Issues for consideration with arid soils in South Australia

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Summary This paper presents some issues that may require consideration during site investigations in arid portions of South Australia. Issues identified include moisture content and strength, the presence of duricrusts and cementation, the potential for collapse settlements and expansive movements, and a few aspects relating to the chemical composition of these soils. The aim of this paper is not to provide a detailed discussion of any of the areas identified. Rather the paper is intended to highlight some important characteristics that may not be considered by practitioners familiar with investigations in wetter climates.

Many of these issues are no more complicated than those addressed by investigations in wetter areas. However, in many cases the issues are less well understood, possibly because the typical remoteness and lower populations of many areas containing arid soils means that fewer investigations are performed and hence practitioners are given less exposure to these soils.

The properties of sand dunes which occur over much of the arid areas of South Australia have not been addressed by this paper as they are considered to be a separate topic.

1. INTRODUCTION

Arid and semi arid soils are defined as those soils which have developed in a climate that has a net moisture deficit, meaning that the annual evaporation exceeds the annual precipitation (Atkinson, 1994). The distinction between arid and semi-arid soils is based on the extent by which evaporation exceeds precipitation. These conditions occur over almost all of South Australia. Most of South Australia possesses a significant depth of soil cover and hence a large quantity of arid or semi arid soils would be expected.

These soils often present a different range of challenges to the geotechnical practitioner. Issues such as bearing capacity, consolidation settlement and liquefaction potential are often of lower significance than for soil profiles that have developed in wetter environments. Arid soils are typically of high strength, reaching that of weak rocks at times. In some situations these factors make the design of footings founded on arid soils a relatively straightforward task. However, dismissing these soils as unworthy of thorough investigation may invite problems from a number of other factors that may not be considered in wetter climates.

Typical characteristics of arid soils include low moisture content, high strength and high salinity, cementation of the soil, the presence of duricrusts, and the potential for collapse settlements or expansive movements. These characteristics are discussed in more detail in the following sections.

2. MOISTURE CONTENT

As evaporation exceeds rainfall in an arid environment, and groundwater is at a significant depth below ground surface over much of the state, soil moisture contents are typically low. The soils are often described as dry in accordance with Australian Standard AS1726, with clayey soils often being at a moisture content well below their plastic limit.

The significance of this factor is clearly evident during earthworks. The soils will often be much drier than the Optimum Moisture Content (OMC) for either Standard or Modified compactive effort, and it is therefore often necessary to increase the moisture content of the soil significantly to enable efficient compaction.

With fine grained soils, particularly of high plasticity, the exercise of moisture conditioning is often extremely time consuming. Achieving an even distribution of moisture throughout previously dry soils is often difficult to achieve with techniques that are successful in moist soils. If inappropriate techniques are adopted it is common to encounter clods of soil with a wet, slippery periphery and a dry core. When this situation occurs further moisture conditioning is often impossible due to the reduced traction available to the conditioning equipment.

The low moisture content often results in high soil suctions. Soil suction may be defined as the ability of a soil to draw moisture from a source and comprises two components, matrix suction and solute suction. Matrix suction is a pressure resulting from the capillary forces acting in the pore spaces of a soil. The capillary forces are strongest in soils with small pore spaces, such as in fine grained soils. Solute suction is the osmotic pressure generated as water attempts to move from areas of low salt concentration to areas of higher salt concentration in order to equalise the concentrations. Where soils contain large proportions of soluble salts the solute suction component becomes large.

In general, soils with a high moisture content have a low soil suction, and soils with a low moisture content will have a high soil suction. Dry, fine grained, saline arid soils will therefore generally have a high ability to draw moisture into their matrix.

The typically low moisture contents and high soil suctions influence many other characteristics of arid soils, including several that are discussed in the following sections.

3. STRENGTH

The high strength and stiffness of many cohesive arid soils often leads to predictions of comparatively higher maximum allowable bearing pressures and lower settlements than would normally be expected from soils of similar composition in wetter climates.

It is noted that where relatively impermeable membranes such as concrete slabs are built over dry arid soils, the high soil suction may draw moisture from any nearby sources. As losses of moisture to evaporation are prevented this may result in the long term wetting up of the soil and a reduction in strength. The strength measured during an investigation of an undeveloped site may therefore be higher than the strength that may occur in the long term after construction.

The high strength of arid soils may also result in high excavation resistance, and hence influence the choice of excavation method and machinery.

4. SOIL CHEMISTRY

Due to the lack of moisture to act as a leaching agent, arid soils will often contain high salt concentrations. Two of the more common salts that influence the engineering characteristics of arid soils are calcium carbonate ($CaCO_3$) and calcium sulphate ($CaSO_4$).

Two examples of the significance of soil chemistry on the material characteristics include gypsiferous soils and the susceptibility of some soils to acid attack.

4.1 Gypsiferous Soils

The presence of calcium sulphate as gypsum ($CaSO_4.2H_2O$) in soils may be significant to the soil properties. Gypsum typically appears as elongated, translucent crystals, which may be present individually but will more commonly appear as aggregations of nested crystals. These aggregations may be quite extensive, with nests of tens of metres in diameter having been reported. Excavation of such materials may be very difficult, even with large excavation machinery. The excavation spoil of such materials may contain sharp particles which may cause damage to elements that are placed in contact with the spoil.

Gypsum contains water of hydration which can be removed from the crystalline lattice by heat. This characteristic must be considered whenever changing the moisture state of such soils, and especially when oven drying the materials. Australian Standard AS1289.2.2.1 provides guidance on the use of low temperature ovens to avoid erroneous measurements of moisture content due to the removal of water of crystallisation from the soil.

4.2 Acid Attack

The presence of carbonates (specifically calcium carbonat may also be significant to many aspects of the soils behaviou One such area is the attack of soils by acids.

The containment of acids is notoriously difficult and spillag or leakages easily occur if stringent handling practices are n maintained. Such problems may occur in areas of ac production, storage, distribution or disposal. When aci contact soils containing carbonates the following reactio occurs :

$$CO_3^- + 2H^+ \rightarrow CO_2 + H_2O$$

Acid attack products are also formed. The composition of t attack products will depend on the type of acid and the salts the soil, for example :

1. Calcium carbonate and sulphuric acid

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

2. Calcium carbonate and hydrochloric acid

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$$

In the above examples the attack products are calciu sulphate and calcium chloride.

Despite the loss of mass due to the formation of carbo dioxide (CO_2) gas, the production of the acid attack produc may cause a net volume increase, leading to the generation swelling pressures (Wrench and Geldenhuis, 1992). In light loaded areas these swelling pressures may result in significa heave. The author has observed heave of up to about 100 m resulting from acid attack.

If the attacked soil is subsequently subjected to water t attack products may be leached from the soil causing lar settlements.

The heave and subsequent settlement movements may cau distress to supported structures. In the case where tho structures form part of the acid handling process, t movements may accentuate existing leaks or create ne sources for leakages to occur, leading to ongoing movemen

The design of structures where acid is involved shou carefully consider the consequences of acid coming in contact with underlying soils, and minimise the risk of t occurrence wherever possible.

4.3 Other Soil Chemistry Issues

The possibility of sulphate attack of concrete structu constructed within gypsiferous soils should be considered.

If water enters a soil containing soluble salts a saline leach is likely to result, which may cause corrosive conditions structures founded in the soil.

5. CEMENTATION

A common characteristic of arid soils is the presence of cementation, consisting of chemical bonds between soil particles. These bonds may significantly increase the dry strength of the soil, sometimes up to that of weak rock, and hence are a key factor in the engineering behaviour of the material.

The chemical composition of the cementing agents may be highly variable, with calcium carbonate being most common. The various cementing agents each have varying solubilities. Where the cementing agents are soluble in water, substantial variations in the engineering characteristics of the materials are likely to occur with variations in the moisture content of the materials. If the chemical bonds are dissolved a loss of shear strength usually occurs. The extent of the changes in strength with moisture content variations is often more dramatic than for uncemented soils.

It is not uncommon for cemented sands containing relatively few fines to be capable of standing in unsupported vertical faces of significant height when in a dry state. In Port Lincoln, on the Eyre Peninsula, near vertical cliffs of weakly cemented sand up to about 100 m in height can be observed. However, rapid instability of these materials may occur following the ingress of water. The instability is often due to the removal of the cementation rather than a build up of excess pore pressures.

6. DURICRUSTS

Duricrusts are defined as hard crusts that form in the upper portion of a soil profile in a semi arid environment. In South Australia they are usually formed from calcium carbonate (calcrete) or silicon oxide (silcrete). Iron oxide (ferricrete) duricrusts also occur.

Calcrete is understood to form by the leaching of wind blown calcium carbonate ($CaCO_3$) down through a soil profile. The calcium carbonate then precipitates from solution, commonly around a lime rich particle. Continuing precipitation on the periphery of the particle will cause growth of a calcrete nodule.

The presence of calcrete is widespread throughout South Australia, usually occurring as gravel sized nodules within the top 1 m to 3 m of the soil profile, but sometimes forming larger aggregations. The nodular calcrete may grow to reach cobble and boulder sizes or may form continuous sheets, generally parallel to the ground surface. These sheets may be massive and contain few defects. The thickness of these sheets may vary considerably, with layers of up to about 1 m thickness being common. Considerably thicker layers may also occur. Calcrete is generally of medium rock strength, but high rock strength materials are not uncommon.

Zones of loose weakly cemented material are common immediately below the base of sheet calcrete. These zones are easily overlooked during site investigations, and careful logging is essential as they may be very significant to the engineering performance of the soil.

Silcretes form by crystallisation of silicon oxide (SiO_2) and may occur as gravel but, in the author's experience, cobbles, boulders and sheet rock are more common. The rock is typically of high to extremely high strength. The occurrence of silcrete in South Australia is less common than calcrete, and is most common in the far north of the state.

Duricrusts typically present higher excavation resistance than their parent soils, particularly when present as sheet rock. The excavation resistance of calcrete may range from low to high, depending on the strength of the rock substance and the presence and orientation of defects. Due to its high to extremely high substance strength silcrete will generally present high resistance to excavation.

7. COLLAPSE OF SOILS

The potential for soils to undergo collapse settlements is widely known, but, in general, poorly understood. Collapse is defined as large settlements that occur when certain soils subsequently become wet. Collapse is most common in low density, wind blown sands or silts, but may also occur in clay soils if the induced stresses are high.

Soils with a high potential for collapse are relatively common in arid environments, probably due to the fact that many of the arid soils are formed at least in part by aeolian deposition. These sediments are often deposited at a low density and, in an arid environment, may not have been subjected to significant quantities of water. Should wetting up of such a soil occur, realignment of the particles to a more dense state may result in large, rapid, settlements.

Collapse settlements are particularly relevant to cemented soils where the cementing agent is soluble in water. Due to their typically high dry strength, cemented soils may initially appear to provide a competent founding medium. However, to limit the assessment of these materials to consideration of the properties at the field moisture state may seriously overestimate the ability of the materials to support applied loads over time. In particular the likely settlements may be grossly underestimated.

Such settlements are usually observed below structures, suggesting that the applied load is responsible for the collapse, however several occurrences of collapse have been observed in domestic residences with low applied bearing stresses. In these instances it is often possible to associate the settlement with the presence of water. It is therefore considered that the movements are initiated by the increased moisture content even at low applied stresses. In some situations collapse of soils under only the overburden pressure may be possible.

The methods of assessment of the collapse are also generally poorly understood. Methods include laboratory oedometer testing, where samples are loaded to a stress state representative of the anticipated loading conditions, and then saturated. Large scale field wetting tests may also be used. Such tests typically involve introducing water into a loaded soil profile and measuring the resulting settlement. These tests may provide high quality information on the large scale behaviour of collapsing soils, but unfortunately such tests are often impractical for an initial site investigation. Other methods of assessment may involve the comparison of the in-situ density with the remoulded density obtained from compaction tests.

The increase in dry strength due to cementation often leads to higher penetration resistance than would be expected for uncemented soils of the same density. Therefore correlations of in-situ density with penetration resistance, either by Electric Friction/Cone Penetrometer Tests (CPT), Standard Penetration Tests (SPT) or Dynamic Cone Penetrometer (DCP) tests are often of limited value for cemented soils. Such tests are therefore generally not appropriate for the assessment of the density or collapse potential of cemented soils during site investigations.

It is therefore extremely important for the field engineer or geologist to identify potentially collapsible soils during the field investigation by careful observation and logging. Further testing is then required, either by field wetting tests or laboratory tests to quantify the likely extent of collapse settlements that may be anticipated.

8. EXPANSIVE MOVEMENTS

The potential for clayey soils to undergo large volumetric changes as a result of variations in moisture content and soil suction is well documented.

The resulting vertical movements are commonly predicted using the following (Australian Standard AS2870) :

$$\Delta H = \Delta \mu \times I_{pt} \times h$$

Where ΔH = predicted movement (mm)
$\Delta \mu$ = change in soil suction (pF)
I_{pt} = Instability Index
h = thickness of layer (mm)

Expansive movements are equally relevant to arid climates but accurate prediction of the movements in remote arid areas is often limited by the lack of information on the seasonal suction changes.

Soils in arid climates typically possess extremely high soil suctions, often above the measurable range for common equipment. Due to the extremely low annual rainfall, the majority of which often occurs at the time of highest evaporation, the seasonal variations in soil suction may not be as large as in areas of higher rainfall. Seasonal movements may therefore be limited by the seasonal suction change rather than the soil reactivity.

Highly reactive soils will however be susceptible to sw as a result of increased soil moisture from other sources, as leaking services or pooled water due to poor site drai Swelling may also result from the wetting of soils b barriers to evaporation such as buildings, as described e in this paper.

The specified moisture content range for compactic clayey materials should be carefully considered, taking account the required density, permeability and the exp equilibrium moisture regime. Careful selection o specified moisture content will optimise the long performance of the compacted material by minimisin potential for shrinkage or swelling of the placed material

9. CONCLUSION

Site investigations in areas containing arid soils often ne address different issues to those in areas containing formed in wetter environments. As with every investigation the relevant issues must be identified a planning stage of the investigation, so that suffi information is recovered during the fieldwork. Diff investigation techniques are often necessary as the typi high strength materials that are typically encountered render conventional sampling and testing met ineffective. The likely long term moisture conditions sh be considered when assessing the characteristics of mate during investigations of undeveloped sites.

The issues involved with arid soils are often no r complex than for other materials, but they are probably well understood due to the fact that most site investiga are performed in the most highly habited areas, which typically the least arid.

10. REFERENCES

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