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Critical issues in soft rocks

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ABSTRACT

This paper discusses several efforts made to study and investigate soft rocks, as well as their physico-mechanical characteristics recognized up to now, the problems in their sampling and testing, and the possibility of its reproduction through artificially made soft rocks. The problems in utilizing current and widespread classification systems to some types of weak rocks are also discussed, as well as other problems related to them. Some examples of engineering works in soft rock or in soft ground are added, with emphasis on their types of problems and solutions.

1. Introduction

Soft rocks are a critical geomaterial since they present several types of problems. First of all, they may present undesirable behaviors, such as low strength, disaggregation, crumbling, high plasticity, slaking, fast weathering, and many other characteristics.

These types of unfavorable behaviors prevent their utilization or tend to avoid the use of the site dominated by soft rocks for important engineering works many times. Dams and hydroelectric power plants look for a better geological condition; tunnels and highways look for a better alignment escaping from weak zones, whenever possible. However, there are entire regions in the world dominated by soft rocks where no good or better rock is encountered, obliging people to accept and to deal with them. This leads to the need of understanding well soft rocks and of developing adequate solutions for the problems they pose.

Secondly, soft rocks have intermediate strength between soils and hard rocks. In some cases, they are too soft to be tested in rock mechanics equipment and too hard for soil mechanics equipment. This indicates that some adjustment in their testing must be developed to well characterize their properties.

The third type of problem is their sampling and site investigation. The percussion boring is prevented when high number of blows for standard penetration tests (SPTs) determination is required. Usually, in practical terms, the ground is considered impenetrable with SPTs greater than 50, and no adequate sampling is possible. On the other side, conventional rotary diamond drillings, even with swivel type double barrels, destroy the sample or bring it in bits and partially destroyed, avoiding to know well the type of subsoil. Even triple barrels, although better, may be inefficient. The most critical and important geological feature is exactly that one not recovered. This leads to the necessity of driving pits or shafts for good reconnaissance of the subsoil.

Last but not least, some types of soft rocks present great difficulty in their geomechanical classification under the usual systems, since these systems were developed mainly for discontinuous media of hard rocks. Therefore, for soft rock masses, it will be necessary to adapt the existing systems or develop new classification systems, which are specific for practically continuous soft rock masses.

Consequently, soft rocks and soft grounds are little studied and understood, and there is little confidence on their properties to be utilized in important engineering works. In this way, conservative parameters are adopted, to guaranty enough safety, but very often against the economy.

All these reasons indicate that the study and understanding of the characteristics of soft rocks are important, mainly because good geological conditions may not be presented in large regions of the world, but mainly the best geological sites have already been used, obliging the present and future engineering works to face and tackle with the available sites dominated by soft rocks.

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It is not the intent of this paper to cover and define the issues here presented, but rather to discuss the main types of problems and shortcomings in the knowledge of soft rocks, hoping to motivate discussion and research, and that the developments made by researchers and institutions be reported as a contribution to the International Society for Rock Mechanics (ISRM) Technical Commission on Soft Rocks.

2. Geotechnical societies' contribution

Besides researches made at universities, research institutes, and some specific investigation carried out by the industry, the main systematic effort for the development of the understanding of soft rocks has been made by the geotechnical societies.

The first known soft rock technical commission was settled by ISSMGE (International Society of Soil Mechanics and Geotechnical Engineering) as TC22 Soft Rocks and Indurated Soils, initially chaired by Prof. Akai, Japan, from 1985 to 1994, followed by Prof. Durville, France, from 1994 to 2001 when the TC was discontinued. It is worth mentioning that the first international symposium on soft rocks was held in Tokyo, in 1985 and that the commission presented a report on Recent Advances on Soft Rock Research at the 12th ISSMGE congress in 1989 in Rio de Janeiro, Brazil.

Meanwhile, some important papers were presented at conferences, among them those of Deere and Vardé (1986) as a general report to an International Association of Engineering Geology (IAEG) conference, where they considered those masses of hard rock as weak rocks but including weakness geological features besides soft or low strength intact rock; a thesis on weak sandstones by Dobereiner (1984) at the University of London; a keynote lecture by Nieto (1982) on soft rock masses at the 1st South-American Congress on Rock Mechanics, at Bogotá and Kanji (1990) at the 3rd South-American Congress on Rock Mechanics, Caracas, on dam foundations on soft rocks. In Brazil, ABGE (Brazilian Association for Engineering Geology) promoted a group study on the geotechnical properties of sedimentary rocks of Brazilian formations, coordinated by Campos (1988).

Some universities and research institutes have also worked on soft rocks. For instance, the sub-society of soft rock engineering (set up in 1996) is very active in China, chaired by Prof. Manchao He, where 13 symposiums on soft rock engineering have been held since 1999, dealing with new concepts regarding soft rocks, soft rock classification and countermeasures for different soft rock engineering problems.

In parallel, Prof. Juan Jose Bosio, from Paraguay, encouraged the geotechnical societies of Argentina, Brazil, Paraguay, and Uruguay, to constitute a Regional Committee on Soft Rocks of the Rio de la Plata Basin, encompassing those countries. The committee worked for some time under his chairmanship, succeeded by this author. The committee was later converted in a regional committee of IAEG, and in 2 or 3 years of existence presented a first report at the end of term of the IAEG President, in 2002, IAEG did not renew the committee.

The first symposium specifically devoted to soft rock at our knowledge was organized by the Spanish geotechnical societies on soils, rocks, and tunnels, and called National Symposium on Soft Rocks, held in Madrid on November 17–18, 1976.

However, the first event at international level was the Tokyo symposium of 1985. It was followed by other international or national ones, although not as a sequence. In 1990, the British Geological Society organized the 26th Annual Conference of the Engineering Group, having published their proceedings in 1993 as a book entitled "The Engineering Geology of Weak Rock". In 1998, the Italian Geotechnical Society organized the International Symposium called "The Geotechnics of Hard Soils–Soft Rocks in Naples". The next one was the 15th European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE) held in Athens, 2011, under the title "Geotechnics of Hard Soils–Weak Rocks". The 2nd South-American Symposium on Rock Excavation was held in Costa Rica, 2012, with a special lecture given by Kanji (2012) about problems and solutions of soft rocks in engineering works. The next IAEG Congress to be held this year (2014) in Torino, will include a technical session on soft rocks, as well as the Brazilian Rock Mechanics Symposium to be held in Goiania, in next September.

In the academic side, some important theses were prepared. To the author's knowledge, the most outstanding ones were those of Dobereiner (1984) at the University of London, on weak sandstones, Jeremias (1997) at the Laboratório Nacional de Engenharia Civil (LNEC), Portugal, on argillaceous rocks, and Galván (1999) at University of São Paulo, Brazil, on the properties of artificially cemented sands to simulate arenaceous soft rocks.

In 2007, Prof. Pedro Pinto, the ISSMGE president, suggested the sister societies IAEG and ISRM to establish a Joint Technical Committee (JTC) on Soft Rocks, which was accepted, and the JTC-7 on Soft Rocks was constituted, among several other ones. The work was launched but in early 2010 due to institutional problems, all JTCs were extinguished, except JTC-1 on Landslides.

Finally, in 2011 during the ISRM Congress in Beijing, a Soft Rock Technical Commission was proposed, having being accepted by the new president, Prof. Xia-Ting Feng and the ISRM board, with fruitful work up to now. The Specialized Conference on Soft Rocks organized by the Chinese Society for Rock Mechanics and the Chinese Sub-society for Rock Engineering and Deep Disaster Control is an activity of the ISRM Technical Commission.

3. What is considered soft rock?

Several authors have classified intact rocks according to their strength in different scales and terms, as summarized in Fig. 1. However, there is a practical coincidence that the upper limit of the strength of what is considered soft is about 25 MPa as unconfined compressive strength (UCS).

On the other side, the lower limit of the strength of soft rock, distinguishing it from soils, is more difficult to establish. An SPT above 50 and an UCS greater than 0.4 MPa were established by Terzaghi and Peck (1967) for materials behaving more like rock than soil. Dobereiner (1984) considered an UCS value of 0.5 MPa. Rocha (1975) distinguished rock when the piece does not crumble or disaggregate when immersed in water. Baud and Gambin (2011) utilized another criterion, based on the limit pressure in pressuremeter testing, indicating values of 2–10 MPa, and depending on the elastic modulus to the limit pressure ratio.

Notwithstanding, the transition between soft and hard rocks and with soil is problematic. In some studies by Galván (1999) to verify whether all rock types conform to the theoretical relationship between dry density and porosity, it was seen that there is a continuous transition between those materials, without any sharp change in that relationship, as shown in Fig. 2 (Kanji and Galván, 1998). Some dispersion around the theoretical line must be due to differences in testing procedures.

The usual rock types that may be called as soft rocks are mentioned in Table 1.

However, it has to be emphasized that the mention of the geological or lithologic name alone may be misleading. For example, sandstone can be cement in different degrees, being very soft if poorly cemented or extremely hard if well cemented. Therefore, the complementary condition must be also mentioned to allow good definition of the material condition.

Even the geological age may be important. In dealing with sedimentary rocks from the Paraná Basin, Bosio and Kanji (1998)

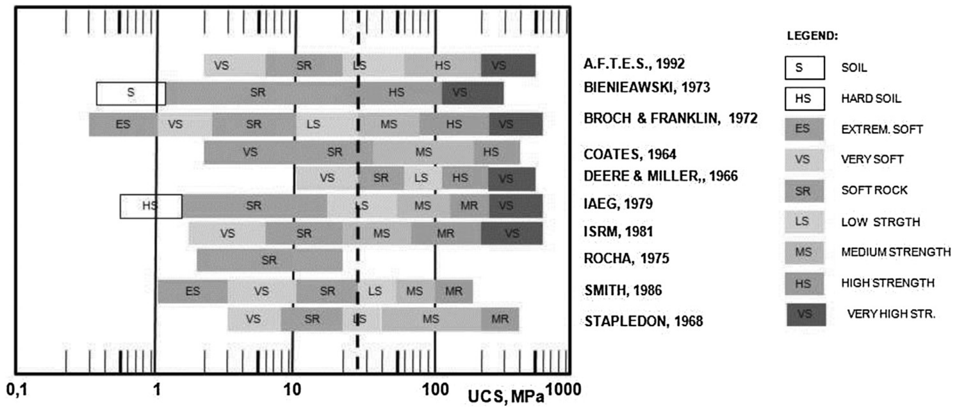


Fig. 1. Classification of rocks according to the strength by various authors (modified after Galván (1999)).

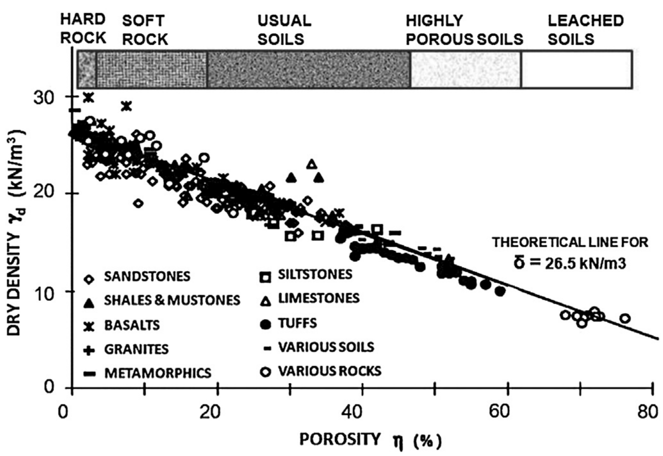


Fig. 2. Graph of dry density vs. porosity with plots of different rock types, indicating usual limits between hard and soft rocks, and with soils (modified after Kanji and Galván (1998)).

have seen that the porosity decreases with age, and then the strength increases, due to the diagenesis and burial pressure, as demonstrated in Fig. 3.

Other rock types which can also be considered as soft rock are the weathering products of crystalline rocks (granite, gneiss, etc.), which bring several geotechnical problems in urban areas, for instance, the slope stability at Rio de Janeiro, Hong Kong, and many other cities and regions.

The above considerations refer to the strength of intact rock. However, there is a great tendency to consider also the behavior of weak rock masses, also as soft rock. Deere and Vardé (1986) pioneered in considering rock masses of harder rock but including structural defects as intense jointing, voids, etc. in addition to intact rock of low strength, determining a weak behavior of the rock mass. Rock masses subjected to high pressures or high temperature may also present a behavior of weak masses. Also hard rocks but suffering rapid weathering may be transformed in the early life of the work in weak or soft rock. This means that the concept of “soft rocks” is not yet well defined, and accepts discussion to establish a definitive concept.

Table 1
Usual types of soft rocks.

Basic types	Subclasses
Sedimentary rocks	*Clastic*: mudstones, shales, siltsones, sandstones, conglomerates and beccias, and marl; *Evaporites*: salt rock, carnallite, etc.; *Soluble*: limestone, dolomite, and gypsum; and *Coal*
Igneous rocks	Volcanic conglomerates, breccias, and lahar; Basaltic breccia; Piroclastic deposits, volcanic ash, tuff and ignimbrite; and Weathering products of crystalline rocks
Metamorphic rocks	Slate, phyllite, schists, quartzite little cemented, Metavolcanic deposits

4. Soft rock properties

Several engineering workings under design or under construction in sites of soft rocks perform field investigation, laboratory tests, and sometimes field tests. The types of tests vary from site to site, according to the geological setting and type of structure, so that seldom a complete set of test results are available. Also, most of the times the results are not public, and are lost when kept for a long time in the office drawers.

It is believed that a collection of soft rock results of field and laboratory tests would be very much beneficial, as their joint analysis could indicate probably with little dispersion the trends of their physico-mechanical properties. In this way, a database built with general contributions would be highly welcomed.

In this trend, a research was made by Galván (1999) collecting and analyzing data from soft rocks published in symposia and congresses in a period of about 30 years, since the symposia of Madrid in 1976 and of Tokyo in 1985. He has elaborated a database

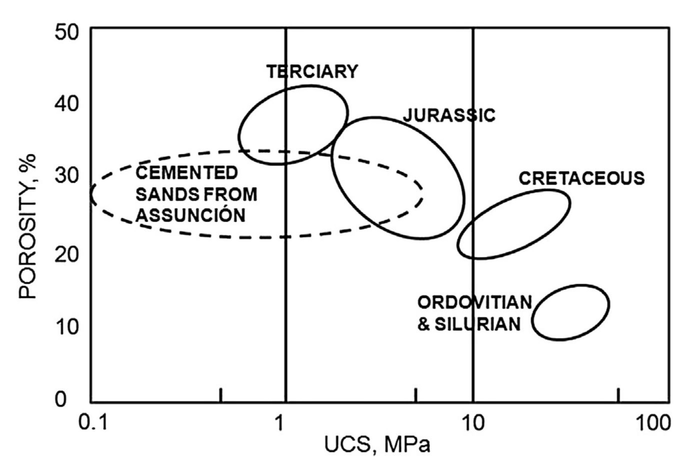


Fig. 3. Sedimentary rocks from the Paraná Basin, showing the decrease of porosity and increase in strength with the geological age (modified after Bosio and Kanji (1998)).

from which it was possible to obtain useful correlations between several physico-mechanical properties of soft rocks, both arenaceous and clayey. The main data have been published also by Kanji and Galván (1998), and are summarized in Figs. 4–8.

Fig. 4 shows the relation between dry density and the UCS, noting that in a semi-log scale the tendency of the results has an S shape, with the exception of a few data obtained from the literature.

Another factor affecting the rock strength is the water content or humidity. Fig. 5 presents a compilation of these variations for different materials and from diverse origins.

The ratio of the elastic modulus at 50% of the ultimate strength (E_{50}) and the UCS was first defined by Deere (1968) and utilized for the basic description of the rock mechanical properties. The database of Galván (1999) is presented in Fig. 6, showing the field where all data fit. The average data follow the dashed line, indicating that the higher the strength is, the higher the ratio E_{50}/UCS is.

The dynamic modulus of elasticity measured by sonic velocity on intact samples is about 1.5–2 times that of the static modulus E_{50}, as indicated in Fig. 7, presenting data from diverse sources and authors, according to Galván (1999). The data corresponding to concrete are presented for the sake of comparison.

An additional correlation was made between absorption and porosity, to verify if diverse types of rocks follow the theoretical relationship or if closed voids would result in data apart from it. As shown in Fig. 8, it was shown that the data follow quite well the theoretical line. A few dispersed data must result from differences in testing procedures.

Further investigations on soft rock properties could be carried out on natural specimens but also on artificially made ones, with which it would be possible to do the tests under controlled conditions.

It has been sought to find some property, which could work as an "index property". The good correlation between absorption and porosity could be a good one, since absorption is a very simple test and that porosity correlates to dry density from where indication from the level of strength can be derived. In short, the absorption is thought to give good indications on the properties and behavior of the soft rock. Perhaps for clayey rocks the slaking test would be also

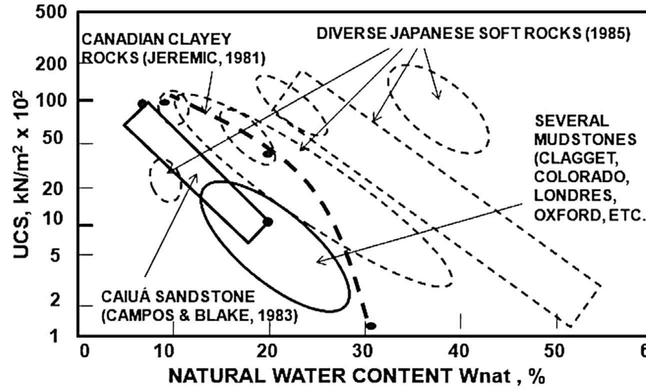


Fig. 5. Graph of the influence of the natural water content on the strength for diverse materials and origins (modified after Nieto (1982) and Kanji and Galván (1998). Japanese Soft Rocks (1985) in Galván (1999)).

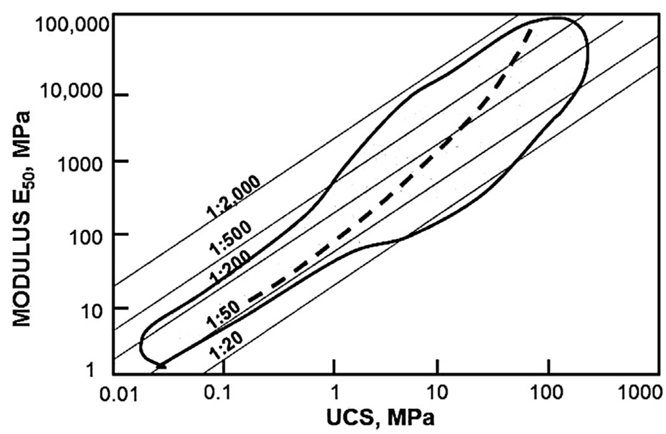


Fig. 6. Relationship of E_{50} and UCS for most soils and rocks. The shadow area is the locus of the data (modified after Deere (1968), Galván (1999), and Kanji and Galván (1998)).

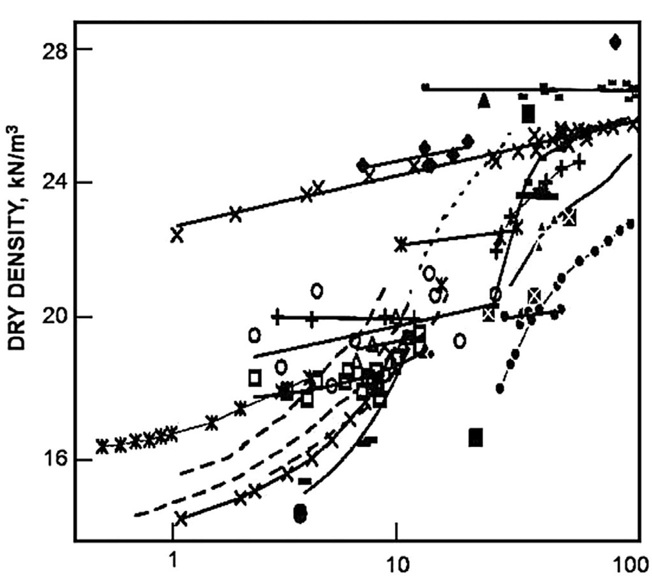


Fig. 4. Graph of dry density vs. UCS. The lines correspond to same materials with varying properties (after Kanji (1990) and Kanji and Galván (1998)).

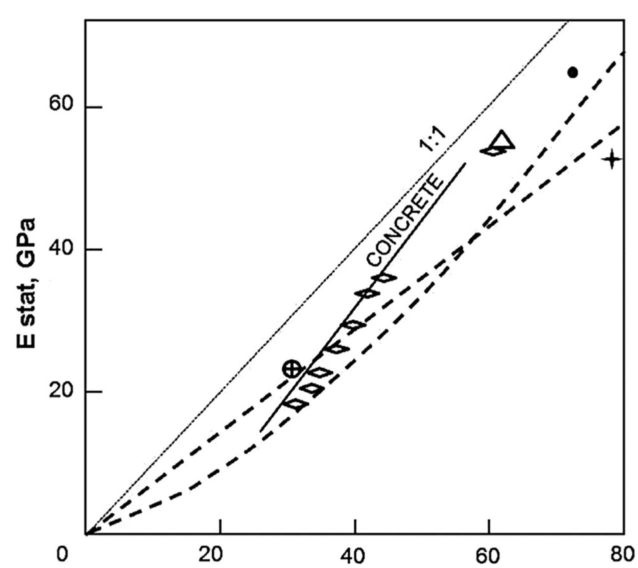


Fig. 7. Relationship between static (E_{50}) and dynamic moduli for intact rocks (modified after Galván (1999)).

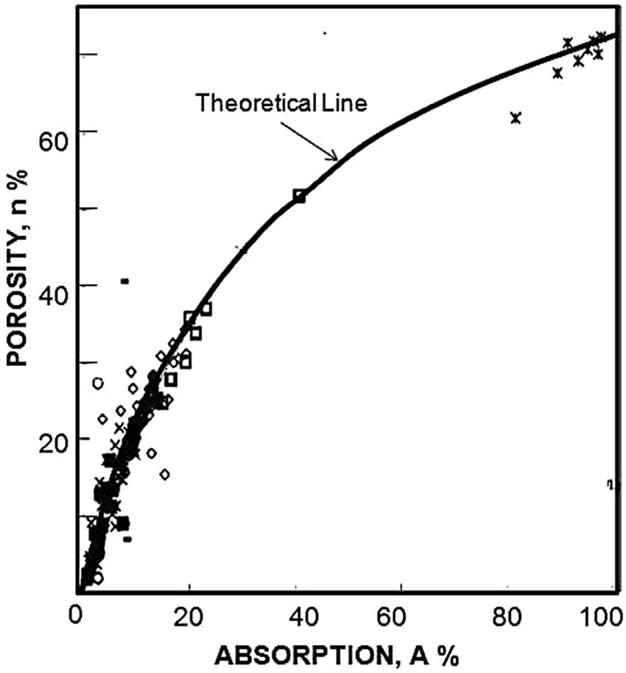


Fig. 8. Relationship between absorption and porosity, for several rock types, compared to the theoretical line (Kanji and Galván, 1998).

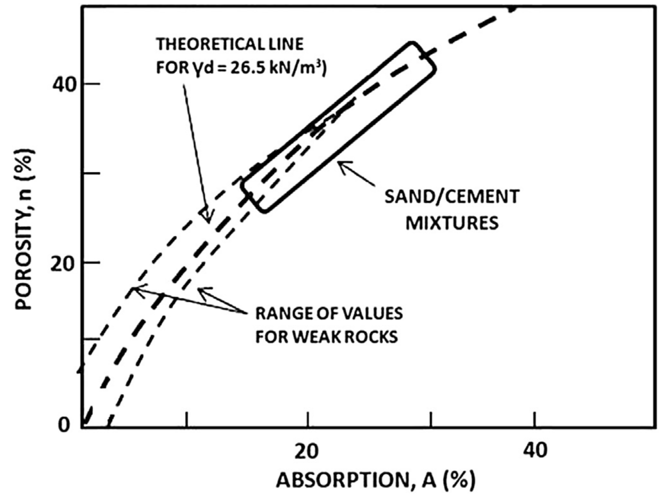


Fig. 10. Graph of absorption vs. porosity of cemented sands compared with data of natural rocks.

needed. A tentative correlation between the main properties is suggested in Fig. 9.

It is important to count with more data of soft rocks. It would be highly desirable to count with a database where data from diverse sources could be uploaded, to be available to every interested person.

5. Artificially made arenaceous soft rock

The same research made by Galván (1999) aimed at verifying whether artificially made sandy soft rocks by cemented sands with variable Portland cement contents would present similar properties to those natural ones. Several specimens were prepared with different cement contents and were subjected to diverse types of tests to determine their physico-mechanical properties, to be compared with the collection of properties of natural rocks above mentioned. The coincidence of determined properties for the sand–cement mixtures with properties of natural soft rocks is striking, as can be seen in Figs. 10–13 reproduced from Galván and Kanji (2011) except for the correlation between dry density and UCS, where the mixtures have shown high strength even with lower dry densities.

The good fit between artificially made and natural rocks indicates that a systematic study of soft rock properties can be made under controlled conditions.

6. Sampling and testing of soft rocks

Due to the low strength of the rock, the sampling and specimen preparation for testing are usually very much problematic, and these issues deserve extended discussion and development.

The field investigation and sampling are normally made by diamond drilling, which causes destruction of parts of the rock core

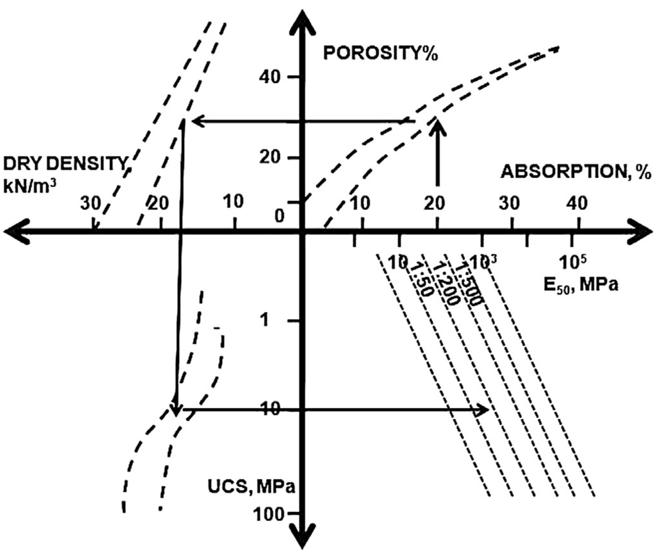


Fig. 9. Tentative correlation between diverse properties starting from absorption.

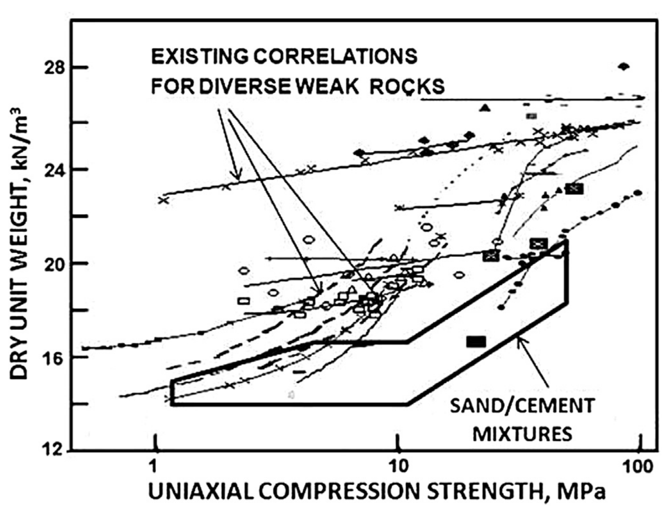


Fig. 11. Dry unit weight vs. UCS of cemented sands compared with data of natural rocks.

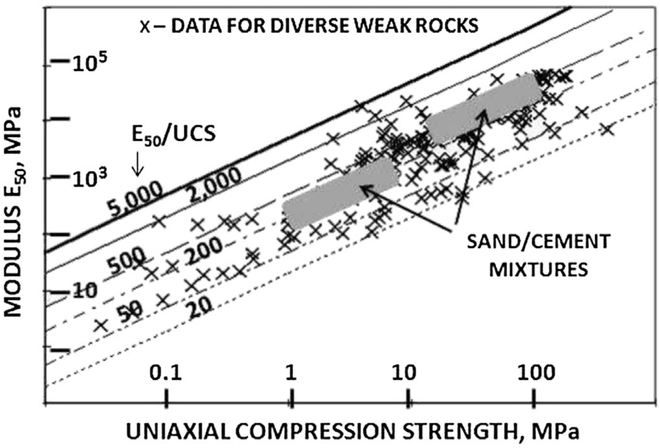


Fig. 12. Graph of E_{50} vs. UCS of cemented sands compared with data of natural rocks.

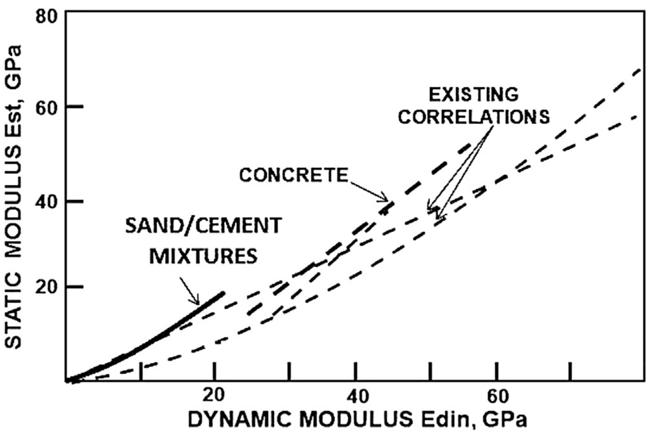


Fig. 13. Graph of static and dynamic moduli of cemented sands compared with data of natural rocks.

due to contact with the drilling water and the friction and vibration of the bit and rods, as exemplified in Fig. 14. The crumbling of some rock types when immersed in water for a small period of time can be seen in Fig. 15.

In several cases, it has been seen that the use of bentonite mud allows better core recovery. In cases that Lugeon tests are scheduled to be run in the boring, it is recommended to utilize chemical muds that degrade after certain time (usually one or a few days). Fig. 16 shows the same volcanic lava recovered in two neighboring drillings, without and with drilling mud, which improved the core recovery.

Swivel barrels and a minimum NX/NW drilling diameter (about 3 inches) are needed. Triple barrels tend to improve still more the

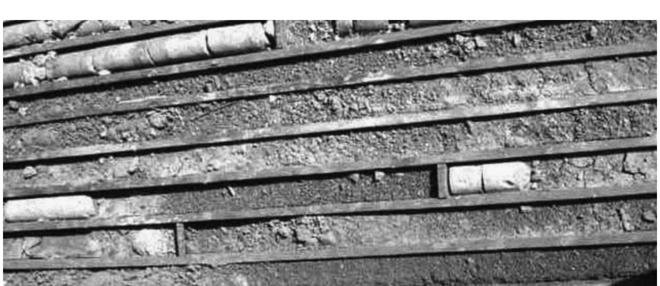


Fig. 14. Photo of a rock core of lava flow completely disaggregated.

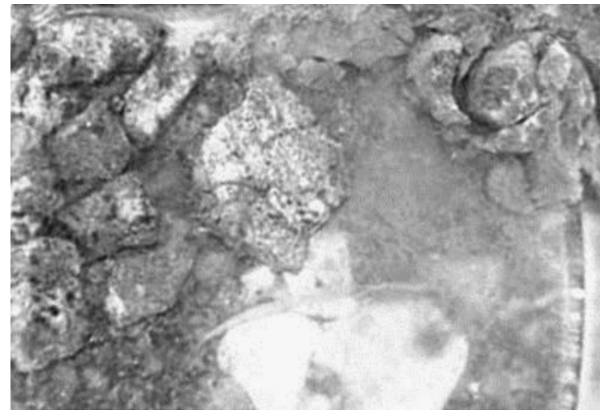


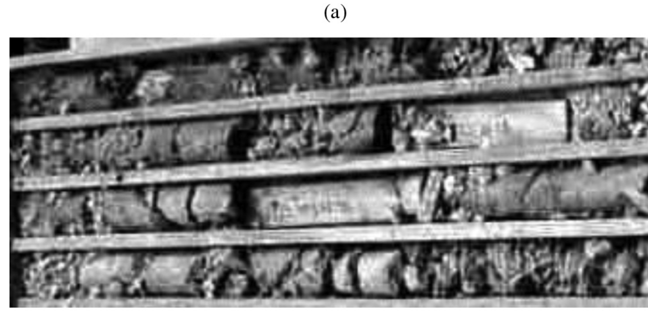
Fig. 15. Crumbling of fragments of volcanic lava immersed in water.

core recovery. Notwithstanding, even then the drilling may lose parts of the sample and fail to indicate the presence of critical features in the ground. Whenever possible, mainly for dam foundations, a test pit excavated by gentle blasting is recommended.

It is believed that further development is required to allow better sampling and preservation of critical soft rocks that disaggregate, or are expansive or heavily affected by contact with water. As an example, it is known that the State Key Laboratory of Geomechanics and Deep Underground Engineering, China University of Mining and Technology (Beijing), has designed and developed a new sampling system for undisturbed samples, both for regular and swelling samples that can be easily utilized in the field. It consists of a compressed air driven drill, a portable sample cutting tool, and a portable sample box, as illustrated by the photos of Figs. 17 and 18.

Geophysical prospection is also recommended for full subsoil recognition. Resistivity methods can show hidden weaker material and seismic refraction can show changes in transmission velocity layers (from which hardness or weathering degrees and stratification can be derived), also allowing to derive dynamic elastic properties.

(a)



(b)

Fig. 16. Volcanic lava recovered in neighboring drillings, without drilling mud (a) and with degradable mud (b).

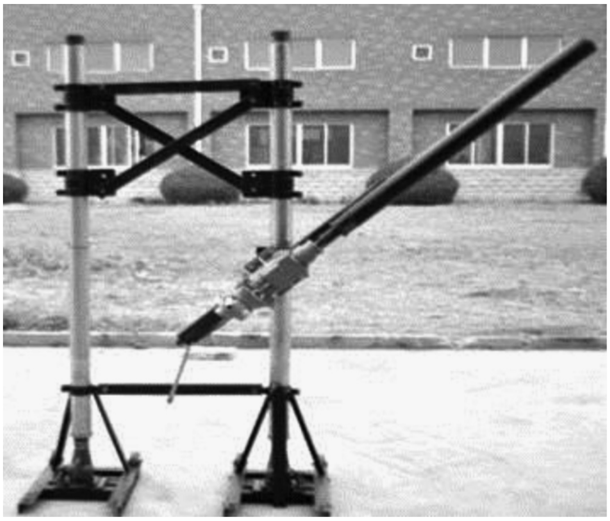


Fig. 17. Light drill for core sampling.

Fig. 19. Motor saw utilized to extract undisturbed soft rock blocks.

Whenever possible, undisturbed samples of soft rocks can be obtained, either by cutting (as shown in Fig. 19) or by secant drilling to isolate sample blocks.

To obtain cylindrical samples from rotary drilling may be very difficult for the above-mentioned reasons. A valid alternative was used at the Reventazón project in Costa Rica, where square prisms as seen in Fig. 20 were produced by sawing with diamond disc shown in Fig. 21.

The UCS results were corrected afterwards for its shape since the square prisms yield an ultimate strength (σ_r) 30% higher than that for cylindrical ones, and for its height (L) to diameter (D) ratio.

The point load test can be a very interesting test, since it requires only irregular pieces of rock, but in very soft and deformable rock the sample significantly deforms before failure, which could lead to false results. The same consideration applies to the Brazilian test in very soft rock.

Many of the laboratory testing can be carried out following the ISRM suggested method (Ulusay and Hudson, 2007), but certainly in some cases the weakness of the sample may not allow it. It will be necessary then to improve and adjust the procedure to allow the test to be made. It will be of utmost importance to describe the procedure and even forward it as a suggestion to be studied by the pertinent Technical Commissions of ISRM (mainly the Testing Methods and the Soft Rock ones).

There is a great demand for deeper investigation and revision of suggested methods specifically for soft rocks of the slake durability, Schmidt hammer, and indentation tests.

One way of overcoming certain laboratory shortcomings for soft rock testing could be in situ tests on large samples, as direct shear and plate load tests, whenever its cost and time required are accepted by the particular project. Geophysics through seismic prospection can be very useful to recognize zones of different properties, leading to further investigation to determine their respective properties.

7. Geomechanical classification

The most common and traditional classification systems are the well-known RMR system (Bieniawski, 1989) and Q system (Barton et al., 1974). Both of them are based on rock characteristics as: UCS, RQD (rock quality designation), joint frequency, joint roughness and infilling, water flow and pressure, and state of stress. The RMR system also includes the position of the structure with respect to tunnel driving, and the Q system includes the index ESR

Fig. 18. Portable saw for core cutting.

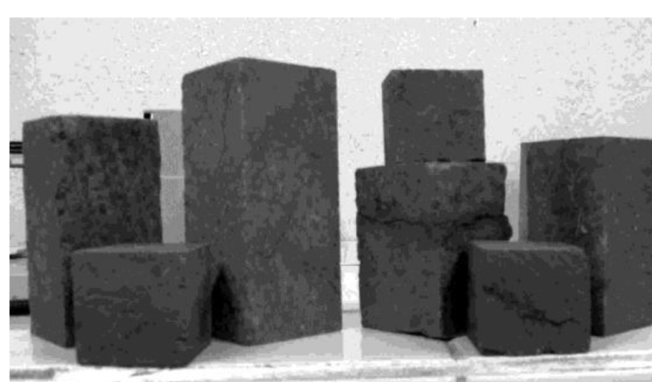


Fig. 20. Square prisms and cubes produced by sawing.

Fig. 21. Circular diamond saw.

Fig. 23. Cut in volcanic breccia.

(excavation support ratio), which works indirectly as a factor of safety. More recently, Hoek et al. (1998) developed a GSI (geological strength index) system, based on the characteristics of the jointing structure of the rock mass and the condition of the joint surfaces.

It is clear that these systems (and other similar ones less common) were developed and applicable to discontinuous media made of hard rocks.

However, when the strength of the rock is very low, and when the rock mass does not present jointing, the above systems are difficult to apply and have major shortcomings. This is particularly the case of homogeneous rocks, although formed by heterogeneous materials, as is the case of conglomerates, breccias, and lahar. The typical aspect of such rocks is illustrated in Figs. 22 and 23.

It can be seen that they are rocks of weak matrix with hard rock fragments, without jointing. Under diamond rotary drilling, the core recovery would be poor, recovering only the hard fragments or pebbles, and the RQD would be close to zero. In the traditional systems, due to the low strength of the matrix, the geomechanical classification would be considered as a rock class III or even IV. Notwithstanding, the openings in these materials are perfectly stable at limited diameters, as shown in Figs. 24 and 25. This indicates that new classification criteria must be developed for such type of materials, which are very abundant in large regions as, for instance, Central America and the Andes region.

Fig. 22. Outcrop of conglomerate with hard fragments and sandy matrix.

It is suggested that the basic factors to be taken into account would be the strength of the matrix and the percentage of hard fragments.

The strength of the matrix could be very difficult to characterize, due to the difficulty in obtaining its sample for testing. One way of determining its strength could be through point load tests in irregular fragments. The Schmidt hammer could also be utilized to improve the strength determination. In both cases it would require a large number of determinations to have a statistical meaning.

In the case of the Reventazón hydroelectric power plant in Costa Rica, the conglomerate at the investigation galleries driven in the abutments had about 30%–50% of hard rock blocks in the sandy matrix. Triaxial tests carried out for the conglomerate resulted in strength of about $c = 1.7$ MPa and $\phi = 36°–39°$. For the undisturbed samples of the matrix sandstone, the values were of about $c = 1$ MPa and $\phi = 25.5°$. Laboratory tests on the sandstone yielded

Fig. 24. Gallery in conglomerate without any support.

Fig. 25. Galleries in volcanic breccia unsupported.

peak values of $c = 0.6$ MPa and $\phi = 38°$, but residual values of $c = 0.3$ MPa and $\phi_{res} = 25.6°$. A multistage in situ direct shear test on the same sandstone, under normal loads up to 1 MPa gave values of $c = 0.27$ MPa and $\phi = 38°$. The tests were performed by Instituto Costarricense de Electricidad (ICE). The above example shows that it is quite possible to determine the strength of the weak matrix.

An additional correction could be made for the percentage of hard fragments in the rock. It is known that the increase of hard fragments or pebbles can increase the strength until the percentage of filling is too large, and the fragments "float" in the matrix, which is also called an "overfilled material". A review of several authors about the influence of the percent of gravel in the clayey soil, confirmed with triaxial tests with varying gravel percentages, was presented by Santos et al. (2002), showing that only above 35%–40% gravel there is an increase in strength, at the rate of some 2.5° for each additional 10% of gravel, according to Fig. 26.

In this way, it is necessary that new empirical geomechanical classification needs to be developed for different types of weak rocks based on observation, at each engineering work to allow a new geomechanical classification.

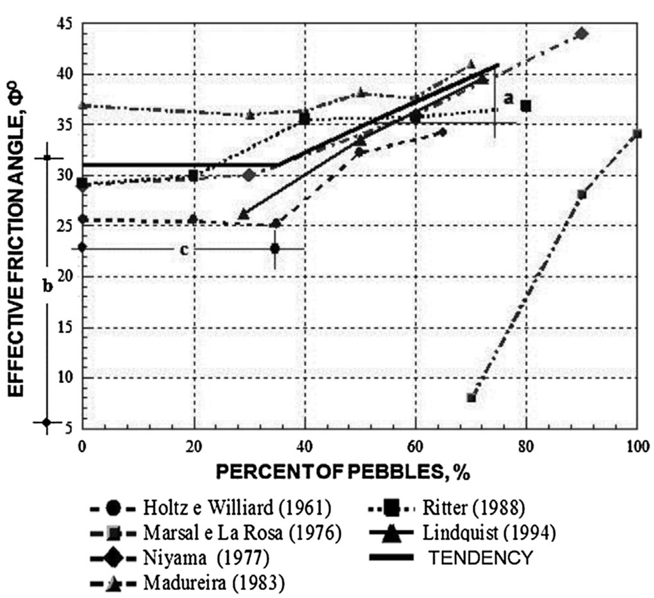


Fig. 26. Effect of the percentage of gravel on the strength of clayey soil according to several authors (Santos et al., 2002).

8. Soft rocks as fill material

The use of soft rocks in fills and earth or rockfill dams has been regarded with suspicion. However, several successful experiences have demonstrated that they can be utilized whenever their properties are well defined and subsequently considered in the design. On this issue, the International Commission on Large Dams (ICOLD) has elaborated a special report "Weak rocks and shales in dams", reporting several examples of dams built with such materials and their characteristics (Marulanda, 2008).

Fill built with soft rocks as shales is usually well "filled", since the finer particles occupy the pores between larger fragments. As a consequence, the stresses in the compressibility after completion are much less as compared to fills in hard rock, which are "under filled".

The design must account for that the lower possibility of weathering of the rock fragments and dam slopes are usually much gentler when compared with hard rock fills. Some dams in England had upstream slopes of 1:4.5 and downstream slopes of 1:3, for instance.

The potential problems with shales could be their expansibility and rapid degradation by weathering and eventual pyrite content. However, it has been considered that if well covered the shale fragments would not have possibility of weathering, but this demands shell covering with good rock. The issue of pyrite content may be hazardous, since with oxidation it can be transformed and produce acid waters that may cause concrete attack and weathering of neighbor rocks.

Anyway, it has been demonstrated in the practice that this material can be utilized whenever well studied.

9. Conclusions

This paper intends to motivate and encourage research on soft rocks, to better understand their properties and characteristics, since the lack of knowledge often leads to the adoption of very conservative parameters in detriment of the economy.

It is hoped that a database could be established in an international level, receiving contributions on soft rocks, being available and accessible to all interested people.

Improvements in sampling are deeply required, as well as for laboratory testing, which could lead to elaborate new "suggested methods" of testing.

The development of a new criterion for geomechanical classification of continuous soft rock masses (as conglomerates, breccia, lahar, etc.) is also required.

It is expected that contributions are made to the ISRM Technical Commission on Soft Rocks.

Conflict of interest

The author wishes to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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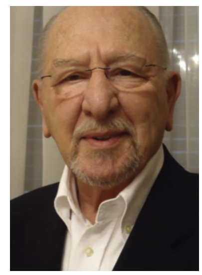

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