SOIL IMPROVEMENT TECHNIQUES

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RINGKASAN

Masalah tapak bina semasa dan setelah siap pembinaan sesuatu projek adalah banyak. Kehadiran air tanah, darjah pengkemasan dan perlekatatan antara zarah serta kepenuhan liang mempunyai pengaruh yang besar dalam sifat dan kelakunan tanah. Terdapat beberapa cara memperelokkan tanah dan usaha telah dibuat, menerusi kertas kerja ini, untuk menerangkan penggunaan kawalan air tanah, pengkemasan cara mekanikal dan penggunaan bahan kimia dalam pengelokan tanah. Namun demikian pemilihan sesuatu cara tertentu bergantung kepada jenis tanah yang terdapat di kawasan pembinaan itu.

SYNOPSIS

The foundation problems faced during and after finishing the construction of a project are numerous. The presence of groundwater, the degree of densification and particulate cementation and void filling have immense contribution in the soil characteristics and performance. Several techniques of soil improvement are available and attempts have been made, in this paper, to explain the utilisation of groundwater control, mechanical means of densification and the usage of chemicals in the treatment of soils. The choice of a particular method is dependent on the type of soil available at site.

Introduction

The construction activities are done on, in or with soils. As the availability of suitable construction sites decreases, the need to utilize poor soils for foundation support and earthwork construction increases. In addition, it is becoming increasingly necessary to strengthen the ground under existing structures to ensure stability against adjacent excavation or to improve resistance to vibratory, seismic or other special loadings. Furthermore, many hundreds of recent successful projects have shown that through the use of suitable reinforcement materials and systems, the use of nature’s most abundant material – soil – can be greatly extended.

The basic concepts of soil improvement; namely drainage, densification, cementation, reinforcement, drying and heating, were developed hundreds or thousands of years ago and remain valid to-day. The coming of machines in the nineteenth century resulted in vast increases in both the quantity and quality of work that could be done. Among the most significant development of the past
fifty years are the introduction of vibratory methods for densification of cohesionless soils, new injection and grouting material and procedures, and new concepts of soil reinforcements.

The aim of this paper is to synthesize the present state-of-the-art of soil improvement into a form presumably suitable for direct application. Because of the extensive scope of the subject, brief coverage of the areas will be discussed.

METHODS AND SCOPE

Groundwater Control

Open excavation may be straightforward or difficult, depending on the soil and groundwater conditions. Terzaghi (5) postulated that with no water in soils there would be no soil mechanics.

There are two cases to be considered here, (a) the case of an excavation into a sandy soil penetrating below the level of groundwater, and (b) the case of a sheeted excavation through an impermeable bed into sand charged with water under pressure.

Considering case (a); unless precautions are taken, the size of a hole dug in a fine sand below water level will begin to slump soon after excavation penetrates below water level. As digging continues, the slumping becomes progressively worse as seepage carries fines, from the ground into the excavation, and the sides of the excavation become unstable and collapse.

Now consider case (b); if without taking any precaution, a cofferdam or braced excavation is sunk through clay into an underline aquifer of sand containing water under pressure, then there will be a sudden in rush of water and sand at the point when the upward pressure of water at the toe of the piles exceeds the downward weight of the remaining soils within the excavated area. This can be prevented either by having a sufficient penetration of the piles or by reducing the pressure head in the aquifer beneath the cofferdam or braced excavation.

It follows, therefore, that in order to avoid unstable ground conditions it is necessary to control groundwater in the neighbourhood of a proposed excavation. Groundwater control may be achieved by:

1. Some geotechnical process which more or less permanently excludes groundwater from a proposed foundation area by forming a relatively impermeable barrier around the area; e.g. sheet piling, grouting in a diaphragm wall.

2. Some geotechnical process which lowers the water levels or water pressures either temporarily or permanently in the region of a proposed foundation area.

The summary of the main methods of groundwater control are given in Table 1.
Improving Soil Properties Using Chemicals

In this case the soil properties are changed by a chemical reaction and the job, usually referred to as chemical stabilization, has a wide coverage which includes grouting processes and soil cement. In stricter sense it covers the mixing of commercial chemicals with soil to produce strong or impermeable layers. Most chemicals are expensive in comparison with Portland Cement and bitumen so that the advantages gained in properties are invariably outweighed by cost. The latter cost may in turn be increased by the problems of mixing in site as the soil concerned may be of a difficult consistency. Grouting and cement are discussed separately below.

Soil Cement

The economy of stabilization of soil by cement depends upon the fact that aggregate does not have to be imported to the site. The proportion of cement required is about 10% of the soil which approaches the cement-aggregate ratio for a low-strength concrete. Where cohesive soils (clays, silts) are cement stabilized, the strength is very much lower than stabilized sands and gravels and the resultant layer should be regarded as a sub-base rather than a base. Soil cement was developed as an alternative to a compacted gravel sub-base for those territories where the cost of hauling aggregates several hundred miles outweighs the use of cement to stabilize the local soil. For road purposes it requires base and wearing coats. It behaves as a flexible (i.e. non-tensile) material but is inferior to a good compacted gravel.

Cement or lime treatment of the top 200 mm of subgrades of cohesive fine granular soils is applied in some European highways and railways. The main benefit is to allow construction traffic to move on the site at an early stage of work. There may be some long term protection from weathering and leaching effects due to the provision of extra calcium ions during the treatment.

Filters

This is a material sufficiently fine to prevent the passage through its voids of particles of the material against which it is laid out but coarse enough to dissipate seepage pressure in the water flowing towards it. It should not erode internally nor migrate into drainpipes or other apertures. Filters can have their grading designed for specific sites for the general problem of protection against cohesive soils. D, size need not be below 0.1 mm. That is, a fine sand is adequate for static conditions, for example behind a retaining wall.

Various design criteria have been proposed mainly as the result of past experimentation by United States Government agencies. More recently work in Czechoslovakia and East Germany has led to more complex criteria supported by design charts for application to specific work. Filters must be designed when

Grouting

The normal grouting processes involve producing fluids of low viscosity with regard to the soil treated with the object of achieving a high penetration into the voids of the soil. (The special case of grouting of Embankment slips involves high viscosities and involves different techniques. It is not penetration grouting whereas track grouting is.) It is not possible to grout clay.

Apart from embankment and track grouting which are not discussed here the applications of grouting are:

1. **Void filling for load transfer**, e.g. behind tunnel linings, in the heating of viaduct piers, behind retaining walls. The effect of grouting here is to transfer the loading from the soil mass, or from live loading, to the masonry skin. The grout must have substantial strength and corrosion resistance to form a permanent part of the structure. It should be noted that it is an important function of the grout to transmit and distribute stresses to the lining consequent upon displacing water which previously filled the void. This replacement of fluid pressures by proper stress distribution is as important in relieving distress in the structure as the strengthening effect. In some cases such as filling voids between a footing and the foundation soil (underpinning) or placing as auxiliary arch to a bridge by a grouted stone construction inside formwork, it is desirable to have an expanded grout to ensure full contact and to counteract shrinkage. Expanding agents (usually aluminium powder) are added to the grout. These depend upon the chemical reaction with Portland cement for their effect and should not be used in the presence of certain aerating agents (e.g. Teepol).

2. **Voids filling for impermeability.** This is to prevent water ingress to excavations, to control quicksand conditions, to reduce frost heave, and to resist scour in river beds and behind sea walls etc. In all these cases the cheapest and strongest grout is chosen consistent with site conditions such as water movement (tides etc.) size of soil void, time of set required, and length of hose.

A special case is the fire in ash fills which is gradually extinguished by grouting air passages around the seat of the fire. The technique requires constant (daily) temperature checks to monitor and direct the effect of the pattern of grouting.
It is not possible to produce a temperature plan of the affected area and expect to grout from this at a later date. The system is very economical for embankments up to 6,6 m high. Above this height treatment costs rise rather quickly.

(3) Strengthening of soil and fill. The best application for this is where cement-sand or cement p.f.a. mixes are possible. This is restricted to sites with high permeability fills and gravels. For finer materials, clay cement grouts may be used but the costs would be substantial compared with alternative construction measures.

**Type of Grout**

The different grouting materials generally rise in cost as they become more complex to obtain lower viscosity. As the viscosity goes down the penetrating capacity into finer soils goes up but the grout strength tends to go down. In the sequence of increasing penetration efficiency they are:

- Cement-sand
- Cement alone, or Cement-p.f.a
- Cement-bentonite, or Bentonite-p.f.a
- Cement-bentonite-silicate
- Bentonite or Bentonite-silicate
- Silica-gel processes (one and two shot)

One shot chemical grouts, e.g. TDM, Chrome lignin, formaldehyde, acetate and various polymer grouts.

The bentonite should be chosen according to the mix concerned, special clays are available for use with p.f.a. The proportion of bentonite required is very small so that its cost per unit volume of grout is not more than that of portland cement. The effectiveness of any type of grout is controlled by the type of equipment available to mix and place it and above all by the knowledge and experience of the grouting supervisor.

**Bentonite**

This material mixed with water at proportions of the order 5% provides a new method for excavating in granular soils with a high water table. No shuttering is required. As excavation proceeds, the bentonite slurry is poured into the hole whilst the soil is grabbed by machine from below liquid level. The slurry pressure supports the side of the excavation. Concrete is placed by tremie after foundation level is reached and the slurry is then pumped out. Instead of concrete alternate fill material special layers may be introduced as a non-structural water cut-off in the ground.

Bentonite possesses the property of thixotropy, which means that the material in suspension goes to a solid state with a low but definite shear strength when left at rest. Upon sufficient agitation it becomes a liquid which can be pumped and regains its “strength” when left at rest (“thixotropic regain”). This is not a true set; however, if bentonite slurries have silicates or cement added to them then an irreversible set does occur.

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**Table 1: Applications of Methods for Groundwater Control (2)**

<table>
<thead>
<tr>
<th>Method</th>
<th>PERMANENT EXCLUSION OF GROUNDWATER</th>
<th>Soils suitable for treatment</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>1. Sheet piling</td>
<td>All Types of soil (except boulder bed)</td>
<td>Practically unrestricted</td>
<td>Difficult to drive and maintain seal in boulders. Vibrating may not be acceptable.</td>
</tr>
<tr>
<td>2. Displacement walls (structural active)</td>
<td>All soils types including those which are permeable, and soft and permeable rock.</td>
<td>Deep basements, subway stations, shafts, dry docks, etc.</td>
<td>Can be designed to form permanent structure. Can be incorporated into soil by injection. There is an upper limit on the amount of reinforce that can be accepted.</td>
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</tbody>
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JERNEL TEKOLOGI BIL. 3 JUN 83
3. Sherry trench cut-off (Wanapum method or parol mine)
Silts, sands, gravels and cobbles
Practically unrestricted. Extensive curtain walls round open excavation
A rapidly installed, cheaper form of diaphragm wall. Can be keyed into impermeable strata such as clays or soft shales
Must be adequately supported. Cost increases greatly with depth. Costly to attempt to key into hard or irregular bedrock surfaces
The driving and extracting of the sheet pile element used to form the membrane limits the depth achievable and the type of soil. Also as for 3

4. Thin, grouted membrane
Silts and sands
As for 3
As for 3

5. Contiguous-bored pile walls
All soil types, but penetration through boulders may be difficult and costly
As for 2. Underpasses in stiff clay soils
Can be used on small and confined sites. Can be put down very close to existing foundations. Minimum noise and vibration. Treatment is permanent
Equipment is simple and can be used in confined spaces. Treatment is permanent
Ensuring complete contact of all piles over their full length may be difficult in practice. Joints may be sealed by grouting externally. Efficiency of reinforcing steel not as high as for 2
Treatment needs to be extensive to be effective

6. Cement grouts
Fissured and jointed rocks
Filling fissures to stop water flow (filler added for major voids)
Filling voids to exclude water. To form relatively impermeable barriers (vertical or horizontal). Suitable for conditions where long term flexibility is desirable, e.g. cores of dams
Equipment is simple and can be used in confined spaces. Treatment is permanent
Filling fissures to stop water flow, e.g., cores of dams, and forming voids to exclude water. To form relatively impermeable barriers. Suitable for conditions where long term flexibility is desirable, e.g., cores of dams

GROUTED CUT-OFFS
7. Clay/cement grouts
Sands and gravels
As for 7 but non-flexible
As for 7 but only some flexibility
Comparatively high mechanical strength. High degree of control of grout spread. Simple means of injection by lenses. Indefinite life. Favoured for underpinning works below water level
Can be used in conjunction with clay/cement grouts for treating finer strata

8. Silicates, loosten, Guttmann and other processes
Medium and coarse sands and gravels
As for 7 but non-flexible
Comparatively high mechanical strength. High degree of control of grout spread. Simple means of injection by lenses. Indefinite life. Favoured for underpinning works below water level
Can be used in conjunction with clay/cement grouts for treating finer strata

9. Resin grouts
Silty fine sands
As for 7 but only some flexibility
Can be used in conjunction with clay/cement grouts for treating finer strata

FREEZING
10. Ammonium/brine refrigeration
All types of saturated soils and rock
Formation of ice in the voids stops water
Imparts temporary mechanical strength to soils. Treatment effective from working surface outwards. Better for large applications of long duration
Treatment takes time to develop. Initial installation costs are high and refrigeration plant is expensive. Requires strict site control. Some ground heave

11. Liquid nitrogen refrigerant
As for 10
As for 10
As for 10, but better for small applications of short duration or where quick freezing is required
Liquid nitrogen is expensive. Requires strict site control. Some ground heave

TEMPORARY EXCLUSION OF GROUND-WATER BY GROUND-WATER LOWERING
12. Sump pumping
Clean gravels and coarse sands
Open, shallow excavations
Simplest pumping equipment
Fines easily removed from ground. Encourages instability of formation
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<tr>
<td>13. Wellpoint systems with suction pumps (including the machine-laid horizontal system)</td>
<td>Sandy gravels down to fine sands (with proper control can also be used in silty sands)</td>
<td>Open excavations including rolling-pipe trench excavations. Horizontal system particularly pertinent for pipe trench excavations outside urban areas</td>
</tr>
<tr>
<td>14. Bored, shallow wells with suction pumps</td>
<td>Sandy gravels to silty fine sands and water-bearing rocks</td>
<td>Similar to wellpoint pumping. More appropriate for installations to be pumped for several months or for use in silty soils where correct filtering is important</td>
</tr>
<tr>
<td>15. Deep-bored filter wells with electric submersible pumps (long-shaft pumps with motor mounted at well head used in some countries)</td>
<td>Gravels to silty fine sands and water-bearing rocks</td>
<td>Deep excavations in, through or above water-bearing formations</td>
</tr>
<tr>
<td>16. Electro-osmosis</td>
<td>Silts, silty clays and some peats</td>
<td>Open excavations in appropriate soils or to speed dissipation of construction pore pressures</td>
</tr>
<tr>
<td>17. Electrochemical consolidation</td>
<td>Soft clays</td>
<td>Improve shear strength of soft clay without causing settlement</td>
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<td>18. Drainage galleries</td>
<td>Any water-bearing strata underlain by low-permeability strata suitable for tunnelling</td>
<td>Removal of large quantities of water for dam abutment, cut-offs, etc.</td>
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<td>19. Jet eductor system using high-pressure water to create vacuum as well as to lift the water</td>
<td>Sands (with proper control can also be used in silty sands and sandy silts)</td>
<td>Deep excavations in space so confined that multi-stage well-pointing cannot be used. Usually more appropriate to low-permeability soils</td>
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</table>
Conclusion

Soil improvement is a necessity in construction. Groundwater needs a proper control to reduce the hazards of level alteration. The choice of improvement technique depends largely on the nature and composition of soils at site.

Reference


