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# Summary of results of frictional sliding studies, at confining pressures up to 6.98 kb, in selected rock materials.

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# SUMMARY OF RESULTS OF FRICTIONAL SLIDING STUDIES, AT CONFINING PRESSURES UP TO 6.98 kb, IN SELECTED ROCK MATERIALS

By R. Summers and J. Byerlee

## Introduction

This report is a collection of stress-strain charts which were produced by deforming selected simulated fault gouge materials.

Several sets of samples consisted of intact cylinders, 1.000 inch diameter and 2.500 inches long. The majority of the samples consisted of thin layers of the selected sample material, inserted within a diagonal sawcut in a 1.000 inch by 2.500 inch Westerly Granite cylinder (fig. 1). Two sorts of inserts were used. The first consisted of thin wafers cut from 1.000 inch diameter cores of the rock being tested. The other consisted of thin layers of crushed material packed onto the sawcut surface.

In several groups of tests using various thicknesses (0.010-inch to 0.160 inch) of a given type material there were variations in the stress level and/or stability of sliding as a function of the fault zone width. Because of this we elected to use a standard 0.025 inch width fault zone to compare the frictional properties of many of the different types of rock materials. This 0.025 inch thickness was chosen partially because this thickness of crushed granite behaves approximately the same as a fractured sample of initially intact granite, and also because this is near the lower limit at which we could cut intact wafers for those samples that were prepared from thin slices of rock.

One series of tests was done with saw cut granite cylinders without fault gouge inserts.

All of these test were done in a hydraulically operated triaxial testing machine. The confining pressure ($\sigma_1$, least principal stress) was applied by pumping petroleum ether into a pressure vessel. The differential stress ($\sigma_3 - \sigma_1$) was applied by a hydraulically operated ram that could be advanced into the pressure vessel at any of several strain rates ($10^{-4}sec^{-1}$, $10^{-5}sec^{-1}$, $10^{-6}sec^{-1}$, $10^{-7}sec^{-1}$, or $10^{-8}sec^{-1}$). All samples were jacketed in polyurethane tubing to exclude the confining pressure medium from the samples. The majority of the samples, with the exception of some of the initially intact rocks, also had thin copper jackets. These served to hold the saw cut parts of the granite sample holders in alignment while the samples were handled and pushed into the polyurethane jackets.

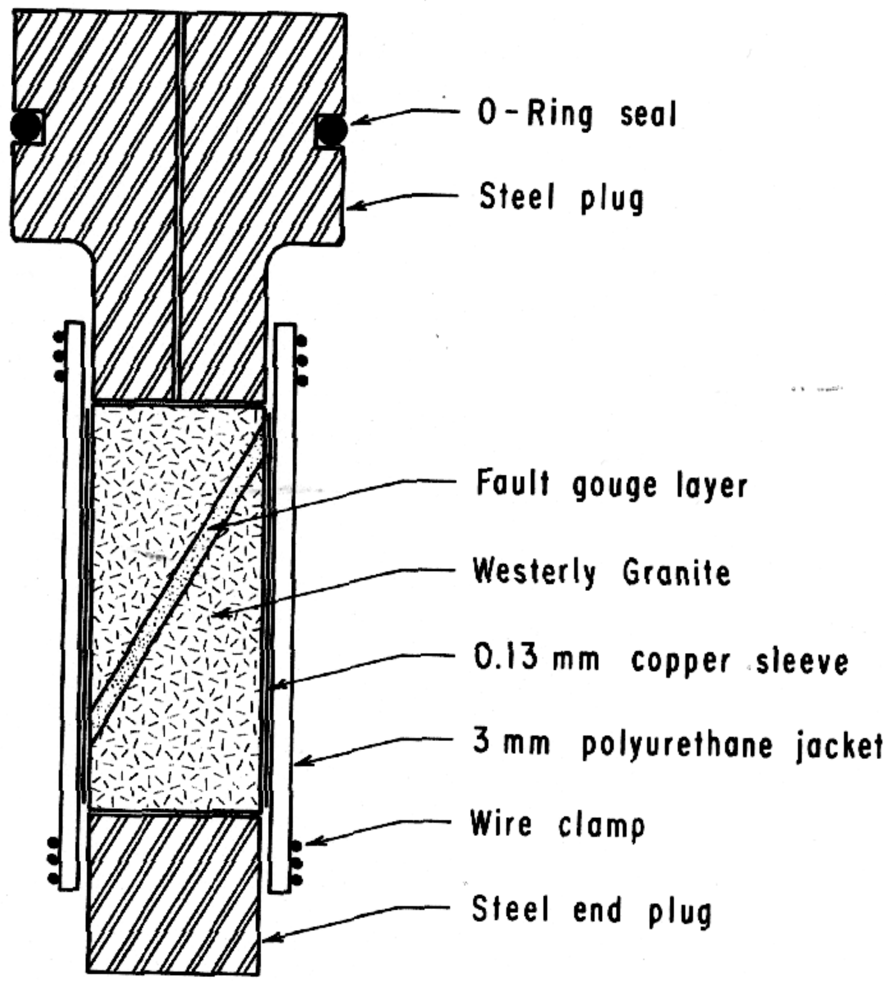

O-Ring seal
Steel plug
Fault gouge layer
Westerly Granite
0.13 mm copper sleeve
3 mm polyurethane jacket
Wire clamp
Steel end plug



FIG. 1

SUMMARY OF EXPERIMENTAL CONDITIONS

| Figure Number | Type of Material | Thickness of: Crushed Gouge Layer OR Solid Wafer (Inches) | Material was: Placed in 30° or 45° saw cut in W. Granite OR used as Intact Cylinder | Confining Pressure | Strain Rate | Gouge was Deformed |
|---|---|---|---|---|---|---|
| 2 | Berea Sandstone | 0.040 wafer | 30° | 0.78-6.27 kb | $10^{-4}$ $sec^{-1}$ | Dry |
| 3 | Berea Sandstone | 0.040 wafer | 30° | 0.78-2.35 | $10^{-4}$ | Dry |
| 4 | Berea Sandstone | 0.080 wafer | 30° | 0.78-6.26 | $10^{-4}$ | Dry |
| 5 | Berea Sandstone | 0.080 wafer | 30° | 0.78-2.37 | $10^{-4}$ | Dry |
| 6 | Chlorite | 0.025 wafer | 30° | 0.74-6.26 | $10^{-4}$ | Dry |
| 7 | Chlorite | 0.025 wafer | 30° | 0.73-6.27 | $10^{-4}$ | Dry |
| 8 | Halloysite | 0.025 layer | 30° | 0.78-6.27 | $10^{-4}$ | Dry |
| 9 | Halloysite | 0.025 layer | 30° | 0.78-6.27 | $10^{-4}$ | Dry |
| 10 | Kaolinite | 0.025 layer | 30° | 0.77-6.27 | $10^{-4}$ | Dry |
| 11 | Illite | 0.025 layer | 30° | 0.74-6.27 | $10^{-4}$ | Dry |
| 12 | Illite | 0.025 layer | 30° | 0.74-6.24 | $10^{-4}$ | Dry |
| 13 | Illite | 0.025 layer | 30° | 6.25-6.27 | $10^{-5}$ | Water Saturated |
| 14 | Montmorillonite | 0.025 layer | 30° | 0.73-6.26 | $10^{-4}$ | Dry |
| 15 | Montmorillonite | 0.025 layer | 30° | 0.74-6.24 | $10^{-4}$ | Dry |
| 16 | Montmorillonite | 0.025 layer | 30° | 6.27-6.28 | $10^{-5}$ | Water Saturated |
| 17 | Vermiculite | 0.025 layer | 30° | 0.78-6.27 | $10^{-4}$ | Dry |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18 | Vermiculite | 0.025 layer | 30° | 0.78-6.27 | $10^{-4}$ | Dry |
| 19 | Five Clay Minerals | 0.025 layer | 30° | 6.27 | $10^{-4}$ | Dry |
| 20 | Graphite | 0.025 wafer | 30° | 0.74-6.26 | $10^{-4}$ | Dry |
| 21 | Graphite | 0.025 wafer | 30° | 0.74-6.24 | $10^{-4}$ | Dry |
| 22 | Muscovite | 0.025 wafer | 30° | 0.78-6.35 | $10^{-4}$ | Dry |
| 23 | Muscovite | 0.025 wafer | 30° | 0.80-6.27 | $10^{-4}$ | Dry |
| 24 | Muscovite | 0.025 wafer | 30° | 6.27 | $10^{-4}$ | Dry |
| 25 | Muscovite | 0.025 layer | 30° | 6.27 | $10^{-4}$ | Dry |
| 26 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 27 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 28 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 29 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | -- | Dry |
| 30 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 31 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 32 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 33 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-7}$ | Dry |
| 34 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Water Saturated |
| 35 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | -- | Water Saturated |
| 36 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ $10^{-7}$ | Water Saturated |
| 37 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |

| | | | | | | |
|---|---|---|---|---|---|---|
| 38 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 39 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 40 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 41 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 42 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 43 | Ottawa Quartz Sand | 0.080 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 44 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 45 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 46 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 47 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 48 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 49 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 50 | Ottawa Quartz Sand | 0.160 layer | 30° | 4.70 | $10^{-5}$ | Dry |
| 51 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 52 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 53 | Ottawa Quartz Sand | 0.160 layer | 45° | 2.60 | $10^{-7}$ | Dry |
| 54 | Ottawa Quartz Sand | 0.160 layer | 45° | 2.60 | $10^{-5}$ | Dry |
| 55 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 56 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 57 | Ottawa Quartz Sand | 0.160 layer | 30° | 2.00 | $10^{-5}$ | Dry |
| 58 | Serpentinite (Almaden) | 0.025 layer | 30° | 0.73-6.25 | $10^{-4}$ | Dry |

| | | | | | | |
|---|---|---|---|---|---|---|
| 59 | Serpentinite (Almaden) | 0.025 layer | 30° | 0.73-6.26 | $10^{-4}$ | Dry |
| 60 | Serpentinite (DelPuerto) | 0.020 wafer | 30° | 0.74-6.22 | $10^{-4}$ | Dry |
| 61 | Serpentinite (DelPuerto) | 0.020 wafer | 30° | 0.74-6.23 | $10^{-4}$ | Dry |
| 62 | Serpentinite (DelPuerto) | 0.025 wafer | 30° | 0.73-6.23 | $10^{-4}$ | Dry |
| 63 | Serpentinite (DelPuerto) | 0.025 wafer | 30° | 0.74-6.22 | $10^{-4}$ | Dry |
| 64 | Serpentinite (DelPuerto) | 0.025 layer | 30° | 0.73-6.24 | $10^{-4}$ | Dry |
| 65 | Serpentinite (DelPuerto) | 0.025 layer | 30° | 0.73-6.25 | $10^{-4}$ | Dry |
| 66 | Solenhofen Limestone | 0.025 wafer | 30° | 0.74-6.23 | $10^{-4}$ | Dry |
| 67 | Solenhofen Limestone | 0.025 wafer | 30° | 0.74-6.22 | $10^{-4}$ | Dry |
| 68 | Talc | -- | Intact | 1.92-5.87 | $10^{-4}$ | Dry |
| 69 | Talc | 0.020-0.080 wafers | 30° | 5.45-5.47 | $10^{-4}$ | Dry |
| 70 | Talc | 0.020-0.080 wafers | 30° | 5.45-5.46 | $10^{-4}$ | Dry |
| 71 | Talc | 0.025 wafer | 30° | 0.74-6.26 | $10^{-4}$ | Dry |
| 72 | Talc | 0.025 wafer | 30° | 0.75-6.23 | $10^{-4}$ | Dry |
| 73 | Westerly Granite | -- | Intact | 0.41-2.77 | $10^{-4}$ | Dry |
| 74 | Westerly Granite | -- | Intact | 5.88-6.27 | $10^{-4}$ | Dry |
| 75 | Westerly Granite | -- | Intact | 3.16-6.32 | $10^{-4}$ | Dry |
| 76 | Westerly Granite | -- | Intact | 3.13-6.84 | $10^{-4}$ | Dry |
| 77 | Westerly Granite | -- | Intact | 6.21 | $10^{-4}$ | Dry |
| 78 | Westerly Granite | -- | Intact | 1.61-2.76 | $10^{-4}$ | Dry |
| 79 | Westerly Granite | -- | Intact | 1.57-4.85 | $10^{-5}$ | Dry |

| | | | | | | |
|---|---|---|---|---|---|---|
| 80 | Westerly Granite | -- | Intact | 0.39–6.98 | $10^{-5}$ | Dry |
| 81 | Westerly Granite | -- | Intact | 0.80–2.85 | $10^{-6}$ | Dry |
| 82 | Westerly Granite | -- | Intact | 0.42–2.35 | $10^{-6}$ | Dry |
| 83 | Westerly Granite | -- | Intact | 1.51–4.73 | $10^{-6}$ | Dry |
| 84 | Westerly Granite | -- | Intact | 2.30–5.45 | $10^{-6}$ | Dry |
| 85 | Westerly Granite | No insert | 30° | 0.78–3.98 | $10^{-4}$ | Dry |
| 86 | Westerly Granite | No insert | 30° | 1.61–6.30 | $10^{-4}$ | Dry |
| 87 | Westerly Granite | No insert | 30° | 0.20–0.98 | $10^{-5}$ | Dry |
| 88 | Westerly Granite | No insert | 30° | 0.39–0.78 | $10^{-5}$ | Dry |
| 89 | Westerly Granite | No insert | 30° | 0.20–0.98 | $10^{-6}$ | Dry |
| 90 | Westerly Granite | 0.010 layer | 30° | 1.54 | $10^{-4}$ | Dry |
| 91 | Westerly Granite | 0.010 layer | 30° | 0.74–6.27 | $10^{-4}$ | Dry |
| 92 | Westerly Granite | 0.010 layer | 30° | 0.75–6.24 | $10^{-4}$ | Dry |
| 93 | Westerly Granite | 0.010 layer | 30° | 6.22 | $10^{-4}$ | Dry |
| 94 | Westerly Granite | 0.025 layer | 30° | 0.80–6.27 | $10^{-4}$ | Dry |
| 95 | Westerly Granite | 0.040 layer | 30° | 0.80–6.27 | $10^{-4}$ | Dry |
| 96 | Westerly Granite | 0.040 layer | 30° | 0.74–6.24 | $10^{-4}$ | Dry |
| 97 | Westerly Granite | 0.040 layer | 30° | 0.75–6.22 | $10^{-4}$ | Dry |
| 98 | Westerly Granite | 0.080 layer | 30° | 3.18 | $10^{-4}$ | Dry |
| 99 | Westerly Granite | 0.160 layer | 30° | 0.75–6.27 | $10^{-4}$ | Dry |
| 100 | Westerly Granite | 0.160 layer | 30° | 1.54–6.27 | $10^{-4}$ | Dry |
| 101 | Westerly Granite | 0.160 layer | 30° | 0.74–6.22 | $10^{-4}$ | Dry |

Berea Sandstone

Fig. 2,3) 0.040"-thick wafers of Berea sandstone placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressures: 0.78 to 6.27 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

Fig.4,5) 0.080"-thick wafers of Berea sandstone placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressures: 0.78 to 6.26 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

Comments:

For most samples the stress levels reached at a given confining pressure were approximately the same regardless of wafer thickness. However, wafer thickness affected the stability of sliding, with the thicker wafers being more stable at a given confining pressure.

The 0.040" layers exhibited stick slip as low as 1.58 kb. The highest confining pressure at which there were no stress drops was 2.35 kb.

For the 0.080" layers pressures of 3.15 and 3.94 kb produced only slight stress drops. Major stress drops began at 4.69 kb.

The two small stress drops at 0.78 kb in fig 5 appear to be anomolous, as a number of samples run at the same or greater confining pressure were stable.

At approximately 3 to 5 kb confining pressure the stress rise was delayed more in the 0.080" wafers than in the 0.040" wafers. The maximum stress levels attained were approximately the same in both cases, but more shearing was required with the 0.080" samples to reach the maximum stress.

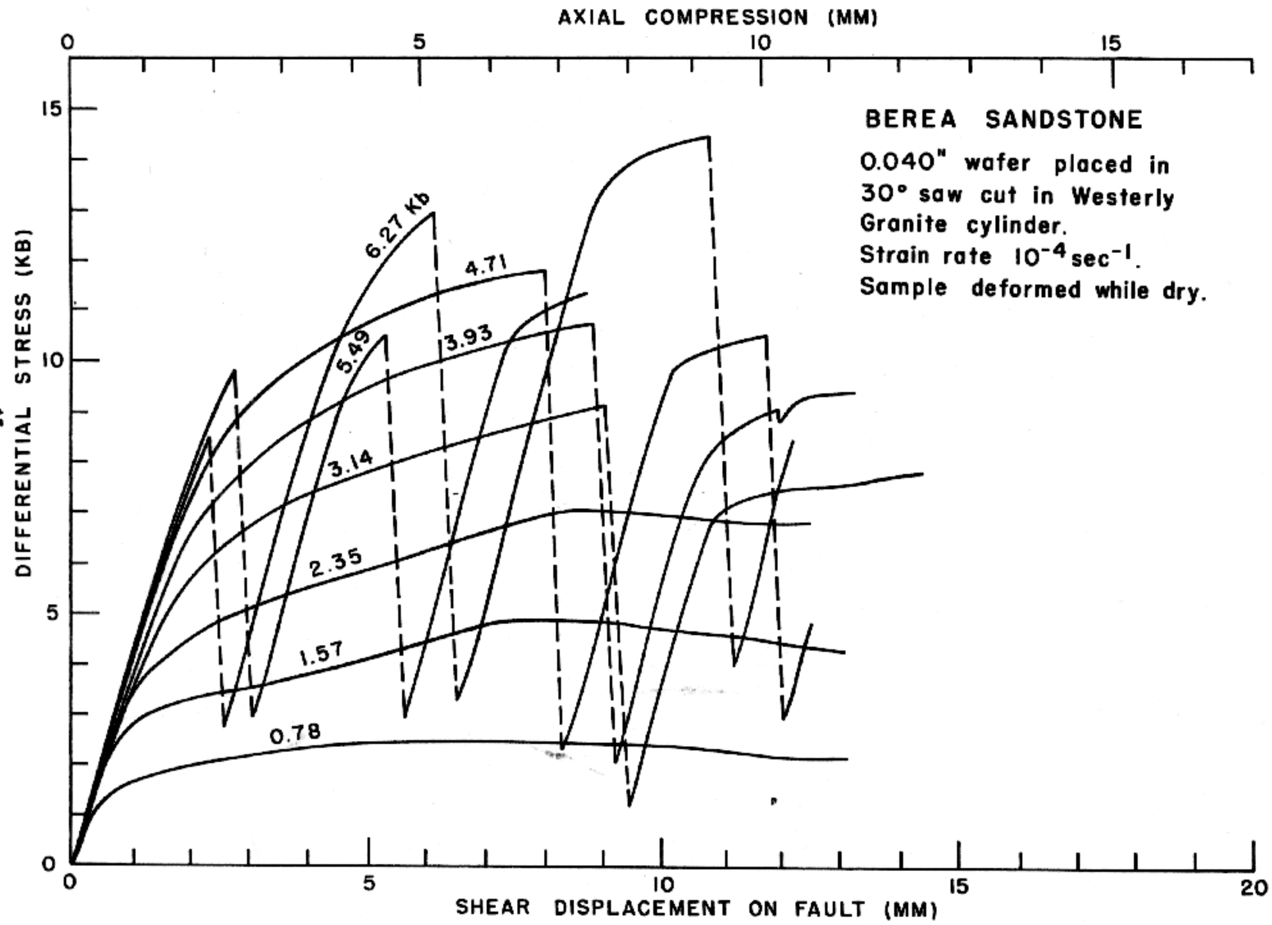

AXIAL COMPRESSION (MM)
0
5
10
15
BEREA SANDSTONE
0.040" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
6.27 Kb
4.71
5.49
3.93
3.14
2.35
1.57
0.78
DIFFERENTIAL STRESS (KB)
15
10
5
0
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 2

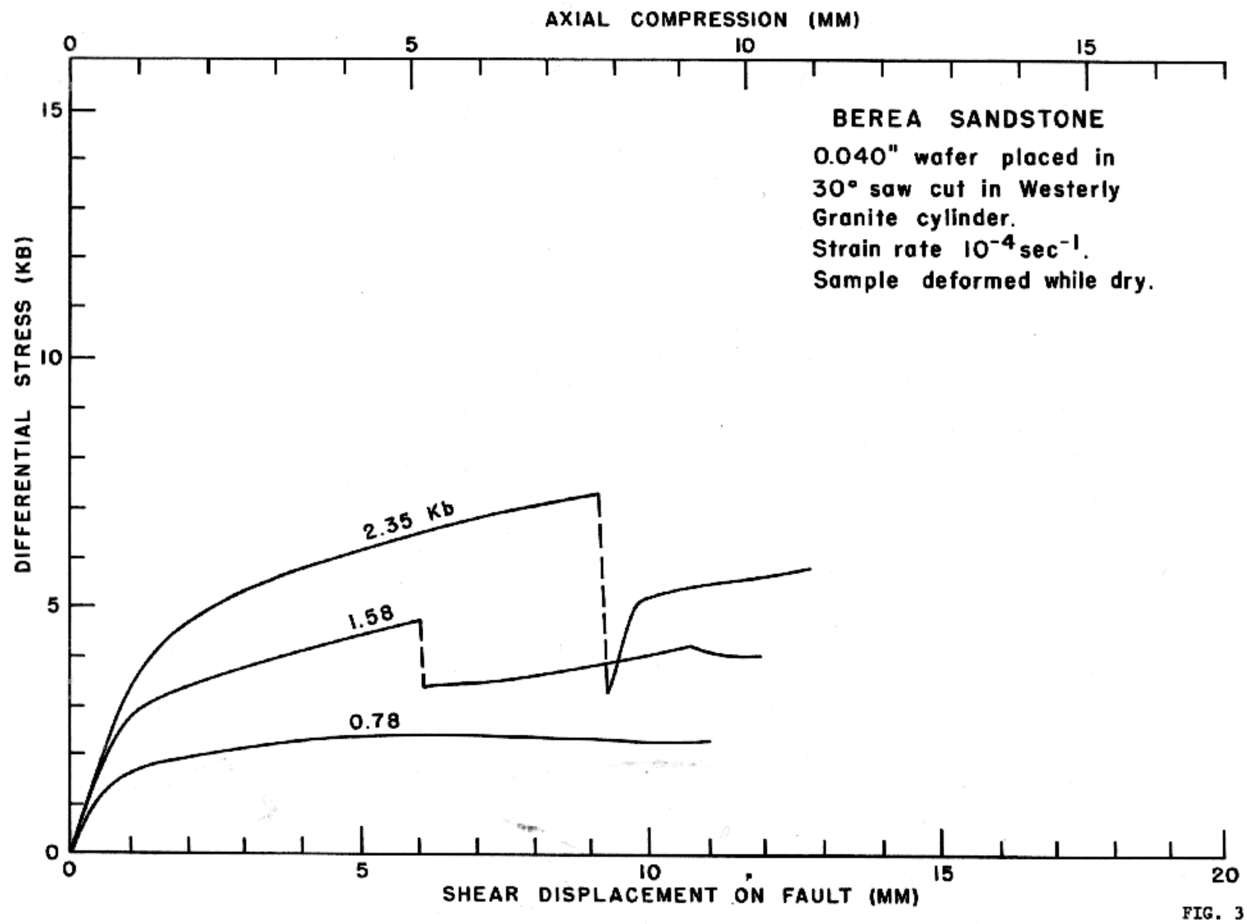
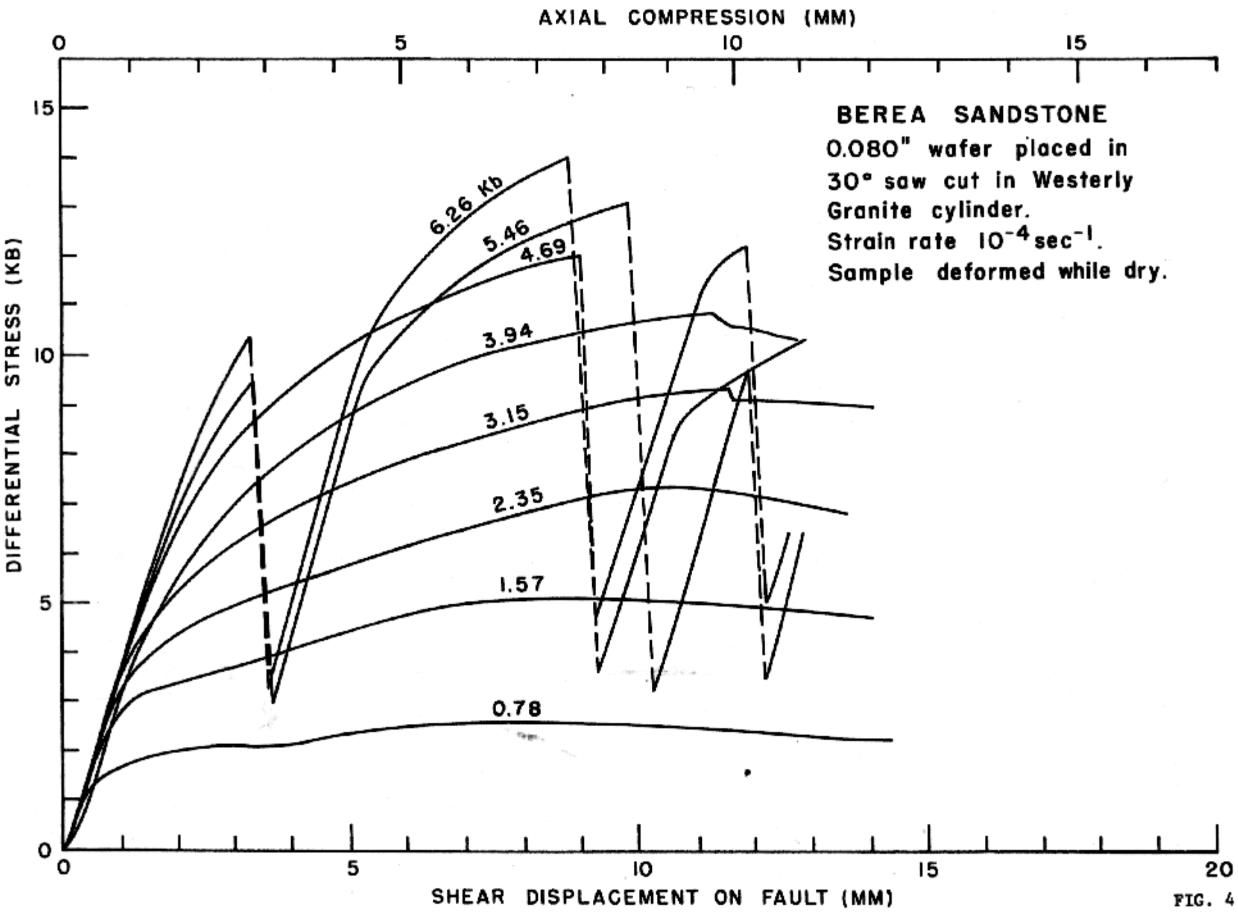

AXIAL COMPRESSION (MM)
0
5
10
15
BEREA SANDSTONE
0.040" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
2.35 Kb
1.58
0.78
SHEAR DISPLACEMENT ON FAULT (MM)
20

FIG. 3



AXIAL COMPRESSION (MM)
0
5
10
15
BEREA SANDSTONE
0.080" wafer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
6.26 Kb
5.46
4.69
3.94
3.15
2.35
1.57
0.78
DIFFERENTIAL STRESS (KB)
15
10
5
0
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 4

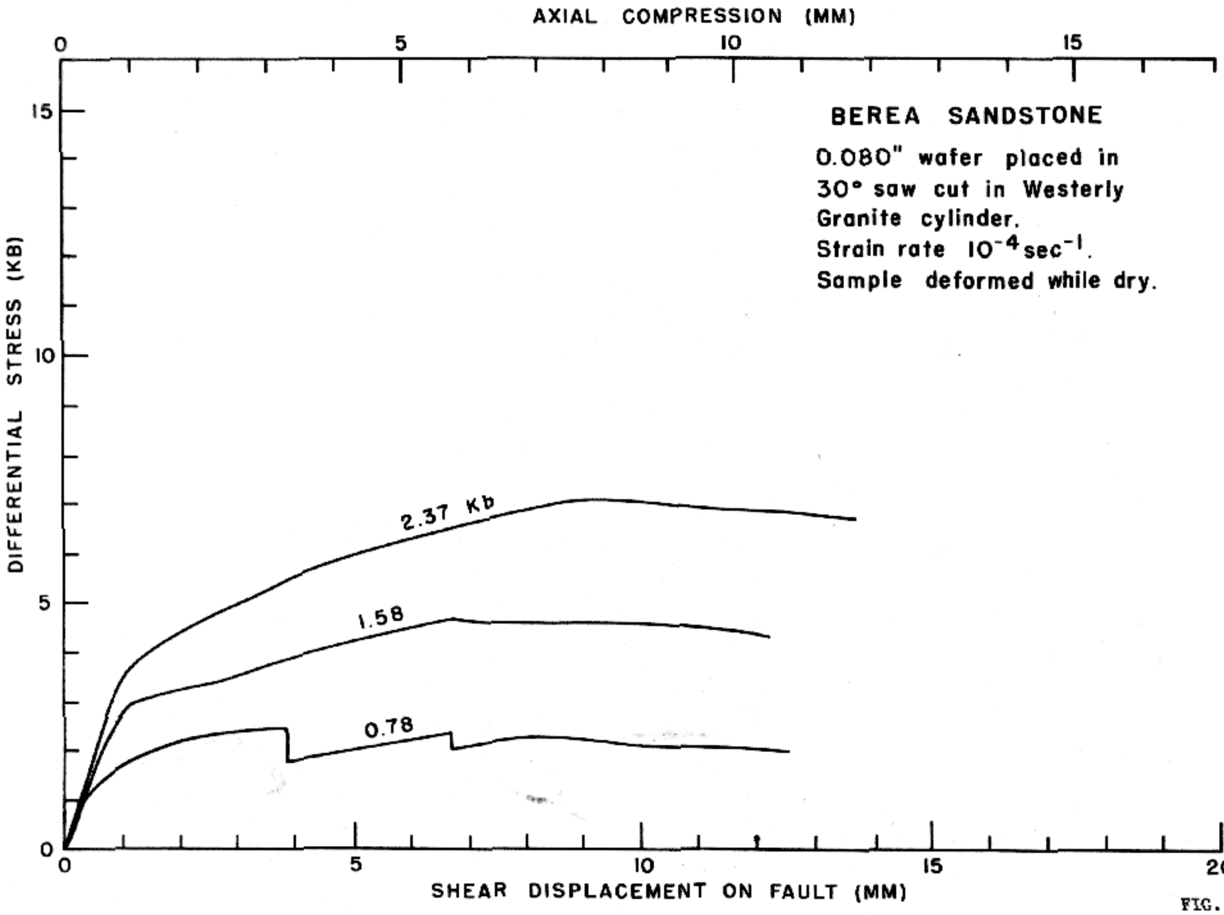

AXIAL COMPRESSION (MM)
0
5
10
15
BEREA SANDSTONE
0.080" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate 10^-4 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.37 Kb
1.58
0.78
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 5

Chlorite

Fig.6,7) 0.025"-thick wafers of ripidolite chlorite from Flagstaff Hill, California, cut parallel to the 001 cleavage plane and placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite.

Confining pressures: 0.73 to 6.27 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

Comments:

The samples run at 3/4 and 1 1/2 kb were stable. The samples run at 3.12 and 6.26 kb included a number of large unstable stress drops.

Stress levels supported at all confining pressures were surprisingly high.

There was a large amount of creep preceeding the first stick slip event at 6 1/4 kb. This was similar to the creep observed at high pressure in materials such as serpentinite and the non-expanding clays.

The samples run at 3.12 and 1.53-1.54 kb exhibit a wavering differential stress level during deformation. This effect appears in several other materials, most notably in the illite clay.

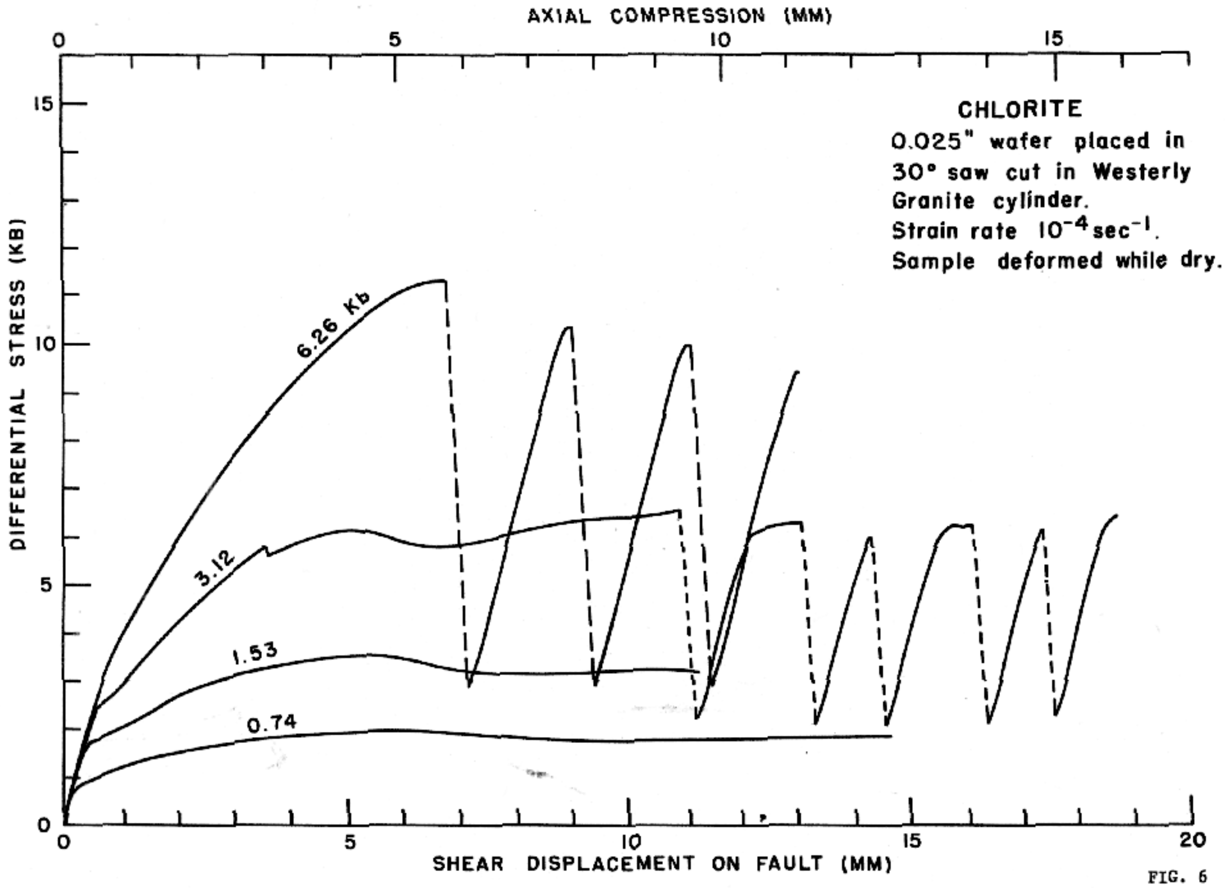

AXIAL COMPRESSION (MM)
0
5
10
15
CHLORITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.26 Kb
3.12
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 6

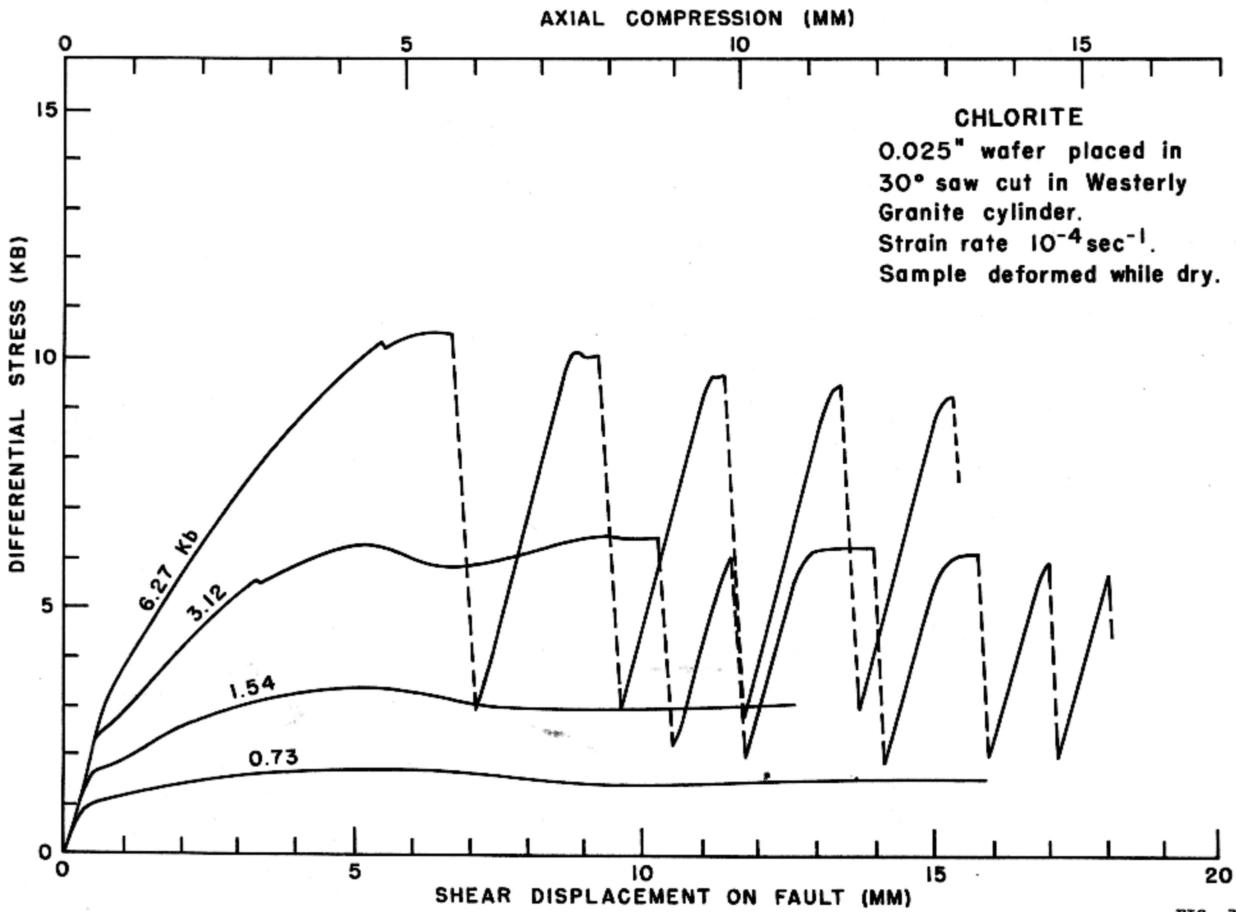

AXIAL COMPRESSION (MM)
0
5
10
15
CHLORITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.12
1.54
0.73
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 7

Clays

Fig. 8,9) Halloysite - dried (0.025" thickness as were all the following)

10) Kaolinite - dried

11,12) Illite - dried

13) Illite - water saturated

14,15) Montmorillonite - dried

16) Montmorillonite - water saturated

17,18) Vermiculite - dried

19) Air dried clays compared: Halloysite, Illite, Kaolinite, Montmorillonite, Vermiculite

Confining pressures: 0.73 to 6.27 kb

Axial compression strain reates: $10^{-4}sec^{-1}$, $10^{-5}sec^{-1}$

Comments:

The Halloysite clay (Fig. 8,9) samples were prepared with water and dried in a vacuum oven. They support high stresses and deform unstably at 3.14 and 6.27 kb. The samples at 1.57 kb deformed mostly stably with a total of two small stress drops, and only one large one. At high confining pressures these samples had relatively large amounts of stable sliding preceeding the first stress drop when compared with similar samples made up using Westerly Granite. This large amount of stable sliding also was observed with the serpentinite and chlorite.

The kaolinite (Fig. 10) was prepared with water and dried in a vacuum oven before running. The 1.58 kb sample developed

Clays (cont)

regular stick slip after a prolonged period of stable sliding. The samples run at 3.15 and 7.27 kb had initial periods of stable sliding and then developed regular stick slip.

The illite samples (Fig. 11,13) were prepared in three different ways which affected both the differential stress level supported and the stability of sliding. The samples in Fig. 11 were prepared with water and dried in a vacuum oven before running. A minor stress drop occurred at 1.53 kb, two major stress drops at 3.12 kb.

Similar samples of illite (Fig. 13) prepared using ethanol instead of water and dried in a vacuum oven produced a major stress drop at 1.53 kb, and regular stick slip at 3.14 kb. The stress levels at all confining pressures were higher than with the water prepared samples. The gradual stress decrease that occurred with the 3.12 kb water prepared illite sample was absent.

The third set of illite samples were run while water saturated. As can be seen in Fig. 13, those samples run at 6.26-6.27 kb were stable, and had significantly lower stress levels than did the dry samples. The samples that were allowed to drain longer before deforming supported higher differential stress.

The montmorillonite samples (Fig. 14,15) were prepared with ethanol and dried in a vacuum oven. All were stable and supported low stress levels. The samples in Fig. 15, which were dried for a longer time, support higher stress levels than those in Fig. 14.

The montmorillonite samples in Fig. 16 were prepared with water and run while water saturated. They support very low stress and deform stably.

Clays (cont)

The vermiculite samples (Fig. 17,18) were prepared with water and dried in a vacuum oven. With the exception of several minor stress drops, the deformation is stable up to 6.27 kb. Up to 1.57 kb the stress soon reaches a maximum and does not increase with deformation. At 3.14 to 6.27 kb the stress level continues to increase with continued deformation to the limit of our experiment.

Figure 19 compares air dried samples of 0.025" thick layers of Halloysite, Illite, Kaolinite, Montmorillonite, and Vermiculite. All of this set of samples were prepared wet and air dried before running. The non-expanding clays (Halloysite, Illite, and Kaolinite) were unstable; the expanding clays (Montmorillonite and Vermiculite) were stable. In addition, the stress levels supported by the expanding clays were very low compared to those supported by the non-expanding clays.

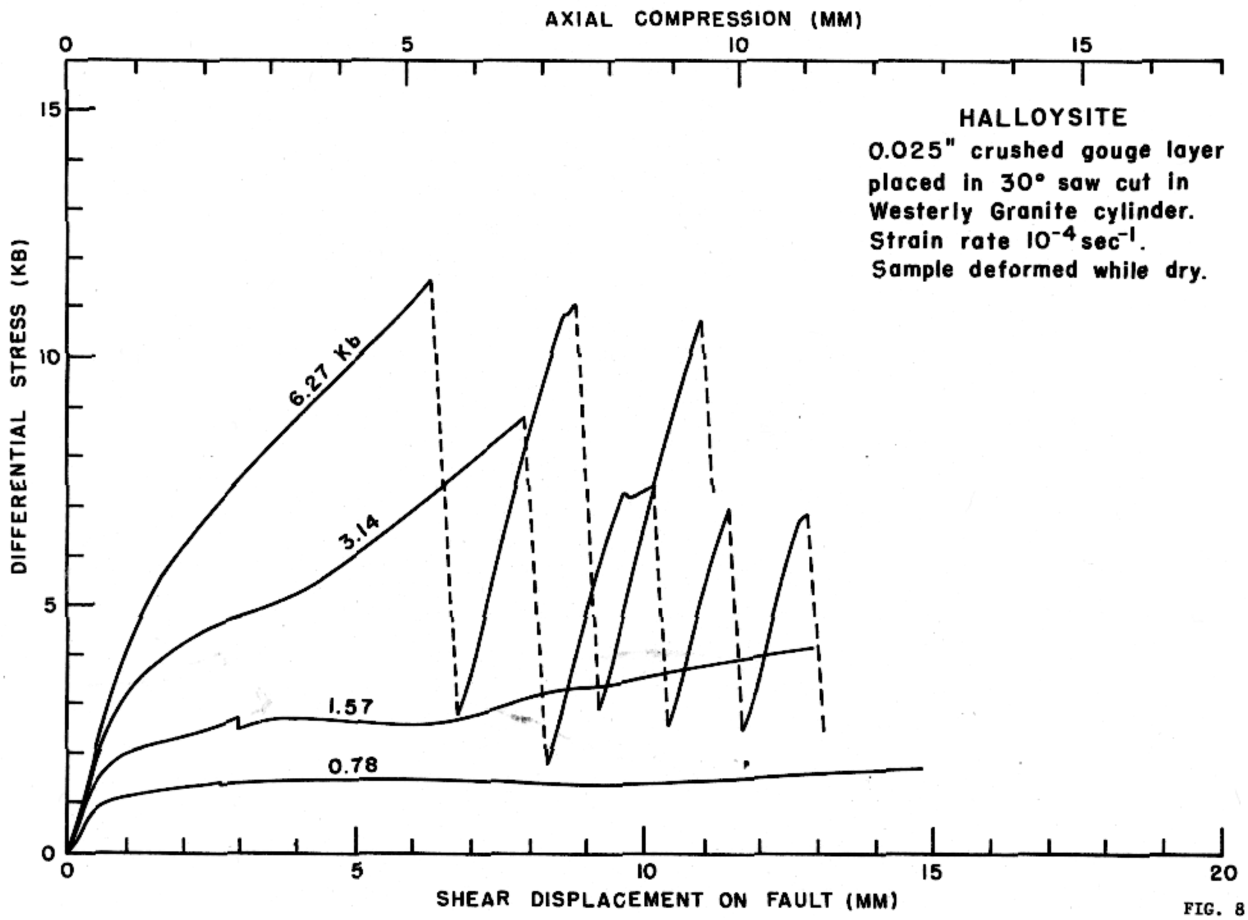

AXIAL COMPRESSION (MM)
0
5
10
15
HALLOYSITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-4}$ $sec^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.14
1.57
0.78
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 8

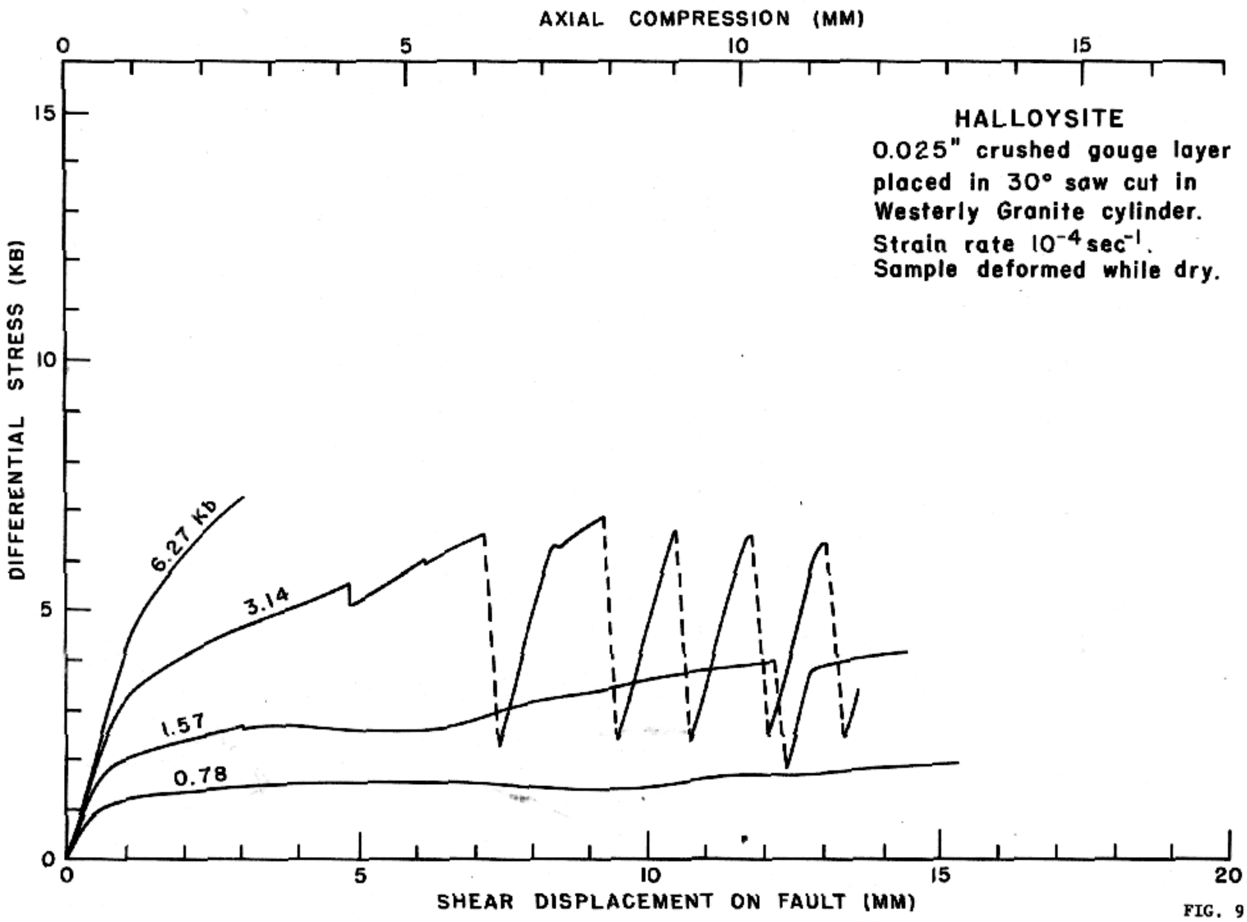

AXIAL COMPRESSION (MM)
0
5
10
15
HALLOYSITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.14
1.57
0.78
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 9

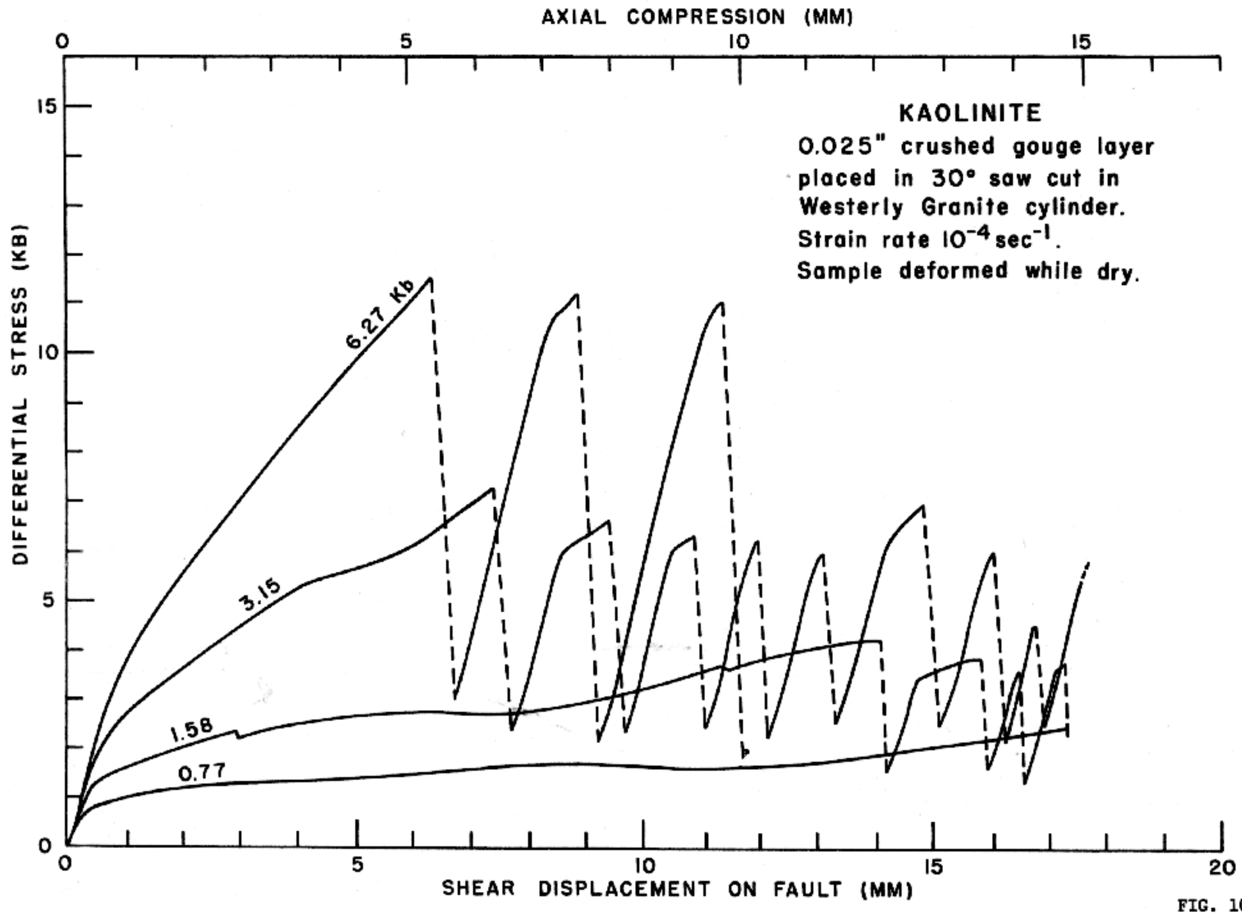

AXIAL COMPRESSION (MM)
0
5
10
15
KAOLINITE
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
6.27 Kb
3.15
1.58
0.77
SHEAR DISPLACEMENT ON FAULT (MM)
20

FIG. 10

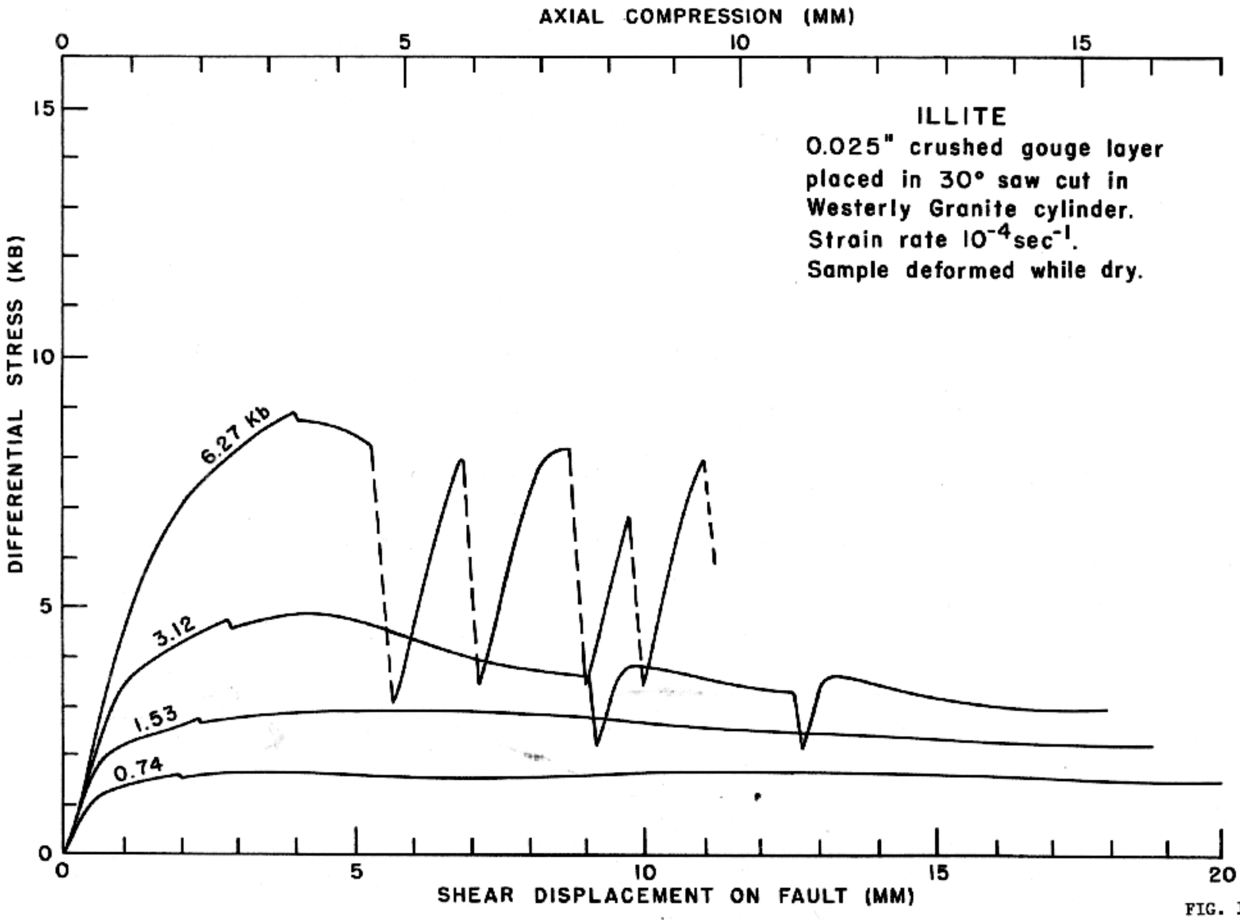

AXIAL COMPRESSION (MM)
0
5
10
15
ILLITE
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.12
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 11

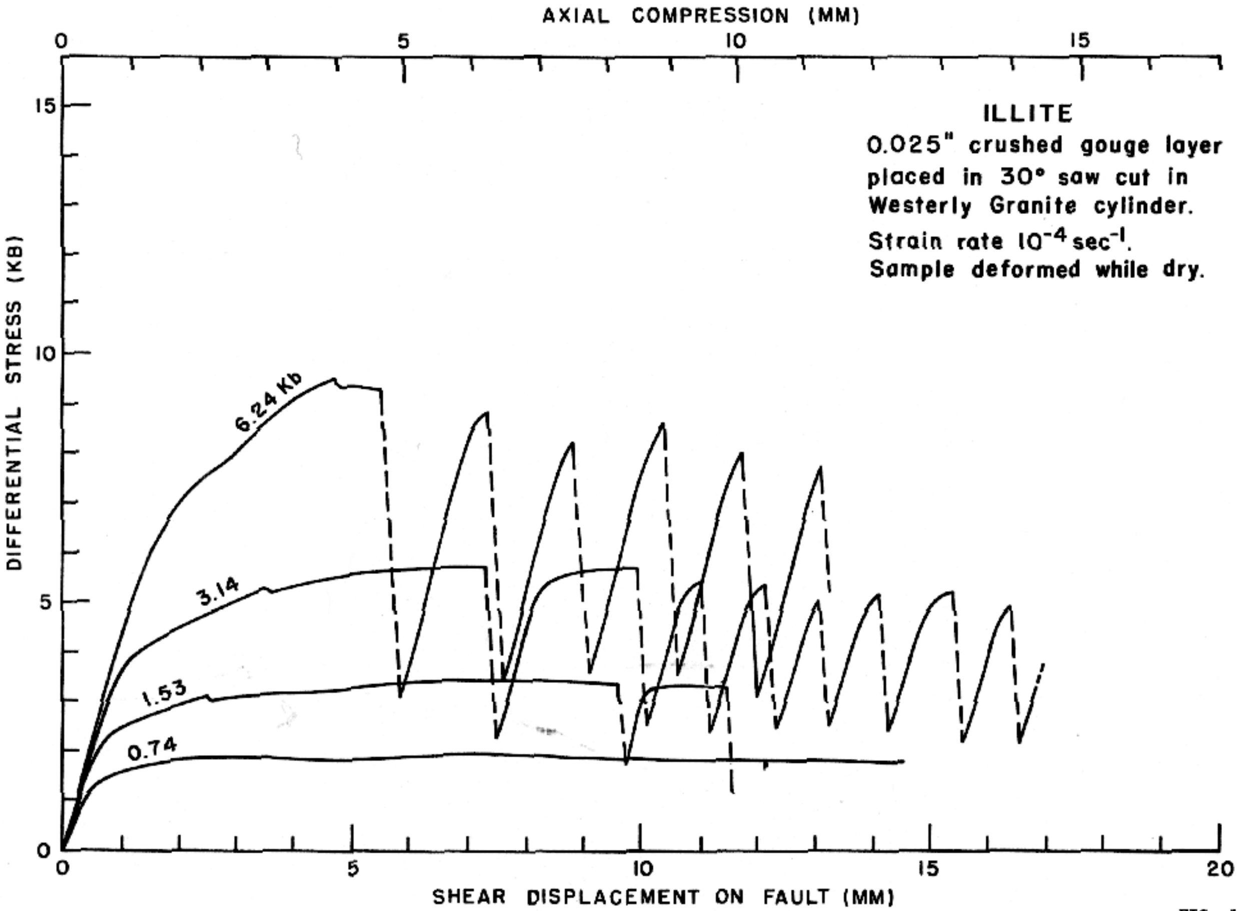

AXIAL COMPRESSION (MM)
ILLITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
6.24 Kb
3.14
1.53
0.74
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 12

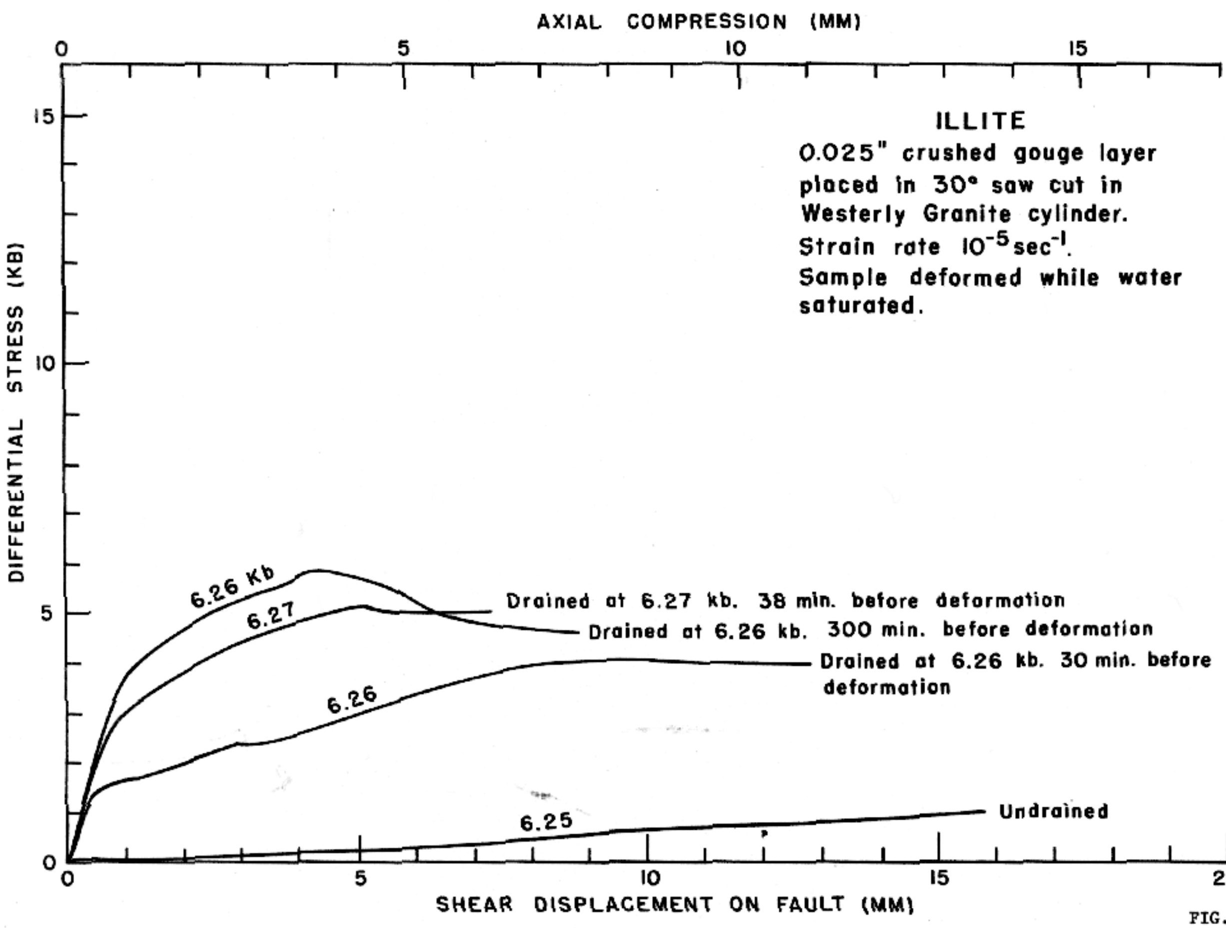
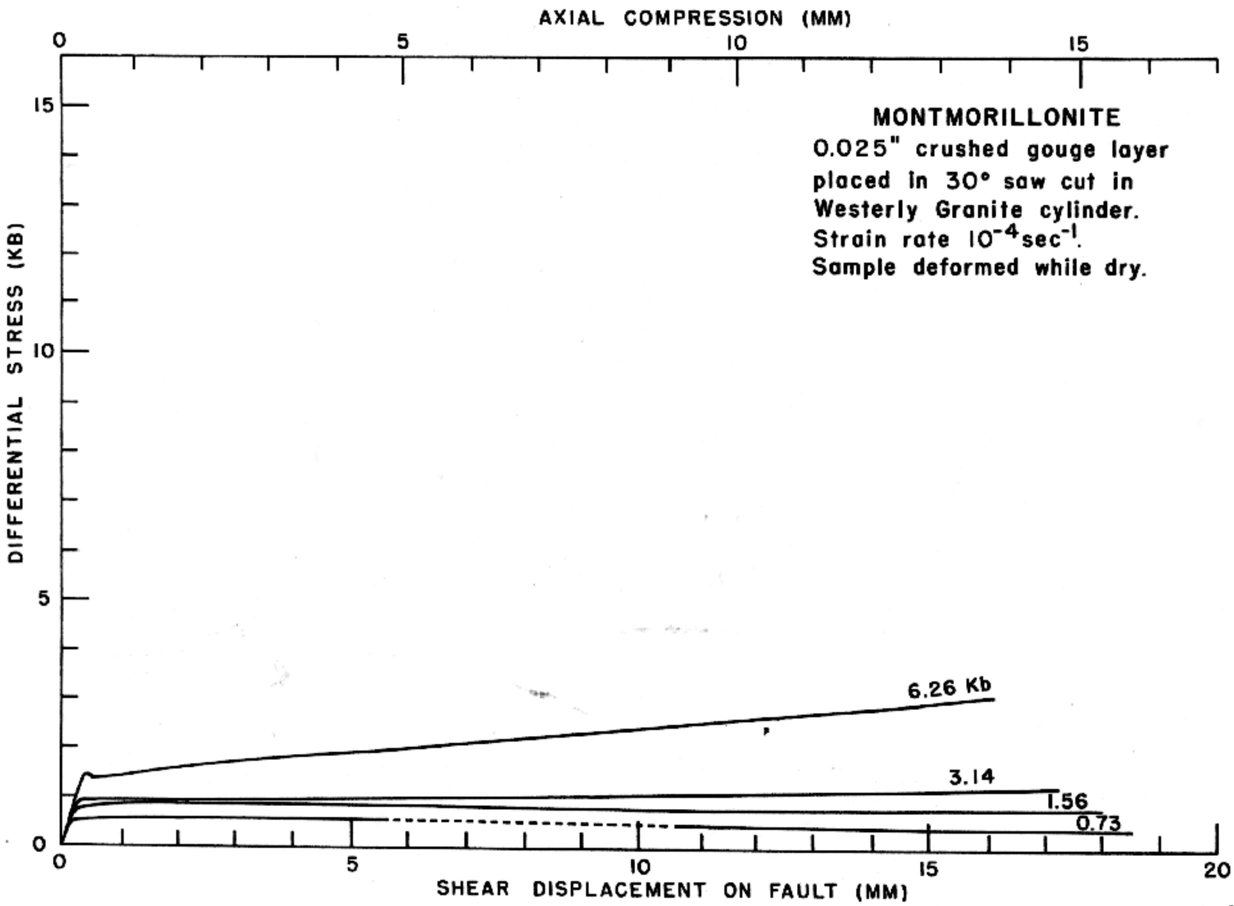

AXIAL COMPRESSION (MM)
ILLITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-5} sec^{-1}$.
Sample deformed while water saturated.
DIFFERENTIAL STRESS (KB)
6.26 Kb
6.27
6.26
6.25
Drained at 6.27 kb. 38 min. before deformation
Drained at 6.26 kb. 300 min. before deformation
Drained at 6.26 kb. 30 min. before deformation
Undrained
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 13


AXIAL COMPRESSION (MM)
0
5
10
15
MONTMORILLONITE
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.26 Kb
3.14
1.56
0.73
SHEAR DISPLACEMENT ON FAULT (MM)
20
FIG. 14

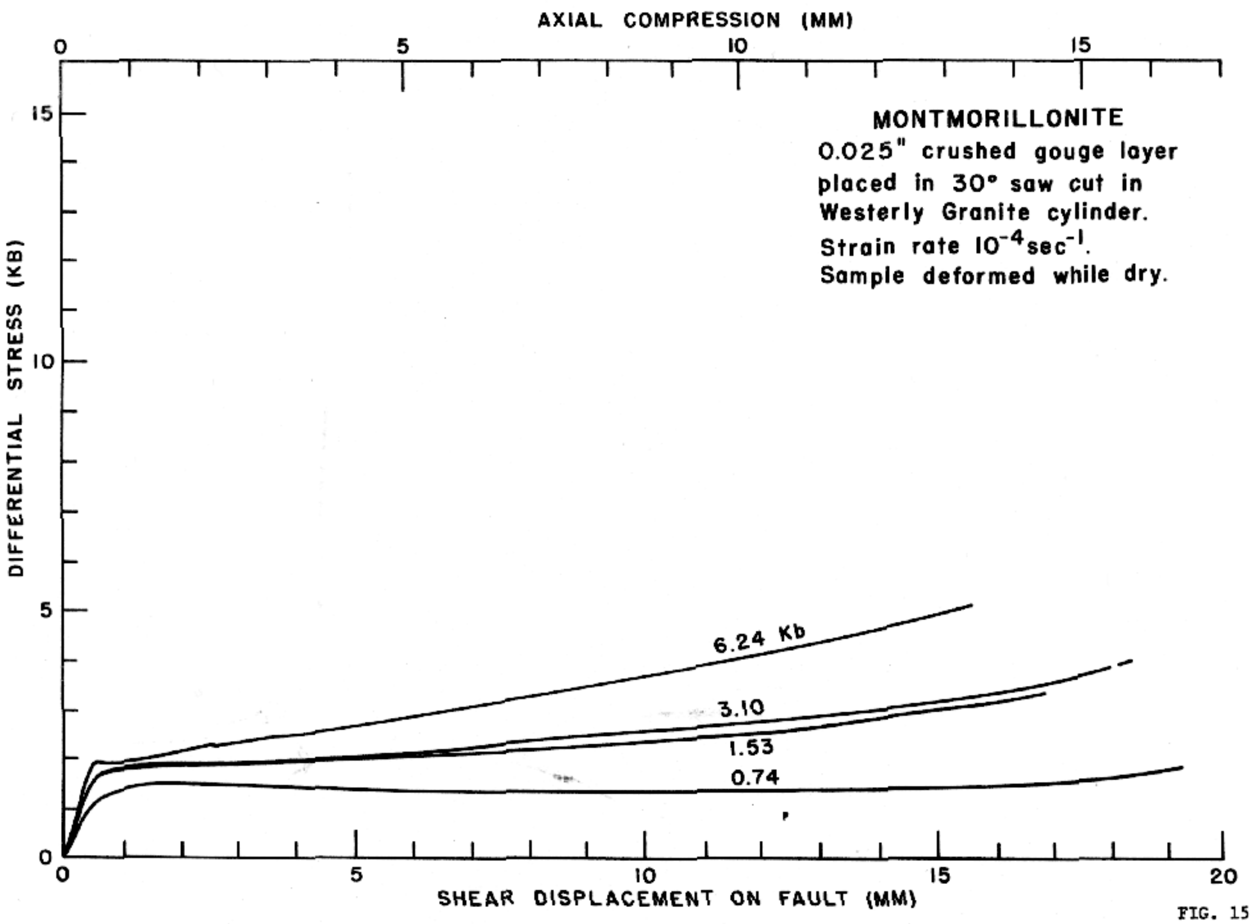

AXIAL COMPRESSION (MM)
0
5
10
15
MONTMORILLONITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-4} sec^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
0
5
10
15
6.24 Kb
3.10
1.53
0.74
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 15

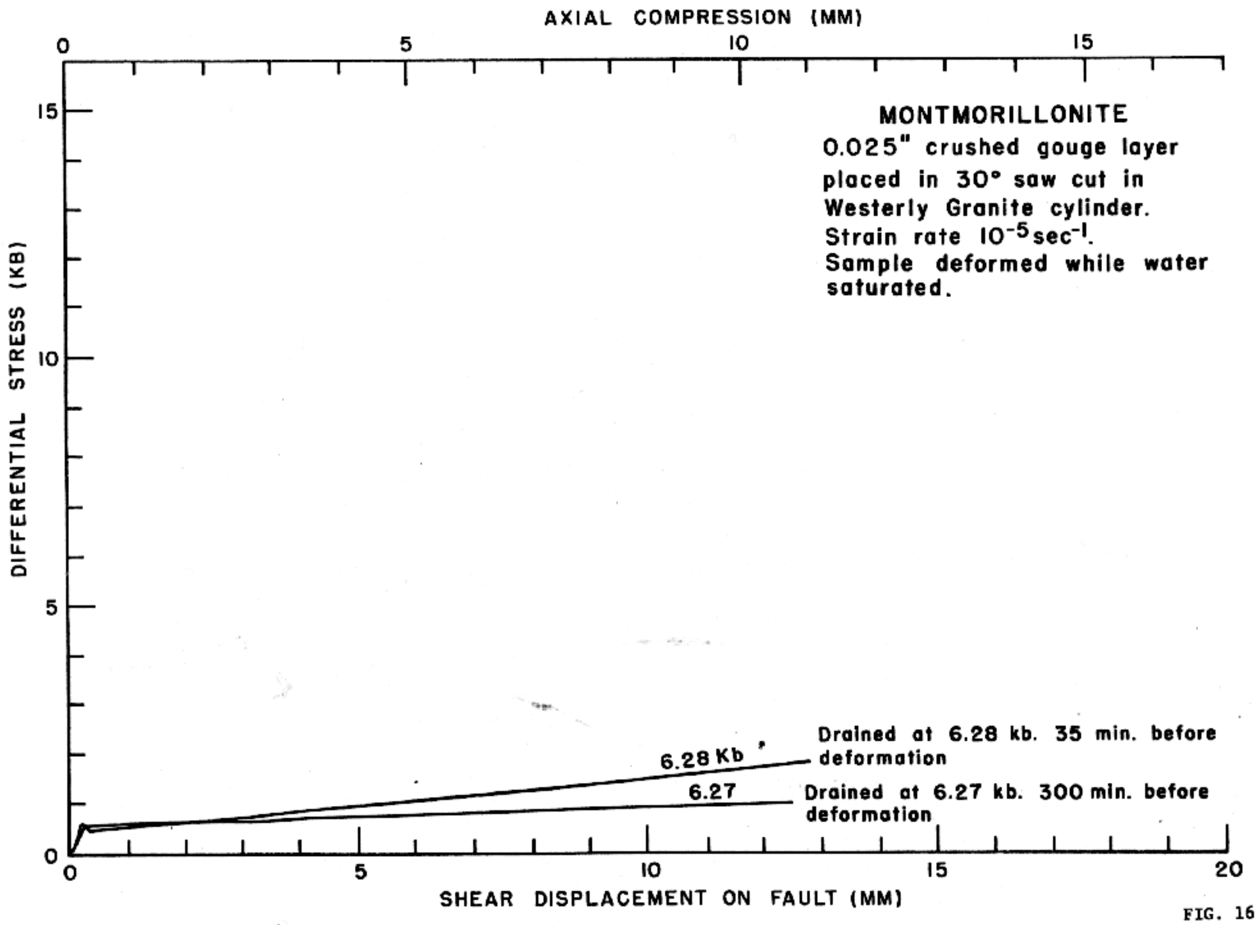

AXIAL COMPRESSION (MM)
0
5
10
15
MONTMORILLONITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ $sec^{-1}$. Sample deformed while water saturated.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.28 Kb
Drained at 6.28 kb. 35 min. before deformation
6.27
Drained at 6.27 kb. 300 min. before deformation
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 16

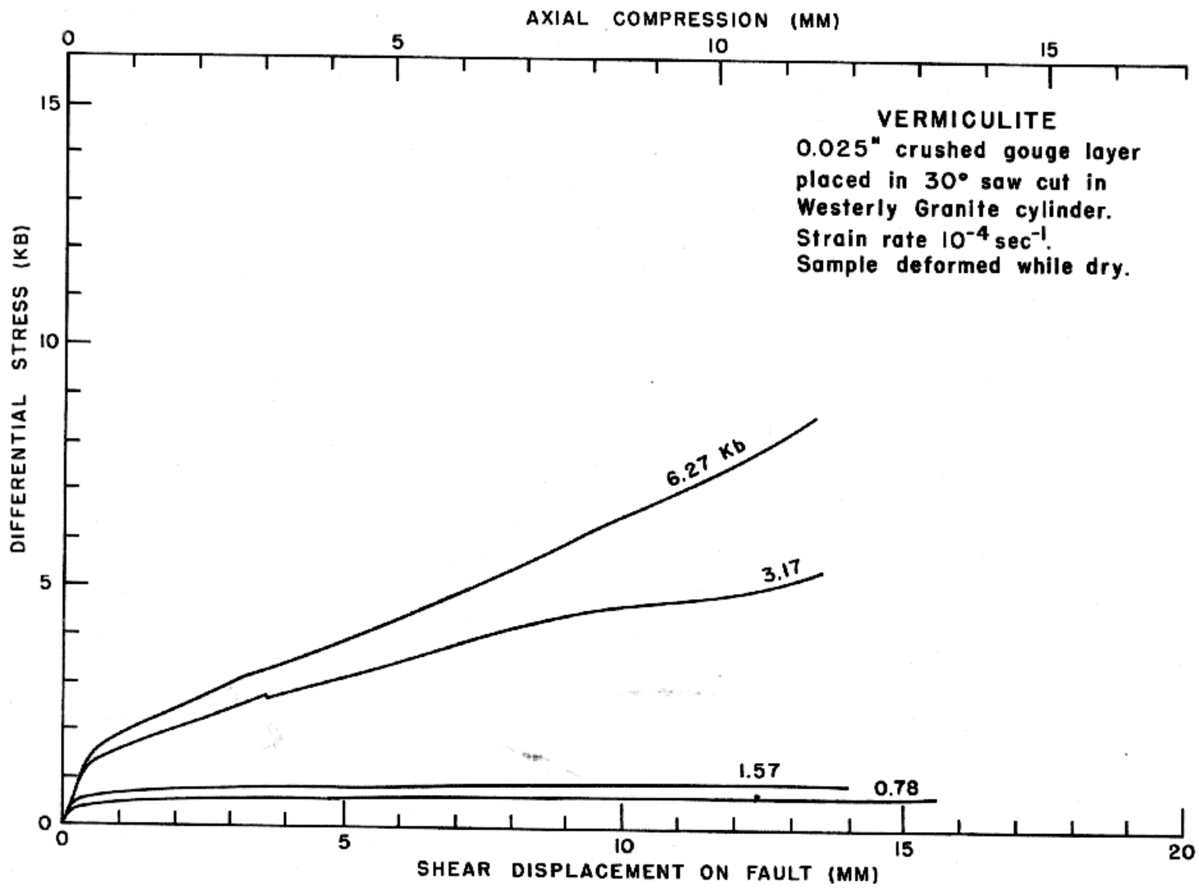

AXIAL COMPRESSION (MM)
VERMICULITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-4}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
6.27 Kb
3.17
1.57
0.78
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 17

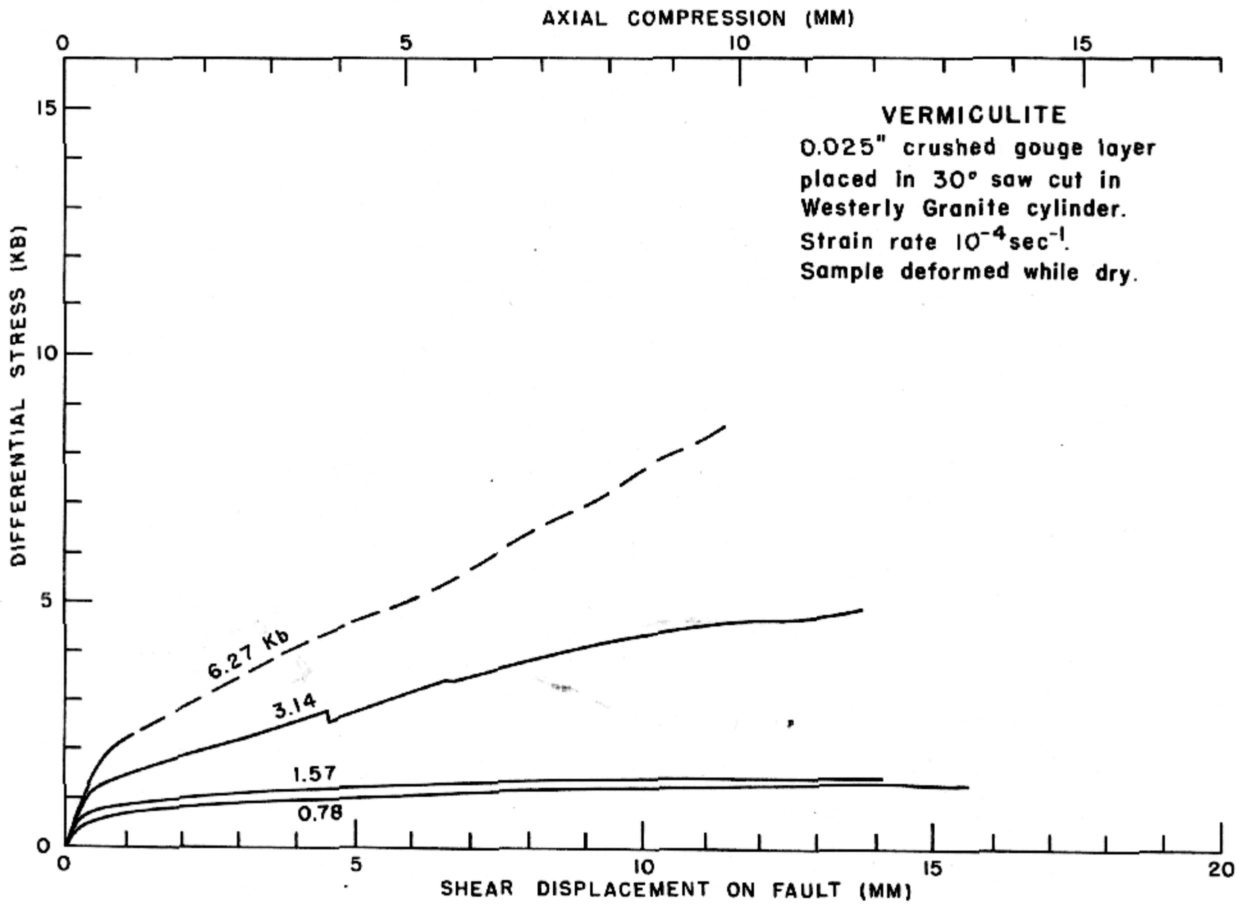
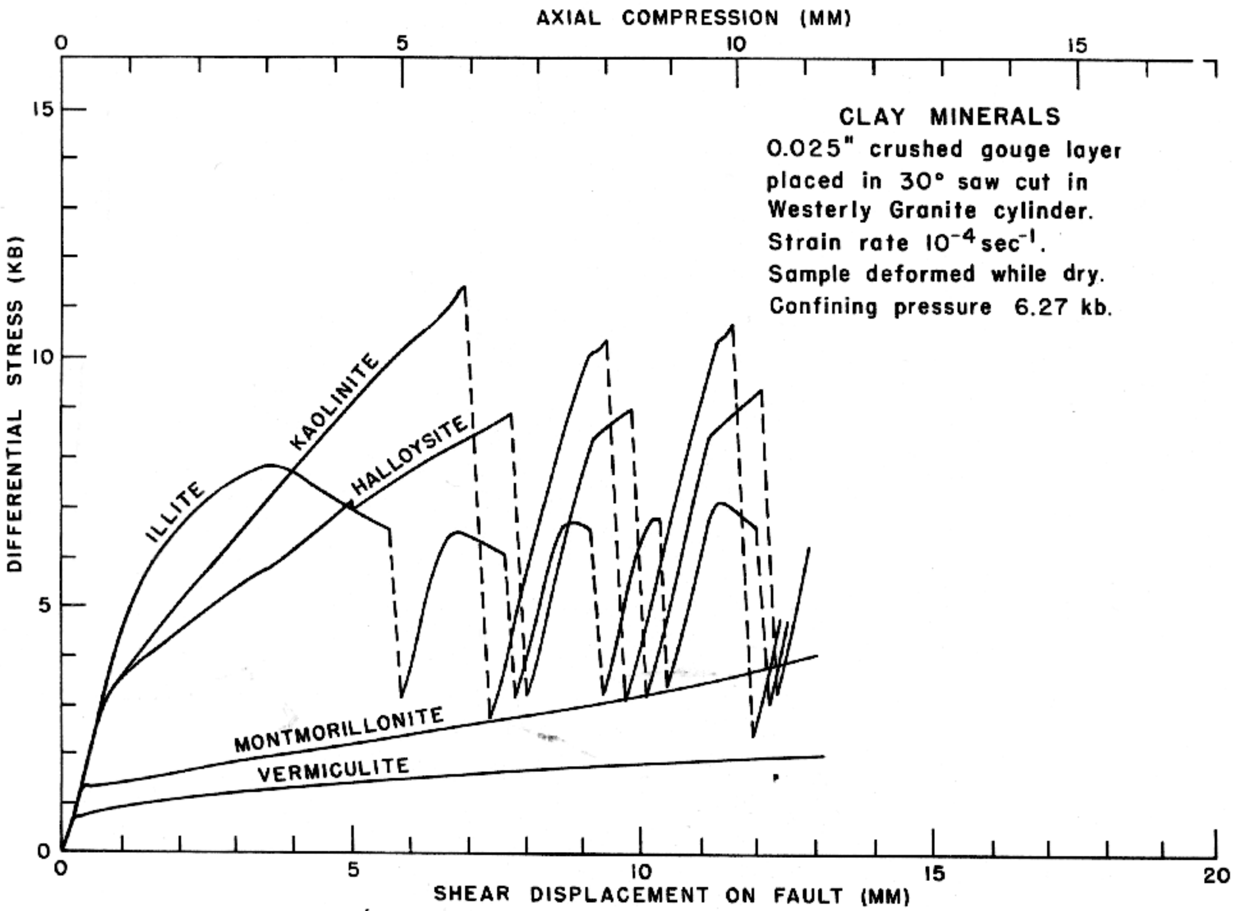

AXIAL COMPRESSION (MM)
VERMICULITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-4} sec^{-1}$. Sample deformed while dry.
6.27 Kb
3.14
1.57
0.78
DIFFERENTIAL STRESS (KB)
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 18



AXIAL COMPRESSION (MM)
0
5
10
15
CLAY MINERALS
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
Confining pressure 6.27 kb.
DIFFERENTIAL STRESS (KB)
15
10
5
0
ILLITE
KAOLINITE
HALLOYSITE
MONTMORILLONITE
VERMICULITE
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 19

Graphite

Fig. 20,21) 0.025"-thick wafers of graphite placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressure: 0.74 to 6.26 kb

Axial compression strain rate: $10^{-4} sec^{-1}$

Comments:

At the lower pressures of 0.74 and 1.53 kb the stress levels were very low and stabilized at a constant value after 1/2 mm of deformation. At 3.10 kb the stress level rose slowly as the displacement progressed. At 6.26 kb the increase in stress level with deformation was more pronounced.

Upper and lower yield points were observed for all the graphite samples from 3/4 to 6 1/4 kb. Similar distinct upper and lower yield points were also observed in some samples of limestone and montmorillonite. The two yield points observed with these samples apparently represent a drop in strength which occurs as frictional sliding begins.

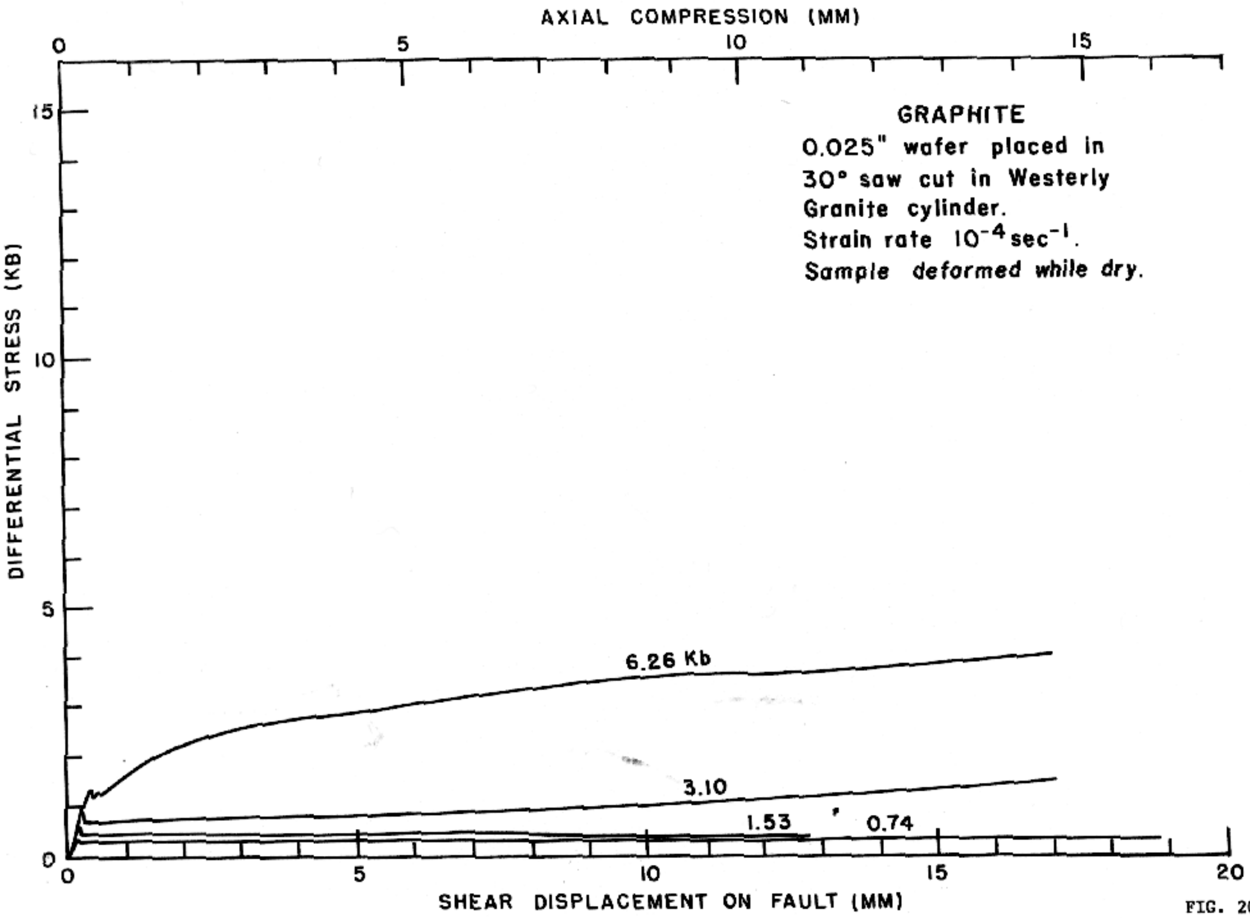

AXIAL COMPRESSION (MM)
0
5
10
15
GRAPHITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.26 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 20

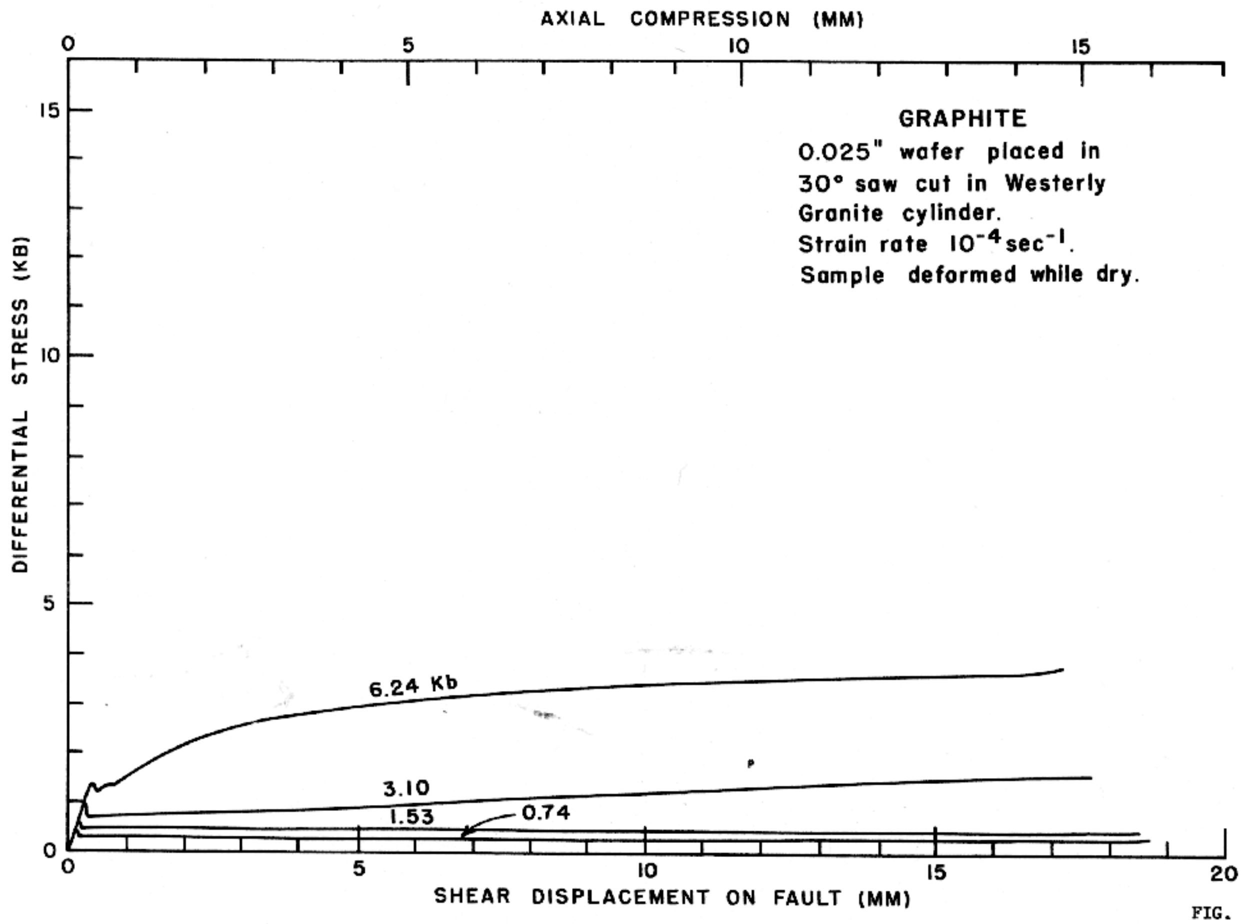

AXIAL COMPRESSION (MM)
0
5
10
15
GRAPHITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.24 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 21

Muscovite

Fig. 22-24) 0.025"-thick intact cleavage sheets placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressures: 0.78 to 6.35 kb

Axial compression strain rate: $10^{-4} sec^{-1}$

25) 0.025"-thick layer of crushed muscovite place in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressure: 6.27 kb

Axial compression strain rate: $10^{-4} sec^{-1}$

Comments:

The intact cleavage sheets (Fig 22-24) consistently supported only low stress, with the deformation being stable. Only a single very small stress drop occurred in one sample at 6.35 kb.

The crushed muscovite (Fig. 25) was prepared by placing cleavage fragments in a blender with water for 5 minutes. The samples were assembled wet and dried before deforming.

The behavior of the crushed muscovite by contrast with the cleavage sheets was radically different. Differential stress levels of up to 11 kb were observed, and there was regular violent stick slip failure. During the first stress rise there was an elastic yield point at just over 2 kb. This yield did not occur on the succeeding stress rises, even though stress levels reached 9-10 kb.

This raising of the elastic limit was also observed with other materials, including chlorite, kaolinite, and halloysite. This appears to be a work hardening effect resulting from the crushing and altered packing during the shearing to which the samples have been subjected.

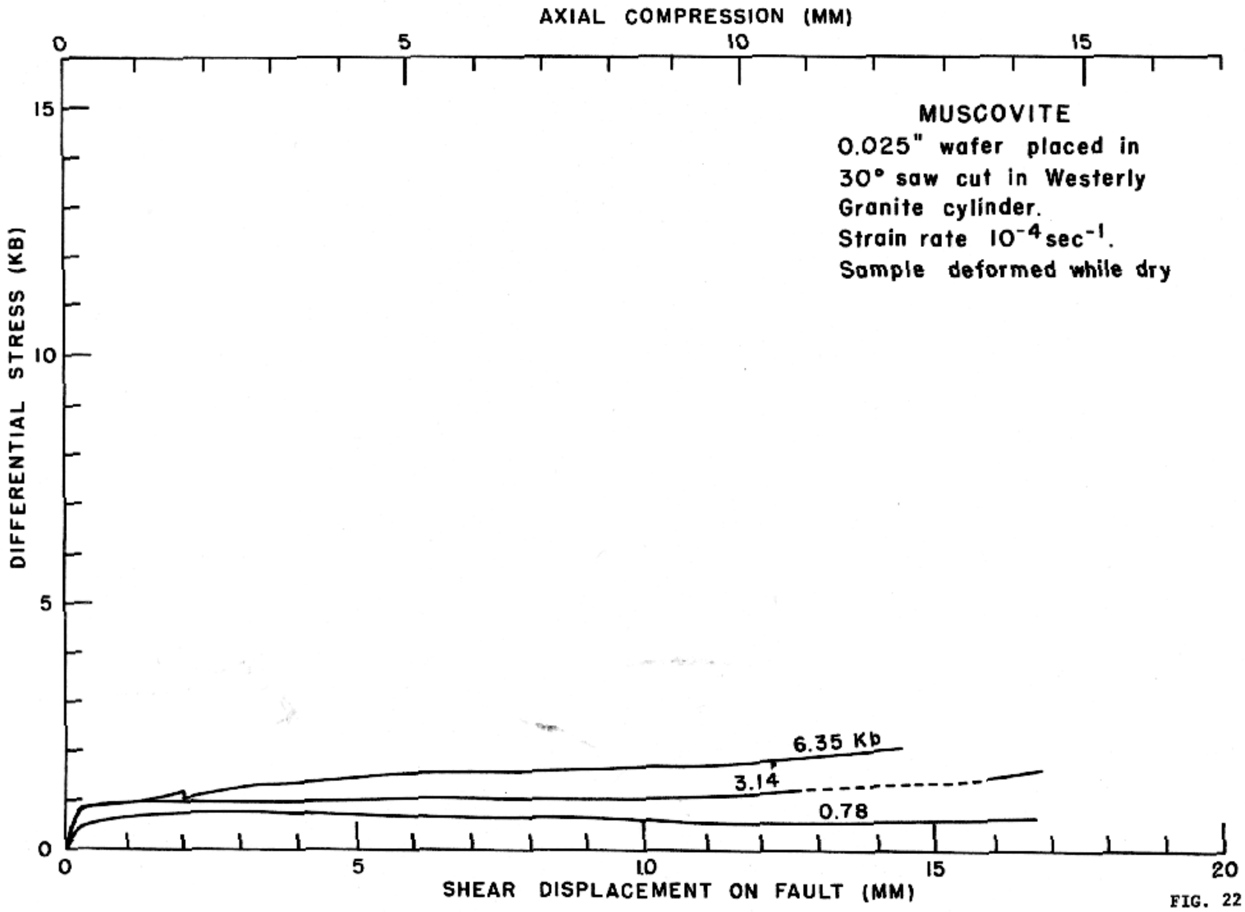

AXIAL COMPRESSION (MM)
0
5
10
15
MUSCOVITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4} sec^{-1}$.
Sample deformed while dry
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.35 Kb
3.14
0.78
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 22

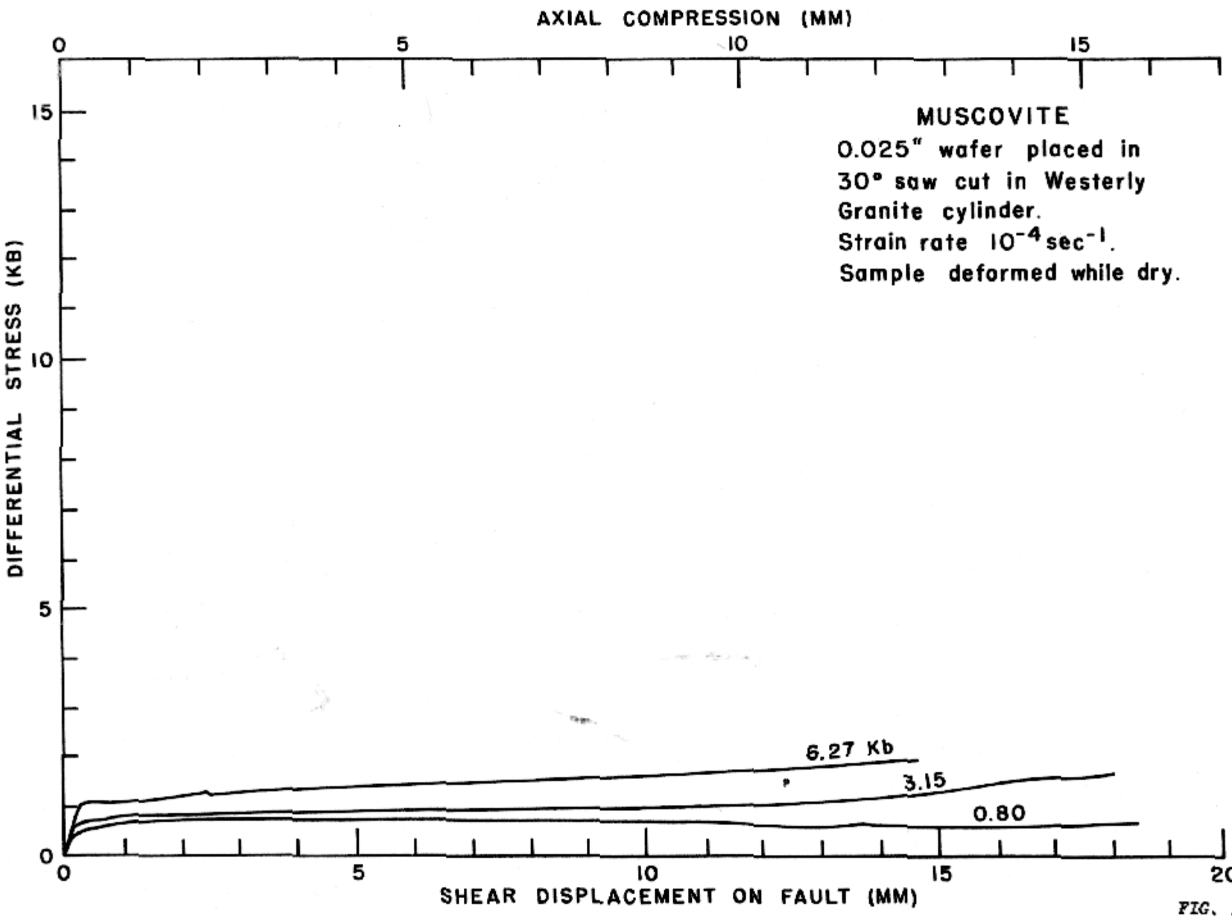

AXIAL COMPRESSION (MM)
0
5
10
15
MUSCOVITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate 10^-4 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.15
0.80
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 23

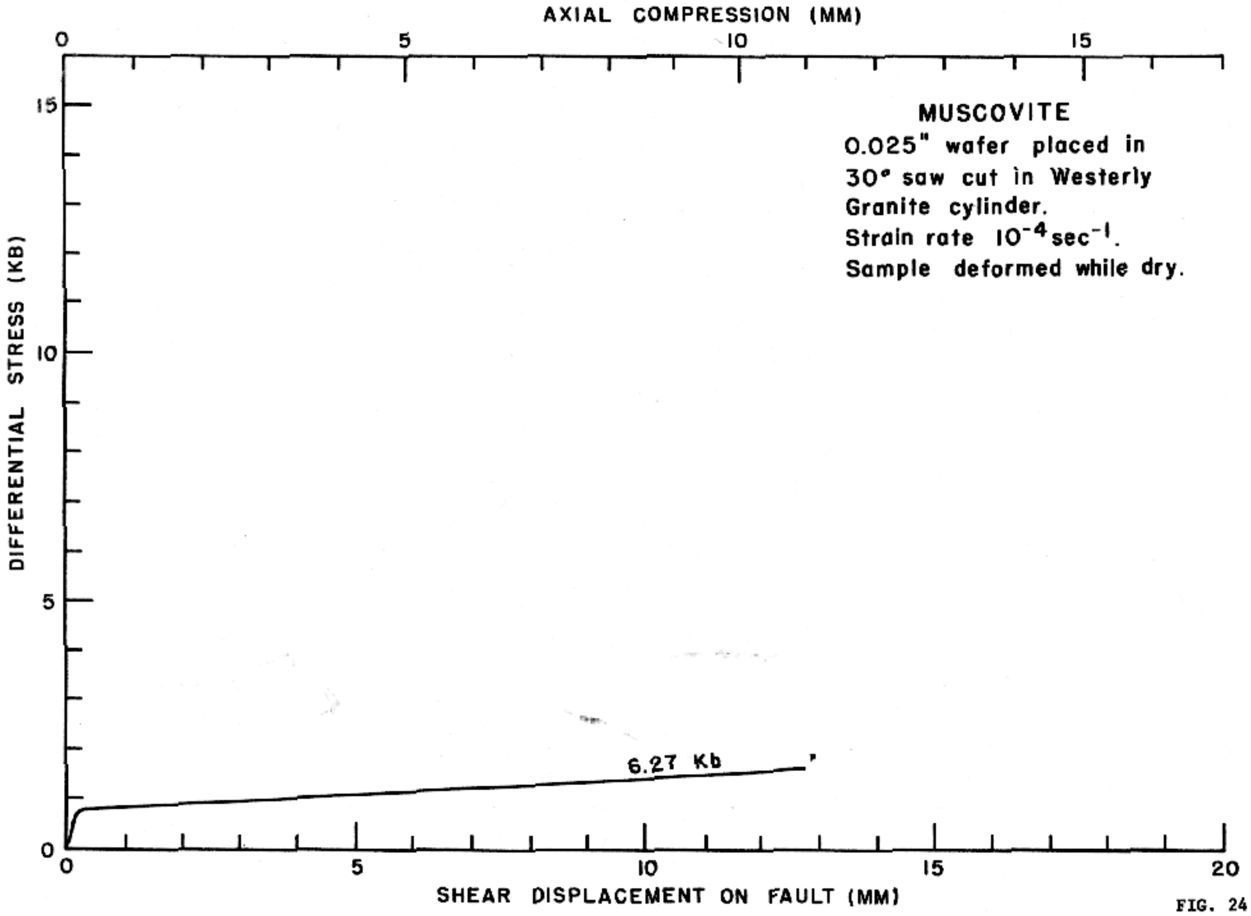

AXIAL COMPRESSION (MM)
0
5
10
15
MUSCOVITE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 24

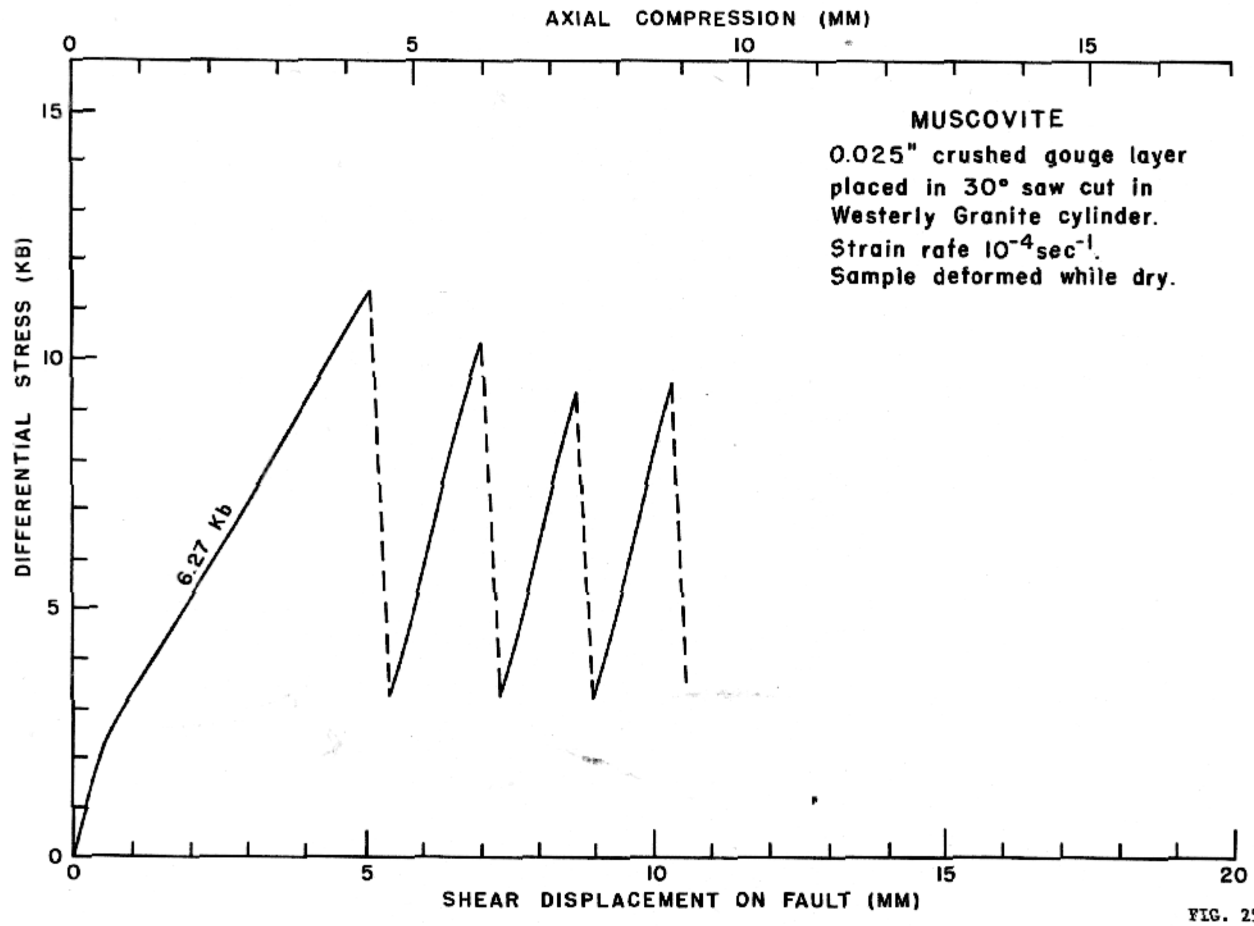

AXIAL COMPRESSION (MM)
0
5
10
15
MUSCOVITE
0.025" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 25

Ottawa Quartz Sand

Fig. 26-57) 0.080" and 0.160" layers of Ottawa Quartz sand (ASTM N°C109) placed in 30° or 45° sawcut in a 1" x 2.5" cylinder of Westerly Granite

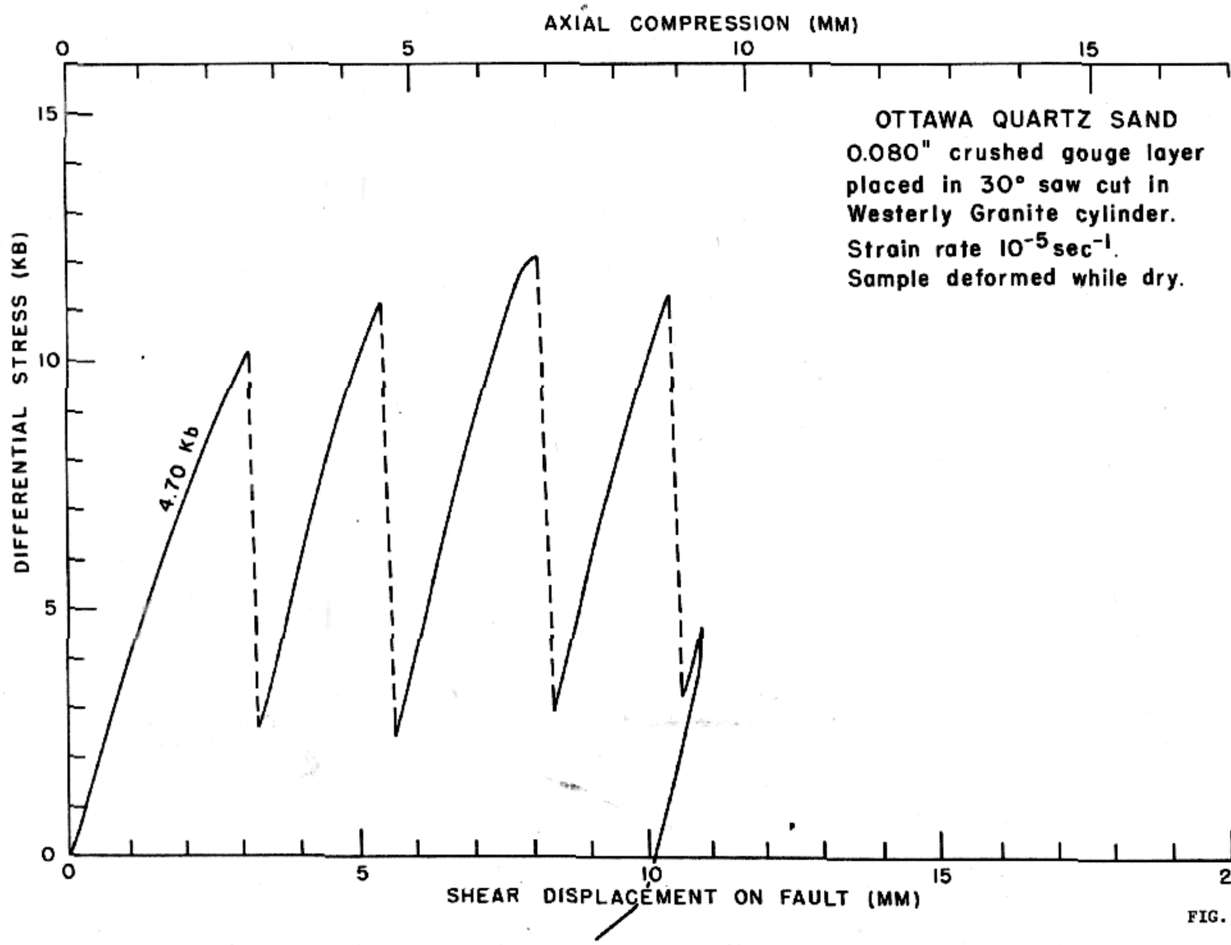
Confining pressures: 2.00, 2.60, and 4.70 kb

Axial compression strain rates: $10^{-5}sec^{-1}$, $10^{-7}sec^{-1}$

Comments:

This series of stress-strain charts was produced during a study of the development of shear structures in an artificial gouge zone. Two thicknesses of gouge were used to investigate their effect on crushing and shearing. The confining pressure was varied to produce stable sliding (at 2.00kb) and stick slip (at 4.70 kb). Most of the samples were used with a 30° fault angle. Two samples were running a 45° fault angle. This was done to determine if the angle of the oblique shear zones that were observed in the gouge were controlled by the fault boundary or by the direction of the maximum principle stress. It was found that the angle of the shears was controlled by the fault boundary.

Thin sections were cut from all of the quartz sand samples to study the shear structures which developed in the gouge zone. The results of this part of the work described in the paper "Structures Developed in Fault Gouge During Stable Sliding and Stick-slip" by J. Byerlee, V. Mjachkin, R. Summer, and O. Voevoda.



AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ $sec^{-1}$.
Sample deformed while dry.
4.70 Kb
DIFFERENTIAL STRESS (KB)
15
10
5
0
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 26

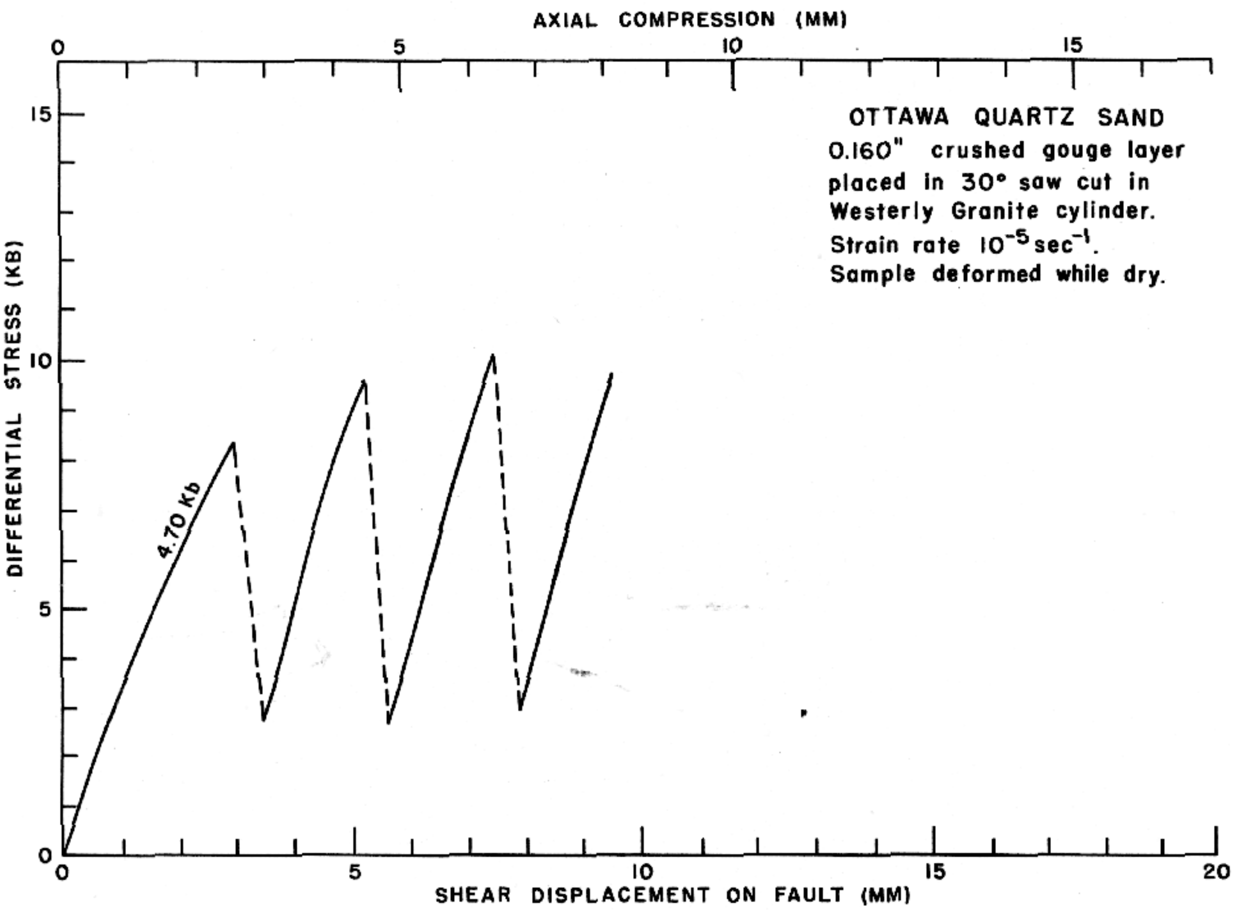

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 27

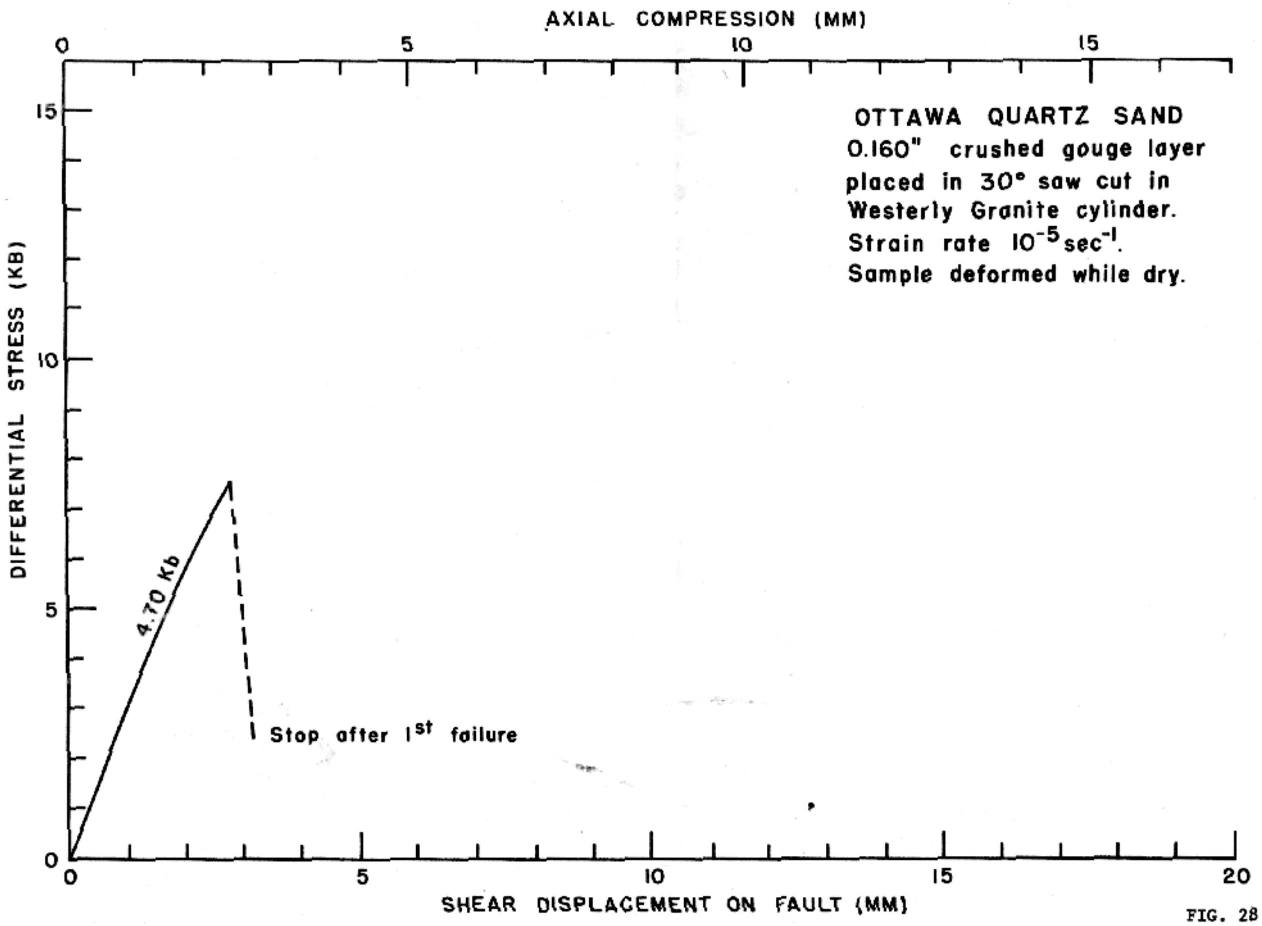

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
Stop after 1st failure
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 28

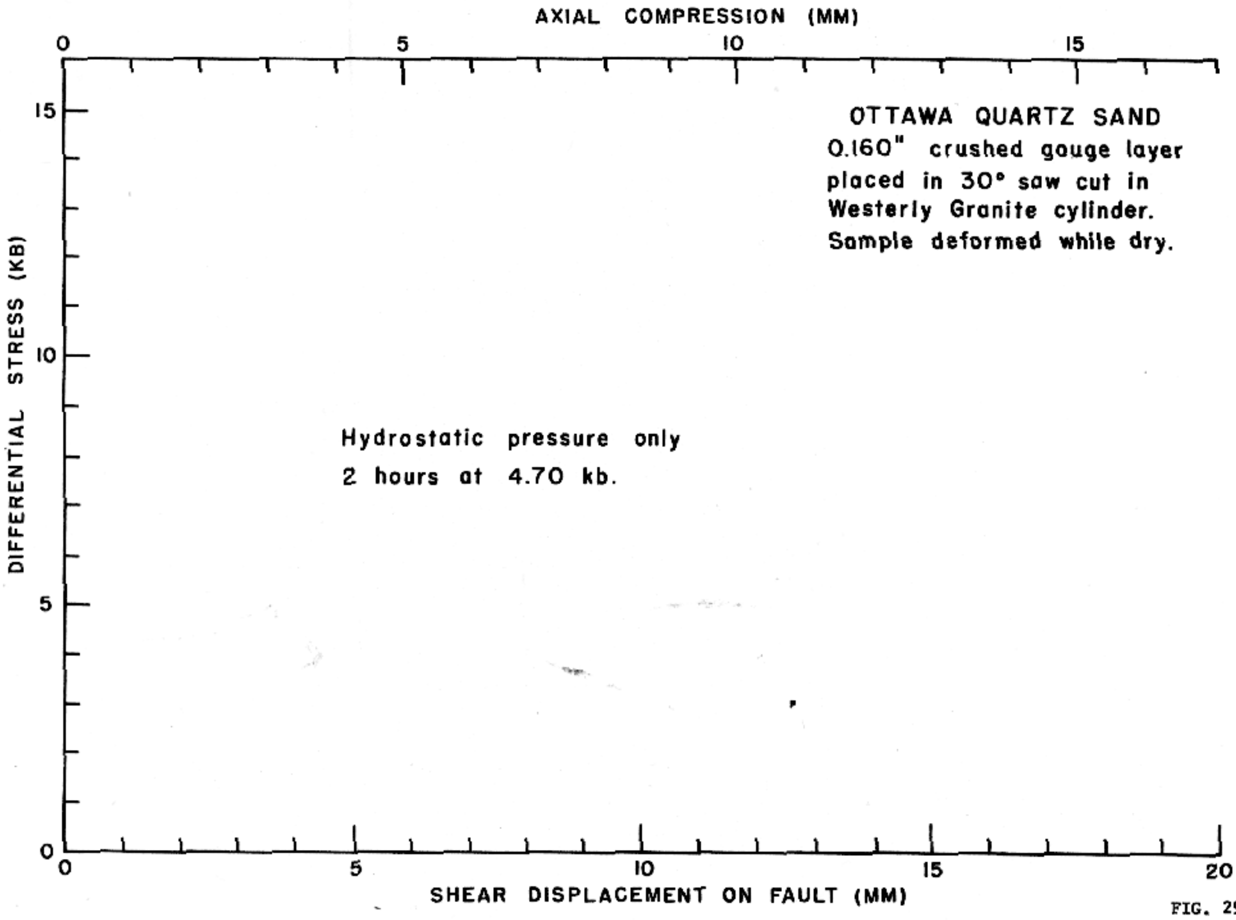

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Sample deformed while dry.
Hydrostatic pressure only
2 hours at 4.70 kb.
DIFFERENTIAL STRESS (KB)
15
10
5
0
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 29

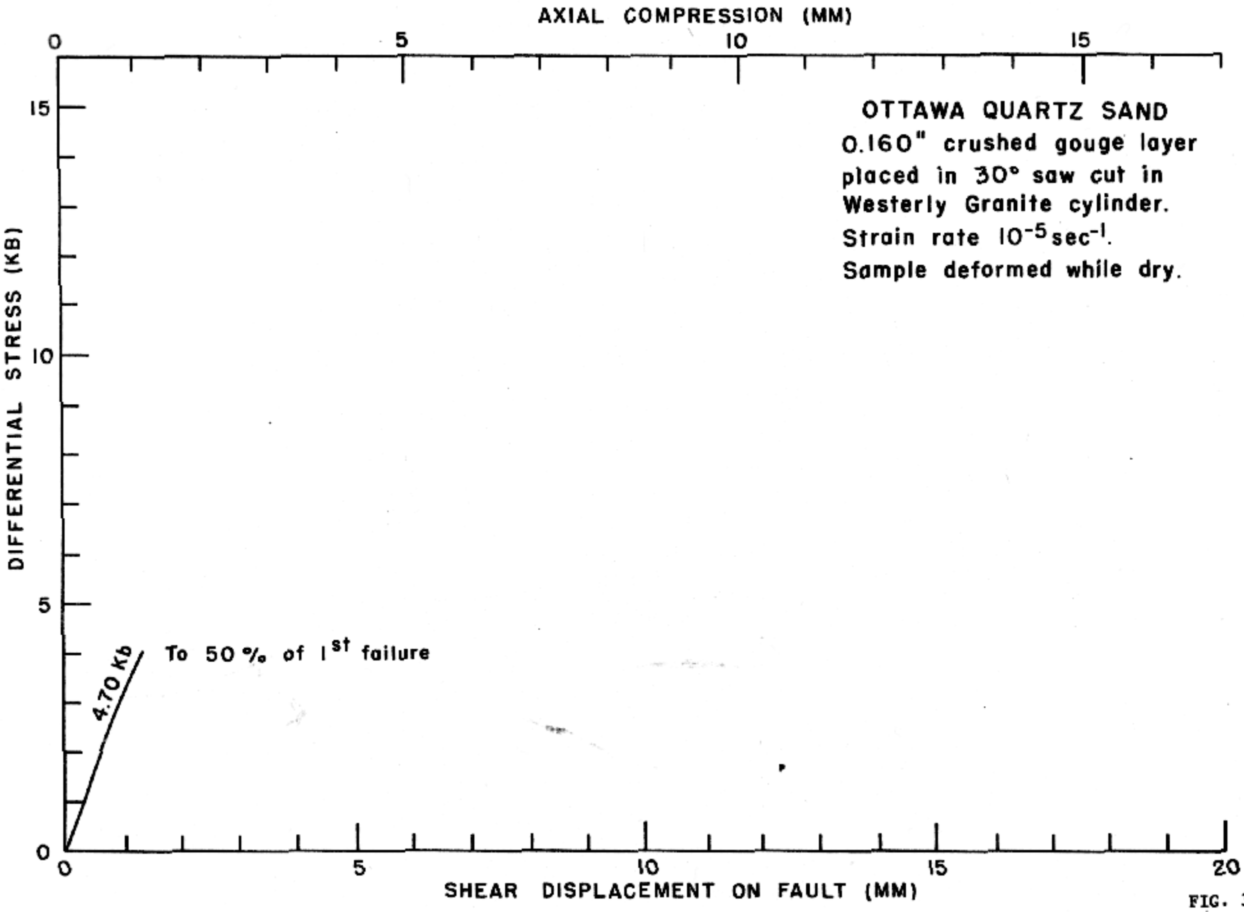
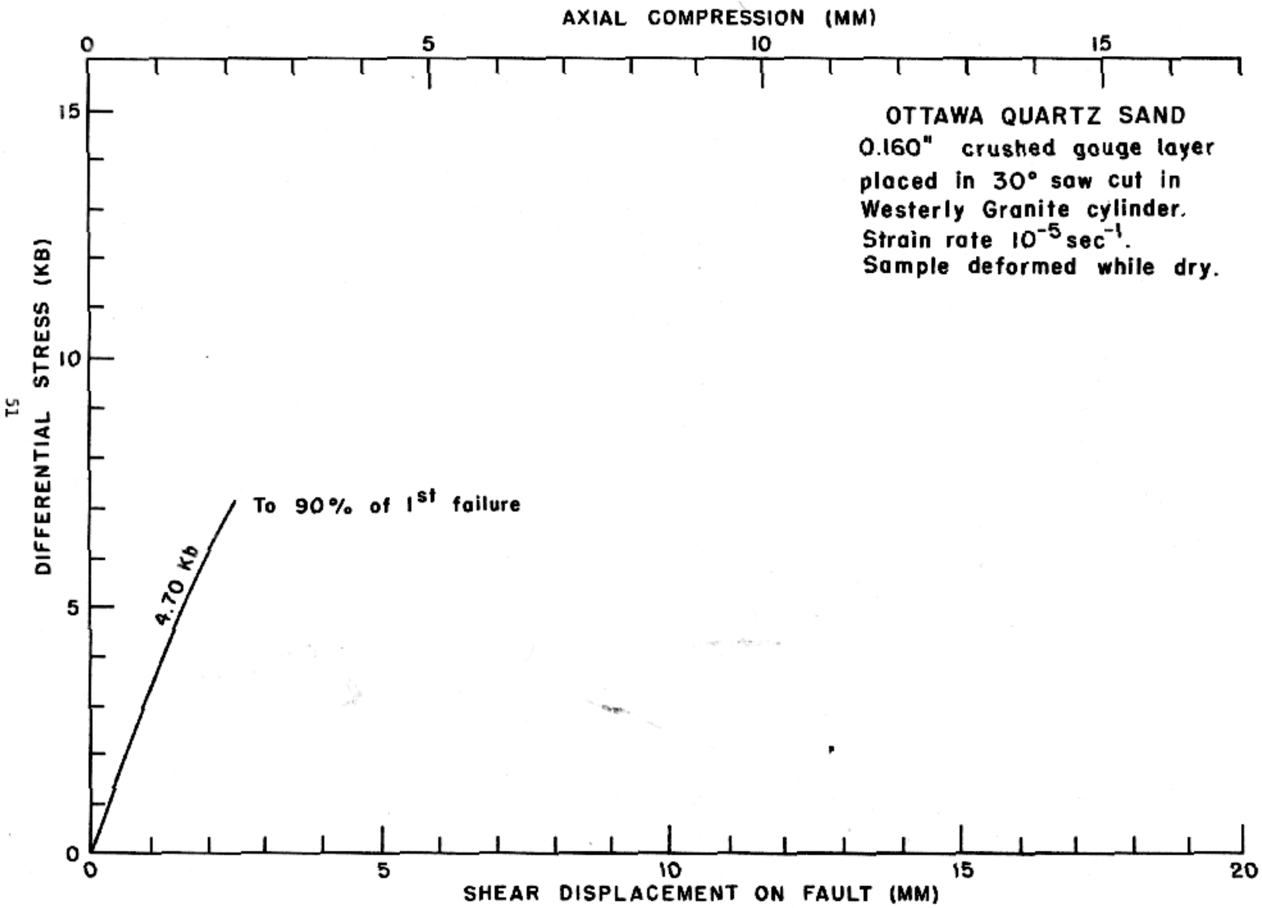

AXIAL COMPRESSION (MM)
0
5
10
15
15
10
5
0
DIFFERENTIAL STRESS (KB)
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
4.70 Kb
To 50 % of 1st failure
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 30



AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate 10^-5 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
To 90% of 1st failure
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 31

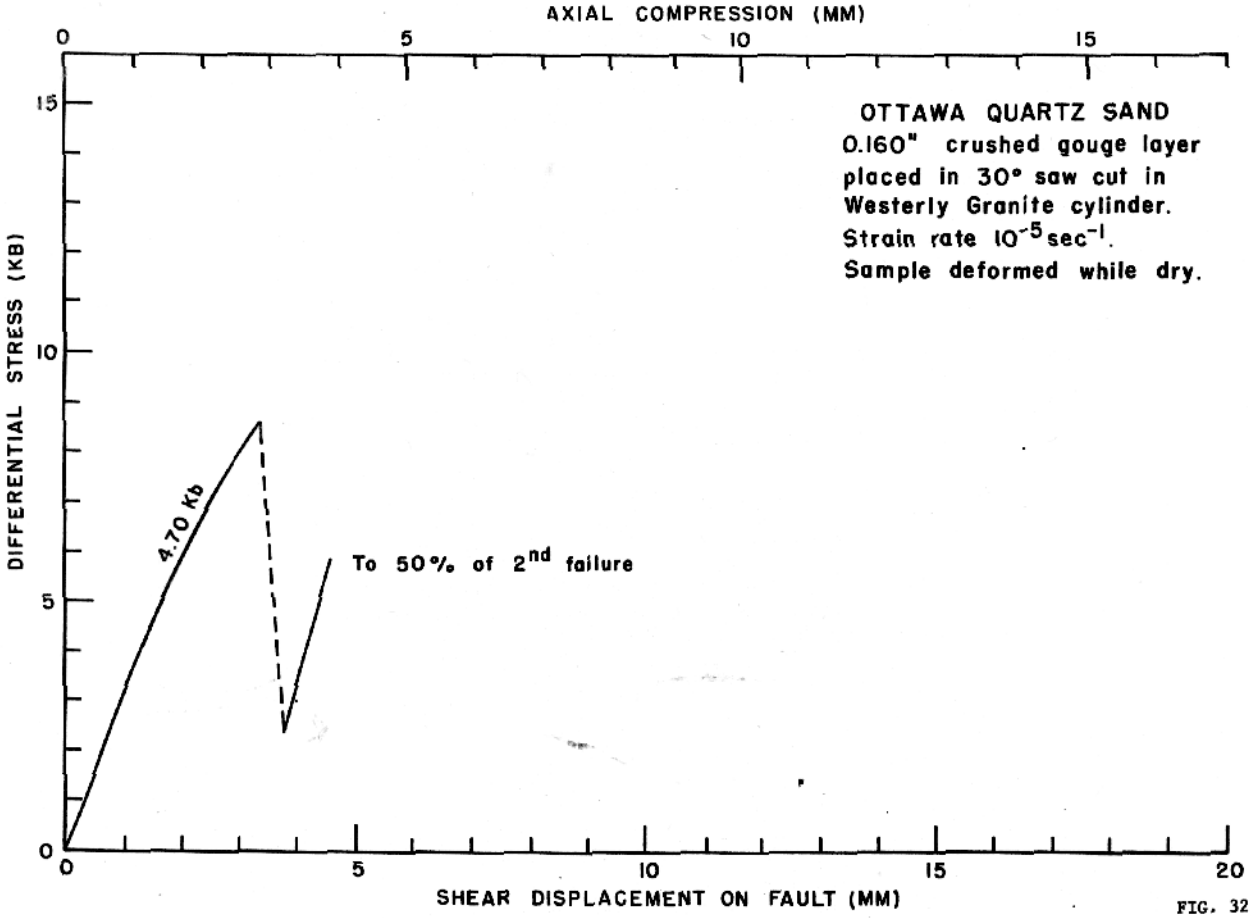

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
To 50% of 2nd failure
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 32

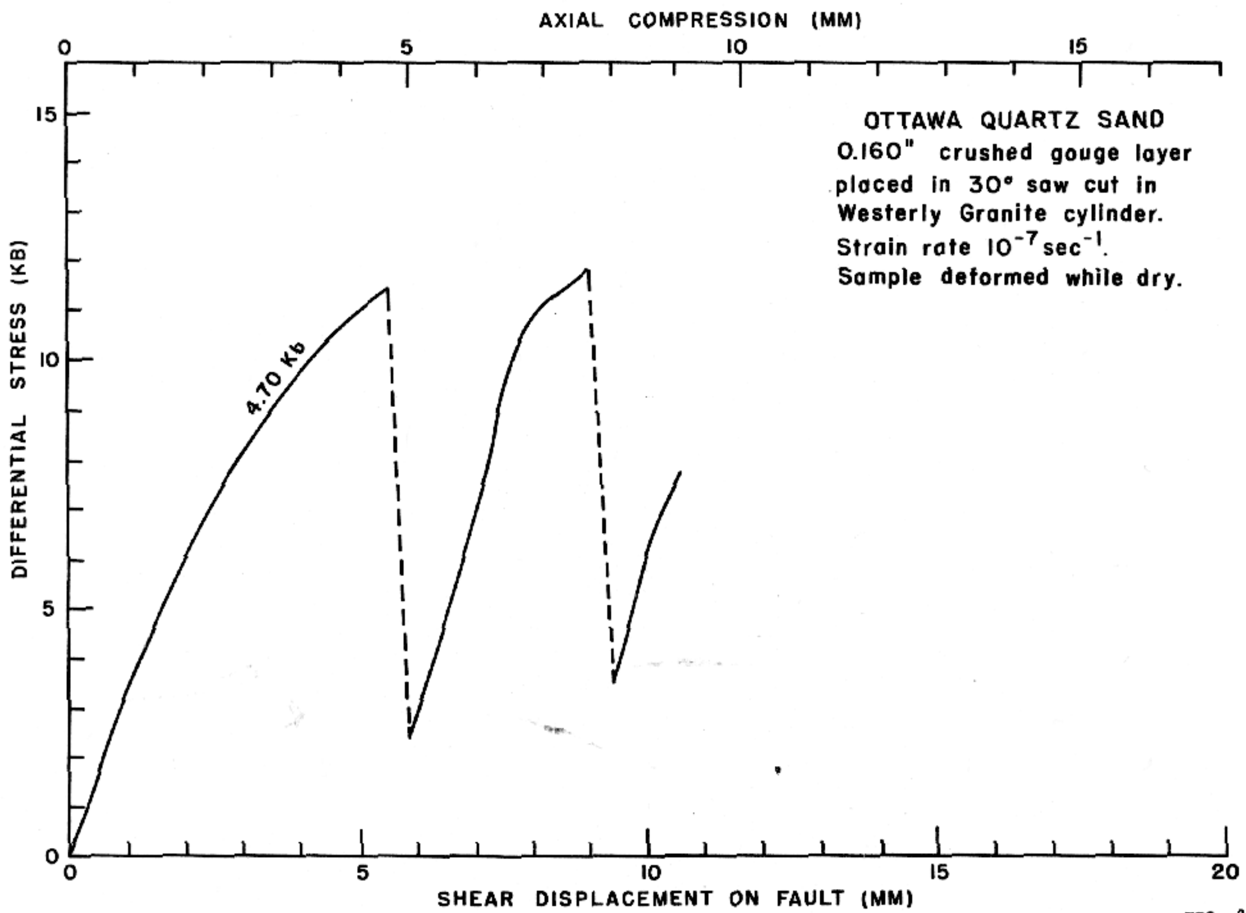
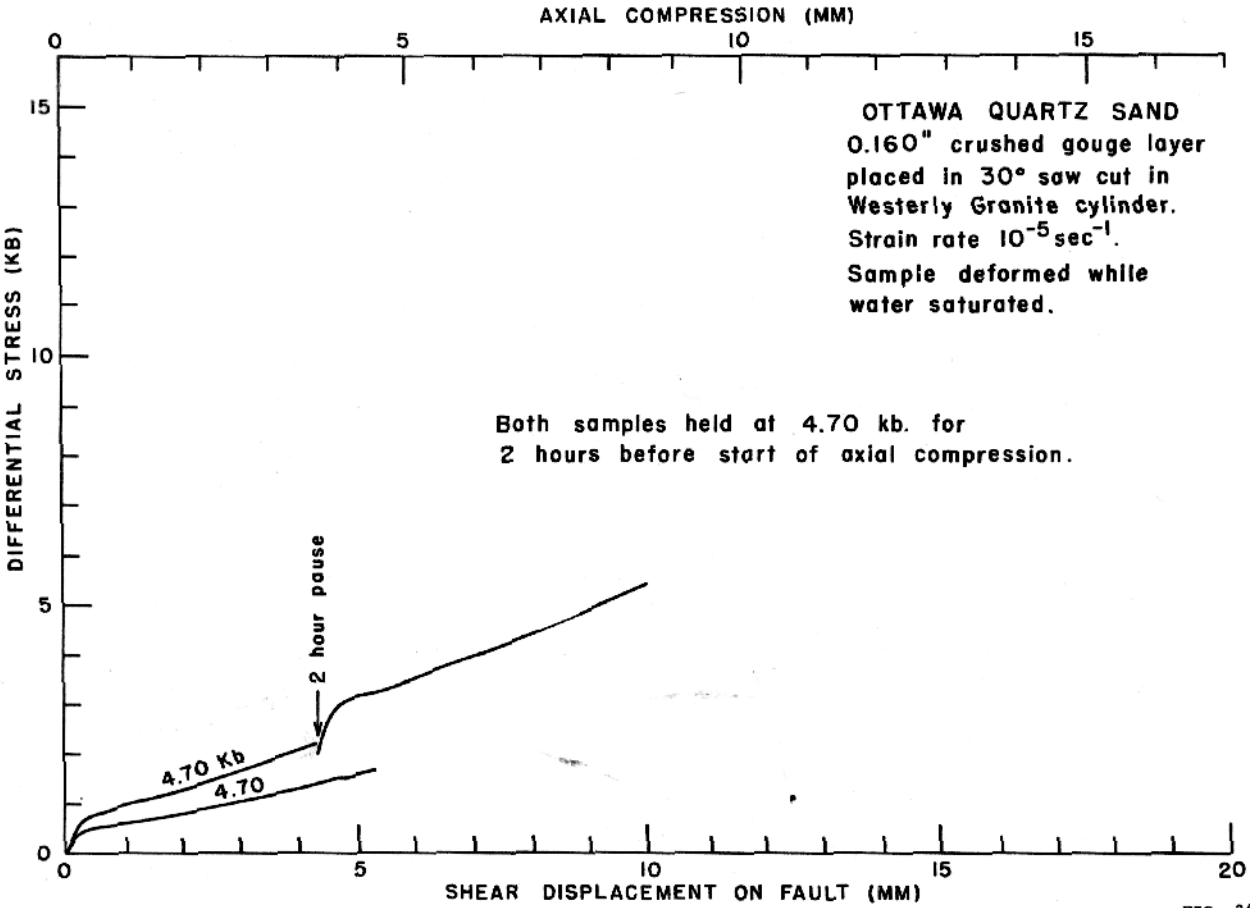

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-7}$ sec$^{-1}$. Sample deformed while dry.
4.70 Kb
DIFFERENTIAL STRESS (KB)
15
10
5
0
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 33

54



AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while water saturated.
Both samples held at 4.70 kb. for 2 hours before start of axial compression.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2 hour pause
4.70 Kb
4.70
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 34

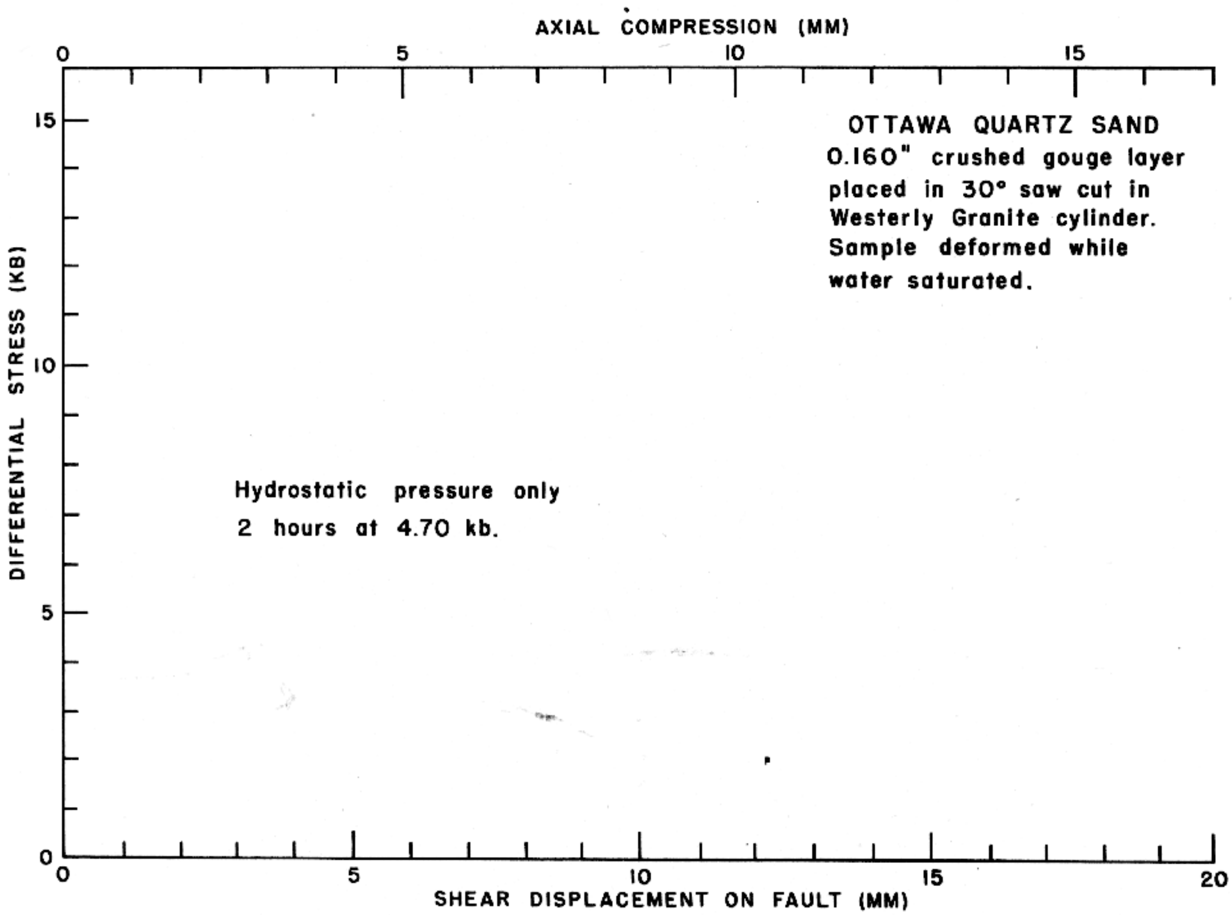

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Sample deformed while water saturated.
DIFFERENTIAL STRESS (KB)
15
10
5
0
Hydrostatic pressure only
2 hours at 4.70 kb.
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 35

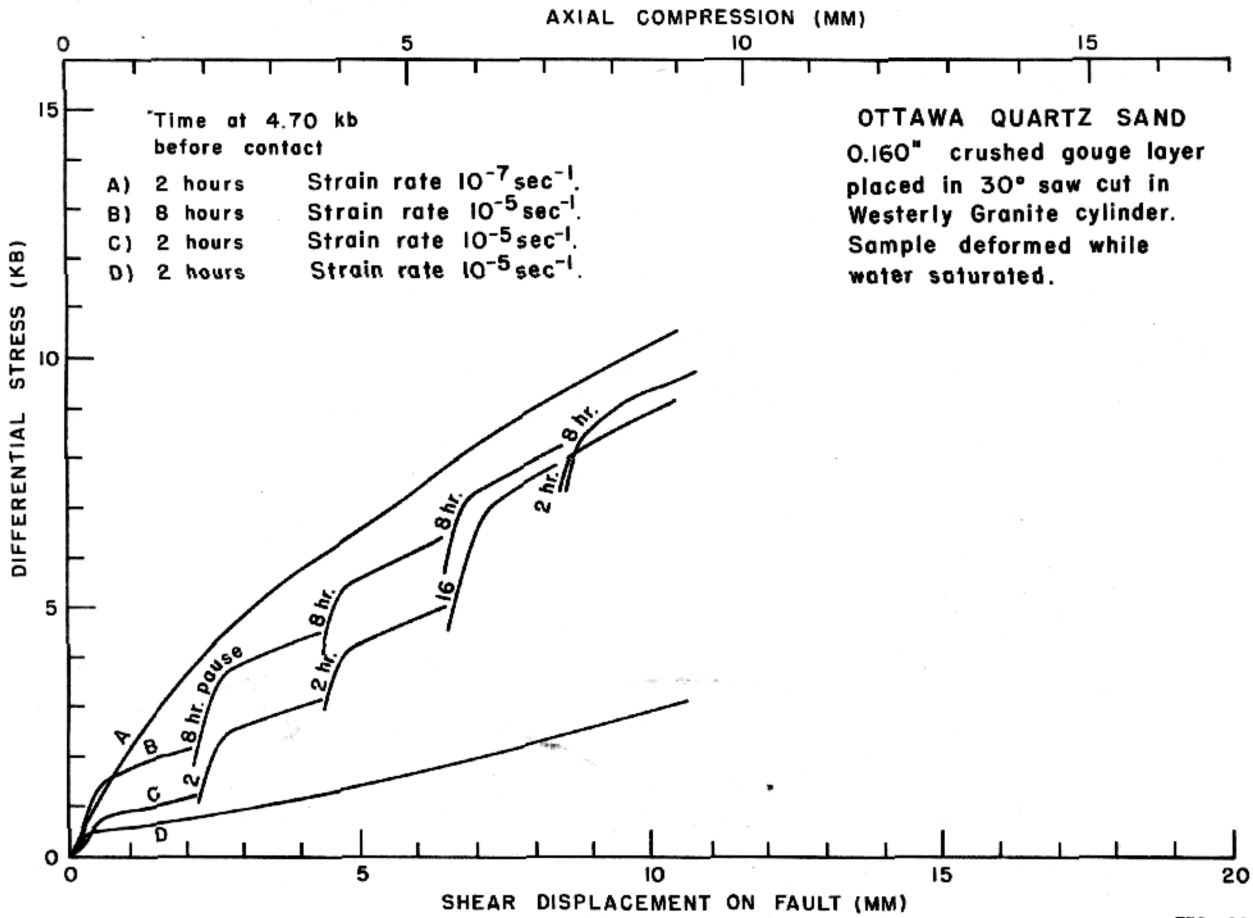

AXIAL COMPRESSION (MM)
0
5
10
15
15
10
5
0
DIFFERENTIAL STRESS (KB)
*Time at 4.70 kb
before contact
A) 2 hours Strain rate $10^{-7}$ sec$^{-1}$.
B) 8 hours Strain rate $10^{-5}$ sec$^{-1}$.
C) 2 hours Strain rate $10^{-5}$ sec$^{-1}$.
D) 2 hours Strain rate $10^{-5}$ sec$^{-1}$.
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Sample deformed while
water saturated.
A
B
C
D
8 hr. pause
2
8 hr.
2 hr.
8 hr.
16
2 hr.
8 hr.
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 36

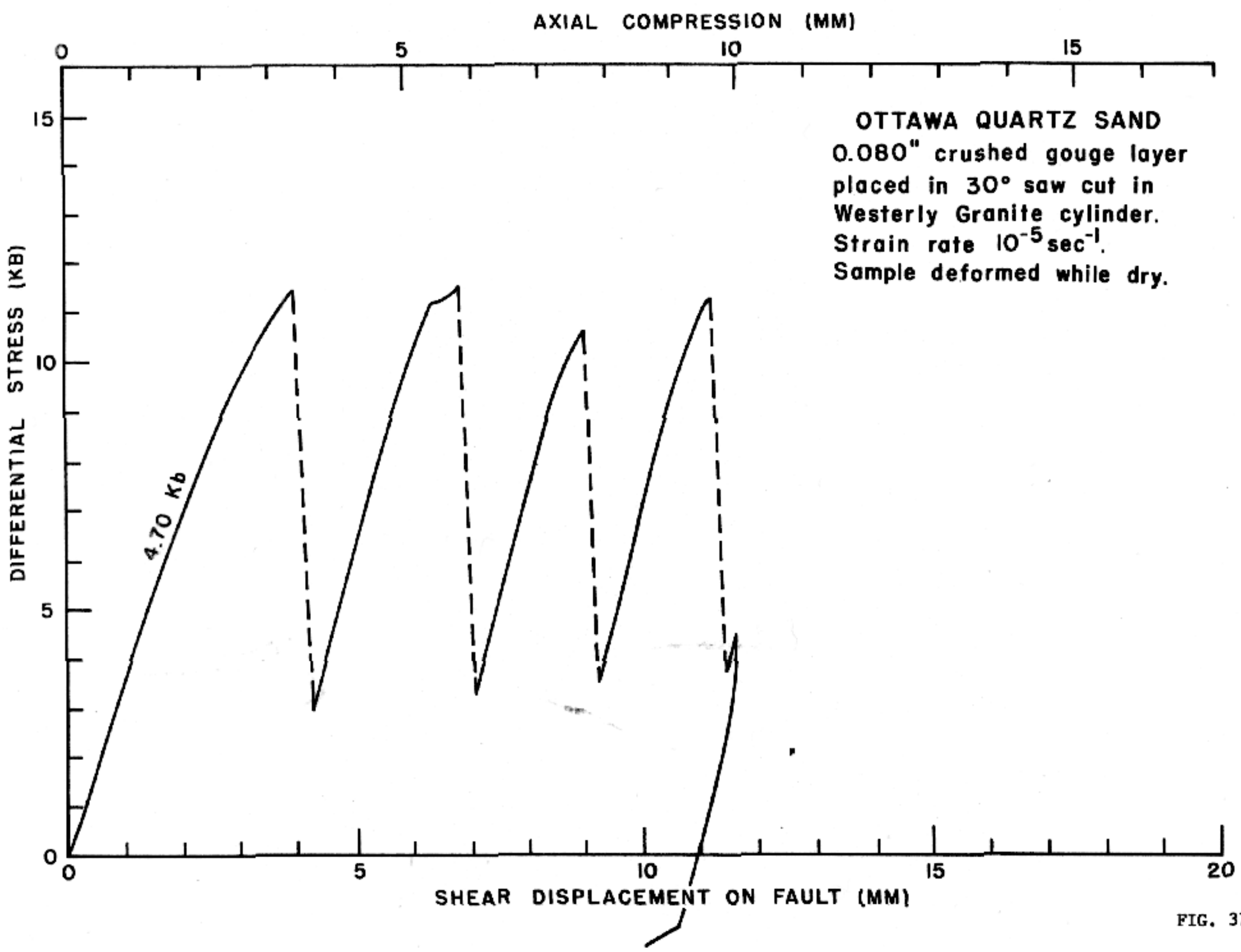

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 37

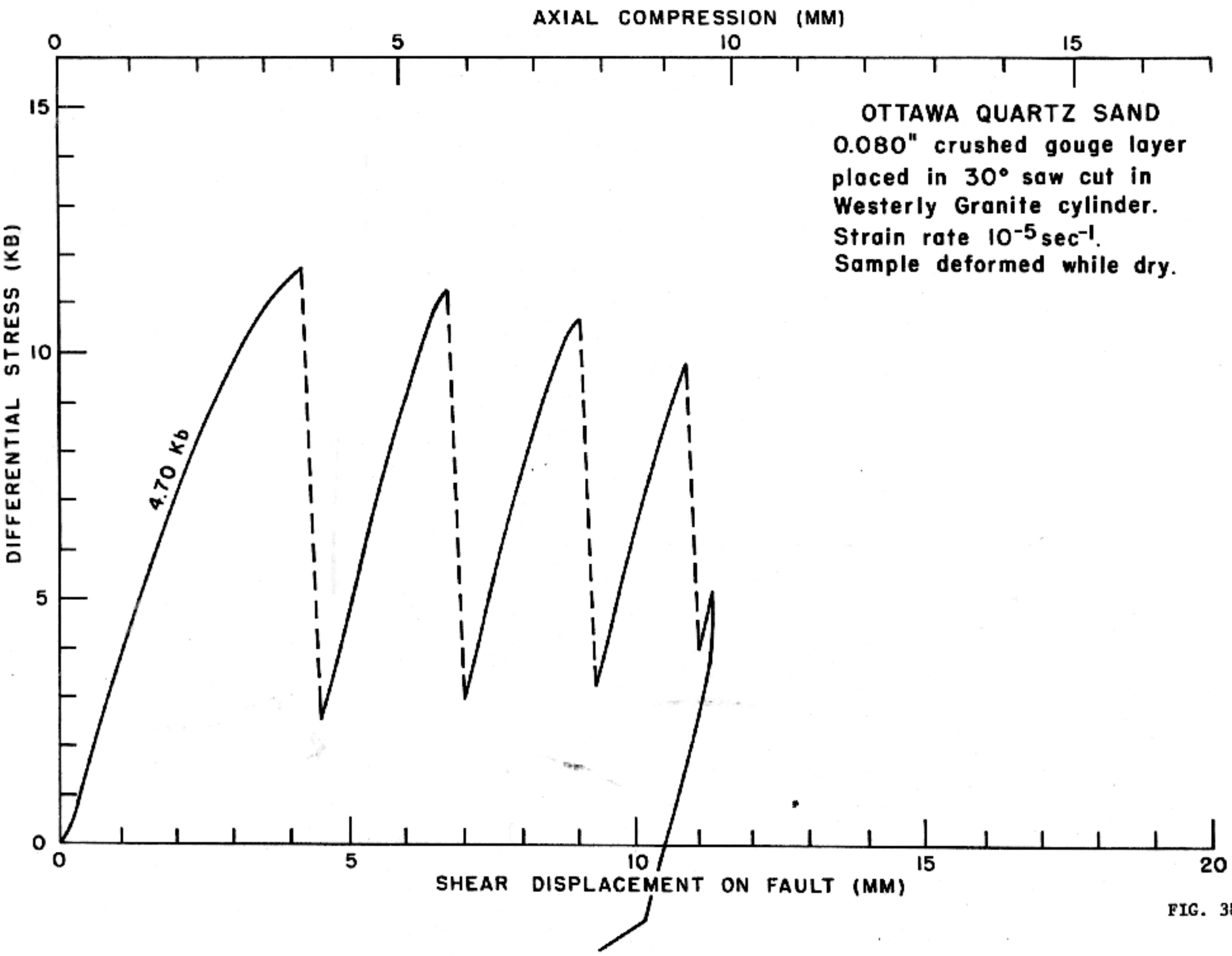

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 38

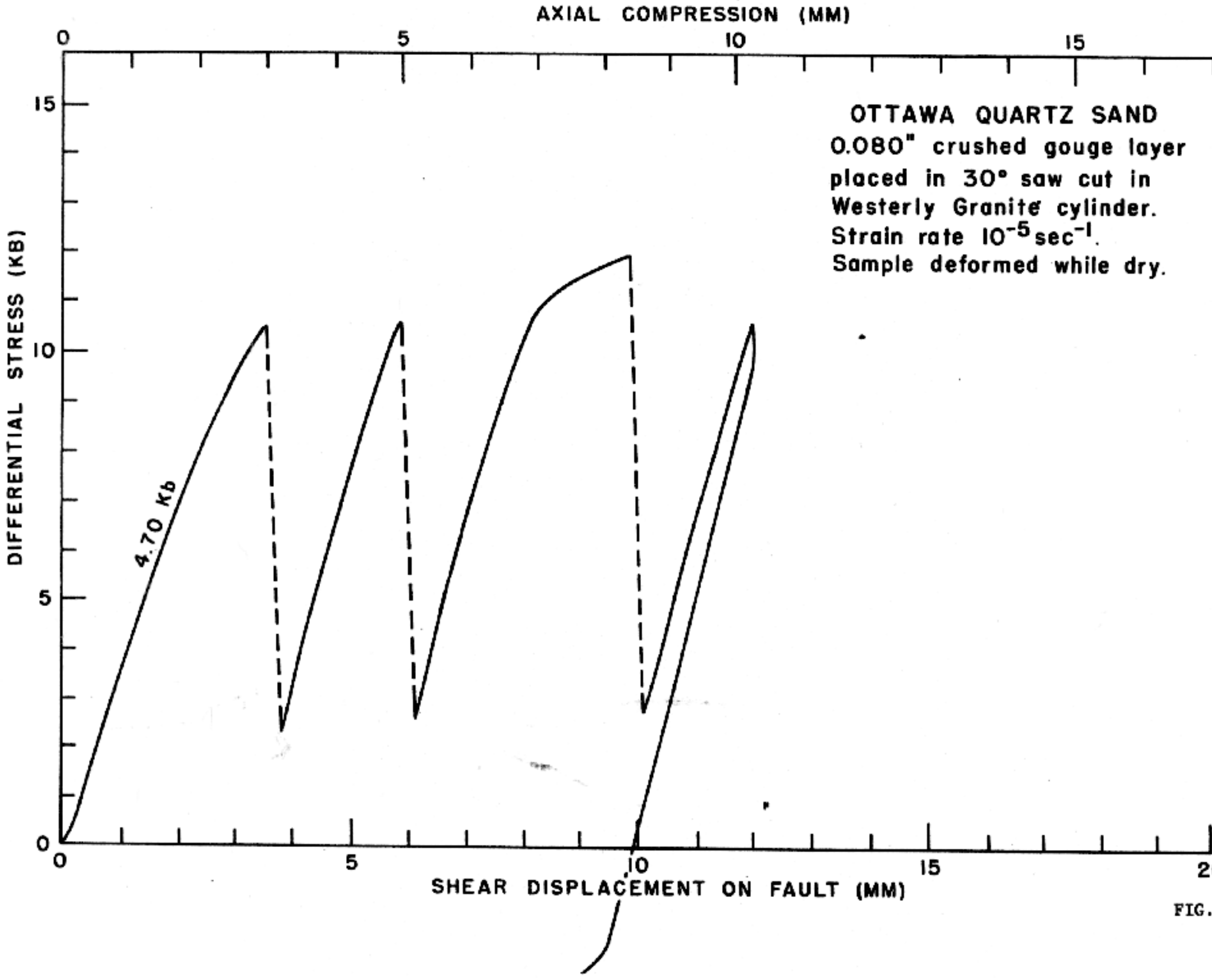

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 39

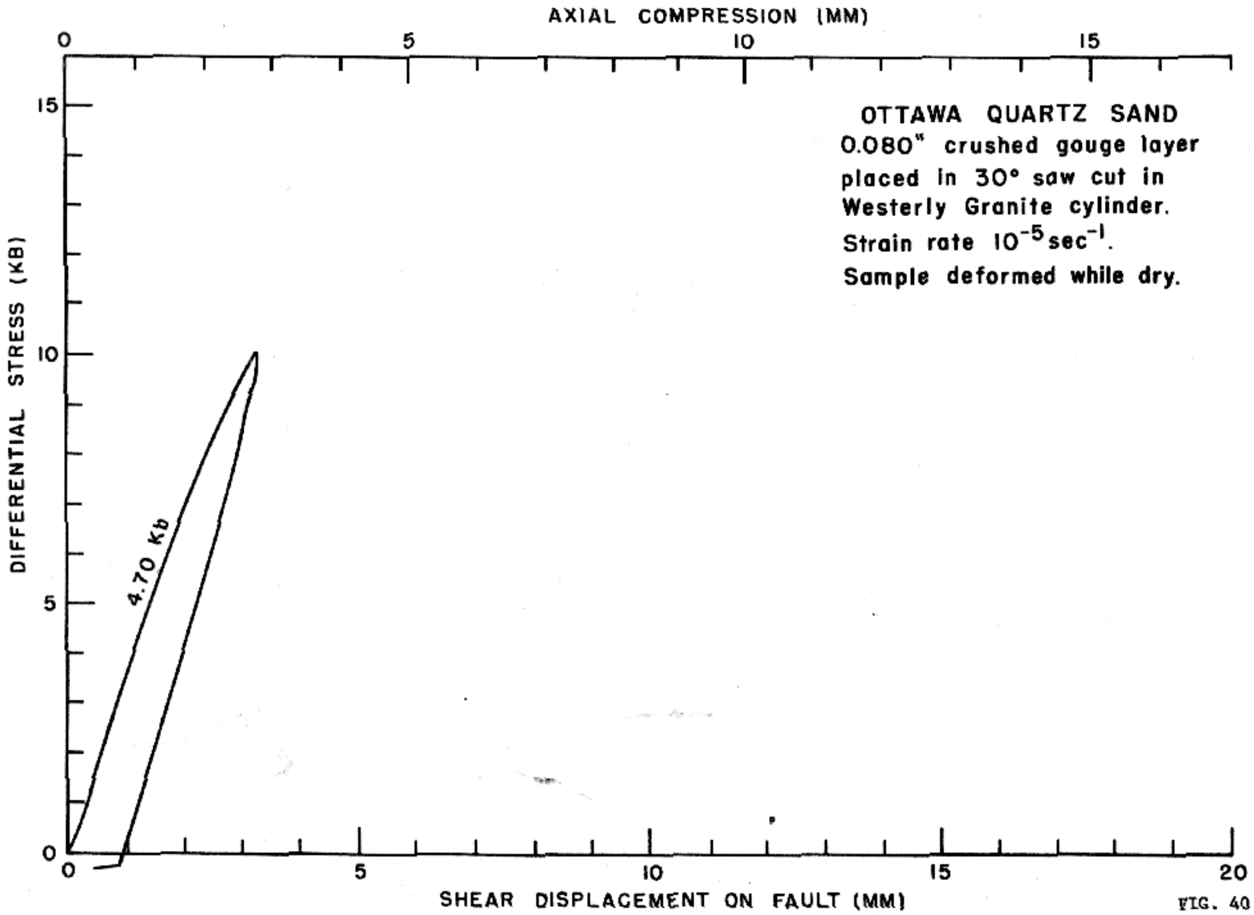

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 40

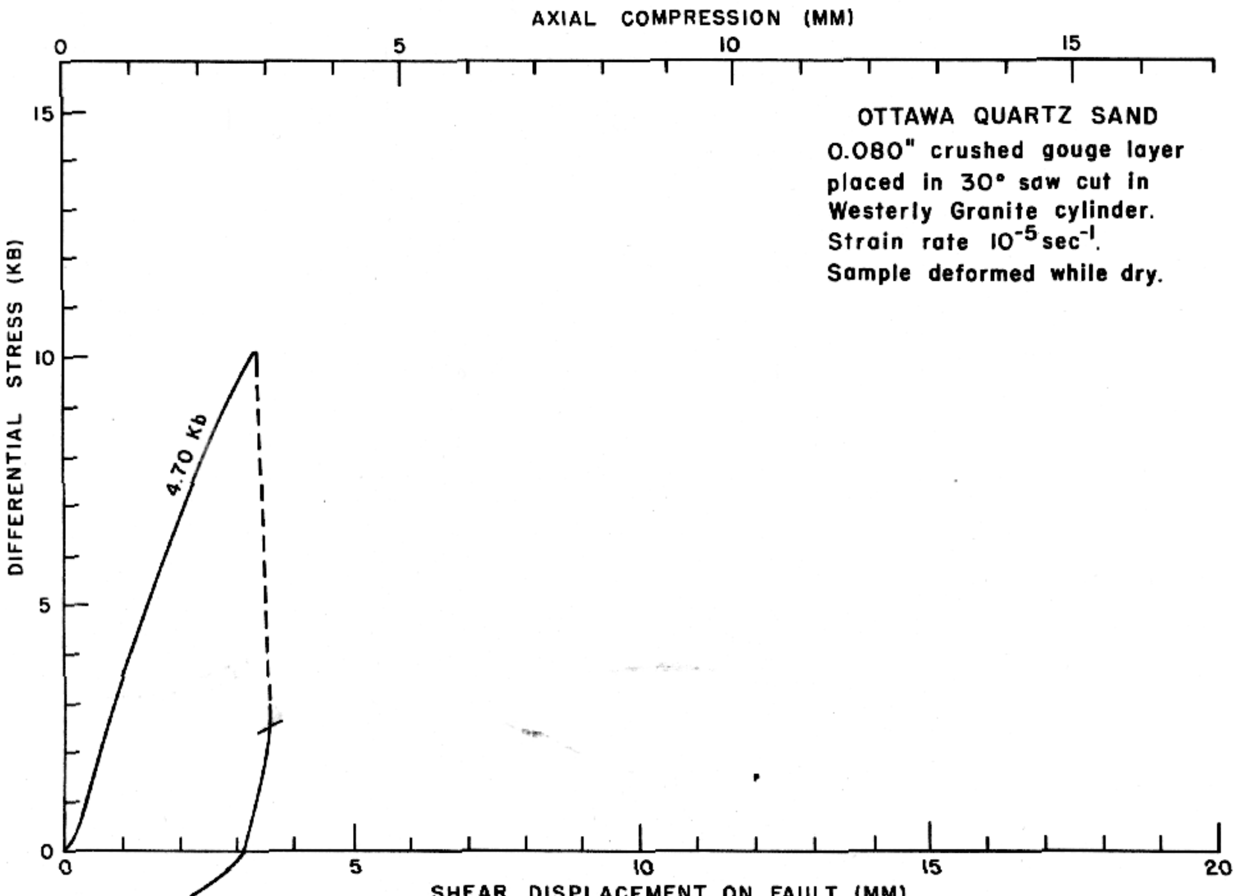

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ $sec^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 41

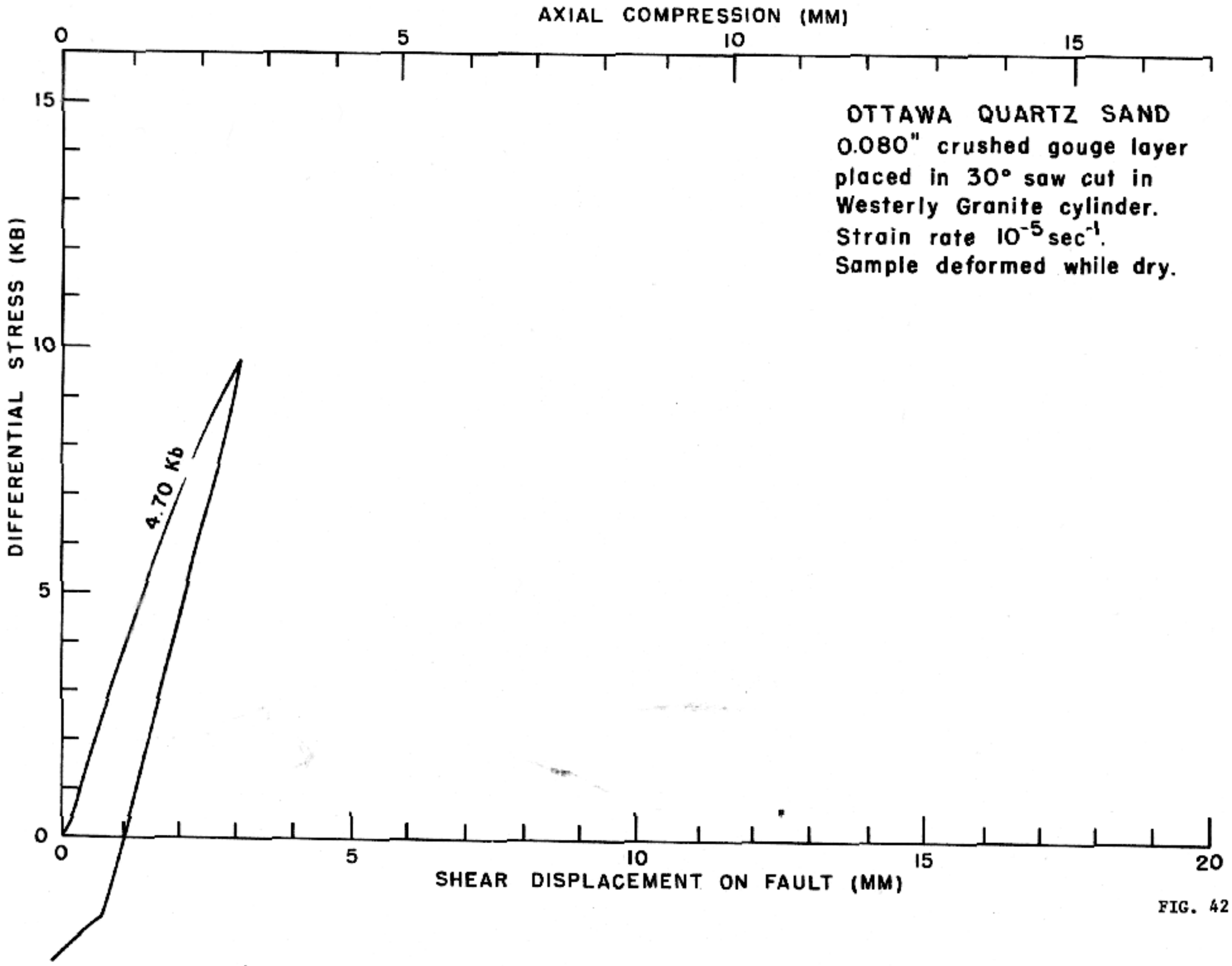

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 42

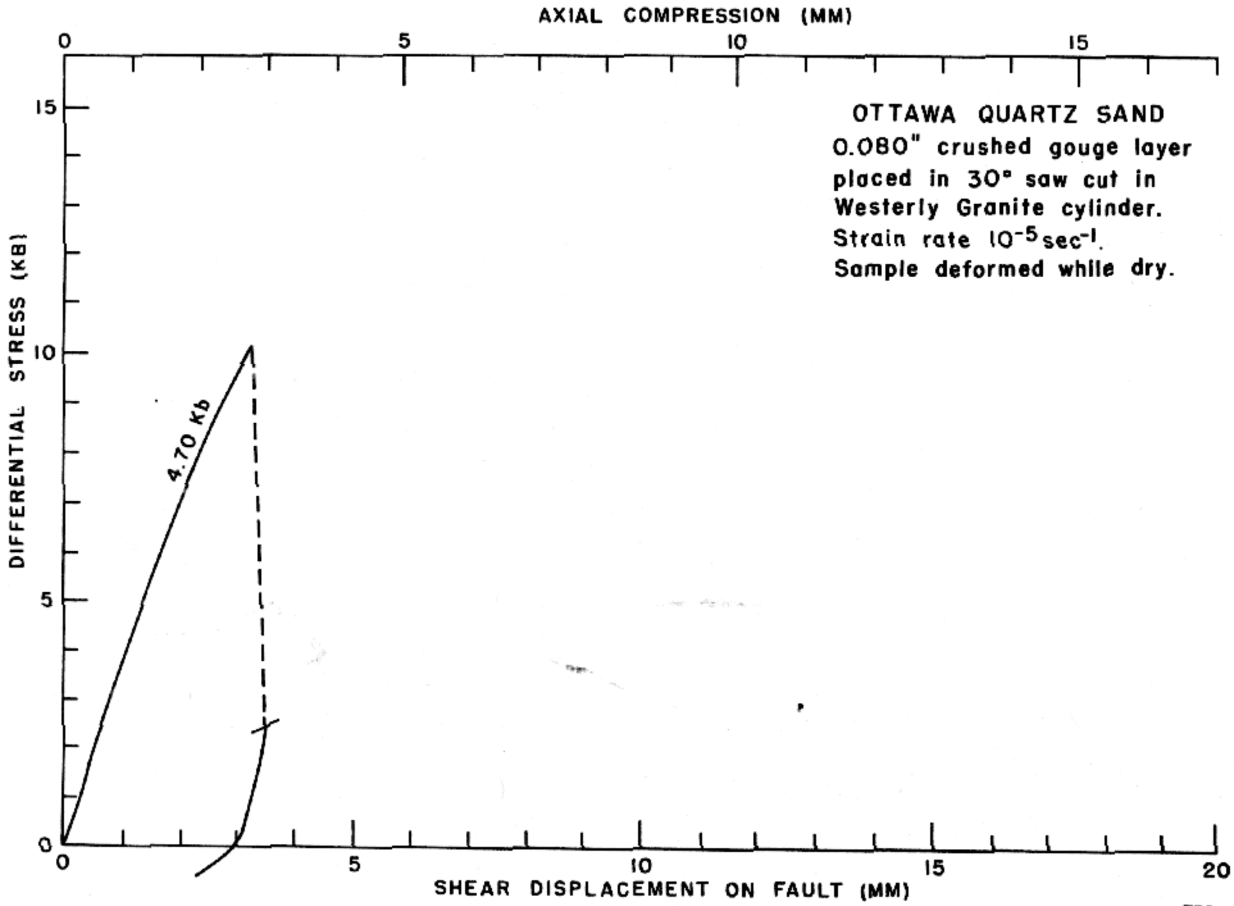

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.080" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 43

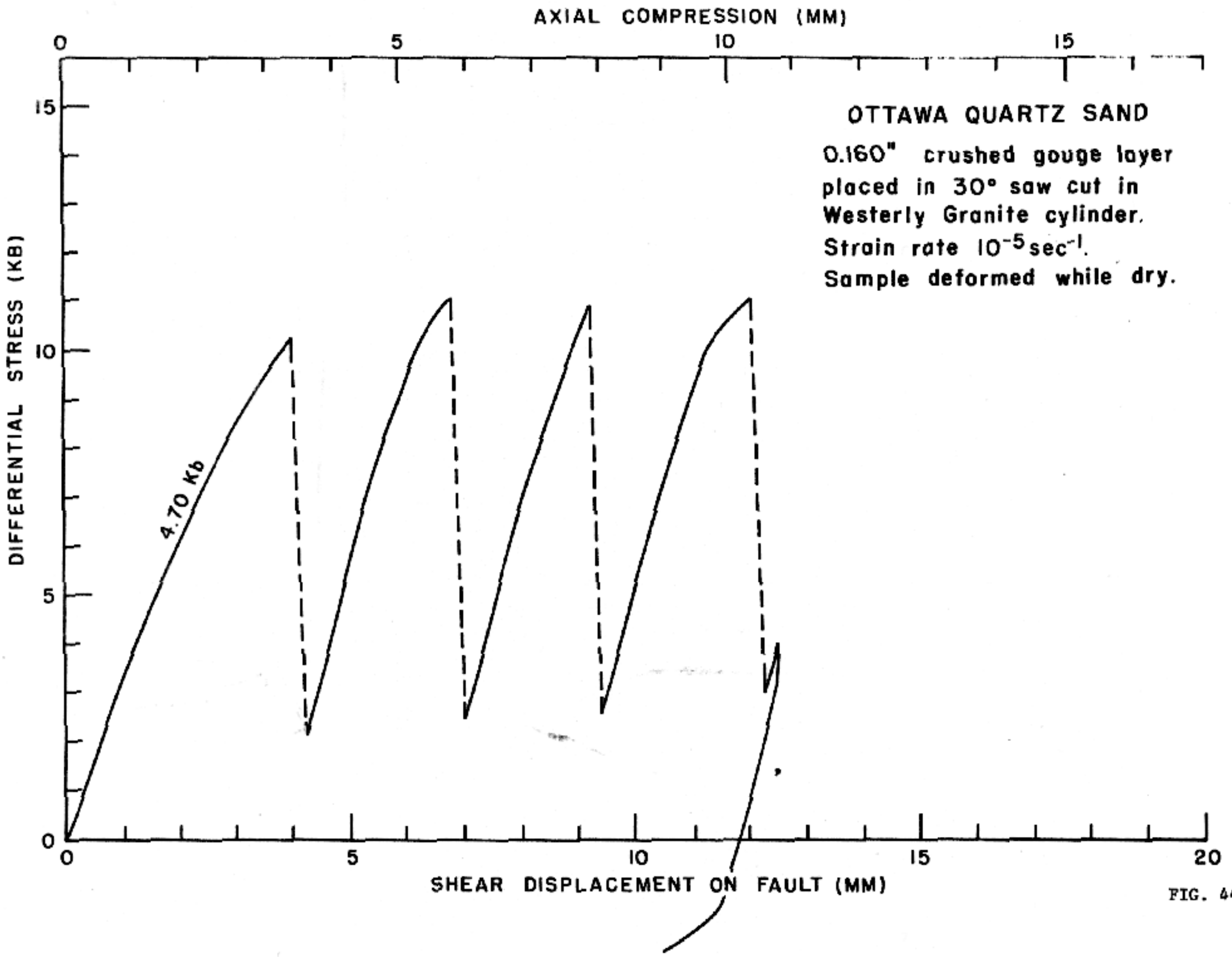
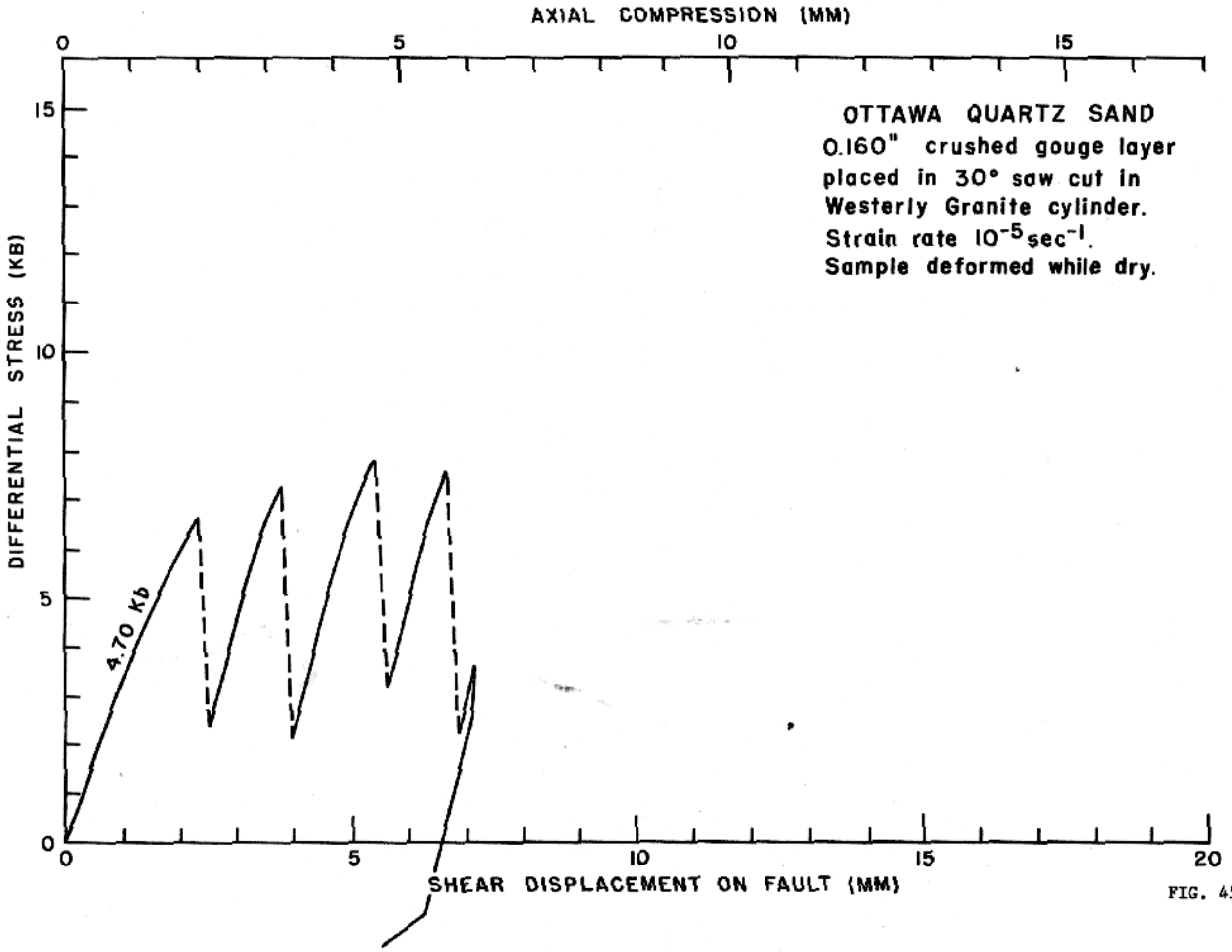

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 44



AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 45

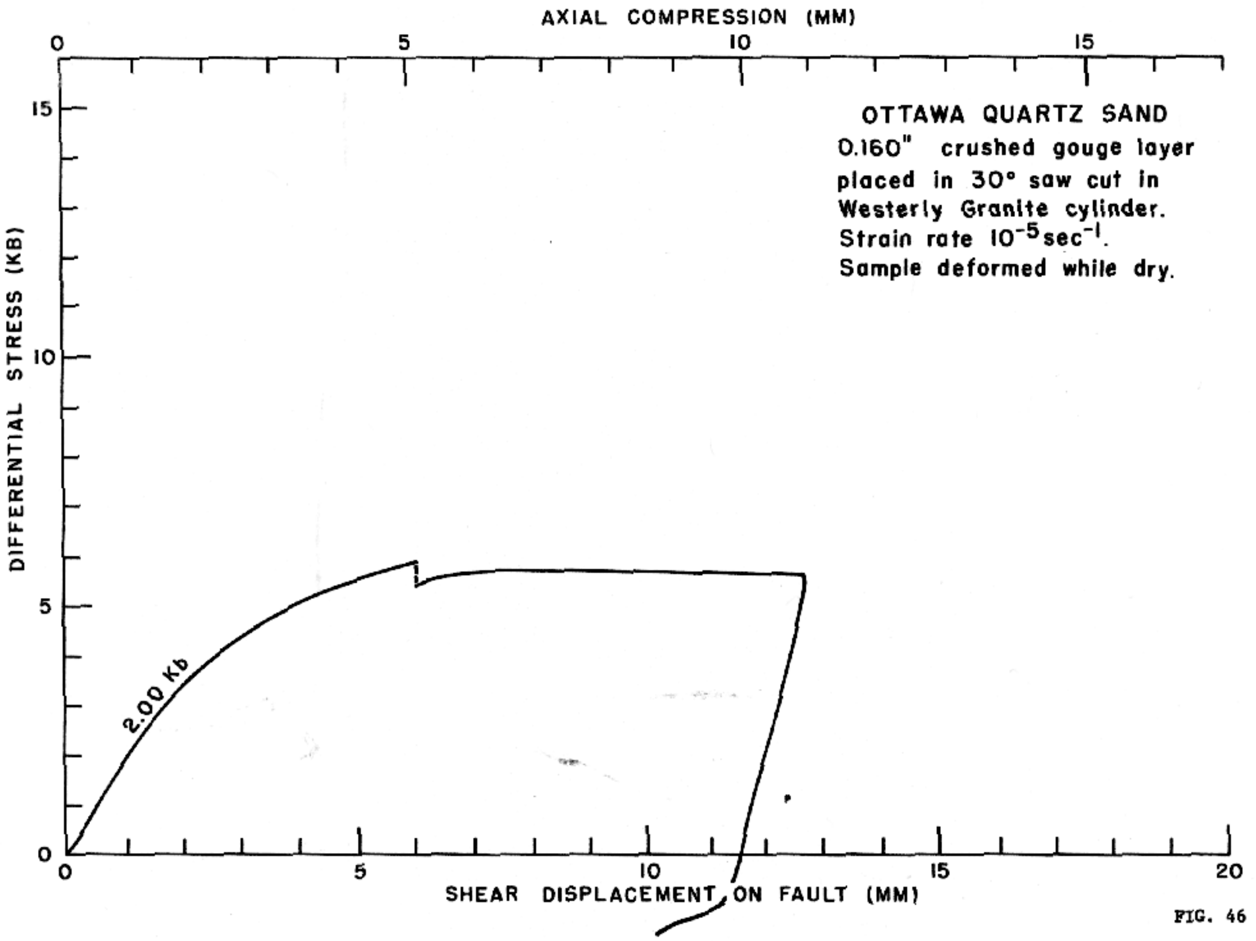

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
0
5
10
15
2.00 Kb
SHEAR DISPLACEMENT ON FAULT (MM)
20

FIG. 46

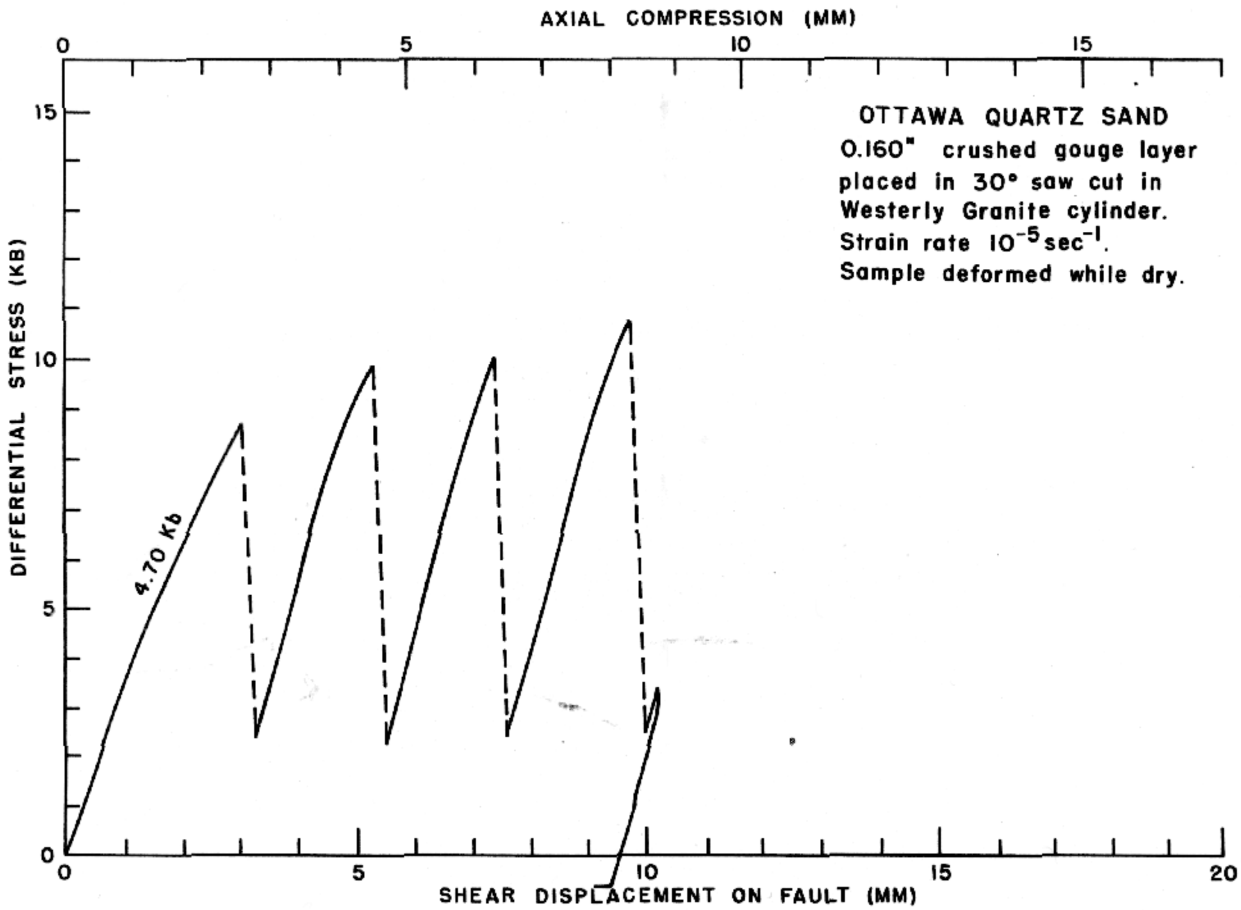
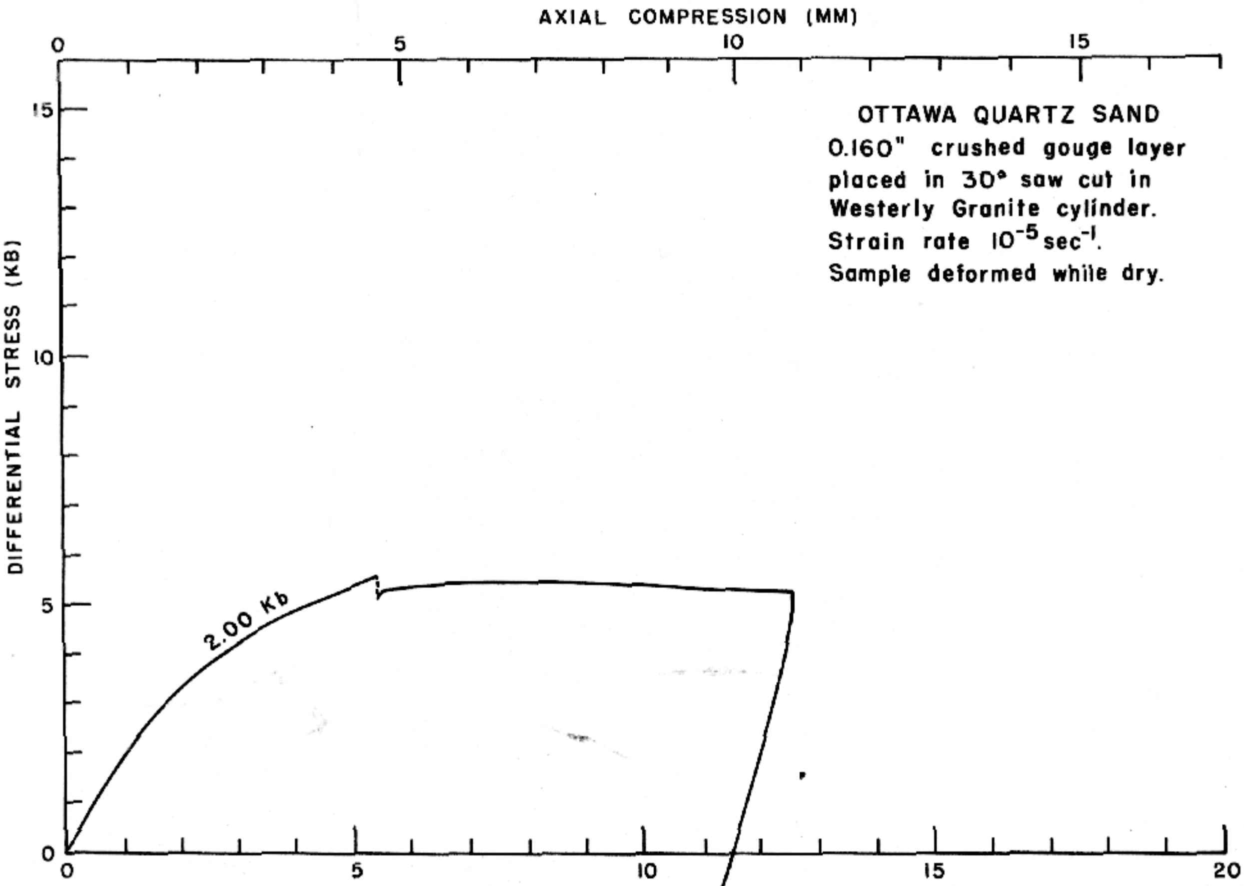

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 47



AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate 10^-5 sec^-1. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.00 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 48

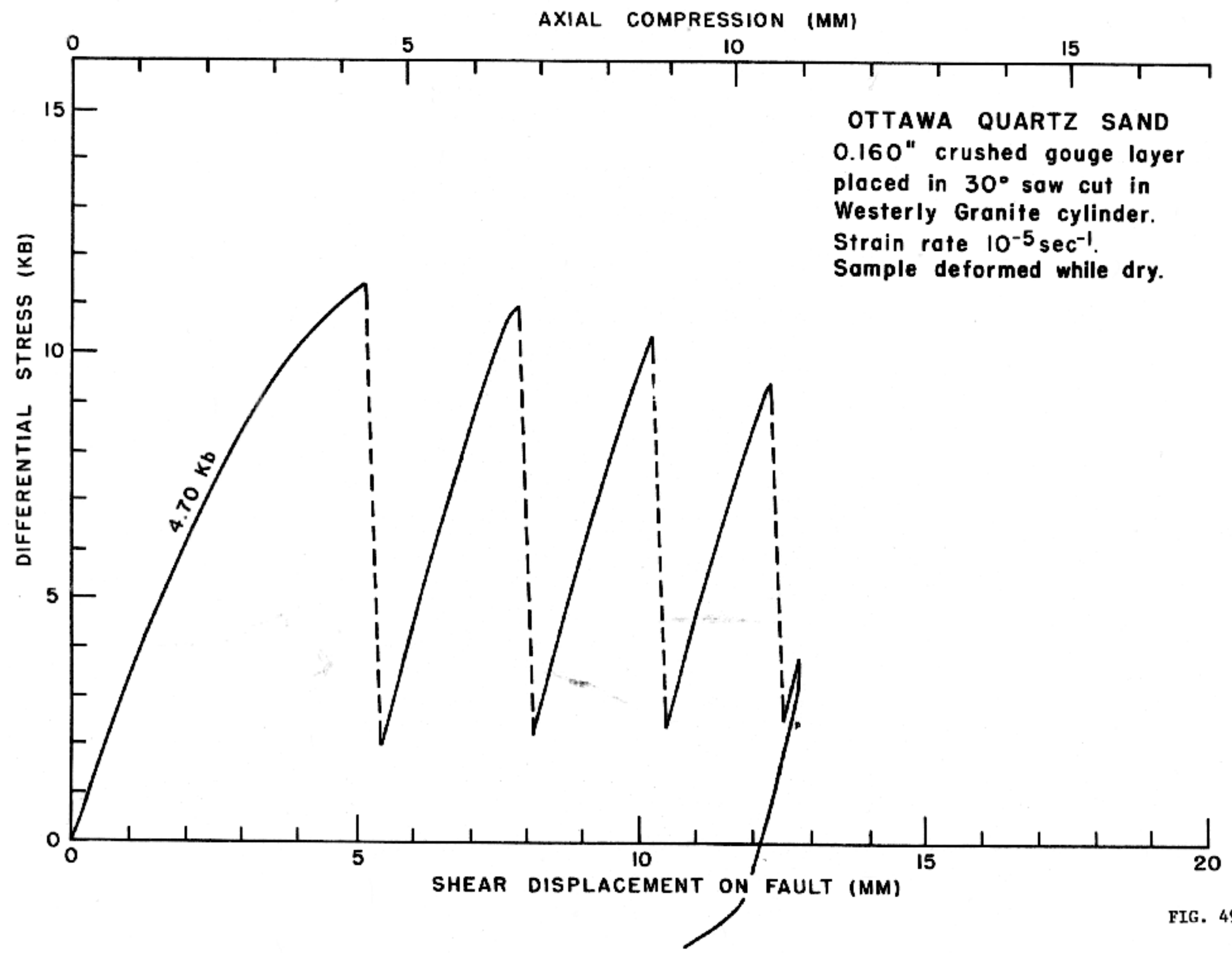

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 49

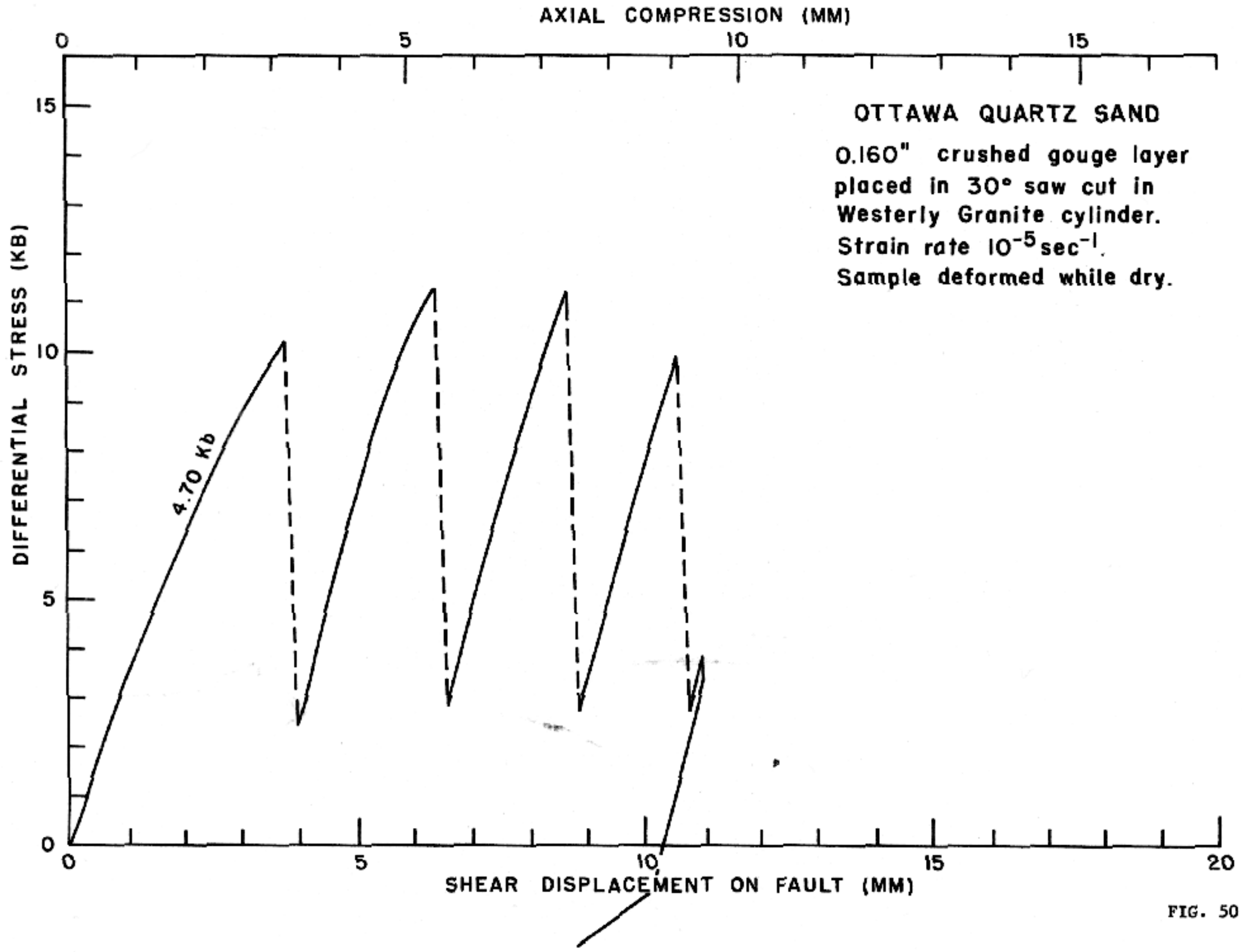

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
4.70 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 50

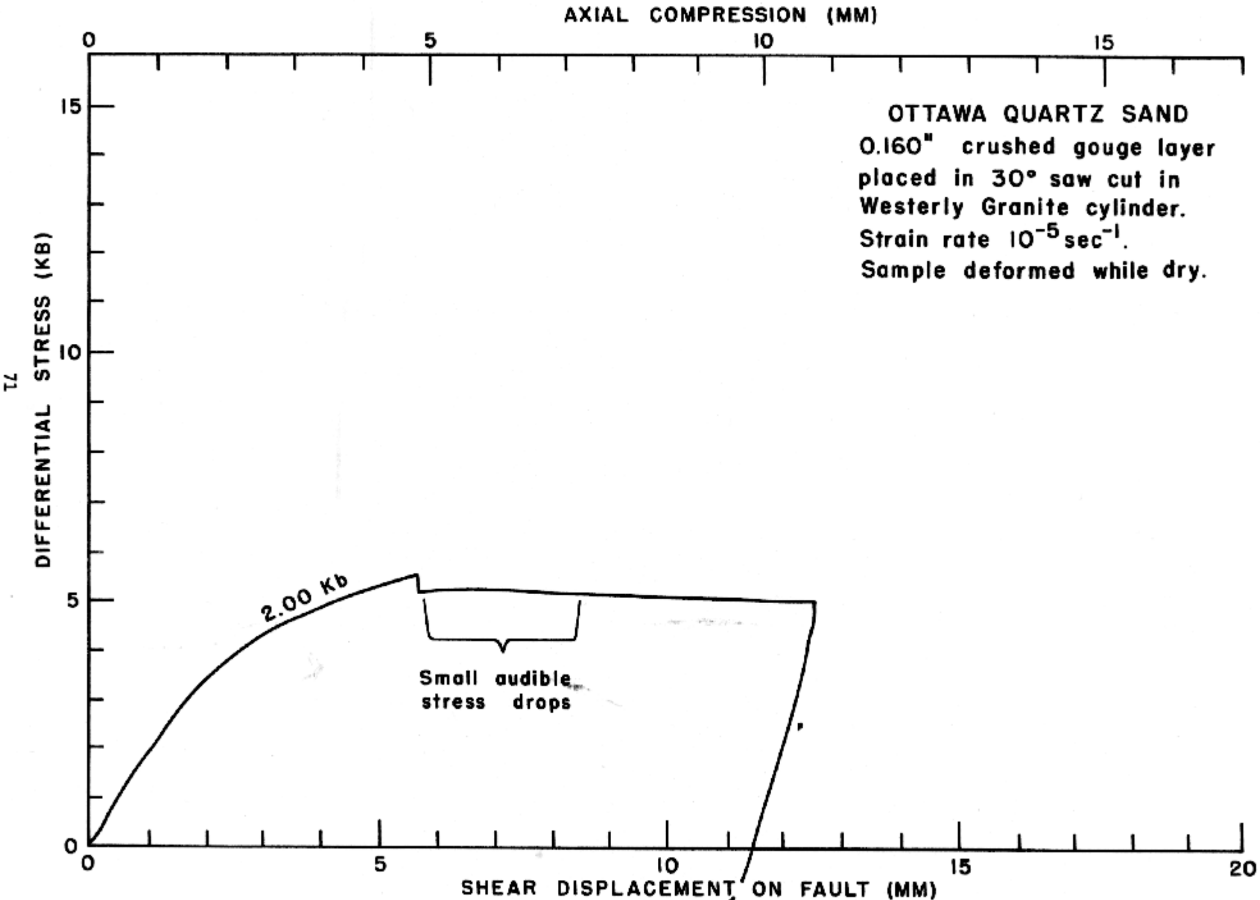

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder. Strain rate $10^{-5}$ sec$^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.00 Kb
Small audible stress drops
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 51

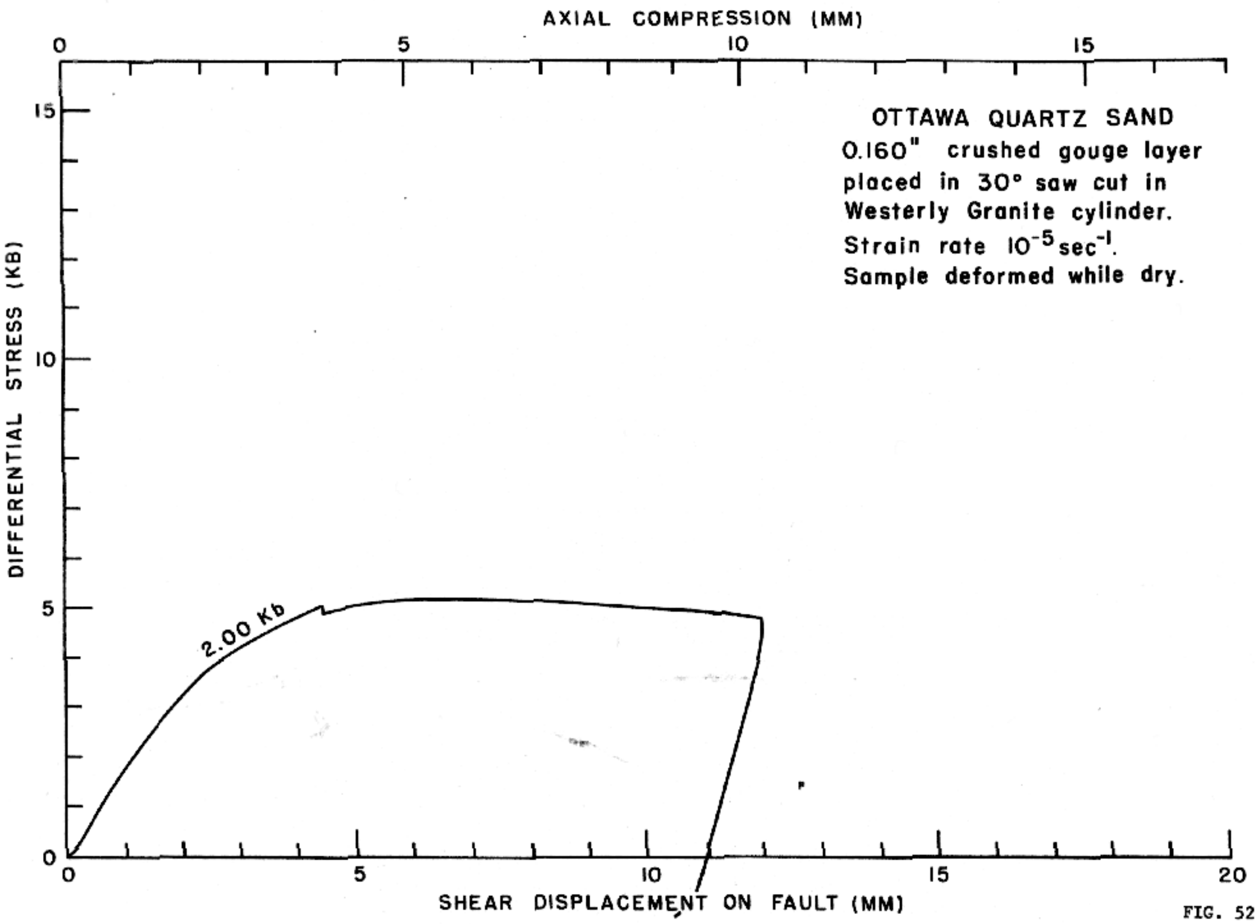

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.00 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 52

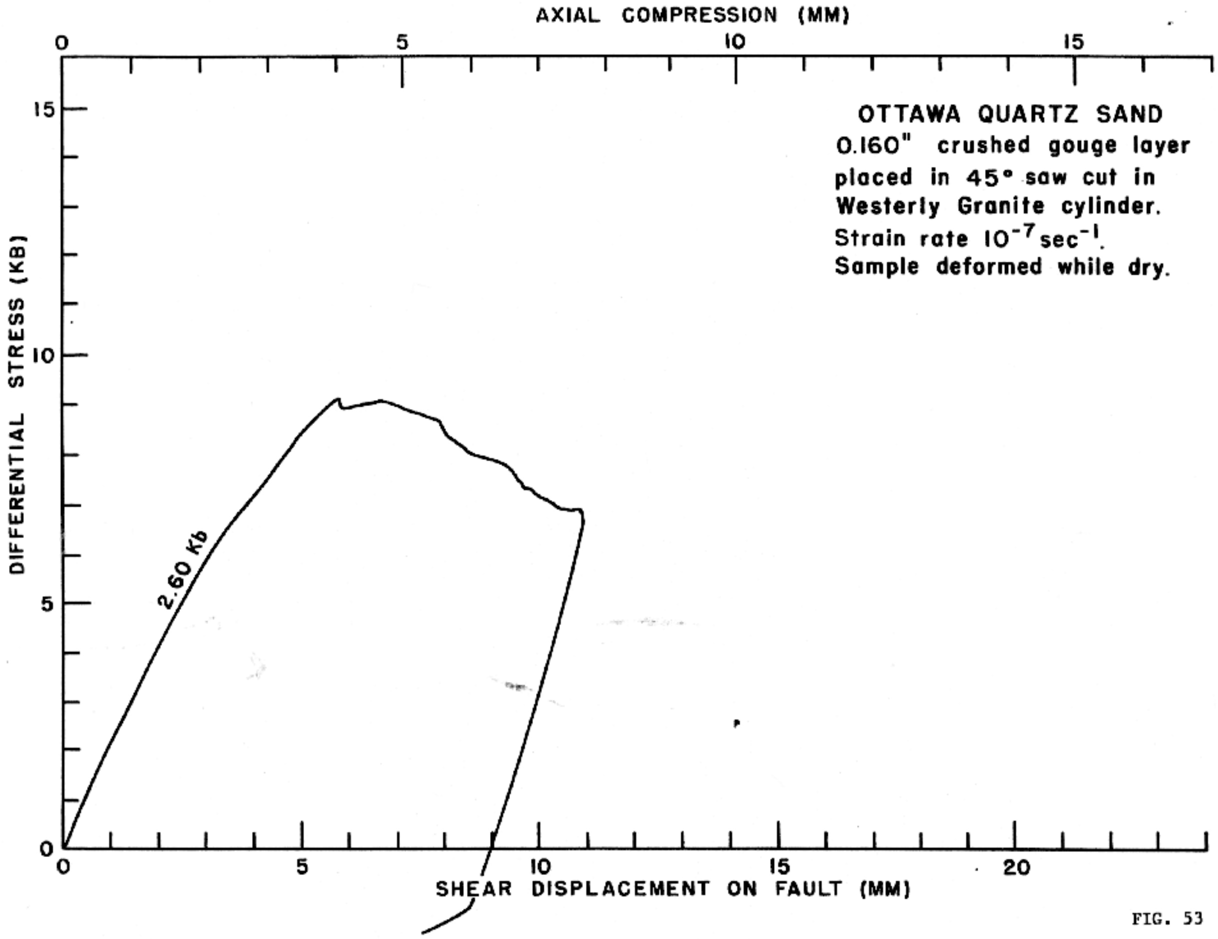

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 45° saw cut in Westerly Granite cylinder. Strain rate $10^{-7}$ $sec^{-1}$. Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.60 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 53

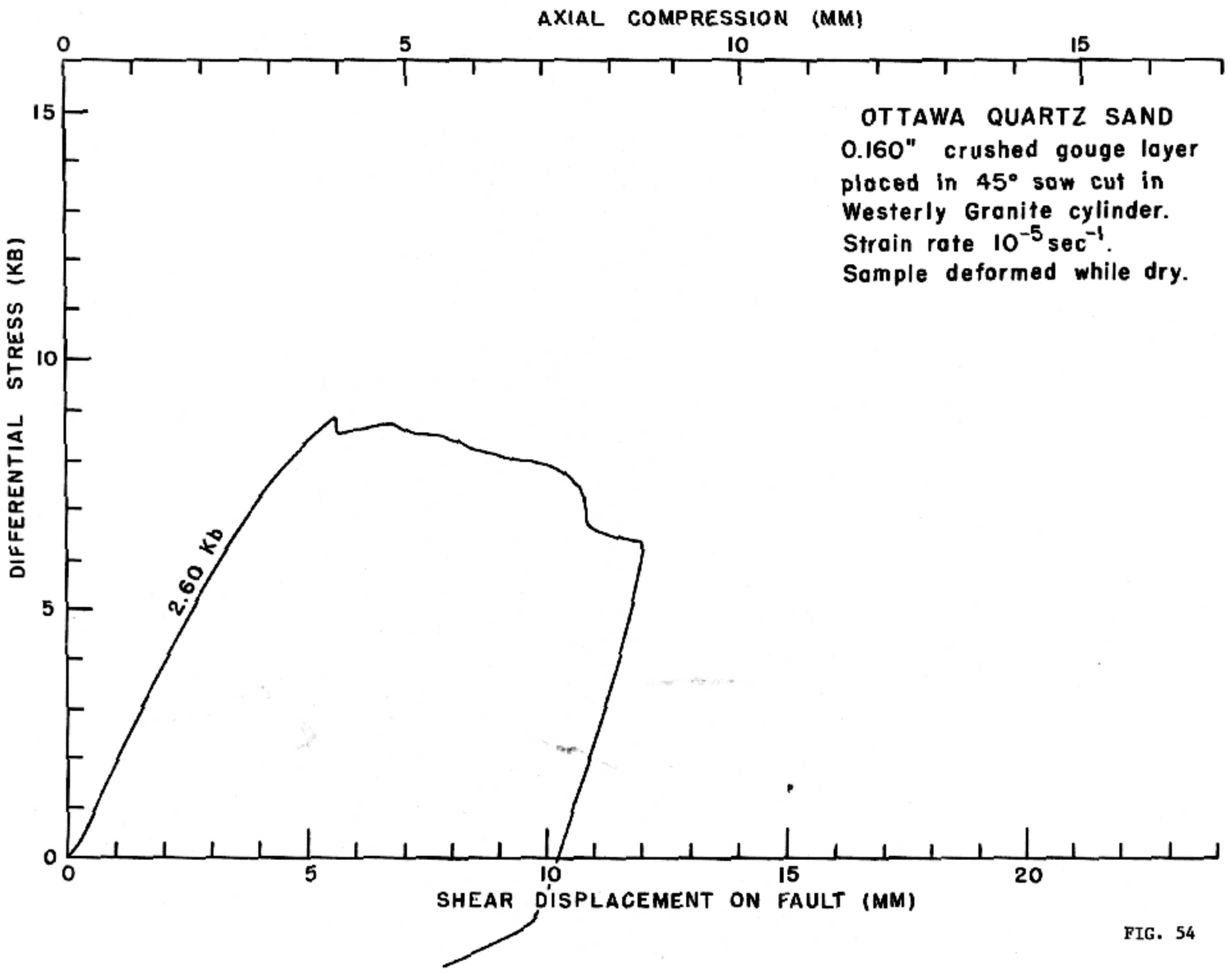

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer placed in 45° saw cut in Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.60 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 54

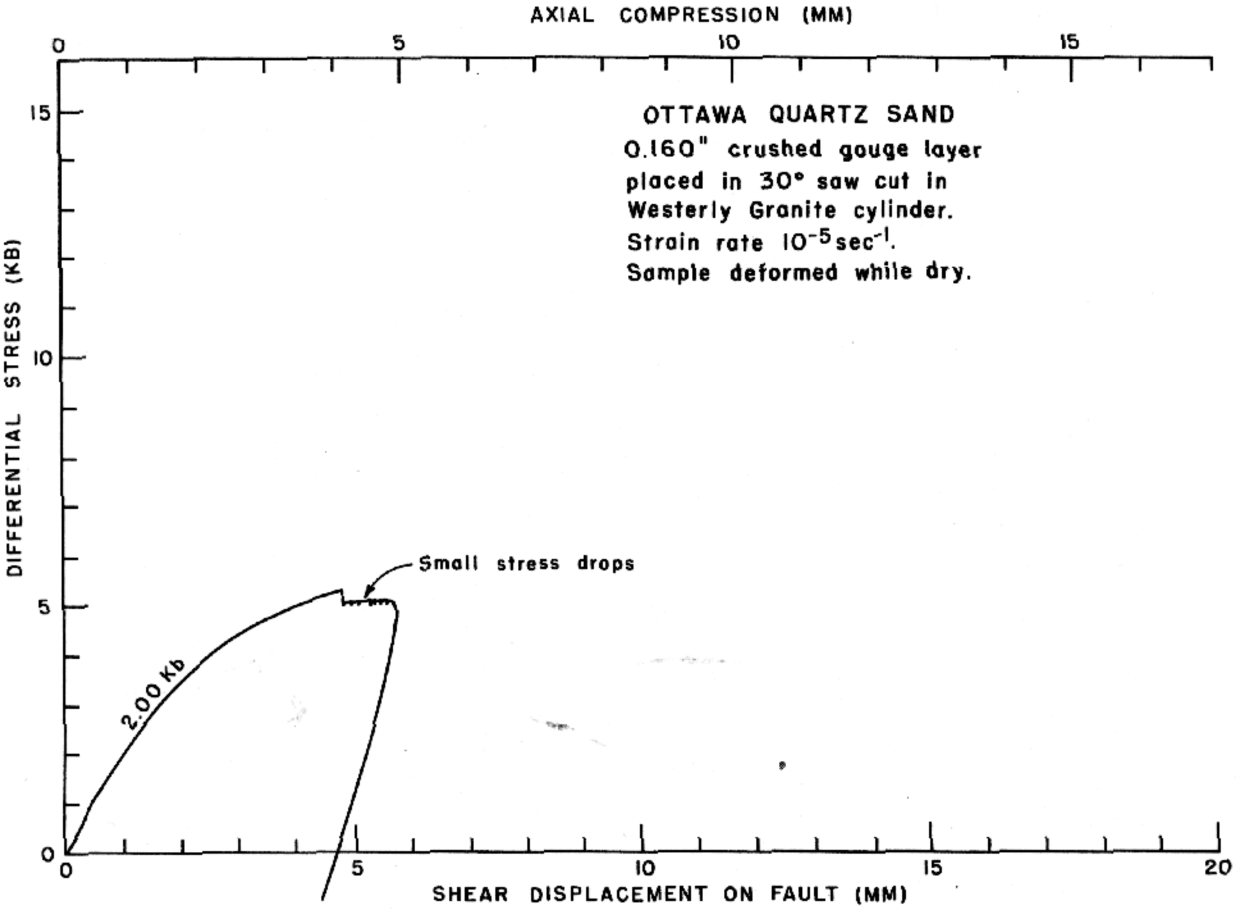

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
Small stress drops
2.00 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 55

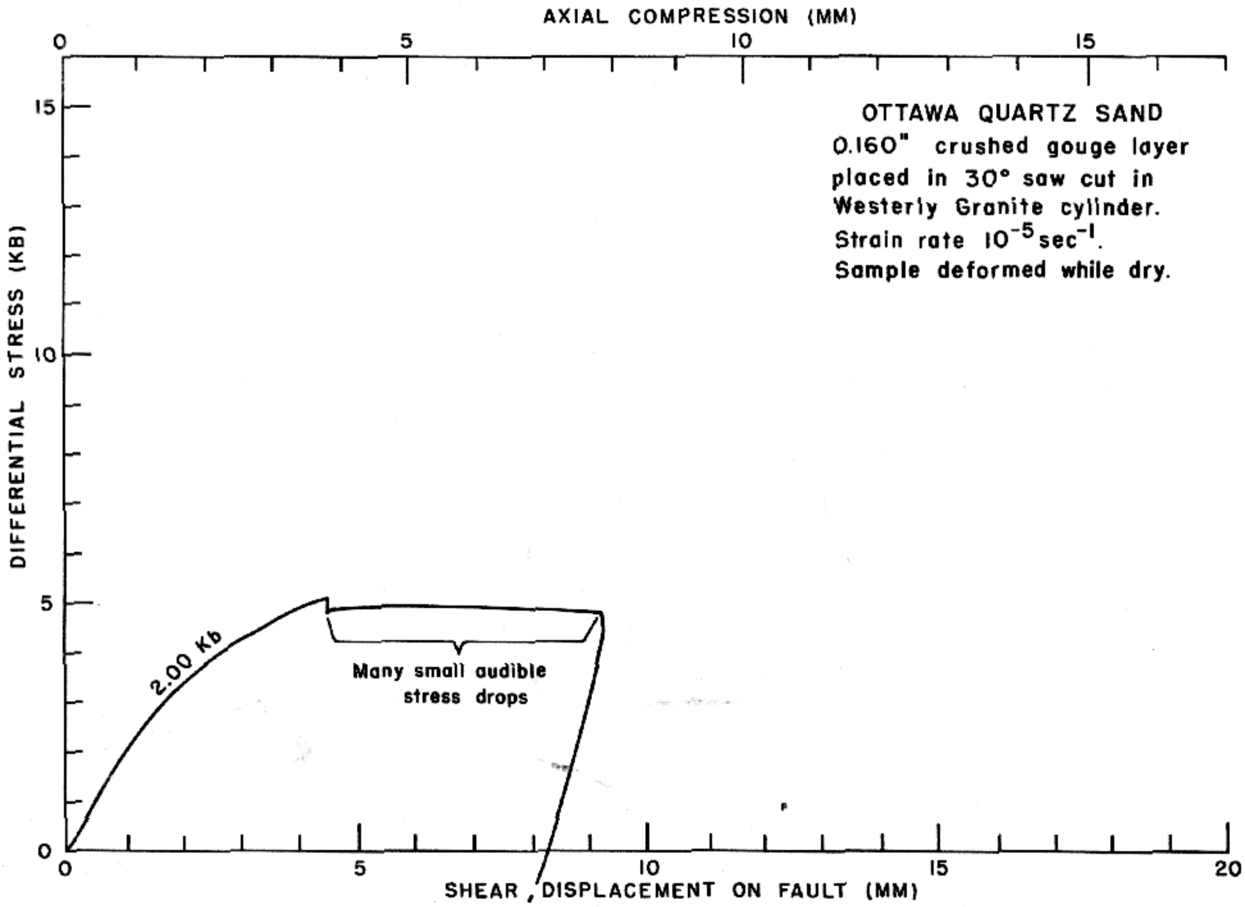

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
2.00 Kb
Many small audible
stress drops
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 56

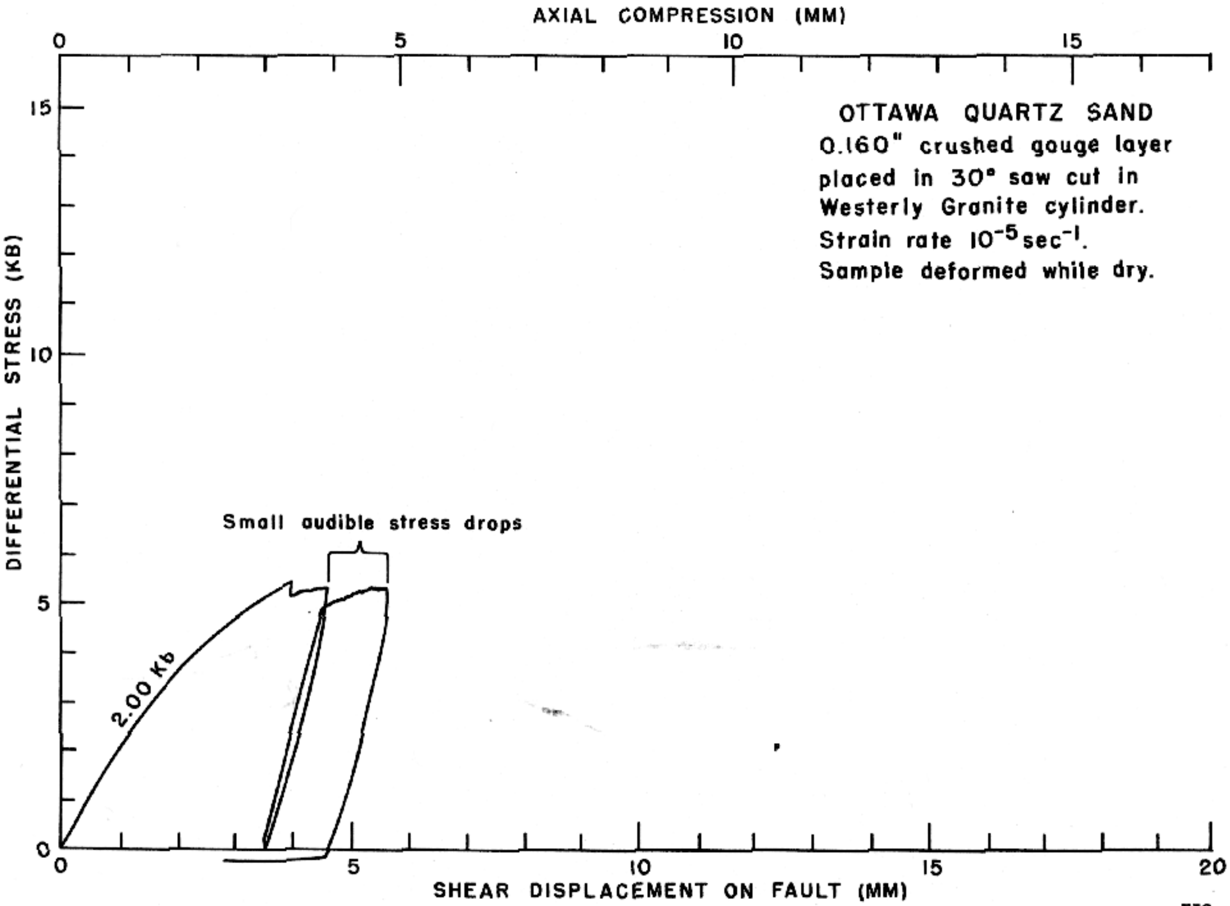

AXIAL COMPRESSION (MM)
0
5
10
15
OTTAWA QUARTZ SAND
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
Small audible stress drops
2.00 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 57

Serpentinite

Fig. 58,59) Crushed antigorite serpentinite from New Alamden, Ca. 0.025"-thick layer with initial grain sizes that pass a 170 mesh sieve, placed in a 30° sawcut in a 1" x 2.5" of Westerly Granite cylinder

Confining pressures: 0.73 to 6.26 kb

Axial Compression strain rate: $10^{-4}sec^{-1}$

60,61) 0.020"-thick wafer of serpentinized harzbergite from Del Puerto Canyon, Ca, placed in a 30° sawcut in a 1" x 2.5" cylinder of Westerly Granite

Confining pressures: 0.73 to 6.23 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

62,63) 0.025"- thick wafer of serpentinized harzbergite from Del Puerto Canyon, CA., placed in a 30° sawcut in a 1" x 2.5" cylinder of Westerly Granite

Confining pressures: 0.73 to 6.23 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

64,65) Crushed serpentinized harzbergite from Del Puerto Canyon, Ca. 0.025"-thick layer with initial grain sizes that pass a 170 mesh sieve, placed in a 30° sawcut in a 1" x 2.5" cylinder of Westerly Granite

Confining pressures: 0.73 to 6.25 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

Comments:

The antigorite collected from a sheared zone near New Alamden was collected as fragments up to several centimeters across and crushed to pass a 170 mesh sieve ($\leq$ 0.090 mm grain size).The crushed grains were packed onto the saw cut face wet and dried after the samples were assembled.

The serpentinized harzbergite collected from Del Puerto Canyon was massive, and was both cored for cutting 0.025" wafers and used as crushed grains ( $\leq$0.090 mm).

In all cases surprisingly high stress levels were supported, and frequent violent stick slip events occurred at high confining pressures.

The samples using the 0.025" intack wafers or layers of crushed Del Puerto serpentinite gave similar results.

The 0.200" intact wafers of Del Puerto serpentinite consistnely showed a more distinct yield point than the 0.025" samples of the same type material.

All but two of the Del Puerto samples produced stick slip at 1 1/2 kb. All Del Puerto samples run at 3/4 kb were stable except for one that had a single stick slip event.

The Almaden serpentinite samples were stable at 0.73 and 1.53 kb but were unstable at 3.11 kb and above.

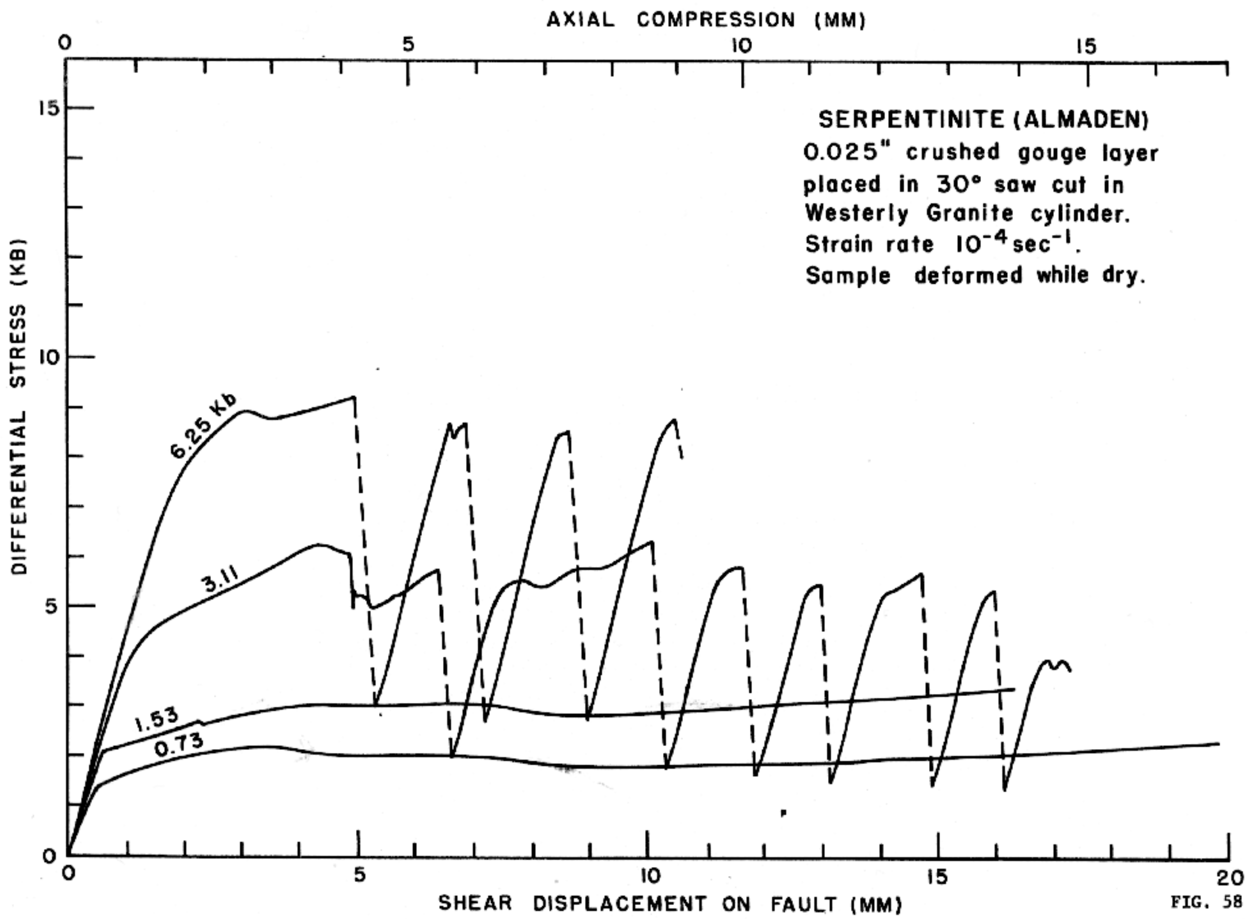

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (ALMADEN)
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.25 Kb
3.11
1.53
0.73
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 58

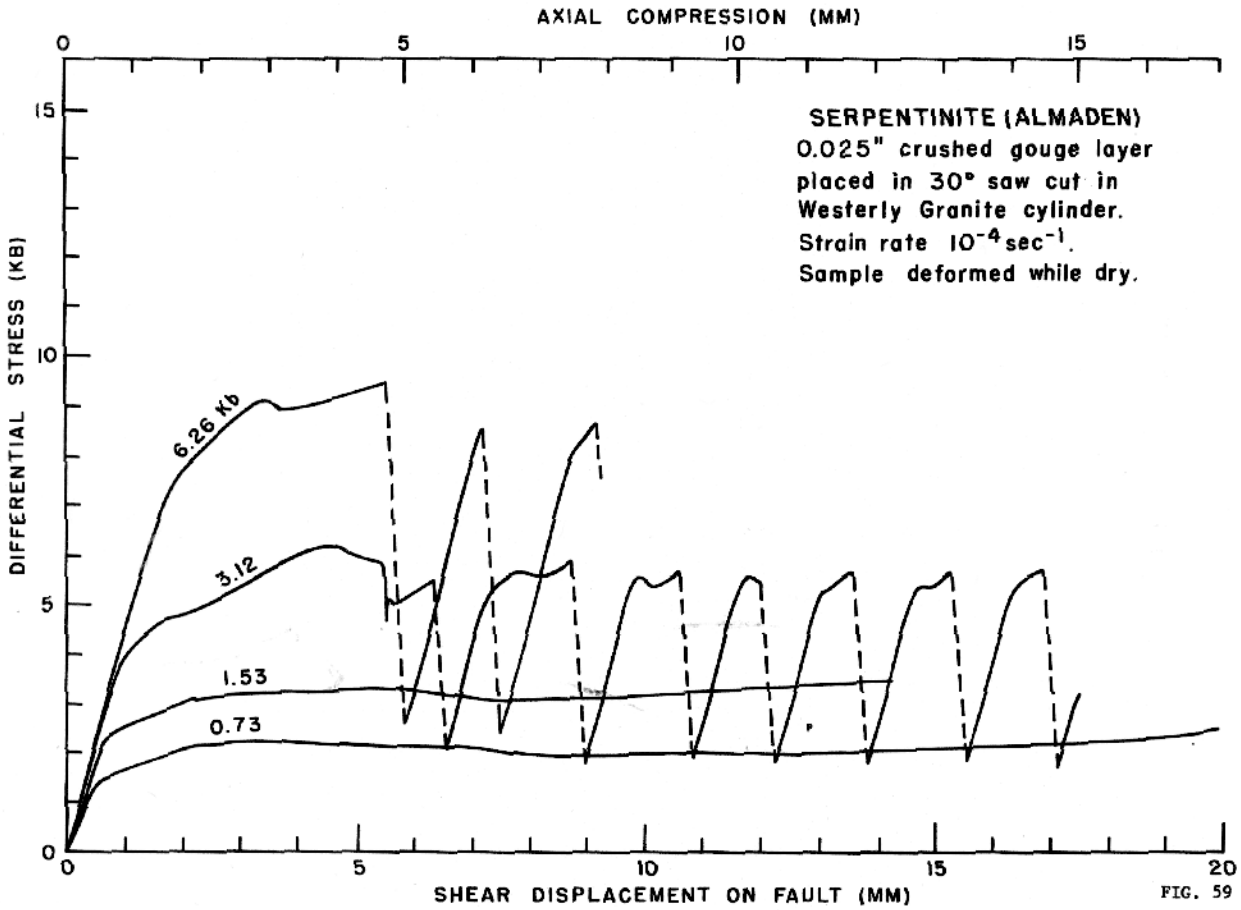

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (ALMADEN)
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate 10⁻⁴ sec⁻¹.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.26 Kb
3.12
1.53
0.73
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 59

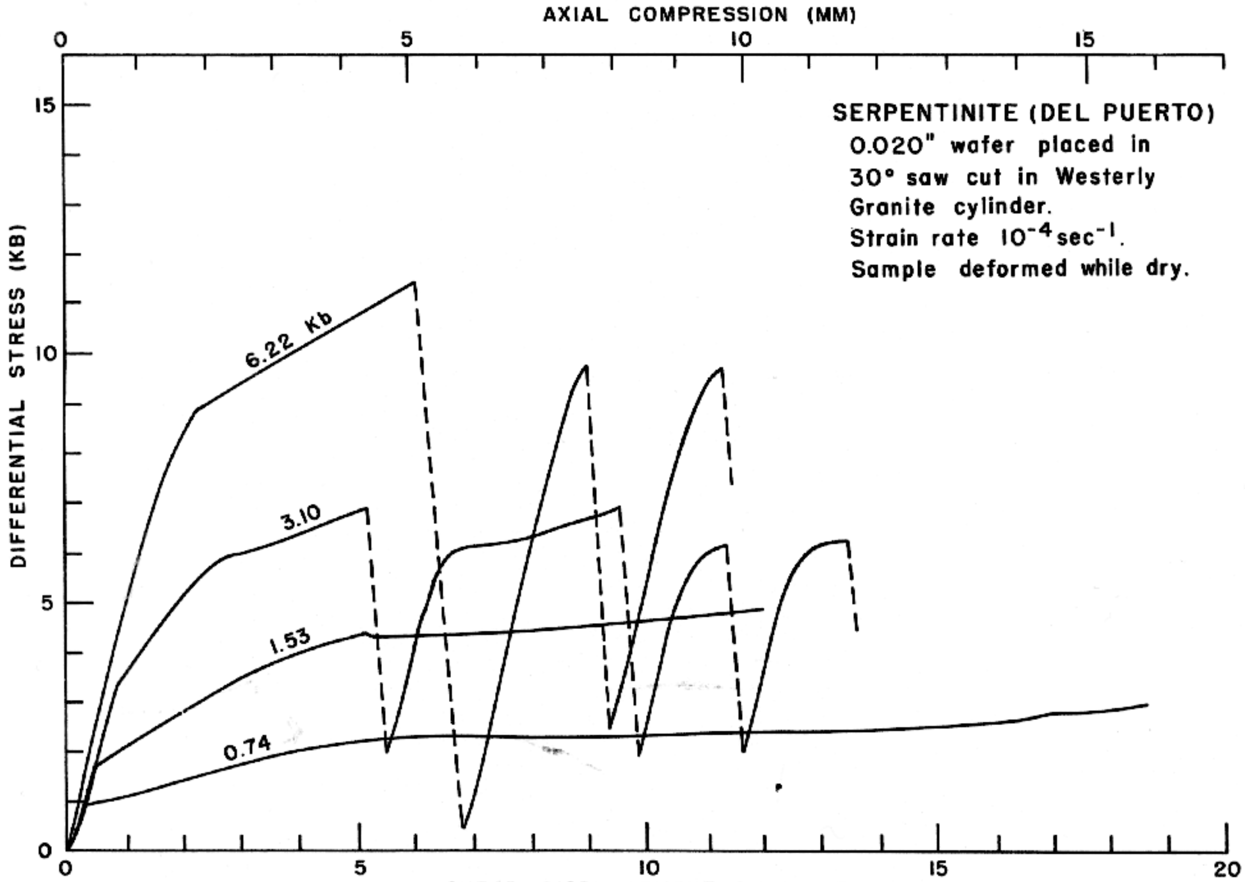

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (DEL PUERTO)
0.020" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.22 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 60

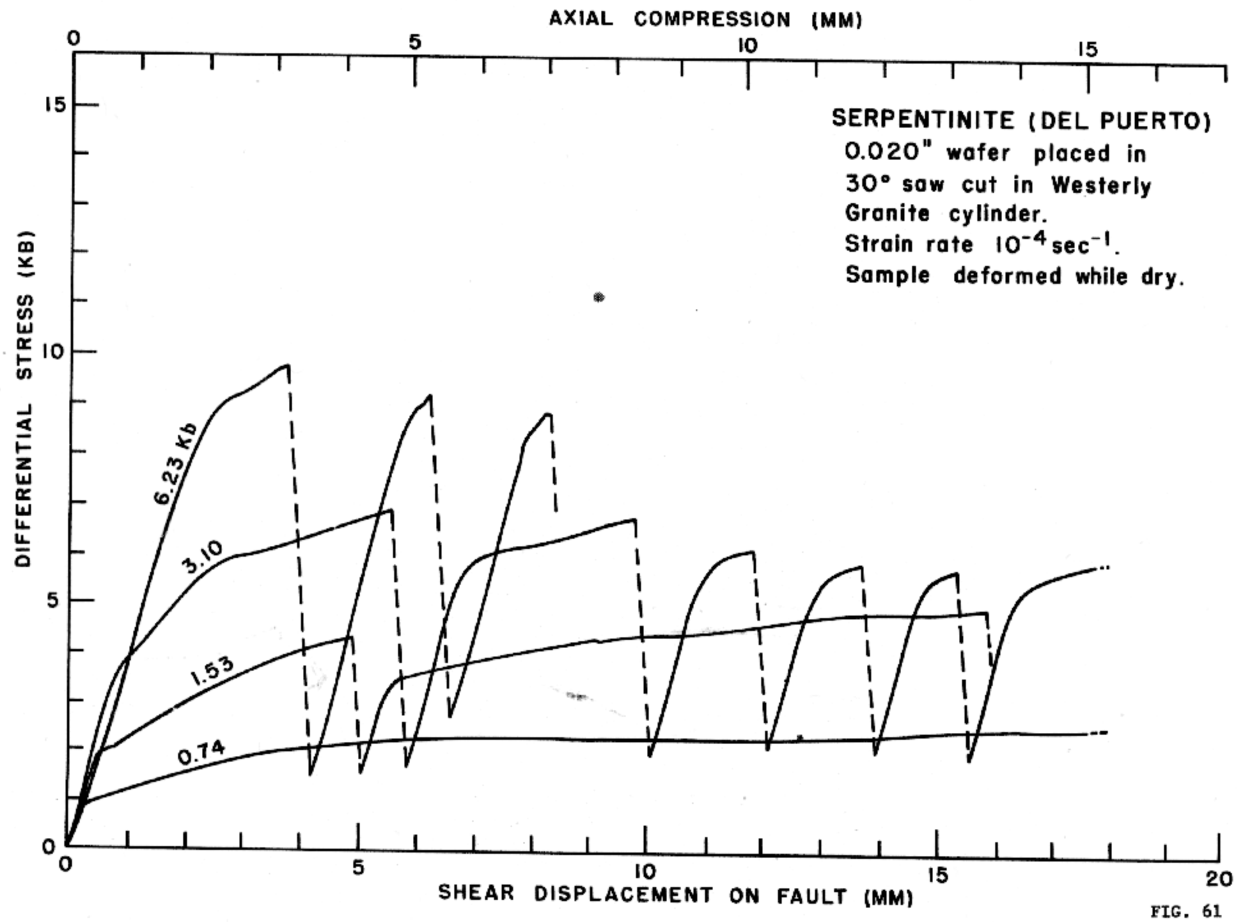

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (DEL PUERTO)
0.020" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.23 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 61

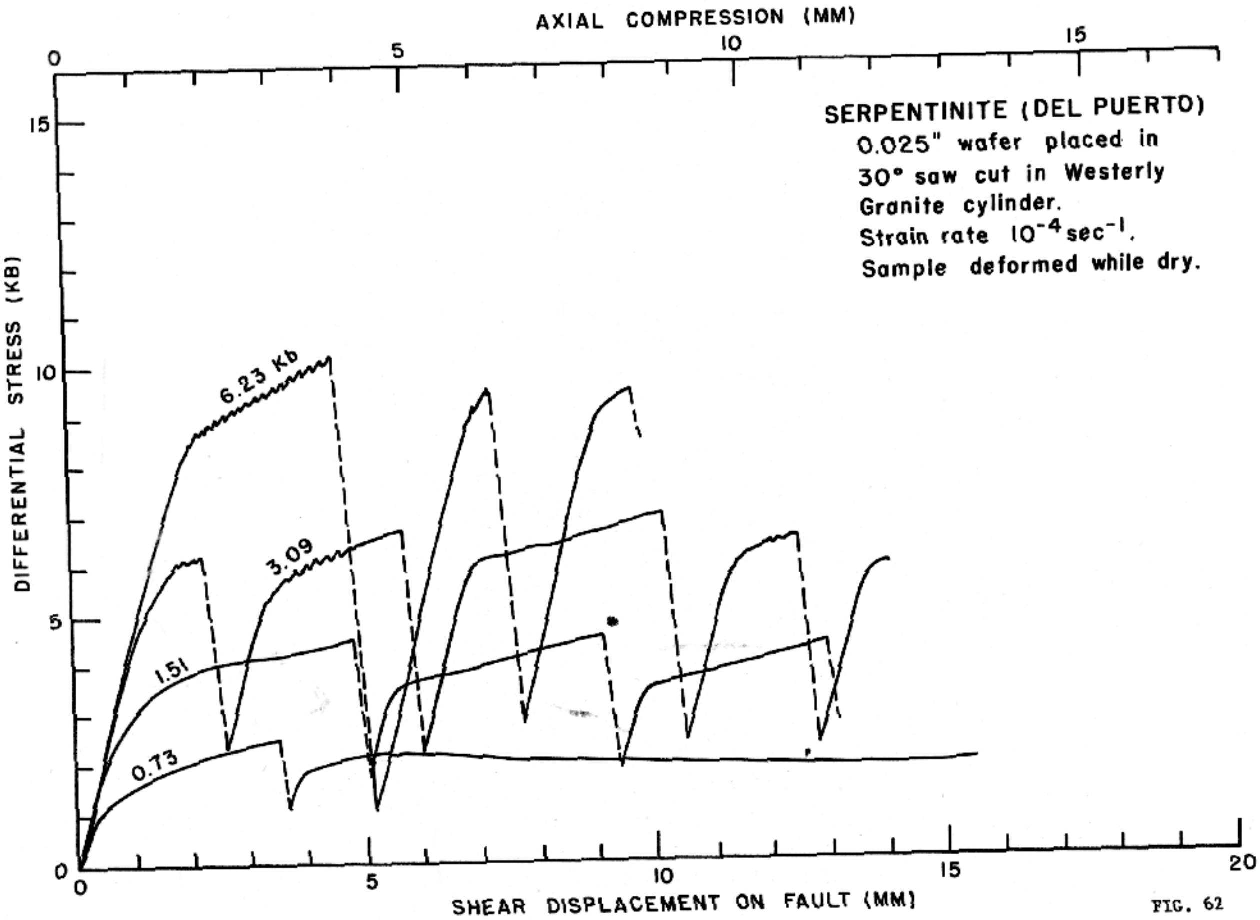

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (DEL PUERTO)
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
6.23 Kb
3.09
1.51
0.73
DIFFERENTIAL STRESS (KB)
15
10
5
0
SHEAR DISPLACEMENT ON FAULT (MM)
0
5
10
15
20

FIG. 62

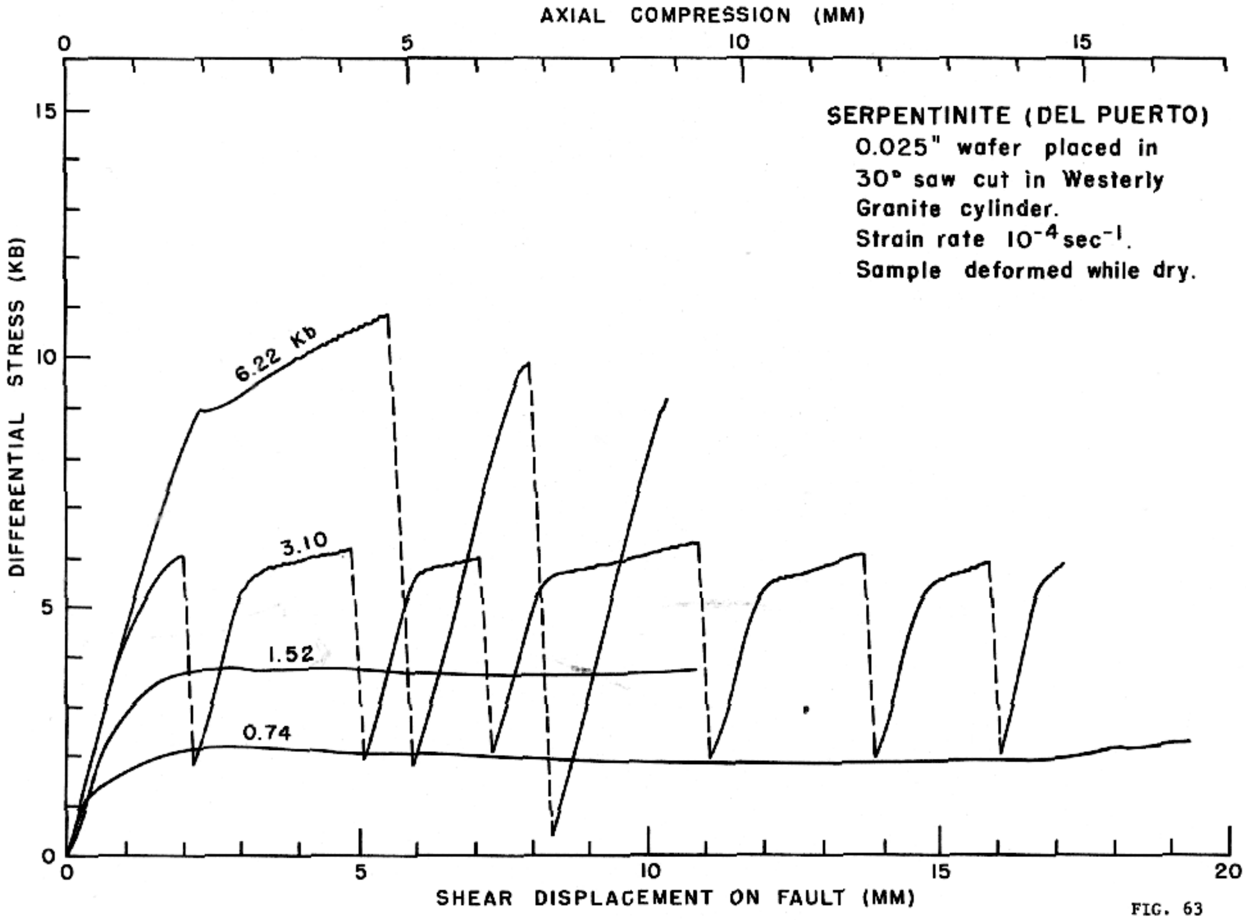

AXIAL COMPRESSION (MM)
SERPENTINITE (DEL PUERTO)
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
6.22 Kb
3.10
1.52
0.74
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 63

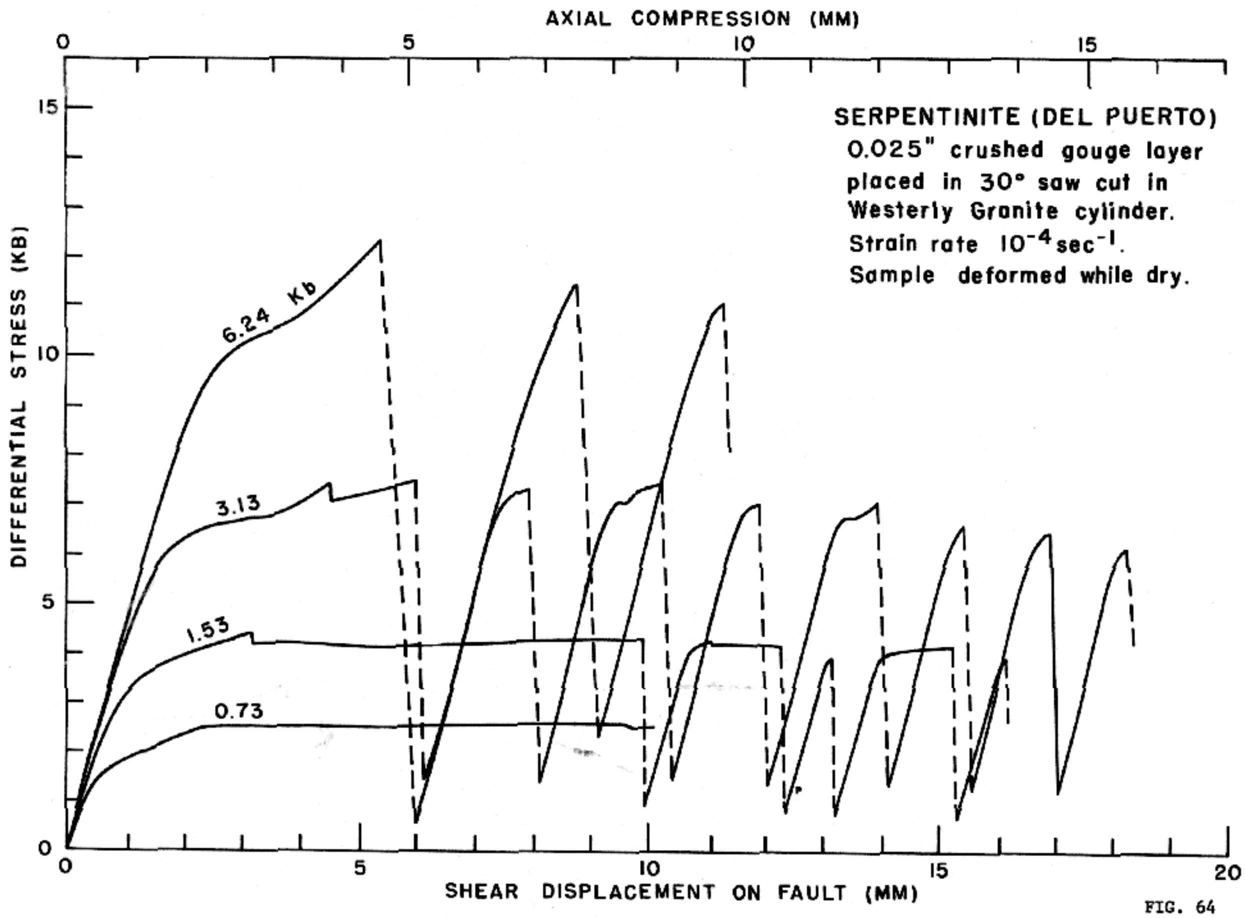

AXIAL COMPRESSION (MM)
0
5
10
15
SERPENTINITE (DEL PUERTO)
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.24 Kb
3.13
1.53
0.73
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 64

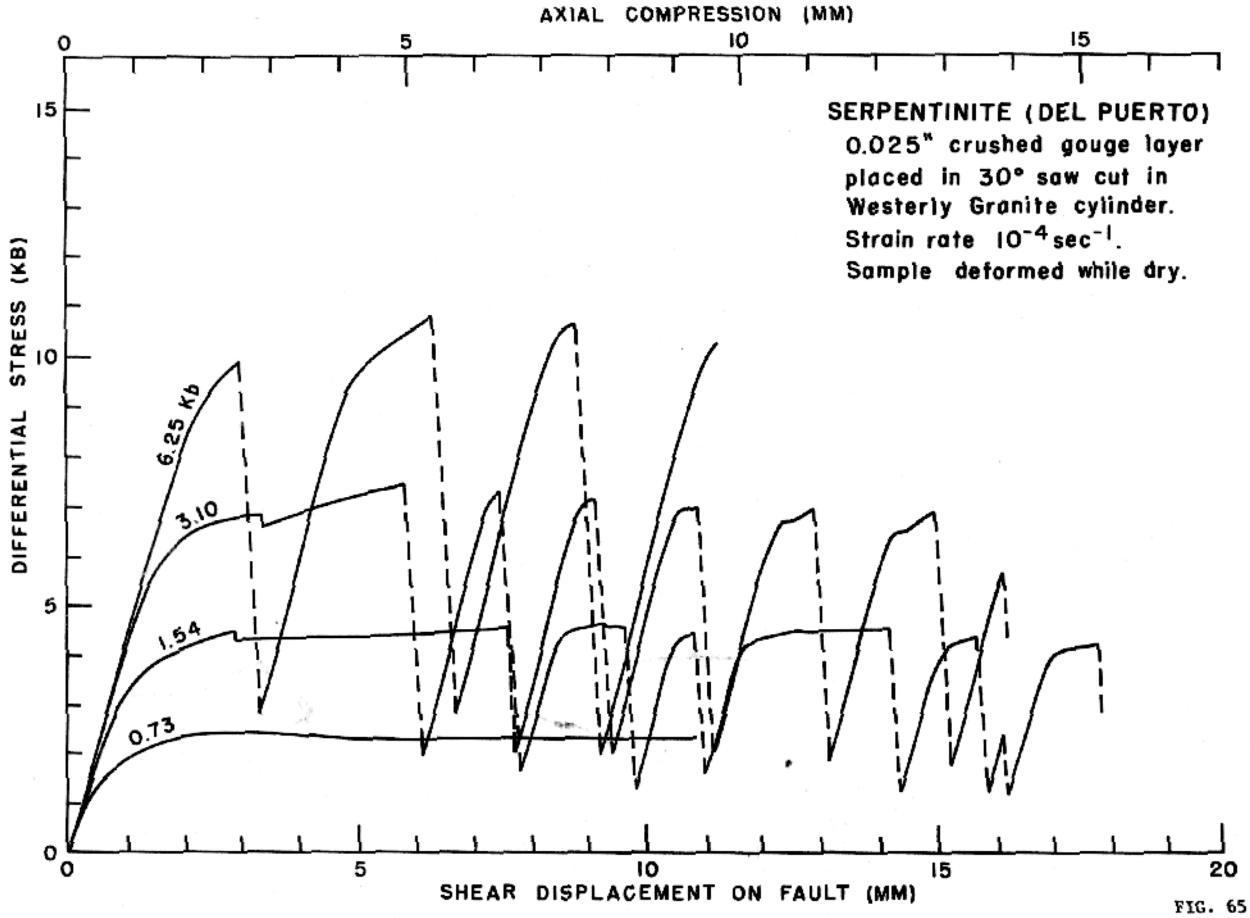

AXIAL COMPRESSION (MM)
SERPENTINITE (DEL PUERTO)
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
6.25 Kb
3.10
1.54
0.73
DIFFERENTIAL STRESS (KB)
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 65

Solenhofen Limestone

Fig. 66,67) 0.025"-thick wafers of Solenhofen Limestone placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressures: 0.74 to 6.23 kb

Axial compression strain rate: $10^{-4} sec^{-1}$

Comments:

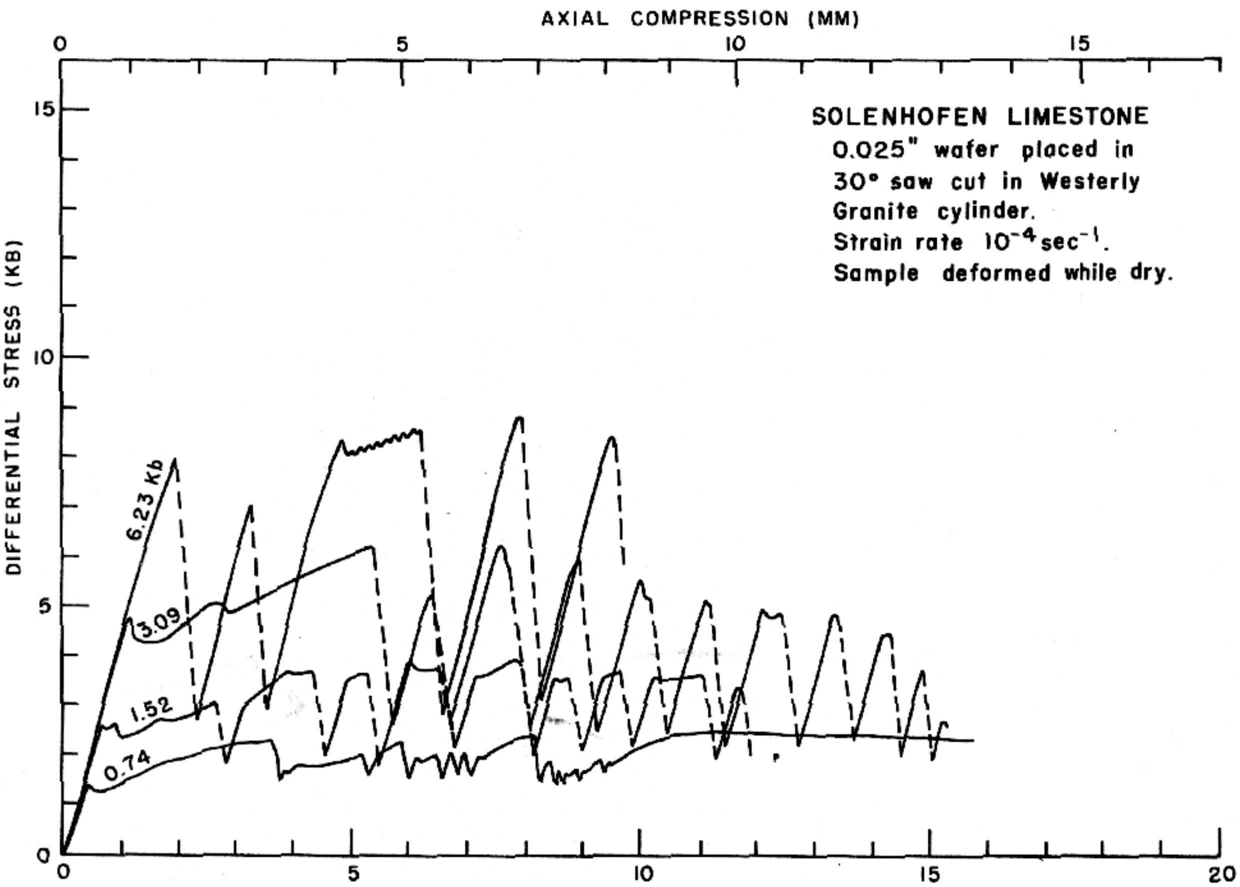
Unstable stick slip was observed at all pressures. At 3/4 to 3 kb the limestone exhibited both upper and lower yield points at the beginning of inelastic deformation.

The unstable behavior at 0.74 kb was unusual and did not occur regularly in 0.025" layers of the other materials tested. Similar behavior was observed with the samples in which the sawcut faces were in direct contact without any insert.

In one of the 0.74 kb samples the unstable stick slip began only after a prolonged period of stable sliding. In the other identical sample, the stick slip occurred between two periods of stable sliding.

Further study is needed to explain the reason for the unstable behavior at 3/4 kb confining pressures.

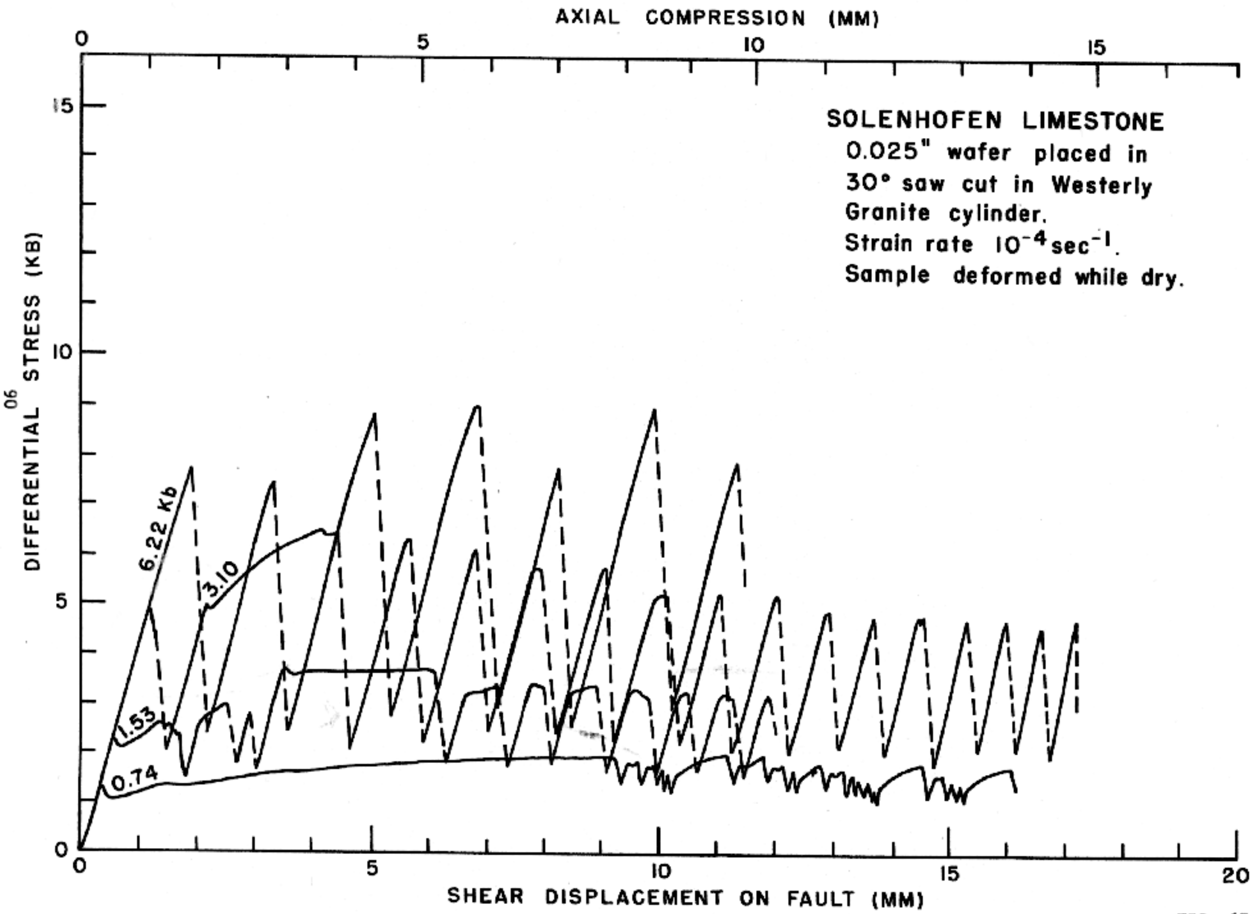
For the samples run at pressures of 1.52 to 3.10 kb the greatest amount of stable sliding occurred during the first portion of the shearing, with the latter part of the shearing being noticeably more unstable.



AXIAL COMPRESSION (MM)
0
5
10
15
SOLENHOFEN LIMESTONE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.23 Kb
3.09
1.52
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


68

FIG. 66



AXIAL COMPRESSION (MM)
0
5
10
15
SOLENHOFEN LIMESTONE
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.22 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)


FIG. 67

Talc

Fig. 68) Intact cylinders (1" x 2.5") of talc

Confining pressures: 1.92 to 5.87 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

69,70) Talc wafers (0.020", 0.040", 0.060", and 0.080" thickness) placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressure: 5.46 $\pm$ 0.01 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

71,72) Talc wafers (0.025" thickness) placed in a 30° sawcut in 1" x 2.5" cylinders of Westerly Granite

Confining pressures: 0.74 to 6.26 kb

Axial compression strain rate: $10^{-4}sec^{-1}$

Comments:

Each intact cylinder of talc (Fig. 68). was run at successively higher confining pressures. The stress level supported increased as the confining pressure was increased. At a given confining pressure the stress increased slowly as deformation proceeded.

Two types of studies were made on the wafers of talc placed in the saw cut granite cylinders. In the first study (Fig. 69,70) several effects were observed which can be attributed to differences in fault zone thickness. Over the range of 0.020" to 0.080" increasing the thickness of the fault gouge layer reduced the level of stress that was supported, and also reduced the magnitude of the observed stress drops. Comparison with the originally intact samples shows that the intact samples supported significantly lower stress and deformed more stably than any of the wafer samples. This may indicate that the effective width of the shear zone formed in the intact samples was greater than than formed in the 0.080" wafer samples.

During the second study (0.025" wafers at varied pressures, Fig. 71,72) increases in confining pressure produced increases in the stress supported by the talc layer. The stress was significantly greater than that observed at comparable confining pressure during the experiments on intact cylinders of talc. For this study, two samples were run at each confining pressure used. At 0.74 to 0.75 kb, all deformation was by stable sliding. At 1.51 to 1.53 kb one sample had a single small stress drop and the other had two small stress drops. At 3.10 kb one sample produced a single large stick slip event after prolonged stable sliding; the other deformed stably. At 6 1/4 kb both samples produced one large stick slip event and one small event.

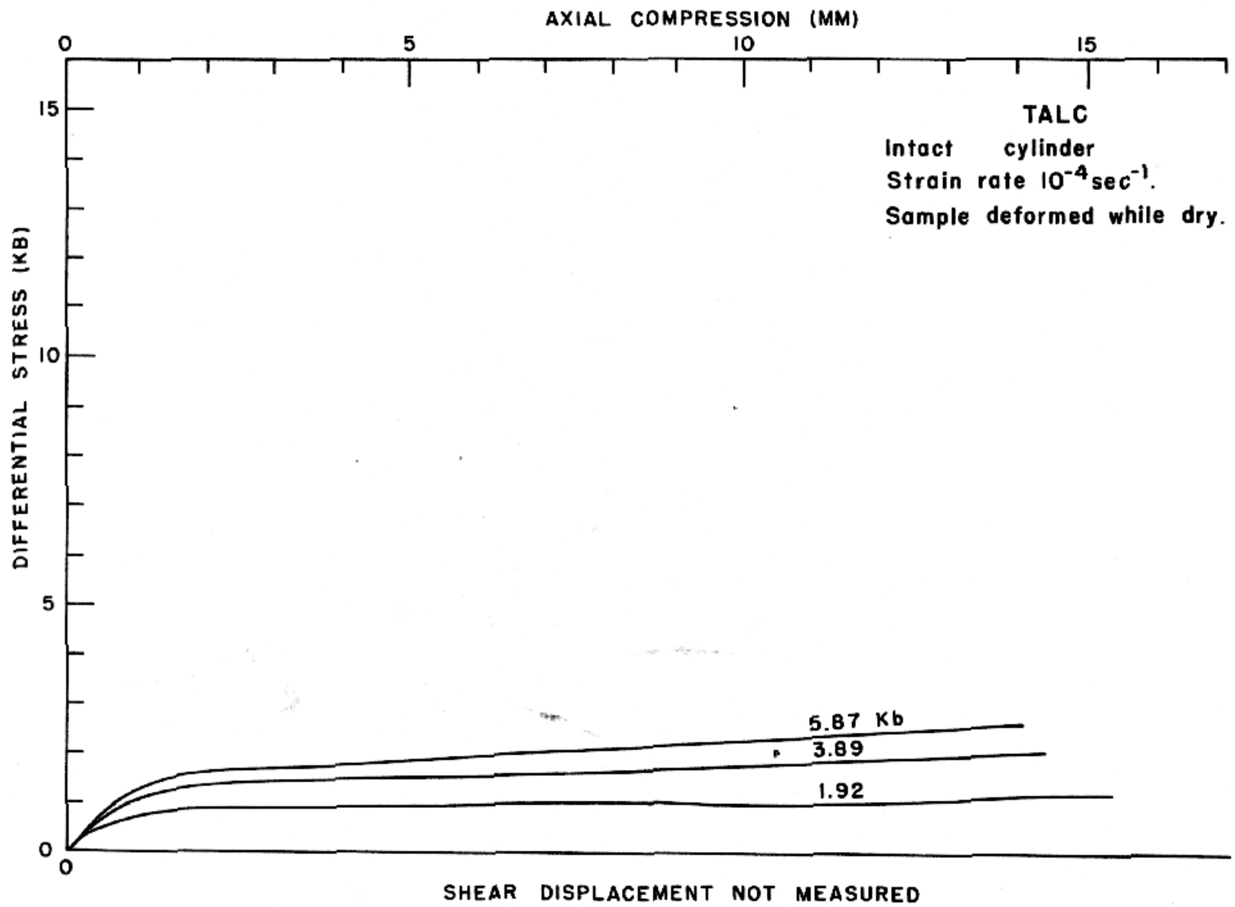

AXIAL COMPRESSION (MM)
0
5
10
15
TALC
Intact cylinder
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
5.87 Kb
3.89
1.92
0
SHEAR DISPLACEMENT NOT MEASURED

FIG. 68

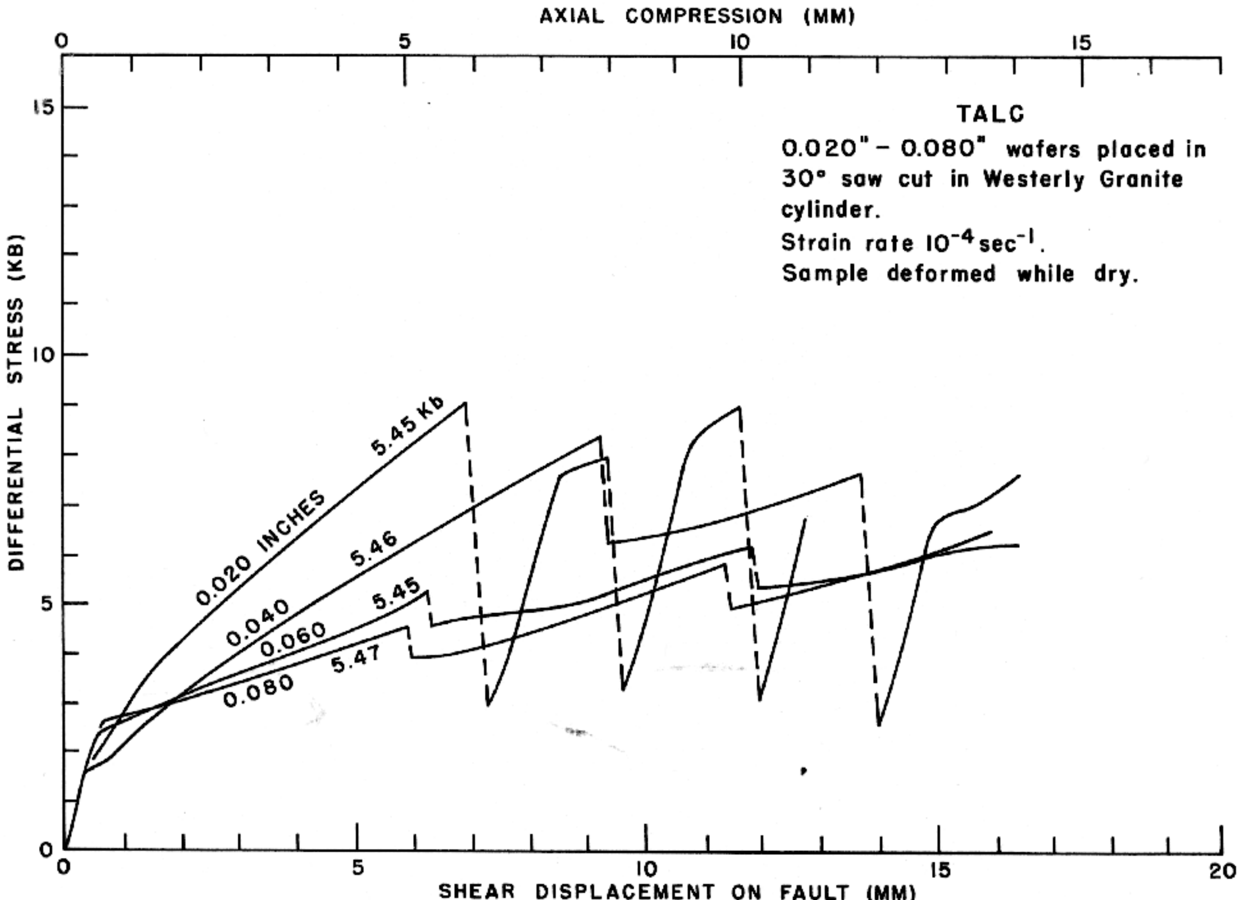

AXIAL COMPRESSION (MM)
0
5
10
15
TALC
0.020" - 0.080" wafers placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
0.020 INCHES
5.45 Kb
0.040
5.46
0.060
5.45
0.080
5.47
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 69

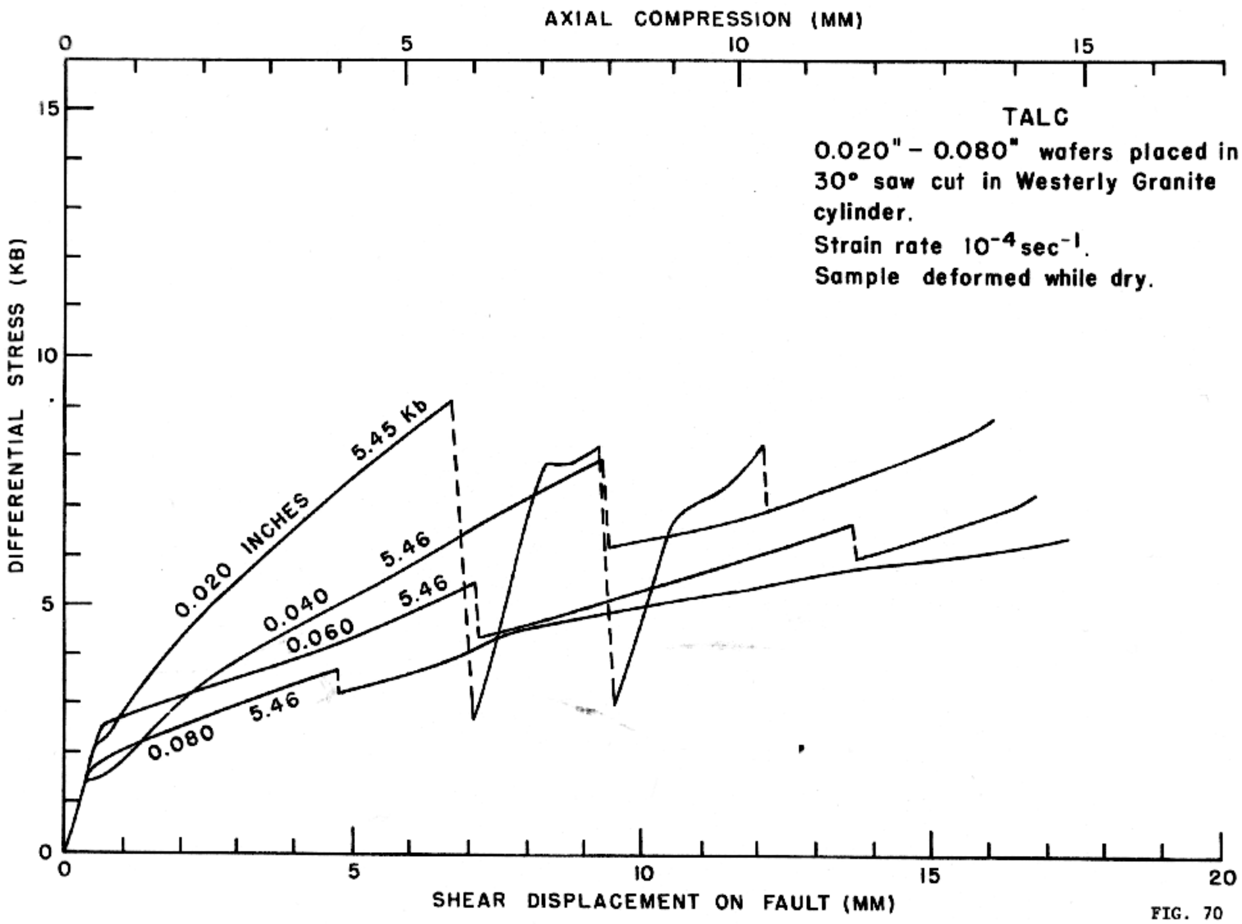

AXIAL COMPRESSION (MM)
0
5
10
15
TALC
0.020" - 0.080" wafers placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
0.020 INCHES
5.45 Kb
0.040
5.46
0.060
5.46
0.080
5.46
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 70

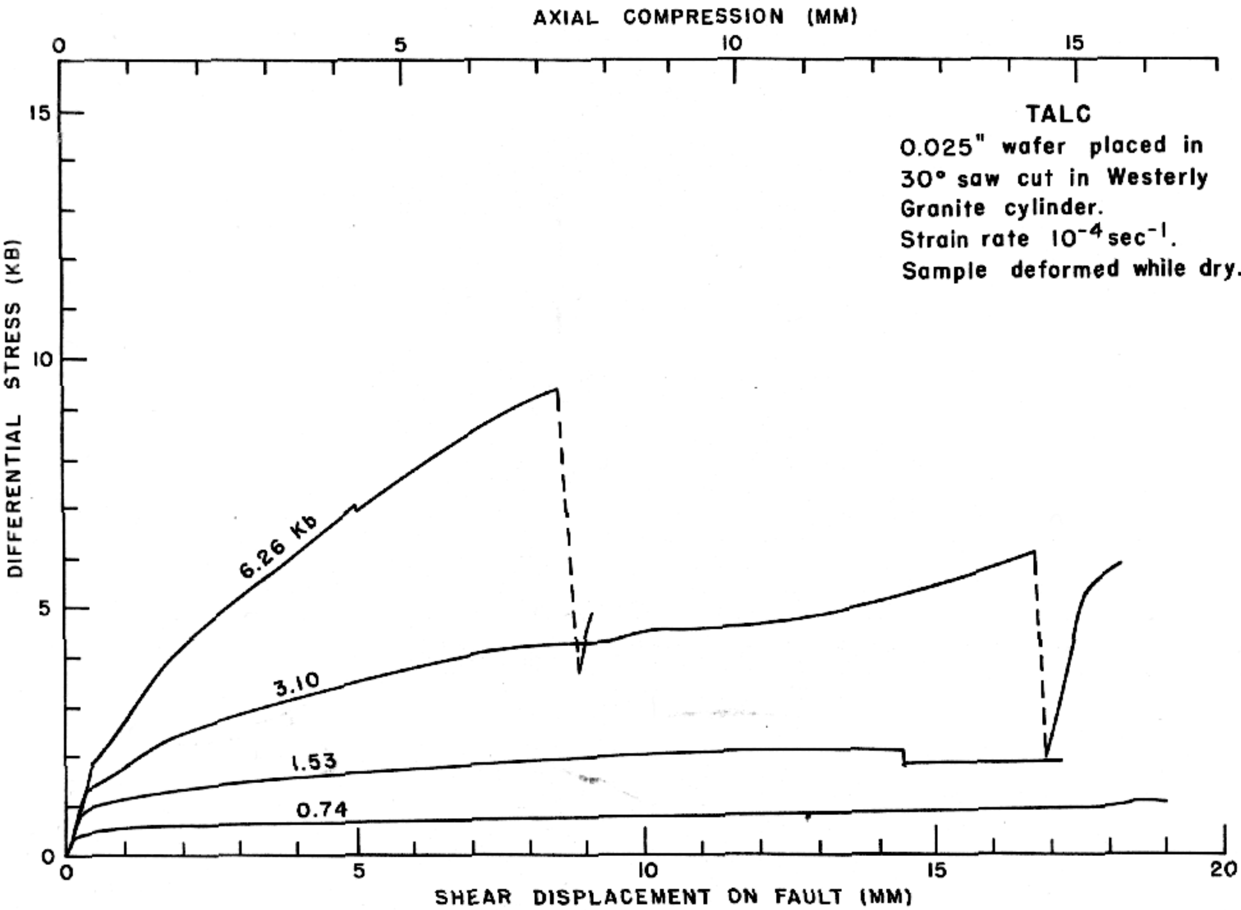

AXIAL COMPRESSION (MM)
0
5
10
15
TALC
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.26 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 71

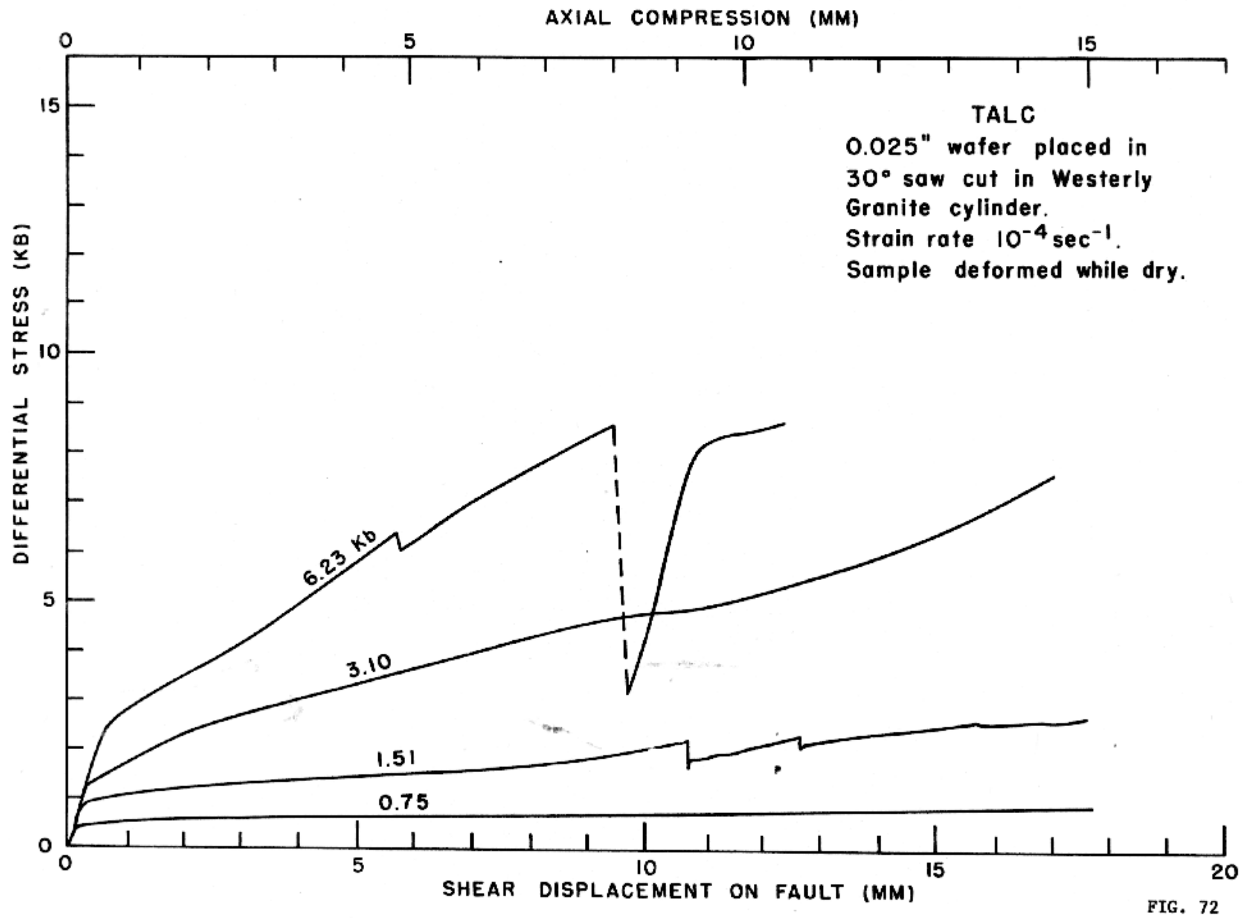

AXIAL COMPRESSION (MM)
0
5
10
15
TALC
0.025" wafer placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.23 Kb
3.10
1.51
0.75
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 72

Westerly Granite, intact

Fig. 73-84) Intact cylinders of Westerly Granite, 1.000" x 2.500"

Confining pressures: 0.39 to 6.98 kb

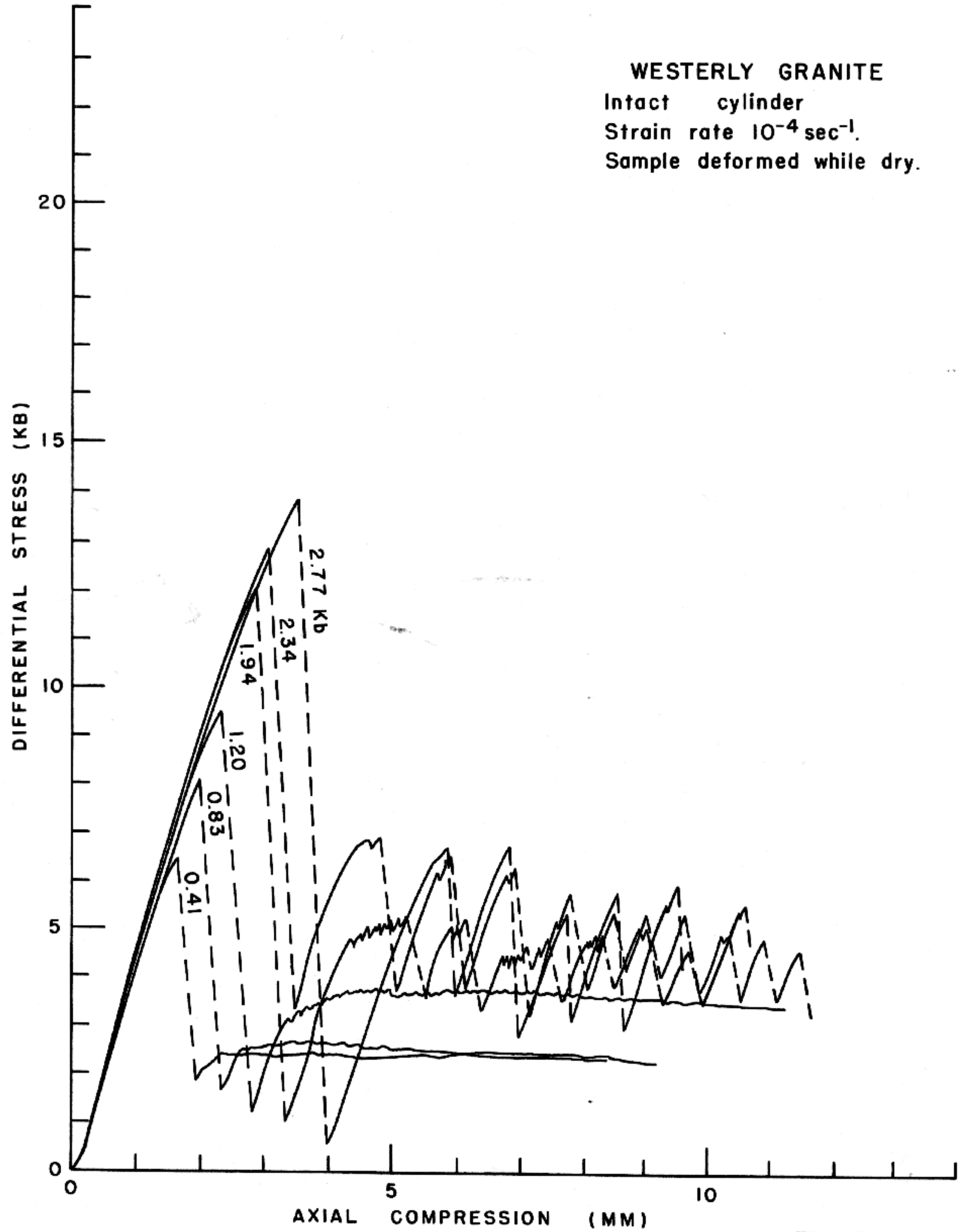
Axial compression strain rates: $10^{-4}sec^{-1}$, $10^{-5}sec^{-1}$, $10^{-6}sec^{-1}$

Comments:

These samples of intact granite were loaded until they failed in compression. If the sample jacket survived the violent failure of the granite, and most did, the deformation was continued by sliding on the resulting fracture plane. The succeeding peaks reflect the axial component of the frictional stress supported across the shear zone.

Stick slip events were observed at confining pressures as low a 0.80 kb. However, most samples below 1.20 kb showed only minor instabilities. Above 1.57 kb violent stick slip always occurred and the stress drops tended to become larger as the confining pressure was increased.

The charts at all strain rates were measured for the amount of creep that preceeded the first stick slip failure. This was found to decrease as the confining pressure was increased. Within the range studied, the amount of creep before slip was independent of the strain rate. This work has been described farther in the paper by Byerlee and Summers, "Stable Sliding Preceeding Stick-slip on Fault Surfaces in Granite at High Pressure" (Pageoph v 113, 1975).



WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
2.77 Kb
2.34
1.94
1.20
0.83
0.41
0
5
10
15
20


FIG, 73

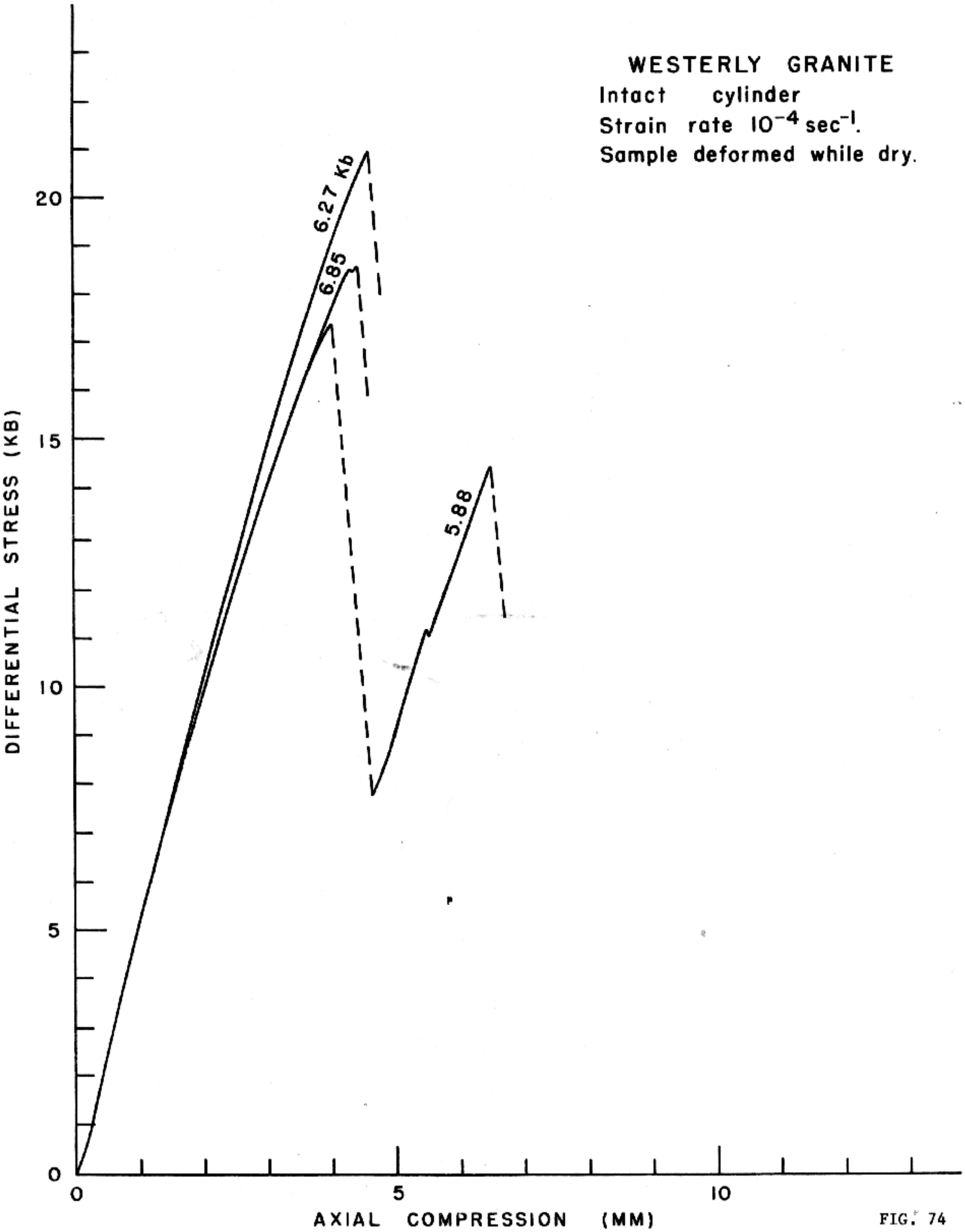

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
6.27 Kb
6.85
5.88
DIFFERENTIAL STRESS (KB)
0
5
10
15
20
0
5
10
AXIAL COMPRESSION (MM)

FIG. 74

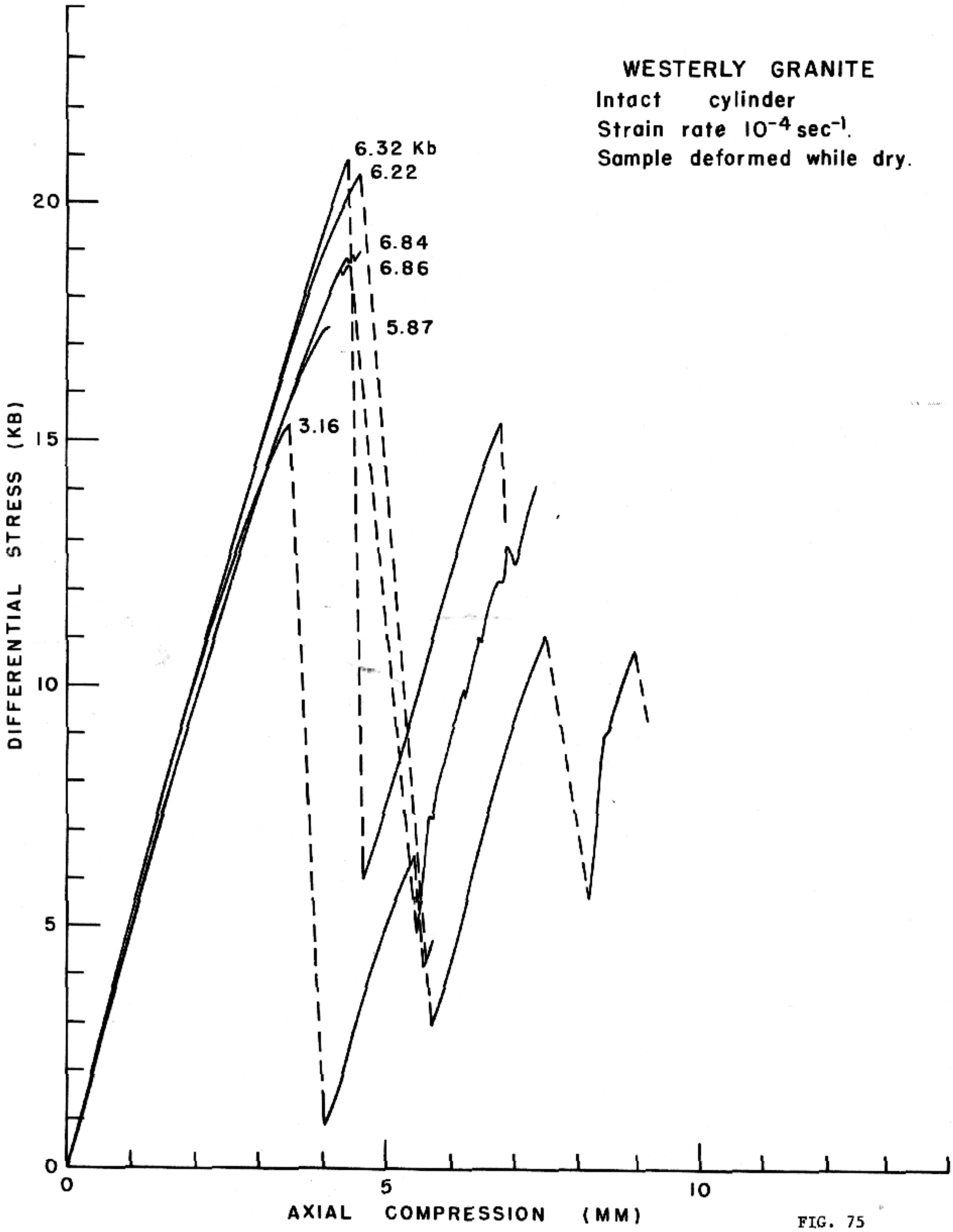

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
6.32 Kb
6.22
6.84
6.86
5.87
3.16
DIFFERENTIAL STRESS (KB)
0
5
10
15
20
0
5
10
AXIAL COMPRESSION (MM)

FIG. 75

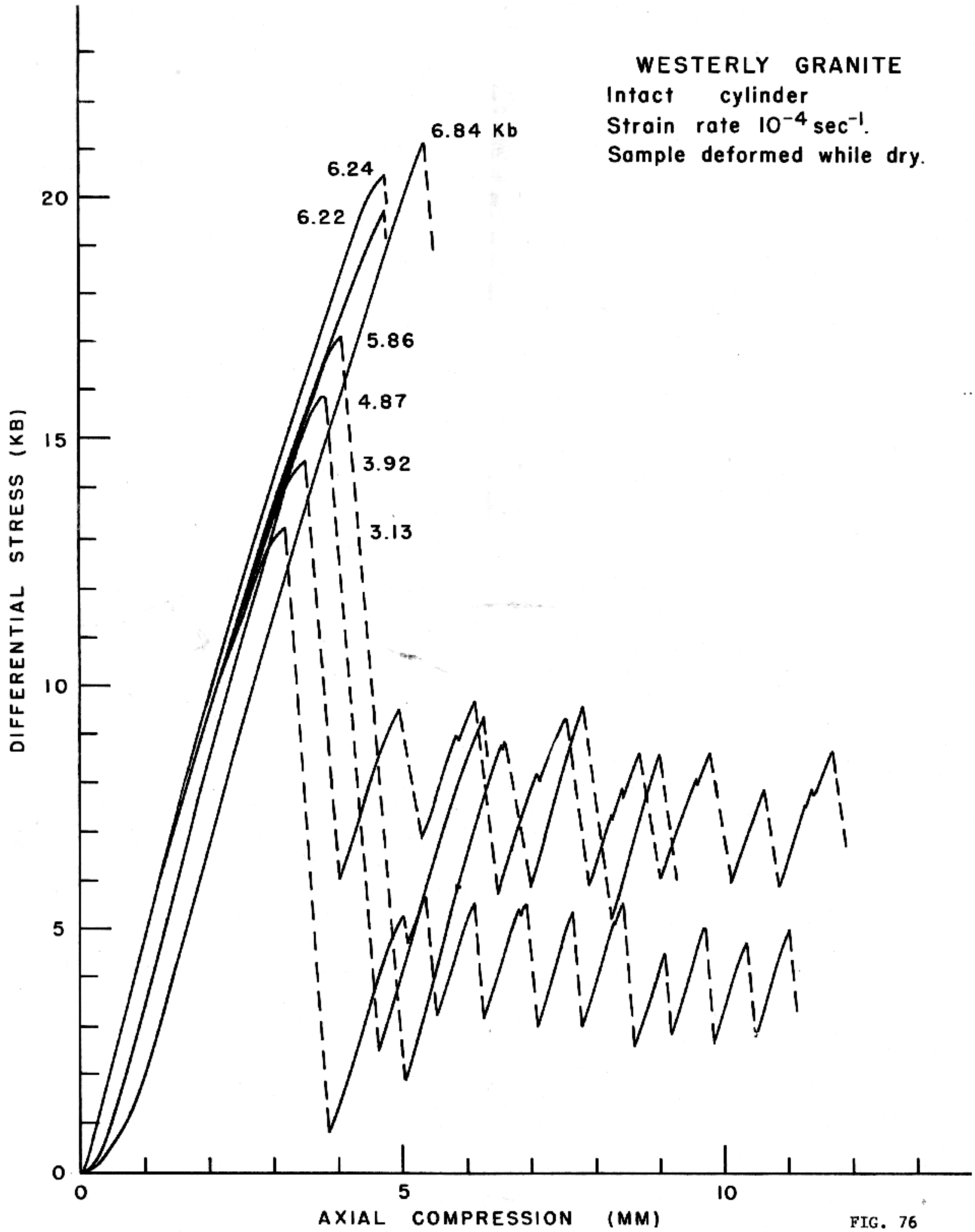

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
6.84 Kb
6.24
6.22
5.86
4.87
3.92
3.13
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
0
5
10
15
20
0
5
10

FIG. 76

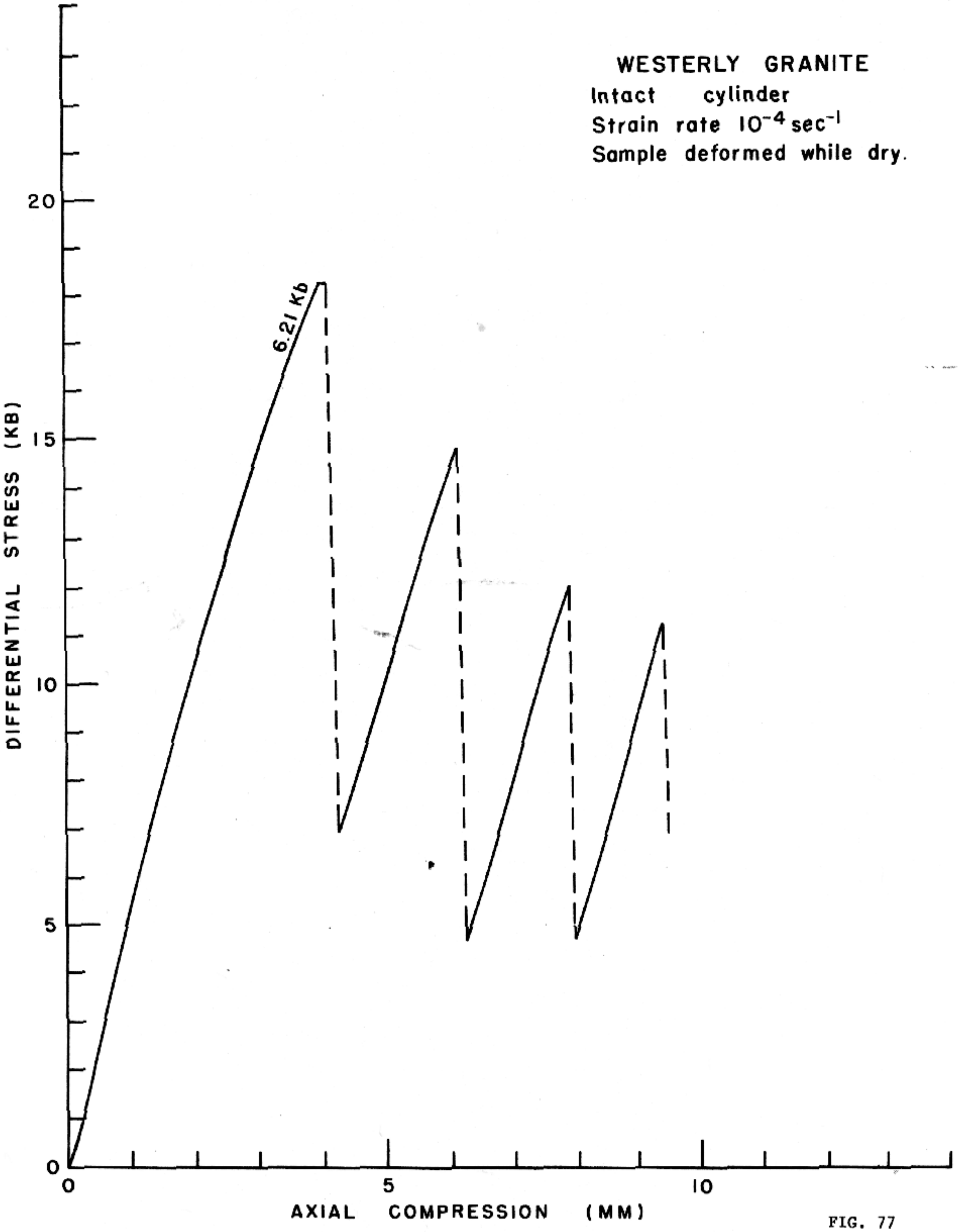

WESTERLY GRANITE
Intact cylinder
Strain rate 10⁻⁴ sec⁻¹
Sample deformed while dry.
6.21 Kb
DIFFERENTIAL STRESS (KB)
20
15
10
5
0
0
5
10
AXIAL COMPRESSION (MM)

FIG. 77

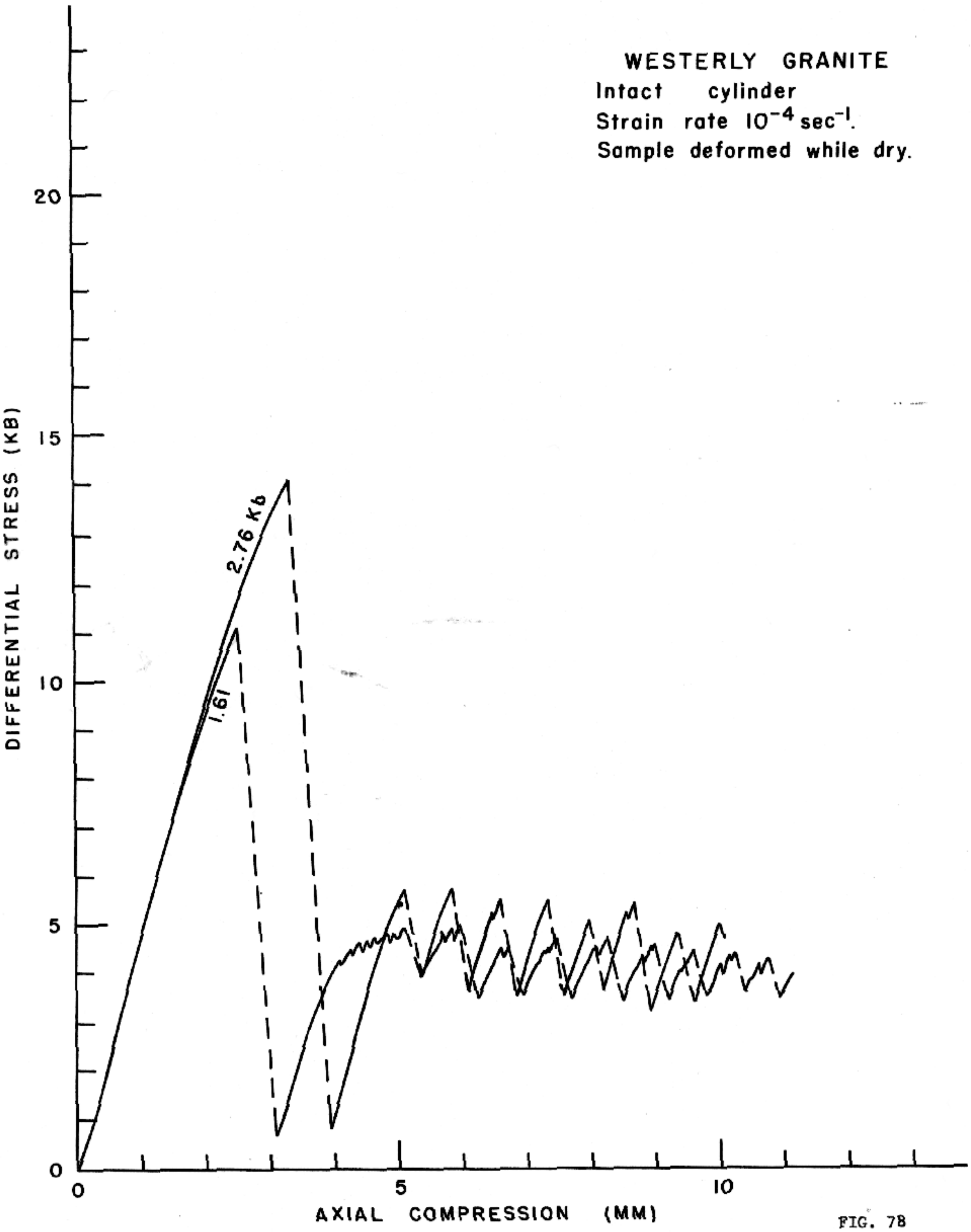

WESTERLY GRANITE
Intact cylinder
Strain rate 10⁻⁴ sec⁻¹.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
2.76 Kb
1.61
0
5
10
15
20

FIG. 78

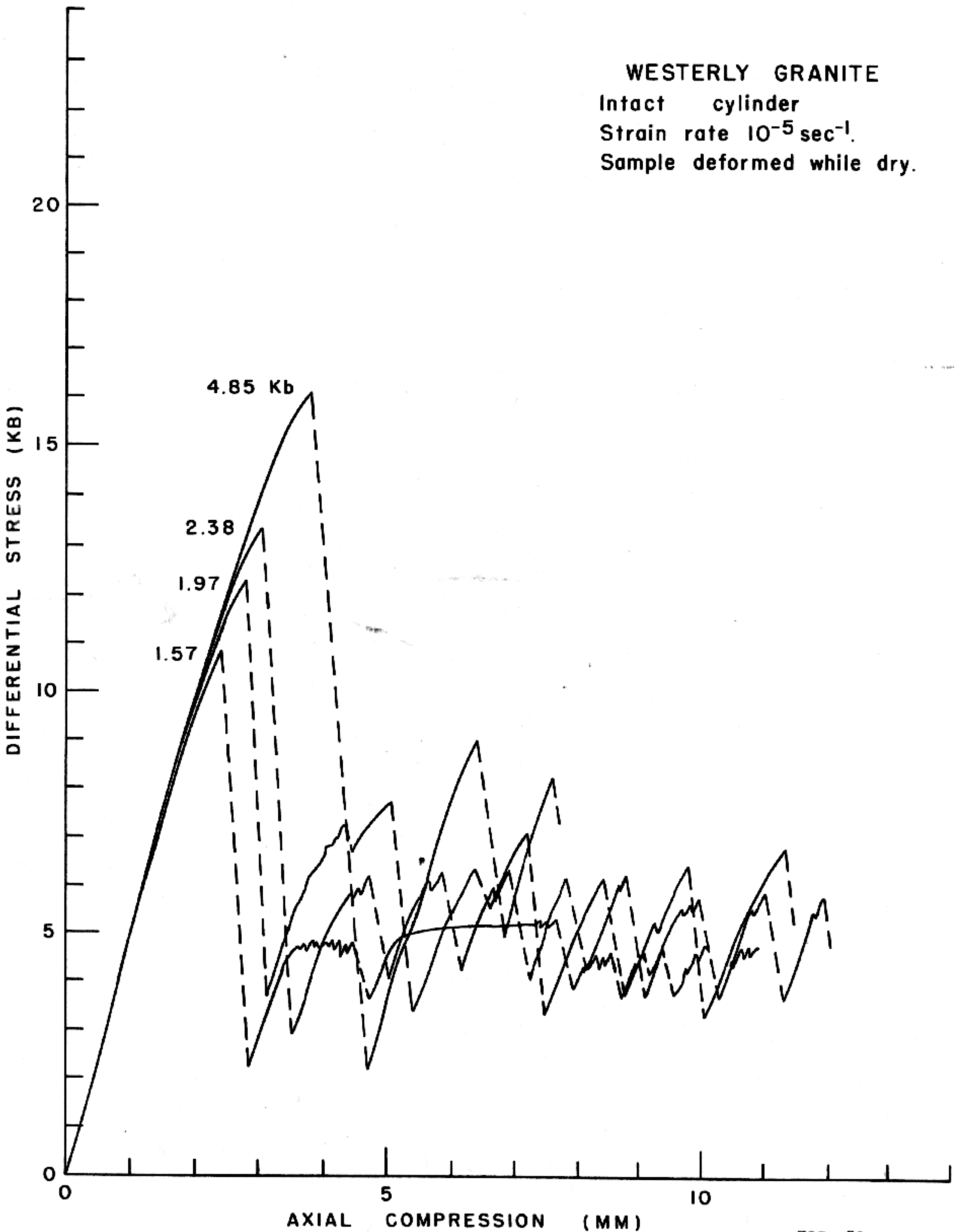

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-5}$ $sec^{-1}$.
Sample deformed while dry.
4.85 Kb
2.38
1.97
1.57
DIFFERENTIAL STRESS (KB)
0
5
10
15
20
AXIAL COMPRESSION (MM)

FIG. 79

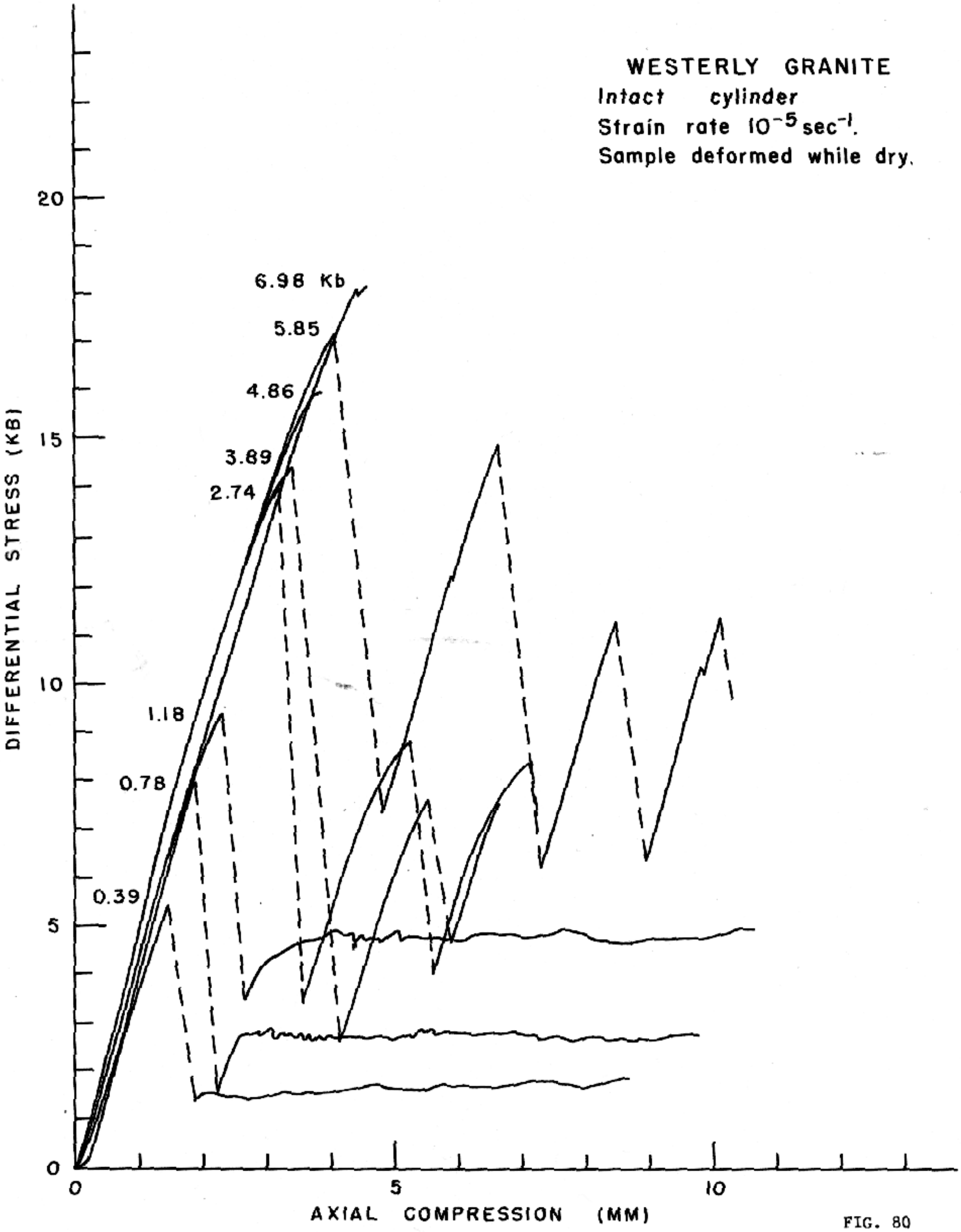

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-5}$ sec$^{-1}$.
Sample deformed while dry.
6.98 Kb
5.85
4.86
3.89
2.74
1.18
0.78
0.39
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
0
5
10
15
20

FIG. 80

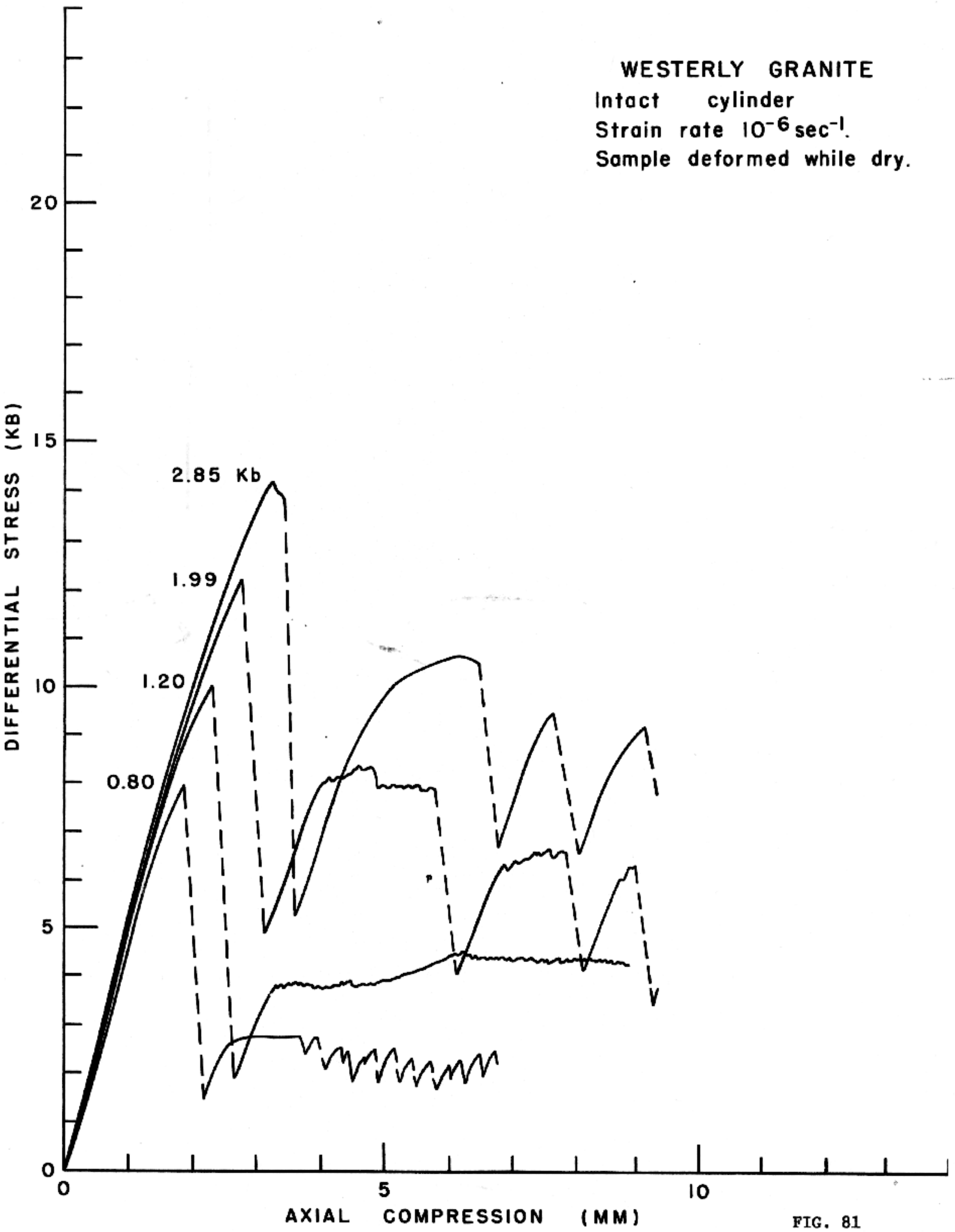
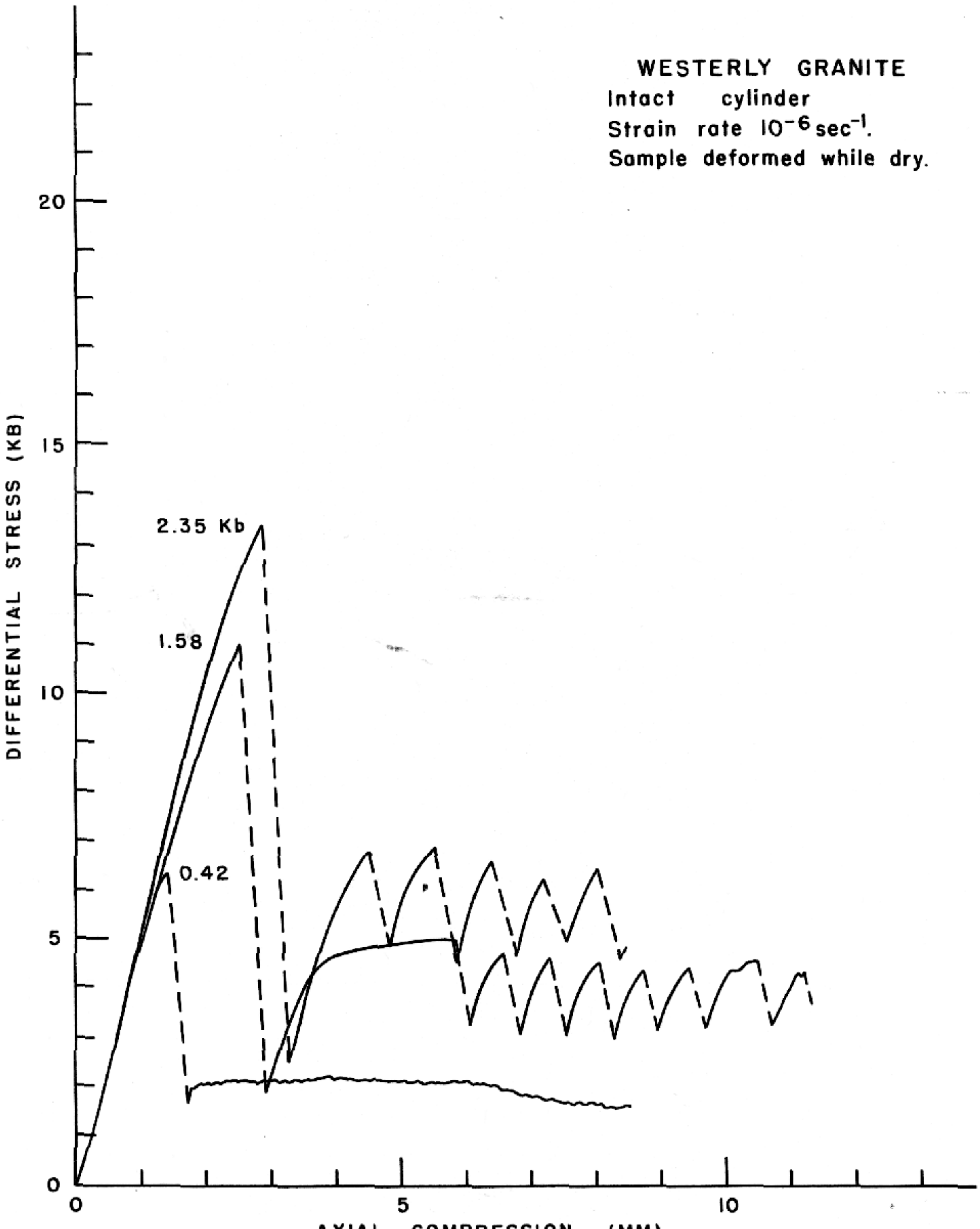

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-6}$ sec$^{-1}$.
Sample deformed while dry.
2.85 Kb
1.99
1.20
0.80
DIFFERENTIAL STRESS (KB)
20
15
10
5
0
5
10
AXIAL COMPRESSION (MM)

FIG. 81



WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-6}$ sec$^{-1}$.
Sample deformed while dry.
2.35 Kb
1.58
0.42
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
0
5
10
15
20


FIG. 82

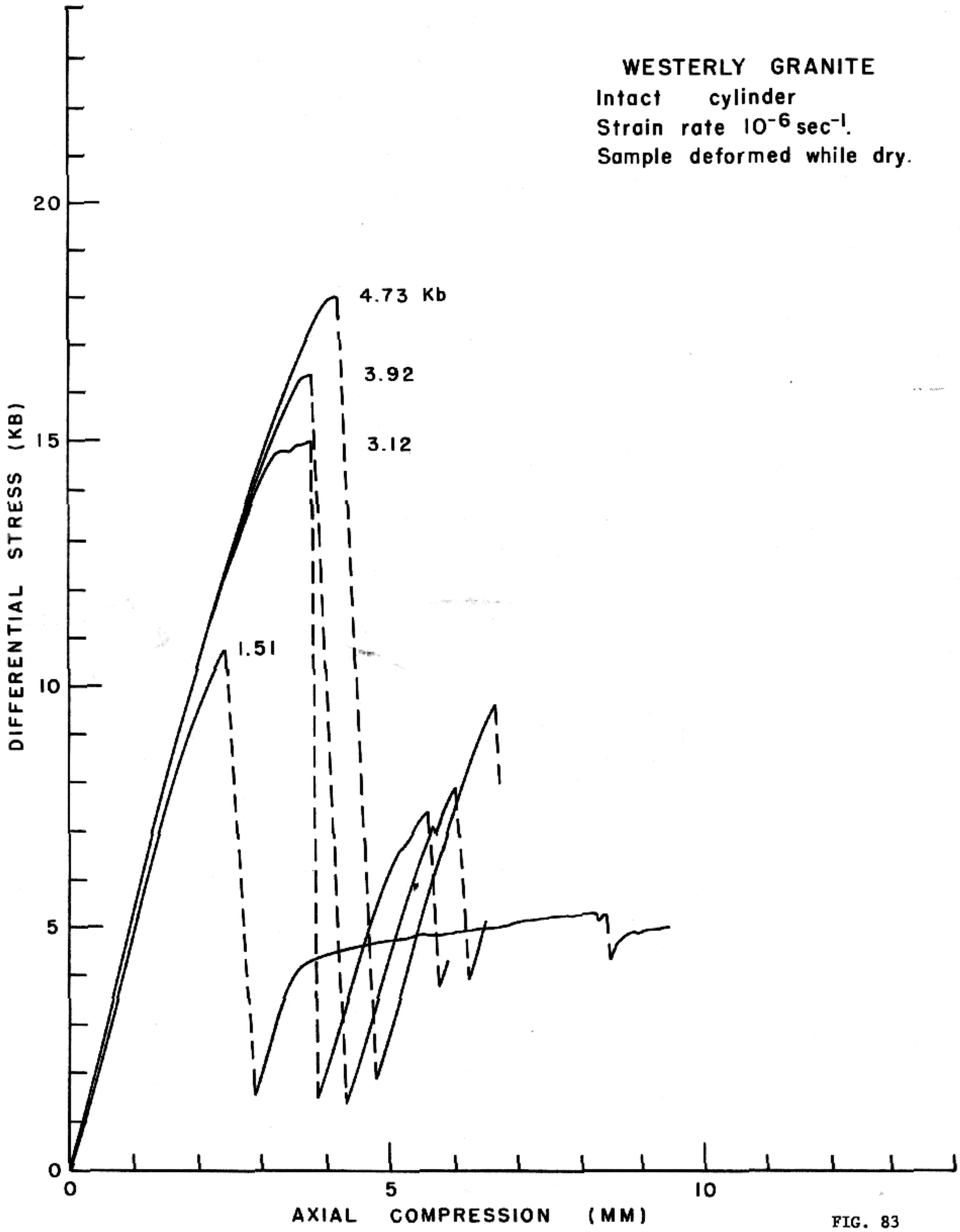
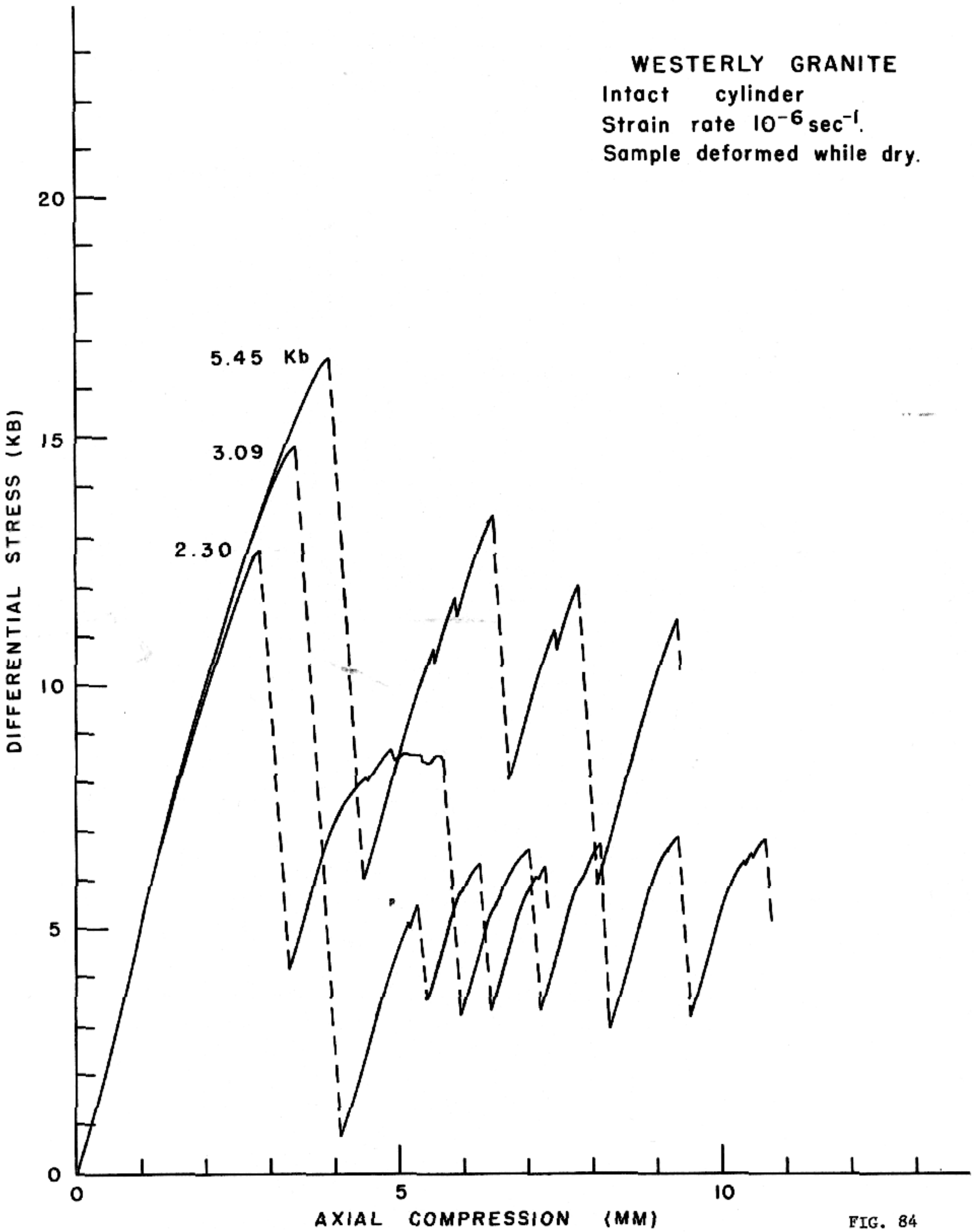

WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-6}$ sec$^{-1}$.
Sample deformed while dry.
4.73 Kb
3.92
3.12
1.51
DIFFERENTIAL STRESS (KB)
20
15
10
5
0
0
5
10
AXIAL COMPRESSION (MM)

FIG. 83



WESTERLY GRANITE
Intact cylinder
Strain rate $10^{-6}$ sec$^{-1}$.
Sample deformed while dry.
5.45 Kb
3.09
2.30
DIFFERENTIAL STRESS (KB)
AXIAL COMPRESSION (MM)
0
5
10
15
20


FIG. 84

Westerly Granite, clean sawcut surfaces

Fig. 85-89 ) 1"x 2.5" cylinders of Westerly Granite with a 30° sawcut. Sliding was on the clean saw cut faces with no insert.

Confining pressures: 0.20 to 6.30 kb

Axial compression strain rates: $10^{-4}sec^{-1}$, $10^{-5}sec^{-1}$, $10^{-6}sec^{-1}$

Comments:

Small unstable stress drops were observed at confining pressures as low as 0.20 kb. As the confining pressure was increased, the stress drops became larger.

A stabilizing tendency was observed in 4 of the samples deformed at $10^{-6}sec^{-1}$ (Fig 89). In those samples run at from 0.39 to 0.98 kb confining pressure, the frequency of stick slip stress drops decreased markedly after the first few millimeters of shearing. This may be due to the creation of a fault gouge zone composed of fragments from the faces of the sawcut.

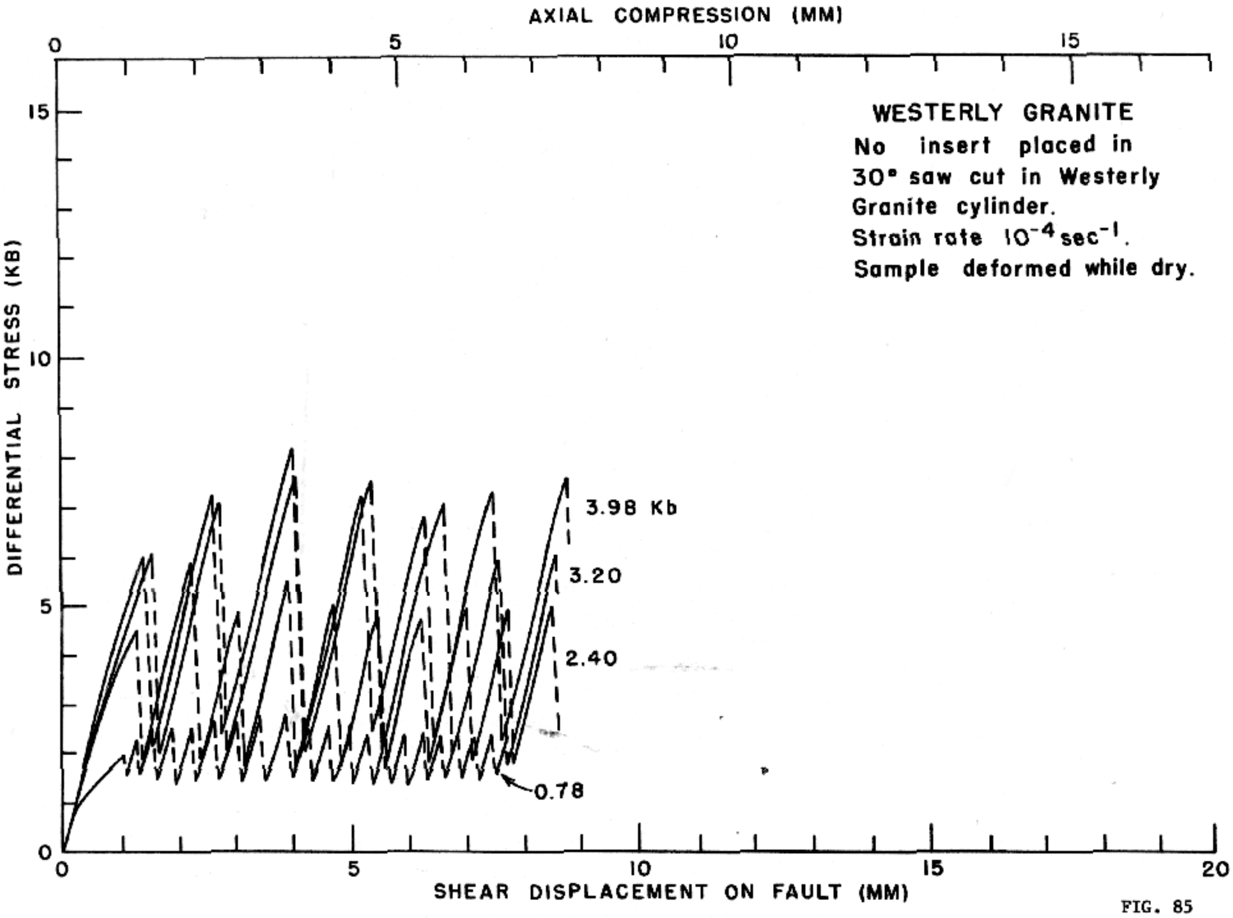

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
No insert placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
3.98 Kb
3.20
2.40
0.78
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 85

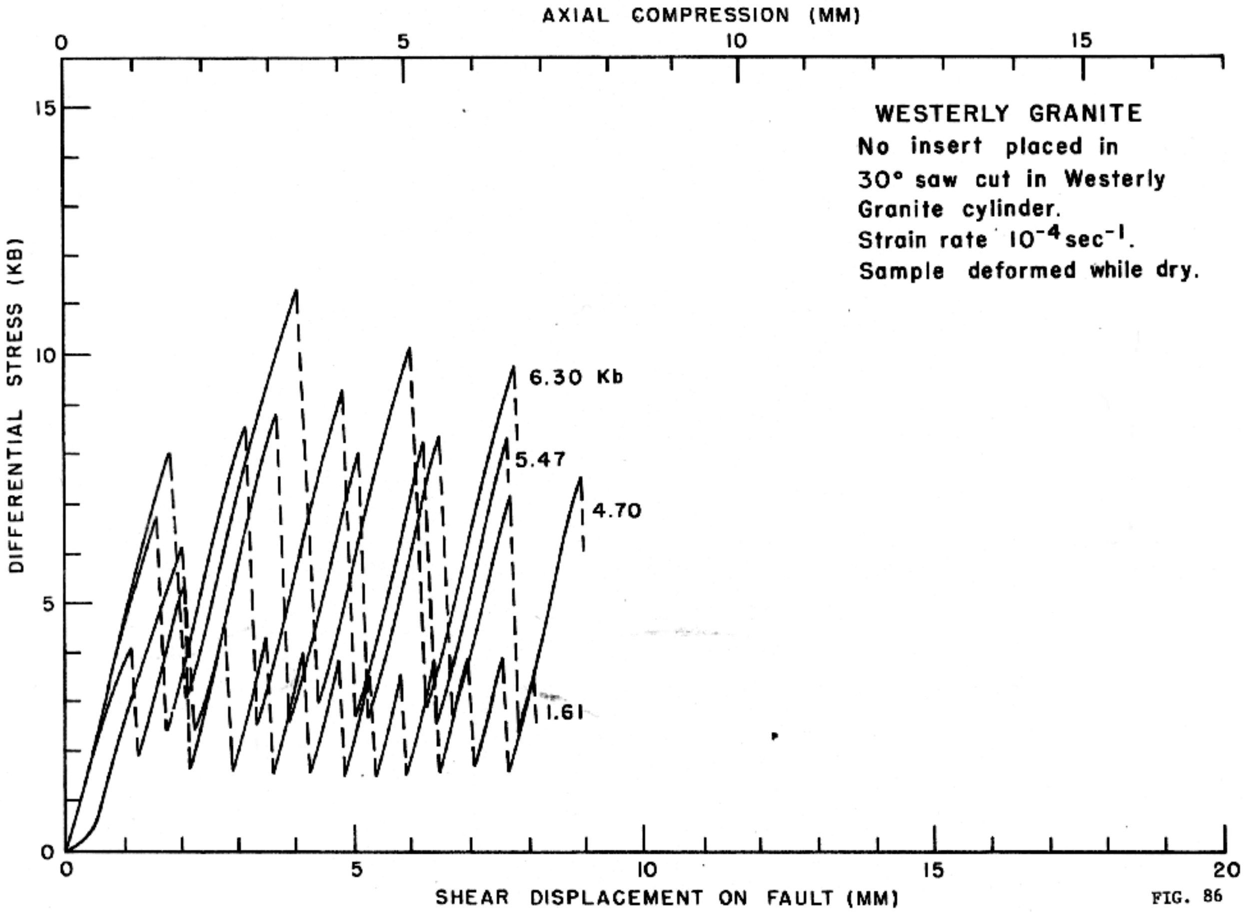

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
No insert placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate 10^-4 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.30 Kb
5.47
4.70
1.61
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 86

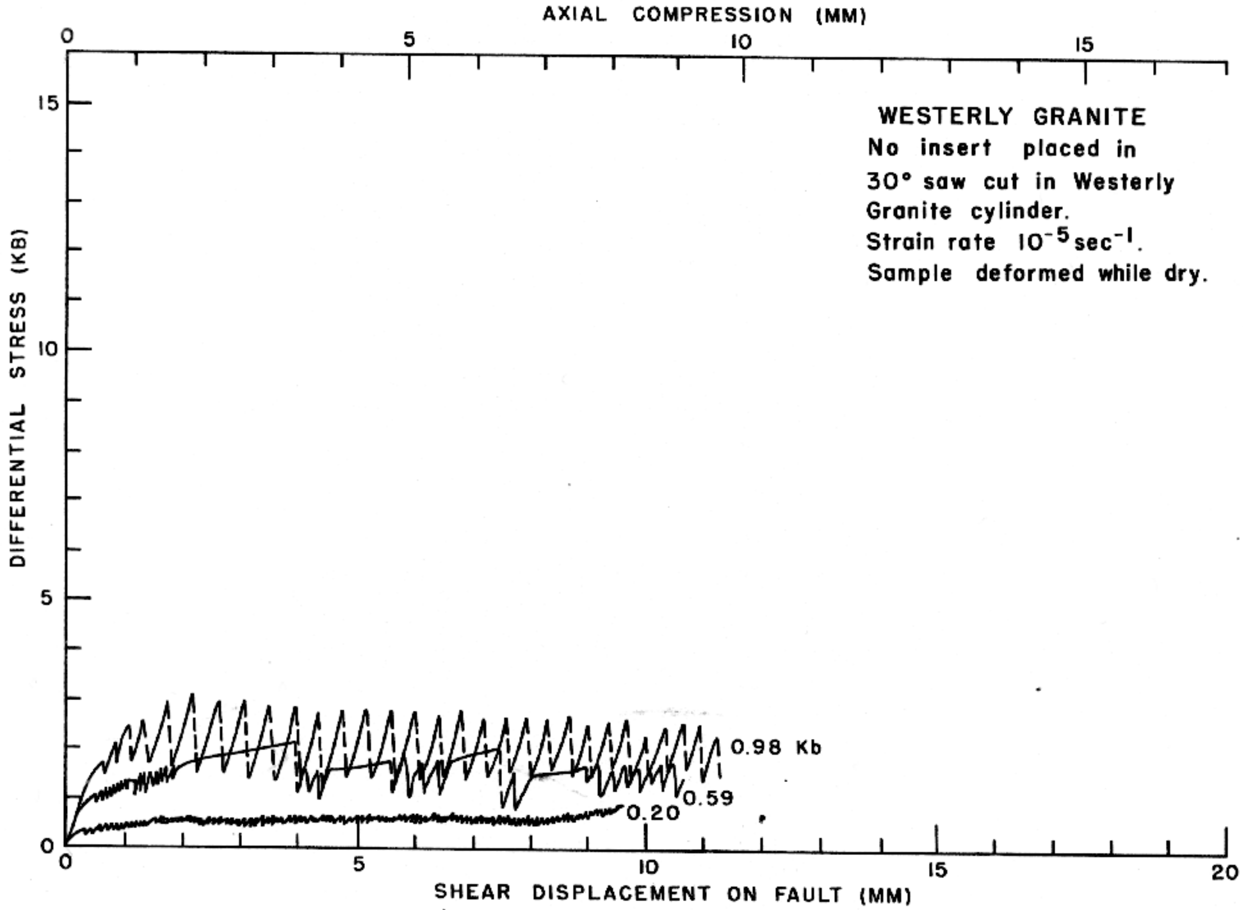

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
No insert placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate 10^-5 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
0.98 Kb
0.59
0.20
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 87

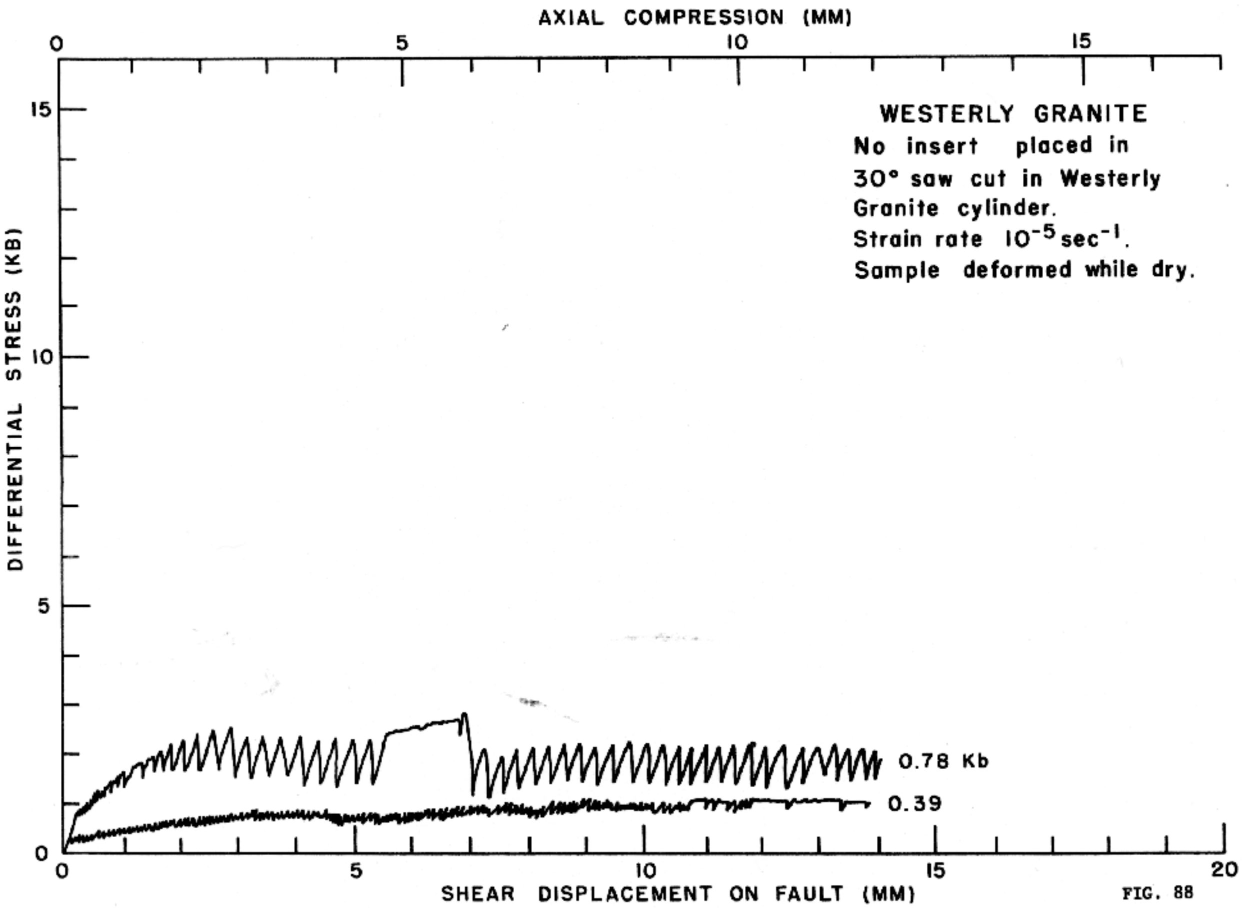

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
No insert placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-5} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
0.78 Kb
0.39
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 88

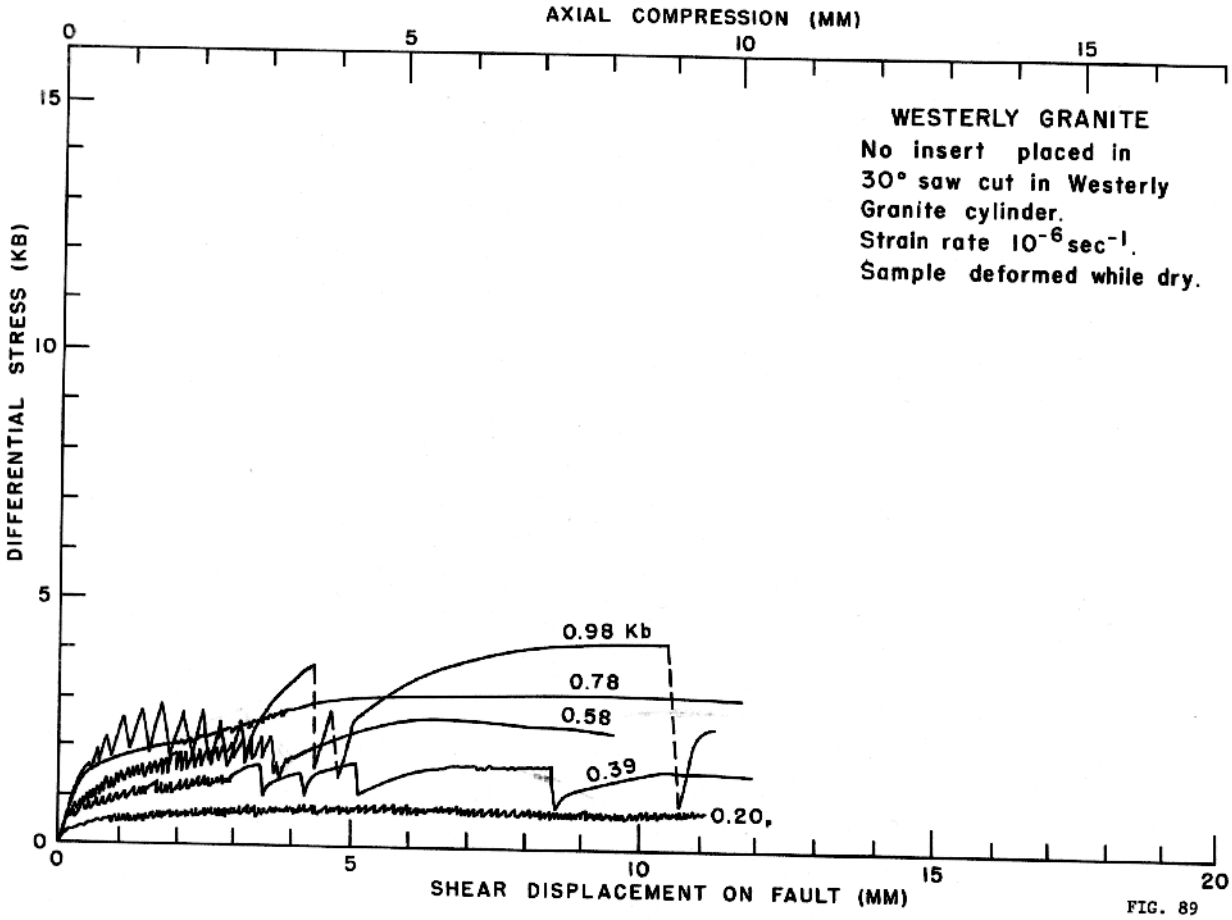

AXIAL COMPRESSION (MM)
0
5
10
15
DIFFERENTIAL STRESS (KB)
15
10
5
0
WESTERLY GRANITE
No insert placed in
30° saw cut in Westerly
Granite cylinder.
Strain rate $10^{-6}$ sec$^{-1}$.
Sample deformed while dry.
0.98 Kb
0.78
0.58
0.39
0.20
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 89

Westerly Granite, crushed

Fig. 90-101 ) Crushed Westerly Granite, grain sizes $\leq$ 170 mesh, 20 mesh. Layer thickness of 0.010, 0.025, 0.040, 0.080, and 0.160 inches.

Confining pressures: 0.74 to 6.27 kb

Axial compresison strain rate: $10^{-4}$ $sec^{-1}$

Comments:

The variation in gouge thickness resulted in marked differences in the stability of sliding, with the thicker layers tending to be more stable. The gouge thickness did not greatly affect the maximum stress level at a given confining pressure.

With the 0.010" samples run at 1.54 to 1.57 kb there was an initial period of stable sliding which ended with a series of small stress drops immediately preceeding the large stress drops.

The two different grain size fractions used did not produce any significantly different results in terms of stress levels or stablility Examining the two size fractions after several of the experiments showed that both had been further crushed, with the smalller grains still being recognizably smaller.

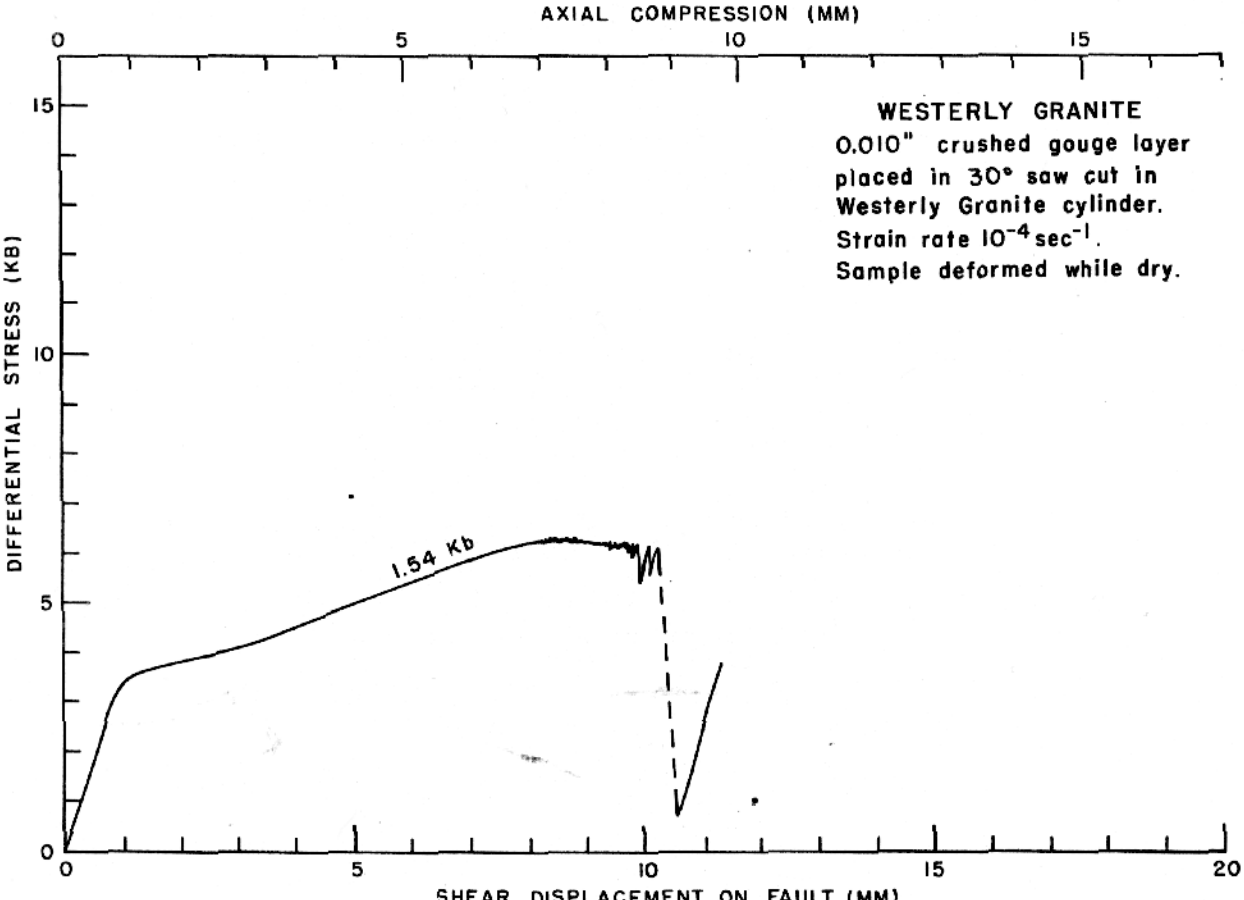

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.010" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
1.54 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 90

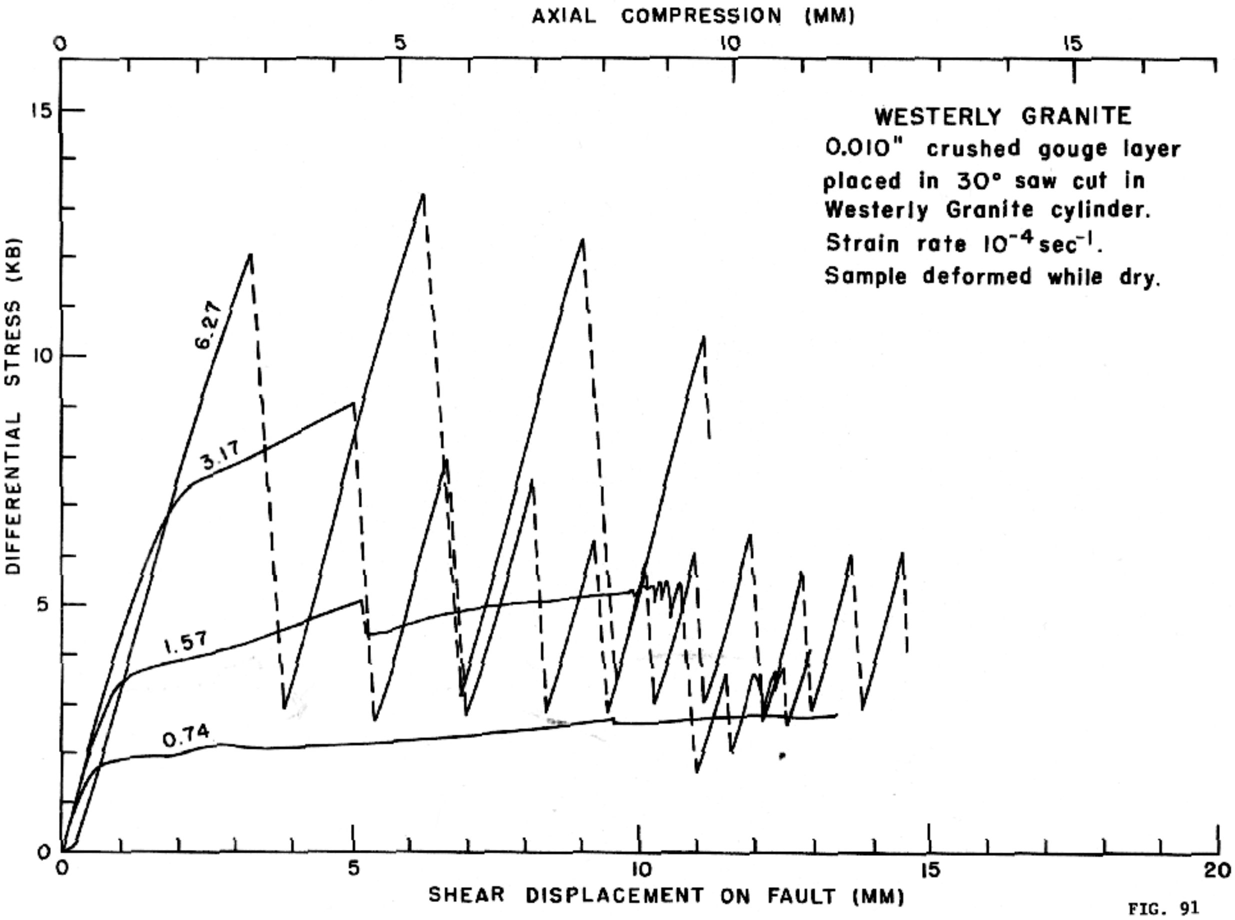

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.010" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27
3.17
1.57
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 91

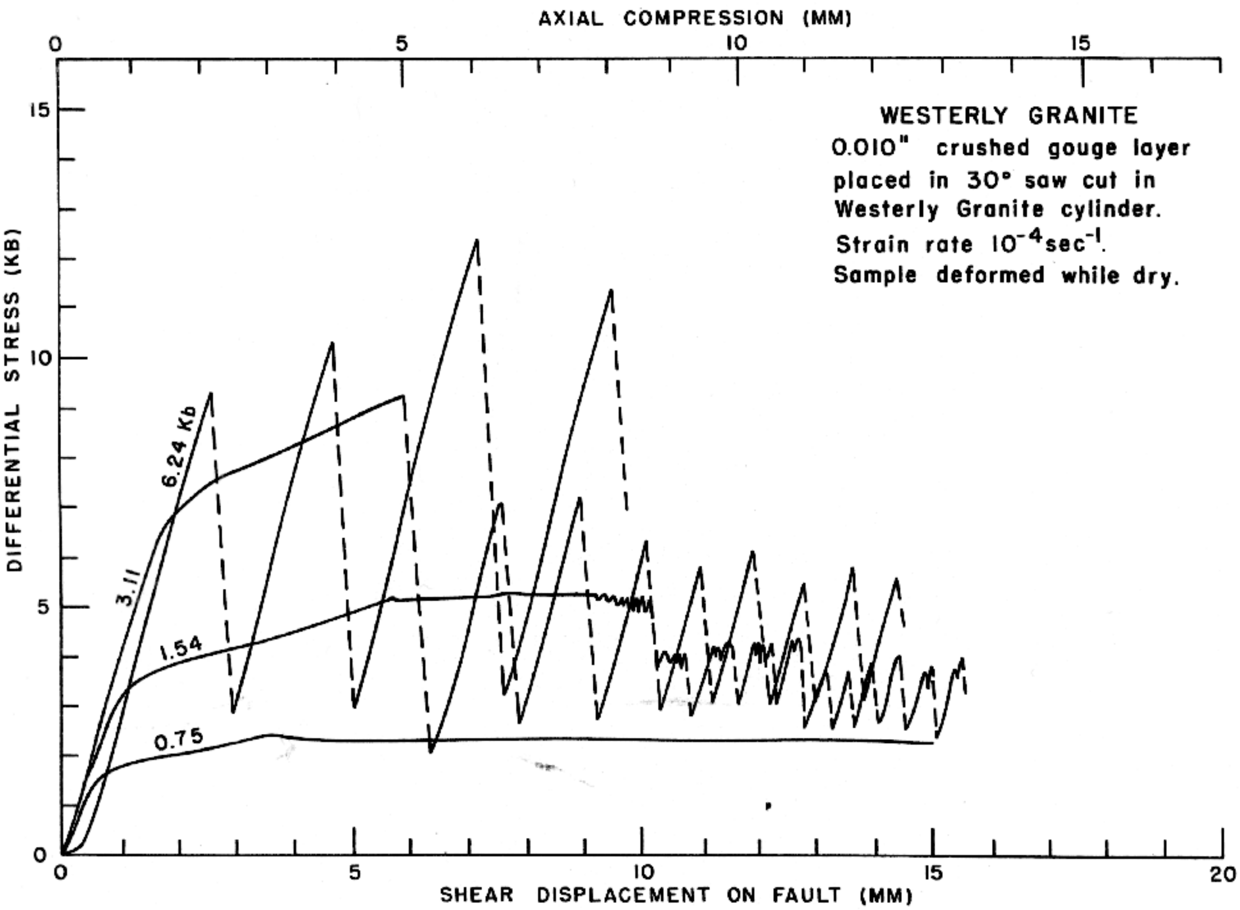

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.010" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.24 Kb
3.11
1.54
0.75
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 92

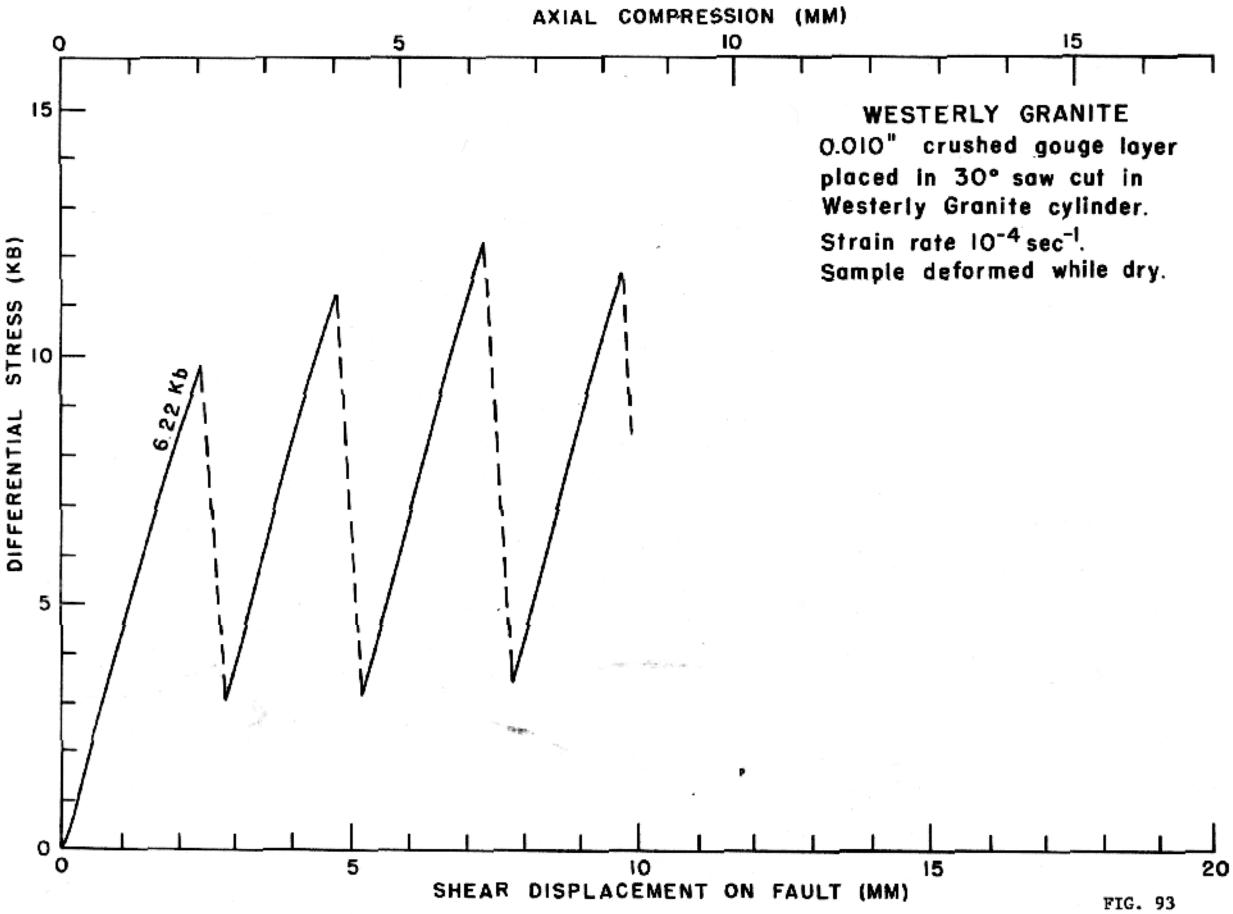

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.010" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.22 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 93

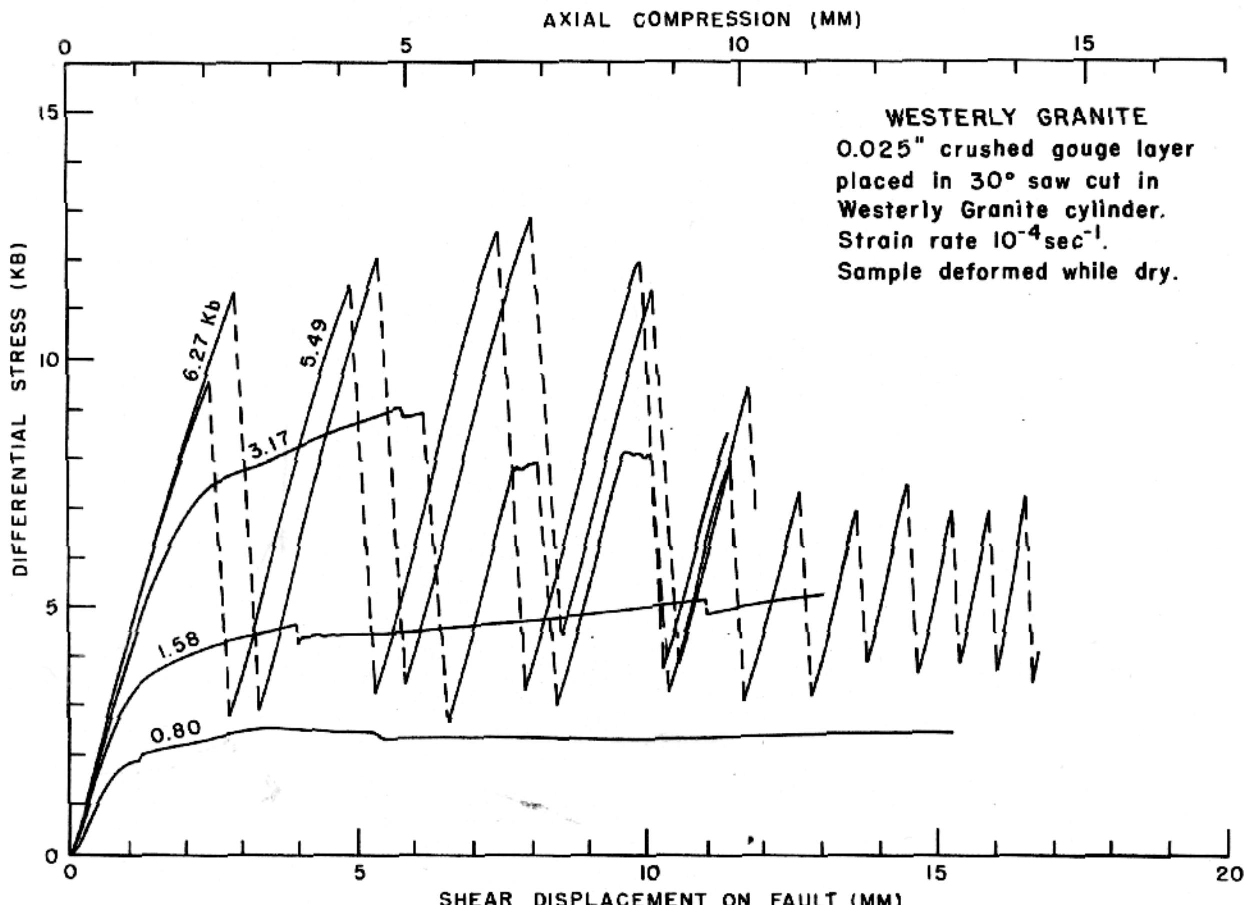

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.025" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate 10^-4 sec^-1.
Sample deformed while dry.
6.27 Kb
5.49
3.17
1.58
0.80
DIFFERENTIAL STRESS (KB)
0
5
10
15
SHEAR DISPLACEMENT ON FAULT (MM)
20

FIG. 94

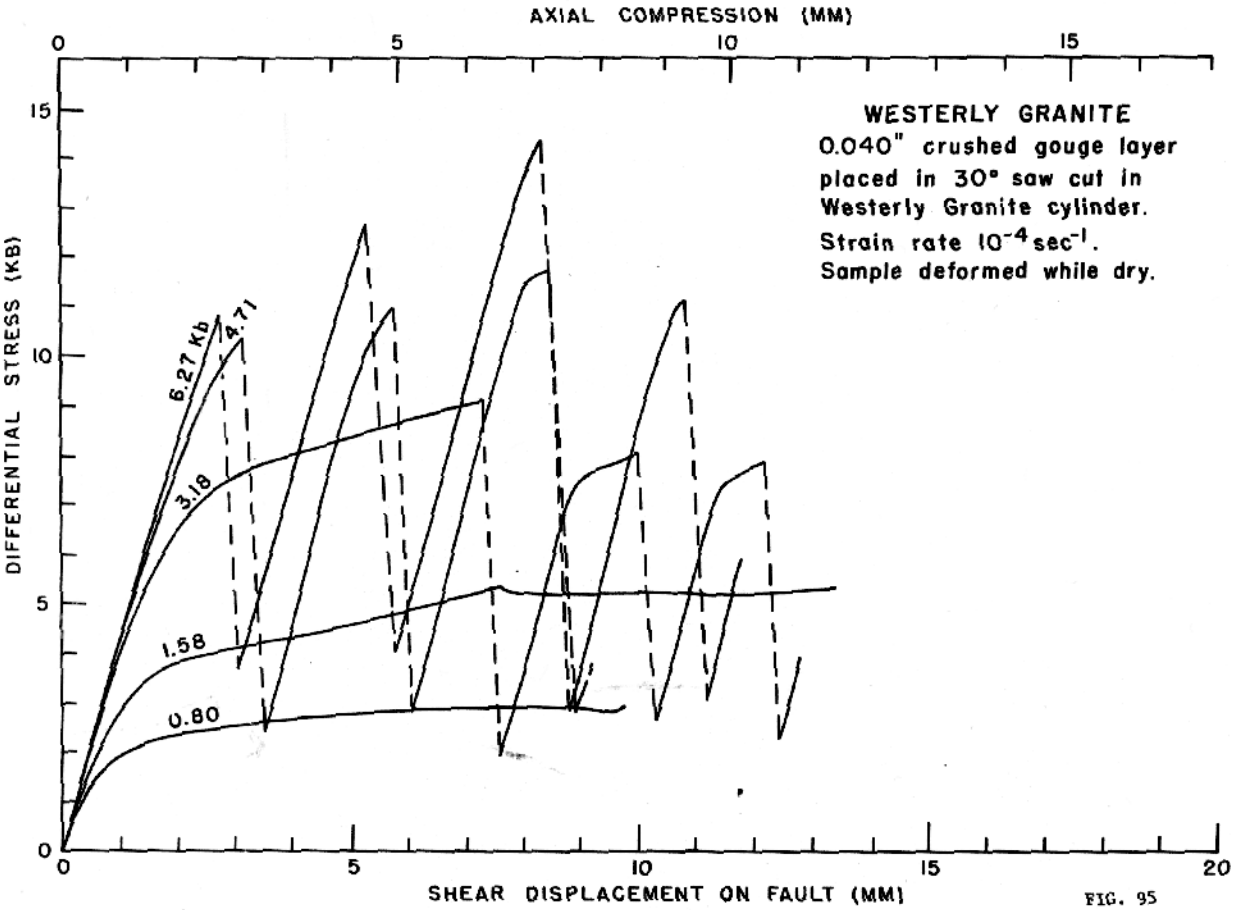

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.040" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
4.71
3.18
1.58
0.80
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 95

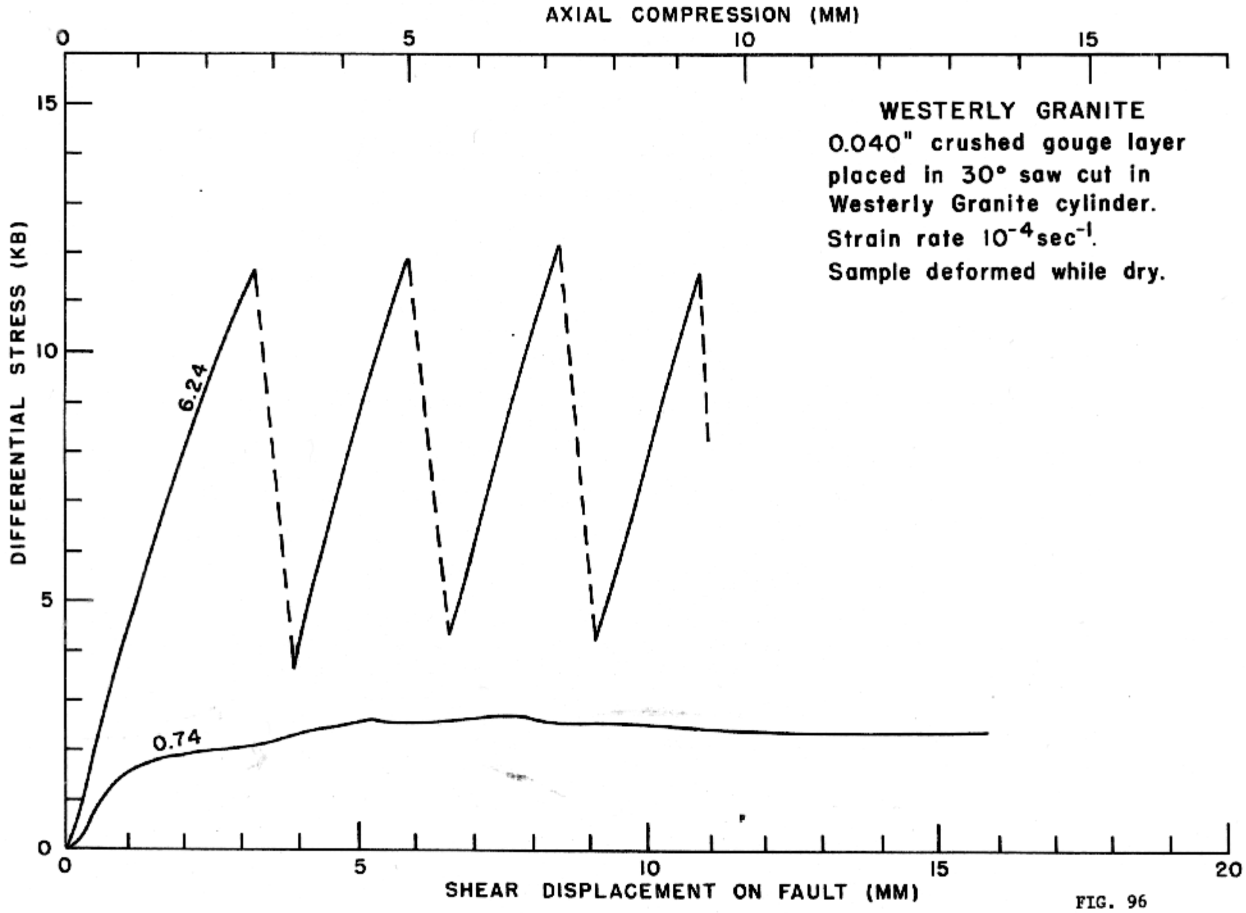

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.040" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4} sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
0
5
10
15
6.24
0.74
SHEAR DISPLACEMENT ON FAULT (MM)
0
5
10
15
20

FIG. 96

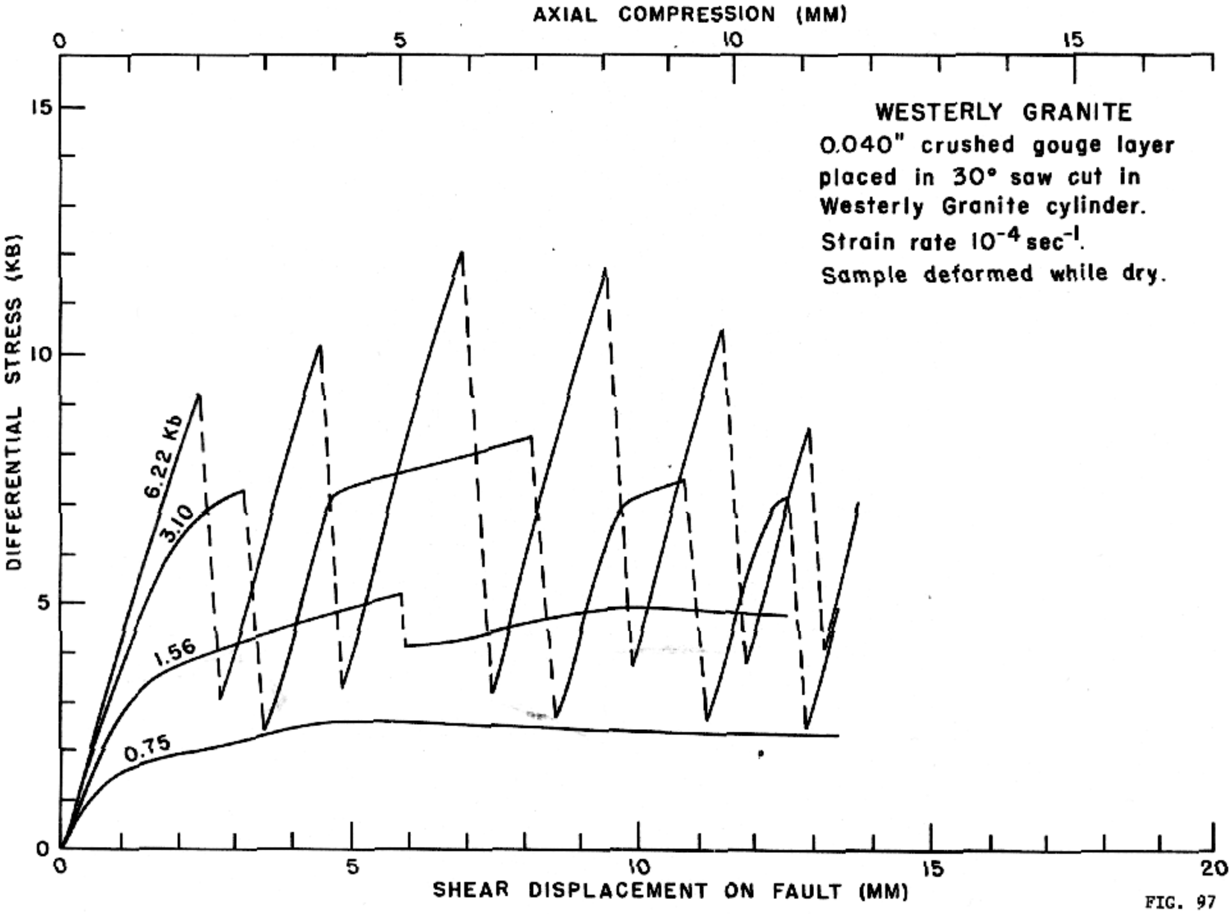

AXIAL COMPRESSION (MM)
WESTERLY GRANITE
0.040" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
6.22 Kb
3.10
1.56
0.75
DIFFERENTIAL STRESS (KB)
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 97

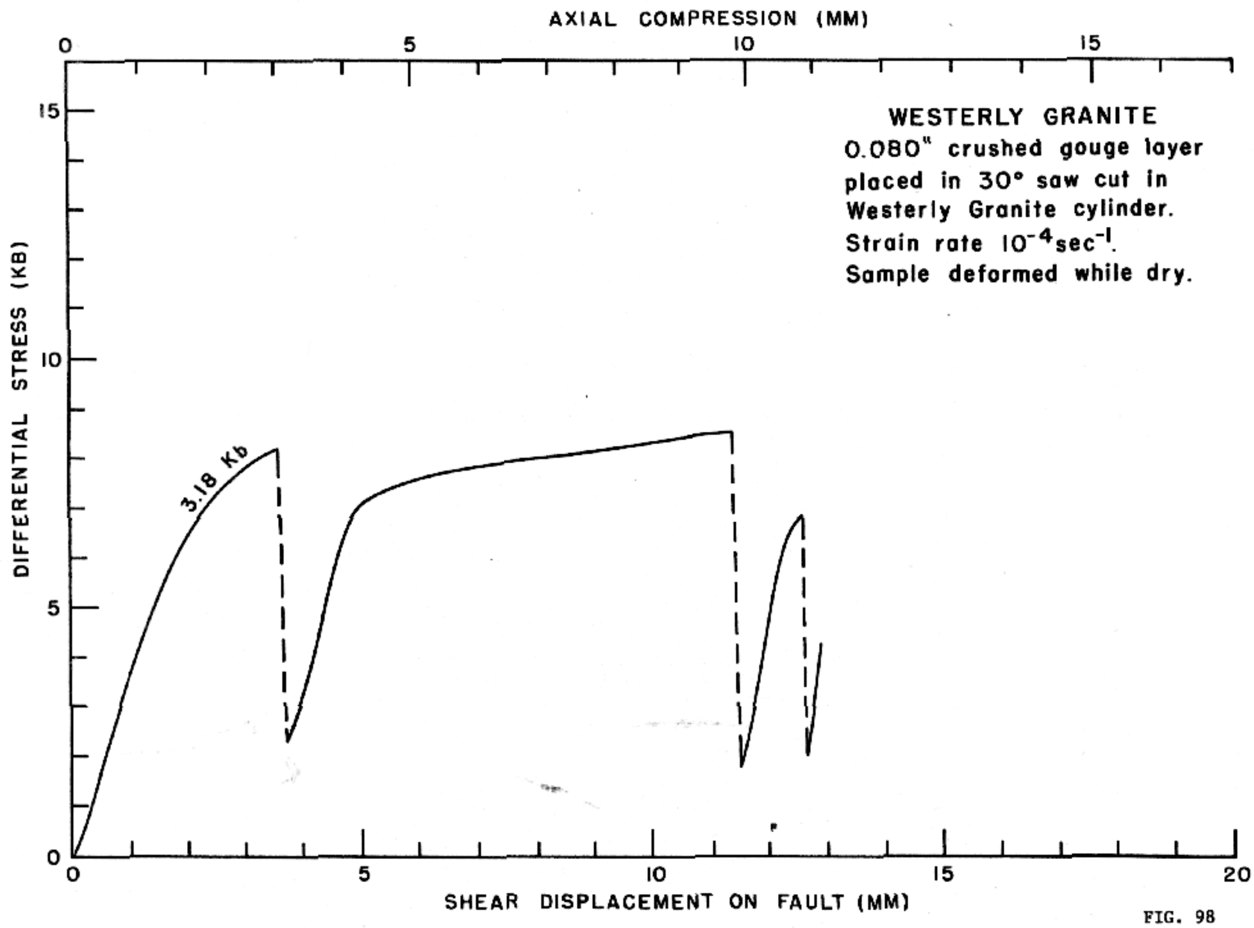
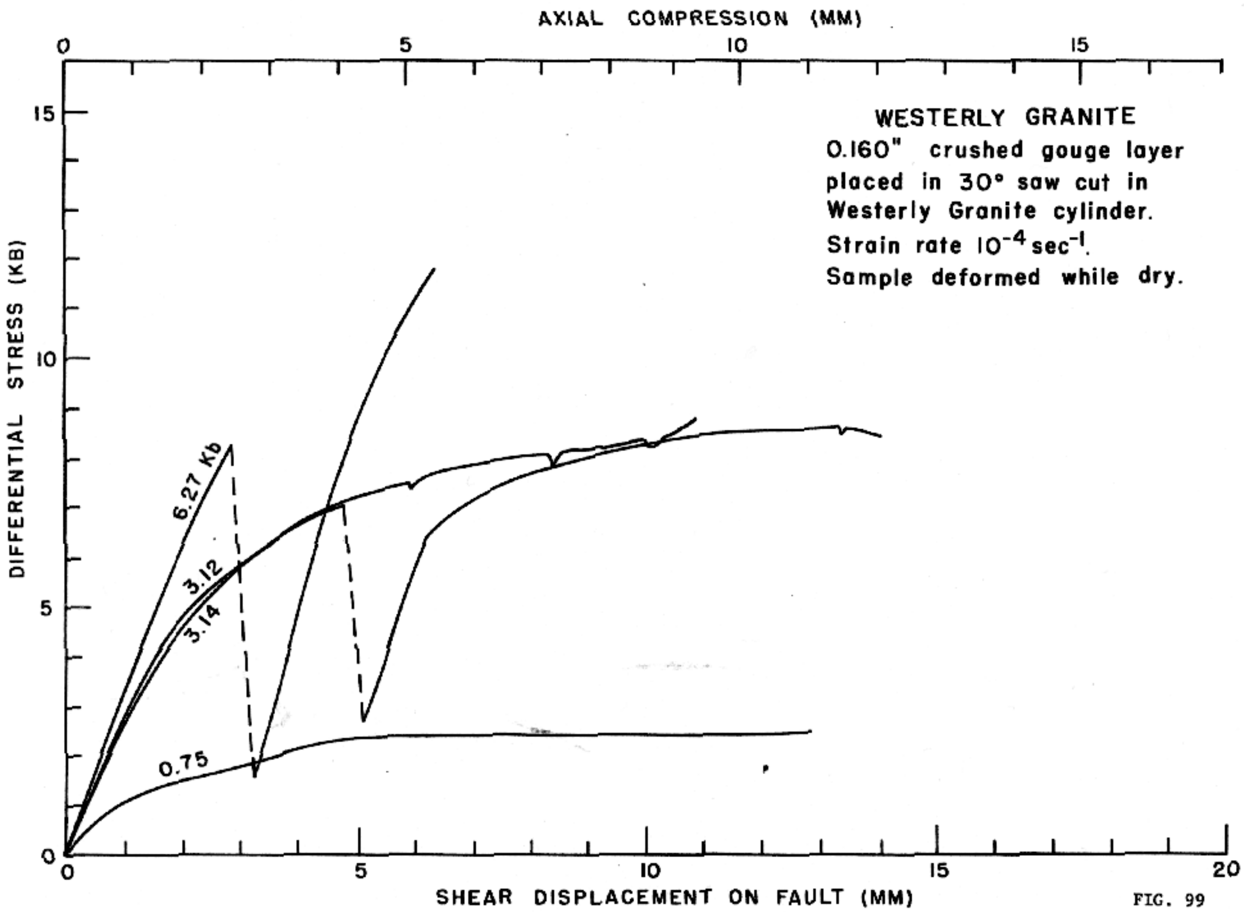

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.080" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate 10^-4 sec^-1.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
3.18 Kb
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 98


AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.12
3.14
0.75
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)
FIG. 99

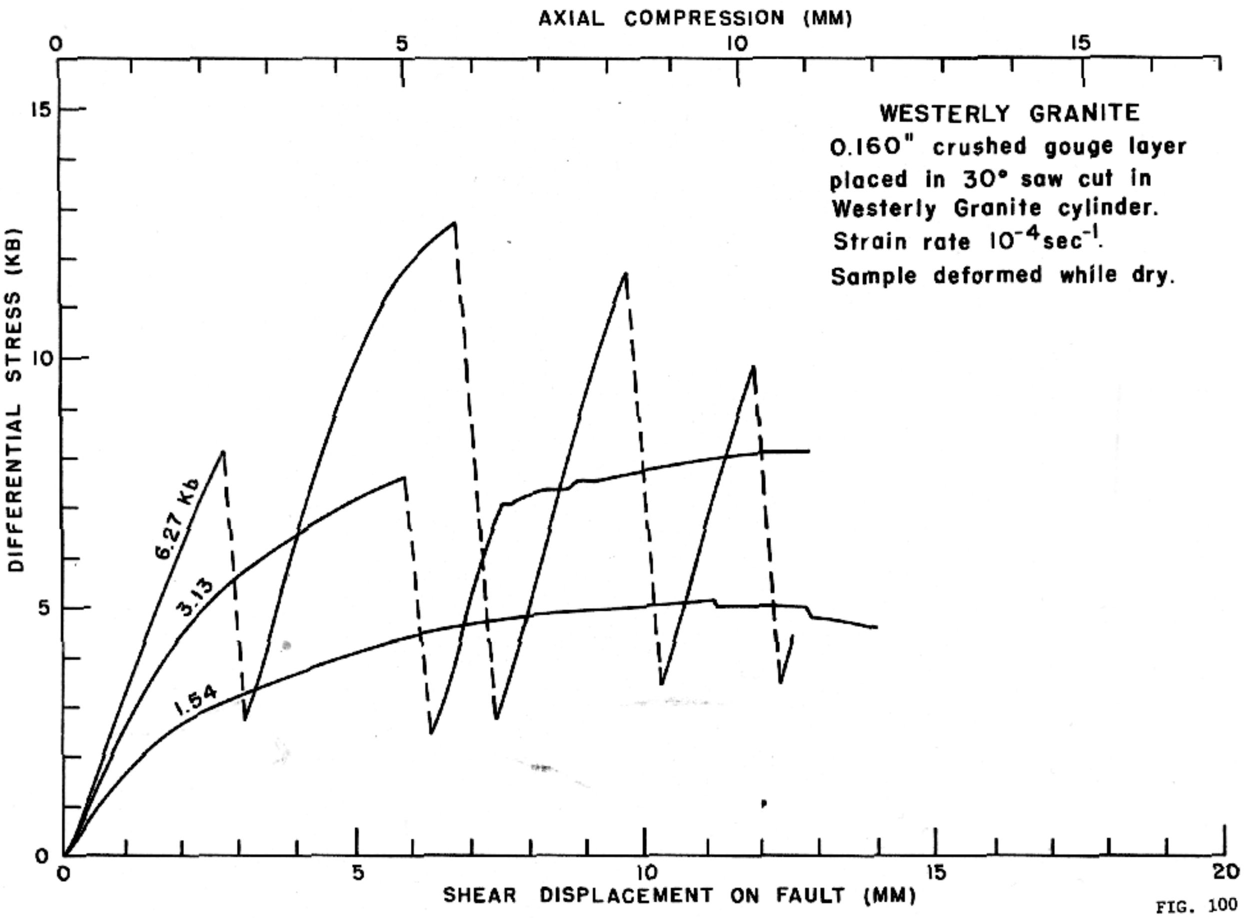

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.160" crushed gouge layer placed in 30° saw cut in Westerly Granite cylinder.
Strain rate $10^{-4}$ sec$^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.27 Kb
3.13
1.54
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 100

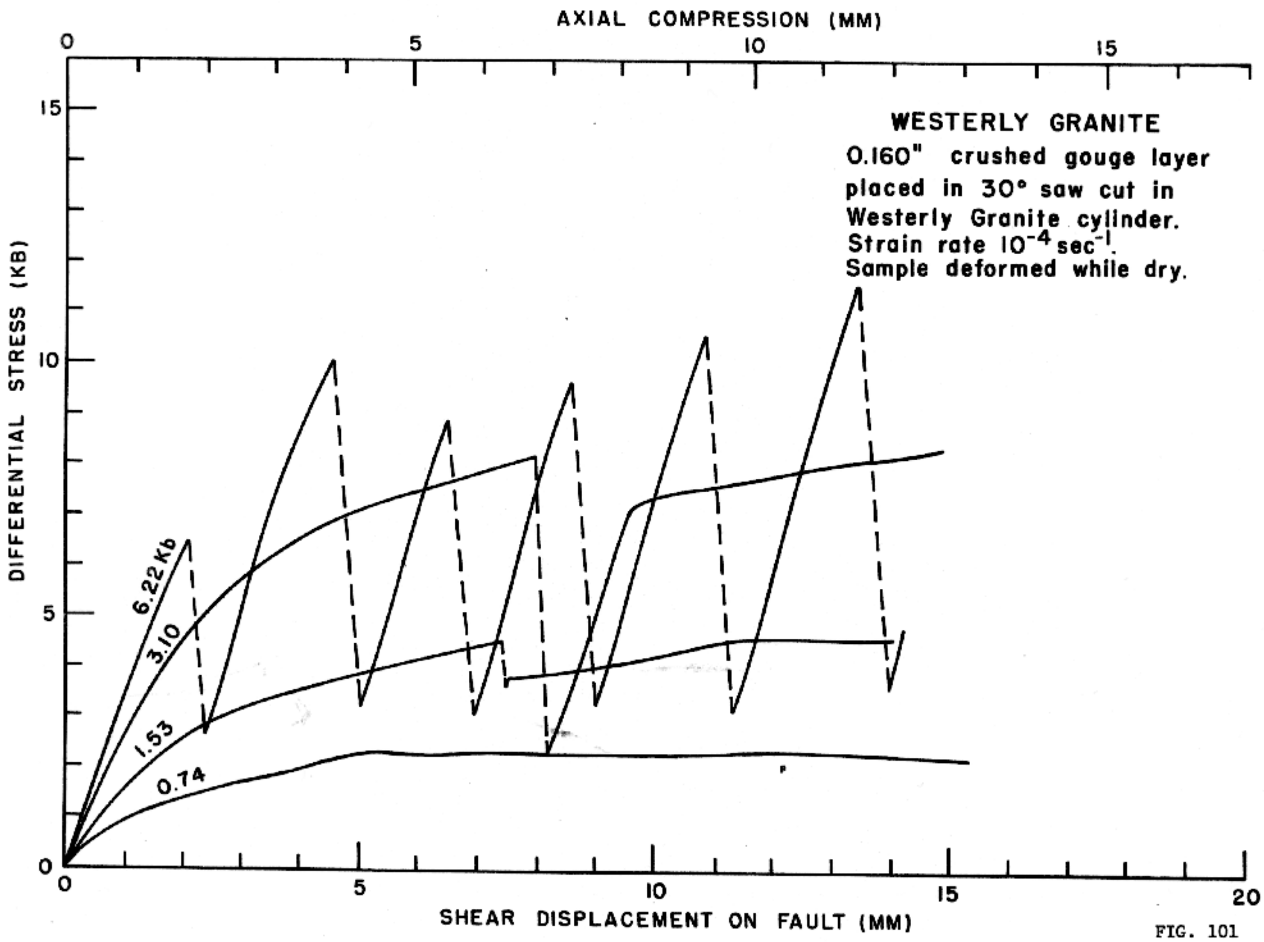

AXIAL COMPRESSION (MM)
0
5
10
15
WESTERLY GRANITE
0.160" crushed gouge layer
placed in 30° saw cut in
Westerly Granite cylinder.
Strain rate $10^{-4}$ $sec^{-1}$.
Sample deformed while dry.
DIFFERENTIAL STRESS (KB)
15
10
5
0
6.22 Kb
3.10
1.53
0.74
0
5
10
15
20
SHEAR DISPLACEMENT ON FAULT (MM)

FIG. 101