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Strength properties of various building stones of N.W.F.P., Pakistan

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ABSTRACT: *Domestic resources of both dimension and crushed stones used for construction are adequate to fulfil the expected demand indefinitely in N.W.F.P. Various types of building and decorative stones including limestone, marble, granite, granitic gneisses, slate, quartzite, dolorite, gabbro, serpentinite etc are found in large amount in NWFP. Geotechnical properties of these rocks including compressive strength and tensile strength show compatible values to the recommended ASTM range for Thana marble, microporphyrites of Shewa Shabaz Ghari, Marbles of Nowshera and Pir-Sabak, limestones of Kohat, Cherat and Nizampur areas, and granites of Ambela, Utla and lower swat. Higher values for compressive, tensile and shear strength are for slate from Attock and Cherat ranges. Though the shear strength values for most of these rocks are low, they are free of geotechnical defects.*

The data is useful not only for those using these rocks as building and foundation stone and crushed and broken material but also for those interested in designing openings in these rocks.

INTRODUCTION

Stone is an important mineral commodity in our modern society. It is not only essential in building highways and railroads, but also has very wide use in all phases of construction. Stone as a construction material can be divided as crushed stone and dimension stone. Desirable properties of crushed stone are toughness, strength, abrasion resistance and low porosity etc., while the dimension stone in addition must be free of fracture and other flaws, and should be capable of taking polish with good looking colour and appearance.

Most of the materials used by civil and mining engineers in the construction of the projects they design, are obtained directly or indirectly from the earth crust. The North-West-Frontier Province (NWFP) is rich in various types of building and decorative stones including lime stone, marble, granite, granitic gneisses, slate, dolomite, quartzite, schist, sand stone etc. (Ahmad, 1963,1965). Some of the major uses of these stones are as construction materials, foundation materials, ballast under railways and highways and mine openings supports in the form of pillars, fillings and linings. In most of these applications rocks are subjected to high degree of compression, tension and shear. No scientific studies of these rocks have been carried out so far. Mostly these rocks are excavated and used without proper knowledge of their engineering properties which is not an economical and safe practice. The present paper describe the compressive, tensile and shear strength properties of certain rocks from parts of NWFP (Fig. 1) as a first step in this context.

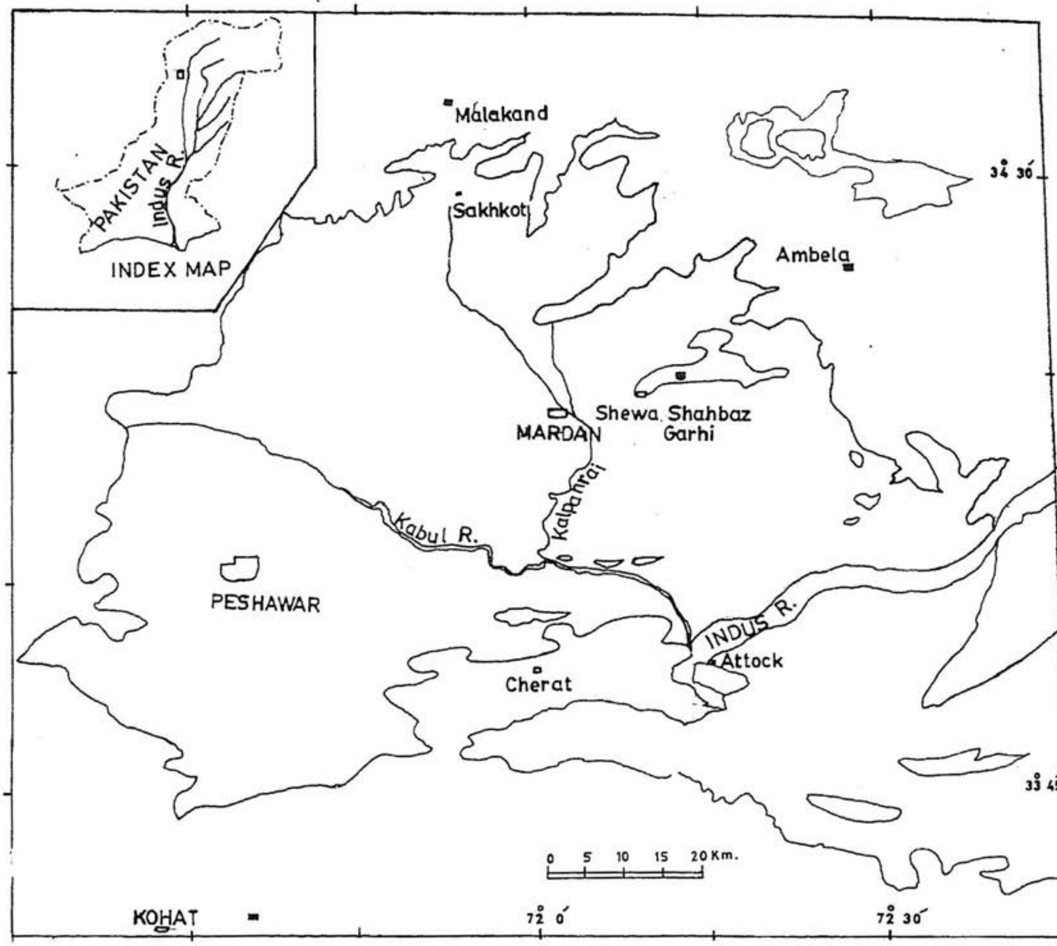

Fig. 1. Location map of some building stones of NWFP, Pakistan.

GEOMECHANICAL PROPERTIES

Laboratory methods

Fresh samples of building stones approximately one cubic foot were collected from different areas. Cores were taken from these samples. The core samples were then prepared with L/D ratio of 2 for unconfined compressive strength test and 0.5 for tensile tests. End surfaces of the cores were polished by polishing machine. Maximum possible numbers of dried samples were then tested in the strength testing machine and the results were then averaged. The test results are given in the Table 1.

Mechanical Properties

The mechanical properties of rocks are important factors in governing the behavior of rocks in response to applied load. The most important mechanical properties which must be investigated when designing foundations, structures and underground openings are hardness, durability, permeability, elasticity, plasticity, deformability and strength of the rocks used.

Strength of a material is its ability to resist externally applied load. The strength of rock depends on qualitative and quantitative mineral composition and texture. Strength of the rock

TABLE 1. SUMMARY OF LOCATION AND AVERAGE COMPRESSIVE, TENSILE AND SHEAR STRENGTH DATA OF THE BUILDING STONES UNDER STUDY.

Rock type	Formation	Locality	Compressive strength (PSI)	Tensile strength (PSI)	Shear strength (PSI)
Granite.	Malakand Granite.	2 km north of Malakand Town (Malakand Pass, Malakand Agency).	3948.59	471.33	760.00
Marble (Metasediment).	Lower Swat-Buner Schists group.	Thana Village (Malakand Agency).	8169.09	1425.41	1600.00
Granite (Microporphyry).	Shewa Shehbaz Ghari Granite.	Shehbaz Ghari Village Mardan Distt.	8320.18	807.73	1600.00
Porphyritic Micro-Granite.	—do—	—do—	3914.69	418.88	680.00
Marble.	Nowshera formation (reef core).	Kundar village Nowshera.	10268.15	839.09	2400.00
Marble.	—do—	Pirsabsak village Nowshera.	13958.96	1295.80	2000.00
Slate.	Attock Slate series (Manki Slate).	Kakasahib, south of Nowshera, Peshawar District.	31349.13	1425.41	3640.20
Granite.	Ambela Granite.	Ambela Village.	14917.60	829.39	1750.00
Marble.	———	Bumphoha.	4099.23	482.26	720.00
Lime stone.	Cherat lime stone.	Spin Kanray Village, near Cherat Cement Factory.	11718.21	808.56	1600.00
Lime stone (Gray colour)	Kohat lime stone	Near Kohat city.	11830.00	851.76	1615.00
Lime stone (Cream colour).	—do—	Near Kohat Cement Factory.	8750.00	787.50	1260.54
Lime stone.	Darwazai formation	Darwazai Village, Nizampur, Peshawar Distt.	6174.54	468.32	800.52
Dolomite.	Inzari lime stone.	Kayi/Inzari Village, Nizampur.	21161.79	1589.40	2700.65
Sand stone.	Patala formation.	Kohat Pass, North of Kohat city.	5330.61	592.29	760.54
Sand stone.	Nagri formation.	Crora, Karak Distt.	2632.00	80.62	—

can be established either experimentally by means of laboratory testing of intact rock specimen or by rock testing in-situ. Laboratory tests are more accurate, cheaper, easier to carry out and intellectually more satisfactory than field tests. There is however the difficulty that rock properties can change over a small area and a joint or fault system in a large rock mass may effect rock reaction in a way which cannot be estimated by laboratory tests. So to be more accurate, laboratory tests should be supported by field tests if possible.

Compressive strength

Compressive strength also called crushing strength is the most commonly determined property of rocks. It is the maximum stress required to crush standard rock specimen. In this test cylindrical, square or a prismatic rock specimen is subjected to uni-axial or tri-axial compressive stress and strength is calculated according to Jumikis, (1983) as following:

Compressive strength = C_S = P/A where P = applied load at failure and A = cross section area of the specimen

For accurate results rock specimen should be free from deformational defects. Comparing the data for compressive strength of the building stones under investigation with allowable data (10,000-12,000 PSI) of the US Bureau of standards (ASTM, 1988) reveals fairly good values for most of the building stones except Malakand granites, microporphyries for Shewa Shahbaz Ghari complex and sand stone of Patala and Nagri formation (Table 1). Fairly good compressive strength values for Nowshera marbles, Cherat and Kohat limestone and Inzari dolomitic limestone are mostly due to their calcareous cement. While higher values for compressive strength of Attock slate series (Manki slate) are generally attributed to their grade of metamorphism, composition and lower degree of recrystallization —, lower values of compressive strength in granites of Ambela, Malakand and marble of Bampukha can be related to their high crystalinity and lesser cement (Fig. 2). The reserve of these building stones are extensive, and can be utilized for several purposes such as foundation stone, decorative stone, milling stone, grinding stone and for special engineering works. With respect to the compressive strength it is reasonable to consider that with a few exceptions, the building stone under investigation are of fairly good quality.

Tensile strength

Tensile strength of a rock is its resistance to failure in tension. Tensile strength of rock can be determined by direct or indirect method. In direct method a rock core specimen with length-to-diameter ratio (L/D) of approximately 2 is fixed in the gripping ends of the testing device and pulled in opposite direction. The tensile strength is calculated as:

Tensile strength = T_S = F/A where F = tensile load at failure and A = cross section area of the specimen

The demerits associated with this method are:

1. Very small scratches on the surface of the specimen cause an appreciable decrease in the strength.
2. Stress concentration takes place at the gripping ends and their is an uneven distribution of stresses.

In the indirect method a rock core specimen with L/D ratio of 0.5 is placed horizontally between the bearing plates of the testing machine and loaded to failure. The tensile strength is given by

$$Ts = \frac{2P}{3.14 \times D \times L}$$

where

P = load at failure

D = diameter of the specimen

L = length of the specimen

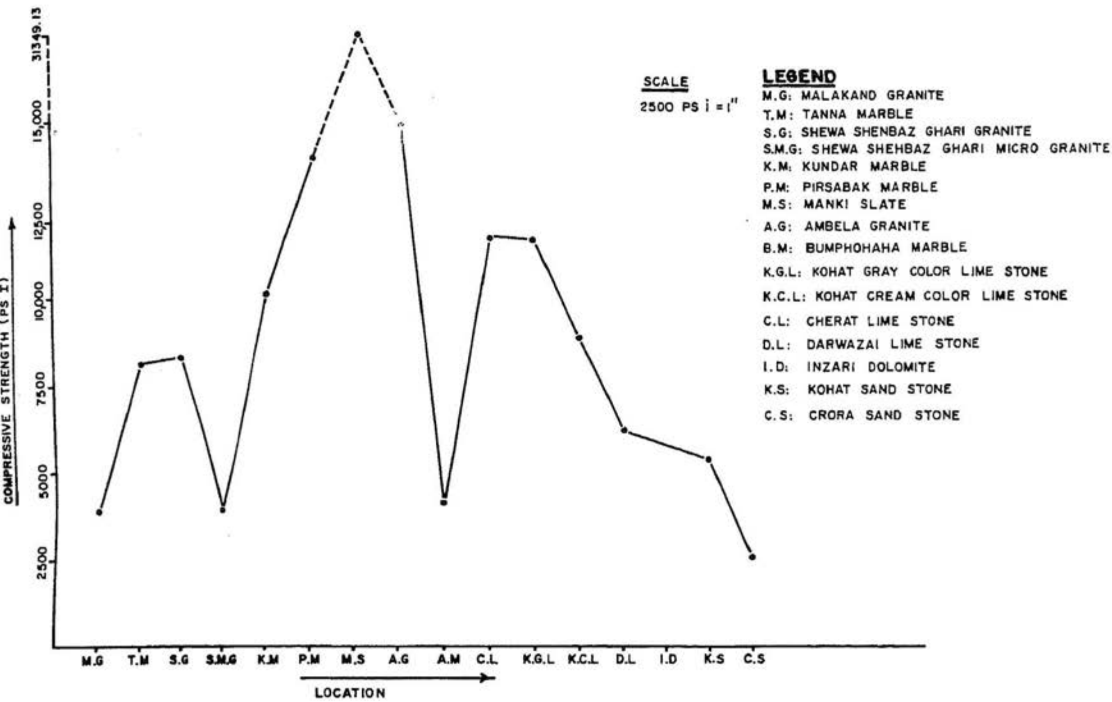

Fig. 2. Minimum and maximum compressive strength of rocks from areas under study.

The variation diagram for tensile strength of rocks under investigation show values from 9.5 to 1853.03 psi (Fig. 3).

Shear strength

There are many designing problems where knowledge about shear strength of rocks is needed. Shear strength of rock is its maximum resistance to deformation by continuous shear displacement upon the action of shear stress and it is the sum of:

i. Internal friction or resistance to translation along the sliding surfaces.
ii. Dilatancy or the interlocking effect between the individual rock grains and
iii. Cohesion along the sliding surface of the rock.

Cohesion is the inherent shear strength of the material in the absence of external stress. Physically it is the resistance of particles to separation without the presence of normal force or pressure. This resistance to separation consists of molecule bonding, ionic attraction and particle interlocking.

Dilatancy refers to the volume change which occur as a result of one particle blocking the path of the other as slip initiates along the sliding plane. A preferred terminology for this phenomenon is particle interference.

Thorough investigation of shear strength of rocks is required in the following important design problems.

— Stability problems of underground openings.
— Stability of rock slopes.
— Behavior of rocks under dams or foundations of other structures.

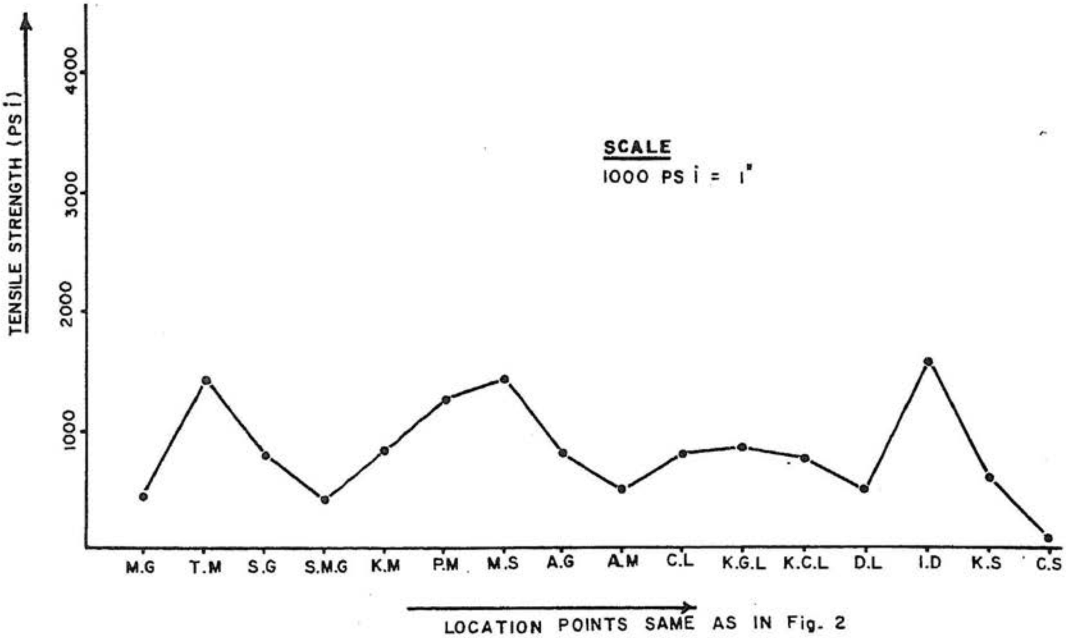

Fig. 3. Relationship between minimum and maximum tensile strength of rocks from areas under study. Location points are the same as in Figure 1.

— Punching of pillars in the roof or downward in the floors.

A number of direct and indirect methods are in use for finding the shear strengths of rocks. The direct methods include shear box test, punch test and torsion test etc. One of the indirect method is the graphical method of estimating shear strength of rocks. In this method unconfined compressive and tensile strength values are used. For rocks under present investigation circles were drawn for corresponding values of compressive and tensile strength on sigma -Taue graph. The intersection of tangent to these two circles gave the approximate shear strength values as represented by OS Line in the generalized Mohr's representation of tensile, compressive and shear strength (Fig. 4). These rock samples mainly limestones, marbles, sandstones and granites show a wide variation in shear strength (680.0 - 2400.0 PSI; Table 1) and these values are below the recommended range (19250 PSI; ASTM, 1988).

The marbles from lower-Swat Buner schistose group, Nowshera formation, limestones from Cherat, Kohat and dolomite from Inzari (Nizampur), show highly variable values of shear strength (Table 1). This variation is probably due to lithologic difference and the effect of tectonics (Fig. 5). However quarrying, compressive strength, hardness and workability, colour and fabric, porosity and texture, durability, and particularly transportation has upgraded their economic value. Based on these properties most of these rocks are already in use for internal and external building decoration. Compressive and shear strength not only favour the stone for internal or external building decoration, but can also be used as foundation stone in small scale structures, as milling stone, grinding stone and for other engineering works. In addition, properties such as colour, hardness, durability have made the rock valuable as chip stones.

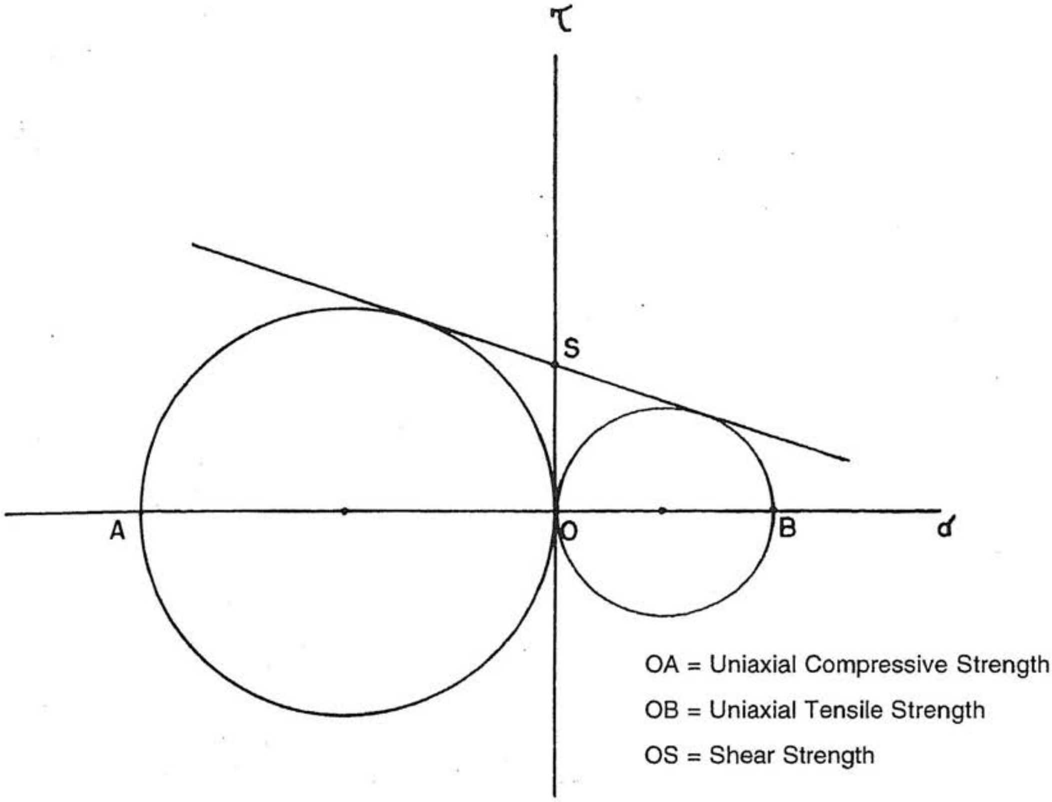

Fig. 4. Generalized Mohr's diagram for calculating the shear strength.

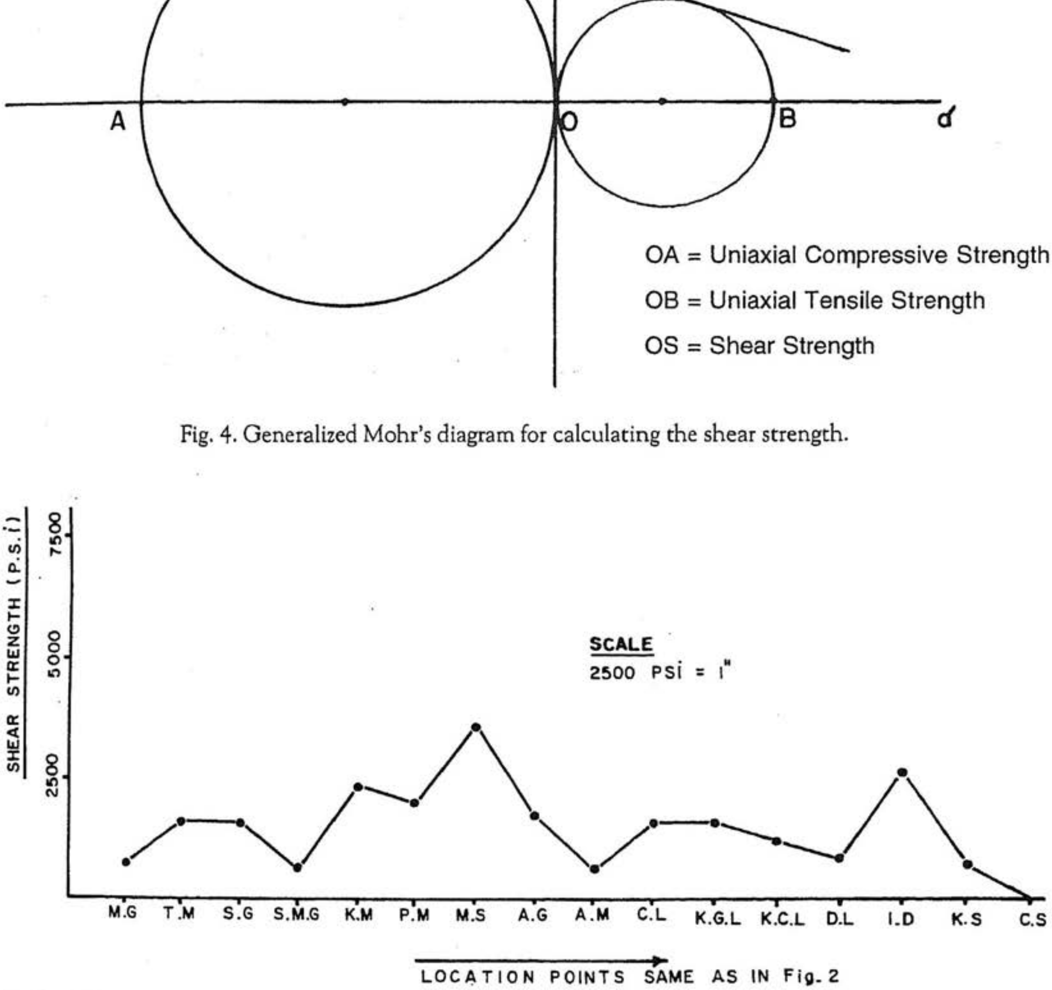

Fig. 5. Relationship between minimum and maximum shear strength of rocks from areas under study on the basis of Obert & Duvall (1967) technique. Location points are the same as in Figure 1.

CONCLUSIONS AND RECOMMENDATIONS

1. Comparing the strength values ofMalakand granite and Manki slate , the Manki slate has higher strength values than the Malakand granite, although the latter type is much harder (because of high quartz content). This is because of difference in grain size and geological defects. Manki slate is fine grained than the Malakand granite and almost free of shear planes. On the other hand the Malakand granite is coarse grained and has more shear planes. This indicates that grain size and geological structure are important factors on which the strength of rocks depends.

2. Comparing the strength values of dolomite of Inzari formation and the Kohat limestones, the dolomite has higher strength values. The reason is that limestone has more inter spaces than dolomite. This indicates that increase in porosity lowers the strength.

3. The results also indicate that rocks of the same type in different areas have different strength values. This is because of difference in mineralogical composition and other physical properties. Thus it can be concluded that change in texture and mineralogical characteristics of rocks due to crystallization, diagenesis and the effects of tectonism appear to effect the strength properties of same rocks in different areas.

4. Specimen preparation and rate of loading both have significant effect upon test results and therefore must be given due consideration.

5. Poorly cemented rocks have much low strength than well cemented rocks. For example sandstone ofNagri Formation have lower strength than the rest of the rocks under investigation.

6. The Ambela granite has comparatively higher shear strength values than Malakand and Shewa Shahbaz Ghari granites and can be used as building stone and for external surfacing in addition to its use in special engineering works.

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