The Major Project on

GEOTECHNICAL CHARACTERIZATION OF SOME INDIAN ROCKS

Submitted in Partial Fulfilment for the Award of the Degree of

MASTERS OF TECHNOLOGY
IN
CIVIL ENGINEERING

With Specialisation in

GEOTECHNICAL ENGINEERING

By

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2011-2013

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CERTIFICATE

This is to certify that the major project report entitled **'GEOTECHNICAL CHARACTERIZATION OF SOME INDIAN ROCKS',** is a bona fide record of work carried out by Syed Md Yousuf (Roll-No 2k11/GTE/13) under my guidance and supervision, during the academic session (2011-2013) in partial fulfillment of the requirement for the degree of Master of Technology in Geotechnical Engineering from Delhi Technological University, Delhi.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

For the Geotechnical Characterization of rocks the samples from Haryana, Jammu and Delhi region have been collected and Geology and mineral resources of all these places were studied respectively. The minerals occurring in these states are primarily china clay, limestone, dolomite, quartz silica sand, quartzite, slate etc. The samples of different shape and size is prepared as per relevant IS codes and various laboratory test like rebound hammer test, ultra sonic velocity test, point load test, Brazilian test, unconfined compressive strength have been performed on all the rock samples. The study on samples of rock collected indicate that the samples from Faridabad region of Haryana is of marble type, similarly of rock from katra region of Jammu and Kashmir is of sand stone type and samples of rock from Nehru place region of Delhi is of quartzite respectively. The results of these tests were compared with the different models proposed by different researchers. The deviation of the different models from experimental results are calculated and reported in detail in the present work.

Dedication

I dedicate this thesis

to my family, my parents and my friends for

supporting me all the way & doing all thee

wonderful things for me.

CHAPTER 1

INTRODUCTION

INTRODUCTION

Rock mass characterization is an integral part of rock engineering practice. Different laboratory test are conducted to characterize a particular type of rock. Rock properties play an important role to categorize a rock sample. Engineering properties of rock are controlled by the discontinuities within the rock mass and the properties of the intact rock. Therefore, engineering properties for rock must account for the properties of the intact rock and for the properties of the rock mass as a whole, specifically considering the discontinuities within the rock mass. A combination of laboratory testing of small samples, empirical analysis, and field observations should be employed to determine the requisite engineering properties

Rocks are no homogeneous and anisotropic in nature though it is collected from the same places it still shows variations in properties and nature. So it is difficult to determine the true or real strength of rock. There are so many methods to determine strength of rock though they are direct or indirect, laboratory or in-situ. Field or in-situ methods are quite costly so we can also find strength by means of laboratory method.

OBJECTIVES

To study the geotechnical characterization of rock samples from Faridabad (Haryana), Katra (Jammu and Kashmir) and Nehru place (Delhi). Following objectives were met for the characterization of rocks.

1. Preparation of samples of different shape and size.
2. Performing the laboratory test to obtain the physical and mechanical properties.
3. Comparison of experimental values with existing models given by different researchers.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

GEOLOGICAL CONDITION OF HARYANA

2.1 General

The geology of Haryana is predominated by the Quaternary alluvium and Aeolian sediments covering nearly 95% of area. The rest of the area comprises Proterozoic and Tertiary rocks exposed in the southern and north eastern extremities of the state, respectively. The Proterozoic rocks of Haryana, represented by the Delhi Super group, are the north eastern continuation of rocks of the Alwar and Khetri basins of north eastern Rajasthan. They occur as isolated hills, parallel ridges, inselberg and discontinuous ridges, confined to the southern parts of the state and extend up to Delhi in the north-east. The lithology of the Delhi Super group comprises schist's, quartzite and marble of Proterozoic age with associated basic flows, tuffs, acid and basic intrusive. GSI (2012)

2.2. Geology and Stratigraphy

The rocks of Delhi Super group constitute a part of the main Aravalli Range originating from Gujarat in the southwest to Haryana in the northeast. This super group comprises thick pile of meta-sediments having a cumulative thickness of 6000 m which is divided into an older Alwar Group and younger Ajabgarh Group. The Alwar Group is dominantly arenaceous with argillaceous intercalations while the Ajabgarh Group is dominantly argillaceous with arenaceous and calcareous components. The demarcation between the groups, in the absence of any unconformity, is based on facies variation, structural discontinuity and lithological characteristics in the rocks exposed in the adjacent state of Rajasthan. The rocks of both these groups are intruded by acid and basic intrusives. The metapelitic rocks exposed in Tosham area are associated with rhyohite and granite, and are tentatively clubbed under undifferentiated Ajabgarh Group, till further classification.

Alwar group

Based on the classification of the rocks of Alwar Group in Haryana are represented by Bayal-Panchnota Formation. The Bayal-Panchnota Formation mainly comprises quartzite with intercalation of mica-schist, amphibole-quartzite, minor kyanite-schist, garnet- schist, chloriteschist, Fe-Mg amphibole-schist, impure marble, amphibolite, sillimanite-schist and porphyroblastic K-feldspar schist.

Ajabgarh group

The lithology of Ajabgarh Group is predominantly argillaceous, comprising slate, phyllite, pelitic schist, limestone and quartzite. These grade upward from calcareous to argillaceous facies. Lithologically, it is divisible into five formations represented by Golwa- Gangutana Formation, Deota-Dantal Formation, Thanaghazi Formation, Asarwas Formation and Tasing Formation in the order of superposition. In the south-western part of Haryana, the rocks of Golwa- Gangutana Formation covers most of the area, whereas, the south-eastern part is occupied by the rocks of Deota-Dantal, Thanaghazi, Asarwas, and Tasing Formations.

2.3 Mineral resources

A host of mineral occurrences have enriched the state of Haryana. The minerals occurring in this state are primarily china clay, limestone, dolomite, quartz/ silica sand, quartzite, slate. Other minerals, such as, barytes, calcite, feldspar, marble, copper, tin and tungsten are noteworthy. Among building stones, granite, slate, marble, quartzite and sandstone are conspicuous. In addition, a number of minerals in minor amount are also reported. GSI (2012)

2.3.1 Marble

Impure calc-silicate rocks or micaceous impure marble of Ajabgarh Group are mostly confined to Mahendragarh District, and are quarried at Dholera, Meghot Hala , Dhancholi, Gangutana and Beharipur which extends for about 3km and is about 100 m thick. Together with this, banded variegated marble of different shades is also reported.

2.3.2 Quartzite

The Alwar and Ajabgarh Groups have yielded good quality quartzite for use as building material. All along the Ajabgarh Group, several quarries exist in Faridabad and Gurgaon districts. In Rohtak District, these are being worked out in Guraora-Guriani area. In Mahendragarh District, these are quarried at Mandlana, Berondla, Luninasibpur, Gohoro and near Gaonri.

2.3.3 China Clay

Pegmatite intrusions in the Delhi Super group have given rise to workable clay deposits in Faridabad and Gurgaon districts. The important occurrences are located near Alipur, Arangpur, Ghamrauj, Ghosgarh, and Sikandarpur. Other occurrences in the area are located near Kasan Ghata Manger and Nathupura. The clay contains mostly poorly crystallized kaolinite with little quartz.

2.3.4 Feldspar

Feldspar is an alumino-silicate mineral consisting of potassium, sodium and or calcium. Though feldspar is amongst the most widely distributed rock forming mineral and occurs as a constituent of most of the rocks, commercial deposits are mainly confined to pegmatite's. Feldspar is chiefly used both in the body of the ware and for glaze in the ceramic and glass industries, besides, its use in manufacture of insulator. Pegmatite intrusions occur in Ajabgarh Group of rocks in Gurgaon and Faridabad Districts where they range in thickness from 2m near Ghamrauj (28°19'N 77°04'E) to more than 25m near Sikandarpur (28°29'N 77°06'E) and occasionally they are as long as 80 m as near Alipur (28°19'N 77°04'E). The main constituents of these pegmatites are feldspar, quartz, muscovite and tourmaline. Feldspars are mostly altered to clay.

2.3.5 Friable Quartzite

Friable quartzite having high silica content is easily amenable to crushing in the manufacture of glass. Weathering of this quartzite produces good morrum and angular sand suitable for building purpose. Such materials are found to accumulate in the numerous nala beds, traversing the Alwar quartzite hills in Faridabad and Gurgaon districts. There are many sand quarries in the Arangpur area and have reached a depth of 20 m. Gritty quartzite at Bajada Pahari is also friable, but limited in its extent.

2.3.6 Saltpetre (Nitre)

Saltpetre is a general trade name for all the nitrates of sodium, potassium and calcium, but scientifically, nitrates of potassium are known as nitre or saltpetre, while those of sodium are called soda- nitre. Nitre finds use in a number of ways like manufacture of explosives, fireworks, matches etc, in metallurgical and chemical processes and as fertilizer. Nitre, in the state occurs as natural efflorescence at a number of places but its economic exploitation depends upon its concentration. It is mainly confined to the Districts of Hissar, Gurgaon, Faridabad, Bhiwani, Sirsa, Ambala, Rohtak, Jind, Sonepat and Kurukshetra.

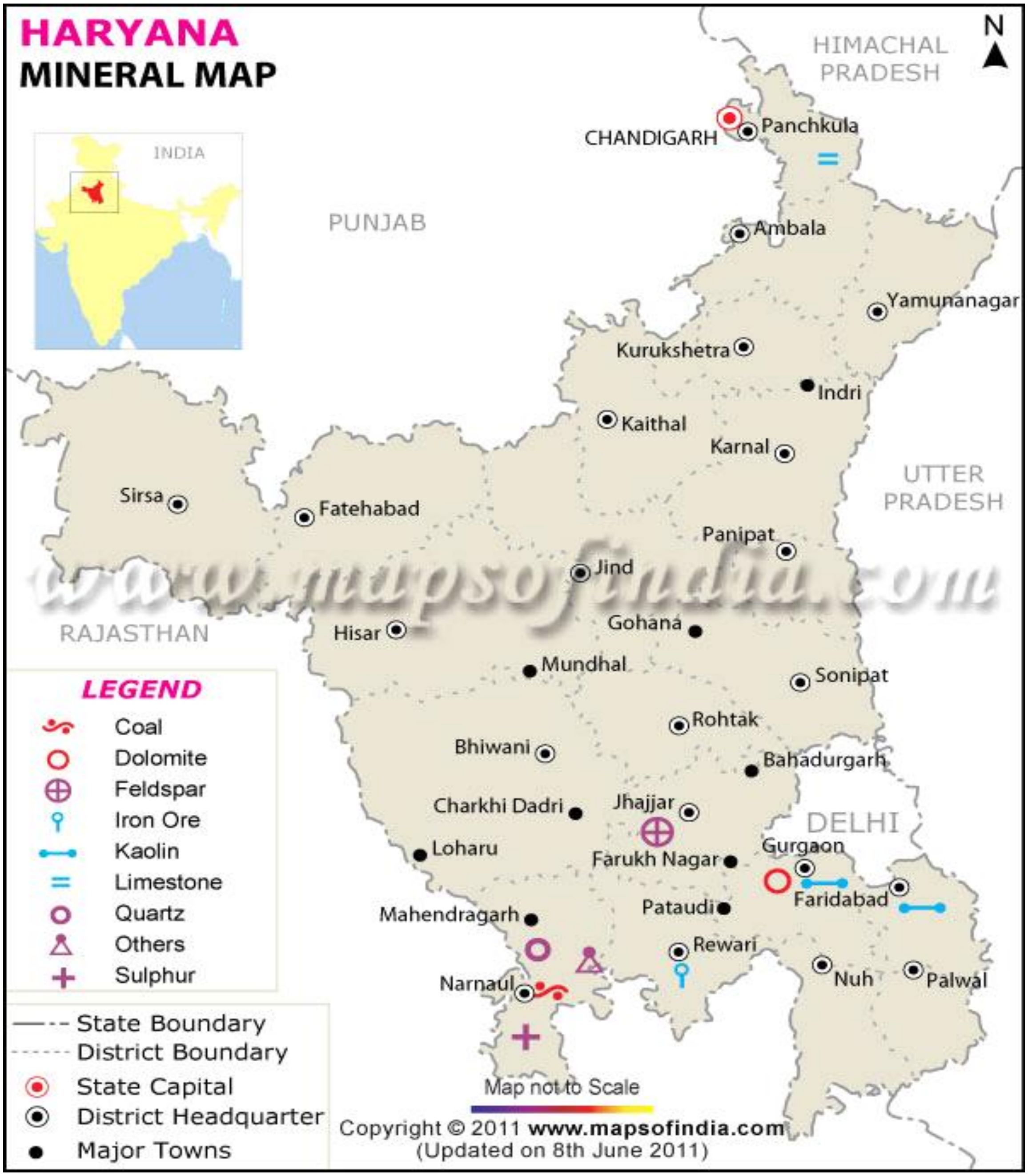

Fig 2.1 :(Mineral map of Haryana)

http://www.mapsofindia.com/maps/haryana/haryanaminerals.htm

This map shows different minerals found at different areas and districts. Our place of interest is Faridabad which is a district of Haryana. Dolomite and kaolin rock are found near Faridabad which is a type of marble.

2.4 Geological Condition of Katra (Jammu)

Katra is a small town at the foothills of Trikuta Mountains of Udhampur district in Jammu and Kashmir. It is located 42 km from city Jammu. Have coordinates as 32.980°N 74.950°E. Katra serves as the base camp for pilgrims who visit Vishnu Devi.

Formation constitutes the sub-montane deposits laid down in the form of piedmont alluvial plains in front of Upper Siwalik hill slopes delineating the northern margin of the plains. These deposits represent reworked material derived from Upper Siwalik Boulder Conglomerate beds and comprise clasts of boulder/ cobble/pebble in the upper fan area, sheet like gravelly and sandy deposits in the mid-fan area and silt and clay deposits with thin gravel bands in the distal fan area. The last zone finally interfingers with the alluvial silts down the slope of piedmont alluvial plain. Hiranagar Formation covers a major part of the alluvial plains in the area. It is composed of fine to coarse grained sand, silt, silty clay and clay of pale reddish brown colour with occasional pebble/gravel beds. The argillaceous units very often exhibit pale yellowish brown colour due to oxidation. Raina (2002)

Pleistocene Vaishno Devi Formation is the oldest Quaternary deposits in the area. It comprises poorly sorted assemblage of angular to subangular fragments of gravel to cobble size with occasional boulders of limestone/dolomite. This formation has developed at the foot of the Trikuta Hill and covers a large tract of Katra - Jhajjar Kotli surface (Katra Fill). In *nala* sections, different cycles of sedimentation have been recognised in the form of alternate layers of boulder/cobble size and pebble/ gravel size clasts within the formation.

2.5 Minerals

Main minerals found in Katra are

1. Copper (Malachite stains along with chalcopyrite and azurite are observed in the Main Boundary Fault zone at Dudura near Katra.).

2. Magnesite (Sizeable magnesite deposits have recently been reported in Sirban limestone in Katra area of Jammu region, occurring parallel to the bedding of the dolomite exposed on the hill slopes). The deposits at Katra occur parallel to the bedding of dolomite and show features that indicate that they are of replacement origin. The average width of mineralised zone is about 50 m. The maximum width being traced along the northern and southern limbs of the fold for about 200 m and 100 m respectively.

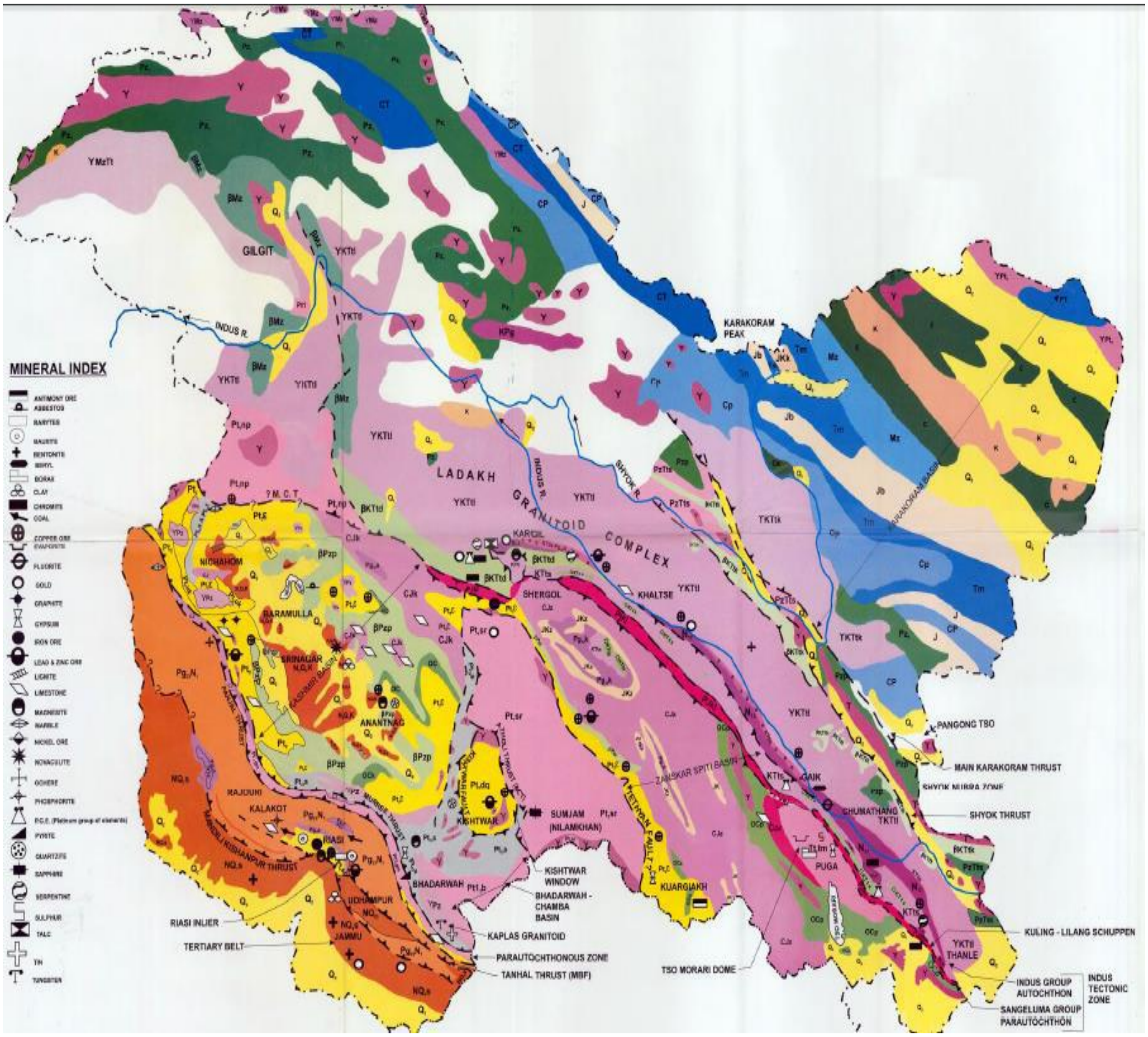

Fig 2.2: Geological Map of Jammu & Kashmir showing minerals occurrence (Govt. Of India)

http://www.portal.gsi.gov.in/gsiDoc/pub/MP30_GM_Jammu&Kashmir.pdf

2.6 Geological Condition of Nehru Place (Delhi)

Nehru place is a large commercial, financial, and business centre in Delhi, India. Though its importance as a financial centre has declined in recent years, Nehru Place is still a prominent commercial area in South Delhi and houses the headquarters of several Indian firms and rivals with other financial centres in the metropolis like Connaught Place, Gurgaon, Bhikaji Cama Place, Rajendra Place and NOIDA. It is widely considered to be a major information technology hub of South Asia. Have coordinates of $28^0$32’50”N $77^0$15’03” E

Tungsten is one of the mineral which is found in Delhi region.

2.7 Minerals

The minerals occurring in Delhi region are grey micaceous fine to coarse grained Sand, Pegmatite, Quartzite, Schist and Phyllite. Our place of interest is Nehru place, which is a commercial place of Delhi, Dolomite and Kaolin rocks are found near Nehru place, which is a type of Marble. Other minerals such as copper, tin and tungsten are also reported in Delhi region.

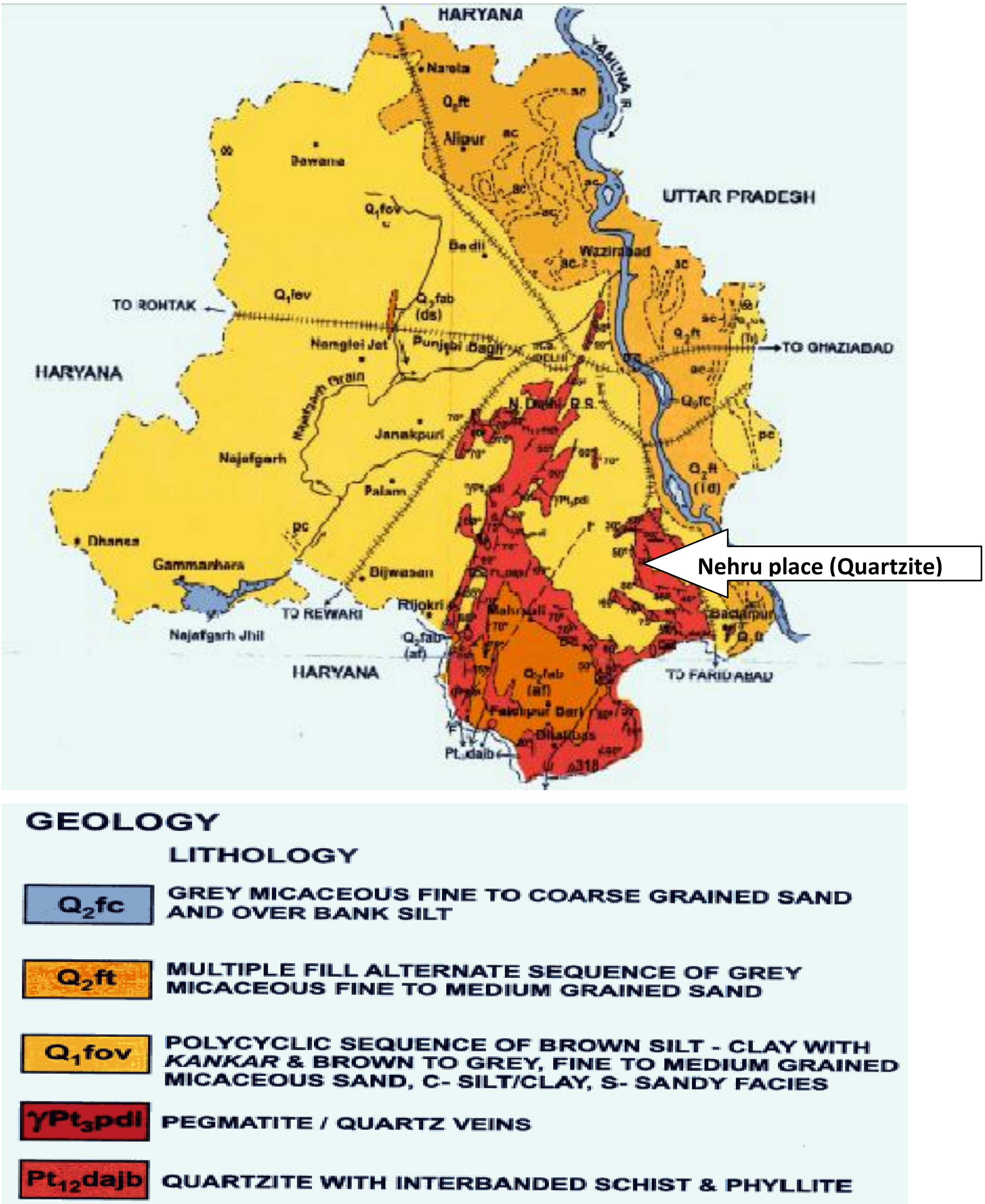

Fig 2.3: (Geological & Mineral Map of Delhi)

http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Map_Delhi_State_Geology_and_Mineral_Maps_Geological_Survey_of_India.pdf

2.8 Physical properties of rock

2.8.1 Rock quality designation

Rock-quality designation (RQD) rough measure of the degree of jointing or fracture in a rock mass, measured as a percentage of the drill core in lengths of 10 cm or more. The most widely used definition was developed by Deere (1994). It is the borehole core recovery percentage incorporating only pieces of solid core that are longer than 100 mm in length measured along the centreline of the core. In this respect pieces of core that are not hard and sound should not be counted though they are 100 mm in length. RQD has considerable value in estimating support of rock tunnels. RQD forms a basic element in some of the most used rock mass classification systems such as Rock Mass Rating system (RMR) and Q-system.

RQD is defined as the quotient:

$$RQD = \frac{\sum Length\ of\ core\ pieces > 100\ mm\ length}{Total\ length\ of\ core\ run} \times 100\ \%$$

2.8.2 Classification table

From the RQD index the rock mass can be classified as follows:

Table I. Rock Quality Designation classification table

RQD	Rock mass quality
<25%	Very poor
25-50%	Poor
50-75%	Fair
75-90%	Good
90-100%	Excellent

2.8.3 Schmidt Hammer Rebound Hardness

The rebound hammer can provide a fairly accurate estimate of concrete compressive strength. Schmidt hammer rebound hardness is often measured during early part of field investigation. It is a measure of the hardness of the rock material by count the rebound degree. At the same time, the hardness index can be used to estimate uniaxial compressive strength of the rock material. Because it is a non-destructive testing device, it can be used on finished concrete structures, such as precast concrete septic tanks. Rebound measurements often are quite variable, so the field investigation should include at least 10 measurements at a given sampling site.

2.8.4 Ultra Sonic Wave Velocity

Measurements of wave are often done by using P-wave and sometimes, S-waves. P-wave velocity measures the travel speed of longitudinal (primary) wave in the material, while S-wave velocity measures the travel speed of shear (secondary) wave in the material. The velocity measurements provide correlation to physical properties in terms of compaction degree of the material. A well compacted rock has generally high velocity as the grains are all in good contact and wave are travelling through the solid. For a poorly compact rock material, the grains are not in good contact, so the wave will partially travel through void (air or water) and the velocity will be reduced (P-wave velocities in air and in water are 340 m/s and 1500 m/s respectively and are much lower than that in solid). It is a non destructive measurements and fast and inexpensive. It may be used to evaluate anisotropy. P-wave is the fastest travelled wave and therefore is the most commonly used one in wave velocity measurements. P wave velocity of igneous rock, gneiss and quartzite is 5000-7000 m/sec and of shale, sand stone and conglomerate 3000- 5000 m/sec.

Fig. 2.4 Ultra sonic pulse velocity test apparatus

Table II. Physical properties of rock material
http://lmrwww.epfl.ch/en/ensei/Rock_Mechanics/ENS_080312_EN_JZ_Notes_Chapter_4.pdf

Rock	Dry Density (g/cm³)	Porosity (%)	Schmidt Hardness Index	Cerchar Abrasivitiy Index	P-Wave Velocity (m/s)	S-Wave Velocity (m/s)	Coefficient of Permeability (m/s)
Igneous							
Granite	2.53 – 2.62	1.02 – 2.87	54 – 69	4.5 – 5.3	4500 – 6500	3500 – 3800	10^{-14} – 10^{-12}
Diorite	2.80 – 3.00	0.10 – 0.50		4.2 – 5.0	4500 – 6700		10^{-14} – 10^{-12}
Gabbro	2.72 – 3.00	1.00 – 3.57		3.7 – 4.6	4500 – 7000		10^{-14} – 10^{-12}
Rhyolite	2.40 – 2.60	0.40 – 4.00					10^{-14} – 10^{-12}
Andesite	2.50 – 2.80	0.20 – 8.00	67	2.7 – 3.8	4500 – 6500		10^{-14} – 10^{-12}
Basalt	2.21 – 2.77	0.22 – 22.1	61	2.0 – 3.5	5000 – 7000	3660 – 3700	10^{-14} – 10^{-12}
Sedimentary							
Conglomerate	2.47 – 2.76			1.5 – 3.8			10^{-10} – 10^{-8}
Sandstone	1.91 – 2.58	1.62 – 26.4	10 – 37	1.5 – 4.2	1500 – 4600		10^{-10} – 10^{-8}
Shale	2.00 – 2.40	20.0 – 50.0		0.6 – 1.8	2000 – 4600		
Mudstone	1.82 – 2.72		27				10^{-11} – 10^{-9}
Dolomite	2.20 – 2.70	0.20 – 4.00			5500		10^{-12} – 10^{-11}
Limestone	2.67 – 2.72	0.27 – 4.10	35 – 51	1.0 – 2.5	3500 – 6500		10^{-13} – 10^{-10}
Metamorphic							
Gneiss	2.61 – 3.12	0.32 – 1.16	49	3.5 – 5.3	5000 – 7500		10^{-14} – 10^{-12}
Schist	2.60 – 2.85	10.0 – 30.0	31	2.2 – 4.5	6100 – 6700	3460 – 4000	10^{-11} – 10^{-8}
Phyllite	2.18 – 3.30						
Slate	2.71 – 2.78	1.84 – 3.64		2.3 – 4.2	3500 – 4500		10^{-14} – 10^{-12}
Marble	2.51 – 2.86	0.65 – 0.81			5000 – 6000		10^{-14} – 10^{-11}
Quartzite	2.61 – 2.67	0.40 – 0.65		4.3 – 5.9			10^{-14} – 10^{-13}

2.8.5 Density, Porosity, Water Content and Specific Gravity

Density is a measure of mass per unit of volume. Density of rock material various, and often related to the porosity of the rock. It is sometimes defined by unit weight and specific gravity. Most rocks have density between 2,500 kg/m^3 to 2,800 kg/m^3.

Porosity describes how densely the material is packed. It is the ratio of the non-solid volume to the total volume of material. Porosity therefore is a fraction between 0 and 1. The value is typically ranging from less than 0.01 for solid granite to up to 0.5 for porous sandstone. It may also be represented in percent terms by multiplying the fraction by 100%.

Water content is a measure indicating the amount of water the rock material contains. It is simply the ratio of the weight of water to the weight of the solid rock material.

Density is common physical properties. It is influenced by the specific gravity of the composition minerals and the compaction of the minerals. However, most rocks are well compacted and then have specific gravity between 2.5 to 2.8. Density is used to estimate overburden stress.

Density and porosity often related to the strength of rock material. A low density and high porosity rock usually has low strength. Porosity is one of the governing factors for the permeability. Porosity provides the void for water to flow through in a rock material. High porosity therefore naturally leads to high permeability.

2.9 Mechanical Properties of Rock

2.9.1 Unconfined Compressive Strength of Rock

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the uniaxial compressive strength or unconfined compressive strength. Usually compressive strength of rock is defined by the ultimate stress. It is one of the most important mechanical properties of rock material, used in design, analysis and modelling.

$$\sigma_1 = \sigma_c \text{ or } q_u$$

Along with measurements of load, axial and lateral deformations of the specimen are also measured.

2.9.2 Tensile strength

Tensile strength of rock material is normally defined by the ultimate strength in tension, i.e., maximum tensile stress the rock material can withstand. Rock material generally has a low tensile strength. The low tensile strength is due to the existence of micro cracks in the rock. The existence of micro cracks may also be the cause of rock failing suddenly in tension with a small strain. Tensile strength of rock materials can be obtained from several types of tensile tests: direct tensile test, Brazilian test and flexure test. Direct test is not commonly performed due to the difficulty in sample preparation. The most common tensile strength determination is by the Brazilian tests.

2.9.3 Point load strength index

Point load test is another simple index test for rock material. It gives the standard point load index,$Is(50)$ calculated from the point load at failure and the size of the specimen, with size correction to an equivalent core diameter of 50 mm. This index test is performed by subjecting a rock specimen to an increasingly concentrated load until failure occurs by splitting the specimen. The concentrated load is applied through coaxial, truncated conical platens. The failure load is used to calculate the point load strength index. The point load strength index can be used to classify the rocks. A common method used is by estimating the uniaxial compressive strength.

2.9.4 Durability

Durability of rock is fundamentally important for all engineering applications. Durability measures the changes in properties of rocks due to processes of chemical and mechanical breakdown. The slake-durability test is regarded as a simple test for assessing the influence of weathering on Rock and its disintegration. Franklin and Chandra indicated that mechanisms in slake-durability tests are subjected to ion exchange and capillary tension. For rocks containing clay materials, the exchange of cat ions and anions take place with the adsorption and absorption of water which makes the rock swell in size and slaking occurs. With the duration of the test of only ten minutes, the wetting process may only take for parts of the rock, particularly for the surface part but due to appropriate rotation speed and the level of the water most of the parts of the rocks get wet. When the rock becomes more saturated, water menisci within the rock pores increase, which then causes the reduction of capillary tension at grain contacts and the tips of cracks. Due to the increase in the water content in the pores, fracture develops in the rock which leads to the weathering of rocks. This mechanism seems to dominate the durability behaviour of porous rock. Water certainly influences the mechanical characteristics of rock. However, in the slake-durability test, not only wet-dry conditions are given to the rock specimen, but also mechanisms correspond to the drum rotation are involved.

Table III. Mechanical Properties of Rock Material

http://lmrwww.epfl.ch/en/ensei/Rock_Mechanics/ENS_080312_EN_JZ_Notes_Chapter_4.pdf

Rock	UC Strength (MPa)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Strain at Failure (%)	Point Load Index $I_{s(50)}$ (MPa)	Fracture Mode I Toughness
Igneous							
Granite	100 – 300	7 – 25	30 – 70	0.17	0.25	5 – 15	0.11 – 0.41
Dolerite	100 – 350	7 – 30	30 – 100	0.10 – 0.20	0.30		>0.41
Gabbro	150 – 250	7 – 30	40 – 100	0.20 – 0.35	0.30	6 – 15	>0.41
Rhyolite	80 – 160	5 – 10	10 – 50	0.2 – 0.4			
Andesite	100 – 300	5 – 15	10 – 70	0.2		10 – 15	
Basalt	100 – 350	10 – 30	40 – 80	0.1 – 0.2	0.35	9 – 15	>0.41
Sedimentary							
Conglomerate	30 – 230	3 – 10	10 – 90	0.10 – 0.15	0.16		
Sandstone	20 – 170	4 – 25	15 – 50	0.14	0.20	1 – 8	0.027 – 0.041
Shale	5 – 100	2 – 10	5 – 30	0.10			0.027 – 0.041
Mudstone	10 – 100	5 – 30	5 – 70	0.15	0.15	0.1 – 6	
Dolomite	20 – 120	6 – 15	30 – 70	0.15	0.17		
Limestone	30 – 250	6 – 25	20 – 70	0.30		3 – 7	0.027 – 0.041
Metamorphic							
Gneiss	100 – 250	7 – 20	30 – 80	0.24	0.12	5 – 15	0.11 – 0.41
Schist	70 – 150	4 – 10	5 – 60	0.15 – 0.25		5 – 10	0.005 – 0.027
Phyllite	5 – 150	6 – 20	10 – 85	0.26			
Slate	50 – 180	7 – 20	20 – 90	0.20 – 0.30	0.35	1 – 9	0.027 – 0.041
Marble	50 – 200	7 – 20	30 – 70	0.15 – 0.30	0.40	4 – 12	0.11 – 0.41
Quartzite	150 – 300	5 – 20	50 – 90	0.17	0.20	5 – 15	>0.41

CHAPTER 3

EXPERIMENTAL WORK

CHAPTER 3
EXPERIMENTAL WORK

3.1 General

In this study an experimental work is conducted to determine the physical and mechanical properties of Faridabad rock, Katra (Jammu) rock & Nehru place (Delhi) rock and compare these test results with the existing results.

3.2 Characterizations of Faridabad rock (marble), Katra [Jammu] rock (sandstone) and Nehru place rock (quartzite)

- Preparation of sample by rock cutting machine
- Determination of rock quality designation.
- Determination of compressive strength and R value by rebound hammer test.
- Determination of sonic velocity
- Determination of moisture content, porosity, specific gravity, dry density.
- Determination of point load index
- Determination of tensile strength by Brazilian test
- Determination of unconfined compressive strength
- Determination of slake durability index
- Determination of shear strength by oblique shear strength

3.3 Preparation of sample by rock cutting machine

Samples of different shape and size are prepared for different laboratory test by rock cutting machine. Rock sample is fixed in the machine and cut by the cutter in wet condition.

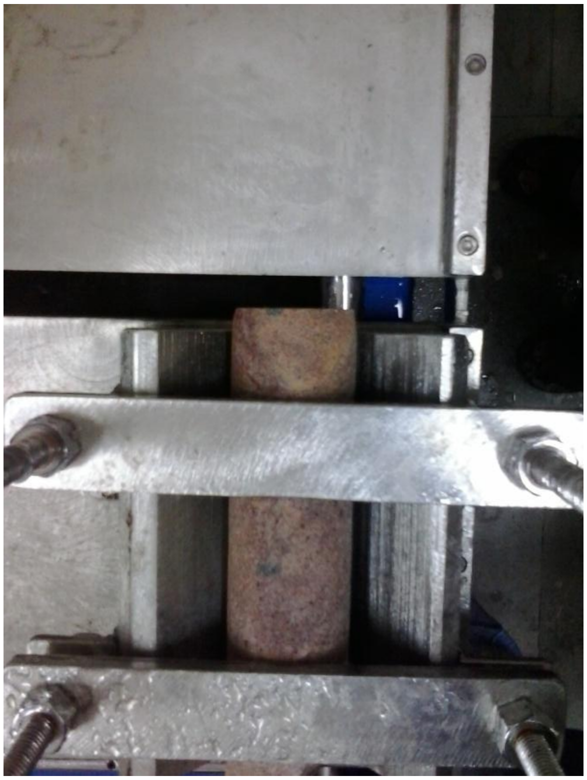

Figure 3.1 Rock sample fixing

Figure 3.2 Preparation of rock sample by rock cutting machine

3.4 Determination of RQD

Table IV. Determination of RQD of Faridabad rock

	Sample 1	Sample 2	Sample 3
Total length (cm)	80	63	40
Length of part 1	65	19	12
Length of part 2	14	12	17
RQD	0.9875	0.4921	0.725
RQD%	98.75	49.21	72.5
Quality	Excellent	Poor	Fair

Table V. Determination of RQD of Katra rock

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Total length (cm)	60	85	87.5	66	102	107
Length of part 1	30	21	30	20	65	57
Length of part 2	11	18	12	18	17	30
Length of part 3	-	11	23	16	20	-
Length of part 4	-	-	-	11	-	-
RQD	0.6833	0.58824	0.74286	0.98485	1.00	0.81308
RQD%	68.33	58.824	74.286	98.485	100	81.308
Quality	Fair	Fair	Fair	Excellent	Excellent	Good

Table VI. Determination of RQD of Nehru place

	Sample 1	Sample 2
Total length (cm)	56	62
Length of part 1	16	21
RQD	0.2857	0.3387
RQD %	28.57	33.87
Quality	Poor	Poor

Fig. 3.3 Rock Sample for RQD (Faridabad)

Fig. 3.4 Rock Sample for RQD (Katra)

3.5 Rebound hammer test [IS: 13311(Part 2) - 1992]

It is a non-destructive test of determination of compressive strength of the rock sample

Procedure

1. Remove hammer from case and press the plunger end against a hard surface to release the plunger from the locked position.
2. Position hammer horizontally with plunger end against tank at a point
3. With the hammer still pressed against the tank, read the rebound number off the scale provided on the hammer. If it is necessary to move the hammer before reading, press the lock button.
4. Repeat the above procedure at different points around the tank until a total of ten readings has been taken.

Table VII. Rebound Number and Compressive Strength Values of Faridabad rock (Marble)

Sample no 1			Length of sample = 100mm			Dia of sample = 50mm		
R value	28	31	29	30	29	27	31	31.5
Compressive strength	26	32	30	30	30	27	31	31
Average R value = 29.5625								
Average compressive strength = 29.625 MPa								

Sample no 2			Length of sample = 100mm			Dia of sample = 50mm		
R value	26	32.5	32.5	33	32	34.5	34	34
Compressive strength	24	35	35	36	34	39	39	39
Average R value = 32.3125								
Average compressive strength = 35.125 MPa								

Sample no 3			Length of sample = 100mm			Dia of sample = 50mm		
R value	29	30	27	35	33	32	32	32.5
Compressive strength	30	30	26	39	36	34	34	35
Average R value = 31.3125								
Average compressive strength = 33 MPa								

Sample no 1		Length of sample = 50mm		Dia of sample = 50mm		
R value	40	41	38	36.5	38	38
Compressive strength	48	50	45	42	45	45
Average R value = 38.58						
Average compressive strength = 45.833 MPa						

Sample no 2		Length of sample = 50mm		Dia of sample = 50mm		
R value	36.5	36.5	37	38.5	38.5	39.5
Compressive strength	42	42	43	46	46	48
Average R value = 37.75						
Average compressive strength = 44.5 MPa						

Sample no 3		Length of sample = 50mm		Dia of sample = 50mm		
R value	33.5	30	32	35	34.5	32.5
Compressive strength	38	30	34	39	39	35
Average R value = 32.92						
Average compressive strength = 35.83 MPa						

Sample no 4		Length of sample = 50mm		Dia of sample = 50mm		
R value	32	35	38.5	38.5	38	35
Compressive strength	34	39	46	46	45	39
Average R value = 36.167						
Average compressive strength = 41.5 MPa						

Sample no 5		Length of sample = 50mm			Dia of sample = 50mm	
R value	38.5	37.5	37.5	38	37.5	35
Compressive strength	46	44	44	45	44	39
Average R value = 37.33						
Average compressive strength = 43.667 MPa						

Sample no 6		Length of sample = 50mm			Dia of sample = 50mm	
R value	37.5	37.5	41	35.5	36.5	35
Compressive strength	44	44	50	40	42	39
Average R value = 37.167						
Average compressive strength = 43.166 MPa						

Fig.3.5. Determination of R value and compressive strength

Table VIII Rebound Number and compressive strength values of Katra (Jammu) rock, sand stone

Sample no 1		Length of sample = 100mm		Dia of sample = 50mm		
R value	24.5	23.5	25	23.5	24.5	25
Compressive strength	22	21	22	21	22	22
Average R value = 24.33						
Average compressive strength = 21.67 MPa						

Sample no 2		Length of sample = 100mm		Dia of sample = 50mm		
R value	25	23.5	24.5	23.5	25	24.5
Compressive strength	22	21	22	21	22	22
Average R value = 24.33						
Average compressive strength = 21.667 MPa						

Sample no 3		Length of sample = 100mm		Dia of sample = 50mm		
R value	26	23.5	25	23.5	26	25
Compressive strength	25	21	22	21	25	22
Average R value = 24.834						
Average compressive strength = 22.667 MPa						

Sample no 4		Length of sample = 100mm		Dia of sample = 50mm		
R value	26	25	23.5	23.5	25	26
Compressive strength	25	22	21	21	22	25
Average R value = 24.834						
Average compressive strength = 22.667 MPa						

Sample no 5		Length of sample = 100mm		Dia of sample = 50mm		
R value	25	26	23.5	25	26	23.5
Compressive strength	22	25	21	22	25	21
Average R value = 24.834						
Average compressive strength = 22.667 MPa						

Sample no 6		Length of sample = 100mm		Dia of sample = 50mm		
R value	23.5	23.5	25	23.5	23.5	25
Compressive strength	21	21	22	21	21	22
Average R value = 24						
Average compressive strength = 21.334 MPa						

Table IX Rebound number and compressive strength values of Nehru place (Delhi) rock, Quartzite

Sample no 1		Length of sample = 100mm		Dia of sample = 50mm		
R value	24	26.5	26	24	25	25
Compressive strength	22	25	24	22	23	23
Average R value = 25.0834						
Average compressive strength = 23.1667 MPa						

Sample no 2		Length of sample = 100mm		Dia of sample = 50mm		
R value	28	29	29	29	30	30
Compressive strength	28	30	30	30	30	30
Average R value = 29.1667						
Average compressive strength = 29.667 MPa						

Sample no 1		Length of sample = 50mm		Dia of sample = 50mm		
R value	29	29	30	32	32	30
Compressive strength	32	32	33	35	35	33
Average R value = 30.334						
Average compressive strength = 33.334 MPa						

Sample no 2		Length of sample = 50mm		Dia of sample = 50mm		
R value	32	33	32	30	33	30
Compressive strength	35	36	35	33	36	33
Average R value = 31.667						
Average compressive strength = 34.667 MPa						

Sample no 3		Length of sample = 50mm		Dia of sample = 50mm		
R value	29	32	30	30	33	33
Compressive strength	32	35	33	33	36	36
Average R value = 31.167						
Average compressive strength = 34.167 MPa						

3.6 Ultra Sonic Velocity test [IS: 13311(Part 1) - 1992]

Procedure

Cylindrical rock sample is prepared by cutting and lapping the ends. The length is measured. An ultra sonic digital indicator consist a pulse generator unit, transmitter and receiver transducers are used for sonic pulse velocity measurement. The transmitter and the receiver are positioned at the ends of specimen and the pulse wave travel time is measured. The velocity is calculated from dividing the length of rock sample by wave travel time. Both P-wave and S-wave velocities can be measured. Firstly ultra sonic velocity test is conducted on dry sample of Faridabad rock

Table X. P-wave velocity in dry samples of Faridabad rock (Marble)

	Sample 1	Sample 2	Sample 3
Time (microsecond)	60.9	17.7	19.8
Length (mm)	100	100	100
Velocity (m/sec)	1642.036	5649.72	5050.5

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	9.2	9	36.8	9.2	10.6	9.1
Length (mm)	50	50	50	50	50	50
Velocity (m/sec)	5434.78	5555.55	1358.69	5434.78	4716.98	5494.5

	Sample 1	Sample 2	Sample 3	Sample 4
Time (microsecond)	4.9	4.5	4.8	5.4
Length (mm)	25	25	25	25
Velocity (m/sec)	5102.04	5555.55	5208.33	4629.63

Test on saturated sample

Table XI P-wave velocity in saturated sample of Faridabad rock (Marble)

	Sample 1	Sample 2	Sample 3
Time (microsecond)	46	17.7	19.7
Length (mm)	100	100	100
Velocity (m/sec)	2173.91	5649.72	5076.14

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	8.9	8.8	28	9.2	10.5	9.4
Length (mm)	50	50	50	50	50	50
Velocity (m/sec)	5617.978	5681.818	1785.714	5434.783	4761.905	5319.149

	Sample 1	Sample 2	Sample 3	Sample 4
Time (microsecond)	4.8	4.6	5	4.7
Length (mm)	25	25	25	25
Velocity (m/sec)	5208.33	5434.783	5000	5319.149

From the result we can see that the velocity is more in saturated sample than the dry sample.

Fig 3.6 P-wave velocity determination in 100mm sample

Fig 3.7 P-wave velocity determination in 50mm sample

Test on dry sample

Table XII. P wave velocity in dry sample of katra (Jammu) rock (Sandstone)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	70.2	68.8	46.6	68.8	69.9	68.5
Length (mm)	100	100	100	100	100	100
Velocity (m/sec)	1425	1435	2146	1453	1431	1460

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	44.1	32.2	33.3	34.8	30.2	27.3
Length (mm)	50	50	50	50	50	50
Velocity (m/sec)	1134	1553	1502	1437	1656	1832

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Time (microsecond)	12.6	19.3	14.2	15	11.8
Length (mm)	25	25	25	25	25
Velocity (m/sec)	1984	1295	1761	1667	2119

Test on saturated sample

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	108.2	71.9	32.6	90.2	72.8	93.5
Length (mm)	100	100	100	100	100	100
Velocity (m/sec)	924	1391	3067	1109	1374	1070

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Time (microsecond)	71.4	42.3	29.5	28.8	25.4	23.6
Length (mm)	50	50	50	50	50	50
Velocity (m/sec)	700	1182	1695	1736	1969	2119

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Time (microsecond)	8.4	26.4	9.8	11	8.2
Length (mm)	25	25	25	25	25
Velocity (m/sec)	2976	947	2551	2273	3049

Table XIII. P-wave velocity in dry samples of Nehru place (Delhi) Quartzite

	Sample 1	Sample 2
Time (microsecond)	111.1	105.5
Length (mm)	100	100
Velocity (m/sec)	900.09	947.86

	Sample 1	Sample 2	Sample 3
Time (microsecond)	36.6	28.4	27.3
Length (mm)	50	50	50
Velocity (m/sec)	1366.12	1760.56	1831.50

Table XIV. P- wave velocity in saturated samples of Nehru place (Delhi) Quartzite

	Sample 1	Sample 2
Time (microsecond)	73.8	104.7
Length (mm)	100	100
Velocity (m/sec)	1355.01	955.11

	Sample 1	Sample 2	Sample 3
Time (microsecond)	27	21.6	19.5
Length (mm)	50	50	50
Velocity (m/sec)	1852	2315	2564.10

Fig.3.8 Ultra Sonic Pulse velocity test

3.7 Determination of moisture content, porosity, specific gravity, dry density. (IS: 13030:1991)

(a) Density of Samples of Regular Shape

The mass of the samples is weighed ($Mbulk$) and its volume ($Vbulk$) is calculated. The bulk density is the mass per unit volume. Saturated mass of the sample is calculated after immersing in water for one day.

$$Density = (Mbulk/Vbulk)$$

(b) Water Content of Rock Samples

$Mbulk$, and $Mdry$ are determined using the same method as that for density and porosity measurement of rock samples with irregular shape. Water content (w) is calculated by

$$w = \frac{(Mbulk - Mdry)}{Mdry} \times 100\%$$

(c) Porosity of Rock Samples

$Mbulk, Msat, Msub\ and\ Vbulk$ are determined using the same method as that for density measurement of rock samples with irregular shape. The samples are dried to a constant mass at a temperature of 105°C in an oven and cooled for 30 min in desiccators, and the dry mass $Mdry$ is measured. Pore volume (Vv) and porosity (n) are calculated by

$$Pore\ volume,\ Vv = (Msat - Mdry)/\rho w$$

$$n = (Vv/Vbulk) \times 100\%$$

(d) Specific Gravity of Rock Samples

Specific Gravity of a rock sample is the ratio of mass of dry rock to the volume of the solid rock material(Vs). It is generally denoted by 'G'. The volume of solid rock material and specific gravity is calculated as under.

$$Vs = Vbulk - Vv;\ \ and$$

$$Specific\ gravity,\ \ G = \frac{Mdry}{Vs}$$

(e) Dry Density of Rock Samples

Dry density (ρdry) of a rock sample is the ratio of dry mass ($Mdry$) of rock to the bulk volume ($Vbulk$) of rock sample.

$$\rho dry = \frac{Mdry}{Vbulk}$$

Table XV. Moisture Content, Porosity, Dry Density and specific gravity values

Faridabad rock (Marble)						Length of the sample = 50mm					
S. N	Weight (gm)	Dry weight (gm)	Saturated weight (gm)	Weight of water (gm)	Moisture content (%)	Volume of void cm^3	Volume of sample cm^3	Porosity (%)	Dry density (g/cc)	Volume of solid cm^3	Specific gravity
1	300.2	299.54	301.12	0.66	0.220	1.58	98.21	1.61	3.05	96.63	3.09
2	305.2	304.58	306.79	0.62	0.204	2.21	98.21	2.25	3.10	96	3.17
3	307	306.03	309.58	0.97	0.317	3.55	98.21	3.61	3.12	94.66	3.23
4	318	317.14	319.89	0.86	0.271	2.75	98.21	2.80	3.23	95.46	3.32
5	314.7	313.41	317	1.29	0.412	3.59	98.21	3.65	3.19	94.62	3.31
6	309.3	308.71	310.36	0.59	0.191	1.65	98.21	1.68	3.14	96.56	3.20

Fig 3.9 Dry samples of Faridabad rock

Fig 3.10 Faridabad Sample after saturation

Table XVI. Moisture Content, Porosity, Dry Density and specific gravity values

Katra (Jammu) rock Sandstone						Length of the sample = 100mm					
S. N	Weight (gm)	Dry weight (gm)	Saturated weight (gm)	Weight of water (gm)	Moisture content (%)	Volume of void cm^3	Volume of sample cm^3	Porosity (%)	Dry density (g/cc)	Volume of solid cm^3	Specific gravity
1	551.13	540.47	566.8	10.66	1.97	26.33	196.43	13.4	2.75	170.1	3.18
2	557.88	549.45	568.6	8.43	1.53	19.15	196.43	9.75	2.80	177.28	3.10
3	580.72	572.95	588.6	7.77	1.36	15.65	196.43	7.97	2.92	180.78	3.17
4	504.71	494.09	519.0	10.62	2.15	24.91	196.43	12.68	2.52	171.52	2.88
5	534.10	525.79	546.4	8.31	1.58	20.61	196.43	10.49	2.68	175.82	2.99
6	557.99	549.48	570.1	8.51	1.55	20.62	196.43	10.5	2.8	175.81	3.125

Fig 3.11 Sand stone sample

Table XVII. Moisture Content, Porosity, Dry Density and specific gravity values

Nehru place rock (Quartzite)						Length of the sample = 50mm					
S. N	Weight (gm)	Dry weight (gm)	Saturated weight (gm)	Weight of water (gm)	Moisture content (%)	Volume of void cm^3	Volume of sample cm^3	Porosity (%)	Dry density (g/cc)	Volume of solid cm^3	Specific gravity
1	266	265.03	270.52	0.97	0.366	5.49	98.21	5.59	2.7	92.72	2.86
2	301.2	299.71	304.25	1.49	0.497	4.54	98.21	4.62	3.05	93.67	3.20
3	291.1	289.45	293.88	1.65	0.57	4.43	98.21	4.51	2.95	93.78	3.09

3.8 Point load test [IS: 8764]

Point load test of rock cores can be conducted diametrically and axially. In diametrical test, rock core specimen of diameter D is loaded between the point load apparatus across its diameter. The length/diameter ratio for the diametrical test should be greater than 1.0. For axial test, rock core is cut to a height between 0.5 D to D and is loaded between the point load apparatus axially. Point load strength, Is, is calculated as:

$$I_s = P / D_e^2$$

Where, P is the load at rupture

De, the "equivalent core diameter", is given by:

$D_e^2 = D^2$ for diametrical test;

$= 4A/\pi$ for axial, block and lump tests;

$A = H \times D$ = Minimum cross sectional area of a plane, through the loading point.

Procedure

1. The Equivalent diameter 'De' shall be measured in mm.
2. The specimen should be held horizontal between the two loading platens.
3. The correct position of the specimen shall be checked first by giving longitudinal rotation to see the distance between loading points is minimum.
4. The platens shall have contact along a single plane of weakness.
5. Core specimens with length/ diameter ratio of 0.3 to 1.0 are suitable for axial test.

6. The load shall be applied to the specimen such that failure occurs within 10-60 sec and the failure load ‘P’ is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading surface.

Figure 3.12 Point load test

Table XVIII. Determination of Point Load Index of Faridabad (Marble)

	Load at failure (KN)	Diameter (mm)	Height between platens (mm)	Equivalent dia, sq (mm^2)	Point load index (N/mm^2)
Sample 1	25	50	50	3182	7.86
Sample 2	22	50	50	3182	6.914
Sample 3	24	50	50	3182	7.54

Average point load index = 7.438 N/mm^2

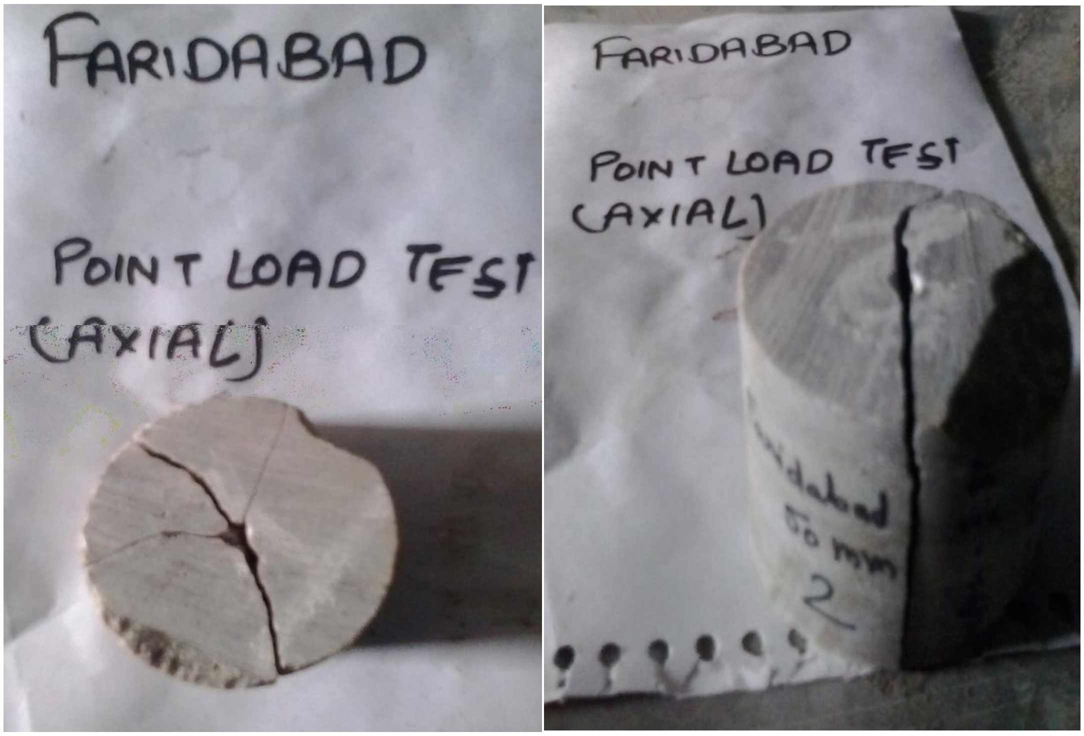

Fig 3.13. Failure pattern in point load test

Table XIX. Determination of point load index of katra (Jammu), Sand stone

	Load at failure (KN)	Diameter (mm)	Height between platens (mm)	Equivalent dia, sq (mm^2)	Point load index (N/mm^2)
Sample 1	2.0	50	50	3182	0.63
Sample 2	1.0	50	50	3182	0.31
Sample 3	1.0	50	50	3182	0.31
Sample 4	0.5	50	50	3182	0.16
Sample 5	1.25	50	50	3182	0.39

Average point load index = $0.36 N/mm^2$

Fig 3.14 Failure pattern in sand stone

Table XX Determination of point load index of Nehru place (Delhi), Quartzite

	Load at failure (KN)	Diameter (mm)	Height between platens (mm)	Equivalent dia, sq (mm^2)	Point load index (N/mm^2)
Sample 1	9	50	50	3182	2.83
Sample 2	8	50	50	3182	2.51
Sample 3	7	50	50	3182	2.20

Average point load index = 2.51 N/mm^2

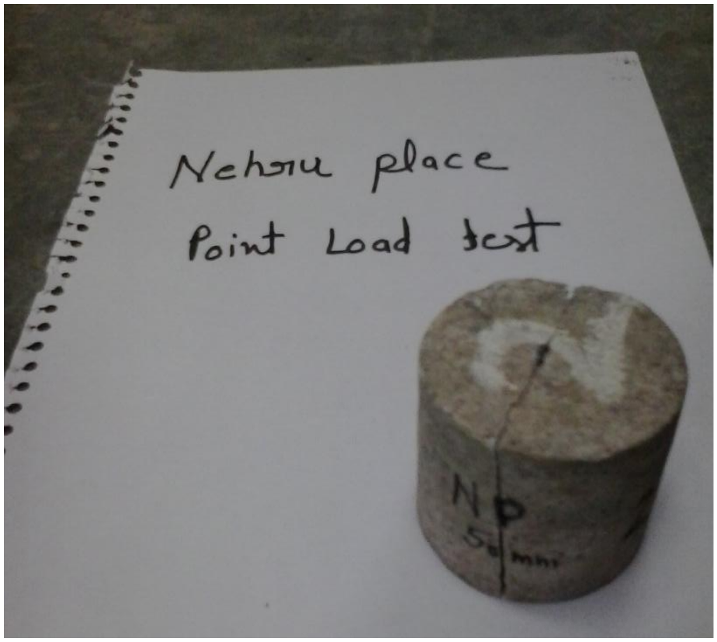

Fig 3.15 Failure pattern in quartzite

3.9 Brazilian Tensile Strength Test (IS: 10082:1996)

Procedure

Cylindrical specimen of diameter approximately equals to 50 mm and thickness approximately equal to the radius is prepared. The cylindrical surfaces should be free from obvious tool marks and any irregularities across the thickness. Loading is applied continuously at a constant rate such that failure occurs within 15-30 seconds. A loading rate of 200 N/sec is recommended. The maximum load on the specimen shall be recorded in 'Newton' with one percent accuracy.

Tensile strength of rock shall be calculated from the following expression

$$qt = \frac{2 \times P}{\pi \times D \times t}$$

Where,

qt = Tensile strength in N/mm^2

P = load at failure in Newton

D = diameter of test specimen in mm, and

t = thickness of test specimen measured at the centre in mm

Fig 3.16 Brazilian test

Table XXI. Determination of Tensile Strength of Marble

	Load at failure (KN)	Diameter (mm)	Thickness (mm)	Tensile strength (N/mm^2)
Sample 1	37	50	25	18.84
Sample 2	44	50	25	22.42
Sample 3	33	50	25	16.82
Sample 4	27	50	25	13.76

Average tensile strength = 17.96 N/mm^2

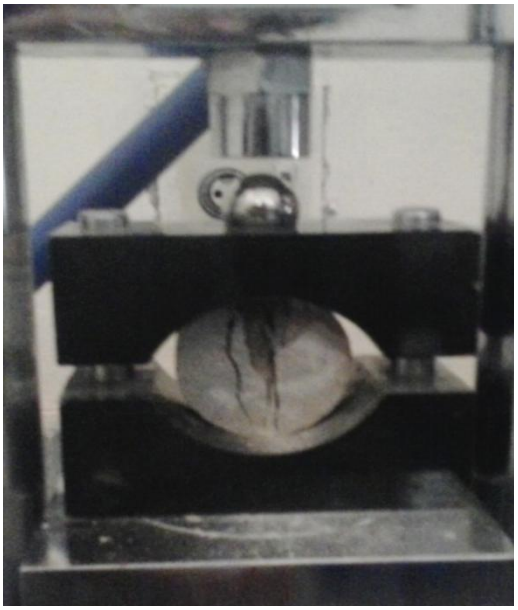

Fig.3.17 Failure pattern in Brazilian test

Table XXII. Determination of tensile strength of Sandstone

	Load at failure (KN)	Diameter (mm)	Thickness (mm)	Tensile strength (N/mm^2)
Sample 1	5.0	50	25	2.55
Sample 2	5.0	50	25	2.55
Sample 3	2.0	50	25	1.02
Sample 4	0.5	50	25	0.26
Sample 5	5.0	50	25	2.55

Average tensile strength = 1.786 N/mm^2

Table XXIII. Determination of tensile strength of Quartzite

	Load at failure (KN)	Diameter (mm)	Thickness (mm)	Tensile strength (N/mm^2)
Sample 1	5.5	50	25	2.8
Sample 2	7	50	25	3.56
Sample 3	8	50	25	4.07
Sample 4	8.5	50	25	4.33

Average tensile strength = 3.69 N/mm^2

3.10 Unconfined Compression test [IS: 9143:1979]

Procedure

Specimens of right circular cylinders having a height to diameter ratio of 2 or higher are prepared by cutting and grinding. The diameter of ten specimen shall be more than ten times the largest mineral grain size in rock preferably 45mm, but in no case less than 35mm. Specimen shall be flat to within 0.05mm the ends shall be flat to each other within 0.002 D where D is the specimen diameter. The cylindrical surface shall be smooth and free from abrupt irregularities, and straight to within 0.3mm over the full length of the specimen. The surfaces of the two bearing discs and the test specimen shall be wiped clean. The specimen shall be kept on the lower disc. The axis of the specimen shall be carefully aligned with the centre of the thrust of the spherical seat. Load on the specimen shall be applied continuously at a constant stress rate such that failure will take place in about 5 to 15 minutes of loading. Alternatively, the stress rate shall be within the limits of 0.5 MPa/sec to 1 MPa/sec. The maximum load on the specimen shall be recorded in N within 1 percent accuracy.

Uniaxial compressive strength, σc, is calculated as the failure load divided by the initial cross sectional area of the specimen.

Table XXIV. Determination of UCS of Marble

	Load at failure (KN)	Area of sample (mm^2)	UCS (N/mm^2)
Sample 1	290	1963.5	147.69
Sample 2	240	1963.5	122.23
Sample 3	220	1963.5	112.04

Average UCS = 127.32 N/mm^2


Fig.3.18 Failure pattern in unconfined compressive test

Table XXV. Determination of UCS of Sandstone

	Load at failure (KN)	Area of sample (mm^2)	UCS (N/mm^2)
Sample 1	30	1963.5	15.28
Sample 2	80	1963.5	40.74
Sample 3	50	1963.5	25.46
Sample 4	60	1963.5	30.56

Average UCS = 28.01 N/mm^2

Table XXVI. Determination of UCS of Quartzite

	Load at failure (KN)	Area of sample (mm^2)	UCS (N/mm^2)
Sample 1	125	1963.5	63.66
Sample 2	100	1963.5	50.93
Sample 3	150	1963.5	76.39

Average UCS = 63.66 N/mm^2

3.11. Slake Durability Test [IS: 10050:1981]

Procedure

Select representative rock sample consisting of 10 lumps each of 40-60g, roughly spherical in shape with corners rounded during preparation. The sample is placed in the test drum of 2 mm standard mesh cylinder of 100 mm long and 140 mm in diameter with solid removable lid and fixed base, and is dried to a constant mass at 105°C. The mass of drum and sample is recorded (Mass A). The sample and drum is placed in trough which is filled with slaking fluid, usually tap water at 20°C, to a level 20 mm below the drum axis, and the drum is rotated at 20 rpm for 10 minutes. The drum and sample are removed from trough and oven dried to a constant mass at 105°C without the lid. The mass of the drum and sample is recorded after cooling (Mass B). The slaking and drying process is repeated and the mass of the drum and sample is recorded (Mass C). The drum is brushed clean and its mass is recorded (Mass D).

The slake-durability index is taken as the percentage ratio of final to initial dry sample masses after two cycles,

Slake-durability index, $Id2 = \frac{(C-D)}{(A-D)} \times 100\%$

The first cycle slake-durability index should be calculated when $Id2$ is 0-10%,

Slake-durability index, $Id1 = \frac{(B-D)}{(A-D)} \times 100\%$

Table XXVII. Slake durability classification

Slake durability index $Id2\%$	Classification
0-25	Very low
25-50	Low
50-75	Medium
75-90	High
90-95	Very high
95-100	Extremely high

Table XXVIII. Calculation of Slake Durability Index of Marble

	Left mesh	Right mesh
A (initial weight in gm)	1703.37	1713.31
C (wt after second cycle in gm)	1700.15	1708.71
D (wt in gm)	1095.01	1112.25
Slake durability index %	99.47	99.23
Durability	Extremely high	Extremely high

Fig 3.19. Slake Durability test

Fig 3.20 Slake durability test

Table XXIX. Calculation of slake durability index of Sandstone

	Left mesh	Right mesh
A (initial weight in gm)	1708.42	1732.65
C (wt after second cycle in gm)	1355.56	1365.10
D (wt in gm)	1095.01	1112.25
Slake durability index %	42.48	40.76
Durability	Low	Low

Table XXX. Calculation of slake durability index of Quartzite

	Left mesh	Right mesh
A (initial weight in gm)	1727.14	1725.36
C (wt after second cycle in gm)	1715.32	1666.75
D (wt in gm)	1095.01	1112.25
Slake durability index %	98.13	90.44
Durability	Extremely high	Very high

CHAPTER 4

COMPARISON WITH THE PREVIOUS RESULTS

CHAPTER 4

COMPARISON WITH THE PREVIOUS RESULTS

Marble

4.1 Point Load Index versus Unconfined Compressive Strength

There exist different empirical correlations between the unconfined compressive strength σc and the point load index $Is(50)$. Table lists some of them.

Table XXXI Correlations between UCS and point load index

Correlations		Reference
1. $\sigma c = 15.3\ Is(50) + 16.3$		D'andrea et al. (1965)
2. $\sigma c = 20.7\ Is(50) + 29.6$		Deer & Miller (1966)
3. $\sigma c = 24\ Is(50)$		Broch & Franklin (1972)
4. $\sigma c = 23\ Is(50)$		Bieniawski (1975)
5. $\sigma c = 18.7\ Is(50) - 13.2$		Singh (1981)
6. $\sigma c = 14.5\ Is(50)$		Forster (1983)
7. $\sigma c = (8\ to\ 54) Is(50)$		Norbury (1986)
8. $\sigma c = 23\ Is(50) + 13$		Chargil & Shakoor (1990)
9. $\sigma c = 24.4\ Is(50)$	for strong rocks	Quane and Russel (2003)

They all are linear relations given by different researchers to determine unconfined compressive strength when point load index is given. I used these correlations to determine UCS from point load index and found out that values obtained from these correlations are not so different from the values obtained from the laboratory test so we can say that these results are relevant and can be used to determine unconfined compressive strength from point load index but we should not always use these correlations, it is better to obtain laboratory results.

Table XXXII UCS values from different correlations

Point Load Index	**D'andrea el al. (1965)** $\sigma c = 15.3\ Is(50) + 16.3$	**Deer & Miller (1966)** $\sigma c = 20.7\ Is(50) + 29.6$	**Broch & Franklin (1972)** $\sigma c = 24\ Is(50)$	**Bieniawski (1975)** $\sigma c = 23\ Is(50)$
For Is(50) = 7.85	136.405	192.095	188.4	180.55
For Is(50)=6.915	122.10	172.741	165.96	159.045
For Is(50) = 7.54	131.662	185.678	180.96	173.42
Experimental Value of **UCS** = 127.32 MPa				
Average Is(50) = 7.435	130.06	183.50	178.44	171.00

A Bar Chart has been plotted between the experimental value of UCS and the values of UCS obtained from different empirical correlations given by different researchers, between UCS (σc) and the point load index Is(50).

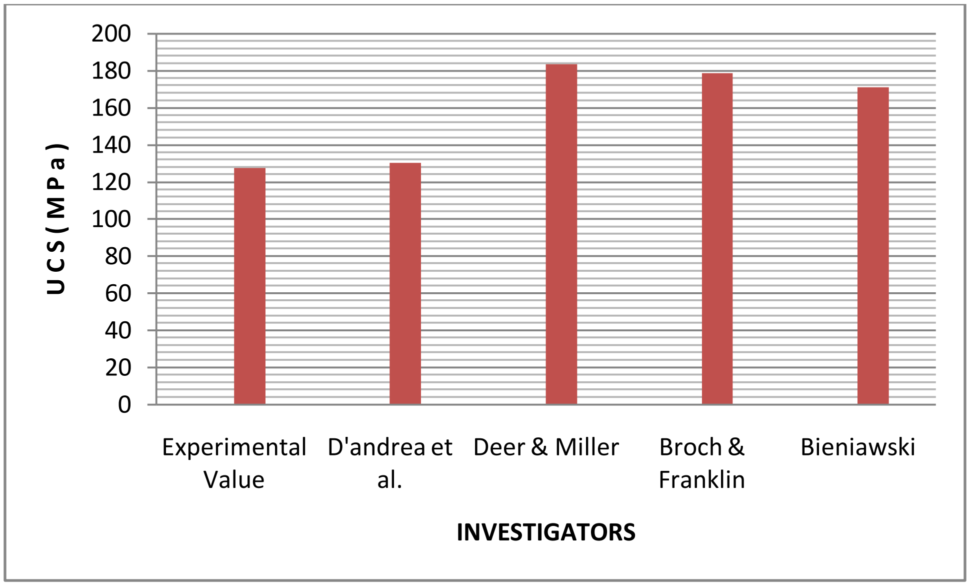

Figure 4.1 Showing (Bar-Chart) between different researchers and the calculated values of UCS, by them & experiment for Faridabad rock (Marble).

Table XXXIII Deviation of calculated UCS from experimental UCS

	D'andrea et al (1965)	Deer & Miller (1966)	Broch & Franklin (1972)	Bieniawski (1975)
Deviation from Exp UCS	2.74 MPa	56.18 MPa	51.12 MPa	43.68 MPa
% Deviation from Exp UCS	2.15%	44.13%	40.15%	34.3%
Remark* Since D'andrea et al. (1965) has least, % of deviation from Exp UCS, therefore it is acceptable.				

4.2 Schmidt Hammer Rebound Number versus Unconfined Compressive Strength

Various empirical correlations have been proposed for calculating the unconfined compressive strength of rocks from the Schmidt hammer rebound number. Table lists a number of empirical correlations for estimating the unconfined compressive strength from the Schmidt hammer rebound number. It is noted that different correlations may give very different unconfined compressive strength values.

Table XXXIV Correlations between UCS and Rebound number

Correlations	Rock type	Reference
$\sigma c = 4.29\ Rn(L) - 67.5$	Marble, limestone, dolomite	Sachpazis (1990)
$\sigma c = 4 \times 10^{-6} Rn(L)^{4.2917}$	Limestone, marble, sandstone, basalt	Yasar & Erdogan (2004a)
$\sigma c = 2.208 \times e^{0.067 Rn(L)}$	Chalk, limestone, marble, syenite, granite.	Katz et al. (2000)

Table XXXV Values of UCS from R values

Rebound number	**Sachpazis (1990)** $\boldsymbol{\sigma c = 4.29\ Rn(L) - 67.5}$	**Yasar & Erdogan (2004a)** $\boldsymbol{\sigma c = 4 \times 10^{-6}\ Rn(L)^{4.2917}}$	**Katz et al. (2000)** $\boldsymbol{\sigma c = 2.208 \times e^{0.067 Rn(L)}}$
For R = 29.56	59.3124	8.2013	16.00
For R = 32.312	71.12	12.017	19.24
For R = 38.375	97.13	25.14	28.88
For R = 38.58	98.01	25.71	29.28
For R = 37.75	94.44	23.43	27.69
For R = 36.16	87.62	19.47	24.89
For R = 32.92	73.72	13.02	20.04
Experimental Value of **UCS** = 127.32 MPa			
Average R = 35.09	83.04	17.12	23.176

Values obtained from these correlations are not matching with the laboratory test results, thus we can't use these correlations to determine unconfined compressive strength, from R values. It is better to get the UCS, from laboratory test for particular rock.

A Bar-Chart has been plotted between the experimental value of UCS and the values of UCS obtained from different empirical correlations given by different researchers, between unconfined compressive strength (σc) and Schmidt hammer rebound number, $Rn(L)$

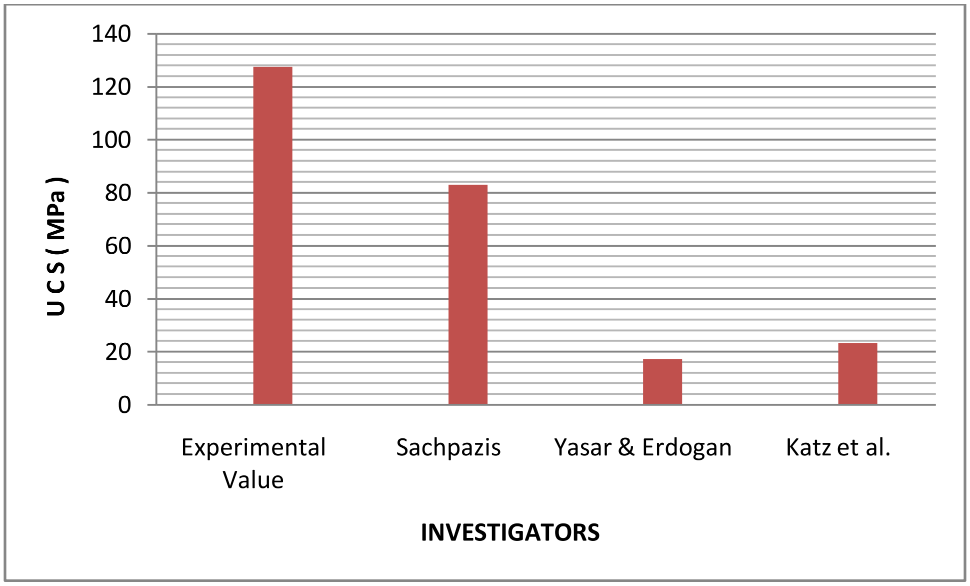

Figure 4.2 Showing (Bar-Chart) between different researchers and the calculated values of UCS, by them & experiment for Faridabad rock (Marble)

Table XXXVI Deviation of calculated UCS from experimental UCS

	Sachpazis (1990)	Yasar & Erdogan (2004a)	Katz et al. (2000)
Deviation from Exp UCS	44.28 MPa	110.2 MPa	104.144 MPa
% Deviation from Exp UCS	34.78%	86.55%	81.8%
Remark* Since Sachpazis (1990) has least % of deviation from Exp UCS, therefore it is acceptable.			

4.3 Ultrasonic pulse velocity versus Unconfined Compressive Strength

Ultrasonic pulse velocity has been used to estimate the compressive strength of rocks by different researchers. Table lists a number of empirical correlations for estimating the unconfined compressive strength (σc) from the P-wave velocity (Vp). It is noted that different UCS values.

Table XXXVII correlations between P-wave velocity and UCS

Correlation	**Rock type**	**Reference**
$\sigma c = 9.95\, Vp^{1.21}$	Dolomite, sandstone, limestone, marl, diabase, serpentine.	Kahraman (2001b)
$\sigma c = 31.5\, Vp - 63.7$	Dolomite, marble and limestone.	Yasar & Erdogan (2004b)

Table XXXVIII UCS Values obtained from P-wave velocity

Wave Velocity (Km/sec)	**Kahraman (2001b)** $\boldsymbol{\sigma c = 9.95\, Vp^{1.21}}$	**Yasar & Erdogan (2004b)** $\boldsymbol{\sigma c = 31.5\, Vp - 63.7}$
For Vp = 5.327	75.317	104.1005
For Vp = 5.124	71.854	97.706
For Vp = 5.363	75.929	105.234
For Vp = 5.241	73.840	101.39
Experimental Value of **UCS** = 127.32 MPa		
Average Vp = 5.264	74.236	102.11

Values obtained from different correlations are listed in the table and we can see that these correlations give different values from the experimental values, some values are close to the experimental value, and some are not, so we can’t always use these correlations to find out unconfined compressive strength.

A Bar-Chart has been plotted between the experimental value of UCS and the values of UCS, obtained from different empirical correlations, given by different researchers, between unconfined compressive strength (σc) and seismic wave velocity(Vp).

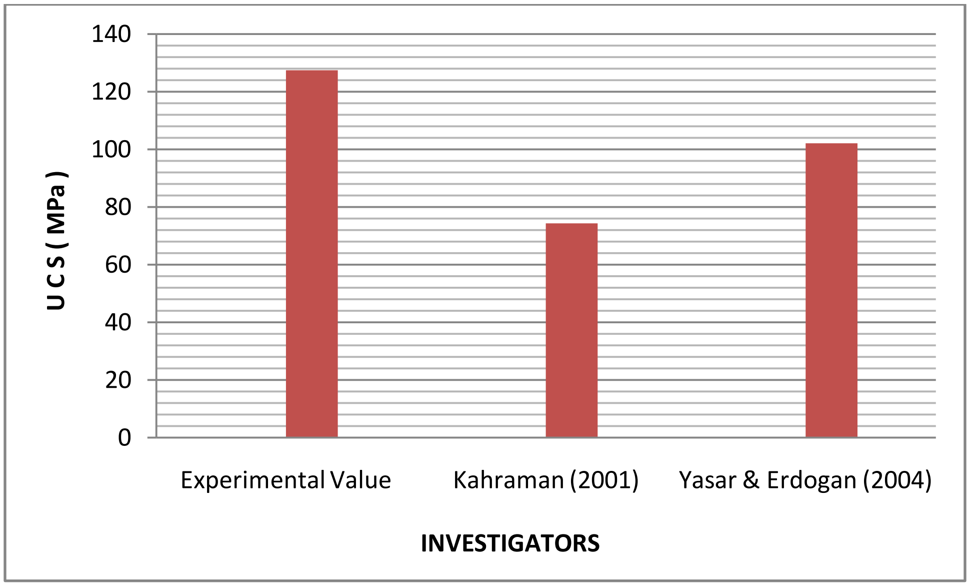

Figure 4.3 Showing (Bar-Chart) between different researchers and the calculated values of UCS, by them & experiment for Faridabad rock (Marble)

Table XXXIX Deviation of calculated UCS from experimental UCS

	Kahraman (2001b)	Yasar & Erdogan (2004b)
Deviation from Experimental UCS	53.08 MPa	25.21 MPa
% Deviation from Experimental UCS	41.69%	19.8%
Remark* Since Yasar & Erdogan (2004) has least % of deviation from Exp UCS, therefore it is acceptable.		

Sandstone

4.4 Point Load Index versus Unconfined Compressive Strength

There exist different empirical correlations between the unconfined compressive Strength, σc and the point load index $Is(50)$. Table lists some of them.

Table XL Correlations between UCS and point load index

Correlations	Reference
1. $\sigma c = 15.3\, Is(50) + 16.3$	D'andrea et al. (1965)
2. $\sigma c = 20.7\, Is(50) + 29.6$	Deer & Miller (1966)
3. $\sigma c = 24\, Is(50)$	Broch & Franklin (1972)
4. $\sigma c = 23\, Is(50)$	Bieniawski (1975)
5. $\sigma c = 16\, Is(50)$	Read et al. (1980)
6. $\sigma c = 19\, Is(50) + 12.7$	Ulusay et al. (1994)
7. $\sigma c = 23\, Is(50) + 13$	Chargil & Shakoor (1990)
8. $\sigma c = 10.3\, Is(50) + 28.1$	Zorlu et al. (2004)

They all are linear relations given by different researchers to determine unconfined compressive strength when point load index is given. I used these correlations to determine UCS from point load index and find out that values obtained from these correlations are not so different from the experimental value, so we can say that these results are relevant and similar with the experimental results.

Table XLI UCS values from different correlations

Point Load Index	**D'andrea et al. (1965)** $\sigma c = 15.3\ Is(50) + 16.3$	**Deer & Miller (1966)** $\sigma c = 20.7\ Is(50) + 29.6$	**Broch & Franklin (1972)** $\sigma c = 24\ Is(50)$	**Bieniawski (1975)** $\sigma c = 23\ Is(50)$
For Is(50) = 0.63	25.94	42.64	15.12	14.49
For Is(50) = 0.31	21.04	36.02	7.44	7.13
For Is(50) = 0.31	21.04	36.02	7.44	7.13
For Is(50) = 0.16	18.75	32.91	3.84	3.68
For Is(50) = 0.40	22.42	37.88	9.60	9.20
Experimental Value of **UCS** = 28.01 MPa				
Average Is(50) = 0.36	21.81	37.05	8.64	8.28

A Bar-Chart has been plotted between the experimental value of UCS and the values of UCS obtained from different empirical correlations given by different researchers, between unconfined compressive strength, σc and the point load index, $Is(50)$

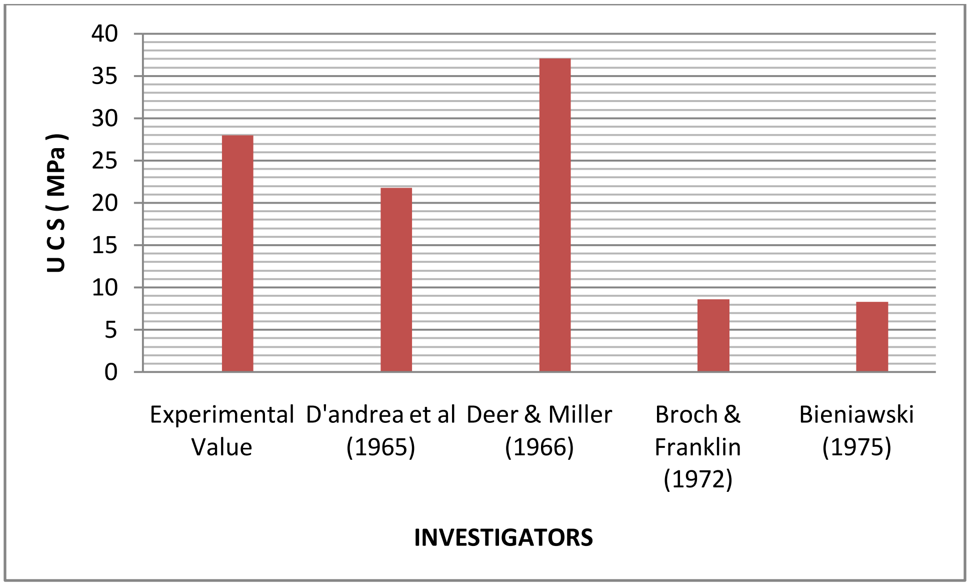

Figure 4.4 Showing (Bar-Chart) between different researchers and the calculated values of UCS, by them & experiment for Jammu, Katra rock (Sandstone)

Table XLII Deviation of calculated UCS from experimental UCS

	D'andrea et al. (1965)	Deer & Miller (1966)	Broch & Franklin (1972)	Bieniawski (1975)
Deviation from Exp UCS	6.2 MPa	9.04 MPa	19.37 MPa	19.73 MPa
% Deviation from Exp UCS	22.13 %	32.27 %	69.15 %	70.44 %
Remark* Since D'andrea et al. (1965) has least % of deviation from Exp UCS, therefore it is acceptable.				

4.5 Schmidt Hammer Rebound Number versus Unconfined Compressive Strength

Various empirical correlations have been proposed for calculating the unconfined compressive strength of rocks from the Schmidt hammer rebound number. Table lists a number of empirical correlations for estimating the unconfined compressive strength from the Schmidt hammer rebound number. It is noted that different correlations may give very different unconfined compressive strength values.

Table XLIII Correlations between UCS and Rebound number

Correlations	Rock type	Reference
$\sigma c = 4.29\ Rn(L) - 67.5$	Marble, limestone, dolomite	Sachpazis (1990)
$\sigma c = 4 \times 10^{-6} Rn(L)^{4.2917}$	Limestone, marble, sandstone, basalt	Yasar & Erdogan (2004a)
$\sigma c = 2.208 \times e^{0.067Rn(L)}$	Sandstone, chalk, limestone, marble, syenite, granite	Katz et al. (2000)

Table XLIV Values of UCS from Rebound number

Rebound number	Sachpazis (1990) $\boldsymbol{\sigma c = 4.29\ Rn(L) - 67.5}$	Yasar & Erdogan (2004a) $\boldsymbol{\sigma c = 4 \times 10^{-6} Rn(L)^{4.2917}}$	Katz et al. (2000) $\boldsymbol{\sigma c = 2.208 \times e^{0.067Rn(L)}}$
For R = 24.33	36.875	3.556	11.27
For R = 24.33	36.875	3.556	11.27
For R = 24.83	39.02	3.88	11.655
For R = 24.83	39.02	3.88	11.655
For R = 24.83	39.02	3.88	11.655
For R = 24.00	35.46	3.354	11.024
Experimental Value of **UCS** = 28.01 MPa			
Average R = 24.525	37.71	3.68	11.42

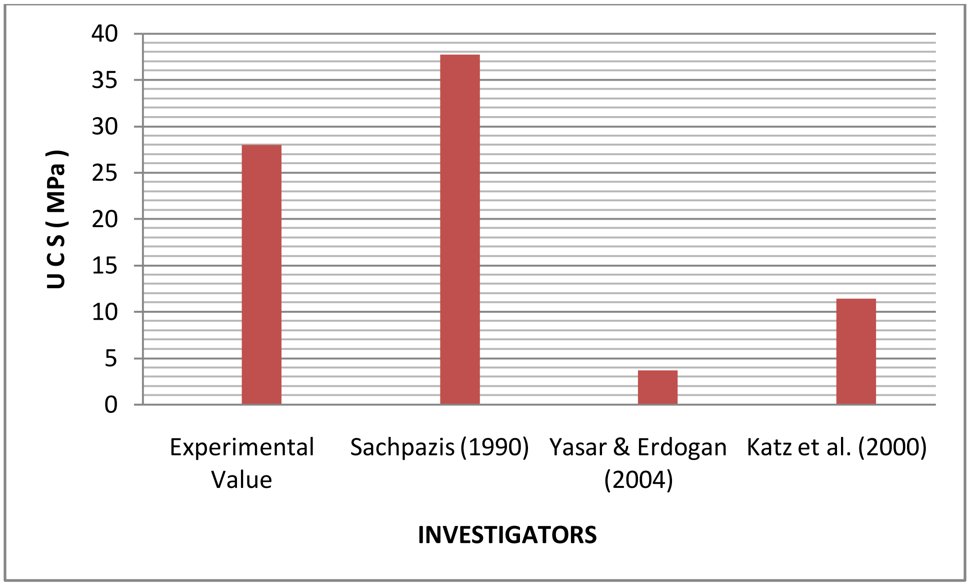

Figure 4.5 Showing (Bar-Chart) between different researchers and the calculated values of UCS, by them & experiment for Jammu, Katra rock (Sandstone)

Table XLV Deviation of calculated UCS from experimental UCS

	Sachpazis (1990)	Yasar & Erdogan (2004a)	Katz et al. (2000)
Deviation from Exp UCS	9.7 MPa	24.33 MPa	16.59 MPa
% Deviation from Exp UCS	34.63 %	86.86 %	59.23 %
Remark* Since Sachpazis (1990) has least % of deviation from experimental UCS, so it is acceptable.			

4.6 Ultrasonic pulse velocity versus Unconfined Compressive Strength

Ultrasonic pulse velocity has been used to estimate the compressive strength of rocks by different researchers. Table lists a number of empirical correlations for estimating the unconfined compressive strength (σc) from the P-wave velocity(Vp). It is noted that different unconfined compressive strength values.

Table XLVI Correlations between P-wave velocity and UCS

Correlations	Rock type	Reference
$\sigma c = 35\, Vp - 31.5$	Sandstone	Freyburg (1972)
$\sigma c = -0.98\, Vp + 0.68\, Vp^2 + 0.98$	Sandy and shaly rock	Gorjainov & Ljachvickij (1979)
$\sigma c = 1277 e^{(-11.2/Vp)}$	Sandstone	McNally (1987)

Table XLVII UCS Values obtained from P-wave velocity

Wave Velocity (Km/sec)	**Freyburg (1972)** $\boldsymbol{\sigma c = 35\, Vp - 31.5}$	**Gorjainov & Ljachvickij (1979)** $\boldsymbol{\sigma c = -0.98 Vp + 0.68 Vp^2 + 0.98}$	**McNally (1987)** $\boldsymbol{\sigma c = 1277 e^{(-11.2/Vp)}}$
For Vp = 1.56	23.10	1.12	0.97
For Vp = 1.49	20.65	1.03	0.69
For Vp = 1.49	20.65	1.03	0.69
For Vp = 1.47	19.95	1.00	0.63
For Vp = 1.77	30.45	1.38	2.28
For Vp = 2.39	52.15	2.52	11.77
Experimental Value of UCS = 28.01 MPa			
Average Vp = 1.695	27.825	1.27	1.724

Values obtained from different correlations are listed in the table and we can see that these correlations give different values from the experimental values, some values are close to the experimental values and some are not, so we can use these correlations to find out unconfined compressive strength.

A Bar-Chart has been plotted between the experimental value of UCS and the values of UCS obtained from different empirical correlations, given by different researchers, between unconfined compressive strength (σc) and ultrasonic pulse velocity (Vp)

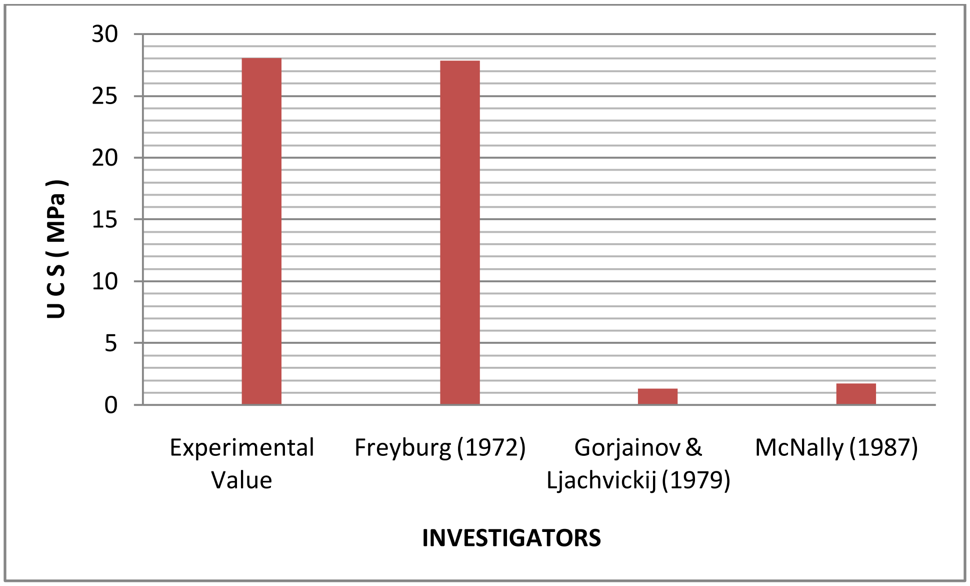

Figure 4.6 Showing (Bar-Chart) between different researchers and the calculated values of UCS by them & experiment for Jammu, Katra rock (Sandstone)

Table XLVIII. Deviation of calculated UCS from the experimental UCS

	Freyburg (1972)	Gorjainov & Ljachvickij (1979)	McNally (1987)
Deviation from Exp UCS	0.185 MPa	26.74 MPa	26.286 MPa
% Deviation from Exp UCS	0.66 %	95.47 %	93.85 %
Remark* Since Freyburg (1972) has very little % of deviation from experimental UCS, therefore this correlation is acceptable.			

QUARTZITE

4.7 Point Load Index versus Unconfined Compressive Strength

There exist different empirical correlations between the unconfined compressive strength σc and the point load index $Is(50)$. Table lists some of them.

Table XLIX. Correlations between UCS and point load index

Correlations		Reference
1. $\sigma c = 15.3\, Is(50) + 16.3$		D'andrea et al. (1965)
2. $\sigma c = 20.7\, Is(50) + 29.6$		Deer & Mille (1966)
3. $\sigma c = 24\, Is(50)$		Broch & Franklin (1972)
4. $\sigma c = 23\, Is(50)$		Bieniawski (1975)
5. $\sigma c = 23.37\, Is(50)$	for Quartzite rocks	Singh & Singh (1993)
6. $\sigma c = 24.4\, Is(50)$	for Strong rocks	Quane & Russel (2003)

They all are linear relations given by different researchers to determine unconfined compressive strength, when point load index is given. I used these correlations to determine UCS from point load index and found out that values obtained from these correlations are similar to the values obtained from the laboratory test. So we can say that these results are relevant and can be used to determine UCS from point load index.

Table L. UCS values from different correlations

Point Load Index	**D'andrea et al (1965)** $\sigma c = 15.3 Is(50) + 16.3$	**Deer & Miller (1996)** $\sigma c = 20.7 Is(50) + 29.6$	**Singh & Singh (1993)** $\sigma c = 23.37 Is(50)$	**Quane & Russel (2003)** $\sigma c = 24.4\ Is(50)$
For Is(50) = 2.83	59.6	88.181	66.137	69.05
For Is(50) = 2.51	54.703	81.557	58.659	61.244
For Is(50) = 2.20	49.96	75.14	51.414	53.68
Experimental Value of **UCS** = 63.7 MPa				
Average Is(50) = 2.51	54.703	81.557	58.659	61.244

A (Bar-Chart) has been plotted b/w the experimental value of UCS and the values of UCS obtained from different empirical correlations given by different researchers, b/w UCS (σc) and the point load index $Is(50)$.

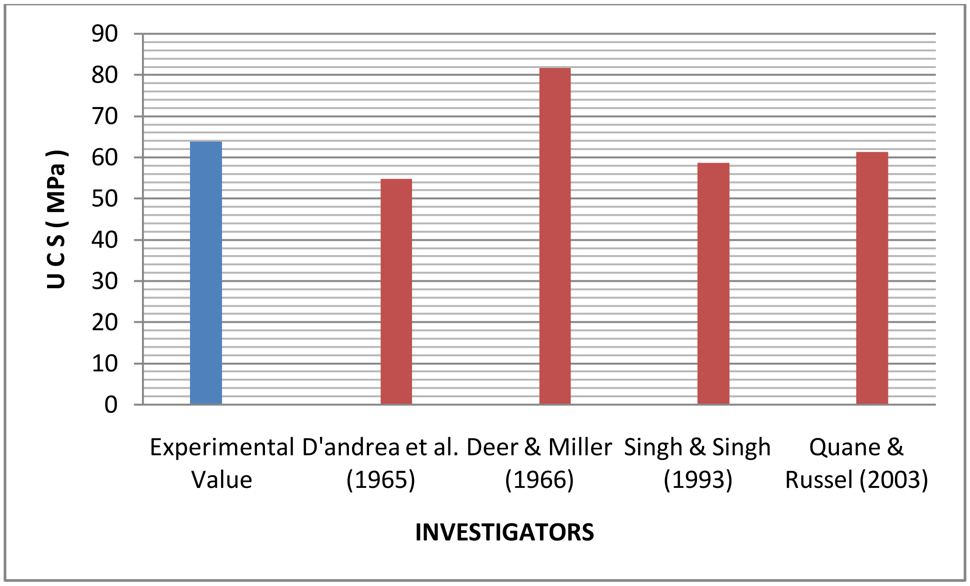

Figure 4.7 Showing (Bar-Chart) between different investigators and the calculated values of UCS by them & experiment, for Nehru Place, rock (Quartzite)

Table LI. Deviation of calculated UCS from the experimental UCS

	D’andrea et al. (1965)	Deer & Miller (1966)	Singh & Singh (1993)	Quane & Russel (2003)
Deviation from Exp UCS	8.997 MPa	17.857 MPa	5.041 MPa	2.46 MPa
% Deviation from Exp UCS	14.124 %	28.03 %	7.91 %	3.86 %
Remark* Since D’andrea et al. (1965), Singh & Singh (1993) and Quane & Russel (2003) have very little % of deviation from the experimental UCS, therefore these are acceptable.				

4.8 Schmidt Hammer Rebound Number versus Unconfined Compressive Strength

Various empirical correlations have been proposed for calculating the unconfined compressive strength of rocks from the Schmidt hammer rebound number. Table lists a number of empirical correlations for estimating the unconfined compressive strength from the Schmidt hammer rebound number. It is noted that different correlations give not very different UCS values. Thus we can use these correlations to determine UCS from R values

Table LII. Correlations between UCS and Rebound number

Correlations	**Rock type**	**Reference**
1. $\sigma c = 6.9 \times 10^{[0.0087 \rho Rn(L) + 0.16]}$ Where, $\rho = 3\ gm/c.c, (Quartzite)$	Base rock types, quartzite	Deere & Miller (1966)
2. $\sigma c = 4.29\ Rn(L) - 67.5$	Marble, limestone, dolomite	Sachpazis (1990)
3. $\sigma c = 2.75\ Rn(L) - 35.83$	Basalt, andesite, tuff	Dincer et al. (2004)

Table LIII. Values of UCS from R values

Rebound number	Deere & Miller (1966) $\sigma c = 6.9 \times 10^{[0.0087 \rho Rn(L) + 0.16]}$	Sachpazis (1990) $\sigma c = 4.29 Rn(L) - 67.5$	Dincer et al. (2004) $\sigma c = 2.75 Rn(L) - 35.83$
For R = 25.08	45.02	40.09	33.14
For R = 29.17	57.57	57.64	44.39
For R = 30.33	61.73	62.62	47.58
For R = 31.67	66.90	68.36	51.26
For R = 31.17	64.92	66.22	49.89
Expt. Value of **UCS**=63.7MPa			
Av R = 29.48	58.65	58.97	45.25

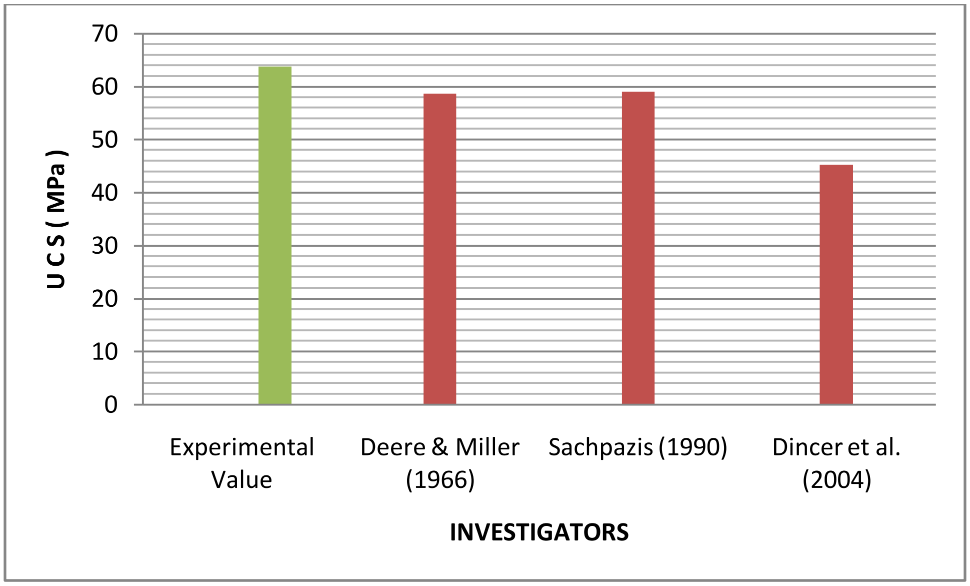

Figure 4.8 Showing (Bar-Chart) between different researchers and the calculated values of UCS by them & experiment, for Nehru Place, rock (Quartzite)

Table LIV. Deviation of calculated UCS from experimental UCS

	Deere & Miller (1966)	Sachpazis (1990)	Dincer et al. (2004)
Deviation from Exp UCS	5.05 MPa	4.73 MPa	18.45 MPa
% Deviation from Exp UCS	7.93 %	7.4 %	29 %
Remark* Since Deere & Miller (1966) and Sachpazis (1990) have very little % of deviation from experimental UCS, therefore both are acceptable.			

4.9 Ultrasonic pulse velocity versus Unconfined Compressive Strength

Ultrasonic pulse velocity has been used to estimate the compressive strength of rocks by different researchers. Table lists a number of empirical correlations for estimating the unconfined compressive strength (σc) from the P-wave velocity (Vp)

Table LV. Correlations between P-wave velocity and UCS

Correlations	**Rock type**	**Reference**
1. $\sigma c = 35.0\,Vp - 31.5$	Sandstone	Freyburg (1972)
2. $\sigma c = 36.0\,Vp - 31.2$	Coal measure rocks	Goktan (1988)
3. $\sigma c = 22.03 \times Vp^{1.247}$	Granites, Quartzite	Sousa et al. (2005)

Table LVI UCS values obtained from P-wave velocity

Wave Velocity (Km/sec)	**Freyburg (1972)** $\boldsymbol{\sigma c = 35.0\,Vp - 31.5}$	**Goktan (1988)** $\boldsymbol{\sigma c = 36.0\,Vp - 31.2}$	**Sousa et al. (2005)** $\boldsymbol{\sigma c = 22.03 \times Vp^{1.247}}$
For Vp = 2.564	58.24	61.1	71.27
For Vp = 2.456	54.46	57.2	67.55
For Vp = 2.315	49.53	52.14	62.75
Experimental Value of **UCS** = 63.7 MPa			
Average Vp = 2.445	54.08	56.82	67.17

Values obtained from different correlations are listed in the table and we can see that these correlations give not very different values from the experimental value, some values are close to the experimental value and some are not, so we can use these correlations to find out unconfined compressive strength.

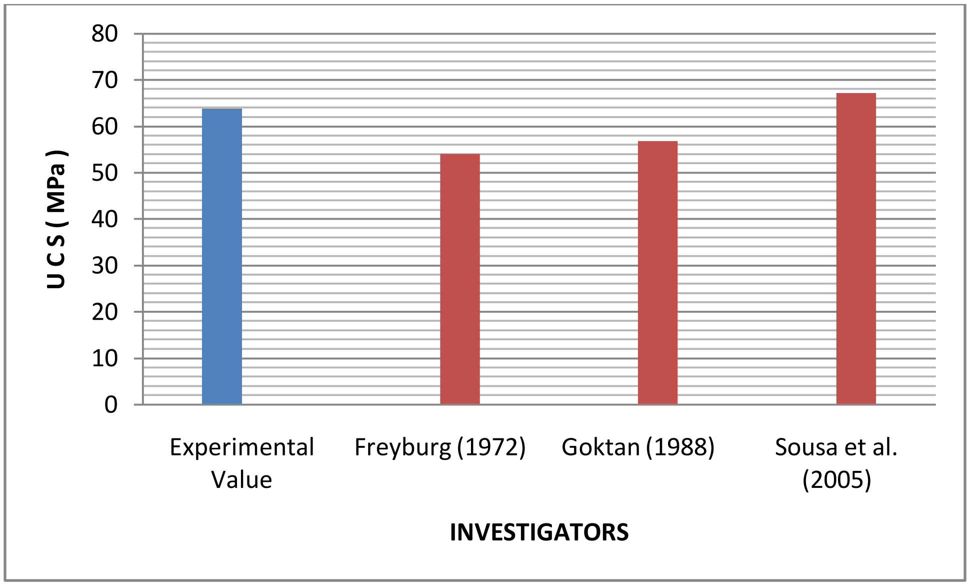

Figure 4.9 Showing (Bar-Chart) between different researchers and the calculated values of UCS by them & experiment, for Nehru Place, rock (Quartzite)

Table LVII. Deviation of calculated UCS from experimental UCS

	Freyburg (1972)	Goktan (1988)	Sousa et al. (2005)
Deviation from Exp UCS	9.62 MPa	6.88 MPa	3.47 MPa
% Deviation from Exp UCS	15.1 %	10.8 %	5.45 %
Remark* Since all correlations have very little % of deviation from experimental UCS, therefore all above three correlations are acceptable.			

CHAPTER 5

CONCLUSION

CONCLUSION

The experimental values of different tests are compared with different correlations available in the literature. It has been found the variation in different parameters from exp values and obtained from the different correlations are as high as 95.47% (for Katra rock) and as low as 0.66% (for Katra rock). It indicates that the proper correlations are important for predicting the different properties of rock. The major conclusions are as given below.

1. For marble rock Model given by D’andrea et al. (1965) has least, 2.15 % of deviation from Exp UCS using point load index.

2. For marble Model given by Sachpazis (1990) gives the UCS value using rebound number, 34.78% which is nearer to experimental value.

3. For marble rock, Model given by Yasar & Erdogen (2004) gives UCS value using wave velocity having least, 19.8% deviation from experimental values.

4. For sandstone rock, model given by D’andrea et al. (1965) using point load index has least, 22.13 % deviation from experimental value.

5. For sandstone Model given by Sachpazis (1990) gives the UCS value using rebound number, 34.63% which is nearer to experimental value.

6. For sandstone Model given by Freyburg (1972) gives UCS value using wave velocity having least, 19.8% deviation from experimental values.

7. For quartzite rock, model given by Quane & Russel (2003) using point load index has least, 3.86 % deviation from experimental value.

8. For quartzite Model given by Sachpazis (1990) gives the UCS value using rebound number, 7.4% which is nearer to experimental value.

These models give nearly values from laboratory values and can be used theoretically but it’s better to perform laboratory test for computing mechanical and physical properties of particular type of rock.

CHAPTER 6

SCOPE FOR FUTURE WORK

Scope for future work

1. More number of tests on different samples of rocks must be done to develop better correlations
2. Statistical study of variations must be done.
3. Tests must also be done on the jointed rocks and similar correlations must be developed.

CHAPTER 7

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REFERENCES

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