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GENERAL CHARACTERISTICS OF STRAIN RELAXATION: A NOTE ON SAMPLE PREPARATION FOR LARGE-SCALE TESTS

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Abstract. Overcoring and large block tests indicate that intact rocks are disturbed upon removal from outcrops so that their laboratory properties are not the same as their *in situ* properties. The disturbance occurs during strain relaxation for which there are general characteristics as listed in this note.

Introduction

The purpose of this note is to review the behavior of intact rock during removal from outcrops. Large block experiments indicate that intact rock is disturbed upon removal from the outcrop so that post removal properties are not the same as *in situ* properties. During sample preparation for large-scale laboratory tests, the operator should be aware of this behavior. Situations may require the precise knowledge of *in situ* properties, in which case *in situ* testing becomes desirable.

The literature contains few examples of the changes in rock properties accompanying removal of samples from the outcrop. Early experiments such as Merrill and Morgan's [1958] showed that *in situ* rock properties may not be the same as those determined in the laboratory. Property changes are documented primarily by comparing seismic velocities of samples *in situ* and after removal from outcrops. Comparison of static tests between the *in situ* and post-removal state of samples is difficult because of changes in loading conditions and sample size. The large block experiments of Pratt et al. [1975] show that a marked decrease in elastic moduli accompanies the separation of a block of Kayenta sandstone from its surrounding outcrop. Prior to excavation, the compressional wave velocity (V_p) was 2.85 km/sec over a 1.6 m path length compared with 1.55 km/sec after excavation. Upon subsequent reloading to pre-relaxation strains, the velocity increased to 2.30 km/sec. Once separated from the outcrop, the block of Kayenta sandstone expanded, reflecting a nonrecoverable strain relaxation. Other experiments show a correlation between strain relaxation and the general decrease in elastic moduli (Table 1). In the five cases cited from Swolfs [1977] and Engelder and Plumb (unpublished data), the rock was anisotropic both *in situ* and after relaxation. The data for the most compliant direction are the strain accompanying relaxation (expansion is positive) and the change in V_p. The change in elastic properties and strain in the stiffest direction may either be larger or smaller than the change in the compliant direction. In Table 1, no attempt is made to distinguish between residual strain and strain from boundary loads. The strain is an average of several overcoring measurements. Although these data are not all inclusive, they indicate that strain relaxation commonly occurs during removal of samples from outcrops and is accompanied by changes in rock properties.

Strain Relaxation

Strain relaxation is generally measured by overcoring strain gauge rosettes or other devices bonded to outcrop surfaces or attached within boreholes. Overcoring is associated with *in situ* stress measurements where strain relaxation is assumed to consist in large part of the recovery of elastic strains imposed by far field boundary tractions. However, many rocks show an instantaneous but nonrecoverable or time-dependent relaxation despite the lack of boundary tractions, as indicated by double overcoring and overcoring into jointed outcrops. Strain relaxation in the absence of boundary tractions is attributed to the relaxation of residual strains [Friedman, 1972].

The mechanisms of strain relaxation are poorly understood and of limited importance to stress measurements when rock stress, say in a mine pillar, is high enough to cause considerable 'elastic' distortion. In high stress environments, a major fraction of the strain relaxation is believed to be elastic and can be recovered in moduli tests to determine *in situ* stress. Yet some infer that changes in rock properties occur on the relaxation of high stresses caused by far field boundary tractions [Strickland and Ren, 1980]. The idea is that microfractures propagating on release of boundary loads are responsible for the property changes on relaxation. However, the evidence for this is circumstantial. In environments where boundary loads are low, such as near surface, strain relaxation may consist largely of the recovery from internal residual strains locked into the rock matrix [Friedman, 1972]. The values for strain given in Table 1 are typical of residual strains. Where changes in rock properties occur during strain relaxation of residual strains, microcrack opening also seems to play some poorly understood role in the property changes (Engelder and Plumb, unpublished data).

Regardless of whether large-scale samples are taken from a low stress or high stress environment, care must be taken to appreciate the changes in rock properties associated with strain relaxation. The same may be said for the preparation of samples for small-scale testing. In considering the merits of large-scale rock mechanics experiments in the laboratory versus *in situ*, the effect of sampling for the laboratory should be considered. There will be instances when laboratory convenience will be traded away for *in situ* tests in which the determination of undisturbed properties will be regarded as most important.

The General Observations

In the event that large samples are prepared for laboratory testing, the operator should be

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TABLE 1. Change in Compressional Wave Velocity Upon Relaxation

V_p - in situ (km/sec)	V_p - Relaxed (km/sec)	Strain (x 10^{-6})	Rock	Reference
3.79	3.44	∿ 100	Barre granite, Vermont	Swolfs [1977]
4.40	4.05	∿ 126	Machias siltstone, New York	Engelder and Plumb (unpub.)
6.18	5.24	∿ 110	Tully limestone, New York	Engelder and Plumb (unpub.)
5.44	4.62	∿ 93	Pyroxene gneiss, New York	Engelder and Plumb (unpub.)
4.89	4.01	∿ 20	Milford granite, New Hampshire	Engelder and Plumb (unpub.)

aware of some general observations concerning strain relaxation. Because sample preparation for large-scale rock mechanics experiments is simply a large overcore, most characteristics of the relaxation of 1 to 2 m diameter cores are the same as the strain relaxation of less than 23 cm diameter cores. The preceding statement is qualified because there may be some yet undiscovered effect of scale size on strain relaxation. These characteristics of relaxation are not written to correlate with specific changes in rock properties but rather as a reminder that there may be a consistent relationship between changes in rock properties and strain relaxation. Using large in situ rock masses, strain relaxation during sample preparation seems unavoidable. However, operators may perform some simple sonic tests to measure the relative magnitude of the effect of relaxation on changing rock properties.

The following general observations for strain relaxation were developed by the author and several colleagues including Marc Sbar and Dick Plumb during more than 400 overcoring tests in many different rock types. References behind each observation indicate that many were verified in papers prior to Engelder, Sbar, and Plumb's work. Although general, no observation is universal.

1) Rock expands on relaxation [Lieurance, 1932] with some exceptions [Swolfs et al., 1974; Nichols, 1975].

2) Expansion accompanies the removal of boundary loads or relief of residual strains or both [Olsen, 1957; Keislinger, 1960].

3) In the absence of stress gradients imposed by boundary loads, the expansion is reproducible on the outcrop scale and sometimes on a regional scale [Hoskins et al., 1972; Engelder et al., 1977].

4) Expansion is anisotropic [Lieurance, 1932].

5) In the absence of boundary loads, maximum expansion indicates the direction of a paleostress field [Engelder, 1979].

6) Maximum expansion parallels the strike of the dominant outcrop joint set [Preston, 1968].

7) Maximum expansion parallels the strike of induced fractures such as hydraulic fractures [Plumb, 1981].

8) Expansion is inversely proportional to fracture spacing [Engelder and Sbar, 1977].

9) Maximum expansion parallels the dominant topographic trend (Plumb, personal communication, 1981).

10) In the absence of boundary loads, maximum expansion parallels the compliant direction of the rock [Engelder et al., 1977].

11) Expansion is associated with a lowering of the seismic velocities of the rock [Pratt et al., 1975].

12) Expansion changes the velocity anisotropy of the rock [Swolfs, 1977].

13) Expansion is correlated with the orientation of such microfabric elements as elastic distortion of grains, microcracks, grain boundaries, a clay fabric, aligned minerals, and a rock cleavage [Friedman, 1972; Engelder et al., 1977; Engelder and Plumb, personal communication, 1981].

14) Expansion is often time-dependent [Nichols and Savage, 1976]

15) Rock properties are not completely recoverable on reloading after relaxation [Pratt et al., 1975].

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