Chapter 49

FRICTIONAL SLIDING AND FRACTURE BEHAVIOR OF SOME NEVADA TEST SITE TUFFS

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ABSTRACT

Deformation studies were performed on tuffaceous rocks from Yucca Mountain, Nevada Test Site to determine the strengths and coefficients of friction under confining pressures from 10–50 MPa at room temperature. Frictional strengths of 30° sawcut samples increased with pressure and reached values of around 150 MPa at the higher confining pressures. However, the failure strengths of the intact samples were quite unpredictable. The coefficients of friction ranged between 0.7 and 0.9 for all specimens. These data can be used in conjunction with in situ stress measurements at Yucca Mountain, to evaluate the potential for earthquake activity in the region.

INTRODUCTION

The tuffaceous rocks of Yucca Mountain at the Nevada Test Site are being studied by the Nevada Nuclear Waste Storage Investigations project (NNWSI) as a possible host for a radioactive waste repository. An understanding of the physical properties of these tuffs, particularly the frictional sliding and fracture behavior, is necessary in order to determine whether in situ stresses or stresses caused by repository mining may exceed the stresses required to cause frictional sliding on faulted surfaces or the failure of intact rock.

SAMPLE DESCRIPTION

The two candidate repository rocks used in this study were the Topopah Spring Member of the Paintbrush Tuff and the Bullfrog Member of the Crater Flat Tuff. The Topopah Spring lies in the unsaturated zone above a deep-lying (400–600 m) water table at Yucca Mountain, whereas the Bullfrog Member is located below the water table. At the horizons of interest, both rocks are devitrified and nonzeolitized, however, the Topopah Spring is more densely welded than the Bullfrog.

PROCEDURE

In order to determine the coefficient of friction of the Bullfrog and Topopah Members, sliding experiments were performed on 63.5 mm long by 25.4 mm diameter cylindrical samples containing a sawcut inclined at 30° to the cylindrical axis (Fig. 1). Confining pressures from 10 to 50 MPa in 10 MPa steps simulated a range of burial depths. Deformation was carried out at a strain rate of 10^{-4}/s until the samples had shortened by 10 mm in the axial direction. To study the possible effects of time, these experiments were repeated at the slower rate of 10^{-6}/s on new samples. All samples were saturated with distilled water. A gas accumulator maintained the pore pressure at 0.5 MPa to ensure complete saturation during the course of the experiments. All tests were performed at room temperature.

Similar studies were carried out on intact specimens of the tuffs to determine the fracture strengths and coefficients of friction for sliding on faulted surfaces. These experiments were also conducted on saturated samples at strain rates of 10^{-4} and 10^{-6}/s and confining pressures from 10 to 50 MPa.

RESULTS

Strength

Fig. 2 shows typical stress-strain (differential stress-axial displacement) curves for sawcut samples of the Topopah Spring member at a strain rate of 10^{-4}/s. The maximum strength is around 150 MPa at a confining pressure of 50 MPa. In each test, there is very little difference between the residual strength and the maximum strength of the sample. These plots are similar to the results for the Bullfrog Member, both in terms of strength levels and the stability behavior. In all cases, strength increased uniformly with confining pressure. The samples frequently exhibited stick-slip behavior at the higher pressures. This usually occurred as a single large stress drop, rather than small multiple events. At the slower strain rate of 10^{-6}/s the results were nearly the same for both tuff members. That is, the strain rate effect was less significant than the differences in strength resulting from sample variability. This can be seen in Fig. 3, where maximum strengths are plotted with confining pressure for both the Bullfrog and the Topopah Spring at the two strain rates. There was no major difference in the strength of the tuffs at the two strain rates. Instead, the most noticeable

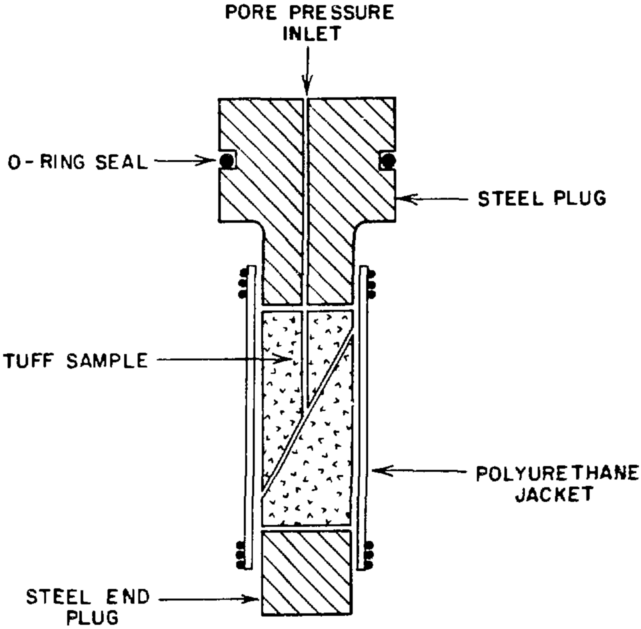


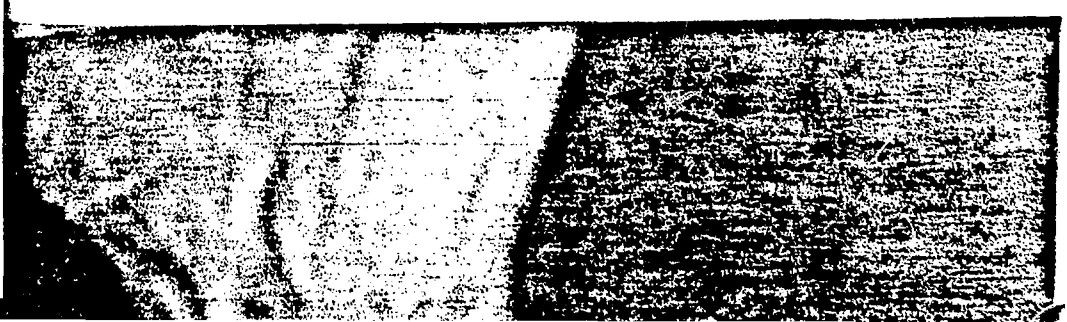
Fig. 1. Sample assembly.

feature here is that the two tuffs were quite similar and had very predictable failure strengths.

Characteristics of the stress-strain curves for intact specimens were also comparable between the two tuff members. The Bullfrog is shown as a typical example in Fig. 4. The variation in failure strength with pressure was much less consistent than that found for the sawcut samples. For instance, the specimen at 40 MPa fractured at a higher differential stress than the one at 50 MPa. At 20 MPa, the tuff exhibited an apparent ductile behavior, with no peak in the differential stress value at all. This behavior was characteristic of the specimens that developed multiple fracture planes (3 out of the 20 intact samples).

After failure, sliding progressed smoothly in all cases, free of stick-slip events. The residual strengths during this segment of the experiments were fairly well ordered according to confining pressure and reached values of around 200 MPa at the higher pressures.

If we plot failure strength against confining pressure for the intact samples (Fig. 5), the major difference between the two tuffs



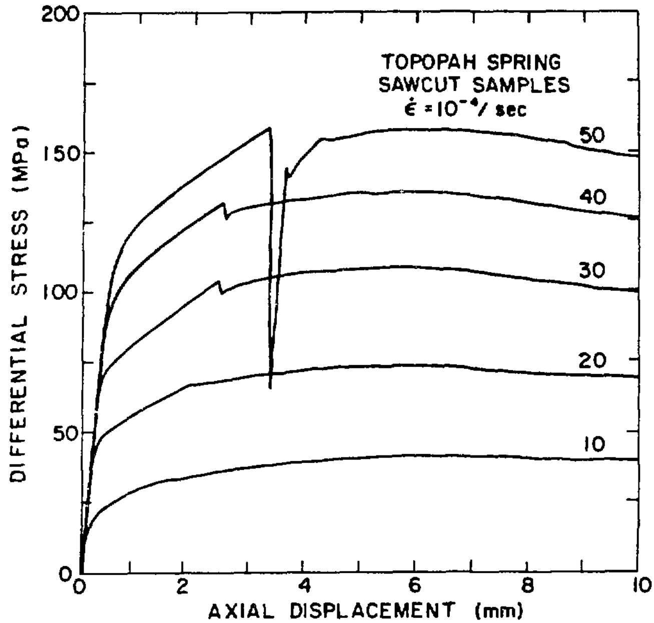


Fig. 2. Differential stress as a function of axial displacement for sawcut samples of the Topopah Spring Member at a strain rate of 10^{-4}/s. Confining pressures in MPa are shown at the right of each curve.

becomes evident. That is, the Topopah Spring is about 50% stronger at failure than the Bullfrog. This is not surprising as it is a much more densely welded rock. The characteristics at failure discussed above are also clearly evident. The unpredictable failure strength due to sample variability, particularly of the Topopah Member, overshadows any time dependent effects.

Friction

Coefficients of friction for the sawcut samples can be determined from Fig. 6. Here shear and normal stress data at 10 mm of sliding are plotted, and the slope of the line gives us the residual friction, μ. We have chosen to plot residual friction rather than initial or maximum values as it is more representative of a natural fault that has undergone extensive displacement. Coefficients of friction ranged between 0.80 and 0.88 for the four groups shown. Byerlee (1978) found that for stresses below 200 MPa, almost all rocks, regardless of type (granite, limestone, etc.), were characterized by a frictional coefficient of around 0.85. This line is

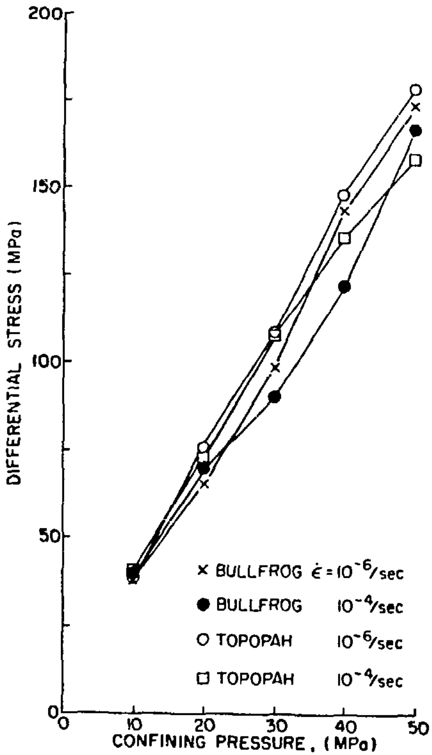


Fig. 3. Maximum strength of all sawcut samples as a function of confining pressure.

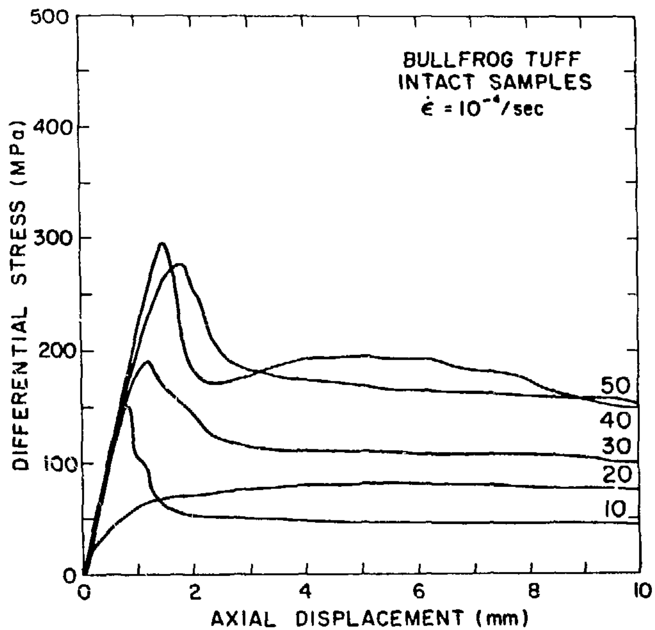


Fig. 4. Differential stress as a function of axial displacement for intact samples of the Bullfrog Member at a strain rate of 10^{-4}/s. Confining pressures in MPa are shown at the right of each curve.

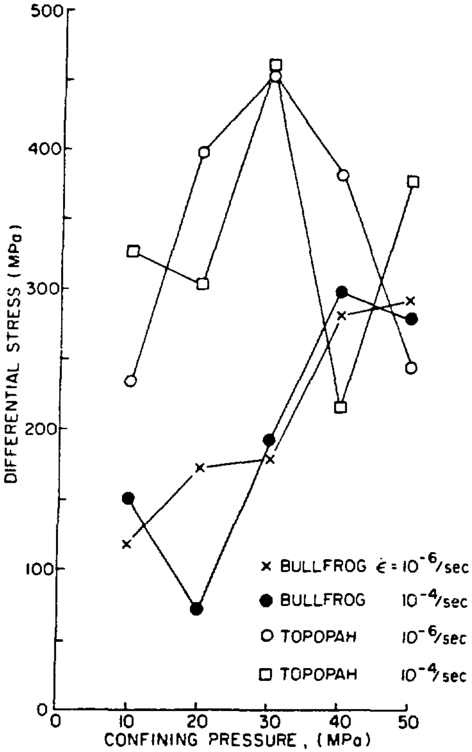


Fig. 5. Failure strength of intact samples as a function of confining pressure.

shown in the figure to illustrate that the frictional properties of the tuffs are very typical of other rock types.

The results for the intact samples were quite similar to the results for the sawcut samples (Fig. 7). We calculated shear and normal stresses assuming a 30° failure angle. Almost all fractures were within a few degrees of this value. There was a greater spread in the stress values because the fracture surfaces were not as regular as the sawcut surfaces. As a result, the coefficients of friction ranged between 0.7 and 0.9 for these samples. A line with a slope of 0.85 is again shown for reference.

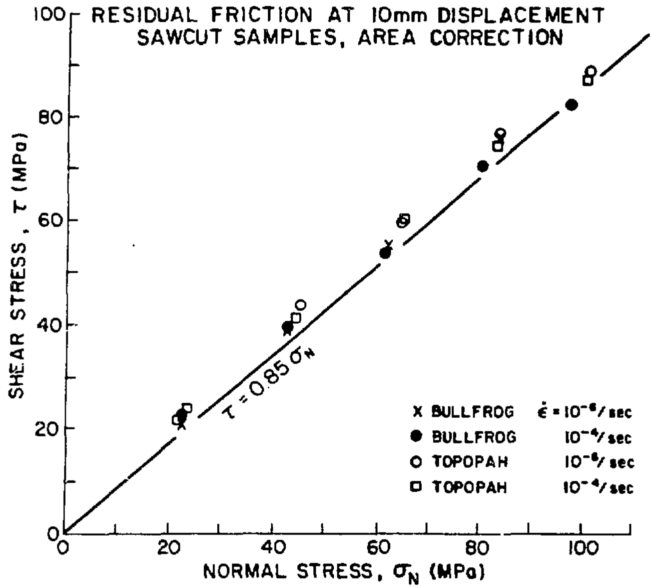


Fig. 6. Shear and normal stress data for all sawcut samples after 10 mm of axial displacement, corrected for the decreasing area of contact during sliding.

SUMMARY OF RESULTS

1) For sawcut samples, the maximum strength increased uniformly with confining pressure. There was a greater tendency for stick-slip behavior at the higher pressures. The Bullfrog and Topopah Spring Members had very similar frictional strengths.

2) Fracture strengths of the intact samples were unpredictable and unsystematic with confining pressure particularly for the Topopah Member. Stable sliding was observed after fracture in all cases and the stress levels during this period were a function of confining pressure. The Topopah Spring Member was about 50% stronger at failure than the Bullfrog.

3) The differences in strength due to sample variability overshadowed any observable effect that may have been due to strain rate.

4) The coefficient of friction for the samples containing a 30° sawcut, both Bullfrog and Topopah Spring, ranged between 0.80 and 0.88. The values for intact samples ranged between 0.7 and 0.9.

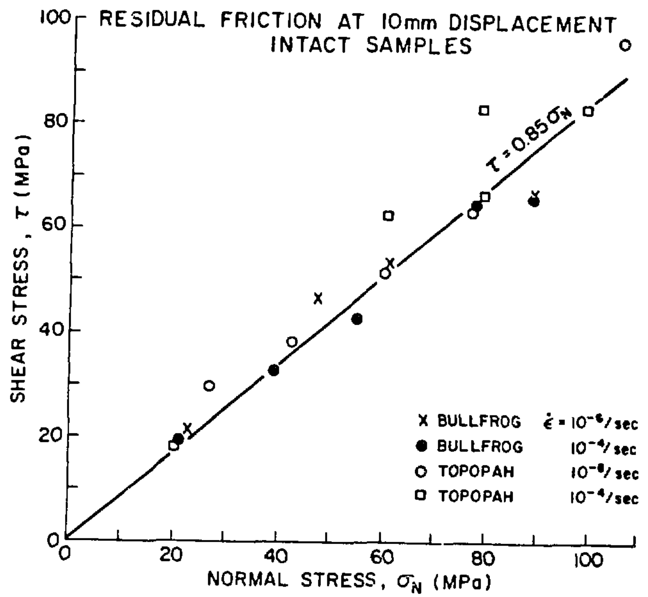


Fig. 7. Shear and normal stress data (assuming a 30° fracture angle) for intact samples after 10 mm of axial displacement.

These coefficients are very typical of the average value of 0.85 for other rock types (Byerlee, 1978) at pressures below 200 MPa.

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REFERENCES

Byerlee, J., 1978, "Friction of rocks," Pure and Applied Geophysics, Vol. 116, p. 615.