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# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1971/130

# LABORATORY MEASUREMENTS ON DRILL CORES FROM THE PROPOSED TUGGERANONG SEWER LINE, A.C.T.

by

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## SUMMARY

The mechanical properties of a number of dacite and rhyodacite drill core samples have been determined on behalf of the Department of Works. The samples were obtained from drill holes along the proposed Tuggeranong sewer line. With the exception of the rhyodacites we found the rock to be mechanically quite strong. The results predict a low penetration rate for mechanical tunnel boring. The rhyodacites were considerably weaker mechanically, but the tunnel penetration rate would still be quite low.

## 1. INTRODUCTION

This report describes the measurement of mechanical properties carried out on NX-type drill core samples from the proposed Tuggeranong sewer line. The measurements were requested by the Department of Works as information for tunnelling tenders.

Several of the tests included in this report were made on behalf of the Bureau (BMR) by outside organizations and paid for by the Department of Works. The Snowy Mountains Engineering Corporation (SMEC) carried out the shear strength and some of the uniaxial compressive strength tests. The Mining Department of the University of Melbourne did the calibration measurements for drillability indexes. The BMR work was carried out by M. Idnurm (Geophysicist), D. Tarlinton (Trainee Technical Officer) and R. Eaton (Technical Assistant), of the Rock Measurements Group.

## 2. GEOLOGY AND GEOPHYSICS

Separate records covering the geological and geophysical aspects of the proposed sewer line are being prepared by the Engineering Geology and Geophysics Groups of BMR. Two types of rock were submitted for the tests: dacites and rhyodacites. The rhyodacites and two of the dacite samples were classified as slightly weathered. The remaining samples were classified as fresh rock.

## 3. MEASUREMENT TECHNIQUES

### Elastic properties

The elastic properties were measured on drill core samples 11 to 18 cm long. The samples were in a laboratory-dry condition.

The longitudinal sound velocities were determined from the transmission times of a sound pulse using a Cawkell ultrasonic instrument type UCT2. The pulse consisted of a damped sine wave of frequency 150kHz.

Young's modulus and Poisson's ratio were calculated from the longitudinal velocity and the resonance frequency of the drill core sample. A Cawkell instrument type SCT4 was used for the resonance measurements. The elastic moduli consequently represent the dynamic rather than the static values. We estimate the experimental errors in velocity and Young's modulus to be within 5%, and in Poisson's ratio within 10%.

### Hardness

The hardnesses were determined by the Shore scleroscope method which measures the height of rebound of a diamond-tipped weight from a flat test surface. A total of 64 readings were obtained from the end faces of each sample and the average of these was taken as the Shore hardness. The reproducibility of the average value between different series of tests was found to be 2 Shore units. The samples were tested in a laboratory-dry condition.

Table 3 lists for comparison the values of Shore hardness of several common rock types. This table was compiled from the information given by Windes (1950).

### Drillability

The drillabilities were determined by the Morris method (Morris, 1969; Lightfoot, 1970). A tungsten carbide button of tip radius 3.2 mm is pressed into a flat surface on the test specimen until the first chip is produced. The drillability index is the ratio of the crater depth to the threshold force required to produce the chip.

Plate 1 shows a typical drillability measurement record. Altogether three tests, shown by the three curves, were made on the sample. The point of failure is indicated by the letter A on curve 3. We note that the stress was not completely relieved after chip formation. The crater depth was therefore measured from the interval BC rather than the interval EF on the record.

The Morris index is strictly applicable only to roller cone type drilling. The index is arbitrary in that it depends on the exact shape of the button used. BMR measurements were calibrated against the equipment of the Mining Department, University of Melbourne. The calibration factor by which our readings were multiplied was $0.44 \pm 0.09$.

The drillability test samples were cast in concrete and allowed to stand for about two days in laboratory humidity conditions after a brief curing period.

## Uniaxial compressive strength

The length-to-diameter ratio of the samples for the compressive strength tests was 2:1. The specimen ends were surface ground to a flatness within 0.025 mm (highest to lowest point). The ends were parallel within half a degree. No lubricant was used on the end faces. The samples were tested in a laboratory-dry condition.

Roughly half the samples were tested by the SMEC and the other half by BMR. The techniques used were nearly identical. The SMEC used a model 7110 DCJ Avery press. Their loading rate was 280 $kg/cm^2/sec$. BMR tests were carried out with the co-operation of the Department of Works on their Avery Press, model 7112 CCG. The loading rate was 390 $kg/cm^2/sec$. We used hardened tool steel platens (Rockwell hardness C 65). Despite considerable efforts it did not prove possible to prepare the platen surfaces to a degree where no roughness could be detected by running a finger nail across the surface.

## Shear strength

The shear strengths tests were made on our behalf by the SMEC. Standard shear test techniques were employed. A constant load of 7.0 $kg/cm^2$ (100 $lb/in^2$) was applied normal to the joint plane, and a shear force applied parallel to the plane. The shear force was increased gradually. The shear stress required to fracture the joint is called here the 'peak stress', and the critical value of shear stress required to cause a slip on an already fractured joint plane is denoted 'residual stress'.

# 4. RESULTS

The elastic properties, specific gravity, and hardness of the proposed Tuggeranong sewer line core samples are shown in Table 1 together with the drill log data.

It should be noted that the properties of the fresh dacite samples are quite uniform between the different drill holes. Table 2 shows the means and standard deviations for the fresh dacites. The properties of the rhyodacites differ considerably from those of the dacites. The most sensitive parameter in Table 1 to differences in rock quality appears to be Young's modulus.

The Morris drillability results are summarized in Table 4. The values marked with asterisks were determined by the University of Melbourne in their calibration tests. The mean and standard deviation of the drillability index of the 17 fresh dacites samples of Table 4 are 0.17 and 0.03 respectively.

Plate 2 shows the calibration curve of Lightfoot (1970). The penetration rate was recorded for a 2-metre diameter raise hole drilled by a roller-cone type bit in a mine in the Kambalda district, Western Australia. The rock was serpentine. Our tests indicate that the penetration rate under similar conditions in the fresh dacites would be approximately 0.7 ft per hour (0.2 m/h).

Tables 5, 6, and 7 list the uniaxial compression test results: Tables 5 and 6 the results of the SMEC tests and Table 7 those of the BMR tests.

The samples in Table 5 were selected from drill cores at approximately the proposed tunnel depth and represent the least jointed sections of the core at that depth. The samples in Table 6 were selected from various depths, the only criterion being absence of visible joints. Since the SMEC reported only one instance (sample 71/78) where compression failure occurred on an obvious joint plane it seems a little surprising that the two sets of results should differ significantly. It is possible that the processes which caused the jointing also weakened the general rock fabric. G.M. Burton (BMR Engineering Geologist) has suggested that incipient joints due to shearing, for example, could account for the lower mechanical strengths of the sections of drill core which contain visible joints.

The selection criterion for the BMR compressive strength test specimens was the absence of visible joints. The results should therefore correspond to those of Table 6. The figures of Table 7 are on the whole significantly higher, however, than the SMEC figures. The means and standard deviations of the two sets of results are

Table 6: Mean 1 800; Standard deviation 260

Table 7: Mean 2 150; Standard deviation 670

This disagreement could be attributed to differences in the surface finish of the BMR and SMEC test platens. As noted earlier the BMR platen surfaces appeared rough on examination with finger nail. The SMEC platens were considerably smoother. In order to check the effects of platen difference two sets of four samples were prepared identically from the same section (about 140 ft depth) of drill core TS 12. The first set was tested on the Department of Works press using BMR platens; the second set was tested using the SMEC press and platens.

The results were

BMR platens: Mean 2 630; Standard deviation 180

SMEC platens: Mean 2 580; Standard deviation 190

The effects of surface finish difference of the platens would therefore appear to be negligible. (It is interesting to note that these results are in good agreement with those of Table 7 for drill core TS 12 at depths around 240 ft: the mean and standard deviation of the latter are 2 680 and 510 respectively).

The remaining experimental factor that could cause a discrepancy in compressive strength is the condition of the sample's end surfaces. It was found that the flatness and surface finish of the samples prepared by BMR were slightly better than those prepared by SMEC. Unfortunately only one of the samples prepared by SMEC was measured for end face flatness. The value obtained, 0.11 mm, is considerably outside the BMR flatness limit of 0.025 mm and this could account at least partly for the lower compressive strengths obtained in the SMEC tests. It is however not possible to draw definite conclusions concerning differences in the testing technique on the basis of such a small number of samples (Yamaguchi, 1970).

The shear test results are shown in Table 8. The samples contained what were judged to be typical cemented joints. We feel that such a small number of tests would give only a very rough indication of the strength of joints in the general rock mass.

## 5. CONCLUSIONS

The results indicate that the mechanical properties of the fresh dacites are fairly uniform between the different drill holes. With the exception of the rhyodacites the rock was found to be mechanically strong. The dacites had approximately the same Shore hardness as fresh granite. From the drillability index values we expect the penetration rates for mechanical tunnelling to be low. The rhyodacites were considerably weaker, but their drillability indexes were still quite small.

## 6. REFERENCES

LIGHTFOOT, R.M., 1970 - Paper in the report of the 1970 Raise and Tunnel Boring Symposium, University of Melbourne.

MORRIS, R.I., 1969 - Rock drillability related to a roller cone bit. Soc. Petrol. Engrs. Drilling and Rock Mechanics Conference, Austin, Texas. Preprint No. 2389, pp. 79-86.

WINDES, S.L., 1950 - Physical properties of mine rocks, Part II. US Bur. Min. Rep. Inv. 4727.

YAMAGUCHI, U., 1970 - The number of test pieces required to determine the strength of rock. Int. J. Rock Mech. Min. Sci., 7, 209.

Conversion Factors

| | | |
|---|---|---|
| Uniaxial compressive strength, | | |
| Shear strength and Young's modulus | : | 1 $kg/cm^2$ = 14.2 $lb/in^2$ |
| Sound velocity | : | 1 m/sec = 3.28 ft/sec. |
| Morris' drillability index | : | 1 mm/ton = 1.79 x $10^{-5}$ in/lb |

TABLE 1 General Results

| Sample No | Drill hole | Depth, feet | Geological* description | Specific gravity | Longit. velocity, m/sec | Young's modulus, $10^5$ kg/cm$^2$ | Poisson's ratio | Hardness, Shore units |
|---|---|---|---|---|---|---|---|---|
| 71/78 | TS 6 | 74 | Rhyodacite SW | 2.67 | 4620 | 4.1 | 0.32 | 49 |
| 71/79 | TS 8 | 51 | Dacite F | 2.67 | 5940 | 8.1 | 0.25 | 93 |
| 71/80 | TS 9 | 58 | Dacite SW | 2.65 | 5510 | 6.9 | 0.25 | 85 |
| 71/81 | TS 11 | 36 | Dacite SW-F | 2.67 | 5740 | 6.3 | 0.32 | 95 |
| 71/82 | TS 12 | 237 | Dacite F | 2.69 | 5860 | 7.8 | 0.26 | 91 |
| 71/83 | TS 1 | 56 | Dacite F | 2.68 | 5940 | 7.5 | 0.28 | 89 |
| 71/84 | TS 3 | 180 | Dacite F | 2.69 | 5830 | 7.8 | 0.25 | 93 |
| 71/92 | TS 2 | 97 | Dacite F | ---- | Shear strength test only | | | |
| 71/93A | TS 2 | 98 | Dacite F | ---- | Drillability test only | | | |
| 71/93B | TS 2 | 98 | Dacite F | ---- | Drillability test only | | | |
| 71/94 | TS 3 | 125 | Dacite F | ---- | Shear strength test only | | | |
| 71/95 | TS 3 | 126 | Dacite F | 2.69 | 6090 | 8.6 | 0.25 | 101 |
| 71/96 | TS 3 | 127 | Dacite F | 2.69 | 6030 | 8.5 | 0.24 | 100 |
| 71/97 | TS 5 | 91 | Dacite F | 2.69 | 5670 | 7.5 | 0.25 | 92 |
| 71/97A | TS 5 | 91 | Dacite F | ---- | Drillability test only | | | |
| 71/98 | TS 6 | 66 | Rhyodacite SW | 2.65 | 4880 | 4.2 | 0.34 | 71 |
| 71/99 | TS 6 | 66 | Rhyodacite SW | ---- | Drillability test only | | | |
| 71/100 | TS 8 | 39 | Dacite F | 2.67 | 5830 | 7.9 | 0.24 | 103 |
| 71/101A | TS 8 | 48 | Dacite F | ---- | Drillability test only | | | |
| 71/101B | TS 8 | 48 | Dacite F | ---- | Drillability test only | | | |
| 71/102 | TS 8 | 49 | Dacite F | ---- | Shear strength test only | | | |

## TABLE 1 General Results (Cont.)

| Sample No | Drill hole | Depth, feet | Geological* description | Specific gravity | Longit. velocity, m/sec | Young's modulus, $10^5$ kg/cm$^2$ | Poisson's ratio | Hardness, Shore units |
|---|---|---|---|---|---|---|---|---|
| 71/103 | TS 12 | 236 | Dacite F | 2.69 | 5900 | 7.8 | 0.26 | 98 |
| 71/104 | TS 12 | 237 | Dacite F | 2.70 | 5820 | 7.8 | 0.25 | 95 |
| 71/105 | TS 12 | 237 | Dacite F | 2.70 | 5800 | 7.8 | 0.25 | 92 |
| 71/106 | TS 12 | 245 | Dacite F | 2.69 | 5900 | 8.0 | 0.25 | 98 |
| 71/107 | TS 12 | 246 | Dacite F | ------- | Drillability test only | ------- | ------- | ------- |
| 71/108 | TS 13 | 240 | Dacite F | 2.67 | 5910 | 8.0 | 0.25 | 92 |
| 71/108A | TS 13 | 240 | Dacite F | ------- | Drillability test only | ------- | ------- | ------- |
| 71/109 | TS 13 | 241 | Dacite F | 2.67 | 6080 | 8.2 | 0.27 | 90 |
| 71/110 | TS 13 | 246 | Dacite F | 2.67 | 5960 | 7.9 | 0.26 | 92 |
| 71/112 | TS 3 | 131 | Dacite F | ------- | Compressive strength test only | | ------- | ------- |
| 71/113 | TS 3 | 131 | Dacite F | | " " " " | | | |
| 71/114 | TS 8 | 43 | Dacite F | | " " " " | | | |
| 71/115 | TS 12 | 239 | Dacite F | | " " " " | | | |
| 71/116 | TS 12 | 240 | Dacite F | | " " " " | | | |
| 71/117 | TS 13 | 226 | Dacite F | | " " " " | | | |

* F denotes fresh rock

SW denotes slightly weathered rock

## TABLE 2

### Means and Standard Deviations for the Fresh Dacites of Table 1

| | Mean | Standard deviation |
|---|---|---|
| Specific gravity | 2.68 | 0.01 |
| Longitudinal velocity (m/sec) | 5900 | 110 |
| Young's modulus ($10^5$ kg/cm$^2$) | 7.9 | 0.3 |
| Poisson's ratio | 0.25 | 0.01 |
| Shore hardness | 95 | 4 |

## TABLE 3

### Shore Hardness Range in Common Rock Types

| Rock type | Shore hardness | No. of localities of sample collection |
|---|---|---|
| Granite | 90 - 100 | 5 |
| Basalt | 69 - 84 | 1 |
| Quartzite | 81 (one value only) | 1 |
| Limestone | 27 - 66 | 4 |
| Sandstone | 31 - 65 | 3 |
| Shale | 34 - 58 | 2 |

(After Windes, 1950)

## TABLE 4 Morris Drillability Index

| Drill hole | Depth, feet | Sample No. | No. of tests | Morris index, $10^{-5}$mm/ton | Standard deviation, $10^{-5}$mm/ton |
|---|---|---|---|---|---|
| TS 1 | 56 | 71/83 | 3 | 0.21 | 0.01 |
| TS 2 | 98 | 71/93A | 3 | 0.19 | 0.03 |
| TS 2 | 98 | 71/93B | 9 | 0.15 | 0.04* |
| TS 3 | 126 | 71/95 | 4 | 0.17 | 0.01 |
| TS 3 | 126 | 71/96 | 8 | 0.22 | 0.12* |
| TS 3 | 180 | 71/84 | 2 | 0.18 | 0.02 |
| TS 5 | 91 | 71/97 | 2 | 0.13 | 0.03 |
| TS 5 | 91 | 71/97A | 7 | 0.16 | 0.04* |
| TS 6 | 66 | 71/98 | 3 | 0.21 | 0.03 |
| TS 6 | 67 | 71/99 | 1 | 0.32 | - |
| TS 8 | 39 | 71/100 | 3 | 0.15 | 0.03 |
| TS 8 | 49 | 71/101A | 4 | 0.19 | 0.05 |
| TS 8 | 49 | 71/101B | 3 | 0.13 | 0.02 |
| TS 8 | 51 | 71/79 | 4 | 0.16 | 0.02 |
| TS 11 | 36 | 71/81 | 1 | 0.17 | - |
| TS 12 | 237 | 71/82 | 3 | 0.19 | 0.05 |
| TS 12 | 246 | 71/106 | 5 | 0.16 | 0.07* |
| TS 12 | 246 | 71/107 | 4 | 0.17 | 0.02 |
| TS 13 | 240 | 71/108 | 2 | 0.21 | 0.04 |
| TS 13 | 246 | 71/110 | 4 | 0.17 | 0.06 |

* Calibration measurement, University of Melbourne

TABLE 5 Uniaxial Compressive Strength

(SMEC results: Samples selected from the proposed tunnel depth)

| Drill hole | Depth, feet | Sample No. | Compressive strength, kg/cm$^2$ | Mode of failure |
|---|---|---|---|---|
| TS 1 | 56 | 71/83 | 1500 | Longitudinal failure through length |
| TS 3 | 180 | 71/84 | 560 | Longitudinal failure through length |
| TS 6 | 74 | 71/78 | 150 | Premature failure through joint plane |
| TS 8 | 51 | 71/79 | 2100 | Fracture into numerous small pieces |
| TS 9 | 58 | 71/80 | 660 | Semi-conical |
| TS 11 | 36 | 71/81 | 770 | Conical |
| TS 12 | 237 | 71/82 | 690 | Longitudinal failure through length |

TABLE 6 Uniaxial Compressive Strength

(SMEC results: Joint-free drill core sections)

| Drill hole | Depth, feet | Sample No. | Compressive strength, kg/cm$^2$ | Mode of failure |
|---|---|---|---|---|
| TS 3 | 131 | 71/112 | 2080 | Fracture into numerous small pieces |
| TS 3 | 131 | 71/113 | 2000 | Fracture into numerous small pieces |
| TS 8 | 43 | 71/114 | 1920 | Fracture into numerous small pieces |
| TS 12 | 239 | 71/115 | 1820 | Fracture into numerous small pieces |
| TS 12 | 240 | 71/116 | 1610 | Fracture into numerous small pieces |
| TS 13 | 226 | 71/117 | 1310 | Fracture into numerous small pieces |

TABLE 7 Uniaxial Compressive Strength

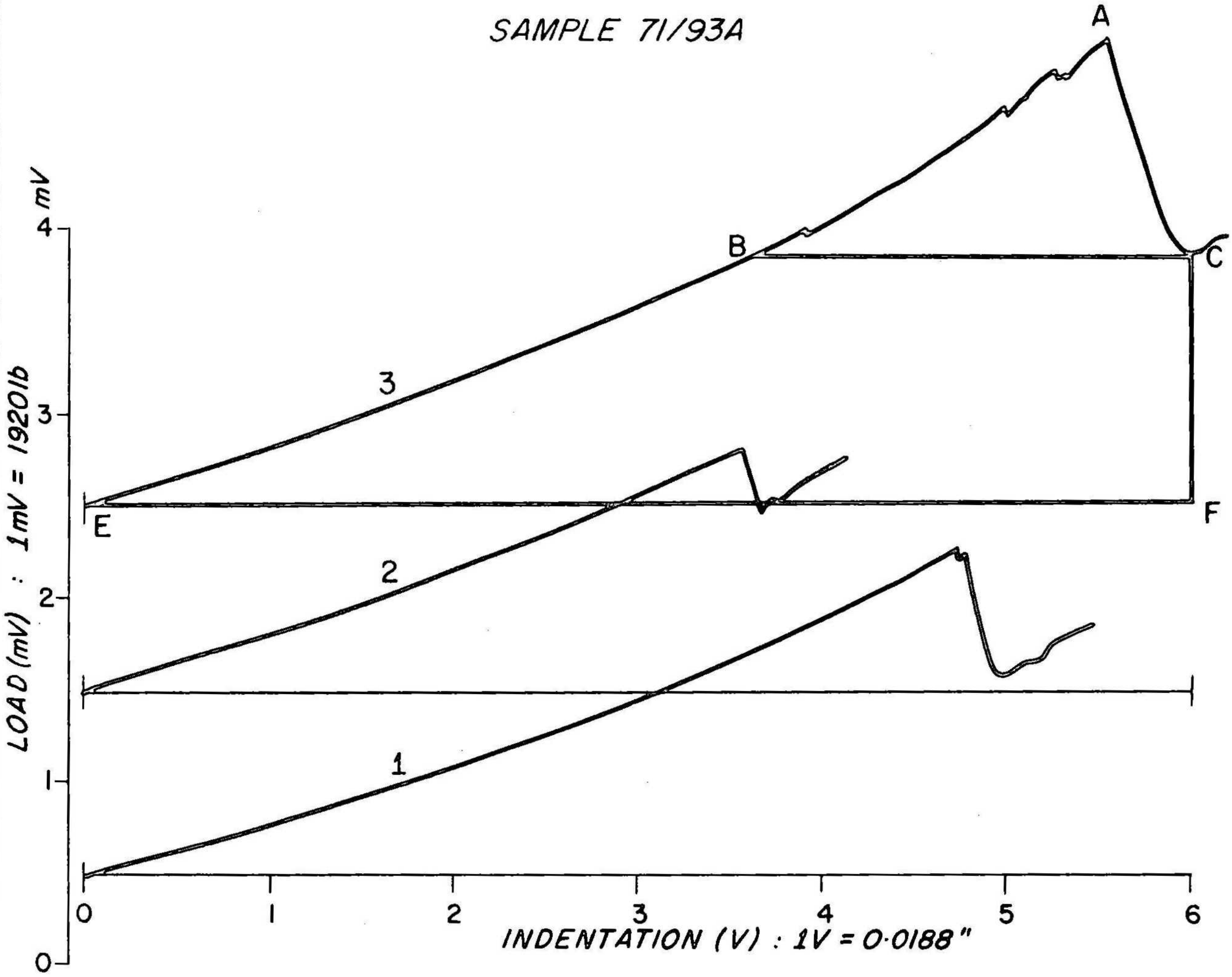
(BMR results: Joint-free drill core sections)

| Drill hole | Depth, feet | Sample No. | Compressive strength, $kg/cm^2$ | Mode of failure |
|---|---|---|---|---|
| TS 3 | 127 | 71/96 | 2760 | Fracture into numerous small pieces |
| TS 5 | 91 | 71/97 | 1740 | Longitudinal failure through length |
| TS 6 | 66 | 71/98 | 1490 | Longitudinal failure through length |
| TS 8 | 39 | 71/100 | 2500 | Fracture into numerous small pieces |
| TS 12 | 236 | 71/103 | 3000 | Fracture into numerous small pieces |
| TS 12 | 237 | 71/104 | 2680 | Fracture into numerous small pieces |
| TS 12 | 237 | 71/105 | 1860 | Fracture into numerous small pieces |
| TS 12 | 245 | 71/106 | 3190 | Fracture into numerous small pieces |
| TS 13 | 240 | 71/108 | 1100 | Semi conical failure |
| TS 13 | 241 | 71/109 | 1570 | Longitudinal failure through length |
| TS 13 | 246 | 71/110 | 1740 | Fracture into numerous small pieces |

TABLE 8 Shear Strength Tests *

| Sample No. | Peak stress | Residual stress |
|---|---|---|
| 71/92 | 11 | 8 |
| 71/94 | 32 | 11 |
| 71/102 | 20 | 12 |

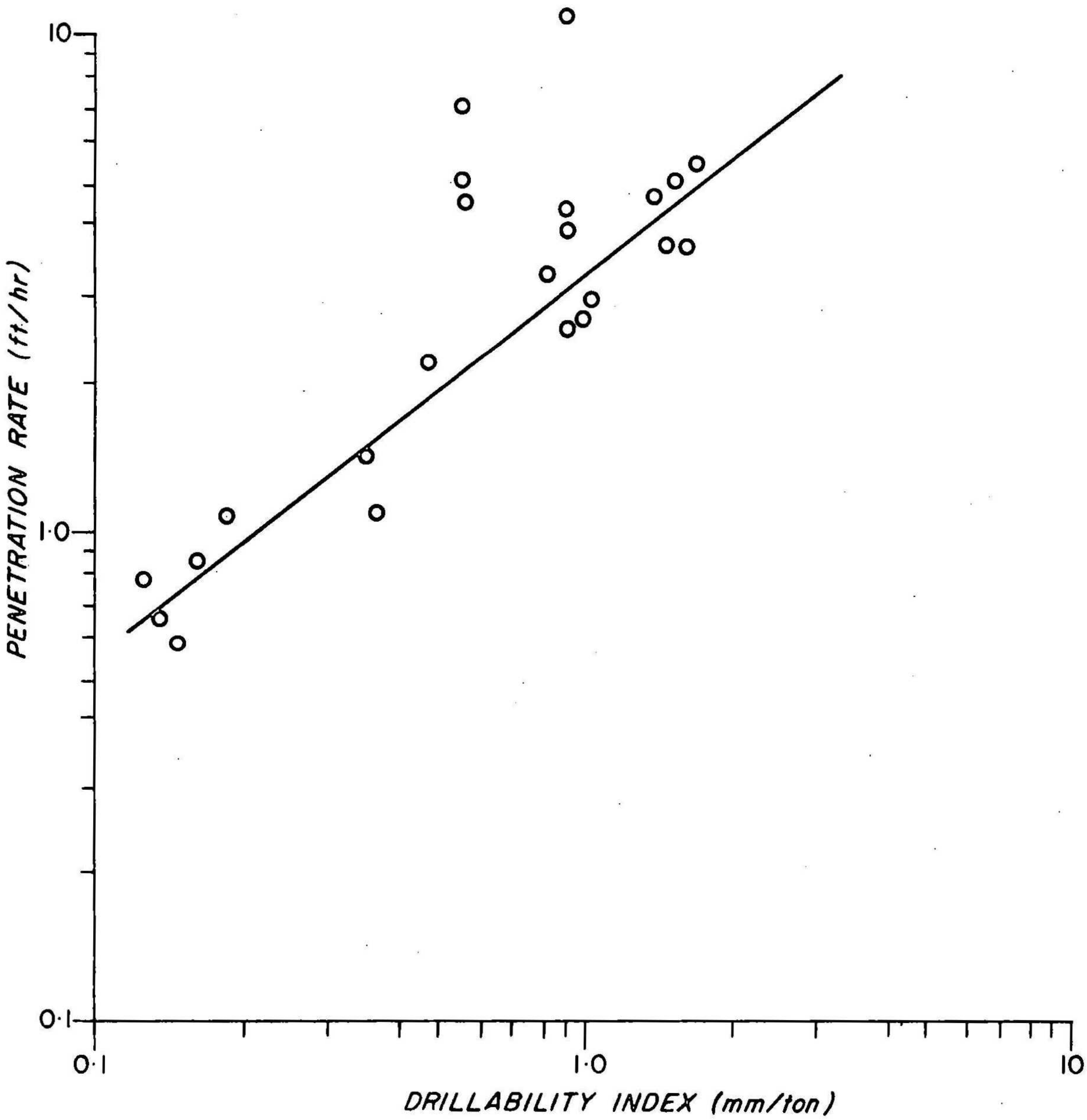
* Normal stress on joint: 7.0 $kg/cm^2$ (100 $lb/in^2$).




| CURVE | $E_{threshold}$ | P | DRILLABILITY INDEX |
|---|---|---|---|
| 1 | 3,460 lb | 0·030" | 0·485 |
| 2 | 2,500 lb | 0·0165" | 0·370 |
| 3 | 4,900 lb | 0·045" | 0·515 |
| | | MEAN | 0·46 |

# DRILLABILITY TEST RECORD

NOTE: Profiles have been separated to avoid overlapping




# DRILLABILITY INDEX CALIBRATION CURVE

*( after Lightfoot, 1970 )*

*To accompany Record No. 1971/130*

G461-5A