WEAKENING CAUSED BY FLUIDS USED FOR DRILLING MUDSTONES

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1 INTRODUCTION

This paper deals with a solution to the problem of measuring changes in the strength properties of weak rocks, associated with changes in moisture content and/or the passage of time.

One method of quantitatively assessing changes of strength involves having a large number of rock samples, with essentially identical strengths and initial moisture contents. By destructively testing one specimen at the end of each increment of time or incremental change in moisture content, a graph of strength versus time or moisture content can be plotted.

This approach is not valid where the number of available specimens is small, or where the natural variability of the test population is large.

In the latter case the variations in strength with time or moisture content may be less than the variations with specimen number or position: causal relationships would be difficult to discern.

2 TESTING OPTIONS

The progressive reduction of strength in a single specimen can be assessed by:

(a) measuring specimen degradation or slaking, as manifested by loss of mass during the course of the test program;

(b) measuring loss of strength, by repeated non-destructive testing during the course of the test program.

The latter is more difficult in the Melbourne mudstones. Although the measurement of ultrasonic pulse velocities is quite feasible for less weathered specimens, even at the highest magnifications on the available cathode-ray-oscilloscopes, no reliably discernible pulse arrivals can be detected after travel through the softer, more intensely weathered materials. Also the pressure necessary to be applied between the transducer heads and the rock, to ensure pulse transmission, is sufficient to cause compressive failure of the weaker specimens.

Rebound hardness can also be measured. A small hard-tipped hammer is dropped through a constant distance, and the height of rebound of the hammer is used as a measure of the rock's hardness. This technique can cause minor crushing, over an area of about a millimetre diameter on the surface of a weak rock. Sequential tests can avoid the damaged spots from previous tests, while still conducting many tests within a few millimetres of each other. The rebound hardness values measured upon the weak weathered Melbourne mudstones are so low (Shore hardnesses less than 10) as to be considered unreliable, for detecting any small variations.

The principle of hardness testing was, however retained in the present investigation. This was to approximate a non-destructive test with a test which damaged an insignificantly small volume of the test specimen, so that replicate tests could be conducted upon an effectively undamaged specimen. Following a review of alternative hardness testing methods it was concluded that the N.C.B. Cone Indenter appeared promising.

3 THE N.C.B. CONE INDENTER

This is a small portable rig developed at the Mining Research and Development Establishment of the British National Coal Board (Szlavin, 1974).

It measures the indentation hardness of rock specimens in a similar fashion to metallurgical hardness testers.

The specimens which are about 25 mm diameter and 6 mm thick, are placed between a standard hardened steel conical point and a flat spring-steel beam. Forcing the cone into the rock surface, and the resultant transmission of force through the rock, causes deflection of the beam. A dial gauge measures this deflection. Calibration of the steel spring allows the deflection corresponding to an applied force of 40 Newtons to be determined. A vernier micrometer is used to force the conical point into the rock specimen until the spring deflection corresponding to the force of 40 Newtons has been attained; the vernier is then read, and the penetration of the cone into the rock is calculated by subtracting the dial gauge reading of spring deflection from the vernier reading of cone advance.

The standard N.C.B. Cone Indenter could not be used for the present test program, because of the small size of the specimens it would accept. It also appeared to us to have the disadvantage that the readings obtained with it were dimensionless numbers, rather than true force/penetration ratios. The readings are "process-dependent", rather than absolute. The standard spring beam load-deflection behaviour is apparently non linear due to pre-tensioning of the instrument and it is not readily adapted to non-standard test modifications.

So, it was decided to construct a larger stiffer instrument, which would accept larger diameter cores, and which would produce absolute measurements of force and penetration.

4 THE MODIFIED CONE INDENTER

This is shown in Figure 1. The standard N.C.B. cone is a conical tip 6 mm long, with an included angle of 40^{o}, formed on the end of a 4.5. mm diameter cylinder, and hardened to a Rockwell "C" hardness value of 65. The rock specimen is placed on the upper surface of a semi-conductor load cell. The cone is forced into the upper surface of the rock by rotating the capstan wheel, and the downward displacement of the cone is measured by a linear variable differential transformer (L.V.D.T.). The outputs from the load cell and the L.V.D.T. are used to drive the 2 axes of an X-Y recorder.

When the pen has moved a distance corresponding to 40 Newtons force the handwheel is reversed and the cone withdrawn from the rock surface. The rock is moved a short distance sideways and another penetration is made. The test can be repeated 5 or 10 times, over an area as small as 1 centimetre diameter, within a few minutes.

Because of the stiffness of the loading frame relative to the force required to penetrate the rock, the readings are entirely reproducible, and any other laboratory could build its own version of the testing machine, and produce comparable results.

The results are expressed as Cone Indenter Ratios, Newtons/millimetre. By consideration of Szlavin's work, it appears that the standard Cone Indenter Hardness Number I_s = Cone Indenter Ratio/62.5.

5 TESTS ON MELBOURNE SILURIAN MUDSTONES

Large diameter vertical holes are being drilled in the Melbourne Silurian mudstones for caisson foundations for a freeway. A large number of holes on a particular site were to be drilled and left uncased for up to a month. At the conclusion of the drilling program, concrete pouring would commence, with all the holes filled in one continuous operation. It was suspected that the more severely weathered mudstones might deteriorate and the holes collapse if they were left uncased and exposed to circulating groundwater for any appreciable length of time. The effects of the bentonite drilling mud upon the stability of the mudstones were also unknown.

A testing program was commenced, at the request of the construction authority. Tanks were filled with groundwater from the construction site and with a mixture of groundwater and bentonite drilling mud (SUPAGEL), at an initial concentration of 2.75 kilograms/100 litres (or 27.5 grams/litre). Diamond drill cores from the exploratory boreholes being drilled on the axes of the caisson sites were sealed against moisture loss and transported to the Melbourne University rock mechanics laboratory.

There they were trimmed by a diamond saw, to a length/diameter ratio of approximately 1.0, cleaned of any surface mud, and placed into the tanks. Stirrers kept the fluids in each tank circulating throughout the 33 days duration of the test program. The rock samples were cut, weighed and subjected to their initial Cone Indenter tests within a few hours of being obtained. They were then placed into tanks of either groundwater alone or groundwater mixed with SUPAGEL, kept circulating by stirrers.

The samples were removed daily, washed gently in clean water to remove sedimented surface deposits, surface-dried by paper towels, weighed and subjected to Cone Indenter tests. Each day's tests were carried out on previously untested spots.

It was found that attempts to achieve a loading of 40 Newtons were often fruitless in weak weathered mudstones, as the cone became completely embedded, after several millimetres penetration, at loads of the order of 10 Newtons. So, the testing criteria were changed to call for a load of 40 Newtons or a penetration of 1 mm, whichever was achieved first; the corresponding penetration or load, respectively, could then be measured.

Table 1 shows the decrease in sample quality over the length of test program.

Figures 2 and 3 show plots of cone indenter ratios versus time for slightly weathered and moderately weathered samples, respectively. They show the general trend of decrease of the cone indenter ratios during the first 5 to 10 days of testing, regardless of the original state of weathering or the circulating fluid in which the samples are immersed.

Results given in Table 2 indicate that the samples immersed in SUPAGEL plus groundwater suffered decreases in strength which were apparently slightly greater (but probably not significantly different) than those for the samples immersed in groundwater alone; on the other hand, the mass losses suffered by the samples immersed in groundwater alone were probably significantly greater than those for the samples immersed in groundwater plus SUPAGEL.

This was probably due to the bentonite forming a flocculant film on the surfaces of the samples, and reducing the slaking (due to the effects of the circulating fluids) and the fretting (due to the effects of handling, surface drying, and cone indenter testing).

To investigate the slake suppression characteristics of the SUPAGEL mix all samples were exposed to air drying for a period of 24 hours and then replaced into the circulating fluids. Mass measurements showed that the samples in the SUPAGEL mix re-absorbed slightly less water after drying; they also showed visibly less deterioration than the samples replaced into groundwater.

At the conclusion of the test program it was concluded that:

(a) Significant reductions in the strength of the Melbourne mudstones, as indicated by the cone indenter ratios, were measured for all degrees of weathering and for both circulating fluids. It appeared that bentonite does not inhibit decreases in strength associated with absorption of water;

(b) Severe degradation of the sample material only occurred in the cases of highly weathered mudstones This degradation was primarily caused by slaking during submersion, accompanied by or following separation along bedding. Visible degradation of samples was much more pronounced in samples submerged in groundwater alone;

(c) Exposure to air drying of the samples significantly increased degradation by slaking and separation along bedding. This behaviour is much more pronounced for samples which had been immersed in groundwater alone;

(d) It appears that the formation of a thin flocculant film on the surface of the samples submerged in SUPAGEL plus groundwater reduced slaking of all but the most severely weathered material.

6 TESTS ON WARRAMUNGA SHALES

The usefulness of the modified cone indenter test, as a measure of the effect of time and /or moisture content upon the strength of a weak rock, was felt to have been proven by the testing program just described. When a question was recently posed as to the probable stability of a planned mining excavation in deeply weathered Warramunga shales in the Northern Territory of Australia, the test was used again.

The material above the depth of 34 metres was not sufficiently rock-like to be cored, but samples from depths of 34 metres (moderately weathered) to 142 metres (fresh) were supplied for testing. Samples from 34 and 47 metres were subjected to the "Duncan" free-swell test and the modified cone indenter test.

Cores were trimmed by diamond saw and oven-dried. A series of numbers was placed with marking pen on each of the cone indenter specimens. They were tested dry, immersed in water for 30 minutes, then re-tested. Subsequently they were re-tested at daily intervals. At each time the cone was pressed into a different sequence of 5 of the inked numbers, so previously undisturbed material was tested each time. The mean of 5 test values is quoted in Table 2.

It was evident that the weathered shale lost more than half its strength when wet, and that it continued to deteriorate slightly throughout the test period. On the other hand, the rock did not exhibit dangerous swelling behaviour.

7 CONCLUSION

An instrument has been constructed at the University of Melbourne, as a modification of Szlavin's N.C.B. Cone Indenter. It has been shown to be a very convenient means of quantifying changes in the strengths of weak rock materials with changing moisture contents with elapsed time. It is able to do this without causing significant damage to the test specimens, and can be regarded as a quasi-non-destructive test, able to give repeatable results on weaker rocks than are able to be tested by other test methods.

8 REFERENCE

Duncan, N., Dunne, M.H. and Petty, S., - Swelling characteristics of rocks - Water Power May 1968, pp. 185-192

Szlavin, J - Relationships between some Physical Properties of Rock Determined by Laboratory Tests - Int. J. Rock Mech. Min. Sci., Vol.11, 1974, pp. 57-66

Table 2 Warramunga shale tests

N.C.B. Cone Indenter Ratios

	Dry	Wet	After 4 days	Duncan Free-Swell Index
37m	91	45	38	0.09%
46m	178	82	73	0

Table 1. Tests on Melbourne Silurian Mudstones

Sample	Degree of Weathering	Length of Immersion (Days)	Decrease in Cone Indenter Ratio (%)	Mass Loss %
Samples in SUPAGEL and Groundwater				
1	Slight	33	35	0.7
2	"	30	38	0.4
3	"	33	46	0.2
4	"	33	45	0.5
		mean	41	0.45
5	Moderate	30	25	2.4
6	"	29	59	1.4
7	"	33	43	1.7
8	"	30	52	1.1
		mean	45	1.65
9	High	30	47	4.2
10	"	33	100	100
		mean	74	52
Samples in Groundwater only				
11	Slight	33	38	0.4
12	Moderate	33	19	3.6
13	"	30	14	6.3
14	"	29	45	4.5
15	"	33	61	1.8
16	"	30	32	1.6
		Mean =	34	3.6
17	High	30	38	13.6

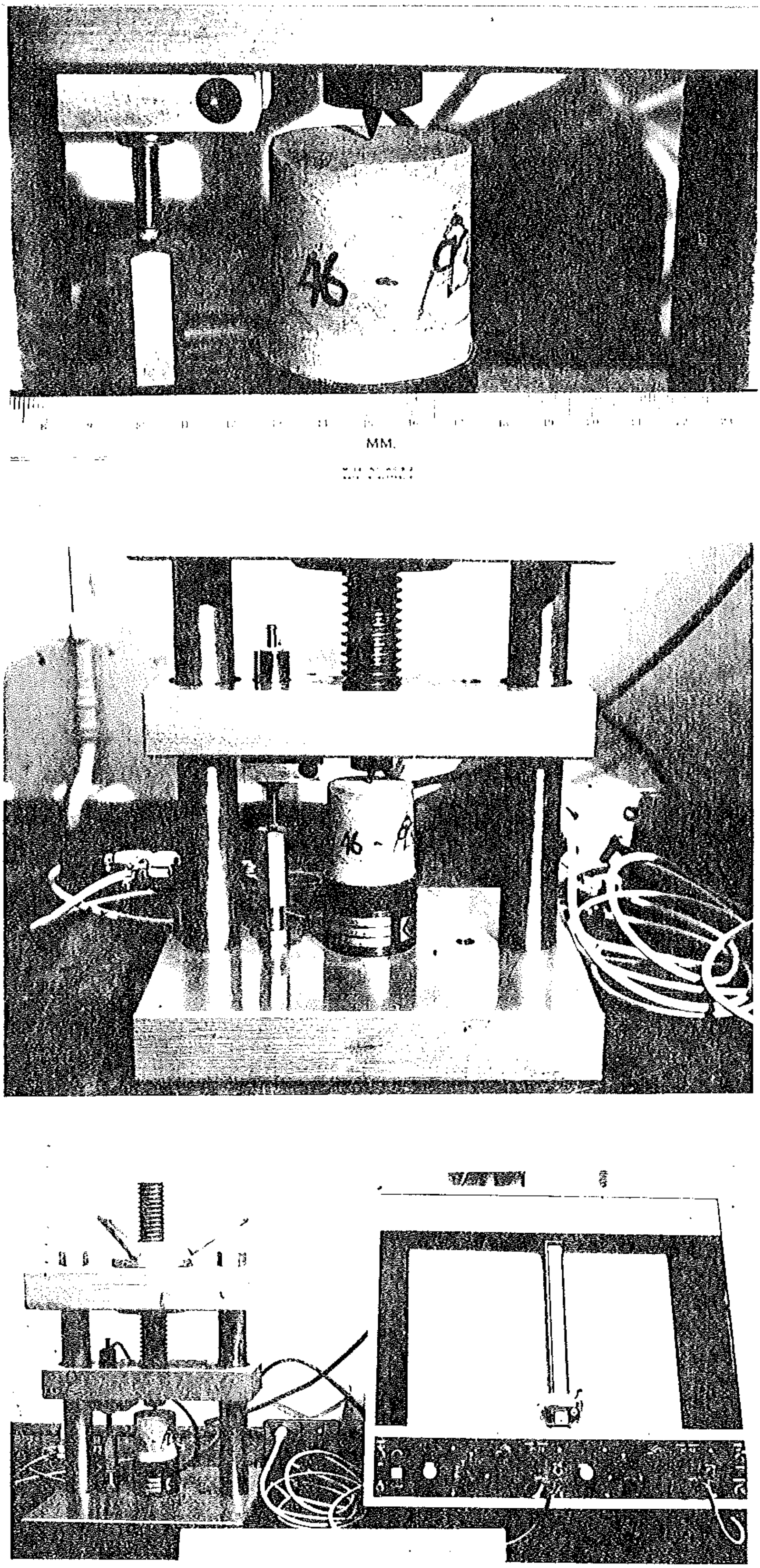

Figure 1 : Modified NCB Cone Indenter Apparatus

Mean Cone Indenter Ratios versus Time

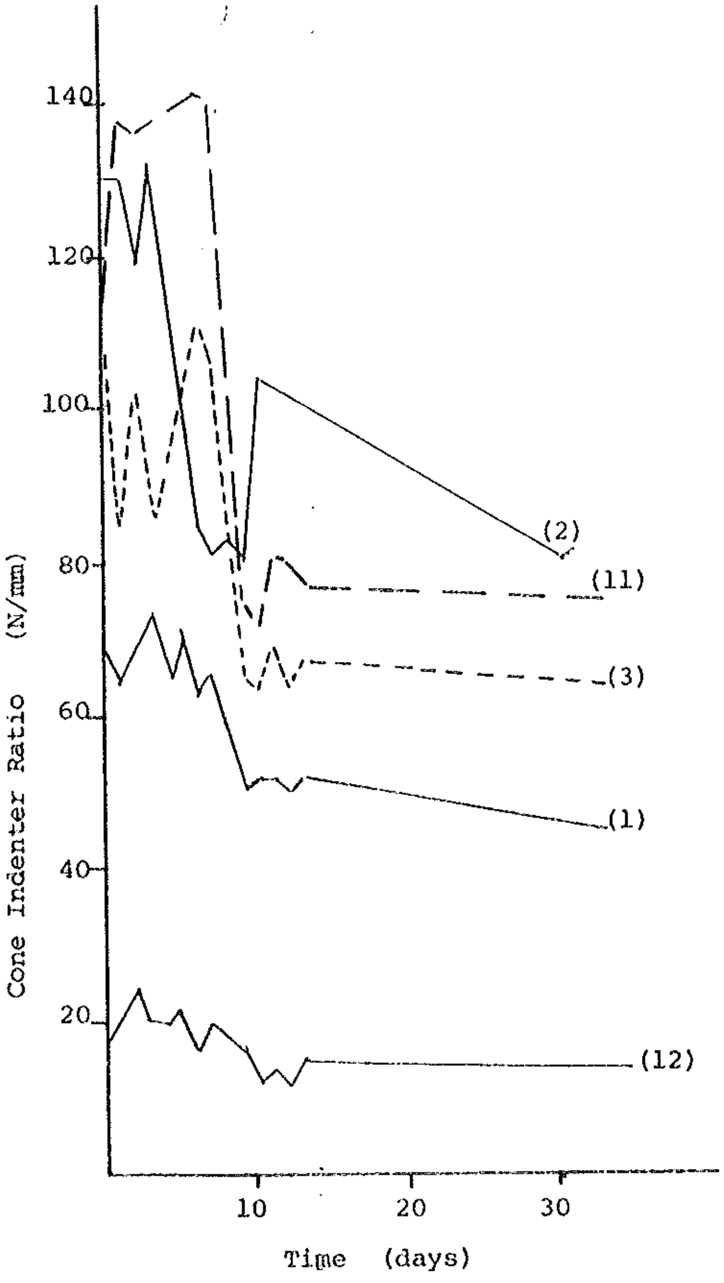

Figure 2 : Slightly Weathered Mudstones

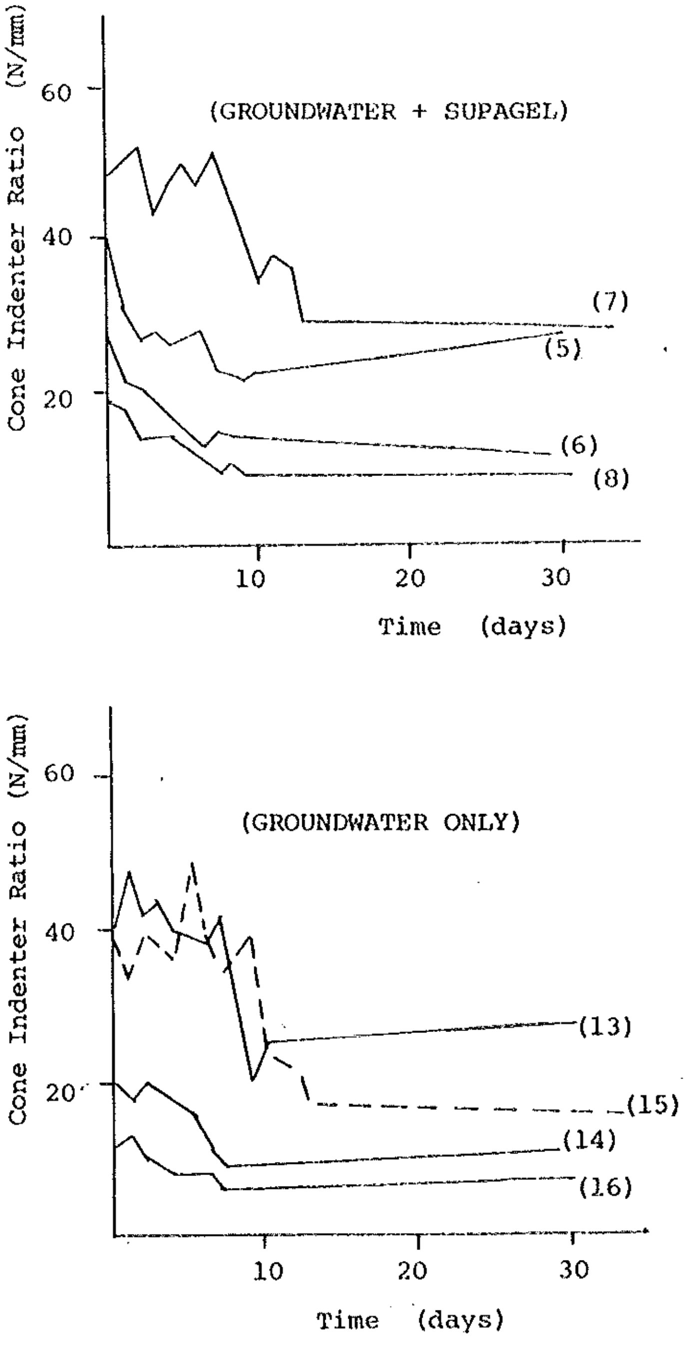

Figure 3 : Moderately Weathered Mudstones