Civil Engineering Dimension, Vol. 9, No. 1, 9–14, March 2007
ISSN 1410-9530

THE UNIAXIAL COMPRESSIVE STRENGTH OF SOFT ROCK

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ABSTRACT

Soft rock is a term that usually refers to a rock material with a uniaxial compressive strength (UCS) less than 20 MPa. This low strength range might be influenced by physical characteristics, such as size, saturation, weathering and mineral content. A number of uniaxial compression tests have been conducted onto soft rock samples. The results showed that the strength reduced significantly in saturation. The reduction was also caused by weathering, the strength of distinctly weathered rocks were lower than that of partially weathered rocks. In conjunction with the uniaxial compression test, point load strength index tests, $I_{S(50)}$, have also been conducted in order to obtain a correlation between the UCS and the point load strength index $I_{S(50)}$. The results showed that the $I_{S(50)}$ could well be correlated with the UCS. A conversion factor of 14 is proposed for soft rock materials.

Keywords: *soft rock, uniaxial compressive strength, physical characteristic, point load strength index, and conversion factor.*

INTRODUCTION

The term soft rock is often referred to rock materials with a uniaxial compressive strength (UCS) lower than that of hard rocks and higher than that of soils. A rock material can be classified as a soft rock if it has a uniaxial compressive strength below 20 MPa, determined directly by uniaxial compression tests [1, 2, 3, 4].

Physical characteristics, such as sample preparation, size, saturation, and mineral content, influence the uniaxial compressive strength of soft rock materials. These factors can considerably reduce the strength of soft rock materials.

The influence of moisture content on the behaviour of rocks has been investigated for more than thirty years [5, 6, 7, 8, 9]. It is frequently associated with mechanisms such as capillary suction and crack propagation. Most researchers agree that the strength of any given soft rock will decrease as the moisture content increases. However, the correlation between strength and moisture content is not always linear.

Hawkins and McConnell [8] found that, for most types of sandstone, a sudden loss of strength occurs between a moisture content of 0% and 1%, and only a slight strength reduction above a moisture content of 1%. Similar results were also obtained by Schmitt et al. [10] for Fontainebleau and Vosges sandstones, which show an exponential correlation; but a relatively linear correlation was obtained for Tournemire shale.

Note: Discussion is expected before June, 1st 2007, and will be published in the "Civil Engineering Dimension" volume 9, number 2, September 2007.

Received 1 Mey 2006; revised 21 July 2006, 18 October 2006; accepted 21 November 2006.

These findings [10] reveal that the sensitivity of rock strength due to changes in moisture content seems to vary from rock to rock. This sensitivity depends on the clay content of the rock being investigated [8]. A similar result was also found by Bell and Culshaw [9]. However, Dobereiner and DeFreitas [11] and Dyke and Dobereiner [12] pointed out that weaker sandstones are more sensitive to changes in moisture content than harder rocks. Dyke and Dobereiner [12] concluded that the texture of the rock, that is the proportion of grain contact, is responsible for reductions in the strength of sandstone. Further, Dyke and Dobereiner [12] found that an increase in moisture content tends to decrease the range of elastic behaviour of sandstone.

From the discussion above, it is interesting to note that the critical condition for rocks containing fewer clay minerals is when the moisture content increases up to 1%, where a sudden strength loss occurs. The reason may be that suction, acting as a confining pressure, suddenly disappears when the moisture content reaches 1%. However, for rocks which are rich in clay minerals, suction disappears gradually up to the degree of saturation of 100% [13].

Sample preparation for soft rock materials is more difficult compared to that of hard rock materials. Agustawijaya [13] indicated that the methods of sample preparation and laboratory testing for soft rocks are similar to those of soils. Such difficulties have been experienced by Agustawijaya [14] in preparing mudstone samples for direct laboratory shear testing; and by Bro [15] in preparing samples for triaxial testing. Soft rocks are sometimes so friable, that the rocks can easily break apart. Instead of machining the samples, Akai [16] suggested the use of hand sculpturing and fine sandpaper to flatten the ends of the friable core specimen. Thus, it is crucial to protect soft core samples from damage as much as possible prior to testing, since excellent testing results will depend to some extent on the quality of the samples.

The International Society for Rock Mechanics (ISRM) [1] suggested a length/diameter (L/D) ratio of 2.5 for samples in compression tests. However, it is not easy to obtain a sufficient number of samples with an L/D ratio bigger than 2, as the drilling program into soft rock is usually difficult, and it might only obtain 10-20% of the drilling length [13]. Thus, the ratio could be less than 2.5.

Due to some degree of technical difficulties, the uniaxial compression test for soft rock is often replaced by a point load strength index test. This test is simpler in procedures than that of the uniaxial compression test, and the test does not need necessarily cylindrical samples. A conversion factor is then applied to the point load strength index, $I_S(50)$, for estimating the uniaxial compressive strength (UCS).

Broch and Franklin [17] suggested a conversion factor of 24 as a correlation between UCS and $I_S(50)$. However, this conversion factor is more effective for hard rock materials than soft rock materials. The strength of soft rock materials is much lower than that of hard rock materials, so the conversion factor should certainly be different. This paper aims to evaluate the uniaxial compressive strength, the influence of some physical characteristics on the strength of soft rock materials, and the correlation between the point load strength index and the uniaxial compressive strength.

METHOD

Methods for uniaxial compression test follows the suggested method given by the ISRM [1]. The tests in this study were conducted under drained conditions. Test specimens were argillaceous rocks (sandstone and siltstone) obtained from rock drilling at five different locations, namely, Desert View Motel (DV), McCormack's dugout (MC), Old Timers Shop/Museum (OTM), Gunther Wagner's dugout (GW) and Les Hoad's dugout (LH) [13]. These specimens were cut with an L/D ratio of 1.6:1 – 2.5:1. For the uniaxial compression test these samples were grouped into two main groups based on the degree of weathering and the degree of saturation for each type of rock.

Laboratory point load strength test follows the methods suggested by the ISRM [18]. In this study the strength index test used a speed control Instron machine with a maximum load cell of 5 kN. Specimens were core samples with a diameter of 37.5 mm, and a thickness of 20 mm. Similar rocks with that for the uniaxial compression tests were tested in the point load tests.

The degree of weathering was described according to the method given by GSEGWP [19]. The two main qualitative classifications were partially weathered (PW) rock and distinctly weathered (DW) rock. Some samples were classified into de-structured (DST) rock, where some parts of the rock have changed to soil.

Samples were further divided into two types of saturation, dry (0% saturation) and fully saturated (100% saturation). Dry specimens were obtained by putting the sample in an oven at a temperature of 105^{0}C for 12 hrs. Fully saturated specimens were obtained by immersing samples in distilled water. They were then vacuumed over 24 hrs [13].

RESULT AND DISCUSSION

Results of uniaxial compression tests on 39 specimens are listed in Table 1. As can be seen in this table, partially weathered rocks give higher uniaxial compressive strength (UCS) values compared to distinctly weathered rocks. The highest UCS value is about 11 MPa for the (PW) LH rock, whereas the lowest UCS value is about 1 MPa for the (DW) GW rock.

Table 1. Uniaxial Compression Test Results

Rock type	Sample	Weathering	Saturation	L/D	UCS (MPa)	Ave (MPa)
DV Sandstone	DV9^	PW	Dry	1.77	10.54	9.78
	DVR1	PW	Dry	2.00	9.01	
	DV3-3DW^	DW	Dry	1.72	3.15	3.72
	DV3-DW0	DW	Dry	2.33	3.07	
	DV8A^	DW	Dry	1.64	4.93	
	DV2-DW1^	DST	Dry	1.75	1.79	1.79
	DV3-1S1	DW	Sat.	2.17	2.45	2.84
	DV3-2	DW	Sat.	2.00	3.32	
	DV3-3	DW	Sat.	1.92	2.76	
	DV2-S1*	DST	Sat.	2.34	1.48	1.64
	DV2-S2*	DST	Sat.	2.22	1.85	
	DV3-1S2	DST	Sat.	2.03	1.52	
	DV3M-S3	DST	Sat.	2.12	1.63	
	DV2-S7	DST	Sat.	1.95	1.74	
GW Siltstone	GW-7M6	DW	Dry	2.20	5.80	4.70
	GW1	DW	Dry	1.67	5.08	
	GW3	DW	Dry	1.62	4.53	
	GW2	DW	Dry	2.04	3.38	
	GW-9M3	DW	Sat.	2.29	1.46	1.16
	GW-10M1	DW	Sat.	2.03	1.00	
	GW-9M5	DW	Sat.	1.97	1.01	
LH Siltstone	LH3-9	PW	Dry	2.13	9.92	10.10
	LH3-11	PW	Dry	2.16	9.29	
	LH3-7	PW	Dry	2.14	11.09	

	LH1-1	DW	Dry	2.13	4.07	4.26
	LH1-22	DW	Dry	2.09	4.33	
	LH1-13	DW	Dry	2.19	4.39	
MC Siltstone	MC2-3-5	DW	Dry	1.68	5.07	5.36
	MC22	DW	Dry	2.27	5.65	
	MC4	PW	Sat.	1.98	6.97	6.05
	MC19	PW	Sat.	2.09	7.20	
	mc16	DW	Sat.	2.03	3.99	3.99
OTM Siltstone	OTM2-10-2	DW	Dry	2.27	4.31	4.92
	OTMi-14	DW	Dry	2.26	5.53	
	OTMo-15	PW/DW	Sat.	2.50	5.50	5.25
	OTMo-17	PW/DW	Sat.	2.21	5.00	
	OTMo12	DW	Sat.	1.89	1.58	2.05
	OTM2-8A	DW	Sat.	1.66	2.13	
	OTM2-11	DW	Sat.	1.87	2.43	

From Table 1, it can be seen that the average UCS values are far below 20 MPa, and only the UCS of LH siltstone is about 10 MPa. It seems that weathering and saturation play an important role in strength reduction. The discussion of strength reduction follows.

Influence of L/D Ratio

The ISRM [1] recommended an L/D ratio of at least 2.5:1 for compression tests. However, a sufficient number of specimens with this ratio are often difficult to obtain [13]. With L/D ratios of 1.6:1 to 2.5:1, no significant indication has been found that the UCS is influenced by the L/D ratio.

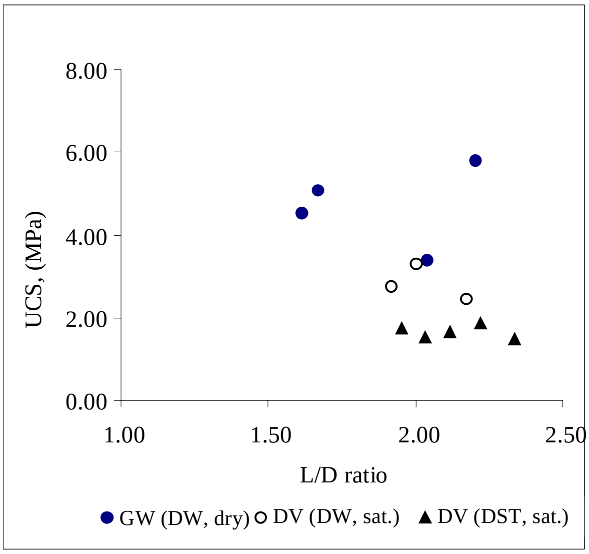


Figure 1. Correlation Between UCS and L/D Ratio

Figure 1 shows a scatter of UCS data of some samples related to their L/D ratios, and there is no general trend to indicate an influence of the ratio on the UCS. For example taking the DV(DST, sat.) samples, the UCS values for these specimens are relatively similar for each different ratio. The scattered data may simply be due to the physical characteristics of the samples. Matthews and Clayton [20] found a similar result for chalk tested with ratios of 2:1 and 2.5:1.

Some researchers [7, 9, 11, 21, 22] have conducted compression tests on soft rocks with an L/D ratio of 2.0. Chiu et al. [7] conducted drained triaxial tests on Melbourne mudstone with L/D ratios from 0.5 to 3.0, and found that the trend of peak deviator stresses and secant Young's modulus tend to be constant when the ratio is at least 2.0.

Chiu et al. [7] pointed out that increased strength with a shorter specimen is due to lateral restraint at the ends of the specimen. It is understood that this lateral restraint is caused by the platens, which may cause non-uniform stress distributions under compression [20]. The volume of the specimen may also influence the results of the test. However, it is the material properties that seem to cause the major effects on the mechanical behaviour of soft rocks. Matthews and Clayton [20] found that samples with ratios of 2.0 and 2.5 both displayed similar behaviour under uniaxial compression stresses. They noted that the uniaxial compressive strength of chalk was more likely to be influenced by the dry density and porosity, rather than by the ratio of the sample dimensions.

Influence of Saturation

The influence of water on rock strength has been known for years [13], it is also known that strength reduction due to saturation varies from one rock to another. The strength reduction for weathered argillaceous rocks can be seen in Table 2.

Table 2. Influence of Saturation in Uniaxial Compressive Strength

Rock type	Weathering	UCS ave. (MPa)		Reduction (%)	Mean (%)
		Dry	Sat		
DV Sandstone	DW	3.72	2.84	23.5	38.2
DV Sandstone	DST	1.79	1.64	8.2	
GW Siltstone	DW	4.70	1.16	75.4	
MC Siltstone	DW	5.36	3.99	25.6	
OTM Sandstone	DW	4.92	2.05	58.4	

From Table 2, the UCS reduction could be up to 75%, although, for de-structured rocks, DV (DST), the reduction might only be 8%. Under dry and fully saturated conditions, these DV (DST) rocks had very low UCS values, below 2 MPa. Thus, in general, the mean value of strength reduction due to water for all rock samples would be about 38%, which is close to the strength reduction of sandstone (36%) found by Bell and Culshaw [9].

Influence of Weathering

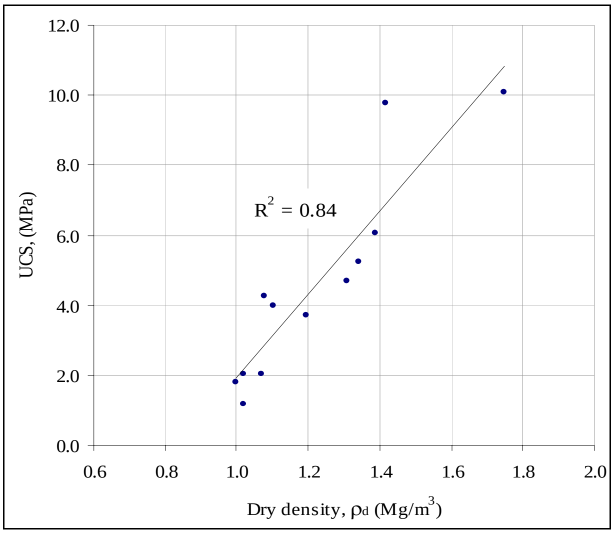
Data in Table 3 show that strength reductions due to weathering could be quite high, to about 82%. Dry and fully saturated samples show similar characteristics.

Table 3. Influence of Weathering on Uniaxial Compressive Strength

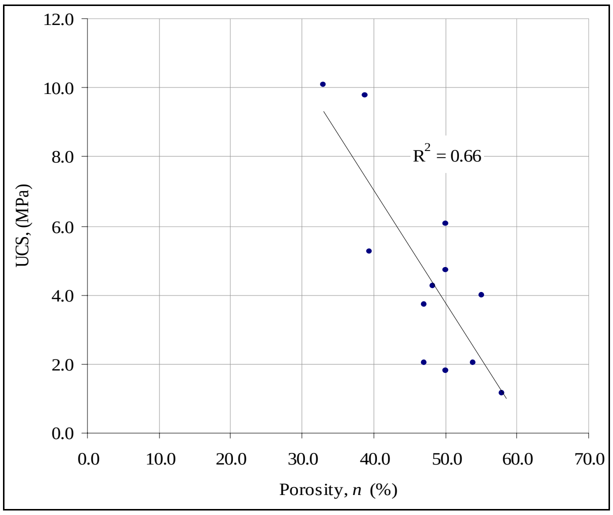
Rock type	Saturation	UCS ave. (MPa)				Reduction (%)	Mean (%)
		PW	PW/DW	DW	DST		
DV Sandstone	Dry	9.78	-	3.72	-	62.0	56.5
DV Sandstone	Dry	9.78	-	-	1.79	81.7	
DV Sandstone	Sat	-	-	2.84	1.64	42.2	
LH Siltstone	Dry	10.10	-	4.26	-	57.8	
MC Siltstone	Sat	6.05	-	3.99	-	34.1	
OTM Siltstone	Sat	-	5.25	2.05	-	61.0	

Dry density and porosity as weathering indicators [13, 20] were correlated with uniaxial compressive strength, and both parameters show a good correlation with uniaxial compressive strength (Figure 2).

From Figure 2, it can be seen that when the dry density increases, the UCS increases. Similarly, as the porosity increases, the UCS decreases, although the correlation between UCS and porosity has a lower R^2, which is about 0.66. These correlations could mean that when rock weathers, its dry density and porosity change, so does it's UCS.



(a)



(b)

Figure 2. Correlation Between UCS and Dry Density and Porosity

Influence of Mineral Content

As the degree of weathering increases, the clay content of the weathered rock increases. For example, the (PW) DV rock may contain a greater proportion of quartz than the (DW) GW rock, which contains dominant kaolinite. It is important to note that gypsum is commonly found in argillaceous rocks. It appear in every level of weathering, but it is most commonly found in distinctly weathered rocks. Robertson and Scott [23] noted that the presence of sulphate minerals, such as gypsum, is due to oxidation of pyrite, which is commonly found in unweathered sandstone. As sandstone weathers, gypsum may become more apparent. However, weathered sandstone is pre-dominated by kaolinitic silty or sandy minerals, which may become a good indicator for weathering in argillaceous rocks [23].

Hawkins and McConnel [8] pointed out that the sensitivity of sandstone to change in moisture content is controlled mainly by the mineralogy and to a lesser extent by texture and microstructure. However, Dobereiner and DeFreitas [11] and Dyke and Dobereiner [12] found that the weaker the sandstone, the more sensitive its strength to moisture content variation.

The important phenomenon observed during the current investigations on argillaceous rocks are that weathering, is a complex feature that may involve not only one process, but also other processes which can occur simultaneously. Referring to Agustawijaya [13], chemical weathering and physical weathering may occur one after the other. As products of weathering, it may be difficult to quantify clay minerals that may dominate over dry density and porosity in controlling the mechanical behaviour of weathered rocks. Thus, both mineralogy and texture should have, to some extent, an equal contribution to the mechanical characteristics of rocks, particularly the uniaxial compressive strength, depending on the degree of weathering.

Correlation Between UCS and Point Load Strength Index

The point load strength index, $I_S(50)$, has been used to predict the uniaxial compressive strength (UCS), with a conversion factor of about 24 [17, 24, 25, 26]. However, this conversion factor may only adequately predict the UCS of hard rocks. For soft rock, the conversion factor could be much less than 24.

Forster [27] found that the conversion factor for sandstone falls in the range between 7.4 and 17.6. More recently, Bowden et al. [28] found that the conversion factor for chalk is from 5 to 24.

In the current research, the UCS and the $I_S(50)$ of the argillaceous rock samples were correlated, as can be seen in Figure 3. The $I_S(50)$ has a good correlation with the UCS, with a correlation coeficient of about 0.9. This is a good correlation that has also been indicated by Bell and Culshaw [9].

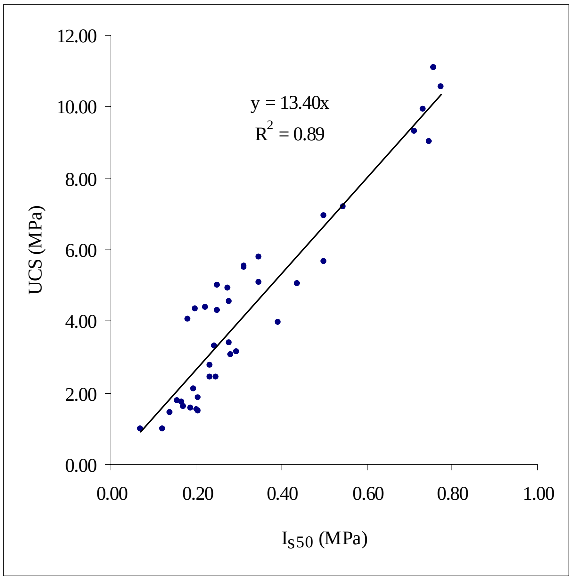


Figure 3. Correlation Between UCS and Point Load Strength Index

From Figure 3, the conversion factor for weathered argillaceous rocks is about 13.4. The conversion factor agrees well with the theoretical conversion factor given by Chau and Wong [29], which is about 14.9. Comparing between the current conversion factor and published data [27, 28, 29] it seems that the value of 14 is the median of all values falling in the range from 4 to 24. This value is 58% of the conversion value for hard rocks, (24), given by Broch and Franklin [17].

CONCLUSION

The uniaxial compressive strength (UCS) values of soft rocks have been found to be far below 20 MPa. The UCS value of some samples approached 1 MPa. This value is certainly very low for rock materials. Weathering and saturation seem to play a significant role in reducing the strength of soft rock materials. The strength reduction could be up to about 80%.

The UCS values were then correlated with the point load strength index values, which show a good correlation. The conversion factor for soft rocks is found to be about 14, which is about 58% of the conversion factor for hard rocks.

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