

Effects of volumetric ice content and strain rates on shear strength and creep rate under triaxial conditions for frozen soil samples

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1 INTRODUCTION

Rock glaciers are special geomorphological phenomena of mountain permafrost. In some rock glaciers that have been investigated recently, a clear shear horizon has been detected (Arenson et al. 2002) in which most deformation takes place. Within an alpine environment, rock glaciers may have temperatures close to 0°C (Vonder Mühl & Haeblerli 1990, Vonder Mühl et al. 2003), which make them very sensitive to global warming. Even though rock glaciers in the Swiss Alps have been investigated intensively since the 1970's (e.g. Barsch 1996), there are still a lot of unanswered questions. In particular, the loss of strength of the frozen geomaterial, which might lead to stability problems of steep slopes, is expected as an effect of a warmer climate and is of major concern in Switzerland (Haeblerli et al. 1997).

Therefore a set of triaxial creep and shear tests were performed to study the effect of the volumetric ice content under natural stress conditions.

2 TESTS

The goal for this project was to examine mechanical response of various ice-solid mixtures from triaxial shear and creep tests. A programme was set up to test the strength under different confining pressures and for a range of strain rates as well as volumetric ice contents. The material was prepared as closely as possible to the natural conditions found in alpine rock glaciers (e.g. Arenson et al. 2002, Vonder Mühl et al. 2003) and tested at equivalent temperatures. To obtain controllable and repeatable tests, the originally soil was mixed in the laboratory. Triaxial shear tests and creep tests were carried out in a cold room with a fixed temperature at the Institute for Geotechnical Engineering at the Swiss Federal Institute of Technology in Zurich. Artificially made samples with an ice content of 30, 50, 80 and 100% by

volume, respectively, were tested under changing testing parameters. The confining pressures σ_3 were 50, 100 and 200 kPa and the strain rates used for the shear tests were 0.25, 2.5 and 25 mm/h. All tests were carried out at a temperature of about -1.5°C. During a test, the temperature variations were about $\pm 0.05^\circ\text{C}$.

3 TEST RESULTS

Figure 1 shows the peak and the residual shear strength for samples with different ice contents at three different strain rates. Figure 2 shows the peak and residual shear strength for samples with different strain rates at four different ice contents.

The tests indicate that the strength of the frozen soil increases rapidly at the beginning of the test, probably due to ice strengthening, after which it reaches peak strength and drops to a lower value due to bonds cracking between the soil and the ice. The authors observed no clear trend between the strength and the confining pressure within the range of confining pressure tested, especially for ice-rich soils. A trend was recognised for soils with lower ice

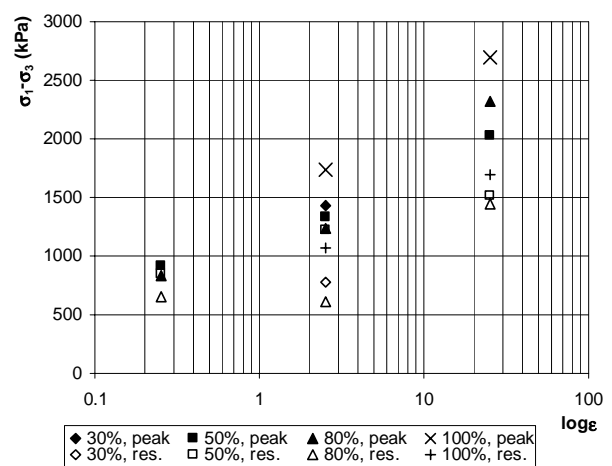


Figure 1. Shear strength ($\sigma_1 - \sigma_3$) versus strain rate $\dot{\epsilon}$ for different ice contents. Confining pressure $\sigma_3 = 100$ kPa.

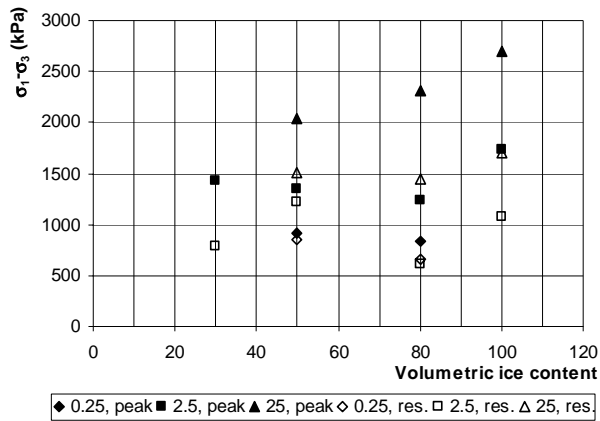


Figure 2. Shear strength ($\sigma_1 - \sigma_3$) versus volumetric ice content at different strain rates $\dot{\epsilon}$. Confining pressure $\sigma_3 = 100$ kPa.

contents (30%). Soils with low volumetric ice content and high confining pressure showed a behaviour similar to unfrozen soils. Soil strengthening takes place due to structural hindrance of the solid particles after an initial slight strengthening of the ice with increasing solid content. This results in an increase of the strength during the test with increasing axial strain, which has also been described by other authors (e.g. Ladanyi 1981, Ting et al. 1983).

There is a clear trend that higher strain rates result in higher shear strengths. In general it is found that the strength increases with decreasing ice content except for the samples with 100% ice, which showed the highest strength (Fig. 1). The authors assume that this is because a different mechanism is at play. The sample showed a brittle behaviour with a sudden loss of strength after a peak value was reached.

Because of limited time, only a few creep tests were carried out. These could not be used for proper analysis. Further tests should be carried out to examine the creep behaviour of the frozen soil in more detail.

4 CONCLUSIONS

The following conclusions can be drawn from the tests on frozen soils presented.

Samples have to be prepared very carefully in order to achieve repeatable tests. The ends of the samples should be cut precisely and parallel to each other so that the stress is equally distributed on the surface. The technique used for sample preparation has proved to be appropriate, but an air content of about 4% was measured. To avoid air in the sample, different methods for the sample preparation should be considered.

The strength and the mechanisms of frozen soil are very dependent on the temperature. Lower temperature leads to higher strength. Small temperature differences in the soil samples and in the cold room

used for tests can explain the different values for strength found for similar tests. On the other hand, small differences in the volumetric ice content might also have influenced the strength of the sample.

Due to the time limitations of this diploma project, it has not been possible to examine everything in depth. Also questions have showed up during the testing of the samples, which are worth investigating further in terms of mechanical behaviour of frozen soil. The volumetric change of the samples should be examined and a better method to measure the volume of the sample should be developed.

The ice content versus shear strength should be examined in more detail. The tests were only made on samples with four different ice contents. To observe trends better, samples with different ice contents should be prepared and tested. In addition, the influence of the air in the sample and the difference between peak strength and high strain rates should be examined.

The reason for testing artificially made samples instead of original samples extracted from a rock glacier is that it should be possible to carry out repeatable tests. This is often not possible, when original samples are used, because the composition of the sample can vary and is not well known until after the test. Furthermore, the recovery of original permafrost samples is very expensive due to the drilling and field work. However, it was the intention to prepare and test the samples under similar conditions found in a real rock glacier. Further investigations on artificial soil samples may help in developing a better understanding of rock glacier dynamics.

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