Soil Stabilisation ⇒ or cementing material is added to natural soil material to improve the one or more properties of soil.

Stabilising Material –

1. Cement 2. Lime 3. Bitumen / asphalt

4. Polymers & other chemicals.

Portland Cement Stabilisation

Stabilisation by Cementing Technology. – Portland Cement / Bitumen

— Binding of soil particles together without their alteration is referred to as soil stabilisation by cementing.

— Most successfully used soil stabilization.

— Cement & soil blended material is referred to as soil-cement.

— Mechanism ⇒ Not fully known. It is generally accepted that Cement reacts with silicious soil to cement the particles together. Here more coarse grained particles are cemented ~~tha~~ & portion of fine grained soil cementation is small.

(15)

Module-IV

What is?

Soil Stabilisation ⇒ Soil is proportioned/added/removed or cementing material is added to natural soil material to improve the one or more properties of soil.

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Physical Properties of Soil-Cement

1. Nature of soil treated 2. Type & amount of cement utilised 3. placement & cure condition adopted.

Natural Soil.

- All inorganic soil which can be pulverized can be stabilised using cement
- Low in organic matter (max[m] 2% organic matter)
- Soil with high specific ~~area~~ surface. require more cement for stabilisation.
- Clay presence cause problem in pulverisation, mixing & compacting the mix ture
- Expansive clay → dificult to ~~stabi~~ ~~lise~~ stabilise by this method
- Presence of exchangable ions in a soil influence the soil treatment. Ca^{++} is the most desirable for ease of cement stabilisation
- Lime/$CaCl_2$ (CaO) is added to clays being stabilised with cement

The soil with following index properties can economically stabilised (HRB, 1943).

Particle size distribution

Maxm size 75 mm.

Passing 4.75mm IS sieve > 50%

Passing 75μ IS sieve < 50%

Plasticity limits

LL < 40%

PI < 18%

Best result obtained for ~~soil with~~ well graded soil having less than 50% particles finer than 75μ & PI < 20%.

Amount of Cement.

soil-cement — cement varies 5 to 20%.

Lambe, 1962

5 to 20% by wt.

For gravelly soil — 7 to 12%

Sand — 12 to 15%

Silts — 12 to 20%

clay —

- Increase in strength is obtained with increasing cement content in soil-cement subject to the condition that the mixture is hydrated satisfactorily.

- Compressive strength increases by raising cement content for various soil-cement mixtures — i) Silty clay ii) Sandy clay iii) clayey sand iv) Uniformly graded medium sand v) Sand gravel.

(17)

- It is observed that for a given increase in cement content for more clayey soils produces a smaller increase in compressive strength than that with sandy soils.

- It is observed that high-early strength cement is more effective than normal cement.

Mixing.

- Uniform mixing of soil, cement & water gives strong & durable soil-cement.

- Optimum level of mixing is required for better result as excessive continued mixing causes segregation of components.

- Mixing after start of hydration of cement has deleterious effect.

- It is observed that mixing in laboratory has higher strengths & greater durability than similar mixture in field.

- Soil-cement made by mix-in-place method & rotary tiller have about 50% & 70% of the strength of laboratory mixtures.

Moisture Content

↑ more influencing factor.

Plays two roles i) influence the compaction characteristics as in case of natural soil.

ii) it provides hydration for cement.

- Soil type & method of compaction influences the M.C.

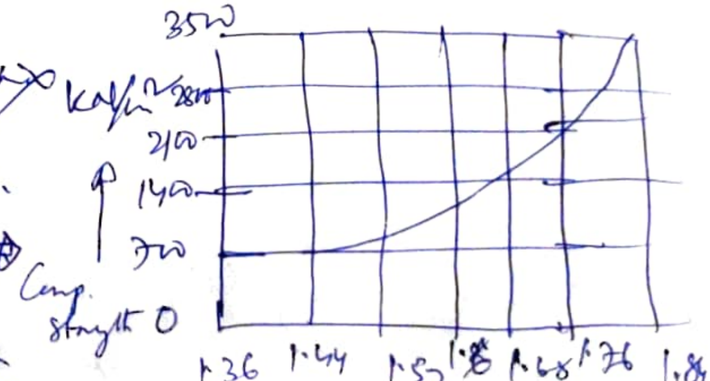
- M.C. ~~reqd~~ reqd. for hydration is adequate ~~which is~~ if that M.C. is enough for maxm. comp requirement.

- w/c reqd. for concrete work has got little effect in case of soil-cement.

Compaction Conditions.

- Adequate compaction is required for satisfactory soil cement.

- For sandy clay mix with 10% Cement.



- It is observed at same cement content, compactive effort, the greatest strength is achieved at approx. OMC.

- Sand should be compacted slightly dry & clays slightly wet of the moulding w.c. which gives maxm. density.

(20)

Age & Curing

- With age, comp. strength increases.
- Soil-cement is cured after compaction under the condn that prevents drying of surface.
- Soil-cement cures rapidly with increase in temp. although it hardens at all temp.

Admixture for Soil Cement

- To accelerate set & improve the properties of soil-cement, lime or $CaCl_2$ is added.
- Addition of some chemicals shows remarkable improvement in strength.

Alkali metal compounds like Na_2CO_3 suits most soil. Plastic soils can be handled with addition of 1 to 3% of lime.

Construction of Soil Cement

⇒ Done by following operations.

i) Shaping the soil to be treated
ii) Pulverizing the soil.
iii) Adding water & Cement
iv) Mixing — in place method, travelling plant method & stationary Plant method are suitable.
v) Compacting
vi) Finishing
vii) Curing.

Controlling

By checking M.C & γd.

Most successful method

Mechanical Stabilisation

achived by following two methods

i) Rearrangement of soil particles

ii) Improves soil gradation.

Materials suitable

— Weak aggregates are preferred for mechanical stabilisation as they will break down under compaction to give a grain size distribution i.e. required for achieving maxm. dry density.

— Aggregates should be correctly proportioned before laying

— Should have sufficient mechanical strength so as to maintain the same grain size during compaction & subsequent use by traffic.

— Should be resistant to weathering

— All kinds of natural rocks, gravel, sand artificial material → slag, burnt shale, etc. are used in road const. with success.

It is necessary to have a well proportioned coarse material containing some clay binder.

$PI \ngtr 6\%$ for base material.

$4\% < PI \leq 9\%$ for surfacing material.

$w_L \ngtr 25\%$ for base material.

$\ngtr 35\%$ for surfacing

Proportioning of Material.

- Natural materials are deficient in one or more of particle size fractions reqd.
- Mechanically stable material can be produced by mixing one or more of the materials in appropriate proportions.
- The method as proposed by Rothfuchs (1935) is widely in use.
- ~~It consists of the following stages.~~

i)

Addition / Removal of Soil Particles.

Engg. behaviour of soil depends on
Particle size distribution ii) Composition of soil particles

- Thus it is possible to change the engg. properties of a soil by adding some selected soil / removing some selected gradation of soil.

Generally 3 types of addition - removal technique are used.

i) **Addition of binder to gravel for road construction.**

- The proper gradation of the soil is to be selected
- The binder the fine material is intended to give cohesion to the mixture.
- Adding fines should be done in such a way that the free drainage of soil should not be disturbed.
- Cheap & powerful technique.

ii) <u>Addition of Material to reduce permeability.</u>

- The properties of clay size vary with composition of material & with the nature of exchangeable ion on the material.

- For reducing permeability of soil, sodium montmorillonite (bentonite) is added as a common practice.

- For example the permeability of silty sand was reduced from 10^{-4} cm/s to 10^{-9} cm/s by addition of 10% of bentonite.

- Other locally available fine-grained soil can also be used in place of bentonite.

iii) <u>Removal of fines from gravel.</u>

Important use of gravels

1) Pavement base course 2) Filter courses

Presence of fines for the above should be less. Particles < 0.02mm should be max^m. upto 3% for non frost susceptible gravel.

The easiest way of removing fines is washing. It needs large quantity of water.

Bituminous (Cementing) Stabilisation

Bituminous Material.

- i) Bitumen — Nonaqueous systems of hydrocarbons & completely soluble in carbon-disulphide.
- ii) Asphalt — primary components are natural or refined petroleum bitumens or combination thereof.
- iii) tars

are bituminous condensates & produced by destructive distillation of organic materials such as coal, oil, lignite, peat & wood.

Mechanism

Bituminous material stabilises soil by

(i) by binding the particles together — cohesive soil

or

ii) by protecting the soil from the deleterious effects of water — for cohesive soil.

or both simultaneously occur.

Out of the above
Asphalt is used widely for stabilisation
known as [soil-asphalt] stabilisation.

Asphalts are produced by

i) Vacuum distillation producing straight run asphalt.

ii) High temp. pyrolysis of refinery heavies producing cracked asphalt.

iii) High temp. air blowing straight-run asphalt producing blown asphalt.

→ has low softening temp. & low net viscosity & is commonly used in soil stabilisation.

— Asphalt is not directly added to soil as it is too viscous. Its fluidity is increased by i) heating ii) emulsifying in water (emulsions) or by iii) cut back with some solvent like gasoline (Cutbacks)

— Both emulsions & cut backs are used in soil stabilisation.

Soil-Asphalt is mostly used in base course of highway & airfield pavements.

Nature of soil

All inorganic soils with which asphalt (emulsion/cutback) can be mixed for stabilisation.

Soil should have following requirements for best results.

- Max^m. particle size < 1/3 rd of the compacted thickness of the treated soil layer
- > 50% finer than 4.75mm size
- 35 to 100% finer than 0.42mm size
- > 10% but < 50% finer than 0.075mm
- LL < 40%
- PI < 18
- Organic matter of acid origin is detrimental to soil ~~asphal~~ asphalt.
- Fine grained soils with high PH & dissolved salts is not suitable asphalt stabilisation.
- Plastic clays are not suitable for mixing problem.

LIME STABILISATION

Lime treatment can be used to improve soft soils and expansive soils.

- **Introduction**
- **Description of method**
- **Applications**
- **Mechanism of stabilization**
- **Shear strength improvements**
- **Settlements Improvement**
- **Foundation Design**
- **Case studies**
- **Quality control measures**
- **Conclusions**

INTRODUCTION

1. Stabilization using lime is an established practice to improve the characteristics of fine grained soils.

2. The first field applications in the construction of highways and airfields pavements were reported in 1950-60. With the proven success of these attempts, the technique was extended as for large scale soil treatment using lime for stabilization of subgrades as well as improvement of bearing capacity of foundations in the form of lime columns.

1(b)

Mechanism of stabilization

The addition of lime affects the shear strength, compressibility, and the permeability of soft clays. These beneficial changes occur due to the diffusion of lime.

Soil-lime reaction

1. Cation-exchange
2. Flocculation
3. Aggregation (time and temperature dependent.)

1(a) **Cation Exchange**

i. It is an important reaction and mainly responsible for the changes occurring in the plasticity characteristics of soil.

ii. The cation replacement takes place in order of their replacing power

$$Li^{+} < Na^{+} < H^{+} < K^{+} < NH4^{+} < Mg^{2+} < Ca^{2+} < Al^{3+}$$

iii. CEC highly depends on the pH of the soil water and the type of clay mineral in the soil. Montmorillonite (highest); Koalinite (Lowest).

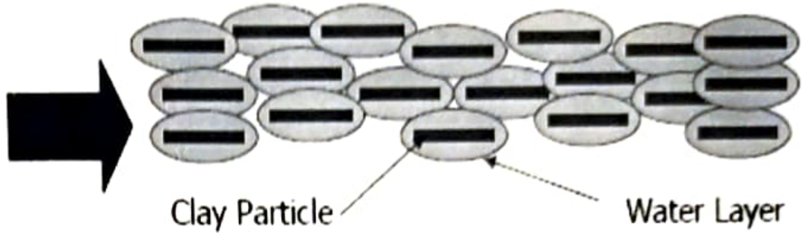
iv. $Ca(OH)_2$ [formed either due to hydration of quicklime or when it is used directly] dissociates in the water.

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.6\ \text{kcal/mole}$$

v. It increases the electrolytic concentration and p_H of the pore water and dissolves the silicates (SiO_2) and aluminates (Al_2O_3) from the clay particles.Na+ and other cations adsorbed to the clay mineral surfaces are exchanged with Ca^{++} ions

1(b) **Flocculation**

Untreated clays have a molecular structure similar to some polymers, and give plastic properties. The structure can trap water between it's molecular layers, causing volume and density changes.



Flocculation/Agglomeration

In treated clays Calcium and Magnesium atoms (from Lime) have replaced Sodium and Hydrogen atoms producing a soil with very friable characteristics

1(c) **Pozzolanic**

Literature review reveals that the addition of lime to soil alters the properties of soil and this is mainly due to the formation of various compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) and micro fabric changes(Pozzolanic reaction).

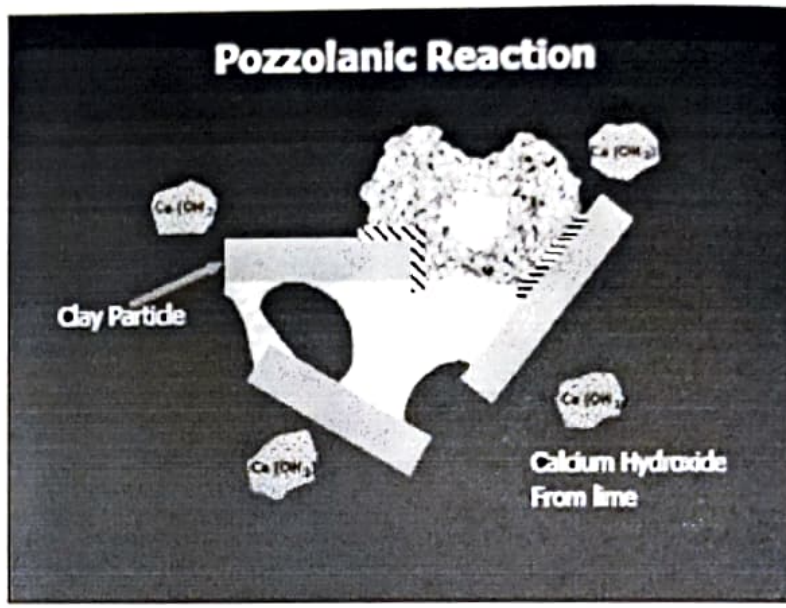
$$Ca^{2+} + 2(OH^-) + SiO_2 \rightarrow CSH$$

$$Ca^{2+} + 2(OH^-) + Al_2O_3 \rightarrow CAH$$

The reaction is much slower reaction than the hydration of cement and hence some times cement is added to increase the rate of reaction.

Pozzolanic Reactions Using Lime (Clay Soil)

On-going reaction with available silica and alumina in the soil forms complex cementitious materials (the POZZOLANIC effect.)



Add lime and fly ash to stabilize soil low in clay.

<u>Factors controlling the characteristics of lime treated clay</u>

i. Type of lime (Quick lime or Hydrated lime)

ii. Lime content

(Lime Fixation Point and Optimum lime content)

iii. Curing time

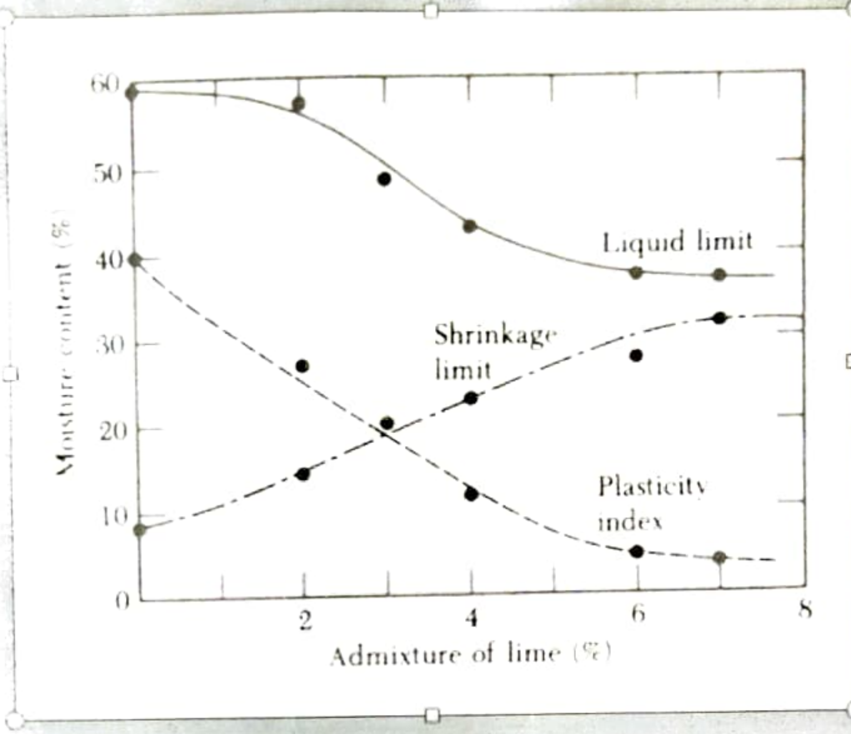
iv. Type of soil

v. Clay mineral

vi. Soil pH

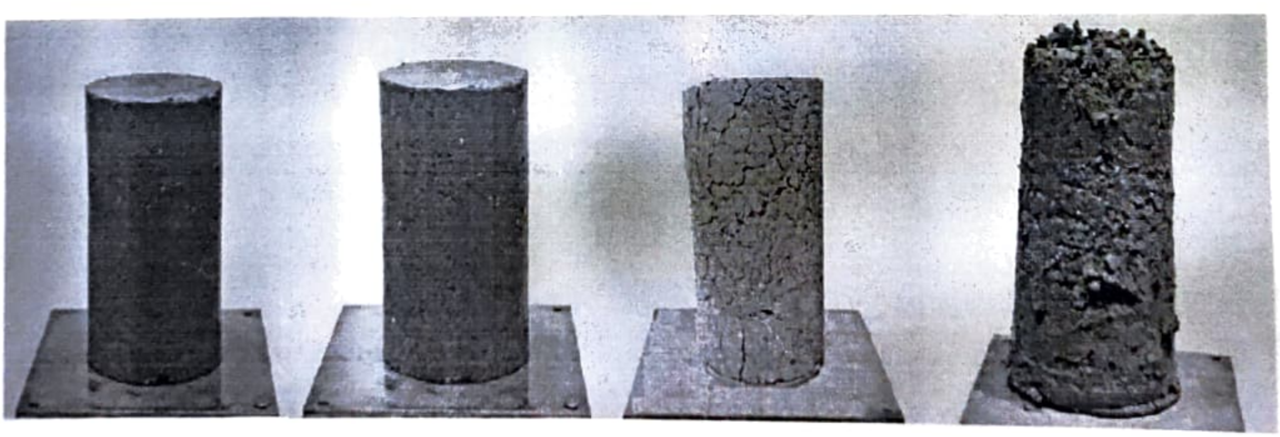
vii. Curing temperature

Variation of index properties with addition of lime



W/D studies

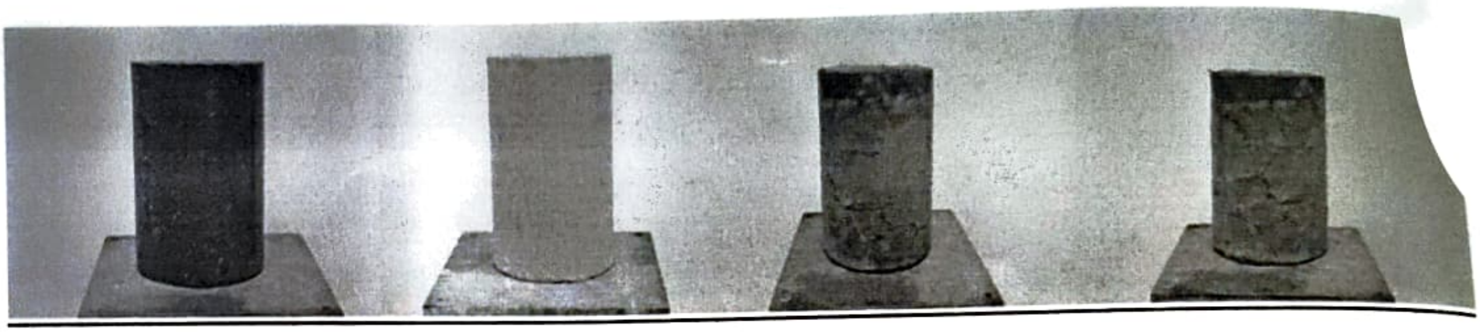
Changes in soil sample (untreated) with Wetting and Drying Cycles



At the start and drying **After Wetting** **After Drying** **After 1 cycle of wetting**

Untreated Paris Clay

W/D studies (Changes in soil sample (treated) with W/D Cycles)



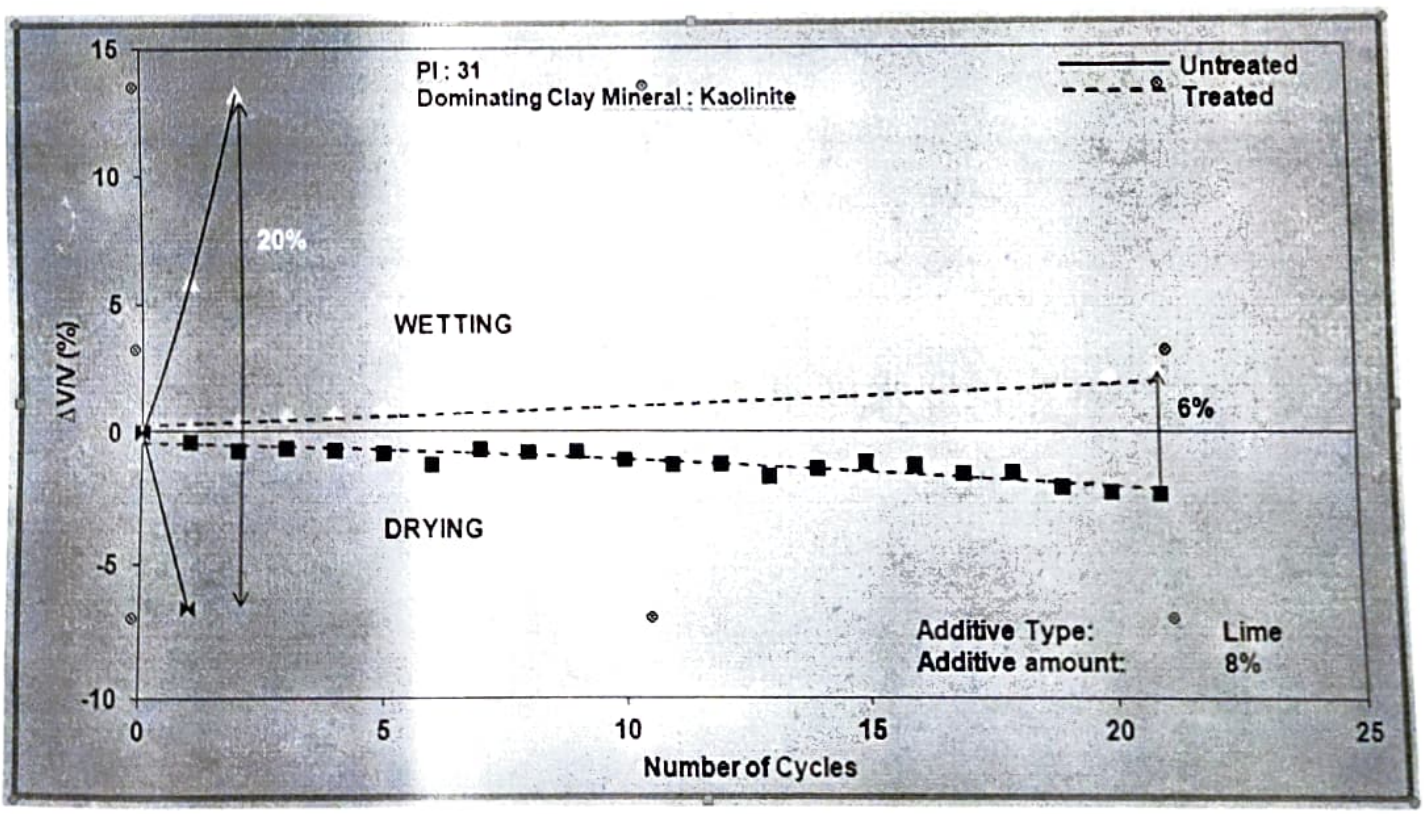
At the start
After 7 cycles

After 3 cycles

After 5 cycles

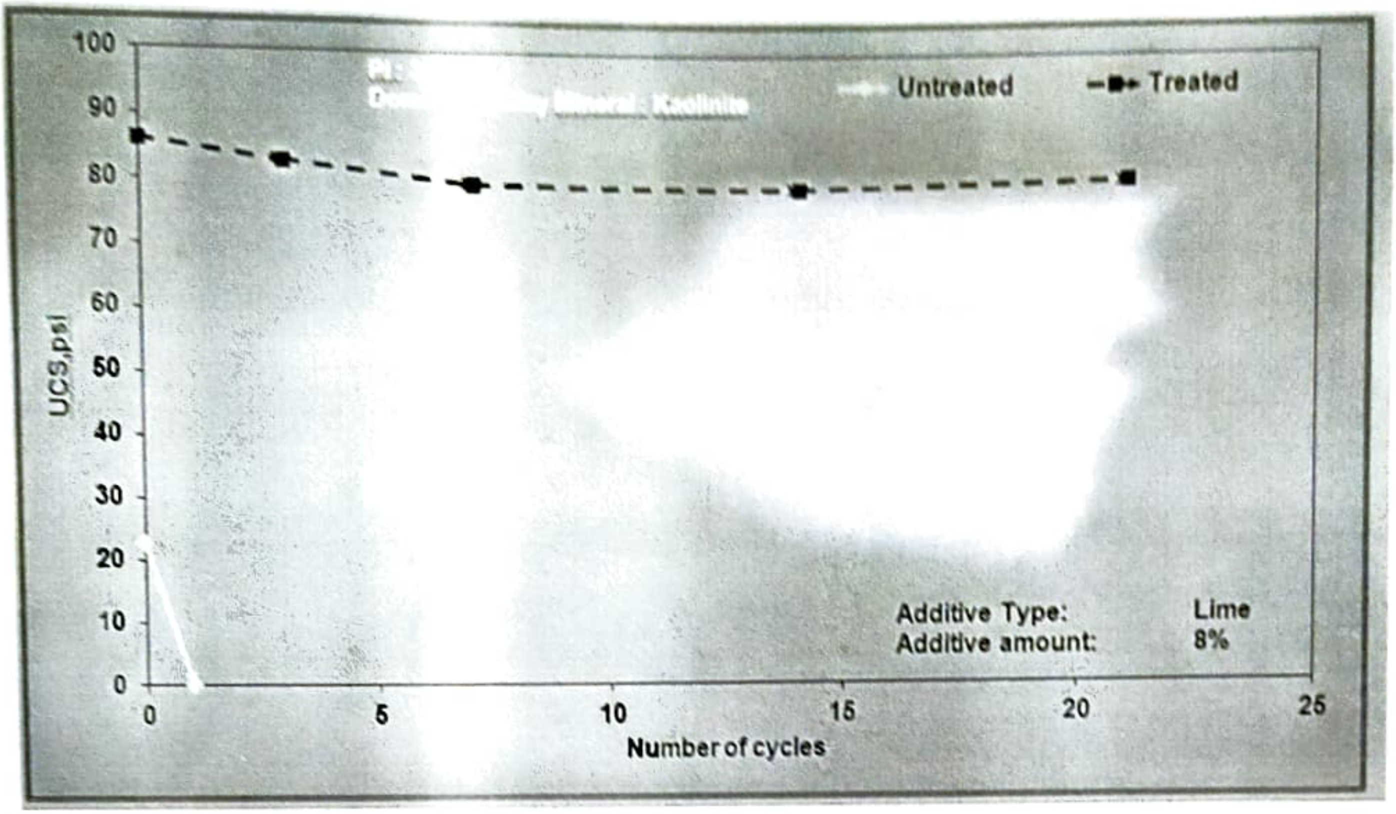
Lime Treated Paris Clay

Results: Bryan Clay



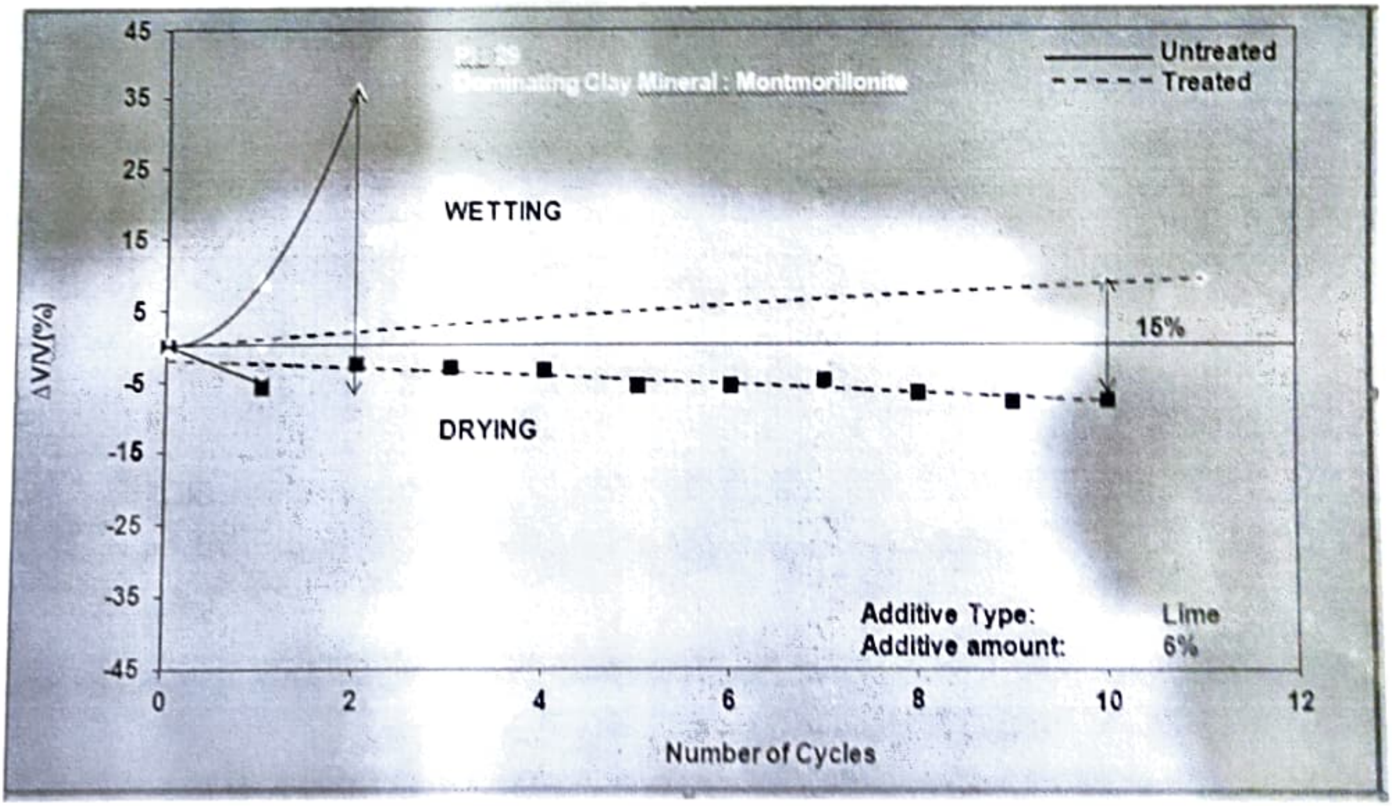
Change in volumetric strain with different W/D cycles

Results: Bryan Clay

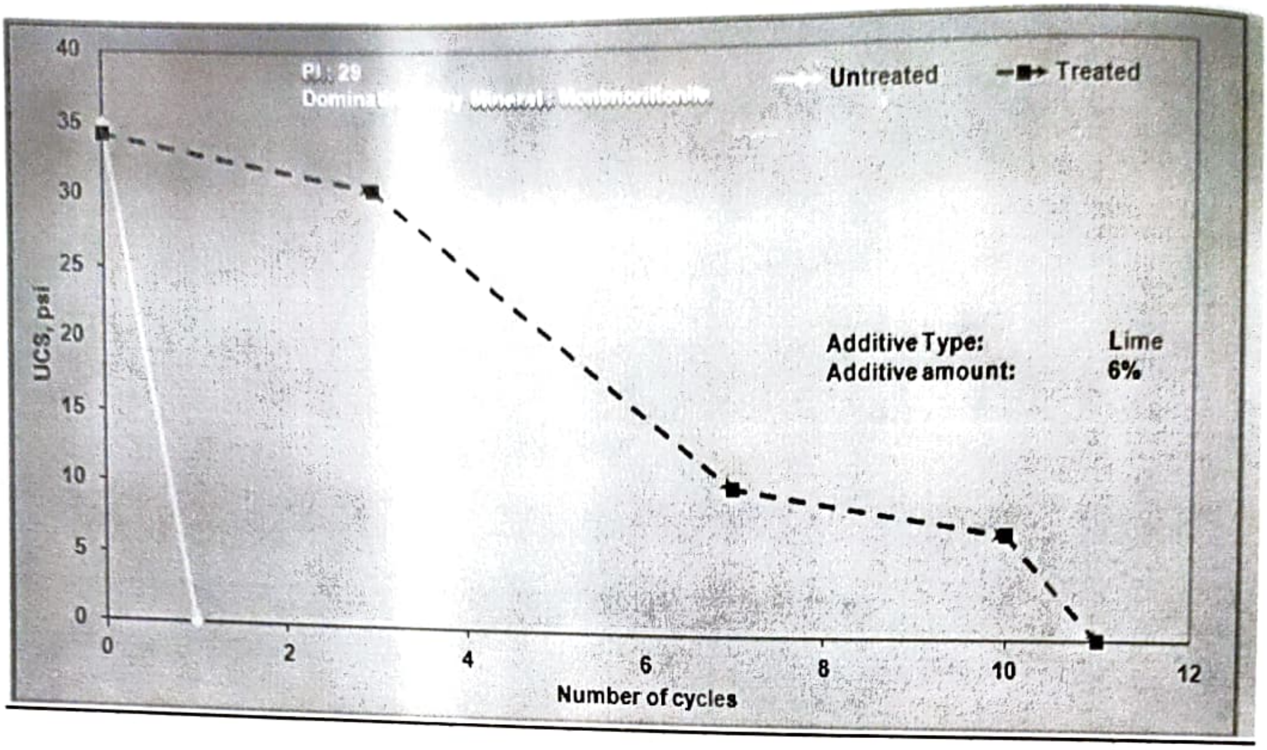


Change in volumetric strain with different W/D cycles

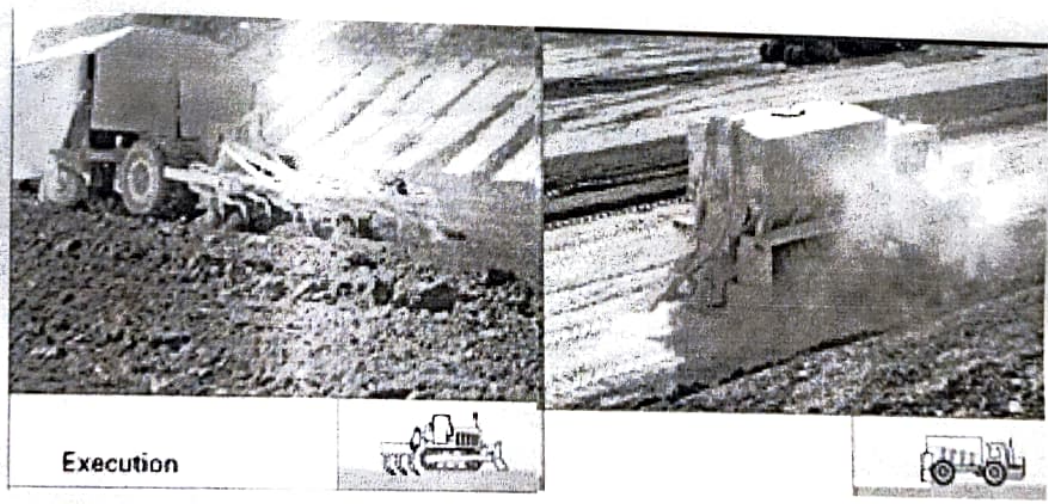
Results: Fort Worth Clay



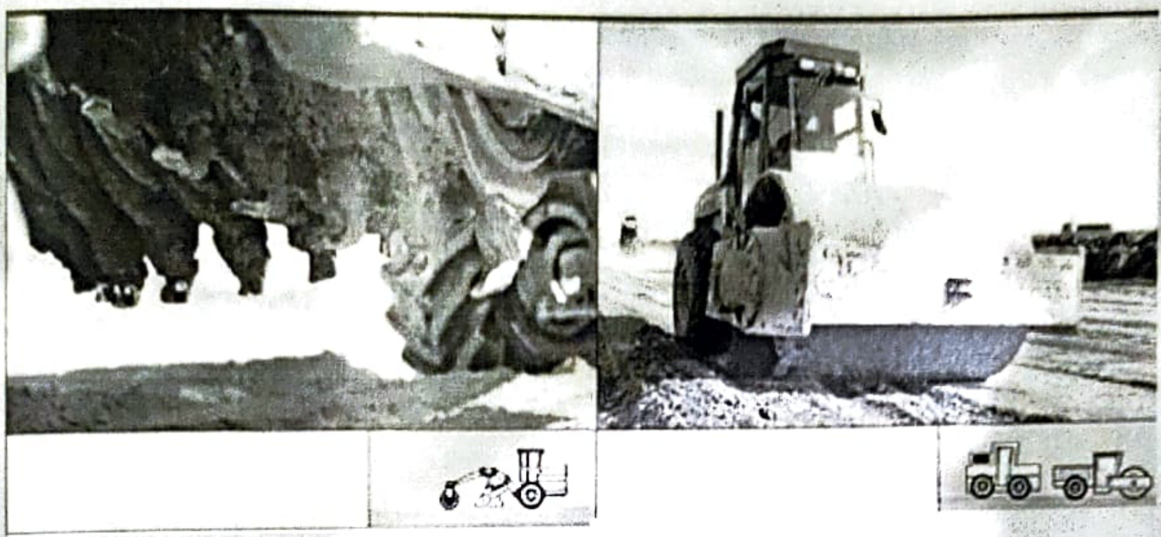
Results: Fort Worth Clay



Change in UC strength with different W/D cycles



Preparation of the soil: to remove large elements which might hinder the mixing-in of lime, and it also helps to modify the humidity of the soil. It may be carried out with a ripper, a harrow or a plough.
Spreading: the lime is dispersed using a spreader fitted with a weighing device. The lime is supplied pneumatically to the spreader, either directly from the silo vehicle or by using buffer silos.



Mixing: the purpose of this operation is to spread out the soil while at the same mixing the lime evenly into it, this work will be done with pulvimixers, rotary paddle mixers, disk ploughs or plough shares

Compaction: when grading, the layer thickness that can be compacted by rolling should be taken into account. After grading, the treated soil has to be compacted using a compacting machine (pneumatic-tyre roller or tamping roller). In warm weather, mixing should be done after two hours to allow for reactions.

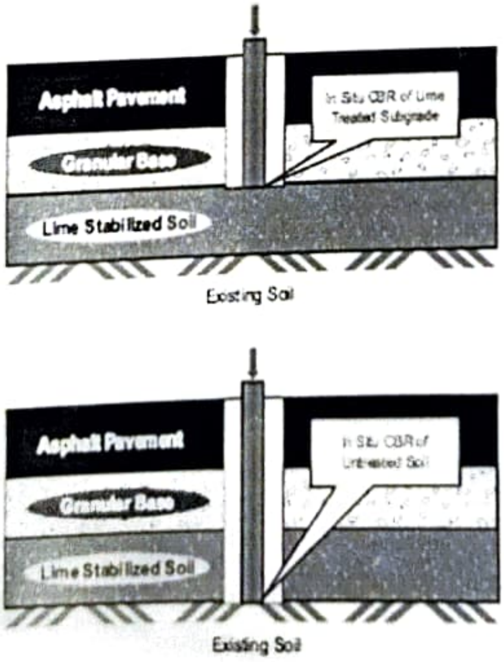


Figure 1: In Situ CBR Measurements

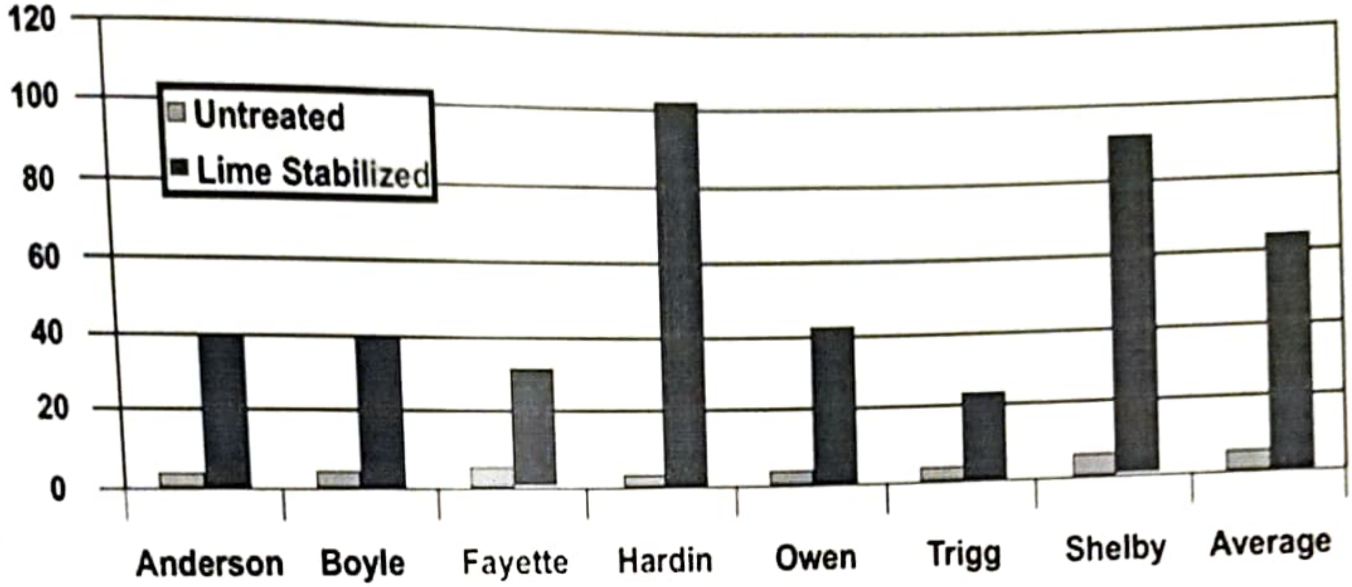


Figure 2: In Situ CBR Values of Untreated and Lime Stabilized Pavement Subgrade

Advantages

- Limitation of the need for embankment materials to be brought in from outside and the elimination of their transporting costs.
- Reduction of transport movements in the immediate vicinity of the construction site. Machines can move about with far greater ease.
- Delays due to weather conditions are reduced, leading to improved productivity. As a result, the overall construction duration and costs can be dramatically reduced.
- Structures have a longer service life (embankments, capping layers) and are cheaper to maintain.

REINFORCED SOIL

- Introduction and historical back ground
- Basic concepts and mechanisms of reinforced earth
- Basic design of reinforced earth wall

What is reinforced earth ?

- Reinforced earth may be defined as a construction material composed primarily of soil whose performance has been improved by the introduction of small quantities of other material in the form of solid plates, perforated plates or fibers or fibrous membrane.

The materials resist tensile forces and interact with soil through friction and/or adhesion.

- Introduction of reinforcement in soil for improving the soil structure is not a new idea.

- Many birds and animals build their nests/habitations using branches of straw, sticks and soil as shown in **Figure 1**. Many people used sticks and soils to reinforce mud dwellings as shown in **Figure 2.**

Figure-1

Figure-2

- One of the greatest examples of reinforced earth is the ‘Great Wall of China’. Mixtures of gravel and clay along with Tamarisk branches as reinforcement were used as construction materials (Department of Transport, 1977).

- We add straw or rice husk with the soil for strengthening the bricks (Old Testament).
- The use of bamboo mats and coconut piles for building core walls or bunds is familiar in Kerala, India.
- The wood branches have been used along the 'Yellow river' in China to form the revetments.
- The Great Wall of China, built more than 2000 years ago, contains some sections where clay and gravel were reinforced with tamarisk branches.

- This concept is very ancient: 3000 years ago the Babylonians used intertwined palm branches to reinforce their "ziggurat". The Aqar-Quf Ziggurat, in the actual Iraq, was made of clay bricks reinforced with woven mats of reed laid horizontally on a layer of sand and gravel at vertical centers between 0.5 m and 2.0 m. This structure was originally over 80 m high.
  - In 1880's, brushwoods were placed for stabilization of the soil along the bank of the Mississippi river (Hass and Weller, 1952).
  - Gravels encased with steel wire meshes or bamboos have been utilized to build the revetments in China and Taiwan. (Design manual).
  - Brushwoods were used in England to repair landslides and for erosion control (Doran, 1948).
  - Wooden beams can be used as reinforcement materials to construct vertical retaining walls (Munster, 1930).
  - In India, bamboos, straws, gunny bags made of jute and coir, woods, palms, sisal, grass, sugar cane, plant leaf, pine apple etc. have exclusively been used for the construction of shelters, bricks, roads and for flood protection particularly in rural areas for many many years. We do not know that this technology is called "Reinforced Earth".

- 'Reinforced earth' is the most emerging and promising alternative design technique come up into the market. It is also cost effective with respect to the traditional construction materials.

- **Historical background of reinforced earth:**
- Henri Vidal (1966), French architect and engineer, is the pioneer of reinforced earth systems.

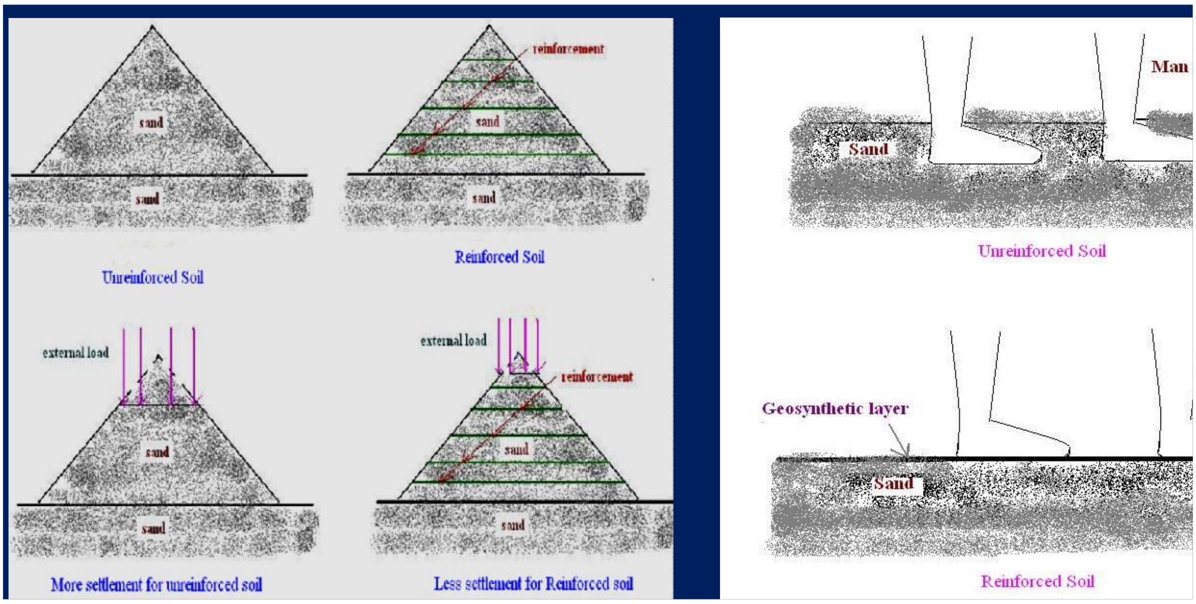


Figure 3 Concept of reinforced earth

<u>Basic Concepts and Mechanisms of Reinforced Earth</u>

Basic concepts

Soil mechanics Interaction Polymer properties

Applications

Soft soil applications Reinforced fill applications

Unpaved roads Embankments Steep slops Retaining walls

Let us consider two soil samples, one unreinforced and the other reinforced as shown in Figure 4**.**

Figure 4   Difference in slope and settlement after loading

Vidal (1966 and 1969) developed the fundamental concepts and mechanisms of reinforced earth. He introduced horizontal steel strip reinforcement of width 'b' to unreinforced soil mass as shown in Figure 5. Reinforcement is placed perpendicular to the direction of applied vertical stress (σ1).

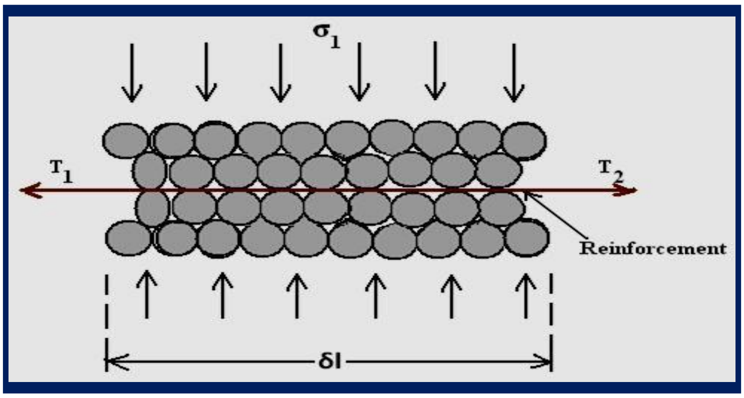


Figure 5

From the above figure

$$T1 - T2 = \delta T = 2\sigma_1 b \delta l \tan\delta$$

Where,

T1 =Tensile strength on left side T2 = Tensile strength on right side

δT = Change in tensile strength

b = Width of strip reinforcement

δl = length of strip under normal pressure

tanδ = Coefficient of friction between soil and reinforcement

No failure by slippage will occur between soil and reinforcement if the following condition is satisfied,

$$\frac{\delta T}{2\sigma_1 b \delta l} \langle \tan\delta$$

Behaviour of reinforced soil:

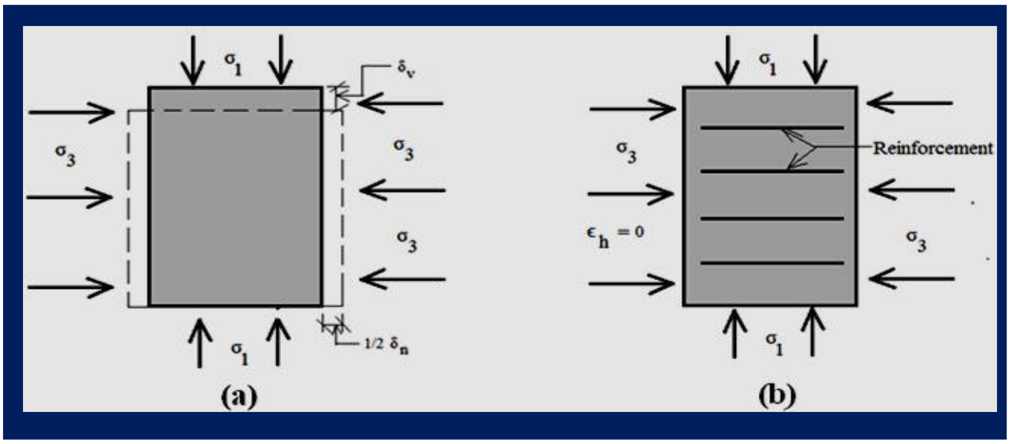


Figure 6

Figure 6(a) shows unreinforced soil mass under vertical stress (σ1). There is development of axial compression (δv) and lateral expansion (1/2 δh) occurs on both sides.

Now, a reinforced soil mass is constructed by introducing horizontal layers of reinforcements as shown in Figure 6 (b) and subjected to same vertical stress (σ1).

- Due to application of reinforcement, there will be development of friction or adhesion between the soil and reinforcement.

- The Young's modulus of reinforcement (E_r) is much higher than the Young's modulus of soil (E_s). Therefore, lateral strain in the reinforced soil mass will be very small, almost negligible compared to that of the unreinforced soil. Therefore, in reinforced condition with higher reinforcement modulus, even in active condition, the soil mass will behave as if in at rest condition.

The soil mass is in active state, but $\delta_h = 0$.
The stress circle will be within the failure envelope. Failure will not occur until the reinforcement may fail by either pullout or breakage.

Let us assume a cubical reinforced soil mass of unit volume at depth 'z' from the ground surface as shown in **Figure 7**.

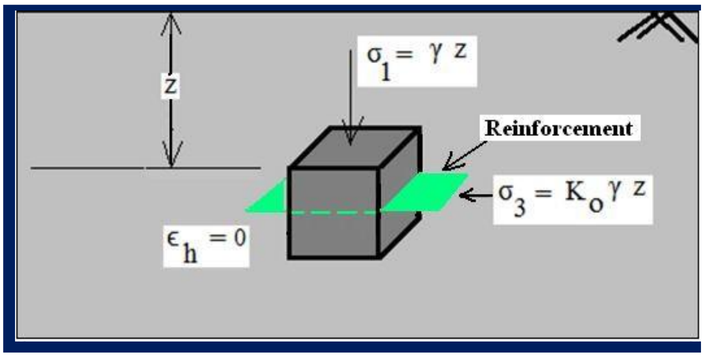


Figure 7.

At active condition,

Vertical stress on the soil mass, $\sigma_1 = \gamma.z$

Horizontal stress on the soil mass, $\sigma 3 = ko.\ \sigma 1 = k_o.\ \gamma.\ Z$

Therefore, total horizontal force on the unit soil mass

$= \sigma_3 \text{ x } (1\text{x}1) = \sigma_3 = k_o.\ \sigma_1$

The lateral force is transferred from soil to the reinforcement. The lateral stress per unit area of reinforcement = $(k_o.\ \sigma_1)/A_r$

If E_r =Young's Modulus of reinforcement, and

Ar = Cross sectional area of reinforcement, The lateral strain (εr) in the reinforcement or soil along the reinforcement = $(k_o. \sigma_1)/(E_r. A_r)$

As the stiffness of reinforcement ($E_r. A_r$) is higher, lateral strain (ε_r) tends to zero.

It should be noted that if the stiffness of reinforcement decreases, the lateral strain (ε_r) increases and earth pressure coefficient (k_0) tends to k_a.

Let us consider a semi infinite soil mass. As the soil is semi infinite, the lateral deformation is zero.

Let us make a vertical cut in the unreinforced soil. There will be change in lateral stress condition.

At a depth 'z' from ground surface, Vertical stress $\sigma_1 = \gamma. Z$.

Lateral stress, $\sigma_3 = k_o. \sigma_1$

Therefore, it is required to apply sufficient hydrostatic pressure ($P = k_o. \gamma. Z$) along the vertical cut to maintain equilibrium.

If horizontal layers of reinforcements are placed in the soil mass along the vertical cut as shown in **Figure 8**, bond or interaction between soil and reinforcements will occur.

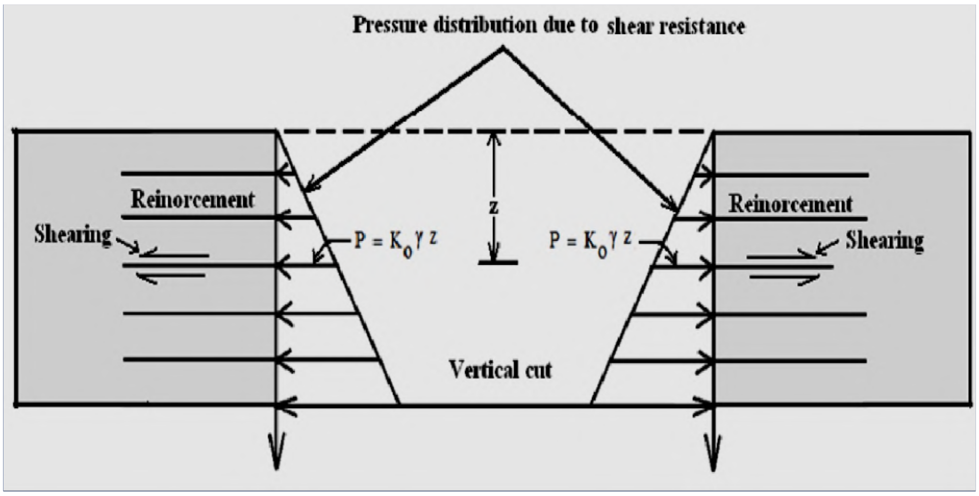


Figure 8

Tensile force induced into the reinforcements develops horizontal shearing stress between soil and reinforcement.

Due to reinforcement, the lateral strain in soil mass remains unaltered though the soil is not at rest condition. The stress state in the soil becomes quite higher and close to failure envelope as shown in **Figure 9** , but failure does not occur.

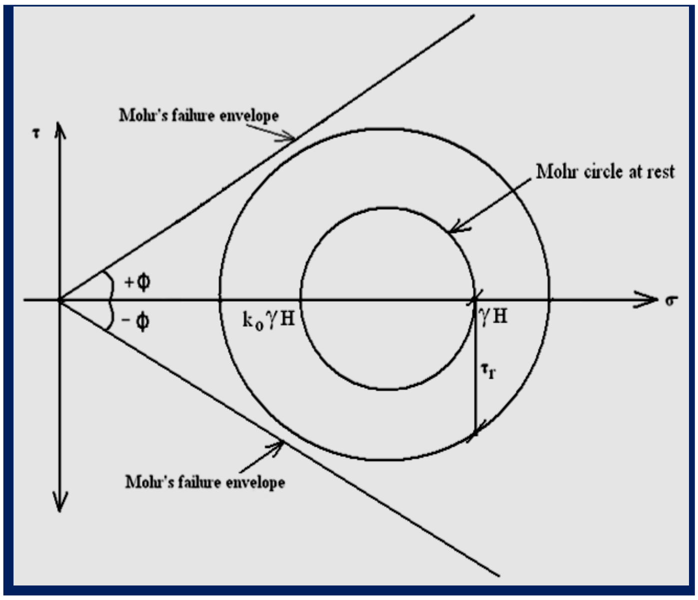


Figure 9