IQRA NATIONAL UNIVERSITY PESHAWAR

DEPARTMENT OF CIVIL ENGINEERING

M.S TRANSPORTATION

Submitted To:

Instructor:

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Course:

Ground Improvement Techniques

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M.S (T.E)

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Q1. (A) How do we improve soil through excavation and replacement? How & which properties of soil are modified through additives, name a few additives with their functions?
(B) What are the various dewatering techniques which are generally used for ground improvement discuss brief?

Answer:

Improvement of Soil through Excavation & Replacement:

There are various techniques used for the improvement of the soil based on the construction activity and type of soil. The soil improvement techniques are,

1. Surface Compaction
2. Drainage Methods
3. Vibration Methods
4. Pre-compression and consolidation
5. Grouting and Injection
6. Chemical Stabilization
7. Soil Reinforcement
8. Geo textiles and Geo membranes
9. Soil Replacement method
10. Other Methods

But here we explain only improvement of soil through Excavation & replacement by improve material.

This method normally used in Road project. This method applicable where CBR valve of sub grade material is very low and material is swell only by small quantity of water. If we do not replace the said soil the rutting will appear on the surface of roads and deterioration of road is started and also maintenance of the road is very difficult.
Step involved in this method.

- Remove the unsuitable soil up to min 3ft for normal traffic roads
- Then made stock pile of improve material
- Spread the material in layers min 6inch and max 9-12 inch
- Each layer be tested through FDT test
- After completing all layers then Sub Base and Road Base material be laid

In Building this method applicable only for Single story Building or Low cost Housing Project in which material has removed and improve material be laid for Raft or mat footing.

This method is very cheaper and easy, where improve material easily/nearby available. But if improve material is not available nearby then above other methods can be used.

Properties of soil are modified through additives, name a few additives with their functions:

Laboratory experiments are conducted to evaluate the effect of some non-traditional additives on the engineering properties of clayey soil, which show problematic phenomenon when used as a construction material. The conducted tests covered the influence of these additives on various parameters like consistency limits, compaction characteristics and CBR value. Two nontraditional stabilizers are selected in this study, polymers and phosphoric acid at three different percent which are (1%, 3% and 5%) of the dry soil weight. It is concluded that addition of the polymer to the clayey soil results in a slight increase in plastic limit while the liquid limit is not affected accompanied by a marginal decrease in the dry unit weight while the optimum moisture content remains unaffected. The addition of phosphoric acid to the clayey soil has no effect on its Atterberg limits. In general, it is observed that polymer is found to be ineffective as a stabilizer to improve clayey soils, especially in small amounts of about (3%). The phosphoric acid treated soil gained better improvement for all amounts of additive used. For (3%) acid treated soil the CBR is about (360%) compared to that of untreated soil, for that, it can be concluded that the improvement using phosphoric acid in the clay soils is a promising option and can be applied to solve the geotechnical stabilization problems.

The strength of soil-lime-fly ash mixtures could be estimated by various methods such as unconfined compression, CBR, the Hveem stabilometer and triaxial tests. The most commonly used method is the unconfined compression test, not necessarily being the most appropriate for all purposes. The strength of soil-lime or soil-fly ash mixtures depends on many variables such as the soil type, the lime and fly ash content, the additive type, the time and method of curing (temperature and humidity), the water content, the unit weight and the time interval between mixing and compaction.

The addition of lime, fly ash, and lime/fly ash to three clayey soils led to a reduction of the plasticity index and contributed to an increase in the optimum moisture content and a decrease in the maximum dry density (Hesham [5]). The optimum lime content ranged from 3 to 5%, while the optimum fly ash content between 16 and 35%. The optimum lime/fly ash content for the three soils was (2.5%L+8%FA), (2%L+12%FA) and (3%L+20%FA). The UCS, Esecant, CBR, and the Velocity of ultrasonic p-waves, Vp, values increased slightly with an increment of the dry density of the untreated compacted soils (due to the compaction process) and strongly due to the addition of the chemical stabilizing agents (lime, fly ash, and lime/fly ash) whereas the formed cementitious compounds (as a result of the chemical reactions between the silica and the alumina and the additives) joined the soil particles.

Basic studies on pozzolanes and on the pozzolanic properties of fly ash have been carried out by Adu-Gyamfi [6] and Brooks [7]. Considering the nature of the lime used in the mixtures, many investigators such as Ingles and Metcalf [8], have shown that calcarious limes gave higher strength results than those given by dolomitic limes. In Greece, many roads have been built using stabilization techniques for the subbase materials. The behaviour of these roads has been judged as fairly satisfactory. The scope in some of these trials was the use of large quantities of fly ash per surface unit, in order to take advantage of the surplus of this material. However, the cost of transporting the material from places of its production or deposition to the areas of the projects under consideration, which are located to a relatively small distance from the power stations, is a very restrictive factor. The Research Centre of Public Works (KEDE) has carried out significant studies on the stabilization of aggregates and clayey soils, mainly with Portland cement and with lime and fly ash since 1982. The exploitation of Megalopolis fly ash and its applications in highway construction in adjacent areas has been examined by Marsellos et al. [9]. Further studies have been undertaken by Greek Universities, the Technical Chamber of Greece, and other researchers. The main objective of this work is to test the capability of lime and fly ash in improving the engineering properties of clayey soils from the areas of Thrace, in order to use them as stabilized layers in road construction and to apply more economic processes in constructing new pavements or improving existing ones.

Materials and methods:

The soils used in this study have been sampled near the villages Aetolofos and Aetokorifi of the Rhodope prefecture in Thrace. The soils are pleio-pleistocene fluvio-lacustrine deposits resulted by the alteration of andesitic tuffs and tuffites of the Zonaia Mountains surrounding the basin. These clayey soils are of black colour near the surface, but they turn to grey or yellowish in the deeper horizons. In some places they are intercalated by lenses or layers of sand and gravels. Disturbed samples were taken from an excavation about 1 m deep in two different locations, near the New Egnatia highway. The soil "S1" is a fine-grained black clay, while the soil "S2" is a brown clay. Cation concentrations of Mg and Ca 5.76 meq/l and 19.21 meq/l, respectively, have been determined for S1. The respective values for S2 were 8.84 meq/l and 92.32 meq/l. The chemical properties of the soils are summarized in Table 1.

Table 1: Chemical composition of the soils tested.

	Black Soil (S1) Brown Soil (S2)	Black Soil (S1) Brown Soil (S2)
Loss on Ignition	11.62 (%)	14.95 (%)
SiO_2	64.18 (%)	57.25 (%)
Al_2O_3	12.73%	11.97%
Fe_2O_3	5.43%	5.43%
CaO	1.55%	7.28%
MgO	1.50%	1.16%
K_2O	1.80%	1.55%
Na_2O	0.70%	0.21%

The soils were air-dried and pulverized, in order to pass the No. 4 (4.75 mm) sieve. The grain size distribution of the representative soil samples is presented in Table 2.

Table 2: Properties of natural soils.

Properties	Soils	
	Black Soil (S1)	Brown Soil (S2)
Specific gravity (kg/cm^2)	2.5	2.7
Liquid Limit (%)	76	51
Plastic Limit (%)	29	23
Plasticity Index (%)	47	28
Linear Shrinkage (%)	13.3	10
Free Swell Index (%)	95	51
Max Dry Density (kg/m^3)	1588	1707
Opt. Moister Content (%)	21.7	17.8
Grain Size Distribution		
Sand & Gravel (%)	24.3	16.2
Silt (%)	22.7	35.8
Clay (%)	53	48
Classification		
AASHTO	A-7-6	A-7-6
USCS	CH	CL
Unconfined Compressive Strength (kg/cm^2)	1.5	2.7

The basic properties of the soils were determined from representative samples and for the soil fraction passing the No 40 (425 μ) sieve. The liquid limit of these soils was found using the Casagrande method. The grain size distribution of the soils has been determined by both the dry method (AASHTO T-27) and hydrometer analysis. The physical properties of the soils studied and their unconfined compressive strength (UCS) are presented in Table 2. Both soils are classified as Group A-7-6 according to the AASHO classification system, while, according to the Unified Classification System, are classified as CH and CL respectively. Soil samples passing the No 4 (4.75 mm) sieve were used in order to find the dry density-moisture content relation with the standard Proctor compaction test. The soils were thoroughly mixed with different moisture contents (14% to 30%) and were cured in a moisture room for 24 hours before they were compacted, for uniformity purposes. The maximum dry density and the optimum moisture content are shown in Table 2. The lime used in this study was a typical commercial hydrated calcitic lime, having a high CaO content (65.25%). It was supplied by the AIMOS Lime Company, Drama, Greece which has a 200 ton daily production. The chemical composition of this lime is shown in Table 3. The term fly ash represents the fine-grained ash residue produced from pulverized coal combustion and carried away by the hot gases comes out of thechimney. This residue is usually collected with appropriate filter put along the chimney. The fly ash used for the preparation of the laboratory specimens was supplied by the Ptolemaida Power Station (6,000,000 ton/year). The chemical composition of the fly ash is shown in Table 3.

Table 3: Chemical composition of the soils tested.

	Lime	Fly ASh
Loss on Ignition	33.25 (%)	13.90 (%)
SiO2	0.01 (%)	29.95%
Al2O3	0.01%	10.85%
Fe2O3	0.11%	4.57%
CaO	65.25	20.0%
MgO	0.50%	1.90%
K2O	0.01%	0.95%
Na2O	0.01%	0.32%

Treatment of soil samples with lime and fly ash

The air-dried soil materials passing the No. 4 (4.75 mm) sieve, were mixed in different proportions by weight with lime (in powder form) and fly ash. Water was added until the optimum moisture content was reached and the mixing process continued till a visually uniform product was achieved. Cylindrical specimens 50 mm in diameter and 100 mm high were then formed in special moulds. The material was placed in the mould in three layers of equal thickness. The quantity of the material for each sample was determined by the optimum moisture-maximum dry density relationship. The compaction to the maximum dry density Proctor was achieved by compressing the required mass in the given volume with an automatic hydraulic press. After their extraction from the mould, the specimens were weighted and sealed in polyethylene bags, in order to keep the moisture content constant during the curing period. For each percentage of additive a set of three specimens was prepared. Care was taken to cure the specimens under stable temperature and moisture conditions. The specimens for the unconfined pressure test were cured for 7, 28 and 90 days before their testing. The additive–soil weight ratios used were: a) for the lime: 4–100, 7–100, 10–100 for both soils. b) for the fly ash: 4–100, 8–100, 12–100. Specimens were also prepared with lime–flyash–soil ratios: 1–3–100, 2–6– 100 and 1–5–100 by weight. For each discrete ratio, the optimum moisture content was determined using the standard Proctor method according to the AASHTO T99 61 specification. The specimens were tested in an unconfined compression machine with strain rate 1.25 mm/min. An X-Ray Diffraction analysis showed that soil S1 had more swelling clay minerals, while soil S2 had more kaolinite and calcite.

Results and discussion

The Atterberg limits, the optimum moisture content and the maximum dry density of the soil-lime, soil-fly ash and soil-lime-fly ash mixtures are presented in Tables 4 and 5 for the black soil S1 and the brown soil S2 respectively. In the same tables the unconfined compressive strength after 7, 28 and 90 days of curing is shown. The addition of lime resulted in a reduction of the liquid limit in comparison with the natural soil. This fact complies to the results obtained by other investigators (Sridharan et al. [10], Akoto [11], Athanasopoulou [12]) who have observed a significant reduction in the LL of fine-grained soils following their treatment with additives. The admixture of lime rapidly initiates flocculation and cation exchange reactions, leading to a reduction of the specific area of the soil. The reduction of the thickness of the diffused double layer causes the reduction of the liquid limit. This reduction was smaller (12% with fly ash and 18% with lime) for the brown clay, in comparison to the black soil (22% with fly ash and 27% with lime) due to higher concentration of calcium and magnesium exchangeable cations and the lower percentage of swelling clay. The admixture of lime and fly ash resulted in a reduction of the maximum dry density (MDD) of the soils. On the other hand, an increase in optimum moisture content (OMC) was observed for the same compaction effort (Tables 4 and 5). The reduction in maximum dry density, following the treatment with lime and/or fly ash, reveals the increased resistance to the compaction effort offered by the flocculated soil-structure.

The change of OMC and MDD was gradual when fly ash was used, whereas with the admixture of lime a rapid change existed with small percentages of additive and remained almost constant thereafter. This could be attributed to the reaction rate between the clayey soil and lime, as well as to its quick flocculation due to quick exchange of soil cations with Ca^{++} from the lime and depression of the double layer. On the other hand, the end change of these properties is greater with fly ash than with lime due to the reaction of the soil with the constituents of fly ash other than CaO, like SiO_2, Al_2O_3 and MgO. Considering the strength change of the soils, the UCS increased both with the percentage of the additive and with the time of curing as it is demonstrated in figures 1 to 4. In the case of lime addition, a dramatic increase occurred in the strength of the soil (more than 10 times) with addition of only 4% lime. This high rate of increase in soil strength was reduced with the increase of lime content and at some 8-10% of lime the UCS remained more or less constant or started to decrease (point of soil satisfaction). This percentage is recognized as the lime modification optimum (LMO) of the soil. The same trends hold true for the fly ash, though the rate of increase was lower and there was no point of soil satisfaction. The strength increased in an almost constant rate when the percentage of fly ash in the mixture was increased. As it is shown in figures 1 to 4 the rate of strength gain and the ultimate strength were different for both the additive and the soil. Lime proved to be much more effective than the fly ash in the case of the soil S1; the opposite has been observed for the soil S2. The difference in the soil behaviour is certainly due to the differences in the mineralogy of the soil and the kind of the exchangeable cations present. The brown soil S2 is almost saturated by Ca++ cations, therefore the addition of lime has little effect on the exchangeable cations of the soil. It is well-known that lime has a more pronounced effect on swelling clay minerals (illite, caolinite) due to the greater depression of the double layer. For the same reasons, fly ash yielded a little better results in soil S1 than in the brown soil S2.

Considering the effect of the curing period, the results followed the same general pattern as with the percentage of additive. That is, for soil S1, the effect of time was more significant in the case of lime than in the case of fly ash, whereas in soil S2 the UCS value raised much more with the curing time when fly ash was added than in the case where lime was used. This difference could also be attributed to the abundance of swelling minerals in soil S1. The more the swelling minerals, the more lime is precipitated in the clay surface and the more cementitious materials ($CaCO_3$) are formed. The increase of strength in swelling minerals is due rather to cation exchange (flocculation of the clay) and to the cementitious reaction than to the pozzolanic one (Xeidakis [13], Baykal et al. [14]). Soil mixtures having lime–fly ash ratios of 1–3 and 2–6 have given a little higher strength values than those of the mixture with each additive alone. So, the 2–6 lime–fly ash ratio resulted to a strength two times and 1.5 times greater than that with the addition of fly ash alone and lime alone, respectively (figures 3 and 4). The soil-lime-fly ash mixtures exhibited final strength values intermediate to those found for the soil-lime and soil-fly ash mixtures.

Conclusions

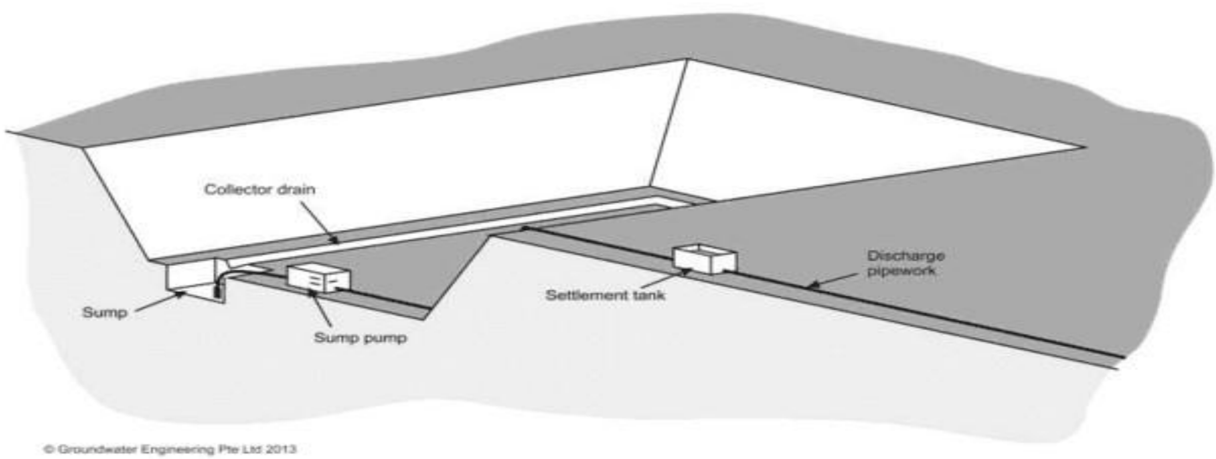
The admixture of lime and fly ash to two expansive clays have led to a significant decrease of the liquid limit probably due to the depression of the diffuse double layer thickness associated with the clay particles, the aggregation of the clay and the coating by $Ca(OH)_2$. A progressive reduction in maximum dry density and increase in optimum moisture content has been observed with the addition of these materials. The decrease of maximum dry density of clay soils, after their treatment with lime and fly ash, is an indication of the increase of the strength of the soil and the increase of its bearing capacity. The strength of the mixtures tested was much higher than that of the natural soils, in all cases. In general, the strength of soil-fly ash and soil-lime mixtures increased with an increase in the additive content, for all curing periods. For both soils and additives, an increase in curing period resulted to an increase in strength. The increase of the UCS for the soil S1 was greater with the addition of lime (up to 20 times greater than the original), than with the addition of fly ash. The best results obtained when 7% lime was added to the soils and a 90 days curing period followed the compaction of the specimens. This is attributed to less Ca++ and a greater percentage of clay minerals in this soil. The strength increase in soil S2 was greater with fly ash than with lime. This may be due to a higher content in Ca++ and caolinite, as well as to a lower content in swelling minerals. The results showed that the mineralogy of the soil plays a decisive role in the stabilization process and greatly affects the ultimate strength of the mixture. The ultimate strength of the soil after its improvement is adequate for the soil to be used as subgrade or embankment material in main roads, or even as subbase in some secondary roads

Various dewatering techniques which are generally used for ground improvement:

Dewatering Techniques
Widely used dewatering techniques

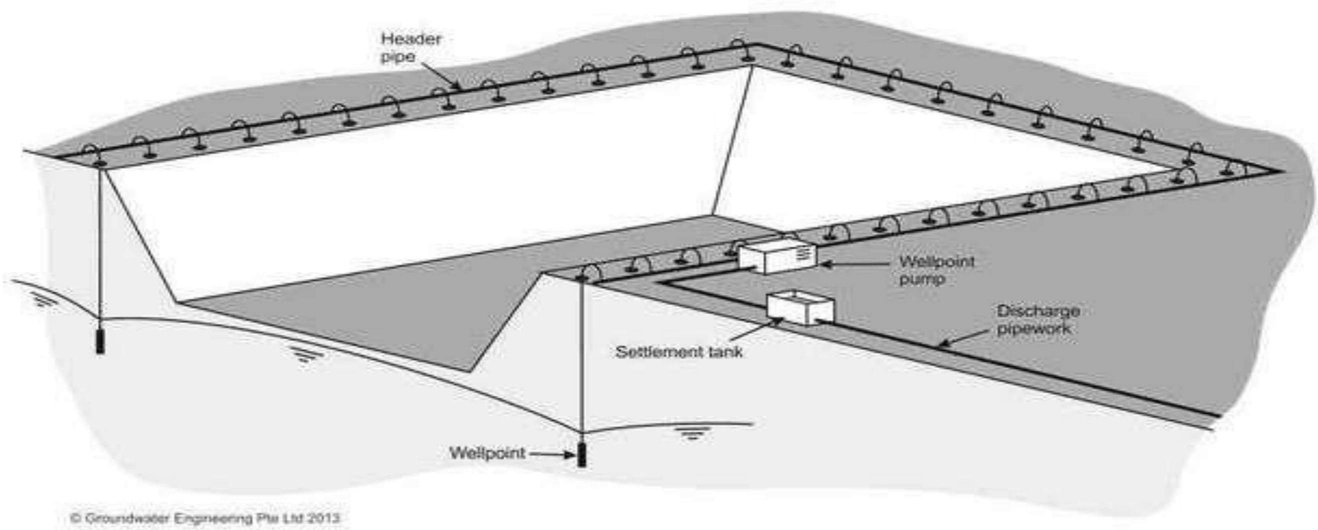
- Sump Pumping
- Wellpoints
- Deepwells
- Ejector wells

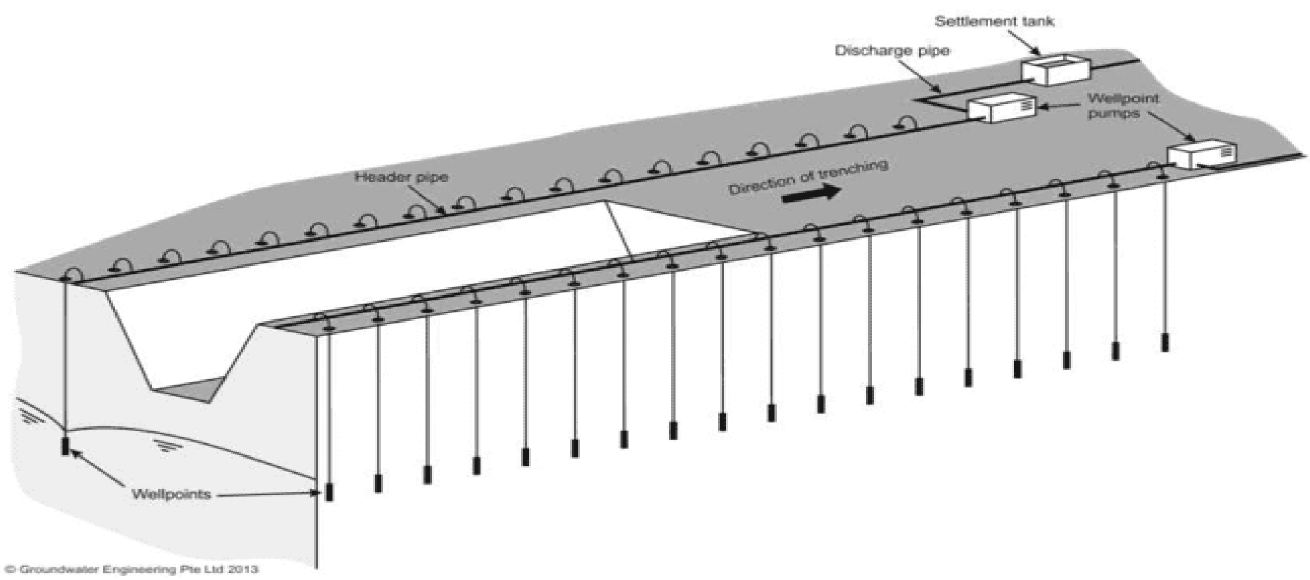
Sump Pumping



- Water is collected in deeper parts of the excavation (called sumps) and pumped away
- Simple and cheap method of dewatering in favourable ground conditions
- Limited to use in relatively coarse soils or fissured rock – if used in fine grained soils can lead to erosion and loss of fines with the risk of resulting instability
- The sump takes up space within an excavation
- Can lead to water pollution problems due to silt-laden water

Wellpoints



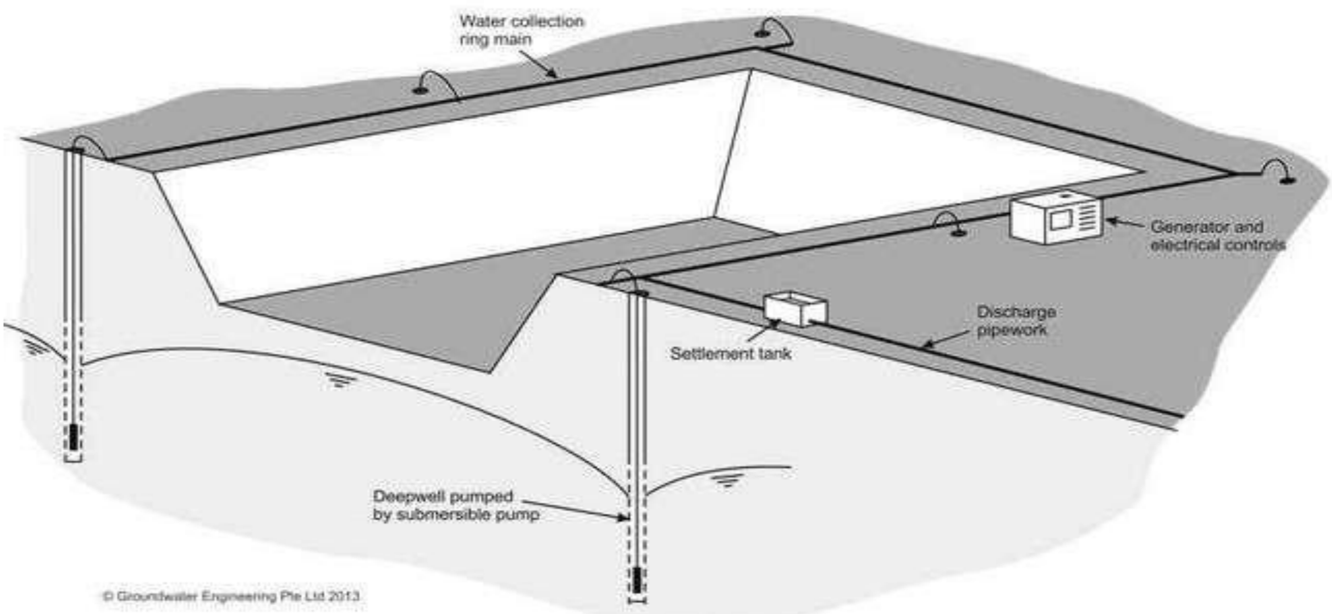


- A line or ring of small diameter shallow wells (called wellpoints) installed at close spacing (1 to 3 m centres) around the excavation.
- Commonly used for dewatering of pipeline trenches
- Can be a very flexible and effective method of dewatering in sands or sands and gravels
- Drawdown limited to 5 or 6 m below level of pump due to suction lift limits

- Individual wellpoints may need to be carefully adjusted

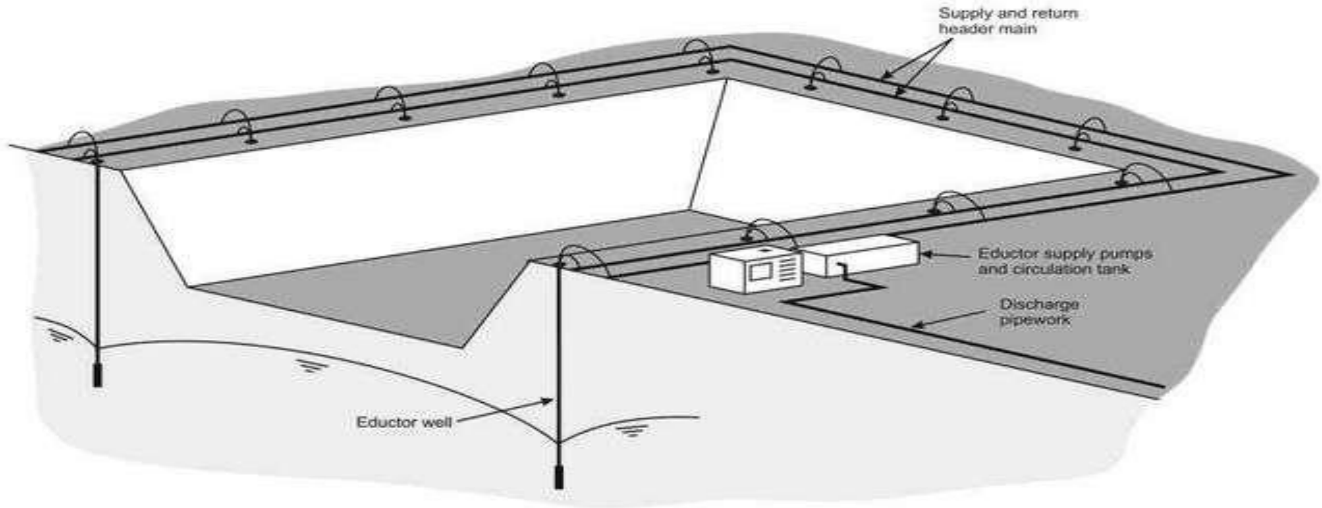
  ("trimming")

<u>Deepwell</u>



- Wells are drilled at wide spacing (10 to 60 m between wells) to form a ring around the outside of the excavation
- An electric submersible pump is installed in each well. Drawdown limited only by well depth and soil stratification
- Effective in a wide range of ground conditions, sands, gravels, fissured rocks

Ejector wells



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- Effective in stabilising fine soils (silts, silty sands) by reducing pore water pressures
- Wells are drilled around or alongside the excavation
- Suitable when well yields are low. Flow capacity 30 to50 litres/min per well
- Drawdown generally limited to 25 to 30 m below pump level
- Vacuum of 0.95 Bar can be generated in the well, making this very effective in low permeability soil

Less commonly used dewatering techniques

- Horizontal wellpoints
- Relief wells
- Artificial recharge
- Groundwater remediation

Q2. (A) What do you understand about soil nailing? Under what condition the soil nailing is preferable?
(B) Discuss the characteristics of a grout where and why grouting is required? What is compaction grouting, discuss the advantages and disadvantages of grouting?

Answer:

Soil Nailing:

Soil Nailing is a technique to reinforce and strengthen ground adjacent to an excavation by installing closely spaced steel bars called "nails", as construction proceeds from top down.

It is an effective and economical method of constructing retaining wall for excavation support, support of hill cuts, bridge abutments and high ways.
The nails are subjected to tension compression, shear and bending moments

Technique came from New Austrian Tunneling Method in 1960.
Stabilization works in underground tunnel in Europe in 1970.
The first recorded use of soil nailing in its modern form was in France in 1972.
The United States first used soil nailing in
1976 for the support of a 13.7 m deep foundation excavation in dense silty sands.

Favorable/Unfavorable Ground Condition

- Critical excavation depth of soil is about 1-2 m high vertical or nearly vertical cut.
- All soil nails within a cross section are located above groundwater table.

FAVOURABLE SOILS

Stiff to hard fine grained soils, dense to very dense granular soils with some apparent cohesion, weathered rock with no weakness planes and glacial soils etc.

UNFAVOURABLE SOILS

Dry, poorly graded cohesion less soils, soils with cobbles and boulders, soft to very soft fine grained soils, organic soils.

Application:

Stabilization of railroad and highway cut slopes.

Excavation retaining structures in urban areas for high-rise building and underground facilities.

Existing concrete or masonry structures such as failing retaining walls and bridge abutments.

Tunnel portals in steep and unstable stratified slopes.

Construction and retrofitting of Stabilizing steep cutting to bridge abutments.

Maximize development space.

B) Characteristics of a grout where and why grouting is required:

Grout is a construction material used to embed rebars in masonry walls, connect sections of pre-cast concrete, fill voids, and seal joints (like those between tiles). Grout is generally composed of a mixture of water, cement, sand, often color tint, and sometimes fine gravel (if it is being used to fill the cores of cement blocks). It is applied as a thick liquid and hardens over time, much like mortar.

Initially, its application confines mainly in void filling, water stopping and consolidation. Nowadays, it extends to alleviate settlement of ground caused by basement and tunnel excavation works, to strengthen ground so that it can be used as a structural member or retaining structure in solving geotechnical problems.

Grouting is the process to inject grout into the ground. Hence, the volume of the ground ready to accept grout is the primary consideration before any other considerations. GROUT can be defined as a solution, an emulsion or suspension in water, which will harden after a certain time interval. It can be divided into two main groups:

a. Suspension Grout

b. Liquid Grout or Solution Grout.

Suspension grout is a mixture of one or several inert materials like cement, clays etc. suspended in a fluid -- water.

According to its dry matter content it is either of the stable or unstable type. Suspension grout is a mixture of pure cement with water.

Liquid grout or solution grout Consists of chemical products in a solution or an emulsion form and their reagents. The most frequently used products are sodium silicate and certain resins.

Use of Grouting in Civil Engg;

Its traceable record can be as early as in the beginning of 1800s.

- In 1802, the idea of improving the bearing capacity under a sluice by the injection of self-hardening cementitious slurry was first introduced
- In 1864, Peter Barlow patented a cylindrical one-piece tunnel shield which could fill the annular void left by the tail of the shield with grout. It is the first recorded use cementitious grout in underground construction.
- In 1893, the first systematic grouting of rock in the USA as performed at the New Croton Dam, in New York.
- In 1960s, jet grouting technique was developed.
- In 1977, first application of compaction grouting for controlling movement during construction of the Bolton Hill Tunnel.
- In 1995, the first industrial application of the compensation grouting concept was conducted at the construction site of the Jubilee Line Extension Project in London.

Compaction Grouting

Compaction grouting involves the injection of a low slump, mortar grout to densify loose, granular soils and stabilise subsurface voids or sinkholes.

Common Use

- Suitable for rubble fills, poorly placed fills, loosened or collapsible soils, soluble rocks and liquefiable soils
- Often selected for treatment beneath existing structures because the columns do not require structural connection to the foundations
- Decrease or correct settlement
- Increase bearing capacity

- Stabilise sinkholes or reduce sinkhole potential

Process:

An injection pipe is inserted, typically to maximum treatment depth, and the grout then injected as the pipe is slowly removed in lifts, creating a column of overlapping grout bulbs. The expansion of the grout bulbs displaces surrounding soils and the grouting increases the density, friction angle, and stiffness of surrounding granular soils.

You can increase effectiveness by sequencing the compaction grouting from primary to secondary to tertiary locations. In all soils, the high modulus grout column reinforces the treatment zone.

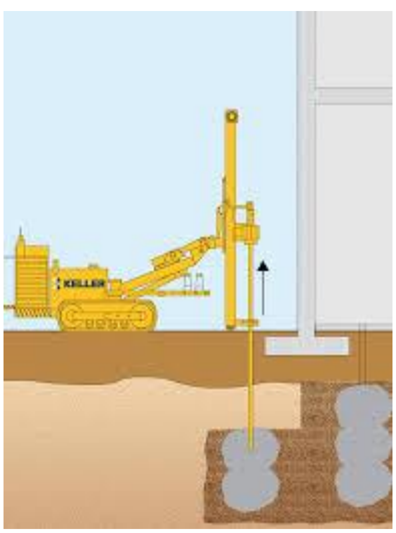
Advantages

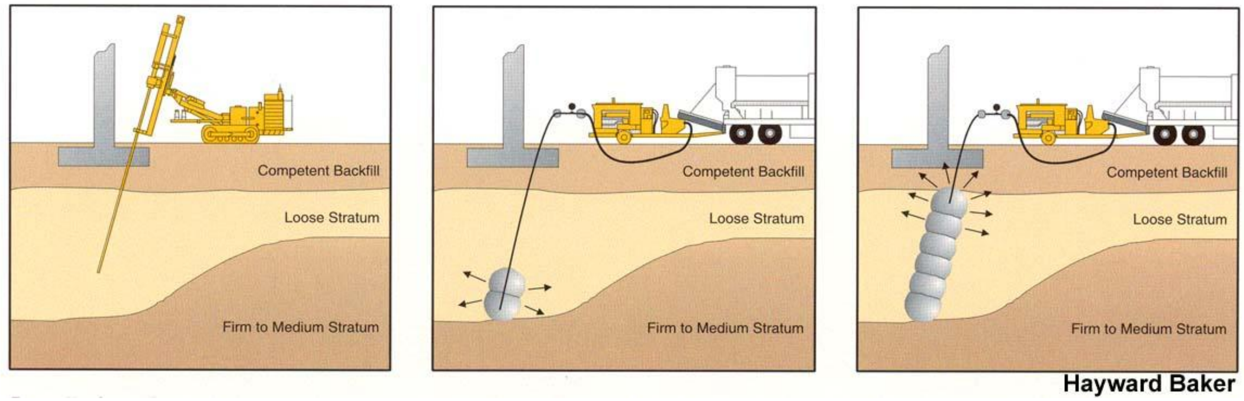
Often more economic than conventional approaches such as removal and replacement, or piling

Can be done where access is difficult and in limited space

Quality assurance

Keller can provide complete solutions which combine compaction grouting with real-time monitoring of affected structures, and has a variety of rig types to accommodate access constraints.





Advantages and Disadvantages of Grouting:

Advantages

In compaction grouting, a grout mixture is injected into the ground at the elevation of the substandard soil, where it then densifies and sturdies the soil. Here are some of the key advantages of this ground-shoring method:

- Compaction grouting causes minimal disruption to the landscape, surrounding soils, and nearby structures.
- This technique can be utilized for projects that have limited access and require more delicate installations.
- It is cost-effective and easy to install compared to some other soil stabilization and ground-shoring methods.
- Engineered Solutions has used this versatile technique on a variety of projects, and it has successfully strengthened ground soils in each instance.

Disadvantages:

Truth be told, there are few disadvantages associated with compaction grouting. It is a very effective, affordable, and practical soil stabilization technique, and many satisfied clients throughout the region have been pleased with the success of this method when installed by Engineered Solutions. The one main disadvantage of this technique is that it is a bit messy and may require cleanup. However, when you work with Engineered Solutions, this is never an issue, as our team strives to leave your property looking as it did when we arrived, only with sturdier ground soils underneath.

If you are interested in the compaction grouting services that we offer to commercial customers in the Chattanooga, TN, area, contact Engineered Solutions today for more information.

Q3. (A) What are the causes for which ground improvement techniquies are under taken?
(B) Identify various geotechnical problem of expansive soil?

Answer:

A) <u>Causes for Ground Improvement Techniques:</u>

(1) To increase the bearing capacity
(2) To control deformations and accelerate consolidation
(3) To provide lateral stability
(4) To form seepage cut-off and environmental control
(5) To increase resistance to liquefaction

Above functions can be accomplished:

- by modifying the ground's character - with or without the addition of foreign material.

The improvement process under the situation when the influence zone is limited to less than 1m (roads etc.) is called surface stabilization.

Geo-Technical process of improving the engineering properties of the soil (density, shear strength, C&O factors are improved while compressibility, settlement and permeability reduced) and making it more stable and durable is called ground improvement.

The ground can be improved by adapting certain ground improvement techniques. Vibro-compaction increases the density of the soil by using powerful depth vibrators. Vacuum consolidation is used for improving soft soils by using a vacuum pump.

Preloading method is used to remove pore water over time. Heating is used to form a crystalline or glass product by electric current. Ground freezing converts pore water to ice to increase their combined strength and make them impervious. Vibro-replacement stone columns improve the bearing capacity of soil whereas Vibro displacement method displaces the soil. Electro osmosis makes water flow through fine grained soils.

Electro kinetic stabilization is the application of electro osmosis. Reinforced soil steel is used for retaining structures, sloping walls, dams etc. seismic loading is suited for construction in seismically active regions. Mechanically stabilized earth structures create a reinforced soil mass.

The geo methods like Geosynthetics, Geogrid etc. are discussed. Soil nailing increases the shear strength of the in-situ soil and restrains its displacement. Micro pile gives the structural support and used for repair/replacement of existing foundations.

Grouting is injection of pumpable materials to increase its rigidity. The jet grouting is quite advanced in speed as well as techniques when compared with the general grouting.

Rapid urban and industrial growth demands more land for further development. In order to meet this demand land reclamation and utilization of unsuitable and environmentally affected lands have been taken up. These, hitherto useless lands for construction have been converted to be useful ones by adopting one or more ground improvement techniques. The field of ground improvement techniques has been recognized as an important and rapidly expanding one.

Latest Ground Improvement Techniques

Following are the recent methods of ground improvement Techniques used for stabilization of soil:

- Vibro Compaction
- Vacuum Consolidation
- Preloading of soil
- Soil stabilization by heating or vitrification
- Ground freezing
- Vibro-replacement stone columns
- Mechanically stabilized earth structures
- Soil nailing
- Micro-piles
- Grouting

Vibro-Compaction Method of Ground Improvement

Vibro-compaction, sometimes referred to as Vibroflotation, is the rearrangement of soil particles into a denser configuration by the use of powerful depth vibration**.** Vibro Compaction is a ground improvement process for densifying loose sands to create stable foundation soils.

The principle behind vibro compaction is simple. The combined action of vibration and water saturation by jetting rearranges loose sand grains into a more compact state. Vibro Compaction is performed with specially-designed vibrating probes. Both horizontal and vertical modes of vibration have been used in the past.

The vibrators used by Terra Systems consist of torpedo-shaped probes 12 to 16 inches in diameter which vibrates at frequencies typically in the range of 30 to 50 Hz. The probe is first inserted into the ground by both jetting and vibration. After the probe reaches the required depth of compaction, granular material, usually sand, is added from the ground surface to fill the void space created by the vibrator. A compacted radial zone of granular material is created

Advantages of Vibro Compaction Method:

- Reduction of foundation settlements.
- Reduction of risk of liquefaction due to seismic activity.
- Permit construction on granular fills.

B) Various Geological Problem of Expansive soil:

Expansive or swelling soil is a highly plastic soil that normally contains montmorillonite and other active clay minerals. Expansive soil is a commonly identified problem which has made scientists concern about the design, protection, and operating of highway and structural systems. Expansive soils can be found in arid/semi-arid areas, where even moderate expansive soils can cause major damages to the structure or in humid environments where just expansive soils with high plasticity index (Ip) can lead the structure to be damaged. The behaviors of an expansive soil can be affected by many factors, among which the principal ones are the availability of moisture, and the amount and type of the clay-size particles in the soil. It is worth mentioning that when the water changes in expansive soil, the volume would be changed as well. These volume changes can lead to either swelling or shrinkage and that is why expansive soils are also known as swell/shrink soils (Ardani, 1992; Day, 2000; Jones & Jefferson, 2012; Zemenu et al., 2009; Ito and Azam, 2010; Liu et al., 2015). Although expansion can be the result of the chemically induced changes, most of the times soils which have swelling and shrinkage behavior contain expansive clay minerals. It can be resulted in the fact that, the more the clay exists in the soil, the higher the soil swells and the more water the soil can absorb. In addition, the more water they absorb, the more their volume increases. In other words, when the water is attracted by these type of soils, they would get increased in volume and hence they would swell. In contrast, the shrinkage happens when the soil gets dry. Researchers have reported the safe expansion percentage equal or smaller than 10% for most of the expansive clays (Jones & Jefferson, 2012). In order to determine the soil shrinkage and swelling amount, the water content in the near-surface zone can be measured. Normally, most of the significant action happens in the depth not more than 3 meters, although if the tree roots exist in the area, this amount can be extended. The characteristics of fine-grained clay-rich soils leads them to be capable enough to absorb large amount of water which makes them to be heavy and sticky. On the other hand, these types of soils can become very hard when they dry, which leads them to shrink and have cracks on their body. This procedure is known as "shrinkageswell" behavior (Jones & Jefferson, 2012). Swelling and shrinkage are not wholly reversible procedure (Holtz & Kovacs, 1981). Shrinkage results in cracks on the body of the soil which cannot close-up completely by re wetting the soil. Therefore, it makes the soil to bulk-out somehow. In addition, it can help the water to penetrate into the soil more easily during the swelling process. It is worth mentioning that when substances like sediment enters the existing cracks in the soil, the soil is unable to get rid of them and go back to its previous situation, hence it will result in the increase in the swelling pressure. Sometimes, the shrinkage cracks may be filled with sediment which leads to the incompatibility of the soil. One of the primary problems with the expansive soil is that deformations are considerably greater than the predicted ones which is obtained from the classical elastic and plastic theory (Jones & Jefferson, 2012). The two major factors in treating expansive soils are: (1) Identifying, and (2) estimating the anticipated potential volume change of the subgrade soils (Ardani, 1992). In this paper, firstly the expansive soil is identified comprehensively. Second, the causes and required treatments for expansive soil is discussed.

Identification of Expansive Soils

The success, safety, and economy of the structure is strongly dependent on the situation of the rock and soil at the place as well as the interaction of the ground materials during and after the construction. Large amount of ground deformations is one of the most significant problems in expansive soils which is the result of swelling and shrinkage of the soil. The excessive movements can lead to both damage and negative impact on the structural performance in terms of cost and time (Reddy et al. 2009). Therefore, identifying the expansive soils can help researchers reduce the imposed damages resulted from the expansive soil to the structure. Identification of the expansive soil can be expressed in the two following categorizations; (1) Those used for mineralogical identification, and (2) those used for direct physical properties (Ardani, 1992). Figure 1 lists the methods used in each group. It is worth mentioning that mineral identification methods are not only too time-consuming, but also requiring special expertise and equipment. Therefore, most experts prefer simple identification tests based on physical properties of the soil.

Mechanics of Expansive Soils

Expansive soils are the ones which generally exhibit a large amount of volume changes due to environmental changes and water absorption of the soil. These types of soils contain clay particles of one or more minerals, which are eager to absorb a large amount of water. When the water is absorbed, these particles grow and hence, the materials containing the clays would have expansion (Ardani, 1992). The soil mineralogy can be explained as the chemical organization of molecules into sheets that results in having the clay smaller than 0.002 millimetre, which have the ability to swell and shrink easily. The clay particles should be made up of many layers, either 1:1 or 2:1. If they are made up of 1:1 clay layers, they would be slightly expansive. On the other hand, if they are made up of 2:1 clay layers, they would be expansive soils. It is important to mention that the non-expansive clay minerals does not exist. Clay minerals can be defined as hydrous aluminium phyllosilicates minerals that are fine grained with sheet like structures and very high surface areas. The clay minerals are the combination of silcon-oxygen tetrahedral, aluminium or magnesium, and the brucite or gibbsite sheet in the octahedral layer (Lucian, 2008). Figure 2 shows the Basic layer structure of a natural clay mineral (Daulton, 2005). Investigation have shown that MONTMORILLONITE minerals have the greatest volume change in comparison to all the other clay minerals. This fact can be expressed as the penetration of the water into the interlayer molecular spaces in MONTMORILLONITE minerals. It is worth mentioning that if the sodium exists in these minerals, it can result in the swelling of the clay multiple times its real volume. The effect of MONTMORILLONITE minerals on expansive soils can be presented by the vertical in situ suction profile (Ardani, 1992). The basic parameters which affect the potential expansiveness of the given soil are: (1) The type and swelling potential of the clay mineral, (2) the moisture content of the soil, and (3) the density of the soil (Ardani, 1992).

Characterization

In order to classify the shrinkage and swelling, the scientists have done many researches to obtain a universally applicable system. Some have even tried to create a unified swelling potential index using commonly used indices (Kariuki and Van Dur Meer, 2004; Yilmaz, 2006) or from specific surface areas (Yukselen-Aksoy and Kaya, 2010), but these are as yet to be adopted. Figure 3 shows the examples of different schemes which are generally used all over the world. Scientists believe that there is still the lack of standard definitions of the swell potential due to the fact that both testing factors and sample conditions vary extensively (Jones & Jefferson, 2012).

Seasonal Variations in Water Content

The seasonal volumetric change of desiccated soil is complex which enhances with severity of the existing shrinkage (Jones & Jefferson, 2012). The vertical in situ suction profile, water content profile and the degree of saturation reflect this fact as it is demonstrated in Figure 4. Here pF is the base 10 logarithm of the water potential in cm. The relative values of suction are dependent on the composition of the soil, specially its particle size and clay mineral content. The soil hydraulic conductivity may fluctuate both seasonally and over longer timescales. It is worth mentioning that fabric changes, tension cracking, and shallow shear failure during the swelling and shrinkage process which may affect the subsequent moisture movements can lead to the secondary permeabilities (Jones & Jefferson, 2012). Expansive soil problems usually happen because of the changes in the water content in the upper few meters, with deep seated heave being rare. The climate and environmental parameters considerably affect the water content in these upper layers. The water content is generally termed the zone of seasonal fluctuations or active zones as shown in Figure 5 (Jones & Jefferson, 2012). In the active zone, negative pore water pressures exist, however, if the surface absorbs extra water or if evapotranspiration is eliminated then water content will enhance and heave will happen. In addition, temperature can influence the migration of water through the zone as it is shown in Figure 5. Therefore, when the site investigation is performed, it is significant to verify the depth of the active zone. The depth of this zone will increase if the drying is greater than rehydration. "Active Zone" have been explained with different meanings which are explained as the followings (Jones & Jefferson 2012):

·Active Zone

The zone of soil that contributes to soil expansion at any particular time.

·Zone of Seasonal Moisture

Fluctuation The zone in which water content change due to climate changes at the ground surface.

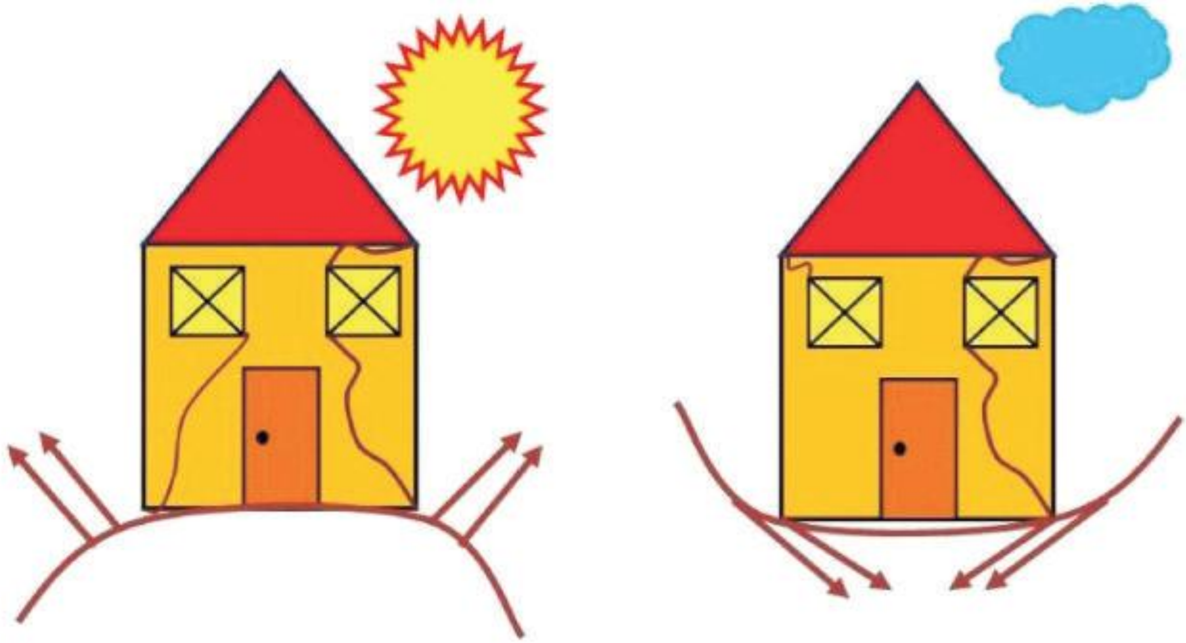
·Depth of Wetting The depth to which water contents have enhanced because of the introduction of water from external sources.

·Depth of Potential Heave

This is the maximum depth of the active zone. The depth at which the overburden vertical stress equals or is greater the swelling pressure of the soil.

Why Expansive Soils Cause Damage?

There are many towns, transport routes and buildings which are located on clay-rich soil and rocks. The clay within these materials is so sensitive to shrinkage and swelling which is due to changes in the water content. This can lead to a significant hazard to engineering construction. Change in water content may be due to seasonal effects which are based on rainfall and evapotranspiration of vegetation, or it might be due site changes such as leakage from water supplier or drains, changes to drainage of the surface and landscaping including paving, or following the planting, removal or severe pruning of trees or hedges, as man is unable to supply water to desiccated soil as efficiently as a tree originally extracted it through its root system (Jones & Jefferson, 2012). The permanent water deficit may grow during a long dry period which leads to the soil higher dry depth than normal and hence, long-term subsidence of the ground. This fact can explain why expansive problems are usually found in arid areas. As this water deficit dissipates, it is possible that long-term heave may occur (Jones & Jefferson, 2012). Pressure resulted from swelling can cause heaving or lifting, while shrinkage can cause differential settlement. In general, when the soil volume changes are unevenly distributed beneath the foundation, failure occurs. For instance, if the water content changes in the soil around the perimeter of the building, it can lead to the swelling pressure beneath it, although the water content of the soil beneath the center of the building stays the same. This results in failure known as end lift. On the other hand, the opposite situation of the end lift is known as center lift, which swelling happens beneath the center of the structure or which shrinkage occurs under the edges (Jones, 2011). Both of the cases are shown in Figure 6. In addition, an example for results in failure known as end lift is shown in Figure 7. Normally, damage foundation due to expansive soil results from tree growth which happens in two general ways, ·Physical disturbance of the ground, and ·Shrinkage of the ground by removal of water. Physical disturbance of the ground caused by root growth is most of the times seen as damage to pavements and Broken walls. Figure 8 shows an example of vegetation induced shrinkage causing differential settlement of building foundation. Vegetation induced changes to water profiles can also have an important effect on other underground feature, including utilities. Clayton et al. (2010) reported monitoring data for a two-year duration of a pipe in London Clay, which led to understanding the significant activities of the ground. These movements are in both vertical and horizontal direction which generate significantly tensile stresses when in the neighbourhood of trees. Such trees induced movement has the ability to be an important contributor to failure of old pipes placed in clay soils near deciduous trees (Clayton et al., 2010). Another case is shown in Figure 9 which the damage is caused by upward soil expansion. In addition, Figure 10 is showing an example of expansive soil problems on the structure of the building.





Methods for Treatment of Expansive Soil

The following methods have been presented for the treatment of expansive soil (Ardani, 1992):

·Sub-excavation and removal of expansive soil and replacement with non-expansive soil.
·Application of heavy applied load to balance the swelling pressure.
·Preventing access of water to the soil by encapsulation.
·Stabilization by means of chemical admixtures.
·Mechanical stabilization.
.Pre-wetting the soil.
·Avoiding the expansive soil.

Stabilization by Means of Chemical Admixtures

In order to change the characteristics of clay mineral and decrease its potential for swelling chemical admixtures can be utilized. Probable materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, chemical grouting, cement, resins or fly ash or bituminous material. The choice of a material or a combination of materials depend on the size and importance of the building and economic consideration of the client. However, the need to strike a proper balance between quality and cost should not be overlooked (Lucian 2008). One of the most effective and economical added materials in stabilizing the expansive soil is lime. The depth of treatment is limited to about 8 to 12 inches by conventional techniques (Ardani, 1992; Calik and Sadoglu, 2014). There are different methods for stabilizing the expansive soil using lime. Ardani has reported two methods of lime shaft and lime-tilled stabilization as the most practical ones used by Colorado DOT. As lime cannot dissolve easily in water, distributing lime through natural soils with water in drill holes have not been successful. On the other hand, lime till stabilization will seal and decrease the swelling potential successfully, if it is combined with the soil to a desirable depth. There have been a numbers of projects which used this method and stabilized the soil by mixing the lime with soil (1 percent to 5 percent hydrated lime) to depth varying from 1 ft. to 3 ft. (Ardani, 1992). Scientists believe that more investigation should perform on understanding of lime-soil interaction due to lacking of enough information. There is still not enough knowledge in estimating the depth of treatment for various expansive soils and appropriate quantity of lime and more research should be done in this area. There are many significant variables which affect this issue which are lime type, soil type, lime percentage, and curing conditions including temperature, time, and moisture. Preferably, the investigation should be based on tests that afford fundamental engineering properties rather than empirical test results (Ardani, 1992).

Mechanical Stabilization

Mechanical stabilization which is also called compaction, is the compression of soil using the application of mechanical energy. Although there would not be much change in water content in this procedure, the densification happens when air is expelled from soil voids. It is important to mention that if significant moisture fluctuations are imposed to these soils, this method may not be valuable. The efficacy of compaction may also reduce with an increase of the fine content, fraction smaller than about 75 µm, of the soil. The reason is that during compaction cohesion and inter particle bonding interferes with particle rearrangement (Little & Nair, 2009).

Conclusion

Expansive soils are one of the most major ground related hazards found worldwide, contributing billions of pounds annually. Expansive soils are found all over the world and are most probable in arid/semi-arid regions, where their high suctions and potential for large water content changes on exposure/deficient which water can cause extensive changes in soil volume. This paper has reviewed the expansive soil and its causes and treatments comprehensively. Based on other researcher's work, the following conclusions has been taken out from their investigations. Removing the expansive soil and replacing with nonexpansive soil can be a reliable cure, however sometimes it is time-consuming and not economical. This method can be valuable in the projects with small amount of expansive soil, but it might cause both problem and a lot of expenses for huge projects. In addition, Granular soils should not be used alone for subexcavation and replacement of the soil as they lead to collection of water at the surface of the underlying in situ materials. Due to higher loading pressure of buildings and structures in comparison to pavements, application of heavy applied load to balance the swelling pressure is more effective for buildings and structures. Hence, it is better this method be used mostly for the structures and buildings. Lime shaft stabilization has not reported a high-quality method for controlling the explosive soil as the lime is only slightly soluble in water and cannot be dispersed enough. On the other hand, Lime till stabilization can be an effective method on sealing and reducing the swelling behaviour only if it is combined with the soil appropriately to a suitable depth. As this method is a very complex one, it needs more research to be done on to recognize the desirable depth of treatment for different expansive soils and pleasant amount of lime. Mechanical stabilization which is the result of the mechanical energy rarely is used and the technique may not be effective if the soils are subjected to significant moisture fluctuations. Ponding has been reported as the most effective applied method for pre-wetting of soil. More research should be done in order to gain the satisfying depth to moisture and also the length of time the material should be ponded. Dry seasons has been suggested as the best time for ponding because the natural cracks are open due to desiccation. Preventing access of water to the soil by encapsulation method can be a satisfactory method if the careful attention is paid to the material which are supposed to be used and also the situation of the expansive soil. The most probable material in this method is Catalytically Asphalt Membranes which mostly is used in pavements and transportation paths. Finally, avoiding the expansive soil is a practical solution, although it can be used only in particular situations.

Q4. A)How stone columns and blasting help soil to stabilize and gain bearing capacity?
B)Which types of ground improvement would be used in black cotton soil and why?

Answer:

A) Stone columns and blasting help soil to stabilize and gain bearing capacity

Stone Column Installation Methods
Stone columns are installed using either top- or bottom-feed systems, either with or without jetted water. The top-feed method is used when a stable hole can be formed by the vibratory probe. With the dry method (top or bottom-feed), the probe is inserted into the ground and penetrates to the target depth under its own weight and compressed air jetting (Taube and Herridge, 2002). Most widely used methods for installation of stone columns are:
• Vibro-Replacement (Wet, Top Feed Method)
• Vibro-Displacement (Dry, Top and Bottom Feed Method) The construction of stone

columns is generally carried out using either a replacement or a displacement method. In the displacement or dry method, native soil is displaced laterally by a vibratory probe using compressed air. This installation method is appropriate where ground water level is low and in situ soil is firm. This method is shown in the Figure 1 and Figure 2. In the replacement or wet method, native soil is replaced by stone columns in a regular pattern where the holes are constructed using a vibratory probe accompanied by a water jet.

APPLICATION OF STONE COLUMNS
Stone column acts as vertical drains and thus speeding up the process of consolidation, replaces the soft soil by a stronger material and initial compaction of soil during the process of installation thereby increasing the unit weight. Stone columns also mitigate the potential for liquefaction and damage by preventing build up high pore pressure by providing drainage path.
Advantages
Weak soil, which has very low shear strength and high compressibility to support structures require strengthening to be capable of carrying loads from structures. Stone columns are ideally suited for structures, because: ∗ To reduction of total and differential settlements. ∗ To reduction of liquefaction potential of cohesionless soil. ∗ To increase the bearing capacity of a site to make it possible to use shallow foundation on the soil. ∗ To increase the stiffness. ∗ To improve the drainage conditions and environment control. ∗ To control the deformation and accelerate consolidation.

Limitations Stone column, when used in sensitive clays, stone columns have certain **limitations.**

There is increase in the settlement of the bed because of the absence of the lateral restraint. The clay particles get clogged around the stone column thereby reducing radial drainage. To overcome these limitations, and to improve the efficiency of the stone columns with respect to the strength and the compressibility, stone columns are encased (reinforced) using geogrids/geocomposites. Deshpande & Vyas (1996), have brought out conceptual performance of stone columns encased in geosynthetic material. Katti et al (1993) , proposed a theory for improvement of soft ground using stone columns with geosynthetic encasing based on the particulate concept.(Malarvizhi, 2004).

Failure Modes of Stone column

Single stone column can be built upon a firm stratum under a soft soil by end bearing capability or as a floating column with tip of column embedded within the soft soil layer. However end bearing columns are more in practice. To make the most optimum application of stone columns, we must understand the various failure mechanisms it can undergo. Four Basic Failure Modes of Stone Columns are:

∗ General shear failure.

∗ Local shear failure.

∗ Bulging failure.

∗ Failure by sliding. Bulging can be encountered as the main factor to influence the failure in stone column, generally it is believed that if the length of column exceeds 2-3 times of the diameter of column, then bulging happens surely. The modes of failure of Stone Columns depend upon the following parameters:

∗ Type of Stone Column (End-bearing or Free Floating).

∗ Type of Loading on columns. ∗ Passive resistance of tributary clay.

Blasting method

Blasting is the use of buried explosives to cause the densification of loose cohesion less ground. The principal is that the blasting of explosives in a predetermined pattern causes liquefaction, followed by the expulsion of pore water and subsequent densification of the ground. Blast densification is being utilized for more than 80 years to densify loose, saturated sand deposits.

The aim of this ground-improvement technique is to densify and improve the engineering characteristics of loose sand deposits and thus prevent or minimize the effects of liquefaction during an earthquake. The liquefaction of loose, saturated sands due to seismically induced ground motions continues to be the major source of damage to facilities and loss of human lives after severe earthquake events.

Procedure of the blasting for ground improvement

- Series of boreholes are drilled and Pipe of 7.5 to 10 cm is driven to the required depth

- The detonator and the dynamic sticks are both enclosed in a water proof bundle and is lowered through casings
- Casing is withdrawn and a wad of paper or wood is placed against the charge of Explosive (To protect it from misfire)
- Boreholes are backfilled with sand to obtain full force of blast
- The charge is fired in definite pattern
- Blasting is more effective in loose sands that contain less than 20% silt and less than 5% clay. In case of partial saturated soil, the capillary action obstructs the densification tendency by preventing soil particles to come close. So this method is not useful for partial saturated soils. When deeper deposits are in question, the blasting is done in stages. Repeated shots are more effective than a single larger one.

B) **Which types of ground improvement would be used in black cotton soil and why:**

In order to achieve the above objective, the black cotton soil has been arbitrarily reinforced with lime. So the suitability of lime is considered to enhance the properties of black cotton soil. A cycle of experiments such as Liquid limit test, Plastic Limit Test, Permeability test, California bearing ratio test (CBR) test, unconfined compressive strength and Hydrometer test is carried out on black cotton soil sample with different percentages of lime. They are performed to study the variation in bearing capacity and other properties like liquidity and plasticity behaviour, and compaction behaviour are also studied. The CBR test is carried out to access the suitability of this composite for a road sub grade material. As a reference test for making evaluation, the above mentioned tests are also carried out for raw soil sample.

Soil Stabilization

Soil stabilization with lime can be done by mixing dosage of unsoaked lime into damp soil creates both immediate and medium – term effects. Some of immediate effects are: Drying: On mixing, there is immediate exothermic hydration reaction. It reduces water content with further reduced by aeration of soil. Water – fall percentage varies by 2 to 3 % of added lime.

Flocculation:

Mixing affects the ultrasonic field between clay particles which changes to granular structure. Reduction in Plasticity Index (PI): It switches from being plastic to stiff and grainy. Improvement in bearing capacity: After two hours of mixing, CBR of a treated soil is between 4 and 10 times higher than that of an untreated soil. The reaction greatly relieves on –site transportation difficulties. 2.2 Soil Lime Stabilization

Basic Properties of Soil Lime Mix Soil

– lime has been widely used as a modifier or as a binder. Soil

– lime is used as modifier in high plasticity soils. Soil

– lime also imparts some binding action even in granular soils.

It is effectively used in expansive soils with high plasticity index.

Factors Affecting the Properties of Soil with Lime

Lime Content: Generally increase in lime content causes slight change in liquid limit and considerable increase in plasticity index. The rate of increase is first rapid and then decreases beyond a certain limit upto lime fixation point.

Types of Lime:

After long curing periods all types of limes produce some effects. However the quick lime has been found more effective than hydrated lime. Calcium carbonate must be treated at higher temperature to form quick lime calcium oxide. Calcium oxide must be slaked to form hydrated lime.

Curing: The strength of soil – lime increases with curing period upto several years. The rate of increase is rapid during initial period. The humidity of the surroundings also affects the strength.

Additives: Sodium metasilicate, sodium hydroxide and sodium sulphate are found to be very much useful.

Lime Meets the Construction Challenge:

Using lime can substantially increase the stability, impermeability and load bearing capacity of the subsurface.

Facts: One million metric tons of lime used annually in the US for soil modification and stabilization.

Black Cotton Soil

Black cotton soil (BC soil) is a highly clayey soil. The black colour in Black cotton soil (BC soil) is due to the presence of titanium oxide in small concentration. The Black cotton soil (BC soil) has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in colour. Expansive soils are the soils which expand when the moisture content of the soils is increased. The clay mineral montmorillonite is mainly responsible for expansive characteristics of the soil. The expansive soils are also called swelling soils or black cotton soils. The structures on Black cotton soil (BC soil) bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. The physical properties of Black cotton soil (BC soil) vary from place to place 40 % to 60 % of the Black cotton soil (BC soil) has a size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 % to 300% and results in swelling pressure as high as 8 kg/cm2 / to 10 kg/cm2 . As such Black cotton soil (BC soil) has very low bearing capacity and high swelling and shrinkage characteristics. Due to its peculiar characteristics, it forms a very poor foundation material for road construction. Soaked laboratory CBR values of Black Cotton soils are generally found in the range of 2 to 4%. Due to very low CBR values of Black cotton soil (BC soil) excessive pavement thickness is required for designing for flexible pavement. Research & Development (R&D) efforts have been made to improve the strength characteristics of Black cotton soil (BC soil) with new technologies. The construction of foundation for structure on black cotton soils poses challenge to civil engineers.