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Differential classification at boundaries of soil and rock

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ABSTRACT: Nearly all naturally occurring soil formations are being created from rock by weathering or are being turned back into rock by the process of lithification.The nature of lithification determines a material that may range between those of soil and rock. The literature have been directed to categorizing this transitional border line material into soil-like and rock-like types. Many of these types are unsaturated with a certain degree of lithification and associated with geotechnical problems. These problems are due to their tendency to volume change and mobilization of swelling or collapse.

The present research aims at integrating the behavior of the material into the framework of unsaturated soil mechanics. Based on testing of 72 samples representing a wide range of soil properties, prediction charts were constructed. The proposed charts were investigated by testing 29 undisturbed samples representing a variety of transitional border line deposits and their deformations were measured. A very good agreement was found between measured and predicted values.

1. INTRODUCTION

Naturally occurring unsaturated deposits that lie on or close to the boundary between soil and rock are difficult to describe in unambiguous terms. A big range of these deposits have engineering properties transitionally between those of soils and rocks. Many weak rocks may behave as soils and conversely some stiff or hard soils may behave as rocks. The range of this overlap of performance is difficult to define.

Recently, this problem has become of common concern among geotechnical engineers and engineering geologists. As a results, international meetings were organized by either specialization to discuss the subject. The first was a session entitled "Mechanical properties of weak material" which was included in the fifth Pan- American conference on soil mechanics and foundation engineering held in Buenos Aires in 1975. This was followed by successive conferences. The most well known of them: international symposium on weak rocks held in Tokyo in 1981; a session on engineering geological problems related to formations and excavations in weak rocks included in the fifth international congress of IAEG held in Buenos Aires in 1986; Leeds conference of the engineering group of the Geological Society of London on weak rocks held in 1990; Geotechnical engineering of hard soils-soft rocks held in Athens in 1993; Geotechnics of hard soils- soft rocks held in Naples in 1998; International Conference on Problematic Soils in 2005, Famagusta, Cyprus (Aboushook et al., 2005) and International

Conference on Advanced Experimental Unsaturated Soil Mechanics, in 2005, Teronto, Italy (El-Sohby et al., 2005).

In these conferences, much has been written about engineering and geological classification of soil/ rock border line deposits. However, we feel that there is, still, a considerable room for the improvement of the framework of our knowledge in that field.

Therefore, the present paper primarily presents fundamental review of the boundary between soil and rock. Then it presents a new approach for classifying and predicting the behavior of naturally occurring deposited unsaturated soil and rock by integrating their properties and behavior into the frame work of soil mechanics.

2. FORMATION OF SOIL/ ROCK BORDER LINE DEPOSITS

Nearly all naturally occurring unsaturated soil formations are being created from rock by the process of weathering or are being turned back into rock by the process of lithification. Lithification in the result of reduction of pore size, re- orientation of particles and cementation. The natural and degree of lithification determine a material that range between those of soil and rock (Bartonet al., 1993; Vaughan, 1997 and Marions, 1997.

There is a great variety of this border line material. Mudrock is a general term used that has gained increasing acceptance in the literatures as the preferred group name.

According to BS, 1981, the general term mudrock is used for lithified homogeneous argillaceous rocks. If the constituents are laminated or the rock is fissile on the bedding plane, the term shale is used.

According to De Freitas, 1993, mudrock is used to encompass argillaceous engineering rocks as opposed to clay soil. As such, it would be equivalent to the lithologies, mudstone, shale, siltstone and claystone. Attewell, 1997 gave an explanation and description of this material based on its formation and constituents as indicated in the following table 1:

3. INTEGGRATING SOIL/ROCK BORDER LINE DEPOSITS INTO THE FRAM WORK OF SOIL MECHANICS

Table 1. Basic Terms

Un-lithtified	Lithified/ Non-fissile	Litified/ Fissile	Approx. Proportions (grain size)
Silt	Siltstone	Silty Shale	2/3 silt size (2-60 micron)
Mud	Mudstone	Shale	Silt& Clay size (< 60 micron)
Clay	Claystone	Clay Shale	2/3 clay size (< 2 micron)

Soil/ rock border line material occurring in Egypt and elsewhere are mostly desert formations developed from argillaceous rocks. They are mainly unsaturated clayey soil deposits that have a certain degree of lithification. The effect of lithification often develop on the engineering properties. The extent of lithification can be measured from parameters determined from tests on intact samples relevant to mass behavior.

Lithified unsaturated soil material consists of four basic components. Clay mineral, non-clay mineral, interparticles bonds and a pore space occupied by air and water. The structure and degree of this material is determined by the nature and degree of lithification. This structure becomes compact due to the interparticle bonding that occupied part of the pore space that was then present. The extent of lithification is, therefore, a function of the density of soil material and the water content. More interparticle bonds will be present in samples of higher density and lower water content.

At high dry density and high clay content, the structure of soil will be dense and mainly composed of clay matrix and particles containing chain of sand and silt grains. Such structure tends to swell upon wetting giving rise to volume increase.

At low dry density and low clay content, the texture of soil will be mainly composed of an open structure of sand and silt which tends to collapse upon wetting giving rise to volume decrease.

Furthermore, in both cases (swell or collapse), the soil is characterized by having relatively high strength at their natural moisture content and a drastic decrease in strength upon wetting.

Therefore, these types of deposits are associated with engineering problems as a result of related volume change that give rise to ground movements and decrease in bearing capacity that may result in damage to structures.

Accordingly, from the engineering point of view, it is more convenient to consider unsaturated lithified deposits that lie on the border line between soil and rock on basis of their behavior rather than being restricted to categorizing it into soil- like and rock- like types.

4. PROBLEMATIC BEHAVIOR OF SOIL/ROCK BORDER LINE DEPOSITS

4.1 Swelling behavior

Swelling of expansive clayey soils was subjected to the study of numerous research workers, among them are: (Gillott, 1988; Tissot& Aboushook, 1983; Chen, 1988; El-Sohby et al., 988 and Taylor, 1988). Their studies may be summarized as that:

The swelling behavior is the result of interaction between the interparticle bonding and the induced swelling pressure. When the induced swelling pressure exceeds the capacity of bonding, failure in tension occur. Therefore, highly cemented clayey soils often have a high resistance to deformation and may be able to absorb significant amount of swelling pressure.

When swelling clay minerals are present and water is available, the minerals take water into their lattice structure. In less dense clayey soils, they tend to expand initially into zones of loose soil before volume increase occurs. In densely packed clayey soil with low void space, the soil mass has to swell more or less immediately to accommodate volume change.

Furthermore, where weak interaction of the cations with the surface of unit layers occur in the clay mineral as with sodium, separation of exchangeable cations from the montmorillonite surface results in double layer repulsion between platelets, tending to separate the platelets as far as possible in the water available until they are dispersed into individual platelets in water.

4.2 Collapse behavior

Collapsible soils were subject to the study of various research workers, among them are: (Feda, 1988 and Houston et al., 1988). Their studies may be summarized in the following:

Soils which are liable to collapse possess porous textures with high void ratios and relatively low densities. The micro - structures of collapsible soils takes the form of a loose skelton built of coarse grained material (sand and silt) and fine grained material (clay). The sand and silt sized particles are separate from each other and are connected by bonds and bridges. These bridges are made of clay sized material. As grains are not in contact, mechanical behavior is governed by the structure and quality of bonds and bridges. Therefore, at their natural low moisture content, these soils possess high apparent strength but they are susceptible to large reductions in void ratio upon wetting. In other words the structure collapses as bonds between the grains break down when the soil is wetted.

5. PREDICTION OF VOLUME CHANGE BEHAVIOR

As previously mentioned, the main problem associated with partially saturated lithified deposits that lie on the border line between soil and rock is their volume change in the presence of water and the mobilization of swelling pressure or collapse potential. Therefore, the main concern of design engineer is to understand the behavior of such soil and to make quantitative estimates of the anticipated volume change upon wetting. This was subject to study by various research workers and numerous relationships were established to predict volume change of unsaturated soils. However, most of the efforts was directed towards investigating either swelling characteristics or collapsibility characteristics.

In attempt to investigate the problem of these formations on one general basis, El-Sohby, 1994 initiated a comprehensive research work using experimental data from tests carried out on 72 samples of soils representing a wide range of soil properties. These soil samples were divided into two main groups each composed of 36 samples. The first group constituted sand- clay mixes with different proportions and the second constituted silt clay mixes.

In this study, the dry unit weight (γ_d) and the type of coarse grained fraction were used to express the micro - structures of soil, and the clay content to express the matrix of internal structure. Both sand and silt were mixed with different percentages of clay 0,10,20,30,40,50,60,80,90 per cent .Thus the two groups of sand-clay and silt-clay mixtures were divided into 18 groups, giving a total of 18 different soils. For each soil ,four specimens with dry densities 14.0,15.5,17, and 18.0 kN/m3 were tested. This gives the data for 72 soil specimens. All specimens were unsaturated and of 8% initial water content. The specimens were tested in the oedometer apparatus. After the specimen had reached equilibrium under 200 kN/m2, it was flooded with water and allowed to swell. The swelling per cent (axial strain) was that measured under 200kN/m2 after inundation.

The test results obtained were tabulated and used to construct charts relating the dry unit weight and clay content to predict quantitatively the swell or collapse potential of soil. This is indicated on table 2 and figures 1&2.

Table 2. Measured and predicted values of axial strain of 29 undisturbed samples

Soil No.	Measured physical properties						Axial strain	
	mo	γ_d	S_r	Clay	Silt	Sand	Measured	Predicted
	(%)	(kN/m3)	(%)	(%)	(%)	(%)	(%)	(%)
1	2.0	13.0	5.0	17	56	27	- 12.5	- 14.0
2	1.5	20.0	11.6	5	10	85	+ 5.0	+ 0.5
3	8.0	18.5	47.0	52	35	13	+ 12.5	+ 12.5
4	7.5	18.6	44.8	54	40	6	+ 13.6	+ 13.30
5	10.0	19.0	61.5	28	22	50	- 4.5	+ 1.50
6	6.0	19.6	54.6	59	37	4	+ 14.0	+ 15.0
7	15.0	16.5	61.9	45	40	15	- 0.5	+ 6.0
8	17.0	17.0	75.7	50	20	30	+ 5.0	+ 5.0
9	5.5	14.6	31.5	18	64	18	- 0.3	- 5.0
10	6.0	19.0	38.5	52	38	10	+ 8.5	+ 14.0
11	2.0	18.0	10.8	13	27	60	- 1.0	00
12	1.5	17.0	6.9	7	27	76	- 5.0	- 0.8
13	5.5	18.5	32.3	48	29	23	+ 8.9	+ 11.0
14	2.0	17.5	9.9	9	3	88	- 1.0	- 0.5
15	5.0	19.5	35.0	50	30	20	+ 15.0	+ 15.0
16	2.0	16.5	8.5	10	25	65	+ 5.0	- 0.9
17	2.0	16.5	8.5	8	5	87	- 7.5	- 0.9
18	9.5	18.0	51.0	52	30	18	+ 14.0	+ 11.5
19	5.4	16.0	21.2	7	18	75	- 3.5	- 1.2
20	8.5	18.5	50.0	48	35	17	+ 15.0	+ 12.0
21	6.5	19.0	41.7	50	33	17	+ 18.5	+ 13.0
22	8.0	19.0	37.0	92	8	00	+ 20.0	+ 25.0
23	4.5	19.0	26.0	60	30	10	+ 18.5	+ 14.0
24	2.0	15.0	6.8	15	45	40	- 6.5	- 3.0
25	3.6	19.5	25.3	53	32	15	+ 12.5	+ 13.0
26	4.0	18.5	23.5	10	31	59	- 2.5	00
27	11.0	17.5	53.0	45	35	20	+ 7.5	+ 7.5
28	3.5	18.0	18.0	48	32	20	+ 8.0	+ 10.0
29	4.0	21.0	33.0	50	35	15	+ 15.0	+ 15.0

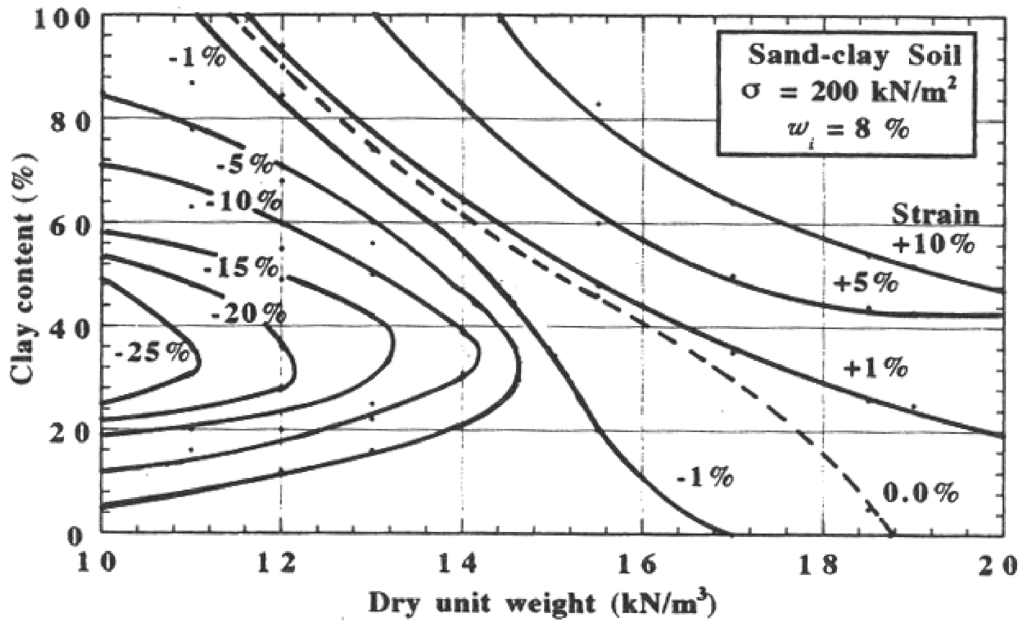

Fig. 1 Axial strain versus dry unit weight and clay content for sandy clayey soils

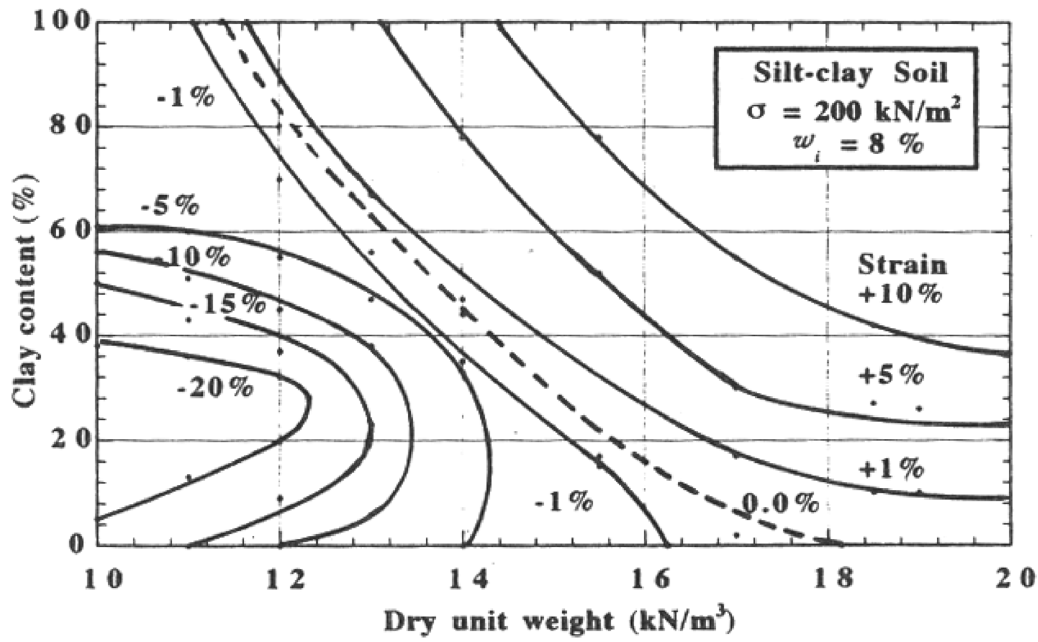

Fig. 2 Axial strain versus dry unit weight and clay content for silty clayey soils

6. TESTING THE VALDITY OF THE PROPOSED CHARTS

A previous work by Aboushook, 1988 included data of 29 undisturbed samples taken from different locations and covering a wide range of geographical areas was used. The axial strain was measured for specimens of size 35 mm in diameter and 50 mm in height. This was used to test the validity of the proposed charts.

Utilizing the proposed charts in terms of the physical properties of the 29 samples, the axial strain of each soil (predicted value) was determined. This was compared with the measured values given by Aboushook, 1994 and tabulated.

7. CONCLUSIONS

- Nearly all naturally occurring soil formations are being created from rocks by the process of weathering or are being turned back into rocks by the process of lithification.
- The nature and degree of lithification determine a material that may range between those of soil and rock.
- Soil/ rock border line deposits are mainly unsaturated formations developed from argillaceous rocks.
- Mudrock is the term used to encompass argillaceous lithified rocks. As such it would be equivalent to the lithologies mudstone, siltstone, claystone and shale.
- This type of deposits have certain degree of lithification. The effect of lithification often develop on the engineering properties. The extent of lithification can be measured from parameters determined from tests on intact samples relevant to mass behavior such as dry density, water content and clay contents.
- Unsaturated lithified deposits are characterized by associated engineering problems. This is due to their tendency to volume change upon wetting and the mobilization of swelling pressure or collapse potential.
- From the engineering point of view, it is more convenient to consider unsaturated lithified deposits that lie on the border line between soil and rock on basis of their behavior rather that being restricted to categorizing it into soil- like and rock- like types.
- To integrate soil/ rock border line deposits into the frame work of soil mechanics, a comprehensive research work was done using experimental data from tests carried out on 72 samples of soils representing a wide range of soil properties. The test results obtained were tabulated and used to construct charts relating the dry unit weight, clay content and water content to predict quantitatively the swell or collapse potential of soil.
- To test the validity of the proposed charts, the axial strains of other 29 undisturbed samples taken from different locations were determined in the laboratory and compared with predicted values using the proposed charts. Almost a complete agreement was found between the measured and the predicted values.
- The proposed charts can be used to predict qualitatively and quantitatively volume change behaviour of unsaturated lithified soil/ rock border line deposits.

8. REFERENCES

Aboushook, M.I; Mazen, S.O. and El- Sohby, M.A. (2005). Correlating predictions for problematic soils with field measurements, International Conference on Problematic Soils, Famagusta, Cyprus.

Aboushook MI (1994) Engineering geological classification of weak argillaceous rocks in some Egyptian deserts.7th Int. IAEG Congress, Lisboa, Portugal, Balkema, Rotterdam,421-427.

Attewell PB (1997) Tunneling and site investigations. Geotechnical Engineering of Hard Soils- Soft Rocks, Balkema, Rotterdam, 1767-1790.

Barton ME, Mockett LD, Palmer SN (1993) An engineering geological classification of the soil/ rock borderline materials between sands and sandstone. The Engineering Geology of Weak Rock, Balkema, Rotterdam, 125-138.

British Standard Institution 5930 (1981) Code of Practice for site investigation

Chen EN (1988) Foundation on expansive soils, Elsevier, Amsterdam, 465pp.

De Freitas M.H (1993) Weak arenaceous materials. The Engineering Geology of Weak Rock, Balkema, Rotterdam, 115-123.

El- Sohby, M.A.; Mazen, S.O. and Aboushook, M.I. (2005). Advancement in oedometer testing of unsaturated soils, International Conference on Advanced Experimental Unsaturated Soil Mechanics, EXPERUS 2005, Teronto, Italy.

El- Sohby Ma (1994) Swelling and collapsing behavior of arid soils Symposium on development in Geotechnical Engineering, Bankok 193-200.

El-Sohby MA, Mazen SO, Elleboudy AM (1988) Comparative study of problematic soils in two areas around Cairo. Proc. Symp. On Environmental Geotechnics and Problematic Soils and Rocks. Asian Insitute of Technology, Bankok, 515-526.

Feda J (1988) Collapse of soil on wetting, Engineering Geology, 25:265-267.

Gillott JE (1988) Clay in engineering geology Elsevier, Amsterdam, 226 pp.

Houston JL, Houston WL, Spadala DJ (1988) Prediction of field collapse of soils due to wetting, Proc. Of ASCE, J. of Geotechnical Engineering Division, 114:40-58.

Marions PG (1997) Hard soil- Soft rocks: Geological features, Geotechnical Engineering of Hard Soils- Soft Rocks. Balkema, Rotterdam, 1807-1818.

Taylor Rk (1988) Coal measures mudrocks, Q. J. Engineering Geology, London, 21:85-99.

Tisot JP, Aboushook MI (1983) Triaxial study of the swelling characteristics, Proc.of the Asian Regional Conference on Soil Mechanics and Foundation Engineering, Haifa,1:94-97.

Vaughan PR (1997) Engineering behavior of weak rocks. Geotechnical Engineering of Hard Soils- Soft Rocks. Balkema, Rotterdam, 1741-1748.