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Carbonate and gypsum soils properties and classification

Les propriétés et la classification des sols gypseux et carbonatés

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SYNOPSIS: Carbonate soils resulting from calcrete development in subhumid to semi-arid climates and gypsum soils resulting from gypcrete development in desert environments exhibit particular properties and engineering behaviours related to the amount of carbonate and gypsum fines. Conventional index properties fail to characterize the engineering behaviour of calcrete and gypcrete soils. The conventional index tests encounter serious restrictions and shortcomings when applied to calcrete and gypsum soils.

This paper briefly reports the properties of calcrete and gypcrete soils and suggests that the calcium carbonate and the gypsum equivalent should be considered as the fundamental index properties for effective characterization and classification of these soils.

1 INTRODUCTION

Continental, carbonate and gypsum soils are mostly derived from incipient and mature calcrete and gypcrete deposits.

Calcrete is the result of calcium carbonate precipitation in soil profiles, rocks undergoing weathering, as well as alluvium and other clastic sediments of the vadose zone. Favourable conditions for calcium carbonate accumulation and the development of calcrete deposits prevail where evapotranspiration exceeds precipitation, namely in subhumid and semi-arid climates. According to estimations by YAALON (1981) carbonate soils cover about 13% of the total area of the emerged lands. The area covered by calcrete in subhumid and semi-arid regions exceeds this figure. In Northern Algeria it was evaluated at 25%.

Gypcrete results from gypsum accumulation in the vadose zone under arid climates. Gypsum soils do not have widespread distribution of carbonate soils and are restricted to some desert areas.

Located far beyond the traditional zones of development of soil mechanics, carbonate and gypsum soils have seldom attracted the attention of geotechnical engineers. They have nevertheless been used as road building materials for a long time in many parts of the world, namely in Southern (NETTERBERG, 1971) and Northern Africa (HORTA, 1978 and 1980).

2 CHARACTERISTIC PROPERTIES OF CALCRETE SOILS

In the process of calcrete formation the host material undergoes different stages of modification with increasing carbonate content. In the initial stages carbonate accumulations take the form of very fine, disseminated calcite crystals and the properties of the host material remain practically unchanged. For increasing carbonate content, white spots appear forming soft flakes in clayey and hard

nodules in sandy host materials. In more advanced stages, calcite increasingly replaces the host materials minerals including clays and typical calcrete structures develop with increasing carbonate content: nodules of variable hardness and millimetric to centimetric sizes, massive and foliated soft crusts and hardpans with thicknesses ranging from a few to 20 - 30 centimetres.

Soils recovered from calcrete deposits represent a mixture of different sizes and types of elements with different specific gravities and widely variable hardnesses: very hard and dense hardpan cobbles, soft and porous crust fragments, nodules, calcretes fines including very fine calcite crystals and calcite cemented silt and clay clusters and various types of host material inherited elements such as pebbles, eolian sand, silt and clay. Mature calcrete deposits give origin to sands and gravels with widely variable granularities. Most calcrete granularities are poorly graded with a gap corresponding to the coarse and medium sand size fractions and an excess of fine sand. Calcrete coarse soils typically exhibit relatively high contents of fines in excess of 10 - 15 %.

The sieve analysis of carbonate soils may result in erratic modifications of grain sizes following attrition of soft particles. As a result of variable specific gravities with particle size, the gradation curve gives a distorted picture of the space arrangement of the particles (NETTERBERG, 1971).

Calcrete fines typically comprise siliceous and calcareous silt, fine calcite crystals and a clay fraction. The clay fraction may be inherited from the host material and/or formed during the calcrete development process. Neoformation of the needle-like clay mineral attapulgite is characteristic of calcrete development. Attapulgite exhibits high plasticity but low swelling potential. The inherited clays may include practically all other clay minerals, such as kaolinite, illite

and the highly expansive montmorillonite.

Calcite or carbonate fines are non plastic and lightly water soluble at ordinary temperatures. Dissolution of carbonates fines by interstitial water liberates calcium ions that saturate clay minerals and decrease the soil plasticity. Dissolved calcite may also act as a cementing agent creating bonds between the soil particles.

Plots of calcrete soils on the CASAGRANDE chart fall on both sides of the A-line showing a tendency of these soils to have higher liquid limits than ordinary soils (NETTERBERG, 1971). Shrinkage limits of calcrete soils tend to be close and even exceed their plastic limits.

Figure 1 shows a plot of the plasticity indexes and the calcium carbonate equivalents of calcrete samples from Algeria and a curve representing the variation of the plasticity index of mixtures of a clay with soft limestone. The plot indicates that the plasticity index of calcrete is conditioned by factors other than the CaCO₃ equivalent and such as the mineralogy of the clay fraction and the presence of quartz sand and silt: for low values of the CaCO₃ equivalent the plasticity

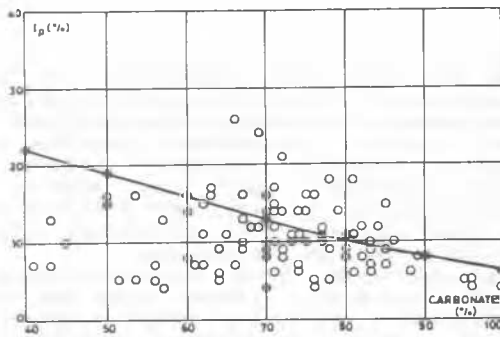


Figure 1. Plot of the plasticity index of calcrete soils from Algeria as a function of the CaCO₃ equivalent. The curve shows the variation of the plasticity index of a mixture of clay with soft limestone fines.

index is not necessarily high and for a given value of the carbonate content it varies in a wide range. However this range of variation decreases with increasing CaCO₃ content and for high values of the CaCO₃ equivalent the plasticity index will not generally exceed some relatively low values. The plot of figure 1 shows a good correlation between the CaCO₃ equivalent and the upper limits of the plasticity index of calcretes.

Most of the samples plotted in figure 1 represent calcrete gravels that were successfully used as base courses of bitumen paved roads in Algeria. The usually accepted specifications would reject base materials with plasticity indexes of 6% and more or about 95% of the samples of figure 1. Some authors, for instance GILLETTE (1934) and authorities such as the Federal Aviation Authority in the USA have suggested more realistic upper limits for the plasticity index of calcrete (caliche) gravels used as base materials, in the range of 10-15%. Figure 1 shows that this values would not be exceeded by most of the samples showing a minimum CaCO₃ equivalent of about 60 to 80 %.

Figure 2 is a plot of California bearing ratios of calcrete samples from Algeria and Morocco as well as quaternary soft limestone samples from Tunisia as a function of the CaCO₃ equivalent. This figure shows that a high

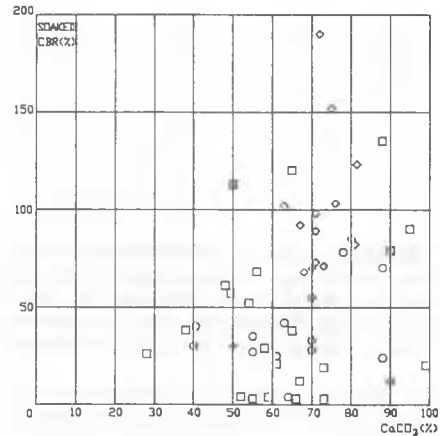


Figure 2. Plot of the CBR of carbonate soils from North Africa as a function of the calcium carbonate equivalent. The soaked CBR were measured on laboratory specimens molded at the modified proctor maximum dry density. Calcrete soils from Morocco are represented by squares (LEGROUN, 1987) and calcrete soils from Algeria by lozenges (PERELLE, 1964 and 1972). Samples from Tunisia (HAMROUNI, 1974) plotted as circles are mostly soft sedimentary limestones.

carbonate content is a necessary but not a sufficient condition for high bearing capacities. The bearing capacity increases with increasing carbonate content but is as well conditioned by other factors such as granularity, fines content, sizes of fine particles, shape and hardness of coarse particles.

In figure 3 the fines content of most of the samples of figure 2 were plotted as a function of the carbonate content and the CBR value was indicated for every single plot. With the exception of two calcrete samples from Morocco with CBR values around 60% and 50 to 60% fines, high CBR values only appear below the horizontal line corresponding to 35% fines. This line and vertical CaCO₃ equivalent = 70% limit an area where all plots have high CBR values in excess of 70%. The value of 30 to 35% is generally considered as the maximum amount of fines for which the friction between the coarse particles of a soil can be mobilized and the plot of figure 3 appears to confirm this value for calcrete soils. In addition this plot shows that the minimum value of 70% for the calcium carbonate equivalent of calcrete gravels is a reliable indication of high bearing ratios.

The above discussed results, the mineral composition of calcrete fines where calcite is most prominent and the process of development of calcrete soils with progressive carbonate enrichment suggest that the CaCO₃ equivalent of the minus 0.4 mm (No 40) size fraction should

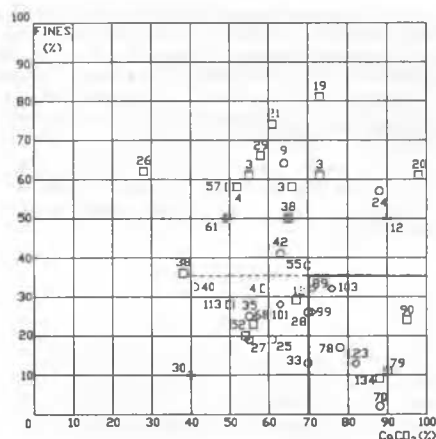


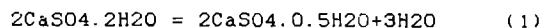
Figure 3. Plot of the carbonate content and the fines content of carbonate soils from Morocco (LEGROUN, 1987), Algeria (PERELLE, 1972) and Tunisia (HAMROUNI, 1974), same legend as figure 2. The soaked laboratory CBR as determined on specimens moulded at modified proctor maximum dry density is indicated for every single plot.

be considered as the fundamental index property for carbonate soils. Actually, the carbonate content can be accurately, quickly and easily determined with a COLLINS-BERNARD calcimetre or a carbonate bomb in comparison to the time consuming and operator skill sensitive determination of the Atterberg limits.

The CaCO_3 equivalent appears so to be in good correlation with the strength characteristics of calccrete soils. Furthermore calccrete and other carbonate soils such as coral limestones have been shown to exhibit self-stabilization and strength gains resulting from dissolution of fine calcite crystals in interstitial water followed by precipitation upon drying (NETTERBERG, 1975) or by crystal growth in moist conditions (BULLEN and WILLIAMS, 1988). This property of carbonate soils is directly related to the carbonate content of the fine fraction.

3 CHARACTERISTIC PROPERTIES OF GYPCRETE SOILS

Most gypcrete soils in the Northwestern Sahara developed in host eolian sand and are composed of quartz and gypsum. Gypsum has a unusual properties quite different from those of the common soil minerals. In equilibrium with the atmosphere, gypsum may partially lose its hydration water at relatively low temperatures in the range of 40 - 60°C or even lower atmospheric relative moistures:



Dehydration of gypsum to β hemihydrate may take place in the drying oven as well as hot desert environments. Dehydration is apparent in macroscopical gypsum crystals as these lose their transparency and limpidity to become opaque white.

Gypcrete most often develops in the capillary fringe of selenituous ground water tables. Old gypcrete deposits havin lost contact with water tables and been exposed to the hot, dry desert

summer atmosphere usually exhibit a prismatic pattern of hygroscopical cracks resulting from shrinkage upon dehydration.

Partially dehydrated old gypcrete deposits originate gypsum sands and silts that actually represent natural plaster moatars setting up after moist compaction and giving stiff pavements. During the hot season, gypcrete pavements develop a block pattern of hygroscopical dehydration cracks.

Gypsum is a relatively soluble salt and the solubility of β hemihydrate is higher than that of gypsum. The hardening of plaster and gypsum soils in hot desert conditions can be explained by the crystalization of gypsum following the dissolution of β hemihydrate.

The specific gravity of gypsum (2.32 g/cm³) is well below the specific gravities of other soil minerals such as quartz (2.65 g/cm³), but the specific gravity of β hemihydrate is higher (2.75 g/cm³).

Another particular property of gypsum is its low hardness: it can be scratched by a finger nail. During quarrying and compaction gypcrete cobbles and boulders are easily crushed and reduced to sand and silt.

The usual index properties fail to characterize gypsum soils with their particular behaviour. Conventional index tests and test methods may result in nonsense when indiscriminately applied to gypsum soils. The standard determination of water content by oven drying at 105°C would cause dehydration. Soil specimens containing gypsum should be dried to constant weight at temperatures lower than 60°C, usually 50 - 55°C, preferably 40°C. The wet sieve analysis would result in dissolution and loss of gypsum fines as well as erratic modification of particle sizes by attrition. Gypsum soils formed in host eolian sand display relatively high plasticity indexes sometimes in excess of 15% in spite of the fact that they practically do not contain clay. This pseudo-plasticity of gypsum soils seems to be related to the flexibility of gypsum needle-like crystals. The specific gravity of gypsum soils is variable with grain size and mineral composition and weather dependent.

The characterization of gypsum soils an index test to determine the gypsum content is essential. The determination of the soluble sulphate content by means of barium chloride after dissolution in hydrochloric acid appears to be a suitable and fundamental index test to be run on the minus 0.4 mm (No 40) size fraction of gypsum soils.

4 THE CLASSIFICATION OF CALCRETE AND GYPCRETE SOILS

Chemical tests with direct reference to the mineral composition of carbonate and gypsum soils are most effective to characterize the particular properties of these soils and the CaCO_3 and gypsum equivalent of the minus 0.4 mm (No 40) size fraction rather than the Atterberg limits should be included in soil classification systems for proper classification of calccrete and gypcrete soils. The following new soil classes would result in the Unified Soil Classification System (USCS).

CALCRETE SANDS are defined as sands having more than 40% CaCO_3 equivalent in the fraction passing the 0.4 mm or No 40 sieve. The

suggested symbol for calcrete sands is SE, where E is the initial of the French word "encroûtement" meaning crust. Over 40% CaCO₃ equivalent the colour of the host material is masked by the white colour of finely divided calcite. Withish colour as well as acid effervescence facilitate identification of calcrete sands in field exposures.

CALCRETE GRAVELS, symbol GE are defined as gravels with more than 60% CaCO₃ equivalent in the fraction passing the 0.4 mm or No 40 sieve. Identification of calcrete gravels in field exposures can be based on calcrete structures. Calcrete gravels correlate with foliated calcrete (crust and hardpan calcrete), calcrete cemented gravels and well developed nodular calcrete. All these calcrete types usually show more than 60% CaCO₃ equivalent in the minus 0.4 mm size fraction.

GYPSUM SANDS, symbol SY and GYPSUM SILTS, symbol MY, where Y is the initial of the Spanish word "Yeso" meaning gypsum, are defined as sands and silts with a minimum gypsum content. The minimum gypsum equivalent of the minus 0.4 mm (No 40) size fraction is tentatively set to 30%, but gypcrete soils usually show higher amounts of gypsum in excess of 50% and as high as 85%. Field classification by trained geotechnicians would be based on the identification of gypsum and typical gypcrete deposits.

The classification of carbonate fine soils is not contemplated here. Actually most calcrete deposits generally represent coarse soils. Carbonate fine sands and carbonate fine soils are very widespread on marine grounds and are currently being studied by marine geotechnicians.

5 CONCLUSIONS

Continental carbonate and gypsum soils derived from calcrete and gypcrete deposits have particular properties and engineering behaviours, which the usual soil index tests fail to characterize.

Calcrete granularities are widely variable and calcrete coarse soils comprise different types and sizes of particles with different specific gravity and different hardness.

The plasticity index of carbonate soils depends on the calcium carbonate equivalent and decreases with increasing CaCO₃ equivalent. The strength of carbonate soils as illustrated by the California bearing ratio increases with increasing CaCO₃ equivalent and a minimum CaCO₃ equivalent of 70% is a reliable indication of high strength. Carbonate fines are lightly soluble in water at ambient temperature and are responsible for strength gains or the self-stabilization of calcrete soils.

Most gypcrete deposits of the Northwestern Sahara developed on eolian sand host materials. They comprise quartz sand and gypsum fines and exhibit very peculiar properties related to the latter. Gypsum is soft, water soluble and unstable in hot desert environments where it dehydrates to β hemihydrate. After compaction with water, partially dehydrated gypsum soils harden like plaster mortars but will develop hygroscopical shrinkage cracks subsequently to dehydration during hot and dry periods.

Chemical tests making direct reference to the mineral composition of carbonate and gypsum

soils are most effective for characterization of the particular properties and engineering behaviour of these soils. The calcium carbonate and the gypsum equivalents rather than the Atterberg limits should be considered as the fundamental index properties of calcrete and gypcrete soils. Based on the former, a classification of the latter into calcrete sands (SE) and gravels (GE) and gypsum silts (MY) and sands (SY) is suggested within the scope of the USCS.

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