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SOIL STABILIZATION

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The subject of soil stabilization has been reviewed. The various stabilizing agents and the different methods of soil stabilization have been considered. Soil stability is dependent on the two important properties of soils-cohesion and internal friction. A proper adjustment of these two properties and also water proofing are the main lines of approach to the problem of soil stabilization.

The different methods of soil stabilization are based on the following principles (1) Mechanical, (2) Physical, (3) Physico-chemical and Colloid-chemical. The mechanical methods are drainage, compaction and vibration. The physical methods are mixing of soils to improve grading, electrosmosis and freezing. The physico-chemical and colloid-chemical methods consist in the use of soil cements, deliquescents, bitumens, waxed paraffin oils, resins, cement grout and sodium silicate.

Introduction

Soil stabilization is the process by which certain properties of soil are improved in order to make the soil serve better as a foundation or construction material. The stabilization process may be either physical or chemical.

Soil stabilization consists not only in improving the physical properties such as compressive strength and shearing resistance but also in providing a defence mechanism against the detrimental effects of weather and microbial activity.

Soil Stability

Soil stability in the engineering sense denotes the maintenance of a reasonably high bearing power. The bearing power connected with volume and shape of a soil is a function of its shearing resistance. For sandy soils which are non-cohesive, shearing resistance=normal pressure × coefficient of friction, whereas, for clay soils which are cohesive, shearing resistance= cohesion. For intermediate soils however shearing resistance=cohesion+ (normal pressure×coefficient of friction).

Different methods of soil stabilization

Internal friction in the engineering sense is a property of coarse grains such as sand and gravel while cohesion is due to clay. Friction is practically independent of moisture whereas cohesion is governed by it. Purely frictional material has no stability unless it is under a confined pressure. Purely cohesive material may have extremely high strength when dry and practically none when wet. These facts indicate the main lines of approach to the problem of soil stabilization 1) Supplying cohesion to purely frictional soils. 2) Supplying friction to purely cohesive soils. 3) Water-proofing of cohesive soils. In addition, stabilization should provide a defence mechanism against the adverse effects of climate.

Classification of stabilization methods

Several attempts have been made to classify the soil stabilization methods both from the engineering and scientific point of view (11). The classification based on the following principles is however useful :—

(1) Mechanical.

(2) Physical.

(3) Physico-chemical and Colloid-chemical.

In practice every soil stabilization method may involve any one, two or all the three principles.

Uses of stabilized soil

Stabilised soil is used as surfacing for low cost roads, farm yards and store yards. It is also used as sub-base for roads, footpaths, cycle tracks, play grounds, car parks, aerodrome runways, farm yards and store yards. Soil stabilization is adopted for the formation of embankments, filling in behind retaining walls, over arches and culverts.

Subgrade is the foundation for a pavement. When the virgin soil itself is used as a support for the pavement, its surface is called subgrade. Sometimes special subgrade layers are used. Ordinarily the subgrade is 1-3 feet thick for highways and 1-6 feet thick for runways.

Requirements of a subgrade are strength, rigidity, incompressibility, freedom from swelling, shrinking and frost action. Strength and rigidity depend upon dry density and water content. In cohesionless soils, water is of little importance but in cohesive soils it has a marked influence.

MECHANICAL METHODS

Drainage

Water is the greatest enemy of subgrades and pavements, as it produces loss of strength, increase in volume and the possibility of frost action. Entry of water can be prevented by suitable drainage. Introduction of a layer of coarse sand between subgrade and the underlying soil and between subgrade and surface can prevent capillary rise of water from below.

Drainage always improves the strength of saturated soils whereas dry soils lose their strength by saturation. Therefore, the process of providing adequate drainage could be a natural and effective process of improving the strength of soils. In providing drainage, it is necessary to prevent the water from carrying away the soil with it, otherwise it leads to internal erosion. Suitable filters are employed to check this erosion.

In the case of roads and runways it is very necessary to have a dense subgrade before the pavement is built. Densification is effected by the removal of water by adequate drainage and evaporation. Many road failures are due to softening of the subgrade by water which occurs in the absence of proper drainage.

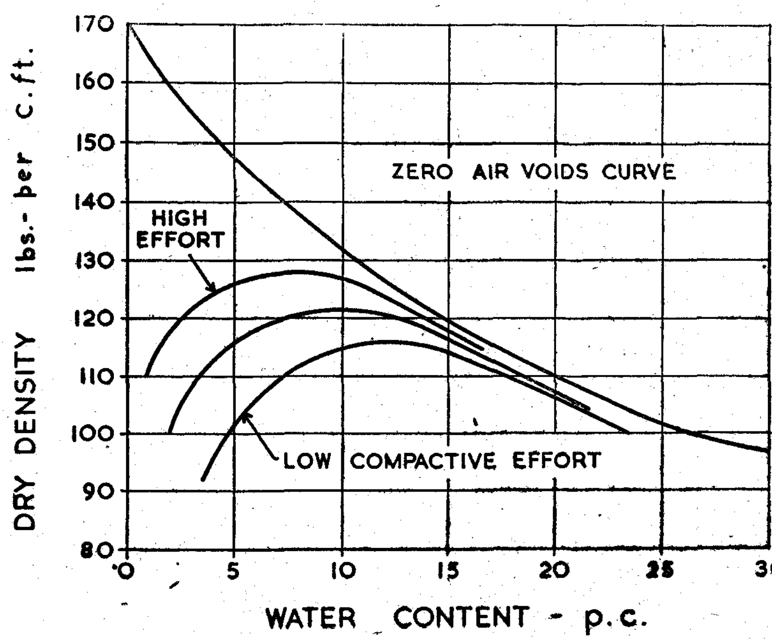
In the case of deep deposits the most effective way of dealing with the water is to catch it in a ring of wells round the site. This method is very useful in excavating the soil in the site.

Compaction

The strength of a soil depends on its water content and its pore volume. Smaller the pore volume and lesser the water content (up to a limit), the stronger is the soil.

Compaction generally increases the density of partially saturated soils. This is followed by an increase in cohesion and internal friction. There is also a decrease in pore volume and its accessibility to water. Compaction is usually adopted in densifying the subgrades of roads, runways, embankments and it is effected by rollers and rammers. For obtaining high density, the soil should be compacted in thin layers.

Another important factor in compaction is the moisture content of the soil. Figure I, indicates that there is an optimum value of the water content for which maximum density can be obtained on compaction. For obtaining the greatest efficiency, compaction must be effected by roller or rammer at this optimum water content. The optimum water content can be determined by the Proctor test.



Moisture-Density curves for different compactive efforts.

For a given soil the greater the dry density smaller is the pore volume regardless of water content. So, maximum dry density is just another way of expressing minimum porosity. For any given water content, perfect compaction would expel all air from the soil and produce saturation. If dry densities corresponding to saturation at different water contents are plotted, zero-pore curve is obtained. It represents the theoretical densities obtained by perfect compaction at different water contents.

If in the method of compaction, the compactive effort is varied, different moisture-density curves are obtained in which the maximum for water shifts. Greater the compactive effort, lesser is the optimum moisture for any soil. For maximum compaction the compactive effort required depends upon the moisture content.

Slightly cohesive soils are compacted by pressure which brings the soil grains closer together. If the force is too great it produces shear failure and a loose soil. For sand and gravels the maximum density is at 8-10 per cent water. For cohesive soils it is roughly 3-4 per cent lower than the plastic limit.

Compaction of a cohesive soil can also be effected by saturating the soil with water and subsequent drying. The force of capillary tension usually brings about compaction. However, this process results in extremely erratic compaction with soft soupy pockets and large cracks in the dried mass. Besides, the method is very slow. Cohesive soils generally require very high pressures for compaction.

Swelling, shrinkage and loss of strength are caused by changes in water due to flooding or prolonged wet or dry seasons.

In preparing the subgrade for roads and runways different types of rollers such as smooth, rubber tyred and sheep's foot rollers are used. In general, the heavier the roller, the better the compaction. For sandy soils vibrating rollers have been developed. For bridge abutments soil compaction is effected by rammers.

Vibration

Deep deposits of loose sands are difficult materials to work with and these may be stabilised by increasing the density by vibration. The vibration may be caused either by explosives or pile-driving. With cohesive soils, vibration method has little effect.

Cohesionless soils become dense when their grains assume new positions reducing the pore space between them. Static pressure is practically useless in compacting cohesionless soils because the grains just wedge against one another and refuse to move. Vibration accompanied by light pressure is very effective and severe shocks produced by impact of a heavy object on the soil surface can increase the density to depths of several feet. If the cohesionless soil is slightly moist, the capillary tension of water film may prevent the effect of vibration. Saturation of the sand however eliminates the capillary tension and permits satisfactory compaction.

Pile-driving is a very effective way of compacting loose and cohesionless soils over great depths. The method is slow and expensive.

The vibroflotation method for sands employs a gigantic vibrator, resembling a concrete vibrator. Water jetted from within the vibrator loosens the sand and the vibration compacts the loosened sand to very dense state.

Jetting and flooding have been used successfully in cohesionless soils of high permeability.

PHYSICAL METHODS

Mixing of soils to improve grading

Stability under both wet and dry conditions can be attained by a proper blending of cohesive soils with granular soils (2). The shear strength of a graded cohesionless soil containing coarse, medium and fine particles is invariably greater than that of a soil in which the particles are uniform in size. In a graded soil the smaller particles fill the pores between bigger particles and thus a high density results. Standard grading limits have been laid down by the American Society of Testing Materials. Well graded soils compact easily and provide high strength. If a soil is poorly graded, it is often possible to mix it up with a soil from another source in order to bring the mixture to the standard grading.

Thus cohesionless soils can be stabilised by adding cohesive soils. Actually in the mixture a crude clay concrete is formed clay acting as a binder. The proportion is fixed by actually testing the strength of the mixtures. To preserve the stabilisation in dry weather, treatment with calcium chloride is necessary. The biggest drawback is the extreme susceptibility of the mixture to frost action.

Proper grading of soils is usually determined by employing sieves and sedimentation. Similarity in the gradation of two soils as determined by sieving and sedimentation does not give any information about such important properties as hardness and angularity of the coarse fractions or shape and minerological and chemical composition of the finer fractions. Hardness and angularity are important for the mechanical stability of sand and gravel whereas the shape and minerological and chemical composition of the clay particles determine the water affinity and the swelling properties of clay.

The method of mixing soils to improve grading is ordinarily limited to surface deposits.

Electrosomosis

In excavations in silty soils, stability can be attained by causing the pore water to flow from the excavated area. On account of the low permeability natural drainage is very slow. This can be hastened by electrosomosis. The passage of electricity causes the soil water to flow from the anode to the cathode, the latter of which is generally a perforated tube. As the water collects in the tube it is pumped out. Several large scale instances of electrosomotic stabilization employed in Germany have been quoted by Casagrande. The method is very interesting, comparatively inexpensive and is conveniently applicable even to very deep deposits.

Freezing

In the silt range, the porosity is very low and therefore the method of injecting stabilizing agents into the soil is not practicable. The ground may be stabilized by freezing the pore water. This method is very costly and is also slow, ordinarily requiring several months to freeze the ground. This method can be successfully applied to any saturated soil and is successful as long as the ground is kept frozen. On account of its limitations, the method is restricted to special cases.

PHYSICO-CHEMICAL AND COLLOID-CHEMICAL METHODS

oil cement

Soil cement is produced by mixing portland cement with natural soil (3). The use of soil cement dates back to Roman times when naturally occurring cements were mixed with soil to provide foundations for roads. When the grading of a soil is poor the cement acts as a binder and the soil with cement will have new properties.

In fixing soil-cement ratio it is necessary to take into consideration the water content, organic matter and sulphates present in the soil. To stabilize a silty sand, a larger amount of cement is required than for sandy gravel. To stabilize clay a large quantity of cement is required. In fact, owing to the main difficulty of mixing, no successful method of stabilizing clay has so far been developed.

The amount of cement ordinarily required for stabilization varies from 8-12 per cent. The amount of cement required is determined by crushing tests on compacted samples containing different amounts of cements. The strength increases with cement and the amount of cement giving a seven day strength of 250 lbs/sq. inch is usually taken as the standard. Satisfactory compaction is important. The water-cement ratio cannot be specified as the amount of water required in the soil for good compaction is very much greater than what is required in the making of good concrete.

Soil cement has been used successfully in the construction of roads, air port bases, as an excellent foundation for concrete pavements. Recently in India, the Government have built over four thousand houses in East Punjab making use of soil cement (6). An excellent account of the role of surface-chemical factors in the hardening of soils by cement has been given by Winterkorn and coworkers (13).

Deliquescents

Deliquescents like calcium chloride, tend to absorb moisture from the atmosphere. Addition of calcium chloride to soil consequently prevents drying out and shrinkage of soil during summer months. In cohesionless soils like sands and silts it produces moisture films which improve the shear strength whereas in cohesive soils it prevents dust. These effects however are temporary and the treatment will not prevent the soil from absorbing water and becoming soft during rainy season.

Though pure calcium chloride is a deliquescent, as a part of soil it may not retain this property fully because a portion may remain in solution as calcium and chloride ions. Calcium may also undergo exchange reaction with soil.

Sodium chloride and sea water when added to soil not only enhance water retaining capacity but also disperse clay leading to increased density and decreased permeability.

Bituminous binders

Bituminous materials have been used to improve the shear strength and reduce the sensitivity of the soil to changes in water (10, 12).

Bitumen when used as a stabilizing agent may act as a binder or as a water-proofing material. Soil-bitumen systems have found the greatest use in the construction of road bases and surfaces.

If a soil is of the cohesive type it possesses satisfactory bearing capacity at low moisture contents. In such a soil bitumen is incorporated as a water proofing agent to maintain a low moisture and adequate bearing capacity. If a soil is of non-cohesive granular type bitumen is incorporated to act as a binding or cementing medium.

The bitumenous materials employed are of two general types asphalts and tars. These are introduced into soil either in solution or in the form of emulsion. Emulsion form is better than solution as in the former form bitumen adheres to the moist soil particles much better.

For stabilization and impermeabilization of foundations, levees and similar structures, bitumen emulsions may be incorporated by injection method. The size and electrical properties of the bitumen globules should be in conformity with the porosity of the soil.

Waxed Paraffin Oil

The petroleum oil containing about 4 percent paraffin wax has been used in the last few years for the stabilization of subgrades (9). The purpose of this stabilizer is not to increase the shear strength but to maintain the existing strength of the soil by water-proofing. Water-proofing is effected by the formation of an oil film of molecular thickness at the air-water interface in the soil pores. The film restricts the movement of water in the soil and thus prevents it from softening in wet weather (4).

Resins

The use of finely ground resins in soil stabilization is increasing during recent years. The introduction of water-proofing material such as vinsol resin into surfaces and subgrades to prevent changes in water content that destroys stability has proved successful.

Resins are ineffective in strongly alkaline soils but such alkalinity can be corrected by the addition of a small quantity of aluminium sulphate. Resin binders are spread or added to the soil in either powder or liquid form. The quantity required is smaller than portland cement and bitumen. Another advantage of resin as a stabilizer is that the mixture of soil and resin is less affected by weather.

The method however is expensive. With the discovery of cheaper and more effective resins the method may become more widespread.

Cement Grout

The process of pumping cement grout has been successful in stabilizing sandy and granular soils. This process reduces the permeability and is applicable only to sandy soils as it is essential for the cement to permeate freely through the pores and fill them up. As the cement sets the shear strength increases and the ground is transformed into an artificial sandstone.

The method of cement grouting is very useful in deep excavations such as tunnels and in producing an impermeable curtain under dams founded on fissured rocks.

Cement grout injection method is applicable to soils of pore size larger than ·1 mm and can be adopted for deep deposits.

Sodium Silicate

The method of cement grouting is not applicable to soils which are less sandy and in which the pores are fine. Cement has the tendency to agglomerate at the point of injection. Therefore for soils of low porosity, sodium silicate (water-glass) has been used. Incorporated with sodium silicate is a second compound which precipitates silica gel after a short interval of time. Alternatively the two may be injected separately. The two-fluid process gives the soil a higher shearing strength than the single fluid process. Like cement grout, water glass injection method is adoptable for stabilisation of deep deposits.

PAVEMENTS OF ROADS AND RUNWAYS

The subject of roads and runway construction has rapidly developed during recent years. A runway differs from a road in having a greater thickness of construction in order to enable it to carry greater loads. The function of the pavement is to distribute the stresses caused by the wheels such that shear failure and deformation of the subgrade are avoided. Obviously a week foundation needs a thick pavement. Therefore to save in the costly pavement, it is economical to strengthen the sub-grade. Compaction of the subgrade would be a good investment.

There are two common types of pavements the "rigid" and the "flexible". The former of these is of concrete and the latter of macadam. The importance of soil stabilization in the construction of aerodrome runways all over the world has resulted in a great increase of research in this subject.

FROST HEAVE

In soils exposed to extreme climates, frost will have serious effect on foundation soils. When the temperature is below 0° c the pore water freezes. The expansion causes rise of the ground surface and this is known as frosted heave. Subsequent thawing is equally harmful.

In a long cold spell of winter the frost may extend down to depth of 12 inches in the ground. The frost heave in such a case is not merely due to the expansion of frozen water in this layer but also due to larger expansion caused by the formation of ice lenses in the soil. The lenses develop horizontally and may be ordinarily few inches thick. The extra water required for the formation of these lenses is sucked from below the zone of freezing.

The mechanism of the formation of these ice lenses is interesting. In a fine grained soil, as the freezing commences from the top, water is drawn from the water table below and ice lenses begin to grow. One important condition favourable for the formation of the ice lenses is that the soil should be fine grained in order to allow the capillary water to rise. In coarse sand and gravel the capillary effect is negligible and therefore there is no ice lense formation. In clay the permeability is poor. It retards the passage of water in the limited period of cold spell. Silts and fine sands are the most likely to be effected by frost.

The remedy against frost heave is to replace the soil in the formation layer which is usually about 12 inches in thickness. The alternative method is to keep the ground water level as low as possible by good drainage. Yet another method in the case of roads is to place a layer of gravel between the silt and the water table.

The main damage of frost heave is not during the ice lense formation but it is during the subsequent thawing. As the lense melts the whole foundation loosens. Frost action should be guarded against in the constructions of roads runways, retaining walls etc.

In places like Alaska and Siberia, soil remains frozen permanently to depth of several hundred feet and only the top few feet over thaw. Important structures in such places must be founded deep in the permanently frozen ground.

In northern parts of United States frost heave is as great as 60 inches. The amount of heave is rarely uniform and the force exerted by the expanding soil may lift roads, walls and buildings. Frost heave is particularly damaging to highways and air field pavements as they are generally built directly on the ground. Unequal heaves can crack concrete pavement slabs. Heave beneath flexible pavements causes bumps and waves on the surface. Small structures with shallow foundations such as small bridges, culverts, walls, sewer inlets and light buildings often suffer if their foundations are above soils which are subject to frost heave.

CONCLUSION

By the rapidly growing need for more aerodromes and highways during the war years and the expansion of civil aviation in the following period, research into the methods of soil stabilization and discovery of new and more effective stabilizing agents was largely stimulated by the joint efforts of the scientists and engineers. The discovery of more powerful stabilising agents has cut down proportionately the bulk of the material involved and this in turn has improved the case of transportation.

About the use of inorganic and organic chemicals like sodium silicate and salts of bi and trivalent cations, there is difference of opinion about their efficacy. They are however satisfactory for deep foundations and treatment of earth dams but unsuccessful for shallow soil stabilization.

The more interesting development is in activating bituminous materials and making them better stabilising agents by adding small amounts of derivatives of rosin, natural and synthetic resins.

Injection methods have the advantage of effecting stabilization at great depths for which the usual methods of surface stabilization are not easily applicable. Injection methods are more for reducing permeability than adding strength. Injection stabilization is a highly technical type of work. An excellent treatise on the theory and practice of injection stabilization has been published by Kollbrunner and Blattner (5).

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