

*Indexed*

# A STUDY ON THE ENGINEERING PROPERTIES OF SRI LANKAN ROCKS

by

U .de S. Jayawardena

---

## Abstract

The development planning of civil engineering works in Sri Lanka has increased in last two decades as a part of the economic development programme of the country. To give the fullest contribution for such civil engineering works, a better engineering geological knowledge is needed as well as useful. Research in this field will be very important to use in the future projects. The objectives of this study are to provide some literature for various engineering properties of Sri Lankan rocks for the benefit of future engineers and engineering geologists, and provide correlation methods between engineering properties of Sri Lankan rocks. Cylindrical and irregular samples of fresh rocks were collected from various project sites and different localities and laboratory experiments were carried out to find the values of various properties. The general range of the values of some physical properties, mechanical properties and deformation moduli by ultrasonic methods were found for major metamorphic rocks in Sri Lanka.

These results will be very important to get a prior knowledge about the engineering properties of rocks before the beginning of any investigation. Therefore these results will be very useful contribution to the literature on the engineering properties of Sri Lankan rocks.

The uniaxial compressive strength of the metamorphic rocks in Sri Lanka is equal to 17 times of point load strength and 14.5 of uniaxial tensile strength. Hence the measurement of point load strength is enough to get the approximate values of uniaxial compressive strength and uniaxial tensile strength of the fresh parent rock. This rough estimation may be very helpful for the preparation of preliminary estimating and designing purposes for any geotechnical engineering project.

## 1. Introduction

### 1.1. General

One factor necessary for designing and evaluating the stability of any engineering structure is a knowledge of the mechanical properties of its material or a knowledge of how the material fails under the action of applied forces. The composition of most structural materials such as metals and concrete is uniform and reproducible. However, the composition of even the more common rock type is highly variable. This may be due to various factors such as rock anisotropy, cementing materials, rock structure and texture, geological actions, alteration and decomposition. Therefore different rock types give rather different values for the same property. This indicates that the determination of the engineering properties of rocks in relation to geotechnical problems is an essential part of most geotechnical investigations. The various ways of determining these properties of rocks are,

by referring to values given in the appropriate literature,  
by in-situ experiments and  
by a programme of laboratory testing.

The rocks have been classified as igneous, sedimentary and metamorphic according to their origin, texture and mineralogy. This classification is not valid for engineering science because rock is another material. Hence the rocks have been classified according to their properties for engineering purposes such as tunnels, underground openings etc. (BELL, 1980). As far as Sri Lankan rocks are concerned, there are no (or very limited) such freely available data to use as literature reviews. A classifica-

*Dr. U.De. S. Jayawardena, BSc (Hon), MSc, DEng, Senior Lecturer, Engineering Geology Department of Civil Engineering, University of Peradeniya.*

tion of the various engineering properties of Sri Lankan rocks is, therefore, a necessity because it gives prior knowledge of these properties by identifying the type of rocks in any site. In-situ testing or laboratory testing for various rocks occurring within the area of the selected engineering site can be carried out after reference to the available literature. And also it can be used for preparation of preliminary designing and cost estimating etc. Experiments to make such a classification and find possible correlation among the direct tests, indirect tests, laboratory tests and field tests are very important for the future engineering projects in Sri Lanka.

There are many engineering properties but all of them are not necessary to measure for a selected project site. Some properties of rocks can be measured by direct methods. There are indirect methods to measure the same property in different ways. The indirect methods are quick, economical and need less man power. The indirect results are related to the direct results both in field tests and laboratory tests. Development of any relationship between laboratory tests and field tests will be very useful to future investigations.

Evaluation of the strength parameters is a prerequisite for engineering classification of rock materials. The uniaxial compressive strength, uniaxial tensile strength and point load strength are such parameters often used in classification. The main objective of the present study is to make a useful contribution to the literature on the engineering properties of Sri Lankan rocks. The author carried out a programme of research to determine these properties and some of the results have been already published (JAYAWARDENA, 1988, 1989, 1996). This paper highlights the values of different engineering properties and interrelationships among them and the development of empirical relations for Sri Lankan rocks.

## 1.2 Summary of The Geology of Sri Lanka

About nine-tenth of Sri Lanka are underlain by Precambrian crystalline rocks. These are mainly high-grade metamorphic rocks, which have been subdivided into three groups, namely the Highland Series, The Vijayan and Wannan complex and the Southwestern Group (COORAY, 1967). The remaining rocks are sedimentary rocks of predominantly Miocene age in the north west with some Jurassic sediments preserved in small faulted basins. The various geological formations in Sri Lanka can be summarized as given below.

Quaternary: Alluvium, beach sands, dune sands, clays, beach-rock, Red Earth, mottled gravels.

Miocene: Jaffna limestone

Jurassic: Tabbowa Beds (sandstone, shale, grits and arkose).

Precambrian:

(a) Vijayan and Wannan Complex:

Migmatites, hornblende-biotite gneiss, biotite gneiss, granite and granitic gneiss.

(b) Highland Series

Quartzites, granulites, garnet-sillimanite graphite schist and gneiss,

Charnockitic gneiss, marble, dolomite and some hornblende biotite gneiss.

(c) Southwestern Group

Wollastonite-scapolite gneiss, cordierite gneiss, charnockitic gneiss and granitic gneiss.

Highland Series rocks are present mainly in the hill country of the island and Vijayan and Wannan complex rocks are found in the low-lying areas on either side of the Highland Series. The Southwestern group rocks occupy the southwestern region of the Island (Fig.1). (COORAY, 1967).

## 1.3 The Engineering Properties of Rocks

The engineering properties can be divided into two as physical properties and mechanical properties. The density, specific gravity, porosity, void index (water content), and swelling and slake durability indices are physical properties. Mechanical properties of rocks include strength and deformability properties of rocks. Uniaxial compressive strength and uniaxial tensile strength of intact rocks are often needed properties in engineering designs of structures in rock. Direct shear strength and triaxial strength are the other important strengths for rocks. The permeability and resistant to abrasion also some other properties.

Indirect tests also use to find the value of uniaxial compressive strength of a rock. Point load strength test and Brazillian test are such indirect methods to find the values of uniaxial compressive strength and uniaxial tensile strength of materials respectively.

Young's modulus of elasticity, Poisson's ratio, shear modulus (or modulus of rigidity) bulk modulus are the deformation properties of rocks (OBERT and DUVALL, 1967). The various deformation moduli of rocks are related to the compressional and shear wave velocities.

Ultrasonic pulse method is more common method to determine the dynamic elastic constants. This is a non-destructive test and therefore it can be performed before a destructive test is done on the same specimen.

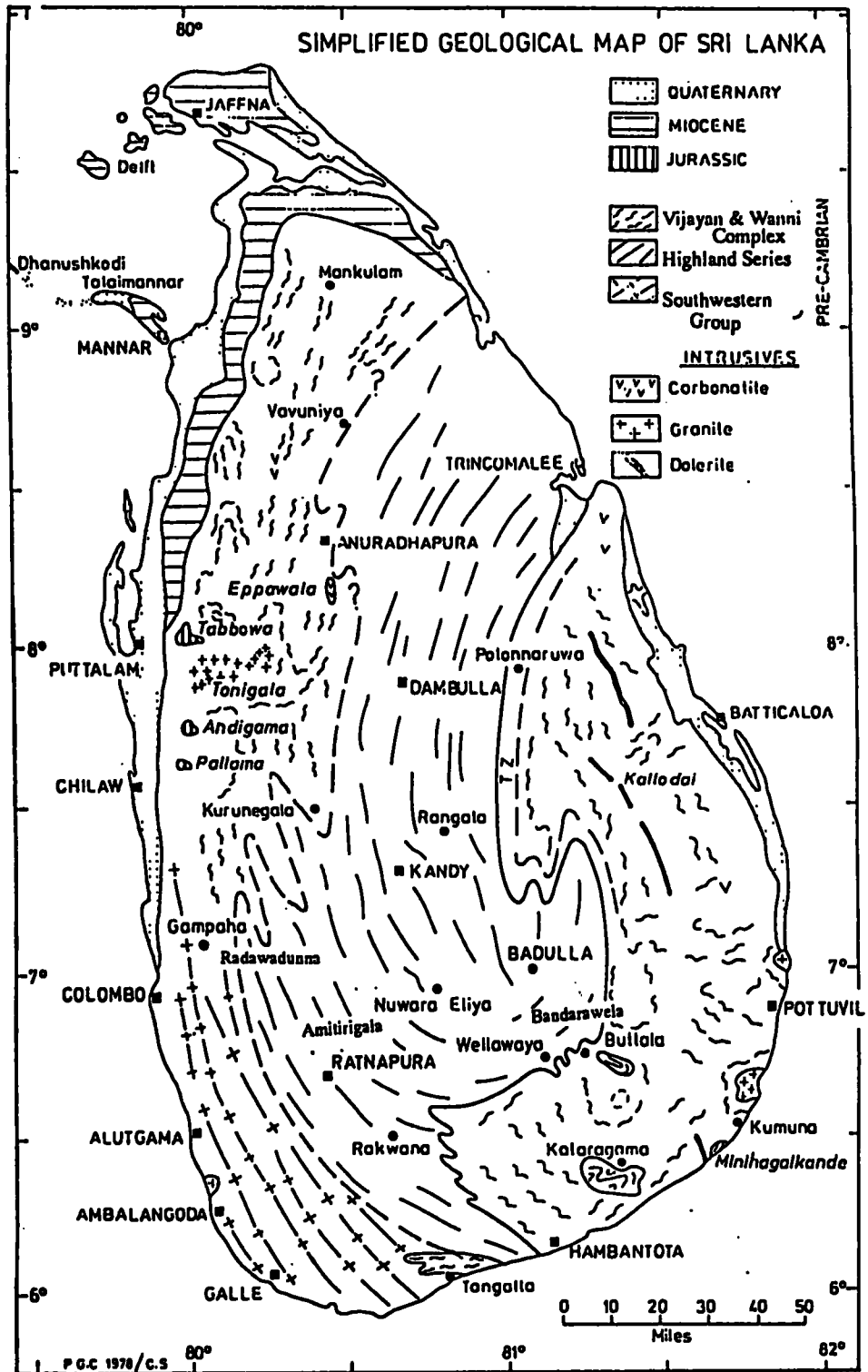


Fig. 1 - The major subdivisions of the geology of Sri Lanka (COORAY, 1967)

## 2. Experimental Method

### 2.1 Sample Collection

#### 2.1.1 Borehole samples

Borehole samples were obtained from various drilling sites belonging to different engineering projects. All samples were NX size (approximately 54 mm). The pieces without cracks, joints and other fractures were selected from the borehole sample boxes for laboratory tests. All collected samples were fresh and different types. No weathered samples were selected for this experiment.

#### 2.1.2 Irregular samples

Representative localities were selected to collect samples for testing from different rock types. In general these are the major rock types in regional basis. Fresh samples were obtained from rock quarries and outcrops. Generally the sample block size was approximately 10 cm in length, width and height. Fig. 2 shows the sampling locations.

### 2.2 Preparation of Samples for Engineering Properties

#### 2.2.1 Bulk density and porosity

Cylindrical samples (about 10 cm height) were cut from both ends to get parallel sides. The same sample was used for both bulk density and porosity measurements. The lengths of the samples are not similar to each other.

#### 2.2.2 Point load strength test

Rectangular block specimens were prepared in various sizes for the tests, according to the recommendations of the ISRM (1985), using the laboratory rock cutting machine. This preparation was done only for the irregular samples collected from various locations. The cylindrical borehole samples were cut into various size slices as test specimens. The height of a sample was between 25-50 mm. The minimum number of specimens per test was 10.

#### 2.2.3 Brazilian tensile strength test

Cylindrical samples of hard rocks were cut into circular discs using a laboratory rock cutting machine in such a way that the thickness of each specimen is equal to the half of the diameter (27mm). The samples were carefully prepared to obtain parallel opposite faces (ISRM, 1977). The minimum number of samples per test was five.

#### 2.2.4 Uniaxial compressive strength

This preparation was in accordance to ASTM (1977) and (1972). Samples were carefully checked to select the most suitable specimens for testing. Samples with joints, cracks, and cavities and with little irregularities were rejected. Specimens were cut from both ends keeping parallel end surfaces. The length of the specimen was two times of the diameter or above (approximately 110-120mm). Laboratory lapping machine and a thick glass plate were used for lapping and smoothing the end surfaces.

#### 2.2.5 Ultrasonic velocity test

Both irregular and borehole samples were prepared for this test. Samples were cut from opposite ends keeping parallel end surfaces. Generally the length of a sample was between 110-120 mm. These parallel and opposite surfaces were smoothed by lapping slowly.

### 2.3 Laboratory Experiments

#### 2.3.1 Bulk density and porosity

The average height, average diameter and weight were used to calculate the bulk density. The same samples were saturated for the calculation of porosity.

#### 2.3.2 Point load strength test

ISRM (1985) suggested method was applied for the test and calculation. These tests were performed with the portable equipment called point load test machine (ELE International Limited, England). About ten specimens of each sample were tested to obtain the value of point load strength.

#### 2.3.3 Uniaxial tensile strength test

Brazilian test described by ISRM Committee on laboratory tests (1977) was performed for each specimen using an apparatus specially made for this (by way of steel jaws). The Universal Testing Machine AVERY-E63695, England was employed for the load application. The cracks present at the center were considered as a satisfied test.

#### 2.3.4 Uniaxial compressive strength test

The test was performed according to ASTM (1977) and ISRM (1972). The samples were tested using a 100 ton Universal Testing Machine, AVERY, England No 62351 with a spherical seating top cap to ensure proper contact. The number of specimens tested for one average value was two.

### 2.3.5 Ultrasonic velocity test

This experiment was performed according to the Laboratory manual for Rock Testing (AIT, 1981). Portable ultrasonic non-destructive digital indicating tester "PUNDIT", manufactured by C.N.S. Electronic Limited, England was employed to measure the signal transmission time for P and S waves through the test specimens.

Some of the samples were selected for uniaxial compressive strength test after this non-destructive test.

After the calculation of P and S wave velocities, Young's Modulus, Poisson's Ratio, Modulus of Rigidity and Bulk Modulus were calculated using the equations described by ATTWELL and FARMER (1976).

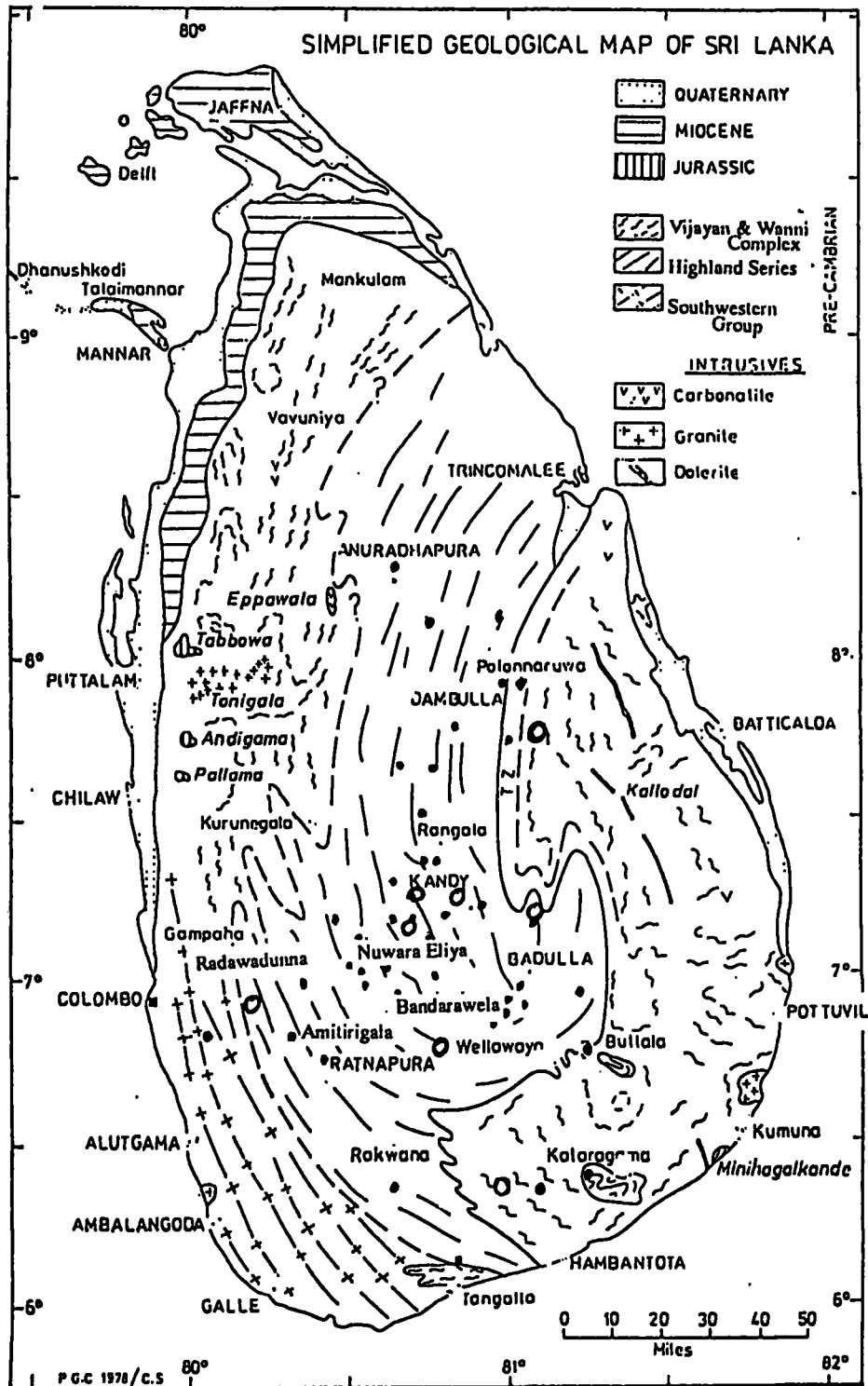


Fig. 2 - Locality map of studied samples (circles for borehole sites and dots for irregular sample sites.)

### 3. Results-Engineering Properties of Fresh Rocks

#### 3.1 General

The major rock types selected for this study were charnockitic gneiss or charnockite, garnet sillimanite gneiss, hornblende biotite gneiss, biotite gneiss, migmatite, quartzite, granulite and marble which are the major metamorphic rocks in Sri Lanka. Some other rocks namely amphibolite, calc gneiss and pink feldspar gneiss also selected though those are not widely distributed rocks in the country. Most of them are from Wet Zone and a few of them belong to Dry Zone.

Table 3.1. Shows the ranges of bulk density, porosity, uniaxial tensile strength, point load strength, uniaxial compressive strength, ultrasonic P wave velocity, ultrasonic S wave velocity and modulus of elasticity for different rock types. Table 3.2. show the number of samples tested including both cylindrical and irregular samples. The graphical variations of the ranges of the values for each property are showing from Fig. 3 to Fig. 10 the summary of each property can be mentioned as given below.

##### 3.1.1 Bulk density

Quartzite shows the lowest value, may be due to the occurrence of some minor cracks in the specimens. Pink feldspar gneiss and charnockitic gneiss also show lower values. This may be due to the highly concentrated light minerals. Some rocks show higher density due to higher concentration of some minerals such as garnet and hornblende (Table 3.3.).

##### 3.1.2 Porosity

Charnockitic gneiss has the lowest values of porosity and quartzite has the highest porosity. However all values are less than 1% and therefore it is considered as normal for metamorphic rocks (Table 3.4.).

##### 3.1.3 Uniaxial tensile strength

The strongest rock, which can hold a much higher tensional force, is charnockitic gneiss and the weakest rock, which cannot bear a considerable tensional force, is marble (Table 3.5.).

##### 3.1.4 Uniaxial compressive strength

The highest value, 231.6 MPa was obtained from charnockitic gneiss and the lowest was from marble rock. In addition to that, charnockitic gneiss has wider

range of uniaxial compressive strength than the other rocks (Table 3.6.).

##### 3.1.5 Point load strength

Similar to uniaxial compressive and uniaxial tensile strengths, charnockitic gneiss has the highest strength and marble has the lowest. In general charnockitic gneiss and pink feldspar gneiss have average higher values than the other rocks and therefore these two can be considered as strong rocks in Sri Lanka. Marble and granulite are generally weaker than the other rocks. The rocks other than strongest and weakest rocks can be considered as general or medium-strong rocks (Table 3.7.).

Point load strength was measured perpendicular to the mineral bands of all banded rocks. Generally the strengths parallel to the mineral bands in those rocks are slightly less than the values measured in perpendicular directions. The highest value was used for comparison with the other rocks.

##### 3.1.6 Ultrasonic velocity

The highest P wave velocity, 6880 m/s was obtained from charnockitic gneiss and lowest 3580 m/s was recorded from quartzite. Pink feldspar gneiss and charnockitic gneiss have the highest wave velocities and quartzite, hornblende biotite gneiss and biotite gneiss have lower velocities. Marble, migmatite, garnet sillimanite gneiss and granulite have medium velocity range comparatively with the other rocks (Table 3.8. & Table 3.9.).

##### 3.1.7 Modulus of elasticity

Shear wave velocities are about 0.5-0.6 times of P wave velocities. Here charnockitic gneiss gives the highest elasticity modulus. Due to the occurrence of minor cracks quartzite shows low values (Table 3.10.).

#### 3.2 Analysis

##### 3.2.1 Graphical analysis

The results obtained from the testing of borehole samples collected from various engineering project sites were used to establish one or many correlation among the properties for the benefit of future engineers in Sri Lanka. The uniaxial compressive strength and uniaxial tensile strength are not possible to find from the irregular rock samples.

Figure 11 and Fig.12 show the variation of point load strength and uniaxial tensile strength against uniaxial compressive strength for charnockitic gneiss and biotite gneiss. Similarly these graphs were drawn for garnet

sillimanite gneiss, hornblende biotite gneiss, quartzite, and marble.

Fig. 13 shows the variation between uniaxial compressive strength and P wave velocity.

### 3.2.2 Statistical analysis

A simple statistical method was used to find out the variations between the ratios of uniaxial compressive strength and point load strength, and between uniaxial tensile strength and point load strength for different rock types. Table 3.11 gives the average of these ratios and overall average and standard deviations for major rocks.

Table 3.1 Summary of results; the dark-upper line shows the results from borehole samples and lower line shows the results from irregular samples for each rock

Rock Type	Density kg/m <sup>3</sup>	Porosity	Tensile Strength MPa	Point Load Strength MPa	Uniaxial Compressive Strength MPa	Ultrasonic Velocity Vp m/s	Ultrasonic Velocity Vs m/s	Ultrasonic Poisson's Ratio	Ultrasonic Young's Modulus of Elasticity, GPa	Ultrasonic Rigidity Modulus GPa
Gneissic Charnockite	2600 - 2981 2627 - 2990	0.12 - 0.98 0.12 - 0.91	7.6 - 15	6.8 - 12.9 10.2 - 16.8	104.2 - 231.6	5620 - 6880 5609 - 6550	2645 - 3535 2750 - 3490	0.28 - 0.35 0.28 - 0.36	50.91 - 95.76 61.20 - 94.53	18.74 - 36.22 20.07 - 36.30
Hornblende Biotite Gneiss	2675 - 2890 2698 - 2950	0.51 - 0.74 0.27 - 0.45	4.1 - 8.8	3.5 - 7.6 4.2 - 7.2	60.3 - 123.5	4420 - 4910 3880 - 5620	2290 - 2560 1879 - 2844	0.3 - 0.34 0.21 - 0.35	37.17 - 48.77 25.85 - 58.92	14.13 - 18.29 9.82 - 23.31
Biotite Gneiss	2620 - 2982 2640 - 2801	0.19 - 0.71 0.23 - 0.87	5.2 - 10.8	4.4 - 10 5.1 - 9.2	74.9 - 159.2	4090 - 5565 4218 - 4950	2070 - 2785 2095 - 2482	0.31 - 0.36 0.31 - 0.37	31.46 - 58.63 31.9 - 45.42	11.83 - 22.04 11.58 - 16.8
Quartzite	2595 - 2739 2538 - 2632	0.56 - 0.90 0.63 - 0.98	5.2 - 8.3	5.1 - 7.5 4.8 - 7.6	70.2 - 118.4	4430 - 5140 3580 - 5120	2280 - 2780 2260 - 2730	0.26 - 0.33 0.28 - 0.35	35.96 - 54.17 37.39 - 55.18	13.62 - 20.94 13.33 - 20.98
Garnet Sillimanite Gneiss	2857 - 3031 2718 - 2917	0.26 - 0.64 0.34 - 0.86	5.2 - 9.2	4.4 - 7.5 5.8 - 7.2	75.1 - 116.3	5325 - 5830 5239 - 5580	2535 - 3155 2790 - 3050	0.27 - 0.35 0.28 - 0.3	49.95 - 73.63 55.10 - 69.66	18.45 - 28.83 21.15 - 27.13
Marble	2674 - 2910 2689 - 2934	0.37 - 0.7 0.2 - 0.57	2.3 - 8.4	2.0 - 6.9 2.5 - 6.4	33.8 - 124.3	5066 - 5580 5133 - 5695	2432 - 2920 2570 - 2875	0.31 - 0.35 0.31 - 0.35	48.13 - 65.07 50.27 - 67.18	16.70 - 24.81 18.62 - 25.26
Granulite	2720-2734	0.62 - 0.78	5.5 - 6.2	4.5 - 5.2	81.4 - 90.7	4912 - 5140	2350 - 2700	0.31 - 0.36	40.7 - 52.41	15.02 - 19.93
Pink Feldspar Gneiss	2603-2693	0.32 - 0.79		10.8 - 12.2		5940 - 6230	2830 - 3095	0.34 - 0.36	56.41 - 68.93	20.84 - 25.79
Migmatite	2795 - 2862	0.23 - 0.63		5.0 - 7.8		5110 - 5440	2570 - 2820	0.32 - 0.33	49.79 - 60.54	18.77 - 22.75
Calc Gneiss	2668	0.86		7.4		5780	2840	0.34	57.7	21.51
Amphibolite	3035	0.25		11.2		6880	3448	0.33	95.82	35.96

Table 3.2 Total number of borehole and irregular samples (FRESH ROCK SAMPLES) used for the experiment

Rock Type	BOREHOLE SAMPLES							IRREGULAR SAMPLES		TOTAL SAMPLES
	Kotmale Project	Victoria Project	MaduruOya Project	Samanalawewa Project	Udawalawe Project	Kandy Project	Avissawella Project	Total	Other Localities	
Charnockitic Gneiss	71	14			2		10	95	43	138
Garnet Sillimanite Gneiss	9							11	6	17
Hornblende Biotite Gneiss	6							19	23	42
Biotite Gneiss	12	5	5		5	8	6	44	14	58
Quartzite	8		4			12	4	12	14	26
Marble	12	4						21	16	37
Migmatite								No	5	5
Pink Granitic Gneiss								No	4	4
Calc Gneiss								No	1	1
Amphibolite								No	1	1
Granulite	5							5	2	7
<b>TOTAL</b>	<b>123</b>	<b>23</b>	<b>9</b>	<b>7</b>	<b>20</b>	<b>5</b>	<b>20</b>	<b>207</b>	<b>129</b>	<b>336</b>

Table 3.3 The ranges of bulk density of different rock types in Sri Lanka

Rock Type	Density Range kg/m <sup>3</sup>	No. of Samples tested
Charnockitic Gneiss	2600 - 2990	138
Garnet Sillimanite Gneiss	2718 - 3031	17
Hornblende Biotite Gneiss	2675 - 2950	42
Biotite Gneiss	2620 - 2982	58
Quartzite	2538 - 2739	26
Marble	2674 - 2934	37
Migmatite	2795 - 2862	5
Pink Feldspar Gneiss	2603 - 2693	4
Calc Gneiss	2668 -	1
Amphibolite	3025 -	1
Granulite	2720 - 2734	7

Table 3.4 The ranges of porosity of different rock types in Sri Lanka

Rock type	Porosity Range %	No. of Samples tested
Charnockitic Gneiss	0.12 - 0.81	138
Garnet Sillimanite Gneiss	0.26 - 0.86	17
Hornblende Biotite Gneiss	0.27 - 0.74	42
Biotite Gneiss	0.19 - 0.87	58
Quartzite	0.56 - 0.98	26
Marble	0.20 - 0.70	37
Migmatite	0.23 - 0.63	5
Pink Feldspar Gneiss	0.32 - 0.79	4
Calc Gneiss	0.86 -	1
Amphibolite	0.25 -	1
Granulite	0.62 - 0.78	7

Table 3.5 The ranges of uniaxial tensile strength of different rock types in Sri Lanka

Rock type	Uniaxial Tensile Strength Range MPa	No. of Samples Tested
Charnockitic Gneiss	7.6 - 15	95
Garnet Sillimanite Gneiss	5.2 - 9.2	11
Hornblende Biotite Gneiss	4.1 - 8.8	19
Biotite Gneiss	5.2 - 10.8	44
Quartzite	5.2 - 8.3	12
Marble	2.3 - 8.4	21
Granulite	5.5 - 6.2	5

Table 3.6 The ranges of uniaxial compressive strength of different rock types in Sri Lanka

Rock type	Uniaxial Compressive Strength Range, MPa	No. of Samples Tested
Charnockitic Gneiss	104.2 - 231.6	95
Garnet Sillimanite Gneiss	75.1 - 116.3	11
Hornblende Biotite Gneiss	60.3 - 125.5	19
Biotite Gneiss	74.9 - 159.2	44
Quartzite	70.2 - 118.4	12
Marble	33.8 - 124.3	21
Granulite	81.4 - 90.7	5

Table 3.7 The ranges of point load strength of different rock types in Sri Lanka

Rock type	Point Load Strength Range MPa	No. of Samples Tested
Charnockitic Gneiss	6.8 - 16.8	138
Garnet Sillimanite Gneiss	4.4 - 7.5	17
Hornblende Biotite Gneiss	3.5 - 7.6	42
Biotite Gneiss	4.4 - 10	58
Quartzite	4.8 - 7.6	26
Marble	2.0 - 6.9	37
Migmatite	5.0 - 7.8	5
Pink Feldspar Gneiss	10.8 - 12.2	4
Calc Gneiss	7.4 -	1
Amphibolite	11.2 -	1
Granulite	4.5 - 5.2	7

Table 3.8 The ranges of ultrasonic P-wave velocity of different rock types in Sri Lanka

Rock Type	Ultrasonic P-wave Velocity range, m/s	No. of Samples Tested
Charnockitic Gneiss	5609 - 6880	138
Garnet Sillimanite Gneiss	5239 - 5830	17
Hornblende Biotite Gneiss	3880 - 5620	42
Biotite Gneiss	4090 - 5565	58
Quartzite	3580 - 5140	26
Marble	5066 - 5695	37
Migmatite	5110 - 5440	5
Pink Feldspar Gneiss	5940 - 6230	4
Calc Gneiss	5780 -	1
Amphibolite	6880 -	1
Granulite	4912 - 5140	7

Table 3.9 The ranges of ultrasonic S-wave velocity of different rock types in Sri Lanka

Rock type	Ultrasonic S-Wave Velocity Range, m/s	No. of Samples Tested
Charnockitic Gneiss	2645 - 3535	
Garnet Sillimanite Gneiss	2535 - 3155	138
Hornblende Biotite Gneiss	2290 - 2844	17
Biotite Gneiss	2070 - 2785	42
Quartzite	2260 - 2780	58
Marble	2432 - 2920	26
Migmatite	2570 - 2820	37
Pink Feldspar Gneiss	2830 - 3095	5
Calc Gneiss	2840 -	4
Amphibolite	3448 -	1
Granulite	2350 - 2700	1
		-

Table 3.10 The ranges of ultrasonic Young's modulus of elasticity of different rock types in Sri Lanka

Rock Type	Ultrasonic Young's Modulus of Elasticity GPa	Poisson's Ratio	No. of Samples Tested
Charnockitic Gneiss	50.91 - 95.76	0.28-0.36	138
Garnet Sillimanite Gneiss	49.95 - 73.63	0.27-0.35	17
Hornblende Biotite Gneiss	25.85 - 58.92	0.21-0.35	42
Biotite Gneiss	31.46 - 58.63	0.31-0.36	58
Quartzite	35.96 - 55.18	0.26-0.33	26
Marble	48.13 - 67.18	0.31-0.35	37
Migmatite	49.79 - 60.54	0.32-0.33	5
Pink Feldspar Gneiss	56.41 - 68.93	0.34-0.36	4
Calc Gneiss	57.70 -	0.34	1
Amphibolite	95.82 -	0.33	1
Granulite	40.70 - 52.41	0.31-0.36	7

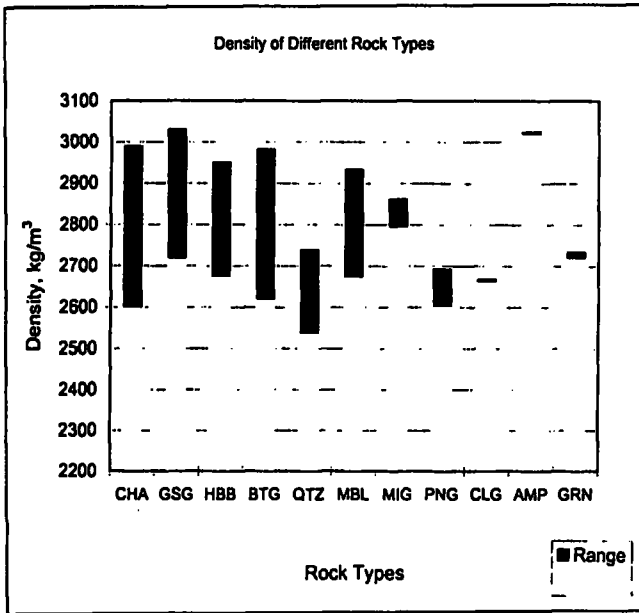


Fig. 3 - Bulk density of different rock types in Sri Lanka

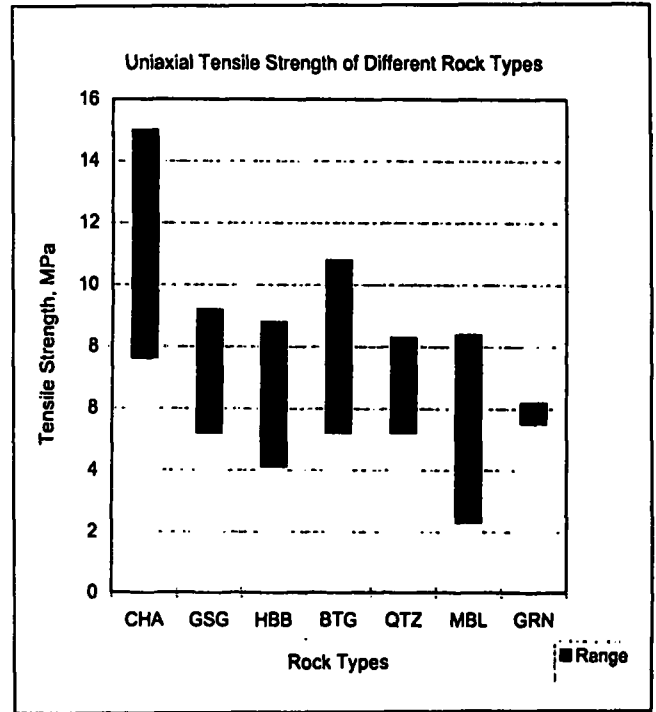


Fig. 5 - Uniaxial tensile strength ranges of different rock types in Sri Lanka

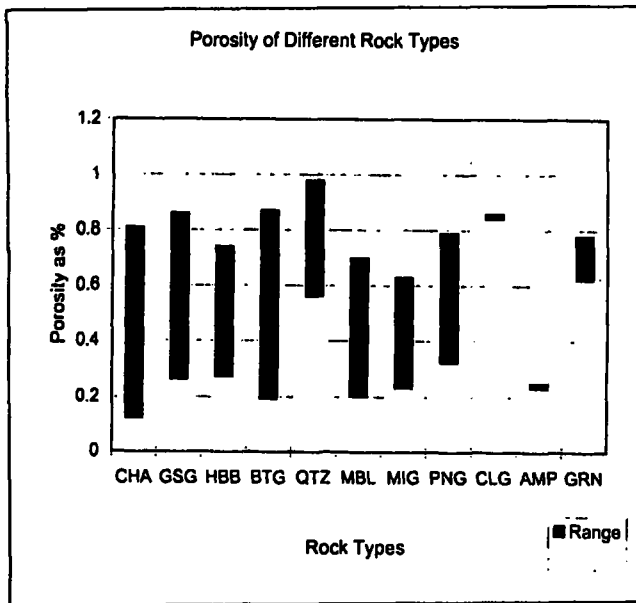


Fig. 4 - The porosity ranges of different rock types in Sri Lanka

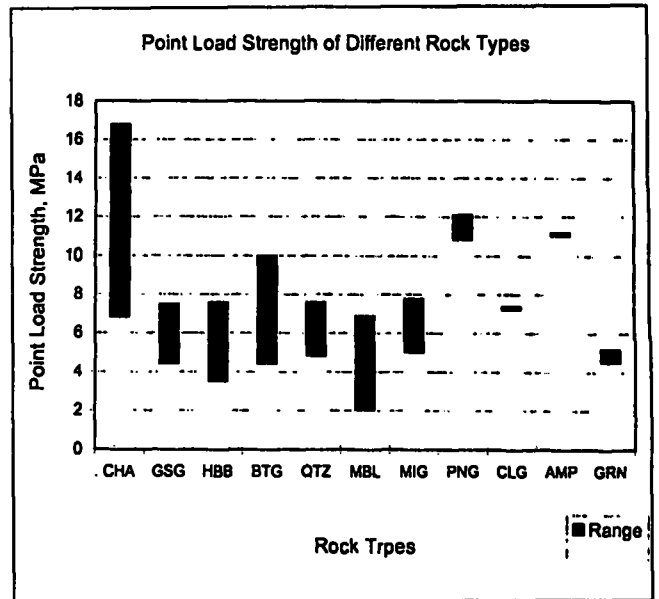


Fig. 6 - Uniaxial compressive strength ranges of different rock types in Sri Lanka

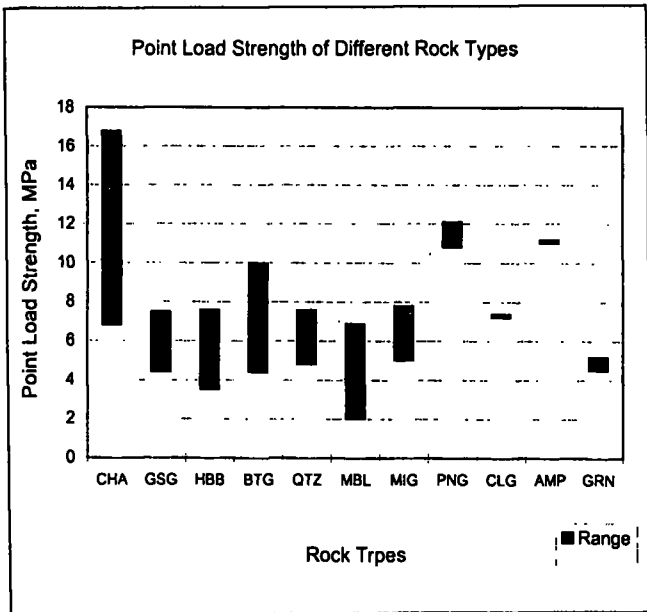


Fig. 7 - Point load strength ranges of different rock types in Sri Lanka

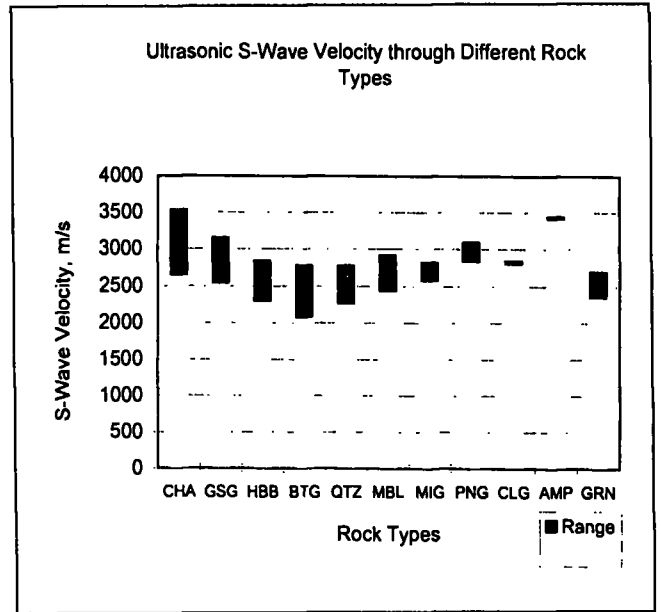


Fig 9 - The Ultrasonic S-wave velocity ranges of different rock types in Sri Lanka

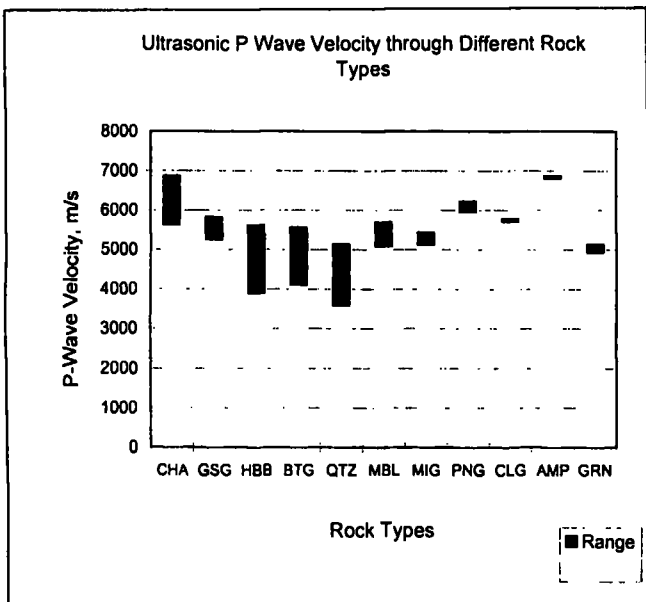


Fig. 8 - Ultrasonic P-wave velocity ranges of different rock types in Sri Lanka

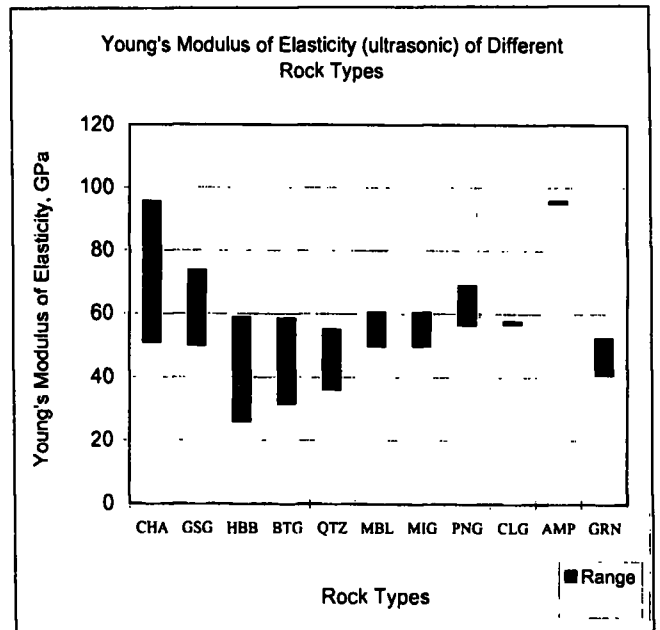


Fig 10 - Ultrasonic Young's modulus of elasticity of different rock types in Sri Lanka

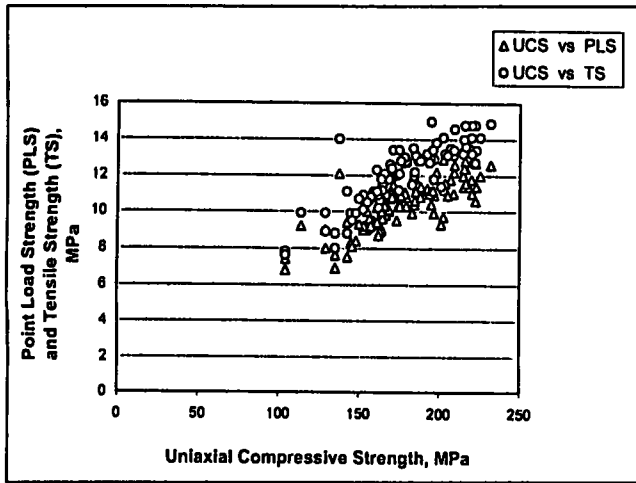


Fig 11 - The variation of point load strength and tensile strength with uniaxial with uniaxial compressive strength of charnockitic gneiss in Sri Lanka

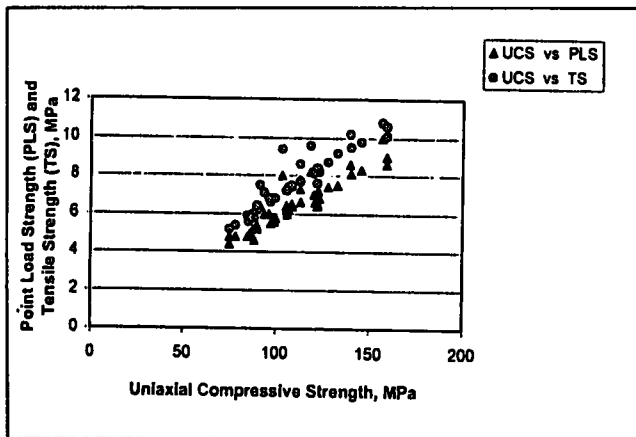


Fig 12 - The variation of point load strength and tensile strength with uniaxial compressive strength of biotite gneiss in Sri Lanka

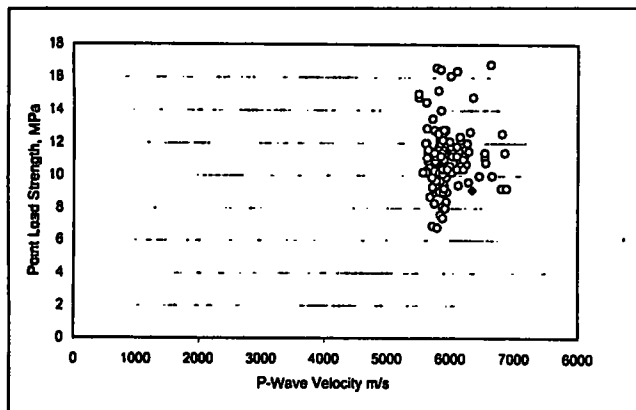


Fig. 13 a - The variation between point load strength and ultrasonic P-wave velocity of charnockitic gneiss of Sri Lanka

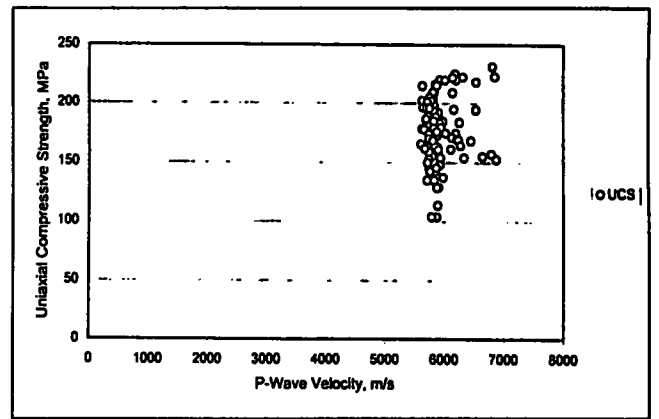


Fig. 13 b - The variation between uniaxial compressive strength and ultrasonic P-wave velocity of charnockitic gneiss of Sri Lanka

#### 4. Discussion

Table 3.1 and from Fig. 3 to Fig. 10 show the general results of the experiments and the ranges of each engineering property for different rock type.

Theoretical consideration of point load test shows that it gives a measure of tensile strength. The results are however, also sufficiently related to uniaxial compressive strength. According to GOODMAN (1976), 24 times of point load strength,  $I_s$  (50), correlates fairly well with the uniaxial compressive strength. The experiments carried out by LUMB (1982) on Hong Kong granite showed that the uniaxial compressive strength was 22 times of point load strength and 14 times of uniaxial tensile strength on average. VUTUKURI and KATSUYAMA (1994) showed that on average the uniaxial compressive strength is 20-25 times of point load strength. However the ratio can vary between 15 to 50 times for many different rock types.

Table 3.11 shows the results of statistical analysis among the different properties. The ratios do not represent the banded rocks or non-banded rocks. The vertical drilling through rocks were not either parallel or perpendicular to the foliation plane. Therefore the loading directions to the specimens were not either parallel or perpendicular to the mineral bands. However the ratio of uniaxial compressive strength to tensile strength does not show very wide range and it can be considered as uniform. Therefore the uniaxial compressive strength generally for all rocks is 14.5 times of uniaxial tensile strength. The ratio between uniaxial compressive strength and point load strength in each rock type was not very near similar to tensile strength ratio. The range was between 15.7 and 17.77. The overall average between the uniaxial compressive strength and point load strength is 16.89. For approximate calculations the uniaxial compressive strength can be considered as 17

times of point load strength for any rock type in general. According to the values of standard deviations the measurements and the calculated averages are acceptable and the errors may be small.

The project sites from where the rock samples were collected for the experiments are located in different places in Sri Lanka and, are not very close each other. And also the rock types selected for the experiments are the major rocks in the country. Therefore the ratios found by this investigation can be used easily for any engineering project in the future.

The point load strength test, which is considered as a field test can be carried out on irregular shaped specimens. The equipment is portable and can be moved out to field very easily. Hence laboratory facilities are not necessary. Therefore the preliminary investigations can be done in the field itself. The field investigations of rock strength by point load strength give an approximate evaluation and classification of the intact rock. This indirect test is quick, economical and one person can handle it. It can be noted that, this is very good field classification and it is a simple method to correlate with other properties. The ratios of uniaxial compressive strength, uniaxial tensile strength with point load strength found by this investigation for the Sri Lankan rocks will be very useful in the future engineering projects of the country.

Figure 13 shows the variation between uniaxial compressive strength and point load strength relative to ultrasonic P wave velocity for fresh rocks. This graphical variation indicates that there is no definite relationship between the strength and the wave velocity directly.

## 5. Conclusion

The general range of the values of some physical properties, mechanical properties and deformation moduli by ultrasonic methods were found for major metamorphic rocks (fresh) in Sri Lanka. These results will be very important to get a prior knowledge about the engineering properties of rocks before the investigation stage. Therefore these results will be very useful contribution to the literature on the engineering properties of Sri Lankan rocks and this paper can be considered as a useful reference for the engineers in Sri Lanka.

The uniaxial compressive strength of the metamorphic rocks in Sri Lanka is equal to 17 times of point load strength and 14.5 of uniaxial tensile strength. Hence the measurement of point load strength is enough to get the approximate values of uniaxial compressive strength and uniaxial tensile strength of the fresh parent rock. This is the simplest low-cost method to find the strength

of any rock within a short period. This rough estimation may be very helpful for the preparation of preliminary estimating and designing purposes for any geotechnical engineering project.

## Reference

- ASIAN INSTITUTE OF TECHNOLOGY, (1981), Laboratory Manual for Rock Testing, Bangkok, Thailand, p 205.
- A.S.T.M. (1977), Standard Test Method for Direct Tensile Strength of Intact Rock Core Specimens, A.S.T.M. Designation, D 2936-71, A.S.T.M. Standards Part 19, pp381-393.
- A.S.T.M. (1977), Standard Test method for Unconfined Compressive strength and Intact Rock Core Specimen, A.S.T.M. Designation, D 2938-71a, A.S.T.M. Standards Part 19, pp 389-390.
- ATTWELL, P.B. and FARMER, I.W. (1976), Principles of Engineering Geology, Chapman & Hall Ltd, London.
- BELL, F.G. (1980), Engineering Geology and Geotechnics, Newnes-Butterworths, London, p497.
- COORAY, P.G. (1967 & 1984 2nd edit.), An Introduction to the Geology of Ceylon, Dept. of National Museums, Govt. Press, Colombo, P 340.
- FOOKES, P.G. and HORSWILL, P. (1969), Discussion on the load deformation behaviour of the Middle Chalk at Mundford, Norfolk, in-situ investigations in Soils and Rocks, British Geotechnical Soc, London, pp53-57.
- GOODMAN, R.E. (1976), Methods of Geological Engineering in Discontinuous Rocks, West Publishing Co., New York.
- INTERNATIONAL SOCIETY FOR ROCK MECHANICS, (1977 and 1978a), I.S.R.M. Committee on Laboratory and Field Tests, Suggested Method for Determining Tensile Strength of Rock materials, Int. Jour. Rock Mech. Min. Sci. & Geomech. Abstr, 15, No.3:99-103.
- INTERNATIONAL SOCIETY FOR ROCK MECHANICS, (1985), Commission on testing methods, Suggested Method for Determining Point Load Strength, International Jour. of Rock Mec, Mineral Sci, & Geomechanical, 22, (2).

- JAYAWARDENA, U.de S. (1988), A note on the dynamic deformation moduli of some metamorphic rocks from Sri Lanka, *Journal of the Geol. Soc. of Sri Lanka*, Vol.1, pp-26-29, Sri Lanka.
- JAYAWARDENA, U.de S. (1990), Point Load Strength of some metamorphic rocks from Sri Lanka, *Journal. of the Geol. Soc. of Sri Lanka*, Vol. 2, pp 56-59, SriLanka.
- JAYAWARDENA, U.de S. (1996), Uniaxial tensile strengths of some crystalline hard rocks of Sri Lanka, *Jour, of the Geol. Soc. of Sri Lanka*, Vol.6 pp 73-77, SriLanka.
- LAMA,R.D. and VUTUKURI, V.S. (1978), *Handbook on Mechanical Properties of Rocks*, Volume II,III and IV, Clausthal, Trans Tech Publications, Switzerland.
- LUMB, p. (1982/83), Engineering properties of fresh and decomposed igneous rocks from Hong Kong, *Eng. Geol*, 19:81-94.
- OBERT, L. and DUVALL, W.I (1967), *Rock Mechanics and the Design of Structures in Rock*, John Wiley & Sons. Inc, New York.
- VUTUKURI, V. S. and KATSUYAMA, K. (1994), *Introduction to Rock Mechanics*, Industrial Publishing & Consulting, Inc. Tokyo.