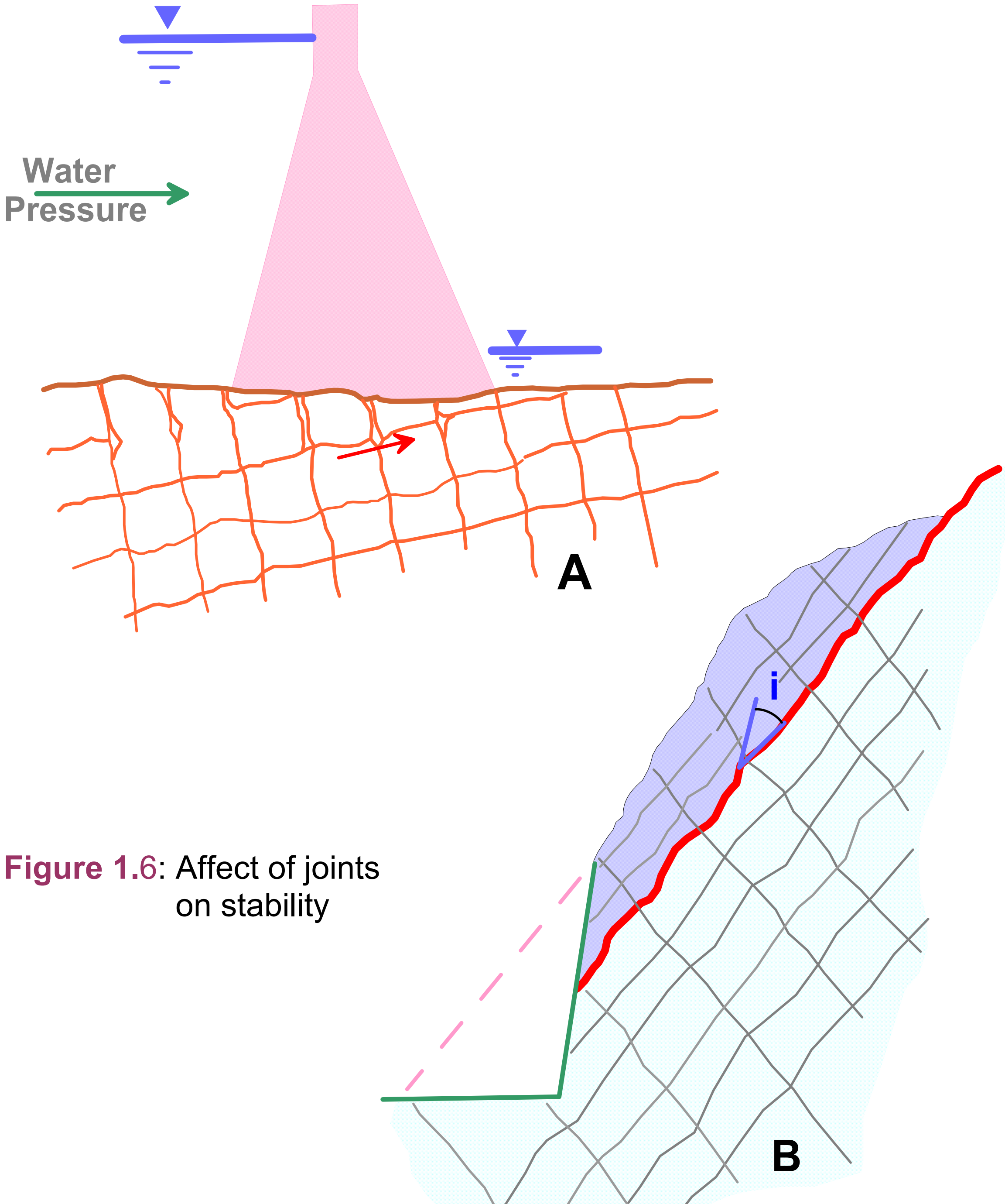

Figure 1.6: Affect of joints on stability

- Hazardous geological processes posing threat to the safety of site or structure.
    - Flood
    - Weathering of slopes
    - Sand movement
    - Earthquakes.

2.2.2 Materials:

a) Foundation materials: Identification and evaluation of those material properties which are relevant to the problem.

- Site investigation
- Lab tests (soil, rock mech.)

b) Construction materials: Accessibility and assessment of quality as well as quantity of geological materials required for construction.

* Distance to the source
* Flat areas vs. rugged one
* Quantity and quality

2.2.3 Prediction of behavior

Understanding of the mechanical behavior of the structure in a given geological setting.

- Tunnel (roof & sides collapse)
- Water fluctuation (swelling, shrinkage of clays)
- Heavy Structure (settlement, tilting)
- Landslides
- Liquafaction

2.2.4 Assessment of behavior:

Assessment of predicted behavior with regard to the specific project requirement.

- Comparison between the ground behavior and the significant of the project.

1.3 Employment Opportunities

Employment for engineering geologists may be found within a wide range of opportunities. Their likely employers will be mainly within the field of civil engineering either as contractors or consultant. In either cases, their work will lie mostly in the field of site investigation. Engineering geologists will also find jobs in applied research organizations, teaching in institutions and ministries of public works, water etc.

CHAPTER II : Engineering Geological Maps

2.1 General Considerations:

2.1.1 Definition: Engineering geological maps provide information about those aspects of geological materials and processes which are significant in land use planning as well as the planning, design and construction of civil and mining engineering work. The task is to develop the country in the best possible harmony with geological environment.

The engineering geological map should be based on a good geological map. The geological maps cannot be used directly in engineering work for the following reasons:

a) Insufficient attention may have been paid to the superficial deposits and rocks of markedly different engineering properties. Part of the problem is that they may be bracketed together as a single unit because they are of the same age or origin.

b) They lack quantitative information such as:
   i. physical properties of rocks and soils,
   ii. the amount and type of discontinuities (faults, joints, shear zones) present
   iii. the extent of weathering
   iv. the groundwater conditions (depth, fluctuation, chemical composition).

2.1.2 Scope

Engineering geological maps are developed due to the cooperation between geologists and engineers in the building of larger engineering works such as tunnel, dams and railways.

The features (components) that could be represented on engineering geological maps are:

a) The character of rocks and soils such as
- distribution
- stratigraphical and structural arrangement
- age and lithology
- physical and mechanical properties.

b) Hydrological conditions: The aim is to predict hydro regime and how to avoid any changes.

- distribution of water-bearing soils and rocks
- depth to water table and its range of fluctuation
- regions of confined water and piezometric levels
- storage coefficients and direction of flow
- infiltration.

c) Geomorphological conditions, including surface topography and important elements of the landscape.

d) Geodynamic phenomena:

- erosion and deposition
- eolian phenomena
- slope movement and subsidence
- volume changes in soil (swelling, shrinkage)
- active faults.

2.2 Classification

Engineering geological maps can be classified according to (i) scale, (ii) purpose or (iii) content.

2.2.1 Scale

a) Large scale: > 1:10,000
b) Medium scale: 1:10,000 – 1:100,000

c) Small scale: < 1:100,000

2.2.2 Purpose

a) Multipurpose: Its information can be used for many purposes either for one or many component of geological environment (ie Strength map).
b) Special purpose maps: The information can be used for special purpose only. (ie. Map for tunnels).

2.2.3 Content

a) Analytical maps: Evaluating and giving details of some parameters. (ie. Weathering grade, joint map, seismic hazard).

b) Comprehensive maps: Maps depicting all principal components of engineering geology environment.

2.3 Description of Soils and Rocks

The Classification of rocks and soils in an engineering geological mapping is according to a certain degree of homogeneity in basic engineering geology properties.

2.3.1 Soil Sample Classification:

The sequence of describing a soil sample is as follows:

a) Compactness or consistency
b) Color
c) Descriptive term
d) Soil identification (Major constituents)
e) Soil identification (Minor constituents)
f) Water content descriptive term.

a) Consistency:_ (stiffness or density)
b) Color: The soil color provide information of soil minerals and environment.
Red: Indicates iron oxide

Pale Yellow: Hydrated iron oxide
Black: Organic soils
Dark brown: or due to dark minerals
Gray: (manganese, magnetite)
Green: Glauconite
White: Silica, gypsum, kaoline clay.

In general use only basic colors. Describe soils with different shades of basic colors by using two basic colors; e.g. gray brown. “Mottled” means marked with spots of color while “streaked” means having color patterns which cannot be considered spotted.

c) Descriptive term:

A. Coarse grained soils

i. Use angular, subangular, rounded shape, rounded etc. to indicate the shape of the grains (**Figure 2.**).

ii. Use coarse medium, fine, coarse to fine, or medium to fine to indicate grain size distribution of the sample.

B. Fine grained soils

Use brittle, friable, spongy, sticky, fissured, slickensided, fibrous, etc. if applicable.

C. Other descriptive terms applicable to both fine grained and coarse grained soils are: with occasional, with frequent, pockets of, layers of, seams of, lenses of, partings of, etc. These will follow the soils identification.

d) Soil identification: (Major constituents)

Identify the major matrix of the soil sample and write this in CAPITAL LETTERS; e.g. GRAVEL, SAND, SILTY, CLAY, or PEAT, **(Table 2.1)**.

Examples:

Sand : Dense, brown, subangular medium grained, trace silt, with pockets of clay.

Gravel : Very dense, gary, angular fine grained, some sand and trace silt, w/seems of clay.

Silty Sand : Medium dense, gray brown, subrounded medium grained with trace gravel and lenses of clay.

Clay : Stiff, dark gray, sticky with some silt.

Table 2.1: Grain Size of Soils

Term	Particle Size	Retained on Sieve No. (Approx. Equivalent)	Equivalent Soil Grade
Very coarse-grained	> 60mm	2 in	Boulders and Cobbles
Coarse-grained	2.60 mm	8	Gravel
Medium-grained	60 mocrons-2mm	200	Sand
Fined-grained	2-60 microns	-	Silt
Very fine-grained	< 2 microns	-	Clay

Note: Grains > 60 microns diameter are available to the naked eye.

e) Soil identification:_ (Minor constituents)
For both fine grained and coarse grained use:

Term	Minor constituent %
"Y"	30 - 50
Some	12 - 30
Trace	1 - 12

Examples

1) SAND, trace fine gravel and some silt; (fine gravel 1-12% , silt 12-30%).
2) SILTY SAND, trace fine gravel ; (fine gravel 1-12% Silt 30-50%).

2.3.2 Rock Classification

The sequence of describing a rock sample is as follows:

a) color
b) grain size
c) strength: See **Table 2.2 a, b, c.**
d) rock identification: identify the rocks using tables in a petrology book. Write the name in CAPITAL LETTERS.
e) Descriptive term

- **Rock mass information**

  - fabric; blocky, tabular or columnar.
  - Block size
  - State of weathering: **Table 2.3**
  - Number of discontinuity sets.

- **Discontinuity data**

  - type: joint, cleavage, schistosity foliation and bedding
  - dip and strike
  - discontinuity spacing: **Table 2.4**
  - aperture: **Table 2.5**
  - infilling: clean, surface staining, non-cohesive, swelling clay, chlorite, talc, or gypsum.
  - roughness: **Figure 2**
  - water content.

Table 2.2 a: Descriptive terms for rock strength (after Deere and Miller, 1966)

Descriptive Terms	Uniaxial Compressive Strength (σ) MPa	Symbols
Very high strength	200	S1
High strength	100-200	S2
Medium strength	50-100	S3
Low strength	25-50	S4
Very low strength	1-25	S5

Table 2.2 b: Rock Material Strength

Term	UCS (σ_c) (MPa)-	Field Estimation of Hardness
Very strong	> 100	Very hard rock-more than one blow of geological hammer required to break the specimen
Strong	50-100	Hard rock-hand held specimen can be broken with single blow of geological hammer.
Moderately Strong	12.5-50	Soft rock-5mm indentations with sharp end of pick.
Moderately Weak	5.0-12.5	Too hard to cut by hand into a triaxial specimen
Weak	1.25-5.0	Very soft rock-material crumbles under firm blows with the sharp end of a geological pick.
Very Weak Rock or Hard Soil	0.60-1.25	Brittle or tough, may be broken in the hand with difficulty.
Very Stiff	0.30-0.60*	Soil can be indented by the finger nail.
Stiff	0.15-0.30	Soil cannot be molded in fingers.
Firm	0.08-0.15	Soil can be molded only by strong pressure of fingers.
Soft	0.04-0.08	Soil easily molded by fingers.
Very Soft	<0.04	Soil exudes between fingers when squeezed in the hand.

* The compressive strengths for soils given above are double the unconfined shear strengths.

Table 2.2 c: Descriptive terms for Rock Quality Designation (after Deere and Miller, 1966)

Descriptive Term	RQD%	Symbols
Very Good	90-100	R1
Good	75-90	R2
Fair	50-75	R3
Poor	25-50	R4
Very Poor	< 25	R5

Table 2.3: Descriptive Terms of State of Weathering (after Geological Society of London, 1977)

Term	Description	Symbol
Fresh	No visible sign of rock material weathering	W1
Slightly Weathered	Discoloration indicates withering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker than in its fresh	W2
Moderately Weathered	Less than half of the rock material is decomposed and/or disintegrated to form soil. Fresh or discolored rock is present either as a continuous framework or as core-stones.	W3
Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil, fresh or discolored rock is present either as a discontinuous framework or as core-stone.	W4
Completely weathered	All rock material is decomposed and/or disintegrated to form soil. The original mass structure is still largely intact.	W5

Table 2.4: Descriptive terms for joint spacing (after Geological Society of London, 1977).

Intervals (cm)	Symbols	Description
200	F1	Extremely wide spaced.
60-200	F2	Widely spaced
20-60	F3	Moderately wide spaced
6-20	F4	Closely spaced
2-6	F5	Very closely spaced
2	F6	Extremely closed spaced

Table 2.5: Aperture of discontinuity surfaces (after geological society of London, 1977)

Term	Aperture (Discontinuities) Thickness (Veins, faults)
Wide	> 200 mm
Moderately wide	60-200 mm
Moderately narrow	20-60 mm
Narrow	6-20 mm
Very narrow	2-6 mm
Extremely narrow	0-2 mm
Tight	Zero

Soil Sample Classification:

The sequence of describing a soil sample is as follows:

g) Compactness or consistency
h) Color
i) Descriptive term
j) Soil identification (Major constituents)
k) Soil identification (Minor constituents)
l) Water content descriptive term.

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E. Fine grained soils

Use brittle, friable, spongy, sticky, fissured, slickensided, fibrous, etc. if applicable.

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Gravel : Very dense, gary, angular fine grained, some sand and trace silt, w/seems of clay.

Silty Sand : Medium dense, gray brown, subrounded medium grained with trace gravel and lenses of clay.

Clay : Stiff, dark gray, sticky with some silt.

CHAPTER III : Engineering Property of Rocks and Soil

3.1 Engineering Geological Problems

3.1.1 Rocks

The engineering geological problems of rocks are influenced by;

- rock type,
- degree of weathering
- rock structure.

Some of the rock engineering problems are shown in Table 3.1**.**

3.1.2 Soil

The engineering geological problems of soil are influenced by;

- Grain size
- Soil gradation
- Mineral type

The soil engineering problems are shown in Table 3.1.

Table 3.1 : Examples of engineering problems

Rock	Soil
.	Sand dunes
Strength	Sand boiling
Tensile strength	Sand piping
Limestone collapse	Landslide
Slope stability	Settlement and tilting
Water leakage	
Earthquake	Expansive soils
Weathering	Collapse soil
Flood	Uplift Pressure
	Ground vibration
	Liquefaction

3.2 Rocks Engineering Properties

Igneous rocks are generally stronger followed by metamorphic then the sedimentary rocks. The jointing is not important in sedimentary but instead the bedding is in control.

3.2.1 Igneous Rocks

The igneous rocks are characterized by high density, durability and strength, and low porosity and permeability. Weathering creates boulders that may roll downhill by earthquake, heavy rainfall, or construction activities. The general engineering properties of the intact rock is shown in Table 1.3.1 .

Table 1.3.1

Rock Type	Density t/m^3	Porosity (%)	UCS MPa	E GPa	Tensile strength MPa	Shear strength MPa	Friction Angle φ°
Granite	2.7	1	50-350	75	15	35	55
Gabbro							
Basalt	2.9	2	100-350	90	15	40	50

Gabbro and basalt have columnar joints that lead to rockfall in slopes or if quarried.

Granite may have faults, open or filled joints, or sheet joints (exfoliation which is a spheroidal cracks within original rock block). These will create problems such as slope failure, leakage, foundation, and excavation. Orthoclase in granite may alter to clay due to carbonic acid:

$$\underset{\text{Orthoclase}}{2(K)Al\,Si_2O_3} + \underset{\text{carbonic acid}}{H_2CO_3} + H_2O \text{ ---------- } \underset{\text{Kaolinite}}{Al_2\,Si_2\,O_5\,(OH)_4} + \underset{\text{Potassium carbonate}}{K_2\,CO_3} + \underset{\text{Quartz}}{4\,Si\,O_2}$$

Mica-rich granite is not suitable as fine aggregate because of its high content of fine material. The granite soil in general is GM, GC, SM, or SC. The silty soil nature causes them to be highly erodable in excavation or rockfill dam.

Some volcanic rocks contain glass which reacts with concrete if used with as aggregate. Basalt have vesicular zones near flow boundaries which is highly permeable. It may also alter to clay minerals such as monmorllonite. This type of clay is expansive.

3.2.2 The Sedimentary Rocks

a) Sandstone

Sandstone comes in three main types;

Quartz arenite: Pure quartz (75%) cemented with silica, calcite, or dolomite (15%).

Arkos: Composed of quarts and feldspars cemented with calcite that are derived from granite.

Graywake: Dark gray with abundant non-quartz silicate plus quartz as well as sand-size particles of other rocks.

The main engineering problems of sandstone are their low strength, durability and its high permeability and porosity. The shear strength may be reduced further by interbeded clay or shale. Porous sandstone may not be suitable as dam site as water may leak. It may create uplift pressure under gravity dams.

The strength may be affected by the type (quartz, calcite, iron oxides, clay or gypsum) and degree of cementation (compacted or friable).

Porous sandstone is not suitable as concrete aggregate due to its high water absorption and tendancy to break down in size.

Friable sandstone lack durability over life time of the project (such as dam or tunnel). It may not be suitable for concrete dam foundation. If necessary, earthfill dam is built instead. It is more flexible (similar to the sandstone) and creates less stress on the ground. Water leakage in the friable sandstone under the dam may leads to piping where internal erosion removes sand grains from the rock forming elongated holes and cause failure.

Calcareous sandstone may develop caves similar to limestone.

Quartz arenite is drilled with difficulty. The rock cause wear of the matrix binding the diamond in the bit. It causes a heath problem if drilled in the tunnel or mine. Silica dust is toxic to the lungs. This type is not wanted in asphaltic concrete as asphalt tends to be stripped free of its bond to quartz by action of water.

b) Limestone

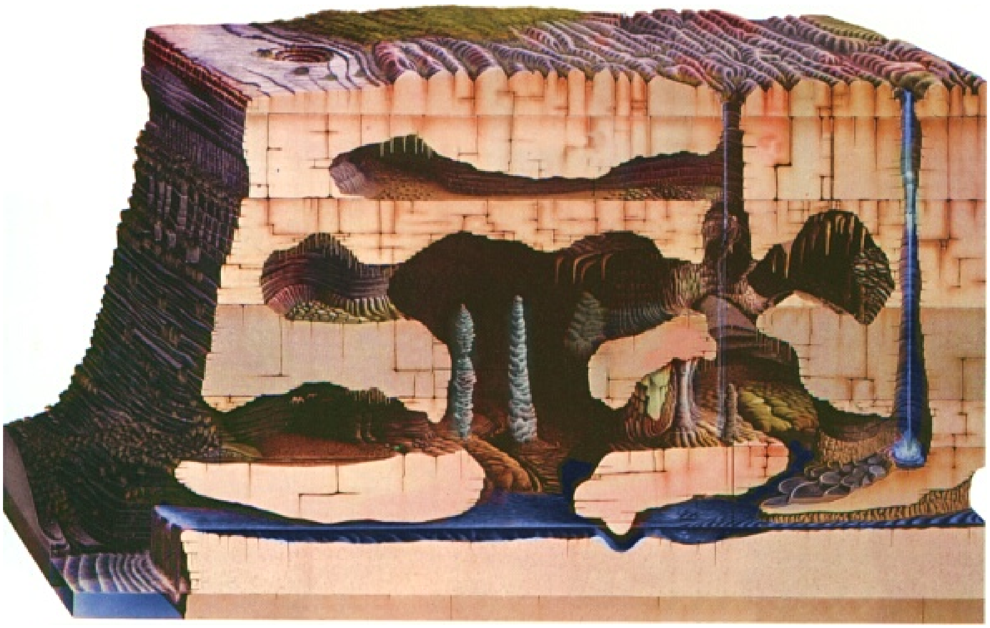
Limestone may originates as

- **Chemical :** It is a direct precipitation of calcite crystals ($CaCO_3$) to form limestone. It originates from the work of organisms in removing $CaCO_3$ from the seawater in building of their shells. With time, Mg^{++} replaces Ca^{++} in the carbonate and if the replacement is 40% or more the rock is called dolomite.

- **Biochemical :** is a biochemical accumulation of microscopic shells (95%) cemented lightly by mud, microscopic shells fragment or clay minerals (5%). If the shells are algal the rock is called Chalk, and if coral the rock is called Coral reef. If the mud in the matrix is more than 13% the rock is called Marl.

Hot springs and Pyrite (FeS_2) in shale may form sulfuric acid (H_2SO_4). This acid may reacts with limestone to form Gypsum :

$$\underset{\text{Sulfuric acid}}{H_2SO_4} + CaCO_3 + H_2O \text{ ---------- } \underset{\text{Gypsum}}{CaSO_4\ 2\,H_2O} + \underset{\text{Carbonic acid}}{H_2CO_3}$$



3.2.3 The Metamorphic Rocks

Metamorphic rock may originate from igneous or sedimentary rocks. Their main engineering problem is anisotropy (directional structure). The engineering problems, especially rock strength are highly dependent on direction (Figure).

3.2.3.1 Metamorphic Structure

Foliation : Laminated structure (layers of 1 cm or less) resulting from segregation of different minerals into layers parallel to schistosity.

Schistosity : The variety of foliation that occurs in the coarse grained metamorphic rocks. It results from of parallel arrangement of platy and ellipsoidal mineral grains.

Gneissosity : Band of coarse grained minerals. The grains are coarser than that of schistosity.

3.2.3.2 Metamorphic Origin

Slate & Mica schist ---- from mudstone (shale) due to regional metamorphism (high temp and high prolong pressure).

Green schist (chlorite schist): regional meta of basalt and Gabbro

Quartzite -------- Qtz arenite
Marble -------- limestone

3.2.3.3 Engineering Problems

Schist weathering

Slope failure is parallel to foliation

CHAPTER IV : Material Improvement

The soil and rock improvement will include two parts; (A) Grouting, and (B) Deep Compaction.

A) Grouting

3.1 Definition:

Injection of fluid material under pressure to improve the geotechnical character of soil and rocks and to stop or reduce water movement.

Grouting is expensive and time consuming process.

3.2 Purpose:

Grout are used to improve the quality of soil and rocks in dams, tunnel, slopes, mines and foundation. The main purpose are:

2. To increase the strength

- **cementing the particles (cohesion)**
- **prevent water**
- **reduce pore water pressure**
- **reduce permeability**

3. To Stop water leakage

3.3 Types of Grout:

a) Particles suspensions

- **Clay grout: clay mixed with water to form colloidal Suspension. The clay may be beotonite.**

the strength is low
reduce the permeability

- **Clay and cement grout**
  to increase the strength
  keeping the permeability low

- **Cement grout:** the cement water ratio is 3 to 5 to prevent clogging the pores.
- **Bitumen:** cheap grout used mainly for water stop.

b) **Grout admixture** : Some of the grouts are a mixture of more than one type to improve the grout quality (Table 4.1).

Table 4.1: The properties of some grout admixture

Grout that accelerate setting time
- $CaCl_2$
- NaOH
- Sodium silicate

Grout that reduce setting time
- Gypsum
- lime

Grout that increase plasticity and reduce shrinkage
- very fine bentonite (volcanic clay)

c) **Chemical grout** : There are hundred of chemical grouts in the form of powder. The material is mixed with water in the site. The amount of powder added to water controls the setting time. The chemical composition are presented in Table 4.2.

Table 4.2: The chemical grout

- ✓ Silicate gel
- ✓ Resins (Acrylic and Phenolic)
- ✓ Phenol-formaldehyde
- ✓ Acrylate
- ✓ Resorcinol- formaldehyde
- ✓ Polyacrylamide
- ✓ Foam
- ✓ Am-9
- ✓ DMAPN
- ✓ Cemex-A

3.4 Site Investigation:

1. Geology

   Rocks: look for fissures, faults, or weakness zones (shear zones)

   Soils: Soil type and permeability

2. Geotechnical survey:

   2.1 Drilling to discover the soil/rock types and boundaries.

   2.2 Soil properties (k)

2.2.1 **Permeability: This will tell us how easy the grouting fluid can penetrate.**

Should be determined in boreholes "site"

$$k = (Q) / 5.5\, r\, H$$

Q = volume of flow
r = radius of casing
H = differential head causing flow

2.2.2 **Porosity:**
It gives an indication of the volume required to fill the soil (rock) with grout fluid.

2.2.3 **Borehole size distribution**
i. **if 20% passes # 200 grouting is not successful**
ii. **grout particles < (1/10) D_{50}**

2.2.4 **Pore size distribution**

Grout particles = soil pore size

3.5 Grout selection :

The correct grout for a given project is selected based on:

- **The purpose (strength and/or water tightening)**
- **The material to be treated (soil or rock)**
  Look Table 7-4 and Table 7-17.
- **The grout viscosity**
- **The grout grain size**
- **The availability in local market**
- **The setting time**
- **The grout price (Table 7-16).**

Example (1): If the ground k-value is $5x10^{-3}$ m/s. What is the grout type if it the purpose is to increase strength.

The selection of grout material based on (Figure 5.5):

(1) purpose,

(2) material to be treated (soil)

(3) permeability

Answer : the grout is Asphalt Emulsion

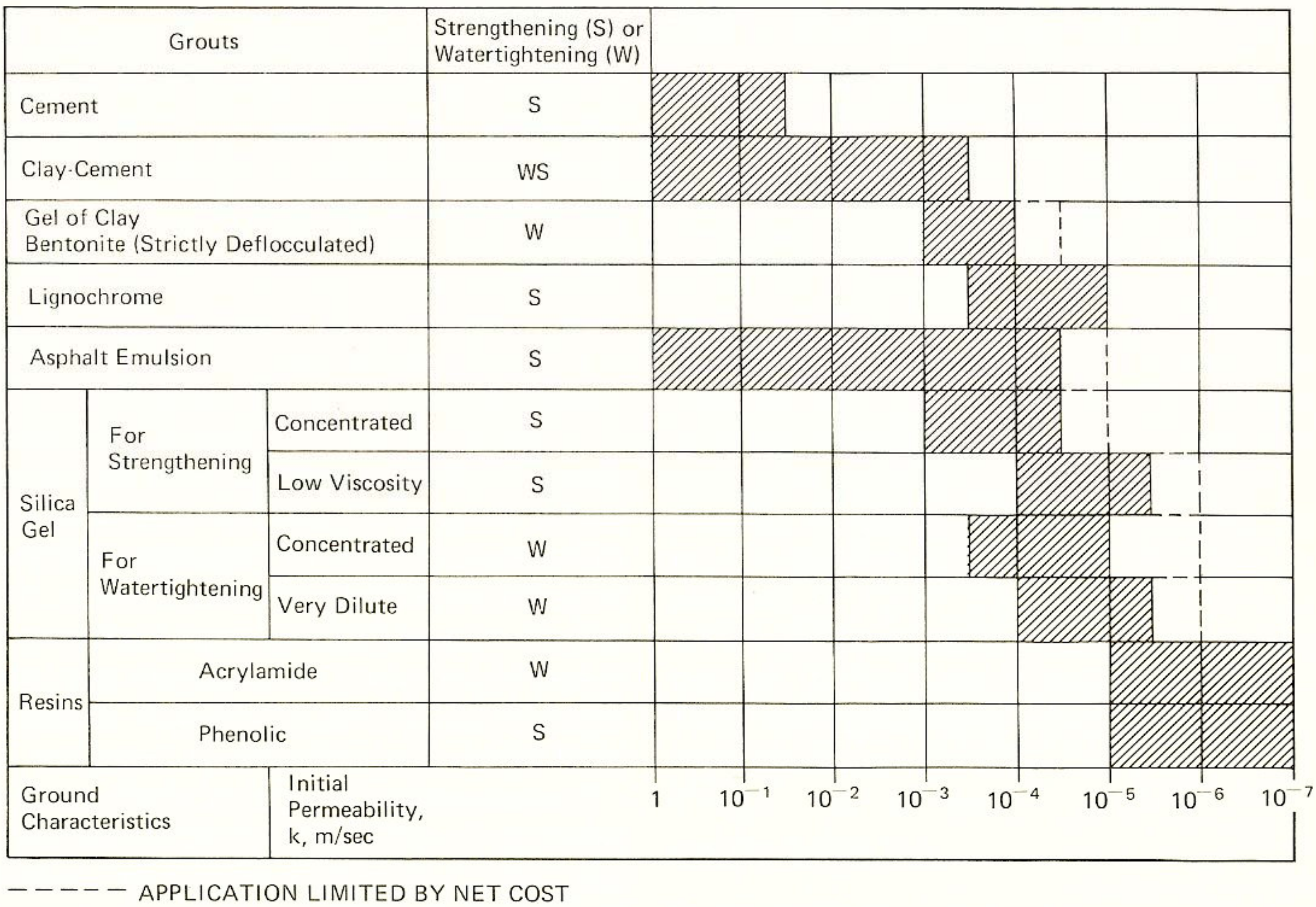


Fig. 5-5. Grout applications in loose soil.

3.6 Ground Treatment : Following the selection of the grout type and ground, the area to be treated should be estimated (in square meters) and the depth of the treatment. Grouting is conducted in the following steps;

- Select the suitable grout type based on the properties and condition of the ground to be treated (***Figure 5.5, Table 7.4, Tables 4.1-4.2***). Check again the grout suitability based on prices (***Tables 7-16***).

- The grout is injected to the ground inside drill holes. The standard of the boreholes is shown in ***Figure 7.39***. The depth of the drilling depends on the thickness of the layer to be treated (5 or 10 m deep).

- The spacing of the drill holes depends on the type of ground material, soil or rock (**Table 7.9**).
- The volume of the grout depends on the porosity of soil (*n*) or the estimation of the fracture size in rocks.

Example (2): Fine sand under a dam is to be treated to increase the strength. The ground surface area is 55 by 25 m, and treatment should be to a depth of 5 m. The soil permeability (k) is $5x10^{-4}$ m/s. The soil porosity (n) is 0.25. The cost of cement is SR 60 per m^3, the relative cost of the grout to be used is 1.5. ***Determine***

1. The grout type to be used
2. The volume of the grout
3. The total cost of the grout

Solution ---

(1) Use ***Figure 5.5*** to determine the grout type based on k value and purpose (strengthening). ….. the suitable grout is **Silicate gel** (for strengthening).

(2) The volume of the treated soil is 55x25x5 m^3 (6,875 m^3).
The volume of the grout depend on the soil porosity (n=0.25), then the volume of the grout (V_g) is

$$V_g = 6,875 \times 0.25 = \mathbf{1,718.75\ m^3}$$

(3) The total grout cost can be estimated as follow:

- the grout volume is 1,718.75 m^3
- the cost of cement is SR 60 per m^3, which means that if the used grout was cement then it cost :

  60 x 1,718 = SR 103,125

  (But remember that we did not use cement).
- the selected grout relative cost is 1.5, then the cost of the selected grout is:

103,125 x 1.5 = SR **154,687.5**

B) Deep Compaction

: **This method is restricted to soil only. The main type of deep compaction are;**

1. **Static Compaction**
2. **Dynamic compaction**
3. **Vibrofloatation**
4. **Deep blasting**

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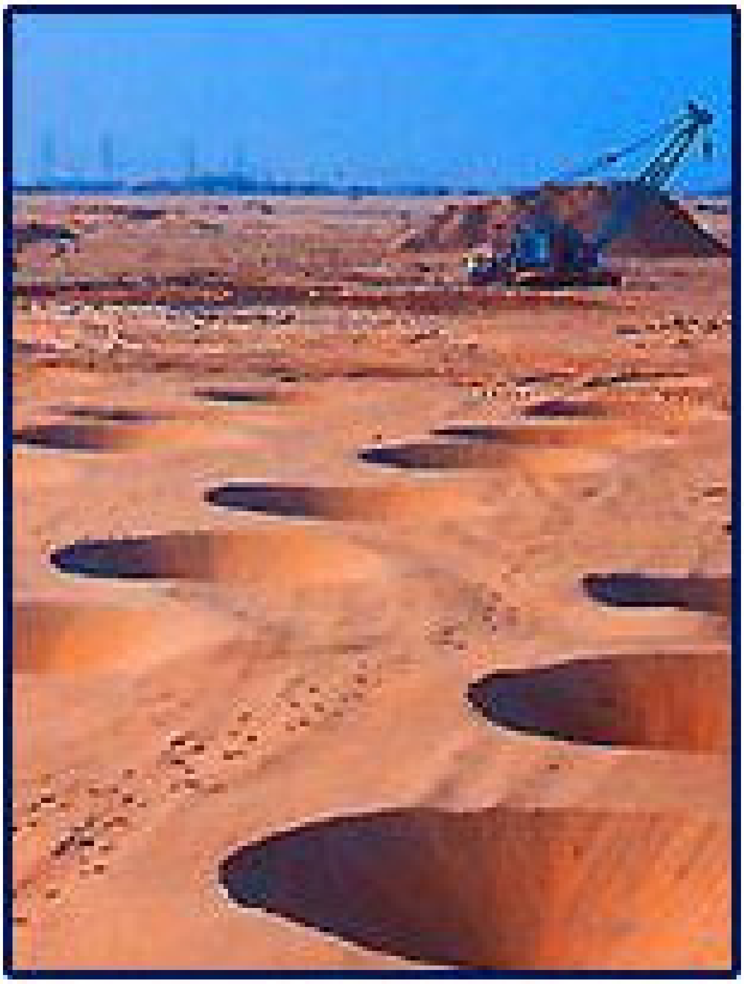
1. **Static Compaction**

This method is slow and used for fine grained soil (silt and clay). Large and heavy rectangular concrete are placed on the soil for months and the soil settlement is monitored.

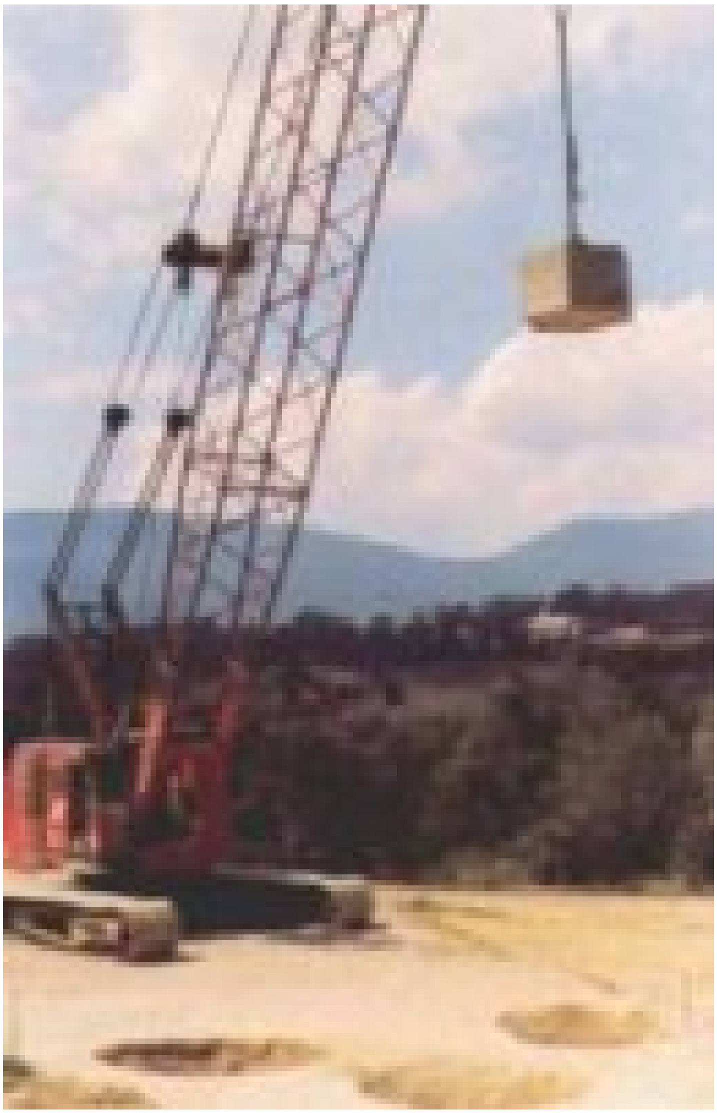
2 Dynamic compaction (*Menard, 1972*)



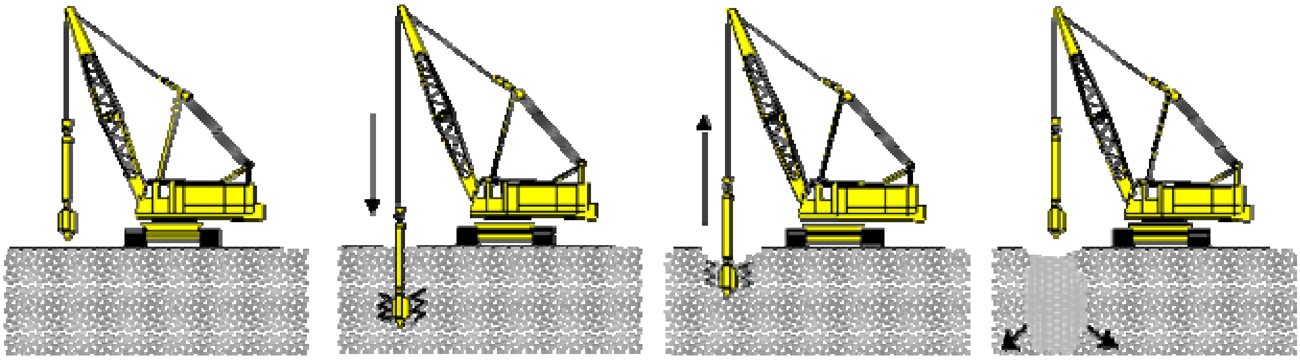
Weight of bounder (Wx) = 5 to 40 tons
Dropping height (hx) = 10 to 40 m
Energy = 4000 ft-ton
Crater depth 1 to 3 m
Effective depth (De) can be calculated from;

$$De = (Wx\ hx)^{1/2}$$

The average De is about 10 to 15 m



3 Vibrofloatation



Good for loose granular soils by rearranging loose cohesionless grains into denser array (*Figure 4.5*). It is more suitable where explosions can not be used.

The degree of suitability depend on the soil PI as follow;

Degree of suitability	PI
Good to excellent	0
Fair to good	0 to less than 8
Not suitable	more than 8

4 Deep blasting

Explosive compaction is carried out by setting off explosive charges in the ground. The energy released causes liquefaction of the soil close to the blast point and causes cyclic straining of the soil. This cyclic strain process increases pore water pressures and provided strain amplitudes and numbers of cycles of straining are sufficient, the soil mass liquefies (i.e. pore water pressures are temporarily elevated to the effective vertical overburden stress in the soil mass so that a heavy fluid is created).

Experience has indicated that the degree of ground improvement obtained by blasting depends on the initial density of the granular subsoils. The density of loose deposits can typically increase considerably to relative densities in the range of 70 to 80%, whereas soils with initial relative densities of 60 to 70% can only be densified by a small amount. Our experience also indicates that EC generally causes volume changes equal to or in excess of what would be anticipated under design levels of earthquake shaking, as described in the attached reference paper by Gohl et al (2000).

The radius of the effected area (r) is:

$$r = (w)^{1/3} / C$$

where

r = radial distance
w = charge weight of explosive
C = charge factor depending on the soil type

Example : if

Wt 6 x 1.2 kg charge
Depth 7 m
Soil is loose sand ------ this will give

Settlement of 0.4 m
And 10 m effective depth

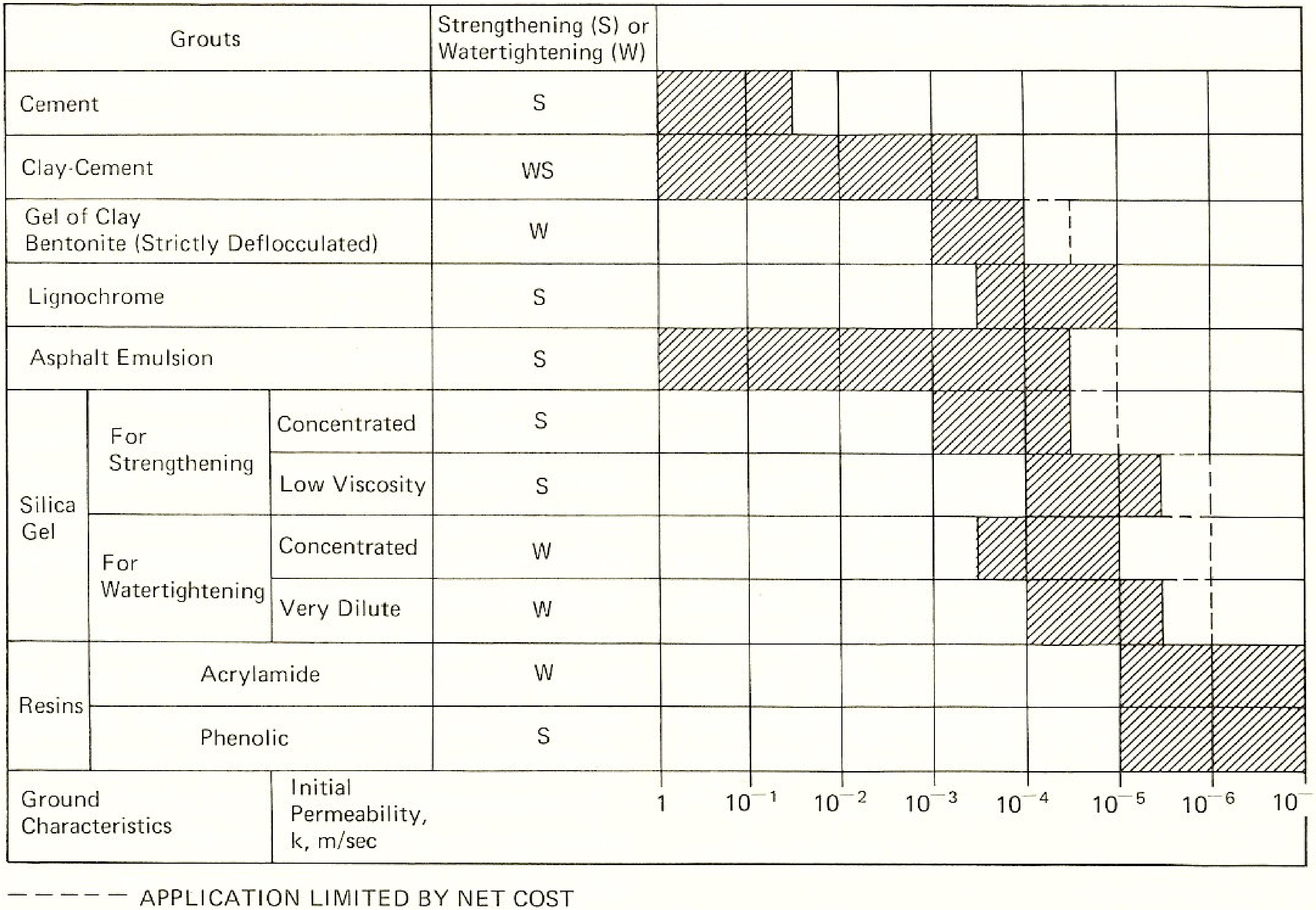


Fig. 5-5. Grout applications in loose soil.

Table 5-3. Characteristics of Major Grouts

		TYPE OF GROUT	UNCONFINED STRENGTH (1)	MATERIAL (2) COST (RATIO)	FIELD OF (3) APPLICATION	GROUTING PROCEDURE
Suspensions	Unstable Grouts	Suspension of cement in water (water/cement ratio ~10:1)	Similar to concrete	4.2	Fissures or cracks in rock or masonry	No limited quantities. Pumping until refusal.
Suspensions	Stable Grouts	Cement and activated mortars: Prepakt, Termocol, Colcrete	Similar to concrete		Filling of large voids	Limited quantities.
		Cements + clay (+ sand)	1 to 700 psi	1	Wide rock fissures and sands and gravels with high permeability	
			<2 psf	1.1		
Liquid Grouts (Chemicals)	Hard Gels	Sodium silicate $+CaCl_2$	150–300 psi mortar up to 600 psi	10.7	$k > 5 \times 10^{-3}$ cm/sec	Grouting in 2 phases Grout of one type
		Sodium silicate + Ethylene Acetate		11		
		Lignosulforate + bichromate k	5 psi (mortar 50 to 70 psi)	6.5 to 8	$k > 2 \times 10^{-4}$ cm/sec	
	Plastic Gels	Sodium Silicate + reagent	7 psi	2 to 4	$k > 5 \times 10^{-3}$ cm/sec	Limited quantities
		Defloculated bentonite	1.5 to 3 psi	1.8	$k > 5 \times 10^{-2}$ cm/sec	
	Organic Resins	AM9	<14 psi	50 to 130		
		Resorcinol formaldehyde	15 to 1400 psi	10 to 40	$k > 10^{-5}$ cm/sec	
		Urea formaldehyde (acid grout)	300 to 1400 psi			
		Precondensed polymers (Epoxy)	up to 14,000 psi comp. up to 4300 psi tensite	150 to 500	Concrete cracks	
	Hydro-Carbon Based Grouts	Bituminous emulsion with silicate	1.5 psi	6	$k > 10^{-3}$ cm/sec	
		Bituminous emulsion or resorcinol	mortar 150 psi	12		
		Hot bitumen	very viscous fluid		abundant water circulation	

(1) Strength given for pure grout (for very low values taken as twice the rigidity)
(2) Base 1 for material cost comparison
(3) Permeabilities shown correspond to granular soil susceptible to impregnation. Excessively fluid viscous grouts should not be introduced into too pervious soils. (inefficient technically and waste of money.)

Modified from Tallard, G. (1975), "Dewatering and Grouting as Supplementary Ground Engineering Techniques," Proceedings of Seminar on Underground Problems, Techniques & Solutions, Chicago, Oct. 20–22.