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ORIGINAL PAPER

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Classification of black decorative stones from Warangal District, Andhra Pradesh, India

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Abstract Despite abundant usage of Indian black decorative stones, no systematic approach has been made to study their properties. In this paper an attempt has been made to study the geoparametrical and geotechnical properties of the stones from ten active quarries in the Dornakal-Balpao-Venkatayapalem, Warangal district, Andhra Pradesh, India, including colour, hardness, texture, grain size, composition, macro- and micro-joints, specific gravity, dry density, moisture content, water absorption, porosity, uniaxial compressive strength (compressive strength), tensile strength, shear strength, rebound hardness number, point load strength index and rock hardness. Regression analyses were undertaken; the correlation coefficient obtained from ranged from 0.80–0.96. On the basis of these results, a new classification system for black decorative stone is proposed with four classes ranging from I (very good) to IV (poor). It is appreciated that the classification is based on limited data but it provides an important advance with implications for improving the present ad hoc, often wasteful quarrying philosophy in India.

Keywords Ornamental rocks · Geotechnical properties · Correlations · Classification · India

Résumé Malgré l'usage important, en Inde, de roches ornementales de teinte foncée, aucune approche systématique n'a été réalisée pour étudier leurs propriétés. Dans cet article une méthode est proposée pour étudier les propriétés pétrophysiques et géotechniques de ces roches issues de dix carrières en activité dans la région de Dornakal-Balpao-Venkatayapalem, district de Warangal, état d'Andhra Pradesh. Les propriétés ou caractéristiques considérées sont: la couleur, la dureté, la texture, la granularité, la composition minéralogique, la présence de macro ou micro fissures, le poids spécifique, la densité sèche, la teneur en eau, la capacité d'absorption d'eau, la porosité, la résistance à la compression simple, la résistance à la traction, la résistance au cisaillement, la valeur de rebond au scléromètre et l'indice de résistance entre pointes. Des analyses de régression ont été réalisées, les coefficients de corrélation obtenus variant de 0,80–0,96. Sur la base de ces résultats, un nouveau système de classification des roches ornementales de teinte foncée est proposé, avec quatre classes, de I (très bon) à IV (médiocre). Il faut retenir que la classification est fondée sur un nombre limité de données et représente une avancée importante par rapport à la situation présente, susceptible d'améliorer la rentabilité des carrières considérées.

Mots clés Roches ornementales · Propriétés géotechniques · Corrélations · Classification · Inde

Introduction

India possesses about 15% of the world's decorative stone reserves. From time immemorial decorative stones were used extensively especially during the Chera, Chola, Pandya and Pallava periods for building the historic temples, palaces and monuments of Indian. Today the decorative stones of India are used in numerous ways (Balasubramanyam et al. 1992; Dixit 1992; Reddy et al. 1992; Power 1975). However, little work has been done towards standardising the quality characteristics of Indian decorative stones. Two decades ago they were quarried as building stones, road metal and for other civil engineering works (DaGama and Afonso 1993). It is only in recent years that decorative stones have been identified as an invaluable mineral resource due to their inherent properties which allow them to take a good polish. Today the ornamental decorative stone industry is well recognized and organized, especially in the western countries and, of late, India has also become an important source area for ornamental decorative stones (Kanishkan 1992a).

In India, the cut stone industry is based more on tradition than on engineering rigour. It is made up of a large number of relatively small companies and there has traditionally been little recruitment of qualified engineers. In more recent years, however, many of the companies have grown and others have been taken over by mining companies and as a consequence there has been an introduction of some engineering design (Indian Bureau of Mines 1990). However, this is still in its infancy and there is much scope for further innovation and development.

In stone quarries there has always been a technical problem with the extraction of large blocks and where explosives are used there is the danger of the generation of unwanted cracking. The development of diamond tools, and their use in the marble industry, naturally led to the investigation of their use in granite quarries. However, the hardness of the rock does pose technical problems. Geological mapping and the detailed classification techniques which commonly apply have not been fully developed in India. A classification system for the fracture patterns and mineralogical stucture, the relationship between macro and micro fractures and mineral cleavage surfaces, blemishes and the geotechnical parameters is needed to enable scientific planning methods to be developed. Such planning methods would replace the present ad hoc methods with geologically sound mine design (Eltringham and Sriram 1992). In contrast to other mineral industries, the continuity of the ornamental stones is frequently not easily established and hence the mining has been developed by experience based on trial-and-error.

In quarries, every piece of rock is checked manually and the direction of further cutting and polishing procedures is marked on the rock. The relevant properties of the granite are not usually visible to the inexperienced observer and to date no technical assessment has been used for determining the optimum direction in which the extraction should take place. Although much work has been done in the area of rock discontinuity characterization, statistical modelling etc., there is no reference to the study of micro-structures and their effect on dimension stone recovery rates. New classification systems based on micro-geoparametrical information are proposed.

Study area and sample collection

An area of some 450 km^2 in Dornakal-Balpao-Venkatayapalem, parts of the Warangal district of Andhra Pradesh (AP), India, have been surveyed for the occurrence of black decorative stones. Ten good productive quarries were selected for the present work, as shown on the location map in Fig. 1.

For the present study rock blocks of various sizes were collected and thin sections, cubes and cores prepared as required for the different laboratory studies conducted in the Indian School of Mines and Central Mining Research Institute in Dhanbad.

Geoparametrical and geotechnical properties

Despite the abundant usage of black decorative stones, no systematic approach has been made to study their properties (Umathey and Venugopal 1992 and Viswanathan et al. 1992). An attempt has therefore been made to understand the geotechnical properties of black decorative stones including colour, hardness, texture, grain size and composition, macro and micro joints, specific gravity, dry density, moisture content, water absorption, porosity, compressive strength, tensile strength, shear strength, rebound hardness number, point load strength index and rock hardness (polishability). The results are given in Table 1.

Colour

The colour of rocks indicates the presence of primary minerals. In black decorative stones the colour variations are influenced by quartz, feldspar, hornblende and biotite. The black colour is due to the predominance of biotite.

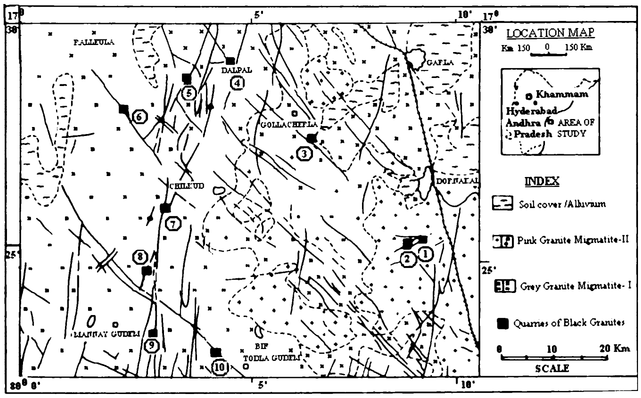

Fig. 1 Location map of the study area showing the rock type and ten quarry locations (after Viswanatham et al. 1992)

Hardness

The hardness of granite depends upon its main constituent minerals such as feldspar, hornblende and quartz; those having abundant quartz being hardest. The mineral hardness is determined by Mohrs' scale based on the scratchability test. The hardness number of the Warangal black decorative stones varies between 6.4 and 7.0.

Texture, grain size and composition

Texture is concerned with the intimate mutual relationship between the different mineral grains and deals only with the external characteristics of rocks. The black decorative stones of the Warangal region exhibit generally fine to medium grain size crystals and occasionally mineralogical banding (Jamwal and Viswanathan 1990). The typical black decorative stone of the area was analyzed in the laboratory and its petrological characteristics studied megascopically and microsopically.

Macro and micro joints (joint set, joint spacing)

In the present study only visible joints in the outcrops were taken into consideration. Accordingly joint set and joint spacing were calculated mathematically and mean values are taken.

Specific gravity

The tests were conducted following IS:1124–1974. The results indicated little variation in the specific gravity of the granites from the various quarries in the Warangal district; the lowest value being 2.68 gm/cm^3 and highest 2.81 gm/cm^3.

Dry density

The tests were undertaken as per IS:1124–1974. The results varied from 2.61 to 2.72 gm/cm^3.

Moisture content and water absorption

The tests were undertaken following IS:1124–1974. In this dense material, not surprisingly the moisture contents were between 0.046% and 0.144%. The value of water absorption capacity ranged from 0.2% to 0.983%.

Porosity

The tests were again carried out as per IS:1124–1974. From the test results the porosity of the decorative stone varies from 0.63% to 1.45%.

Compressive strength

The IS:9143–1979 and Brown (1981) suggested methods to conduct compressive strength tests on rock specimens

Table 1 Geoparametrical and geotechnical parameters of black decorative stones from ten quarries

Property	Quarry number									
	1	2	3	4	5	6	7	8	9	10
Specific gravity (gm/cm^3)	2.68	2.78	2.81	2.80	2.78	2.76	2.71	2.73	2.76	2.74
Dry density (gm/cm^3)	2.66	2.64	2.66	2.67	2.68	2.68	2.69	2.70	2.72	2.69
Porosity (%)	0.63	0.76	0.88	0.94	1.26	1.15	0.99	1.27	1.31	1.45
Moisture content and water absorption.	0.29	0.294	0.986	0.235	0.448	0.287	0.263	0.513	0.19	0.413
Compressive strength (kg/cm^2)	752	889	1066	1185	1221	1285	1295	1338	1351	1360
Tensile strength (kg/cm^2)	78	87	90	95	101	96	105	109	99	111
Shear strength (kg/cm^2)	85	94	97	99	126	166	163	160	162	178
Rebound hardness No.	58	62	63	65	70	68	72	69	71	73
Point load strength index (kg/cm^2)	200	285	310	350	360	375	395	390	400	410
Rock hardness No.	22	30	35	38	47	42	46	48	50	52

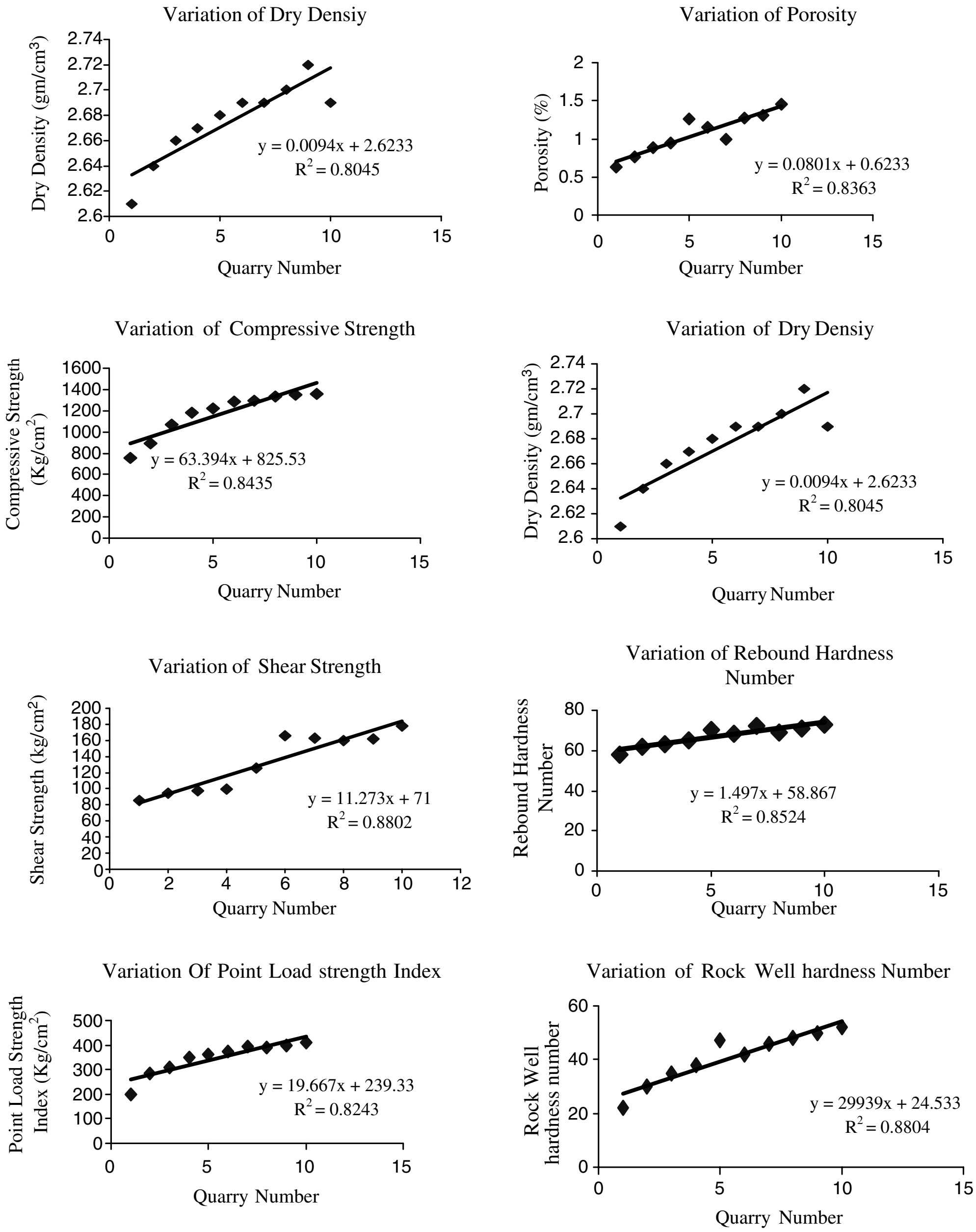

Fig. 2 Variation of different properties and linear regression equations corresponding to their respective quarry location

were used in the present study to test the samples in the dry condition. A considerable variation was found with strengths ranging from 74 to 134 MPa. From the test results it is observed that the compressive strength is approximately inversely proportional to the porosity.

Tensile strength

The indirect (Brazilian) test was carried out in the laboratory as per IS:107082–1981 and the procedure recommended by Brown (1981). The tensile strength of the granite was found to range from 7.6 to 10.9 MPa and was about 5–10% of the compressive strength.

Shear strength

The punch shear test was carried out following IS:1121 (Part-IV) 1974 and Brown (1981). This indicated the strength against shear failure varied between 8 and 17 MPa.

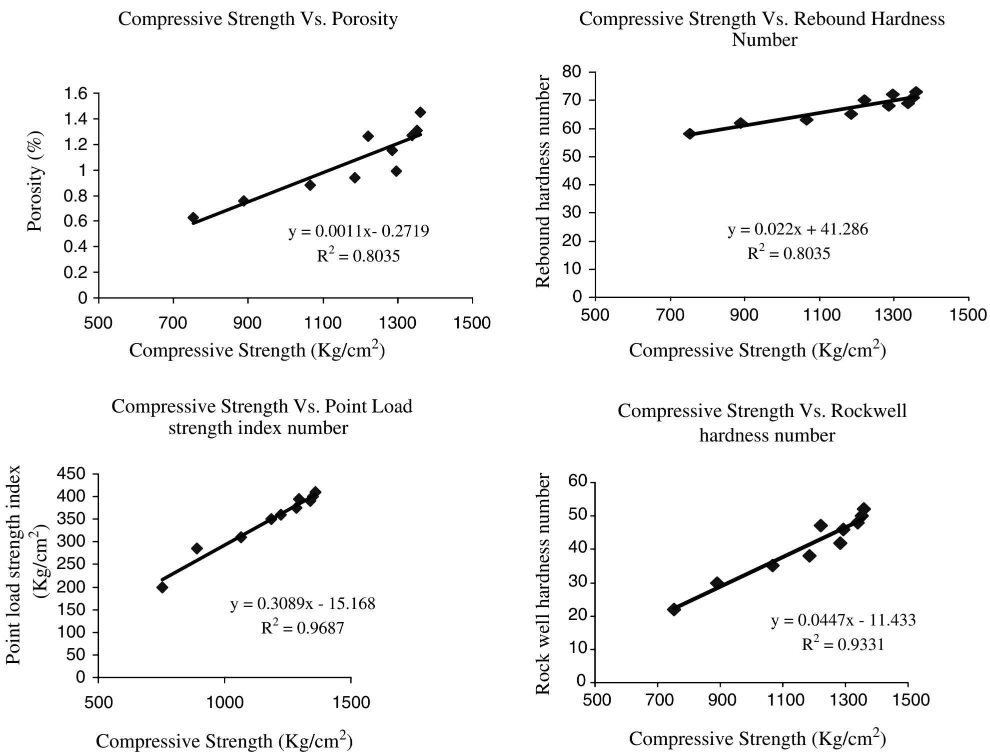

Fig. 3 Bivariate linear regression equations among compressive strength, porosity, point load strength index, rebound hardness number and rock hardness number

Table 2 Classification parameters and their ratings

Parameters and ratings	Ranges of values			
Comp. strength (kg/cm^2)	2200–1800	1800–1400	1400–1000	< 1000
Rating	25	15	10	5
Tensile strength (kg/cm^2)	> 90	90–80	80–70	70
Rating	20	12	8	4
Porosity (%)	0–0.25 10	0.25–0.50	0.50–1.00	1
Rating	10	6	4	1
Rock hardness	> 70	70–65	65–60	60
Rating	10	7	5	3
Joint set (n)	1–2	2–3	3–4	4
Rating	10	8	6	4
Joint spacing (m)	> 2	2–1	1–0.5	0.5
Rating	10	6	4	3
Texture	Very fine grained	Fine grained	Medium grained	Coarse grained
Rating	5	4	3	2
Colour	Black uniform dark	Grey	Prophyritic	Variegated
Rating	5	5	5	1
Hard mineral (%)	> 20	20–15	15–10	10
Rating	5	4	3	2
Classes determined from total rating				
Rating	100–75	75–50	50–25	25
Class no.	I	II	III	IV
Description	Very good	Good	Fair	Poor

Rebound hardness number

The rebound hardness number was evaluated to obtain a Schimdt rebound number based on ten field tests and at least three laboratory tests for each rock type.

Point load strength index

The point load test was undertaken following the procedures described by Broch and Franklin (1972) and ISRM (1985). The diametrical method of testing was chosen. The cores used were drilled parallel to the bedding or foliation and the load applied at right angles to these structural phenomena. For each of the twenty rock samples, three cores were tested.

Rock hardness

Polished sections of samples are measured on the C scale. For each surface five readings were taken.

Analysis of data

Regression analyses have been done on the test results (see Fig. 2) in order to assess the future development of quarries in the area. An attempt has been made to

Table 3 Quality of black decorative stones determined from proposed classification

Parameter	Quarry Number									
	1	2	3	4	5	6	7	8	9	10
Comp. strength (kg/cm^2)	10	10	5	10	10	10	10	10	15	10
Tensile strength (kg/cm^2)	20	20	12	20	12	20	20	20	20	20
Porosity (%)	4	4	4	4	4	10	10	4	10	4
Rock hardness no.	3	3	3	4	4	5	5	4	4	3
Joint set (n)	10	10	10	10	10	10	10	10	10	10
Joint spacing (m)	10	10	10	10	10	10	10	10	10	10
Texture	5	5	5	5	5	5	5	5	5	5
Colour	5	5	5	5	5	5	5	5	5	5
Hard mineral (%)	5	4	5	5	5	5	5	5	5	5
Total rating	72	71	59	73	65	80	80	73	84	72
Class no.	II	II	II	II	II	II	II	II	II	II
Description	Good	Good	Good	Good	Good	Very good	Very good	Good	Very good	Good

establish a mathematical relationship between the compressive strength and a number of other physical properties: compressive strength, porosity, point load strength index, rebound hardness number and rock hardness (Fig. 3).

Proposed classification

A classification is proposed on the basis of the laboratory tests and subsequent analysis of the data. In the stone industry this type of classification is essential as in a commercial industry it is not practical to measure all the rock properties. It is considered that by using this system, the class of black decorative stone can be obtained by testing only one property.

The classification is based on nine rock properties namely: compressive strength, porosity, rock hardness, joint set, joint spacing, texture, colour and percentage of hard mineral. The properties are weighted to reflect their influence on the geoparametrical and geotechnical properties. Although it is appreciated the data are limited, nevertheless the classification system gives excellent results where it has been cross checked in productive quarries. The basic ideas are taken from other rock mass classification techniques (Murthy 1992; Kanishkan 1992b), but the aim of this study was to emphasise the use of the classification in the small scale mining sector and to assist with the identification of appropriate quarrying techniques. The proposed classification together with the parameters and ratings given are illustrated in Table 2. On the basis of the proposed classification scheme, ratings for each quarry have been computed and are listed in Table 3.

Conclusions and recommendations

The project aimed to develop a standard analysis system based on micro geoparametrical and geotechnical studies which would help in the determination of the in-situ value of decorative stones.

A further outcome of the study was the appreciation that the diamond wire saw could be used in black decorative stone mining, which would reduce noise and air pollution as well as enhancing recovery. This technique is more accurate than the ad hoc methods currently used for quarrying and will reduce wastage of good quality stones, improve handling and have significant transport savings.

Such a classification system is also helpful in managing the environment as regards land use. Although the proposed classification system is on a limited amount of data, it is valuable in the area studied and illustrates a possible way forward for the industry in general.

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