INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Collapse of rockfill

Effondrement d'enrochement

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SYNOPSIS: The rockfill materials display collapse deformations due to wetting or saturation. In this paper the quantification of this phenomenon is shown for soft and hard rockfills tested in 1-D compression and triaxial apparatus. The results pointed to more important collapse in soft rockfill, to equal final settlements obtained after saturation of dry samples or if the specimens are saturated prior to tests, and to some variation of Poisson's ratio due to saturation.

1 INTRODUCTION

Although the phenomenon of collapse has been widely recognized in rockfills - mainly owing to wetting, saturation or submersion - its practical significance is sometimes neglected.

This work presents a laboratory characterization of the collapse of soft rocks ordinarily used in the Portuguese fill dams. As indicated collapse deformations can be very large and affect safety in several types of fill dams, and particularly their performance.

2 MECHANICS OF COLLAPSE WITH PARTICULATE MATERIALS

Collapse can frequently take place in particulate media namely in rockfill materials. It consists of a volumetric change under constant total stress due to increase of the water content of the material.

Important work has been developed on collapse of clayey and sandy soils, the role of the structure of the phenomenon becoming evident.

This paper concerns collapse deformations of rockfill resulting from wetting, saturation or submersion.

The physical reasons for the rockfill collapse are not just the same as for the clayey and sandy soils. In these soils the collapse is due to a metastable structure with units (particles or particle aggregates) whose contacts and bonds are of very different nature (capillary suction, chemical cementing, clay buttresses). But the most important characteristic of the collapsible soils is that all links between the units, whatever the bonding nature, are weakened by the addition of water.

For rockfills, the main factors influencing collapse are the state of stress, rock type, the embankment void ratio and the grain size curve. Besides the mechanisms associated with changes in water content are very different from those of soils.

The interparticle forces must be considered and the values of these forces depend mainly on the number of interparticle contacts and the installed stress. It is well known that the forces between rockfill elements are very high, which also means high stresses in the contact "points" from which results important local yielding.

The failure stress depends on rock type but the presence of water can increase the microfissuration of the rock crystals and modify their surface energy thus playing an important role on the mechanical behaviour of the contact zones.

So, the water added will produce rapid yielding in contact areas with the consequent strains on the rockfill mass. These strains can even increase if the mentioned local yielding gives rise to relative displacements between elements, originating a denser structure.

Among the procedures used to predict rockfill deformations due to collapse, the experimental determination of the parameters to be used in adequate constitutive equations can raise some difficulties typical to this kind of materials. As a matter of fact, rockfill laboratory tests must be made on samples with a modified grain size curve because the field granulometry presents a great number of elements of high dimension.

To permit the laboratorial quantification of the mechanical characteristics of rockfill important studies were developed on the granulometric modelling of those materials and consequently reasonable knowledge was achieved on this subject.

3 LABORATORY EQUIPMENT FOR COLLAPSE QUANTIFICATION

Even if the modelling of the grain size curves of the materials is carried out, use must be made of large size equipment when rockfills are to be tested. Thus triaxial shear tests and one-dimensional compression tests were conducted with large-size equipments that were developed in LNEC. The diameter of the specimens was 0.30m for the triaxial test and 0.50m for the one-dimensional compression test. Referring to the equipment for the latter test it seems worth mentioning that it consists of a cell formed of either aluminium or rubber rings alternately placed. By this way practically null radial strains are obtained (as should be expected with one-dimensional compression tests); however, the axial deformability of the system is so high that no shear stresses develop near the walls formed by the rings, in spite of the considerable height of the specimen.

The homogeneous distribution of stresses in the test specimen is thus ensured during the test. By means of strain gauges glued to the aluminium rings it is possible to measure the radial stress during the test, and thus to measure the value of k_o.

When submersion of the material is enforced by introducing water in the cell, usually temperature changes occur in the aluminium rings, and the corresponding effects have to be taken into account.

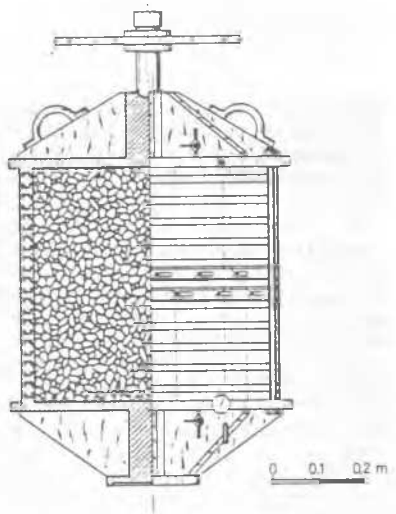

Figure 1. 1-D compression cell.

Fig. 1 shows a sketch of the 1-D compression cell and Fig. 2 gives a view of the equipment during a test.

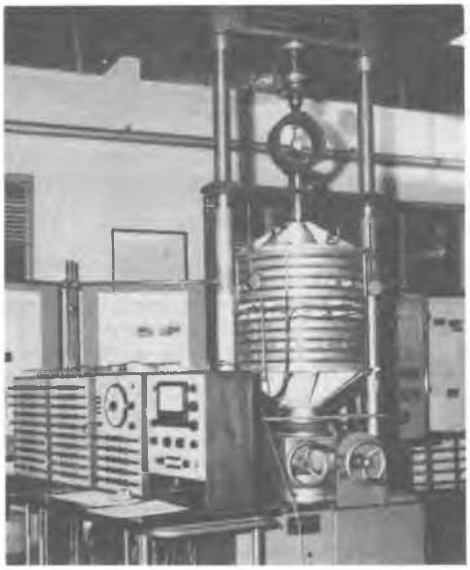

Figure 2. 1-D compression test equipment in operation.

4 GRAIN SIZE MODELLING

Fig. 3 shows the mean grain size distribution curves of the materials as they occurred in fill construction and after introduction of some modifications required by the laboratory tests referred to in 2.

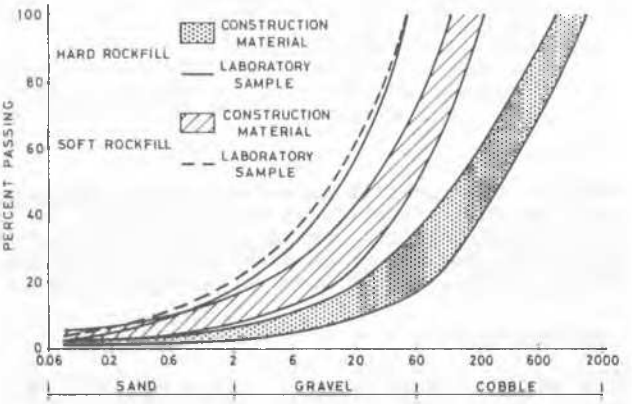

Figure 3. Grain size curves of construction materials and laboratory samples.

One was dealing with mixed schists and graywackes. Specimens of soft rockfill and of hard rockfill were tested.

As can be concluded from Fig. 3, preparation of samples from real soils was not limited to the elimination of the coarser elements. In fact such a practice would lead to increase in the percentage of fines (size below 0.074 mm), which the grain size modelling of rockfills showed to be an unfavourable condition.

5 LABORATORY TESTS

Next we shall describe results of 1-D compression tests and triaxial tests carried out to quantify collapse due to submersion.

5.1 One-dimensional compression tests

Two soft rockfill specimens were initially tested in dry conditions. The specimens were saturated under the axial stress of 0.2 and 1.0 MN/m^2 respectively. Another specimen with the same initial void ratio (e_o) was tested after initial saturation.

Stress-strain results are presented in Fig.4. As can be seen, the stress-strain paths after saturation are approximately equal to those of initially saturated specimens.

The same behaviour can be observed during hard rockfill tests, as Fig. 5 shows. This experimental conclusion regarding rockfills, which other authors have already agreed to, is very important for the mathematical modelling of the collapse phenomenon.

Comparison of test results for soft rockfills and hard rockfills shows that collapse is fairly more significant in the former case. For instance the volumetric strain due to collapse of soft rockfill under an axial stress of 1.0MN/m^2 is about 4.7%. Under the same axial stress the hard rockfill shows only a volumetric strain collapse of 1.3%, that is 3.6 times lower.

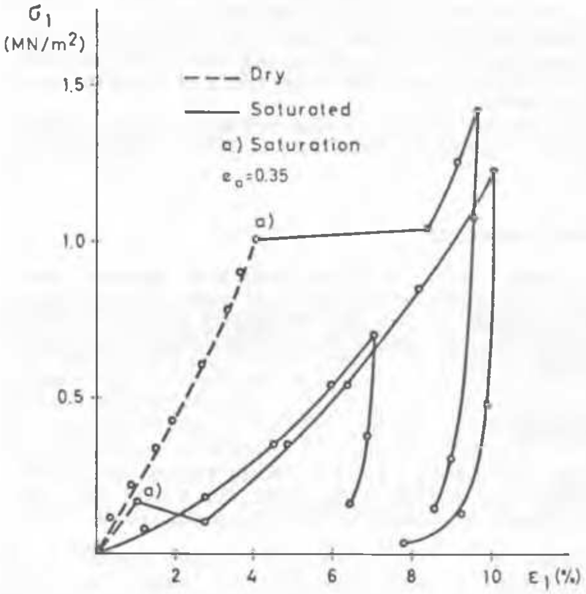

Figure 4. 1-D compression tests (soft rockfill).

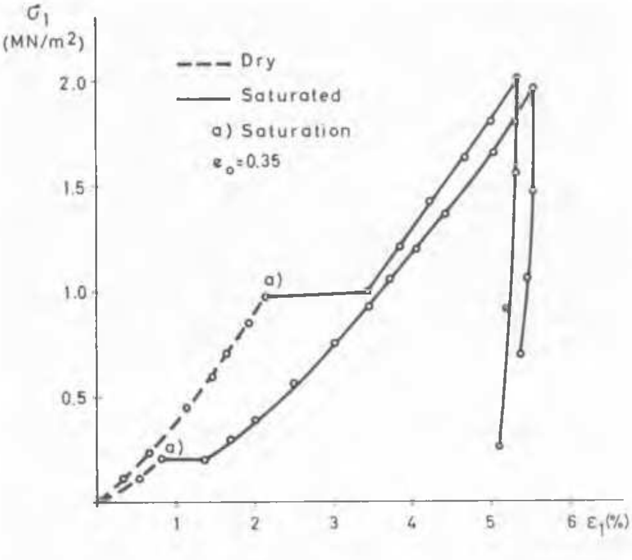

Figure 5. 1-D compression tests (hard rockfill).

As should be expected the saturated hard rockfill is not so deformable as the soft rockfill. The value of the secant oedometric modulus (E_{oed}) is 38 MN/m^2 in the case of hard rockfill; for soft rockfill the same value is three times smaller.

During the tests the value of k_o ($=\sigma_3/\sigma_1$) was measured. Thus Fig. 6 presents results of k_o variation associated wich soft rockfill collapse. As far as the authors know this is the first time results of this type are published, which show that k_o varies during the collapse, contrary to what has so far been assumed. Needless to say, these results are extremely important for approaching the collapse phenomenon in stress-strain analysis of rockfills.

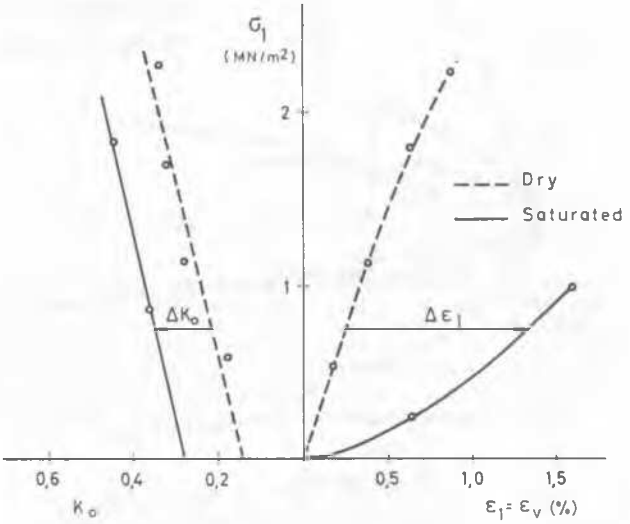

Figure 6. 1-D compression tests on soft rockfill (dry and saturated).

5.2 Triaxial Tests

Figs. 7 and 8 give the results of triaxial tests with soft and hard rockfill respectively. Samples were saturated during the shear phase, excepting for two samples of soft rockfill that were previously saturated.

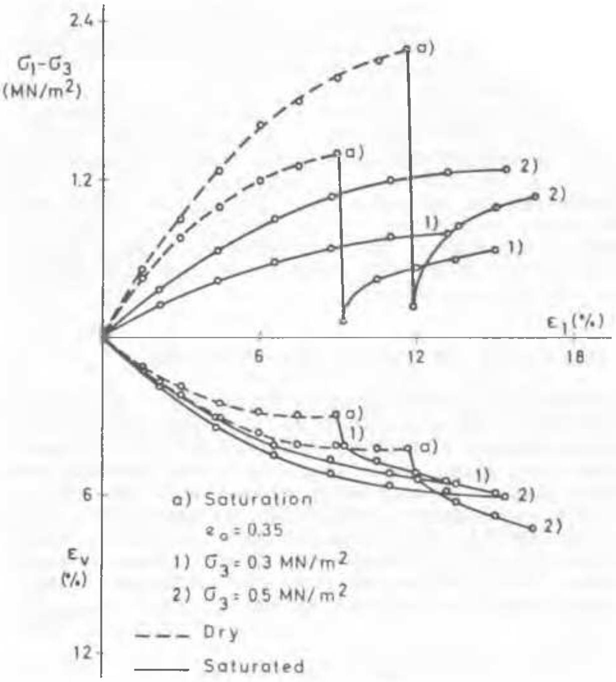

Figure 7. Triaxial compression tests (soft rockfill).

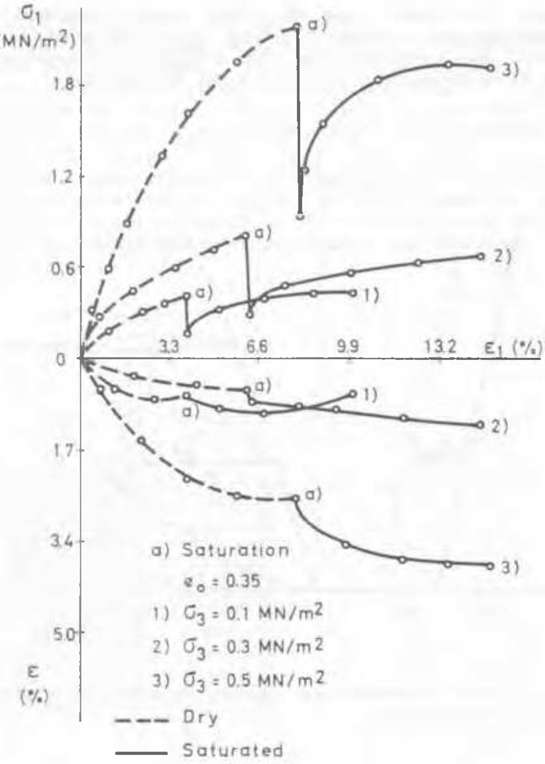

Figure 8. Triaxial compression tests (hard rockfill).

As should be expected for similar states of stress the collapse is more significant in soft rockfill. Moreover the larger the confining stress, the larger will be both the variation (decrease) of shear stress and collapse (hence the volumetric variation).

As regards soft rockfill (Fig. 7), specimens under the same confining stress σ_3 were tested, one having been previously saturated, the other being saturated during the shear phase. As can be seen, for this type of stress paths too, the stress-strain curves after saturation (collapse) evolve in such a way as to overlap the stress-strain curves of the initially saturated material, which is of the utmost interest for modelling rockfill collapse.

6 RELIABILITY OF GRAIN SIZE MODELLING

Considering the grain size modelling to which rockfills were submitted for laboratory tests, a question arises as to the reliability of such modelling. That is to say, will the parameters quantified in those tests be suitable for predicting collapse of rockfills by means of appropriate constitutive equations? An earlier work on the subject (Maranha das Neves and Veiga Pinto, 1989) suggested that the techniques adopted for grain size modelling are in fact adequate.

7 CONCLUSIONS

As can be inferred from the test results already mentioned, collapse phenomena in rockfills may be fairly significant, depending on the rock type and on the degree of weathering.

We can also conclude that, for similar stress paths, strains in the material after saturation are close to those shown by the previously saturated material.

Only stress paths in the triaxial plane were analysed (triaxial test and 1-D compression test).

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REFERENCES

Maranha das Neves, E. and Veiga Pinto, A.(1989) "Modelling collapse on rockfill dams" (to be published in Computers and Geotechnics).